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Cumulative Effects of Forest Harvesting on the Kitimat River, British Columbia

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CUMULATIVE EFFECTS OF FOREST HARVESTING ON THE KITIMAT RIVER, BRITISH COLUMBIA

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ABSTRACT

An abrupt decline of salmonid escapements occurred in the 1970's within the Kitimat River watershed, North Coastal British Columbia. The decline appears to have been associated with severe floods in 1974, 1976, and 1978. Logging of the riparian forest in the main Kitimat valley required only about 8 years, from 1963 to 1970. The active riparian area of the middle Kitimat River has increased by 25% over a 25 year period from the 1960's. The main mechanism of the increase has been channel breakouts along the old, stable riparian forest side channel network. Up to 40% of that sidechannel network has been impacted, with extensive bank erosion. Changes in the Kitimat River could not be linked directly to the overall rate of forest harvesting. The clearcut equivalencies of most constituent watersheds ranged from 5% to about 20%. which are not considered excessive. Moreover, rain-on-snow, considered to be the main hydrological concern associated with clearcuts in coastal watersheds, is not a significant factor in the generation of the highest peakflows. The Kitimat watershed is hydrologically desynchronized by the time (mid-November) that rain-on-snow becomes a factor in the elevation range of most clearcuts. A partial bedload sediment budget for an 8 km section of the Kitimat River indicates the recent formation of several bedload wedges between Hirsch Creek and the Wedeene River. The bedload wedges may be destabilizing the channel as they move downstream.

RÉSUMÉ

Le bassin versant de la Kitimat, sur la côte nord de la Colombie Britannique, a connu une brusque diminution du nombre d'échappées de salmonidés au cours des années 1970. Cette diminution semble être liée à de graves inondations survenues au cours des années 1974, 1976 et 1978. L'exploitation de la forêt riveraine de la principale vallée de la Kitimat n'a nécessité qu'environ 8 ans, de 1963 à 1970. La zone riveraine active du cours moyen de cette rivière s'est agrandie d'à peu près 25% sur une période de 25 ans à compter des années 1960, en raison surtout de la modification en profondeur de l'ancien réseau stable de chenaux latéraux occupé par la forêt ripicole. Jusqu'à 40% de ce réseau, victime d'une érosion importante des berges, a été touché. On ne peut pas relier directement les changements survenus dans la Kitimat au rythme général d'exploitation forestière. Dans la plupart des bassins versants de la rivière, les coupes à blanc équivalaient de 5% à 20%, ce qui n'est pas considéré comme excessif. En outre, la pluie sur la neige, considérée comme la principale préoccupation de nature hydrologique liée aux coupes à blanc dans les bassins versants côtiers, n'est pas un facteur important dans la production des débits de pointe les plus élevés. Le bassin versant de la Kitimat est déjà déjà désynchronisé, du point de vue hydrologique, lorsque la pluie sur la neige devient un facteur déterminant (à la min-novembre) dans la fourchette d'altitudes où se font la plupart des coupes à blanc. Un bilan partiel de la charge de fond à l'égard d'une section de 8 km de la Kitimat indique la récente formation de plusieurs conis d'alluvions entre le ruisseau Hirsch et la rivière Wedeene. Les coins de la charge de fond pourraient déstabiliser le chenal au fur et à mesure de leur progression en aval.

1.0 INTRODUCTION

The Kitimat River study began in 1987 as a pilot project to develop a procedure and format for recording and evaluating habitat decisions made under the newly adopted "no net loss" National Habitat Policy of the Canadian Department of Fisheries and Oceans (DFO). The Kitimat Watershed was chosen in part because the recently approved 5 year (1986-1990) Management and Working Plan for Tree Farm License (TFL) 41, including the Kitimat Watershed, provided a convenient focus for a pilot project. The choice of the Kitimat River was influenced by several other factors, including the extensive record of land use changes and industrial development within the past 40 years, a perception of habitat degradation and declining fish stocks in the Kitimat River, and a perceived linkage between declining fish stocks, habitat degradation, and the rate of forest harvesting within the basin. In recent years, the perception of habitat degradation had been reinforced by flood damage to structures along the channels of the Kitimat River and its tributaries, such as the CNR bridge over the Little Wedeene River and facilities at Hirsch Creek Park in 1988, the domestic water supply intakes of the Municipality of Kitimat on the Kitimat River in 1989/90, and Highway 37 in 1991.

In addition to developing a recording procedure and format for current habitat decisions, past habitat decisions were also evaluated as part of the Kitimat Study. The historical evaluation of the Kitimat watershed was limited initially to the analysis of the hydrological effects of the rate of forest harvesting, perceived locally to be the main agent of channel stability change and habitat degradation in the Kitimat. As the study proceeded, it became apparent that other factors were involved in changes along the channel of the Kitimat River and its tributaries. Several lines of evidence suggested that the overall rate of forest harvesting offered at best only a partial explanation of river channel changes. Other evidence pointed to the role of riparian management practices during logging and changes in the coarse (bedload) sediment budget as agents of river channel change. An examination of the climate records of the North Coast area suggested that recent climate fluctuations may also have played a role in recent river channel changes. This report presents the evidence concerning each factor that may have affected the channel of the Kitimat River and offers a synthesis of the information.

Three objectives were defined for the Kitimat River study:

1. Evaluate the historical changes in Kitimat River salmonid stocks;
2. Identify the locations and quantify the extent and timing of historical channel changes on the Kitimat River and its major tributaries;
3. Document the relative influence of the main agents of river channel change on the channel of the Kitimat River and its tributaries. These agents may include the overall rate of forest harvesting, sediment supply and transport, large woody debris supply and transport, riparian land use practices, and climatic/geological events and trends.

The Kitimat study included analyses of the following:

1. Historical changes in the salmonid escapements of the Kitimat River System.
2. Channel changes on the Kitimat River and several of its main tributaries, particularly the Little Wedeene River, Wedeene River, Hirsch Creek, Chist Creek and Nalbeelah Creek.
3. Historical streamside forest harvesting practices along the lower Kitimat River.
4. Stream peakflow and precipitation fluctuations on the North Coast of B.C.
5. The rate of forest harvesting within the Kitimat watershed.
6. The hydrometeorology of peakflows in the Kitimat watershed, including the Little Wedeene River and Hirsch Creek tributary watersheds.
7. Estimate of changes in the sediment load of the Kitimat River.

2.0 ENVIRONMENTAL SETTING

The following description of the environmental setting summarizes the characteristics of the Kitimat watershed that are most relevant to this study: physiography, climate, hydrology, and river channel characteristics. More comprehensive descriptions are provided by Bell and Kallman (1976) and Clague (1982).

The Kitimat River drains two mountain blocks of the Kitimat Range, a part of the Coast Mountains of B.C. (Holland, 1964). The mountain blocks are located on the east and west sides of the Kitimat Valley, which comprises the lower 30 km of a 4-9 km wide lowland corridor linking the head of Douglas Channel with the Skeena River at Terrace, 55 km to the north. (Fig. 1) Covering the floor of the Kitimat Valley are Pleistocene and Recent surficial deposits forming the terraces, tributary alluvial fans and the flood plain of the lower Kitimat River, mapped and detailed most recently by Clague (1982). The major tributary watersheds of the Wedeene and Little Wedeene Rivers on the west, Hirsch Creek, Chist Creek, and the upper Kitimat River on the east drain the adjacent mountain ranges, formed mainly of granitic rocks Gottesfeld (1985). The upper valleys are glacially sculpted, broad U-shaped valleys typical of the Kitimat Range. Moderately steep valley sides rise to predominantly domed ridge tops, with cirque basins along the north and east margins. Steeper peaks are scattered along the ridge tops, particularly on the eastern boundary ridge of the upper Kitimat valley and the western ridges of the upper Wedeene valleys.

Most of the Kitimat Valley lowland is below 200 m. in elevation. Valley bottoms of the tributary valleys range in elevation from 100 m. at the junction with the lower valley up to 600 m. in the upper valleys. Ridge elevations are generally in the 1500 to 1800 m. range, with overall relief of 1500 m. A maximum elevation of about 2350 m. occurs in the Dog's Ear Peaks of the upper Kitimat Valley. The median elevation of the watershed is about 800 m., relatively low for Kitimat Range watersheds because of the extensive lower Kitimat Valley, which comprises about 15% of the watershed area (Table 1).

The Kitimat watershed contains about 150 small glaciers, comprising less than 5% of the basin area. Glaciers in the region have been retreating since the last "Little Ice Age" maximum in the 19th century (Ricker, 1985). The absence of glacierized area and major lakes within the Kitimat basin suggests that the major hydrological buffers within the system are the winter snowpack and the wetlands/permeable soils of the lower valley.

The Kitimat watershed, at the head of a major fjord system, has a transitional climate between the coast and the interior, with a primarily coastal annual precipitation regime, influenced both in summer and winter by interior temperature conditions. Annual precipitation is highly seasonal, with 79% of the annual total falling in the months from October to April. The Kitimat watershed is affected by two notable regional trends in precipitation, a coast to interior drying trend, and a south to north drying trend along the Kitimat Valley. The coast to interior trend is illustrated by the annual unit runoff volumes of Little Wedeene River on the west side, and the Hirsch Creek watershed on the east side, 2895 mm and 1960 mm respectively (Table 1). The south to north trend is shown by the October to April precipitation amounts for the Kitimat TS climate station, near the mouth of the basin, and Terrace Airport station some 20 km to the north of the Kitimat watershed, 1750 mm and 1000 mm respectively.

The continental influence of temperature on precipitation is particularly evident in winter, during which even the lowland portions of the watershed receive considerable snowfall. About 23% of the annual precipitation occurs as snowfall at Kitimat TS (130 m. elevation), increasing to 30% at Terrace Airport (200 m. elevation). It is estimated from the stations at Terrace Airport and Tahtsa Lake West at 860 m. elevation (70 km. to the southeast) that over 50% of the annual precipitation falls as snow above 600 m. The snowfall regime is discussed in more detail in Section 6.0.

The transitional climate of the Kitimat basin is manifested in the hydrological regimes of the rivers. About 60% of the annual runoff volume occurs from May to September as summer snowmelt; only 21% of the annual precipitation occurs during this period (Table 2). Peakflows occur both in the summer as a result of snowmelt and in the fall/winter as a result of heavy rain on saturated soils or shallow snowpacks (rain-on-snow). The summer peakflows are centered on mid-June, but typically have less than half of the discharge of the fall/winter peakflows. The fall and winter peakflows are centered on late October or early November. Both the summer and fall peakflows have a wide scatter (standard deviations of 26 and 38 days), reflecting the variety of processes that can influence peakflow timing. Much of the variability in summer peakflow timing is introduced by late summer peakflows in July and August, which probably result from heavy summer rainstorms rather than snowmelt. Variability in the fall/winter timing of peakflows is associated with early winter peakflows in December and January, resulting from rain-on-snow.

The Kitimat River channel is divisible into relatively homogenous sections, called reaches, based on the nature and extent of lateral channel movement. Seven reaches were identified on the Kitimat River for this study, three on the lower Kitimat below the Highway 37 bridge at River km 38, and four on the upper river. Reaches 4 and 6 on the upper river are confined sections in which lateral channel movement is constrained. The other two reaches are laterally unstable. The first reaches of Hirsch Creek, Little Wedeene River, Wedeene River, Chist Creek and Nalbeelah Creek were included in this study. All the tributary first reaches are on alluvial fans, with laterally unconstrained, unstable channels.

The Kitimat River and its tributaries support runs of six species of Onchorhynchus salmonids, cutthroat trout, and Dolly Varden char. Salmonid production from the Kitimat system is the major component of the Area 6 commercial, sports, and Native food fisheries.

2.1 Land Use History

The Kitimat basin was undeveloped prior to the building of the Alcan aluminum refinery in the early 1950's. The construction of the refinery and associated townsite resulted in extensive land use alterations in the lower 10 km of the Kitimat Valley, between Hirsch Creek and the estuary. The urbanized and industrialized areas have continued to expand slowly, with the building of the Eurocan pulp mill in 1969, and the Ocelot Industries methanol and ammonia plants in 1983 and 1986 respectively. The urban and industrial lands have little bearing on the channel and watershed changes above 10 km from the mouth of the river because of their location near the mouth of the basin and relatively insignificant total area with reference to the total basin area. The linear development of the CN railway and Highway 25 from Terrace to Kitimat, constructed at the same time as Kitimat, affect the channel of the Kitimat River and several tributaries locally, but have little effect on the hydrology of the watershed.

Small-scale logging activity began in the Kitimat Valley prior to 1963, with contract logging of some of Alcan's timber holdings within the Municipality and other private holdings near the town. The small-scale logging continued through the early 1960's. Crown Zellerbach Ltd. began to develop its extensive TL holdings in 1963, with scale-up to full production occurring from 1965 to 1967 (Table 3). MacMillan Bloedel Ltd. followed, beginning logging operations on its TL's in 1968, with scale-up to full production by the following year. Eurocan began cutting in TFL 41 in 1969-70, with scale-up by 1971. The peak rate-of-cut occurred from 1969 to 1974. In 1975, both CZ and MB began scaling down their operations as their logging plans neared completion. Scaled down operations continued on CZ's licences until 1979/80, and on MB's holdings to 1982/83. Eurocan has had the largest share of the area harvested since 1976, and continues with an annual cut of approximately 1000 hectares.

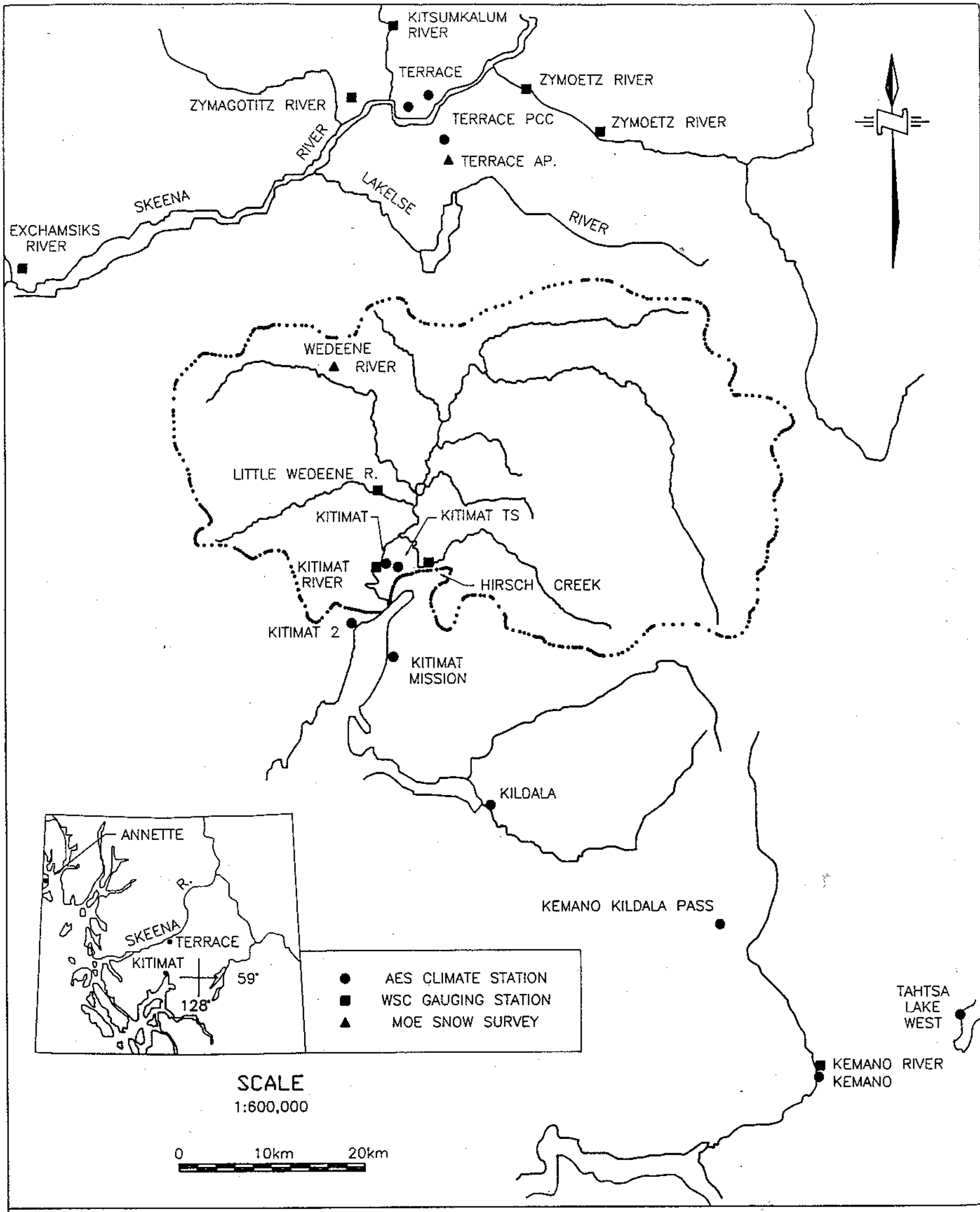


FIGURE 1: LOCATION OF THE KITIMAT RIVER WATERSHED, SHOWING CLIMATE STATIONS, STREAM GAUGING STATIONS AND UPPER AIR STATIONS USED FOR SNOW CLIMATE ANALYSIS.

TABLE 1 PHYSIOGRAPHIC CHARACTERISTICS OF KITIMAT WATERSHEDS

	KITIMAT	UPPER KITIMAT	LITTLE WEDEENE	HIRSCH	WEDEEN	CHIST	NALBEELAH
BASIN AREA (KM2)	1990	663	188	347	321	158	49.1
PERCENT OF AREA BELOW 300 M.	22	5	7	37	16	9	26
PERCENT OF AREA BETWEEN 300 AND 450 M.	26	24	15		34	26	31
PERCENT OF AREA BETWEEN 450 AND 600 M.			14				
PERCENT OF AREA BETWEEN 600 AND 750 M.			14				
PERCENT OF AREA BETWEEN 750 AND 900 M.	10		13		10	25	
PERCENT OF AREA BETWEEN 900 AND 1050 M.	42		16		40		
PERCENT OF AREA BETWEEN 1050 AND 1200 M.			13			40	
PERCENT OF AREA ABOVE 1200 M.			8				
MEDIAN BASIN ELEVATION (M.)	800		750		750	930	650
MEAN ANNUAL UNIT AREA RUNOFF (MM)	2080		2895	1965			

TABLE 2 HYDROLOGICAL CHARACTERISTICS OF KITIMAT WATERSHEDS

DISTRIBUTION OF ANNUAL FLOW

MONTH (% of annual flow)

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
KITIMAT R.	3.2	3.2	2.9	5.9	12.6	16.9	12.6	9	8.5	11.6	8.7	4.8
HIRSCH C.	2.6	2.3	2.2	5	13.4	18.5	13.2	8.4	8.7	12.1	8.7	4.7
L WEDEENE R.	3.1	2.8	2.6	5.9	15	19.6	12.7	7.6	8.2	10.6	8.2	3.8

	KITIMAT R.	HIRSCH C.	LITTLE WEDEENE
MEAN DATE OF ANNUAL MAX SUMMER PEAKFLOW	JUNE 12	JUNE 13	JUNE 19
MEAN DAILY MAX FLOW OF SUMMER PEAK (CMS)	487	94.3	74
HIGHEST DAILY SUMMER PEAK	665	142	93.7
MEAN DATE OF MAJOR FALL PEAKFLOWS	OCT 30	OCT 26	NOV 3
MEAN DAILY MAX FLOW OF MAJOR FALL PEAKS (CMS)	1059	243	133.5
HIGHEST DAILY FALL PEAK	2500	566	274
HIGHEST INSTANTANEOUS PEAK	3030	807	585

TABLE 3

KITIMAT RIVER RATE-OF-CUT
(HECTARES, 1963 - 1990)

YEAR	TOTAL	CUMULATIVE
1963	281	281
1964	269	550
1965	695	1245
1966	635	1880
1967	1115	2995
1968	1506	4501
1969	2698	7199
1970	408	9607
1971	2811	12418
1972	2269	14687
1973	2018	16705
1974	1599	18304
1975	1431	19735
1976	1224	20959
1977	1177	22136
1978	1041	23177
1979	884	24061
1980	661	24722
1981	692	25414
1982-85E	4000	29414
1986	1157	30571
1987	1073	31644
1988	1171	32815
1989	1059	33874
1990 E	1365	35239
		(17.7%)

ESTIMATED TOTAL AREA LOGGED
1963 - 1990

Kitimat River (whole)	17.7%
Little Wedeene River	14.5%
Big Wedeene River	19.6%
Chist Creek	13.0%
Hirsch Creek	14.0%
Nalbeelah Creek	34.0%
Upper Kitimat River	4.8%

3.0 FISH ESCAPEMENTS

The Kitimat River is one of the three primary producers of salmon on the Douglas Channel section of the North Coast of mainland British Columbia. The Kitimat has a median escapement in excess of 100,000 salmon of all species combined. The main commercial fishery is a net fishery for pink salmon, conducted near the entrance to the Douglas Channel complex, some 80 to 120 km to the southwest of the Kitimat River estuary. A secondary net fishery for chum salmon is conducted in the same area. The chinook and coho salmon from the Kitimat River support a recreational fishery conducted throughout the Douglas channel area. Chinook, coho, and steelhead also support a sport fishery on the Kitimat River itself.

