Watershed Management Considerations For Operational Planning on T.F.L. #39 (Blk 6A), Graham Island

D.A.A. Toews and D. Wilford

Land Use Unit
Habitat Protection Division
Resource Services Branch
Fisheries and Marine Service
Department of Fisheries and Oceans
1090 West Pender Street
Vancouver, B.C. V6E 2P1

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Fisheries and Marine Service

Manuscript Report 1473

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WATERSHED MANAGEMENT CONSIDERATIONS FOR OPERATIONAL PLANNING ON T.F.L. #39 (BLK 6A), GRAHAM ISLAND

by

D.A.A. Toews and D. Wilford[1]

Land Use Unit
Habitat Protection Division
Resource Services Branch
Fisheries and Marine Service
Department of Fisheries and Oceans
1090 West Pender Street
Vancouver, B.C. V6E 2P1

[1] Research Division
B.C. Ministry of Forests
Smithers, B.C.

TABLE OF CONTENTS

ABSTRACT

Toews, D.A.A., and D. Wilford. 1978. Watershed management considerations for operational planning on T.F.L. #39 (BLK 6A), Graham Island. Fish. Mar. Serv. MS Rep. 1473: 32p.

Available climatic, topographic, hydrologic and resource information relating to the Yakoun, Tlell, Mamin, Florence and Honna watersheds of the Queen Charlotte Islands were analysed for the purpose of making recommendations concerning the rate and pattern of timber harvesting. As forest harvesting has the potential to alter water quality and peak flows, particularly in the upland areas, recommendations are made for a conservative, but flexible approach to planning logging operations to ensure the preservation of fish habitat. Suggestions are made for further forest hydrology research.

Key words: Watersheds, logging, hydrology.

RÉSUMÉ

Toews, D.A.A., and D. Wilford. 1978. Watershed management considerations for operational planning on T.F.L. #39 (BLK 6A), Graham Island. Fish. Mar. Serv. MS Rep. 1473: 32p.

Les renseignements climatiques, topographiques, hydrologiques et sur les ressources, dont on dispose pour les bassins hydrographiques de la Yakoun, la Tlell, la Mamin, la Florence et la Honna de îles Reine-Charlotte, ont été analysés afin de faire des recommandations sur le taux et le mode d'abattage du bois d'oeuvre. Étant donné que l'exploitation forestière peut nuire à la qualité de l'eau et modifier les débits maximaux, en particulier dans les régions de moyenne montagne, les recommandations visent une méthode conservatrice mais souple de planification de l'abattage du bois afin d'assurer la préservation de l'habitat du poisson. On propose de poursuivre les recherches en hydrologie forestière.

Mots-clefs: Bassins hydrographiques, abattage du bois, hydrologie.

INTRODUCTION

This paper relates the available information (climate, streamflow, and some broad watershed features) to forest hydrology theory with a view to making recommendations on the spatial and temporal distribution of forest harvesting within selected watersheds in Block 6A of T.F.L. #39.

This report was precipitated by concern of resource agency staff with potential problems associated with a MacMillan Bloedel five year logging program proposed in areas of high sensitivity and watershed values. The five year plan was initially presented in Masset on June 9, 1977 and preliminary recommendations based on an early draft of this report were presented at a subsequent meeting on August 4, 1977.

Recommendations focus on minimizing the impact of forest harvesting activities on water and aquatic resources. Consideration has been given to maintaining water quality, quantity and regime including stream channel integrity and upland slope stability.

The recommendations are designed to apply to the areas specified and extrapolations to other geographic or climatic areas should be made with a degree of caution in view of hydrologic variability.

THE SETTING

LOCATION AND PHYSIOGRAPHY

Block 6A of T.F.L. #39 occupies much of the southeast quarter of Graham Island, the northern major island of the Queen Charlotte Islands (Figure 1). The majority of the area within the 5 year plan lies within the Skidegate Plateau, with the remainder of the Queen Charlotte Lowlands (Figure 1). The Skidegate Plateau is a partially dissected peneplain that slopes northeastward. Relief is moderate with the highest elevations being 900 meters above sea level. The Queen Charlotte Lowland is an extensive, low lying (less than 150 meters above sea level), boggy area. The surficial material is a blanket of glacial outwash that overlies flat or gently dipping marine shales and sandstones (Calder and Taylor, 1968).

The main watersheds within the area are the Yakoun, Mamin, Honna, Florence and Tlell. These watersheds are in the Coastal Western Hemlock Biogeoclimatic Zone and due to their generally low elevation are for the most part totally forested with commercial stands. The stands have an average of 700 m^3 per hectare (J. Gooding, personal communication), and are composed of western hemlock, Sitka spruce, western red cedar and yellow cedar. Information on these and tributary watersheds is presented in Table 1.

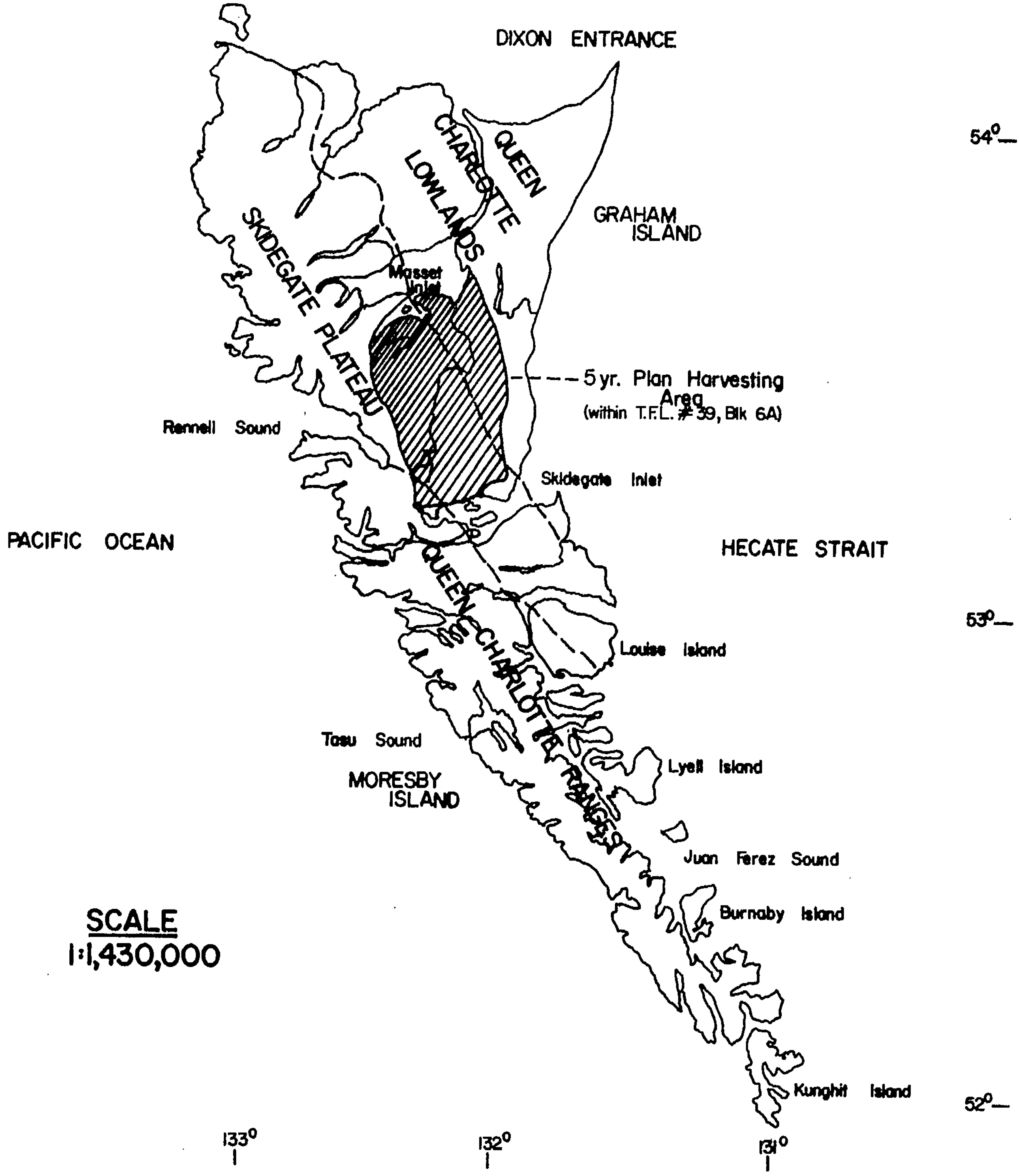

FIGURE I – PHYSIOGRAPHIC REGIONS OF THE QUEEN CHARLOTTE ISLANDS

TABLE 1. Some physical characteristics of the Watersheds.

