EXTREME FLOODS IN THE PACIFIC COASTAL REGION

by

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ABSTRACT

The research program developed hydrograph procedures for estimation of extreme rain-on-snow floods on ungauged watersheds in the Pacific coastal region. A multi-disciplinary investigation was undertaken encompassing the areas of hydrometeorology, snow hydrology and hydrologic modelling. Study components include assessment of flood producing mechanisms in the coastal region; analysis of regional rainfall characteristics for input to a hydrograph model; examination of the role of a snowpack during extreme events; and application of a hydrograph model.

Based on an assessment of atmospheric processes which affect climate, examination of historical flood data, and analysis of flood frequency, it is shown that the area bounded by the crests of the coastal mountains forms a hydrologic region with similar flood characteristics. Extreme floods in the coastal region are rainfall-induced, either as runoff from rainfall-only or as a combination of rain and snowmelt.

Recorded storm rainfall along the coast was examined to determine whether regional characteristics could be identified from available data even though the magnitude of rainfall varies between stations. Multi-storm intensity data available from Atmospheric Environment Service and rainfall intensities occurring within single storms that were identified as part of this study were analyzed. Results show that ratios of shorter duration intensities to the 24-hour rainfall are in a relatively narrow range in the coastal region for both multi and single storm intenstity data, and this range set limits on the hourly intensities that need to be considered as input rainfall data to a hydrograph model.

With regard to basin response to extreme rain-on-snow, available literature suggests that for a ripe snowpack, development of an internal drainage network within the snowpack is the dominant routing mechanism for liquid water. Consequences of this conclusion on hydrograph procedures are that a watershed undergoes a transition from snow-controlled to more terrain-controlled water movement and basin storage characteristics approach conditions which would occur on the same basin without a snowcover.

Lag and route hydrograph techniques were investigated to assess whether this method can be applied to rain-on-snow floods. Results from analysis of two rain-on-snow floods suggest this procedure can be applied when the following methodology is adopted: 1) estimate travel time through the basin from channelized and overland flow considerations; 2) select a storage coefficient which simulates basin response; 3) take water inputs as the sum of snowmelt and rainfall; and 4) consider there are no losses to groundwater.

The combination of results from each study component provides a methodology for estimating input rainfall data and for undertaking hydrograph analysis for extreme rain-on-snow floods in the mountainous Pacific coastal region.

TABLE OF CONTENTS

TABLE OF CONTENTS

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TABLE OF CONTENTS

(continued)

LIST OF TABLES

LIST OF TABLES
(continued)

LIST OF TABLES
(continued)

LIST OF FIGURES

LIST OF FIGURES
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1. INTRODUCTION

Most development projects such as dams, railroad and highway extensions, mine sites, pipeline installations and new townsite planning require that flood analysis be undertaken for project design purposes. However, due to the relatively sparse hydrologic data collection network in much of the Pacific Northwest coastal region, flood analysis must be undertaken in many instances without adequate site specific data.

The most common methods in current engineering practice for estimating flood flows can be categorized as either statistical analysis of streamflow data or the application of a model which simulates the runoff process for a basin. The application of these flood estimation techniques in coastal British Columbia is especially difficult. For example, typical problems commonly encountered by the practicing engineer in British Columbia include:

i) the streamflow gauge network operated by Water Survey of Canada and the precipitation gauge network which reports to the Atmospheric Environment Service are relatively sparse in remote regions;

ii) available streamflow and precipitation data cannot be readily transposed with confidence over long distances due to mountainous terrain with its corresponding local variations in climate;

iii) many streamflow and precipitation stations currently in operation do not have long term records and, therefore, meaningful statistical analysis often cannot be undertaken;

iv) available streamflow data are often limited to mean daily flow estimates, though an estimate of maximum instantaneous flood discharge is usually required for design.

The overall goal of this research is to overcome the shortcomings in data described above by establishing a rational basis for estimating extreme floods in instances when sufficient site specific design data are not available. Extreme flood is a subjective classification and is commonly used in context with a specific design objective. For this study extreme flood generally refers to any flood with a return period greater than about 20 years.

While the focus of this investigation is on coastal British Columbia, the results are also generally applicable to the entire northern Pacific coastal region which includes southeast Alaska and the coastal region of Washington and Oregon. Accordingly, some data and results from studies in these other segments of the coastal region are included in this investigation of coastal British Columbia floods.

A multi-disciplinary investigation is undertaken encompassing the areas of hydrometeorology, snow hydrology and hydrologic modelling. Research is presented in four components whose primary objectives are as follows:

CHAPTER 2: to develop an understanding of the flood producing mechanisms for the region by identifying those flood characteristics which are common to the coastal hydrologic region. The emphasis of this study component is on identifying those climatic and runoff conditions which lead to extreme floods, as these are the flows of interest in many instances of engineering planning and design.

CHAPTER 3: to provide a basis for estimating the time distribution of rainfall for input to a hydrograph model. This assessment is undertaken on a region wide scale, although it is recognized that when supplemental site data are available for a basin of interest the more general trends identified for the coastal region may be improved.

CHAPTER 4: to assess basin conditions which affect runoff leading to extreme floods. In particular, the role of a snowpack is investigated with regard to its contribution of snowmelt to total runoff and its effect on the amount and rate of rainfall runoff through the snow.

CHAPTER 5: to develop a hydrograph model that is capable of producing flood estimates for conditions which lead to extreme floods in the coastal mountains of the Pacific Northwest. Hydrograph procedures commonly applied for rainfall events are examined for their potential application to extreme rain-on-snow flood events.

Even though each study component is presented separately in a different Chapter, it is the combination of results which ultimately leads to an understanding of flood mechanisms in the coastal region and the development of analytical procedures for extreme flood hydrograph analysis.

The initial task for any flood analysis is to establish the flood producing mechanism which must be simulated by hydrograph methods. In the coastal region, floods are generally either snowmelt-induced in spring and summer or rainfall-induced in fall and winter. Floods which are rainfall-induced result from rainfall-only or a combination of rain and snowmelt runoff. The situation is complicated further because some basins experience both types of floods during the year. Based on an assessment of atmospheric processes which affect climate in the region, examination of historical flood data and analysis of flood frequency undertaken in this study, it is shown that extreme floods on most basins in the coastal region are generated from rain-on-snow events. Therefore, hydrograph procedures capable of simulating rain-on-snow floods are required for the mountainous coastal region.

A requirement common to all hydrograph models is that the time distribution of storm rainfall onto the basin must be estimated. Therefore, the natural starting point in the development of rain-on-snow hydrograph procedures is analysis of storm rainfall for input to a model. This assessment is an essential task of hydrograph analysis, and can be undertaken separately from assessment of basin response and runoff characteristics.

At an ungauged watershed two steps are usually required to produce a hyetograph for input to a hydrograph model. First, storm rainfall characteristics are estimated at a regional station where rainfall intensity data are available, and then these data are transposed to the project site. The existing gauge network which records rainfall intensity in coastal B.C. consists of only 58 stations and is relatively sparse compared to recommendations (World Meteorological Organization, 1970) for network density in mountainous terrain. Therefore, it is common that a precipitation gauge is not located near a project site. Even when a regional gauge is available, transposing data to a project site is especially difficult in mountainous regions because rainfall can vary over short distances both in plan and elevation.

Because of the difficulty in estimating storm rainfall for hydrograph analysis in the mountainous coastal region, one goal established for this study is to examine whether regional characteristics can be identified from available data even when the magnitude of rainfall varies between stations. Assessment of regional rainfall characteristics in a region as extensive and diverse as the coastal region is uncommon, and is undertaken as an exploratory exercise without previous knowledge as to whether the analysis will produce usable results.

Two types of rainfall intensity data can be used to produce synthetic hyetographs for input to a hydrograph model. One type results from analysis of rainfall intensties from many different storms and the other from analysis of intensities occurring within a single storm. Atmospheric Environment Service summarizes multi-storm intensity data at each of their stations by producing Intensity-Duration-Frequency (IDF) Curves. IDF curves provide average intensities for a given duration and return period, but do not provide information regarding variations in rainfall intensities within a single storm. Development of synthetic hyetographs based on intensity data from IDF curves is an approach commonly applied only because single storm data are seldom available. To improve upon methods employed using IDF curves, analysis of rainfall intensities occurring within single storms is also undertaken as part of this study. This exercise requires all hourly data recorded at each of the 58 stations in the coastal region be obtained on magnetic tape, and computer programs written to scan the tape, identify extreme rainfall events and extract hourly intensities within the storm for further analysis.

The procedure adopted for analysis of regional rainfall characteristics is to examine multi-storm intensity data available from AES and single storm data identified in this study in a ratio format. For example, ratios of 1, 2, 6 and 12-hour to 24-hour precipitation are calculated at each station and then compared to corresponding ratios at all other stations. This method is one approach to identifying regional characteristics even when the amount of rainfall is different between stations. For both sets of intensity data, computer programs are written to extract the necessary data from magnetic tape and undertake the required calculations.

Results of the analysis show that regional characteristics for both IDF and single storm data can be identified in coastal B.C. In practice, these results can be used to set limits on the range of hourly intensities that need to be considered by a design engineer in the absence of site data.

One concern regarding results of analysis of B.C. data is that there are no high elevation stations which record rainfall intensity in the coastal region. To supplement B.C. data, rainfall intensity data from Oregon and Washington are also obtained to illustrate further the regional applicability of rainfall characteristics identified in B.C. and to provide results from stations at higher elevations than are currently available in B.C. Results of analysis of U.S. data show regional characteristics similar to those calculated for lower elevations in B.C.

The next step in developing hydrograph procedures capable of simulating rain-on-snow floods is to assess the role of a snowpack with regard to its contribution of snowmelt to total runoff and its effect on runoff response from the basin. A fundamental question which arises for extreme rain-on-snow is whether water percolation through the snow medium or development of internal drainage channels is the dominant routing mechanism. Quantitative formulations have been proposed describing water percolation through snow in a vertical unsaturated zone (Colbeck, 1971, 1972) and a basal saturated layer (Colbeck, 1974a). However, evidence is also available to suggest that an internal drainage network, not water percolation, controls runoff during extreme rain-on-snow floods.

The approach taken in this study to assess the role of a snowpack is: (i) to review available literature in the general areas of snow physics and snow hydrology; (ii) to assess results of research studies which pertain to the flow of liquid water through snow; and (iii) to interpret results with regard to their impact on hydrograph procedures required for rain-on-snow floods. Once the role of a snowpack on basin response to rain-on-snow is assessed, then requirements of a hydrograph model can be established.

Perhaps the most important concept to recognize in snow hydrology is that snowpack response is not constant, but rather varies with physical properties of the snow. Therefore, discussion of snowpack response must be qualified by a description of snow properties being considered. In the coastal region, much of the snowpack can be categorized as "warm" (Smith, 1973). Warm snowpacks are those whose interior temperatures remain near 0°C during most of the snow season. Also, snow can be categorized as "wet" when liquid water is present (Colbeck, 1982a). Some liquid water is held in a snowpack as absorbed or capillary water, but once saturation is achieved water inputs are transmitted by processes dominated by gravity (Colbeck and Davidson, 1973). A warm, wet snowpack is commonly referred to as a ripe snowpack.

Research results and observations of snow hydrologists for response of ripe snowpacks to inputs of liquid water show: (i) snowpack response is usually less than predicted by theories for water percolation, and the apparent explanation is formation of distinct flow channels; (ii) once preferential drainage routes are initiated, they are self-perpetuating and drainage from the snowpack becomes more rapid as melt channels develop; and (iii) development of flow channels causes a snowcovered watershed to undergo a transition from snow-controlled to terrain-controlled water movement. The above observations suggest that development of an internal drainage network is the dominant routing mechanism during extreme rain-on-snow.

Consequences of the above conclusions on hydrograph procedures for extreme rain-on-snow are: (i) water percolation processes do not need to be simulated in a hydrograph model, and (ii) as water movement in a snowcovered watershed becomes terrain controlled, it is possible that basin response characteristics might approach conditions which would occur without a snowcover. This assessment of snowpack response forms the basis for hydrograph procedures developed in this study for application to extreme rain-on-snow floods in the coastal region.

Unit-hydrograph and lag and route techniques are investigated in this study to assess whether empirical relationships and coefficients employed by each method for rainfall-only could be modified for application to rain-on-snow floods in mountainuous regions of the Pacific Northwest. This investigation is undertaken as an exploratory exercise without knowing whether snowpack response, even with the formation of an internal drainage network, can be simulated using conventional hydrograph procedures.

Initial screening of the two methods leads to the conclusion that the lag and route hydrograph procedure warrants more detailed investigation in this study for application to rain-on-snow. One attraction of the lag and route method is that rainfall and snowmelt inputs to the model can be distributed across the basin. This option more accurately represents conditions in mountainous terrain. Also, travel time of a water particle through each watershed can be estimated based on hydraulic principles rather than having to rely on equations developed for other basins and regions. This procedure is particularly attractive for ungauged watersheds.

The lag and route hydrograph method requires estimates for travel time through the basin and a storage coefficient which simulates characterists of the watershed. Procedures are demonstrated in this study for estimating travel time based on channelized and overland flow velocity estimates, without any additional time increment added for water movement through the snowpack. Storage coefficients calculated from recorded extreme rain-on-snow flood hydrographs are tabulated as preliminary estimates for use with lag and route procedures.

No suitable watersheds in coastal B.C. are identified which satisfy data requirements for rain-on-snow hydrograph analysis to a standard needed for research. Alternatively, drainage basins are examined in other segments of the coastal hydrologic region of the Pacific Northwest and suitable watersheds are identified in the Cascade Mountains in Oregon.

Two drainage basins, Mann and Lookout Creeks, are selected to examine the potential for applying lag and route hydrograph procedures to simulate rain-on-snow floods. Development of hydrograph procedures includes: (i) analysis of a rainfall-only event on Mann Creek to confirm that the fast runoff contribution to flood peaks in mountainous regions can be simulated using one storage coefficient; (ii) analysis of a rain-on-snow event on Mann Creek to examine whether the model can be adapted for rain-on-snow, and to compare the storage coefficient with that on the same basin for rainfall-only; and (iii) analysis of a rain-on-snow event on Lookout Creek to undertake a second application of the model, and to assess storage coefficients during more extreme flood events.

Results from Mann and Lookout Creeks show lag and route hydrograph procedures can be applied to simulate rain-on-snow flood hydrographs when the following methodology is adopted: (i) estimate travel time through the basin from channelized and overland flow considerations; (ii) select the appropriate storage coefficient; (iii) specify water inputs to the basin as the sum of snowmelt and rainfall; and (iv) consider there are no losses to groundwater.

Selection of a storage coefficient for the fast component of runoff is an important consideration in application of lag and route procedures. One question which arises is how does the storage coefficient for rain-on-snow floods compare on the same basin with that for rainfall floods. Storage coefficients on Mann Creek for a rainfall and a rain-on-snow hydrograph differ by a factor of two. However, the rain-on-snow flood on Mann Creek is not a very extreme event and perhaps runoff is still partly snow-controlled. If this is the case, then data from the two Mann Creek floods cannot be used to test the concept that an internal drainage network within a snowpack causes basin response to be similar to that for rainfall floods. It is worth noting that the storage coefficient for an extreme rain-on-snow event on Lookout Creek is similar to the coefficient for rainfall-only on Mann Creek. This result may be coincidence or it may demonstrate a more terrain-controlled basin response for extreme rain-on-snow floods. Until further research is undertaken, it is recommended that preliminary storage coefficients calculated in this study from recorded extreme rain-on-snow floods be adopted for use with lag and route hydrograph procedures.

Available evidence suggests that extreme rainfall combined with relatively high temperatures on Lookout Creek produces much greater snowmelt than predicted by the Corps of Engineers temperature-index equation developed for this region. It is likely that temperature index equations, such as developed by the Corps of Engineers, will continue to be applied to ungauged mountainous watersheds because other climatic data needed for alternative melt equations are seldom available. Therefore, snowmelt occurring during the special case of extreme rain-on-snow is highlighted as an important topic requiring further analysis in the development of procedures for estimating extreme rain-on-snow floods.

2. FLOOD CHARACTERISTICS IN THE COASTAL REGION

2.1 CLIMATE

The climate of the northern Pacific coastal region along British Columbia has been described by various authors including Chapman (1952), Hare and Thomas (1974), Schaefer (1978), and Chilton (1981). The coastal climatic region extends the entire length of the province and is generally bounded by the crest of the Coastal Mountains as shown in Figure 2.1. This climatic region extends southward into Washington and Oregon bounded by the Cascade Mountain Range, and includes southeast Alaska immediately adjacent to northern British Columbia.

The primary climatic features of the coastal region include relatively high annual precipitation with the wettest months occurring in fall and winter, and a relatively small annual range of temperature. Within the coastal region, however, local variations exist in precipitation and temperature due to the complex interaction between atmospheric circulation patterns and major topographic features distributed along the coast which serve as barriers to the movement of air masses. For example, distinct zones within the coastal region can be identified along west facing mountain slopes which tend to have more clouds and receive more precipitation than eastern faces of the mountains. Also, the southeastern lowlands of Vancouver Island, the islands of the Strait of Georgia and the Fraser River estuary comprise a zone which lies in the rainshadow of Vancouver Island and the Olympic Mountains in Washington

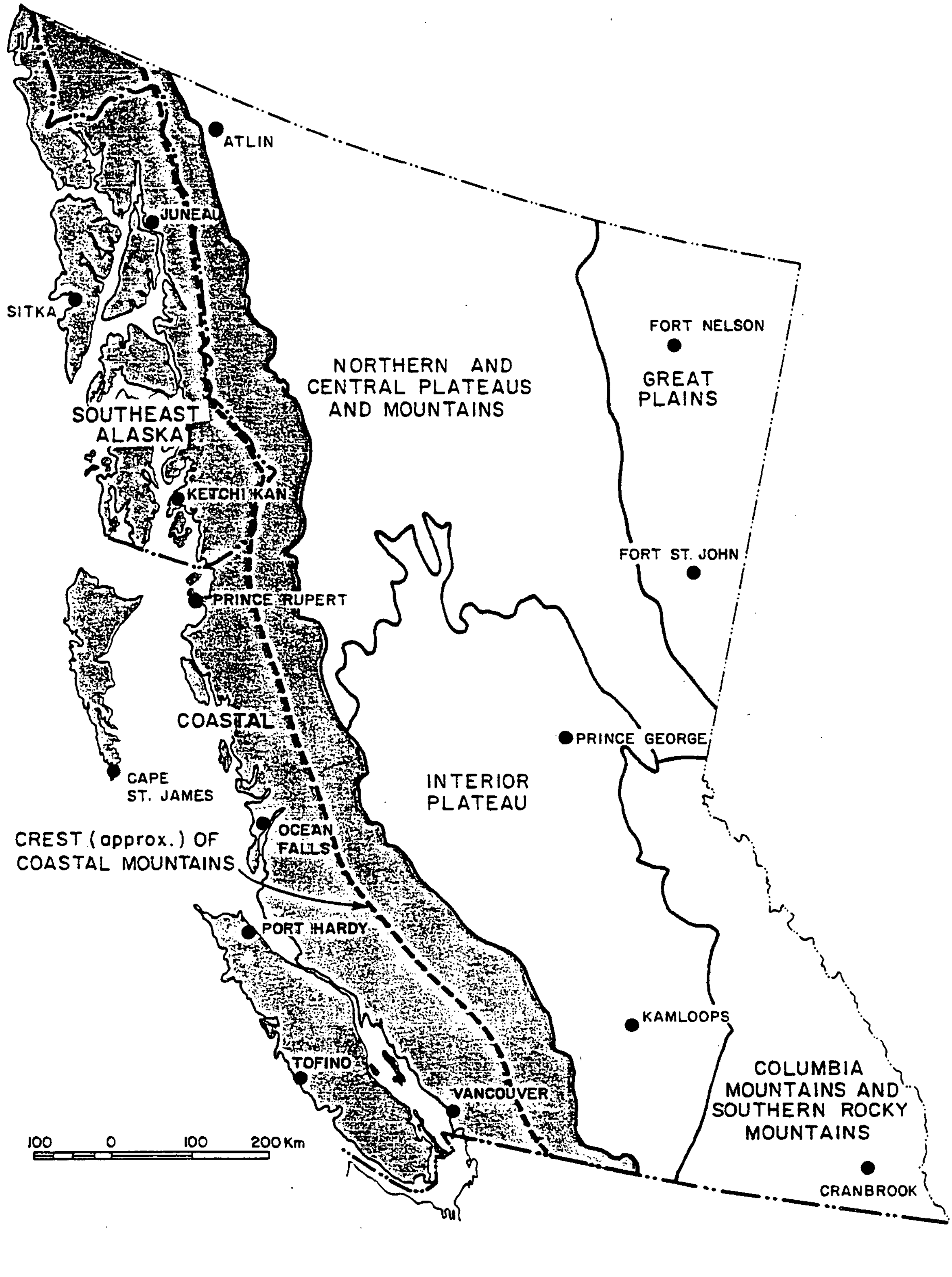


Figure 2.1 Physiographic Regions of British Columbia

State. This zone is the driest segment of the coastal region and is also the warmest with more hours of bright sunshine during the summer months.

Monthly precipitation data are included in Table 2.1 for representative coastal stations extending from Vancouver, British Columbia in the south to Sitka, Alaska in the north. These data illustrate the variability in precipitation along the coast yet also show that on a monthly percentage basis the distribution of precipitation is similar for the region. For example, annual precipitation ranges from 1259 to 4388 mm for representative stations included in Table 2.1. However, on a percentage basis at each station, a summer month receives in the order of only 3 to 6 percent of the annual precipitation while each of the wettest winter months receive about 10 to 15 percent. Comparison of these data also shows that the period of high precipitation starts earlier in the northern than in the southern segments of the coastal region. Williams (1948) noted a southward progression in the occurrence of maximum daily precipitation for the year of about one degree of latitude for each 4.5 days.

TABLE 2.1

MEAN MONTHLY PRECIPITATION FOR REPRESENTATIVE COASTAL STATIONS*

	Vancouver U.B.C.		Tofino Airport		Port Hardy Airport		Ocean Falls		Cape St. James		Prince Rupert Airport		Sitka	
	mm	% of annual precip.	mm	% of annual precip.	mm	% of annual precip.	mm	% of annual precip.	mm	% of annual precip.	mm	% of annual precip.	mm	% of annual precip.
Jan	173	14	404	12	211	12	459	10	162	11	228	9	197	8
Feb	133	11	366	11	159	9	392	9	137	9	222	9	162	7
Mar	116	9	372	11	142	8	346	8	130	8	201	8	177	7
Apr	69	5	234	7	108	6	302	7	107	7	190	8	136	6
May	60	5	143	4	69	4	217	5	85	6	140	6	118	5
June	43	3	102	3	71	4	192	4	74	5	130	5	88	4
July	37	3	86	3	52	3	151	3	58	4	103	4	132	5
Aug	53	4	114	3	69	4	227	5	79	5	158	6	200	8
Sept	72	6	163	5	136	7	376	9	125	8	233	9	292	12
Oct	133	11	392	12	245	14	625	14	198	13	367	15	388	16
Nov	162	13	432	13	245	14	514	12	187	12	268	11	305	12
Dec	208	16	479	15	277	15	587	13	191	12	284	11	258	11
Annual	1259		3287		1784		4388		1533		2524		2453	

* Station locations shown on Figure 2.1

Temperature data plotted on Figure 2.2 for three representative stations along the coastal region illustrate the relatively small annual range at a given station and the similar annual trend in temperature between stations. Chapman (1952) noted an average reduction in mean annual temperature (corrected to sea level) along the coast from 60° to 24°20' north latitude of about 0.6°C per degree of latitude.

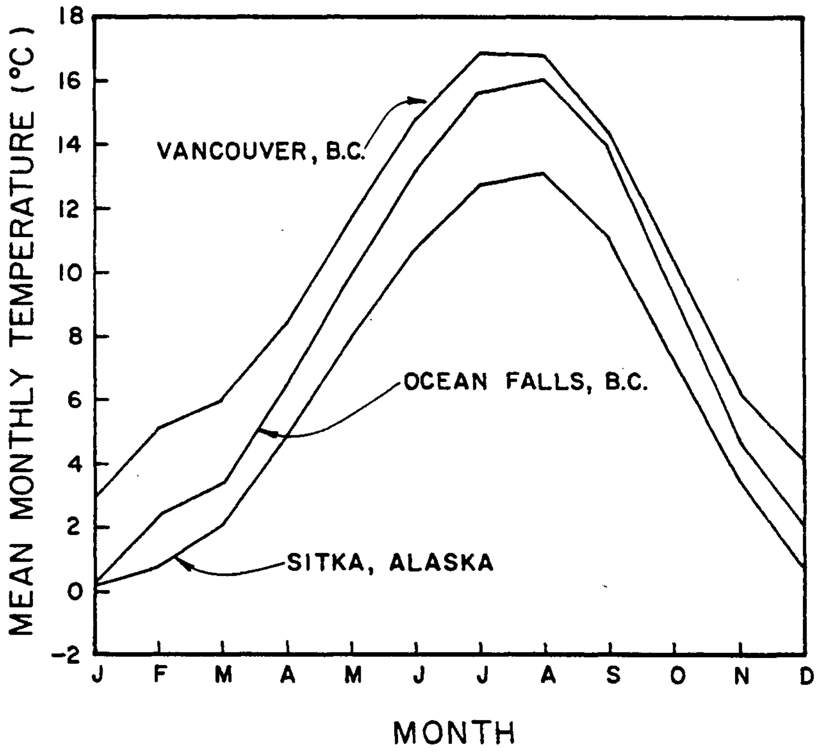


Figure 2.2 Mean Monthly Temperatures for Coastal Stations

The climate of the coastal region is controlled on a seasonal basis by macro-scale atmospheric processes. During winter months vigorous circulation is produced by a strong temperature gradient between tropical and polar latitudes. During this season low pressures over the Gulf of Alaska and high pressures inland combine to produce strong pressure gradients over western Oregon, Washington and British Columbia where southerly surface winds prevail. Mean sea level atmospheric pressure patterns for December (Thomas, 1977) are shown on Figure 2.3.

The winter atmospheric circulation pattern causes numerous storms to develop rapidly in the northern Pacific Ocean and move in a northeasterly direction to the Gulf of Alaska where they dissipate. On a smaller scale, frontal systems break away from the storm centers and impinge upon the coast, often bringing strong southwesterly flows of warm moist air aloft which are responsible for the coastal region's heaviest rainfalls.

During summer months a weaker atmospheric circulation develops (Thomas, 1977). The summer coastal climate is controlled by the dominance of a large high pressure centre which expands northward as shown for the month of July on Figure 2.4. For this summer condition pressure gradients are weaker than in the winter, northwesterly winds prevail along much of the coast, and the frequency and intensity of Pacific storms is diminished.

The summary of atmospheric circulation patterns suggests how similar annual trends develop for temperature and precipitation for the entire coastal region. Variations within the region, however, result from the effect of more local topographic features such as elevation, slope and aspect on circulation patterns as frontal systems impinge of the very diverse coastline.

