Precipitation and Runoff Characteristics, Queen Charlotte Islands

Land Management Report NUMBER 60

ISSN 0702-9861

FEBRUARY 1990

Ministry of Forests

FISH/FORESTRY INTERACTION PROGRAM

This study as undertaken as part of the Fish/Forestry Interaction Program (FFIP), a multi-disciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Islands forest base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the Islands and prompted the establishment of the 5-year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining the improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines and helicopters, and by logging planning to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests (Research Branch), and the B.C. Ministry of Environment (Fisheries Branch). Participating agencies include Forestry Canada (Pacific Forestry Centre), and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

Program results are published through the B.C. Ministry of Forests, Land Management Report series, as well as in papers presented at symposiums, conferences, and through technical journals.

For information about the program contact Ministry of Forests, Research Branch, 31 Bastion Square, Victoria, B.C. V8W 3E7.

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February 1990

Ministry of Forests

Canadian Cataloguing in Publication Data

Hogan, Daniel Lewis 1954-
Precipitation and runoff characteristics, Queen Charlotte Islands

(Land management report, ISSN 0702-9861 ; no. 60)

Bibliography: p.
ISBN 0-7718-8766-3

1. Precipitation (Meteorology) - British Columbia - Queen Charlotte Islands. 2. Stream measurements - British Columbia - Queen Charlotte Islands. 3. Hydrometeorology - British Columbia - Queen Charlotte Islands. 4. Queen Charlotte islands (B.C.) - Climate I. Schwab, J. W. (James W.) 1951-. II. British Columbia. Ministry of Forests III. Title IV. Series.

QE2830.B7H63 1990 551.57'53'7271131 C89-092118-0

Published by the
Research Branch
Ministry of Forests
31 Bastion Square
Victoria, B.C. V8W 3E7

Copies of this and other Ministry of Forests titles are available from Crown Publications Inc., 546 Yates Street, Victoria, B.C. V8W 1K8.

ABSTRACT

The report provides a regional evaluation of precipitation and streamflow on the Queen Charlotte Islands. All available hydrometeorological data were consolidated from federal and provincial government agencies. The Queen Charlotte Islands were stratified into regions with homogeneous precipitation regimes. This regionalization was then used to develop relationships between monthly runoff and monthly precipitation. Frequency analyses for large magnitude rainstorms and runoff events are presented and used to determine the relationship between storm runoff and storm precipitation. For design purposes, where no data exists for storm precipitation characterisitics, a statistically significant relationship for estimating mean annual peak flows, based upon watershed properties and mean annual precipitation, is presented. Standard hydrology analyses are used. The relationships presented in the paper are statistically significant. However, limitation noted in the report indicated that long-term hydrometeorological data must be collected for the Queen Charlotte Islands so that more reliable precipitation-runoff relationships and more confident return period estimates can be developed.

TABLE OF CONTENTS

APPENDICES

TABLES

FIGURES

APPENDIX TABLES

APPENDIX FIGURES

1 INTRODUCTION

Many studies over the past decade have dealt with natural resource issues on the Queen Charlotte Islands. These studies have encompassed fisheries, forestry, mining, and recreation. In all of them, regional and local climate has been discussed in various degrees of detail. Precipitation and stream runoff data have been required in Fish/Forestry Interaction Program (FFIP) reports (Tripp 1986; Hogan 1986; Karanka 1986; Roberts 1987), and in B.C. Forest Service (BCFS) reports dealing with landslides (Wilford and Schwab 1982; Schwab 1983) and biogeoclimatic zone classification (Banner *et al*. 1984). In addition, mining development applications routinely require an evaluation of precipitation and runoff data.

Although these studies identify the importance of climate to natural resource planning on the Queen Charlotte Islands, none has included a complete review of local and regional hydrometeorology. The one exception is an early report by Williams (1968). However, at that time only 2 years of data for a single west coast climate station (Tasu Sound) were available and of that no continously recorded streamflow data were included. This seriously limits the usefulness of Williams' work to resolve contemporary issues.

Several ongoing and proposed studies on the Queen Charlotte Islands require hydrometeorological information. These include BCFS investigations of landslides[1] and fluvial sediment distributions (FFIP), and proposed studies of the temporal adjustment of stream channels to abnormally large sediment inputs by landslides. Furthermore, hydrometeorological information forms an important supplement to an ongoing study[2] which evaluates the meteorological antecedent conditions associated with landslides. This work logically requires a review of regional hydrometeorology. Also, the Forest Service is often requested by internal and external organizations for data previously compiled for various projects. Response to these requests has been difficult because of the diverse nature of the data collected for each project.

