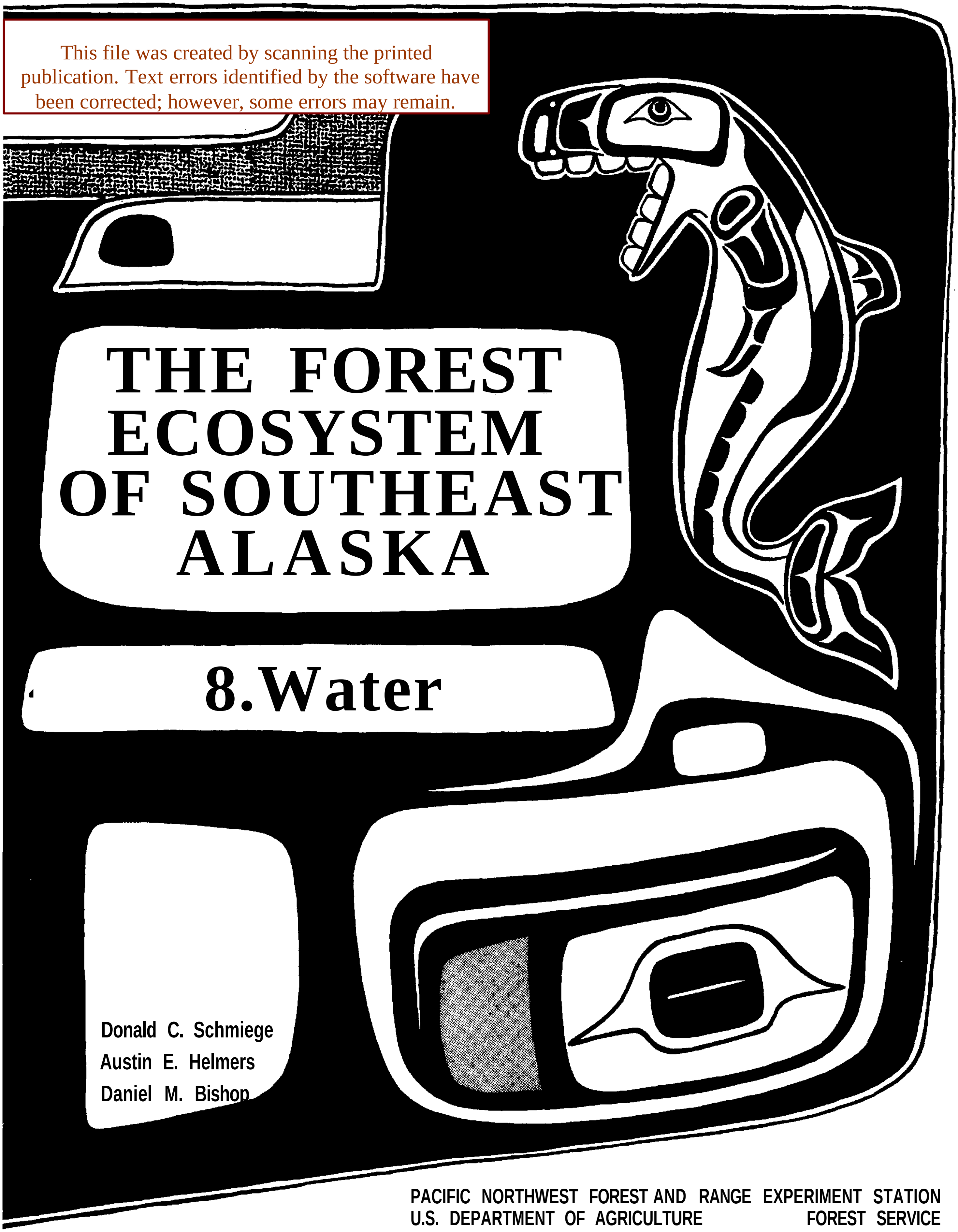
1974
USDA FOREST SERVICE GENERAL TECHNICAL REPORT PNW-28



THE FOREST ECOSYSTEM OF SOUTHEAST ALASKA

8. Water

Donald C. Schmiege
Austin E. Helmers
Daniel M. Bishop

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

CONTENTS

ABSTRACT

One of the most striking characteristics of southeast Alaska is the abundance of water. Large glaciers, icefields, and thousands of streams result from heavy precipitation throughout the year.

Published and unpublished data on water regimen, temperature, sedimentation, and chemistry are combined. These serve as a basis for understanding how this valuable resource may be used and protected so that high quality water may always be abundant and available. A brief section on needed research is included.

Keywords : **Watershed Management, water quality research, Alaska.**

DONALD C. SCHMIEGE, project leader, and AUSTIN E. HELMERS, principal watershed scientist, with Pacific Northwest Forest and Range Experiment Station. DANIEL M. **BISHOP was formerly with Region 10, U.S. Forest Service.**

PREFACE

This is the eighth in a series of publications summarizing knowledge about the forest resources of southeast Alaska.

Our intent in presenting the information in these publications is to provide managers and users of southeast Alaska's forest resources with the most complete information available for estimating the consequences of various management alternatives.

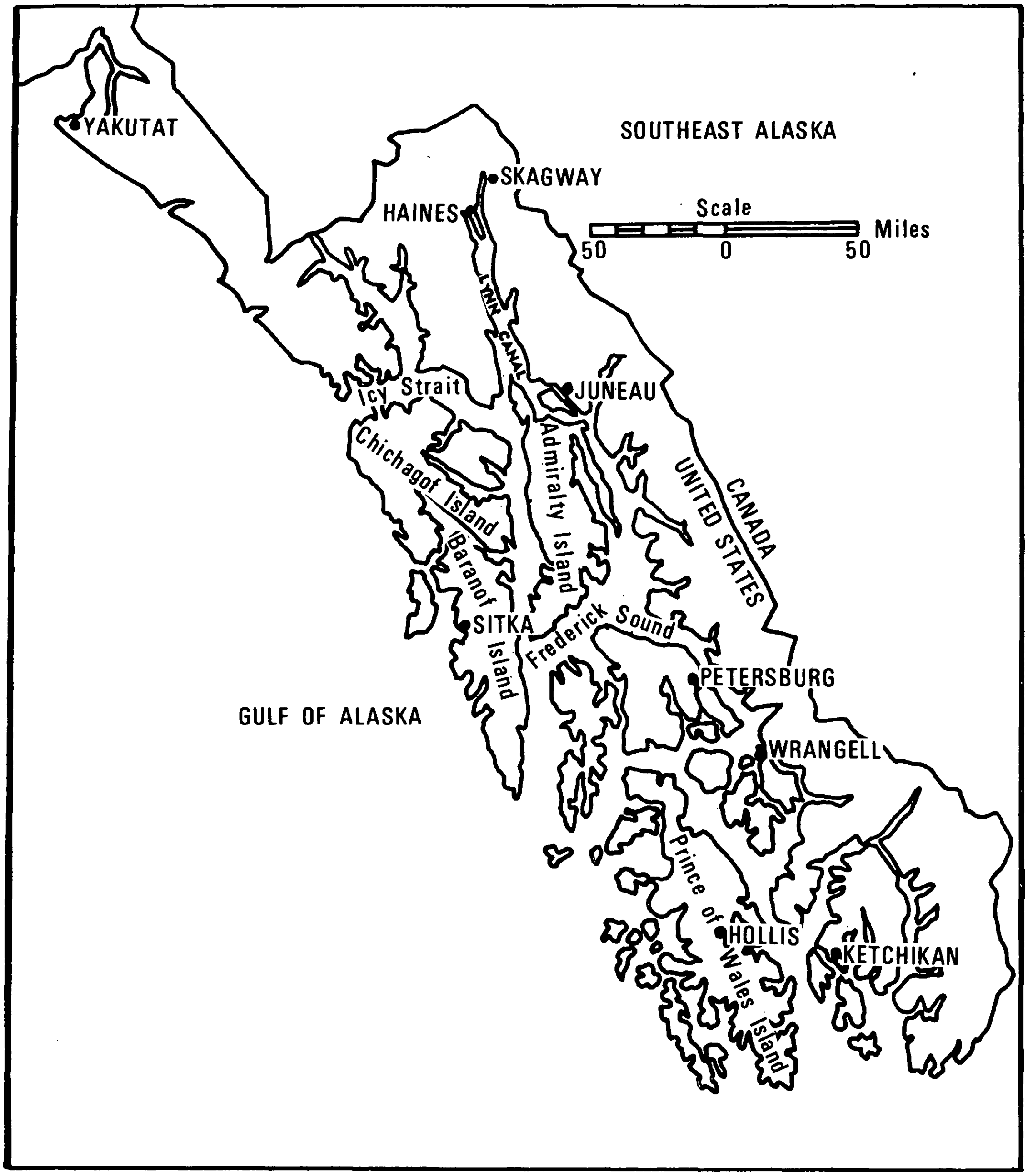
In this series of papers, we summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in southeast Alaska. These compilations will be valuable in planning future research on forest management in southeast Alaska. The extensive lists of references will serve as a bibliography on forest resources and their utilization for this part of the United States.