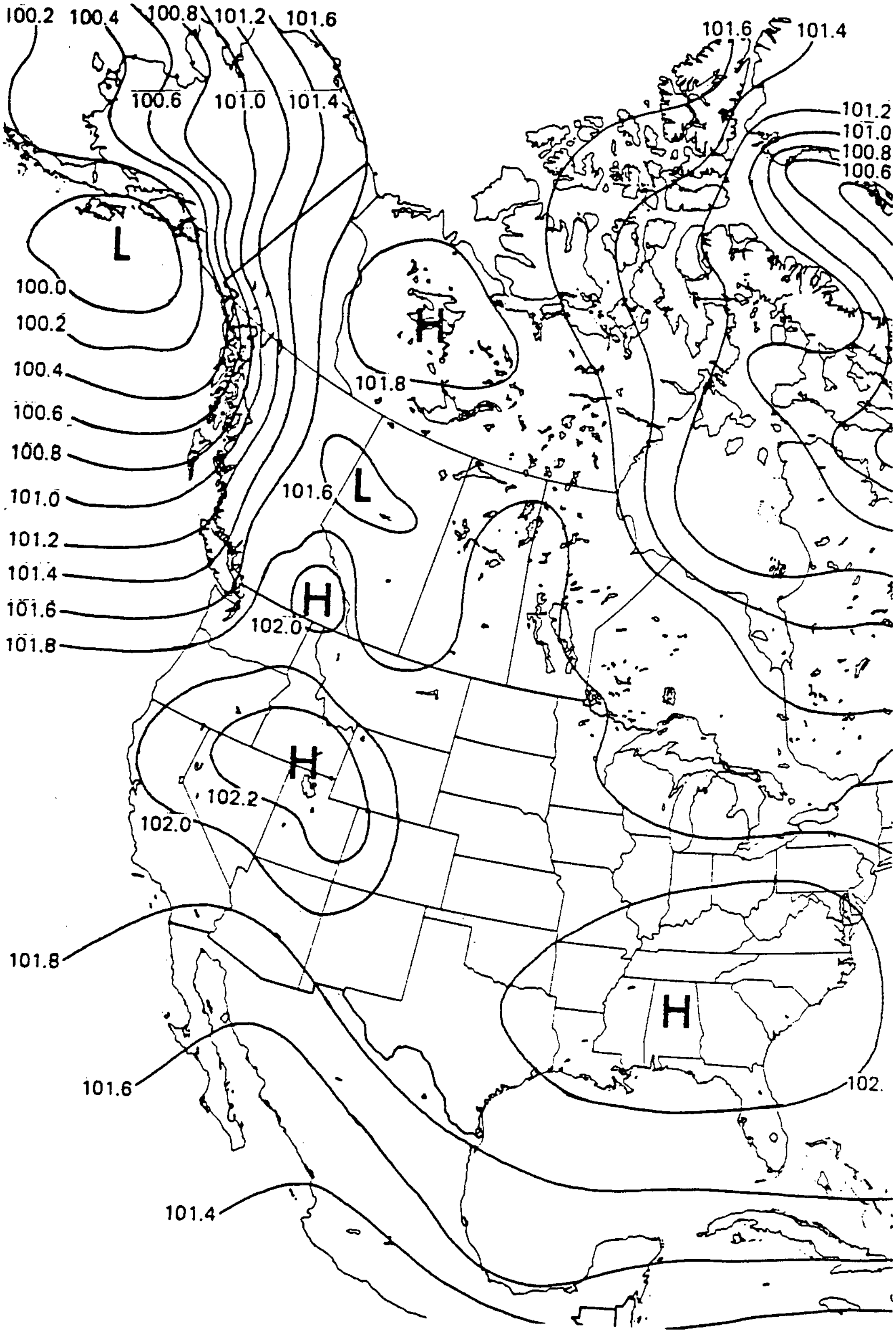


Figure 2.3 Mean Monthly Sea Level Pressures (kPa) for December, after Thomas (1977)

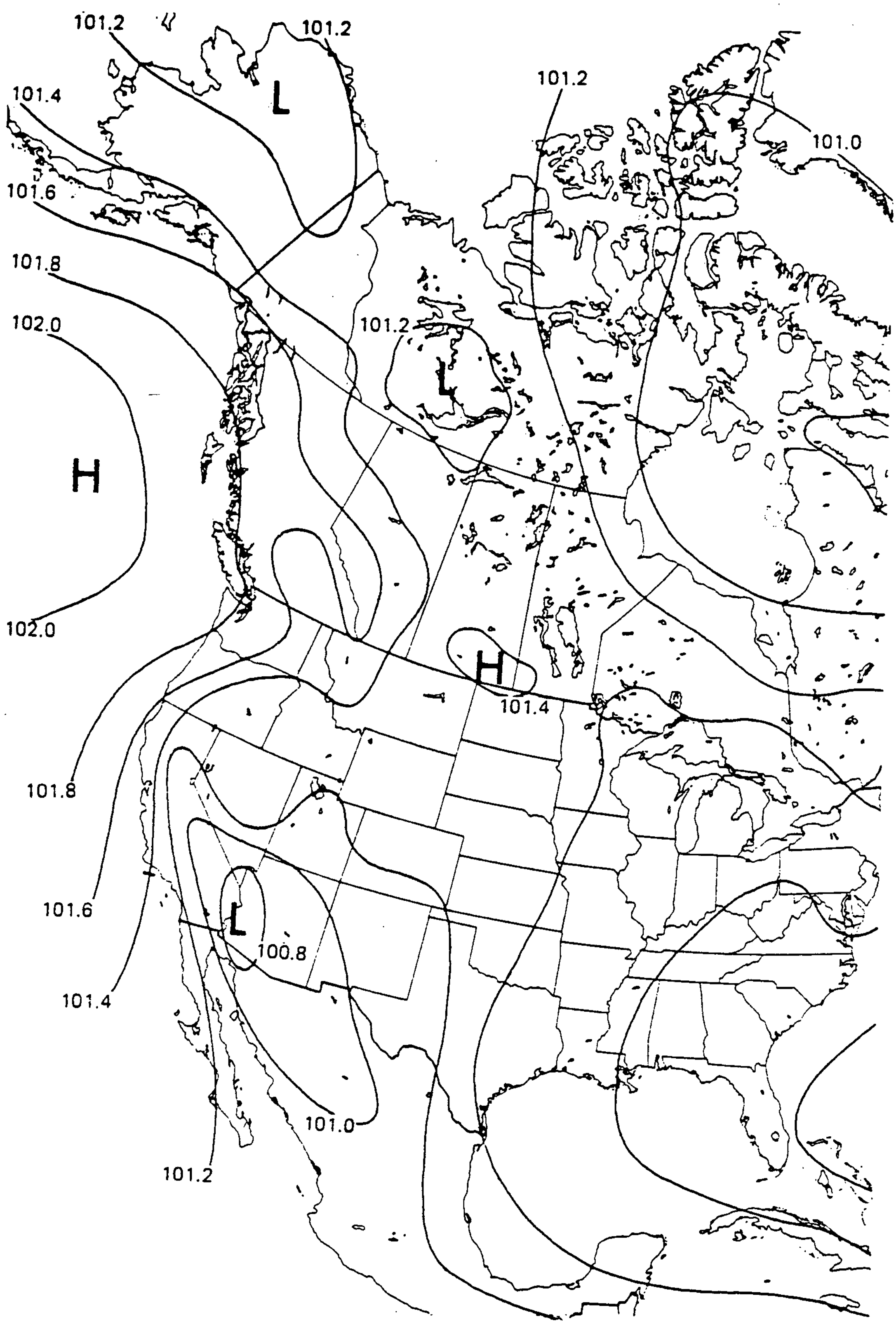


Figure 2.4 Mean Monthly Sea Level Pressure (kPa) for July, after Thomas (1977)

2.2 HISTORICAL STREAMFLOW RECORDS

Historical flood data for the coastal region of British Columbia and southeast Alaska were reviewed to establish the typical range of extreme floods that have been recorded and to identify general trends and similarities among the data. These flood characteristics were documented by examining unit discharge (discharge per unit area), ratios of maximum instantaneous to maximum daily discharge, flood producing mechanisms and period of year when extreme floods have occurred.

Identification of streamflow gauging stations within the coastal region of British Columbia and southeast Alaska and the selection of stations for review in this study proceeded as follows:

i) stations located within coastal British Columbia were identified in a reference index (Environment Canada, 1983b) and those in southeast Alaska were obtained from a report prepared by the U.S. Geological Survey (Lamke, 1979). Flood data through 1982 were readily available for British Columbia (Environment Canada, 1983a), while Alaska flood data from the 1979 report were updated to 1982 by the USGS office in Anchorage.

ii) stations which were designated as having regulated flows were omitted.

iii) major rivers, such as the Fraser, Skeena, Stikine and Taku Rivers which flow through the coastal region but whose drainage basins extend inland beyond the coast were omitted.

iv) only data from those stations with ten or more years of record were reviewed.

The screening process resulted in the selection of 66 stations in coastal British Columbia and 47 stations in southeast Alaska. In British Columbia some rivers had more than one station so that only 58 different rivers were represented by the 66 stations. The list of stations is included in Appendix I.

Before analyzing flood data available for the coastal region, it is important to recognize sources of scatter in any results derived from analysis of these data. As one would intuitively expect, variability in local climate and basin runoff characteristics across the entire coastal region produce a range in the magnitude of floods on record for a given drainage area. In addition there are limitations in the data records themselves which inherently lead to scatter in any results derived from analysis of the available flood data. These data limitations include:

i) periods of record are not concurrent for all stations, although in general most flood data are for more recent years.

ii) length of record varies among stations. A station with a long record is likely to have experienced a more rare event flood than a station with a shorter record.

iii) flows are published based on a fixed 24-hour time period. When a short duration storm hydrograph spans two days, the corresponding mean daily flow may be deceptively low compared to the recorded peak for each day.

iv) the magnitude of an extreme flood is normally estimated from the portion of the stage-discharge rating curve at each station that is relatively ill-defined due to absence of gauged flows in this range.

Maximum floods on record at coastal British Columbia and Alaska stations are plotted on Figure 2.5 as unit discharge versus drainage area. Even though the data points are scattered, a single band of data is nevertheless defined when viewed against other regions. For example, the largest floods on record from the adjacent interior plateau of British Columbia are also included on Figure 2.5 for comparison. The single band of flood data reinforces the concept of a single hydrologic region, while the range of data illustrates the effects of local climatic variations across the region.

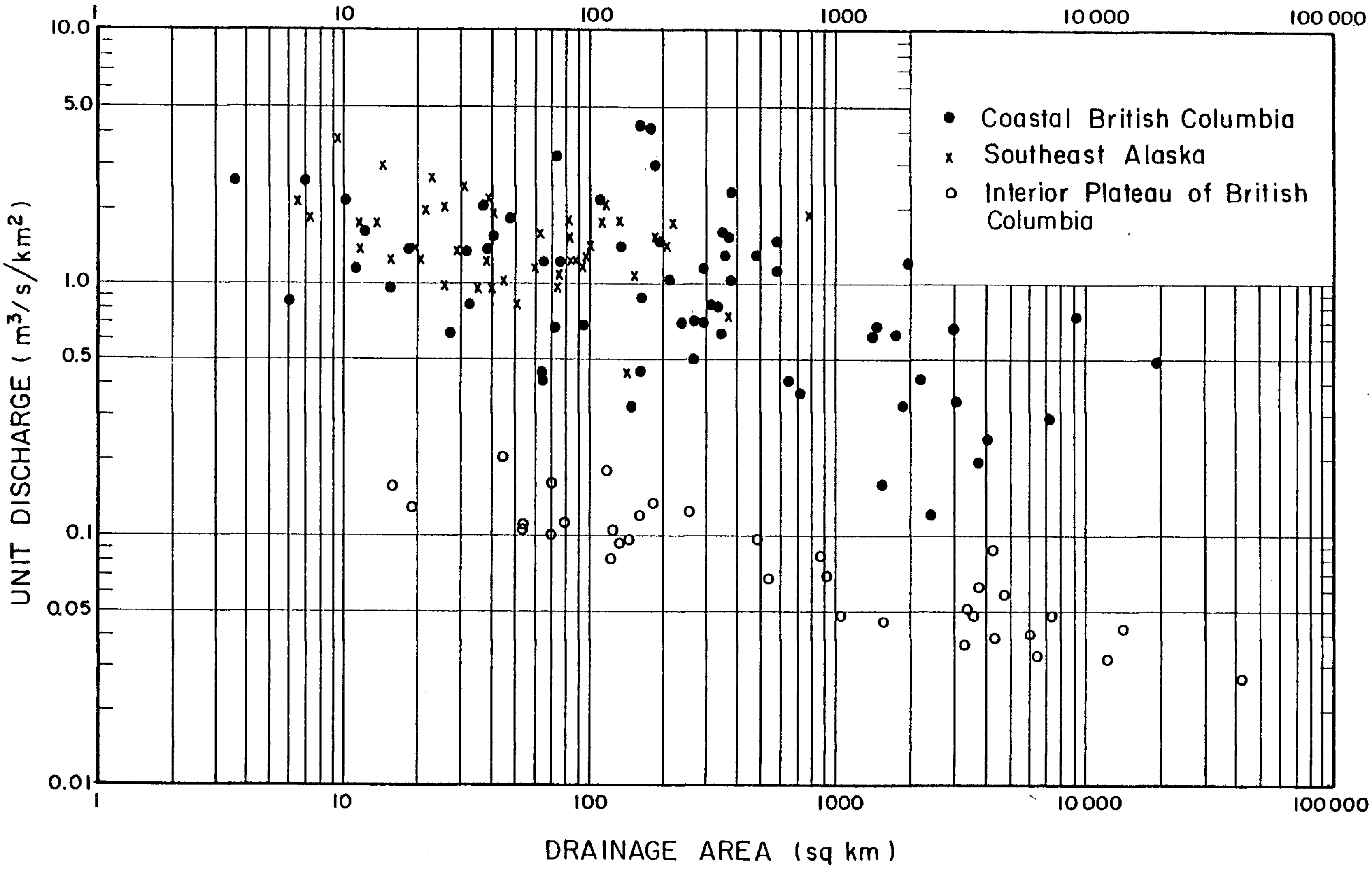


Figure 2.5 Maximum Floods on Record

Additional insight to the characteristics of coastal floods can be obtained by examining the period of year when these floods occurred. The monthly distribution of the maximum floods on record for coastal British Columbia and southeast Alaska are shown in Tables 2.2 and 2.3, respectively. The tables illustrate that the most extreme floods in the coastal region have occurred during the fall and winter period when over 90 percent have been recorded.

TABLE 2.2

MONTHLY DISTRIBUTION OF MAXIMUM FLOODS ON RECORD
IN COASTAL BRITISH COLUMBIA*

	Number of Floods	Percent
Spring/Summer		
March	0	0
April	1	2
May	0	0
June	3	5
July	0	0
August	0	0
	4	7%
Fall/Winter		
September	3	5
October	13	22
November	10	17
December	16	28
January	10	17
February	2	4
	54	93%

* 1. List of coastal British Columbia stations in Appendix I.
2. Only one station considered for main stem of each river.

TABLE 2.3

MONTHLY DISTRIBUTION OF MAXIMUM FLOODS ON RECORD IN SOUTHEAST ALASKA*

	Number of Floods	Percent
Spring/Summer		
March	0	0
April	0	0
May	0	0
June	0	0
July	0	0
August	4	9
	4	9%
Fall/Winter		
September	14	32
October	13	30
November	8	18
December	3	7
January	1	2
February	1	2
	40	91%

* List of southeast Alaska stations in Appendix I.

As part of a study undertaken by Water Survey of Canada (Environment Canada, 1982), flood data were examined on drainage basins in B.C. and the Yukon. The primary objective of the study was to conduct a flood frequency analysis at each station with 9 or more years of record. An examination of the flood data revealed, however, that annual maximum discharge alone was not an adequate criterion for selecting flows for flood frequency analysis. It was observed that some stations on the B.C. coast experienced floods that were either rainfall-induced in the fall and winter or snowmelt-induced in spring and summer, while others experienced both types such that two distinct flood regimes were identifiable on the same basin. These flood regimes had to be identified at each station to ensure that flood data selected for frequency analysis resulted from a similar flood producing mechanism. A summary of flood regimes determined by Water Survey of Canada for the 58 different basins considered in this study is included in Table 2.4.

TABLE 2.4

SUMMARY OF FLOOD REGIMES AT COASTAL BRITISH COLUMBIA STATIONS

Flood Regime	Number of Stations
Predominantly rainfall-induced floods in fall and winter	43
Predominantly snowmelt-induced floods in spring and summer	1
Both rainfall-induced floods in fall and winter and snowmelt-induced floods in spring and summer	14
	58

For the 14 stations classified as having both rainfall and snowmelt flood regimes on the same basin, Water Survey of Canada conducted a separate flood frequency analysis with each set of data. Examination of the results of these separate flood frequency analyses showed that for each of the 14 stations the 50, 100 and 200-year return period flood estimates were greater for rainfall-induced floods than those derived for the same basin for snowmelt floods. Flood frequency curves are shown separately for rainfall and snowmelt-induced floods on Figure 2.6 for a typical coastal B.C. station.

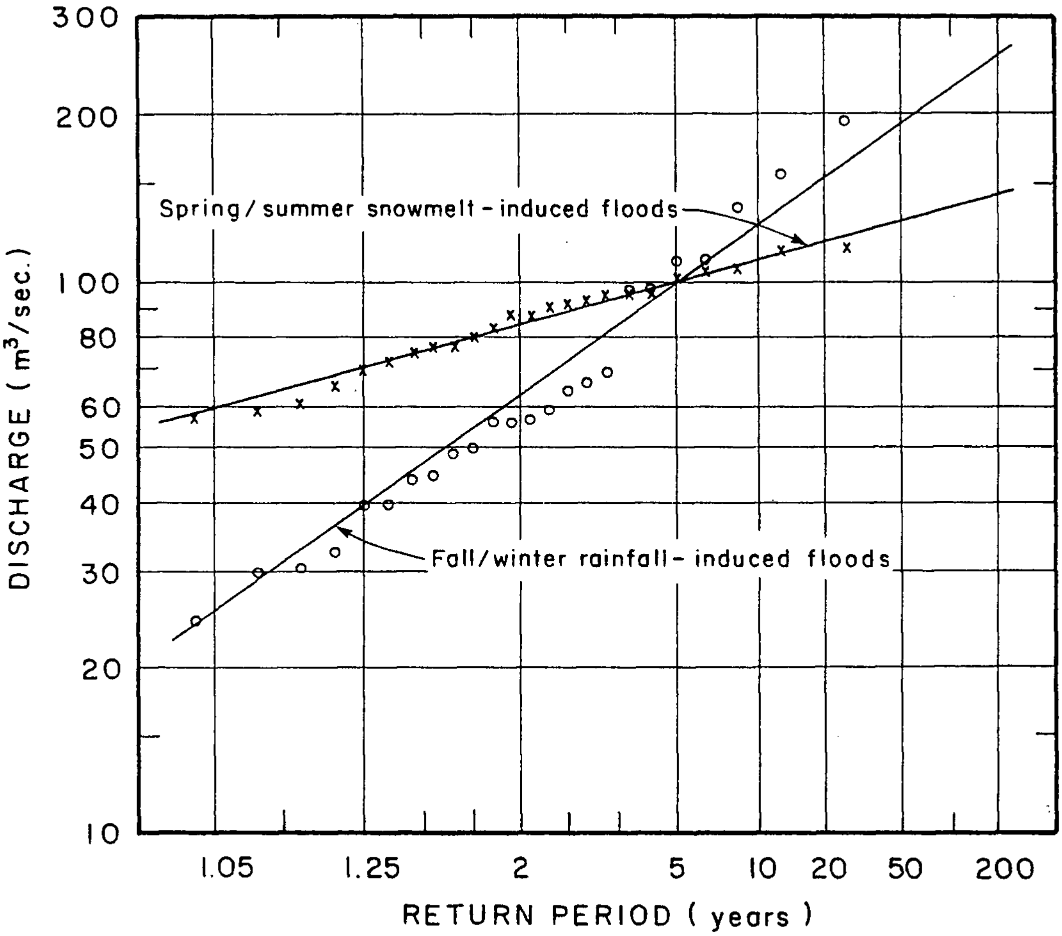


Figure 2.6 Flood Frequency Curves for Cheakamus River Near Mons (1924-47)

Ratios of maximum instantaneous to maximum daily discharge for the max-ium floods on record for all coastal British Columbia and southeast Alaska stations reviewed for this study are plotted on Figure 2.7. These data indicate that the range of flood ratios for small basins is significantly greater than for larger basins. The larger flood ratios illustrate the flashy nature of floods which are rainfall-induced on many basins in the coastal region.

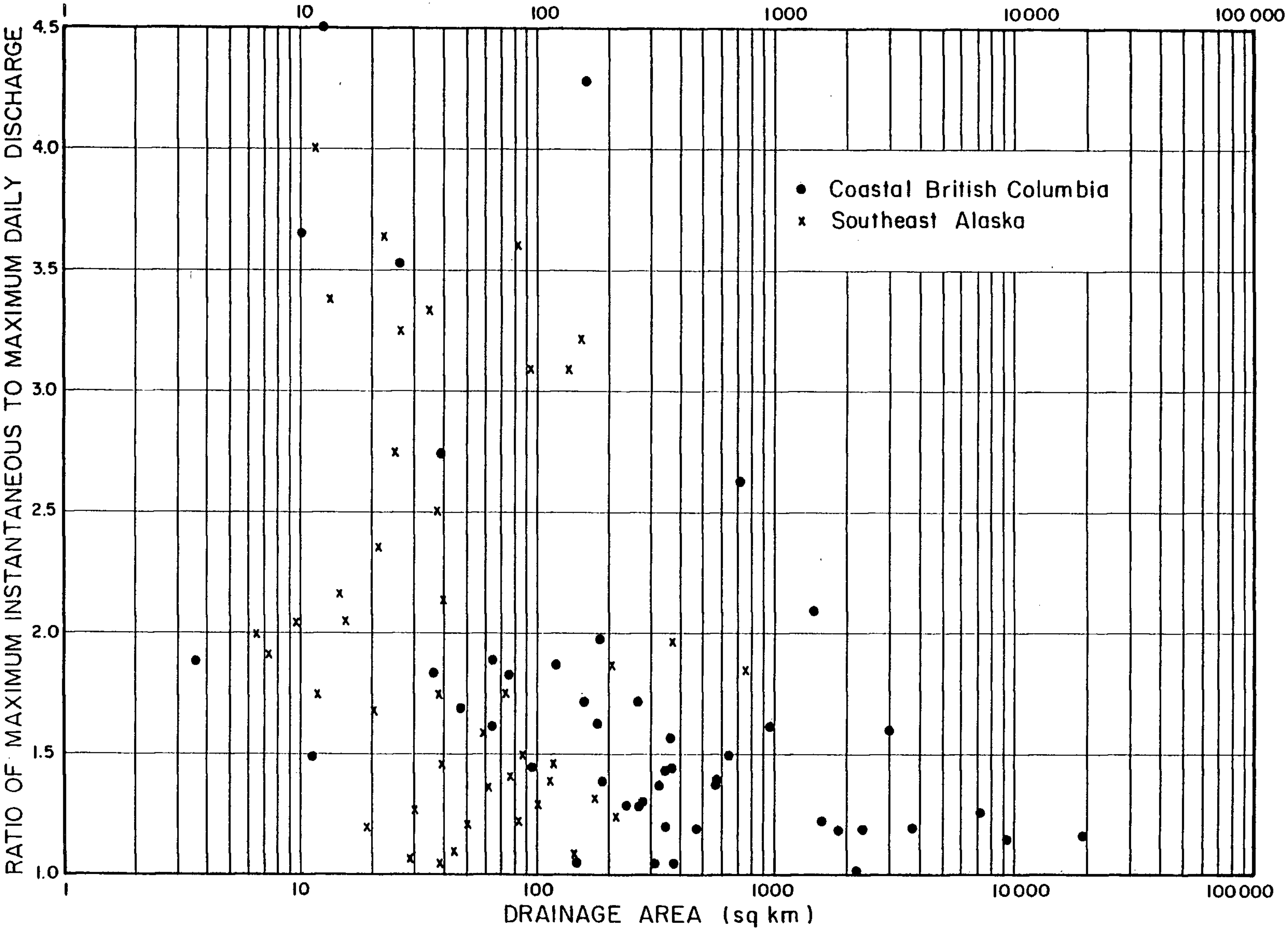


Figure 2.7 Ratios of Maximum Instantaneous to Maximum Daily Floods

2.3 CASE STUDIES

Four case studies are selected to illustrate characteristics described in preceding sections which lead to extreme floods in the coastal region. These characteristics generally include storms which result from low pressure systems in fall and winter; floods which are rainfall-induced either as rainfall-only or as rain-on-snow; and flood hydrographs which are very flashy in the mountainous coastal region.

November, 1978 Flood near Terrace, British Columbia (Schaefer, 1979)

A multi-day rainfall event, heaviest on October 31 and November 1, 1978, resulted in serious flooding in the area surrounding Terrace, British Columbia. Both the Zymoetz River near Terrace and the Kitimat River to the south experienced their largest flood on record during this storm, estimated to be about the 100-year return period flood.

The storm resulted from a frontal wave which approached from the south-west with winds aloft of about 85 knots and reached the coast north of the Queen Charlotte Islands. The airmass which was the source of the storm's heavy precipitaion was close to saturation from the surface to 5000 m with considerable moisture at higher levels. Freezing levels which averaged 1500 m in the Terrace area prior to the storm increased to 3000 m. By the afternoon of November 1 a cold front impinged on the mainland coast, after which the airmass cooled and dried out markedly.

The time distribution of precipitation recorded at Terrace Airport for the storm period is shown on Figure 2.8. The greatest rates of accumulation for periods greater than one hour occurred during the first morning of the storm on October 31, although relatively heavy rain also fell near the end of the storm during the afternoon of November 1.

For durations of less than one hour, peak intensities occurred during showers which effectively ended the storm. The return periods for a range of storm durations at Terrace Airport are shown on Figure 2.9. The storm was unremarkable for durations less than one hour with estimated return periods less than two years; for longer durations from 2 to 4 days estimated return periods ranged from 85 to 95 years.

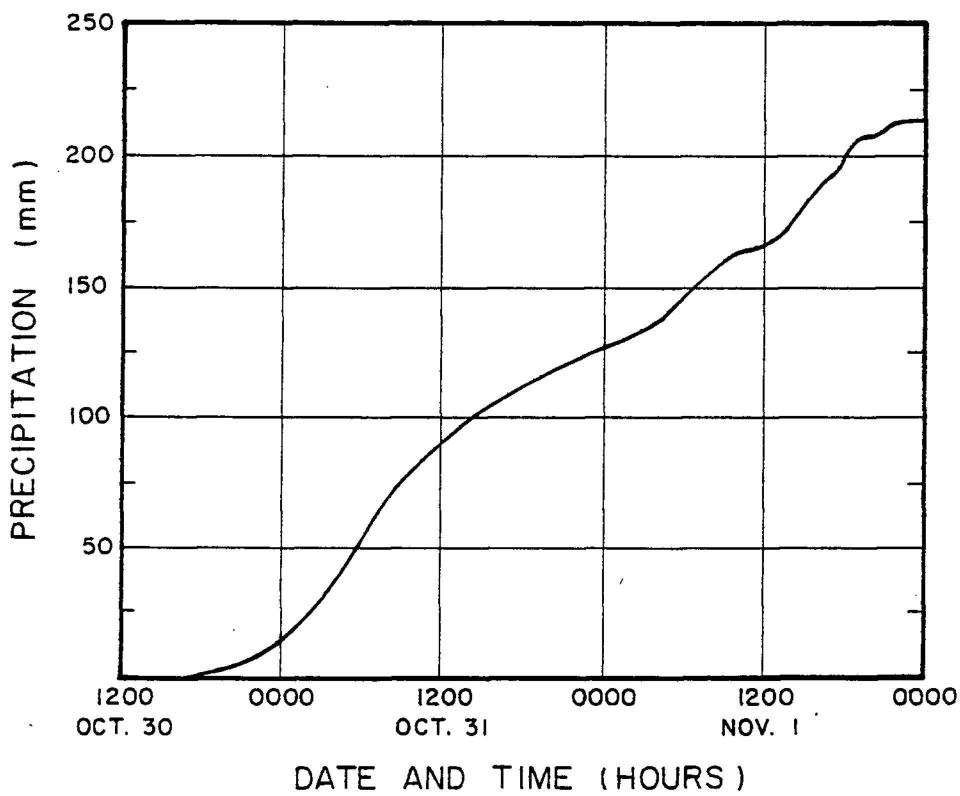


Figure 2.8. Precipitation at Terrace Airport for Oct. 31 - Nov. 1, 1975

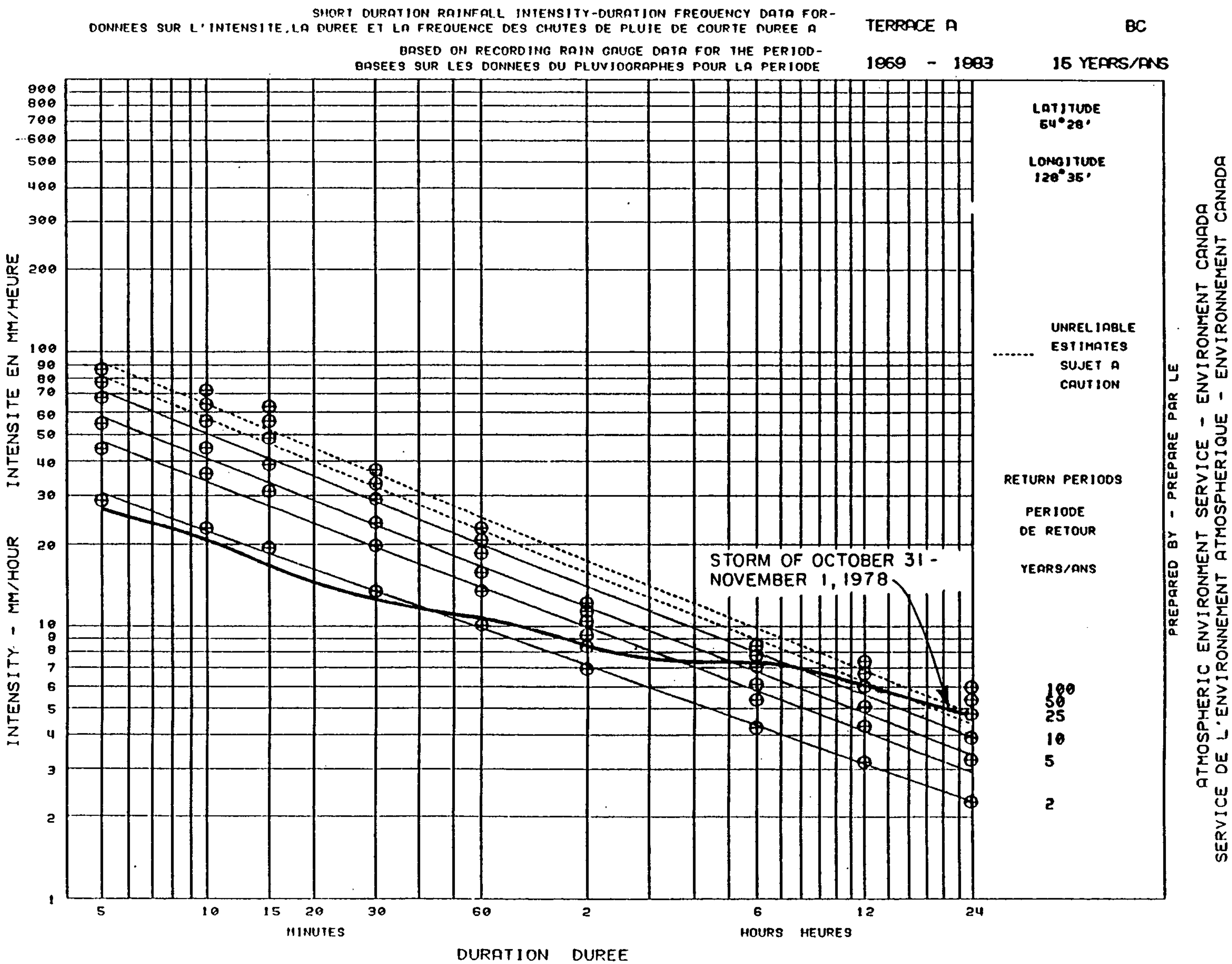


Figure 2.9 Intensity-Duration-Frequency Curves for Terrace Airport

<u>December, 1972 Rainstorm at Vancouver, British Columbia (Eddy, 1979)</u>

A storm began in the early morning hours on December 25 and lasted from 23 to 26 hours at climatological stations in the Vancouver area. This storm produced the largest 24-hour precipitation on record at Vancouver International Airport (92.9 mm) and in Vancouver's city centre (141.5 mm) while other stations in the area experienced near record amounts. The storm caused extensive flooding in the greater Vancouver area.

During the morning of December 25th, a deep low pressure area was moving northward over the Gulf of Alaska. An associated tongue of warm air aloft with winds from the southwest was at this time lying across the Queen Charlotte Islands. While the deep low continued to move towards the Alaska coast, the frontal wave associated with the tongue of warm air continued eastward across Vancouver Island and the mainland coast. Precipitation ended quite abruptly when this system passed and a weak ridge of high pressure began to build over the area.

