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THE PHYSICAL EFFECT OF LOGGING ON SALMON STREAMS OF SOUTHEAST ALASKA

G. A. JAMES

ALASKA FOREST RESEARCH CENTER
U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
JUNEAU, ALASKA
R. F. TAYLOR, FORESTER IN CHARGE

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THE PHYSICAL EFFECT OF LOGGING ON SALMON STREAMS

A Summary Report Covering a 5-year Calibration Period on Four Streams in Southeast Alaska

by

George A. James, Forester
Alaska Forest Research Center

SUMMARY

The principal and most valuable industry of Alaska has been the salmon fisheries. Future development of Southeast Alaska, however, will depend on an increasing utilization of its important forest resource. The fisheries resource and the timber resource are intimately related. Reliable answers are therefore needed as to whether large-scale pulp-timber logging is harmful to the spawning facilities of salmon streams.

The Alaska Forest Research Center began a program of research in 1949 to relate logging practices by Forest Service standards to changes in the large-scale physical factors of the stream environment.1/ The study is divided into two parts: (1) collection of quantitative information on type and extent of physical change which takes place in these streams prior to logging, and (2) quantitative change following logging. Four streams, located in the Kasaan Bay area, Prince of Wales Island, were selected for long-term study. Two of the study watersheds will be logged; two will not be logged. Measurements are being made of such factors as climate, streamflow, storms and associated runoff, base flow, water temperature, stream channel change, sedimentation, and others.

Rate and characteristics of streamflow influence both the physical and the biotic elements of the stream. This phase of the study will determine the effect of timber harvest on stream runoff. Basic data collected include a continuous record of stream height, discharge velocity associated with stream height, snow and ice conditions, analysis of storm flow, and ground-water depletion. Data are presented showing mean monthly stream height, mean monthly discharge, the relationship between rainfall and runoff, analysis of flood peaks, ratio of maximum to minimum stream discharge, and ground-water depletion.

1/ The author is indebted to several foresters who helped in the establishment of this study, notably L. W. Zach. R. M. Godman, and J. L. Hall. Special acknowledgment is made to R. E. Marsh and R. I. Mayo, Water Resources Division, U. S. Geological Survey, for help in various technical phases; to E. G. Dunford of the Pacific Northwest Forest and Range Experiment Station, and Wm. L. Sheridan of the Fisheries Research Institute, University of Washington, for review of the manuscript.

A continuous record of daily stream temperature has been obtained. Mean monthly fresh-water temperatures were found to be moderate. Maximum monthly mean for Maybeso Creek was 54.0° F., Harris River 55.1° F., Indian Creek 56.8° F., and Old Tom Creek 57.4° F. Maximum water temperatures were also moderate. The highest temperatures recorded were 66.0° F., occurring in Indian Creek and Old Tom Creek. Duration of these temperatures was only 1.5 hours in both streams. The lowest temperature recorded in any stream was 30.0° F. The longest duration of this temperature was 11 hours. Stream temperatures of 32° F. were common. A layer of ice 6 to 12 inches thick may form in the streams during extended periods of cold weather, but the streams usually continue to flow under this ice layer.

Mapping of all streams was begun in 1949 to determine the extent of natural stream channel change, including such factors as (1) amount of debris, (2) number and size of log jams, (3) change in streambed composition, (4) streambank cutting, and (5) change in pools, riffles, gravel bars and stream channels.

Several methods are being used to determine stream sedimentation. These include collection of suspended sediment and streambed gravel samples, establishment of cross sections to determine movement of streambed material and streambank cutting. An intensive study is being made to determine the movement of fragmental debris in an intertidal zone. Thirty-three cross sections, established at the confluence of two of the study streams, reveal that considerable movement of streambed material takes place under natural conditions. A net deposition of approximately 556 cubic yards of material occurred between July 1953 and July 1954 in a 200-foot section of the intertidal zone.

This report presents the results of research for the first five-year period. Continuing observations will be made to determine the effect of logging on all of these factors.

INTRODUCTION

The principal and most valuable industry of Alaska has been the salmon fisheries. Close to 90 percent of the entire United States salmon production and 55 percent of the world production comes from this area. Approximately 70 percent of Alaska tax revenues come from salmon products (16).

National forest lands of Alaska constitute an important source of fresh water streams and lakes in which several important phases of the salmon life cycle[2/] take place. Spawning occurs in the hundreds of small and medium size streams found on these forests. It is estimated that the annual value of the fisheries resource of the Tongass and Chugach National Forests is approximately $53,000,000, representing over 50 percent of the Alaska salmon pack. The Tongass National Forest[3/] in Southeast Alaska accounts for 85 percent[4/] of this total; the annual wholesale value is about $45,000,000.

The salmon fishery is not, however, the only important natural resource of this region. Dense stands of commercial timber--spruce, hemlock, and cedar--cover approximately 3 million of the 16 million acres of the Tongass National Forest with a total volume of approximately 72 billion board feet. Future development of Southeast Alaska will depend on an increasing utilization of this forest resource. It has been estimated that the forest products industry in this region will take its place with the fishing and mining activities as a steady contributor to a solid economy for the Territory (8).

[2/] Five species of salmon are found in Alaska: pink (Oncorhynchus gorbuscha), chum (O. keta), red (O. nerka), silver (O. kisutch) and king (O. tshawytscha). This study is concerned chiefly with pink and chum salmon, however, as the streams of Southeast Alaska are used primarily by these two species. All five species of salmon are anadromous and come from salt water in the summer or fall to spawn either in fresh water streams or lakes. The red salmon generally spawns in streams in which lakes are accessible to the fry. Eggs are deposited in gravel beds in the fall and hatch the following spring. The fry, after absorption of the yolk sac, emerge from the gravel and either move immediately to the sea, as does the pink salmon, or live from 1 to 4 years in the stream or lake, as does the red. The next phase of the life cycle is spent at sea where the salmon remain for a period of 2 to 5 years, according to species and latitude. All pink salmon spawn at 2 years of age, cohos and chums at 3 to 5 years, and reds and kings at 4 to 7 years. The mature adults return again to the parent stream to spawn and die.

[3/] This study is limited to salmon streams on the Tongass National Forest.

[4/] Average for period 1926 to 1953, inclusive.

The fisheries resource and the timber resource are closely related. The availability of suitable spawning grounds, probably more than any other factor, controls the distribution and abundance of salmon (16). Concern is sometimes expressed that logging may disturb the spawning facilities of the salmon streams.

Sawtimber operations in the past have been confined chiefly to relatively small cuttings located near tidewater. The beginning of pulptimber operations in Southeast Alaska will bring about larger logging operations and an accelerated rate of cutting. These will exert a greater influence on the watersheds of important salmon streams than the earlier operations. Clear cutting, however, will not denude large, unbroken areas of individual watersheds because commercial timber stands are intermingled with areas of non-merchantable types. Area of commercial forest on the four watersheds selected for study ranges from approximately 18 to 36 percent of the total watershed.

The prospect of a pulp industry in Alaska brought attention to the need for reliable answers as to whether logging is harmful to salmon spawning facilities. The effects of large-scale pulptimber logging on salmon streams in Southeast Alaska are not known. Knowledge of the influence of forest and other vegetal cover conditions on streamflow, stream siltation, water temperature, and other factors is needed.

The Alaska Forest Research Center began a program of research in 1949 to determine the effects of logging on the physical factors of salmon streams. Four streams, located in the Kasaan Bay area, Prince of Wales Island, were selected for long-term study. These are representative of the small- to medium-size island streams found in Southeast Alaska. No cutting had previously been made on any of the adjacent watersheds. The principal objective of the study is to determine whether logging by Forest Service standards5/ results in damage to the spawning facilities of salmon streams. The project has been primarily a forest management study and will assess only physical change. The relation of the salmon to any environmental change will be analyzed by trained fisheries biologists in a cooperative study now being started.

The study of physical factors is divided into two main parts: (1) collection of information on the type and extent of physical change which takes place in these streams prior to logging, and (2) change during and following logging. Two watersheds will be logged; two will not be logged. The design permits analyses within groups and between groups, i.e. (a) before and after logging on two watersheds, and (b) logged watersheds versus unlogged watersheds. The study will continue over a 12- to 15-year period. For streams whose watersheds are to be logged, this period

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5/ The Alaska Region of the U. S. Forest Service has long incorporated certain standard provisions in timber sale contracts and agreements for protecting salmon streams. Adequate safeguards are included in the logging plan to protect the spawning beds; felling timber or leaving logging debris in stream channels or diverting streams is not allowed.

will be divided into three distinct parts: (1) pre-logging calibration period, (2) transition period, and (3) post-logging period. The calibration period will continue as long as a watershed remains uncut. Logging began on one of the watersheds, Maybeso Creek, in August, 1953.

This report presents a summary of the results of research for the first 5-year period.

CLIMATE AND WATERSHEDS OF SOUTHEAST ALASKA

Climate

Precipitation is generally heavy in Southeast Alaska and is well distributed throughout the growing season. Total annual precipitation varies from approximately 20 inches in the extreme northern portion to over 150 inches in the southern and southwestern portions (fig. 1). The least amount of rainfall occurs during the months of May, June, and July, and ranges from 10 to 15 percent of the annual. The largest percentage occurs during the months of September, October, and November; frequently being 35 percent of the annual. As a general observation, at least 50 percent, and sometimes 60 percent, of the annual precipitation occurs during the five months of September through January (7). Wide departures from these average conditions occur, however. Stations with long records show that precipitation during the wettest years ranges from 20 to 65 percent above normal years, while the driest years may show a range of 10 to 44 percent below normal.

The climate of Southeast Alaska is characterized by mild winters and cool summers; a relatively narrow range exists between temperature extremes during the year (1). Snowfall is moderate except on elevated mountain slopes. Near sea level the first frosts generally occur in September or October, and the last in May or early June. Average length of growing season, which varies considerably with location, is about 180 days (2).

Watersheds

Southeast Alaska is composed of a narrow strip of continental land bordered by a large and unbroken chain of mountainous islands. Streams of the Alexander Archipelago and of the mainland are typically short and empty into salt water. The watersheds, which are generally small, have soils with thin, poorly developed mineral horizons, and deep unincorporated organic layers. Many muskegs, consisting of deep, poorly decomposed and water-logged organic materials, are found in the drainage area. The prevalence of large quantities of organic matter in these soils is conducive to high water-holding capacity. The impermeable nature of underlying materials, steep slopes, and general shallowness of the soils, however, severely limit ground-water storage. In addition, soils are often near the saturation point in this region of high precipitation. Runoff is generally rapid, except in streams which head in lakes, and streams are frequently reduced from maximum to minimum flow within a short time after precipitation ceases (11) (21). Figs. 2 and 3 show Indian Creek during high and low stream stages.

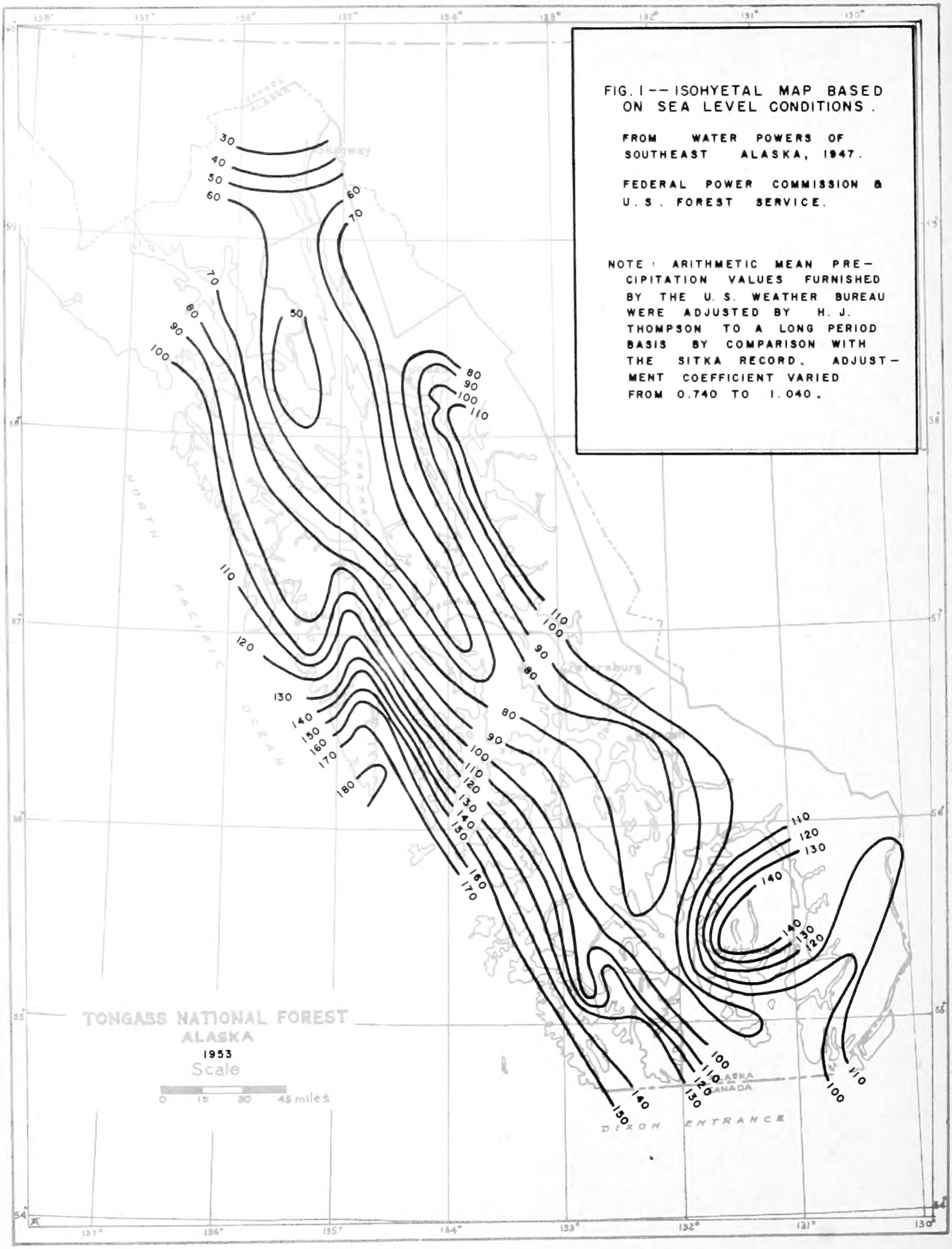

FIG. 1 -- ISOHYETAL MAP BASED ON SEA LEVEL CONDITIONS.