Previous publications in this series include:

1. The Setting
2. Forest Insects
3. Fish Habitats
4. Wildlife Habitats
5. Soil Mass Movement
6. Forest Diseases
7. Forest Ecology and Timber Management

Robert E. Buckman

ROBERT E. BUCKMAN, Director
Pacific Northwest Forest and Range
  Experiment Station
Portland, Oregon



Map of southeast Alaska east of the 141st meridian.

INTRODUCTION

Southeast Alaska is a water-oriented region. It is nearly 400 miles long and about 120 miles wide from the Canadian boundary to the western shores of the islands of the Alexander Archipelago. The total land area is 35,527 square miles and includes hundreds of islands (Federal Power Commission and U.S. Forest Service 1947). There are 9,000 miles of shoreline. From the mainland and the great variety of islands arise thousands of stream and lakes. There are also numerous bays and estuaries with a variety of oceanographic features. It has been estimated that there are more than 1,100 salmon spawning streams of which the more important have'been described and cataloged (U.S. Department of Interior 1959, 1963a, 1963b, 1965a, 1965b). Glacial and alluvial gravel deposits provide abundant spawning areas for the millions of salmon and trout that migrate into the streams annually.

From 1911 to 1945, 51 stream gaging stations operated throughout southeast Alaska. Most streams in southeast Alaska have small short drainages, and wide ranges in discharge, The mean annual discharge in cfsm (cubic feet per second per square mile) ranged from 8.5 to 19.1. The median discharge was 13.8 cfsm (Federal Power Commission and U.S. Forest Service 1947).

Icefields are nearly continuous on the Coast Range of the mainland, and there are many glaciers that empty into the main fiords. Water and ice have sculptured a rugged mountain scene of unrivaled beauty (fig. 1). Even the saltwater which forms the inland passage of the Alexander Archipelago is in constant motion due to the large tides.

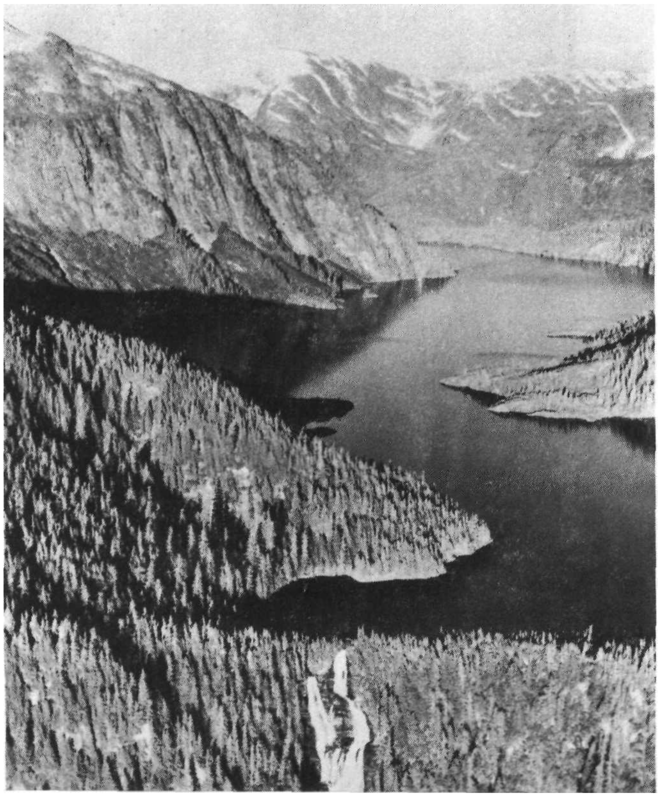
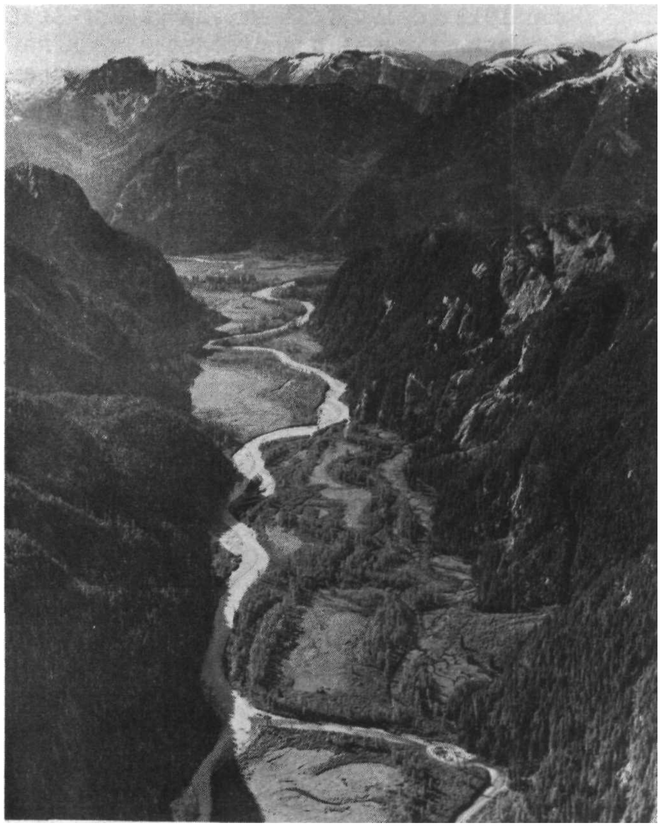


Figure 1.--A mountain lake on the mainland of southeast Alaska.

Heavy precipitation during most months supplies a large runoff volume that is carried to the sea by streams of all sizes. This streamflow provides freshwater habitat that supports valuable commercial and recreational fisheries. The abundant rainfall typical throughout southeastern Alaska supports dense stands of western hemlock and Sitka spruce that are often referred to as temperate "rain forests." Muskegs are a common feature of the landscape from sea level to ridgetops.

Many mainland rivers have their origins in the glaciers and snowfields of the Coast Range and St. Elias Mountains. Drainage is generally westward except at the northern end of the region where drainage is also southward to Lynn Canal and Glacier Bay. Some of the largest rivers, such as the Alsek, Taku, and Stikine, have glacial origins in the Yukon Territory or the plateaus of British Columbia. The Chilkat, Skagway, Speel, Whiting, Unuk, Chickamin, and Salmon Rivers arise in snowfields and glaciers of mountain range headwaters which reach into Canada (fig. 2). The mainland slopes are steep, rocky, and deeply incised by glaciation so that there are many small drainage basins adjacent to the tidal inlets and bays that indent the coastline. Some of these smaller streams have glaciers at their headwaters. Many have lakes fed by semipermanent snowfields or have lakes along their courses.

Figure 2.--The Chickamin River--its headwaters drain glaciers in British Columbia.



The watersheds on the islands of the Alexander Archipelago drain mainly to the east or west directly into tidal waters. The westerly slopes draining toward the ocean are more gradual than the drainage slopes toward the mainland so that generally the streams flowing westward are longer.

One of the largest streams on the islands is the Hasselborg River, on Admiralty Island, with a drainage area of 107 square miles. Other large streams are the Medvetcha and Maksoutof Rivers, both of which drain westward on Baranof Island, and Thorne River on Prince of Wales Island,

STREAMFLOW REGIMEN

The average surface water runoff for the main United States and Canadian contributing basins east of the 141st meridian in southeastern Alaska is about 601,000 cfs (Wilson and Iseri 1969). The drainage area is about 77,900 square miles; therefore the unit runoff for the basins combined is roughly 7.7 cfsm. However, since a large part of the drainage area for many of the larger mainland streams is in Canada, there is a net water production from southeastern Alaska of about 480,630 cfs (table 1).

Table 1.--River discharge to the sea from Alaska east of the 141st meridian, and the flow of water from Canada to southeast Alaska

River basin	River total discharge	Flow, Canada to Alaska	Net flow from within Alaska
	- - - - - - - - - -	cfs	- - - - - - - - - -
Chickamin	8,000	1,600	6,400
Unuk	9,000	6,200	2,800
Stikine	61,000	54,600	6,400
Whiting	10,000	8,000	2,000
Speel	3,700	370	3,330
Taku	15,000	11,200	3,800
Alsek	45,000	34,500	10,500
Chilkat	8,000	3,900	4,100
Total, east of 141st meridian	601,000	120,370	480,630

Source: Wilson and Iseri (1969).