The time distributions of rainfall recorded at Vancouver Airport and in Vancouver's city centre are shown on Figure 2.10. The return periods for a range of durations are shown on Figure 2.11 for Vancouver Airport. The storm characteristics plotted on Figure 2.11 show that while precipitation intensities for durations less than about two hours were relatively low, longer duration intensities were more extreme with the 24-hour amount exceeding an estimated 50-year return period event. It is interesting to note that on Hollyburn Ridge, a higher elevation station at 951 m overlooking Vancouver, snow changed to rain early on December 25, 1972.

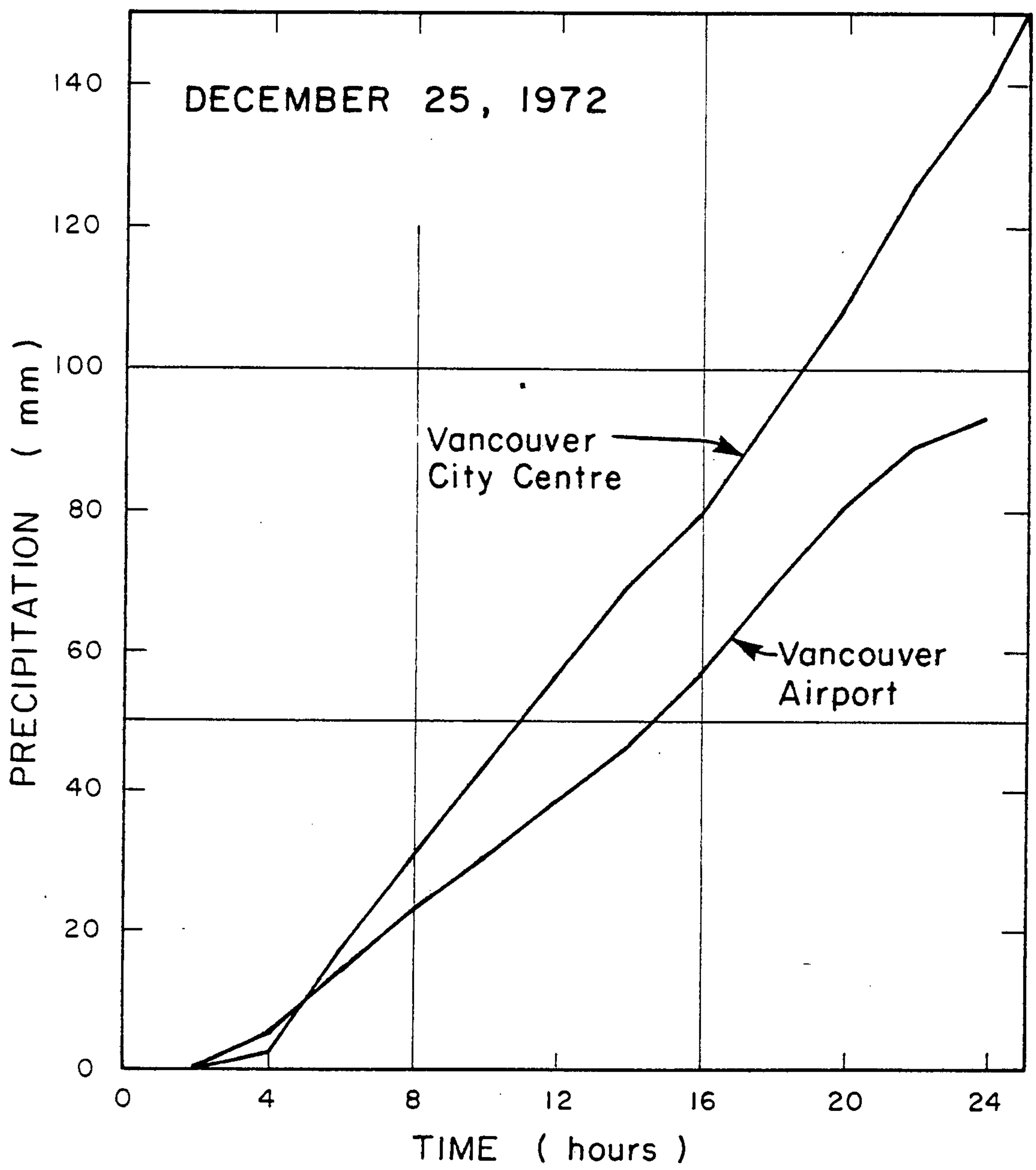


Figure 2.10. Precipitation in Vancouver Area on December 25, 1972.

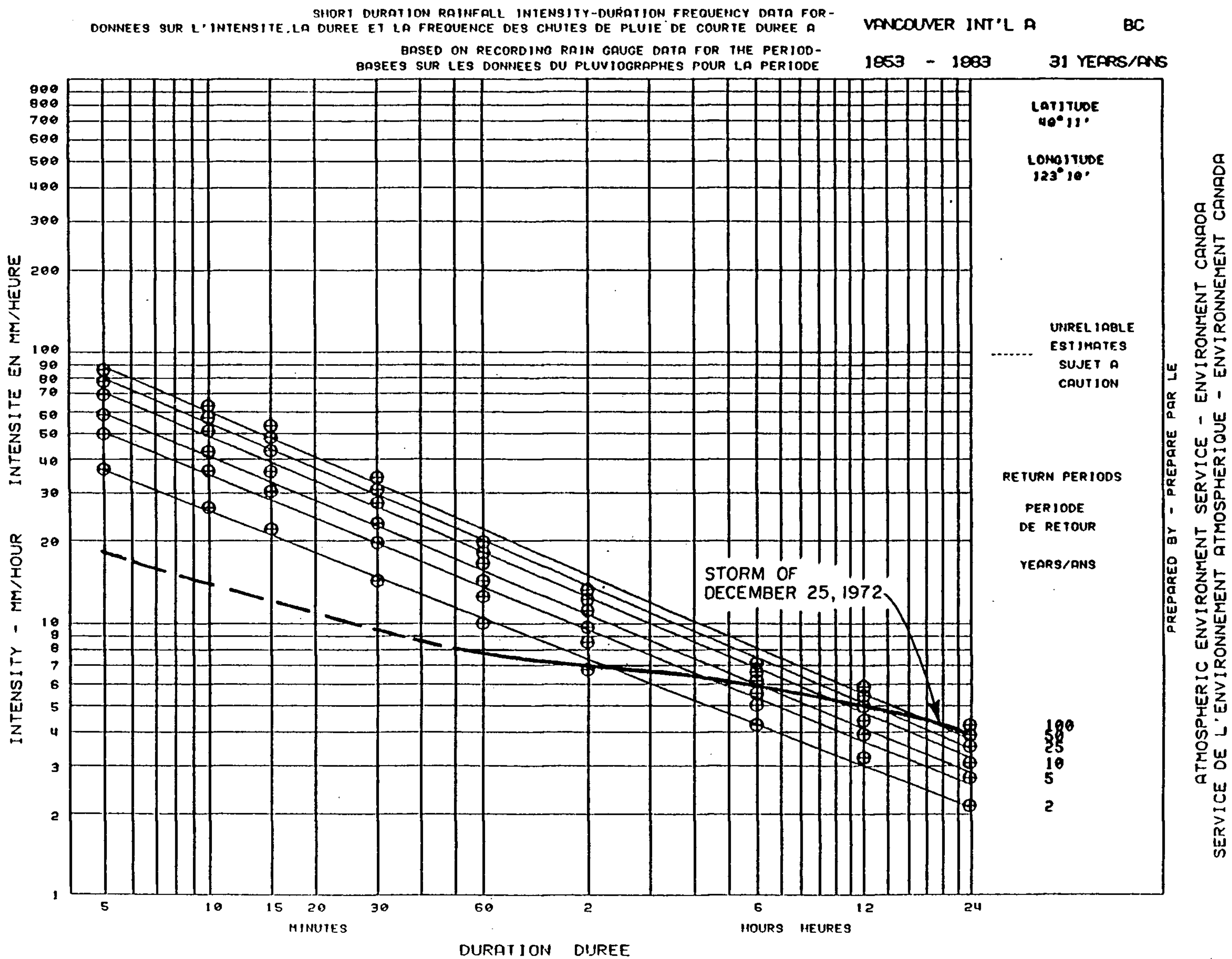


Figure 2.11 Intensity-Duration-Frequency Curves for Vancouver Airport

Probable Maximum Precipitation - Coquitlam Lake Watershed (Schaefer,1981)

An analysis of meteorological conditions associated with the generation of a probable maximum flood was undertaken for the Coquitlam Lake watershed located approximately 30 km northeast of downtown Vancouver. Elevations in the 181 sq km basin range from 153 to 2000 m with several peaks reaching 1400 m around the drainage basin boundary.

As part of the study, the most extreme precipitation events on record for durations of one to four days were analyzed at Coquitlam Lake and Vancouver International Airport. At Coquitlam Lake eight multi-day events were analyzed for the period of record from 1924 to 1981, and at Vancouver International Airport seven multi-day events were analyzed from 1937 to 1981. The eight most extreme events analyzed at Coquitlam Lake occurred during the period from November through February, while the seven events at Vancouver Airport occurred from October through January. Although details differed from case to case, common features in all events included frontal waves, surface low pressure areas and strong southwesterly air flows aloft. Vertical instability was ruled out as a significant contributing factor to the total precipitation in all storms considered in the analysis. This finding is consistent with a U.S. Weather Bureau study (1966) which concluded that severe thunderstorms were not a factor in the region west of the Cascade Mountains.

The five largest one day storms for each calender month were also analyzed for the two stations in conjunction with recorded temperature and moisture data to estimate the maximum precipitable water available in each storm. Based on this analysis it was concluded that the probable maximum precipitation (PMP) would occur in December, and ratios were developed for the relative amount of precipitation that could occur in other months of the year, Table 2.5.

TABLE 2.5

MONTHLY ADJUSTMENT FACTORS FOR PROBABLE MAXIMUM PRECIPITATION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Coquitlam Lake	0.91	0.76	0.68	0.62	0.59	0.58	0.59	0.65	0.78	0.91	0.99	1.00
Vancouver International Airport	0.85	0.69	0.59	0.54	0.48	0.46	0.49	0.56	0.69	0.83	0.96	1.00

Flood of December 1964 in Coastal Oregon (Waananen et al, 1971)

During the period from December 19-23, 1964 extensive flooding occurred along coastal Oregon and in the Willamette River valley which lies between the Coastal and Cascade Mountain ranges. Many rivers experienced their largest floods on record during this period and it is estimated that without flood regulation, the peak flow on the Willamette River would have been the second largest flood on record behind that which occurred in 1861. In the Willamette River valley 85,000 ha of agricultural land was inundated, three lives were lost and flood losses were more than $65 million. Along coastal Oregon six lives were lost and flood losses were more than $60 million.

Prior to the December 19-23 storm a high pressure airmass over the Pacific Ocean occupied most of the ocean area between Hawaii and Alaska. An arctic airmass spread over Oregon from December 14-18 and partly froze much of the ground. Initial storm precipitation from December 18-20 was accompanied by low temperatures and consisted largely of snow over much of the region. The Pacific high located northeast of Hawaii eroded on December 20 and allowed storms with warm moist tropical air to move across the ocean at successively lower latitudes as they approached the west coast. Mixing of warm moist air with cold Arctic air west of the coast caused the storm systems to intensify.

From December 21-23 temperatures rose sharply and freezing levels rose to 3000 m causing almost all precipitation to occur as rain. In the Willamette River basin the storm brought as much as 380 mm of rain to the valley during December 19-23 and 460 mm of rain to higher altitudes in the Cascade Range. Average precipitation along the coast ranged from 150 to 280 mm for the same period with point measurements as high as 550 mm in the Coast Range. Precipitation rates in excess of 200 mm in 24-hours were recorded at a few stations in Oregon.

The response of river flows to this storm was extremely rapid as heavy rainfall runoff was supplemented by snowmelt. In some instances, flows increased twenty-fold from the start of the storm on December 19 to a peak on December 22. Examination of flood hydrographs for many stations in the region showed two-fold increases in discharge over periods as short as four hours. The flashy nature of streamflow response to extreme rainfall combined with snowmelt is illustrated on Figure 2.12 for representative stations. Each flood hydrograph plotted on Figure 2.12 represents a flood discharge with an estimated return period of at least 50 years.

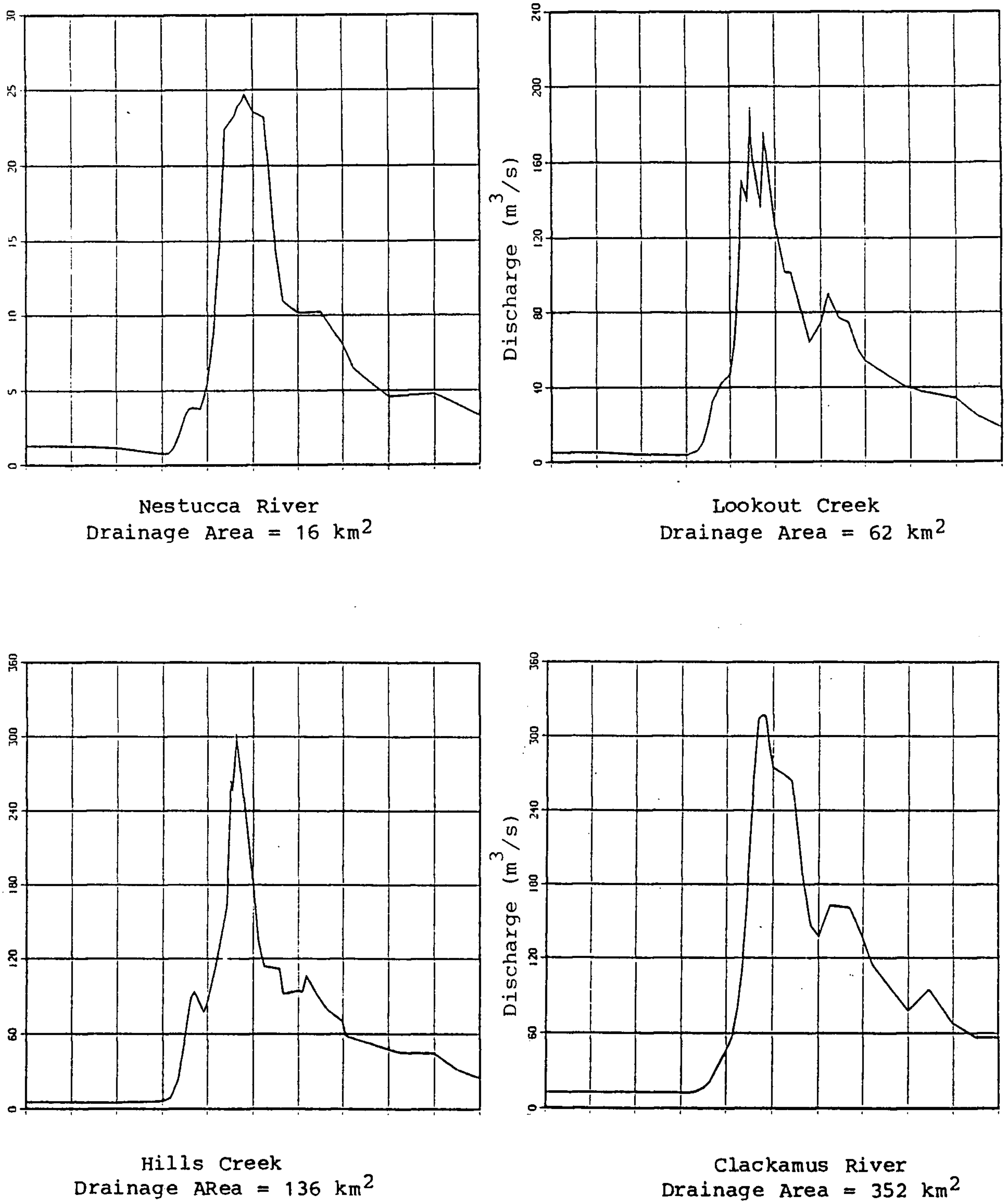


Figure 2.12. Rain-On-Snow Flood Hydrographs

2.4 SUMMARY

1) A single hydrologic region exists along the coast which extends the entire length of the province and includes southeast Alaska, and is bounded to the east by the crest of the Coastal Mountain range.

2) Climatic features in the coastal region include consistent annual trends in precipitation with the wettest months occurring in fall and winter. A relatively small annual temperature range occurs. Within the coastal region, however, local variations exist in precipitation and temperature due to the complex interaction between atmospheric circulation patterns and major topographic features distributed along the coast.

3) The climate of the coastal region is controlled on a seasonal basis by macro-scale atmospheric processes. During winter months low pressure areas over the Gulf of Alaska cause numerous storms to form over the Pacific Ocean and move from the southwest towards the Gulf. During summer months a high pressure centre forms off-shore and the intensity and frequency of Pacific storms is diminished compared to winter.

4) Detailed meteorologic analyses conclude that the most extreme storms in the coastal region will occur during the winter months and will result from storm systems which develop from low pressure areas offshore and generally approach the coast from the southwest.

5) Extreme floods occur in the fall and winter on most drainage basins in the coastal region. These floods are rainfall-induced. Rainfall-induced floods result from rainfall runoff only or from a combination of rain and snowmelt runoff.

6) For those stations in coastal British Columbia determined to have both a fall/winter rainfall and a spring/summer snowmelt-induced flood regime, extreme rainfall-induced floods are greater than those estimated on the same basin for snowmelt floods.

7) Any hydrologic analysis undertaken to model coastal basins in order to predict extreme floods must be capable of simulating both rainfall runoff and runoff resulting from the interaction between rain and snow. A model of these runoff processes must undertake calculations with a time step much less than one day in order to simulate the flashy nature of most coastal floods.

3. CHARACTERISTICS OF STORM RAINFALL IN THE COASTAL REGION

3.1 INTRODUCTION

An assessment of storm rainfall is required for flood analysis in coastal B.C. since extreme floods on most drainage basins are rainfall-induced during fall and winter months. Major obstacles facing the practicing engineer in design situations in the coastal region include: the precipitation gauge network is relatively sparse in remote regions; most stations are located at relatively low elevations; many stations in current operation do not have long term records; available data cannot be readily transposed with confidence over long distance due to mountainous terrain; and many stations report only 24-hour data so that shorter duration storm intensities are not available.

The shortcomings in data described above are not easily overcome. One recent study by Hogg and Carr (1985) produced a rainfall frequency atlas as shown on Figure 3.1 which illustrates general trends in the distribution of 24-hour precipitation in B.C. Engineering design in the coastal region, however, requires more detailed rainfall distribution data at a much larger scale than is currently available.

Analysis of rainfall data presented in this chapter was undertaken with the primary goal of identifying regional characteristics which can be used to estimate rainfall in instances where local data are not available. The premise that such characteristics might exist for the diverse coastal region extending the length of the province was based on the following:

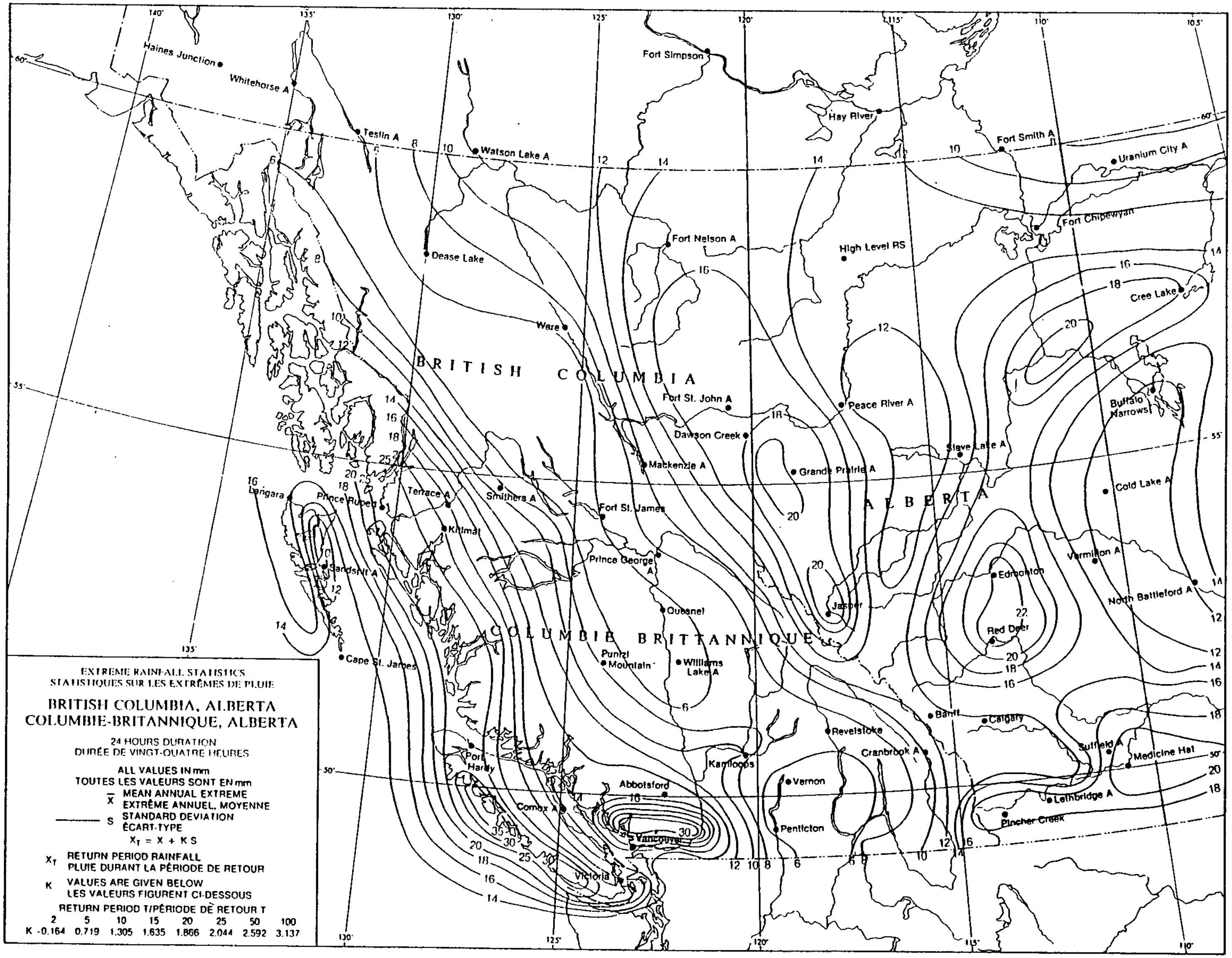


Figure 3.1 Twenty-Four Hour Precipitation in British Columbia (after Hogg and Carr, 1985)

i) atmospheric pressure maps presented on Figures 2.3 and 2.4 in Chapter 2 suggest similar macro-scale circulation patterns affect climate along the entire coastal region.

ii) monthly precipitation data for coastal B.C. stations presented in Table 2.1 in Chapter 2 illustrate that even though the magnitude of precipitation varies considerably along the coast, monthly distribution on a percentage basis is similar among the stations.

The two observations noted above prompted the region-wide analysis of storm rainfall presented in the following sections. That is, if trends in the monthly distribution of precipitation exist in the coastal region, then perhaps trends can also be identified for storm precipitation. Ratios of rainfall depth for a given duration to that of a reference duration are used in the analysis rather than rainfall magnitude alone. This method is one approach to identifying regional characteristics when the amount of rainfall is quite different between stations.

3.2 OVERVIEW OF PRECIPITATION SYSTEMS

The following discussion of precipitation systems is included in this section, prior to presenting analysis undertaken with rainfall data in coastal B.C., to provide an overview of the nature and structure of storms. Oke (1978) used a consensus of the literature to develop a classification system for atmospheric phenomena based on horizontal scales. Braun and Slaymaker (1981) incorporated similar concepts of scale in their discussion of atmospheric and hydrologic systems. In general, atmospheric phenomena can be classified as follows:

i) Macroscale (or synoptic scale) processes include those with horizontal scales of 100-10 000 km and lifetimes from one day to a week. Examples of this scale include low and high-pressure systems which often affect weather over large regions for a period of a few days. The basis for weather prediction at the synoptic scale is weather-map analysis which reduces vast amounts of data into meaningful patterns that can be interpreted by a meteorologist.

ii) Microscale processes include those with horizontal scales in the order of 1 cm to 1 km and with time scales varying from a second to several minutes. These phenomena include convection cells which form from differential heating of adjacent airmasses and mechanical turbulence caused by air flowing over rough terrain. Tornados are an example of microscale motion and possess typical characteristics such as rapid growth, vigorous updrafts and downdrafts, and random movement.

iii) Local and mesoscale processes include those which lie between micro and macroscale phenomena and have horizontal scales ranging from 100 m to 500 km with a time scale up to a day. Examples of mesoscale processes include land-sea and mountain-valley breezes, and squall lines of thunderstorm activity.

In addition, precipitation is usually divided into three principal types according to the primary mode causing uplift of air (Barry and Chorley, 1982). These categories of precipitation are described below:

i) Convective precipitation results when a local instability is generated as a portion of air is heated and the airmass column rises.

ii) Cyclonic precipitation is caused by the ascent of air through horizontal convergence of airstreams in an area of low pressure. In some instances this is reinforced by uplift of warm moist air along an airmass boundary.

iii) Orographic precipitation is caused by uplifting of an airmass as it passes over a topographic feature.

Meteorological phenomena described above provide a convenient framework for categorizing physical processes for analytical study. In reality, however, meteorological observations are affected by many scales of motion occurring simultaneously and which continuously change with time. For example, rising topography may induce orographic precipitation but also trigger convective instability from differential heating of mountain slopes, increase cyclonic precipitation by retarding the rate of movement, and cause uplift through funnelling effects of valleys on airstreams.

The structure and evolution of five storms as they approached the Vancouver region in coastal B.C. were examined by Bonser (1982) based on radar-derived precipitation measurements. Even though the study area was limited to the Vancouver region, characteristics of precipitation patterns observed by Bonser can be considered in a qualitative manner as typical for many storms as they impinge on coastal B.C. mountains. The range of scales of meteorological phenomena observed for a single storm in December 1980 is described below:

i) Macroscale. Precipitation resulted from a low pressure system passing over the Vancouver area.

ii) Mesoscale. Precipitation was identified as a band moving in the direction of the front and as irregular patches ahead of the front. As a rainfall band approached the mountains north of Vancouver it was retarded relative to other portions of the system behind it.

iii) Microscale. Individual convective cells formed within broad rainfall areas and appeared to remain in the same position relative to the rainfall band.

Radar data together with data processing and visual display software provide a means of examining movement of storm systems and growth and decay of cells within the system. Unfortunately, the radar station in

Abbotsford, B.C. used by Bonser in his study ceased operation in 1982 and there is currently no station operating anywhere in British Columbia.

The interaction of different scales of motion is one of the most difficult problems of quantitative meteorology, as it is not yet possible to treat numerically all relevant scales which range from a centimetre to thousands of kilometres in size and from seconds to months in time (Anthes et al., 1978). Lacking adequate radar techniques and physical models, data recorded at rain gauge networks remain the most important source of information available for storm analysis by engineering hydrologists.

3.3 SOURCE OF B.C. RAINFALL INTENSITY DATA

Rainfall data are available from Atmospheric Environment Service (AES) for stations throughout Canada. In coastal B.C. there are currently 58 stations (Table 3.1) at which rainfall intensity data are recorded. Data analyzed in this study were provided by AES on magnetic tape and computer programs were written to extract pertinent data from the tape and to undertake calculations with these data as described in the following sections.

Of the 58 coastal B.C. stations, 27 are located in the Vancouver/Lower Mainland area, 6 in the Victoria/Saanich Peninsula area and 25 are distributed across the remainder of the region. The network density for the coastal region outside of the Vancouver and Victoria areas is compared in Table 3.2 to recommendations by the World Meteorological Organization (WMO, 1970).

TABLE 3.1

COASTAL B.C. STATIONS WITH RAINFALL INTENSITY DATA

Station	Location North Latitude		Location West Longitude		Elev. (m)	No. of Years of Record
Abbotsford A	49	02	122	22	58	7
Agassiz CDA	49	15	121	46	15	26
Alouette Lake	49	17	122	29	117	13
Alta Lake	50	09	122	57	668	13
Bear Creek	48	30	124	00	351	7
Bella Coola Hydro	52	22	126	49	14	14
Buntzen Lake	49	23	122	52	17	15
Burnaby Mtn BCHPA	49	17	122	55	465	9
Campbell River BCFS	50	04	125	19	128	10
Campbell River BCHPA	50	03	125	19	30	11
Carnation Creek	48	54	125	00	61	7
Chilliwack Microwave	49	07	121	54	229	17
Clowhom Falls	49	43	123	32	23	15
Comox A	49	43	124	54	24	14
Coquitlam Lake	49	22	122	48	161	13
Courtney Puntledge	49	41	125	02	24	20
Daisy Lake Dam	49	59	123	08	381	15
Estevan Point	49	23	126	33	7	10
Haney Microwave	49	12	122	31	320	20
Haney UBC	49	16	122	34	143	20
Jordan River Diversion	48	30	124	00	393	10
Jordan River Generating	48	25	124	03	5	11
Kitimat	54	00	128	42	17	10
Ladner BCHPA	49	05	123	03	2	13
Langley Lochiel	49	03	122	35	101	12
Mission West Abbey	49	09	122	16	221	21
Nanaimo Departure Bay	49	13	123	57	8	13
North Vanc. Lynn Creek	49	22	123	02	191	19
Pitt Meadows STP	49	13	122	42	5	9
Pitt Polder	49	18	122	38	2	19

TABLE 3.1
(continued)

COASTAL B.C. STATIONS WITH RAINFALL INTENSITY DATA

Station	Location North Latitude		Location West Longitude		Elev. (m)	No. of Years of Record
Port Alberni A	49	15	124	50	2	15
Port Coquitlam City Yard	49	16	122	46	7	13
Port Hardy	50	41	127	22	22	10
Port Mellon	49	31	123	29	8	11
Port Moody Gulf Oil Ref.	49	17	122	53	130	13
Port Renfrew BCFS	48	35	124	24	6	11
Prince Rupert A	54	18	130	26	34	14
Saanich Densmore	48	30	123	25	38	10
Sandspit A	53	15	131	49	5	12
Spring Island	50	00	127	25	11	8
Stave Falls	49	14	122	21	55	8
Strathcona Dam	50	00	125	35	201	15
Surrey Kwantlen Park	49	12	122	52	93	22
Surrey Municipal Hall	49	06	122	50	76	20
Terrace A	54	28	128	35	217	15
Terrace PCC	54	30	128	37	58	15
Tofino A	49	05	125	46	20	13
Vancouver A	49	11	123	10	3	31
Vancouver Harbour	49	18	123	07	0	8
Vancouver Kitsilano	49	16	123	11	23	30
Vancouver PMO	49	17	123	07	59	10
Vancouver UBC	49	15	123	15	87	6
Victoria Gonzales Heights	48	25	123	19	69	51
Victoria Int. A	48	39	123	26	19	19
Victoria Marine Radio	48	22	123	45	32	17
Victoria Shelbourne	48	28	123	20	38	9
Victoria U. of Vict.	48	28	123	20	46	19
White Rock STP	49	01	122	46	15	18

Note: Station descriptions from Environment Canada (1981b)

TABLE 3.2

DENSITY OF RAIN GAUGE NETWORKS

Recommendations by WMO:	
Flat regions	600-900 km^2/station
Mountainous regions	100-250 km^2/station
Small mountainous islands with irregular precipitation	25 km^2/station
British Columbia:	
Coastal region excluding Vancouver and Victoria areas:	225 000 km^2/25 stations = 9 000 km^2/station

Information presented in Table 3.2 illustrates the shortcomings of rainfall intensity data in coastal B.C. with regard to network density. It also emphasizes that for much of the region, engineering design requiring rainfall analysis often has to be undertaken without data from the project site or from the immediately surrounding area.