FROM WATER POWERS OF SOUTHEAST ALASKA, 1947.

FEDERAL POWER COMMISSION & U. S. FOREST SERVICE.

NOTE: ARITHMETIC MEAN PRECIPITATION VALUES FURNISHED BY THE U. S. WEATHER BUREAU WERE ADJUSTED BY H. J. THOMPSON TO A LONG PERIOD BASIS BY COMPARISON WITH THE SITKA RECORD. ADJUSTMENT COEFFICIENT VARIED FROM 0.740 TO 1.040.

Extreme variation exists in the spawning potential of the streams of Southeast Alaska. One important factor is the great variation in stability of streamflow. Streams with relatively large watersheds tend to have higher salmon productivity than streams with smaller watersheds, probably because of greater streamflow stability.[6] For this reason, streams whose watersheds contain lakes tend to be better producers of salmon than streams of approximately equal drainages without lakes.

DESCRIPTION OF WATERSHEDS AND STREAMS

Harris River and Maybeso Creek are study streams whose watersheds are to be logged. The watersheds of Indian Creek and Old Tom Creek will not be logged. Location of these streams is shown in fig. 4. A typical watershed map is shown in fig. 5.

Details of area and cover type are summarized as follows:

	Maybeso Creek	Harris River	Indian Creek	Old Tom Creek
Acres of sawtimber, hemlock and spruce	2,229	3,622	294	1,420
Acres of sawtimber, western redcedar	1,294	2,203	670	--
Acres of young growth, seedlings and saplings	82	57	--	1,266
Acres of scrub, nonforest and non-commercial	6,123	14,470	4,540	2,040
Total acreage of watershed	9,728	20,352	5,504	4,726
Percent of total watershed in merchantable timber	36	29	18	30
Volume of merchantable timber, M board feet	131,400	221,713	28,347	Not cruised

Stream gradients vary but are gentle. Maybeso Creek from its mouth to the lower falls (2,500 feet) has a 0.42 percent grade, from there to the upper falls (500 feet) is 4.66 percent and from the upper falls for 3.5 miles up the creek is 0.82 percent. Harris River with no falls has an average gradient of 0.30 percent for 3.3 miles. Indian Creek's average gradient for 1.8 miles is 1.0 percent. Old Tom Creek from the mouth to the lake on the north fork has a gradient of 0.85

6/ H. E. Andersen, Watershed management practice and research on salmon streams of Southeast Alaska. Mimeo. 4 pp., 1956.

Figure 2.--Indian Creek at low stage. Gage height 0.65 feet; discharge about 5 second feet.

Figure 3.--Indian Creek during flood stage. Gage height 3.25 feet; discharge 660 second feet.

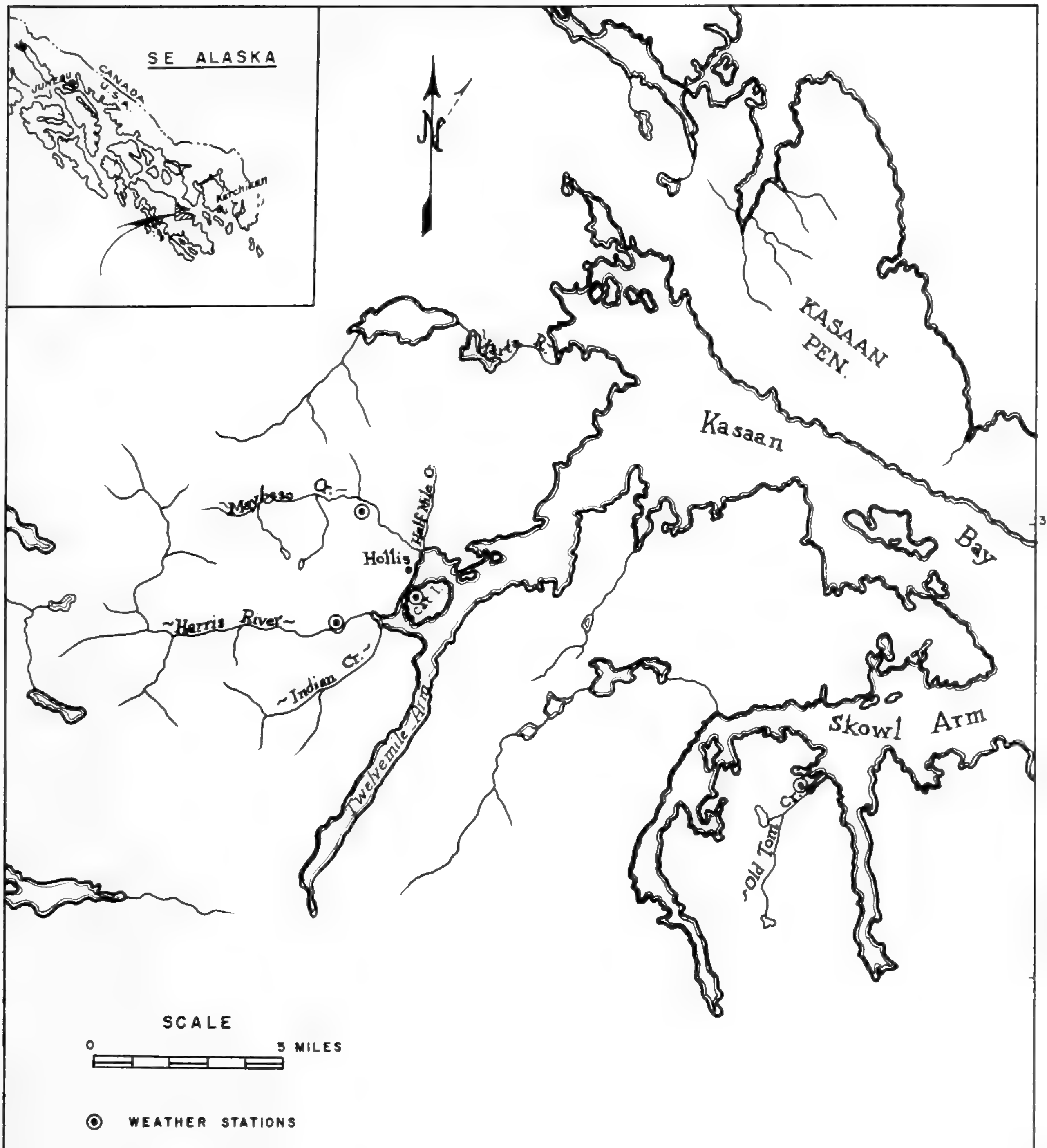

Fig. 4 -- Location of Study Streams
Prince of Wales Island

FROM Craig, Alaska - Quadrangle
U.S. GEOLOGICAL SURVEY, 1:250,000 SERIES

percent. From the mouth to a series of falls at 2.1 miles on the south fork the gradient averages 0.72 percent. It has two sizeable lakes in its watershed; one 85 acres, the other 62 acres in area. Indian and Old Tom Creeks are controls and will not be cut; in fact, the Old Tom Creek watershed is a Natural Area.

PRECIPITATION AND AIR TEMPERATURE

Precipitation is measured at four stations, air temperature at two stations. One sea level station is located at Old Tom Creek, Skowl Arm; one on the Maybeso Creek watershed at an elevation of 300 feet;[7] one on the Harris River watershed at an elevation of 100 feet. The fourth stations is located at the Hollis headquarters, at sea level (fig. 4). Standard non-recording rain gages were used prior to 1953 at all stations. Continuous-recording rain gages were installed at Hollis and on the Maybeso Creek and Harris River watersheds in 1953.

Most storms which occur in the study areas appear to be general in nature and deposit rain over a relatively large area. This is clearly shown by a composite discharge hydrograph for Maybeso Creek, Harris River, and Indian Creek (fig. 6). Rainfall is also plotted to show relationship between runoff and precipitation. Discharge of these three streams rises and falls nearly simultaneously, in minor as well as in major variation, indicating that all three adjacent watersheds receive precipitation during all, or most, storms which are recorded at Hollis. The total amount and intensity of precipitation, however, probably varies from watershed to watershed.

The four climatological stations provide records which are fairly representative of conditions on all of the study watersheds. The same number and location of stations will be used for the duration of the study. Precipitation and temperature records for Hollis and Old Tom Creek are shown in tables 1(a) and 1(b).

STREAMFLOW

Rate and characteristics of streamflow influence both the physical and the biotic elements of the stream. An increase in rate of discharge may have detrimental effects on the spawning facilities of the stream as water velocity is a critical factor in the movement of streambed material. When water velocity is doubled, its cutting power is increased about four times, its carrying power is increased about 32 times. Considerable quantities of gravel may be shifted from one position to another, carried downstream, or deposited on dry land when flood waters overflow their banks. Movement of stream bed material during the period when salmon eggs and fry are present in the stream gravels may be detrimental to them. In addition, it may be physically impossible for spawning salmon to use otherwise desirable spawning beds because of high water velocity. It has been observed during this study that in stream sections where velocity is too great, spawning is very light or entirely lacking.

7/ Approximately 25 percent more rain occurs at the 300-foot elevation gage on the Maybeso Creek drainage, and 20 percent more at the 100-foot elevation gage on Harris River drainage, than falls at the Hollis weather station which is located at sea level.