The objectives of this report are: 1) to consolidate available precipitation and streamflow data; and 2) to conduct basic data analyses to satisfy the types of questions most frequently asked about the climate of the Queen Charlotte Islands. The questions usually asked are: What is the relationship between precipitation and runoff in the Queen Charlotte Islands? What is the relationship between precipitation and geographic location in the Queen Charlotte Islands (pattern of spatial precipitation variability)? What is the relationship between geographic location and runoff in the Queen Charlotte Islands? In response to these questions, the following analyses were undertaken:

- development of relationships between precipitation events and storm runoff amounts;
- regionalization of precipitation and runoff regimes;
- estimation of the influence of elevation on precipitation amounts;
- frequency analyses for extreme precipitation and stream flood events; and
- development of a relationship between watershed and streamflow characteristics.

This report evaluates the suitability of the currently available precipitation and runoff data to address common information requirements. It also identifies the limitations placed on the analyses due to data quality and quantity problems. These deficiencies are identified to show where more monitoring is required and to place confidence limits on the analyses presented here.

[1] Schwab, J.W. 1985. Historical Documentation of Mass Wasting, North Coastal B.C. EP782.07. B.C. Min. For., Victoria, B.C.

[2] Hogan, D.L. and J.W. Schwab. 1986. Meteorological conditions associated with hillslope failures on the Queen Charlotte Islands. EP782.09. B.C. Min. For., Victoria, B.C.

2 DATA SOURCES AND METHODS

2.1 Data Sources

Long-term precipitation records (30-year normals) were obtained from the Canadian Atmospheric Environment Service (AES). Short-term records (4 years of daily values and simulated 30-year normals) were obtained from the British Columbia Ministry of Environment, Resource Analysis Branch (RAB). The location of each station is shown in Figure 1. A list of selected stations, record lengths, and the reliability of each data set are presented and discussed in Appendix 1. Also, continuous precipitation records of less than 2 years in duration were collected by field staff during the Fish/Forestry Interaction Program (FFIP)[3] and obtained for three watersheds. Their reliability is considered in Section 5. Standard tipping bucket rain gauges and mechanical chart event recorders were used at the FFIP sites. Site characteristics at these locations complied with correct site conditions as outlined by the provincial Air Studies Branch (ASB) and the federal AES.

Long-term streamflow records were obtained from the Water Survey of Canada (WSC). Only three stations have more than 2 years of records available for the Queen Charlotte Islands (Table A2.2). Continuous streamflow records were also obtained for three sites by FFIP personnel. These records, which are between 1 and 2 years in length, are not completely reliable (Section 5) and had to be carefully reviewed before the data were accepted and used in this study. The FFIP streamflow gauging stations were located in pool sections of the channel, and immediately upstream of stable riffles. Each site was equipped with a Stevens stage recorder and stilling well. Stream gauging was conducted on numerous occasions (more than 12 times at each station) to construct and maintain the stage-discharge rating curve. A Price Type A or OTT meter was used to measure flow velocity. All field and analytical procedures followed were in accordance with methods given by Church and Kellerhals (1970). All stage records were digitized by computer. Daily mean, maximum, and minimum discharge records, in addition to the stage recorder chart, are on file at the B.C. Ministry of Forests Prince Rupert Regional Office in Smithers.

2.2 Frequency Analysis

Frequency analyses were performed on the long-term AES precipitation and WSC flow data. All analyses were done by the relevant government agency and standard techniques were used.

2.2.1 Precipitation

Maximum annual 1-day, 2-day and 3-day precipitation totals for each AES station on the Queen Charlotte Islands were collected from the published AES data summaries. The AES provided the detailed frequency analysis tables (Table A2.1).

2.2.2 Streamflow

Daily, monthly, and annual streamflow data for each station on the Queen Charlotte Islands were collected from the published WSC data summaries. Instantaneous and daily maximums for each year are compiled and entered into files on the B.C. Ministry of Environment computer system[4]. The Ministry of Environment program provides frequency analysis using four distributions:

1. three-parameter log-normal distribution, fitted by the method of maximum likelihood;
2. Gumbel distribution, method of moments;
3. Pearson Type III distribution, method of moments; and
4. Log-Pearson Type III distribution, method of moments.

[3] Data collected by L. Beaven, D. Boulion, and F. Noone.
[4] All computer work was conducted by R. Wyman, B.C. Ministry of Environment, Victoria, B.C.