The quantity of streamflow depends first on precipitation and then on basin characteristics. The latter include factors that can be modified by land management practices such as logging, roadbuilding, mining, and community developments and expansion.

The unit runoff is high, but the relationship of runoff to precipitation is poorly understood because most precipitation measurements are from low elevation stations. Such stations do not show the large amounts of precipitation occurring at higher elevations, Surface runoff in southeast Alaska from lower elevation basins is about 60-100 inches annually and 150-200 inches from intermediate and higher elevations. Streamflow records near sea level (Feulner et al. 1971) showed that basin runoff exceeds precipitation. Waananen (1950) stated that "Streamflow records indicate that maximum precipitation at the higher altitudes in the southern portion exceeds 250 inches annually." Walkotten and Patric (1967) measured a 0.02-inch increase in rain per 100-foot increase of elevation near Hollis on Prince of Wales Island. Murphy and Schamach (1966) estimated that the normal annual precipitation at 3,400-foot elevation near Juneau should be at least 285 inches, compared with the normal 90.98 inches at the Juneau city gage exposed 71 feet above sea level.

An analysis of snow pit data and rainfall measurements from various points on the Juneau icefield has provided an estimate of high elevation precipitation. For example, on Ptarmigan and Lemon Glaciers near Juneau, a number of pits measured near the time of maximum snow accumulation indicated from 75-114 inches of water equivalent (above the previous year's surface) at elevations between roughly 3,000 and 3,900 feet. Summer rainfall in the vicinity of these glaciers can range from 30-60 inches. The magnitude of annual precipitation thus could be 160 or more inches, compared with a sea level normal of 55 inches at the Juneau Airport. This rough analysis does not take into account the likely effects of wind and subsequent snow transport. Upper-elevation (4,000-5,000 feet) precipitation in this area probably should average more than 200 inches, because the average discharge of Lemon Creek, which is supported in part by these glaciers, is equivalent to 174 inches annually. As this runoff includes flow from three diminishing glaciers above the gaging stations, an excess of runoff over precipitation should be expected even if precipitation could be accurately measured.

The bulk of what is known about water production in southeastern Alaska consists of the records published by the U.S. Geological Survey. As of 1970, the U.S. Geological Survey published daily discharge data and several summaries for 30 streams that have 5 or more years of record. Record length was up to 52 years. The area of these gaged watersheds ranges from 2.5 to 226 square miles. Additional scattered, unpublished data are available from the U.S. Geological Survey and from study data on timber-salmon relationships on file at the Forestry Sciences Laboratory at Juneau.

James (1956) summarized southeast Alaska streamflow based on studies on Prince of Wales Island:

> 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....
>
> Heavy precipitation during October, November, and early December causes numerous floods which produce a highly fluctuating discharge hydrograph. Cold weather and snowfall from December until April are responsible for a declining flow and the shaping of a 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.
>
> 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...streamflow for these two months is considerably less than in June. This results primarily from loss of water through increased evapo-transpiration rates.
>
> 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...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 a 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.
>
> ...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....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 snowmelt.

A typical discharge pattern for a nonglacial stream is shown in figure 3. The extreme runoff gaged in 1970 was 329 inches from Sashin Creek, near Little Port Walter on Baranof Island, where the sea level precipitation was 265 inches for the period. This is another example of the common southeast Alaska situation in which basin runoff exceeds sea level precipitation. Elevation-precipitation relationships should affect runoff. However, techniques for estimating runoff are of limited reliability because precipitation patterns and relationships are poorly understood (Childers 1970, p. 36).

Glaciers are a major component of the water resource, and one that is highly significant along the mainland where glaciers and icefields occupy about 2,000 square miles of the highlands (Field 1958). Glaciers regulate streamflow.

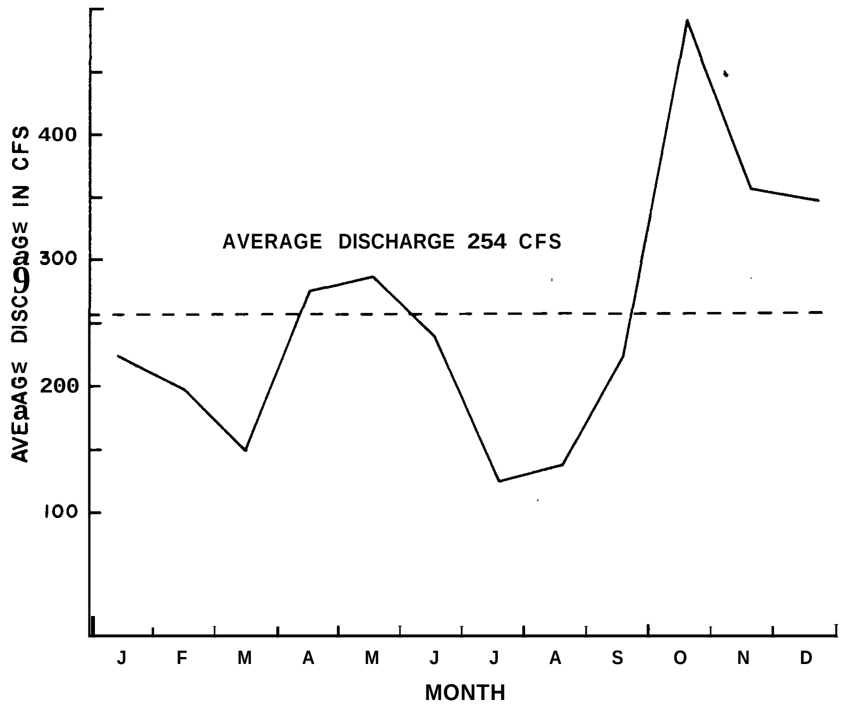


Figure 3.--Average monthly discharge for Harris River, 1950-64. This stream reflects the typical seasonal discharge of southeast Alaska streams. The below average discharges of the January-March period are the result of snow and ice accumulation. The rise above average during the April-June period is due primarily to snowmelt. Precipitation is relatively low and evapotranspiration high in the summer, resulting in a second low flow period. Heavy rains associated with fall storms result in peak flows.

Streamflow from streams with glacier systems in their basins in the Juneau area peak at about 23 and 24 percent of the water-year runoff in July and August, primarily in response to snow and ice melting, Snowmelt also contributes to the 15-percent runoff in June; rain probably is a factor in the 20-percent runoff amount for September. The higher elevations and consequent lower temperatures of glacierized watersheds cause a rapid drop in runoff beginning in October and a low base flow in December through April. The low flow probably is also related to the bare rock and coarse mantle materials common at the upper elevations. Runoff from glacier-free basins in the Juneau area peak at about 13 and 14 percent of the year's runoff in May and June in response to snowmelt and peak again at approximately 14 percent in September due to rain. Summer flows are quite uniform, with about 12 percent maintained for July, August, and October.

Timber harvesting is the land use activity most likely to significantly affect the quantity of streamflow, Since studies of such effects have been limited to research on clearcutting-salmon relationships, it is worthwhile to consider also general experience elsewhere which has local application.

According to Hewlett and Hibbert (1961, p. 6 and 16),

> 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 removed or cut down....First-year increases in the order of 5 to 16 inches may be expected at Coweeta [North Carolina] after complete clear-cutting of a mature hardwood forest....Experiments of all types within the temperate zones of the world, neglecting Coweeta, suggest increases in streamflow up to about 10 inches per year as a result of clear-cutting forested watersheds, but the average would seem to be about half this amount.

Meehan et al. (1969, p. 2) summarized subsequent experience:

> 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 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.

Water level studies from 1949 to 1964 made on two streams, at Hollis, before, during, and after clearcutting of 20 to 25 percent of the watersheds did not show changes in water yield (Meehan et al. 1969). A response to the clearcutting undoubtedly occurred, but it was too small to be detected by the available stream gaging conditions.

It appears that one-fourth of the watershed area, at lower elevations only, might be clearcut without substantially changing the quantity of water. production. However, there may be changes in pattern of runoff which are often critical to fish. As large proportions of watershed areas are cut, involving increasingly higher elevations, undoubtedly there will be greater changes in water production.

WATER QUALITY

SEDIMENT

Streamload consists of suspended material and bedloads carried within a water column or along the streambed. Sediment may be suspended as part of the freeflowing, above-streambed water of a stream, and in this form it causes the turbid or murky appearance of the water. Bed material occurring in the stream may be the result of suspended or bedload movement or both. Suspended sediment is the only fraction of streamload that has been sampled to a major extent in southeast Alaska.