Watershed	Area (hectares)[1]	Physiographic Region		Approximate Elevational Ranges (meters)
		QCL[2]	S.P.[3]	
Yakoun (total)[4]	47,964	20%	80%	0 - 750
Canoe	2,133	70%	30%	15 - 600
Gold	3,154		100%	50 - 600
Brent	3,594		100%	105 - 600
King	2,051		100%	60 - 750
Ghost	4,306		100%	75 - 750
Phantom	1,691		100%	90 - 600
Honna	4,671		100%	0 - 900
Tlell				
Survey	7,916	10%	90%	15 - 300
Feather Lake	4,915	35%	65%	15 - 450
Florence	3,650	65%	35%	0 - 450
Mamin	13,835	10%	90%	0 - 600
Blackwater	8,232		100%	60 - 600

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[1] Area data supplied by MacMillan Bloedel, Queen Charlotte Division.
[2] QCL - Queen Charlotte Lowlands.
[3] S.P. - Skidegate Plateau.
[4] The remaining 31,036 ha are within a unit adjacent to the mainstream and not including the following tributaries.

CLIMATE

An excellent description of the climate of the Q.C. Islands has been prepared by G.V.D. Williams and presented in Calder and Taylor's (1968) "Flora of the Queen Charlotte Islands". Much of the following description is taken from this source.

In a summary statement, the above author states:-

"The main distinguishing features of the climate of the Queen Charlotte Islands are the very cool summers, the very mild winters, the prevalence of cloudy skies and strong winds, and the excessive late fall and early winter rainfall."

The Queen Charlotte Islands as a whole, and the study area in particular have a rather unique climate. Using the Köppen system of climatic classification the islands are classified as Cfb due to the humid, temperate climate with mild winters and cool summers. Williams (1968) notes that this type occupies less than 1 percent of Canada, where it is found only in British Columbia, and there chiefly within 50 miles of the Pacific Ocean. Williams (1968) speculates that as climate data is collected, the interior of the islands may possibly be classified as the Cfc type. He notes that this type is not found in any other part of Canada, but does occur in such areas as the Aleutian Islands and southern Iceland.

TABLE 2. Precipitation totals of climatic stations within study area and of nearby long term stations.

Climatic Station	Elevation (m)	Total June 1976 Jan. 1977 (mm)[2]	Long Term Average June to Jan. (1947-1963) (mm)	(Average Annual) Precipitation (1947-1963) (mm)
Masset[1]	3	843	963	1326
Tlell[1]	6	792	793	1047
Mamin R.	61	1139		
Marie L. Low	64	1327		
Marie L. N.	226	1374		
Marie L. S.	207	1322		
Marie L. R.	398	1478		
Marie L. Hi	468	1202 [3]		

[1] Long term A.E.S. Climatic stations (after Calder and Taylor, 1968), other data from Resource Analysis Branch, B. C. Ministry of Environment.

[2] Undercatch due to exposed locations and high winds is probable at all stations.

[3] Estimated due to missing data.

Monthly Rainfall Averages (1947 - 1963)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Masset mm	110	105	101	89	67	70	58	78	112	194	172	169	1325
Tlell mm	93	74	77	62	41	46	56	68	93	159	137	140	1046

(after Calder and Taylor, 1968)

Monthly Snowfall Averages (1947 - 1963)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Masset mm	279	155	69	0	0	0	0	0	0	2	58	165	728
Tlell mm	196	140	50	2	0	0	0	0	0	0	48	102	538

(after Calder and Taylor, 1968)

Long term climatic information for the area within T.F.L. #39 under consideration is limited. The nearest long term climatic stations are found near the east coast of Graham Island at Tlell and Masset. Fourteen precipitation and temperature recording stations were established in the study area during the summer of 1976 by the Resource Analysis Branch (R.A.B.) of the provincial Ministry of Environment. Precipitation data from R.A.B. stations and long term stations are compared in Table 2. The precipitation appears to be considerably higher in the interior of the island than on the east coast. An examination of the rainfall totals available for the interior (June 1976 - January 1977) would indicate approximately 1.5 times as much precipitation in the vicinity of Marie Lake and Mamin River as that recorded in Masset (Table 2).

The watersheds under consideration would be expected to have somewhat colder average temperatures than those recorded at the coastal climatic stations. In Calder and Taylor (1968) it is suggested that temperatures in the 300-600 m elevation zone would be 1.7°C to 3.3°C colder than those recorded at coastal stations. This temperature difference is enough to produce snow rather than rain during many winter storms. Temperatures colder than 1°C will generally produce snow rather than rain (Calder and Taylor, 1968; Corps of Engineers, 1956). Average wintertime temperatures at Masset and Tlell are illustrated in Table 3. An examination of the temperature records at Tlell and Masset indicate mean daily temperatures between 1.8°C and 5.1°C between November and March (Table 3). At Masset, the mean minimum temperature is below 0°C between 23% and 52% of the time between November and March. Assuming temperatures 1.7°C to 3.3°C lower on the interior of the island, considerable quantities of snow are expected.

TABLE 3. Monthly Temperature Averages.[1]

Mean Daily Temperatures (0°C)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year Average
Masset	1.9	3.3	3.8	6.0	8.9	11.7	13.8	14.4	12.6	8.6	5.1	3.1	7.8
Tlell	1.8	3.1	3.7	5.9	8.8	11.9	13.8	14.5	12.3	8.6	4.7	2.8	7.7

(after B.C. Dept. of Agriculture)

Mean Daily Minimum Temperatures (0°C)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year Average
Masset	-0.8	0.4	0.5	2.1	4.8	7.8	10.1	10.6	8.6	5.0	2.0	0.6	4.3
Tlell	-1.0	0.2	0.2	2.1	4.9	8.5	10.1	10.9	8.4	5.2	1.7	0.4	4.3

(after B.C. Dept. of Agriculture)

% of Days with Minimum Temperatures Below 0°C

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Masset	52	43	36	18	5	0	0	0	0	7	23	35

(after Calder and Taylor, 1968)

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[1] Based on available data between 1941 - 1970.

There is no published data on snow accumulation and depths in the study area. The long term average snowfalls at Tlell and Masset are 54 cm and 73 cm respectively. Many of the watersheds experience considerable quantities of snow as shown by the fact that forest harvesting is restricted during mid-winter months in many areas. The upper Mamin, Brent, Ghost, and Phantom watersheds are apparently considered to be relatively heavy snow accumulation areas (Personal communication, M & B staff). Although snow accumulations are moderate compared to higher elevations on the mainland coast, a considerable snowpack will accumulate during many winters.

The Queen Charlotte Islands are considered to be one of the windiest areas in Canada (Calder and Taylor, 1968). The climatic stations with anemometers are located mainly on the perimeter of the islands so it is difficult to establish an accurate picture of the wind in the interior. The maximum hourly wind speed at Sandspit during the period 1955-1959 was 128 km/hr and it is estimated that gusts up to 200 km/hr would occur (Calder and Taylor, 1968). The most obvious evidence of the high wind velocities is the unusual amount of blown down timber.