3.1 Methods of Analysis

Historical fluctuations of salmon populations in the Kitimat system were evaluated using the salmon escapement data (SED) for the Kitimat River and its tributaries. Spawning escapement records began on the Kitimat River in 1953, and on the major tributaries Wedeene River, Little Wedeene River, and Hirsch Creek in 1957 or 1958. Spawning records on Nalbeelah Creek and Humphrey's Creek also extend back to 1958. Escapement counts began later on Chist Creek (1969) and Cecil Creek (1980).

The SED's are a less than ideal data set to use for analysis. There are reliability problems with the data related to how the escapements are estimated in the field: the data may not be homogenous because observers and observing methods may change. Nevertheless, the SED's are the only available long term data base for assessing changes in fish stocks. The annual escapement data for pink, coho, chum and chinook salmon were smoothed with a 4 year moving mean filter to synchronize with the 2 year cycle of pink salmon and the predominatly 4 year cycles of the other salmonids. The 4 year moving averages for each of the four species were plotted on a semi-logarithmic scale, superimposing the data for each species from each of the data sets. A semi-logarithmic scale was used because the moving means of fish escapement data vary by three orders of magnitude.

Although the use of moving means can be criticized for several statistical weaknesses, including aberrations introduced by serial correlation (Barrett,1979 qouted in Karanka, 1986), it was justified in this instance because of the nature of the data base and the intent. The data base features differences of three orders of magnitude between individual data, a non-normal probability distribution, and a nonhomogenous data base. The intent was to demonstrate order-of-magnitude changes in the various data sets. Greater precision was neither attainable nor necessary for the purposes of the analysis.

3.2 Changes in Fish Escapements

The pattern that shows up consistently for all fish species and rivers within the Kitimat watershed is a sharp decline by an order of magnitude in escapement numbers in the mid 1970's (Figs. 2-5). It was this decline that prompted the building of the Salmonid Enhancement Program Hatchery at Kitimat in the late 1970's. The hatchery was built originally to boost the stocks of chinook salmon, but has more recently begun stock enhancement programs for chum and coho salmon. Chinook, chum, and coho escapement numbers have all increased rapidly during the operational period of the hatchery, with the most dramatic results shown by the chinook stocks. Chum and coho numbers were already recovering before the hatchery program for these species began. Pink salmon are not enhanced in the Kitimat River, but escapements have recovered by an order of magnitude in numbers since the early 1980's.

A similar but more spotty pattern of decline and recovery is evident in the mid 1960's to early 1970's. The pattern is most consistent for chum escapements on Hirsch Creek, Little Wedeene River, Big Wedeene River, Nalbeelah Creek and Humphries Creek. The pattern may also be present in the chinook escapement data for Hirsch Creek and Little Wedeene River. The 1960's to 1970's pattern does not appear in any species on the mainstem Kitimat River, or in species other than chum and possibly chinook in the Kitimat tributaries.

The 1970's to 1980's decline and recovery of salmonid stocks undoubtedly is a real event (not an artifact of changes in the way the data was gathered or analyzed in this study). The decline is present consistently in all escapement data series from the Kitimat River and its tributaries. The 1960's to 1970's decline is a more shadowy event, because it is detectable only in the chum escapement data of several Kitimat tributaries.

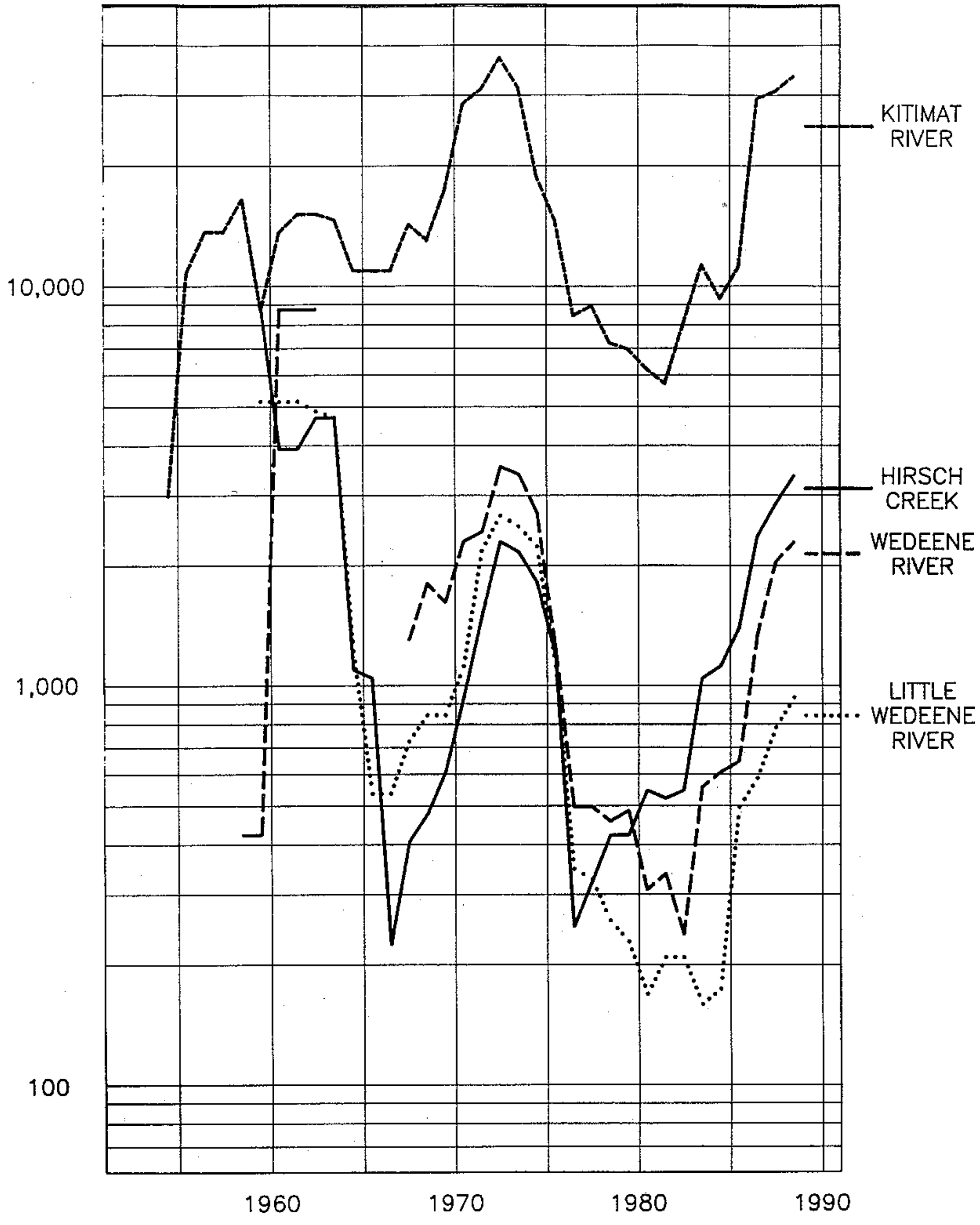


FIGURE 2: FOUR YEAR MOVING MEAN, CHUM SALMON ESCAPEMENT IN THE KITIMAT WATERSHED.

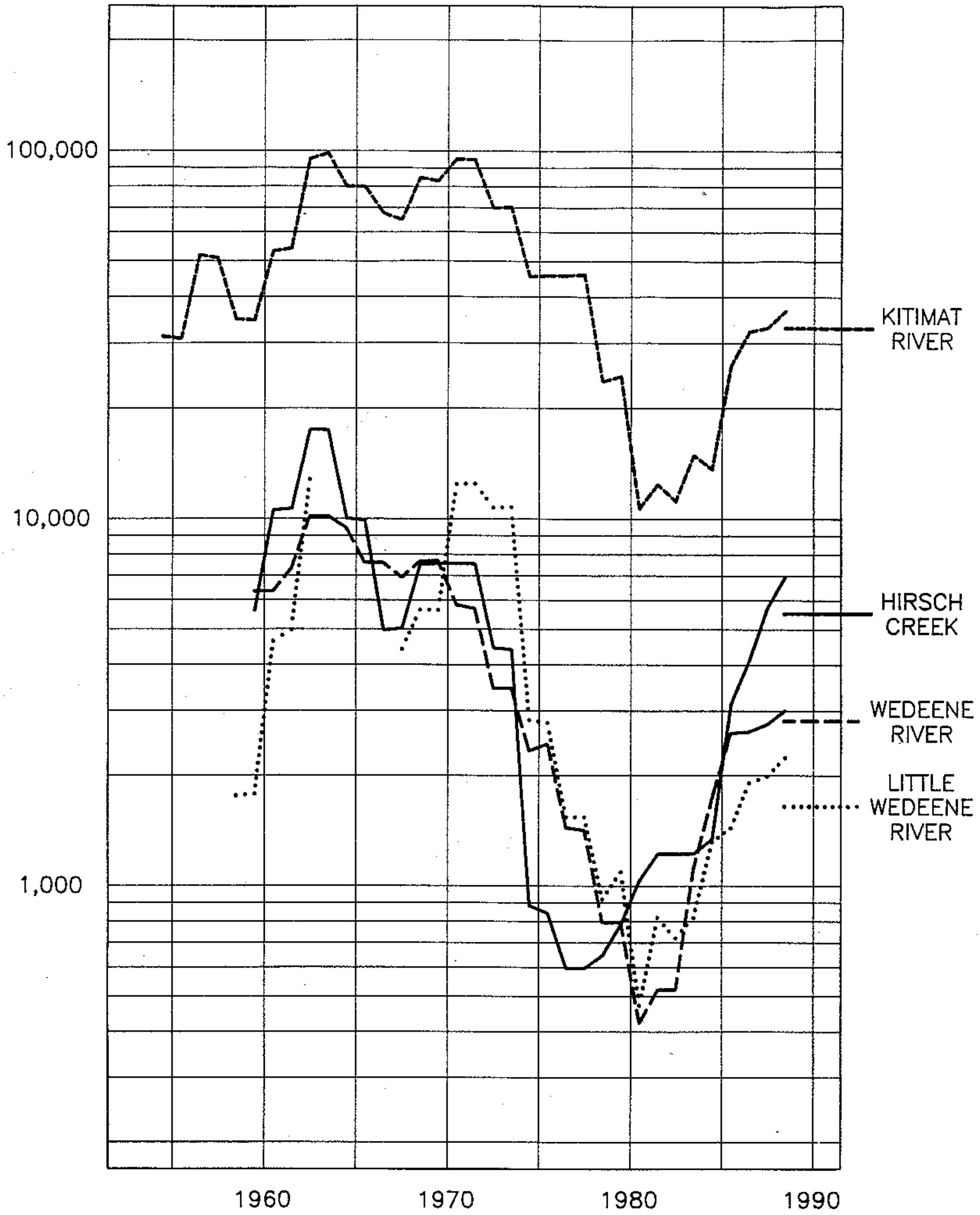


FIGURE 3: FOUR YEAR MOVING MEAN, PINK SALMON ESCAPEMENT IN THE KITIMAT WATERSHED.

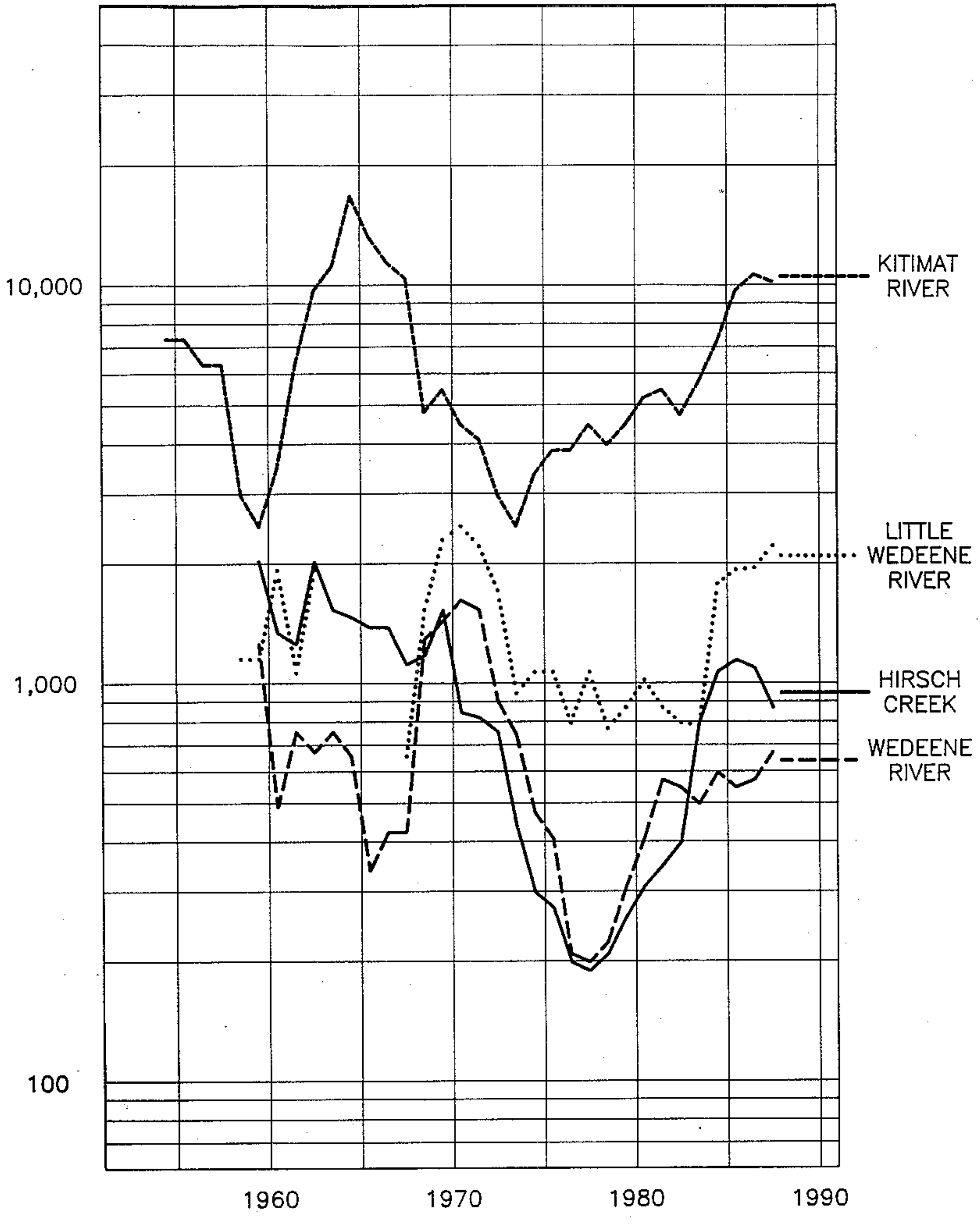


FIGURE 4: FOUR YEAR MOVING MEAN, COHO SALMON ESCAPEMENT IN THE KITIMAT WATERSHED.

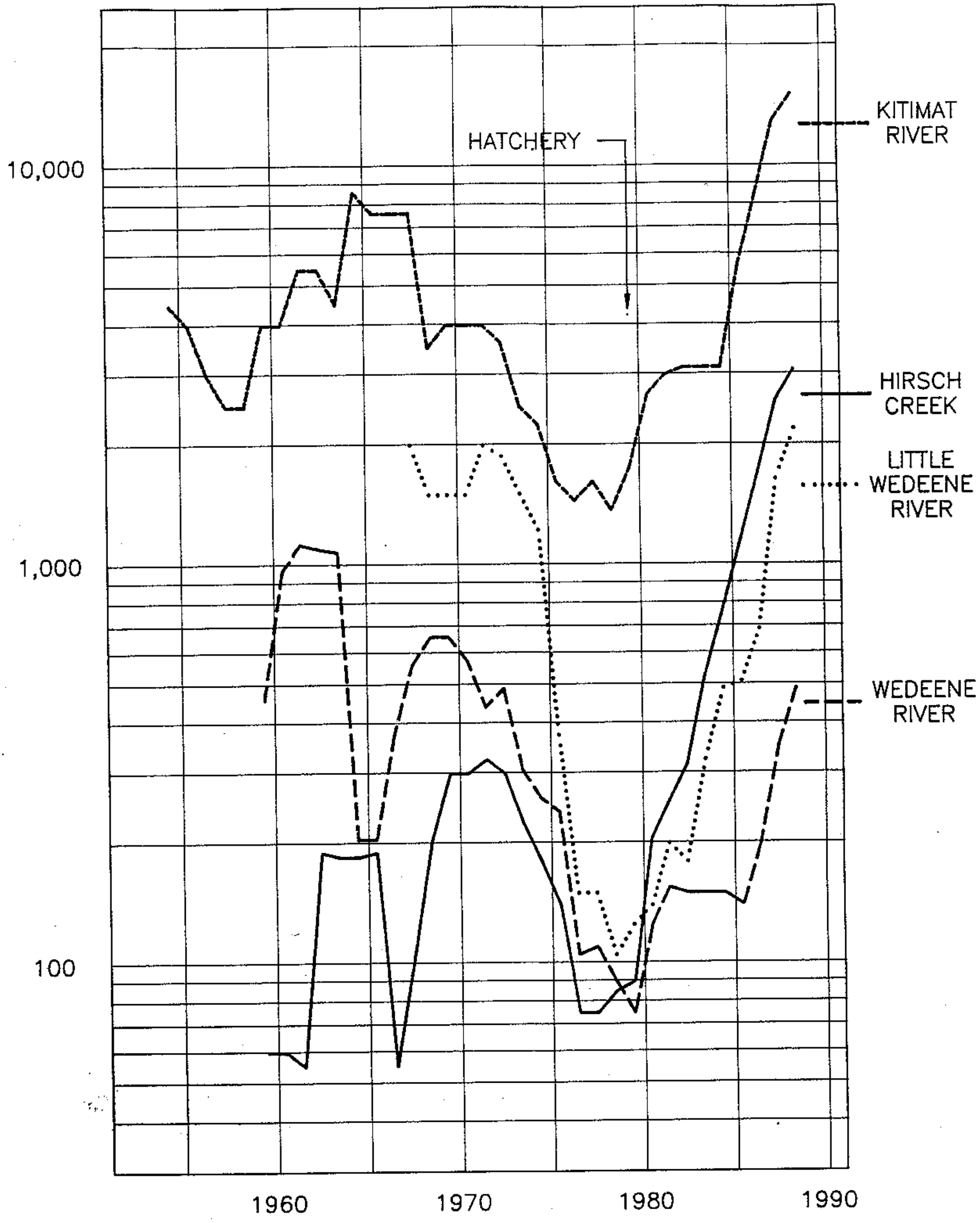


FIGURE 5: FOUR YEAR MOVING MEAN, CHINOOK SALMON ESCAPEMENT IN THE KITIMAT WATERSHED.

