SOME EFFECTS OF CLEARCUTTING ON SALMON HABITAT OF TWO SOUTHEAST ALASKA STREAMS

W.R. MEEHAN
W.A. FARR
D.M. BISHOP
J.H. PATRIC

INSTITUTE OF NORTHERN FORESTRY
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
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AUTHORS

William R. Meehan is Research Fishery Biologist, Institute of Northern Forestry, Juneau, Alaska.

Wilbur A. Farr is associate Research Mensurationist, Institute of Northern Forestry, Juneau, Alaska.

Daniel M. Bishop, formerly Hydrologist with the Institute of Northern Forestry, is now Watershed Scientist, Alaska Region, Forest Service, U.S. Department of Agriculture, Juneau, Alaska.

James H. Patric, formerly Research Hydrologist at the Institute of Northern Forestry, Juneau, Alaska, is now Project Leader, Watershed Management Research, Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Parsons, West Virginia.

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INTRODUCTION

A primary concern of land resource managers in southeast Alaska is the effect of timber harvesting on the fresh water environment of salmon. Salmon and timber are the two most important renewable resources in this region; they occur together — most of the watersheds that contain salmon streams also support commercial timber that will be harvested.

Spawning by adult salmon, as well as egg and fry survival, may be influenced by timber harvest which may change the quantity, regimen, and quality of streamflow or impair adult migration by obstacles originating on logged watersheds.

The economic importance of timber and associated forest resources, such as recreation and wildlife, is increasing with the expanding woodpulp market, improving access, growing population, and expanding tourism. The amount of timber harvested has about doubled in the last 10 years; the present rate is expected to nearly triple by the end of the next 10 years.[1] One aim of land management is to conduct this harvest in a manner that is compatible with salmon production.

Before the pulpmill at Ketchikan was completed in 1954, most logging had been concentrated in the better stands along beaches and nearby valley bottoms. Subsequently, large-scale logging expanded inland to valleys and adjacent slopes, beginning near Hollis on Prince of Wales Island. This harvest provided an opportunity to study logging effects on the physical characteristics of salmon spawning streams. James (1956)[2] has described the Hollis study area in considerable detail and discussed preliminary results obtained by the Alaska Forest Research Center (now the Institute of Northern Forestry). Since 1955, research has continued cooperatively with the U.S. Fish and Wildlife Service, Fisheries Research Institute of the University of Washington, and the Alaska Department of Fish and Game.

The original objective of this study, which began in 1949, was to determine if clearcutting and high-lead yarding affected salmon migration and spawning. As the study progressed, the environmental requirements of salmon in fresh water and the effect of clearcutting on watershed factors became better understood. Consequently, the objective gradually changed to the determination of the effect of clearcutting on the physical factors of salmon spawning streams.

This report summarizes the research and describes the main conclusions regarding the effect of clearcutting on streamflow,[3] suspended sediment, water temperature, and log debris.

LITERATURE REVIEW

Cordone (1956) and Chapman (1962) provided surveys of literature concerning logging effects on fish resources, with emphasis on studies from the western United States. Bullard (1950) summarized most of the earlier American research on forest watershed management. Our review will concentrate on more recent studies of physical effects of logging as evidenced by the quantity, regimen, and quality of streamflow. An exhaustive review of the literature is not attempted; rather, the present view of American forest hydrologists will be expressed in terms of recently published research findings. These findings highlight certain hydrologic principles that should be applicable in southeast Alaska.

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[1] U.S.D.A. Forest Service. Annual statistics, 1916-1964. Region 10, Timber Business Records, 1967. (Unpublished report on file at Forest Service, U.S. Department of Agriculture, Juneau, Alaska.)

[2] Names and dates in parentheses refer to Literature Cited, p. 42.

[3] The hydrologic terminology used in this report is defined by Langbein and Iseri (1960).

However, they serve only as clues to quantitative relationships, because there is not a sufficient knowledge of southeast Alaska hydrology to provide a basis for adjusting results from other areas to local conditions.

STREAMFLOW

Quantity

> There can be little doubt that in most well-watered lands conversion of mature forest to low-growing vegetation will increase supply of water to streams. When considered independently of other factors, such as aspect, elevation, soil depth, and precipitation, first-year increases in yield seem roughly related to the percent of the fully developed stand that is removed or cut down. First-year increases in the order of 5-16 [area] inches may be expected at [the] Coweeta [Hydrologic Laboratory] after complete cutting of mature hardwood forests. Experiments of all types within the temperate zones of the world, neglecting Coweeta, suggest increases in streamflow up to about 10 [area] inches per year as a result of clearcutting forested watersheds, but the average would seem to be about half this amount. (Hewlett and Hibbert 1961.)

Increased streamflow following clearcutting has been documented in several subsequent studies. Rowe (1963) reported annual increases, depending on rainfall, ranging from 4.4 to 14.4 area-inches following removal of riparian woodland in California. Reinhart et al. (1963) reported increases of 1 to 5 inches following logging; the increased flows were roughly proportional to stand removal. For a tributary of Oregon's McKenzie River, Rothacher (1965) found 12 to 28 percent increased low flows following 30-percent vegetation removal, and an 85-percent increase following 80-percent removal. On an Arizona watershed, conversion of 80 acres of moist-site forest to grass increased streamflow about 55 percent (Rich 1965). Eschner and Satterlund (1966) reported a 7.72-inch decrease in annual streamflow between 1912 and 1950 when forest density notably increased on the Sacandaga River watershed in New York. Analysis of discharge measurements by Riggs (1965) for nine small streams in Virginia indicated that discharge per square mile was directly related to the percentage of the drainage basin cleared of trees and brush. Clearing land along channels seemed to produce a greater effect on discharge than clearing over the basin generally. This effect of clearing was most pronounced at extremely low levels of discharge and became negligible at high discharges.

Regimen

The rate of water absorption through the soil surface may be lower than the rate of water delivery to the surface; if so, some of the water delivered will flow upon the soil surface to streams (Colman 1953, p. 50). Little solid evidence is available that logging impairs the ability of soil to absorb water (i.e., causes surface runoff) except on roads and other areas of extreme disturbance.

On logged, nonroad surfaces, Steinbrenner and Gessel (1955) found a 34.9-percent average reduction in permeability, negligible change in bulk density, and an average porosity increase of 6.4 percent following tractor logging in Washington. Dyrness (1965) showed that tractor logging caused more soil surface disturbance (38 percent of the logged area) than high-lead logging (21 percent of the logged area). These authors implied that runoff rates increased following logging but did not demonstrate that infiltration rates were reduced below maximum rainfall rates.

Hoover (1944) and Kovner (1957) observed that no overland flow occurred on two clearcut watersheds in North Carolina. On these watersheds, the relationship of baseflow to stormflow remained unchanged several years after clearcutting (Dils 1957). Hewlett and Hibbert (1961) noted that overland flow was negligible at Coweeta except on watersheds abusively treated by overgrazing or farming. Peak flows in Oregon (Rothacher 1965) and southern California (Rowe 1963) were unaffected by logging. Reinhart et al. (1963) reported that augmented high flows followed heavy cutting during the growing season but that stormflows were unaffected by logging during dormant seasons. Here, the construction of roads contributed to storm runoff. Annual logging of less than 6 percent of the Snow Creek basin in western Washington had no apparent effect on runoff (U.S. Geological Survey 1963).

Surface runoff is sharply reduced by revegetating damaged watersheds. Legumes planted on severely gullied land in South Carolina greatly reduced peak flows and stopped soil loss (Metz 1958). Two years after revegetation, stormflow on a mountain farm in North Carolina had returned nearly to preclearing levels (Dils 1957). Reforestation of the White Hollow watershed, Tennessee, reduced peak discharges 73-95 percent of levels observed before the area was reforested (Tennessee Valley Authority 1961). In Ohio, stormflow reductions following reforestation ranged from 52 percent in small storms to 84 percent in large storms (Hill 1960).

WATER QUALITY

Only the effects of logging on suspended sediment and stream temperature are considered in this review.

Suspended Sediment

The literature on suspended sediment in streams draining logged watersheds must be rigorously evaluated to determine damage due solely to roads (Packer 1966). Lieberman and Hoover (1948) showed that roads were the major sediment source during logging; their original notes (filed at Coweeta Hydrology Laboratory) implicitly state that the hydrologic functioning of nonroad surfaces was unimpaired by logging. Reinhart et al. (1963) observed that streamflow usually was clear on watersheds where road grades seldom exceeded 10 percent. Where most roads had 21- to 30-percent grades, stream turbidity of 5,000 parts per million (p.p.m.) was recorded. This sediment source became negligible 2 years after logging when roads had revegetated. When all roads were located away from streams and held below 10-percent grade, there was little increase in suspended sediment during logging (Black and Clark n.d.; Jones[4]). Rowe (1963) reported no detectable increase in erosion or storm peak discharges after clearcutting except from one or two minor washes along a newly constructed road. Statistical analysis showed no difference in mean annual sediment yields between logged and unlogged watersheds in Colorado (Leaf 1966). Anderson and Wallis (1963) presented equations for estimating sediment discharges from logged watersheds in Oregon and northern California but did not distinguish between cutover land and roads as sediment sources. About 2 percent of the Naselle River watershed, Washington, has been logged each year since 1921. Despite rainfall up to 51 inches per month and burning on 7 percent of the logged area, there has been no evidence of surface erosion (Martin and Tinney 1962). Watersheds supplying Seattle (Thompson 1960) and Oregon City (Horne 1960) were logged for several years with negligible damage to water quality.

[4] Jones, Le Roy. A watershed study in putting a hardwood forest at the Coweeta Hydrologic Laboratory in the Southern Appalachian Mountains under intensive management. 1956. (Master's thesis on file at Univ. Georgia.)

Stream Temperature

The brief American literature on rise of stream temperature after logging is summarized in the following tabulation. Although stream temperature responses to logging varied greatly over the United States, they invariably occurred during midsummer.

Logging location	Maximum stream temperature increase (degrees F.)	Source of data
Lookout Creek tributary, Oregon	0	Oregon State Game Commission (1952, p. 278)
Maybeso Creek, Alaska	0	James (1957)
Rapid City, South Dakota	1	File data, Rocky Mountain Forest and Range Experiment Station
Franklin, North Carolina	4	File data, Southeastern Forest Experiment Station
Lookout Creek, Oregon	5	Oregon State Game Commission (1952)
Parsons, West Virginia	8	Reinhart et al. (1963)
Connecticut	10	Titcomb (1926)
Franklin, North Carolina	11.5	Greene (1950)
Glendora, California	16	File data, Pacific Southwest Forest & Range Experiment Station
Alsea River, Oregon	16	Hall (1967)

Reinhart et al. (1963) stated that " . . . dormant-season minimums were reduced on the average by 3-½° [F.]" on the clearcut watershed in West Virginia. A slight effect in the same direction was apparent on the Diameter Limit Watershed with no appreciable effects on Selection Watersheds. Hornbeck and Reinhart (1964) reported in addition that both maximum and minimum temperature differences from forest streams were reduced by half in the second year after logging.

LOG-DEBRIS JAMS

The damaging effects of large log-debris jams have been well documented, particularly in California and Oregon (California Department of Fish and Game 1955a, b, c; Corthell 1962). The most undesirable effects of large jams in salmon streams are blocking upstream salmon migration and causing excessive deposition and clogging of the streambed by sediment and debris.

Problems of jam obstructions and streambed sedimentation are particularly severe in the salmon streams of coastal Washington, Oregon, and California. All of the Pacific Coast States have codes or statutes that prohibit obstructing the passage of fish in a stream. These requirements have frequently proved inadequate (Calhoun and Seeley 1963). State fish and game departments generally favor leaving a vegetated strip next to streams. This has been incorporated into timber sales contracts in some areas (California Department of Fish and Game 1955c).

Much stream clearance and improvement work has been done in recent years. On the Coquille River of Oregon in 1960, $50,000 financed removal of 23 individual large jams and 5 miles of generally continuous jams on smaller tributary streams (Corthell 1962). On the north coast of California, 296 log jams on the Noyo River system were removed by State prison inmates; about 100 cubic feet of wood debris were removed per man-day (Holman and Evans 1964). In Alaska, Bishop[5] suggested an approach wherein the criteria for jam removal depend primarily upon stream gradient and streambed roughness.

In southeast Alaska, valleys tend to have a U-shape typical of recent glaciations. Valleys of the Pacific Coast Ranges tend to be V-shaped. Thus, problems of log-

[5] Bishop, D. M. Relationship between streambed pools and salmon spawning area in a southeast Alaska stream. 1964. (Unpublished report on file at Inst. North. Forest., Juneau, Alaska.)

debris jams differ. Jams in southeast Alaska are usually small and seldom obstruct migration. Measurments taken at two artificially built log jams near Hollis, Alaska, showed that the jams increased streambed movement and instability and reduced fine material content in the streambed (Helmers 1966). Intragravel dissolved oxygen may have been increased. Although the effect of small log-debris jams on salmon production remained undetermined, temporary or unstable jams were judged to be detrimental. Bishop[6] estimated that in the same stream, pools caused by log debris occupied about 10 percent of the streambed area, thus reducing available potential spawning area by a similar amount.

THE STUDY AREA

Location. — The study area, a part of the Tongass National Forest, is near Hollis, Alaska, on Prince of Wales Island, about 45 miles west of Ketchikan. It includes the Maybeso Experimental Forest (the entire Maybeso Creek drainage) and two adjacent watersheds, Harris River and Indian Creek (figs. 1, 2, 3, 4).

Climate. — Proximity of the Pacific Ocean holds both daily and seasonal temperatures within a narrow range. Daily fluctuations rarely exceed 15° F., and the mean monthly temperature ranges from near freezing in winter to about 60° F. in summer (Day 1921). Although the mountains are steep, few on this part of the island rise above 3,500 feet. Nevertheless, the rugged terrain has great effect on kind and amount of precipitation. Snow falls at Hollis between October and March. Snow accumulations greater than a foot are infrequent at sea level, but much more of the precipitation falls as snow in the mountains where patches often persist throughout the year. Since Hollis is in the path of storms moving east across the Gulf of Alaska, heavy precipitation (100 or more inches per year) and much cloudiness are the rule.

Although rainfall is greatest in the fall, intensity remains low, with 0.47 inch per hour the maximum recorded at Hollis. During a representative month, October 1953, measurable rain fell on all but one day at Hollis with a total of 20.32 inches; numbers of 1-hour periods having rain of specified intensity were:

Intensity (inches per hour)	Hours of rain
Trace to 0.05	356
0.06 to 0.10	67
0.11 to 0.15	48
0.16 to 0.20	11
0.21 to 0.25	3

Geology and soils. — Sedimentary rocks (graywacke, shale, black argillite, and conglomerate) predominate over the study area. Faulting, folding, and metamorphism have developed a considerable variety of bedrock structure and composition. The geology of Maybeso valley has been reported in detail by Swanston.[7] The region was extensively glaciated, resulting in oversteepened, unstable valley sides sometimes subject to landsliding (Bishop and Stevens 1964). Thus, most forest soils are derived from glacial or colluvial material on mountainsides or from alluvium in the valleys. Organic bog soils are common. Mineral soils usually are podzolized very gravelly or stony loams or silt loams containing a high proportion of gravel and stones. Many soils have rock or dense till substrata, but weathered horizons, ranging from 1 to 3 feet deep, are very porous and highly permeable. All soils are covered with litter, moss, and permanently moist duff ranging from 5 to 12 or more inches deep. Soil profile development is

[6] See footnote 5.

[7] Swanston, Douglas N. Geology and slope failure in the Maybeso valley, Prince of Wales Island, Alaska. 1967. (Unpublished doctoral thesis on file at Department of Geology, Mich. State Univ., East Lansing.)