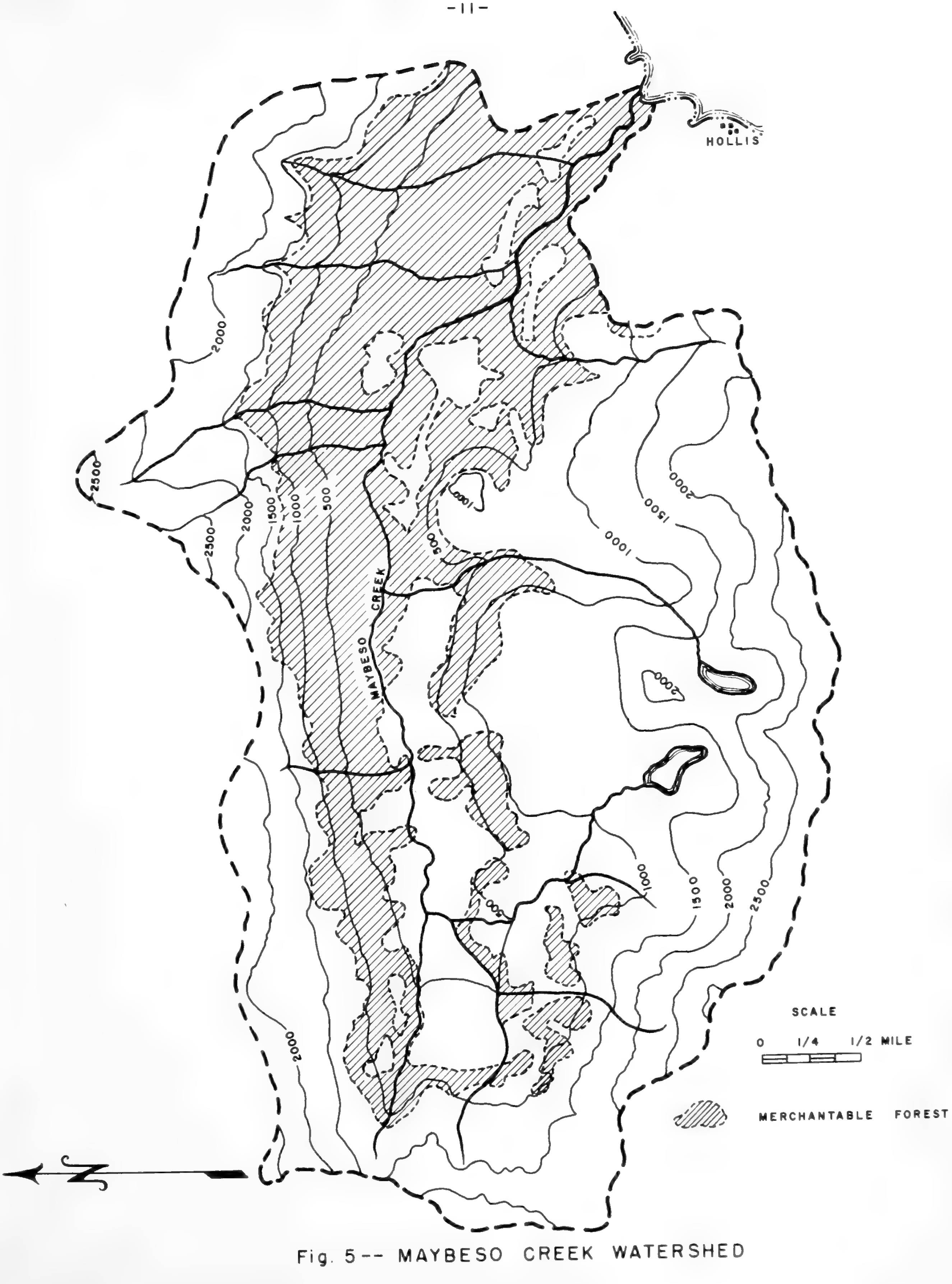

Fig. 5 -- MAYBESO CREEK WATERSHED

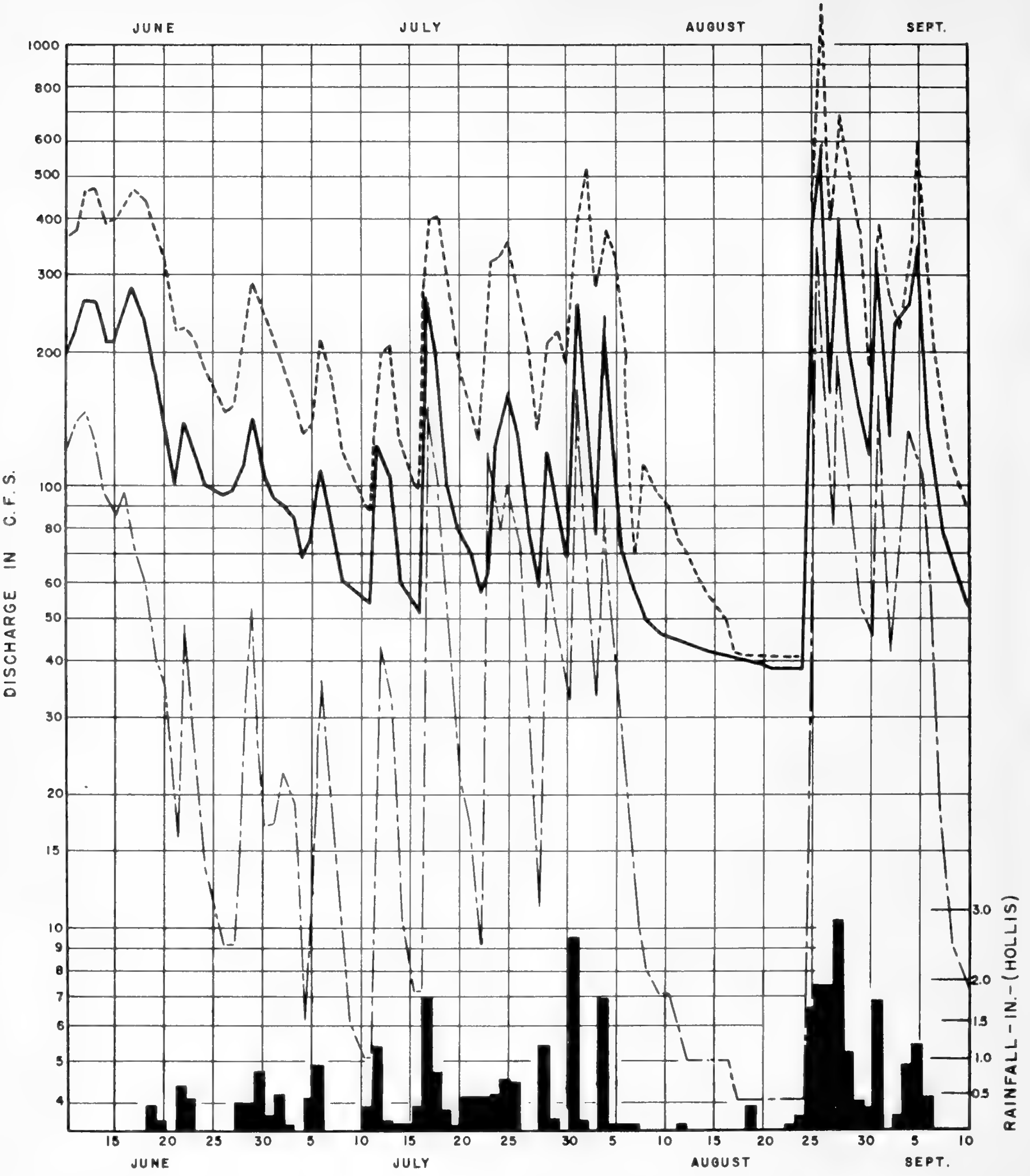

Fig. 6 — — Daily Discharge and Precipitation — — June through Sept. 1950

MAYBESO CREEK
INDIAN CREEK
HARRIS RIVER

Table 1(a).--Mean monthly precipitation in inches, and temperature in degrees F, 1949-1953. Hollis, Alaska

Month	1949		1950		1951 1/		1952		1953		Average 2/	
	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.
May	--	--	4.42	44.8	--	47.6	--	47.4	--	50.0	4.42	47.5
June	5.38	--	1.78	56.0	--	50.8	3.36	52.5	1.77	55.4	3.07	53.7
July	2.76	--	5.60	55.3	--	57.7	3.74	59.4	2.21	58.4	3.58	57.7
Aug.	5.27	--	7.47	60.0	--	57.0	3.98	59.6	5.49	57.5	5.55	58.5
Sept.	11.42	--	9.24	52.6	--	53.0	12.91	53.2	10.44	53.0	11.00	52.9
Oct.	--	--	--	47.5	--	--	--	--	20.32	45.0	20.32	45.0

Table 1(b).--Mean monthly precipitation in inches, and temperature in degrees F, 1949-1953. Old Tom Creek

Month	1949		1950		1951		1952		1953		Average	
	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.
May	--	--	3.44	--	2.67	--	3.49	46.0	5.99	48.2	3.90	47.1
June	--	--	2.77	--	1.50	49.9	2.81	52.0	1.20 3/	54.3	2.07	52.0
July	--	--	--	--	2.34	50.8	2.57	58.6	1.66	--	2.19	58.6
Aug.	--	--	--	--	1.97	54.7	3.18	58.0	4.56	54.5	3.24	58.0
Sept.	--	--	12.30	--	4.71	52.3	12.01	51.1	10.67	49.5	9.92	51.0
Oct.	--	--	--	--	--	43.1	--	47.1	--	45.6	--	43.1

1/ No 1951 record available for the Hollis station. Temperature values shown for 1951 are from a thermograph installed at the stream gage station on Maybeso Creek. The values from the thermograph cover periods ending at midnight; whereas the values for all other years are based on a daily period ending at 6 p.m.

2/ Average derived from only those months for which the record covers a period of 21 days or more.

3/ Measurements were not made daily during the period June 17 to August 11, but total accumulated rainfall was measured. These values were obtained by pro-rating total accumulation on the basis of Hollis records.

The combination of steep slopes, heavy precipitation and limited water-holding capacity of watersheds in Southeast Alaska results in fairly unstable characteristics of flow. This is especially true in streams without sizeable lakes in their watersheds which afford natural regulation of streamflow. Discharge responds quickly to rainfall intensity and fluctuates quite rapidly between maximum and minimum values within relatively short periods of time. The flashy nature of storm runoff is shown by an analysis of a storm which deposited 1.25 inches of precipitation within a 16-hour period on the Maybeso Creek drainage (11). The stream rose from a height of 0.8 feet to a height of 2.6 feet within a few hours after the first rain fell on the watershed.

Heavy precipitation during October, November, and early December causes numerous floods which produce a highly fluctuating discharge hydrograph (fig. 6). Cold weather and snowfall from December until April are responsible for a declining flow and the shaping of a hydrograph which drops in a rather long and flattening curve. Snowmelt generally begins in May and produces a gradually rising hydrograph which shows a diurnal peak and trough corresponding to the crest made by melted snow. When the snow is gone, the flow declines and the hydrograph drops in a long, flat curve on which the occasional summer storm of June, July, and August places minor peaks. Storm frequency and intensity generally begin to increase in September.

Each stream has its own flow characteristics which vary with general characteristics of its drainage area. Drainage characteristics include: shape, size, topography and gradient of watershed; presence or absence of lakes; vegetational density and type; depth and character of soil; and geological formation. Land-use practice plays a major role in the pattern of stream runoff.

Characteristics of Streamflow

Fig. 9 shows graphically the relationship between runoff and precipitation for Maybeso Creek[8/] from May to October, inclusive. Table 2 presents a summary of mean monthly discharge and stream level at the gage station.

Maximum water loss takes place through evaporation and transpiration in Southeast Alaska from May through September. During May, especially at the lower elevations, rainfall is generally heavy, air temperatures increase, vegetation begins to grow, and evaporation and transpiration rates increase. Precipitation generally decreases to its lowest value in June, but snowmelt holds the runoff pattern up. Rainfall increases each month from July through October. Though precipitation is greater during July and August than in June, fig. 9 reveals that streamflow for these two months is considerably less than in June. This results primarily from loss of water through increased evapo-transpiration rates.

8/ The watersheds of Maybeso Creek, Harris River and Indian Creek react to precipitation in an almost identical manner. Discussion is therefore limited to Maybeso Creek to avoid repetition. The relationship between precipitation and runoff cannot be determined for Old Tom Creek at this time because a stage-discharge rating curve has not yet been developed.

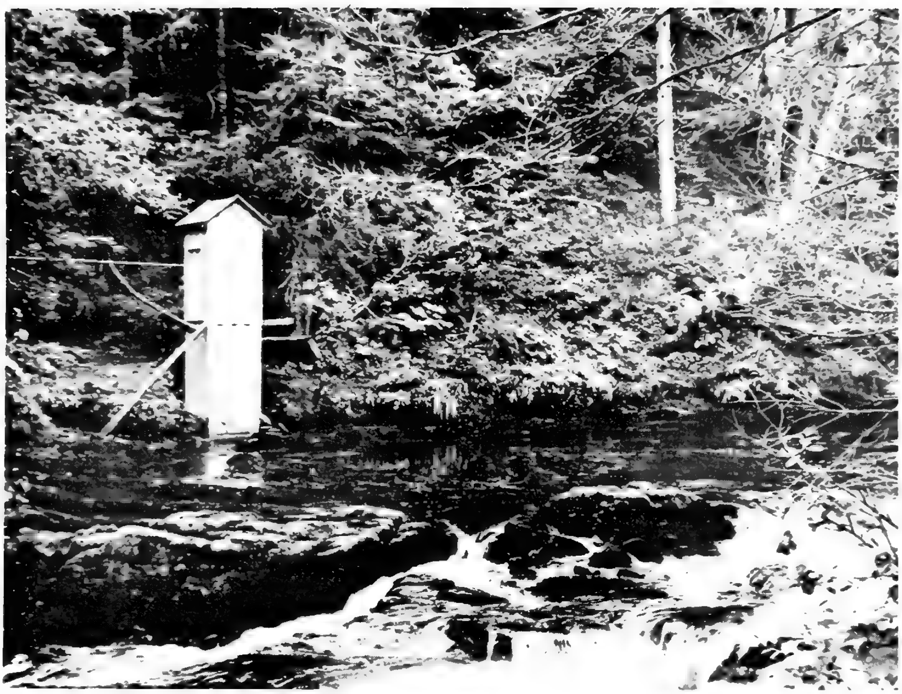

Figure 7.--Gage house on Harris River at low water stage.

Figure 8.--Stream discharge measurement station, Maybeso Creek.

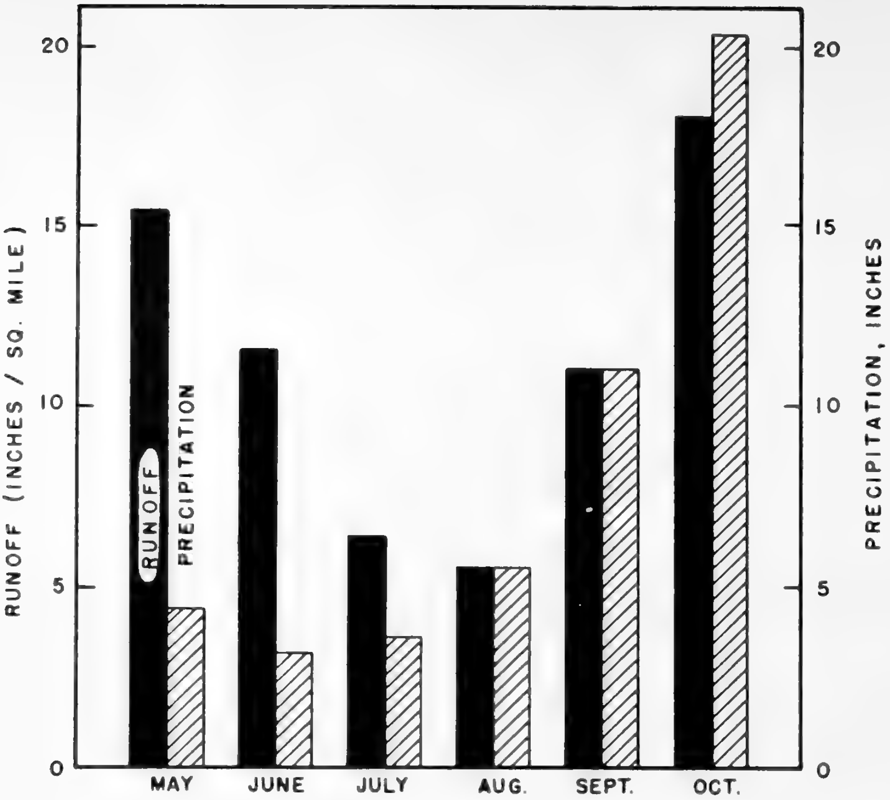

Fig. 9--Mean Monthly Precipitation and Runoff, Maybeso Creek. 1949-1953

Evaporation and transpiration rates decrease considerably in October and stream runoff swings sharply upward. Precipitation is heavy during this month--generally the wettest month in Southeast Alaska (7)--and quite rapidly satisfies any soil moisture deficit which might have resulted from evaporation and transpiration. Stream discharge generally continues to increase through the months of November, and a portion of December, until cold weather and snowfall result in storage of precipitation in the form of snow. Rains are quite common during this season when the watersheds may be frozen and snow-covered, and associated runoff is rapid.

Records show that snow first begins to melt on the Maybeso Creek drainage some time in April or early May. It swells stream discharge until some time in July. Fig. 9 shows that the magnitude of stream runoff during the months of May and June is considerably out of proportion to precipitation intensities received during these months. A considerable quantity of this total runoff comes from snow melt.