4.0 RIVER CHANNEL CHANGES

The Kitimat River is a "wandering gravel bed river" (Church, 1983) characterized by sedimentation zones in which the river is laterally unstable, seperated by relatively stable single channel reaches. In the sedimentation zones, the location of the main channel may change annually, sometimes splitting up into several channels. Over a longer term, vegetated islands may form and disappear on the gravel bars, while the importance of specific side channels in a generally extensive side channel network may change.

The Kitimat River channel is divisible into reaches that have relatively homogenous channel characteristics distinguishable from adjacent reaches. The lower Kitimat River, from 0 to 38km, consists of three reaches; the upper Kitimat River from 38km to 68km includes 4 reaches. The first reaches of streams tributary to the Kitimat were also examined for this study. The lowest reach of the tributaries is generally a gravel bed river on a fluvial fan. Sediment accumulation is an active process on fluvial fans. The resulting channels tend to be laterally unconfined and unstable.

4.1 Methods of Analysis

Three aspects of channel stability and channel change were examined, based on measurements made on a historical series of aerial photographs and planimetric maps. The stability of the channel thalweg (the line connecting the deepest part of the flowing channel) was examined on three Kitimat River reaches only. The origins and stability of the side channel network were also analyzed only on three Kitimat River reaches. Finally, changes in channel area were studied on three Kitimat River reaches, two reaches on Hirsch Creek, and one reach each on Little Wedeene River, Wedeene River, Nalbeelah Creek, and Chist Creek.

4.1.1 Main and Side Channel Identification

The main channel thalweg and side channel networks of the Kitimat River were identified on aerial photographs and transferred to large scale planimetric maps. The Kitimat Watershed is mapped at three different scales. Planimetric mapping at 1:10,000, based on 1980 aerial photography, extends from Hirsch Creek upstream to Chist Creek. Below Hirsch Creek, map coverage changes to 1:5,000 orthophoto topographic floodplain maps, based on 1977 aerial photography. The upper Kitimat watershed and upper Hirsch Creek are mapped at a scale of 1:20,000, based on 1968 aerial photography.

Distances along the thalweg were measured on the maps with an electronic digitizing table, from a starting point established at the 5.2 meter flood elevation contour near the mean high tide line at the mouth. Distances (in Kilometers) were marked on the aerial photos and maps to points of interest along the channel . The distance points along the main channel were used to reference the side channel networks as well as sections of the main channel.

The side channels of the Kitimat River were identified and classified in a 1987 study. (Karanka, 1987) The side channels that joined the main channel directly were given reference numbers based on the distance along the main channel at the junction, and on the location of the side channel on the left or right bank of the main channel (looking downstream). Thus, the sidechannel identified as 8.5R joins the main channel on the right bank at 8.5 kilometers from the starting point at the mouth.

In many instances, the side channel joining the main river was the collector channel for a system of branching sidechannels. The branch sidechannels in such networks were identified sequentially upstream along the designated main side channels. They were referenced by their sequence upstream on the left and right banks of the side channel. Thus, 8.5R1L indentifies the first upstream side channel branch on the left bank of the collector side channel joining the main channel on the right bank at 8.5 km. Four levels of branching hierarchy were required to reference all the branches in some side channel systems. Side channel lengths were measured on an electronic digitizing table.

4.1.2 Channel Thalweg Stability Index

The frequent aerial photography coverage of the Kitimat River (Table 4) suggested a method for quantifying the stability of the channel thalweg since the first aerial photography in 1938. The position of the thalweg on the various sets of aerial photography was mapped onto mylar overlays on the base maps. The thalweg sections that remained stable between successive aerial photographs were measured on the overlay as an index of channel stability. A channel was classified as stable between the dates of photography if the thalwegs were flowing parallel and within 5mm (100 meters) on the overlay. The proportions of channel length that remained stable were converted to a stability decay rate over time in years. Negative exponential, logarithmic and power functions were tested for goodness of fit to the thalweg stability data.

Effects of logging on the stability of the channel thalweg were tested in Reach 3 by dividing the aerial photography into pre- and post-logging observations and comparing the rate of change of the channel thalweg, using the above procedure.

4.1.3 Channel Area

Historical changes in stream channel area in the Kitimat basin were analyzed by comparison of channel areas in key reaches on aerial photography and maps. The procedure used for comparison of channel area was as follows:

1. Define upstream and downstream reach boundaries and locate on all sets of maps and aerial photography to be compared.

2. Identify and draw boundaries of the active (main) channel using a stereoscope.

3. Determine the scale of the photography at the elevation of the reach.

4. Digitize the channel area on the map or air photo. A Hewlett Packard electronic digitizing table, and mini-computer software package were provided by the B.C. Ministry of Enviroment and Parks in Victoria. The digitizing program automatically converts the area measured on the map into hectares or other area units, based on the scale determined in Step 3.

Ideally, the channel areas should be digitized on scale-rectified planimetric or orthophoto maps, such as the 1977 Flood Plain mapping of the lower Kitimat. If scale-rectified maps are unavailable, a large-scale unrectified photo mosaic or an air photo enlargement provides the next best alternative. Air photo mosaics done under contract to Alcan were available for the 1956 and 1967 channel area measurements in the lower Kitimat. The poorest alternative is to measure channel areas directly on aerial photography contact prints. This alternative is least accurate because the channel area is usually small, making it more difficult to measure with precision. Often, measurement of channel area directly on aerial photographs is the only alternative available.

A cautious methodology was adopted for measurement of channel area because of the diversity of data sources and errors inherent in measuring areas directly from aerial photographs. When large scale planimetric maps were available for a stream channel, test measurements of channel area were made on both the planimetric map and the aerial photographs from which the map was compiled. Eight sets of test measurements were done, with differences in measured area ranging from 0.5% to 3.8% between the aerial photo measurements and map measurements. Measurement errors in the 1 to 4% range are negligible when the actual changes in channel area are an order of magnitude larger, 10% to 40% plus.

Channel areas were measured on nine reaches of the Kitimat River system: Reaches 2, 3, and 7 of the Kitimat River mainstream; Reaches 1 and 3 of Hirsch Creek; Reach 1 of Wedeene River, Little Wedeene River and Chist Creek; and Reach 2 of Nalbeelah Creek. (Fig. 7). Comparative channel area measurements were also available from the Dala and Kildala Rivers, unlogged watersheds which adjoin the Kitimat River to the south.

Reach 1 of the Kitimat River, the tidal river channel extending about 1km upstream, was not examined for this study. Reach 2, extending from 1km to 14 km upstream, is a single thread channel that formerly included four major meander bends along its course. Channel area was measured on two sections of Reach 2: from the beginning at km 1 to the bridge at km 7.2, and from the bridge to the upper boundary at km 14.

Reach 3 extends from km 14, 2km above Hirsch Creek, to the Highway Bridge at km 38 and includes the most unstable sections of the lower river. The channel follows a split course in about 12 km, or half the reach. One channel is dominant in most of the split channel sections. The recently active channel area varies from 200m to 1000m in width and includes a melange of active channels and side channels, abandonned channels in various stages of re-vegetation, gravel bars, and islands with mixed age alder/cottonwood cover. Channel area was measured in all of Reach 3, but the channel was divided into two sections. The first section extended from the lower boundary at km 14 to the former Crown Zellerbach bridge at km 22. The second section extended from the C. Z. bridge site to km 37, about 1 km below the Highway 37 bridge.

The upper Kitimat River consists of four Reaches. Reach 4 and Reach 6 are confined channels with limited local lateral activity. Reaches 5 and 7 are similar to Reach 3 in the extent of lateral activity. Channel area was measured between km 55 and km 68 in Reach 7.

Changes in channel area were measured on 5 tributaries to Reach 3 of the Kitimat River. All of the measured sections are on fluvial fans, either unconfined (Little Wedeene River) or partially confined (the others). The channel area of Hirsch Creek was measured on Reach 1, from the Kitimat River confluence upstream to the Highway 25 Bridge, 5.5km upstream. Reach 3 begins at 6km upstream of the Highway 25 Bridge, above the Reach 2 canyon, and extends upstream for 10 km.

Reach 1 of Little Wedeene River extends from the Kitimat River confluence to the Skeena Sawmills logging road bridge at km 4.5. Channel area was measured only on the upper section, between the CN railway bridges and the logging road (2.5km to 4.5km). Channel area was measured on all of Reach 1 of the Wedeene River, extending 3km upstream from the Kitimat River confluence. Channel area was measured on Reach 2 of the Nalbeelah Creek, extending from 2km to 5.5km upstream of the Kitimat River confluence. The Chist Creek channel was measured in a 3km section from the Kitimat River confluence upstream to the Skeena Sawmills logging road bridge.

The channel area data were plotted versus the year of photography. The various channel area data sets were not easily comparable because they ranged from around 10 to 15 hectares for Nalbeelah Creek to over 400 hectares for the Kitimat River Reaches. To increase comparability, they were reduced to common units, expressed as percentage differences from the smallest area measured in each data set. For example, a set of channel area observations such as: 1950, 50 hectares; 1960, 45 hectares; and 1980, 60 hectares was plotted as 1950: +11%; 1960: 0; and 1980: +33%

The effect of logging on channel area was tested on Reach 3 of the Kitimat River using pre- and post-logging channel area data sets.

4.1.4 Sidechannel History

The side channel network and the 1977/1980 main channel thalweg sections were examined and classified on a sequence of aerial photographs from 1938 to 1988. Each side channel and main channel segment indentified on the 1977/1980 aerial photographs was classified on each set of aerial photographs used for the historical analysis. The objectives of the historical analysis were to analyze changes in the overall amount of side channel habitat in the various classes, identify side channels that have undergone a change in status since the mid-1960's, and determine the stability of the side channels and main channel segments.

Age classes for many side channels could be determined by comparing their classifications over time. Age classes used were as follows:

1. Younger than 10 years (side channel has formed since the 1977 or 1980 aerial photograph).
2. 10 to 15 years old (side channel formed between 1972 and 1977 or 1980 aerial photographs).
3. 15 to 25 years old (side channel formed between 1963 and 1972 aerial photographs).
4. 25 to 40 years old (side channel formed between 1947 and 1963 aerial photographs).
5. 40 to 50 years old (side channel formed between 1938 and 1947 aerial photographs).
6. Older than 50 years (side channel formed before the 1938 aerial photographs).

Some side channels have gone through several phases in their history, alternating between main and side channel status.

During compilation of the historical side channel data base, a log was kept of logging and other land-use related changes evident on the aerial photographs along side channels.

4.2 Results

Channel change is an ongoing, natural process on gravel bed rivers. In looking for the effects of cumulative watershed changes on active river channels, changes in the pattern of river channel change may have more significance than the fact of channel instability.

4.2.1 Main Channel Stability

The channel thalweg stability index described in Section 3.1 was measured in Reach 1 between km 1 and km 14 and in Reach 2 between km 14 and km 38. Negative power functions (Equations 1 and 2, shown in Figure 6) fit the stability decay rates with correlation coefficient of - 0.97 and - 0.94 respectively.

$$y = 120\,x^{-0.43} \quad (1) \qquad\qquad y = 124x^{-0.27} \quad (2)$$

where y = the proportion (expressed in %) of the main channel thalweg in the same location.

and x = the time in years between channel thalweg location observations.

An interpretation of the power function decay rate is that channel thalwegs change location at different rates, depending on stability factors specific to each reach. The "half life" of the thalweg location is only 8 years in Reach 3, but is 25 years in Reach 2.

Over longer periods of time, the channel thalweg occurs at the same location at a nearly constant rate, 25 to 30% in Reach 3 and 35 to 40% in Reach 2. The consistency over longer periods of time can be interpreted in two ways: either there are stable sections embedded within the reach that stay in the same locations over long periods of time while the rest of the channel is in a state of flux, or else channel locations coincide by chance at a nearly constant rate. In Reach 2, stable sections are embedded within the reach. The age structure of the main channel in Reach 3 (Table 5) indicates that many channel locations coincide by chance rather than because of embedded stable sections. Only 10% of the main channel in Reach 3 is older than 40 years, and 16% older than 25 years. The channel stability index suggests that 25% of channel locations should coincide after 40 years and 30% after 25 years, indicating that about 1/2 to 3/5 of the channel location coincidence after 25 years is due to chance and 2/5 to 1/2 is due to stable sections.

There is no significant difference in the stability of the main channel in the pre- and post-logging periods. Preliminary aerial photo analysis indicates that half the length of the main channel thalweg shifts position by more than 50 meters within ten years in both the pre- and post-logging periods.

4.2.2 Changes in Main Channel Area

As a group the channel area measurements record four episodes of channel widening dating back to the 1930's. Six of the reaches show more than 1 episode of channel widening, the other four having only 1 episode in the record. The four episodes that are evident are: the 1930's, early 1960's, late 1970's and late 1980's.

The 1930's event is present on four Kitimat channel area records: Section 2 of Kitimat River Reach 3 (Between km 22 and 37), Wedeene River, Chist Creek, and Upper Hirsch Creek. The 22 to 37 km Kitimat River Reach 3 section and Upper Hirsch Creek recorded their maximum channel areas in the 1930's event, and it is the only event recorded on Upper Hirsch Creek to 1988. (Table 6, Fig. 8). The Dala River channel study section also recorded its maximum area in the 1930's measurement. Like the adjoining upper Hirsch Creek, the 1930's event is the only one detectably present on the Dala River up to 1988.

The 1930's event is significant because it predates logging, is widespread in the Kitimat River region, and resulted in maximum channel areas on a 15 km section of the lower Kitimat River, upper Hirsch Creek, and the Dala River (up to 1988).

The 1960's event is present in 7 channel area records: Kitimat River Reach 2, both sections of Reach 3, and Reach 7; Hirsch Creek Reach 1, Little Wedeene River and Big Wedeene River. The 1960's event achieved the maximum channel area on Kitimat Reach 2, Section 1 of Reach 3 (from km 14 to 22), Reach 7, and Hirsch Creek Reach 1. It is the only event recorded on Kitimat Reaches 2 and 7 up to 1988.

The 1960's event is significant because it occurred prior to logging and its trace is widespread, particularly on the Kitimat River mainstream and lower Hirsch Creek. Because it occured prior to 1963, it pre-dates the gauging station records, hence cannot be correlated with a specific hydrologic event. A clue to the timing of the event is that a meander bend cutoff occurred in Kitimat River Reach 2 in 1961, resulting in most of the channel area increase recorded in the Reach between 1956 and 1963. (The area within the old meander bend is now the site of the Eurocan pulp mill effluent ponds.)

The 1970's channel enlargement is recorded on three of the measured reaches: Wedeene River, Chist Creek, and Nalbeelah Creek. It resulted in the maximum recorded channel area on Chist Creek and Nalbeelah Creek, and is the only event recorded on Nalbeelah Creek. The 1970's event is also well known on the Little Wedeene River below the section measured for channel area. There, it resulted in a large log jam which subsequently blew out through a different route from the original channel.

The 1970's channel enlargement is correlated with 3 hydrological events: the October 15, 1974 flood, the October 27, 1976 flood, and the November 1, 1978 flood,. These rank as the numbers 3, 5, and 2 floods respectively in the Kitimat River daily flow record. The 1974 and 1978 floods rank numbers 1 and 2 on Hirsch Creek, while the 1976 and 1978 floods rank numbers 3 and 2 on the Little Wedeene River.

The 1980's channel enlargement is documented in 5 of the channel area measurement sections: Kitimat River Reach 3 (Section 1 from km 14 to 22 only), Hirsch Creek, Little Wedeene River, Wedeene River, and Chist Creek. It resulted in the maximum channel area on the Little and Big Wedeene Rivers, but is not the sole event recorded on any of the study sections. The enlargement occurred between the 1985 and 1988 aerial photography. One large flood occurred during this period, on September 21, 1987. The September 1987 flood ranks as the number 4 flood on both the Kitimat River and Hirsch Creek, and number 6 on the Little Wedeene River.

Active (unvegetated) channel area has actually decreased slightly from the pre-logging to the post-logging period on Reach 3 of the Kitimat River. Average area of the pre-logging channel was about 565 hectares, +/- 10 percent. Average area of the post-logging channel was about 520 hectares, +/- 8 percent.

4.2.3 Changes in Side Channel Network

Analysis of changes in the Kitimat River side channel network concentrated on Reach 3. Reach 3 has a very high ratio of side channel length to main channel length, about 4.5 to 1. The 107km of side channels along the 24km of Reach 3 were classified by origin of the water flow and by age. Three basic types of side channels were identified. Type 1 side channels are fed by water sources not directly connected to the main channel, such as ground water seepages, distributaries from large tributaries, and small tributaries draining terraces or valley walls. The flow of Type 2 side channels originated in the main channel, with a stage-dependent connection at the side channel entrance. Type 2 channels are generally parts of a braided main channel network, and often were once part of the active main channel. Type 3 side channels have both a non-main channel and a main channel flow component. Type 3 channels tend to be a distinct group, often resulting from the cut off and abandonment of a meander band. The side channel occupying the old meander band collects non-main channel drainage, has an open connection with the main channel at the downstream and, a stage-dependent upstream entrance. The various subclasses of Types 1, 2, and 3 side channels are identified and discussed in Karanka, 1987.

The network of Type 1 side channels has remained stable over the historical period of record, both in total length and morphological characteristics (Fig. 9). Type 1 side channels do not connect with the main channel at the upper end, so do not conduct flood overflows with sufficient velocity to physically degrade the channel.

Much of the Type 1 side channel network lost its streamside cover as a result of logging. The Type 1 channels were subjected to the effects of increased exposure over a 10 to 15 year period. Water temperature increases may have been in the order of 3 to 6 C. Other possible impacts include in-channel disturbance from machinery, blockage of fish access, re-routing of water sources and drainage, and general sedimentation due to soil exposure. The aerial photographs suggest that localized in-channel disturbance was widepsread: machinery crossings are scattered throughout the valley. It is not apparent from the aerial photographs whether the crossings were fords or temporary bridges.

The length of the network of Type 2 and 3 side channels increased at a rate of about 0.5km/year from 1947 to 1975 (Fig. 9) From 1975 through 1985 the rate of formation of Types 2 and 3 side channels tripled to 1.7km/year. A side effect of the proliferation of side channels is that the number of partially dry channels is increasing. The length of Type 2c side channels has increased over 2.5 times since 1975 (Table 7). Type 2c channels are not connected to the main channel at low flow stages and generally contain disconnected, nearly stagnant pools. The Type 2a and 2b side channels, which are connected to the main channel at most flow stages, has decreased by a third since 1975. The 1975, 1977, and 1985 aerial photographs were taken at nearly identical flow stages (Table 8), thus eliminating stage as a factor in classifying the Type 2 side channels.

Type 2 side channels more than 50 years old are the only group of side channels that have been decreasing in total length. Since 1980, about 5km of the original 21km of old type 2 side channels have been eroded and turned into potions of the main channel.

Specifically three side channel blowouts account for most of the 5km reduction: 14.1 R (opposite Cablecar water intake), 18.8 R (from Wedeene River junction to old CZ bridgesite), and 27.0 R(Deception Creek junction). The rate of channel enlargement for side channels 14.1 R and 18.8 R are detailed in Table 9 and shown in Figure 10. The growth rate is essentially exponential through the 1988 aerial photography. The channel enlargement rate for side channel 27.0 R is not shown because it occurred between 1980 and 1985, a period during which there are no aerial photographs to document intermediate rates of enlargement. Another 2km of old side channels in clear cut areas have been severely scoured since 1970, without a main channel breakthrough.