Another form of stream transported material is called bedload, which includes particles rolling or bouncing downstream. Although recognized as important, this bedload fraction of streamload has not been adequately sampled, largely because of the great difficulties in obtaining meaningful results.

Sediment in streams comes from both geologic processes and man's activities. Southeast Alaska is a geologically youthful region in which soil and debris movements and stream system development are particularly active. These natural processes create sediment. Steep terrain and large amounts of rainfall make the land sensitive, in terms of sediment production, to such activities as road construction and timber harvesting. Ameliorating influences include coarse-textured soils with thick organic surface layers, high permeability, high infiltration, and conditions that favor rapid revegetation of disturbed soil. There also seems to be little overland flow (Stephens 1966).

Sampling of streambed gravels and deposited sediments by various agencies over a number of years shows that composition by size class may include particles from silts and fine sands through large boulders and shapes that range from angular to nearly spherical. The composition of streambed materials as well as ranges of stream energy affects the stability of a stream bottom. These parameters therefore affect the stability of a stream as habitat for fish.

Over the past 50 years, the basic concepts concerning mechanics of streamflow and the effects of various stream parameters (depth, gradient, velocity, bedload, channel configuration, etc.) on sediment transport and deposition have been developed, Gross differentiation of streams according to gravel stability can be made (Gilbert 1914, Rubey 1938, Kalinske 1947, Brooks 1958, Colby 1961).

The principles relating stream parameters to sediment transport and deposition were developed from observations and measurement of streams in watersheds much older geomorphologically than those in southeastern Alaska. The gradients and velocities were much lower, the flows more constant, and the sediment load finer. Consequently, although the basic concepts of stream mechanics and sediment transport remain the same for all streams, quantitative results obtained in these other areas cannot be applied directly to conditions in southeastern Alaska.

Suspended sediment loads of nonglacial streams in southeast Alaska are extremely low, even in heavily logged watersheds. For instance, in two watersheds near Hollis where clearcuts exceeded 2,000 acres in size, suspended sediment during and following logging in the Harris River never exceeded 3.7 ppm (parts per million) under average flow conditions or 148 ppm during peak flows, and in Maybeso Creek 7 ppm during average flow or 38 ppm during peak flows. Such low suspended sediment levels are due to the unique watershed characteristics, namely, low intensity rainfall; soils with thick, tough, organic surfaces; extremely rapid infiltration and percolation rates; and lack of surface runoff except on badly disturbed ground. The difficulty of obtaining precise measurements in the field may also have been a factor.

As a basis for understanding the behavior of suspended sediments in southeast Alaska streams, an examination was made of suspended sediment data as of September 30, 1970, for 45 sample streams. These data were taken from U.S. Geological Survey water quality reports (288 samples) and from values published by the Institute of Northern Forestry[1] for Hollis area streams (230 samples).

Using these data, along with actual experience on many of the basins that were sampled, a classification system was devised that rated streams according to differences or similarities in origin of suspended sediment. This rating system provides a tool that can be useful in developing plans for prevention or regulation of suspended sediment, provided it is recognized that the system is tentative and in need of more research. The classes of streams are:

Glacial
Lake-fed
Groundwater-fed
High relief, glacier-€om watershed

Glacial streams.--Streams that originate from glaciers may be divided into three subtypes according to the presence or absence of accessory features such as glacial lakes and the contribution of melt water to the net flow. These subtypes are:

1. Glacial streams where melt water is the main source:

Samples taken by the U.S. Geological Survey indicate that suspended sediment concentrations in glacial streams are highly dependent on volume of melt water flow. Streamflow can, therefore, be used to estimate suspended sediment concentration. At high flows, concentrations may reach 200-600 ppm or more; and midrange flows may contain 20-100 ppm. Suspended sediment concentrations from November through April seldom exceed 20 ppm, because the amount of glacial melt water is lowest during that period. Glacial streambeds are probably "cleanest" in midspring to late spring just before glacial melt resumes.

Because of the youthful nature of watersheds of glacial origin, they usually contain landslide-prone mantle materials that may generate suspended sediment. The occurrence of fine-textured soils in these watersheds is highly variable depending upon occurrence of uplifted marine sediment or upon local sediment deposits. These watersheds do not contain ash deposits. Glacial sediments present during most high flows may mask the relative impact and conspicuous nature of sediments from other sources.

Little is known about the morphological characteristics of suspended sediment carried by glacial streams. The few analyses made of suspended sediment samples from these streams indicate that nearly all suspended material is less than 0.5 mm in diameter (coarse to medium sand) and that 75-95 percent is less than 0.25 mm (medium to fine sand).

---

[1] Now the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station.

2. Glacial streams with a lake catchment:

Thirteen suspended sediment samples from the Mendenhall River and Long River illustrate some characteristics of this stream type. These samples suggest that maximum sediment concentrations below lakes seldom exceed 300 ppm but do not drop as low as glacial streams without lakes. This is a logical consequence of greater temporary storage of fine sediment in the glacial lakes. It also follows that suspended sediments from this group of streams will be somewhat finer and will pass farther into the estuaries. Colloidal sediments will be similar in character to those of subtype 1 above. The description of sediment-producing soils as applied to subtype 1 also applies here.

3. Glacial streams with a small glacial influence:

This group of streams probably has the most variable intrastream suspended sediment concentrations. Like subtype 2, there are few samples available to represent this group of streams (21 samples). Yet, there are many streams that have a small but significant glacial influence. This group is very important.

There were no samples with concentrations greater than 170 ppm. Maximum concentrations have occurred from July through September and probably rarely exceeded 200 ppm. During winter seasons, concentrations drop to less than 10 ppm. Soils in these watersheds are more likely to produce sediment following roadbuilding or logging than most other soils. Landslide-prone soils often occur in these drainages. Landslides commonly occur toward the end of the glacial melt season, or shortly after the main part of the melt, when heavy rainfall and saturation of mantle materials occur.

Suspended landslide sediments contain organic material seldom found in glacial sediments and may be lower in specific gravity than fine glacial sediments. Consequently, these organic sediments do not settle as rapidly into the streambed as equally fine-grained glacial sediments. They will flush more rapidly from the surface of the streambed during high flow. Fine sediments from older soils may be more apt than glacial deposits to form aggregates or cementations when deposition occurs. The few suspended sediment samples from this group suggest that suspended material is less than 0.5 mm in diameter, with 60-95 percent less than 0.25 mm.

Ash soils provide a sediment hazard on Kruzof Island, northern Baranof Island, parts of southern Chichagof Island, and Revillagigedo Island; and the streams carry heavy bedloads. Though no significant measurements have been made in southeast Alaska, it is possible that the streambeds in this group are changed about every 5 years by bedload transport of streambed materials.

Lake-fed streams.--The criteria for streams of this group are that the watershed must be free from active glaciation and contain sufficient lake area to significantly influence surface runoff and storage characteristics.

Twelve streams in southeast Alaska for which suspended sediment data are available are in this group. One would expect lake-fed streams to have similar suspended sediment characteristics. Based on records for nine of the streams, there are uniformly low concentrations of less than 15 ppm during variable discharges. In contrast, however, three lake-fed streams, each located in very steep country, show high sediment concentrations. Concentrations up to 380 ppm for a Takatz Creek sample and to 300 ppm for a Harding River sample have been recorded. In the case of Takatz Creek, suspended sediment may have come from a sizable tributary entering the creek below the lake outlet.

Deer Lake, about 40 miles south of Takatz Lake, shows a high concentration of 184 ppm. This sediment evidently comes from V-notches on the steep lakeside walls or from melt water of a remnant hanging glacier at the head of the lake; the sediment is probably nearly colloidal in size since larger sediments apparently settle out in the lake system.

Harding River, containing Fall Lake in its drainage, exhibits special noteworthy suspended sediment characteristics.

- A high "normal" range of suspended sediment for a lake stream (1 to 29 ppm), suggesting large supplies of frequently disturbed fine sediments.
- High concentrations during a spring flush-out period. This is not evident in any other stream of southeast Alaska that has been studied.
- No evidence of increase in suspended sediment with fall high flows.

The source for suspended sediment in Harding River drainage should be identified and understood so that this information can be applied to other mainland drainages, There are not sufficient suspended sediment particle analyses made to represent this group,

Landslide-prone soils are not as prevalent as in glacial stream watersheds, High-hazard, fine-textured soils often occur in these watersheds. Ash soil conditions occur near Sitka and on Revillagigedo Island,

Since these streams are below lake catchment basins, bedload supplies to the streams are often limited. The flows are usually more regulated and consequently do not move rapidly. These streambeds are vulnerable to the adverse effects of sedimentation.