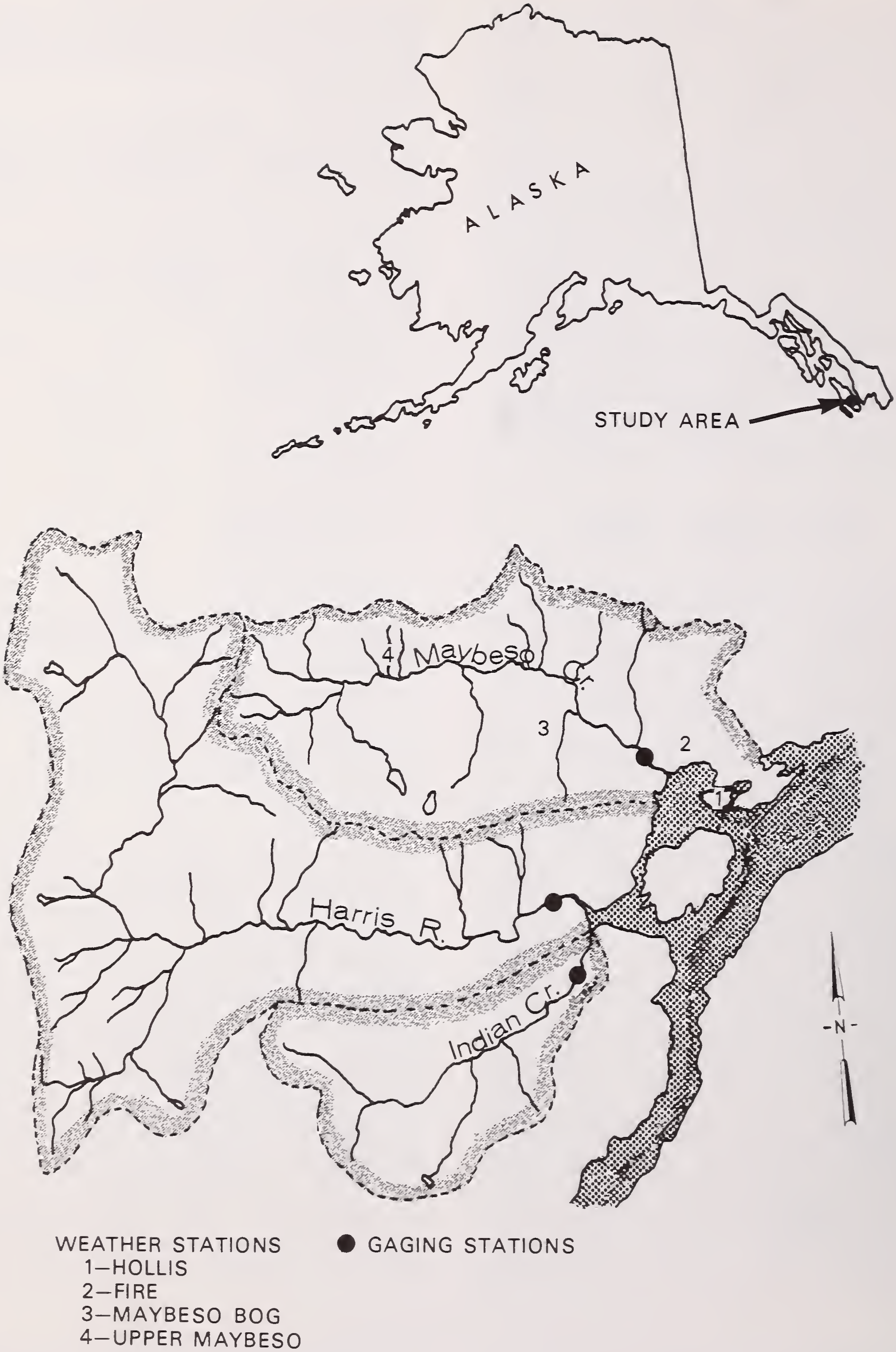

Figure 1—*Map of three gaged watersheds near Hollis, Prince of Wales Island, Alaska.*

Figure 2 — *Maybeso Creek watershed, Prince of Wales Island, Alaska, 1961.*

Figure 3 — *Harris River watershed, Prince of Wales Island, Alaska, 1961.*

Figure 4 — *Indian Creek watershed, Prince of Wales Island, Alaska, 1961.*

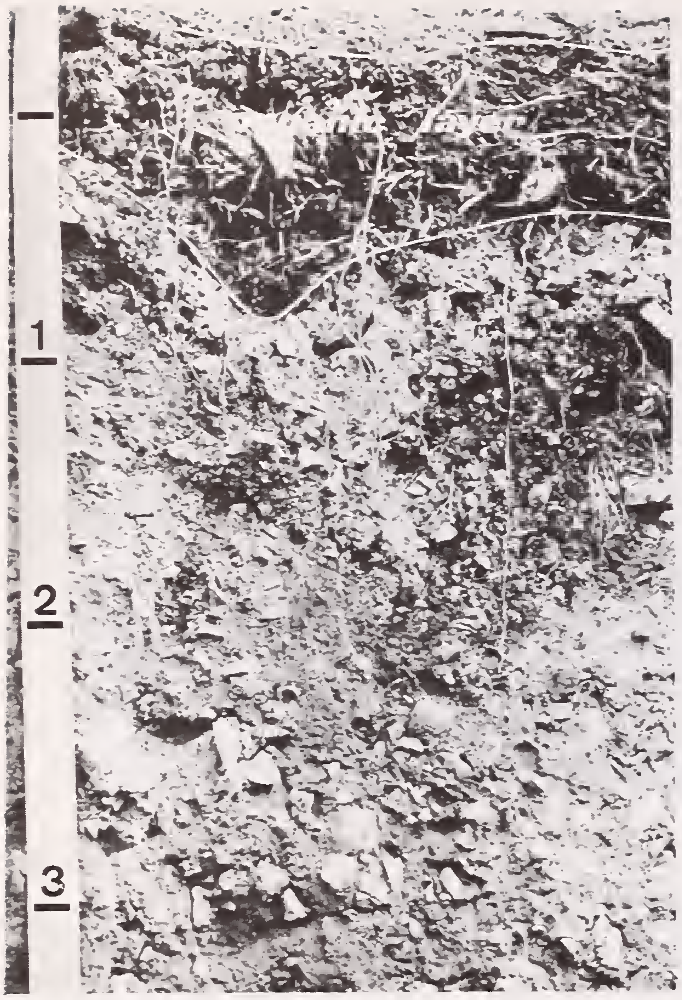

Figure 5 — *A productive forest soil commonly found in the study area, Hollis, Alaska (scale in feet).*

deeper and more pronounced at lower elevations. The study area soils have been mapped and described by Gass et al. (1967). A typical forest soil profile is shown in figure 5.

Forests. — The study area was densely forested with western hemlock *(Tsuga heterophylla* (Raf.) Sarg.), Sitka spruce *(Picea sitchensis* (Bong.) Carr.), Alaska-cedar *(Chamaecyparis nootkatensis* (D. Don) Spach), and western redcedar *(Thuja plicata* Donn.) comprising 76, 20, 2, and 2 percent of the stand, respectively. Stands of commercial value usually grew at elevations below 1,500 feet and occupied about one-third of the watershed area. Nonforested bogs occupied about one-sixth of the land area, the balance being noncommercial forest, alpine meadow, and rock outcrop (Gass et al. 1967). Godman (1952) has described in considerable detail the composition of old-growth forests typical of southeast Alaska.

Watershed characteristics. — The description in table 1 is drawn primarily from James (1956), who previously discussed the study area streams.

Fish. — Pink salmon *(Oncorhynchus gorbuscha* (Walbaum)) and chum salmon *(O. keta* (Walbaum)) are the major species maintaining spawning populations in the study streams. Coho salmon *(O. kisutch* (Walbaum)) occur in smaller numbers, and a few sockeye salmon *(O. nerka* (Walbaum)) are observed in some years. Harris River and Maybeso Creek also support populations of steelhead trout *(Salmo gairdneri* Richardson).

Table 1—*Some characteristics of watersheds near Hollis, Alaska*

Characteristic	Maybeso Creek	Harris River	Indian Creek
Main channel gradient . . . . percent	0.86	0.30	1.0
Main channel length . . . miles	5.8	10.9	3.2
Watershed area . . . . acres	9,728	20,352	5,504
Area logged . . . . acres	2,472	4,025	0
Area logged . . . . percent	25.4	19.8	0
Merchantable timber . . . . MM bd. ft.	131.4	221.7	28.3
Peat land and organic soil . . . . percent	15	19	37
Orientation . . . . . . direction	ESE.	S. and E.	NE.
Maximum elevation . . . . feet	3,392	3,806	2,267
Average rate of discharge[1] . . . . c.f.s.[2]	136	256	86.1
Maximum stormflow . . . . . . c.f.s.m.[3]	249	307	905
Minimum streamflow c.f.s.m.	.60	.35	.22

[1] 1949-64 (U.S. Geological Survey 1965, pp. 35-81).
[2] Cubic feet per second.
[3] Cubic feet per second per square mile.

METHODS

Timber harvesting by the clearcutting method began above the stream gaging station in Maybeso valley in 1953 and ended in 1957. The Harris River valley was harvested by the same method in 1959-61. Clearcutting is an efficient method of harvesting mature stands and of preparing the sites for growing new stands. The extent of clearcutting can be approximated from figures 2 and 3. High-lead logging was used on most of the area; some of the flatter valley bottoms were logged with tractors.

Logging roads in the valley bottoms were constructed by laying crushed rock and gravel over the undisturbed forest floor where road grades seldom exceeded 5 percent. These roads ordinarily were located several hundred feet from major stream channels, well outside the 50- to 100-foot minimum spacing between road and creek recommended by Trimble and Sartz (1957). Valley-side roads were excavated full width, then covered with crushed rock and gravel. Grades on these roads seldom exceeded 15 percent; water drained into inside ditches and crossed under roads through log culverts. All streams were crossed at about right angles with log bridges. After logging, bridges and culverts were removed from abandoned roads, and cross-drain ditches were installed.

Climatic data were collected at four stations in the study area (fig. 1). The following tabulation summarizes, for each station, the types of data obtained and the period of record. Recording gages were used at all stations except at Maybeso bog where monthly precipitation was measured in an 8-inch U.S. Weather Bureau standard gage.

	Period of operation	Climatic factors measured
Weather station:		
Hollis[1]	1949-62, year around	Temperature Precipitation
Fire weather station	1957-61 May to October	Relative humidity Temperature Precipitation Wind
Maybeso bog	1953-60 May to October	Precipitation
Upper Maybeso	1958-61 May to October	Precipitation

[1] From 1949 to 1962, summer (May-October) weather observations were made at Cat Island; from 1953 to 1962, winter (October-May) records were maintained at the Hollis logging camp, approximately 0.7 mile northwest of the Cat Island weather station.

Water levels were recorded from 1949 to 1964 on strip chart instruments at Harris River and Maybeso and Indian Creeks. Gaging sites for these streams were chosen at bedrock sections close to tidewater. For each gaging section, stage-discharge curves were developed by use of a current meter. Gaging stations were serviced as often as possible, but visits sometimes were a month or more apart at this remote location.

A thermometer component of the water stage recorder provided most of the temperature data from each gaged stream. The thermometer bulb was placed as close as possible to midchannel and just under the gravel surface in Maybeso and Indian Creeks. The thermometer bulb in Harris River was on bedrock. In addition, a mercury thermometer provided checks of recorded temperature during service visits to the stream gaging stations.

Suspended sediment was sampled occasionally in each stream from 1950 to 1963 and at weekly intervals and during stormflows in the summer and fall of 1960 and 1961. In periods of low flow, suspended sediment was sampled with a USDH 48 hand sampler (fig. 6); a larger cable-suspended sampler was used during high flows. Total organic and inorganic content were measured by the Gooch Crucible Technique (American Public Health Association 1962, p. 327) by use of commercially prepared crucible filters.

Until 1960, log-debris jams in the study streams were mapped annually on base maps prepared by planetable in 1949. After 1960, large-scale aerial photography (about 1:1,800) was used to reduce mapping time and to increase accuracy. Logs, chunks, and stumps were counted individually, except in large jams where estimates were necessary.

Since 1948, annual aerial and ground surveys by various agencies concerned with fish populations have provided estimates of salmon escapement to the study streams; i.e., the numbers of spawners escaping fishermen and other offshore hazards to reach the spawning beds.

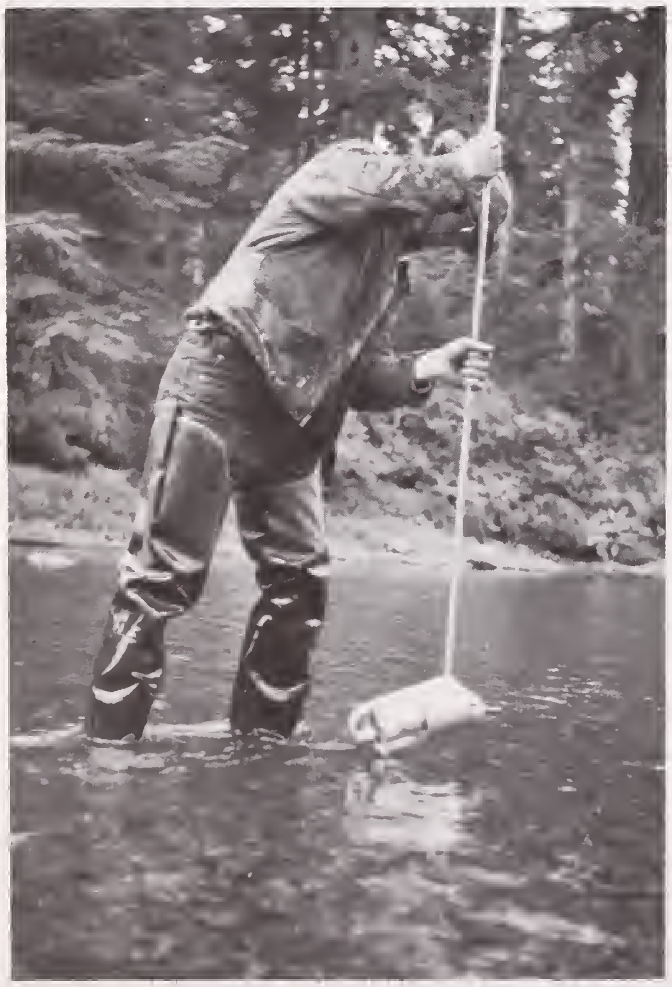

Figure 6 — *Sampling suspended sediment with a USDH 48 sampler.*

Table 2 summarizes 13 years of climatic data from the Hollis weather station; daily and monthly values have been published by the U.S. Weather Bureau (1952-63). Monthly rainfall at Hollis and at three other locations in the Maybeso valley (fig. 1) are summarized in table 3. These data show that, on the average, more rain falls upvalley than at Hollis. For the period of record, the Maybeso bog location received about 20 percent and the upper Maybeso location about 26 percent more summer rainfall than was recorded at Hollis. The fire weather station and Hollis received similar amounts of rainfall.

Figure 7 compares the rainfall catch at Maybeso bog with coincident gage catch at Hollis for 62 storms. Distribution of points about the 1:1 line (denoting equal rainfall distribution) suggests that rainfall within the watershed varies greatly between storms even though, on the average, more rain falls upvalley.