About 30% of the Type 2 side channels older than 50 years have been severely degraded over the past 25 years. Although some of the damage occurred before logging, most damage has been sustained since the cutting of the old-growth stands through which these channels flowed. The damage is the result of flow diversions into the side channels, which subsequently widen through bank erosion. In several instances, the original side channel has become the main channel, involving considerable erosion and loss of productive riparian land.

Type 2 channels younger than 50 years have generally not been directly impacted by logging because they are located within the alder/cottonwood island zone of the valley flat with no adjacent merchantable timber.

Type 3 side channels have also not been disturbed by logging, although all have been logged on the bank furthest away from the main channel. Type 3 side channels are essentially abandonned meander bends, with insufficient flow velocity even during floods to erode logged banks. The islands between the side channel and the main channel may contain pockets of merchantable timber.

TABLE 4 AERIAL PHOTOGRAPHY COVERAGE OF THE KITIMAT BASIN

FLIGHT LINE	YEAR	APPROX. SCALE	COVERAGE
B.C. 40-55	1938	1:15,000	Complete.
B.C. 446-447	1947	1:34,000	Lower Kitimat below Chist Creek.
B.C. 1023-1024	1949	1:36,000	Complete.
B.C. 1923	1954	1:36,000	Lower Kitimat below Wedeene River.
A 14638:14814	1955	1:60,000	Complete.
Alcan mosaic	1956	1:16,000	Lower Kitimat below Little Wedeene C.
B.C. 5083	1963	1:37,000	Lower Kitimat below Chist Creek.
Alcan mosaic	1967	1:16,000	Lower Kitimat below Little Wedeene C.
B.C. 5303	1968	1:39,000	Upper Kitimat above Chist Creek.
B.C. 7173	1969	1:12,000	Lower Kitimat below Little Wedeene C.
B.C. 5397	1970	1:31,000	Lower Kitimat below Cecil Creek.
B.C. 5474	1972	1:16,000	Lower Kitimat between Hirsch and Chist Creek.
B.C. 5559	1973	1:16,000	Lower Kitimat between Hirsch and Chist Creek.
A 24738	c.1972-74	1:60,000 +	Complete
B.C.C. 100	1974	1:6,000	Lower Kitimat below Little Wedeene C.
B.C. 5608:5612	1974	1:60,000	Complete
B.C.C. 113	1975	1:12,000	Lower Kitimat below Wedeene River.
B.C. 5664	1975	1:10,000	Lower Kitimat below Chist Creek.
B.C. 77029	1977	1:20,000	Lower Kitimat below Chist Creek.
		1:5,000	Flood plain maps.
B.C. 80030:32:33	1980	1:10,000	Lower Kitimat between Hirsch and Chist Creeks. Upper Kitimat below Hoult/Davies Jct.
B.C. 81042	1981	1:49,000	Upper Kitimat between Chist and Davies Creeks.
B.C.C. 385:386	1985	1:10,000	Lower Kitimat below Chist Creek.
B.C. 88038	1988	1:80,000	Complete
B.C. 89033	1989	1:17,000	Lower Kitimat

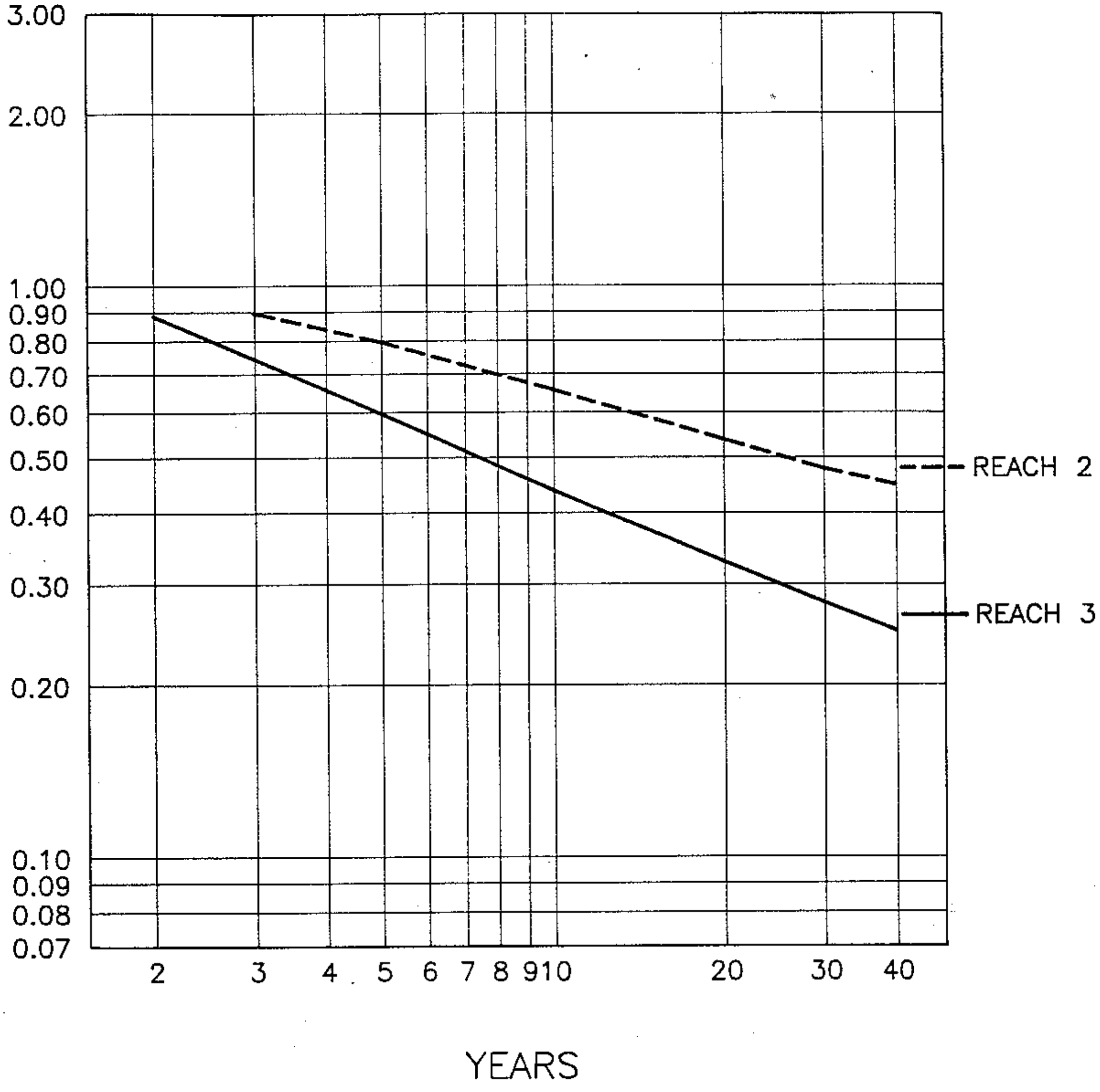


FIGURE 6: KITIMAT RIVER CHANNEL THALWEG STABILITY THE LINES REPRESENT THE PROPORTION OF THE CHANNEL THALWEG AT THE SAME LOCATION AFTER X-YEARS

TABLE 5

AGE STRUCTURE OF KITIMAT RIVER MAIN CHANNEL, REACH 3 (1985)

AGE (YRS)	LENGTH (KM)	%TOTAL
0-5	5.4	22
5-10	5.4	22
10-15	3.6	15
15-20	2.9	12
20-25	3.1	13
25-40	1.5	6
>40	2.3	10

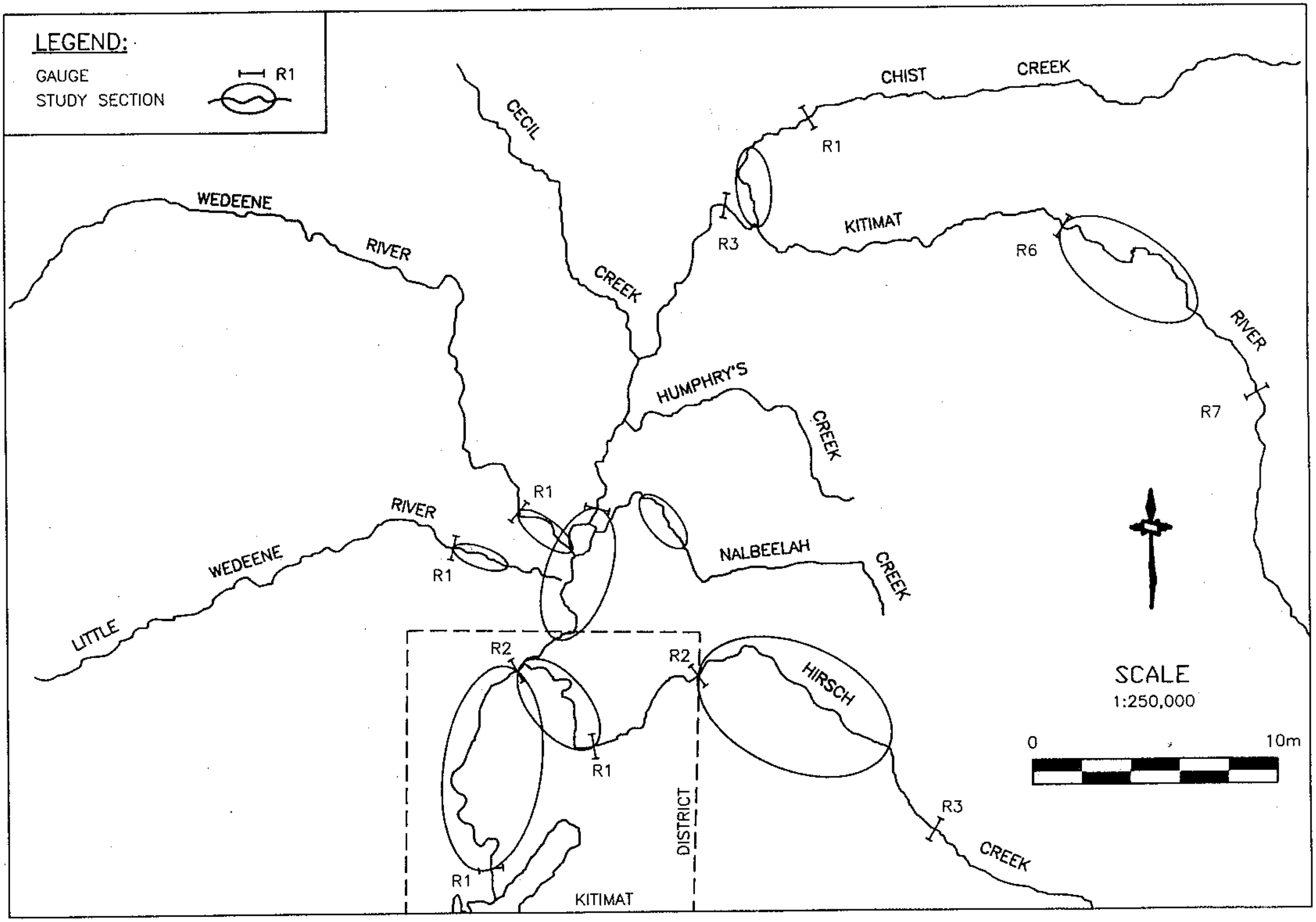


FIG. 7: KITIMAT RIVER STUDY AREA, SHOWING LOCATIONS OF STUDY SECTIONS FOR CHANNEL AREA MEASUREMENTS AND SIDE CHANNEL MEASUREMENTS

TABLE 6 CHANGES IN CHANNEL AREA, KITIMAT RIVER AND TRIBUTARIES, 1912 TO 1988

REACH
(CHANNEL AREA IN HECTARES)

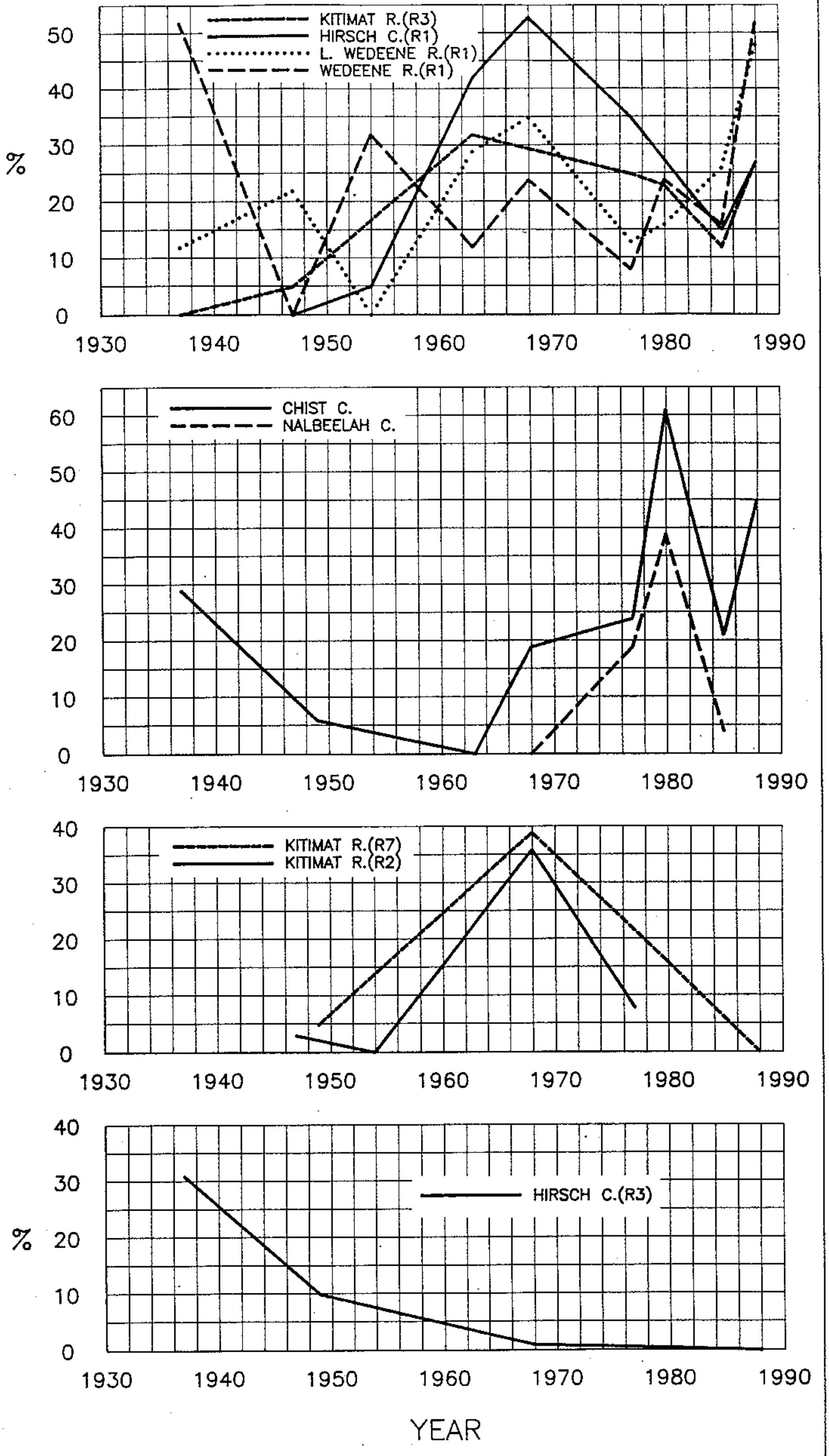
YEAR	MIDDLE KITIMAT (km 14-22)	MIDDLE KITIMAT (km 22-37)	UPPER KITIMAT	LOWER HIRSCH	UPPER HIRSCH	LITTLE WEDEENE	BIG WEDEENE	CHIST CREEK	NAL-BEELAH
1912	166	N.A.	N.A.	77	N.A.	N.A.	42	N.A.	
1937	162	414	N.A.	*	132	28.2	47	40	
1947	170	343	N.A.	55	N.A.	25	38	N.A.	
1949	N.A.	N.A.	128	N.A.	111	N.A.	N.A.	33	
1954/6	N.A.	N.A.	N.A.	58	N.A.	33	31	N.A.	
1963	214	388	N.A.	78	N.A.	28	40	31	
1967/8	N.A.	*	170	85	102	31	42	37	10.7
1977	203	*	N.A.	74	N.A.	27	35	38.5	12.7
1980/1	199	342	141	N.A.	N.A.	31	36	50	14.9
1985	181	*	N.A.	63	N.A.	29	39	37.5	11.1
1988	205	315	122	70	101	38	46	45	

***INFORMATION AVAILABLE, BUT NOT MEASURED**
N.A. INFORMATION NOT AVAILABLE

FIGURE 8:

CHANGES IN CHANNEL AREA, KITIMAT R. AND MAIN TRIBUTARIES

(EXPRESSED AS PERCENT ABOVE THE MINIMUM AREA MEASURED OVER THE PERIOD OF RECORD)



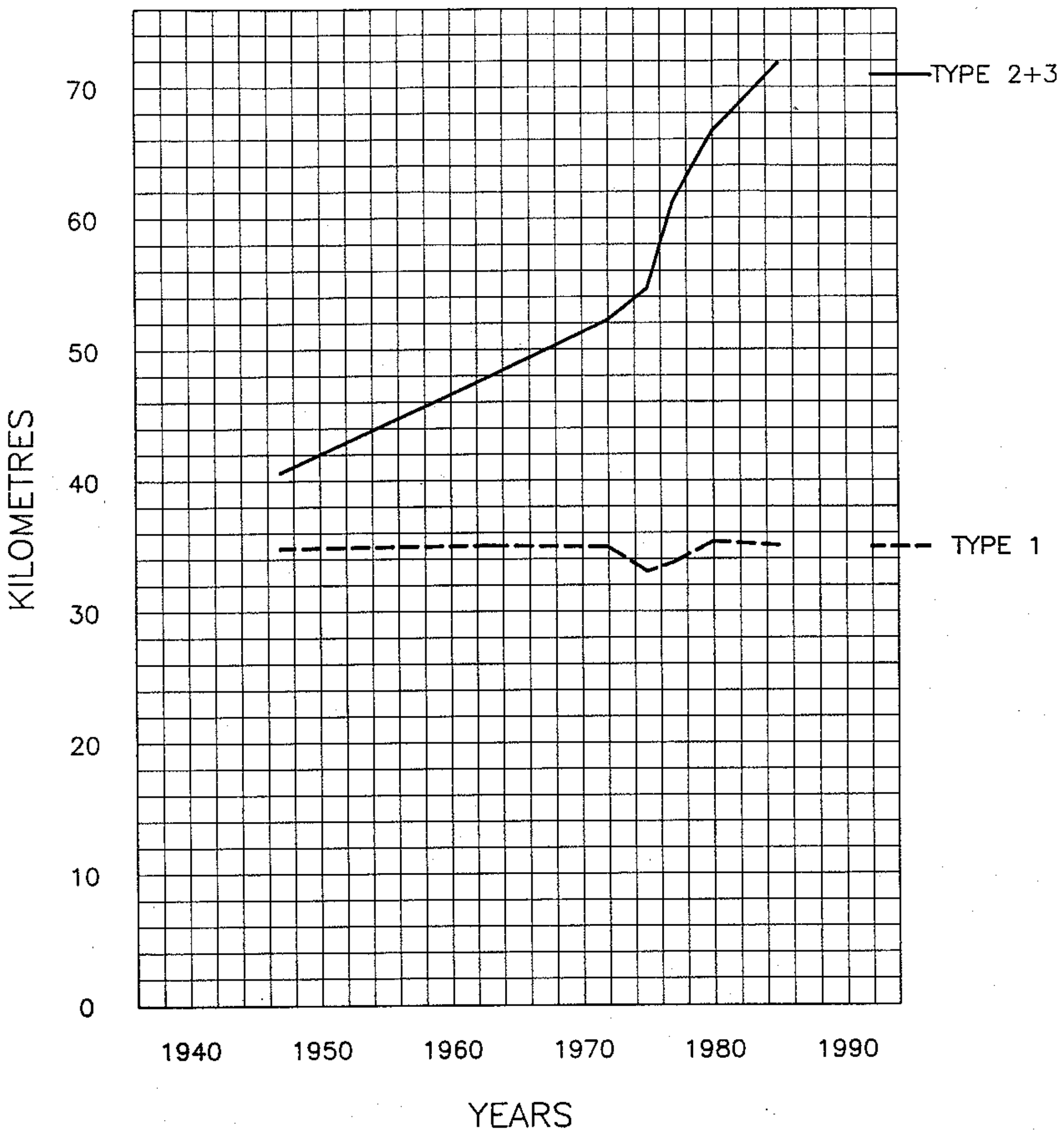


FIGURE 9: LENGTH OF TYPE TWO AND THREE SITE CHANNELS IN KITIMAT RIVER REACH THREE

TABLE 7 LENGTH OF SIDE CHANNELS BY CLASS

YEAR	CLASS (LENGTH IN KM) 1	2a	2b	2c	3	MAIN CHANNEL	NON-CLASSIFIED
1947	34.9	14.8	12.1	10.1	3.7	14.4	12.4
1963	35.1	13.4	15.3	17.3	2.0	16.1	3.0
1972	35.0	17.8	23.4	9.4	1.7	13.9	1.0
1975	33.1	20.1	26.1	6.8	1.7	13.4	-
1977	33.8	21.8	24.6	11.9	3.0	6.0	-
1980	35.4	21.4	25.6	15.1	4.6	-	-
1985	35.1	15.3	15.4	32.6	8.6	4.1	-

TABLE 8

MEAN DAILY DISCHARGE AND PROBABILITY OF EXCEEDANCE ON DATES OF KITIMAT RIVER AERIAL PHOTOGRAPHY

DATE OF PHOTOGRAPHY	DISCHARGE (M3/SEC)	PROBABILITY OF EXCEEDANCE	NO. OF DAYS/YEAR EXCEEDED
12 JUNE 69	496	.013	5
4 JULY 71	419	.026	10
19 JUNE 75	409	.027	10
14 JULY 77	262	.106	39
24 JUNE 89	249	.12	44
6 JUNE 80	233	.14	51
18 JULY 85	233	.14	51
17 AUG 74	170	.267	98
14 SEP 73	131	.378	138
18 JUL 88	122	.42	153
22 SEP 84	101	.49	179
25 AUG 70	85	.559	204

TABLE 9 INCREASES IN AREA OF TWO OLD-GROWTH SIDE CHANNELS FOLLOWING LOGGING ALONG THE MIDDLE KITIMAT RIVER.