The wind in the individual watersheds depends strongly on the direction of the prevailing winds and orientation of the watershed. The southeasterly winds (average approx. 40 km/hr at Sandspit during January) are expected to be particularly strong in the subject watersheds.

STREAMFLOW

Streamflow information for this area is limited. The only streamflow gauge is on the Yakoun River; this information collected by Water Survey of Canada (1974, 1975, 1976 & 1977) is summarized in Figure 2. The Yakoun is the largest river in the area, and should not be considered to give completely accurate estimates on streamflow for the other streams since it is buffered by a number of lakes, the largest being Yakoun Lake. The maximum annual daily peak flows are distributed throughout the months October to January with the greatest number occuring in November and December (Figure 2A). Calculations of peak flows for the Yakoun River are presented below.

	Maximum Daily Discharge		Maximum Instantaneous Discharge	
25 year return period	$617m^3/sec$	$1.26m^3/sec/km^2$	$820m^3/sec$	$1.67m^3/sec/km^2$
50 year return period	$700m^3/sec$	$1.42m^3/sec/km^2$	$926m^3/sec$	$1.89m^3/sec/km^2$

(after D. Reksten, Water Investigations Branch, Ministry of Environment, personal communication)

FIGURE 2A -TIMING OF MAXIMUM DAILY DISCHARGE - YAKOUN RIVER (1962-74)

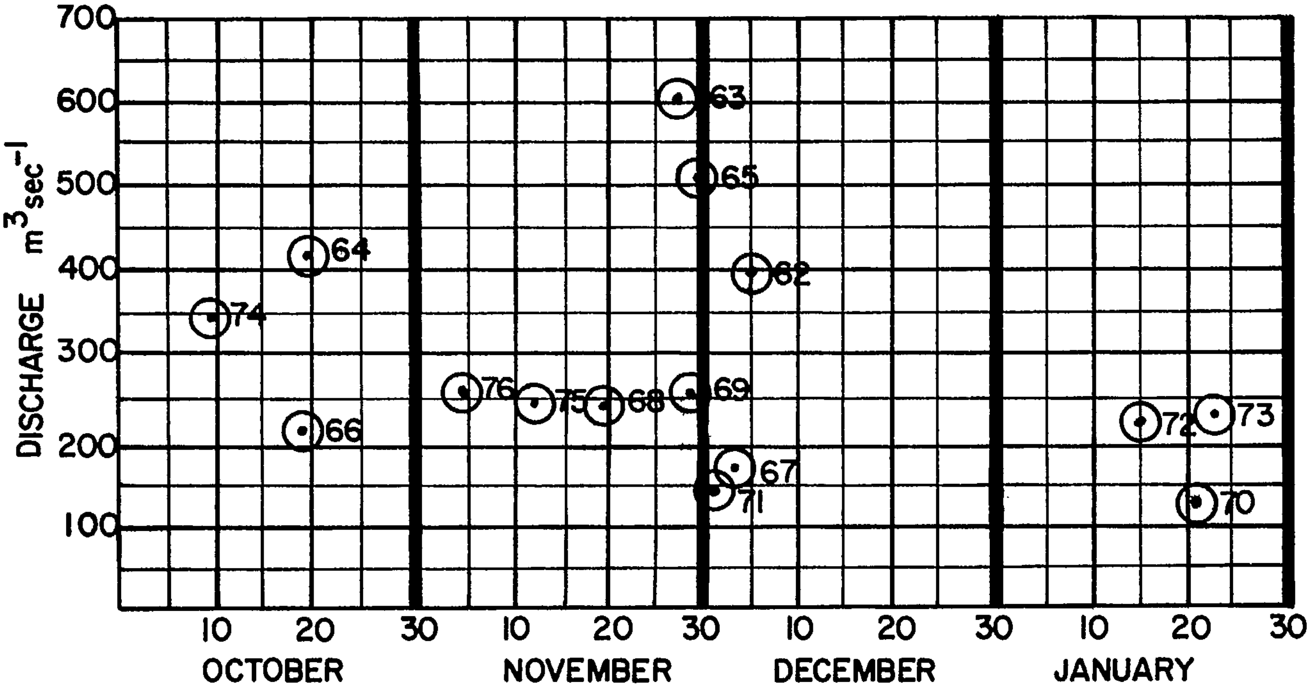
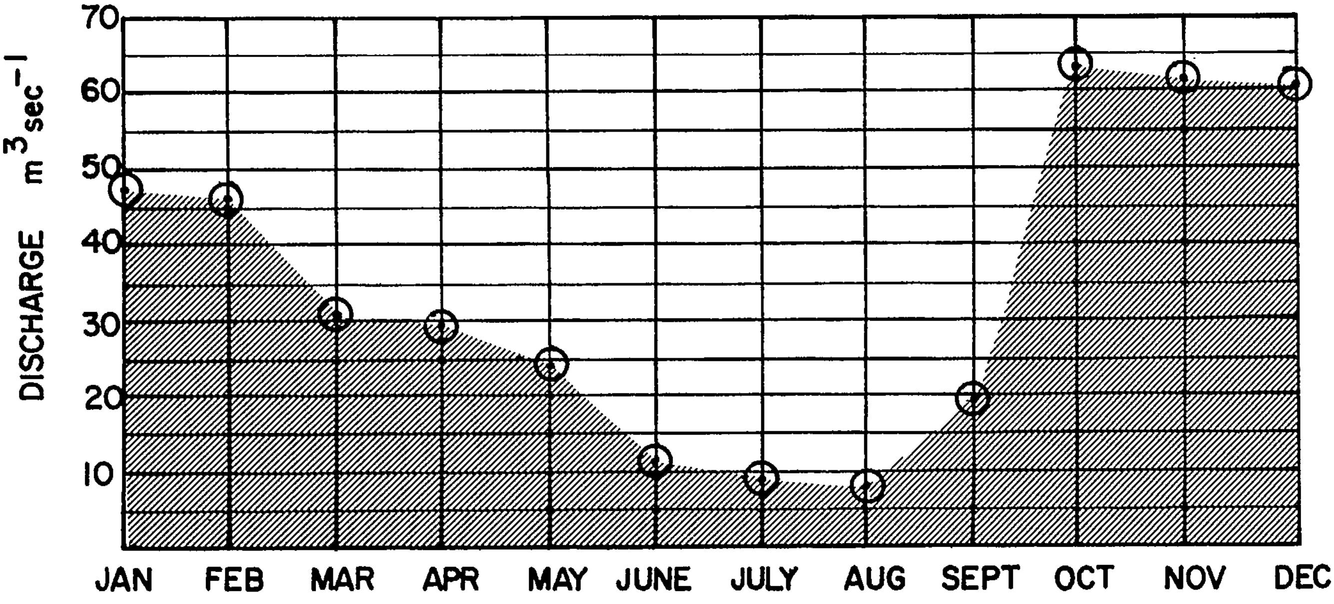


FIGURE 2B - MEAN MONTHLY DISCHARGE - YAKOUN RIVER(1962-76)



FISHERIES RESOURCE

All 5 species of Pacific salmonids and the steelhead trout occur in the study area. Several species of resident sport fish (Dolly Varden, cutthroat trout) also reside in the streams. Approximate average annual escapements of the anadromous salmonids are indicated in Table 4.[1]. The main commercial stock is the even year pink salmon. All of the major streams in the study area except Blackwater Creek are accessible and utilized by anadromous fish. The Yakoun is the largest river on the Queen Charlotte Islands and provides spawning habitat for the only significant local chinook salmon stocks.