Even in instances when rainfall intensity data are available from a local station the period of record is often too short to confidently undertake statistical analysis of the data. Lengths of record for the 58 stations which record rainfall intensity in the coastal region are illustrated on Figure 3.2. This summary shows that over half of the coastal stations have less than 15 years of data and only two stations have more than 30 years of record.

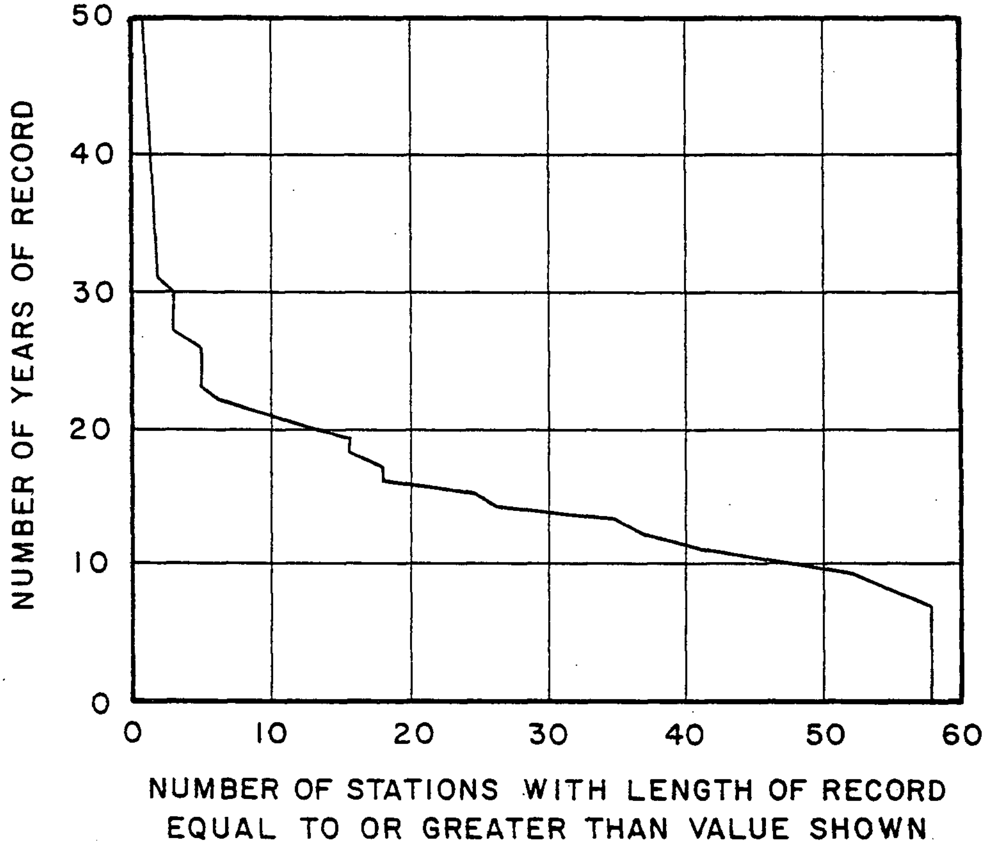


Figure 3.2 Lengths of Record at Coastal B.C. Stations

In addition to the 58 stations which record rainfall intensity, there are approximately 250 stations in coastal B.C. which record only 24-hour data (Environment Canada, 1981a). A particular benefit of identifying regional characteristics of rainfall intensity would be that these 24-hour stations could then be used to greatly expand the data base currently available for design purposes.

3.4 INTENSITY-DURATION-FREQUENCY CURVES

3.4.1 Development and Use of IDF Curves

Intensity-duration-frequency (IDF) curves are prepared by Atmospheric Environment Service for each of the 58 coastal B.C. stations which record rainfall intensity. The procedure used by AES to develop IDF curves at each station consists of producing from recorded data annual maximum series of rainfall intensities for durations ranging from 5 minutes to 24 hours, conducting an extreme value frequency analysis with each annual maximum series, and finally generating a set of best fit curves for selected return periods and for the range of durations.

A typical IDF curve produced by AES is shown on Figure 3.3. Plotted points for each duration are results of the extreme value frequency analysis and illustrate the "depth-frequency" relationship for that duration. Best fit lines connecting points with the same return period illustrate the "depth-duration" relationship for a particular return period.

It is important to recognize in the development of IDF curves that since annual maximum series are generated for each duration, rainfall intensity for one duration is not necessarily related to the intensity for another duration with the same return period. That is, the set of rainfall intensities for durations from 5 minutes to 24 hours do not generally occur within the same storm to produce the 24-hour rainfall depth. IDF curves provide average intensities for a given duration and return period, but do not provide information regarding variations in rainfall intensities within a single storm.

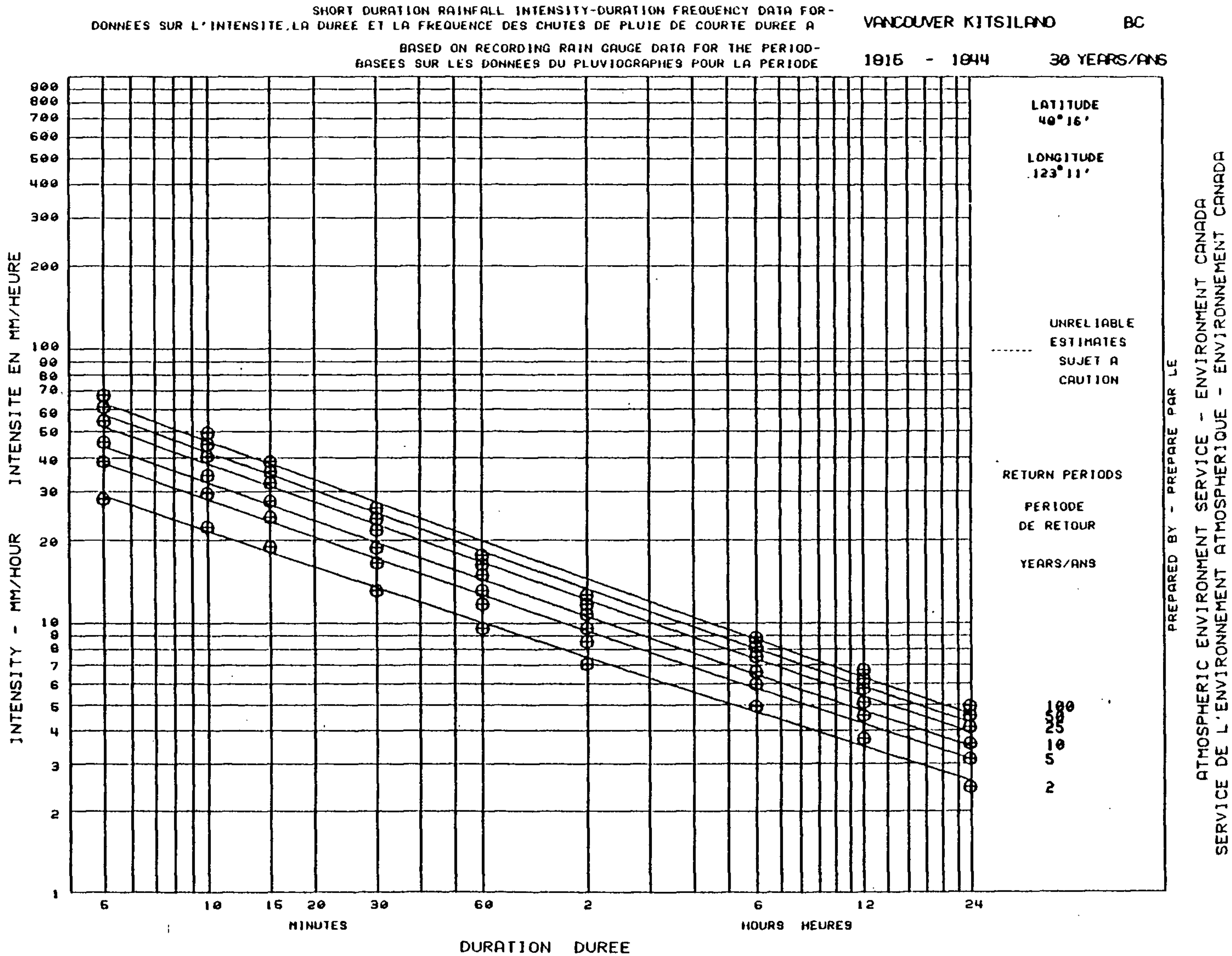


Figure 3.3. IDF Curves For Vancouver Kitsilano

Use of IDF relationships to develop synthetic hyetographs for flood analysis has been widely incorporated in Canadian practice (McKelvie, 1982). One procedure is commonly referred to as the Chicago method and was originally proposed by Keifer and Chu (1957). In this method a design storm is generated such that the resulting hyetograph is comprised throughout the storm duration of incremental rainfall intensities with the same return period. As noted above, however, IDF curves are developed with data from a variety of storms and generally do not represent a sequence of intensities in a single storm. Nevertheless, this procedure is used partly because of limited alternatives for design.

In the Chicago method the time sequence of rainfall intensities within the design storm is determined from analysis of historical storm records. The relative timing of peak intensity within storms on record is used as a guide for choosing the time sequence for a synthetic hyetograph developed from IDF curves. An alternative method is to distribute rainfall intensities symmetrically with time. Even though this second approach appears quite arbitrary, it has been applied extensively and is still recommended by the U.S. Bureau of Reclamation (USBR, 1977) for flood studies.

Regional characteristics of IDF curves are investigated in this study by analyzing depth-duration and depth-frequency relationships separately. The initital data base consisted of rainfall depths produced by AES from extreme value frequency analysis, prior to estimates by AES of best fit curves included on IDF graphs. For each station depth-duration characteristics are assessed by calculating ratios of short duration rainfall to the 24-hour depth, and depth-frequency characteristics for a given duration are assessed by calculating ratios to a reference depth taken as the 10 year period.

Rainfall depth-duration-frequency data analyzed in this investigation are included in Appendix II for each of the 58 coastal B.C. stations.

3.4.2 Depth-Duration Relationships

3.4.2.1 Analysis of B.C. Data

Rainfall intensity data available from AES are analyzed to determine the relationship between rainfall depth and duration for a given return period and to assess the variability of this relationship throughout the coastal region. Regional "depth-duration" characteristics provide a basis for estimating rainfall for a range of durations in instances when rainfall is known only for one duration.

Depth-duration relationships for the coastal region are assessed by calculating ratios of short duration rainfall to the 24-hour depth. Rainfall depths were obtained at each of the 58 available coastal B.C. stations included in Appendix II for durations of 1, 2, 6, 12 and 24 hours. These rainfall depths were used to calculate the ratio of depth for each duration to the 24-hour depth with the same return period. Depth ratios calculated by this procedure are tabulated in Appendix II for each individual coastal station.

Rainfall data and depth-duration ratios calculated for Pitt Polder in southwestern B.C. are included in Table 3.3 to illustrate typical results of analysis undertaken in this study. These results for Pitt Polder show that the ratio of rainfall on IDF curves for a given duration to the 24-hour depth is relatively constant with return period.

TABLE 3.3

DEPTH-DURATION DATA FOR PITT POLDER

Rainfall Data (mm) From AES

Duration	Return Period (Years)					
	2	5	10	25	50	100
1 hr	12.4	14.7	16.2	18.1	19.1	20.9
2 hr	18.9	22.9	25.4	28.7	31.2	33.6
6 hr	42.7	51.7	57.7	65.3	70.9	76.4
12 hr	67.3	80.3	88.9	99.8	107.9	115.9
24 hr	98.9	119.0	132.2	149.0	161.5	173.8

Depth-Duration Relationships

Duration	2	5	10	25	50	100
1 hr	0.13	0.12	0.12	0.12	0.12	0.12
2 hr	0.19	0.19	0.19	0.19	0.19	0.19
6 hr	0.43	0.43	0.44	0.44	0.44	0.44
12 hr	0.68	0.67	0.67	0.67	0.67	0.67
24 hr	1.00	1.00	1.00	1.00	1.00	1.00

Examination of results of analysis of rainfall intensity data from across the region shows depth-duration ratios have minimal variation with return period at each of the available coastal B.C. stations. Furthermore, the magnitude of these depth ratios from all available stations are in a relatively narrow range for the coastal region. Mean values of depth-duration ratios for 58 coastal stations are listed in Table 3.4 and shown graphically on Figure 3.4.

TABLE 3.4

DEPTH-DURATION RATIOS FOR IDF CURVES

Duration (Hours)	Depth Ratios for Coastal Region — Return Period (Years) 2	5	10	25	50	100	Mean (all values)	Std. Dev. (all values)
1	0.16	0.16	0.16	0.16	0.17	0.17	0.16	0.06
2	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.06
6	0.48	0.46	0.45	0.44	0.43	0.42	0.45	0.06
12	0.72	0.69	0.68	0.67	0.67	0.66	0.68	0.05
24	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-

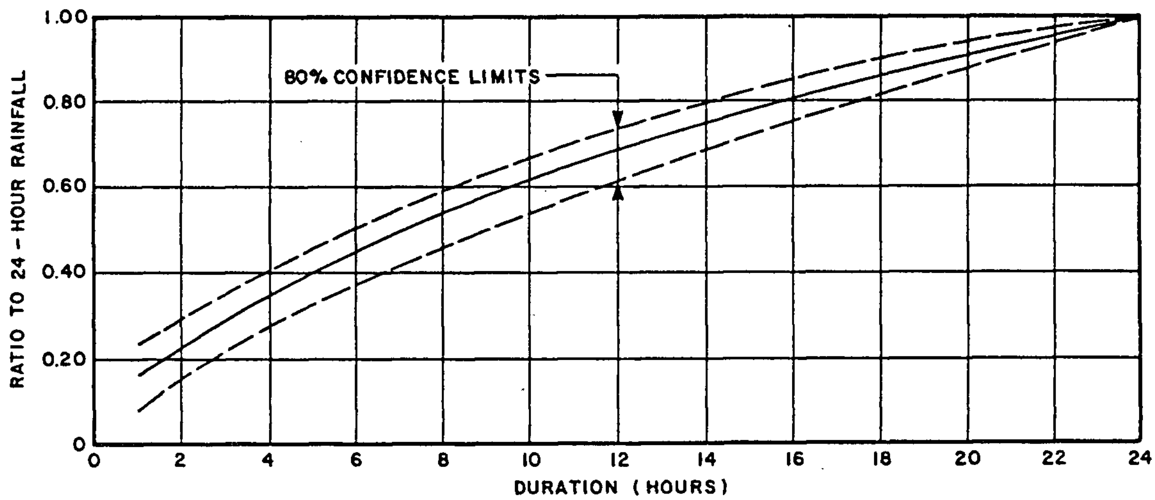


Figure 3.4 Depth-Duration Ratios for IDF Curves

These results are particularly interesting considering that the magnitude of rainfall varies considerably between stations across the region. For example, the 24-hour storm rainfall with a 100-year return period ranges from 75 to 380 mm for the available 58 coastal stations; mean annual precipitation at these stations ranges from about 650 to 3500 mm.

The regional characteristic of IDF curves identified for depth-duration ratios is especially useful for application to the approximately 250 coastal B.C. stations which record only 24-hour data. When a project site is near one of these stations, frequency analysis can be undertaken to provide an estimate of a 24-hour rainfall with a desired return period. Then, depth-duration ratios can be applied to estimate rainfall depths for any shorter durations which may be required for design purposes.

Depth-duration ratios from other regions of British Columbia are included in Table 3.5 for comparison. These data show that even though a range of ratios has been calculated for the coastal region, values within this range are distinct from those ratios calculated in other regions of British Columbia.

TABLE 3.5

COMPARISON OF DEPTH-DURATION RATIOS

Location	Physiographic Region	Duration 1 hour	6 hours	12 hours
Mean of 58 Stations	B.C. Coast	0.16	0.45	0.68
Castelgar, B.C.	Southeast Mountains	0.44	0.79	0.87
Kamloops, B.C.	Interior Plateau	0.35	0.62	0.77
Fort St. John, B.C.	Great Plains	0.42	0.74	0.87

3.4.2.2 **Formulas for B.C. Data**

Results of analysis of coastal British Columbia data presented on Figure 3.4 provide a graphical description of how rainfall depth varies with duration. This section provides formulas relating depth and duration which are in a more convenient format for programming purposes by users of the results.

Various formulas which relate rainfall depth to duration have been proposed. Chen (1976) summarized the main types of formulas which are commonly applied to rainfall data as part of a study of rainfall intensities at 34 cities across the United States. These formulas and that currently applied by AES to Canadian data are included in Table 3.6.

TABLE 3.6

FORMULAS RELATING RAINFALL DEPTH TO DURATION

No.	Equation	Reference	Comment
3.1	$I = \frac{a}{t + b}$	Meyer (1921, 1928)	Bernard (1932) concluded after analyzing further much of the data initially reviewed by Meyer that Eq. 3.1 is only suitable for short durations of about 5 to 120 minutes.
3.2	$I = \frac{a}{t^b}$	a) Bernard (1932)	a) Because of the apparent limitation of Eq. 3.1, Bernard proposed Eq. 3.2 for longer durations of 2 to 24 hours.
		b) Environment Canada (1983c)	b) AES applies Eq. 3.2 to stations across Canada for durations of 5 minutes to 24 hours, except where inspection of IDF curves shows the equation to be inappropriate.
3.3	$I = \frac{a}{(t + c)^b}$	Sherman (1931)	Sherman found Eq. 3.3 to be applicable for the complete range of durations from 5 minutes to 24 hours. Chen (1976) used Eq. 3.3 in his study of rainfall intensities in 34 cities in the U.S.
3.4	$I = \frac{a}{t^b + c}$	Keifer and Chu (1957)	Used by Keifer and Chu in their development of a procedure for generating synthetic hyetographs, commonly referred to as the Chicago Method.

I = rainfall intensity; t = duration; a, b and c = station coefficients

Formulas presented in Table 3.6 are generally considered as "standard-form" types of relations. These formulas are all empirical and it is reasonable to suppose that their acceptance as standard equations is based mostly on precedent. Considering that the formulas were proposed in an era which generally predates computer analysis, commonly applied curve fitting techniques were likely very simple compared to those currently in use. Review of Eq. 3.2 shows that this relationship represents a straight line on a log-log plot. Perhaps Eqs. 3.3 and 3.4 were developed as an extension of Eq. 3.2 because rainfall intensity data often do not plot as a straight line over an entire duration range from 5 minutes to 24 hours. Rainfall intensities plotted on log-log scales are commonly concave up or down over the 5-60 minute range compared to longer duration intensities.

Eq. 3.2 is currently applied by AES to rainfall intensity data from stations across Canada. Fitting a curve in the form of Eq. 3.2 to Canadian data for durations ranging from 5 minutes to 24 hours results in one of the following: rainfall intensity data fit the curve well over the entire duration range; the curve does not fit the data well over the entire range but is nevertheless considered by AES to be an acceptable approximation; or Eq. 3.2 does not fit the data well enough to be recommended by AES in which case no alternative intensity-duration formula is provided. The criteria described above are generally applied in a subjective manner by AES based on inspection of plotted rainfall intensity data (Hogg, 1985). Inspection of IDF curves developed by AES for the 58 available coastal B.C. stations shows many stations are in the second category.

Based on assessment of procedures currently applied by AES to develop empirical equations relating intensity to duration for a 5 minute to 24-hour range and on inspection of the results of these methods on IDF curves in coastal B.C., the equations provided by AES are not included in this investigation of regional rainfall characteristics. Alternatively, Eq. 3.2 was applied to intensity data with durations ranging only from 1 to 24 hours and a nonlinear curve fitting routine, NL2SOL, available from the UBC Computing Centre (Moore, 1984) was used to calculate the coefficients a and b in Eq. 3.2 which best fit the available data.

A summary of coefficients derived for each coastal station is included in Table 3.7. Coefficient a is quite variable in the coastal region because it reflects magnitude of rainfall. For a given duration, this coefficient will vary between stations which receive different amounts of rain and at the same station because intensity varies with return period. Coefficient b is more representative of a regional characteristic as it shows the interrelationship between intensities at a station for a range of durations with the same return period.

TABLE 3.7

DEPTH-DURATION FORMULAS FOR COASTAL B.C.*

Station	Return Period											
	2-years		5-years		10-years		25-years		50-years		100-years	
	a	b	a	b	a	b	a	b	a	b	a	b
Abbotsford A	85	0.46	183	0.58	265	0.60	384	0.64	483	0.67	588	0.69
Agassiz CDA	53	0.39	69	0.41	80	0.42	94	0.43	104	0.44	115	0.45
Alouette Lake	45	0.31	55	0.32	61	0.33	69	0.33	75	0.33	82	0.33
Alta Lake	40	0.42	43	0.40	45	0.39	47	0.38	49	0.38	51	0.37
Bear Creek	150	0.45	289	0.51	393	0.54	534	0.56	644	0.57	757	0.59
Bella Coola Hydro	40	0.32	45	0.30	49	0.29	55	0.28	59	0.28	63	0.27
Buntzen Lake	58	0.34	72	0.33	81	0.33	93	0.33	102	0.33	110	0.33
Burnaby Mtn BCHPA	49	0.36	61	0.37	69	0.38	80	0.39	87	0.39	95	0.40
Campbell River BCFS	69	0.45	102	0.49	125	0.51	156	0.52	180	0.53	204	0.54
Campbell River BCHPA	106	0.51	223	0.61	325	0.66	478	0.71	606	0.74	746	0.76
Carnation Creek	45	0.32	53	0.31	59	0.30	66	0.30	71	0.30	77	0.29
Chilliwack Microwave	63	0.45	92	0.49	114	0.51	141	0.52	163	0.54	185	0.55
Clowhom Falls	45	0.36	63	0.39	76	0.40	93	0.42	106	0.43	118	0.43
Comox A	56	0.43	80	0.46	96	0.47	119	0.49	135	0.50	152	0.50
Coquitlam Lake	42	0.26	43	0.24	45	0.23	46	0.22	48	0.21	49	0.21
Courtney Puntledge	44	0.37	57	0.38	65	0.39	77	0.39	85	0.40	93	0.40
Daisy Lake Dam	46	0.37	85	0.44	115	0.47	155	0.50	187	0.52	220	0.53
Estevan Point	79	0.36	99	0.36	112	0.36	128	0.36	140	0.36	152	0.36
Haney Microwave	67	0.41	87	0.42	101	0.43	119	0.44	132	0.44	145	0.45
Haney UBC	51	0.35	61	0.36	69	0.36	78	0.36	85	0.36	91	0.36
Jordan River Diversion	112	0.39	174	0.42	218	0.43	275	0.44	318	0.45	361	0.45
Jordan River Generating	44	0.34	46	0.32	47	0.30	49	0.29	50	0.28	52	0.27
Kitimat	45	0.32	51	0.30	55	0.29	60	0.29	64	0.28	69	0.28
Ladner BCHPA	52	0.45	65	0.46	74	0.47	85	0.48	94	0.48	102	0.49
Langley Lochiel	71	0.45	101	0.48	123	0.49	152	0.51	174	0.52	198	0.53

TABLE 3.7

DEPTH-DURATION FORMULAS FOR COASTAL B.C.*
(continued)

Station	Return Period											
	2-years		5-years		10-years		25-years		50-years		100-years	
	a	b	a	b	a	b	a	b	a	b	a	b
Mission West Abbey	95	0.47	151	0.52	194	0.55	251	0.57	296	0.59	342	0.60
Nanaimo Departure Bay	72	0.50	201	0.63	313	0.68	474	0.72	603	0.75	740	0.77
North Vancouver Lynn Creek	52	0.31	58	0.29	62	0.28	67	0.27	71	0.27	75	0.26
Pitt Meadows STP	71	0.43	125	0.48	165	0.50	217	0.53	258	0.54	299	0.55
Pitt Polder	47	0.33	54	0.32	59	0.32	66	0.32	71	0.31	75	0.31
Port Alberni	45	0.34	74	0.39	96	0.42	128	0.45	153	0.47	180	0.48
Port Coquitlam City Yard	46	0.35	58	0.36	66	0.37	76	0.38	84	0.39	91	0.39
Port Hardy	33	0.29	32	0.25	32	0.23	32	0.22	33	0.21	33	0.20
Port Mellon	73	0.33	75	0.31	76	0.30	78	0.29	80	0.28	82	0.27
Port Moody Gulf Oil Refin.	39	0.32	51	0.33	58	0.34	68	0.35	75	0.35	83	0.35
Port Renfrew BCFS	73	0.30	125	0.36	165	0.39	220	0.42	263	0.43	308	0.45
Prince Rupert A	55	0.37	55	0.33	56	0.31	57	0.30	58	0.28	60	0.28
Saanich Densmore	34	0.36	35	0.33	36	0.32	38	0.31	39	0.30	40	0.29
Sandspit A	66	0.45	79	0.45	88	0.45	99	0.45	107	0.46	114	0.46
Spring Island	61	0.34	68	0.32	73	0.31	79	0.30	83	0.30	88	0.30
Stave Falls	50	0.35	49	0.31	48	0.29	49	0.27	50	0.26	50	0.25
Strathcona Dam	84	0.48	146	0.52	191	0.55	254	0.57	302	0.58	352	0.60
Surrey Kwantlen Park	59	0.41	85	0.43	103	0.45	126	0.46	143	0.46	160	0.47
Surrey Municipal Hall	50	0.41	78	0.45	97	0.47	123	0.49	143	0.50	163	0.51
Terrace A	68	0.47	91	0.47	106	0.48	125	0.48	139	0.48	154	0.48
Terrace PCC	45	0.42	85	0.47	114	0.49	151	0.51	179	0.51	207	0.52
Tofino A	78	0.36	88	0.35	95	0.35	103	0.35	110	0.35	116	0.35
Vancouver A	68	0.47	92	0.49	108	0.50	129	0.50	145	0.51	160	0.51
Vancouver Harbour	95	0.49	182	0.57	252	0.61	353	0.65	436	0.68	522	0.69
Vancouver Kitsilano	47	0.39	58	0.39	65	0.39	74	0.39	80	0.39	86	0.39

TABLE 3.7

DEPTH-DURATION FORMULAS FOR COASTAL B.C.*
(continued)

	Return Period											
	2-years		5-years		10-years		25-years		50-years		100-years	
Station	a	b	a	b	a	b	a	b	a	b	a	b
Mission West Abbey	95	0.47	151	0.52	194	0.55	251	0.57	296	0.59	342	0.60
Vancouver PMO	43	0.36	44	0.33	45	0.31	47	0.30	49	0.29	50	0.28
Vancouver UBC	60	0.44	87	0.47	106	0.49	131	0.50	150	0.51	169	0.52
Victoria Gonzales Heights	36	0.39	41	0.36	44	0.35	49	0.34	52	0.33	56	0.33
Victoria Int. A	42	0.40	47	0.38	50	0.37	54	0.37	57	0.36	59	0.36
Victoria Marine Radio	43	0.37	55	0.37	63	0.38	73	0.38	80	0.38	87	0.38
Victoria Shelbourne	46	0.43	51	0.41	55	0.40	60	0.40	63	0.39	67	0.39
Victoria U. of Victoria	37	0.37	38	0.34	38	0.32	40	0.31	41	0.30	43	0.29
White Rock STP	105	0.53	291	0.66	453	0.71	685	0.75	874	0.78	1070	0.80
Mean		0.39		0.41		0.41		0.42		0.43		0.43
Std. Dev		0.06		0.09		0.11		0.12		0.13		0.14

* intensity-duration equation $I = \frac{a}{t^b}$

The relationship between two intensities I_1 and I_2 can be shown as follows:

$$\frac{I_1}{I_2} = \frac{at_1^{-b}}{at_2^{-b}} = \left(\frac{t_2}{t_1}\right)^b \qquad \text{.............................(3.5)}$$

Converting to rainfall depth, R, Eq. 3.5 becomes:

$$\frac{R_1}{R_2} = \frac{t_1}{t_2}\left(\frac{t_2}{t_1}\right)^b \qquad \text{.........................(3.6)}$$

Setting $R_1 = R$ and $t_1 = t$ to represent rainfall depth for any time less than 24 hours, and setting $R_2 = R_{24}$ and $t_2 = t_{24}$ hours (1440 minutes) to represent rainfall depth in 24 hours, Eq. 3.6 simplifies to:

$$\frac{R}{R_{24}} = \frac{t}{1440}\left(\frac{1440}{t}\right)^b \qquad \text{.........................(3.7)}$$

Finally, inserting the mean value of b for the coastal region from Table 3.7 yields:

$$\frac{R}{R_{24}} = \frac{t}{1440}\left(\frac{1440}{t}\right)^{0.41} = 0.0137t^{0.59} \qquad \text{..............(3.8)}$$

Comparison of rainfall depth ratios presented in Table 3.4 with those calculated with Eq. 3.8 is included below.