YEAR	**AREA OF HYDRO-LINE TO CABLE CAR SIDECHANNEL**	**CZ BRIDGE TO WEDEENE RIVER SIDECHANNEL**
1963	2.5 HECTARES	N.A.
1969	3.9	N.A.
1972	4.0	3.9 HECTARES
1973	4.2	3.5
1975	5.0	4.4
1977	6.0	6.1
1980	7.1	8.4
1985	9.3	12.2
1988	13.8	18.7
1989	17.2	N.A.

CLEARCUTTING WAS DONE IN 1962 OR 1963 ON THE HYDRO-LINE TO CABLE CAR SIDECHANNEL AND IN 1968 ON THE CZ BRIDGE TO WEDEENE RIVER SIDECHANNEL.

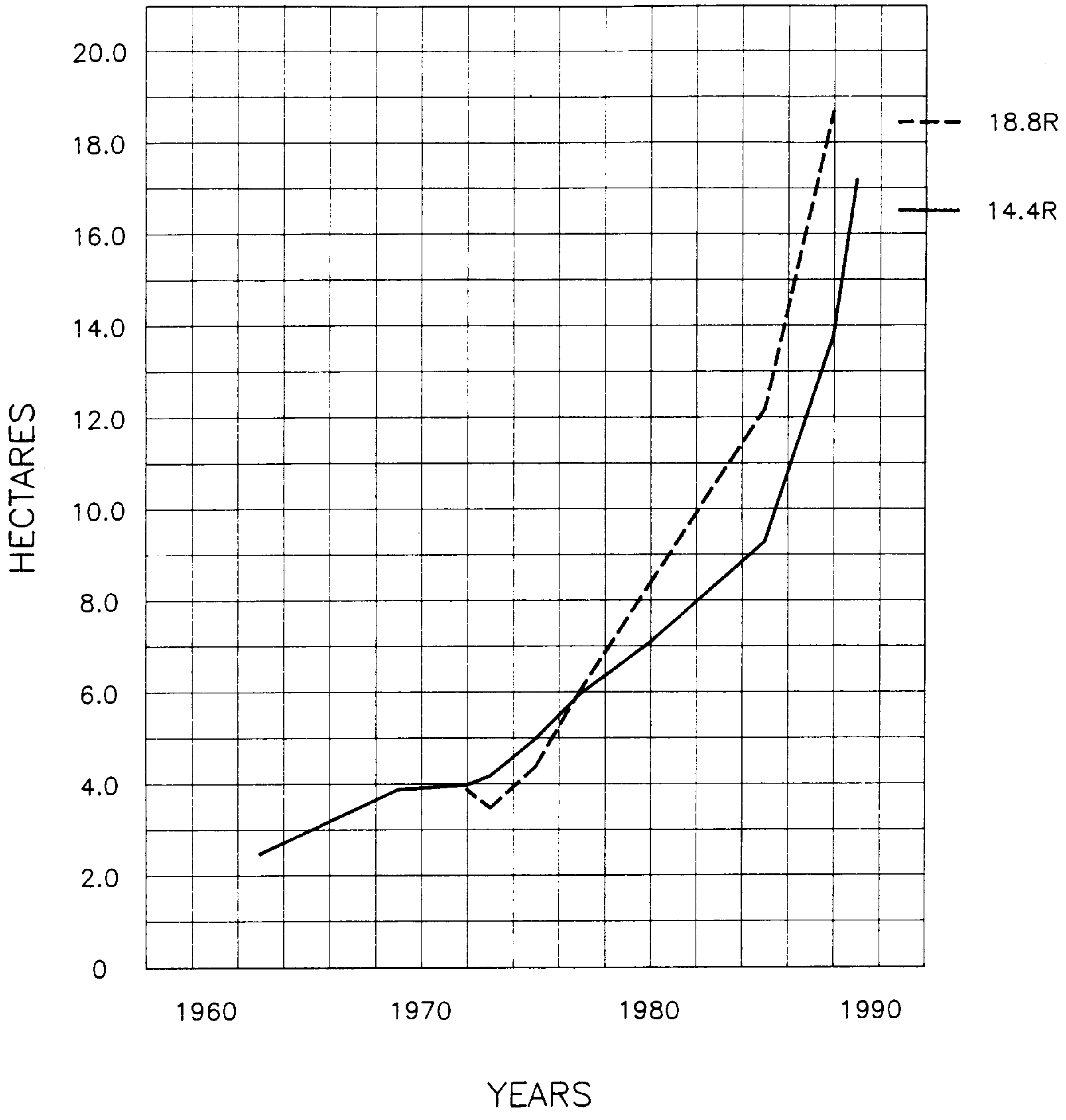


FIGURE 10: CHANNEL AREA OF SIDECHANNELS 14.1R (OPPOSITE CABLECAR) AND 18.8R (WEDEENE R.) IN KITIMAT R. REACH 3

5.0 STREAMSIDE MANAGEMENT PRACTICES

Reach 3 of the Kitimat River has two riparian zones of side channels. The inner riparian zone is the area within which the main channel has been active within historical time. In the parlance of the Coastal Fish-Forestry Guidelines (CFFG), this area would be termed the Streamside Management Zone. It consists of a melange of side channels of various ages and stages of connection to the main channel, the main channel itself with associated gravel bars at various stages of revegetation, and islands with varied-aged stands of cottonwood and coinfers. Side channels in the inner riparian zone are predominantly Type 2 and 3.

The outer riparian zone includes mainly Type 1 side channels, but also includes some Type 2 side channels. The outer riparian zone was originally covered by stands of old-growth conifers, interspersed with wet lands. Under the CFFG, this zone would be termed the Fisheries Sensitive Zone.

5.1 Methods of Analysis

The active riparian zone, defined by the outer boundary of the area within which the main channel has been active during a specified period, was delineated along Reach 3 of the Kitimat River on the various sets of photographs, using 1938 as the starting point. The pre- and post-logging active riparian areas were compared.

Streamside management practices during forest harvesting along the Kitimat River were analyzed from aerial photography, cutting area maps, Ministry of Forests and Lands and DFO file records, and field verification notes from August, 1987. The analysis was restricted to Reach 3 of the Kitimat River from km 14 above Hirsch Creek to the Highway 37 bridge at km 38. The status of the banks of the main channel and side channels in the 1963 aerial photography was defined as the starting point for the analysis. Information gathered about streamside management related to forest harvesting included year of logging, method of logging, streamside treatment, subsequent changes and streamside role of LOD. The information was referenced by kilometre distance from the mouth along the main channel, and by left bank, right bank or island identification number. Side channel information was referenced by side channel reference numbers. The streamside management information was also cross-referenced to cutting area and Timber License or Special Timber Licence number.

5.2 Results

The pre-logging active riparian zone covered about 1170 hectares. About half of the area (550-600 hectares) was active river channel at any one time. Prior to logging, about 65% of the main channel of the Kitimat River was bordered by old growth forest along Reach 3. It should be noted that about 35% of the riparian banks along the Kitimat River are on terraces above the flood plain. The remaining 35% was lined with cottonwood/alder stands of various ages.

The riparian lands of the Kitimat Valley were logged in the 1960's, prior to the enactment of Coastal logging planning guidelines in 1972, and the "P1" clauses in 1979. Prior to the 1972 and 1979 guidelines and clauses, there was no formal mechanism for delineating riparian buffer areas along stream channels. In fact, comments relating to streamside logging cutblocks in the Kitimat were not found in DFO files until 1986. As a result, everything merchantable was often logged to the streambank well into the 1980's.

About 85% of the riparian old growth was removed in just 8 years, from 1962 to 1969. Today, only about 2 km, or about 7% of the original riparian old growth remains along Reach 3, mainly in the Cablecar Subdivision area. About 80 hectares of forest were also cut on 17 islands within the active riparian zone.

The post-logging active riparian area has expanded by over 270 hectares, or an increase of 25% from the pre-logging period. About 60 hectares of the expansion have occurred through bank erosion. The other 210 hectares are associated with six channel avulsions/cutoffs along side channels through clearcut areas.

Road and ground disturbance patterns on aerial photos indicate that most of the logging was done by ground skidder. The skidder logging resulted in a high density of roads and tracks leading right up to the stream bank. Road and track densities as high 18 km per square kilometer were measured on several clearcut islands in Reach 3. More significant from a channel stability perspective is that on islands the tracks are often laid out parallel to the river channel. Such parallel tracks can become channels during floods. Two islands had significant damage from channel erosion along skid roads. One island at 24 km was ultimately destroyed; the other island, at 19.5 km, was saved through measures taken to seal off the erosion channel entrances.

Channel avulsions and cutoffs through side channel entrances along a clearcut river bank have been the more common form of post-logging damage. Seven such events have occurred along the Kitimat

River between km 14 and km 28. Three of the avulsions were documented above in section 4.2.3. A fourth major avulsion formed during the 1989 flood at Km. 27, and eroded the lower 1.2 km of Humphrey's Creek. The other three events were meander bend cutoffs along preexisting sidechannels within clearcut areas.

It is difficult to ascribe a direct cause-effect relationship between streamside logging and the channel cutoffs/avulsions. In virtually all instances, there is no recoverable record of any disturbances at the side channel entrance during logging. Moreover, the lag between the logging operation and the beginning of significant side channel erosion has been 10 to 15 years for the avulsions at 14.1 km, 18.8 km, and Deception Creek. The Humphrey's Creek avulsion occurred 23 years after logging. On the other hand, it is clear that the locations at greatest risk to post-logging erosion are associated with disturbed side channels that extend outside of the active riparian zone.

6.0 SEDIMENT YIELD

The watershed sediment budget and channel sediment transport regime are very important components of the channel stability equation. Suspended and bedload sediment yield are difficult to estimate in the absence of data such as suspended sediment concentrations, repeat channel cross-section surveys, and repeat longitudinal channel surveys, none of which are available in the Kitimat watershed. An inventory of sediment sources, such as recently completed as a first step in the Tsitika River Sediment Monitoring Program (Hogan, pers. comm.) is also not available for the Kitimat watershed. In the absence of the above types of information, only a limited analysis of coarse bedload sediment was attempted.

6.1 Methods of Estimating Sediment Yield

The expected annual sediment budget of the Kitimat River was estimated from suspended sediment regionalization analysis (Sutek Services Ltd. and Kellerhals Engineering Services Ltd., 1989). The regionalization estimate was compared with an estimate of the volume of delta advance at the Kitimat River estuary since 1953 (Gottesfeld, 1985), and with bedload sediment yield estimates in several other coastal watersheds of British Columbia. The volume of bank material eroded on the Kitimat River between Hirsch Creek and the old Crown Zellerback logging road bridge (km 12 to 20) was estimated from the total area eroded, assuming an average 2m depth of erosion. This section of the Kitimat River includes the junctions of the Little Wedeene and Wedeene Rivers. The volume of material entrained from bank erosion on the Little Wedeene and Wedeene Rivers was also estimated. The volumes of material entrained from bank erosion sources were then compared with yields estimated with the regionalization techniques, and yields estimated in the other British Columbia coastal watersheds. The objective was to determine whether the sediment regime of the Kitimat River is a likely concern for channel stability.

6.2 Results

Gottesfeld (1985) estimated that the delta of the Kitimat River has advanced about 300 meters since 1953, comprising an approximate volume of 10 million cubic meters over 30 years, or about 330,000 cubic meters/year. The Gottesfeld estimate is equivalent to 530,000 tonnes/year, or 0.7 Mg Km-2 day-1 of suspended sediment, placing the Kitimat River in the lightly glacierized category of Sutek Ltd. and Kellerhals Ltd. (1989). Suspended Sediment Regionalization for B.C. (Sutek and Kellerhals, op. cit.) suggest that the gravel load of a lightly glacierized basin on the west side of the Coast Mountains may be 5 to 8% of the suspended load, or about 17,000 to 26,000 cubic meters/year.

Another estimate of the gravel load or bedload of the Kitimat River can be made from several independent estimates of bedload in coastal B.C. watersheds. Sutek and Kellerhals (op.cit.) estimated the annual gravel load of the Lillooet River at about 30,000 to 40,000 cubic meters/year by several methods, equivalent to 13.9 to 18.5 cubic meters/km-2/year-1. Carnation Creek bedload was measured at 267 tonnes/year from 1972 to 1984, equivalent to 167 cubic meters/year or about 16.5 cubic meters km-2year-1 (Tassone, 1988). A third estimate of bedload was made for the Tsitika River, from lateral bank erosion rates along two sections of the river near the month. Rollerson (1983) measured erosion rates of about 0.4 hectares/year over a 20 year period (1961-1981). Assuming an average 2m depth of bedload sized materials in the eroded area, the bedload generated is estimated at 8000 cubic meters/year, or about 20 cubic meters/km-2year-1. Thus, three widely disparate coastal rivers, ranging in size from the glacierized 2160 km2 Lillooet to the unglacierized 400km2 Tsitika and the 10km2 Carnation Creek all appear to have a bedload ranging from 14 to 20 cubic meters/km-2/year-1. Applied to the Kitimat River these estimates suggest a bedload of 28,000 to 40,000 cubic meters/year, somewhat higher than the Suspended Sediment Regionalization estimate.

The two major areas of bank erosion in the Kitimat River Reach 3 study section were the side channels at 14.1R and 18.8R. From 1977 to 1988 or 1989, the total areas of erosion were 11 hectares and 13 hectares respectively. Assuming a 2 meter depth of bedload sized materials in the eroded bank column, approximately 220,000 and 280,000 cubic meters of bedload may have entered the channel of the Kitimat River from these two sources between 1977 and 1989.

About 11 and 11 hectares of bank erosion occurred between 1977 and 1988 along the lowest 3 km and 4km of the Wedeene and Little Wedeene Rivers respectively. Thus, up to 220,000 cubic meters of bedload sized materials may have been entrained along the two tributary channels.

The locations and timing of the bedload entrainment from bank erosion may have an important bearing on the recent history of the Kitimat River channel in the section between Hirsch Creek and the Wedeene River. The two side channel bedload source areas discharge into the Kitimat River about 4.5 km apart, at 14.1 and 18.8 km. The Little Wedeene River enters the Kitimat about a kilometer above the entrance to side channel 14.1R, and two kilometers below the sidechannel 18.8R/Wedeene River junction. The Wedeene River, however, joins the Kitimat at the discharge point of the 18.8R sidechannel source. Distance of travel of bedload can be estimated as about one half of the meander wavelength. On the lower Kitimat River, the meander wavelength is about 2km, suggesting an estimated travel distance of about one kilometer when bedload is entrained. Because of the distances separating the main bedload sources along Reach 3, the bedload from the 14.1 km sidechannel, the Little Wedeene River, and the 18.8 km sidechannel/Wedeene River should be moving downriver as separate lobes.

The timing of the bedload releases from the above sources is unevenly distributed over time since 1977. The estimates of change in side channel areas (Table 6) indicate that the bedload entrainment has occurred mainly since 1985. The sidechannel at 14.1 km released between 4000 and 10,000 cubic meters of material from 1972 to 1985, a rate well within the capacity of the Kitimat River to transport. Since 1985, however, the rate increased abruptly to 30,000 cubic meters/year from 1985 to 1988, and nearly 70,000 cubic meters in the single year 1988 to 1989. It is likely, moreover, that most of the releases from 1985 to 1988 (90,000 cubic meters) also occurred in the single year, 1987 to 1988.

The sidechannel at 18.8 km released between 9,000 and 17,000 cubic meters of materials per year from 1973 to 1985. This rate also appears to be within the transport capacity of the Kitimat River. From 1985 to 1988, the rate increased to over 40,000 cubic meters per year. Most of the total volume released (130,000 cubic meters) probably occurred in one year, 1987 to 1988. More importantly, the Wedeene River, which joins the Kitimat River at the discharge point of the 18.8 km side channel, also released about 45,000 cubic meters per year from 1985 to 1988 from a source area immediately adjacent to the Kitimat River. Thus, the combined volume of material entering the Kitimat at the Wedeene/18.8 km junction may have been nearly 90,000 cubic meters per year from 1985 to 1988, mostly in the single year 1987-1988.

In between the 14.1 km sidechannel and the Wedeene/18.8 km sidechannel source areas, the Little Wedeene River entrained about 60,000 cubic meters of bank materials per year from 1985 to 1988 in the section between the CN railway bridge and the Eurocan logging road bridge. Since this source area is about 2 km away from the Kitimat River, it is unclear how much of the material has reached the Kitimat.

The above estimates do not account for and are only a partial estimate of the bedload sediment transport and deposition patterns on the lower Kitimat River. Moreover, no comparable data from the pre-logging period were measured. Imperfect though they may be, the above estimates of bedload sediment introduction into the Kitimat River from bank erosion indicate that an imbalance may have developed since 1985 between the estimated normal bedload sediment yield of the Kitimat River and the amount being supplied to the channel, in the reach between Hirsch Creek and the Wedeene River.