Table 2.--Mean monthly discharge and stream level at gage station, Maybeso Creek, 1949-1953

Month	Item	Year					Mean
		1949	1950	1951	1952	1953	
May	Discharge*	--	12.8	15.2	17.0	16.6	15.4
	Stream level*	--	1.92	2.06	2.17	2.15	2.08
June	Discharge	12.2	13.1	11.3	13.8	7.1	11.5
	Stream level	1.84	1.97	1.82	2.01	1.54	1.84
July	Discharge	6.1	7.0	5.6	8.3	3.6	6.1
	Stream level	1.42	1.49	1.31	1.55	1.17	1.39
August	Discharge	7.0	8.7	2.7	4.5	3.8	5.3
	Stream level	1.43	1.48	1.05	1.20	1.14	1.26
September	Discharge	13.2	11.5	3.8	14.4	12.1	11.0
	Stream level	1.63	1.74	1.15	1.93	1.77	1.64
October	Discharge	24.6	13.5	11.8	16.8	23.0	18.0
	Stream level	2.36	1.79	1.72	2.05	2.41	2.07

* Discharge--inches per square mile of drainage area.
Stream level--feet and tenths.

A change in time and rate of snowmelt, or in total snow accumulation, may influence the fresh-water temperature regime. Kittredge (13) has found that the greatest accumulation of snow is found in openings where the distance across them is at least equal to the height of the surrounding trees. He also found that rate of melting and date of disappearance of snow is accelerated as a result of more rapid evaporation and melt by the removal of forest cover. Stream-stage hydrograph records permit an accurate determination to be made of dates of first and last snowmelt.

Dates on which snowmelt began and ended its contribution to streamflow are shown in table 3. The period of first and last snowmelt is quite uniform from year to year on all streams. Continuing observations will be made on snowmelt to determine the effect of logging on total snow accumulation, and dates of first and last snowmelt.

The relationship between runoff and precipitation is an indicator of change in stream regimen and hydrologic characteristics of a watershed following changes in land use. Runoff, expressed as a percent of sea level precipitation, is shown in table 4 for Maybeso Creek, Harris River, and Indian Creek. Percentage values range from 88 to 374 for Maybeso

Table 3.--Duration of snowmelt contribution to streamflow, 1950-1953

Year	Maybeso Creek		Harris River		Indian Creek		Old Tom Creek	
	Begin	End	Begin	End	Begin	End	Begin	End
1949	--	7/20	--	7/22	--	7/4	--	--
1950	4/28	7/5	4/16	7/3	3/31	7/2	5/31	6/19
1951	4/25	--	4/27	7/4	4/3	6/24	4/28	6/8
1952	5/1	7/22	4/19	7/14	4/17	7/1	4/2	6/28
1953	4/8	7/15	--	7/11	4/5	6/19	4/15	6/24

Table 4.--Percentage relationship between mean monthly sea level precipitation and stream runoff, 1949-1953*

Month	Maybeso Creek	Harris River	Indian Creek
	Runoff expressed as a percent of precipitation, (inches per square mile ÷ precipitation in inches)		
May	348	290	392
June	374	309	228
July	170	148	72
August	95	95	68
September	100	91	91
October	88	79	76

* Average for 1949 to 1953, inclusive.

Creek, 79 to 309 for Harris River, and 68 to 392 for Indian Creek. It is not uncommon for precipitation measured at low elevation stations to be less than stream discharge, as rainfall at higher altitudes is usually greater than it is at sea level. Snowmelt and saturated watersheds are partly responsible for the high percentages which occur in May and June.

Storm Analysis

Magnitude and frequency of floods are considered to be valuable aids in evaluating the effect of changes in land use on stream regimen. Serious watershed disturbance, or removal of forest, may have definite effects on the magnitude of flood flows (13). A marked increase in magnitude of discharge, or frequency of floods, following logging would be a strong indication that the changes are attributable to forest cutting; providing there has been no significant change in climatic factors.

The first step in the analysis was the cataloging of floods[9] for the entire period of record. Seasonal distribution of floods occurring on all streams is shown in fig. 10. Table 5 presents a summary of average, maximum, and minimum number of floods by months. The highest frequency of floods occurred in October. The greatest number of floods occurred in the 4.00- to 4.99-foot class on all streams. Very few flood peaks exceeded 7 feet.

Table 5.--Seasonal distribution of flood peaks greater than 4.0 feet, 1949-1953

Month	Maybeso Creek			Harris River			Indian Creek			Old Tom Creek		
	5-yr. Ave.	Max. 1-yr.	Min. 1-yr.	5-yr. Ave.	Max. 1-yr.	Min. 1-yr.	5-yr. Ave.	Max. 1-yr.	Min. 1-yr.	5-yr. Ave.	Max. 1-yr.	Min. 1-yr.
Jan.	1	1	0	1	2	0	0	1	0	1	4	0
Feb.	0	1	0	0	0	0	0	0	0	1	3	0
Mar.	1	2	0	0	1	0	1	3	0	0	1	0
April	1	1	0	0	2	0	0	0	0	1	3	0
May	0	1	0	1	2	0	0	0	0	0	2	0
June	0	1	0	0	2	0	0	0	0	0	0	0
July	0	1	0	0	0	0	0	0	0	0	0	0
Aug.	1	3	0	1	2	0	0	0	0	0	0	0
Sept.	2	4	0	4	6	0	1	3	0	1	2	0
Oct.	5	6	4	7	9	6	1	3	0	3	8	0
Nov.	2	3	2	3	6	2	0	1	0	2	5	0
Dec.	2	4	1	2	5	1	0	1	0	1	4	0

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[9] A flood is a relatively high flow as measured by either gage height or discharge quantity. In this section, a flood has been defined as a high-water stage of four feet or higher.

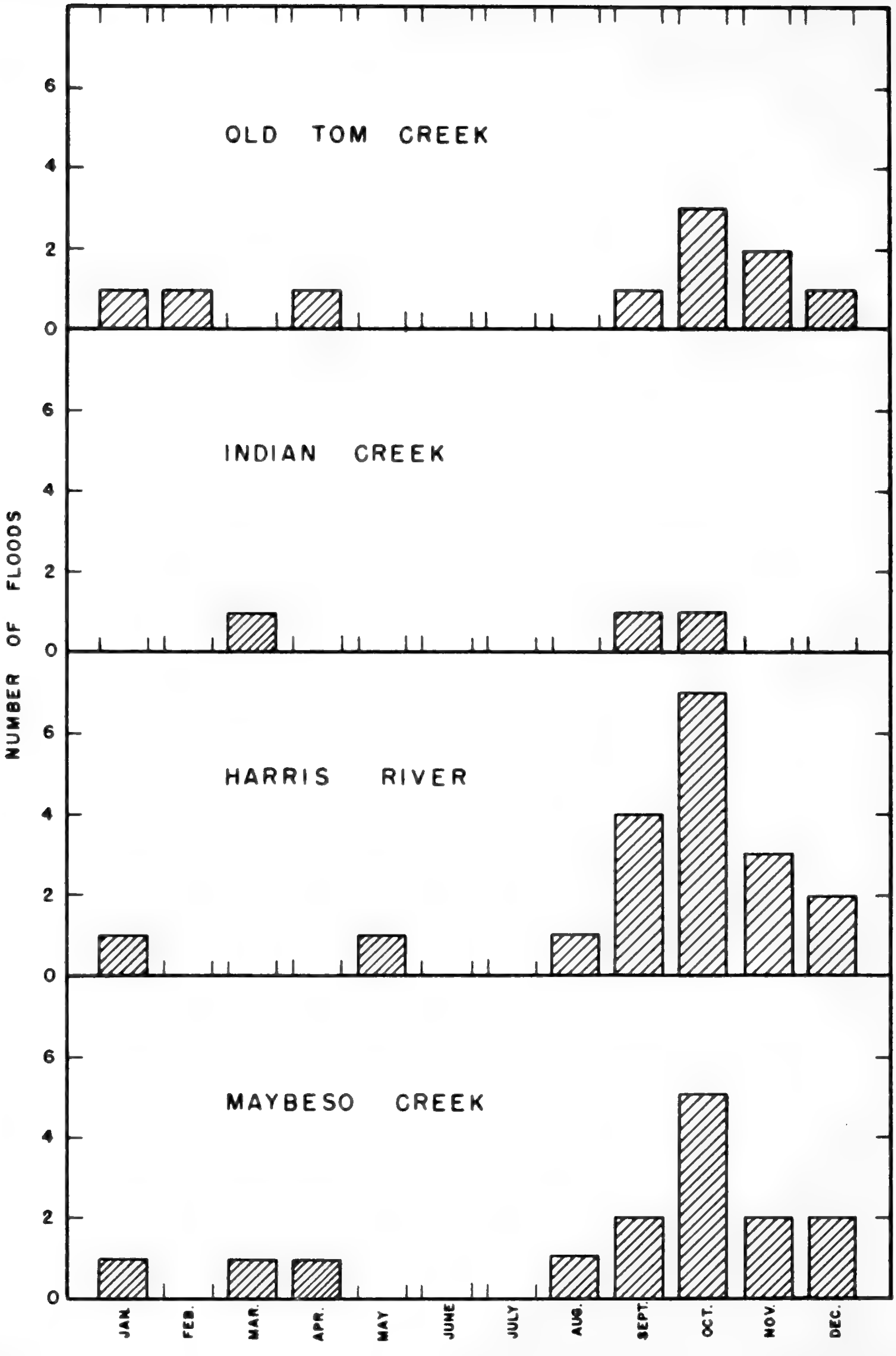

Fig. 10 -- SEASONAL DISTRIBUTION OF FLOOD PEAKS GREATER THAN 4.0 FEET. AVERAGE FOR PERIOD 1949 – 1953

(RECORD IS NOT COMPLETE FOR ALL MONTHS)

Ratio of Maximum to Minimum Stream Discharge

The ratio of maximum to minimum stream discharge is an indicator of the water storage function and of change in hydrologic characteristics of the watershed following change in land use. The ratio of maximum to minimum streamflow has generally been found to be larger for disturbed or denuded areas than for undisturbed areas (13). As an illustration, in the Wagon Wheel Gap experiment it was found that before denudation the ratio was 12:1, and after cutting it was 17:1. This ratio varies widely between streams according to many factors. In some cases the ratios are narrow, while in other cases the ratios are wide.

A determination has been made of the ratio of maximum to minimum flow[10] for all streams. The ratio is generally based on maximum 1-day flood and minimum 1-day flow. However, 5 inches of rain fell within 24 hours on October 13, 1949. This resulted in an extremely high stream discharge rate which greatly distorted the ratio. Median values of maximum 1-day flood discharge and minimum 1-day flow were found to be more realistic. Median values, instead of absolute values, will therefore be used in comparisons between pre-logging and post-logging periods.

The ratios of median values of maximum 1-day flood and minimum 1-day flow vary between 42:1 and 152:1 for Harris River, Maybeso Creek, and Indian Creek (table 6). This ratio cannot be shown for Old Tom Creek because a discharge rating curve has not been developed as yet.

Table 6.--Ratio of maximum/minimum stream discharge, May-October, 1949-1953

Stream	Median value maximum 1-day flood	Median value minimum 1-day flow	Ratio
	c.f.s.	c.f.s.	
Maybeso Creek	802	17	47:1
Harris River	1,250	30	42:1
Indian Creek	456	3	152:1

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[10] a. The maximum 1-day flood is defined as the highest average rate of discharge for any 1-day between May and October, inclusive.

b. The minimum 1-day flow is the lowest average flow for any 1-day between May and October, inclusive.

c. The median 1-day flood is the median value of the maximum 1-day floods between May and October, 1949 to 1953, inclusive.

d. The median 1-day minimum flow is the median value of the minimum 1-day flow between May and October, 1949 to 1953, inclusive.

Ground-water Depletion

The principal source of water for streamflow during rainless periods is the ground-water flow resulting from infiltration of precipitation during storms. Minimum streamflow is a sensitive indicator of change in stream regimen and watershed characteristics resulting from the removal of trees from the watershed. Ground-water depletion curves[11] were prepared for each of the study streams using a somewhat modified procedure from the method[12] used by Johnstone and Cross (12).

Depletion curves for Maybeso Creek, Harris River, and Indian Creek are shown in fig. 11. Base flow for Maybeso Creek decreases from approximately 35 c.f.s. after 10 rainless days to 13 c.f.s. after 30 days[13]; Harris River from 64 c.f.s. after 10 days to approximately 26 c.f.s. in 30 days; Indian Creek from approximately 5 c.f.s. after 10 days to 3 c.f.s. after 30 days. Base flow has not yet been determined for Old Tom Creek. Base flow values for the three study streams vary according to size of watershed[14] and indicate that base flow characteristics are, among other factors, a function of watershed size.

The effect of deforestation on the minimum flow of streams is variable. Deforestation may decrease interception and transpiration more than evaporation is increased, thus augmenting streamflow whether at flood or at minimum stages. In other cases, denudation has been found to reduce minimum flow because of an increase in surface runoff with a resultant reduction of infiltration. Date of summer minimum flow may be later as a result of deforestation (13).

Continuing observations will show what effect, if any, clearcutting has on magnitude and date of occurrence of minimum flow.

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[11] Presumably representing the hydrograph that would result from ground-water flow alone over a protracted dry period.

[12] The lowest arc (ground-water flow) of the daily flow hydrograph was traced backward in time from the lowest discharge to a period of surface-water runoff. The tracing paper was then moved horizontally until another arc of the hydrograph coincided in its lowest part with the arc already traced. The second arc was plotted on top of the first. This process was continued until all the available arcs were plotted on top of one another. The upswinging portions of the individual arcs are disregarded as they are presumably affected by surface runoff or channel storage or both. The remaining continuous arc is a "mean" depletion curve. Stream stage values were than converted to discharge values and plotted on semi-log paper.

[13] Johnstone and Cross (12) caution that the best that can be said in any given case is that the base flow is probably not less than about _____, nor more than about ______.

[14] Size of watershed in square miles: Harris River - 31.8; Maybeso Creek - 15.2; Indian Creek - 8.6.