TABLE 3.8

COMPARISON OF RAINFALL DEPTH RATIOS

Duration (Hours)	Mean Depth Ratios for Coastal Region Table 3.4/Figure 3.4	Eq. 3.8
1	0.16	0.15
2	0.23	0.23
6	0.45	0.44
12	0.68	0.66
24	1.00	1.00

Depth-duration equations which represent 80 percent confidence limits on Figure 3.4 are derived by inserting the appropriate value for b as shown below for lower and upper limits, respectively:

$$\frac{R}{R_{24}} = \frac{t}{1440}\left(\frac{1440}{t}\right)^{0.55} = 0.0379t^{0.45} \qquad \text{..........(3.9)}$$

$$\frac{R}{R_{24}} = \frac{t}{1440}\left(\frac{1440}{t}\right)^{0.27} = 0.0049t^{0.73} \qquad \text{.........(3.10)}$$

A closer examination of coefficient b listed for individual coastal stations shows some interesting local variations. For example, comparison of Terrace A with Terrace PCC shows that coefficient b can vary between stations in close proximity. Comparison of Coquitlam Lake and Mission West Abbey, two stations located in the mountains immediately north of the Fraser River near Vancouver, shows that coefficient b for Coquitlam Lake is one of the lower values calculated for the coastal region while the corresponding value for Mission West Abbey is one of the higher values in the region. The above observations suggest that proximity alone is not adequate to transpose reliably precipitation depth ratios calculated at one station to another site without also considering the range of depth ratios observed for the coastal region.

3.4.3 Depth-Frequency Relationships

3.4.3.1 Analysis of B.C. Data

Rainfall intensity data available from AES are analyzed to determine the relationship between rainfall depth and return period for durations ranging from 1 to 24-hours and to assess the variability of this relationship throughout the coastal region. Regional "depth-frequency" characteristics provide a basis for estimating rainfall for a range of return periods in instances when rainfall is known only for one return period.

Variation of rainfall depth with frequency of occurrence for a given duration is assessed in this study by calculating ratios to a reference depth. Rainfall depths were obtained at each of the 58 available coastal B.C. stations included in Appendix II for return periods of 2, 10, 25, 50 and 100 years. These rainfall depths were used to calculate ratios of depth for each return period to a reference depth taken as the 10-year return period. Depth ratios calculated by this procedure are tabulated in Appendix II for each individual coastal station.

Rainfall data and depth-frequency ratios calculated for Pitt Polder in southwestern B.C. are repeated in Table 3.9 to illustrate typical results of depth-frequency analysis. Results for Pitt Polder show that the ratios on IDF curves for a given return period to the 10-year return period depth is relatively constant for a range of durations from 1 to 24-hours.

TABLE 3.9

DEPTH-FREQUENCY DATA FOR PITT POLDER

Rainfall Data (mm) from AES						
	Return Period (Years)					
Duration	2	5	10	25	50	100
1 hr	12.4	14.7	16.2	18.1	19.1	20.9
2 hr	18.9	22.9	25.4	28.7	31.2	33.6
6 hr	42.7	51.7	57.7	65.3	70.9	76.4
12 hr	67.3	80.3	88.9	99.8	107.9	115.9
24 hr	98.9	119.0	132.2	149.0	161.5	173.8

Depth-Frequency Relationships						
	Return Period (Years)					
Duration	2	5	10	25	50	100
1 hr	0.77	0.91	1.00	1.12	1.21	1.29
2 hr	0.74	0.90	1.00	1.13	1.22	1.32
6 hr	0.74	0.90	1.00	1.13	1.23	1.32
12 hr	0.76	0.90	1.00	1.12	1.21	1.30
24 hr	0.75	0.90	1.00	1.13	1.22	1.31

Analysis of rainfall intensity data throughout the B.C. coastal region shows that at each station depth-frequency ratios do not vary greatly with duration. This result is particularly useful because there are approximately 250 coastal B.C. stations, in addition to 58 stations with IDF data, which record only 24-hour precipitation. These 250 stations greatly expand the data base across the region with which local assessments of depth-frequency ratios for shorter duration rainfall intensities can be undertaken. That is, depth-frequency ratios calculated for 24-hour data can be used to develop a frequency curve for shorter duration rainfall which may be required for design purposes. Mean values of depth-frequency ratios for 58 coastal stations are listed in Table 3.10 and shown graphically on Figure 3.5. Results are shown with reference to the 10-year return period, although arithmetic calculations can convert these curves to reference any desired return period. Also, the statistical inference of the depth-return period results is that the coefficient of variation in the coastal region for the mean, upper and lower 80 percent confidence limits are 0.28, 0.35 and 0.21, respectively.

TABLE 3.10

DEPTH-FREQUENCY RATIOS for IDF CURVES

Duration (hours)	Return Period (Years) 2	5	10	25	50	100
1	0.70	0.88	1.00	1.15	1.27	1.38
2	0.74	0.89	1.00	1.13	1.23	1.33
6	0.76	0.90	1.00	1.12	1.22	1.31
12	0.73	0.89	1.00	1.14	1.24	1.34
24	0.69	0.88	1.00	1.15	1.27	1.38
(all values)						
Mean	0.72	0.89	1.00	1.14	1.24	1.35
Std. Dev.	0.05	0.02	-	0.02	0.02	0.03

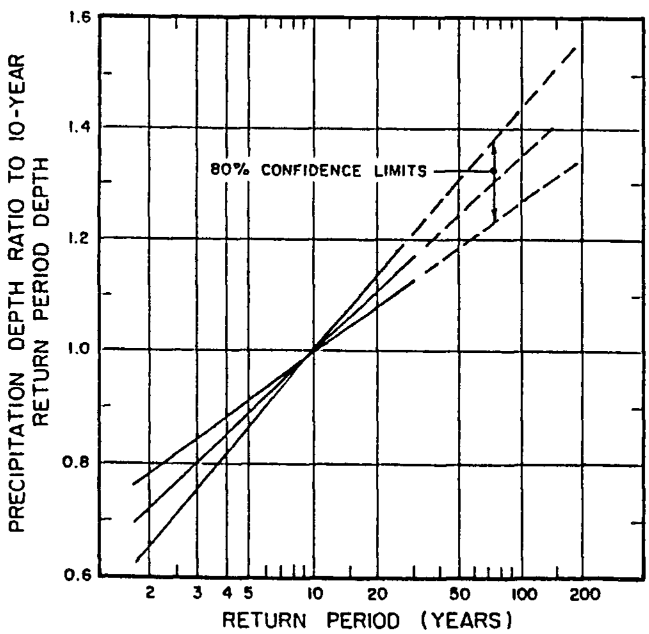


Figure 3.5: Depth-Frequency Ratios for IDF Curves

Observations noted previously in discussion of depth-duration ratios also apply to results of analysis of depth-frequency ratios in the coastal region. That is, the range of ratios is relatively small considering the diversity of the region and that the magnitude of rainfall varies considerably between stations. Results of depth-frequency analysis are derived for coastal stations where 24-hour storm rainfall with a 100-year return period ranges from 75 to 380 mm and mean annual precipitation ranges from about 650 to 3500 mm.

3.4.3.2 **Formulas for B.C. Data**

An expression relating rainfall depth and frequency for the extremal distribution was presented by Chow (1951, 1959) as follows:

$$R_T = \bar{R} + K_T \sigma \qquad (3.11)$$

where R_T = rainfall depth with return period T; $\bar{R}$ = mean of recorded rainfall data; σ = standard deviation of rainfall data, and K_T = frequency factor which varies with return period and record length.

For the extreme value distribution, the ratio between any two points establishes the ratio between any two other points on the frequency curve. If the ratio between two rainfall depths, R_1 and R_2, with respective return periods T_1 and T_2 is known, then the ratio between any other rainfall R_T with return period T and a known rainfall depth can be expressed.

Consider:

$$R_1 = \bar{R} + K_1 \sigma \qquad \text{.......... (3.12)}$$

$$R_2 = \bar{R} + K_2 \sigma \qquad \text{.......... (3.13)}$$

Solving Eq. 3.12 and 3.13 simultaneously yields:

$$\bar{R} = \frac{K_1 R_2 - K_2 R_1}{K_1 - K_2} \qquad \text{.......... (3.14)}$$

$$\sigma = \frac{R_1 - R_2}{K_1 - K_2} \qquad \text{.......... (3.15)}$$

Substituting Eq. 3.14 and 3.15 into Eq. 3.11 and 3.12 and taking the ratio R_T/R_1 yields:

$$\frac{R_T}{R_1} = \frac{K_T - K_2}{K_1 - K_2} + \frac{K_1 - K_T}{K_1 - K_2}\left(\frac{R_2}{R_1}\right) \qquad \text{.......... (3.16)}$$

Eq. 3.16 shows how the ratio between rainfall depths can be determined for the extreme value distribution when the ratio between any two depths on the frequency curve is known. Eq. 3.16 is in a convenient form for numerical presentation of depth-frequency relationships in the coastal region, while the results presented on Figure 3.5 provide a more illustrative description of how depth ratios vary with return period.

3.4.4 Comparison with Other Pacific Northwest Data

Rainfall intensity data available for the coastal region of Washington and Oregon are compared with results obtained in this study for B.C. These data from the U.S. were obtained to illustrate further the regional applicability of rainfall characteristics documented for coastal B.C. In addition, U.S. stations provide data for higher elevations than stations currently available in coastal B.C.

Sources of U.S. precipitation data considered in this study include the Precipitation-Frequency Atlas of the Western United States (Miller et al, 1973) and results of frequency analyses undertaken at six stations in the Cascade Mountains of Washington (Brunengo, 1985). Data from isopluvial maps in the precipitation-frequency atlas were obtained for this study only at points where precipitation gauges are known to be located.

Depth ratios were calculated with data from U.S. stations in the same format that was applied to B.C. data. A summary of depth ratios calculated at coastal stations in Washington and Oregon and comparison of these values to those calculated for coastal B.C. is included in Table 3.11 for depth-duration ratios and in Table 3.12 for depth-frequency ratios.

TABLE 3.11

DEPTH-DURATION RATIOS IN THE PACIFIC NORTHWEST

Station	Location Latitude		Location Longitude		Elev. (m)	Ratio to 24-Hr Depth 1-hr	6-hr	12-hr
Coastal B.C.	-		-		-	0.16	0.45	0.68
Washington								
Palmer (1)	47	18	121	51	280	0.18	0.45	0.68
Mud Mtn Dam (2)	47	09	121	56	399	0.18	0.47	0.70
Cedar Lake (1)	47	25	121	44	476	0.19	0.40	0.64
Lester (1)	47	12	121	29	497	0.18	0.47	0.68
Greenwater (1)	47	08	121	38	527	0.14	0.47	0.70
Rainier Longmire (2)	46	45	121	49	842	0.17	0.47	0.74
Snowqualmie Pass (2)	47	25	121	25	921	0.13	0.41	0.71
Stampede Pass (2)	47	17	121	20	1207	0.11	0.39	0.63
Stevens Pass (2)	47	44	121	05	1241	0.16	0.48	0.73
Mt. Baker Lodge (2)	48	52	121	40	1265	0.13	0.41	0.71
Oregon								
Haskins Dam (2)	45	19	123	21	256	0.17	0.46	0.73
Hills Creek Dam (2)	43	43	122	26	380	0.16	0.41	0.71
McKenzie Bridge (2)	44	10	122	10	419	0.13	0.38	0.69
Sexton Summit WB (2)	42	37	123	22	1170	0.17	0.46	0.73

(1) Data from Brunengo (1985)

(2) Data from Miller et al (1973)

TABLE 3.12

DEPTH-FREQUENCY RATIOS IN THE PACIFIC NORTHWEST

Station	Location Lat		Long		Elev. (m)	Ratio to 10-Yr Return Period 2	25	50	100
Coastal B.C.	-		-		-	0.72	1.14	1.24	1.35
Washington									
Palmer (1)	47	18	121	51	280	0.74	1.13	1.22	1.32
Mud Mtn Dam (2)	47	09	121	56	399	0.71	1.13	1.24	1.35
Cedar Lake (1)	47	25	121	44	476	0.78	1.10	1.20	1.27
Lester (1)	47	12	121	29	497	0.74	1.15	1.23	1.33
Greenwater (1)	47	08	121	38	527	0.67	1.14	1.29	1.39
Rainier Longmire (2)	46	45	121	49	842	0.60	1.18	1.31	1.43
Snowqualmie Pass (2)	47	25	121	25	921	0.64	1.19	1.31	1.41
Stampede Pass (2)	47	17	121	20	1207	0.67	1.15	1.28	1.40
Stevens Pass (2)	47	44	121	05	1241	0.64	1.18	1.31	1.40
Mt. Baker Lodge (2)	48	52	121	40	1265	0.63	1.15	1.25	1.42
Oregon									
Haskins Dam (2)	45	19	123	21	256	0.69	1.17	1.31	1.53
Hills Creek Dam (2)	43	43	122	26	380	0.70	1.14	1.28	1.40
McKenzie Creek (2)	44	10	122	10	419	0.75	1.17	1.29	1.38
Sexton Summit WB (2)	42	37	123	22	1170	0.70	1.17	1.31	1.43

(1) Data from Brunengo (1985)

(2) Data from Miller et al (1973)

Results of analysis of U.S. data included in Tables 3.11 and 3.12 show that depth ratios calculated for stations in the coastal region of Washington and Oregon are in the same range as those in coastal B.C. This result is particularly informative as some of the U.S. stations are at relatively high elevations in the Cascade Mountains. Also, examination of precipitation data for individual stations in Washington shows the variation in depth-duration ratios with return period and depth-frequency ratios with duration is relatively small just as was observed for coastal B.C. stations.

3.5 TIME DISTRIBUTION OF SINGLE STORM RAINFALL

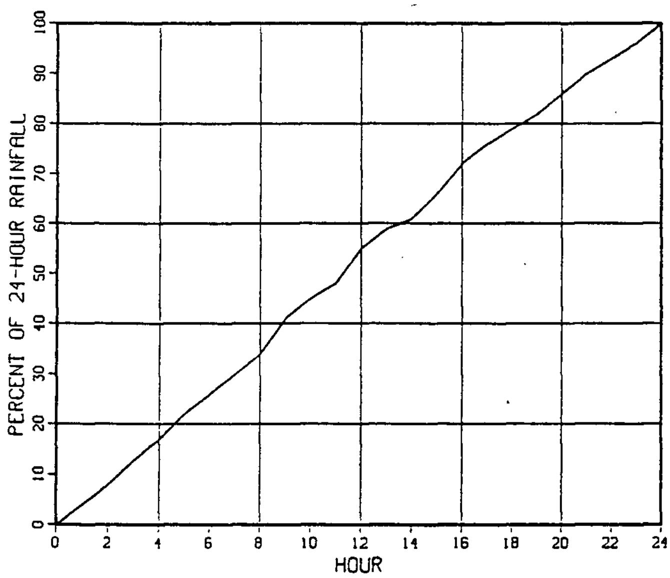
3.5.1 Analysis of B.C. Data

Analysis of rainfall intensities within single storms is undertaken for this study to assess whether regional characteristics also exist for single storm data in coastal B.C. As noted in the preceding sections, development of synthetic hyetographs based on intensity data from IDF curves is an alternative approach commonly applied in design situations only because single storm data are seldom available.

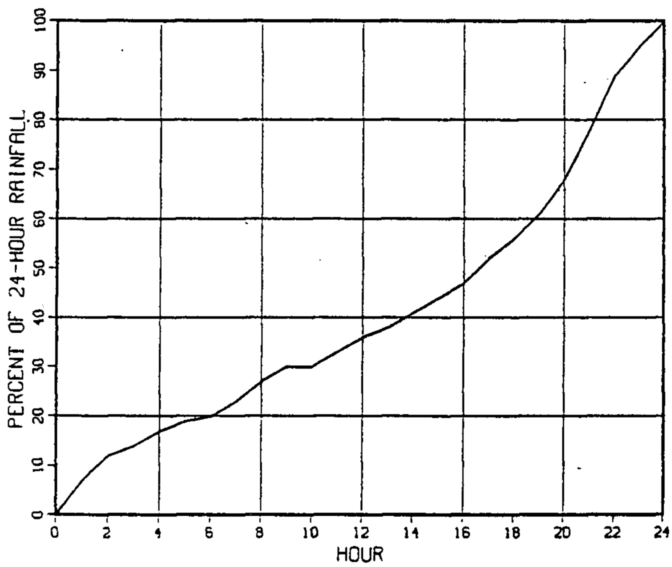
Rainfall intensities occurring within single storms are investigated at the same 58 stations in coastal B.C. for which AES prepared IDF curves. A computer program was written to scan recorded hourly data provided on magnetic tape by AES. At each station, maximum 24-hour rainfall on record, hourly increments within the 24-hour rainfall and time of occurrence of peak intensities within the 24-hour period were identified. Analysis was undertaken for continuous 24-hour periods and was not limited to a calendar day time period. Even though maximum 24-hour rainfall on record occurred within a storm of longer duration in many instances, analysis of intensities within a 24-hour period of maximum rainfall is usually sufficient for hydrograph development in the coastal region.

Time distribution of maximum 24-hour rainfall was analyzed in a ratio format similar to that applied to IDF data so that regional assessment could be more readily undertaken. Maximum 24-hour rainfall on record at each station was identified and its time distribution was analyzed on an hourly basis as a percentage of the 24-hour rainfall. Results are tabulated in Appendix III for each of 58 coastal B.C. stations. Twenty-one different storm periods are represented by the 58 stations because in some instances the same storm produced the maximum rainfall on record at more than one station.

Typical 24-hour distributions for maximum rainfalls on record in the coastal region are shown on Figure 3.6. Data from Bear Creek, Bella Coola and Strathcona Dam are selected to illustrate graphically the range in distributions of storm rainfall calculated in this study for coastal B.C. The somewhat linear distribution for Bear Creek is common for many of the maximum 24-hour rainfalls on record at stations across the region. Bella Coola and Strathcona Dam are selected as illustrative examples of more non-linear distributions with higher intensity rainfall occurring at late and early stages of the 24-hour period, respectively. Each of the 58 stations in the coastal region experienced maximum 24-hour rainfall distributions similar to those shown on Figure 3.6. A summary of the 58 rainfall distributions identified in this study is also illustrated on Figure 3.6 which shows the relatively narrow band of rainfall data. The magnitude of 24-hour rainfall from stations across the region ranged from 65 to 340 mm.

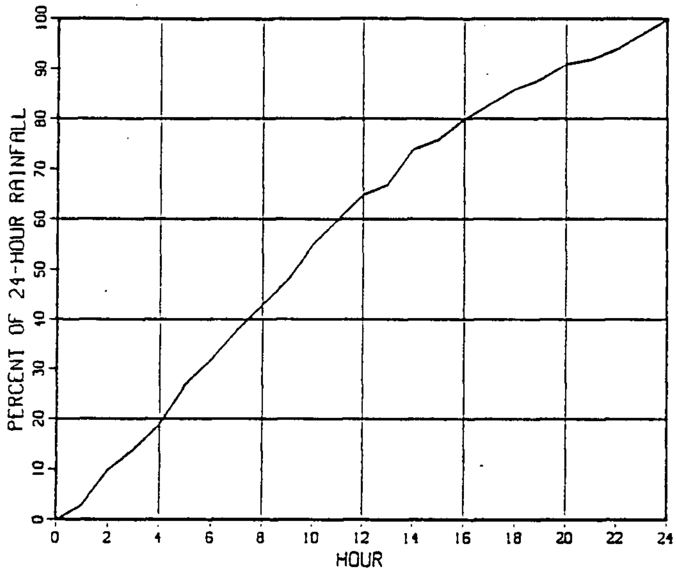


(a) Maximum 24-Hour Rainfall at Bear Creek (300.5 mm)

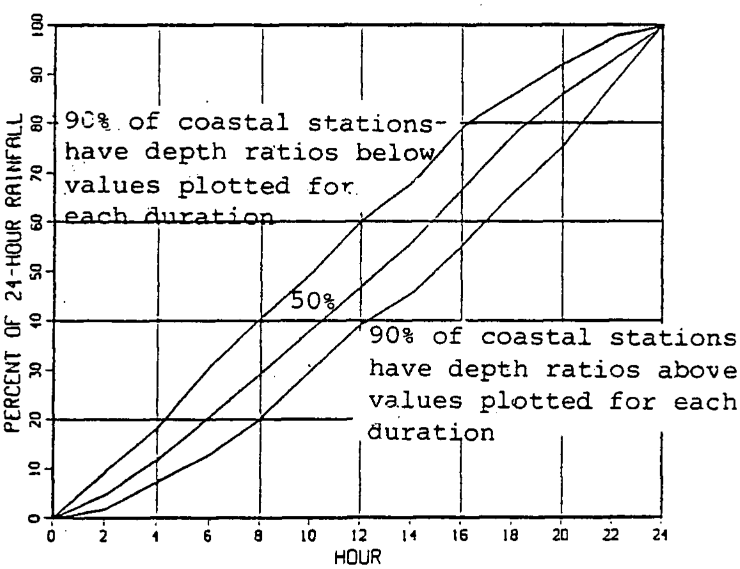


(b) Maximum 24-Hour Rainfall at Bella Coola (131.4 mm)

Figure 3.6. Maximum 24-Hour Rainfall on Record



(c) Maximum 24-Hour Rainfall at Strathcona Dam (155.2 mm)



(d) Range of 24-Hour Rainfall Distributions

Figure 3.5 Maximum 24-Hour Rainfall on Record

A study of 12-hour rainfall data across Canada (Hogg, 1980) found that storm distributions were more variable in other regions of Canada than in coastal B.C. Hogg analyzed rainfall data from Agassiz, Vancouver, Victoria and Comox in the coastal region. Twelve-hour rainfalls were selected at each station to form a partial duration series with one event for each year on record. Data from all four stations were combined to create a "coastal B.C." data base. Similar procedures were also applied to regions designated as the East Coast, Southern Ontario and the Prairies.

Results of analysis undertaken by Hogg are shown on Figure 3.7 which illustrates the range of 12-hour rainfall distributions in each region for a wide range of return periods represented by the partial duration series. Storm distributions for coastal B.C. fit a much narrower range than corresponding data for the East Coast, Southern Ontario and the Prairies. This result suggests that regional rainfall characteristics of single storms in coastal B.C. may be more readily identifiable than for other regions of Canada.

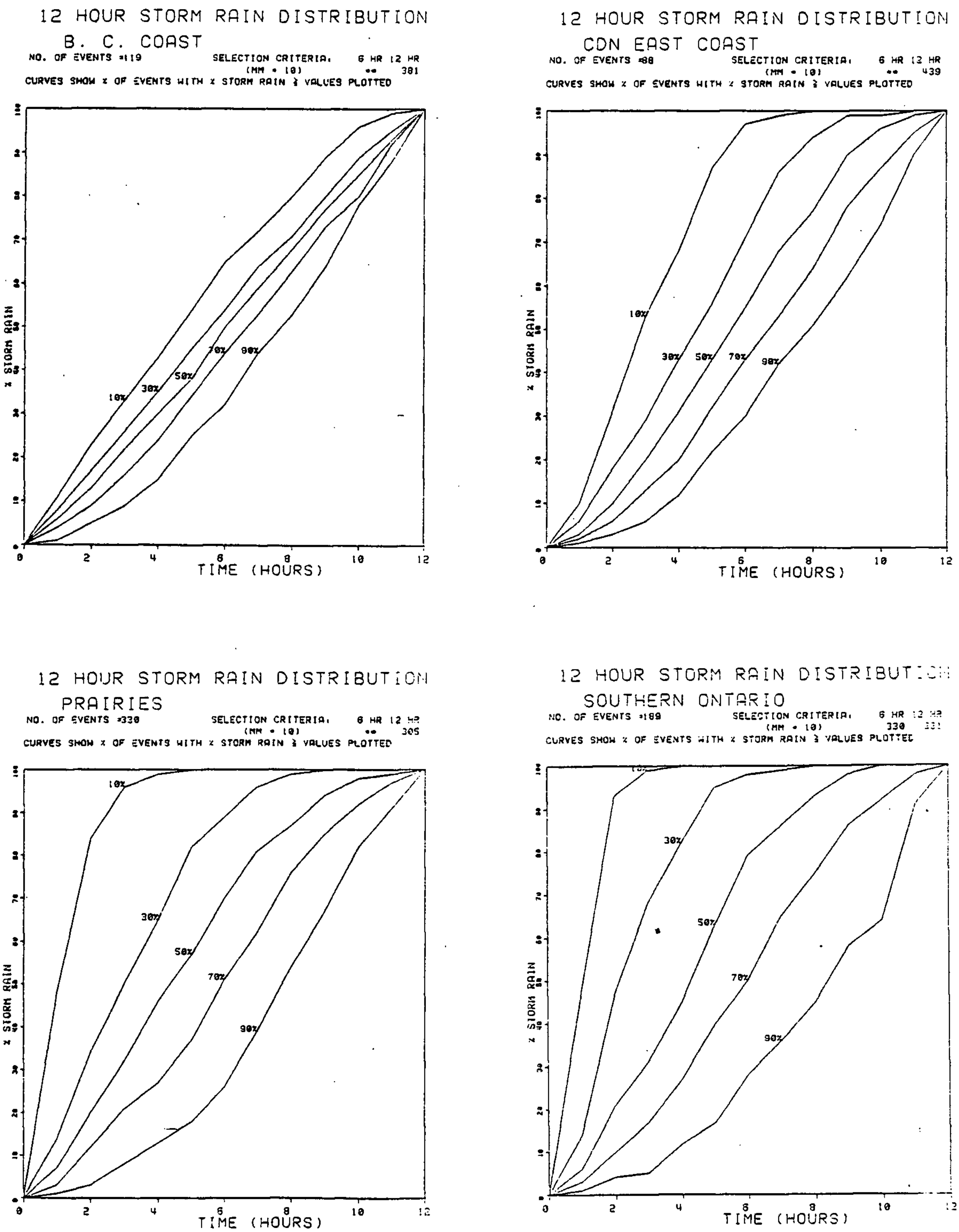


Figure 3.7 Time Distribution of 12-Hour Rainfall (after Hogg, 1980)

Regional rainfall characteristics for coastal B.C. are investigated in this study by analyzing maximum 1, 2, 3, 4, 6, 8 and 12-hour rainfalls occurring within the maximum 24-hour rainfall on record at each station. These data are listed for each coastal station in Appendix III. Analysis of these inter-storm data shows that on a percentage basis, maximum incremental rainfalls within the largest storms on record do not vary greatly across the region. Results are shown on Figure 3.8 in a format similar to that used previously for IDF data. The lower limit shown on Figure 3.8 represents those storms which tend to be linear and the upper limit illustrates characteristics of 24-hour rainfall which have periods of higher intensity within the 24-hour period.

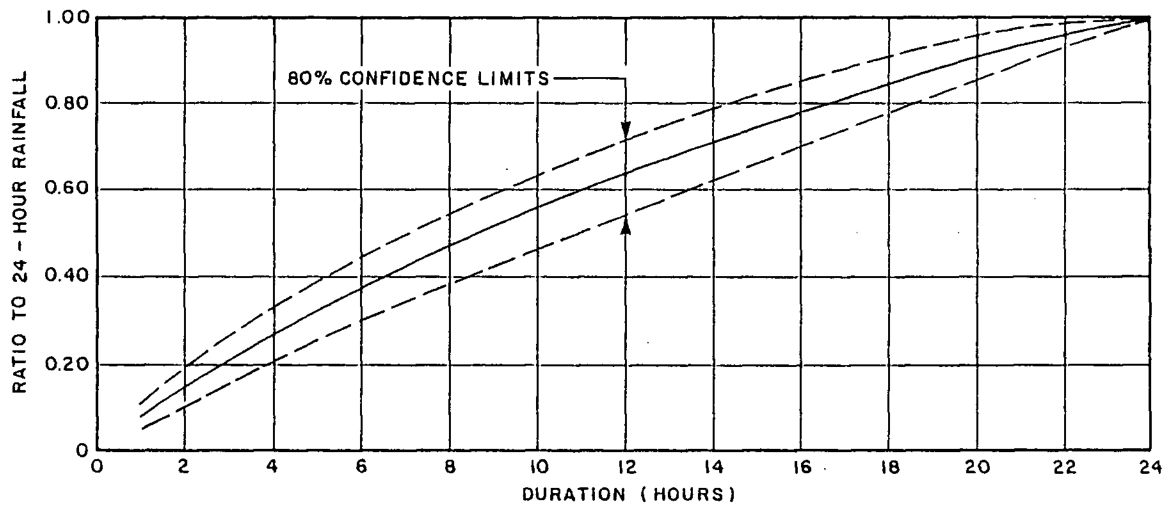


Figure 3.8 Depth-Duration Ratios for 24-Hour Rainfall

Comparison of hourly rainfall intensities in Figure 3.4 based on IDF curves and in Figure 3.8 based on single storm data shows that beyond about 6-hour durations the two curves are quite similar. For shorter durations, rainfall intensities estimated from IDF curves would produce a synthetic hyetograph with greater maximum hourly intensities than have been observed to occur within single storms. In practice the two curves can be used to set limits on the range of hourly rainfall intensities to be considered by the design engineer in the absence of site data.

For each coastal station, maximum rainfall intensities on record for durations less than 24-hours and maximum occurring within 24-hour storms are compared in Appendix III. Examination of these data shows maximum short duration intensities on record occurred within the maximum 24-hour rainfall on record in many instances. This occurrence, sometimes referred to as "nesting", is consistent with the similar results for depth ratios obtained from separate analysis of IDF and single storm rainfall data. The potential for nesting is apparent by examining the period of year of occurrence of maximum 1, 6, 12 and 24-hour rainfalls on record in coastal B.C. as shown on Figure 3.9.