Table 2—*Average monthly climatic data for Hollis, Alaska, 1952-64*

Month	Precipitation	Temperature	Potential evapo-transpiration[1]
	Inches	Degrees F.	Inches
January	9.64	32.4	0
February	9.07	34.4	0.23
March	6.90	36.2	.61
April	7.59	40.7	1.38
May	4.53	48.0	2.79
June	4.27	54.0	3.67
July	3.30	58.5	4.11
August	5.16	58.0	3.75
September	7.95	52.1	2.54
October	18.69	36.9	.46
November	13.01	36.9	.46
December	13.47	34.4	.21
Annual	103.58	44.2	20.21

[1] Thornthwaite and Mather (1957).

Table 3.—*Total monthly rainfall at four locations in the Maybeso Experimental Forest, Prince of Wales Island, Alaska, 1953-61*

Date	Hollis (Cat Island)	Fire weather	Maybeso bog	Upper Maybeso
	Inches			
1953:				
June	1.77	—	(1)	—
July	2.21	—	(1)	—
August	5.49	—	6.81	—
September	10.44	—	(1)	—
October	20.32	—	—	—
1954:				
June	2.86	—	3.09	—
July	2.95	—	3.20	—
August	.42	—	.57	—
September	5.48	—	7.09	—
October	16.17	—	19.40	—
1955:				
June	3.21	—	5.53	—
July	.91	—	.89	—
August	7.14	—	9.30	—
September	8.28	—	10.15	—
October	16.20	—	—	—
1956:				
June	2.91	—	3.46	—
July	1.73	—	2.10	—
August	9.15	—	11.03	—
September	4.53	—		—
October	15.98[2]	—	22.70[3]	—
1957:				
June	5.67	5.73	5.69	—
July	3.24	2.98	4.00	—
August	3.26	3.12	3.88	—
September	6.09	6.59	7.53	—
October	—	—	—	—
1958:				
May	6.88	6.89	8.48	10.40
June	.56	.53	.58	.45
July	2.99	2.94	3.68	3.11
August	5.77	(1)	7.31	7.87
September	7.33	(1)	8.29	9.94
October	—	—	—	—
1959:				
May	3.60	(1)	5.33	5.40
June	5.12	(1)	5.51	5.49
July	6.06	(1)	7.22	7.59
August	3.91	(1)	4.87	6.57
September	7.90	(1)	8.78	10.03
October	13.90	—	—	—
1960:				
May	4.31	4.36	4.38	5.15
June	4.73	4.47	6.73	6.70
July	3.79	3.02	3.24	5.21
August	4.93	4.83	5.45	4.81
September	7.85	8.06	8.70	12.02
October	22.31	—	24+	25.57
1961:				
May	2.87	2.73	—	3.42
June	4.03	3.86	—	6.30
July	2.67	2.69	—	3.02
August	5.32	5.53	—	7.41
September	8.65	9.09	—	10.29
October	32.26[4]	—	—	21.30[5]

[1] Data incomplete.
[2] Total rainfall between October 1 and 25, 1956 = 14.04 inches.
[3] Total rainfall for the period September 1 to October 25, 1956.
[4] Total rainfall between October 1 and 16, 1961 = 21.16 inches.
[5] Total rainfall for the period October 1 to 16, 1961.

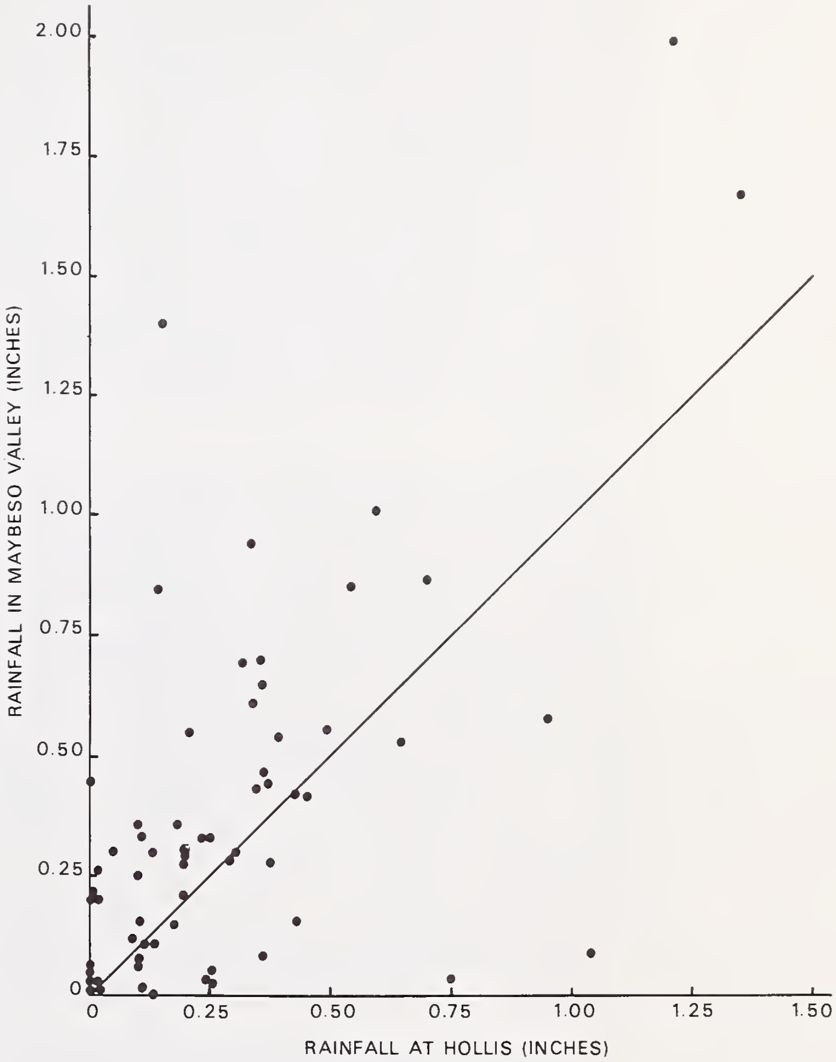

Figure 7 — *Comparison of rainfall at the Maybeso bog station with coincident rainfall at Hollis, Alaska, weather station during the summer of 1953. The 1:1 line denotes equal rainfall distribution.*

RESULTS

STREAMFLOW

Daily flows from the gaged watersheds have been published by the U.S. Geological Survey (1965). Annual precipitation at Hollis and flow data for the study streams are summarized in table 4. These summaries also show that watershed precipitation was greater than sea level precipitation recorded at Hollis, a situation characteristic of hydrologic data from southeast Alaska (Federal Power Commission and U.S.D.A. Forest Service 1947) and more recently observed near Hollis by Walkotten and Patric (1967).

Figure 8 shows the highest, average, and lowest streamflows recorded for the study streams. Snowmelt caused high flows in April and May; those in October were caused by heavy rain. Declining peak and average streamflows in November reflect reduced precipitation. Frequent rains and rapid snowmelt probably caused the high flows in December and January. These streams have low midsummer flows, typical of other streams of the region that are not glacially fed. Very low summer flows in Indian Creek may be related to the high proportion of bog soils in its headwaters.

Double mass plotting (Searcy and Hardison 1960) of water yield (fig. 9) indicates no evident increase of streamflow following clearcutting.

Figure 10 compares rainfall at Hollis with associated increases in the discharge of Harris River, before and during clearcutting. Covariance analysis of data before vs. during clearcutting indicated no significant influence of this treatment on stormflow regimen. A small nonsignificant decrease in peak flows during clearcutting, as shown in figure 10, can be attributed to one very high discharge value before clearcutting.

Table 4—*Annual precipitation and runoff at Hollis, Alaska, 1950-64*

Annual precipitation (year and inches)		Runoff		
		Maybeso Creek	Harris River	Indian Creek
		Area-inches [1]		
1950	(2)	110.11	101.48	101.0
1951	(2)	92.93	95.31	96.42
1952	81.72	132.84	118.98	126.87
1953	(2)	141.76	126.31	153.08
1954	84.45[3]	131.89	119.54	118.17
1955	(2)	114.77	113.30	133.87
1956	102.73	133.32	119.10	139.02
1957	72.51	82.57	81.35	86.30
1958	100.58	124.59	129.50	141.32
1959	117.61	149.86	146.50	145.81
1960	106.74	132.75	134.99	167.04
1961	118.05	113.28	136.86	141.91
1962	101.01	133.37	126.23	161.37
1963	(2)	(2)	128.38	139.58
1964	(2)	—	—	—

[1] Depth to which the watershed area would be covered if all the runoff for a given year were uniformly distributed on it.

[2] Incomplete data.

[3] December missing.

WATER QUALITY

Suspended Sediment

Figure 11 compares sediment in water samples obtained from Harris River before, during, and after clearcutting. The basic data (table 5) were transformed to logarithms, and this transformation was fairly successful in equalizing variances about regression.

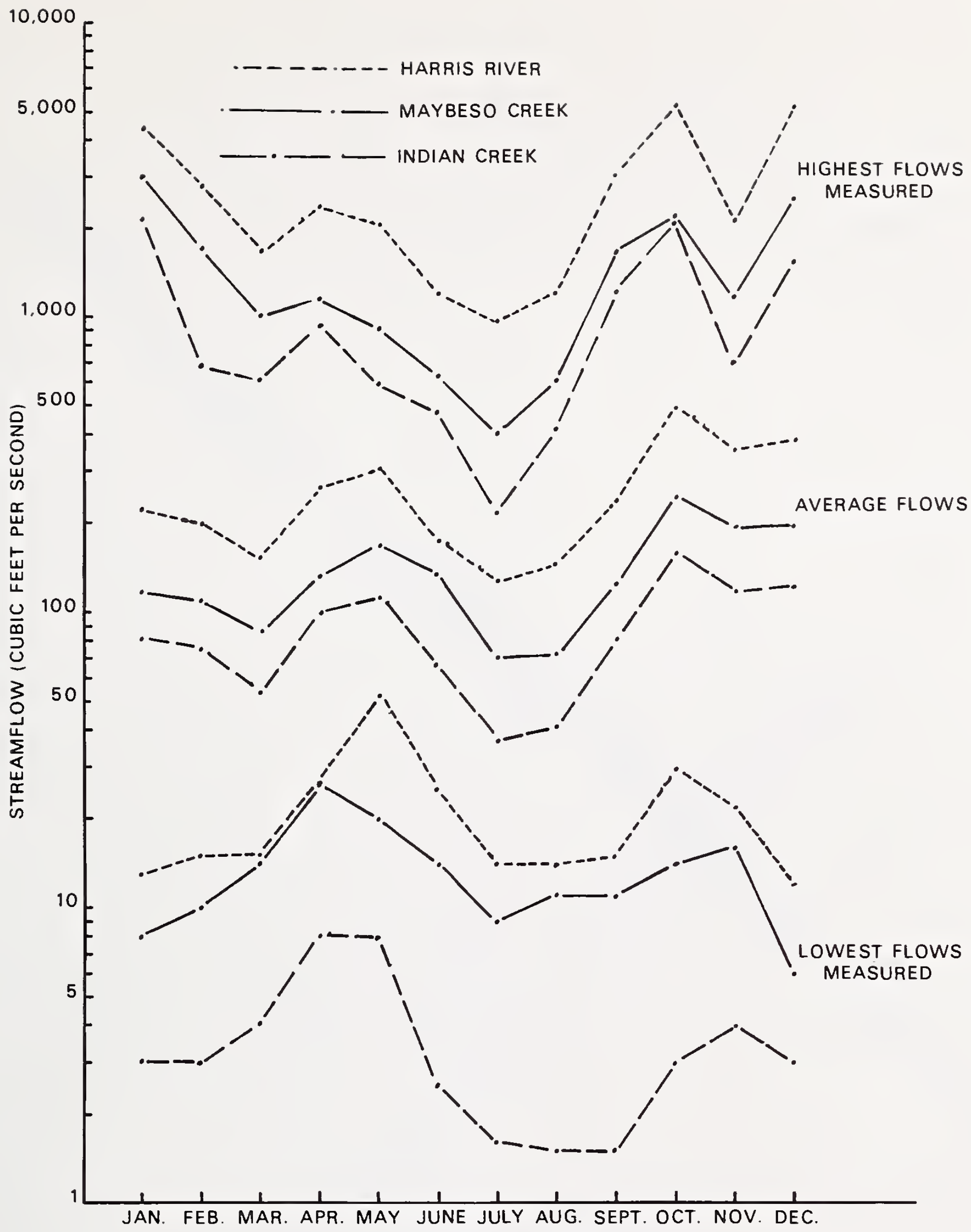

Figure 8 — *Monthly average flow of three gaged streams near Hollis, Alaska, 1949-64.*

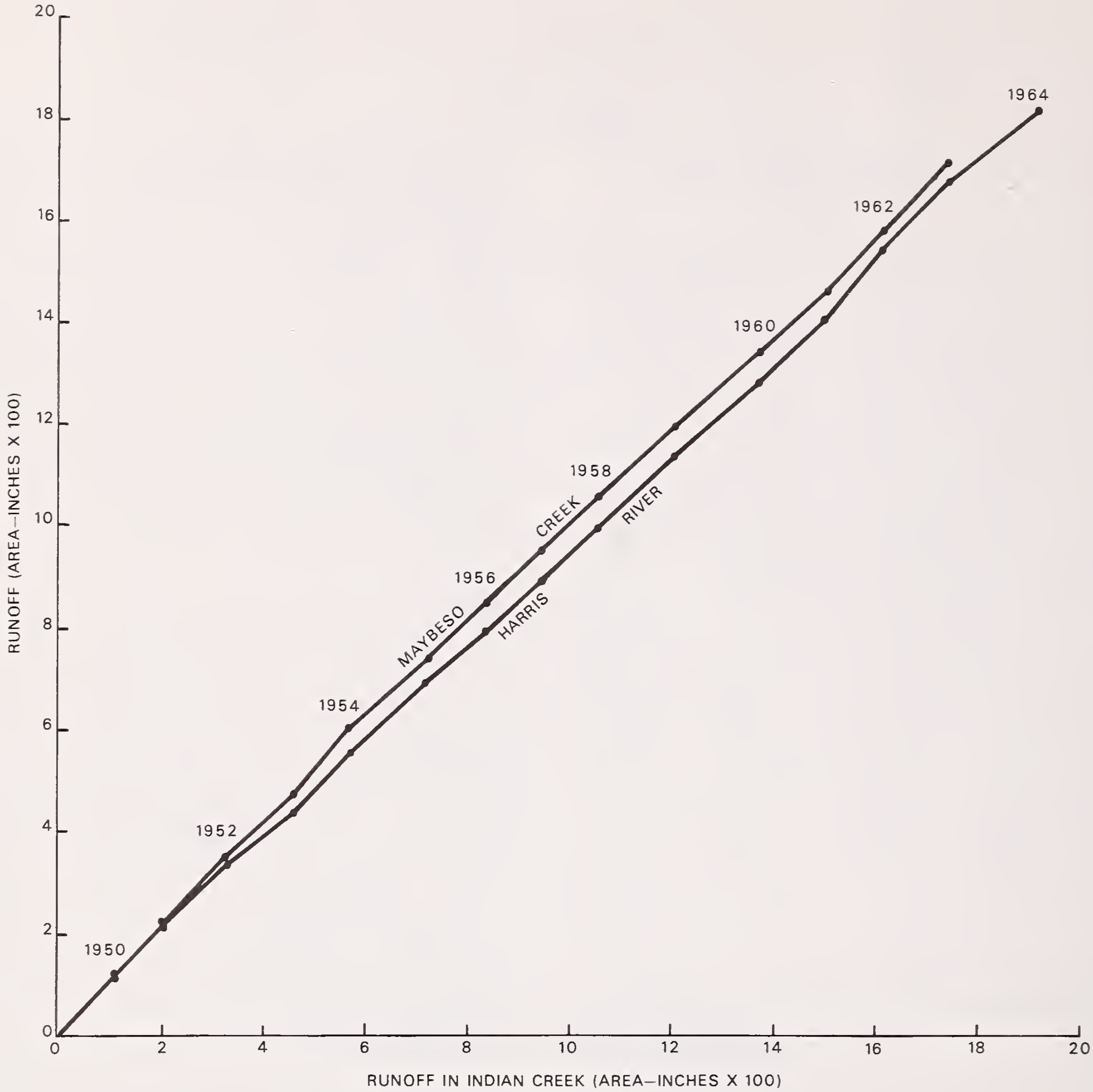

Figure 9 — *Double mass curves of runoff from Harris River and Maybeso Creek vs. Indian Creek, Prince of Wales Island, Alaska, show no departures from a linear relationship that can be attributed to clearcutting.*