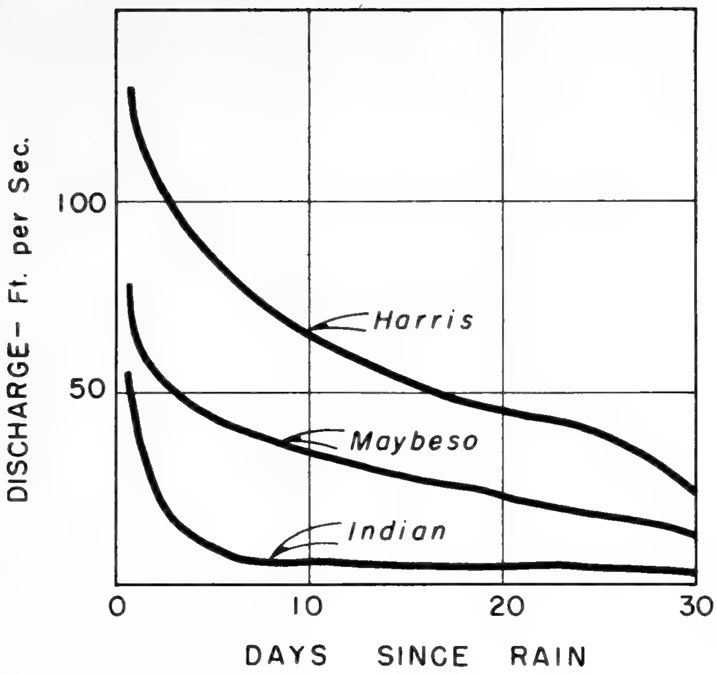

Fig. 11 GROUND WATER DEPLETION CURVES

May to Oct. incl.

STREAM TEMPERATURE

Fresh water temperature plays an important role in the physiology of aquatic organisms: it affects the metabolism rate; it alters various physical, chemical and biotic factors in the waters of the stream. Temperature may influence the spawning impulse of salmon; it influences egg incubation, and fry development up to the point of emergence from the gravel. Pritchard (15) has found that high temperatures appear to shorten, and low temperatures to lengthen, the incubation period of pink salmon eggs. Donaldson and Foster (6) show the optimum temperature range for sockeye salmon fry to be 53° to 62° F. Studies by Hanavan and Skud (9) indicate that abnormally cold fresh-water stream temperatures, which result in a low salmon fry survival rate, may be modified by warmer tidewater to create conditions more favorable for survival in the inter-tidal zone. Water temperature may play an important role in stimulating the migratory movement of salmon. Davidson, et al (4), however, found no relationship between variations in stream temperature and the upstream movement of salmon. Experience in warmer climates has shown that streams may attain temperatures which are critical for certain fish species.

Removal of vegetation from the watershed may influence stream temperature in several different ways. Water temperature may be increased by the removal of riparian vegetation from the streambank. A survey in Connecticut (20) revealed a stream temperature increase of 10 degrees along a half-mile section in which all brush had been removed. The feeding of sun-warmed ground-water into the stream from the logged area may increase water temperature. A general lowering of stream height as a result of hydrologic changes to the watershed following logging might increase water temperatures above normal during warm months, and lower it during cold months. Snow accumulation and period of snowmelt might be affected by clearcutting.

Stream temperature exerts its influence on various phases of the life cycle of the salmon during all months of the year. Pink and chum salmon fry do not remain in the streams but migrate to salt water soon after hatching. The fry of other species may spend one or more years in the parent stream.

Objectives of this phase of the study include a determination of fresh water temperatures under natural conditions, and the magnitude of change, if any, following logging. A secondary objective includes determination of the relationship between water temperature and such factors as air temperature, stream height, and precipitation.

Maximum Fresh Water Temperature

Donaldson and Foster (6) found that young sockeye salmon fingerlings were not able to tolerate water temperatures as high as 78° F. for more than a few days, and were able merely to maintain themselves at temperatures of 70° F. Donaldson (5) found that tolerance of king salmon eggs varied with stage of development. Eggs exposed to 67° F. died in every stage of development, while those exposed to 65° F. and 63° F. did not show appreciable mortalities until after the stage of development associated with the approach of hatching. An exposure of six days to 65° killed nearly 50 percent of the eggs. Ninety percent mortality occurred when the eggs were exposed 10 days to 67° temperatures, 16 days at 65°, and 25 days at 63°.

Stream temperatures in Southeast Alaska are moderate. Mean monthly water temperatures of the study streams are shown in table 7. The highest mean monthly temperature for any stream from 1950 to 1953, inclusive, was only 55.1° F. The maximum monthly mean for any single month of record was only 57.4° F. Highest mean monthly temperature occurred either in July or August in all streams.15/

Maximum instantaneous water temperatures are shown in table 8. The highest instantaneous temperature recorded on any stream was 66° F., occurring twice during the period. These maximum temperatures occurred

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15/ Sub-surface water temperature. Temperature elements were placed in depressions in the stream bottom in order to protect them from freezing, and from debris and ice-flow. This practice is expected to give reliable results as the temperature of running water is relatively uniform.

Table 7.--Mean monthly water temperatures[1]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1950						
Maybeso Creek	--	--	--	--	37.8	44.3	48.9	48.6	48.0	42.3	--	--
Indian Creek	--	--	--	--	34.5	44.4	51.8	54.4	49.3	42.4	--	--
Old Tom Creek	--	--	--	35.7	38.4	40.6	50.8	54.3	50.2	45.8	--	--
						1951						
Maybeso Creek	--	--	--	--	38.4	44.5	54.4	54.0	49.3	--	--	--
Indian Creek	--	--	--	31.4	36.5	46.8	55.8	52.8	48.2	--	--	--
Old Tom Creek	--	--	--	36.7	40.0	46.6	57.4	54.9	51.9	47.4	--	--
						1952						
Maybeso Creek	--	--	--	--	--	--	--	--	49.8	46.9	41.6	36.6
Indian Creek	--	--	--	--	--	--	--	--	51.2	46.9	39.7	34.1
Old Tom Creek	--	--	--	38.7	41.2	43.4	53.3	56.8	52.0	48.7	42.5	36.8
						1953						
Maybeso Creek	34.0	34.1	35.2	36.1	41.4	46.0	52.5	53.3	49.8	45.5	40.9	37.4
Indian Creek	33.4	33.5	34.0	35.0	40.2	50.2	56.8	56.3	50.9	45.7	40.3	--
Harris River	--	--	--	--	43.1	48.4	52.6	55.1	50.0	46.3	41.6	37.9
Old Tom Creek	33.8	34.2	35.6	37.4	39.8	44.6	51.3	52.5	49.1	45.4	40.8	36.0
						Average						
Maybeso Creek	34.0	34.1	35.2	36.1	39.2	44.9	51.9	52.0	49.2	44.9	41.2	37.0
Harris River				Not sufficient data								
Indian Creek	33.4	33.5	34.0	33.2	37.1	47.1	54.8	54.5	49.9	45.0	40.0	34.1
Old Tom Creek	33.8	34.2	35.6	37.1	39.8	43.8	53.2	54.6	50.8	46.8	41.6	36.4

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[1] Mean monthly figure may have one or more days of record missing.

in July of different years and held for only 1.5 hours. Of 71 occurrences of temperatures between 61° and 66°, all occurred during June, July, or August; 5 in June, 36 in July, and 30 in August. Duration of these temperatures was short, averaging 3.7 hours. Longest duration of any temperature over 60° was only 6.5 hours.

Table 8.--Maximum and minimum water temperatures recorded and duration*

Stream	Max. temp.	Duration	Month	Min. temp.	Duration	Month
	F°	hours		F°	hours	
Maybeso Creek	64.0	Unknown	July	32	4	May
Harris River	64.0	1	Aug.	36	27	Dec.
Indian Creek	66.0	1.5	July	30	11	May
Old Tom Creek	66.0	1.5	July	32	144	Jan. & Feb.

* Harris River based on short period. In 1954, temperatures of 32° F. occurred in January, February, and March.

Minimum Fresh Water Temperatures[16]

Hatching of salmon eggs is directly related to accumulated temperatures in the streambeds. A certain number of temperature units[17] are required for the eggs to hatch, and for the hatched fry to work up to the surface of the gravel. In a controlled experiment with steelhead trout, Shapovalov (17) found the eggs required 563.0 to 585.5 temperature units to maximum hatch and 1074.6 to 1206.1 temperature units to maximum emergence from gravel. Temperatures below certain limits cause low survival. Abnormally low stream temperatures which occur early in the incubation period of the pink salmon may damage the developing eggs, particularly between the sixth and tenth weeks (9).

The lowest mean monthly water temperature recorded for any stream was 33.4° F. A mean monthly value of 31.4° F. was recorded in 1951 on Indian Creek, but this average was based on an incomplete month. The lowest temperature recorded on any stream was 30° F. and occurred several times. The longest duration of this temperature was 11 hours. Temperatures of 32° occurred several times and held for periods as long as six days. Temperatures of 33° were common and persisted for periods up to 11 days. A layer of ice 6 to 12 inches thick may form during extended periods of cold weather, but the streams usually continue to flow under this ice layer.

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[16] Winter water temperature records are not complete. 1953 is the only complete year covering all months.

[17] One temperature unit (t.u.) equals 1° F. above 32° for a period of 24 hours (17).

The importance of minimum temperatures during the critical winter and spring months make it necessary to obtain a complete temperature record during this period. Temperatures lower than those shown in table 8 may have occurred in the study streams. Continuing observations will be made to obtain a complete record of minimum water temperatures.

Salt Water Temperatures

Salt water temperatures measured three inches below the surface were taken periodically during August and September, 1952, in the Twelvemile Arm area near three of the streams. The average salt water temperature for August was 59.3° F., for September 54.4° F. Salt water temperatures were, respectively, 7.3° and 4.6° higher than corresponding mean fresh water temperatures in Maybeso Creek; 4.2° and 4.4° higher than Harris River; and 4.8° and 4.5° higher than Indian Creek. Although these salt water records are not complete, it appears that upstream migrating salmon are exposed to lower fresh water temperatures than to salt water temperatures during this period.

Relationship between Water Temperature and Other Factors

Data from all streams indicate a strong direct relationship between air and water temperature. Rising air temperature resulted in rising water temperature; decreasing air temperature resulted in decreasing water temperature. Davidson, et al (4), found that daily variations, as well as seasonal trends, in stream temperature were closely associated with changes in air temperature. Pritchard (15) reports that water temperatures of McClinton Creek, B. C., are directly correlated with the air temperatures in the region.

Fig. 12 shows graphically the relationship between mean monthly water temperature and mean monthly air temperature for Maybeso Creek. The relationship is very similar in all study streams. Air temperatures during May through September were several degrees warmer than corresponding water temperatures. Mean temperature differences between air and water were quite uniform in all streams (table 9). Water temperature during October was generally warmer than air temperature.

Mean monthly water temperature of all streams is shown graphically in fig. 12 also. The figure reveals the modifying influence of lakes on stream temperature. Old Tom Creek, whose watershed contains two lakes, was found to be slightly warmer during most winter months than streams without lakes. Water temperatures during summer months also appear to be modified slightly.

An inverse relationship was found to exist between water temperature and stream stage. Fig. 12 shows the relationship between mean monthly water temperature and stream stage in Maybeso Creek. A lowering stream stage resulted in an increase in water temperature, and vice versa. On all four study streams the highest water temperatures were associated with the lowest stream levels; the lowest water temperatures

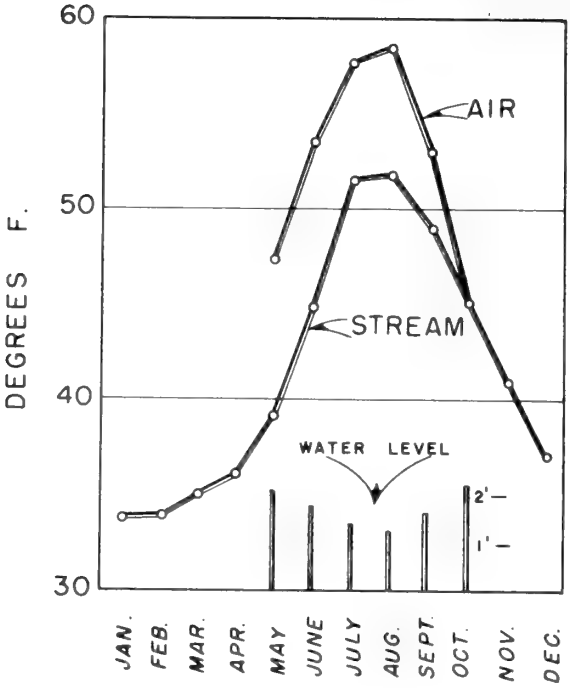

Fig. 12 MEAN MONTHLY AIR and STREAM TEMPERATURES with CORRESPONDING WATER LEVEL

MAYBESO CREEK

with the highest stream stages. Water temperature of shallow streams appears to respond more rapidly than deeper streams to seasonal air temperatures and other modifying influences such as snowmelt and precipitation. For example: mean monthly water temperature of Indian Creek, the shallowest of the study streams, was several degrees colder during winter months and generally warmed more quickly during the summer months than did the other streams (fig. 13).

Table 9.--Mean monthly temperature difference between air and water, 1950-1953*

Month	Maybeso Creek	Harris River	Indian Creek	Old Tom Creek
May	+ 8.3	+ 4.4	+ 10.4	+ 7.3
June	+ 8.8	+ 5.3	+ 6.7	+ 8.2
July	+ 5.8	+ 5.1	+ 2.9	+ 5.4
August	+ 6.5	+ 3.4	+ 4.0	+ 3.4
September	+ 3.7	+ 2.9	+ 3.0	+ 0.2
October	+ 0.1	- 1.8	+ 0.0	- 4.0

* A plus indicates air temperature is warmer than water temperature. A minus indicates air temperature is cooler than water temperature.