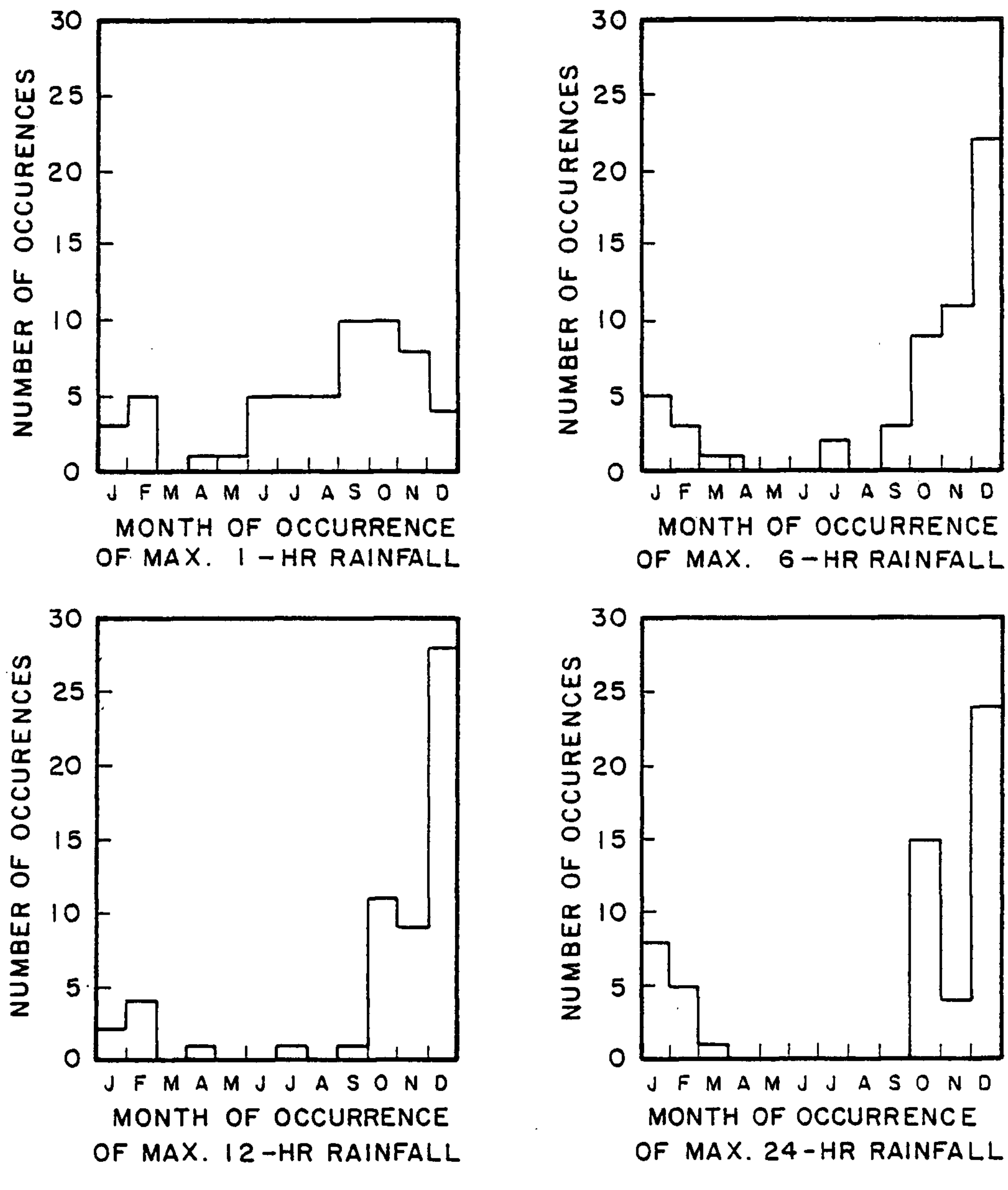


Figure 3.9 Monthly Distribution of Maximum Rainfalls on Record

Results presented on Figure 3.8 provide a basis for estimating hourly rainfall increments occurring within single storms, but do not provide information on the time sequence of occurrence needed for development of a synthetic hyetograph. Therefore, time of occurrence of maximum hourly intensities within the maximum 24-hour rainfall on record at each of the 58 stations was examined. Maximum 24-hour rainfalls on record were investigated to determine the time of occurrence of maximum 1, 3 and 5-hour intensities within the 24-hour period. A summary of results for all stations in the coastal B.C. region is included in Table 3.13.

TABLE 3.13

TIME OF OCCURRENCE OF MAXIMUM INTENSITIES

Maximum 1-Hour		Maximum 3-Hour		Maximum 5-Hour	
Time of Occurrence (Hours)	No. of Occurrences	Time of Occurrence (Hours)	No. of Occurrences	Time of Occurrence (Hours)	No. of Occurrences
0-1	0	0-3	0	0-5	1
1-2	0	1-4	0	1-6	1
2-3	2	2-5	1	2-7	3
3-4	2	3-6	3	3-8	1
4-5	2	4-7	3	4-9	2
5-6	2	5-8	1	5-10	2
6-7	1	6-9	5	6-11	5
7-8	4	7-10	2	7-12	3
8-9	2	8-11	3	8-13	2
9-10	2	9-12	2	9-14	3
10-11	5	10-13	1	10-15	2
11-12	1	11-14	2	11-16	2
12-13	3	12-15	5	12-17	2
13-14	3	13-16	2	13-18	5
14-15	5	14-17	5	14-19	5
15-16	3	15-18	4	15-20	4
16-17	3	16-19	3	16-21	4
17-18	3	17-20	5	17-22	4
18-19	3	18-21	2	18-23	1
19-20	2	19-22	5	19-23	5
20-21	4	20-23	1		
21-22	3	21-24	2		
22-23	1				
23-24	1				

Results presented in Table 3.13 suggest for the coastal B.C. region that there is no apparent strong bias for periods of high intensity to occur either early or late within large 24-hour rainfalls. The consequences of this observation to the design engineer in this region are two-fold. First, hourly rainfall increments within a synthetic hyetograph for the coastal region can be arranged in many different time sequences and still produce 24-hour events with similar probabilities of occurrence. Secondly, selection by a design engineer of a time sequence of maximum hourly intensities within a 24-hour synthetic hyetograph can be governed by response characteristics of the basin under consideration.

3.5.2 Comparison With Other Pacific Northwest Data

Single storm rainfall data available for the coastal region of Washington and Oregon are compared to results obtained in this study for B.C. These data from the U.S. were obtained to illustrate further the regional applicability of single storm rainfall characteristics documented for coastal B.C. In addition, U.S. stations provide data for higher elevations than stations currently available in coastal B.C.

Single storm precipitation data were obtained at four stations at relatively high elevations in the Cascade Mountains of Washington and at four stations in the coast and Cascade Mountains in Oregon. Precipitation data presented for each station in Washington represent the largest 24-hour event identified from a visual inspection of long term records. Precipitation data for Oregon are from the same storm period in December 1964 when extreme floods with return periods ranging from about 50 to 100 years occurred over most of the coastal region.

Depth ratios for maximum hourly increments within 24-hour events are calculated with data from U.S. stations in the same format that was applied to B.C. data. A summary of depth ratios calculated with U.S. data and comparison of these values to those calculated for coastal B.C. is included in Table 3.14. Results of analysis of U.S. data show that inter-storm hourly increments calculated with single storm data from coastal Washington and Oregon are in the same range as those in coastal B.C.

TABLE 3.14

SINGLE STORM PRECIPITATION DATA IN THE PACIFIC NORTHWEST

Station	Location		Elev	24-Hour	Max. Occurring Within 24-Hours (Ratio to 24-Hour Precipitation)			
	Latitude	Longitude	(m)	Precip (mm)	1-Hour	2-Hour	6-Hour	12-Hour
COASTAL B.C.	-	-	-	-	0.08	0.15	0.37	0.63
WASINGTON								
Snowqualmie Pass[1]	47 25	121 25	921	178	0.10	0.16	0.38	0.72
Stampede Pass[1]	47 17	121 20	1207	202	0.08	0.15	0.38	0.64
Stevens Pass[1]	47 44	121 05	1241	130	0.08	0.14	0.33	0.53
Mt. Baker Lodge[1]	48 52	121 40	1265	127	0.06	0.12	0.32	0.58
OREGON								
Haskins Dam [1]	45 19	123 21	256	138	0.09	0.18	0.42	0.72
Hills Creek Dam [1]	43 43	122 26	380	92	0.07	0.14	0.36	0.62
McKenzie Bridge RS [1]	44 10	122 10	419	103	0.08	0.11	0.29	0.55
Sexton Summit WB [1]	42 37	123 22	1170	113	0.10	0.19	0.37	0.57
SCS TYPE 1A [2]	-	-	-	-	0.15	0.25	0.47	0.69

(1) data from U.S. National Weather Service
(2) after Soil Conservation Service (1982)

A regional 24-hour rainfall distribution developed by the U.S. Soil Conservation Service (SCS, 1973, 1982) for use on the coastal side of the Sierra Nevada and Cascade Mountains of Oregon, Washington and northern California, and the coastal regions of Alaska is also compared in Table 3.14 to B.C. data. Data presented for the coastal storm distribution proposed by SCS are not in the same range as those calculated at individual coastal stations. However, this apparent discrepancy can be resolved by examining procedures used by SCS to develop their regional curve.

Procedures outlined by SCS (1973) indicate their single storm distribution is derived from IDF data obtained from rainfall atlases. Comparison of hourly increments proposed by SCS for a single storm distribution to rainfall depth ratios calculated for coastal B.C. based on IDF data (Table 3.4) shows these values are similar. Therefore, application of the SCS storm distribution in the coastal region produces a hyetograph with greater maximum hourly intensities than have been observed from analysis of single storm data.

Finally, SCS also proposes a time sequence for hourly increments within a 24-hour rainfall. The storm distribution is plotted on Figure 3.10. Examination of the curve shows the maximum 1-hour rainfall occurs early in the storm from hour 7 to 8 and the maximum 4-hour increment occurs from hours 7 through 10. SCS states, however, selection of the period of maximum intensity is based on design considerations rather than meteorological factors. Therefore, it is reasonable to conclude that this storm distribution was proposed to provide a standardized synthetic hyetograph which generally produces conservative results, especially considering that hourly increments are based on IDF data.

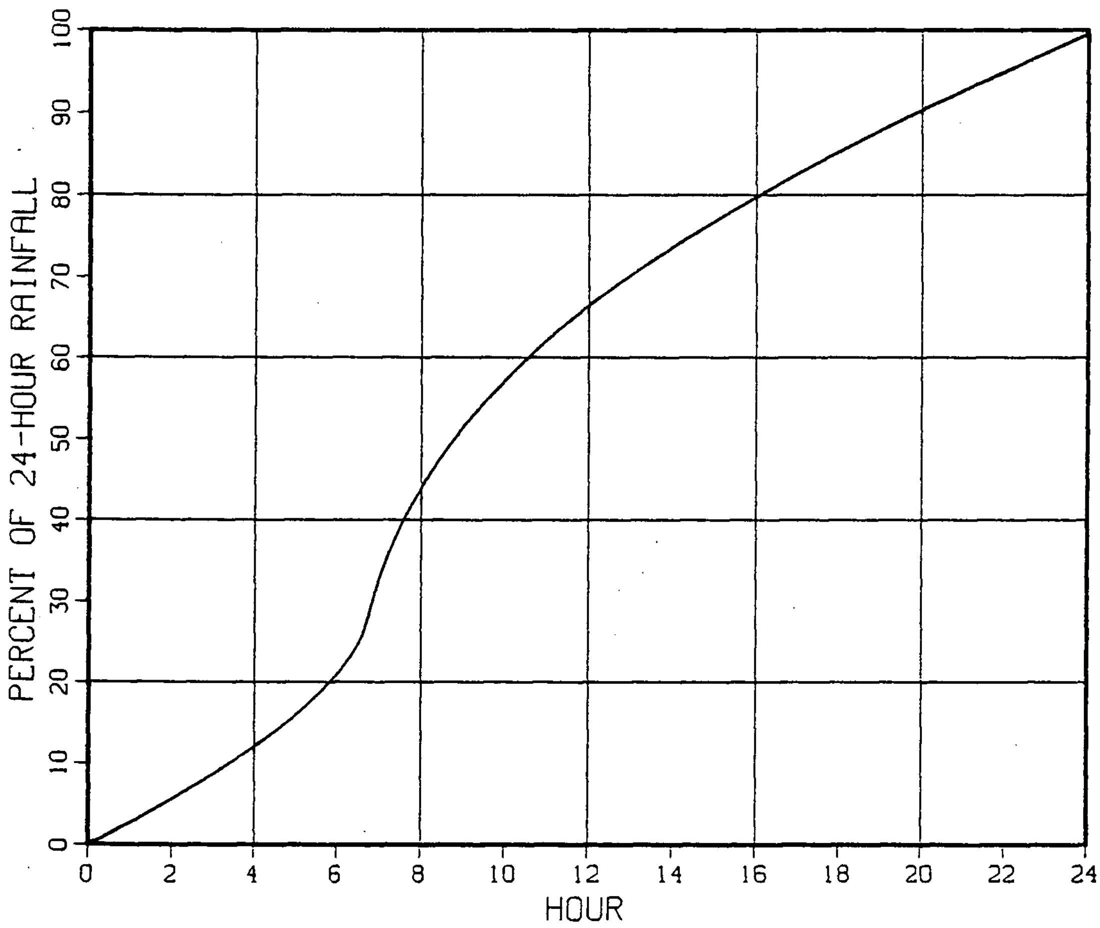


Figure 3.10 Soil Conservation Service Type 1A Storm Distribution

3.6 ELEVATION EFFECTS ON STORM RAINFALL

3.6.1 Background

Regional characteristics of storm rainfall presented in the preceding sections can be used to develop synthetic hyetographs at a point within a drainage basin. A point estimate for rainfall is sometimes an adequate indicator of rainfall across an entire basin. Hydrograph analysis in mountainous regions of coastal B.C., however, usually requires storm rainfall to be distributed with elevation.

Examination of elevation effects as storm systems interact with mountainous terrain can be undertaken in two different frames of reference. In a Lagrangian reference frame one moves with the storm and observes its temporal growth and decay. This approach is most commonly adopted by meteorologists and is a basis for weather forecasting. The Lagrangian approach to storm analysis has not yet received widespread application in engineering studies, perhaps due in part to a shortage of necessary facilities such as precipitation radar stations. There is little potential in B.C. for exploring the application of a Lagrangian approach to storm analysis for engineering studies as there is no precipitation radar station currently in operation.

Engineering studies traditionally utilize a Eulerian reference frame where an observer remains stationary and records rainfall as a storm passes through a region. This approach leads to development of a hyetograph for one point in the basin, which in turn is used to estimate rainfall over the remainder of the drainage basin under study. The difficulty with which a point measurement can be transposed across a basin increases greatly when there are large variations in elevation. For example, mountainous terrain may induce orographic precipitation within storms and also trigger convective instability from differential heating of mountain slopes, increase cyclonic precipitation by retarding the rate of movement, and cause uplift through funnelling effects of valleys on airstreams.

The complexity of atmospheric processes affecting interaction of storm systems and mountainous terrain can be demonstrated by examining conclusions of three detailed meteorological studies. Hetherington (1976) analyzed 42 storms in the coastal mountains north of Vancouver, B.C. and concluded the amount of orographic rainfall is related primarily to wind speed normal to a mountain barrier, moisture content of the lower atmosphere, freezing level and air mass stability. Another physically-based meteorologic analysis of the distribution of storm rainfall in mountainous regions (Elliot, 1977) showed the relation of orographic rainfall to elevation "depends in a complex way upon the character of the terrain, on the efficiency with which microphysical mechanisms remove cloud condensate as precipitation, the wind direction and speed, the depth of cloud, and the air mass stability". Finally, a comprehensive review of the structure and mechanism of orographically enhanced rain conducted by Browning (1980) concluded that the principal influencing factors are the form of airflow induced by rising topography, magnitude of relative humidity, wind strength, wet-bulb temperature, existence of potential instability, and presence and nature of pre-existing precipitation.

The above discussion illustrates that local variations in storm rainfall with elevation are affected by the interaction of many site specific phenomena. Examination of annual precipitation by Rasmussen and Tangborn (1976) at 38 stations in the Northern Cascade Mountains of Washington illustrates further that precipitation amounts are affected by factors in addition to elevation alone. Precipitation data are shown on Figure 3.11 for a region extending from the Canadian border southward for about 190 km and for stations only on the western slope of the Cascades. These data illustrate that even within a relatively local region there is wide variation in precipitation for a given elevation.

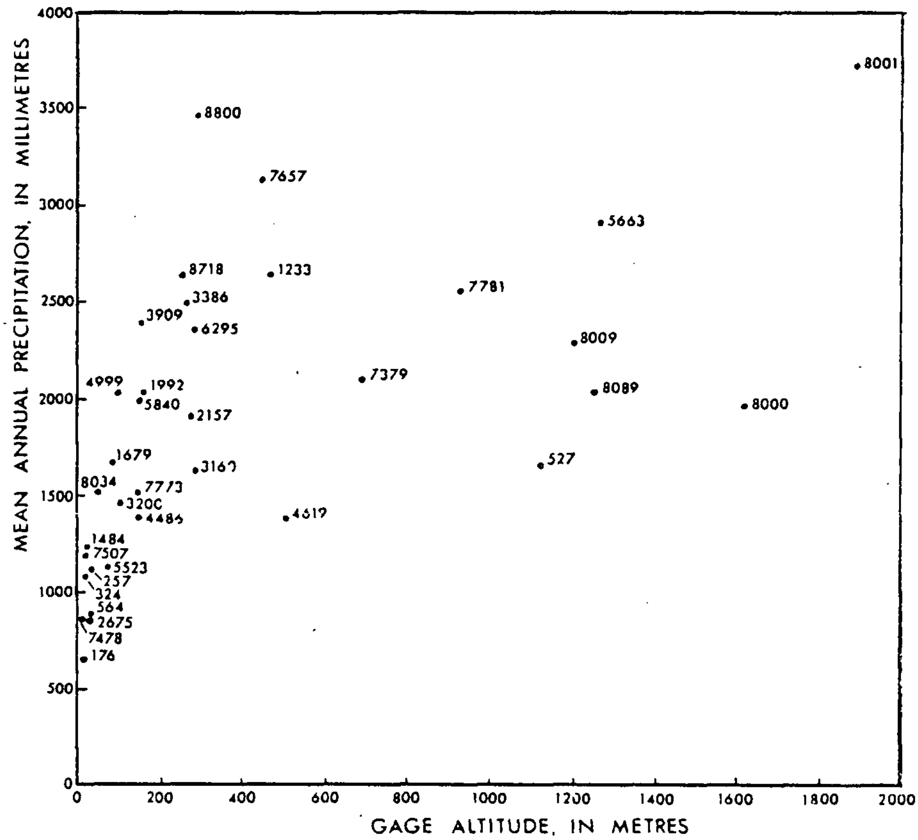


Figure 3.11 Annual Precipitation in the North Cascade Mountains

Detailed meteorologic investigations of elevation effects on storm rainfall, similar to those noted above by Hetherington (1976) and Elliott (1977), are not undertaken in this study of regional rainfall characteristics. Alternatively, analysis is undertaken to establish those characteristics which can be identified with limited data currently available in coastal B.C. The data base and network density currently available for analysis restricts region wide investigation of elevation effects on storm rainfall. Nevertheless, some trends can still be identified which can be applied immediately to engineering studies, and which serve as a basis for more comprehensive research of elevation effects than is possible in this study.

3.6.2 Analysis of Selected Storm Data

Analysis of elevation effects on storm rainfall in coastal B.C. is limited for two reasons. First, as described in the preceding section, atmospheric processes affecting interaction of storm systems and mountainous terrain are very complex. Secondly, the existing rain gauge network in coastal B.C. is generally not of sufficient density to examine local variations in rainfall from low valley bottom elevations to higher elevations near mountain crests.

The approach adopted for this study is to assess results of meteorological investigations undertaken by B.C. Hydro at two locations in the coastal region, and then compare trends identified in their reports to recorded rainfall data at other stations in the region. Data from gauge networks along mountain slopes immediately north of Vancouver were selected for comparison to the meteorologic studies as network densities in other segments of the B.C. coastal region are not adequate.

Two meteorologic investigations of storm rainfall in mountainous areas include probable maximum precipitation (PMP) studies for the Coquitlam Lake Watershed (Schaefer, 1981) located about 30 km northeast of Vancouver's city centre and for the Cheakamus Project (B.C. Hydro, 1983) located approximately 100 km north of Vancouver. The methodology adopted for these studies was established by the World Meteorological Organization (WMO, 1973) and is known as the orographic separation method. The technique involves making separate estimates for an orographic component of precipitation induced by the lifting of air flow over mountains and for a convergence component of precipitation resulting from atmospheric processes. The two components are summed to produce estimates of storm rainfall with increasing elevation.

Each of the meteorologic studies produced PMP estimates for the range of elevations in each basin. Results were presented in the Coquitlam basin for an elevation range of 156 - 1750 m, and for the Cheakamus project from 200 - 1800 m. Even though results of the PMP studies are site specific for each basin, two trends in the results are apparent and were considered to merit additional investigation. The two trends are:

i) storm rainfall increased linearly with elevation.

ii) the linear relationship generally extended to the highest elevation in the basin.

Each of the above trends derived from meteorological analysis are investigated further in this study by examining recorded rainfall data from other coastal B.C. stations not used in the PMP studies. Data were obtained from stations along two different transects in the mountains immediately north of Vancouver as shown on Figure 3.12. Stations shown along Transect A from Burrard Inlet to Grouse Mountain record precipitation data for Atmospheric Environment Service and those included on Transect B to Mount Seymour are temporary locations established as part of a Ph.D. research program (Fitzharris, 1975).

Elevation effects on precipitation along Transect A are shown on Figure 3.13 which presents the average annual maximum 24-hour precipitation at each station versus elevation. This relationship appears linear just as was calculated in meteorologic investigations of single storm PMP events. In addition, the highest station in the transect at elevation 1128 m is within about 200 m of crest elevations along the top of the slope.

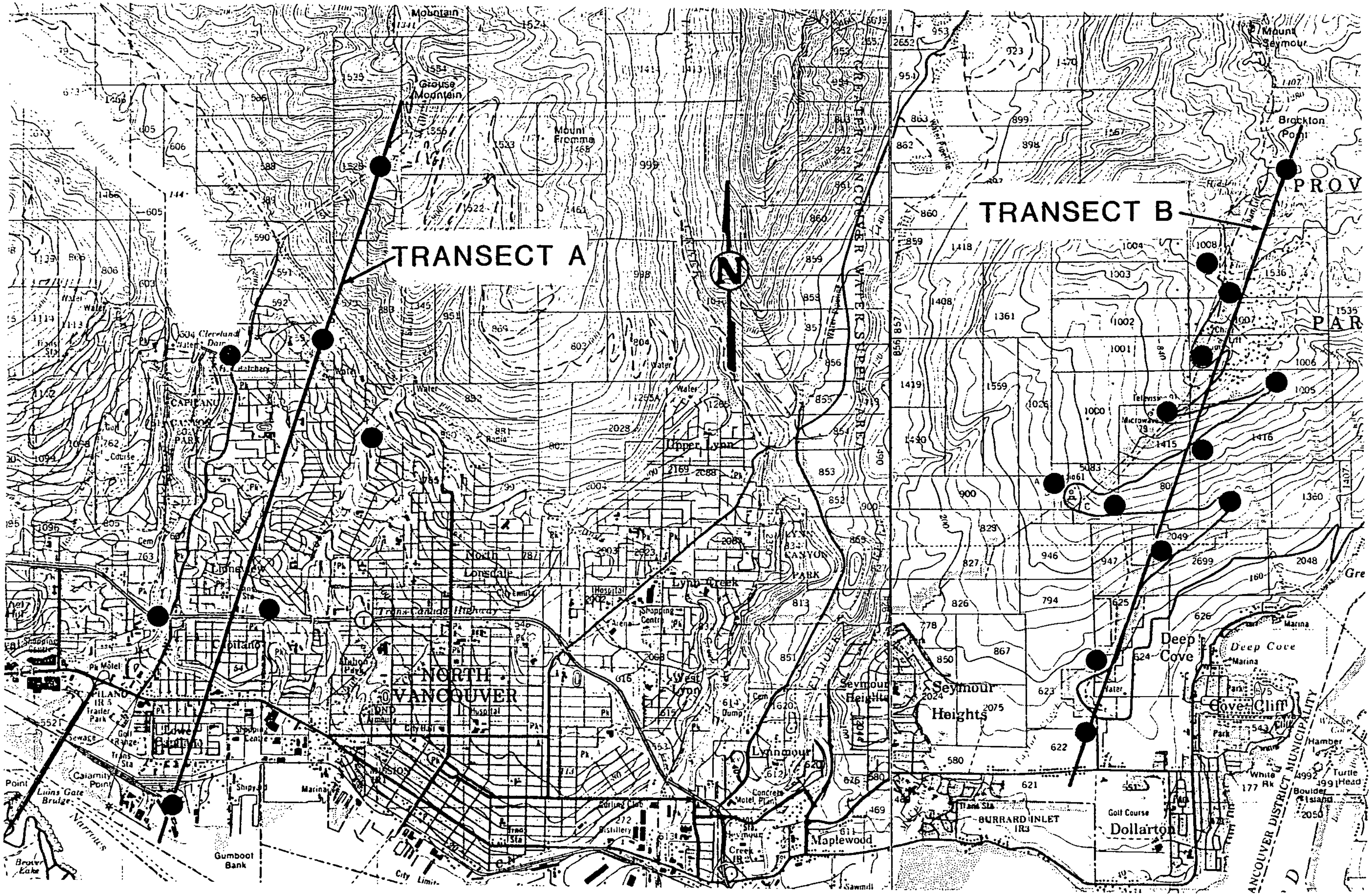


Figure 3.12 Station Locations in North Vancouver

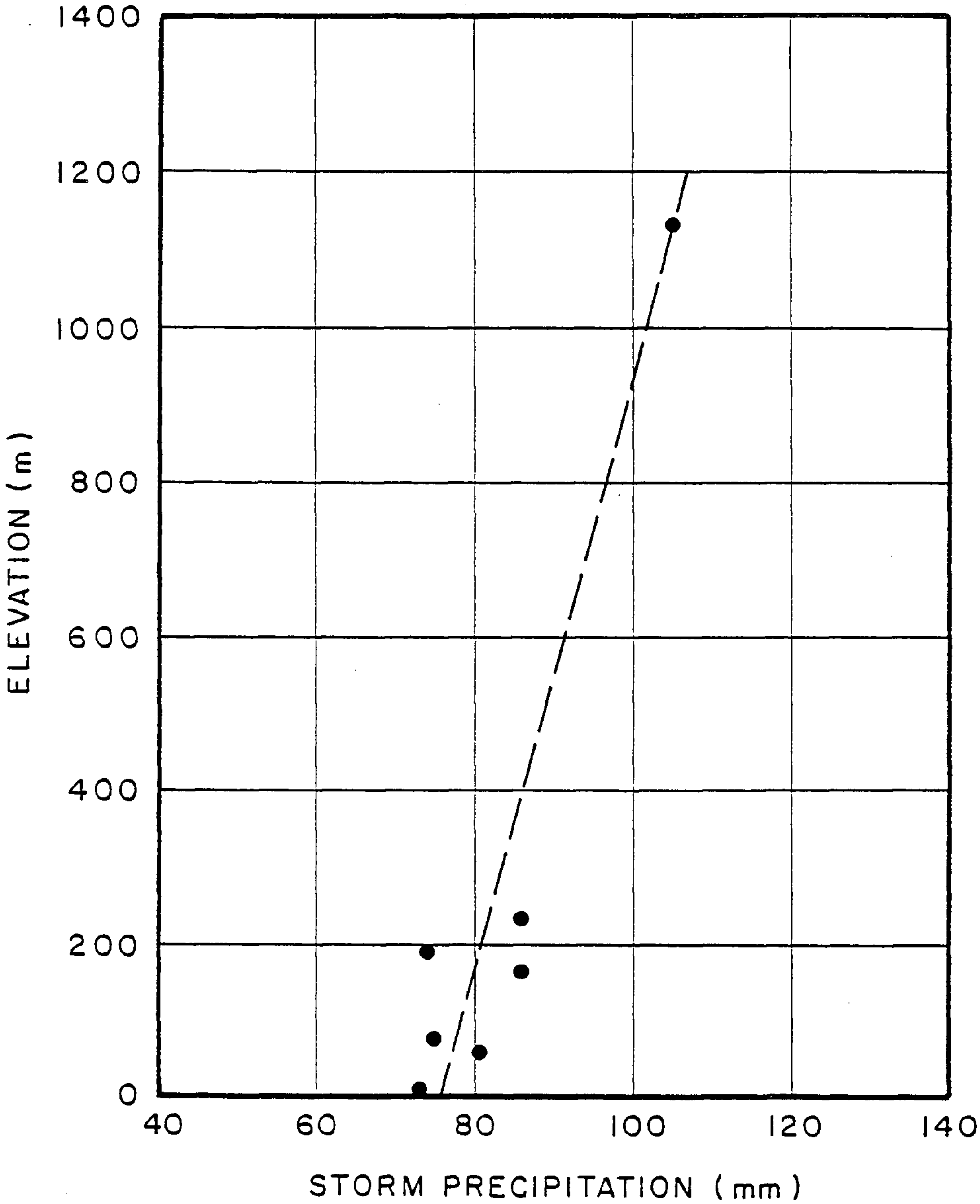


Figure 3.13 Transect A: Elevation vs 24-Hour Precipitation

Storm data along Transect B were collected by Fitzharris (1975) for 73 storms ranging from 2 to 81 hours during the 1969-70 winter and for 74 storms ranging from 6 to 91 hours during the 1970-71 winter. Most of the precipitation events examined by Fitzharris had return periods less than about 2 years. The complexity of atmospheric processes is apparent from examination of all 147 storms which showed no consistent trends in elevation effects on storm rainfall. However, three events listed on Table 3.15 were identified as being of interest to this study of storm rainfall leading to extreme floods. Each of the three events experienced relatively large precipitation amounts for the brief period of record and consisted of rain over most of the elevation range with rain mixed with snow at the top of the mountain.

Table 3.15

Storm Data Near Mount Seymour (Fitzharris, 1975)

Date	Storm Duration (hrs)	Precipitation Amount (mm) Elevation 120 m	Elevation 1260 m
Dec 6-7, 1970	26	53	82
Dec 9-11, 1970	31	50	107
Feb 13-15, 1971	43	74	137

Precipitation data from each of the three storms are plotted on Figures 3.14 through 3.16 for twelve sampling locations over a 120 to 1260 m elevation range. The highest sampling station is within about 200 m of the peak of Mount Seymour. Linearity of these single storm profiles of precipitation with elevation along Transect B supports results of two PMP studies for B.C. Hydro and of the profile of average annual maximum 24-hour precipitation recorded along Transect A.