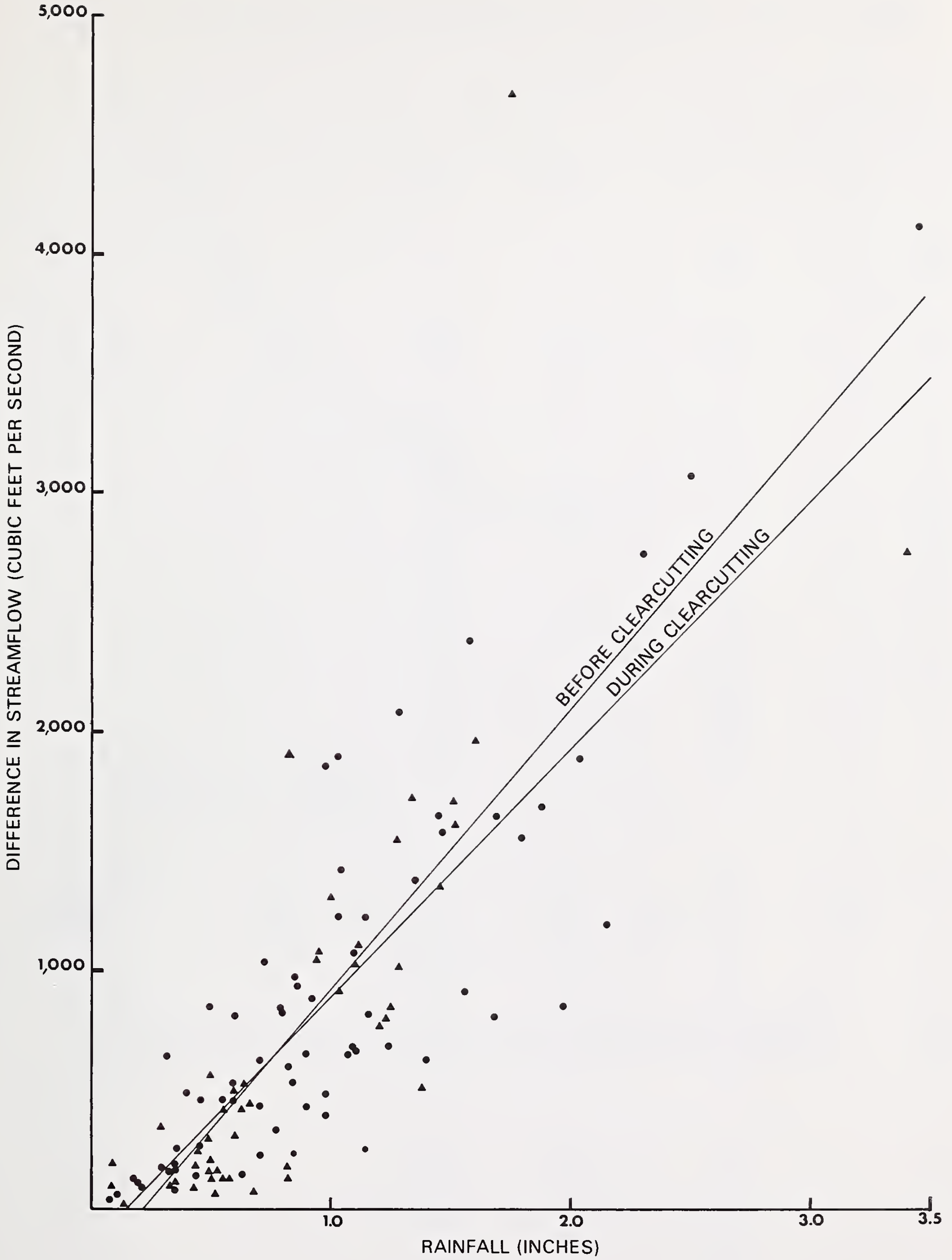

Figure 10 — *Stream discharge response to rainfall in Harris River, Prince of Wales Island, Alaska, before and during clearcutting.*

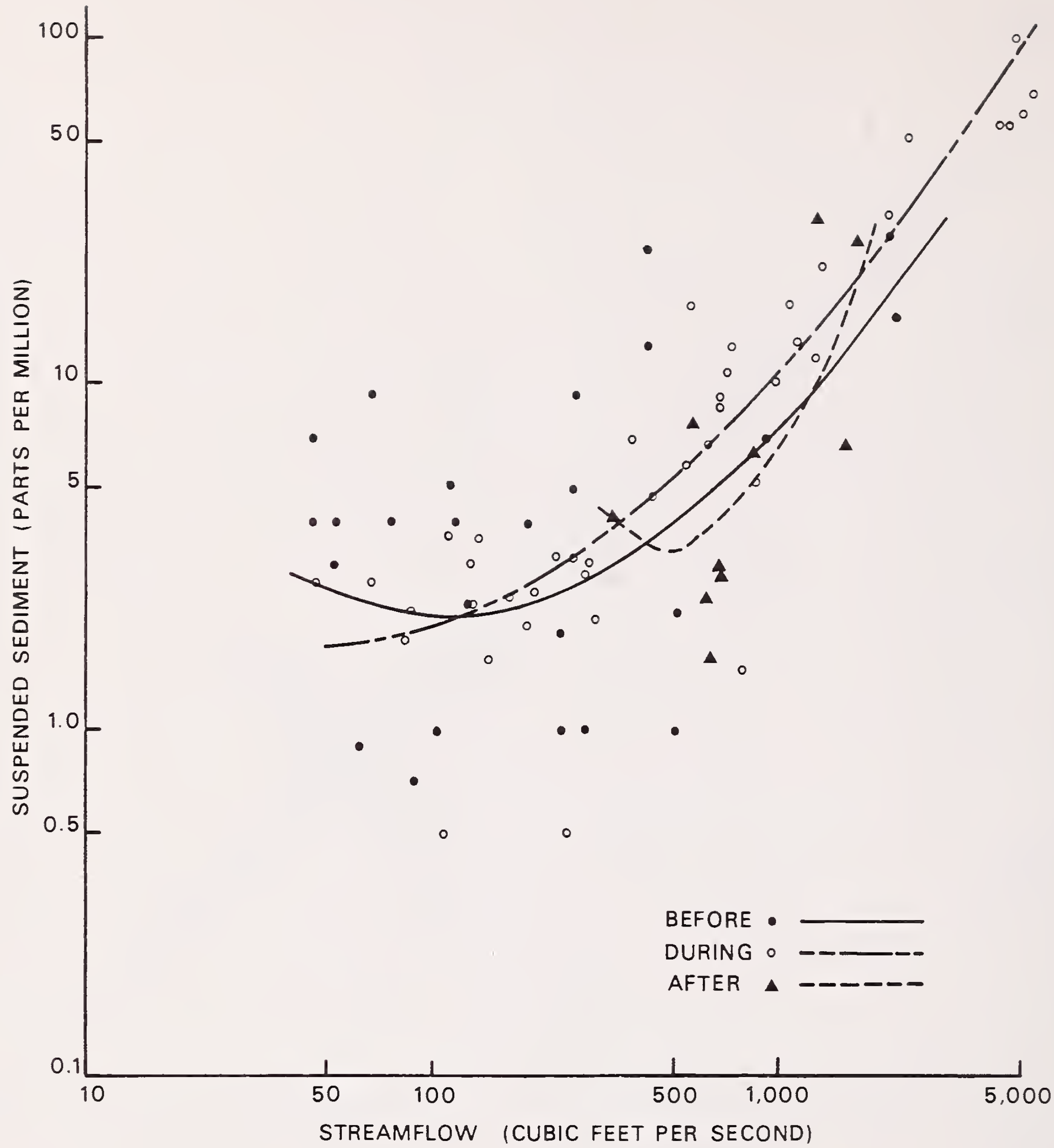

Figure 11 — *Suspended sediment in Harris River, Prince of Wales Island, Alaska, before, during, and after clearcutting.*

Table 5—*Water level, discharge, and suspended sediment measurements; Harris River, Prince of Wales Island, Alaska, 1955-63*

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	P.p.m.		
1955:						
June 9		—	—	1.0	0	1.0
August 12		—	—	1.0	0	1.0
1956:						
May 22		2.97	548	1.0	0	1.0
June 19		2.19	278	1.0	0	1.0
August 20		3.70	905	7.0	4.0	3.0
1957:[1]						
—		1.00	45	4.0	0	4.0
—		1.00	45	7.0	—	—
—		1.00	45	7.0	—	—
—		2.01	232	1.0	0	1.0
—		1.38	103	1.0	—	—
—		1.83	189	4.0	1.0	3.0
—		1.52	128	3.0	0	3.0
—		1.05	52	3.0	0	3.0
—		1.05	52	4.0	—	—
—		1.22	76	4.0	—	—
—		1.22	76	4.0	—	—
—		1.46	117	4.0	—	—
—		2.61	414	13.0	7.0	6.0
—		2.61	414	25.0	17.0	8.0
—		1.48	120	5.0	—	—
—		2.08	250	5.0	1.0	4.0
November 13		2.00	230	1.9	—	—
December 27		1.10	58	0	0	0
1958:						
January 8		1.90	205	—	—	—
February 24		1.70	161	0	0	0
May 13		5.35	2,115	16.0	0	16.0
June 12		1.08	55	0	0	0
July 22		1.12	61	.9	0	.9
July 27		1.30	89	.7	—	—
July 31		2.10	255	9.3	3.3	6.0
August 7		2.29	307	0	0	0
August 13		1.15	66	0	0	0
August 13		1.15	66	9.3	1.3	8.0
August 20		2.85	500	2.2	0	2.2
September 17		1.50	124	2.3	—	—
1959:						
May 27		2.10	255	3.1	—	—
June 9		2.07	248	2.0	—	—
June 29		1.57	137	3.6	—	—
July 14		2.99	556	17.0	—	—
July 20		2.04	240	4.4	—	—
July 26		1.53	129	2.3	—	—
August 20		1.28	86	2.2	—	—
September 8		3.43	785	1.5	—	—
September 11		3.10	605	6.8	—	—
September 24		1.83	189	2.0	—	—
December 4		3.60	850	5.2	3.3	1.9
1960:						
July 1	1000	1.61	144	1.6	.1	1.5
July 11	1115	1.73	167	2.4	1.0	1.4
July 12		2.25	295	2.1	1.2	.9
July 18	1620	1.87	198	2.5	.7	1.8
July 25		1.41	108	.5	0	.5

See footnote at end of table.

Table 5—*Water level, discharge, and suspended sediment measurements; Harris River, Prince of Wales Island, Alaska, 1955-63*—Continued

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	P.p.m.		
1960 (cont.):						
August 1		1.15	66	2.7	.1	2.6
August 8		1.02	48	2.7	0	2.7
August 15		1.26	83	1.8	0	1.8
August 22	1000	—	—	.6	0	.6
August 29	1000	—	—	2.7	.2	2.5
September 6	0935	—	—	2.0	.7	1.3
September 12	1530	1.42	110	3.7	3.1	.6
September 22		2.94	536	6.0	2.8	3.2
September 22	0800	3.37	730	13.0	6.5	6.5
September 22	0845	3.25	672	8.8	6.5	2.3
September 23		3.26	677	8.6	7.3	1.3
September 26		2.05	242	2.0	.4	1.6
October 3		2.05	242	.5	0	.5
October 5		4.05	1,110	13.5	6.8	6.7
October 5		4.35	1,315	22.1	12.1	10.0
October 6		3.80	960	10.2	6.6	3.6
October 6		4.00	1,080	17.2	5.3	11.9
October 6		4.31	1,287	12.1	7.3	4.8
October 9		5.26	2,034	31.9	19.3	12.6
October 10		5.58	2,322	53.1	36.3	16.8
October 17	1030	1.99	228	3.2	.2	3.0
October 24		2.17	272	2.8	1.2	1.6
October 27		3.27	682	9.4	2.4	7.0
October 27		3.34	715	11.0	5.3	5.7
1961:						
August 25		2.20	280	3.1	1.0	2.1
August 28		2.68	438	4.8	3.9	.9
August 30		2.47	364	7.0	3.3	3.7
September 17		3.39	740	13.0	5.9	7.1
October 2		6.82	3,602	148.7	110.7	38.0
October 3		5.30	2,070	27.2	18.7	8.5
October 14	1020	8.30	5,300	70.9	54.5	16.4
October 14	1055	8.00	4,940	61.4	47.2	14.2
October 14	1110	7.90	4,820	101.5	84.8	16.7
October 14	1125	7.70	4,580	58.3	42.6	15.7
October 14	1220	7.45	4,280	58.7	39.9	18.8
1962:						
September 23		4.78	1,634	26.5	18.3	8.2
October 6		3.57	834	6.3	.3	6.0
October 16		3.10	605	2.4	.9	1.5
1963:						
September 24		4.30	1,280	30.1	—	—
October 10		2.31	313	4.2	2.3	1.9
October 12		3.16	632	1.6	.3	1.3
October 12		3.27	682	2.8	.9	1.9
October 14		3.00	560	7.8	2.8	5.0
October 19		4.65	1,530	6.8	3.5	3.3
October 28		3.22	659	3.0	.1	2.9

[1] Specific dates up to November not available for 1957.

Covariance analysis was used to test the hypothesis that regression coefficients and adjusted means were not changed by clearcutting. The covariance analysis forced us to choose a single equation form; a quadratic form was chosen since one of the three relationships was quadratic. Graphical solutions to the three quadratic equations are shown in figure 11. The drastic curvature at the lower end of the "after logging" curve is at the limit of the actual data.

Two covariance tests were made: the first with all three groups of data (before, during, and after), and the second for the two groups before and after. There was no evidence in either test of a difference between regression coefficients or adjusted means. It appears, therefore--based upon this limited sample--that logging did not significantly affect the relationship between suspended sediment and streamflow in Harris River.

Samples from Maybeso Creek (table 6), though fewer in number, indicated lower suspended sediment levels than in Harris River (table 5). It is evident that suspended sediment in all of these streams has remained at low levels throughout the period of record (see also table 7).

Suspended sediment was sampled in Harris River while logs were being yarded across the streambed[8]. Water samples from one-fourth mile above this operation averaged 3.7 p.p.m. suspended sediment; samples obtained one-half mile downstream averaged 9.7 p.p.m.

Stream Temperature

Stream temperature was highly correlated with air temperature and time of year. As shown in the comparison of monthly averages (fig. 12), streams warmed more slowly in the spring and cooled more slowly in the fall than did the air. Average air temperature was highest in July, and average stream temperature was highest in August.

Temperature differences between streams also were apparent. Indian Creek, the smallest stream, tended to be colder than the other study streams in springtime but responded more quickly to increasing air temperature and was warmer than the others from June to September. This character is probably due to differences between the watersheds (table 1). Temperatures of Maybeso Creek and Harris River were similar throughout the year.