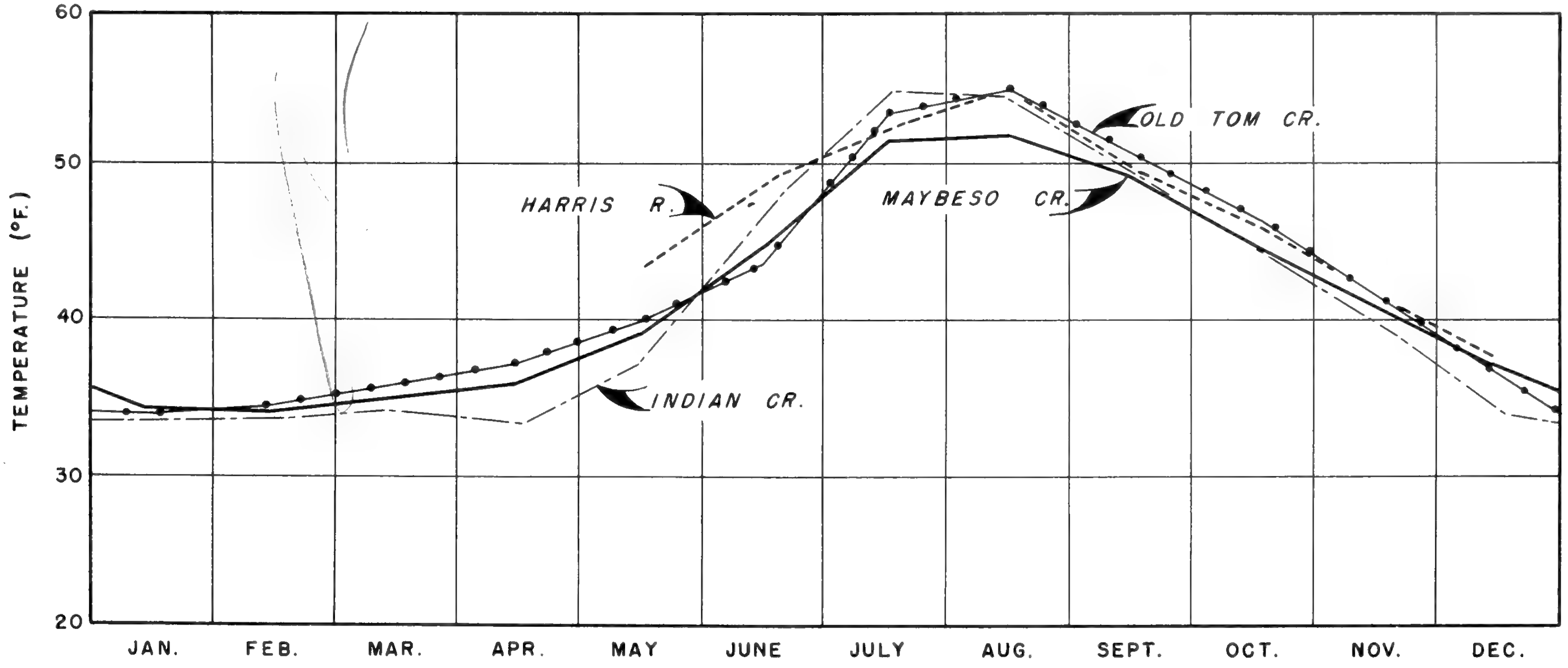

Figure 13 -- Mean Monthly Water Temperature, Study Streams, 1950-1953

Precipitation was found to have little direct affect on water temperature. Precipitation modified maximum and minimum temperatures during, and for a period of 24 to 48 hours following, the storm, but the variations were small and did not lower average water temperature. Similar results were noted at the Coweeta hydrologic laboratory (3). The factor which probably exerts the greatest modifying influence is not precipitation, but rather the overcast skies and cool air temperatures associated with the storm. These factors are jointly related and it is difficult to test the influence of any one of them.

STREAM CHANNEL CHANGE

Continuous changes in beds and channels of streams are natural phenomena. Most of the valleys and mountains of both the mainland and the islands were buried under an ice sheet during the Pleistocene epoch. Glaciation has resulted in the formation of broad, flat-floored and U-shaped valleys with steep sides (2). Earthslides occur as a result of weathering of certain rock formations and saturation of soils which allows the mass to slide from the steep slopes. Aerial photos and ground reconnaissance indicate that approximately 250 years ago a large slide blocked Harris River and changed its course.

The choking of stream channels by material other than landslides is of relatively common occurrence. High flood water undermines many trees growing along the stream channel. Stream banks are cut in one section and filled in another; new gravel bars are formed, others are washed out. Evidence of this can be readily seen in mudbars, cutbanks, in log tangles embedded in stagnant pools, and in many other forms. Especially vulnerable to alteration are unstable streams which are subjected to flash floods during periods of heavy precipitition. This change is characteristic of many of the salmon streams of Southeast Alaska.

The objective of this phase of the study is to determine to what extent, if any, the process of stream channel change is accelerated by logging.

Debris, Windfalls, and Log Jams

Table 10 shows the number of branches, broken logs and/or trees protruding into the main channels of the study streams during the pre-logging period 1949 to 1953, inclusive. The period has been one of accumulation with Maybeso Creek showing an average yearly accumulation of 30 pieces per mile, Harris River 19 pieces, Indian Creek 20 pieces, and Old Tom Creek, 33 pieces. These values indicate that a considerable amount of debris exists in all study streams under natural conditions.

In what form has this accumulation taken place? Is the debris accumulating as scattered material, or as log jams of constantly increasing size? Table 11 shows jams by total number and size. A large number of jams does not exist in any of the streams. The most rapid build-up of jams has occurred in Maybeso Creek with an accumulation of 4 jams containing 10 to 14 logs, 2 containing 15 to 29 logs, and 1 containing 30

Table 10.--Number of branches, broken logs, and trees, 10 feet or more in length,[1] protruding into main stream channel 1949-1953

Year	Maybeso Creek	Harris River	Indian Creek	Old Tom Creek
1949	517	228	110	226
1950	713	254	144	374
1951	764	329	167	382
1952	863	425	230	535
1953	944	451	252	601

1/ Only debris thought large enough to interfere with normal streamflow, or the upstream migration of salmon, was recorded. No logs were included which had less than 10 feet of their length protruding into the main stream channel.

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or more logs. The slow build-up of log jams is an indication that the accumulation is occurring as individual logs, or as jams containing less than 10 logs. Fig. 14 shows a natural log jam in Maybeso Creek.

Figure 14.--A natural log jam in Maybeso Creek.

Table 11.--Number and size of log jams, 1949-1953

Stream	Jams containing 10 or more logs[1]					Jams containing 15 or more logs[1]					Jams containing 30 or more logs[1]				
	1949	1950	1951	1952	1953	1949	1950	1951	1952	1953	1949	1950	1951	1952	1953
Maybeso Creek	9	8	10	14	16	4	4	4	6	6	0	1	1	1	1
Harris River	1	2	3	3	3	1	1	1	1	1	0	0	1	1	1
Indian Creek	1	2	3	2	3	0	0	0	0	0	0	0	0	0	0
Old Tom Creek	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0

[1] Logs 10 feet or more in length. Values shown are cumulative, i.e., the "10-log" jam also includes values shown under "15-log" and "30-log" jams, etc.

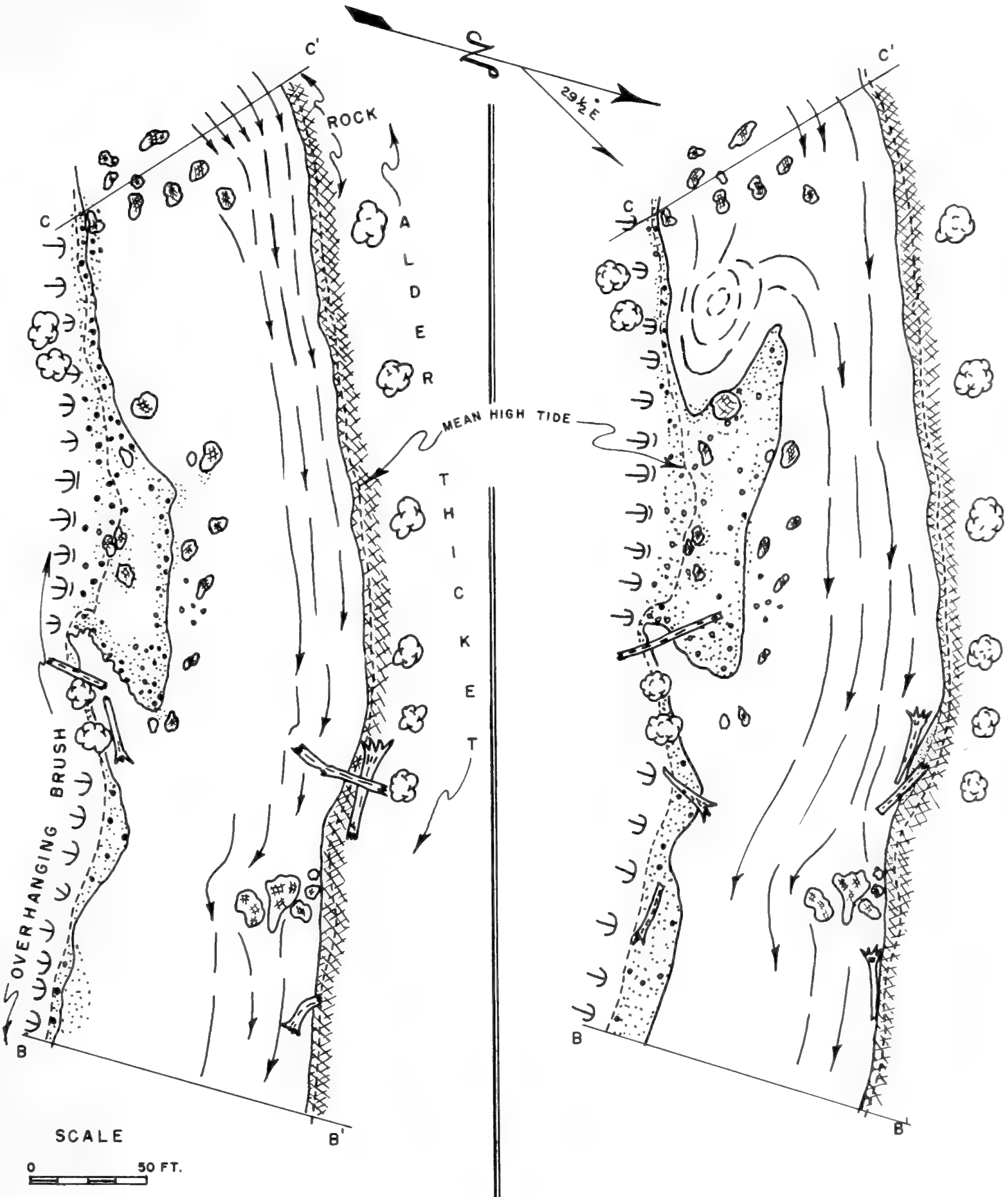

Fig. 15--Sheet 9 of Harris River Map

1949

1951

Heavy accumulation of debris in critical areas may be harmful in that it may block the upstream migration of spawning salmon. Debris may change the stream course and thus set up a reaction which is felt for many miles downstream. The effect of debris and log jams in streams is not as yet settled, however. The presence of this material may be beneficial as well as harmful. Stream barriers are generally transient in nature and new channels are soon formed under or around these barriers. Pools created by jams provide natural hiding places for the salmon. During mapping and spawning surveys it was observed that salmon congregated in considerable numbers in places where a protecting cover of debris existed.

Pools and Riffles

The difficulty of mapping pools in place, and the subjective nature of pool identification, prevents a quantitative determination of the status of pools from year to year. The mapping project demonstrated, however, that pools may change in shape, depth, and total number from year to year. Water action was observed to deepen a pool in one area, while another pool was being filled with sand and gravel. Debris, in the form of stumps and large windfalls, was observed to play an important part in the formation, or elimination, of pools. The obstruction may change the natural waterway a slight amount, and by so doing, may set the stage for the creation of a pool where at present a gravel bar exists (fig. 15).

The study reveals that the equilibrium of stream channels under natural conditions is subject to great change and that new pools are constantly being formed and old pools filled as a result of water action.

Area of stream in riffles does not appear to be greatly changed from year to year as a result of water action. Riffles mapped during 1949 were still present in the same general position in 1953 on all streams.

Streambank Cutting

Very little cutting of overhanging mud and clay banks has occurred. Maybeso Creek has received approximately 1300 lineal feet of bank cutting; Harris River 100 feet; Indian Creek 450 feet; and Old Tom Creek 165 feet.

A considerably greater amount of streambank cutting occurs than is indicated by the above figures. The greatest proportion of streambank material is composed of glacial-lain deposits of sand and gravel. This material is easily molded and reworked by running water. It is usually difficult to recognize, and to map planimetrically, fresh cutting in sand and gravel unless the change is of large magnitude. An intensive cross-section study was begun at the confluence of Harris River-Indian Creek in 1950 to determine the extent of yearly cutting in sand and gravel. This study is described later. Twelve additional cross-section stations were established on Maybeso Creek and six on Harris River in 1954 and 1955.

Very little qualitative change in type of streambed material is apparent on any of the study streams. Stream sections mapped in 1949 as consisting of sand and gravel were also mapped as sand and gravel in subsequent years. An intensification of this phase of the study was begun in 1955 with the installation of silt traps and sampling of gravel.

MOVEMENT OF FRAGMENTAL DEBRIS[18] IN AN INTERTIDAL ZONE

The intertidal zones[19] of many streams in Southeast Alaska, as well as elsewhere, are widely used by pink salmon as spawning areas (9). A high percentage of the total number of pink salmon using Harris River and Indian Creek spawn in the riffle area at the confluence of these two streams. Salmon eggs and fry buried in the gravels in this zone are covered with salt water during a substantial part of the incubation period. The intertidal zone at the confluence of Harris River-Indian Creek is composed of alluvial deposits of sand and gravel (fig. 16). Intertidal sections are frequently less stable than stream channels above high-tide level (9), and streambed material is easily molded and reworked by heavy fall and winter floods. The stream mapping project, discussed earlier in this report, revealed that a considerable amount of streambed material is shifted annually in this zone.