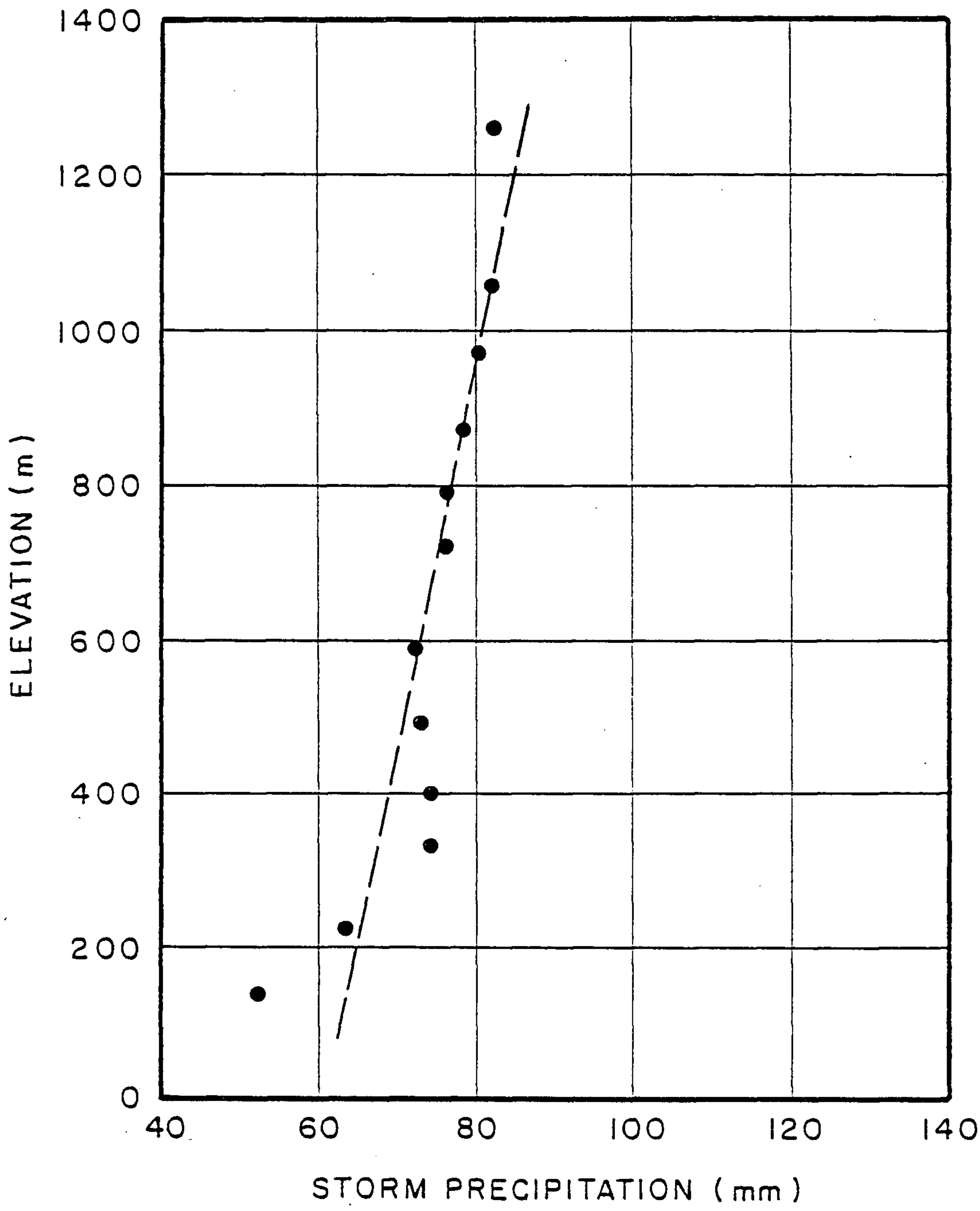


Figure 3.14 Transect B: Rainfall Distribution for December 6-7, 1970

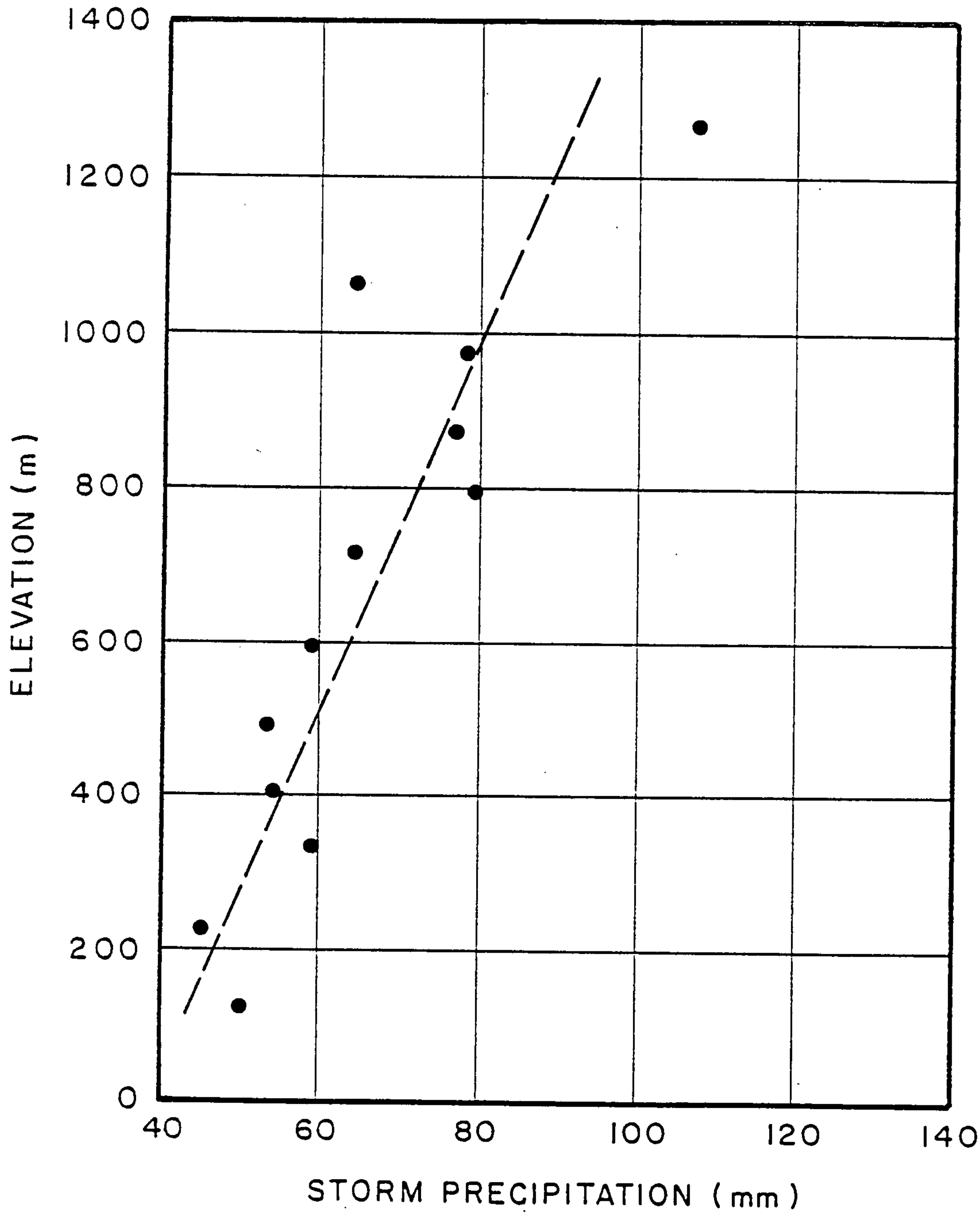


Figure 3.15 Transect B: Rainfall Distribution for December 9-11, 1970

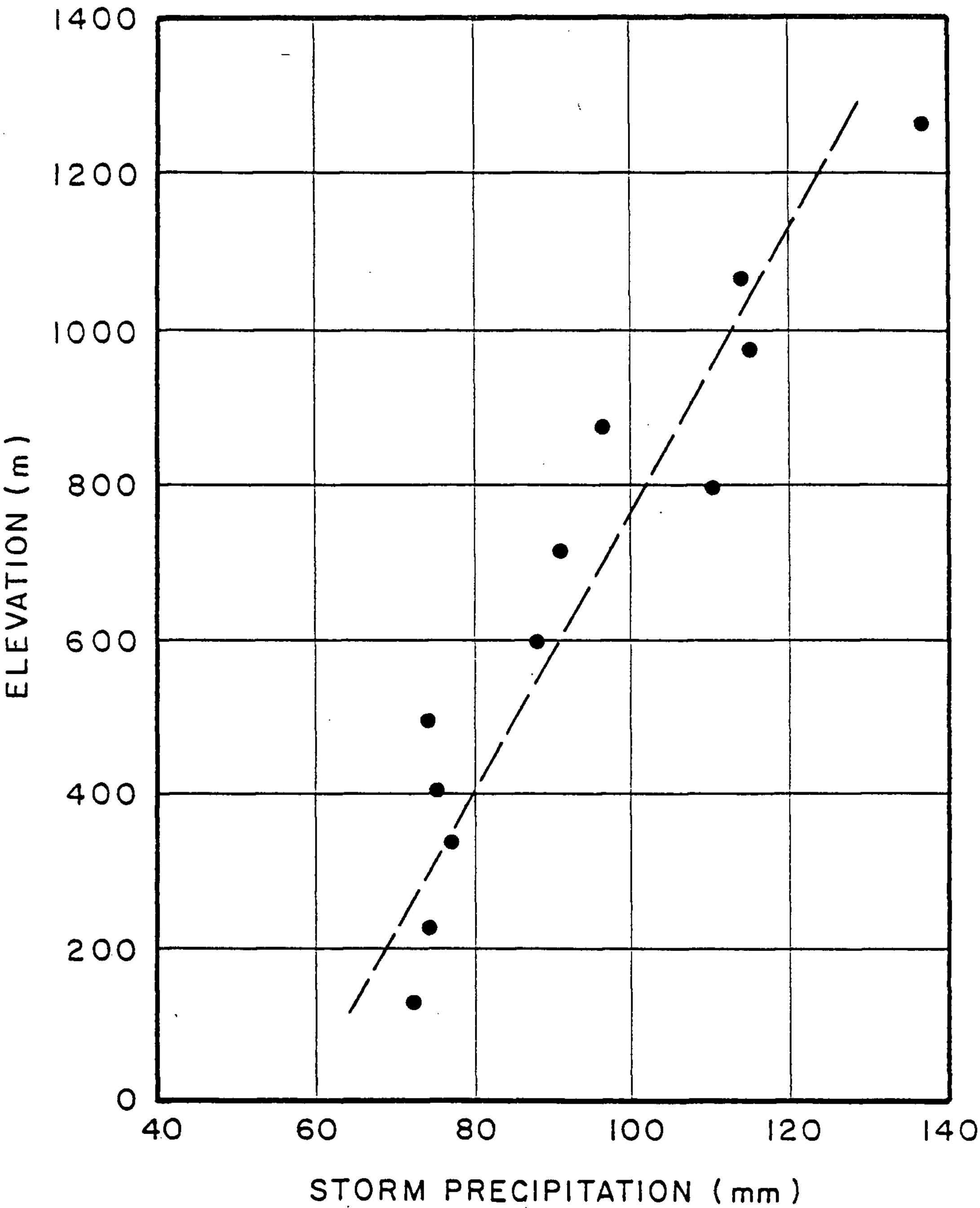


Figure 3.16 Transect B: Rainfall Distribution for February 13-15, 1971

Precipitation profile data currently available for coastal B.C. are not yet sufficient to support definitive conclusions for the region. Nevertheless, available evidence suggests that a linear increase with elevation of storm rainfall during extreme events is a reasonable approximation for individual slopes with a constant aspect in the coastal region.

Inasmuch as precipitation profile data analyzed in this study are derived from events with a wide range in frequency of occurrence, the magnitude of the rate of increase with elevation cannot be compared between studies. Additional research of elevation effects on storm rainfall in the coastal region which examines atmospheric processes during extreme events and supports results of analytical study with recorded data is greatly needed for engineering use. In the absence of regional meteorologic studies of storm rainfall, the following section presents an alternative method which can serve as a guideline to estimate the distribution of storm rainfall with elevation.

3.6.3 **Relationship to Annual Precipitation**

For engineering design situations when the distribution of storm rainfall cannot be assessed directly based on local historical data, alternative methods must be applied. In these instances the approach is generally to assess other factors which may be indices of storm rainfall. For this study of regional rainfall characteristics in coastal B.C. the relationship between annual and short duration precipitation is examined. The premise that annual precipitation distribution may be an index for storm rainfall is based on the fact that most annual precipitation occurs during the fall and winter and results from the same type of low pressure system which produce the regions largest 24-hour rainfall events.

Annual and 24-hour precipitation data were obtained for all available coastal B.C. stations and are plotted on Figures 3.17. For quick reference, data are plotted separately for Vancouver and Fraser Valley, east coast of Vancouver Island inlcuding Victoria and the Gulf Islands, west coast of Vancouver Island, and other B.C. coastal stations.

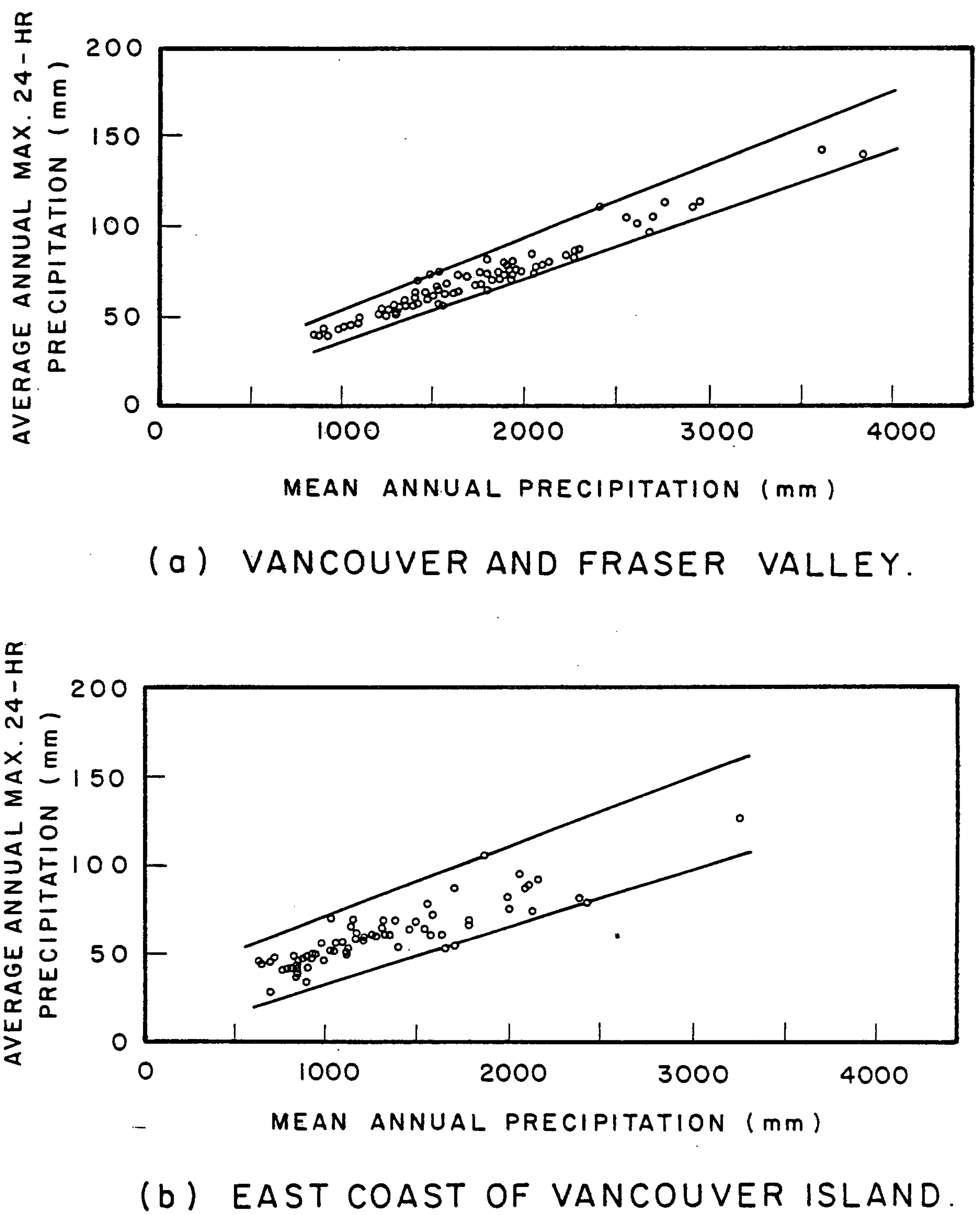
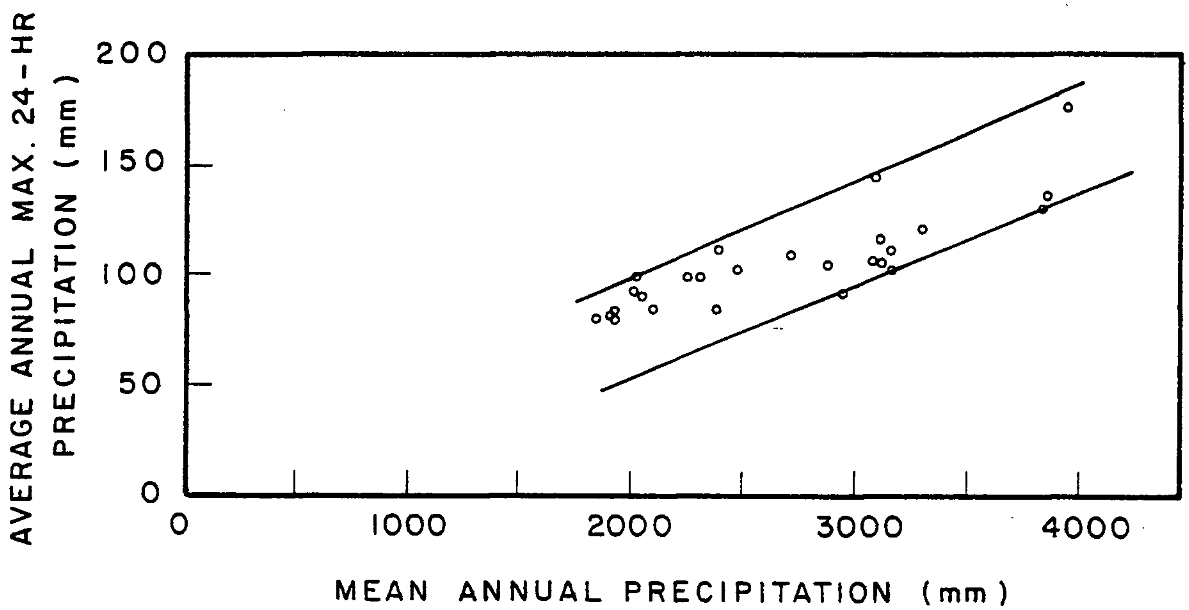
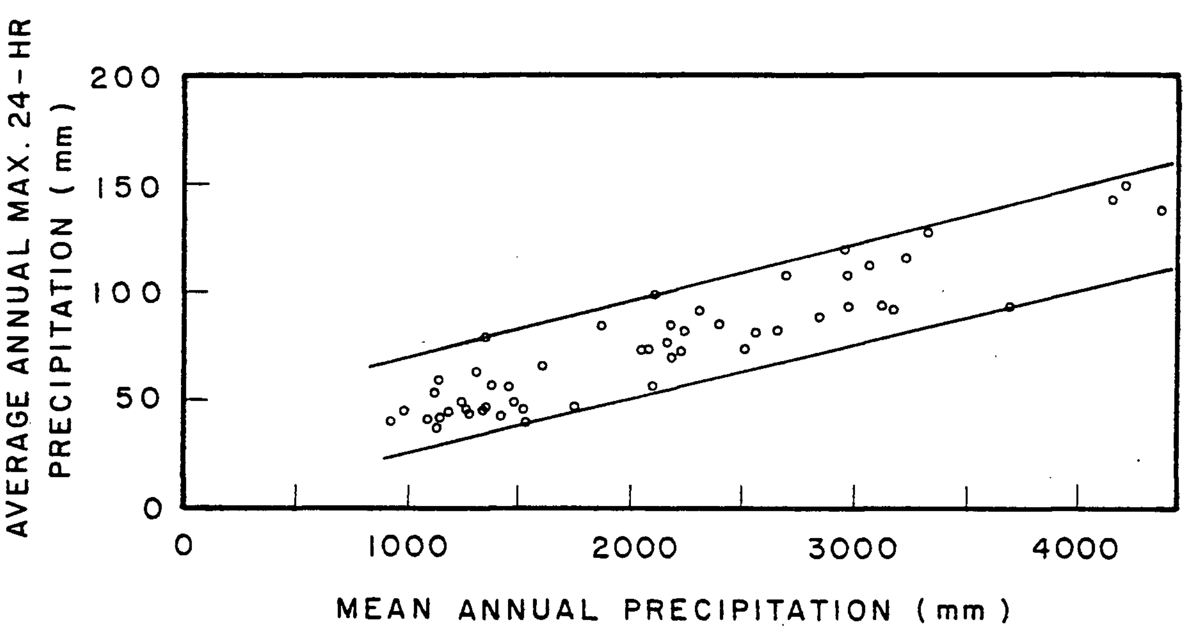


Figure 3.17 Relationship Between 24-Hour and Annual Precipitation



(c) WEST COAST OF VANCOUVER ISLAND.



(d) OTHER B.C. COASTAL STATIONS.

Figure 3.17 Relationship Between 24-Hour and Annual Precipitation

Envelope curves are included on Figure 3.17 to illustrate the consistent relationship in the coastal region between annual and 24-hour precipitation at a station. These relationships are summarized in Table 3.16 which lists the range in percentages of 24-hour precipitation versus annual precipitation represented by envelope curves on each Figure.

Table 3.16

Relationship Between 24-Hour and Annual Precipitation

Annual Precip. (mm)	Ratio of 24-Hour to Annual Precipitation (percent) West Coast of Vanc. Island	East Coast of Vanc. Island	Vanc and Fraser Valley	Other Coastal Stations
1000	-	3.3-7.1	3.6-5.3	2.6-7.0
2000	2.7-4.9	3.3-5.5	3.6-4.7	2.6-4.6
3000	3.2-4.8	3.3-5.5	3.6-4.5	2.6-4.1
4000	3.4-4.7	-	3.6-4.4	2.6-3.7

Results included in Table 3.16 indicate that a 24-hour precipitation estimate can be made based on annual precipitation at a location. Therefore, it is reasonable to suppose that the distribution of long term precipitation with elevation is an index for the distribution of storm rainfall. This conclusion is supported by examining further precipitation data from Transects A and B on Figure 3.12. For Transect A, distribution of mean annual precipitation with elevation is compared to that for average annual maximum 24-hour precipitation on record, and at Transect B the distribution of 1970-71 winter precipitation is compared to that for three storms. Results are shown in Table 3.17 where ratios of precipitation at 600 and 1200 m to a reference value taken at elevation 200 m are included for short and long durations.

Table 3.17

Distribution of Short and Long Duration Precipitation

	Ratio of Precipitation Amounts 600 m:200 m	1200 m:200 m
TRANSECT A		
Average Annual Precip.	1.13	1.28
Ave. Annual Max. 24-Hr Precip.	1.13	1.31
TRANSECT B		
Winter 1970-71	1.31	1.79
Dec 6-7, 1970	1.12	1.31
Dec 9-11, 1970	1.35	1.88
Feb 13-15, 1971	1.32	1.79

Even though results shown in Table 3.17 suggest annual precipitation can be used as an index for 24-hour precipitation, judgement is still required for engineering design situations when local recording stations are not available. However, distribution of longer duration precipitation is oftentimes more recognizable than that for storm rainfall. For example, variations in vegetation and forest cover may be apparent during a site reconnaissance, or interviews with local residents may be more reliable regarding observations such as areas of deeper snow or wetter fields. In the absence of sufficient precipitation records on site, investigative procedures noted above may provide the only basis on which to assess the distribution of storm precipitation for engineering design purposes.

3.7 SUMMARY

1. Rainfall intensity data are available from Atmospheric Environment Service (AES) for 58 stations in the coastal region of British Columbia. Gauge density in most of the region is much less than that recommended by the World Meteorological Organization (1970) for mountainous terrain.

2. Atmospheric Environment Service summarizes rainfall characteristics at each station by producing Intensity-Duration-Frequency (IDF) Curves. IDF curves provide average intensities for a given duration and return period, but do not provide information regarding variations in rainfall intensities within a single storm.

3. Regional characteristics of IDF curves are investigated in this study by analyzing the variation in rainfall depth with return period for a given duration (depth-frequency relationships) and variation of depth with duration for a given return period (depth-duration relationships).

4. Ratios of rainfall depth are used in the analysis rather than rainfall magnitude alone. This method is one approach to identifying regional characteristics when the amount of rainfall is different between stations. For the 58 stations available in coastal British Columbia, 24-hour rainfall with a 100-year return period ranges from 75 mm to 380 mm, and mean annual precipitation ranges from 650 mm to 3500 mm.

5. Results of regional analysis of IDF curves are shown for depth-duration and depth-frequency relationships in Figure 3.4 and 3.5, respectively. The relatively narrow range of depth ratios on each figure illustrates regional characteristics of storm rainfall in coastal British Columbia.

6. Regional analysis of the time distribution of single storm rainfall are investigated in this study at the same 58 stations for which AES prepared IDF curves. Development of synthetic hyetographs based on intensity data from IDF curves is an approach commonly applied in design situations only because single storm data are seldom available.

7. Results of analysis of single storm rainfall data in coastal British Columbia are shown in Figure 3.8. The lower curve represents 24-hour rainfalls which tend to be linear and the upper limit illustrates those which have periods of higher intensity. Typical time distributions of extreme 24-hour rainfalls recorded in coastal British Columbia are shown on Figure 3.6.

8. Comparison of hourly rainfall intensities in Figure 3.4 based on IDF curves and in Figure 3.8 based on single storm data shows that beyond about 6-hour durations the two curves are similar. For shorter durations, rainfall intenstities estimated from IDF curves would produce a synthetic hyetograph with greater maximum hourly intenstities than have been observed to occur within single storms.

In practice the two curves can be used to set limits on the range of hourly rainfall intensities to be considered by the design engineeer in the absence of site data.

9. Analysis of rainfall intensity data from Oregon and Washington produces results similar to those documented for coastal British Columbia. Analysis of U.S. data, included in Tables 3.11, 3.12 and 3.14, illustrates further the regional applicability of rainfall characteristics identified in British Columbia, and provides results from stations at higher elevations than are currently available in coastal British Columbia.

10. Regional characteristics of IDF curves and single storm rainfall are especially useful for application to approximately 250 coastal B.C. stations which record only 24-hour data. Regional rainfall characteristics can now be applied to 24-hour data at these stations to estimate shorter duration intensities and, therefore, greatly expand the data base currently available for design purposes.

11. Local variations in storm rainfall with elevation are not constant for all storms. Rainfall distribution is controlled by site specific meteorologic conditions which exist during each storm. Preliminary assessment of limited available data in coastal B.C. suggests that during extreme events, rainfall increases linearly with elevation up to mountain crests. In the absence of historical storm data, the distribution of annual precipitation can be used as an indicator for the distribution of extreme storm rainfall.

4. PHYSICAL ASPECTS OF WATER FLOW THROUGH SNOW

4.1 INTRODUCTION

Development of hydrograph procedures capable of simulating rain-on-snow floods requires that the role of a snowpack be assessed with regard to its contribution of snowmelt to total runoff and its effect on runoff response from the basin. A fundamental question which arises for extreme rain-on-snow is whether water percolation through the snow medium or development of internal drainage channels is the dominant routing mechanism. Quantitative formulations have been proposed describing water percolation through snow in a vertical unsaturated zone and a basal saturated layer. However, evidence is also available to suggest that an internal drainage network, not water percolation, controls runoff during extreme rain-on-snow floods.

The approach taken in this study to assess the role of a snowpack is: (i) to review available literature in the general areas of snow physics and snow hydrology; (ii) to assess results of research studies which pertain to the flow of liquid water through snow; and (iii) to interpret results with regard to their impact on hydrograph procedures required for rain-on-snow floods. Once the role of a snowpack on basin response to rain-on-snow is assessed, then requirements of a hydrograph model can be established.

Only those physical aspects of water flow through snow which affect rain-on-snow flood hydrographs in the coastal region of the Pacific Northwest are assessed in this study. In particular, snowpack response to inputs of liquid water is examined. Available literature describing physical aspects of water flow through snow is extensive. For example, Gerdel (1945, 1954) provided some of the earliest quantitative descriptions of water transmission through snow; Colbeck developed theories for vertical percolation through unsaturated homogeneous snow (1971, 1972), saturated flow along the base of a snowpack (1974a), water flow in a dry snowpack (1976) and flow through heterogeneous snow (1979a); more microscopic analyses of water and snow interaction and snow metamorphism have been undertaken by deQuervain (1973) and Colbeck (1982a, 1983); water pressure and capillary effects within a snowpack were assessed by Colbeck (1974b) and Wankiewicz (1978a); and grain clusters and geometry were analyzed by Colbeck (1979b, 1982b). An overview of much of the research noted above is available from Colbeck (1978) or Wankiewicz (1978b). A summary of water percolation processes through homogeneous snow is included in Appendix IV.

It was originally envisioned that a contribution of this study would be the incorporation of water percolation processes into a hydrograph model. However, assessment of snow metamorphism and flow path development following inputs of liquid water to a snowpack suggests that an internal drainage network, not water percolation, is the dominant routing mechanism during extreme rain-on-snow. Examination of available literature which leads to this conclusion and the consequences of the conclusion on hydrograph procedures are presented in this Chapter.

Development of hydrograph procedures considering than an internal drainage network is the primary routing mechanism through the snowpack is presented in Chapter 5. Preliminary results of application of these procedures in Chapter 5 confirms that during extreme rain-on-snow floods, no additional runoff delay needs to be included for water percolation through the snow.