Considering the relatively small drainage areas of these watersheds, the salmon escapements are extremely high. Smaller streams are often more sensitive to a broad range of hydrologic impacts than are larger watersheds and extreme care in evaluating harvesting proposals is therefore in order.

It is worth noting that the escapements of pink salmon were historically much higher than current levels. A large even year pink salmon fishery took place in Masset Inlet but was terminated because of declining stocks. The pink catch in 1966 and 1968 were 597,000 and 675,000 fish respectively. The fishery were closed after 1970 (catch of 42,000) as a conservation measure. A decline in the quality and extent of spawning habitat due to forest harvesting practices is probably partially responsible for this decrease.

Recreational fisheries in the Queen Charlottes are concentrated in this area because of the access to the Islands' main population centers and the presence of appropriate fish stocks.

PRESENT FOREST MANAGEMENT PRACTICES

Presently most of the area is natural, mature stands and thus forest managers are just beginning to regulate the area to sustained yield, with a planned rotation of approximately 80 years. To date most of the harvesting has been conducted in the valley bottom and the silvicultural system in use is the clearcut method with natural regeneration. It has been found that no site treatments are necessary for regeneration. Clearcuts have been large (80-160 ha) and progressive, with the result that openings in the forest canopy have been extensive. In the last 5 years there has been a trend towards patch clearcutting (80 ha openings). As noted in the climatic section, the area is susceptible to high winds with the result that windthrow has been a problem. Attempts have been made to extend clearcuts to windfirm boundaries which again has led to some large clearcuts. The yarding system is generally high lead with some crawler tractor skidding in the valley bottom.

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[1] "Escapement" refers to the number of adult fish returns to spawning streams. The term "catch" refers to the number of fish harvested.

TABLE 4. Average salmonid escapement from 1966-76.

River	Chum	Coho	Pinks (even year)	Pinks (odd year)	Sockeye	Chinook	Steelhead
Honna	4,800	1,600	18,700	500			
Mamin		2,300	40,000		200		450
Tlell		13,000	6,200	4,000			
Yakoun		7,400	348,000	800	11,000	1,700	5,800

TABLE 5. Summaries of past and proposed forest harvesting by watershed. (Data from MacMillan Bloedel, Queen Charlotte Islands Division.)

Watersheds	Total Area (hectares)	% of Watershed Harvested by the End of 1977	% of Watershed[1] Harvested by the End of 1982	Area to be Harvested in the[1] 5 year plan (hectares)	Years Since Harvesting Commenced
Honna	4,671	29	42	615	12
Mamin (total)	13,835	32	38	830	32
Mamin	10,603	33	37	425	32
Blackwater	3,232	27	41	453	21
Yakoun (total)	47,964	15	21	2,877	27
Yakoun (partial)	31,036	13	15	619	27
Canoe	2,133	7	10	65	15
Gold	3,154	17	33	506	27
King	2,051	14	22	166	16
Ghost	4,306	9	20	492	13
Brent	3,594	35	46	392	12
Phantom	1,691	5	6	0	3
Florence	3,650	30	37	255	16
Datlamen	5,406	0.2	0.2	0	22
Tlell					
Survey	7,916	6	11	320	8
Feather Lake	4,915	0	0	0	0
Awun	6,726	2	2	0	23

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[1] Area proposed in the 5 year plan presented to agencies in July, 1977. Final plans negotiated at meeting of August 4, 1977 were slightly different.

Harvested areas regenerate naturally to western hemlock and Sitka spruce with a delay of approximately 1 - 2 years. Regeneration growth is rapid with observed heights of 3 meters, 10 years following establishment and 7.5 meters, 20 years following establishment (M & B personnel. pers. comm.). Most of the harvesting has been conducted in the valley bottom and rates of growth are somewhat slower on hillslope positions.

Prior to 1962 approximately 4,000 hectares had been harvested, mainly in the Yakoun and Mamin River watersheds. Since 1962, approximately 10,000 hectares have been harvested, primarily in the Florence, Mamin, Yakoun and tributary watersheds. The total area under consideration is approximately 75,000 hectares (this includes those areas in the Yakoun, Honna, Tlell, Florence and Mamin watersheds within T.F.L. #39).

The area calculations and proportions of watersheds cut are indicated in Table 5. A more complete summary of historical annual timber harvest is presented in Appendix I. Also listed in Table 5 are the percentages of the watersheds and area summaries that were proposed for harvest in the original 5 year plan. The final harvesting plans that resulted from discussions between company and agency personnel at a meeting on August 4, 1977 are somewhat altered from those presented in Table 5.

These watersheds are unusual in coastal B.C. in that they are almost completely forested with commercial timber (J. Gooding, B.C. Forest Service, personal communication).

REGIONAL HYDROLOGIC PROCESSES

AN OUTLINE OF THE HYDROLOGIC CYCLE

The components of the hydrologic cycle are outlined in Figure 3A. The water that falls as precipitation (rain or snow) leaves the watershed as either streamflow, or evaporation. The processes by which water moves from the point where it reaches the earth's surface to where it emerges as streamflow is termed streamflow generation. Water may leave the watershed almost immediately or may be stored for some time as snow, soil water, groundwater, or surface water (lakes). In this report those processes by which water moves through the watershed to become streamflow are of primary importance because the rates of these processes determine the shape of the storm hydrograph.

The storm hydrograph is simply a graph of stream discharge versus time (Figure 3B). If the volume or magnitude of peak flows are increased as a result of watershed changes, the storm hydrograph will illustrate these changes.

Water reaches the stream through four primary routes:

1. Channel interception is precipitation which falls directly into a stream channel. This component forms a very small part of storm hydrographs.

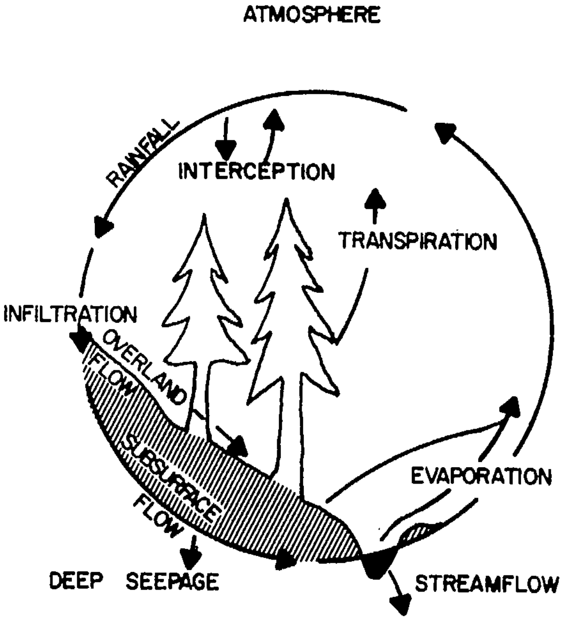


FIGURE 3A - THE FOREST HYDROLOGIC CYCLE (after Harr 1976)

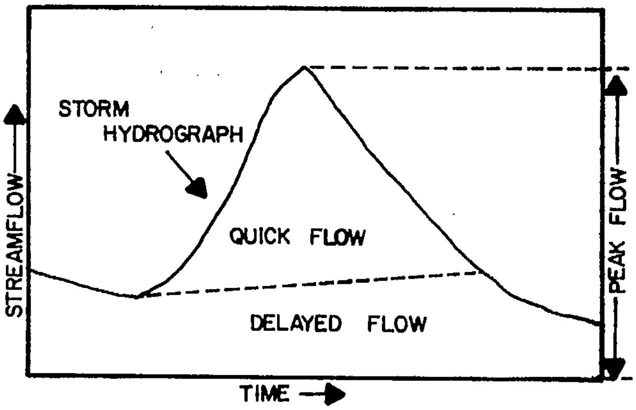


FIGURE 3B - A STORM HYDROGRAPH ILLUSTRATING THE TERMS USED FOR HYDROGRAPH SEPARATION (after Harr 1976a)

2. Overland flow is that water which does not enter the soil mass but flows directly over the surface until it enters the stream channel. In well vegetated areas overland flow is the exception rather than the rule.