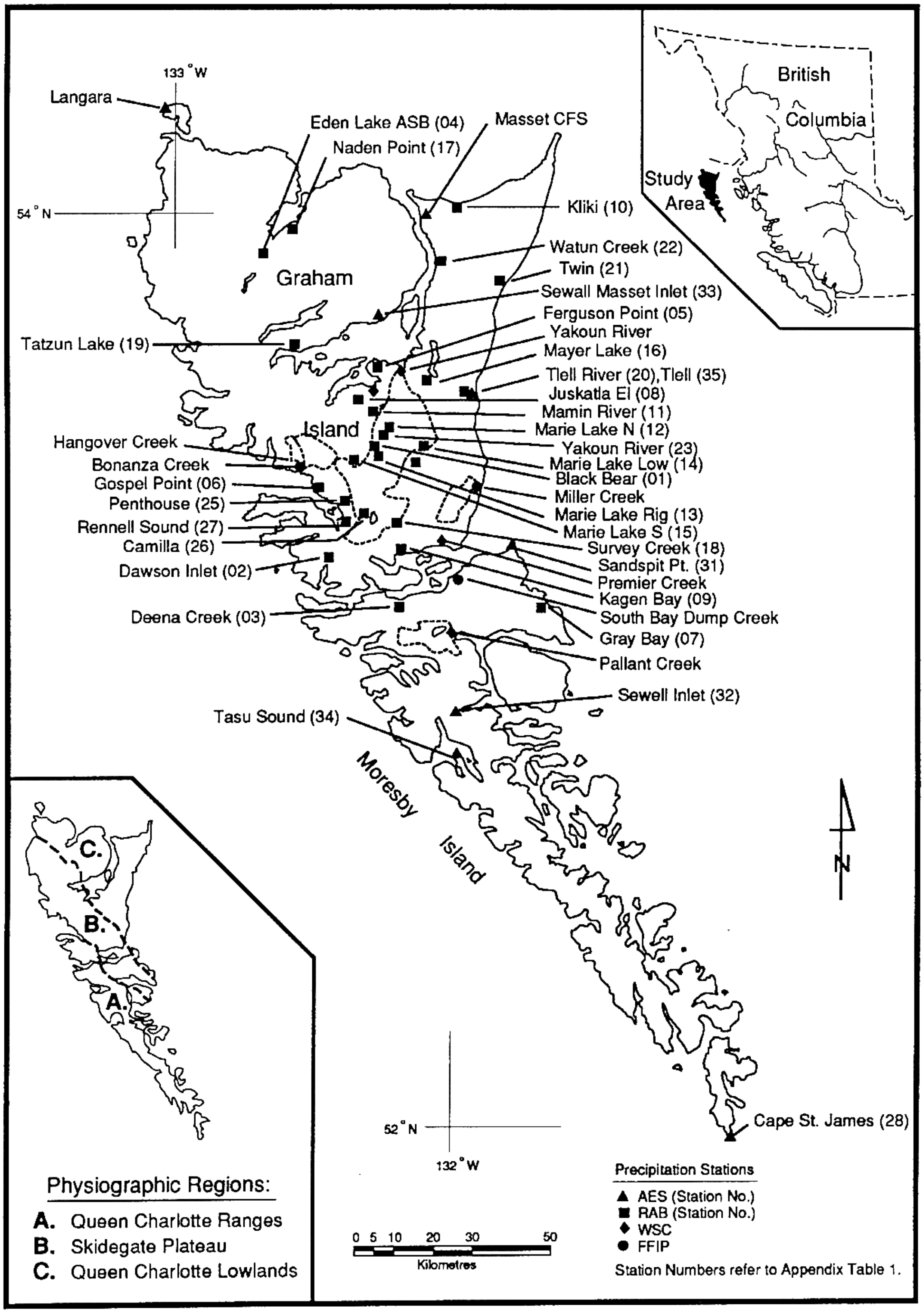

FIGURE 1. Location of hydrometeorological stations on the Queen Charlotte Islands.

The final choice of the distribution use is left to the discretion of the individuals requesting the data analysis.

The ‘‘unbiased’’ or Cunnane formula for plotting positions is used; but, for each data set, plotting positions are provided using the Weibull, and Weibull and Hazen formulas (Appendix 2). The program provides standard errors and 95% confidence limits for all but the Gumbel distribution.

The following procedure was used to decide on the ‘‘best’’ distribution for each application of the program:

- The statistics for the Kolmogorov-Smirnov (K-S) test for goodness of fit, provided by the program for each distribution, were analyzed. The program documentation provides guidelines for using these statistics.
- The standard errors for the 20-year estimate were compared.
- The data points and the four fitted distributions were plotted, and the fit of the distributions to the data was qualitatively examined. Log-Gumbel paper was used for plotting and the graphs are included in Appendix 2 (Figure A2.2).