Groundwater-fed streams.--Two streams of the Mendenhall Valley, Duck Creek and Jordan Creek, represent this group. The one set of samples for each creek shows 22 and 21 ppm suspended sediment. This small sample is insufficient for extrapolation to other groundwater systems. Furthennore, these two streams are high in iron, and one is badly polluted.

Managing the soils and streamside conditions of groundwater-fed stream systems may offer few problems as long as channels are not disturbed. These streams can carry only fine-sized particles, and their gradient can easily be upset by sediment in the channel.

High relief, glacier-form watershed streams (fig. 4). --This is the largest group of streams in terms of available sample information and is probably also the dominant stream system type in southeast Alaska.

From 16 streams sampled in this group, of 263 samples, 162 were from Hollis. At the time the Harris River watershed was being logged, two samples exceeded 100 ppm suspended sediments, and five other samples exceeded 50 ppm. Few of

Figure 4.--Punch Bowl Lake which drains into Rudyerd Bay.

the remaining samples exceeded 20 ppm, though Gold Creek at Juneau contained 230 ppm. The suspended sediment particle analysis from Gold Creek showed that, at high suspended sediment conditions, 99 percent of the Suspended material was less than 0.5 mm and 96 percent less than 0.25 mm.

These streams often have landslides or slumps that enter directly into the stream channel and may produce torrents. This slump-slide action occurs in areas of till soils (example: Falls Creek near Thorne Bay) or ash soils (example: Kruzof Island soils).

The bedload of many of these streams is high, which limits the lasting influence of suspended sediment in the streambed.

SEDIMENTATION PROCESS

A general description of the sedimentation process in southeast Alaska streams will help evaluate the risk of sediment problems caused by man's activities. The discussion below describes sedimentation at various streamflow stages: during the rising stage, at peak flow, and during the falling stage. Some parts of this discussion are speculative in that the views expressed are not supported by measured observations. Other portions are based upon measured Observations or samples, They are reasonable conclusions that attempt to tie together isolated measurements.

Virtually all of the gravel composition, bedload scour, and stream channel samples or observations are related to fish habitat research in riffles that are potential spawning areas. These were also areas accessible for sampling. A significant portion of each stream was thus eliminated from sampling and representation, with the sampled portions tending toward similar composition and bedload movement rate.

Rising stage.--On channel surfaces, sediment particles of fine sand size or smaller become suspended as turbulence increases. As flow rates and turbulence increase, material as large as coarse sand becomes suspended, removing more material from streambed surfaces. At the highest flows, materials as large as gravels move rapidly, and gravel and cobble material roll downstream. Streambed areas with flows that are constricted either by canyon walls, steep banks, or by debris in the channel will be frequently scoured. During periods of increasing flows, materials as large as cobbles will be swept downstream.

During this flow stage, the streambed form is altered to most efficiently handle both the flood flow and sediment load. Rising or high flows tend to produce scouring in upstream areas having steeper gradients--where earlier low flows have left sediment deposits--while favoring deposition in downstream locations having shallower gradients. In situations where rapid coastal uplift is accompanied by lowered sea level, either cutting or a reduced deposition rate will occur immediately above the area of tidal influence, and the stream's ability to carry bedload will be increased due to an increase in gradient near tide level. This situation is generally true north of Petershurg and to a greater extent on the west coast, as at Sitka, than on the mainland, e.g., near Juneau. There are other areas where the coastline may be subsiding, as on Kuiu Island. In these areas, stream profiles to tidewater are shortened, and the head of the tideland delta, in effect, moves upstream due to the rise in sea level resulting in a reduction in the sediment carrying capacity of the stream.

Peak flows.--During high flows, the entire streambed will be in motion to a variable depth. Depth of the moving bed will, of course, vary with the stream--some beds may be 6 to 12 inches deep over bedrock or marine sediments. Other streams of an active nature may have 2 feet or more of depth over a sub-bed deposit. Material suspended at peak flows moves at stream velocity, while larger material moves much more slowly along the bed. Some stream morphologists now contend that the mean annual flood is the event that has the most control on the form of the streambed, and presumably on streambed composition. Gravel sampling in southeast Alaska shows that many streambeds are regularly altered by stormflows, at least every 5 years.

Falling stage.--Material entering main streams as suspended load from steep tributaries may, in part, become bedload in main streams, particularly during the falling stage. Within stream channels, coarse material drops out first in pools and depressions. Successively finer materials settle into place as flows decrease. Part of the sands and other fines (small particles such as silts and clays) enter the streambed; another portion rests on or near the bed surface and remains in position for further moving or "flushing" downstream. Thus part of the sands and other fines are available as bed material to be "cleaned" from the streambed surface without requiring flow velocities that actually put the entire streambed in motion. Streams with high flows of short duration may be more limited in the volume of fine materials that are left on the bed surface during recession. On the other hand, streams with high flows of long duration may not only leave more fines on the bed, but may flush fines farther downstream during storms. The location and volume of deposited fine materials in or on streambeds thus become important in whether subsequent flows can clear the bed. The cleaning process depends upon periodic storm events that "plow" the bed and leave fine materials at the surface. This type of limitation to flushing exists if we assume that Vaux (1962) is correct in stating that fines, once in a streambed, cannot "flush out" unless the entire bed is in motion.

TEMPERATURE

It is well established that summer stream temperatures usually increase following the removal of streamside vegetation. Meehan et al. (1969) found that, following complete clearcutting of about 7 miles of main stream in Harris Creek and 5 miles of Maybeso Creek, temperatures rose an average of 7.2° C (4° F) and 16.2° C (9° F), respectively, during a single day.

The principal source of heat for stream water is direct solar radiation (Sheridan 1962, Brown 1969). When shade-producing streamside vegetation is removed, water temperatures may increase several degrees. The magnitude of increase depends on several other factors, too, such as volume of streamflow, ground water influences, length of channel exposed to solar radiation, and general climatic conditions. The most drastic changes are observed in small streams. Lakes and estuaries are affected more than streams (fig. 5).

Figure 5.--Chaik Bay on Admiralty Island with a typical intertidal zone and estuary.

Sheridan (1962) reported that stream temperature differences result from:

1. Geographic location of the stream
2. Size of watershed
3. Amount and type of precipitation falling on the watershed
4. Height of source region above sea level
5. Whether stream is lake fed or nonlake fed
6. Whether the watercourse is shaded or open

He concluded that the greatest temperature variation between streams occurred during the spring and summer. In the fall, stream temperatures from both cold and warm streams tend to show less differences, and the least variation occurs during winter and early spring when both cold and warm streams are nearly the same temperature.

Stream-water temperatures are especially important since they affect fish habitat. For example, pink and chum salmon do not utilize fresh water for rearing, only for spawning and incubation of eggs and alevins. Although some minor feeding may occur immediately following emergence, feeding and growth generally take place in the marine environment. Water temperature plays its kin role in regulating the duration and timing of incubation, hatching, and emigration from the freshwater system. From the time of egg deposition and fertilization, a certain number of temperature units[2] are required for the eggs to develop into free-swimming fry. If this development is accelerated or delayed by even a very minor temperature increase, for example, 0.5° F, due to removal of streamside vegetation, fry may emerge considerably earlier or later than they normally would in that stream. Downstream migration to the sea might be impeded at that time, or conditions for growth and survival in the ocean might be unfavorable at that time of year. These are considerations that have largely been overlooked until recently.

In rearing areas, water temperature changes may affect habitat in different ways. Aquatic insects and other invertebrates which are food organisms may respond to temperature changes in terms of species composition as well as biomass. In some cases increased temperatures might be favorable. Cold streams shaded by dense forest canopies may not be optimum trout habitat (White and Brynildson 1967). Thinning riparian canopy would allow more solar energy to reach the stream, raising water temperature a few degrees and possibly increasing production of algae and aquatic insects.

Water temperatures can also affect growth rates and behavior of fish and other aquatic organisms. Metabolic rates and growth increase as temperatures rise.

In some situations where water temperatures were warm to begin with, an increase in temperature could contribute to decreased dissolved oxygen supplies and might promote the growth of slime bacteria or fungi which could cause excessive mortality of incubating eggs. Winter temperature change resulting from removal of insulating riparian vegetation is another area in which we lack definitive information. In southeast Alaska, where sustained periods of well-below-freezing air temperatures are common, a slight alteration of water temperature in winter might be more critical than summer increases.

---

[2] A temperature unit (TU) is defined as 1" of temperature Fahrenheit above freezing for 24 hours; e.g., at 34° F constant temperature, eggs accumulate 2 TU's per day.