3. Subsurface storm flow or interflow comes from water that infiltrates into the soil, and is intercepted in its downward course by a layer of restricted permeability such as hardpan or bedrock. It is directed laterally and flows downslope until it reaches the channel.

4. Baseflow is that portion of precipitation which infiltrates deep into the soil and sustains streamflow during long dry periods.

During winter storms in a coastal B.C. area, subsurface stormflow makes up a large portion of the storm hydrograph volume. A change in the rate of water movement or a change in the input will alter the storm hydrograph.

The storm hydrograph is often divided into the components quickflow and delayed flow (Figure 3B). Although the division of these components is somewhat arbitrary, the quickflow volume consists of subsurface storm flow whereas the delayed flow portion consists of base flow.

Examination of streamflow records in coastal B.C. indicate that streams respond to rainfall extremely rapidly (i.e., the ratio of quickflow to delayed flow is high). Peak streamflow usually occurs very quickly following the precipitation event. Infiltration capacities (the maximum rate at which water can enter the soil) are considerably higher than the maximum recorded rainfall intensities.

POSSIBLE LAND USE IMPACTS

Land use activities can affect water yield (quantity), water regime (timing of flows), and water quality. Watershed studies throughout the world have documented water use by forest vegetation (Hibbert, 1967). Increases in water yield of up to 450 mm per unit area following harvesting have been recorded (Hibbert, 1967). The increase in yield is proportional to the area harvested. In the Queen Charlotte study area, water is not heavily used other than as habitat for fish, and changes in annual yield are not a major concern. The increases in flow are primarily during the spring, summer and fall (i.e., when the vegetation would have been using water for transpiration). Although the summer increases are small in an absolute sense (annual water yield) they would add a significant increment to minimum flows and would normally be beneficial.

Removal of vegetation can also alter the distribution of runoff in time (i.e., streamflow regime). Specifically the volume and magnitude of peak flows can be altered; in most cases they are increased

(Harr *et al*, 1975). Peak flows have the potential to shift gravel, debris, soil and rock in torrents and to sluice out stream channels. A recent field examination of the study area indicates the occurrence of such events in the past.

Many studies have demonstrated increased sedimentation following forest harvesting (Anderson *et al*, 1976). The sources of the sediment include increased surface erosion as well as an increased rate of mass wasting.

PEAK FLOW GENERATION

Jeffrey (1970) has identified four general types of floods (Table 6). Peak flows in the study area will generally be of types 1 or 2.

1. Floods with storage elements full but no snowmelt.

Considerable research has been conducted in Oregon and elsewhere into possible effects of harvesting on type 1 floods. The results of these studies have been summarized by Harr *et al* (1975) for the Alsea project and by Rothacher (1973, 1970, 1965) on the H.J. Andrews Forest. The results generally indicate that by decreasing interception and transpiration by vegetation, partial clear-cutting increases peak flow, quick flow, delayed flow and total storm hydrograph volume. The most dramatic results occurred during the fall, before the soils were completely saturated. The average increases in winter peak flows were smaller than those recorded in the fall.

A small increase in peak flows during a fall flood could have deleterious effects on fishery values because sediment transport is often high during such storms. Sediment that has accumulated in stream channels during the summer is moved at this time. An increased movement of sediment into redds that have recently been formed has a deleterious effect on incubating eggs.

The studies cited in the preceding paragraphs were undertaken using mean values for a number of storms. Many of these storms are so small that increased channel damage is not likely to occur, even if storm hydrograph parameters were increased.

It is worth noting at this point that relatively permanent effects of roads on the storm hydrograph were documented in the above studies (Harr, 1976). Large peak flows were increased when at least 12% of a watershed was compacted by road building, tractor skidding, or other similar activity. Clearcut and high lead areas can average 15 - 17% total disturbance due to roads, landings, and minor skid roads (Smith and Wass, 1976; Schwab, 1976).

It has been suggested that the interception and evapotranspiration effects of forest harvesting decrease logarithmically with a return to normal after 20 years (Harr, 1976; after Kovner 1957 and Ziemer, 1964). The decrease would be more rapid on Graham Island with its rapid regeneration and growth.

TABLE 6. Types of floods occurring in B.C.

Type of Flood

1. Floods with storage elements full but no snowmelt.

   Result from long duration, low intensity, frontal storms falling on a saturated landscape. This type of storm typically generates peak flows in coastal areas of B.C., particularly in low elevation watersheds.

2. Floods with all storage elements full and with snowmelt.

   Winter floods resulting from precipitation plus snowmelt of a preexistent snowpack.

3. Floods with storage elements not full.

   High-intensity rainfall whose rate of delivery exceeds the soil-infiltration rate.

4. Floods with no precipitation, but sudden release of storage elements.

(modified after Jeffrey, 1970)

2. Floods with all storage elements full and with snowmelt.

A second type of runoff process operative in the area is rain-on-snow runoff generation. These types of events have the potential to cause massive flooding. The floods that occurred in northwestern B.C., November 8 - 11, 1974 and southwestern B.C., November 13, 1975 were of this type. It is our hypothesis that this type of runoff event could be significantly increased by forest harvesting.

The energy components of melt during rain falling on snow consist of convection for overlying air, condensation, conduction from underlying soil and warm rain, solar radiation, and terrestrial radiation (Reifsnyder and Lull, 1965 after Wilson, 1941). The solar radiation component and conduction from underlying soil are generally considered to be small (Corps. of Engineers, 1956). A small amount of heat may be transmitted from warm rain; however, the major sources of melt would be condensation and convection.

Condensation melt results from the flow of water vapour down a vapour pressure gradient in the air above the snow surface, and the subsequent release of its latent heat of vaporization (2450 J/g). For every gram of water condensed, 7.5 grams of snow will be melted yielding 8.5 grams of melt and condensate.

Convection melt is the result of the often observed temperature inversion above a snow surface. Sensible heat flows down this gradient to the snow.

Both of the above are turbulent exchange processes and are dependent on wind velocity. Graphical solution of condensation and convection melt calculations are presented in Figure 4. These graphs apply particularly to melt at plots in the open.

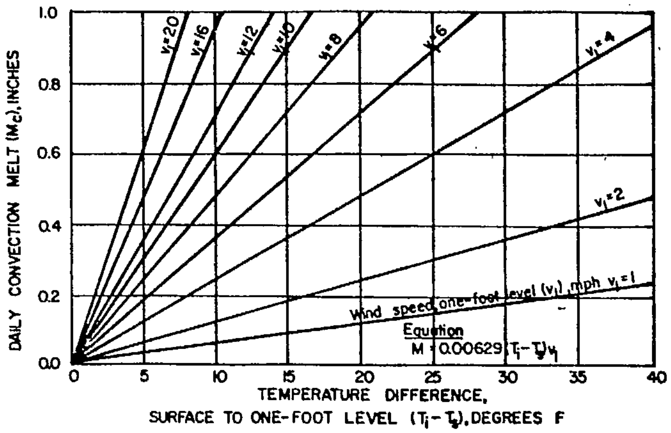
Formation of a large forest opening would increase wind velocity considerably over a snow pack. Several wind profiles within forest stands are graphically illustrated in Barry and Chorley (1968) who cite Kittredge (1948). A 24 km/hr wind (at 30 m elevation) produced about 3 km/hr wind 30 cm above the ground in a forested stand, whereas 13 km/hr of wind was recorded 30 cm above the ground in open country under 24 km/hr winds.