2.3 Calculation of Precipitation and Runoff Relations

The general relationship between precipitation and runoff was evaluated by reviewing RAB, AES, and WSC data. Precipitation data were taken either from the closest weather station to the corresponding watershed, or from the average of a number of stations. The relationships developed are based on regression analyses incorporating monthly precipitation and monthly runoff (mm) totals for Pallant Creek and Yakoun River.

All precipitation-runoff events were identified and selected from Hangover, Miller, and South Bay Dump creeks (FFIP). The corresponding time periods were obtained for the Yakoun River, Pallant Creek, and Premier Creek (WSC).

Discharge hydrographs were plotted for each event and stream. Hydrograph separation was accomplished by projecting the pre-storm baseflow under the peak and drawing a line from the point directly beneath the peak flow to a point on the recession limb N days after the peak, where N (days) = $A^{0.2}$ (mi^2), according to Dunne and Leopold (1978). Stormflow volumes were calculated by planimetering the area beneath the curve, as shown in Figure 2. Event timing was based on the lag time between maximum precipitation and peak streamflow.

Precipitation intensity was calculated as the amount of storm precipitation divided by the storm duration. The calculation of three different intensity values were required because of record variations between stations: ‘‘average intensity’’ refers to the mean daily precipitation for duration of the storm; the ‘‘maximum 24-hour intensity’’ refers to the single day with the greatest amount of precipitation (all AES stations); and ‘‘maximum intensity’’ for all FFIP stations refers to the steepest segment of the hourly cumulative precipitation chart.

Antecedent moisture conditions were defined according to the precipitation characterization methodology of Kohler and Linsley (1951, in Linsley *et al*. 1975). This technique assumes that soil moisture decreases logarithmically with time during periods of no precipitation,

$$I_t = I_o K^t$$

where I_o is the initial value of the antecedent-precipitation index, I_t is the reduced value t days later, and K is a recession factor ranging normally between 0.85 and 0.98. The available water capacity multiplied by the depth of soil profile provides the first estimate of I_o (Dunne and Leopold1978). Soils considered typical for the study area are Ferro-humic podzols 1 m deep (Smith *et al.* 1986). The k value used was 0.9. The I_o was calculated as 100 mm, which assumes soils are of a sandy loam texture. The 10-day period before each storm was considered.

Storm analyses were conducted in a consistent manner. Only rainfall that produced the runoff was selected. Small showers occurring after the hydrograph had started to recede were not included. The

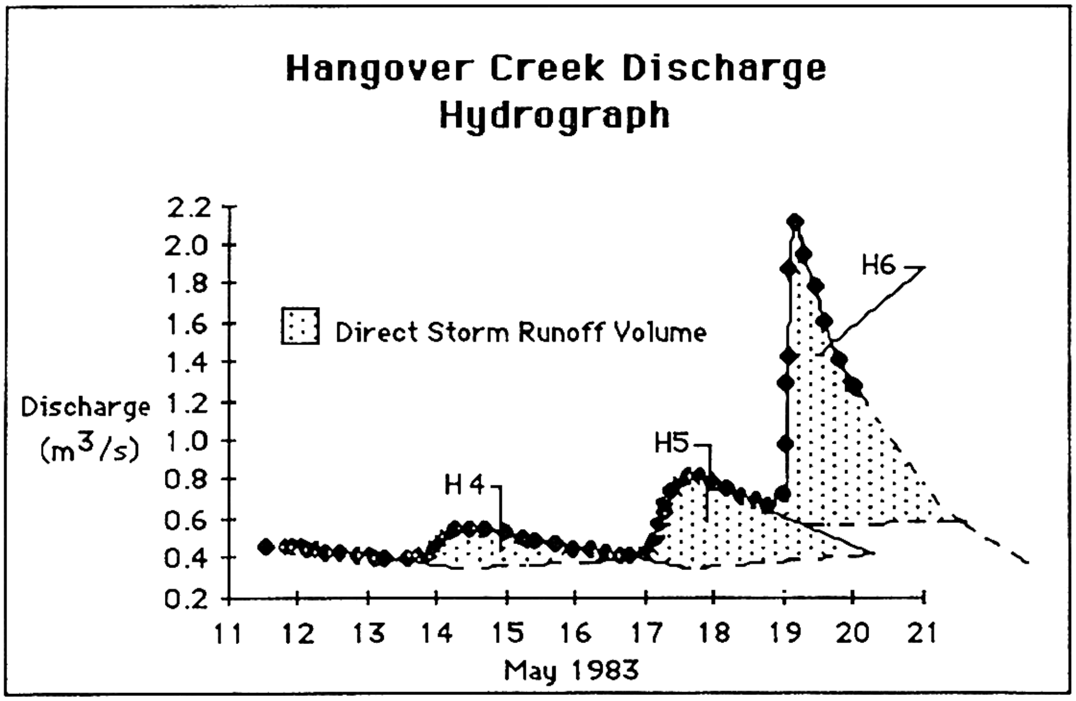

FIGURE 2. Example of method used for hydrograph separation.