Figure 16.--Intertidal zone at confluence of Harris River-Indian Creek.

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[18] Particles of gravel, sand, silt, and clay.

[19] The intertidal zone is considered to be the stream sections between the lower low-tide and higher high-tide level (9).

The welfare of salmon eggs and fry which are buried in the streambed gravels is directly affected by the magnitude of movement of fragmental mineral debris in important spawning areas. Heavy mortality of eggs and fry might occur as a result of deposition of fine material, or streambed scouring which removes the protective covering of gravel.

Another agent of disturbance in intertidal areas is the action of ice. Large sheets of ice are broken and moved over the spawning beds. This action results in considerable grinding and scouring of streambeds.

The importance of intertidal zones as spawning areas necessitated a study to determine the extent of sediment movement in these areas. A study was begun in 1950 to measure quantitatively the movement of fragmental debris which occur from year to year in an intertidal zone.

Thirty-three cross-section stations were established in 1950 at the confluence of Harris River and Indian Creek (fig. 17). Elevations of the stream channel were determined to the nearest 0.1-foot at 5-foot intervals along each cross section. Yearly measurements have been made from 1950 to 1955, inclusive, and show elevational changes from July of one year to July of the following year.

Six cross sections were selected for analysis to show the extent of gravel movement. These are shown in heavy lines in fig. 17.

Four depth-classes were established, based on depth of material moved from year to year:

Depth Class	Disturbance (inches)
Light	1.2 to 5.0
Moderate	5.1 to 9.0
Heavy	9.1 to 15.0
Severe	15.1 and over

Changes less than 1.2 inches were not considered significant since elevations were taken only to the nearest 0.1-foot. The number of lineal feet in each depth-class was determined for each cross section for the periods 1950-1951, 1951-1952, 1952-1953, and 1953-1954. Percent of stream width in each depth-class was then determined for each section. Percent depth-class for all six cross sections was averaged to show mean change per year. Fig. 18 A-D shows in detail yearly stream channel changes which occurred at station 8 + 00 on Harris River during the period 1950 to 1954, inclusive.

A further step was taken to determine the cubic volume of material moved in a typical reach of the stream. The volume of material moved during July 1953 to July 1954 was determined in the reach between cross section station 0 + 00 and 2 + 00 in the confluence by use of the prismoidal formula (10):

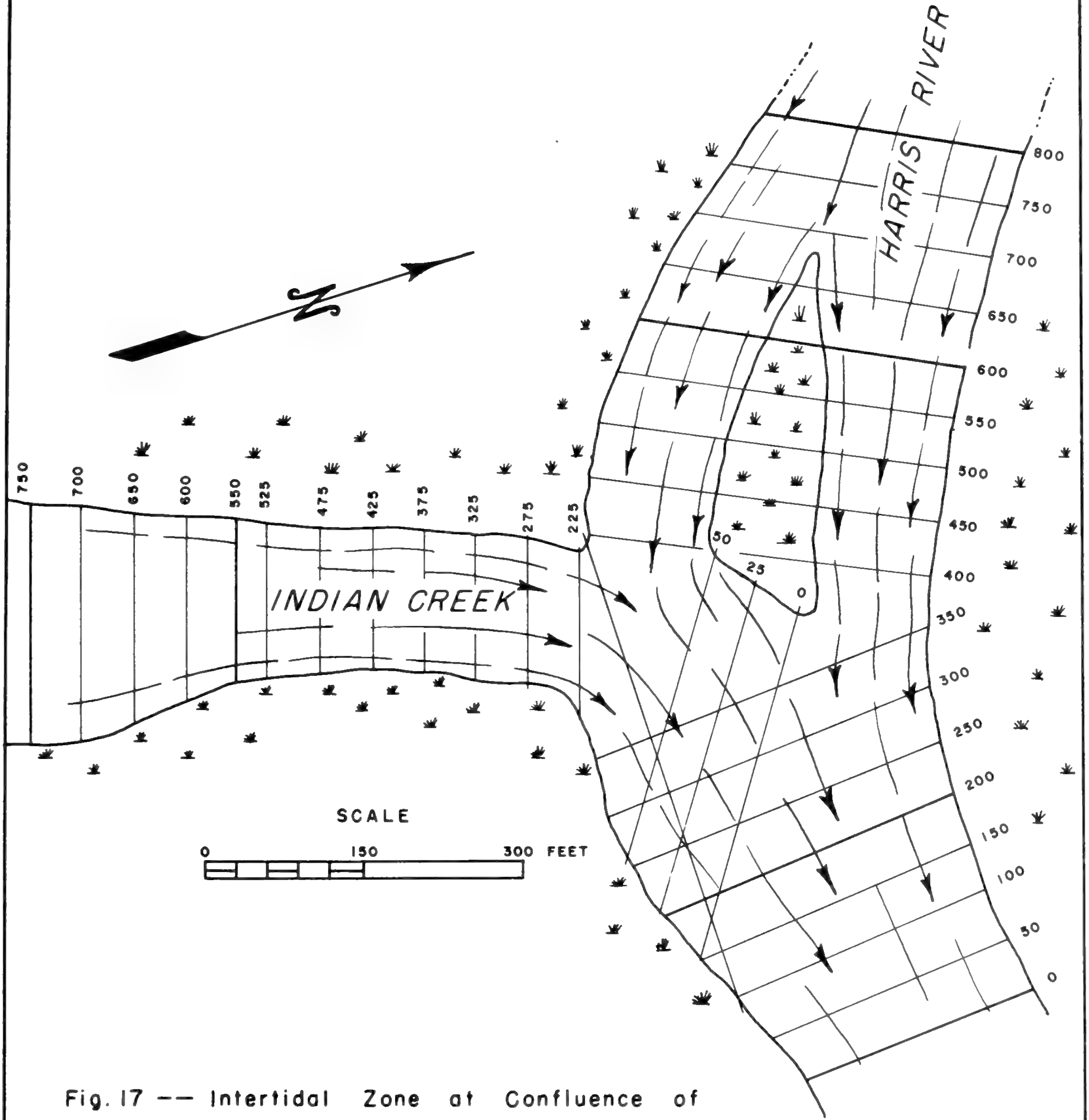

Fig. 17 -- Intertidal Zone at Confluence of Harris River — Indian Creek Showing Location of Cross Sections.

$$s \text{ (in cubic yards)} = \frac{L}{6 \times 27} (A + 4M + A')$$

where s = volume in cubic yards between two adjacent sections
L = length of section in feet
A and A' = the area of the segments at the two parallel ends
M = the area of the segment midway between the ends

Depth of Disturbance

Extent of sediment movement by depth-class for the six cross sections is shown in table 12. A considerable amount of gravel movement is shown to take place under natural conditions each year in the intertidal zone. The greatest disturbance in both cut and fill occurred in the 1.2 to 5.0 inch depth-class. Only a small percentage of cut and fill occurred which was greater than 9.1 inches.

Cutting exceeds filling during some years, whereas filling exceeds cutting during other years. For example: scouring greater than 1.2 inches, during the period 1952-1953, was 49.2 percent, whereas deposition accounted for only 24.9 percent of the total change. The reverse was true during 1953-1954 as deposition accounted for 63.7 percent and scouring only 13.2 percent. Deposition exceeded erosion during the entire period of record by approximately 4.7 percent. Fig. 19 shows graphically the percentage relationship between cut and fill greater than 1.2 inches, and undisturbed sections.

Severity of cut was found to be correlated with flood peaks six feet and greater which occurred on Harris River (table 13). The highest percent of heavy and severe cutting occurred during the period July 1951-July 1952 when the only flood greater than 7.0 feet occurred (7.95 feet, December 10, 1951). The lowest percentage of heavy to severe cutting occurred during July 1952-July 1953 when no floods greater than 6.0 feet occurred. No correlation was found between severity of cut and floods less than six feet in crest, indicating that only very high precipitation rates result in heavy and severe scouring in the gravel at the intertidal zone. Cutting is probably confined to periods of low tide when the "reservoir action" of tides does not decrease the velocity of streamflow in this area. No correlation was found between floods and severity of fill.

Volume of Gravel Moved

A quantitative analysis was made of the material moved in a section below the confluence of Harris River-Indian Creek during one winter. Volume of material moved between stations 0 + 00 and 2 + 00 (fig. 17) during July 1953 and July 1954 is shown below:

Section	Cut (cu. yds.)	Fill (cu. yds.)
Stations 0 + 00 to 2 + 00, intertidal zone	61	556

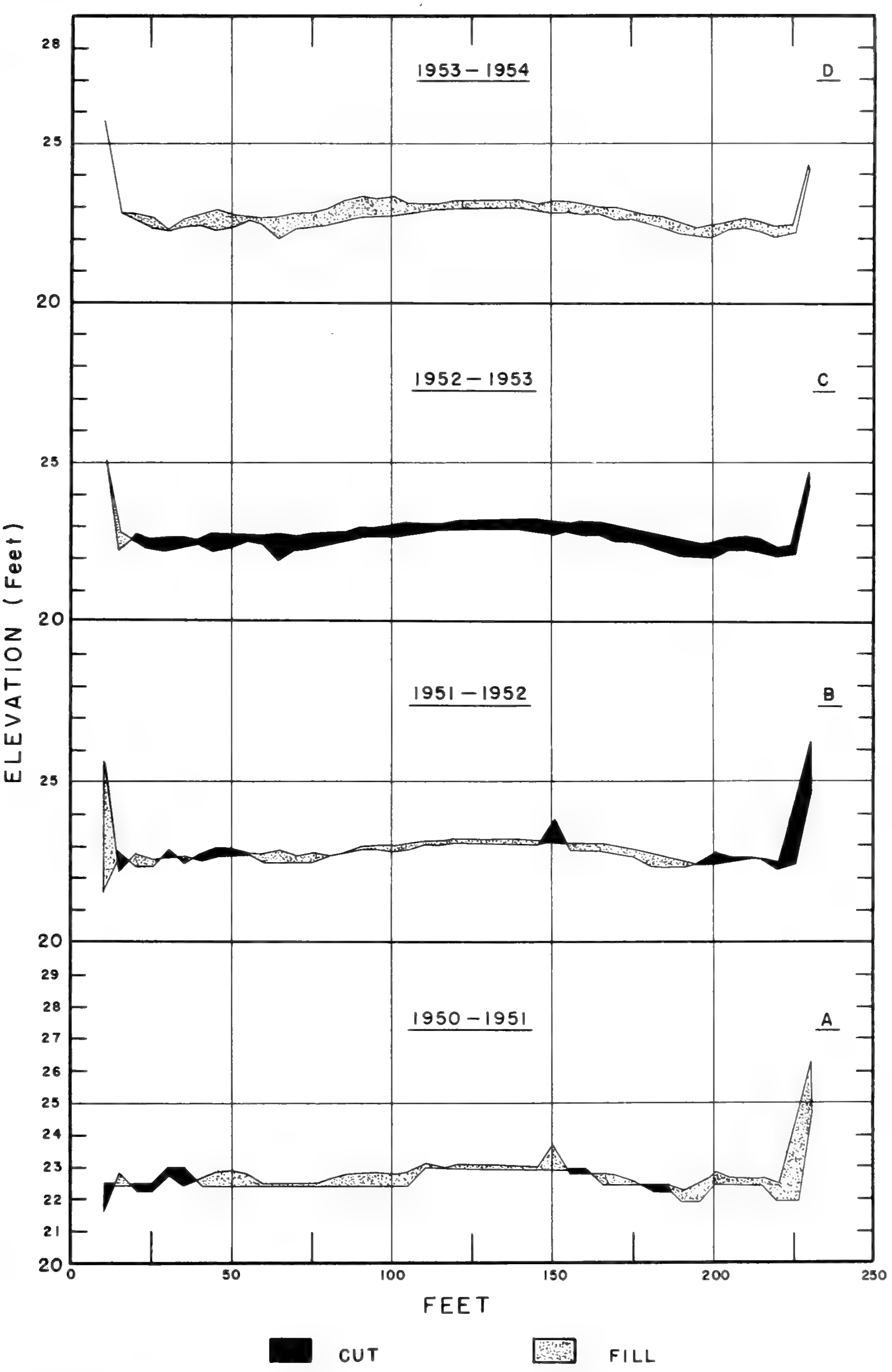

Fig. 18 -- Harris River Cross Section Station 8 + 00 Showing Cut and Fill during Period 1950 – 1954.

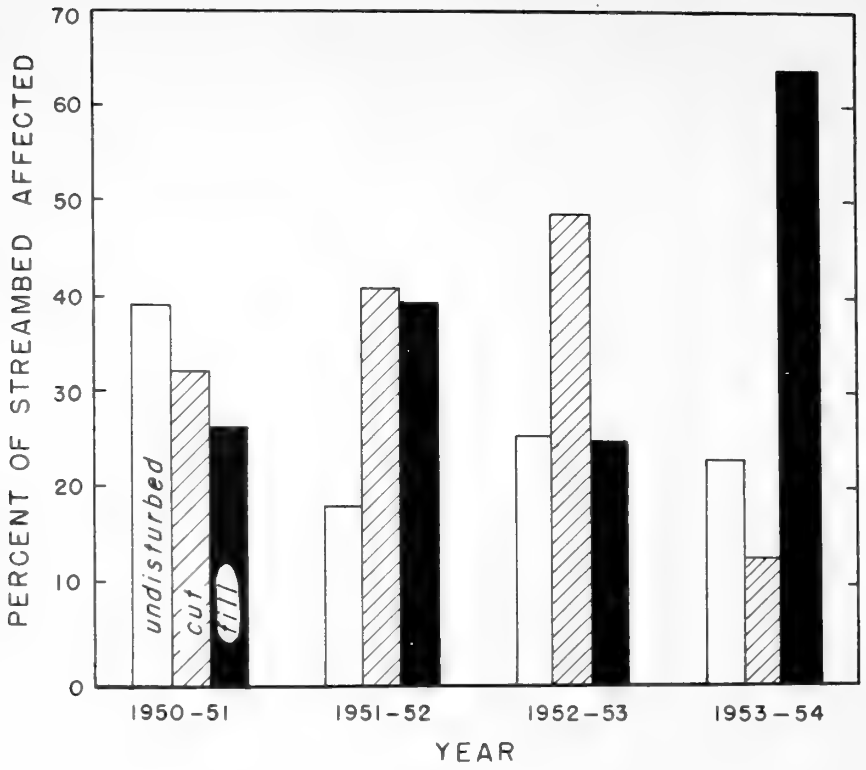

Fig. 19-- Relationship between cut and fill greater than 1.2 inches, and undisturbed sections.