In Appendix II the effect of a "typical" winter frontal storm on an open and forested snow covered plot is calculated. The results of these calculations are presented below:

	Forested Area	Clearcut Area
Radiation Melt (cm)	0.59	0.59
Convection Melt (cm)	0.84	2.11
Condensation Melt (cm)	1.37	3.42
Rain Melt (cm)	0.13	0.13
Total Melt (cm)	2.93	6.25
Rain (cm)	2.54	2.54
Total (cm)	5.47	8.79

Figure 4 - Graphical Solutions of Convection Melt and Condensation Melt Equations (after Corps. of Engineers, 1956)

CONVECTION MELT



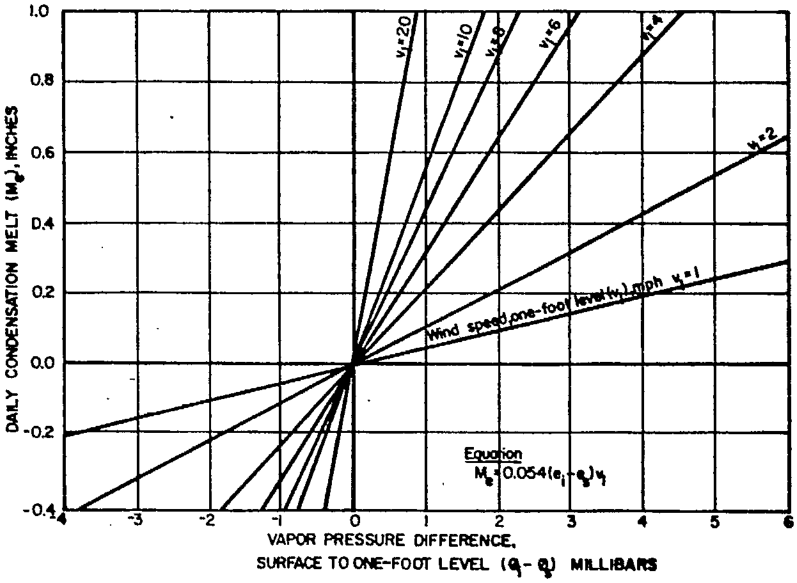
NOTES:

The general equation for daily convection melt (M_c) in inches, is as follows

$$M_c = 0.00629(p/p_0)(Z_a Z_b)^{-1/6}(T_a - T_s)v_b$$

where $\underline{p/p_0}$ is the ratio of atmospheric pressure at the site to standard sea level pressure; $\underline{Z_a}$ is the height in feet above the snow surface of the air temperature measurement, $\underline{T_a}$ (in degrees F), and $\underline{Z_b}$ is the height in feet above the snow surface of the wind speed measurement, $\underline{v_b}$ (in mph); $\underline{T_s}$ is the snow surface temperature.

CONDENSATION MELT



NOTES:

The general equation for daily condensation melt (M_e) in inches, is as follows

$$M_e = 0.054(Z_a Z_b)^{-1/6}(e_a - e_s)v_b$$

where $\underline{Z_a}$ is the height in feet above the snow surface of the vapour pressure measurement, $\underline{e_a}$ (in mb), and $\underline{Z_b}$ is the height in feet above the snow surface of the wind speed measurement, $\underline{v_b}$ (in mph); $\underline{e_s}$ is the saturated vapour pressure at the snow surface temperature.

It should be noted that the direct transfer of heat from warm rain produces a relatively small component of melt.

Forest harvesting could have an effect on peak flows during this type of runoff event, considering there was more than a 60% increase in melt plus rain derived from a plot. The factor that greatly increases the melt is the wind velocity at ground level.

A word of caution is certainly in order because these equations were not derived for the purpose of comparing forested and nonforested watersheds. Also, these are plot calculations and do not explicitly represent what is happening throughout a large watershed. A recent theoretical study by Weisman (1977), however, suggests that point melt calculations can give a reasonably accurate estimate of total melt.

During a series of rain storms that fell on the Corps of Engineers snow hydrology research site in the Willamette Basin in Oregon, the hydrographs were analyzed using plot data to determine which component of runoff was condensation and convection melt (Corps of Engineers, 1956). The entire heavily forested basin was covered with snow, temperatures were between 0°C and 10°C, and maximum average daily winds were less than 5 km/hr. Condensation and convection melt made up about 30% of the peak flow hydrograph. It is probable that under the high wind conditions that exist in the Queen Charlotte Island study watersheds, snowmelt would have been much greater following a similar series of storms on a snowpack.

Forest clearing can change the water transmission characteristics of a watershed (Smith, 1974). The previous discussion has assumed that subsurface flow occurs for the most part unchanged, whether there is snow on the ground or not. This would be reasonable as long as the ground under the snow remains unfrozen. Freezing and thawing cycles can, however, create snow crusts which cause water to be transmitted laterally downslope directly into stream channels rather than into the soil (Smith, 1974). Water would reach the stream channel more quickly in this manner.

TEMPORAL CONSIDERATIONS

A number of processes must be considered within a temporal framework in order to determine the period for hydrologic stabilization. These processes include slope stability, surface erosion, streambank and channel stability, effect on rain-on-snow hydrographs and effect on fall and winter rain storm hydrographs.

SLOPE STABILITY

Forest harvesting and road construction both lead to an increased incidence of soil mass wasting in steep terrain (Rice *et al*, 1972).

Root decay, windthrow along clearcut edges, debris accumulation in gullies, and changes in drainage as a result of gouging during yarding are factors related to accelerated mass wasting in clearcuts. Work by a number of researchers indicates that roots smaller than 1 cm in diameter are particularly important in providing strength to the soil mass (O'Loughlin, 1974; Burroughs and Thomas, 1977). These roots decay within 2 - 7 years following harvesting. The result is an increased incidence of mass wasting during and beyond this period (Bishop and Stevens, 1964). In order for clearcut sites to stabilize, it is necessary for new roots to reoccupy the soil mass. The time period required for this to occur is related to the rate and vigour of regeneration establishment. Few references can be found in the literature which discuss this time period. Anderson *et al* (1976) cite Nakanos (1971) observations that 30 years were required for root strength of the new stand of trees to reach half effectiveness in reducing the frequency of landslides.

Forest roads have been recognized as a major sediment source through both surface erosion and mass wasting. Surface erosion is discussed below. Mass wasting can occur during construction with the loading of saturated soils, or may be delayed a number of years as sidecast and road fill materials which overload slopes, fail. Where inadequate road drainage structures lead to a concentration of surface water, failures can develop due to saturation of the road or adjacent sites. These failures generally occur shortly after construction, but may be delayed a number of years. While roads can cause mass wasting, they can also act as check dams, stopping debris from mass movements which occur on the slopes above. It is usual, however, for suspended sediment to continue downslope. In some cases the roads are permanent check dams while others fail with time. On steep slopes the material should be generally end-hauled, as sidecasting or piling on the outside of the road induces further mass wasting.

Extreme hydrologic events have been observed to initiate soil mass movements on sites which have been stable for a long period of time. Therefore the frequency of mass movements is related to storm intensity as well as forest harvesting and roads. Generally the majority of road and clearcut induced mass movements would occur within the first 20 years following logging, and thereafter decrease in frequency to the preharvest level.

SURFACE EROSION

Surface erosion occurs when water or (wind) detaches and transports particles of exposed soil. This type of erosion is not spectacular like mass wasting but it may move equally large volumes of soil.

In climates like the Queen Charlotte Islands, surface erosion is present wherever soil is exposed. Studies ongoing at Carnation Creek on Vancouver Island indicate that the majority of surface erosion occurs during the actual soil disturbance activity (e.g., road construction). Ongoing surface erosion can be a problem on road surfaces, especially where abandoned roads are not adequately cross drained or revegetated. Except where roads become new stream channels, in many areas surface erosion discontinues within 5 years. However, all mass wasting sites are surface erosion sites and the mass wasting events frequently are delayed a number of years.