procedure of selecting WSC records that corresponded to the same runoff event measured at FFIP sites caused minor analytical problems. These resulted from a difference in storm timing at the WSC stations: because of different storm track directions, the same storm would arrive at the WSC site either before or after its arrival at the FFIP sites. In these cases, precipitation and runoff from slightly different time periods would be analyzed. Also, the storm intensity would often change between the FFIP and WSC sites, so that in some cases rather small events were included in the analyses.

Peak Flow Estimation Based on Precipitation and Watershed Characteristics

Two methods are used to estimate streamflow in ungauged watersheds. First, a simple graph relating watershed area[5] and mean annual maximum instantaneous discharge (Benson 1962) was plotted. Streamflow values were obtained from the frequency analysis data conducted by the B.C. Ministry of Environment.

Hangover and Bonanza creeks were included to extend the range of watershed sizes (drainage basin areas of 20.2 and 45.2 km^2, respectively). Data for these watersheds were derived from Hogan (1985). The mean annual maximum instantaneous discharge is used and refers to the flow corresponding to a recurrence interval of 2.33 years[6] assumed to be equal to the bankfull discharge based on morphological evidence.

Second, a multiple regression model was developed relating mean annual maximum instantaneous discharge to mean annual precipitation, basin relief, elevational bands (proportion of basin below 150 m, between 150 m and 1000 m and above 1000 m) and area occupied by lake. Precipitation values were estimated from geographical precipitation zones in Figure 8. Basin characteristics were obtained from 1:50000 topographic maps for the large basins (Yakoun and Pallant) and from air photographs for the smaller watersheds. Areas were measured with a digital planimeter. The elevation limits selected were based on biogeoclimatic zones (Banner *et al*. 1984).

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[5] Watershed areas were obtained from WSC records with the exception of Premier Creek which was determined from 1:20000 air photographs.

[6] Record length of 2 years is insufficient for frequency analysis (a minimum of 10 years is required).

3 REGIONAL PRECIPITATION

The Queen Charlotte Islands are characterized by a humid, temperate climate with mild winters and cool summers. Williams (1968) presents a relatively thorough review of the climate patterns and Karanka (1986) provides an assessment of long-term temporal climatic variability. Spatial patterns of precipitation only are considered in the present paper.

The AES operates eight weather stations on the islands. These are not representatively distributed: only one station was located on the west coast (Tasu, which was discontinued in 1984). The AES records indicate that the mean annual precipitation varies from approximately 1200 mm on the northeast coast of Graham Island to over 4200 mm on the west coast. Higher elevations on the west coast probably receive far in excess of this value (Williams 1968). Snowfall amounts appear to be insignificant when compared to annual rainfall amounts (1% of the mean annual precipitation at Cape St. James and 5% at the other stations), although no snow gauges or courses are operated on the islands.

3.1 Synoptic Patterns

The climate of all mid-latitude locations is characterized as a zone of prevailing westerly winds, with migratory high and low pressure systems moving generally west to east from regions of formation to their eventual dissipation. The general synoptic climatology of the Pacific Northwest has been documented by Maunder (1968), Suckling (1977), Zishka and Smith (1980), and Yarnal (1983).

Cyclonic storms are particularly important because their frequencies are related to the general variability of inclement weather at a site and are important to the seasonal and annual variation in precipitation. Patterns of cyclone development, movement and dissipation have been detailed by Klein (1957) and Reitan (1974). Lewis and Moran (1985) have discussed the synoptic setting of 125 severe storms which occurred off the west coast of British Columbia. An example of their data is presented in Figure 3; this depicts the atmospheric conditions during an early winter storm in 1978. The heavy rainfall received on the islands during this storm was due to the passage of a strong frontal zone ahead of a deep low pressure cell centred over western Alaska (Schaefer 1979a and b).

Figure 4 shows 25-year composite storm track summaries for October, November, and December. Clearly, severe winter storms are a relatively common occurrence in areas adjacent to and north of the Queen Charlotte Islands.