7.0 CLIMATE FLUCTUATIONS

The relationship between climate fluctuation and river channel change is complex. One study in Kansas (Schumm and Lichty 1963, quoted in Gregory and Walling, 1973) showed that a period of river channel widening coincided with a period of below normal precipitation amounts, but above normal flood peakflows, while channel narrowing occurred in the reverse climate circumstances. Fluctuations in annual precipitation amount may therefore not be a good indicator of river channel change, especially in a region where most channel changes are associated with specific flood events.

7.1 Methods of Analysis

The relationships between channel changes and climatic variation in the Kitimat watershed were investigated by analysis of regional indexes of precipitation and stream discharge. Regional indexing methods are detailed in Karanka (1986). Two regional hydrometric variables were investigated: maximum September to August one day precipitation and maximum daily September to April stream discharge. Seasonal indexes were selected because the most significant hydrological activity occurs during the fall-winter period, and the timing of the water year beginning in September/October is more closely related to the annual hydrological cycle of the Kitimat River than the calendar year.

The maximum seasonal one day precipitation and maximum daily stream discharges are extreme value data that require some type of transformation for normalization. Natural logarithm transformed data were used for the analysis.

The regional long-term climate stations used for precipitation analysis were screened by correlation analysis of station data as detailed by Karanka (1986). All stations with correlation coefficients of 0.7 or greater were accepted for the regional index. Individual station data were not screened for data homogeneity.

The choice of stream discharge data for regional peakflow analysis has some flexibility since 1960, when regional correlation analysis becomes possible. Annual fall and winter peakflow maxima in the September to March period were identified on gauged streams draining into the heads of fjords (and analogous positions) on the Northern mainland Coast of B.C. Streams in this category with discharge records longer than 20 years were identified as: Kitsumkalum, Zymoetz, Zymagotitz, Exchamsiks, Kitimat, Hirsch, Little Wedeene, and Kemano. The maximum daily September to April discharges of the Zymoetz River, Kitimat River, Hirsch Creek, and the Kemano River have correlation coefficients greater than 0.8, and are the stations used for the regional index since 1953. There is no flexibility in data choice prior to 1953: The data available from the Kitsumkalum River must be assumed to be regionally representative to extend the data time base back to 1930.

7.2 Results

Four periods of higher than normal peakflow are evident: 1932-1940, 1953-1967, 1974-1980, and 1987 to present, with intervening periods of lower than normal peakflow from 1941-1952, 1967-1973, and 1981-1986 (Figure 11).

Although the 1932-1940 period of high peakflows is based on data from a single station; Kitsumkalum, corrobarative data is available from as far away as Northern Vancouver Island. High peakflows are attested during this period on the central B.C. Mainland Coast, in 1932 and 1933 on the Wannock River, in 1934 and 1936 on the Bella Coola River (Church and Russell, 1979) and in 1935 on Lakelse River just north of the Kitimat watershed (McMillan, et el 1979). Peakflows on the Marble River of Northern Vancouver Island were high in 1939 and 1940.

The high peakflows in the 1953-1968 period are widely corroborated in peakflow data series: Revillagigedo Island in the Alaska Panhandle (1958-1965), the central mainland coast of B.C. (1961-1968), and northern Vancouver Island (1956-1968).

The 1974 to 1980 period of high peakflows is well known for the 1974 and 1978 floods in the Kitimat - Terrace area. Since 1987, another series of high peakflows has occurred in the Kitimat area, culminating in the floods of October, 1991. The latter event set peakflow records on the Kitimat River, Little Wedeene River, and the Kemano River. Three high regional peakflows (1974, 1976 and 1978) sustain the 1974-1983 period of high peakflows.

Cumulative October to April 1 day maximum precipitation indices for Terrace and Kitimat (Fig. 12) have a pattern similar to the regional stream peakflow index. Periods of higher than normal 1 day maximum precipitation occur from 1922-1935, 1955-1960, 1970-1979, and 1986-1990, corresponding in part to each of the periods of higher than normal stream peakflows.

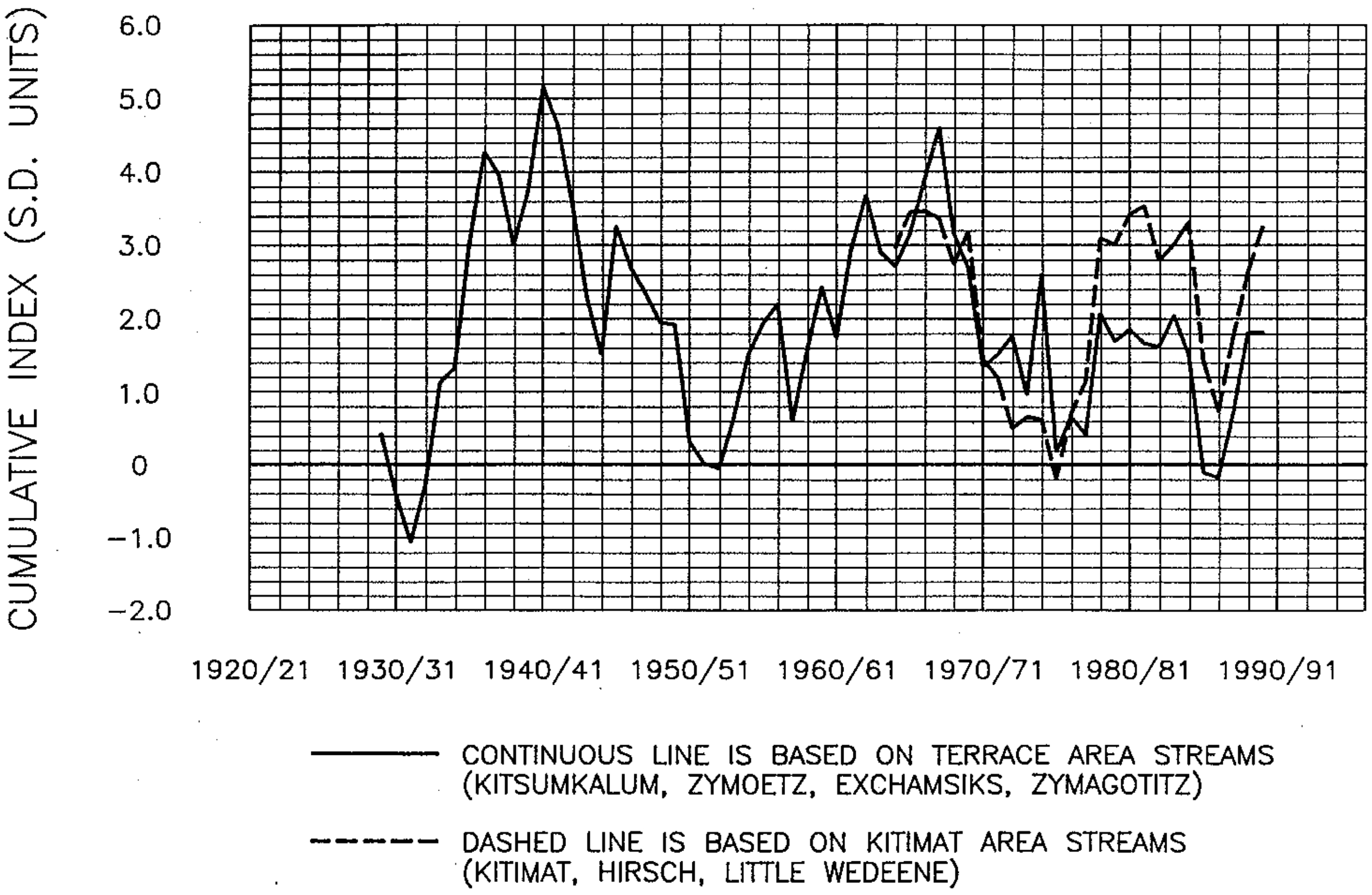


FIGURE 11: REGIONAL INDICES OF ANNUAL (SEPT.—APR.) MAXIMUM DAILY PEAKFLOW ON THE NORTHERN MAINLAND COAST OF BRITISH COLUMBIA

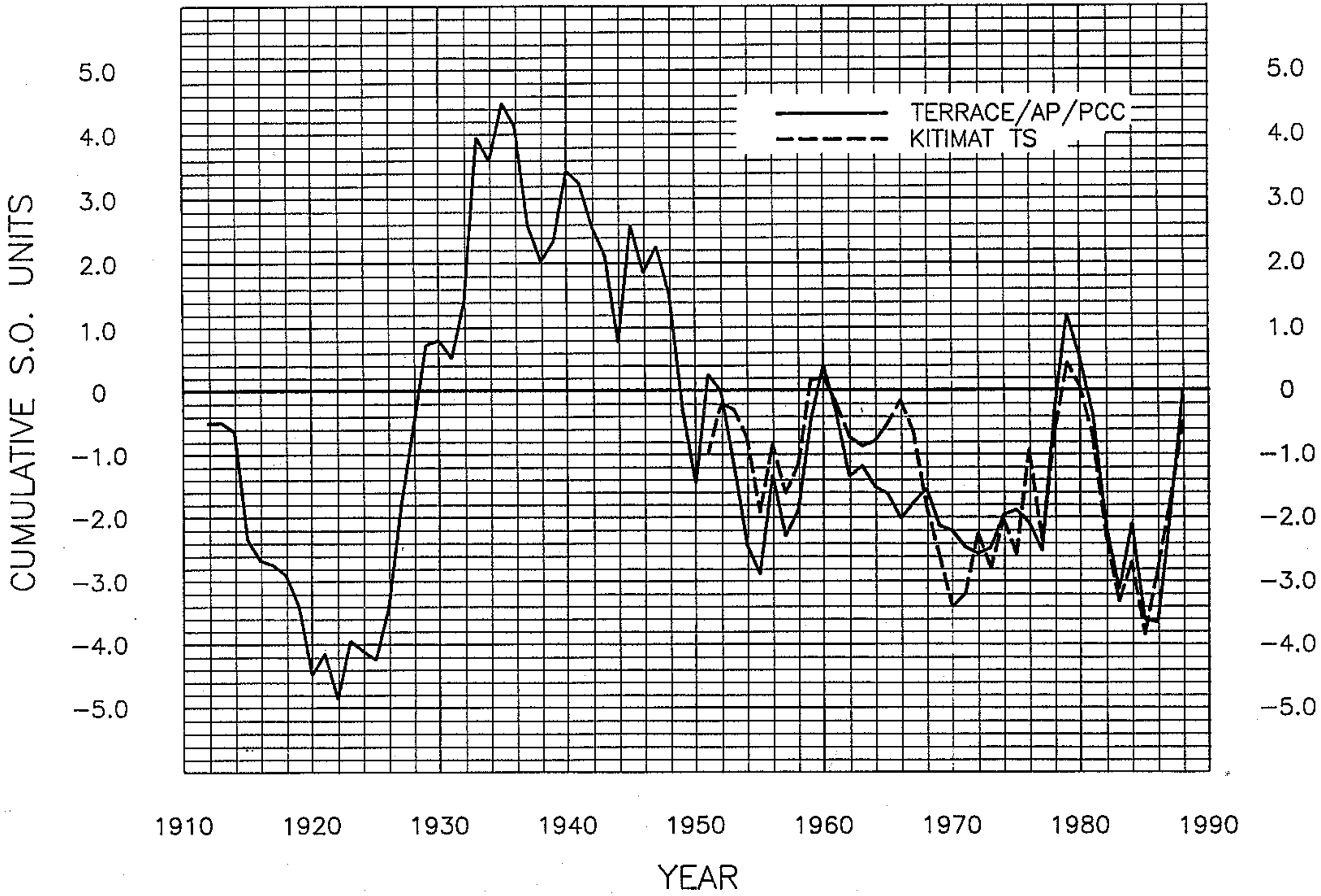


FIGURE 12: CUMULATIVE DEVIATION OF ANNUAL MAXIMUM ONE DAY PRECIPITATION AT TERRACE/KITIMAT FROM THE LONGTERM GEOMETRIC MEAN. (LOGNORMAL)

8.0 RAIN-ON-SNOW AND THE TRANSIENT SNOW ZONE

Meteorological energy balance equations generally predict that clearcutting of a forest should increase the rate of snowmelt during rainfall with a shallow snowpack on the ground. The resulting increase in peakflows from the clearcut watershed area over the peakflows from a comparable forested watershed area is the physical basis for concern about the rate of forest harvesting in a watershed. Harr (1986) suggested that the hydrological effect would be greatest and most frequent in the "transient snow zone", defined as the range of elevations where shallow snowpacks (generally less than 50cm deep) accumulate and melt several times each winter. Berris and Harr (1986) showed that in test plots situated in the Oregon Cascade Range, the net energy fluxes into a snowpack were 2 to 3 times greater in a clearcut plot than in a forested plot in low wind conditions during rain-on-snow. The net energy flux was up to 6 times greater in the clearcut plot during windy rain-on-snow conditions. Moreover, the snowpack in the clearcut plot was deeper and had a greater snow water equivalent than the snowpack in the forested plat as a result of the canopy interception and early snowmelt that occurs in the forest.

Watershed runoff data confirming the energy balance model predictions and test plot findings for rain-on-snow runoff from clearcuts have been more difficult to find. Most watershed studies in the coastal Pacific Northwest have not been designed to monitor the effect of clearcutting on rain-on-snow runoff. As a result, the hydrological data are often difficult to interpret for the effect of clearcutting on rain-on-snow runoff. Harr (1986) suggested that streamflow data from one paired-watershed study in the Oregon Cascades showed a significant increase in post-logging peakflows associated with rain-on-snow in the clearcut watershed. In the Oregon study, the study watersheds were located entirely within the transient snow zone (elevation range 350 to 1100m in the Oregon Cascades), and 100% of the experimental watershed was clearcut versus no cutting in the control watershed. Moderate sized peakflows showed increases of 10 to 20% in the clearcut basin, with little or no difference for larger peakflows. The results were significant, but only at a 0.10 level of probability. Golding (1987) concluded that the clearcutting of about 20% of the Jamieson Creek basin in the Seymour River watershed, north of Vancouver, B.C., resulted in a maximum 13.5% increase in peakflows associated with rain-on-snow. No significant difference was found in the amount of change between flows of different magnitudes.

Harr (op.cit.) defined a Transient Snow Zone (TSZ) that is active all winter, and identified the upper boundary of the TSZ in Oregon at the elevation where the winter snowfall exceeds 30% of the total annual precipitation. Another criterion used by Harr for helping define the transient snow zone is a maximum snow pack depth of 50cm, rarely exceeded within the Oregon Cascades transient snow zone.

8.1 Methods For Analysis

Long term daily rainfall, snowfall, and snowdepth data from Terrace Airport (elevation 217 m.),Tahtsa Lake West (863 m.), Kemano (70 m.) and Kitimat TownSite (128 m.) climate stations were used to analyze the characteristics of the Transient Snow Zone in the vicinity of the Kitimat watershed. Short term daily data from Kemano Kildala Pass (1609 m.) were used to increase the elevation range of the climate station coverage. In addition to Harr's TSZ criteria, the following definitions were used to define the Transient Snow Zone:

1. The lower elevation boundary occurs on the date and at the elevation where snowfall exceeds 10% of the total precipitation for the date.

2. A middle boundary divides the TSZ into a lower zone where the snowpack is intermittant and a upper zone where the snowpack is permanent but fluctuating. Accumulation of a fluctuating but permanent snowpack generally begins when snowfall exceeds 30% of total precipitation.

3. The upper elevation boundary occurs on the date and at the elevation where snowfall exceeds 50% of the total precipitation for the date.

The availability of daily rainfall, snowfall, and snowdepth records from an elevation band ranging from sea level to 1600 meters in the vicinity of the Kitimat basin allows not only an estimation of the proportion of the basin within the TSZ throughout the winter, but also a modelling of the changing elevation/basin area characteristics of the TSZ as it descends in elevation in the fall.

8.2 Results - Kitimat Transient Snow Zone

By Harr's criterion of 30% annual precipitation as snowfall, Kitimat TS at 130m elevation and 23% annual precipitation as snowfall is clearly within the all-winter Transient Snow Zone, even though mean snow pack depths exceed 50cm at the end of January (Fig. 13). Terrace Airport, 50km further inland at 200m, with 30% of annual precipitation as snowfall, is at the upper boundary of the TSZ. Although mean and median snowpack depths at Terrace Airport are below 50cm on any given day throughout the winter, the mean maximum snowdepth for the entire winter season is 51cm. Snowpack depths exceeding 50cm occur in 3 out of 4 winters at Terrace Airport, with a mean duration of 26 days and a median duration of 15 days. Both Terrace Airport and Kitimat TS have snowpack continuity throughout most winters from mid December to mid March and frequently exceed 50cm in depth, thus exceeding Harr's 50cm snowpack depth criterion. Month end mean snowpack depths at the Wedeene snow course (elev. 310m) and the Thornhill Mountain climate station (elev. 520m), both near Terrace Airport, exceeded 50cm from at least the end of January to the end of March, and the end of December to the end of February respectively (Table 9). Both stations are clearly above the TSZ as defined by Harr. Thus, only the portion of the Kitimat basins below 300m in elevation falls within the all-winter TSZ as defined by Harr. About 15% of the Kitimat basin is within the TSZ, most of which has been clearcut.

Harr defined a transient snow zone that is active all winter. In basins with a climate and elevation distribution like the Kitimat, the all-winter transient snow zone comprises only 10 to 20 percent of the basin area. But there is also a seasonally active transient snow zone at higher elevations before snow pack accumulation begins. Assuming that a transient snow zone becomes an active source of rain-on-snow runoff when the long-term proportion of snowfall to total precipitation exceeds 10%, and becomes inactive when the proportion exceeds 50% as a result of snowpack accumulation, the high elevation TSZ can be estimated from long-term daily data at Kemano, Terrace Airport, Tahtsa Lake West and Kemano Kildala Pass.

At Tahtsa Lake West (elev. 860m) the TSZ becomes active around October 13th. The TZS at Kemano (elev. 70m) and Kitimat TS (elev. 130m) becomes active around November 13th, an average rate of descent of 25m/day for the 10% snowfall level. Assuming that permanent snowpack accumulation begins, on average, when the long-term proportion of snowfall to total precipitation exceeds 50%, then Tahsta Lake West at 860m is above the transient snow zone by about November 10th. Terrace Airport achieves the 50% snowfall proportion by December 5th, indicating the same rate of descent of

25m/day as for the 10% snowfall proportion. Below 200 meters, distance inland from the ocean becomes a factor in defining the TSZin the Kitimat Valley. Kemano and Kitimat TS do not reach 50% snowfall level until January 7, and then only for a short period. The empirial rate of change of the 50% snowfall to total precipitation rate is confirmed by the rate of descent of the median freezing level at Annette Alaska (Fig. 14).

Using the criteria of 10% snowfall and 50% snowfall to total precipitation as the lower and upper boundaries of the transient snow zone, their rates of descent in the autumn, and the distribution of basin elevations, the changing proportions of the watershed within the TSZ can be modelled through the fall and each winter (Table 11 and Fig. 15). The Kitimat basin area within the TSZ rises from about 10% around September 22nd, in the 1500 to 2000m elevation zone, to a maximum of 55% around November 10th, in the 0 to 900m elevation zone. After November 10th, the proportion of the basin drops to the all-winter TSZ of about 15% by early December. The high elevation transient snow zone is 2 to 4 times larger from mid-October to mid-November than the all-winter low-elevation transient snow zone after November 30th. In addition, during October, 20 to 70% of the remaining basin area is contributing runoff from rain.

The estimate of the proportion of the Kitimat basin within the TSZ represents long-term average conditions, from which conditions during individual storms can deviate considerably: The TSZ estimates nevertheless suggest that most major peakflows should occur prior to November 10th, before the 0-200m elevation zone becomes an active source of rain-on-snow runoff.