Salmon stream catalogs for southeast Alaska use 13" C (55.4° F) as a division between streams that are cool or warm during the spawning period. A few streams exceed 15" C (59° F) occasionally. For management purposes Bishop[3] proposed that streams be classified in one of four categories: (1) glacial, (2) cool, <10° C (50° F), (3) moderate, 10°-15.6° C (50°-60° F), and (4) warm, >15.6° C (60" F).

It is possible in some situations to predict with fair accuracy how stream temperatures will be affected by removal of streamside vegetation (Sheridan 1962, Brown 1969). Factors which influence this type of calculation include amount of streamflow, available radiation, surface area of stream exposed to solar energy, and length and time of travel of the stream through clearings. Confounding conditions include entry of surface water and ground water--the latter being the more complicated factor to deal with. Some study of volume of low summer flows should be done.

Streams that are considered sensitive to temperature changes have been identified on maps and in timber harvest guidelines. Recommendations include:

1. No more than 25 percent of streamside overstory canopy may be removed in the initial timber harvest entry.

2. When timber harvest occurs to the stream edge, a clearcut no longer than 1,320 feet on the cool side and 660 feet on the warm side may be made. This prevents extended stream exposure to the sun.[4]

Small streams that have extreme low flows are the most vulnerable to temperature increases following clearcutting. Studies now in progress show that stream temperatures rose for brief periods to critically high levels in some small streams that were clearcut to the streambank (see footnote 4). Other studies now in progress show that many of these small streams are critical rearing areas for some species of fish such as coho salmon and Dolly Varden char.

WATER CHEMISTRY

The water found in lakes, streams, oceans, and wells is never completely free of organic and inorganic matter. Water is a solvent and a mechanical erosive agent so it contains many dissolved minerals as well as those present as undissolved sediments in suspension.

The dissolved-solids content is often considered the most important criterion for assessing chemical quality, because suitability for drinking and industrial uses decreases as dissolved solids increase. (However, the reverse

---

[3] D. M. Bishop. A proposal for classification of streams of the Tongass Forest. Unpublished report in U.S. Forest Service files, Juneau, Alaska, 8 p., 1969.

[4] USDA Forest Service Environmental Statement, Ketchikan Pulp Company Timber Sale 1974-1979 Operating Period. On file at U.S. Forest Service, Juneau, Alaska.

relationship often applies for aquatic productivity.) Concentrations of dissolved solids may range from a few milligrams per liter (mg/l) in snowmelt or rainwater to over 35,000 mg/l in seawater. Freshwater as defined by Feulner et al. (1971) contains not more than 1,000 mg/l dissolved solids. Most Alaskan streams are freshwater, by this definition.

Water may be classified as fresh and still be unfit for many uses. The present standard for public water supplies recommends that the dissolved solids content not exceed 500 mg/l (U.S. Public Health Service 1962). Most industrial and municipal users prefer water with dissolved-solids content of 250 mg/l or less. Some Alaskan streams and much of the ground water contains more than 250 mg/l, so this factor may be important in selecting a source for municipal or industrial supplies, as well as for assessing the range of conditions for fish habitat quality.

Sampling from 38 points in southeast Alaska showed that dissolved-solids content ranged from 3 mg/l to 120 mg/l in the summer and from 1 to 105 mg/l in the winter. The average was 18 mg/l in the summer and 19 mg/l in the winter. Water in the northern portion generally had a higher dissolved-solids content than that in the southern portion. Surface water dissolved-solids content is generally of the calcium bicarbonate type with a few samples high in iron. All of the surface water samples were of acceptable quality by U.S. Public Health Service standards.

Often the most noticeable characteristic of water is its hardness. The ions of several metallic elements cause hardness, but those of calcium and magnesium are the most important. At one time, hardness was defined as a measure of the water's soap-consuming powers. Hardness also affects the tendency to form scale on heated metal surfaces such as boilers or tea kettles.

Stream-water hardness depends mainly on the kinds of bedrock exposed in the watershed. Streams draining granitic rocks contain soft water, whereas streams draining watersheds underlain by limestone are hard. Areas with high rainfall usually have streams with softer water than streams in areas with low rainfall. Ground water is usually harder than stream water in the same area (Feulner et al. 1971). The tabulation below defines hardness ranges.

Hardness range (mg/l of $CaCO_3$)[5]	Hardness description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Water hardness may not be a critical consideration in developing domestic water supplies but is an important criterion in developing larger water systems for industrial uses.

The relative quantities of some of the ions affect the suitability of water for various uses. Many ions may be present in very small amounts without

---

[5] Milligrams per liter represents the weight of solute or sediment per unit volume of water.

affecting quality. Usually only a few are present in sufficient quantity to affect water quality appreciably. The four major cations are calcium, magnesium, sodium, and potassium. The four principal anions are bicarbonate, sulfate, chloride, and nitrate.

Ionic composition is important from the standpoint of drinking water quality. Sodium concentrations are usually not limiting, and potassium and bicarbonates are generally not limiting for most uses. Sulfate and chloride concentrations up to 250 mg/l each are acceptable for most purposes, although water becomes corrosive and unpalatable at high concentrations.

Silica is the major un-ionized constituent in most water and a vital ingredient from a biological standpoint. Silica is necessary for the growth of diatoms which are organisms basic to the food chain. In some Alaskan water, silica is a limiting nutrient. Most Alaskan surface water seldom contains more than 10 mg/l silica, but some streams contain as much as 30 mg/l. Ground water usually contains more silica than surface water. Silica concentrations from 30 to 60 mg/l are common in ground water in some areas of Alaska.

Iron and manganese are a problem in water all over Alaska, particularly in ground water. Iron and manganese are often found in shallow wells but may be absent from deep wells in the same area. Iron probably causes more problems than any other constituent because it causes both scale and stains, Iron and manganese together should not exceed 0.3 mg/l (U.S. Public Health Service 1962).

Information on the surface and ground water chemistry in Alaska is variable in coverage. Some regions have been periodically sampled for many years, and other areas are represented by only a few scattered samples. Although there is variation in chemical characteristics of the lakes and streams in Alaska, the ranges in concentrations are less than those found in the "lower 48" States. Most Alaska streams contain water of a calcium bicarbonate type usually containing less than 20 mg/l dissolved solids. Streams in the lowlands usually contain harder water than streams in the mountains. Water in lakes is usually more variable in mineral content than river water. The water in some mountain lakes is very similar to rainwater in mineral concentration,

The water chemistry of lakes and streams may be affected by land use activities such as timber harvesting, roadbuilding, and mining. Gregory (1956) found that soil temperatures increased significantly following clearcut logging near Hollis on Prince of Wales Island. In addition to soil temperature changes, many nutrients in the soils and litter may be released following disturbance and by the soil warming caused by timber harvest.

In an area near Petersburg, Alaska, soils scientists sampled soil and creek water nutrient content before and after logging. Results are shown in table 2.

Such increases in nutrients can cause an increase in growth of algae, slime bacteria, and other indicators of stream eutrophication. This is unlikely to occur in free-flowing streams but occurs in streams with low gradient or obstructed flow, as well as in lakes and ponds. Associated with eutrophication and decomposing organic matter are reductions in dissolved oxygen content. Since a supply of oxygen is critical to all aquatic organisms, eutrophication as a result of human activity is unacceptable from a land-manager's viewpoint.

Table 2.--Nutrient content of soils and surface water before and after timber harvest[1]

Nutrient	Surface water (creeks)		Soil water			
			Tokeen Soils (well drained)		Wadleigh Soils (somewhat poorly drained)	
	Timbered	Clearcut	Timbered	Clearcut	Timbered	Clearcut
		- -	grams p			
Nitrate	0.062	0.094*	0.055	0.116*	0.067	0.195"
Phosphate	.86	1.04	1.02	.914	.76	.915
Iron	.07	.15*	.1	.07	.1	1.30*
Calcium	1.72	1.45	1.30	2.23"	1.38	2.35*
Magnesium	,185	.24	.16	.34"	.20	.17
Potassium	.52	.85*	.35	.70*	1.68	2.65"
Sodium	1.12	1.16	1.60	2.26"	1.15	1.15
Organic carbon	4.8	6.3	7.0	12.5	7.0	30.0*

*Indicates that differences between samples from clearcut and timbered areas are probably real, judging by the magnitude of difference and variation between duplicate samples. Analysis by Federal Water Quality Laboratory, Fairbanks, Alaska.

[1] USDA Forest Service Environmental Statement, Ketchikan Pulp Company Timber Sale 1974-1979 Operating Period. On file, U.S. Forest Service, Juneau, Alaska,

The chemistry of surface water in Alaska may also be altered by the use of pesticides and fertilizers. Except for the use of herbicides on roadsides, there is no widespread use of either pesticides or fertilizers in Alaska yet; but modern land use practices include an increasing amount of insecticides, rodenticides, fungicides, herbicides, and other chemicals.