3.2 Precipitation and Topography

Precipitation gradients are highly influenced by orographic uplifting across the Insular Mountains (Figure 1). Mean annual precipitation reaches 4500 mm per year within 20 km of the windward outer coast and diminishes gradually across the leeward slope of the Skidegate Plateau (Karanka 1986). The leeward coastal plain is relatively flat and usually does not exceed 150 m in elevation. Annual precipitation in the eastern areas varies from 1200 to 1500 mm.

No clear pattern emerges between mean annual precipitation and elevation when all AES and RAB stations are compared (Figure 5). Although precipitation usually increases with elevation, there is too much variability to allow a general relationship to be developed. This variability is likely a result of the inclusion of stations on both the leeward and windward sides of the north-south trending mountain range of the Queen Charlottes. The scatter of certain points is possibly also due to operational problems associated with high-elevation stations (e.g., wind exposure and snow accumulations).

Two locations with multiple rain gauges were considered so that the importance of elevation to precipitation amounts within similar areas could be evaluated. The stations in the Marie Lake area and immediate vicinity were operated for between 4 and 8 years by the RAB. These stations were located in the Skidegate Plateau Region (see Figure 1) and consisted of a series of 15 precipitation gauges. The stations

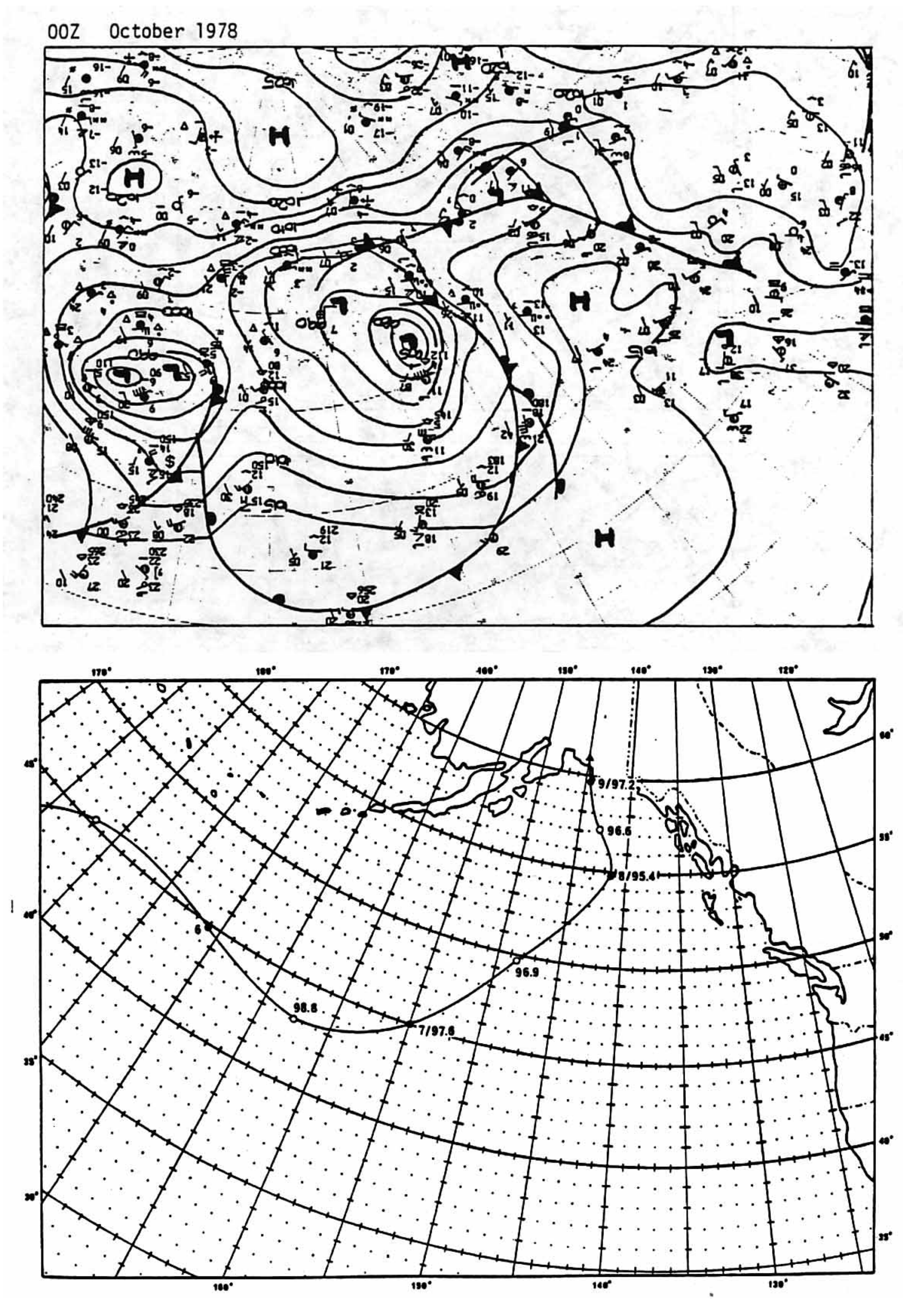

FIGURE 3. Surface synoptic chart for October 30, 1978, storm (from Lewis and Moran, 1985).