Most Kitimat tributary watersheds have TSZ conditions similar to Kitimat with two notable exceptions, Little Wedeene River and Cecil Creek. Little Wedeene River has more lower mid slope area than the other watersheds. Consequently, its maximum TSZ occurs earlier than the other tributary watersheds and has a higher maximum TSZ area, peaking around October 31, at 65% of the watershed. 80% of Cecil Creek watershed is below 300m in elevation. In consequence, virtually all of the basin is within the all-winter TSZ. The maximal TSZ area is over 90%, occurring in mid November.

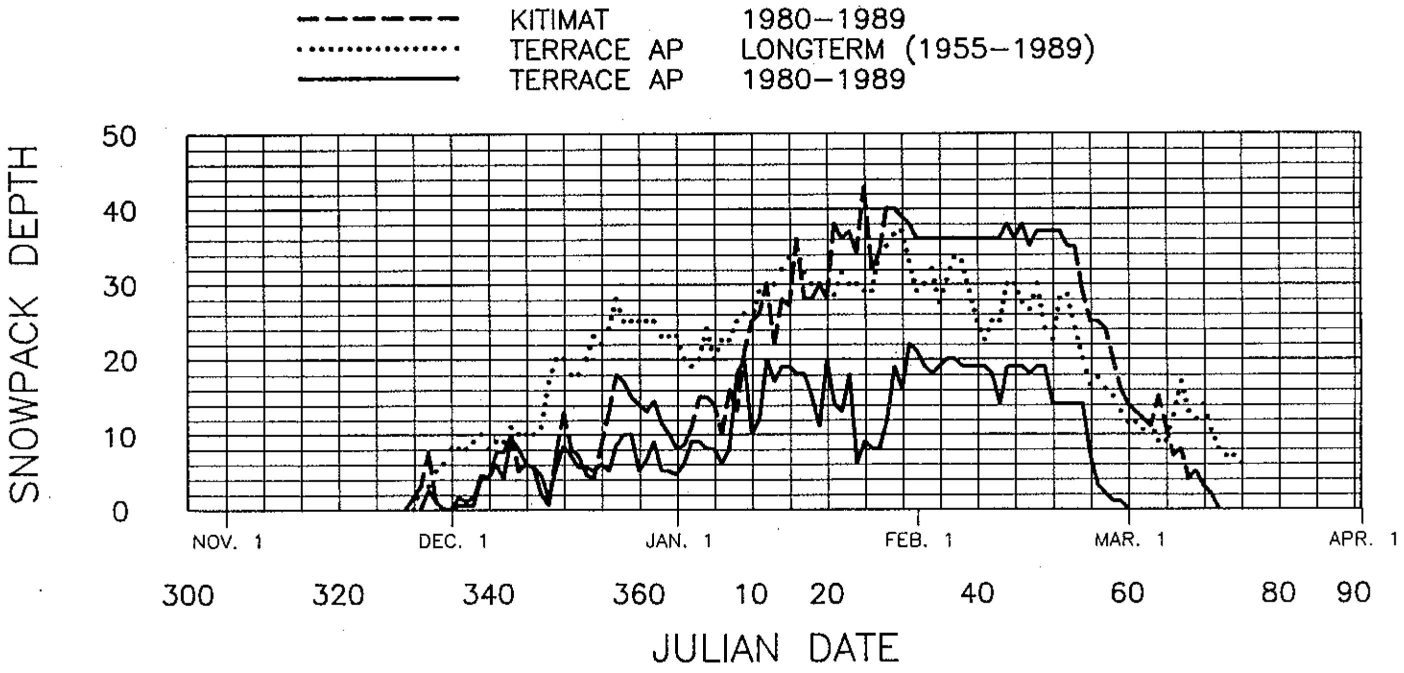


FIGURE 13: SHORT TERM (1980–89) AND LONG TERM MEDIAN SNOWPACK DEPTHS AT KITIMAT AND TERRACE AP.

TABLE 10 SNOWFALL AND SNOWDEPTH CHARACTERISTICS OF KITIMAT WATERSHED

KITIMAT TS (1954-1986) ELEV. 128 M.	OCT	NOV	DEC	JAN	FEB	MAR	APR	OCT-APR
1. MEAN SNOWFALL (CM)	5	58	129	189	100	56	10	548
2. % OF TOTAL PRECIPITATION	1	19	40	62	44	43	9	30
3. MEAN MONTH END SNOW DEPTH (CM)			34	57	44			
4. MAXIMUM MONTH END SNOW DEPTH (CM)			203	145	158			
TERRACE AP (1953-1986) ELEV. 217 M.								
1. MEAN SNOWFALL (CM)	4	49	106	116	72	44	12	403
2. % OF TOTAL PRECIPITATION	2	26	55	66	54	49	21	38
3. MEAN MONTH END SNOW DEPTH (CM)		12	29	37	28	8		
4. MAXIMUM MONTH END SNOW DEPTH (CM)		56	150	107	127	48		
KEMANO (1951-1986) ELEV. 70 M.								
1. MEAN SNOWFALL (CM)	2	26	72	97	53	24	3	277
2. % OF TOTAL PRECIPITATION	TR	11	30	43	29	20	3	19
KILDALA (1966-1986) ELEV. 30 M.								
1. MEAN SNOWFALL (CM)	1	25	79	120	66	35	5	331
2. % OF TOTAL PRECIPITATION	TR	9	26	47	33	22	4	15
3. MEAN MONTH END SNOW DEPTH (CM)		31	61	66	33			
4. MAXIMUM MONTH END SNOW DEPTH (CM)		74	122	180	132			
TAHTSA LAKE WEST (1952-1986) ELEV. 863 M.								
1. MEAN SNOWFALL (CM)	49	154	242	204	169	122	66	1007
2. % OF TOTAL PRECIPITATION	16	58	61	61	82	61	62	64
3. MEAN MONTH END SNOW DEPTH (CM)		57	141	169	217	212	147	
4. MAXIMUM MONTH END SNOW DEPTH (CM)		114	241	320	330	325	254	
KILDALA PASS (1952-1959) ELEV. 1609 M.								
1. MEAN SNOWFALL (CM)	254	178	326	248	287	264	203	1767
2. % OF TOTAL PRECIPITATION	71	74	97	100	97	100	99	90
3. MEAN MONTH END SNOW DEPTH (CM)	165	232	384	389	471	525	538	
4. MAXIMUM MONTH END SNOW DEPTH (CM)	279	279	526	437	516	635	630	
THORNHILL MTN (1974-1982) ELEV. 521 M.								
3. MEAN MONTH END SNOW DEPTH (CM)		36	53	76	67	47		
4. MAXIMUM MONTH END SNOW DEPTH (CM)		121	61	99	122	102		
TERRACE AP SNOWCOURSE (1974-1985) ELEV. 180 M.								
3. MEAN MONTH END SNOW DEPTH (CM)		21	38	39	23			
4. MAXIMUM MONTH END SNOW DEPTH (CM)		51	64	100	86			
WEDEENE R. SNOWCOURSE (1974-1985) ELEV. 340 M.								
3. MEAN MONTH END SNOW DEPTH (CM)			88	104	75			
4. MAXIMUM MONTH END SNOW DEPTH (CM)			193	202	157			

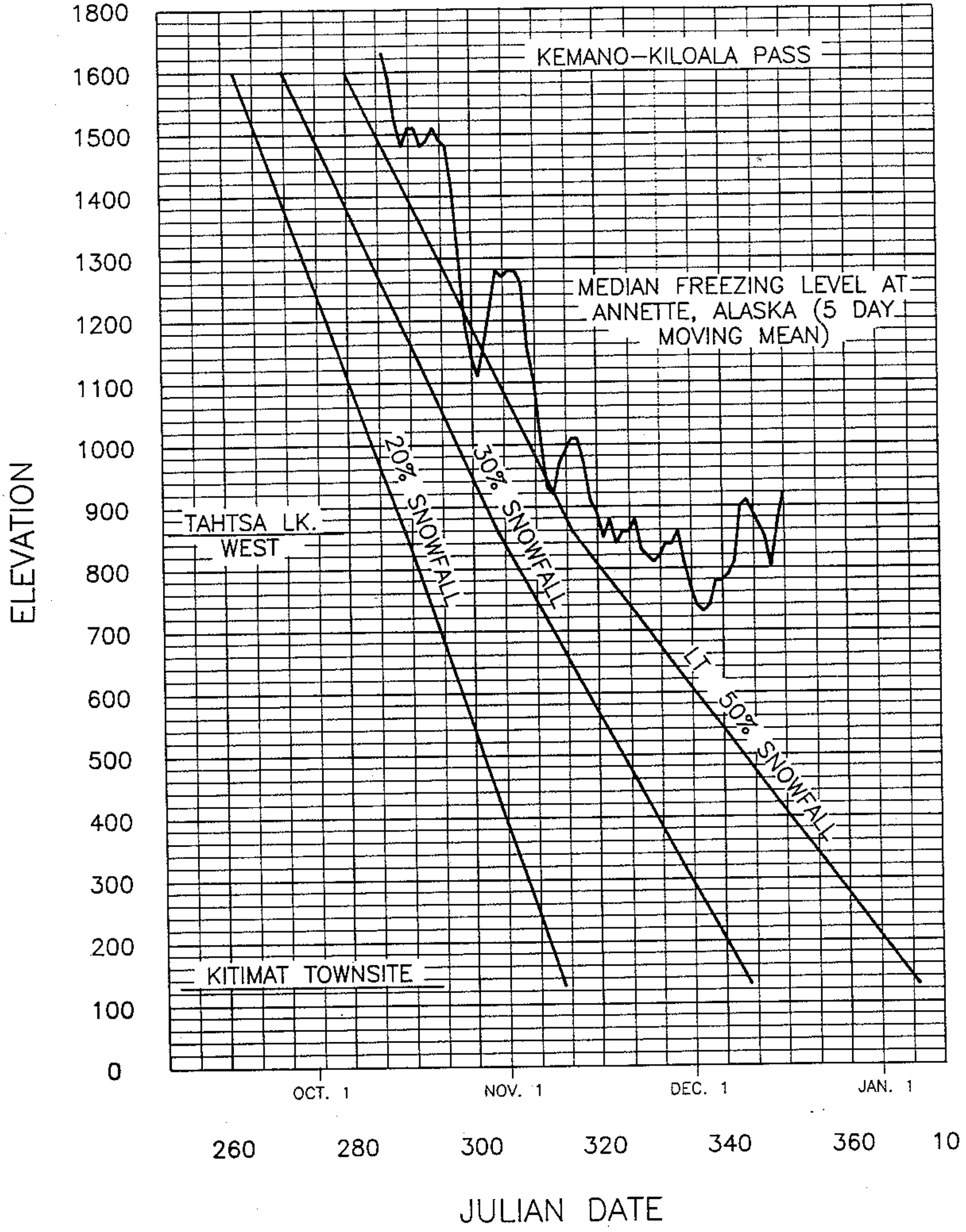


FIGURE 14: KITIMAT AREA LONG TERM SNOWFALL–ELEVATIONS RELATIONSHIPS, COMPARED WITH MEDIAN FREEZING LEVELS AT ANNETTE, ALASKA

TABLE 11 TRANSIENT SNOW ZONE DATA FOR THE KITIMAT (LONG TERM)

	MEAN DATE WHEN THE PROPORTION OF SNOWFALL TO TOTAL PPT EXCEEDS 10%	MEAN DATE WHEN THE PROPORTION OF SNOWFALL TO TOTAL PPT EXCEEDS 50%
KITIMAT TS (130M)	NOVEMBER 10	JANUARY 5
TERRACE AP (200M)	NOVEMBER 3	DECEMBER 2
TAHTSA LAKE W. (860 M)	OCTOBER 13	NOVEMBER 12
KILDALA PASS (1610 M)	SEPTEMBER 17	OCTOBER 9

KITIMAT WATERSHED

DATE	ELEVATION (M) OF 10% SNOW:PRECIPITATION EXCEEDANCE	ELEVATION (M) OF 50% SNOW:PRECIPITATION EXCEEDANCE	% OF WATERSHED BETWEEN 10-50% SNOW:PRECIPITATION EXCEEDANCE	% OF WATERSHED WITH GREATER THAN 50% SNOW:PRECIPITATION EXCEEDANCE
SEPT 1	2100	2450	0	0
SEPT 15	1700	2150	5	0
SEPT 30	1300	1800	15	5
OCT 15	900	1500	35	10
OCT 31	300	1100	45	30
NOV 15	SEA LEVEL	750	50	50
NOV 30	SEA LEVEL	300	20	80

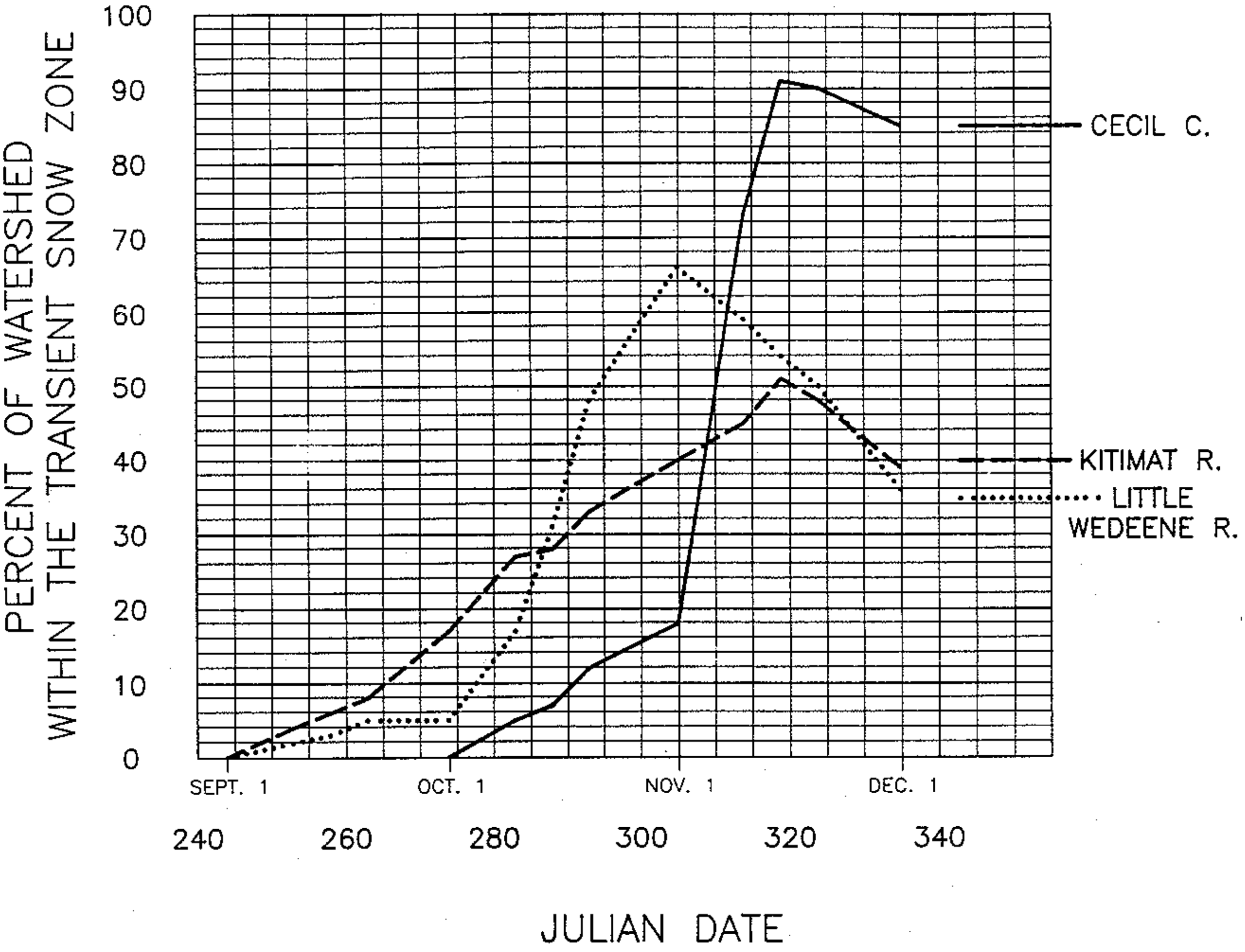


FIGURE 15: LONG TERM TRANSIENT SNOW ZONE CHARACTERISTICS OF THE KITIMAT, LITTLE WEDEENE, AND CECIL WATERSHEDS

9.0 KITIMAT WATERSHED PEAKFLOW HYDROLOGY

Summer peakflows in the Kitimat Watershed generally occur from late May to July and result from radiation snowmelt of mid to high elevation snowpacks. The fall and winter peakflows, occurring from September to January, are generally higher than the summer peakflows and result from rain on saturated soil and/or rain-on-snow. The major fall and winter peakflows were defined on the Kitimat, Hirsch Creek and Little Wedeene River as all peakflows from September 1 to March 31, greater than the highest summer peakflow (greater than 700m3/sec, 140m3/sec, and 90m3/sec respectively). The maximum daily discharge was used for the analysis, because the maximum instantaneous discharge was not available for all the selected events.

9.1 Methods for Analysis

The major peakflows of the Kitimat Watershed were defined as the daily discharges in the September to April period that exceeded the highest recorded spring-summer peakflows at the Kitimat River, Hirsch Creek and Little Wedeene River stream gauging stations. The latter were, respectively, 700m3/sec., 140m3/sec., and 90m3/sec. Based on the above criteria, the Kitimat had 32 major fall and winter peakflows in 24 years of record (Up to the winter of 1989-90). Hirsch Creek and Little Wedeene River had 26 and 32 events respectively, including 16 events that did not meet the major peakflow selection criterion on the Kitimat. Forty-eight separate events were identified since the beginning of records in 1964.

The meteorological conditions resulting in each of the peakflows were analyzed, using data from the climate stations at Kitimat TS, Kemano, Terrace Airport, and Tahtsa Lake West. Daily rainfall and maximum temperatures were compiled for each climate station in the seven day period leading up to and including the day of peakflow. Cumulative snowfall prior to the peakflow and days since the last snowfall prior to the peakflow were compiled for each climate station. Freezing levels at Annette, Alaska and Port Hardy Airport were also analyzed during the 5 day period prior to and including the day of the event.

9.2 Kitimat Watershed Peakflow Characteristics

Since the presence of a snowpack on the ground is the key factor in peakflows generated by rain-on-snow, the 48 peakflows were classified by the estimated snowpack conditions within the Kitimat watershed and ranked by the maximum daily discharge rate for each basin (Table 12).

Type 1 peakflows had no snow at the valley bottom and less than 10cm of prior snowfall at Tahsta Lake West. Type 1 peakflows are essentially rainfall only up to at least the median basin elevation in the Kitimat. The upper 50% of basin could be generating rain-on-snow runoff during a Type 1 peakflow, but the lower 50% of the basin is contributing rain-only runoff. Twenty-four of the 48 major regional peakflows were classified as Type 1, including the 5 highest ranked peakflows.[1] Freezing levels for a Type 1 peakflow at Annette, Alaska are typically above 1200m throughout a Type 1 event (Fig. 16).

Type II peakflows had little or no snow at any of the valley bottom stations, but considerable snow (20-250cm cumulative snowfall) at Tahsta Lake West. During a Type II event, the lower 300-400m of the basin would be contributing rain-only runoff, with rain-on-snow occurring in at least the 300-1000m elevation zone, which comprises 50% of the basin area in the Kitimat watershed, and over 70% of the area in the Little Wedeene watershed. The upper 20-30% of the watersheds (above 1100m) may or may not be generating rain-on-snow during a Type II peakflow, depending on the event freezing level and depth of snowpacks. Twelve of 48 major peakflows were Type II peakflows. Freezing levels at Annette, Alaska during Type II peakflows generally rise 1000m from the 400-1200m level in the days preceding the event (Fig. 16).