CHANNEL STABILITY

Stream channels are dynamic and constantly integrate the hydrologic processes occurring within the watershed. Modification of flow regime and quantity, changes in debris input, gravel recruitment and sediment all have an impact on the stream channel. As long as harvesting activities continue, and as long as the impacts continue, the channel can be affected.

Very little is reported in the literature on the temporal aspects of stream channel stabilization. Swanson *et al* (1976) in a western Oregon study suggested that disturbed stream channels may require many decades to stabilize.

STORM HYDROGRAPHS

When an area is harvested, the evapotranspiration is reduced and microclimate is altered. Due to higher soil moisture levels, early fall rainstorms produce higher than normal peak flows.

As regeneration progresses this effect declines, probably logarithmically, with preharvest conditions being approximated after 20 years (Harr, 1976; after Kovner 1957 and Ziemer, 1964). As discussed in a previous section, rain-on-snow events are usually associated with turbulent, warm, moist air. With clearcutting, the speed of winds at the ground surface are increased, which results in a greater heat and moisture exchange, and thus accelerated melting. This melting occurs on a greater snowpack since more snow accumulates in openings than in the adjacent forest (Berndt, 1965; Gary, 1974; Hoover and Leaf, 1967). The time required to return to preharvest snowmelt conditions has not been thoroughly discussed in the literature.

In order for a forest stand to approximate preharvest snowmelt conditions the canopy should be closed in order to shelter the snowpack from winds. This would require approximately 20 to 30 years.

WATERSHED MANAGEMENT CONSIDERATIONS

In the context of coastal B.C., the watersheds of Block 6A, T.F.L. #39 are relatively unique in that they are for the most part completely forested with commercial stands. Considering the size of the watersheds, salmon escapements are high. With the exception of the Blackwater, the streams are accessible and utilized throughout. Therefore, any acceleration of upslope erosion, combined with modified hydrologic processes, has a high probability of directly affecting salmonid habitat.

A consideration which must be borne in mind is that the watersheds identified in Table 5 are relatively large and that they are composed of smaller salmon producing subwatersheds. Thus while the proposed harvesting and possible hydrologic impact in the larger watershed may appear reasonable, the subwatersheds may be completely harvested under these proposals and have a high potential for impact. It is therefore important to consider the proportion of these watersheds being harvested.

The previous discussion has treated erosional and hydrologic processes individually. Watershed management required that the combined effect of these processes be considered in evaluating the potential modification to salmonid habitat and production. Any one factor such as accelerated gully erosion may by itself have limited impact, but when combined with windthrow, increased runoff or logging debris it may have a major impact on the aquatic environment. The potential for individual factors or processes to combine continues for a considerable period of time as discussed in the section on temporal considerations. Generally, these factors have stabilized or returned to approximate preharvest levels only after 20 to 30 years. However, extreme climatic events may precipitate damage to aquatic habitat beyond this time period.

SUMMARY AND RECOMMENDATIONS

GENERAL RECOMMENDATIONS

The previous discussion identified the characteristics, values and hydrologic processes of some watersheds within Block 6A,T.F.L. #39. It identified the complex nature of rain on melting snow events and the problems in determining the temporal aspects of watershed stability. It also outlined a number of impacts resulting from changes to hydrologic processes as a result of harvesting. Considering the complex interaction of the other hydrological processes which are modified by land use practices, it is apparent that there is no precise method of determining the exact spatial and temporal distribution of forest harvesting to minimize hydrological impacts. Recognizing this, a conservative but flexible approach to watershed planning is proposed. As a principle for forest management planning, it is recommended that a moderate proportion of a watershed (1/3rd) be harvested over a period such as 25 years. This would allow the watershed to be monitored, observed, and maintained in some degree of stability. Research may indicate that a higher proportion of the watersheds be cut over a shorter period of time with quite acceptable hydrological impacts.

The upland watersheds (Phantom, Mamin, Blackwater, King, Ghost) have a greater potential for accelerated erosion and altered hydrographs following clearcutting and road construction, than the lowland watersheds (Florence, Survey, Canoe, Feather Lake, Honna). As a result, a more rapid rate of watershed harvest may be more acceptable in the lowland watersheds than in upland watersheds.

When considering the spatial distribution of forest harvesting, it is recommended as a planning principle that the harvest should include the various hydrologic units in proportion to their presence in a watershed. For example, the harvest should include stands on steep slopes as well as on the valley bottom in proportion to their presence. This will avoid the situation where one pass would involve the harvesting of stands with a high potential for hydrologic modification. Thus, mixing of terrain or hydrologic units should either eliminate the impact of forest harvesting or reduce it and spread any adverse effects out over time.

When planning this spatial layout, it is recommended that road mileage be kept as low as possible, especially on hillslope positions. This will require a comparison of long term options for road network development. All unused roads should be properly "put to bed".

These are general recommendations. For example, in those watersheds where slope and channel stability has become or appears to be a problem, any additional harvesting should be carefully assessed, regardless of the acreage harvested.

RECOMMENDATIONS FOR INDIVIDUAL WATERSHEDS

The following recommendations and observations are based on concepts discussed in this report as well as on a limited field knowledge of the area. The recommendations are meant to serve as an aid to the local resource managers in applying their detailed knowledge of the area in assessing forest harvest proposals.

1. Mamin - Blackwater Watershed

The Mamin River systems shows signs of excessive gravel movements. It is a relatively small system with an extremely high salmonid escapement. Fisheries Service records (Walker *et al*, 1971) indicate a history of problems associated with forest harvesting and gravel removal. Because of higher elevations and steeper slopes harvesting and roadbuilding in the upstream portion of the watershed has a high potential for altering the storm hydrograph. Accordingly we would recommend against further large scale harvesting at this time.

A shift in harvest from the Mamin to the Blackwater has been proposed. Although anadromous fish do not utilize the Blackwater system, approximately 30% of the Mamin River escapement spawn below the confluence of Blackwater Creek. Local resident staff consider the Blackwater to have a high snow accumulation potential and hence a considerable hydrograph alteration potential exists. A scaled down plan from the original proposal is recommended.

2. Yakoun River

The Yakoun is the largest river on the Queen Charlotte Islands and is utilized by all species of Pacific salmonids. The proposed harvesting within the total watershed, (6% over 5 years) appears reasonable.

Tributaries

Gold Creek

Considerable harvesting (506 hectares) was proposed in the Gold Creek drainage. Although 33 percent of the drainage will have been harvested over a 27 year period, there are several lakes in the drainage that would tend to buffer peak flows.

A slight relaxation of the general guideline (1/3 over 25 years) may therefore be acceptable. Site specific considerations may, however, preclude the harvest of many cutblocks.

Brent, Ghost and King Creeks

The plan proposed a heavy concentration of cut in the upper tributaries of the Yakoun River. Approximately 615 hectares were projected to be cut into the Brent Watershed, which would bring the total watershed harvest to 45.6 percent in 17 years. This is a watershed where the storm hydrograph would have been altered considerably. We would recommend against further harvesting in the Brent Creek watershed at this time.

A relatively high development over a short period is proposed in the Ghost and King Watersheds (492 and 166 hectares respectively). The area to be cut does not appear to be a problem, however particular effort should be directed to identifying potential stability problems.

3. Honna Creek

A cut of 615 hectares (13%) is proposed for the Honna Creek Watershed. In view of potential hydrograph alteration and high fishery habitat values it is recommended that a reduced cut be considered.

FURTHER RESEARCH

The recommendations in this report are in part, based on probable alterations to the storm hydrograph brought about by harvesting activities. Obviously more precise information would be useful in determining the rate and patterns of possible clearcuts. Recommended areas of further research include:

1. Plot Studies. Investigations to document melt processes using energy balance techniques (e.g., Corps of Engineers, 1956; Anderson, 1968), plot studies of snowmelt and accumulations patterns (e.g., Gary, 1974; Goldings, 1977), and studies of water transmission through soil (e.g., Harr, 1977) would be particularly useful. A problem associated with these methods is that extreme variation in terrain over relatively small areas limit the applicability of results.