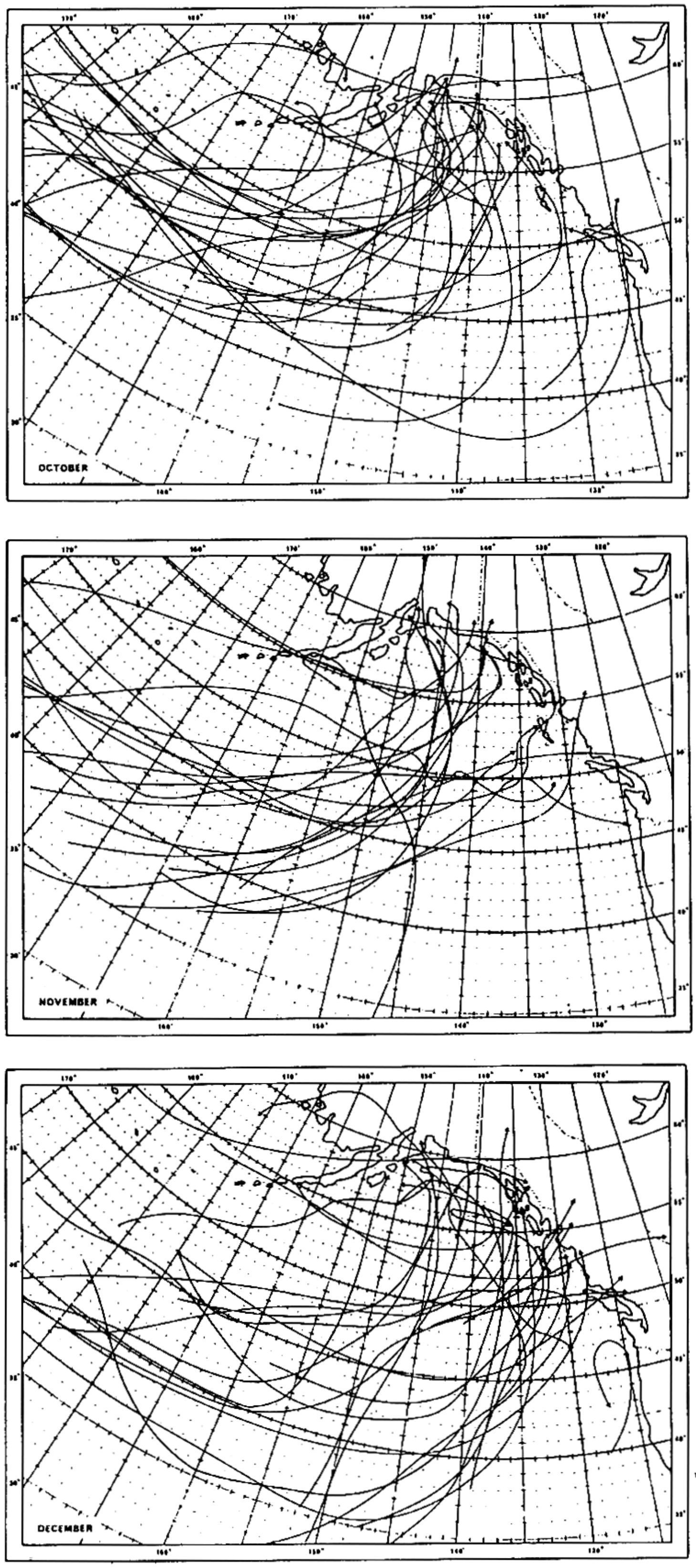

FIGURE 4. Composite storm track summary for the months of October, November, and December, 1957 - 1983 (from Lewis and Moran, 1985).