Considerable snowfall had occurred at valley bottom stations as well as at Tahtsa Lake West prior to Type III peakflows. All of the runoff in a Type III event is rain-on-snow and is the only event Type that involves rain-on-snow runoff generation from the all-winter transient snow zone in the region of the Kitimat Watershed. Twelve of 48 major peakflows in the Kitimat watershed were Type III peakflows. Freezing levels at Annette, Alaska generally rise over 1000m during Type III events from the 200-500m level in the days preceding the event (Fig. 16).

The mean dates of occurrance and mean maximum daily peakflows for Types I, II, and III peakflows are shown in Table 13 for the Kitimat, Little Wedeene and Hirsch watersheds. The mean dates of occurrance for Types I, II, and III peakflows are significantly different at a 99% level of confidence, using the Student's Test for unpaired samples. The Type I peakflows, in addition, have a standard deviation about one half of the standard deviations of Types II and III peakflows. This indicates a timing constraint for Type I peakflows probably involving the pinching out of the upper

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[1] The Kitimat River, Little Wedeene River, and Hirsch Creek peakflows of Oct. 10, 1991, are not included in this analysis. Although the daily weather data for this event are unavailable at the moment of writing, it appears to have been another Type I event.

elevation TSZ. Types II and III3 time distributions are also in accord with the long term TSZ conditions, but these types can occur over a greater time period as a result of the variability of basin conditions involving the low to mid elevation TSZ between individual storm events.

The small sample sizes of Types I and III events, the extreme value distributions represented by peakflow data, and the non-comparable peakflow values between the three basins posed problems in testing for the statistical significance of peakflow differences, both within each basins' data set and in the form of a combined data set. The selection criteria for major peakflow events yielded similar numbers of events for each basin. Expressed as a unit area discharge however, the selection criteria change inversely with basin size. Peakflows expressed as unit area discharges are therefore not comparable between basins because of the systematic variation between the basins. The ratios between peakflows and their respective basin selection criteria seemed the best method for combining data from different basins to increase the sample sizes of Types 2 and 3 events, without introducing systematic biases into the combined data set. The peakflows in all three basins for all 48 major events were required for the analysis, including the peakflows that did not meet the initial selection criteria.

Since the parent peakflow are assumed to have similar, non-normal probability distributions, the Wilcoxson Mann-Whitney Rank Sum Test was used to test the statistical significance of differences between the three peakflow Types. The Wilcoxson Mann-Whitney Rank Sum Test is significant at the .95 probability level for differences between Type 111 flows and Types 1 and 11 flows, for both the intra-basin and the combined basin data sets. The Type 111 peakflows are significantly smaller than the Types 1 and 11 peakflows. Differences between Types 1 and 11 peakflows are not significant for any of the data sets.

Two other observations are pertinent. Although Types 1 and 11 peakflows are not significantly different statistically, the 5 highest ranked peakflows in the Kitimat Watershed (1974, 1976, 1978, and 1988) have all been Type 1 events, whith the TSZ above the median basin elevation. The role of the middle and high elevation TSZ in peakflow generation in the Kitimat Watershed is further illustrated in the Little Wedeene sub basin. The estimated long term TSZ of the Little Wedeene reaches a maximum of 75% of the basin area around October 31st, all of the TSZ area being above 300m in elevation. The Type 11 events, in the Little Wedeene have a higher mean ratio (to the peakflow used as the selection criterion) than the Type 1 events, unlike either Hirsch Creek or the Kitimat River. In spite of the higher overall rankings of Type 11 peakflows in the Little Wedeene River, the peakflows ranked #1, 3 and 4 have been Type 1 events.

The best example of a Type III low elevation rain-on-snow peakflow in the Kitimat watershed is not included in the sample set because it occurred after the analysis was completed. The Dec. 7, 1990 peakflow occurred following a heavy rainfall on nearly a meter of fresh snow. This peakflow would be ranked twelfth if included in the Kitimat River peakflow sample set.The relative lack of response of systems like the Kitimat to rain-on-snow events in the all-winter transient snow zone below 500m (Type III peakflows) is explicable by the progressive de-synchronization of runoff from the upper basin, through the accumulation of a snowpack, by the time the all winter transient snow zone becomes an active source of rain-on-snow runoff in November.

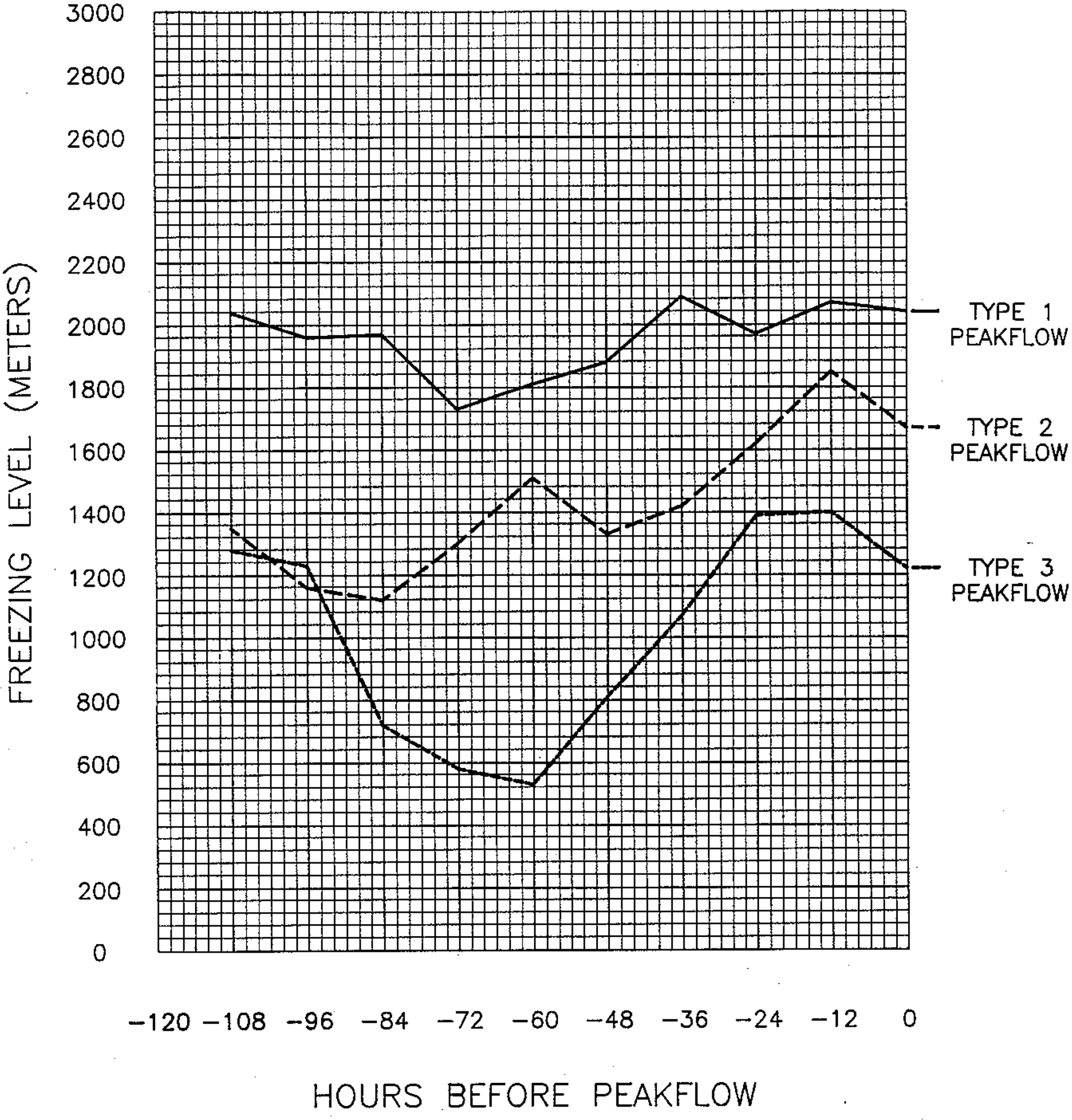

FIGURE 16: FREEZING LEVELS AT ANNETTE, ALASKA DURING TYPE 1, 2, AND 3 PEAKFLOWS IN THE KITIMAT RIVER

TABLE 12 MAJOR DAILY PEAKFLOWS IN THE KITIMAT WATERSHED

DAILY PEAKFLOW MAGNITUDE - M3 SEC(RANKING)

PEAKFLOW DATE	TYPE OF PEAKFLOW	KITIMAT R.	RANKING	HIRSCH C.	RANKING	LITTLE WEDEENE R.	RANKING
OCT. 12, 1964	1	892	21				
OCT. 22, 1965	2	1100	11				
OCT. 24, 1966	2	1120	9	187	18		
SEP.23, 1967	1	886	22			123	18
OCT. 10,1967	1	787	29			116	24
JAN. 22, 1968	3	881	24				
NOV. 19, 1968	3					107	26
NOV. 30, 1969	2	1300	7	282	7	97.1	31
SEP. 12, 1971	1					98	30
OCT. 03, 1971	1	722	33				
NOV. 19, 1971	3	739	31	163	22		
OCT. 08, 1972	2			141	29		
OCT. 07, 1974	1	821	27	228	9	92	34
OCT. 15, 1974	1	1650	3	566	1	131	15
DEC. 16, 1974	3	736	32				
JAN. 17, 1976	3					98.8	29
OCT. 13, 1976	1			142	28		
OCT. 27, 1976	1	1390	5	221	12	124	17
NOV. 03, 1976	2					210	3
JAN. 17, 1977	3			174	21	119	20
OCT. 22, 1977	1	1240	8	265	8		
NOV. 11, 1977	3					106	28
NOV. 01, 1978	1	2410	2	541	2	274	2
NOV. 06, 1978	2	1110	10	224	11		
NOV. 21, 1979	2					156	8
DEC. 27, 1979	3	794	28				
SEP. 29, 1980	1					92.6	33
OCT. 06, 1980	1	1100	12	183	19	148	10
OCT. 28, 1980	1					107	27
NOV. 05, 1980	1	883	23			135	13
DEC. 16, 1980	2	877	25	191	17	120	19
JAN. 19, 1981	2					117	23
NOV. 11, 1981	2	930	18			157	7
SEP. 07, 1982	1			144	26		
OCT. 10, 1982	1	718	34	144	27		
SEP. 26, 1983	1	931	17			190	4
OCT. 03, 1984	1	976	16	227	10	125	16
SEP. 21, 1987	1	1530	4	343	4	161	6
OCT. 30, 1987		909	19	178	20	94.8	32
NOV. 10, 1987	2					143	11
NOV. 20, 1987	3	757	30			136	12
SEP. 30, 1988	1	1300	6	320	5	164	5
OCT. 21, 1988	1	907	20	215	13	118	22
DEC. 04, 1988		852	26	193	15	109	25
NOV. 03, 1989	2			283	6	134	14
NOV. 18, 1989		1020	14	204	14	154	9
DEC. 02, 1989	2	990	15	147	25		
DEC. 25, 1989	3			154	24		
NOV. 12, 1990				159	23		
DEC. 07, 1990	3	1090	13	193	16	119	21
OCT. 10, 1991	1	2500	1	467	3	N.A.	1

TABLE 13 CHARACTERISTICS OF KITIMAT WATERSHED PEAKFLOWS BY TYPE

	KITIMAT R.	HIRSCH C.	L. WEDEENE R.	COMBINED
TYPE 1 PEAKFLOWS				
i. MEAN MAX DAILY FLOW	1130	265.1	135	N.A.
ii. MEAN RATIO OF DAILY FLOWS TO SELECTION FLOW (=1.00)	1.57	1.88	1.47	1.35
iii. MEAN DATE OF OCCURRENCE (S.D.)	OCT 11	OCT 9	OCT 9	OCT 9 (16)
TYPE 2 PEAKFLOWS				
i. AS ABOVE	1080	207.3	142.6	N.A.
ii. AS ABOVE	1.50	1.47	1.55	1.23
iii. AS ABOVE	NOV 13	NOV 10	DEC 2	NOV 16 (30
TYPE 3 PEAKFLOWS				
i. AS ABOVE	790	169.2	107.6	N.A.
ii. AS ABOVE	1.10	1.20	1.17	0.88
iii. AS ABOVE	DEC 21	DEC 19	DEC 17	DEC 19 (30

10. DISCUSSION

Transient snow zone (TSZ) analysis, and analysis of individual storms associated with major peak flows both indicate that rain-on-snow runoff from clear cut areas is not a hydrological problem at the present time in the Kitimat River Watershed. The Kitimat River as a whole and the major tributaries (Wedeene River, Little Wedeene River, Hirsch Creek, and Chist Creek) at present have total logged areas between 13 and 20%. Most logging is currently concentrated in the upper Kitimat Watershed, with about 5% of the area above the Highway 37 bridge logged in the 5 years since operations began in 1986. The two smaller tributary watersheds of Humphries Creek and Nalbeelah Creek exceed the 30% in 25 years rate of cut guideline of the Coastal Fish-Forestry Guidelines, Edition 3. A Watershed Workbook evaluation is therefore required prior to any new logging. The low elevation Deception Creek and Cecil Creek watersheds are 80% logged, greatly exceeding the hydrological guideline. However, much of the land surface of the Cecil Creek watershed is a permeable sand and gravel aquifer with no surface runoff channels. The most likely hydrological effect on Cecil Creek was an increase in growing season groundwater recharge in the first ten years following logging.

Both the transient snow zone analysis and the analysis of individual storms associated with major peak flows indicate that most major peak flows in the Kitimat system are associated with mid to high elevation TSZ, generally above the 300m elevation (Type 1 and 2 peak flows). The early autumn mid to upper slope TSZ during Type 1 and 2 peakflows can be 2 to 3 times the size of the all-winter valley bottom TSZ associated with Type 3 peakflows. The logged portions within the mid to high elevation TSZ constitute less than 10% of the total watershed area within most of the Kitimat watersheds. Most of the logged area in the Kitimat watershed is below 300 meters in elevation. Peak flows associated with a valley bottom TSZ (Type 3 peak flows) are significantly smaller than Type 1 and 2 peakflows, and rarely occur before mid-November. By the time Type 3 peakflows occur after mid November, the upper 50-60% of the Kitimat Watershed (above 800m) is already accumulating a snowpack, and has been effectively de-synchronized from peakflow runoff generation. The desynchronization of the upper watershed is the reason why Type 3 peakflows are significantly smaller than Type 1 and 2 peakflows.

Aerial photography and regional hydrological/climatological data provide evidence of four episodes of channel enlargement/widening in the past 60 years. Evidence for a channel widening episode in the 1930's is present on only 4 of 9 reaches measured in the Kitimat River Watershed, but there is considerable regional corroboration in the hydrologic and climatological records, and evidence from other rivers in the area, such as Williams Creek, Lakelse Lake, Zymoetz River (M. Miles, pers. comm.), and Dala

River. The 1960's episode is widespread, being present in 7 of the 9 reaches measured. Meander bend cutoffs and avulsions shortened the channels in Reach 1 of Hirsch Creek, Reach 1 of Little Wedeene River, and Reaches 2 and 7 of the Kitimat River, perhaps associated with a flood in November, 1961. Channel enlargement accompanied by braiding occurred on the other three reaches. Both the 1930's and 1960's episodes occurred prior to logging in the watershed.

The 1970's episode of channel enlargement is associated with three floods occurring in 1974, 1976, and 1978, ranked 3rd, 5th and 2nd respectively in the daily peakflow record of the Kitimat River up to the end of 1991. The decline in wild fish stocks of the Kitimat River is strongly associated with the 1970's channel enlargement. The decline is particularly notable in pink salmon. Prior to the 1970's floods, the Kitimat River pink salmon run had a dominant even year spawning cycle, which occurs in late summer, before the fall floods. The pink salmon stock was apparently decimated by major floods in the successive spawning cycle years of 1974, 1976, and 1978. Other salmon stocks were also affected, but to a lesser degree because they are less dependant on one dominant spawning cycle. The pink salmon run has rebounded in the past decade, but it is the odd year cycle, which escaped the main floods in the 1970's, that has become more dominant (through 1991).

The river channel changes identified on the Kitimat River and its tributaries - enlargement with braiding, proliferation of shallow, partly dewatered side channels, and erosion of old, stable side channels in logged riparian forest areas - also began during the 1970's floods. The 1970's channel enlargement is evident in three or four of the 9 study reaches.

The 1980's channel enlargement episode is associated with a string of four major floods in five years from 1987 to 1991 (to the end of 1991), including the first, fourth and sixth ranked daily peakflows in the Kitimat River record. The types of channel changes that began in the 1970's continued through the late 1980's episode. Some fish stocks were protected from impact by the SEP facility at the Kitimat Hatchery, and so far, the pink run is still rebuilding. Economic impacts of the 1980's episode include damage to Highway 37, the water intakes of the District of Kitimat, the B.C. Hydro line and the Pacific Northern pipeline crossing on the Kitimat River, the CN Rail crossing on Little Wedeene River, and the Hirsch Creek Park facilities along Hirsch Creek. The 1980's channel episode is evident in five of the nine study reaches.

Differences in the timing of maximum channel area from 1938 to the present may reflect differences in the roles played by Large Organic Debris (LOD) and the riparian forest along different sized river channels. The maximum river channel areas in the two largest watersheds (Kitimat - Reaches 2, 3, and 7, and Hirsch Creek - Reaches 1 and 3) occurred in the 1930's and 1960's, prior to logging. Channel stability on the larger river channels may be controlled more by regional hydrological and basin sedimentation events, than the relatively local channel influence of LOD and the riparian forest. The maximum river channel areas in the four smaller watersheds (Wedeene, Little Wedeene, Chist, and Nalbeelah) occurred in the post-logging period of the 1970's and 1980's. The riparian forest and large in-channel organic debris may be a more important influence on the stability of the smaller channels, including the riparian forest side channels along the larger main channels.

The focal points of the channel instability on the lower Kitimat River, Chist Creek and Wedeenes have been the entrances of side channel systems within logged areas. The mechanism appears to be the breakup of the log jams protecting the entrances, in the absence of a fresh supply of anchor logs. Once the flow gains increased access to the side channel, the banks are no longer protected by trees or LOD. from the logged areas. About 40% of the side channel network conveying main channel water through the original coniferous riparian timber along Reach 3 of the Kitimat River has been disrupted, as have the lower ends of Deception Creek and Humphries Creek. In consequence, the active riparian area of the Kitimat River, Reach 3, has increased by over 270 hectares, or 25% since riparian logging was conducted from 1962 to 1970. Evidence for the role of logging in initiating the side channel instability includes skidder logging disturbance around the side channel entrances and along the banks of the side channels, and washout of skid trails aligned parallel to the main river on islands between the side channels and the main channel.

Differences in the role that Large Organic Debris plays in influencing channels of varying sizes should be emphasized. In small streams, LOD becomes incorporated directly into the structure of the channel, forming an integral part of channel hydraulics and the habitat complex. LOD in larger channels, such as the main channel of the Kitimat is peripheral to the main hydraulic structures, and is typically found along banks of meander bends, at the upstream ends of islands, and at the upstream entrances of side channels. The LOD plays a role in the stability of all three features. LOD assumes the hydraulic and habitat roles characteristic of small channels in the side channel complexes alongside the main channel.

The habitat changes associated with the evolving side channel network includes the loss of stable side channel spawning areas that probably escaped the periodic bed scouring that occurs in the main channel. It is difficult to quantify the impact on the salmonid stocks of the Kitimat River because it is not known from historical records how much of the spawning occurred in the stable side channel network. Another effect of the proliferation of new, shallow side channels is periodic de-watering in low flow periods, reducing the habitat quality for rearing coho and chinook juveniles.

All the evidence in this report points toward the importance of bedload supply and movement in defining the channel stability characteristics of the Kitimat River. Yet, bedload supply and transport are the processes about which the least is known in the Kitimat watershed. There is no inventory of upslope sources, and the present study made only a preliminary assessment of bank erosion sources along a 6 km section of the Kitimat River.

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