HARRIS RIVER-INDIAN CREEK INTERTIDAL ZONE

The period has been one of net deposition with a fill of 556 cubic yards and a cut of only 61 cubic yards in the 200-foot section. This accumulation is net and represents the minimum change which took place during the period. A greater gross volume change may have taken place as these gravels are continuously being shifted from one position to another.

The analysis has shown quite decisively that the intertidal zone at the confluence of Harris River-Indian Creek is unstable under natural conditions and subject to considerable movement of streambed material. The alluvial meterial in this zone is easily molded and reworked. The intertidal zone may be more susceptible to sediment deposition than to erosion because tidal action in this reach produces a fluctuating reservoir. Deposition is induced during periods of slack water because the incoming tide reduces the particle carrying capacity of the freshwater stream. Deposition of material is also induced by the chemical action of flocculation and precipitation (14). The greatest amount of shifting usually occurs during periods of high stream runoff, particularly during the fall months when eggs are deposited in the gravel.

Table 12.--Percent of streambed disturbed, by depth-class, Harris River-Indian Creek intertidal zone, 1950-1954

Period	Undisturbed less than 1.2 in.	CUT (Basis: 6 cross sections)				
		Light 1.2-5.0 in.	Moderate 5.1-9.0 in.	Heavy 9.1-15.0 in.	Severe Over 15 in.	Total cut greater than 1.2 in.
				percent		
1950-51	40.0	25.2	6.4	1.3	0.3	33.2
1951-52	18.6	25.5	12.2	0.9	2.8	41.4
1952-53	25.9	41.9	6.0	0.9	0.4	49.2
1953-54	23.1	10.1	1.6	0.9	0.6	13.2
Mean	26.9	25.6	6.6	1.0	1.0	34.2

Period	FILL (Basis: 6 cross sections)				
	Light 1.2-5.0 in.	Moderate 5.1-9.0 in.	Heavy 9.1-15.0 in.	Severe Over 15 in.	Total fill greater than 1.2 in.
			percent		
1950-51	23.7	1.7	0.7	0.7	26.8
1951-52	27.6	8.7	1.6	2.1	40.0
1952-53	20.6	2.8	0.8	0.7	24.9
1953-54	43.6	14.0	4.0	2.1	63.7
Mean	28.9	6.8	1.8	1.4	38.9

Table 13.--Relationship between flood peaks greater than 6.0 feet, and scouring at intertidal zone, Harris River-Indian Creek

Period	Flood Crests		Cut
	6.00 to 6.99 ft.	7.00 ft. and greater	Cross-sectional area undergoing heavy and severe cutting
			percent
1950-51	1	0	1.6
1951-52	2	1	3.7
1952-53	0	0	1.3
1953-54	2	0	1.5

The average depth of pink salmon nests is 6 to 8 inches (9), ranging between approximately four to twelve inches. Scouring which removes material to a depth of 9.0 inches, or more, would wash a high percentage of the deposited eggs from their nests. The percent of streambed receiving disturbance greater than 9.0 inches was small, however, averaging only 2 percent over the period with values ranging from 1.3 to 3.7 percent.

Percent of streambed receiving cutting disturbance in the 5.1- to 9.0-inch class was relatively high. Average yearly disturbance was almost 7 percent with values ranging from 1.6 to 12.2 percent. Scouring in this depth-class would very likely have a significant effect on egg and fry survival. The eggs and fry which were not washed from their nests would be covered with only a thin layer of gravel, and would be more susceptible to low water temperatures than eggs and fry having a thicker covering of gravel.

The effect of additional material on top of pink eggs which are buried at normal depth is not known. The addition of a few inches of gravel probably has little effect on the buried eggs. An additional overburden of 9 or more inches might possibly have a significant effect on both eggs and fry. This consideration is probably one of small significance, however, as an average of only 3.2 percent of the stream was affected by deposition greater than 9 inches.

The principal factor regarding deposition is the nature of the deposition material, i.e., whether gravel, sand, silt, or clay. Fine deposits which result from the dropping of suspended sediment loads would be particularly harmful. The "reservoir action" at the intertidal zone may cause deposition of considerable quantities of suspended sediment which might silt the spawning beds and cause heavy mortality to both eggs and fry buried in the gravels. Part of this load would probably be carried out to sea again by ebb tide currents, but part of it undoubtedly remains in place. This phase has not been investigated to date.

The volume determination shows clearly the unstable nature of the intertidal zone in terms of cubic yards of material moved during a typical winter period. Five-hundred and fifty-six cubic yards of material were moved in a 200-foot section between July 1953 and July 1954. An examination of nine cross sections uniformly spaced over the study area shows that deposition which occurred in the reach between stations 0 + 00 and 2 + 00 was typical of the other cross sections also. On this basis, a total net volume of approximately 4,100 cubic yards of material was moved over the 1,375 lineal feet of stream included in the study.

The apparent high sensitivity of the Harris River-Indian Creek intertidal zone to the actions of scouring and deposition make it an excellent area in which to study this phase of the investigation. The cross sections in this area will be remeasured yearly to determine whether a significant change occurs following logging on the Harris River watershed.

SEDIMENTATION

Erosion material alters the environment of fish in a number of different ways and is generally recognized as harmful to fish population. One of the most important effects is the blanketing of spawning beds with heavy silt which may cause mortality to the buried eggs and fry by retarding the free circulation of dissolved oxygen to them. Other changes include: (1) creation of unfavorable stream bottom conditions by the retention of organic material and other substances, (2) alteration of temperature-change rates, and (3) screening out light. Silt has been found to limit the food supply (19).

Several studies have been made which offer rather conclusive evidence that heavy stream siltation may cause severe mortality to salmon eggs and larvae. Shaw and Maga (18) conducted a controlled hatchery experiment with fertilized silver salmon eggs. They found that during incubation, application of silt-laden[20] water for short periods to the gravel which contained the fertilized eggs reduced the yield of fry from an average of 16.2 percent for the unsilted control, to 1.16 percent for the silted gravel beds. They also found that size and vigor of surviving fry may be reduced as a result of siltation. Shapovalov (17), in a controlled experiment with steelhead trout (Salmo gairdnerii), concludes that silting may result in high mortality to eggs buried in the gravel. Smith (19) reports that placer mining silt, when fairly heavy, will smother salmon and trout eggs.

Heavily silted streams do not stop the upstream migration of mature salmon. Salmon spawn in glacial streams which carry large quantities of suspended material. The available literature provides good evidence, however, that the most successful spawning does not occur in the heavily

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20/ Mine tailings of unpolluted soil and gravel.

silted waters. Smith (19) states that most spawning occurs in the clear water of the tributaries. Other observers report that spawning in glacial streams is generally confined to areas where the water velocity is great enough to prevent silting of the streambed.

Most salmon streams carry natural silt during flood stages. This material reaches stream channels by (1) surface runoff, (2) undercutting of channel banks, (3) slow gravitational creep of mantle material, and (4) avalanches and land slides. The formation of mud flats and the presence of silt at the mouths of most creeks and rivers in Southeast Alaska attest to the magnitude of the siltation process under natural conditions.

Most logging activities on watershed slopes tend to disturb the soil and increase erosion. Construction of logging roads, however, has generally been considered to be the principal source of stream turbidity and sedimentation. It is estimated that the construction of access roads accounts for 75 percent, or more, of the stream turbidity and sedimentation associated with logged watersheds in the States.[21/]

Sedimentation resulting from road construction may be minimized by (1) location of roads away from stream channels, on benches and ridges, with as little side-hill construction as possible, and (2) endhauling to reduce overcasting on side hills where fill material may erode directly into stream channels. Road construction on the Maybeso Creek drainage has not resulted in excessive siltation because roads have been located well away from the streams and have generally been constructed by borrowing and endhauling sub-grade material; side-hill road construction and sidecasting have been held to a minimum.

Material suitable for road-subgrade and surfacing is limited in this region. Two sources of road-building material are available, rock outcrops and stream deposits. Rock outcrops, which consist mostly of shales and greenstone in the general area under study, must be quarried. Stream deposits are glacial tills which have been reworked and sorted by stream action. These deposits contain a rather high content of silt and clay and it is generally necessary to first remove these fines by washing before the material is used for road-building purposes.

A large portion of the road-building material used in the Maybeso Creek sale area has been obtained from a small stream, Half-Mile Creek, which empties into the tidal zone below the mouth of Maybeso Creek (fig. 4). Approximately 100,000 cubic yards of sub-grade and surfacing material have been removed. A detailed study was made in 1955 to

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[21/] Bullard, William. Use of water supply watersheds for road construction and logging operations. Talk given to joint meeting of Pollution Control Council and Columbia Basin Inter-Agency Subcommittee on Pollution Control at Harrison Hot Springs, B. C., Sept. 18, 1951.

determine the amount of silt and clay deposition which has occurred as a result of gravel removal and washing. The operation has resulted in the deposition of approximately 5,000 cubic yards of silt at the mouth of this stream. Depth of this material ranges from less than one inch to several feet.

The study clearly indicates the undesirability of allowing road-building material to be removed from, and washed in, tributary streams which empty directly into important salmon streams. To date, no gravel removal has been allowed in streams tributary to Maybeso Creek. The problem warrants careful study. Studies are needed to determine comparative costs and suitability of quarry material for road-building purposes.

Silt persistence, and not solely silt quantity, is the important factor of potential damage to spawning facilities of a stream. The quantity of suspended sediment in the stream, though an index to the erosion behavior of the watershed, is not in itself an indicator of potential damage. The important question is how much of the erosion material which enters a stream remains to silt the bottom, and how much of it is carried out by normal floods. Shaw and Maga (18) state that the greatest damage to spawning beds occurs when silt enters a stream during dry periods when the water velocity is insufficient to carry the sediment in suspension. Water velocities necessary to dislodge deposited particles are far greater than the velocities required to carry the same particles in suspension. The introduction of silt into streams during dry periods results in a considerable amount of bottom deposition which may reduce the total amount of stream suitable for spawning. The quiet water of deep holes, and the slower stream sections, may allow the fine material to settle and form a layer of silt on the stream bottom.

The objective of this phase of the study is to determine the degree of stream siltation which occurs under natural conditions, and to what extent, if any, it is accelerated as a result of logging on the study watersheds.

The sediment content of samples taken to date has been low. The samples taken in Maybeso Creek, in 1955, are from a stream where logging has been in progress for two years. These samples show a negligible suspended sediment content of only 1 and 4 p.p.m. On the other hand, a suspended sediment content of 1,520 p.p.m. was found in Half-Mile Creek during the process of removing and washing road-building material in the stream (table 14).

An intensified program of suspended sediment sampling is planned in 1956. Sampling of suspended sediment will be done at all water stages. Analysis of these samples will be made by the U. S. Geological Survey Laboratory, Palmer, Alaska, and will show (1) inorganic fraction, (2) organic fraction, and (3) total concentration.

Table 14.--Suspended sediment content of streams

Stream	Gage height feet		Sediment Concentration			
			p.p.m.	p.p.m. 1955		
	1950	1955	1950	Inorganic	Organic	Total
Maybeso Creek	2.77		48			
" "		1.78		0	1	1
" "		2.32		2	2	4
Harris River	4.10		132			
" "			148			
" "	4.80		34			
" "	4.70		78			
" "		2.09		0	1	1
" "		1.83		7	2	9
" "		2.40		0	1	1
Indian Creek	2.70		101			
" "		1.57		0	1	1
" "		1.30		0	1	1
" "		0.91		7	4	11
Old Tom Creek				1	1	2
Mouth of Half-Mile Creek				1,410	107	1,520

Streambed Siltation

Thirty-three stream-bottom samples were taken in 1951 by forcing the open end of a number 2 can horizontally into the gravel with the top side of the can as near the top of the gravel surface as possible. The samples were separated into four size classes: (1) over one-half inch; (2) 0.0489- to one-half inch; (3) 0.0098- to 0.0489-inch; and (4) smaller than 0.0098-inch.

A gravel sampling tool was constructed in 1955 to permit gravel sampling to a depth of approximately 10 inches. The tool was eight inches in diameter and constructed of heavy metal (fig. 20). The tool is driven vertically into the gravel, a shovel inserted under the lower end, and the entire sample removed and placed in containers. Sixteen gravel samples were obtained from Maybeso Creek in 1955. Separation has not been made of these samples to date.

The accurate sampling of stream bottom gravel to determine its content of fine material is a difficult task. The sampling tools used to date have not been entirely satisfactory. Large rocks, presence of bedrock, and swift, deep water make it difficult to obtain samples in many desired locations. A considerable amount of the fine material in the sample is lost, as it is washed out in the water trapped in the sample.

Figure 20.--Streambed gravel sampling tool.

In 1955, large fruit juice cans, filled with washed gravel and small rocks which had been run through a half-inch separator screen, were buried in the stream bottom with the top of the can slightly below the stream-bottom surface. This method avoids many of the difficulties encountered in the other methods. The cans will be removed in 1956 or 1957 and a separation made to determine the quantity of silt which has been deposited during the period.

A combination of these sampling methods should provide realistic information regarding the content of fine material in the upper few inches of the stream bottom. New techniques of gravel sampling will be investigated. An intensified program of sediment sampling is planned for 1956.

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