The storage and transportation of logs may also affect the chemistry of both freshwater and saltwater in Alaska environments, Bark and other debris, knocked off logs at dumping sites and in raft storage areas, forms a thick suffocating layer in subtidal and intertidal areas (Ellis 1970). Animals such as clams and crabs were scarce or absent at some dump sites that have been studied. Tidal currents in other dump sites prevented heavy bark accumulation.

Leachates also are released when logs are stored or transported in water. (These organic compounds, which are leached from all species of wood, condense and precipitate in seawater.) Pease (1974) found that high concentrations of leachates occurred at two log raft storage sites in southeast Alaska: Herring Cove near Sitka and Thorne Bay on Prince of Wales Island. Limited tidal flushing at Herring Cove resulted in continuous high leachate concentrations. Laboratory tests show leachate concentrations can be toxic to pink salmon fry. The density of benthic fauna was noticeably reduced in the vicinity of both active and inactive log dump sites, Recommendations from Pease's study included:

1. Log bundles should not be unbanded in water unless sunken logs can be recovered.
2. Log bundles should not be stored in estuaries where they may be grounded at low tide.
3. Studies should be made of the feasibility of dredging bark deposits and removing bark from logs before dumping.
4. The benthic community of an area should be studied before dumping so that effects can be monitored.

Leachates also create a dissolved oxygen demand on the water during biodegradation and may lead to foaming problems (Schaumburg 1973).

Color-producing substances in the ligninlike leachates also reduce the esthetic quality of water and may make water unfit for drinking or recreation.

More studies need to be undertaken to provide additional criteria for designating dumping and raft storage sites in order to minimize possible environmental degradation caused by logging-associated debris and leachates.

WATER POWER

Steep topography and heavy precipitation combine to provide many waterpower sites in southeast Alaska. From a waterpower standpoint, the region may be characterized as having small drainage basins, heavy runoff, high heads, and rather short runs to tidewater. Natural storage basins and accessibility to navigable waters combine to make the area potentially desirable for waterpower development. There are about 200 potential power sites which could produce an estimated 1,008,370 average horsepower (Federal Power Commission and U.S. Forest Service 1947).

The close relationship of potential waterpower and timber brought about a consolidation of efforts to inventory the waterpower resources. The Regional Forester of the U.S. Forest Service, Region 10, acted as the Alaska representative of the Federal Power Commission and a report was issued in 1947. The Federal Power Commission had issued a previous report called the "Dort Report" (1924) covering 50 waterpower sites. The engineers of the Federal Power Commission advocated an overall development so that many power sites could be combined to develop a large output of horsepower. Nothing was said of how this power would be used.

Waterpower has been and continues to be used in many places throughout Alaska to provide electricity for mining, sawmills, pulpmills, homes, and other uses. Large power installations such as the Snettisham project south of Juneau have recently been installed, and even larger projects have been proposed..

ESTHETICS

It is difficult to precisely define esthetic values of water. Many people in Alaska have never experienced polluted water. Many people in other parts of the world have experienced only water made safe by chemical additives. Esthetic values are related to the visual impact of water as well as the satisfaction derived from recreational use such as fishing, boating, and swimming.

Much of the water in the lakes, streams, .ponds, marshes, and estuaries of Alaska still remains unaltered by man's activities. The rapid increase in population and resource development will almost certainly result in drastic changes to the land and water resources. Some of the more important activities that may affect water quality include mining, building dams and roads, logging, urbanization, and some forms of recreation.

It is not necessary to repeat the mistakes made during the development of the conterminous States. Much of the knowledge needed to protect the water and land resources is available. Technology has also advanced steadily in efficient ways to convert raw materials to manufactured products with little or no pollution.

The Wilderness Act of 1964, the Wild and Scenic Rivers legislation of 1968, and the Environmental Protection Act of 1971 all reflect a growing public concern for maintaining a high quality environment. Water is not only one of the more important resources that need to be maintained and protected, it is a requirement for life itself.

Some form of zoning or resource allocation is an important part of protection. The Alaska Department of Fish and Game has cooperated with the U.S. Forest Service in establishing an inventory of unique areas requiring special protection. This has been accomplished by correspondence and reviews of multiple-use plans.

Legislation is also an important part of maintaining water quality. The Alaska Department of Environmental Conservation (1973) has established regulations that will, if enforced, insure protection of the water resource.

When one views southeast Alaska with its thousands of miles of coastline, numerous fiords, bays, inlets, streams, and lakes, the word pristine comes to mind as a descriptive term (fig. 6). Maintaining pure water as a part of the pristine state is one of the most important challenges that land managers are confronted with today.

OUTLINE OF WATER RESEARCH NEEDS

Some of the research needed on water will overlap fisheries.research needs. Water is also connected with recreation, wildlife, and esthetics. The more critical research needs are:

Figure 6.--Skowl Arm near old Kasaan on Prince of Wales Island.

1. Precipitation amounts, types, and patterns--Rain and snow intensity and duration pattern, effects of elevation and topography patterns (such as island orientation), interception by major vegetation communities.

2. Land and its cover--Effects of vegetation covers, timber harvesting, other land uses and patterns on streamflow regimen, production and quality, including the regulation of streams by watershed manipulation.

3. Soils--Soil moisture fluxes and their regulation in precipitation-runoff relationships.

4. Streamflow--Responses of regimen, quantity, and quality to precipitation, vegetation, and soil factors.

5. Stream channel development--Streambed geometry in relation to watershed characteristics; gravel morphology, composition, and stability as functions of stream characteristics and stream energy factors.

6. Dynamics of glaciers, icefields, and snowfields and the glaciohydrology of mainland streams--The response of streamflow and sedimentation to glacier nourishment, ablation, and climatological factors; glacier and icefield management for controlled water storage and release; factors affecting their development as a recreational resource.

LITERATURE CITED

Alaska Department of Environmental Conservation
1973. Water quality standards, Chapter **70.** Title 18. Environmental conservation. Register **47.** Alaska Dep. Environ. Conserv., Juneau, Alaska.

Brooks, Norman H.
1958. Mechanics of streams with moveable beds of fine sand. **Am.** Soc. Civ. Eng. Trans. **123: 526-549,** illus.

Brown, George W.
1969. Predicting temperatures **of** small streams. Water Resour. Res. 5(1): **68-75,** illus.

Childers, Joseph M.
1970. A proposed streamflow-data program for Alaska. Water Resour. Div., Alaska Dist. U.S. Geol. Surv. Open File Rep., 55 p.

Colby, Bruce R.
1961. Effect of depth of flow on discharge of bed material. U.S. Geol. Surv. Water Supply Pap. **1498-D,** 12 p., illus.

Dort, Joseph Cummings
1924. Water powers of southeastern Alaska. **172** p., illus. Washington, D.C.: Gov. Print. Off.

Ellis, Robert J.
1970. Report on a study of effects of log rafting and dumping on marine fauna in southeast Alaska, June **6-9,** 1970. U.S. Dep. Commer. Natl. Marine Fish. Serv., Auke Bay, Alaska.

Eschner, Arthur R., and Donald R. Satterlund
1966. Forest protection and streamflow from an Adirondack watershed. Water Resour. **Res.** 2(4): **765-783,** illus.

Federal Power Commission and U.S. Forest Service
1947. Water powers of southeast Alaska, **168** p., illus. Fed. Power Comm., Washington, **D.C.,** and U.S. For. Serv., Juneau, Alaska.

Feulner, Alvin,J., Joseph M. Childers, and Vernon W. Norman
1971. Water resources of Alaska. Water Resour. Div., Alaska Dist. U.S. Geol. Surv. Open File Rep., **60** p., illus.

Field, W. O.
1958. Glaciers of the coast mountains. Alaska and adjoining parts of Canada. Part IIa: Geographic study of mountain glaciation in the northern hemisphere, p. 2a.l.l. New York: **Am.** *Geogr.* Soc.

Gilbert, G. K.
1914. Transportation **of** debris by running water. **U.S.** Geol. *Surv.* Prof. Pap. 86, **263** p., illus.

Gregory, R. A.
1956. The effect of clearcutting and soil disturbance on temperatures near the soil surface in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 7, 22 p., illus.

Hewlett, John D., and Alden R. Hibbert
1961. Increases in water yield after several types of forest cutting. Int. Assoc. Sci. Hydrol. Bull. VI, Annee 3: 5-17, illus.

James, G. A.
1956. The physical effect of logging on salmon streams of southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 5, 49 p., illus.