A 10-year record for Indian Creek, in the unlogged watershed, showed considerable variation in year-to-year average monthly stream temperatures (fig. 13). Temperatures of Harris River and Maybeso Creek also showed similar differences before logging. Tables 8, 9, and 10 give the complete summary of maximum, average, and minium monthly temperatures for all three study streams. Table 11 (which was prepared from the average monthly stream temperatures presented in tables 8, 9, and 10) shows the year-to-year variation in stream temperature differences.

Maximum Stream Temperatures

Daily temperatures of all streams often exceeded 60° F. during the months of June, July, and August (tables 5, 12, 13, 14, 15, and 16). Average monthly temperatures exceeded 50° F. only during the months of June to September. An average monthly stream temperature of 60° F. or greater was recorded only during the exceptionally warm month of July 1958.

Stream Temperature Changes Due to Logging

Increases in stream temperatures were detected on both logged watersheds after certain operations (table 11). Winter stream temperatures at the gaging sites showed little, if any, change.

[8] Yarding across the stream was observed once in Harris River and once in Maybeso Creek.

Table 6—*Water level, discharge, and suspended sediment measurements; Maybeso Creek, Prince of Wales Island, Alaska, 1957-63*

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	P.p.m.		
1957:[1]						
—		1.56	85	2.0	0	2.0
—		1.40	63	3.0	0	3.0
—		1.43	67	2.0	—	—
—		1.30	51	4.0	—	—
—		.95	20	2.0	0	2.0
1958:						
January 30		1.57	86	0	0	0
May 9		1.86	132	0	0	0
May 14		4.66	1,100	8.9	0.5	8.4
June 4		1.57	86	2.4	—	—
June 10		1.21	41	.3	—	—
July 24		.90	17	1.1	0	1.1
July 31		1.38	61	2.4	—	—
August 5		2.93	360	6.4	1.0	5.4
August 14		1.45	69	.6	0	.6
September 15		1.00	23	0	0	0
1959:[1]						
—		2.30	219	2.5	—	—
—		1.64	196	0	—	—
May 18		1.86	133	1.8	0	1.8
May 27		2.16	189	2.2	—	—
June 4		3.18	454	6.8	4.0	2.8
June 30		1.40	63	1.4	—	—
July 15		1.95	149	2.8	—	—
July 20		1.64	96	2.4	—	—
July 26		1.64	96	3.0	.3	2.7
August 3		1.95	149	2.4	—	—
August 24		1.19	39	5.2	0	5.2
September 8		1.27	48	1.4	—	—
September 18		1.25	46	3.1	—	—
September 24		1.58	87	1.7	—	—
September 25		3.98	737	24.0	16.1	7.9
1960:						
July 1	0830	1.65	99	1.1	.1	1.0
July 11	1010	1.52	79	.4	0	.4
July 12	0850	2.00	160	2.6	1.0	1.6
July 18	1705	1.58	87	2.3	1.4	.9
July 26		1.30	51	.5	0	.5
August 1		1.18	39	1.7	.6	1.1
August 15		1.33	55	18.5	10.5	8.0
August 18	2200	1.95	149	3.9	.8	3.1
August 22		1.30	51	5.6	3.7	1.9
August 29	0935	1.60	90	2.1	.3	1.8
September 12	1500	1.32	53	1.8	1.1	.7
September 19	1130	1.51	53	5.0	2.6	2.4
September 26	0915	1.71	107	2.1	.1	2.0
October 3		1.72	107	.8	.2	.6
October 11	1630	2.17	190	7.0	2.5	4.5
October 17	0930	1.76	117	4.0	1.4	2.6
October 24	1035	1.88	137	1.0	0	1.0
1961:						
August 30		2.47	258	6.9	3.2	3.7
1962:						
September 10		1.63	95	1.7	0	1.7
September 10	1240	1.60	91	3.2	.8	2.4
September 12	1500	—	—	2.8	.2	2.6
September 12	1505	—	—	1.2	0	1.2
September 12	1810	—	—	4.6	4.0	.6
September 16	1045	—	—	10.0	8.2	1.8
September 23	1830	—	—	38.6	33.2	5.4
October 19		3.15	435	7.9	6.3	1.6

See footnote at end of table.

Table 6—*Water level, discharge, and suspended sediment measurements; Maybeso Creek, Prince of Wales Island, Alaska, 1957-63* —Continued

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.		P.p.m.	
1963:						
September 24	1015	4.50	940	46.6	34.7	11.9
October 10	1530	2.77	332	4.6	1.2	3.4
October 12	1000	2.62	292	3.6	2.5	1.1
October 12	1400	3.10	493	5.5	2.8	2.7
October 12	1535	—	—	5.1	2.6	2.5
October 12	1705	2.54	274	1.9	.6	1.3
October 14		4.35	880	11.0	2.6	8.4
October 19	1440	3.35	510	7.4	5.9	1.5
October 27	1445	2.74	323	2.0	1.9	.1
October 28	1130	2.39	240	1.6	.5	1.1

[1] Specific dates not available for 1957 and part of 1959.

Table 7—*Water level, discharge, and suspended sediment measursements; Indian Creek, Prince of Wales Island, Alaska, 1955-62*

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.		P.p.m.	
1955:[1]						
—		—	—	1.0	0	1.0
—		—	—	1.0	0	1.0
—		—	—	11.00	7.0	4.0
1956:[1]						
—		1.96	142	1.0	0	1.0
—		1.70	125	1.0	0	1.0
—		1.28	59	1.0	0	1.0
1957:[1]						
—		.90	20	5.0	0	5.0
—		.98	27	3.0	—	—
—		1.06	35	4.0	0	4.0
—		1.82	146	3.0	0	3.0
—		1.00	29	3.0	—	—
—		.72	9	2.0	—	—
November 3		.90	20	3.6	—	—
December 29		.50	3	1.4	—	1.4
1958:						
January 8		1.10	39	.7	—	—
February 24		1.20	50	.7	—	—
May 14		2.86	420	2.5	0	2.5
June 12		.54	4	0	0	0
July 22		.94	24	1.2	—	—
July 31		1.45	84	0	0	0
August 7		1.61	110	0	0	0
August 13		1.00	29	.8	—	—
August 20		1.88	156	0	0	0
August 20		1.95	170	1.7	0	1.7
September 17		1.16	46	0	0	0

See footnote at end of table.

Table 7—*Water level, discharge, and suspended sediment measursements: Indian Creek, Prince of Wales Island, Alaska, 1955-62* —Continued

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	P.p.m.		
1959:						
June 8		1.22	52	3.5	—	—
June 8		1.12	41	.6	—	—
June 29		.72	9	0	0	0
July 14		2.18	216	1.9	.3	1.6
July 20		1.23	54	1.4	—	—
July 29		.96	25	1.9	—	—
August 20		.90	20	3.5	—	—
September 11		2.64	332	5.3	1.5	3.8
September 18		.96	25	2.7	—	—
September 24		1.30	62	2.4	—	—
December 4		3.00	490	2.6	.2	2.4
1960:						
July 1	1345	.98	27	0	0	0
July 11	1100	1.00	29	.7	.4	.3
July 12	1220	1.52	95	3.2	.9	2.3
July 18	1430	1.08	37	2.7	1.8	.9
July 25		.94	24	.9	0	.9
August 1		.74	10	4.0	0	4.0
August 8	1230	.65	6	5.6	2.6	3.0
August 15		2.20	220	4.1	1.5	2.6
August 22		.93	23	.8	0	.8
August 29	1100	1.16	57	2.4	.9	1.5
September 6	1025	1.43	81	5.2	.8	4.4
September 12	1610	.91	21	3.4	1.7	1.7
September 19	0940	1.29	61	3.5	.2	3.3
September 22	0800	1.77	137	2.3	0	2.3
September 22	1030	1.65	116	2.7	.2	2.5
September 23		1.67	120	.6	.1	.5
September 26	1015	1.18	48	2.1	.9	1.2
October 3		1.35	69	.8	.2	.6
October 5		2.99	485	6.3	1.4	4.9
October 10		3.30	690	10.0	3.6	6.4
October 10	1025	3.46	802	12.5	5.8	6.7
October 17	1100	1.27	58	6.8	3.8	3.0
October 24	1000	1.31	63	3.1	1.3	1.8
1961:						
August 28	0900	2.08	215	6.4	4.9	1.5
August 30		1.93	175	2.0	.6	1.4
September 7		6.60	6,460	57.6	20.0	37.6
September 17	1300	2.50	350	7.4	4.8	2.6
October 1		2.26	265	1.7	.2	1.5
October 2		4.67	1,800	42.8	20.0	22.8
October 3	1015	2.76	450	7.1	2.0	5.1
1962:						
September 12		1.67	120	5.3	1.4	3.9
October 6	1300	2.20	220	3.8	.9	2.9

[1] Specific dates for 1955 to November 3, 1957, not available.

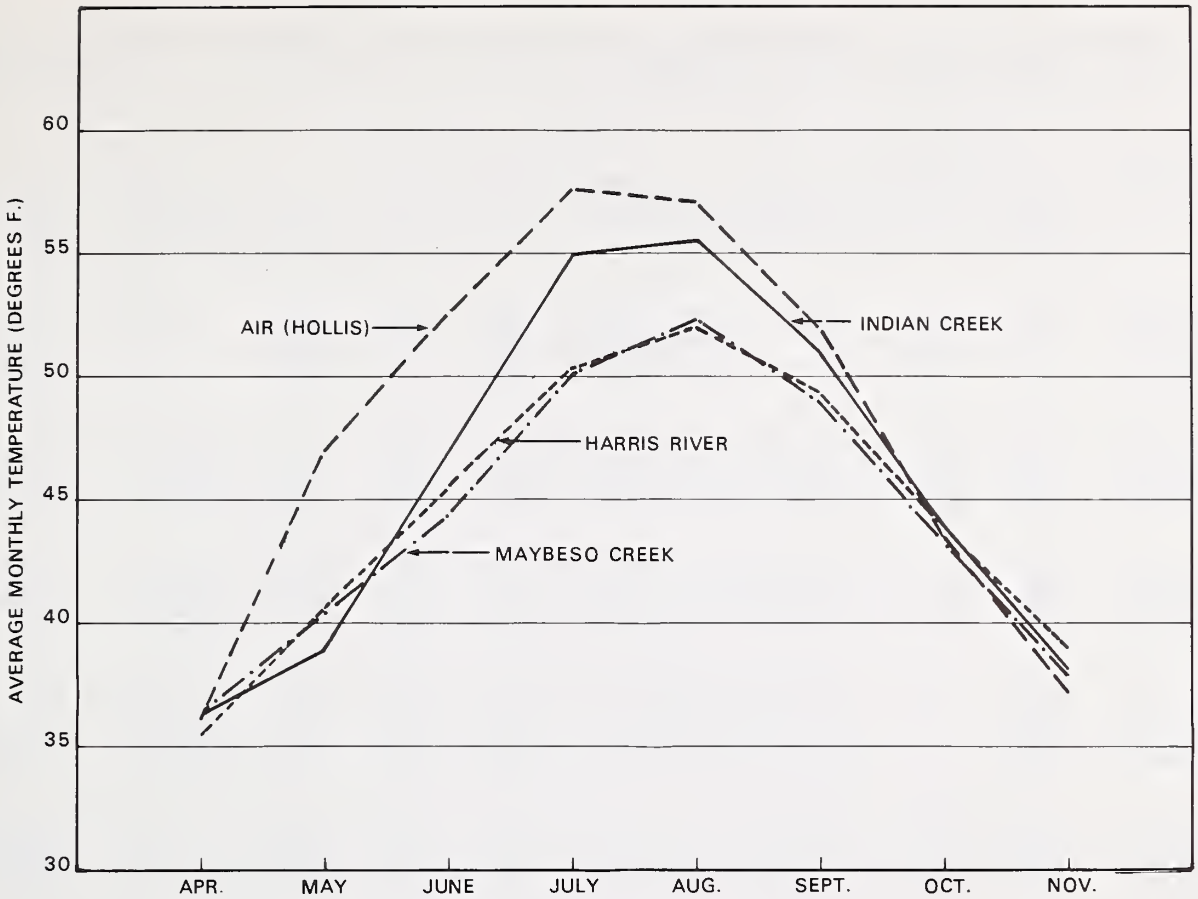

Figure 12 — *Average monthly air and stream temperatures in the study area, Prince of Wales Island, Alaska, 1953-56.*

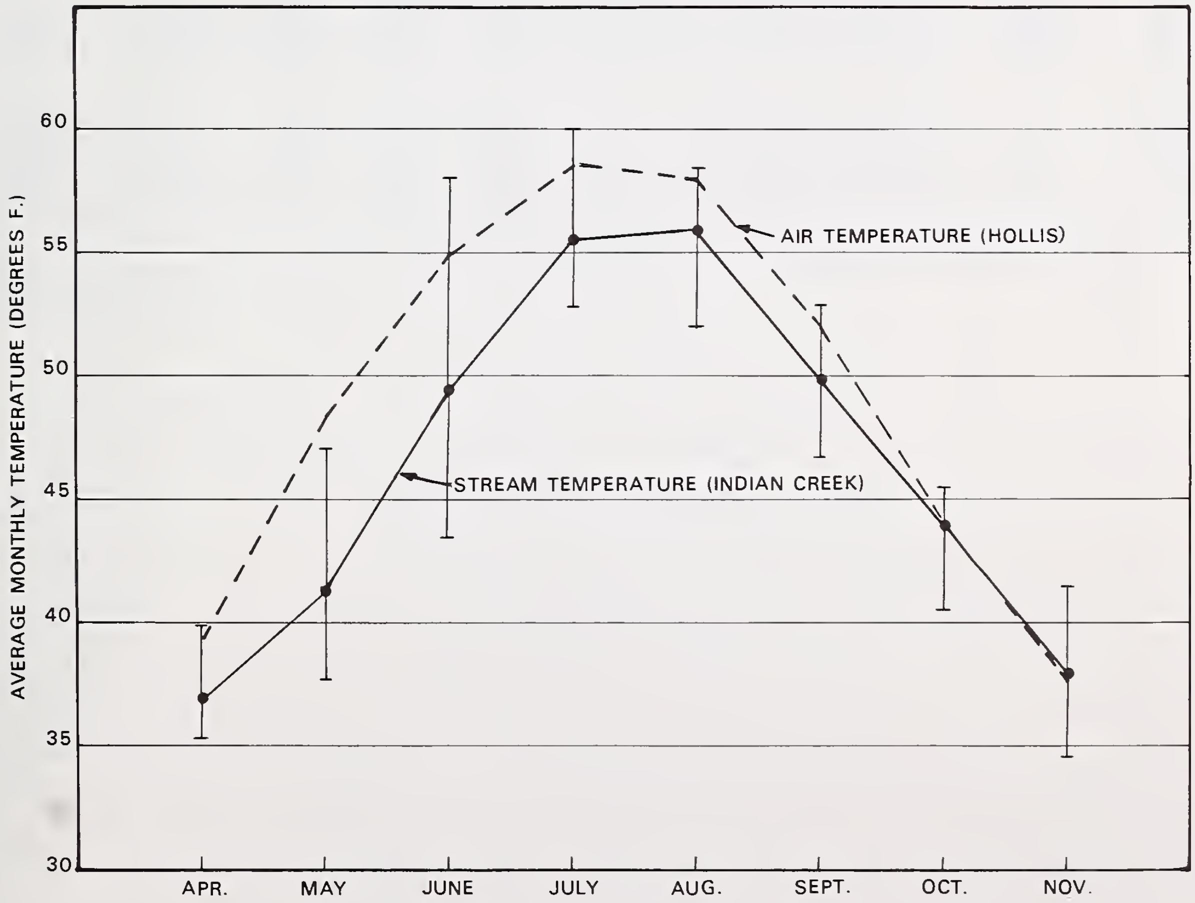

Figure 13 — *Average monthly air temperature at Hollis (dashed line) and stream temperature of Indian Creek (solid line), Prince of Wales Island, Alaska, 1953-62. Vertical lines denote range of average monthly stream temperature over the 10-year period.*