2. Watershed Studies. These studies involve calibration of streamflow parameters between two or more similar watersheds, followed by a land use

change accompanied with an analysis of hydrograph changes attributed to treatment. Many of the studies referred to in this report (particularly Harr, 1976) are based on these methods.

3. Streamflow Monitoring. Streamflow measurements will aid in the identification of general hydrograph characteristics, however it is usually impossible to identify the effects of harvesting unless there is a systematic comparison of logged and unlogged watersheds under similar topographic and climatic conditions.

Swanson and Hillman (1977) have successfully documented changes in water yields using these types of methods. In coastal B.C. the lack of topographic and climatic homogeneity may limit the applicability of this approach.

4. Watershed Modelling. Various watershed models are successfully used to predict streamflow and to regulate reservoirs in complex river systems. Examples of such models include the Stanford model, the SSARR Watershed model, and the Sacramento model. The success of these models in predicting streamflow is dependent on their calibration with existing streamflow records. Although these models are based on physical processes in a broad sense, they lack the precision to determine the effects of land use changes on streamflow.

Models have been developed by Leaf and Alexander (1975) to simulate timber yields and hydrologic impacts resulting from timber harvest on subalpine watersheds in Colorado and Wyoming. Components of the model are based on long term watershed and process research carried on at Fool Creek and elsewhere in the region. As studies of this precision do not exist anywhere in B.C. it would be difficult to develop any type of mathematical model that would predict land use effects on streamflow.

We suggest there is no method for definitively determining "rate of cut" on Queen Charlotte watersheds that is based on sound hydrologic principles or reasoning. Streamflow modelling holds the most promise, but in order to build an adequate model more documentation of the energy balance and knowledge of hydrologic changes attributable to land use are required. Our current watershed management prescriptions must therefore be based on probable changes in hydrologic processes attributable to harvesting.

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APPENDIX I. Temporal distribution of timber harvest by watershed at the end of 1976 (data from MacMillan Bloedel, Queen Charlotte Division)

		% of Watershed Harvested by Time Interval			
Watershed	% Harvested	0 - 5 yrs. (1972-76)	5 - 10 yrs. (1967-71)	10 - 15 yrs. (1962-66)	15 yrs. + Previous to 1962
Honna	29	(not available)			
Mamin					
Mamin	32	5	3	14	10
Blackwater	27	4	3	7	13
Yakoun					
Yakoun (Partial)	13	2	2	6	2
Canoe	4	0	0	1	3
Gold	16	1	1.5	1.5	12
King	13	8	0	5	1
Ghost	6	1	2	3	0
Brent	31	11	20	0	0
Phantom	1	1	0	0	0
Tlell					
Survey	5	3	2	0	0
Feather Lake	0	0	0	0	0
Florence	30	13	9	7	1

APPENDIX II. Snowmelt Calculations

Equations from Corps of Engineers, 1956

Total Snowmelt

$$M = Mrs + Mrl + Mc + Me + Mr + Mg$$

where M - total melt

Mrs - melt resulting from short wave radiation

Mrl - melt resulting from long wave radiation

Mc - melt resulting from exchange of heat between atmosphere and snow (convection)

Me - melt resulting from condensation of water vapour into snowpack

Mr - melt resulting from heat from rain

Mg - melt resulting from heat from the ground

Based on work by the Corps of Engineers (1956) Mrs and Mg are small (average 0.07 in/day and 0.02 in/day respectively) and for the purpose of these calculations will be considered to be negligible.

The various components for melt during a storm will be compared for a forested and clearcut plot. The main difference in melt rates results from the differing wind speeds. The time period is one day.

Assume a winter storm with the following conditions:

- 1 inch rain in 24 hours
- 40^0F. (4.44^0C) - Average temperature
- Snowpack throughout the watershed with a minimum of 5 inches water equivalent
- Snow is ripe (i.e., consists of large crystals) and transmits water rapidly
- Mean wind velocity above forest canopy is 30 mph (at 30 ft.)
- Saturated vapour pressures at 32^0F and 40^0C and 6.11 mb and 8.02 mb respectively
- Relative humidity is 95% and vapour pressure of overlying air will then be 7.62 mb

The 30mph wind at 30ft. was calculated to be reduced to 12 mph (at 30 ft.) within the forest canopy. This reduction of 60% is within the range of 40 - 90% suggested by various authors (see list below). A 0.55 correction factor, as suggested by the Corps of Engineers (1956) was used to calculate the wind speed at the 1 ft. level.

Snowmelt from a Forested plot

Radiation Melt

Long Wave Radiation Melt

$Mrl = 0.029\ (Ta - Ts)$

where Mrl - long wave radiation melt in inches

Ta - air temperature in degrees F

Ts - temperature of melting snowpack (assume 32^0F)

$Mrl = 0.029\ (40 - 32)$

$= 0.23$ in (0.59 cm)

Convection Melt

$Mc = 0.00629\ (Ti - Ts)\ Vi$

where Mc - melt in inches

Ti - air temperature

Ts - temperature of melting snowpack (assume 32^0F)

Vi - wind velocity in mph at one foot level

$Mc = 0.00629\ (40 - 32)\ (0.55 \times 12)$

$= 0.33$ in (0.84 cm)

Condensation Melt

$Me = 0.054\ (ei - es)\ Vi$

where Me - melt in inches

ei - vapour pressure of overlying air

es - vapour pressure at the snow surface

Vi - wind velocity in mph at one foot level

$Me = 0.054\ (7.62 - 6.11)\ (.55 \times 12)$

$= 0.54$ inches (1.37 cm)

Rain Melt

$Mr = 0.00695\ (Tr - 32)\ Pr$

where Mr - rain melt (inches)

Tr - temperature of rain (^{o}F)

Pr - rainfall (inches)

$Mr = 0.00695\ (40 - 32)\ 1$

$= 0.05$ inches (0.13 cm)

Precipitation = 1 inch (2.54 cm) as rain

Snowmelt from Clearcut plot

Radiation Melt

$Mrl = 0.23$ in (0.59 cm) (similar to forested plot)

(some sources suggest that radiation melt may be slightly greater in a forested plot because of long wave radiation from the forest canopy)

Convection Melt

$Mc = 0.00629\ (Ti - Ts)\ Vi$

$Mc = 0.00629\ (40 - 32)\ (30 \times 0.55)$

$= 0.83$ inches (2.11 cm)

Condensation Melt

$Me = 0.054(ei - es)\ Vi$

$= 0.054\ (1.51)\ (.55 \times 30)$

$= 1.34$ inches (3.42 cm)

Rain Melt

$Mr = .05$ in (0.13 cm) (similar to forested plot)

Precipitation = 1 inch (2.54 cm)

Total Melt

	Forested Plot	Clearcut Plot
Mrl	0.59 cm	0.59 cm
Mc	0.84 cm	2.11 cm
Me	1.37 cm	3.42 cm
Mr	0.13 cm	0.13 cm
M (Total melt)	2.93 cm	6.25 cm
Rain	2.54 cm	2.54 cm
Total Rain and melt	5.47 cm	8.79 cm

Effect of a Forest Canopy on Wind Speed at 30 ft Elevation

Study	% Reduction of wind
Meeres, 1977	32 - 63%
*Fons and Kittredge (after Barry and Chorley 1968)	87%
Reifsnyder, 1955	50 - 70%

*Barry and Chorley (1968) suggest that increases in external winds have little effect on windspeed within the canopy.

Reference Cited in Appendix

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Reifsnyder, W.E. 1955. Wind profiles in a small isolated forest stand. Forest Science 1:289-297.