Kalinske, A. A.
1947. Movement of sediment as bedload in rivers. Am. Geophys. Union Trans. 28(4): 615-620, illus.

Meehan, W. R., W. A. Farr, D. M. Bishop, and J. H. Patric
1969. Same effects of clearcutting on salmon habitat of two southeast Alaska streams. USDA For. Serv. Res. Pap. PNW-82, 45 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Murphy, Thomas D., and Seymour Schamach
1966. Mountain versus sea level rainfall measurements during storms at Juneau, Alaska. J. Hydrol. 4(1): 12-20, illus.

Pease, Bruce C.
1974. Effects of log dumping and rafting on the marine environment of southeast Alaska. USDA For. Serv. Gen. Tech. Rep. PNW-22, 58 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Reinhart, K. G., Eschner, A. R., and Trimble, G. R., Jr.
1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA For. Serv. Res. Pap. NE-1, 79 p., illus. Northeast. For. & Range Exp. Stn., Upper Darby, Pa.

Rich, Lowell R.
1965. Water yields resulting from treatments applied to mixed conifer watersheds, p. 12-15. Proc. Arizona Watershed Symposium, Sept. 22, 1965, Tempe.

Riggs, H. C.
1965. Effect of land use on the low flow of streams in Rappahannock County, Virginia, p. C196-C198, illus. In Geological Survey Research 1965, Chapter C, Geol. Surv. Prof. Pap. 525-C. Washington, D.C.

Rothacher, Jack
1965. Streamflow from small watersheds on the western slope of the Cascade Range of Oregon. Water Resour. Res. 1: 125-134, illus.

Rowe, P. B.
1963. Streamflow increases after removing woodland-riparian vegetation from a southern California watershed. J. For. 61(5): 365-370, illus.

Rubey, William W.
1938. The force required to move particles on a stream bed.. U.S. Geol. Surv. Prof. Pap. 189-E, 21 p., illus.

Schaumburg, Frank D.
1973. The influence of log handling on water quality. EPA-R2-73-085, 105 p., illus. U.S. Environ. Prot. Agency, Washington, D.C.

Sheridan, William L.
1962. Relation of stream temperatures to timing of pink salmon escapements in southeast Alaska. Symp. on pink salmon, H. R. MacMillan Lectures in Fisheries 1960, p. 87-102, illus. Univ. B.C., Vancouver.

Stephens, F. R.
1966. Soil and watershed characteristics of southeast Alaska and some western Oregon drainages. 16 p., illus. USDA For. Serv. Alaska Region, Juneau, Alaska.

U.S. Department of Interior
1959. Stream catalog of eastern section of Ketchikan management district of southeastern Alaska. U.S. Fish & Wildl. Serv. Spec. Sci. Rep. Fish. No. 305, illus.

——— 1963a. Stream catalog of southeastern Alaska Regulatory District No. 2. U.S. Fish & Wildl. Serv. Spec. Sci. Rep. Fish. No. 453, illus.

——— 1963b. Stream catalog of southeastern Alaska Regulatory Districts Nos. 3 and 4. U.S. Fish & Wildl. Serv. Spec. Sci. Rep. Fish. No. 465, illus.

——— 1965a. Stream catalog of southeastern Alaska Regulatory Districts Nos. 5, 6, 7, and 8. U.S. Fish & Wildl. Serv. Spec. Sci. Rep. Fish. No. 523, 443 p., illus.

——— 1965b. Southeastern Alaska stream catalog for Regulatory District No. 9. U.S. Fish & Wildl. Serv. Spec. Sci. Rep. Fish. No. 524, 197 p., illus.

U.S. Public Health Service
1962. Drinking water standards. U.S. Public Health Serv. Publ. 956, 61 p.

Vaux, Walter G.
1962. Interchange of stream and intragravel water in a salmon spawning riffle. U.S. Fish & Wildl. Serv. Spec. Sci. Rep. Fish. No. 405, 11 p., illus.

Waananen, Arvi O.
1950. The hydrology of Alaska, p. 151-162. *In* Science in Alaska. Arctic Inst. North Am. Spec. Publ. No. 1, 305 p.

Walkotten, W. J., and J. H. Patric
1967. Elevation effects on rainfall near Hollis, Alaska. USDA For. Serv. Res. Note PNW-53, 8 p., illus. Pac. Northwest For, & Range Exp. Stn., Portland, Oreg.

White, R. J., and O. M. Brynildson
1967. Guidelines for management of trout stream habitat in Wisconsin. Tech, Bull. 39, 65 p., illus. Wis. Div. Conserv., Madison, Wis.

Wilson, Alfonso, and Kathleen T. Iseri (compilers)
1969. River discharge to the sea from the shores of the conterminous United States, Alaska, and Puerto Rico. U.S. Geol. Surv. Hydrol. Invest. Atlas HA-282,

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

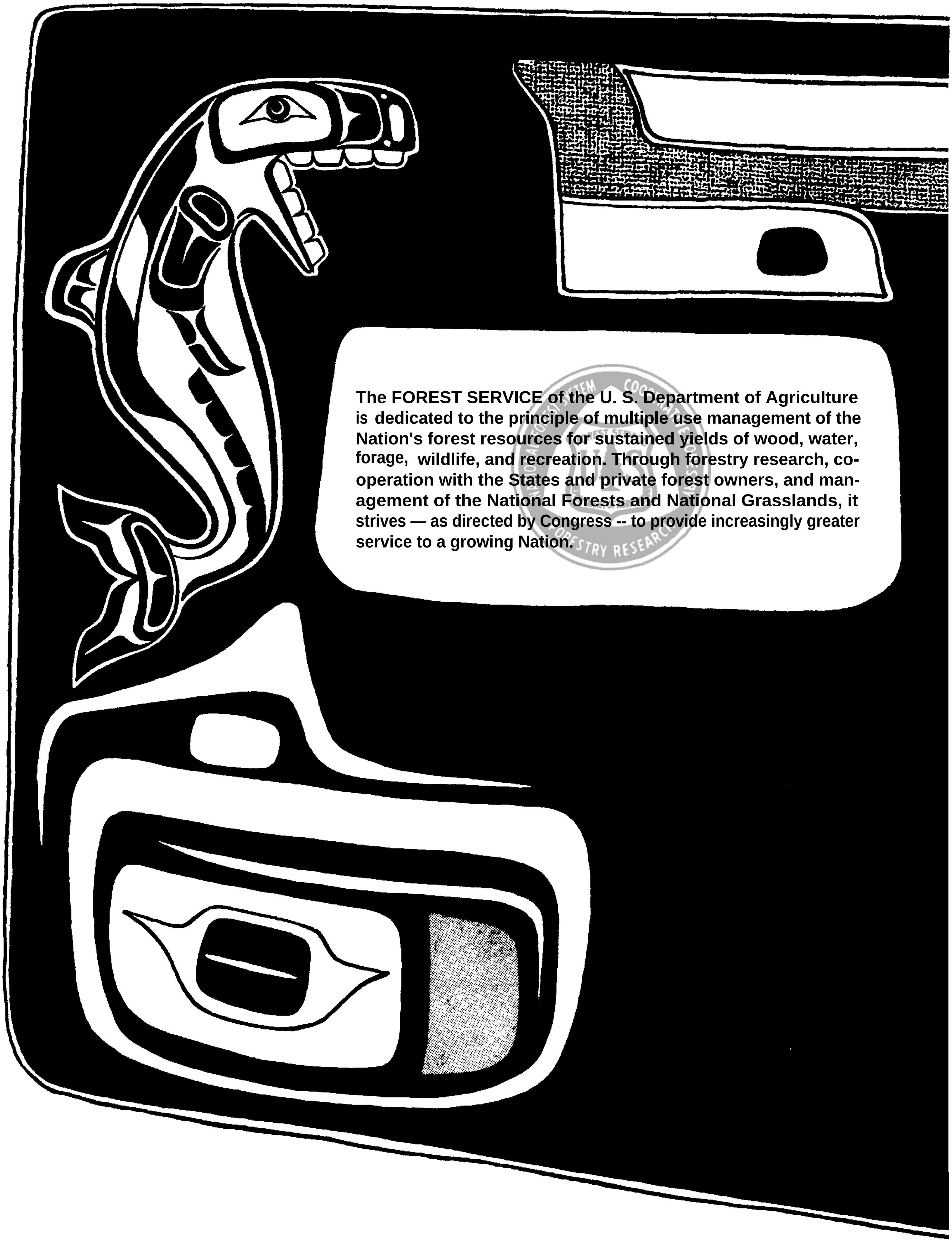
1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corwallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

***Mailing Address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208***

GPO 991-768



The FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress -- to provide increasingly greater service to a growing Nation.