Table 8—*Maximum, average, and minimum monthly temperatures (degrees F.) of Maybeso Creek, Prince of Wales Island, Alaska, 1950-62*[1]

Month	Before logging			During logging					After logging				
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
April:													
Maximum	—	—	—	—	41.0	41.0	40.0	43.0	47.0	—	42.0	—	41.0
Average	—	—	—	—	36.5	36.6	36.2	37.5	40.6	—	37.6	—	37.5
Minimum	—	—	—	—	34.0	33.0	34.0	33.0	37.0	—	35.0	—	35.0
May:													
Maximum	43.0	47.0	—	46.0	44.0	44.0	43.0	51.0	54.0	47.0	45.0	—	49.0
Average	37.8	38.4	—	41.4	40.7	40.2	39.1	42.8	45.3	43.0	39.5	—	43.4
Minimum	34.0	32.0	—	39.0	37.0	37.0	37.0	39.0	41.0	38.0	37.0	—	39.0
June:													
Maximum	54.0	54.0	—	52.0	47.0	46.0	47.0	54.0	65.0	56.0	55.0	—	57.0
Average	44.3	44.5	—	46.1	45.2	43.0	42.8	48.6	58.1	46.8	46.0	—	46.7
Minimum	35.0	38.0	—	42.0	43.0	40.0	40.0	45.0	52.0	42.0	40.0	—	43.0
July:													
Maximum	55.0	64.0	—	57.0	52.0	54.0	59.0	62.0	69.0	57.0	65.0	—	62.0
Average	48.9	54.4	—	52.4	48.2	49.2	50.8	53.2	62.3	53.0	52.9	—	52.8
Minimum	44.0	48.0	—	47.0	45.0	44.0	44.0	48.0	57.0	49.0	48.0	—	47.0
August:													
Maximum	54.0	60.0	—	58.0	56.0	54.0	57.0	64.0	60.0	60.0	67.0	66.0	—
Average	48.6	54.0	—	53.3	53.4	50.2	52.3	56.9	56.4	54.3	55.1	58.1	—
Minimum	43.0	49.0	—	51.0	51.0	49.0	50.0	52.0	52.0	51.0	47.0	53.0	—
September:													
Maximum	53.0	56.0	51.0	53.0	55.0	49.0	54.0	60.0	55.0	52.0	55.0	58.0	—
Average	48.0	49.3	49.8	49.7	50.4	47.6	48.3	53.3	48.9	50.1	49.6	52.2	—
Minimum	39.0	38.0	48.0	46.0	45.0	45.0	43.0	49.0	44.0	48.0	47.0	45.0	—
October:													
Maximum	45.0	—	50.0	48.0	45.0	47.0	45.0	53.0	47.0	50.0	48.0	52.0	—
Average	42.3	—	46.9	45.6	42.9	43.6	41.3	44.8	43.3	46.0	45.1	46.4	—
Minimum	38.0	—	44.0	43.0	39.0	41.0	36.0	41.0	40.0	43.0	42.0	43.0	—
November:													
Maximum	—	—	45.0	43.0	—	42.0	38.0	45.0	44.0	—	44.0	42.0	—
Average	—	—	41.6	40.9	—	36.0	36.6	40.6	39.0	—	40.3	40.0	—
Minimum	—	—	39.0	38.0	—	34.0	36.0	38.0	36.0	—	37.0	35.0	—

[1] Maximum and minimum temperatures recorded to nearest degree.

Table 9 — *Maximum, average, and minimum monthly temperatures (degrees F.) of Harris River, Prince of Wales Island, Alaska,1953-62*[1]

Month	Before logging						During logging			After logging,
	1953[2]	1954	1955	1956	1957	1958	1959	1960	1961	1962
April:										
Maximum	—	40.0	—	40.0	41.0	48.0	43.0	46.0	49.0	46.0
Average	—	35.8	—	35.4	36.8	40.2	39.1	40.2	41.4	40.7
Minimum	—	33.0	—	33.0	33.0	37.0	35.0	36.0	37.0	38.0
May:										
Maximum	48.0	45.0	46.0	46.0	51.0	57.0	48.0	52.0	54.0	52.0
Average	42.8	40.0	40.3	39.6	42.5	45.5	42.8	45.0	47.5	46.1
Minimum	40.0	36.0	37.0	35.0	38.0	40.0	39.0	42.0	42.0	40.0
June:										
Maximum	57.0	49.0	49.0	50.0	54.0	67.0	56.0	—	59.0	58.0
Average	48.2	45.4	43.4	45.0	48.3	57.1	47.4	—	51.3	48.5
Minimum	42.0	42.0	40.0	41.0	45.0	51.0	43.0	—	48.0	44.0
July:										
Maximum	62.0	54.0	55.0	62.0	63.0	67.0	59.0	—	67.0	67.0
Average	57.8	49.6	48.2	53.0	51.8	60.5	51.6	—	56.6	56.4
Minimum	47.0	46.0	43.0	46.0	47.0	50.0	47.0	—	51.0	48.0
August:										
Maximum	—	49.0	51.0	59.0	62.0	57.0	57.0	—	67.0	—
Average	—	55.0	48.7	52.3	56.1	53.7	52.4	—	58.2	—
Minimum	—	51.0	47.0	49.0	52.0	50.0	49.0	—	53.0	—
September:										
Maximum	53.0	58.0	50.0	53.0	54.0	57.0	52.0	55.0	57.0	—
Average	50.0	51.1	47.3	49.2	49.9	49.7	50.2	50.6	51.5	—
Minimum	46.0	45.0	43.0	43.0	45.0	46.0	48.0	48.0	45.0	—
October:										
Maximum	48.0	47.0	47.0	46.0	50.0	50.0	51.0	50.0	52.0	—
Average	46.4	43.5	42.9	41.9	42.8	45.0	46.1	47.9	46.1	—
Minimum	43.0	39.0	40.0	36.0	38.0	41.0	40.0	45.0	41.0	—
November:										
Maximum	44.0	44.0	41.0	39.0	44.0	46.0	45.0	45.0	41.0	—
Average	41.6	42.5	34.4	37.5	42.0	38.7	39.1	40.9	38.0	—
Minimum	39.0	39.0	32.0	35.0	39.0	35.0	34.0	36.0	33.0	—

[1] Maximum and minimum temperatures to nearest degree.
[2] First year of record.

Table 10—*Maximum, average, and minimum monthly temperatures (degrees F.) of the unlogged watershed of Indian Creek, Prince of Wales Island, Alaska, 1950-62*[1]

Month	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
April:													
Maximum	—	—	—	—	—	41.0	37.0	39.0	46.0	40.0	39.0	44.0	38.0
Average	—	—	—	—	—	37.0	35.4	35.5	39.8	36.7	36.2	38.8	36.5
Minimum	—	—	—	—	—	35.0	34.0	33.0	36.0	34.0	34.0	36.0	34.0
May:													
Maximum	41.0	48.0	—	—	—	44.0	43.0	54.0	58.0	48.0	44.0	51.0	45.0
Average	34.5	36.5	—	—	—	38.4	37.7	42.2	47.0	41.1	40.3	47.0	40.8
Minimum	30.0	30.0	—	—	—	36.0	36.0	37.0	41.0	37.0	37.0	43.0	37.0
June:													
Maximum	59.0	64.0	—	63.0	52.0	50.0	50.0	58.0	68.0	62.0	54.0	55.0	54.0
Average	44.4	46.8	—	51.0	47.8	43.5	45.2	51.7	58.0	50.8	48.1	51.6	49.0
Minimum	33.0	36.0	—	42.0	45.0	39.0	39.0	46.0	49.0	45.0	42.0	50.0	44.0
July:													
Maximum	62.0	64.0	—	67.0	58.0	63.0	64.0	62.0	67.0	61.0	60.0	63.0	57.0
Average	51.8	55.8	—	57.3	52.8	54.7	54.4	53.6	60.0	54.5	53.3	57.8	54.7
Minimum	45.0	49.0	—	50.0	49.0	48.0	48.0	49.0	54.0	51.0	51.0	52.0	51.0
August:													
Maximum	64.0	62.0	—	63.0	60.0	57.0	61.0	62.0	61.0	58.0	61.0	64.0	—
Average	54.4	52.8	—	57.5	56.6	52.0	54.9	57.0	55.7	53.8	54.6	58.5	—
Minimum	49.0	44.0	—	52.0	52.0	50.0	51.0	51.0	51.0	50.0	48.0	55.0	—
September:													
Maximum	56.0	58.0	54.0	59.0	57.0	54.0	54.0	57.0	56.0	53.0	53.0	54.0	—
Average	49.3	48.2	51.2	51.4	51.4	49.9	49.6	52.8	46.9	50.6	49.9	53.2	—
Minimum	39.0	36.0	49.0	45.0	43.0	45.0	42.0	46.0	42.0	48.0	48.0	48.0	—
October:													
Maximum	46.0	—	51.0	49.0	—	48.0	45.0	52.0	50.0	51.0	49.0	52.0	—
Average	42.4	—	46.9	45.6	—	42.8	40.6	43.7	44.9	44.8	45.5	45.0	—
Minimum	38.0	—	44.0	42.0	—	38.0	34.0	38.0	39.0	39.0	41.0	39.0	—
November:													
Maximum	—	—	45.0	—	—	40.0	38.0	45.0	46.0	44.0	45.0	40.0	—
Average	—	—	39.7	—	—	34.7	36.5	41.7	38.6	36.0	39.6	36.3	—
Minimum	—	—	34.0	—	—	34.0	34.0	38.0	35.0	32.0	36.0	34.0	—

1 Maximum and minimum temperatures recorded to nearest degree.

Table 11—*Average stream temperature differences (degrees F.), Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1950-62.*

MONTH	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
Maybeso Creek minus Indian Creek:													
April	—	—	—	—	—	-0.4	0.8	2.0	0.8	—	1.4	—	1.0
May	3.3	1.9	—	—	—	1.8	2.4	.6	-1.7	1.9	-.8	—	2.6
June	-.1	-2.3	—	-4.9	-2.6	-.5	-2.4	-3.1	.1	-4.0	-2.1	—	-2.3
July	-2.9	-1.4	—	-4.9	-4.6	-5.5	-3.6	-.4	2.3	-1.5	-.4	—	-1.9
August	-5.8	1.2	—	-4.2	-3.2	-1.8	-2.6	-.1	.7	.5	.5	-0.4	—
Sept.	-1.3	1.1	-1.4	-1.7	-1.0	-2.3	-1.3	.5	2.0	-.5	-.3	-1.0	—
Oct.	-.1	—	0	0	—	.8	.7	1.1	-1.6	1.2	-.4	1.4	—
Nov.	—	—	1.9	—	—	1.3	.1	-1.1	.4	—	.7	3.7	—
Maybeso Creek minus Harris River:													
April	—	—	—	—	.7	—	.8	.7	.4	—	-2.6	—	-3.2
May	—	—	—	-1.4	.7	-.1	-.5	.3	-.2	.2	-5.5	—	-2.7
June	—	—	—	-2.1	-.2	-.4	-2.2	.3	1.0	-.6	—	—	-1.8
July	—	—	—	-5.4	-1.4	1.0	-2.2	1.4	1.8	1.4	—	—	-3.6
August	—	—	—	—	-1.6	1.5	0	.8	2.7	1.9	—	-.1	—
Sept.	—	—	—	-.3	-.7	.3	-.9	3.4	-.8	-.1	-1.0	.7	—
Oct.	—	—	—	-.8	-.6	.7	-.6	2.0	-1.7	-.1	-2.8	.3	—
Nov.	—	—	—	-.7	—	1.6	-.9	-1.4	.3	—	-.6	2.0	—
Harris River minus Indian Creek:													
April	—	—	—	—	—	—	0	1.3	.4	2.4	4.0	2.6	4.2
May	—	—	—	—	—	1.9	1.9	.3	-1.5	1.7	4.7	.5	5.3
June	—	—	—	-2.8	-2.4	-.1	-.2	-3.4	-.9	-3.4	—	-.3	-.5
July	—	—	—	.5	-3.2	-6.5	-1.4	-1.8	.5	-2.9	—	-1.2	-1.7
August	—	—	—	—	-1.6	-3.3	-2.6	-.9	-2.0	-1.4	—	-.3	—
Sept.	—	—	—	-1.4	-.3	-2.6	-.4	-2.9	2.8	-.4	.7	-1.7	—
Oct.	—	—	—	.8	—	.1	1.3	-.9	.1	1.3	2.4	1.1	—
Nov.	—	—	—	—	—	-.3	1.0	.3	.1	3.1	1.3	1.7	—

Table 12—*Occurrence of stream temperaturesof 60° F. or more in Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66.*

Stream and year	Maximum stream temperature	Total time	Maximum duration	Days
	Degrees F.	Hours	Hours	Number
Maybeso Creek:				
1953	< 60	0	0	0
1954	< 60	0	0	0
1955	< 60	0	0	0
1956	< 60	0	0	0
1957	64	123	11	18
1958	69	765	187	35
1959	60	4	4	1
1960	67	128	15	13
1961[1]	66	167	44	14
1962	62	14	7	2
1963	64	198	14	25
1964	< 60	0	0	0
1965	65	367	150	28
1966	68	162	17	18
Harris River:				
1953	62	27	7	5
1954	< 60	0	0	0
1955	< 60	0	0	0
1956	62	23	6	6
1957	63	63	7	12
1958[1]	67	190	37	21
1959	< 60	0	0	0
1960[2]	—	—	—	—
1961[1]	67	322	34	29
1962	67	244	64	18
1963	65	608	134	35
1964[1]	< 60	0	0	0
1965	64	264	91	24
1966	65	155	19	17
Indian Creek:				
1953	67	312	44	27
1954	60	14	8	2
1955	63	32	12	6
1956	64	69	12	11
1957	62	95	11	13
1958	68	594	39	48
1959	64	36	7	5
1960	61	43	11	5
1961	64	447	231	30
1962	< 60	0	0	0
1963[2]	—	—	—	—
1964[2]	—	—	—	—
1965[2]	—	—	—	—
1966	65	127	16	13

[1] Instrument was not recording part of season.
[2] No data.