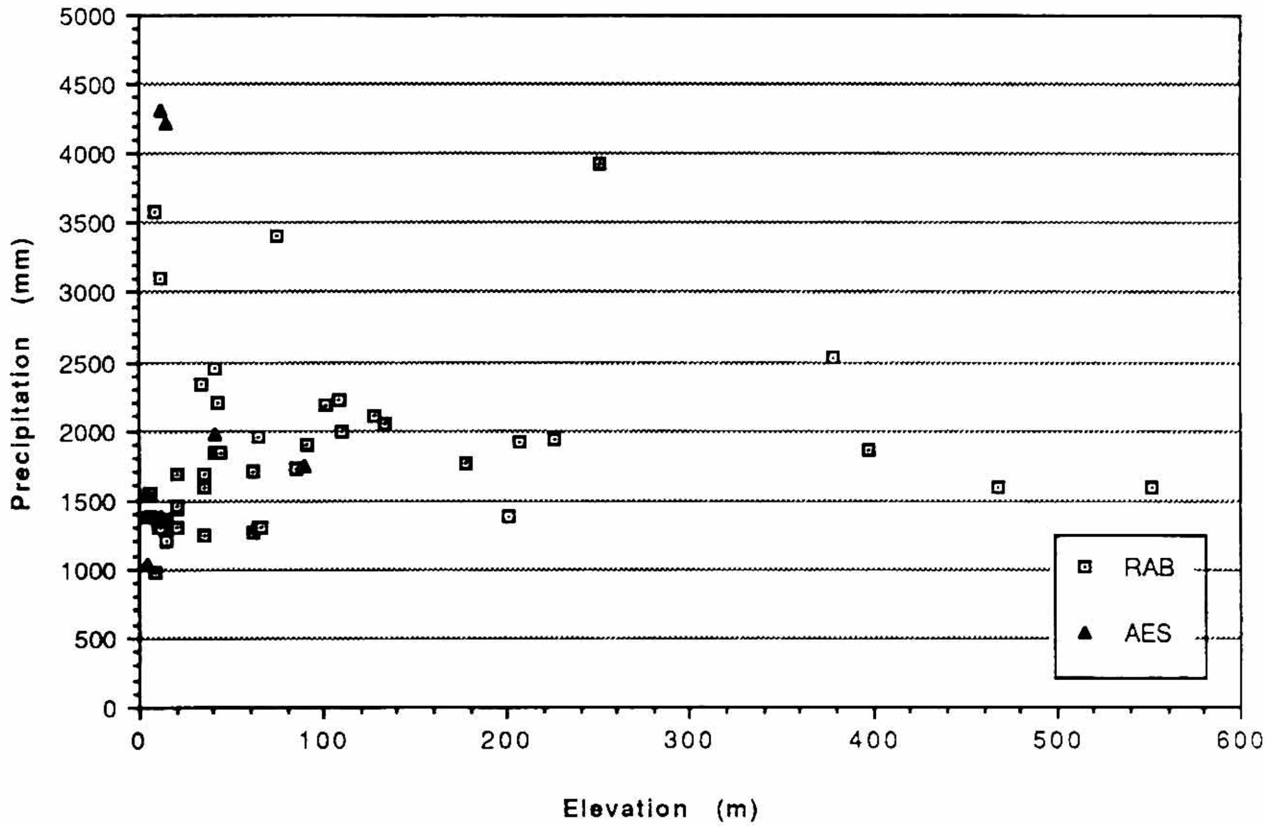

FIGURE 5. Mean annual precipitation (30-year normals) at 8 AES and 44 RAB stations. Note that the RAB values are estimates of the long-term mean annual precipitation as calculated by that agency.

ranged in elevation from near sea level to approximately 470 m above sea level. There is speculation that the highest station suffers from exposure problems during high winds (B. Marsh, pers. comm., Air Studies Branch ASB), which leads to lower than actual estimates of precipitation for this elevation. The South Bay Dump Creek network, installed by FFIP personnel, consisted of six gauges and was operated from May 1983 until March 1984.

The relationships between precipitation and elevation (Figure 6) are as follows:

	South Bay Dump:	PRECIP	=	1108.024 + 0.321 ELEV (n = 6, r = 0.830)
	Marie Lake:	PRECIP	=	341.678 + 0.279 ELEV (n = 15, r = 0.696)
or	Marie Lake:	PRECIP	=	337.770 + 0.399 ELEV (n = 14, r = 0.760, excludes high-elevation station)
where:		PRECIP	=	total precipitation (mm) for period of record
		ELEV	=	Elevation (m)

The graphs in Figure 6 indicate that elevation exerts a significant influence on precipitation amounts (at 95% confidence level). Precipitation increases by approximately 30-40 mm for each 100-m increase in elevation for the given records. Only the slope of the regression line is important because the record lengths do not correspond to a given time period (e.g., month, season, year). The intercept reflects the particular record length (5 months for the Marie Lake and vicinity stations, and 6 months for the South Bay Dump Creek stations).