Table 13—*Total number of days when stream temperature was from 60° to 70° F. in Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	60	61	62	63	64	65	66	67	68	69	70
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	18	12	11	6	3	0	0	0	0	0	0
1958	35	37	32	30	27	22	19	15	11	3	0
1959	1	0	0	0	0	0	0	0	0	0	0
1960	13	8	7	6	6	5	1	1	0	0	0
1961[1]	14	12	12	10	6	3	3	0	0	0	0
1962	2	2	1	0	0	0	0	0	0	0	0
1963	25	19	11	5	2	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	28	21	19	18	13	10	1	0	0	0	0
1966	18	14	10	9	6	3	3	3	2	0	0
Harris River:											
1953	5	3	1	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	6	2	1	0	0	0	0	0	0	—	—
1957	12	6	3	1	0	0	0	0	0	—	—
1958[1]	21	13	11	8	8	4	2	1	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	29	25	20	14	9	4	2	1	0	—	—
1962	18	14	11	10	8	6	5	4	0	—	—
1963	35	26	22	14	4	1	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	24	15	14	8	3	0	0	0	0	—	—
1966	17	12	9	7	5	2	0	0	0	—	—
Indian Creek:											
1953	27	16	10	9	5	3	2	1	0	0	—
1954	2	0	0	0	0	0	0	0	0	0	—
1955	6	3	2	1	0	0	0	0	0	0	—
1956	11	4	3	2	1	0	0	0	0	0	—
1957	13	7	3	0	0	0	0	0	0	0	—
1958	48	38	29	24	22	13	13	7	1	0	—
1959	5	4	3	0	0	0	0	0	0	0	—
1960	5	1	0	0	0	0	0	0	0	0	—
1961	30	20	12	8	3	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	13	10	7	5	3	2	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Table 14—*Total number of hours when stream temperature was 60° to 70° F., in Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	60	61	62	63	64	65	66	67	68	69	70
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	48	22	28	14	12	0	0	0	0	0	0
1958	174	142	115	77	68	50	42	32	47	18	0
1959	4	0	0	0	0	0	0	0	0	0	0
1960	39	14	11	9	14	18	2	3	0	0	0
1961[1]	47	27	35	23	18	5	12	0	0	0	0
1962	4	7	3	0	0	0	0	0	0	0	0
1963	77	57	40	15	9	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	121	96	43	28	33	42	4	0	0	0	0
1966	47	32	19	24	14	5	7	9	5	0	0
Harris River:											
1953	14	11	2	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	16	6	1	0	0	0	0	0	0	—	—
1957	38	17	6	2	0	0	0	0	0	—	—
1958[1]	76	38	26	17	20	7	4	2	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	112	65	57	43	24	12	5	4	0	—	—
1962	64	54	29	28	21	18	15	15	0	—	—
1963	359	88	77	60	21	3	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	162	29	40	23	10	0	0	0	0	—	—
1966	53	36	22	20	16	8	0	0	0	—	—
Indian Creek:											
1953	119	86	44	33	13	13	2	2	0	0	—
1954	14	0	0	0	0	0	0	0	0	0	—
1955	12	7	10	3	0	0	0	0	0	0	—
1956	46	5	11	3	4	0	0	0	0	0	—
1957	49	37	9	0	0	0	0	0	0	0	—
1958	212	114	88	60	56	22	25	15	2	0	—
1959	14	12	10	0	0	0	0	0	0	0	—
1960	37	6	0	0	0	0	0	0	0	0	—
1961	186	127	71	40	23	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	37	33	22	17	12	6	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Table 15—*Number of consecutive hours when stream temperature was greater than 59° to 69° F., Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	> 59	> 60	> 61	> 62	> 63	> 64	> 65	> 66	> 67	> 68	> 69
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	11	9	8	6	5	0	0	0	0	0	0
1958	187	156	58	19	16	14	12	10	9	6	0
1959	4	0	0	0	0	0	0	0	0	0	0
1960	15	12	10	9	7	6	5	3	0	0	0
1961[1]	44	16	12	9	8	7	4	0	0	0	0
1962	7	6	3	0	0	0	0	0	0	0	0
1963	14	11	9	7	5	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	150	37	15	12	9	6	0	0	0	0	0
1966	17	16	12	11	10	9	7	5	3	0	0
Harris River:											
1953	7	6	2	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	6	5	1	0	0	0	0	0	0	—	—
1957	7	5	4	2	0	0	0	0	0	—	—
1958[1]	37	14	11	9	7	4	3	2	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	34	17	13	11	9	8	6	4	0	—	—
1962	64	37	19	15	12	10	8	5	0	—	—
1963	134	18	14	9	7	3	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	91	15	10	8	6	0	0	0	0	—	—
1966	19	15	13	9	7	4	0	0	0	—	—
Indian Creek:											
1953	44	38	34	16	12	8	3	2	0	0	—
1954	8	0	0	0	0	0	0	0	0	0	—
1955	12	9	7	3	0	0	0	0	0	0	—
1956	12	10	8	7	4	0	0	0	0	0	—
1957	11	8	5	0	0	0	0	0	0	0	—
1958	39	36	16	12	10	8	4	3	2	0	—
1959	7	6	4	0	0	0	0	0	0	0	—
1960	11	6	0	0	0	0	0	0	0	0	—
1961	231	42	17	12	10	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	16	13	12	9	8	3	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Table 16—*Greatest number of consecutive hours when stream temperature was 60° to 70° F., Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	60	61	62	63	64	65	66	67	68	69	70
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	5	3	5	4	5	0	0	0	0	0	0
1958	27	11	18	5	7	6	5	5	7	6	0
1959	4	0	0	0	0	0	0	0	0	0	0
1960	6	2	3	1	5	5	1	3	0	0	0
1961[1]	10	3	7	6	6	1	4	0	0	0	0
1962	1	4	3	0	0	0	0	0	0	0	0
1963	8	6	7	5	5	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	11	20	6	7	6	6	0	0	0	0	0
1966	4	5	3	7	4	1	2	2	3	0	0
Harris River:											
1953	4	6	2	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	4	3	1	0	0	0	0	0	0	—	—
1957	7	4	2	2	0	0	0	0	0	—	—
1958[1]	10	11	6	2	6	2	2	2	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	17	11	8	5	5	4	4	4	0	—	—
1962	5	17	5	6	5	5	4	5	0	—	—
1963	50	10	10	8	6	3	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	34	5	6	7	6	0	0	0	0	—	—
1966	0	6	3	4	5	4	0	0	0	—	—
Indian Creek:											
1953	12	14	17	6	4	5	1	2	0	0	—
1954	8	0	0	0	0	0	0	0	0	0	—
1955	5	3	6	3	0	0	0	0	0	0	—
1956	7	2	6	5	4	0	0	0	0	0	—
1957	7	8	5	0	0	0	0	0	0	0	—
1958	22	8	9	5	8	4	3	3	2	0	—
1959	7	6	4	0	0	0	0	0	0	0	—
1960	11	6	0	0	0	0	0	0	0	0	—
1961	31	21	13	11	10	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	5	7	5	7	4	3	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Maybeso Creek. — Clearcutting began on the Maybeso Creek watershed in 1953 and ended in 1957. Stream temperature changes were not apparent when areas to the northeast of the creek were clearcut between 1953 and 1956, but during the summer of 1957, increases were detectable after two blocks were clearcut on the southwest side of the creek near the gaging site. Normal variations in sream temperature probably masked small changes during the other months.

Analysis of covariance was used to test for logging effect on average monthly stream temperature. In conduction of the analysis, each month (April through November) was considered separately. A combined linear model was not used because average monthly stream temperatures for any given year are serially correlated. It was also evident that the relationship between temperature of Indian Creek, the control stream, and those of Maybeso Creek and Harris River, was a function of time of year (fig. 12). A month-by-month comparison eliminated both problems.

For the analysis of covariance by month, the temperature of Indian Creek was used as a covariate in one series of tests and the temperature of Harris River as a covariate in a second series (table 17). July and August showed significant (at the 5-percent level) stream temperature increases due to logging. November also showed a significant stream temperature increase due to logging when the temperature of Indian Creek was used as a covariate. Other monthly increases were nonsignificant or there was insufficient data to test the hypothesis that logging did not affect stream temperature. From this analysis it appears that, at the gaging site, the maximum increase in average monthly stream temperature was about 4° F.

A comparison of maximum observed stream temperatures (tables 8-10 and 12-16) also indicates that significant changes in maximum stream temperature occurred only during the months of July and August. The increase in maximum temperatures was about 9° F.

Table 17—*Increase in average stream temperatures due to logging; Maybeso Creek (1953-57) and Harris River (1959-61), Prince of Wales Island, Alaska*

Month	Temperature increase		
	Maybeso Creek, with Indian Creek as a control	Maybeso Creek, with Harris River as a control	Harris River, with Indian Creek as a control
		Degrees F.	
April	0.67	0.06	2.64*
May	.74	1.36	3.33*
June	.35	1.16	1.45
July	3.12*	4.24*	1.97
August	3.50*	2.77*	([1])
September	.95	1.36	1.18
October	.05	.50	1.37
November	3.10*	1.97[1]	1.22

*Significant at the 5-percent level.
[1] Insufficent data for a good test.

Winter temperatures, taken at the Maybeso Creek gaging site, showed no detectable change after clearcutting. After ice formed on the stream, temperatures remained between 32° and 34° F. until spring.

Harris River. — Clearcutting operations began in the Harris River watershed in the summer of 1959. By the spring of 1960, there was an indication that logging was affecting stream temperature (table 11). Unfortunately, however, detailed stream temperature comparisons during and after clearcutting were not possible, as much of the 1960-62 data for Harris River and the other streams are incomplete. An analysis of covariance was run on the available data using the temperature of Indian Creek as a covariate. Results of the analysis (table 17) showed an average increase for all months from April through November of from 1° to 3.5° F. However, only the months of April and May showed a significant change in average monthly stream temperature. Possibly if more data had been available, other months would also have shown significant increases.

It is evident from comparison of the maximum stream temperatures of Harris River and Indian Creek (tables 9-10 and 12-16) that maximum stream temperatures rose from 4° to 9° F. for the months April through September as a result of logging. October and November show no noticeable increase in maximum stream temperatures. Logging also caused an increase in the range of monthly temperatures.

Even though we could not prove it statistically, there is considerable evidence to indicate that, for the months of April through November, the temperature of Harris River was affected by logging the watershed. Average monthly stream temperature rose from 1° to 3.5° F., and the range between maximum and minimum temperatures increased.

Available winter temperatures from the Harris River gaging site suggest that clearcutting had little, if any, effect on winter temperatures. As in the case of Maybeso Creek, after Harris River froze over, stream temperatures at the gaging site remained between 32° and 34° F. until spring.

LOG-DEBRIS JAMS

Debris obstructions in the study streams were not observed to impede salmon migration. Numbers of wood pieces large enough to jam the study streams are tabulated below, indicating more logging debris in Maybeso Creek than in Harris River.

	Maybeso Creek	Harris River	Indian Creek
Before clearcutting	1,120	224	410
During clearcutting	1,819	282	442
After clearcutting	1,603	284	402

Equal lengths of streambank (3.4 miles) were clearcut along Maybeso Creek and Harris River, although more than 5 miles were mapped to show log-debris jams. Only 3.6 miles of streambank were mapped along Indian Creek.

SALMON POPULATIONS

Escapement surveys (U.S. Fish and Wildlife Service 1963) were made by different observers using different counting methods and aircraft under various conditions of light, weather, and availability of time, funds, and personnel (fig. 14, table 18). These estimates are useful for fishery regulation but are unreliable as measures of logging effects on salmon populations; they indicate increases in salmon production following logging, the probable reasons for which are discussed later.

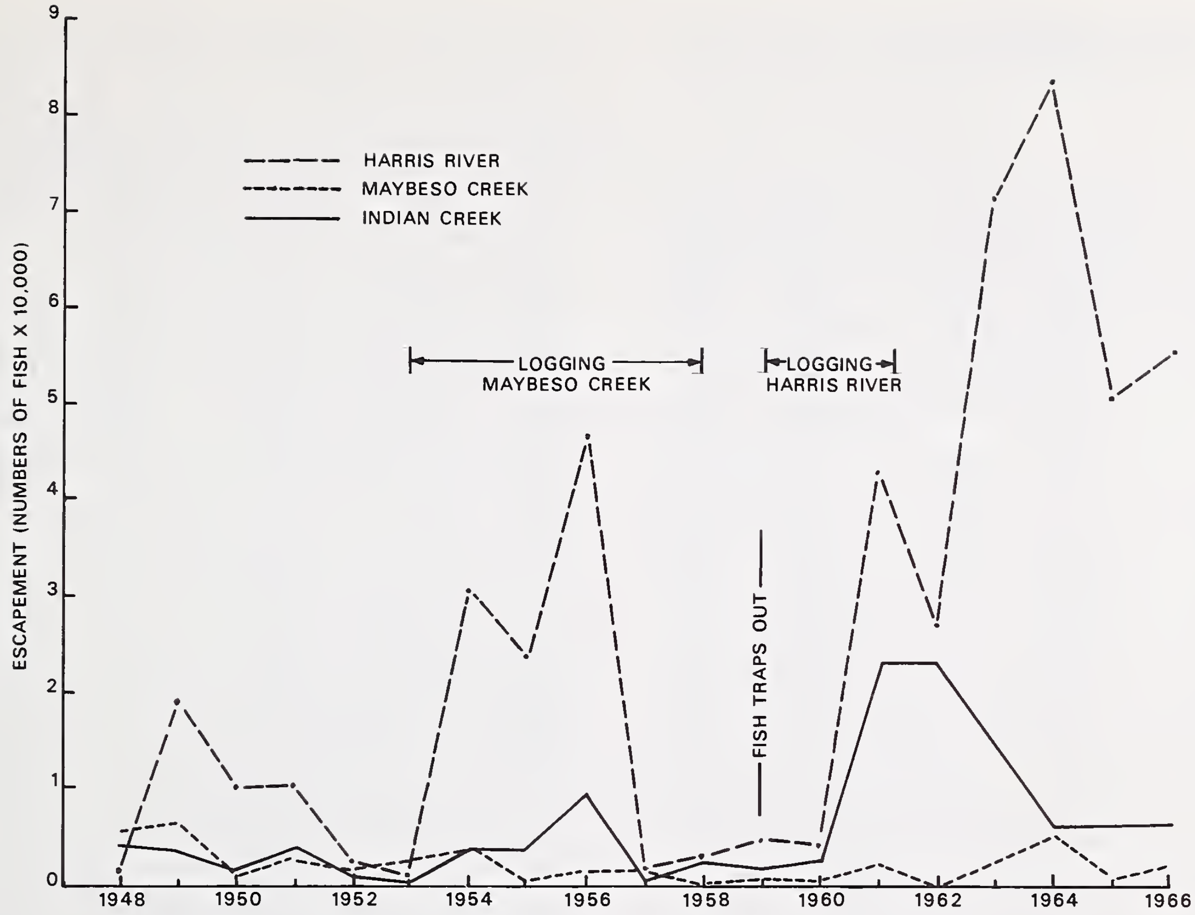

Figure 14 — *Estimated numbers of pink and chum salmon spawning in Hollis area streams, Prince of Wales Island, Alaska, 1948-66.*

Estimates of live pink salmon alevins (preemergent fry) per square meter in the intertidal area of Harris River (Sheridan and McNeil 1968) were:

Year	Alevins per square meter (Number)
1958	12
1959	107
1960	123
1961	71
1962	82
1963	168
1964	116
1965	203

These data, based on annual samples dug from the spawning beds, are a more reliable index of salmon production than spawner counts. Unfortunately, this technique[9] was not developed until 1958, so comparable alevin counts are unavailable for the prelogging period. However, Sheridan and McNeil's data (1968) may be compared with the following standards established by the Alaska Department of Fish and Game (Hoffman 1966):[10]

Good production more than 250 alevins per square meter.

Fair production, 100-250 alevins per square meter.

Poor production, less than 100 alevins per square meter.

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[9] McNeil, William J. Mortality of pink and chum salmon and chum salmon eggs and larvae in southeast Alaska streams. 271 pp., 1962. (Ph.D. thesis on file School of Fish., Univ. Wash.)

[10] These are preliminary values subject to change.

Table 18—*Escapements of spawning pink and chum salmon into study streams, Prince of Wales Island, 1948-66*

Year	Maybeso Creek			Harris River			Indian Creek		
	Pink	Chum	Total	Pink	Chum	Total	Pink	Chum	Total
1948	100	5,200	5,300	10,000	4,000	14,000	3,700	100	3,800
1949	5,500	900	6,400	17,300	1,600	18,900	3,500	100	3,600
1950	300	500	800	8,600	1,600	10,200	1,400	0	1,400
1951	700	2,000	2,700	6,200	4,300	10,500	3,600	500	4,100
1952	100	1,400	1,500	2,100	300	2,400	800	0	800
1953	0	2,000	2,000	600	300	900	300	0	300
1954	2,700	1,300	4,000	30,000	600	30,600	4,000	0	4,000
1955	100	300	400	22,000	1,700	23,700	3,500	0	3,500
1956	400	800	1,200	45,000	1,800	46,800	9,000	100	9,100
1957	0	1,100	1,100	1,500	300	1,800	500	0	500
1958	0	0	0	2,800	200	3,000	2,100	0	2,100
1959	100	0	100	4,700	0	4,700	1,500	0	1,500
1960	0	400	400	4,600	0	4,600	2,400	0	2,400
1961	0	2,400	2,400	—	—	43,000	23,000	0	23,000
1962	0	0	0	—	—	27,000	23,000	0	23,000
1963	2,500	0	2,500	63,000	8,300	71,300	([1])	([1])	([1])
1964	1,000	4,000	5,000	82,000	1,500	83,500	6,000	0	6,000
1965	800	100	900	—	—	50,400	—	—	—
1966	—	—	2,100	—	—	55,000	6,100	0	6,100

[1] Not surveyed after August 15.

DISCUSSION

Our results will be discussed within the framework of the study objective; i.e., the effects of clearcutting on various aspects of salmon habitat. For better presentation of this material, some interpretations of the effects of clearcutting on streamflow will be incorporated in the discussion.

STREAMFLOW

Quantity

Changes in water yield were not detectable by the methods used, but the effect of clearcutting on water yield can be deduced from other studies. In its simplest form, the streamflow equation (streamflow = precipitation — evaporative loss) shows how. Clearcutting more than 20 percent of forests in humid regions usually reduces evaporative losses and increases streamflow (Douglass 1966). Initial increases tend to be largest, then streamflow decreases as forest vegetation regrows (Hewlett and Hibbert 1961). A practical upper limit of initial streamflow increase appears to be about 4.5 mm. (0.18 inch) per year for each percent reduction in forest cover (Hibbert 1967). Since 20 percent of Harris River and 25 percent of Maybeso Creek watersheds were clearcut, a maximum increase of about 4½ inches of streamflow is all that could be expected. Lesser increases must have occurred because the clearcutting took several years to complete and streamflow probably declined as trees and other vegetation regrew on earlier cuttings. A somewhat different approach provides a similar estimate of streamflow increase. If clearcutting prevented all evaporative loss, then the maximum streamflow increase possible would be about 25 percent (fraction of watersheds clearcut) multiplied by 21.41 (potential evapotranspiration at Hollis), or 5.4 inches. Since evaporative loss was decreased by clearcutting but never prevented, a streamflow increase of 3 to 4 inches seems realistic. Detection of this increase by streamflow measurements would require rain-gage networks and weirs capable of estimating precipitation and streamflows to accuracy of $\pm$ 2 to 3 percent. Since our measurements lacked this prohibitively expensive degree of accuracy, streamflow increases following clearcutting could not be demonstrated.

Because increased annual flow following clearcutting is consistent with world experience (Hibbert 1967), it is relevant to speculate as to when during the year augmented flows would have appeared. Hibbert's review suggests that occurrence of increased streamflow depends on kind of precipitation. Streamflow increases in springtime usually result from snowmelt, whereas streamflow increases during the growing season usually result from rainfall. The study watersheds, being amply supplied with both rain and snow, probably had augmented flows whenever air temperatures rose above freezing. This reasoning also suggests augmented low flows during both summer and winter.

Regimen

Clearcutting evidently had little effect on regimen of the study streams. It is unlikely that logging influenced the water-conducting capabilities of deep soil or bedrock. The scant evidence available suggests that logging in other regions decreased the infiltration rate by compaction; i.e., decreased macroscopic pore space of surface soils. We closely examined the literature for evidence of how clearcutting might influence infiltration.

"Infiltration is the first modifier in the land phases of the hydrologic cycle. It is the major factor determining the disposition of water falling as rain and, further, it is a highly manageable process; yet, it is most frequently circumvented in hydrologic computations" (Holtan et al. 1967).

There is no doubt that vehicle traffic, falling trees, dragging logs, and human foot travel compacted soil on clearcut land. Questions of how deeply the soil was compacted, how infiltration rates were influenced, and how long impairment of hydrologic functions persisted cannot be answered to complete satisfaction. Lull's (1959) review suggests that compaction may be temporary in forest soils of other regions. He states that "under wetter conditions, imbibition and swelling of fine-textured soils reduces density. Freezing and thawing (with the concomitant 9-percent change in volume of moisture) would also be a factor in loosening compacted soils." Patric (1967) reported frost penetration to 18 inches on a clearcutting near Juneau. Although there is probably less soil freezing at Hollis due to the warmer climate, there is ample frost action to break up minor forest soil compaction. Lull (1959) cites another experiment in which buried cores of puddled soil showed structural restoration within a year in the presence of high organic content and exposure to moisture and temperature variation. The rapid revegetation of Maybeso valley reported by Harris (1967) also would tend to reduce soil compaction by root penetration. The pedologic characteristics, described by Gass et al. (1967) and summarized on page 5 and in figure 5, make timbered soils resistant to damage by clearcutting. Infiltration remains high after clearcut logging because the deep organic layer is not usually scoured away to mineral soil. Water moves very rapidly through the mineral soil, which also has high resistance to erosion. Patric and Swanston (1968) irrigated reforested plots in Maybeso valley at the rate of 0.7 inch per hour for periods ranging from 18 hours to 1 month. Over 400 inches of water were applied to one plot; minor surface runoff occurred only when a broken pipe caused 6 inches of water per hour to fall on a small area. Since the estimated 100-year maximum rainfall rate for the region is only 1.4 inches per hour (Miller 1963), we concluded that surface runoff rarely, if ever, occurred on the clearcut areas of the watershed.

WATER QUALITY

Suspended Sediment

Suspended sediment samples from the study streams are our best evidence that clearcutting had little or no effect on water quality. Materially reduced infiltration rates would have started the familiar sequence of surface runoff and sediment laden streams. Had stormflows increased even slightly, soils and organic matter scoured from streambanks also would have entered the streams. The logging road surfaces show little evidence of erosion but washouts, scouring ditches, and unvegetated cut or fill slopes remain as sediment sources. Most sediment, however, is trapped on the absorbent litter and soil between source areas and streams.

Heavy rains in October 1961 caused a marked increase in debris avalanches (defined by Sharpe 1960) and debris flows (defined by Rapp 1961) on clearcut portions of the Maybeso Creek watershed (Bishop and Stevens 1964). It is estimated that approximately 11 percent of a mile-square clearcut area in Maybeso valley has been affected by these forms of erosion since 1959 (Harris 1967).

Debris avalanches are common on forested Karta soil (Gass et al. 1967) and are a normal part of postglacial adjustment in southeast Alaska.[11] More than a hundred debris avalanches have occurred in Maybeso valley since 1953 when logging began in the area; only one of these actually reached Maybeso Creek. Avalanche material usually came to rest at the base of steep slopes, well removed from the main stream channel.

Debris flows probably contributed sediment to salmon streams, but our data suggests that this contribution was small. Several debris flows occurred on the clearcuttings, where logging slash had formed temporary dams in steep-walled tributary streams. These dams burst during heavy rain and carried sediment to Maybeso Creek and Harris River. The unvegetated scars remain as sediment sources.

We believe that clearcutting and logging increased suspended sediments slightly but that water quality was only briefly reduced.

Stream Temperature

Clearcutting operations in Maybeso Creek and Harris River watersheds apparently did not appreciably alter the factors that control stream temperature at the gaging sites. After analysis of the data, we conclude that winter temperatures were little affected and that average temperature changes at other times of the year were 4° F. or less.

As with most stream temperature data that has been gathered elsewhere in the past, sampling within and between streams was not detailed enough to analyze the total effect of stand treatment on stream temperature. It is possible that the single temperature probe in each stream was located in an area that showed either maximum or minimum temperature change. Maybeso Creek temperatures, for example, showed no change until the timber on the southwest side of the stream near the gaging site was clearcut. Even then, it was not possible to evaluate accurately the increase in temperature, as comparisons with Indian Creek and Harris River temperatures showed year-to-year variation (table 11). This variation may, in part, reflect differences between the watersheds.

[11] See footnote 7.

It is possible that removal of timber along the banks of streams in coastal Alaska is the most significant factor in altering stream temperature. In summer months this allows more solar radiation to reach the stream and in winter the streams are more exposed to colder air temperatures. In winter months, under an ice layer, stream temperature remained in the 32° to 34° F. range. We do not know if removal of streamside timber affects freezing of the streambeds.

LOG-DEBRIS JAMS

The reasons for fewer log-debris jams in Harris River are unknown. The marked increase in debris jams in Maybeso Creek during and after clearcutting may be explained in that the logged portions of Maybeso Creek drainage were more densely forested than those of Harris River. In addition, red alder *(Alnus rubra* Bong.*)*, growing along Maybeso Creek, was poisoned in 1952 to minimize seed sources of this species (Anderson 1953); dead alder fell into the stream and was incorporated into jams.

Aerial photographs taken in 1961 and 1962 indicated that major shifts of debris jams accompanied stormflow peaks during heavy autumn rains (fig. 15). Shifts in pool and riffle structure accompanied these debris shifts. Helmers' (1966) summary of observations showed that debris jams in Maybeso Creek tended to increase streambed movement and decrease sediment levels in streambed gravel. Even small storms sometimes caused major relocations of log jams and stream channels on all the study streams.

BIOLOGICAL EFFECTS

The final effects of man's activities on salmon habitat are best observed by examination of the fish populations themselves.

Figure 15—*During stormflow peaks, major shifts of log-debris jams caused streambed changes. Gravel deposits above or below jams washed downstream when obstructions were carried away, and pools under jams refilled with bedload material.*

Results show that salmon populations in the study streams did not decrease after logging; in fact, they generally increased, particularly in Harris River. However, two concurrent events may have affected salmon production in the Hollis streams: (1) removal of fish traps from nearby waters and (2) clearcutting. The probable increase in escapement resulting from trap removal could have masked any change in production resulting from clearcutting — if a change occurred.

Another way to evaluate the possible effects of clearcutting on salmon production is to consider how changes in streamflow and temperature could influence the fresh water phases of salmon life history. Pink and chum salmon deposit their eggs in streambed gravels late in the summer. The eggs incubate over winter, and fry hatch during late winter and early spring. When the yolk sac is almost fully absorbed, the fry emerge from the gravel and migrate downstream to the sea. After spending 1½ to 4½ years at sea, they return to their natal streams to spawn and die. In general, then, when streamflow is usually low (June-August), pink and chum salmon fry are not in the streams. Adult salmon begin to enter the streams in August, after which spawning takes place.

Our data showed no measurable effect of clearcutting on flow of study streams; however, streamflow must have slightly increased. Increases during the summer months could be beneficial by making spawning grounds more accessible. On the other hand, greatly increased streamflow during spawning could result in egg deposition in gravel beds which would be exposed and frozen during low winter streamflows.

The year-to-year variation in average monthly stream temperatures tended to mask effects of clearcutting on study streams, although the entire range of temperature shifted upward after clearcutting. Warmest stream temperatures occurred between June and mid-August; the maximum temperature recorded in any study stream was 69° F. in Maybeso Creek. Since most of these maximum temperatures occurred when pink and chum salmon generally are absent from the study streams, biologically significant effects on these two species would not be expected.

It appears that clearcutting caused average temperatures in the study streams to increase not more than 1° to 4° F. from April through November. The natural year-to-year variations in average temperatures during these months often are greater than the treatment effect. Therefore, in some years, the incubation and hatching of eggs and fry might be unaffected by clearcutting. During years of exceptionally warm temperatures in September-November, the additional 1°-3° F. treatment effect in these months could accelerate incubation and hatching. If fry hatched somewhat earlier than usual, they might adjust to this situation by remaining somewhat longer in the streambed gravels before emerging. However, if stream temperatures were unusually warm during late summer and early fall, it is conceivable that fry might emerge from the gravel and migrate to sea prior to freezeup, perhaps in December. It would appear that the marine environment at this time of year would not be favorable for good growth and survival of the young salmon.

In streams of high gradient and velocity, occasional stable debris jams could serve to reduce velocity on upstream spawning reaches and cause sediment to be deposited in the immediate vicinity.

In slower streams with less gradient, jams probably are more harmful since they tend to reduce velocity even further and, perhaps, prohibit natural flushing of sediment from spawning gravels. If jams are numerous on a given stream, they could occupy considerable space.

In either case, if a jam blocks passage of anadromous fishes to suitable spawning and rearing areas upstream, it may limit production in that system. Unstable jams may shift or dislodge debris during high water, thereby scouring gravels from downstream areas. The size composition, structure, and stability of bed material would also be important considerations in evaluating the effects of a jam in a given stream.

In general, then, the results of this study do not indicate any obvious effects of clearcutting on the salmon populations in the two streams considered. Some more subtle changes may have occurred that were not measurable within the scope and instrumentation accuracy of this study. The less direct effects of logging on species having extended fresh water stages in their life histories, such as steelhead trout and coho salmon, were not measured in this study.

SUMMARY

One of the first major timber harvests in Alaska began in the mid-1950's on Prince of Wales Island, providing an opportunity for study of some of the physical effects of logging on salmon stream habitat.

Three watersheds in the vicinity of Hollis, on Prince of Wales Island, were selected as the study area; about one-fourth of the Maybeso Creek watershed (total area, 15.2 square miles) and one-fifth of the Harris River watershed (31.8 square miles) were clearcut by high-lead cable logging methods.

Streamflow from the two logged watersheds did not change in comparison with nearby, unlogged Indian Creek. Similarly, Harris River showed no influence of clearcutting on the relationship between rainfall and peak flows. Likely changes in streamflow as a result of logging might have been detected if precipitation and streamflow had been measured with an accuracy of ± 2-3 percent. This accuracy was not approached.

Although sampled concentrations of suspended sediment for given levels of Harris River were higher during logging than before, these changes were not statistically significant.

Maximum increase in average monthly stream temperature at the gaging sites in Harris River and Maybeso Creek was 4° F. However, maximum observed temperatures appear to have increased up to 9° F. in the summer months. The temperature increase is believed to be associated with removing streamside timber. Although changes in winter stream temperatures resulting from logging are not conclusive, the data suggest that logging has little effect on the 32° to 34° F. temperatures that extend to spring.

Mapping and aerial photography indicated that logs and debris increased in Maybeso Creek during and after logging. This is probably due to logging of relatively high-volume timber and to poisoning of alder on the streambanks. A small increase in absolute number of logs and debris pieces occurred in Harris River during and after clearcutting. The initial number of pieces was small compared with Maybeso Creek and remained so during and after logging.

Clearcutting apparently did not adversely affect the salmon spawning habitat, based upon the returns of pink and chum salmon spawners to the study streams in the years during and after logging. An increase in numbers of spawners following clearcutting undoubtedly was associated with nonrelated factors. The greatest increases in summer stream temperatures occurred when pink and chum salmon spawning runs were just beginning to enter the systems in sizable numbers; somewhat higher stream temperatures in October and November conceivably could alter the normal incubation, emergence, and seaward migration of salmon eggs and fry, although supporting evidence is lacking. Increased amounts of logs and debris in the streams during and after clearcutting could reduce access to and amount of suitable spawning area; however, such barriers were not observed during the study.

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