4.2 FLOW PATHS AND SNOW METAMORPHISM

A mountainous snowpack is highly variable in both time and space. A snowcover is deposited by a sequence of discrete storms and is usually a layered medium. For example, the snow surface may be rearranged by drifting which breaks down grains and repacks them into a higher density wind crust, the surface may be glazed by absorption of solar radiation, and freeze-thaw cycles can lead to the formation of ice layers. The state of snow metamorphism at any given time, therefore, is the result of preceding climatological conditions.

Layering within snowpacks occurs throughout the season and affects flow paths taken by melt water. Wankiewicz (1978b) categorized layers depending on whether the snow horizon would impede, accelerate or have no effect on flow through the pack. For example, some layers impede downward percolation, some regions cause a redistribution of flow, and fingering can develop where flow concentrates below impeding horizons. In British Columbia these phenomena are well documented by dye studies of water flow through snow undertaken by Wankiewicz (1976) and Jordan (1978).

Perhaps the most important concept to recognize in snow hydrology is that snowpack response is not constant, but rather varies with physical properties of the snow. Therefore, discussion of snowpack response must be qualified by a description of snow properties being considered. Much of the snowpack in the coastal mountains of the Pacific Northwest can be categorized as "warm" (Smith, 1973). Warm snowpacks are those whose interior temperature remain near 0°C during most of the snow season. This snow can also be categorized as "wet" when liquid water is present (Colbeck, 1982a). A warm, wet snowpack is commonly referred to as a ripe snowpack.

Analysis is presented in the following sections for warm snowpacks, isothermal at 0°C, and for wet snow whose liquid water content exceeds the "irreducible-water saturation". Irreducible-water saturation is a measure of water held in place as absorbed or capillary water and has been shown through experimentation (Scheidegger, 1957) to equal about 7% of the pore volume. Once irreducible-water saturation is satisfied, additional water inputs are transmitted through the snowpack by processes dominated by gravity (Colbeck and Davidson, 1973).

The effects of water content and grain size on water percolation through homogeneous snowpacks have been investigated in a theoretical study by Colbeck (1976). For an input of rain, water percolation for three different snow conditions was examined as shown on Figure 4.1. Figure 4.1a shows the rainfall input, and 4.1b through 4.1d show the corresponding

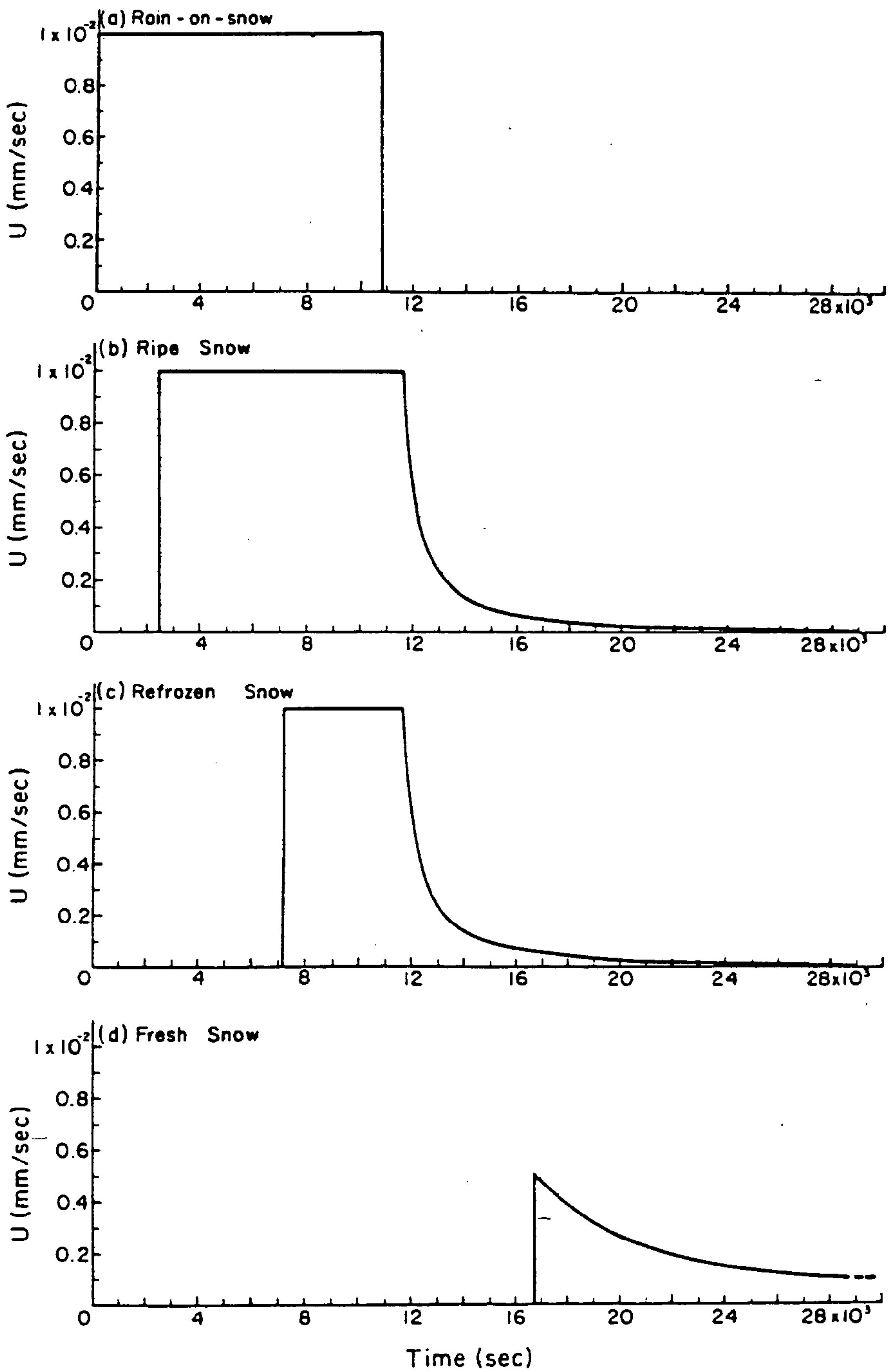


Figure 4.1 Snowpack Response to Rain-On-Snow (after Colbeck, 1976)

response for: ripe snow whose absorbed and capillary water requirements are satisfied; refrozen snow which has the same grain sizes as ripe snow but whose residual water is refrozen; and fresh snow comprised of smaller grain sizes. As illustrated on Figure 4.1, response of ripe snow is relatively fast, inflow and outflow shapes are similar, and all inflow occurs as outflow; refrozen snow requires an initial water input to raise snow temperature to 0°C and then responds much as ripe snow; and response time of fresh snow is longer because water is needed to satisfy the irreducible water content, and water movement through finer grain sizes is slower. These three examples illustrate that in some instances outflow from a snowpack following a rain-on-snow event may be relatively small, while for a ripe snowpack outflow can be fairly rapid and equal in volume to rain and snowmelt inputs.

Introduction of liquid water into a snowpack causes metamorphic processes to accelerate rapidly. Characteristics of this aging process are summarized by Colbeck (1977) and include:

i) rapid grain growth occurs until uniform grain diameters of 2 to 3 mm develop.

ii) permeability of wind crusts and ice-layers increases rapidly when liquid water moves through the snowpack.

iii) snow generally densifies during melt metamorphism.

In conjunction with field studies of the transmission of water through snow, Gerdel (1954) observed that ice planes in wet snow rapidly disintegrate; horizontal and vertical internal drainage channels develop; flow channels are directed to small streams, and when the internal drainage network is established discharge of snowmelt and rain will be approximately equal to the rate of water input at the snow surface. Colbeck (1974a) admitted in his paper which presented theories for both vertical unsaturated flow and basal saturated flow through snow that "further study is needed ... to determine the extent of saturated flow versus open channel flow beneath the snowpack".

Colbeck (1977) noted that even in relatively homogeneous snow, wetting-front advance follows distinct routes. Once flow paths are established, their permeability increases due to grain growth and frictional melting and they become preferential routes for subsequent flow. Additional frictional melting causes channels to enlarge and, consequently, decreases the response time of the snow cover.

A comprehensive review of snow accumulation, distribution, melt and runoff undertaken by leading researchers in snow hydrology (Colbeck et al., 1979) provides the following summary:

i) delay in runoff from a snowpack is usually less than that predicted by theory based on homogeneous snow. The apparent explanation is the development of distinct flow channels.

ii) initiation of flow channels is probably controlled by the detailed structure of the snow cover rather than the inherently unstable flow known as fingering.

iii) once preferential drainage routes are initiated, they are self-perpetuating.

iv) drainage from the snowpack becomes more rapid as melt channels develop.

v) development of flow channels during snow metamorphism effectively causes a snowcovered watershed to undergo a transition from snow-controlled to terrain-controlled water movement.

The above observations suggest development of an internal drainage network is the dominant routing mechanism during extreme rain-on-snow. Consequences of this conclusion on hydrograph procedures for extreme rain-on-snow are: (i) water percolation processes do not need to be simulated in a hydrograph model, and (ii) as water movement in a snow-covered watershed becomes terrain controlled, it is possible that basin response characteristics might approach conditions which would occur without a snowcover. This assessment of snowpack response forms the basis for hydrograph procedures developed in Chapter 5 for application to extreme rain-on-snow floods in the coastal region.

4.3 WATER INPUTS DURING RAIN-ON-SNOW

Water transmitted through a snowpack during a rain-on-snow event is contributed by both rainfall and snowmelt. Typical input rates for the coastal region are derived in this section based on hourly rainfall intensities determined in Chapter 3 and on snowmelt estimates using temperature-index equations.

As shown in Chapter 3, estimates for 24-hour rainfall with a 100-year return period in coastal British Columbia range from about 75 mm to 380 mm. During these events minimum and maximum hourly intensities are typically about 3 and 8 percent, respectively, of the 24-hour rainfall. The corresponding range of hourly rainfall intensities for three 24-hour events chosen for illustration are shown in Table 4.1.

TABLE 4.1

HOURLY RAINFALL INTENSITIES

24-Hour	Hourly Intensities (mm/hr)		
Rainfall (mm)	Minimum	Average	Maximum
75	2	3	6
150	5	6	12
380	11	16	30

The generation of snowmelt is a thermodynamic process where the amount of melt is dependent on the net heat exchange between the snowpack and its environment. Various sources and processes which influence heat transfer with a snowpack include absorbed shortwave (solar) radiation, net longwave (terrestrial and atmosphere) radiation, convective heat transfer from the air, latent heat released by condensation from the air, conduction of heat from the ground, and heat content of rain water. Detailed analysis of these processes is available from the U.S. Army Corps of Engineers (1956), and various site specific studies are available in proceedings of annual snow conferences (e.g. Western Snow Conference, 1985).

In this study, temperature-index equations are used to estimate typical snowmelt rates during rain-on-snow events. Use of temperature-index equations to estimate snowmelt is an alternative approach to detailed thermo-budget snowmelt analysis. The U.S. Army Corps of Engineers (1956) showed that temperature can be used as an index for snowmelt by deriving empirical relationships which simulate more complex physical phenomena. Temperature-index equations have been applied extensively for snowmelt modelling in the Pacific Northwest both in the United States (U.S. Army Corps of Engineers, 1972) and Canada (Quick and Pipes, 1976).

Seven equations available in the literature for estimating snowmelt during rain-on-snow events have recently been evaluated by Kattelmann (1985) for isothermal snowpack at 0°C at two sites in the Sierra Nevada Mountains of California. Snowmelt was measured and compared to estimates from each of seven snowmelt equations for rain-on-snow events occurring over an 11-year period on one basin and a 24-year period on the other. The snowmelt equation that had the lowest computed root mean square error (RMSE) at each of the two basins was proposed by Dunne and Leopold (1978):

$$M = (0.142 + 0.051U_2 + 0.0125P)T_a + 0.25 \qquad \text{............. (4.1)}$$

where M = daily snowmelt (cm); U_2 = windspeed at 2 m (m/s); P = daily rainfall (cm); and Ta = mean air temperature (°C).

The relationship proposed by Dunne and Leopold is similar to the widely used equation developed by the U.S. Army Corps of Engineers (1956), except the Corps of Engineers equation has a larger coefficient for the wind term:

$$M = (0.133 + 0.086U_{15} + 0.0126P)T_a + 0.23 \qquad \text{............. (4.2)}$$

where U_{15} = windspeed at 15 m (m/s).

The U.S. Army Corps of Engineers (1956) developed another snowmelt equation for rain-on-snow, not included in the study by Kattleman (1985), for forested areas:

$$M = (0.339 + 0.0126P)T_a + 0.13 \qquad \text{............. (4.3)}$$

Eqn 4.3 is commonly applied to estimate snowmelt because wind data are seldom available for a project site. Representative snowmelt rates estimated using Eqns. 4.1 and 4.3 for rain-on-snow in the coastal mountains are included for comparison in Table 4.2 for a range of climatological conditions shown for illustration.

TABLE 4.2

REPRESENTATIVE SNOWMELT RATES

24-Hour Rainfall (mm)	Mean Air Temperature (°C)	Daily Snowmelt (mm) Eqn. 4.1 u = 0 m/s	Eqn. 4.1 u = 10 m/s	Eqn. 4.3
75	2	7	17	10
75	8	21	62	36
150	2	9	19	12
150	8	29	70	44
380	2	15	25	18
380	8	52	93	67

Comparison of results in Table 4.2 shows the effect of wind speed on snowmelt estimates and illustrates the difficulty in estimating snowmelt on ungauged watersheds where climate data are not available.

Results from Tables 4.1 for typical rainfall rates and 4.2 for snowmelt estimates based on Eqn. 4.3 are combined for illustration in Table 4.3 to produce representative water inputs to a snowpack in the coastal region for a range of rainfall events and mean air temperatures.

TABLE 4.3

REPRESENTATIVE RAINFALL AND SNOWMELT INPUTS

Mean Temp. (°C)	Rainfall Daily (mm)	Rainfall Ave. Hrly (mm/h)	Snowmelt Daily (mm)	Snowmelt Ave. Hrly (mm/h)	Total Ave. Hrly (mm/h)
2	75	3.1	10	0.4	3.5
8	75	3.1	36	1.5	4.6
2	150	6.3	12	0.5	6.8
8	150	6.3	44	1.8	8.1
2	380	15.8	18	0.8	16.6
8	380	15.8	67	2.8	18.6

4.4 SUMMARY

1. Development of hydrograph procedures capable of simulating rain-on-snow floods requires that the role of a snowpack be assessed with regard to its contribution of snowmelt to total runoff and its effect on runoff response from the basin. A fundamental question which arises for extreme rainfall on ripe snowpacks is whether water percolation through the snow medium or development of internal drainage channels is the dominant routing mechanism. Available evidence suggests that the drainage channel routing mechanism controls runoff during extreme rain-on-snow events.

2. Temperature, water content and grain size affect response of snowpacks to rain-on-snow as shown, for example, on Figure 4.1. Introduction of liquid water into a snowpack causes metamorphic processes to accelerate rapidly such that rapid grain growth occurs, permeability of wind crusts and ice-layers increases and snow densifies.

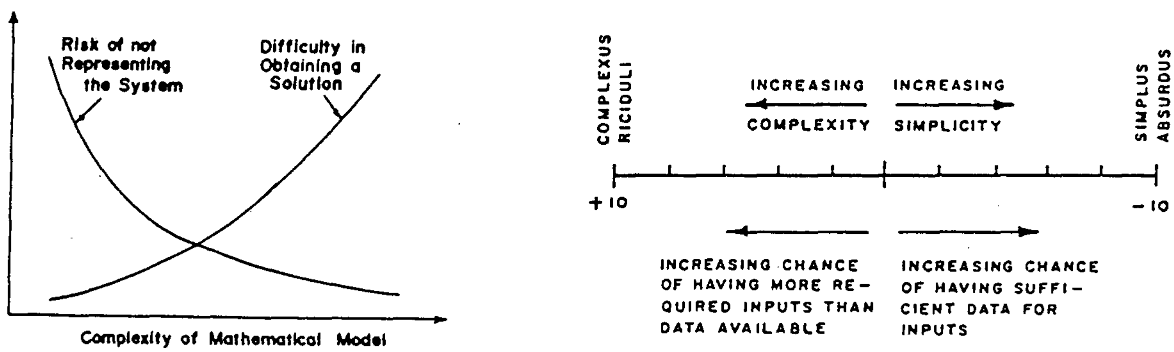
3. A comprehensive report by Colbeck et.al., 1979 concludes snowpack response time is usually less than predicted by water percolation theory, and the apparent explanation is development of distinct flow channels. Development of flow channels during snow metamorphism effectively causes a snow covered watershed to undergo a transition from snow-controlled to terrain-controlled water movement.

4. If the development of an internal drainage network is the dominant routing mechanism during extreme rain-on-snow, then the consequences on hydrograph procedures for extreme rain-on-snow are: (i) water percolation processes do not need to be simulated in a hydrograph model, and (ii) as water movement in a snowcovered watershed becomes terrain controlled, it is possible that basin response characteristics might approach conditions which would occur without a snowcover. This assessment of snowpack response forms the basis for hydrograph procedures developed in Chapter 5 for application to extreme rain-on-snow floods in the coastal region.

5. DEVELOPMENT OF RAIN-ON-SNOW HYDROGRAPH MODEL

5.1 PERSPECTIVE ON HYDROLOGIC MODELS

Development of a hydrologic model for application purposes requires that a balance be maintained between model complexity and data available for model implementation. For example, a detailed physical description of runoff processes may require input data which are often unavailable, while a less complex model which operates with more readily available data may not adequately describe basin response in all cases. The key to successful modelling, therefore, is often dependent on the model developer's ability to simulate a complex process within the limitations of available data. This process of trade-offs is illustrated on sketches presented on Figure 5.1.



a) Trade-off Diagram (after Overton and Meadows, 1976)

b) Modelling Complexity (after Haan and Barfield, 1978)

Figure 5.1 Perspective on Hydrologic Models

There are still many approaches to hydrologic modelling which can be adopted in addition to those necessitated by trade-offs noted above. Project objectives may dictate both the approach and output requirements of the model, while in other instances analytical procedures may be incorporated into a model based simply on the personal preference of the developer. General categories of hydrologic models proposed by Clarke (1973) are noted below and brief descriptions are provided to contrast differences in their approach.

Deterministic vs Stochastic:

When variables of a model are specified by probability distributions, the model is stochastic; when each variable is assigned a single value for a specified condition, the model is deterministic.

Physically-based vs Empirical:

Physically-based models undertake analysis by rigorous solution of mathematical formulas which describe runoff processes; empirical models incorporate coefficients and relationships derived from observation, experience and experiment.

Continuous vs Event:

Continuous models generate hydrographs over long periods of time and operate through low and high flow seasons; event models are usually implemented only to estimate a single hydrograph for a specified set of input variables.

Lumped vs Distributed:

Lumped models treat a watershed as if it were homogeneous; in a distributed model, input data and basin response characteristics are varied across the basin.

The goal of this study is to develop a hydrograph procedure capable of simulating rain-on-snow floods in the coastal mountains of the Pacific Northwest. It is intended that the procedures be applicable to extreme flood conditions. Extreme flood is a subjective classification and is commonly used in context with a specific design objective. For this study extreme flood generally refers to any flood with a return period greater than about 20 years.

Specifying that only extreme rain-on-snow floods will be analyzed is analogous to selecting a specific case from the wide spectrum of runoff events which occur from a basin through the years. Extreme floods are of importance in many instances of engineering planning and design.

Development of hydrograph procedures for rain-on-snow floods is undertaken with an awareness of data commonly available for engineering design situations in the coastal region of the Pacific Northwest. These data are generally limited to the following (although supplemental site information may also be available in some instances):

i) topographic mapping at approximate scale 1:50 000. Even at this relatively large scale a 60 km^2 basin, for example, is only about 12 by 20 cm on a topo map.

ii) estimate of rainfall over the basin. These design data are usually estimated for the basin of interest based on analysis of rainfall data recorded at a regional station. Even without site data for confirmation, a design engineer must nevertheless assess the applicability of regional data to the basin. In mountainous regions this assessment is especially difficult because precipitation can vary over relatively short distances both in plan and elevation.

iii) estimate of snowmelt over the basin. Procedures for estimating snowmelt include an energy balance approach and empirical temperature-index equations. Sufficient climatological data for an energy budget approach to snowmelt are generally unavailable at remote mountainous locations and, therefore, temperature-index equations are usually applied.

iv) site photos and/or site reconnaissance. Site information is usually obtained for specific design projects to allow qualitative assessment of such items as land use, forest cover and drainage network development.

Based on the objective of this study to analyze only extreme rain-on-snow flood conditions and on limitations of data generally available, the following guidelines are established for development of hydrograph procedures:

i) rain-on-snow floods will be analyzed as a single event in response to specified input rainfall and snowmelt.

ii) a deterministic approach will be adopted.

iii) runoff characteristics of the basin will be represented by empirical relationships.

iv) provision for distributing rainfall and snowmelt across the basin will be incorporated in the model.

5.2 CONTINUOUS FLOW VS EVENT MODELS

The effect on modelling approach of analyzing only extreme rain-on-snow floods can be illustrated by examining a fundamental difference between continuous flow and event models.

Continous flow models are developed to operate over long periods of time and for a wide range of climatic and runoff conditions. Therefore, their simulation capabilities are different from those of an event model which operates for a short period in response to a single set of input conditions. Continuous flow models in operation in the Pacific Northwest include the SSARR (Streamflow Synthesis and Reservoir Regulation) Model developed by U.S. Army Corps of Engineers (1972) and the UBC Watershed Model (Quick and Pipes, 1976). The SSARR Model is applied extensively in the Columbia River Basin to guide reservoir regulation decisions related to flood protection, navigation and hydro power. The UBC Model is used by the B.C. Ministry of Environment for annual flood forecasting on the Fraser River and by B.C. Hydro on the Columbia and Peace River systems.

One primary requirement of a continuous flow model is to maintain a water balance over long periods between water inputs in the form of rain and snow and outflow from the basin. This is generally accomplished by separating precipitation inputs into one of three modes of travel through the basin: surface runoff, stormflow and groundwater flow. Each of these runoff components has a different response characteristic and therefore occurs downstream as river flow at different times. For example, routing characteristics of surface runoff is important for simulating peak flows following periods of high intensity rainfall, while routing of groundwater flow is necessary to estimate low flows which occur long after storm periods.

Event models are developed to simulate flood flows which result from basin response to a specified set of input data. These models operate only for that period of runoff dominated by processes with relatively fast response times which contribute to the flood peak. Inputs to groundwater are treated as "losses" during the computation period since their contribution to streamflow occurs at a later period than the generated flood hydrograph.

In summary, a continuous streamflow model must account for water inputs over long periods by routing runoff components separately. An event model focuses only on those runoff processes which generate a flood hydrograph. Project objectives dictate the type of information required which, in turn, establishes a modelling approach to be implemented. The goal of this study is to develope hydrograph procedures for estimating flood peaks resulting from rain-on-snow. Emphasis, therefore, is concentrated on examining the proportion of rain and melt inputs which contribute to the flood peak and the routing characteristics of relatively fast runoff components.

5.3 SELECTION OF MODELLING PROCEDURE

Two procedures in common use for generating flood hydrographs from rainfall were examined for possible application to rain-on-snow flood occurrences. One method applies a unit-hydrograph concept and the other employs a lag and route technique. Discussion of the conceptual development and application of each of these procedures is available in standard hydrology texts both in the U.S. (Linsley et al., 1982) and Canada (Gray, 1970). Examples of hydrologic models commonly applied in engineering practice using unit-hydrograph procedures include HYMO (Williams and Haan, 1973), SCS-TR20 (Soil Conservation Service, 1973) and OTTHYMO (Wisner and PNG, 1982). The lag and route procedure is incorporated in the HEC-1 Flood Hydrograph Package (U.S. Army Corps of Engineers, 1973).

Unit-hydrograph and lag and route techniques are investigated in this study to assess whether empirical relationships and coefficients employed by each method for rainfall-only could be modified for application to rain-on-snow in mountainous regions of the Pacific Northwest. An overview and initial screening of each method is undertaken in this section to assess its potential for application to rain-on-snow floods and its merits for more detailed examination.

Each of the hydrologic models noted above which employ unit-hydrograph concepts utilizes a different procedure to estimate unit-hydrograph shape. However, even with these differences each procedure requires that basin lag and recession constant(s) of the unit-hydrograph be determined. When recorded flood hydrographs are unavailable to make this assessment for a watershed, basin lag and recession constant can often be estimated from empirical relationships.

A general expression for basin lag is presented by Watt and Chow (1985). It is based on data available from throughout the U.S. and from Quebec and southern Ontario in Canada, but does not include data from coastal British Columbia. Because of this absence of verification even for rainfall events in the coastal mountain regions, it was concluded that modifications of unit-hydrograph procedures would not be attempted for this investigation of rain-on-snow floods.

A second consideration for discarding conventional unit-hydrograph techniques is their inability to provide readily for spatial variations in rainfall and snowmelt across a basin. Unit-hydrographs require basin averaged conditions to be input to the model. In instances when the variation in rainfall and snowmelt must be accounted for across the basin, unit-hydrograph procedures require that the drainage basin be sub-divided into smaller watershed elements.

The lag and route procedure for hydrograph analysis was first proposed by Clark (1945) and is based on the principle that rainfall onto a basin is modified by two factors: travel time through the basin and storage characteristics of the watershed. Storage is actually distributed across the basin, although in the lag and route procedure it is considered to occur at the basin outlet and is simulated by a single linear reservoir.

Travel time of a water particle through a basin can be estimated based on hydraulic principles. This feature is particularly attractive for ungauged mountainous basins when only topographic maps and site photos are available. In this instance, topography can serve as an indicator to assess variation in travel time from different parts of the basin to the outlet. Lines connecting points of equal travel time, called isochrones, from various segments of the basin to the outlet can then be established.

Lag and route procedures simulate storage with one linear reservoir and a single storage coefficient. In instances when continuous flow simulation is required for long periods a single routing coefficient is not adequate to simulate runoff (U.S. Army Corps of Engineers, 1972; Quick and Pipes, 1976). However, for analysis of a single flood event, that portion of the runoff hydrograph affected by fast response characteristics can be more readily represented by a single routing coefficient (U.S. Army Corps of Engineers, 1973). Application of lag and route procedures to rain-on-snow events requires, therefore, investigation to determine if storage coefficients can be derived for snow covered basins in a similar manner as is applied for rainfall-only. A second question is whether storage coefficients determined for rain-on-snow events are different than those from rainfall-only on the same basin.

Based on preliminary assessment described above of unit hydrographs and lag and route procedures, the lag and route procedure is selected for further investigation of its potential for application to rain-on-snow floods. The focus of analysis will be on examining methods for estimating travel time and the storage coefficient for a snow covered watershed. The lag and route procedure allows for spatial variation in rain and snowmelt inputs and basin response, and achieves a balance between model complexity and available data.

5.4 SOURCES OF RAIN-ON-SNOW DATA

Research into the development of hydrograph procedures for extreme rain-on-snow floods requires a watershed with the following features and available data for analysis:

(i) high elevation mountainous basin
(ii) unregulated streamflow
(iii) local gauge which records rainfall intensity
(iv) continuously recording streamflow gauge
(v) snow over entire basin
(vi) rainfall occurring over entire snowpack
(vii) local gauge which records air temperature
(viii) basin which has experienced and recorded extreme flood event

Based on review of available streamflow, precipitation intensity and other climatological data, it was concluded that there is no suitable watershed in coastal British Columbia which satisfies all of the above requirements to a standard needed for research. Alternatively, drainage basins were examined in other segments of the coastal hydrologic region of the Pacific Northwest and suitable watersheds were identified in the Cascade Mountains in Oregon.

Two basins in Oregon were selected for detailed analysis of rain-on-snow floods. One is the Mann Creek basin which forms part of the Willamette Basin Snow Laboratory (WBSL) established by the U.S. Army Corps of Engineers for research studies of snowmelt. Results from this snow laboratory are incorporated in the text Snow Hydrology (U.S. Army Corps of Engineers, 1956); a climatological summary is available in the WBSL Hydrometeorological Log 1949-51 (U.S. Army Corps of of Engineers, 1952);

and a special research note (U.S. Army Corps of Engineers, 1955) is available which documented a rain-on-snow event on the basin in February 1951.

The second basin is Lookout Creek which experienced an extreme rain-on-snow flood in December 1964. An overview of the areal extent of the flood and damage to the coastal region was presented previously in Chapter 2.3 The U.S. Geological Survey (USGS) documented hourly streamflow data during the December 1964 storm for recording gauges in the coastal region in a special publication (Waananen, et al, 1971); precipitation and climatological data for the region are available from the U.S. Weather Bureau (1965a, 1965b).

In addition to detailed analysis of Lookout Creek, hydrographs recorded on six other watersheds in Oregon during the December 1964 storm are also analyzed to assess storage characteristics during extreme rain-on-snow floods. Drainage basins analyzed in this study are described in Table 5.1 and their locations in Oregon are shown on Figure 5.2.

Perspective on the relative magnitude of available rain-on-snow flood data can be gained by comparing unit discharges in Table 5.1 with those for maximum floods on record in coastal British Columbia shown previously on Figure 2.5. This comparison shows some of the December 1964 flood peaks rate among the highest on record, while the rain-on-snow hydrograph recorded on Mann Creek is not a very extreme event.

TABLE 5.1

SOURCES OF RAIN-ON-SNOW FLOOD DATA

Station*	Latitude		Longitude		Drainage Area (km^2)	Gauge Elev (m)	Date of Flood	Maximum Discharge (m^3/s)	Maximum Unit Discharge ($(m^3/s)/km^2$)
1. Nestucca River	45	19	123	25	16.0	552	22 Dec. 1964	24.8	1.6
2. Grave Creek	42	39	123	13	57.3	718	22 Dec. 1964	177	3.1
3. Lookout Creek	44	13	122	15	62.4	376	22 Dec. 1964	189	3.0
4. S. Fork Coquille R.	42	44	124	01	105	570	22 Dec. 1964	340	3.2
5. W. Fork Illinois R.	42	03	123	45	110	462	22 Dec. 1964	456	4.1
6. Hills Creek	43	41	122	22	137	497	22 Dec. 1964	303	2.2
7. Elk Creek	42	53	122	55	141	390	22 Dec. 1964	251	1.8
8. Mann Creek	44	18	122	10	13.0	817	7 Feb. 1951	7.3	0.6
Mann Creek					(rain only)		1 Nov. 1950	15.6	1.2

* see Figure 5.2 for station location

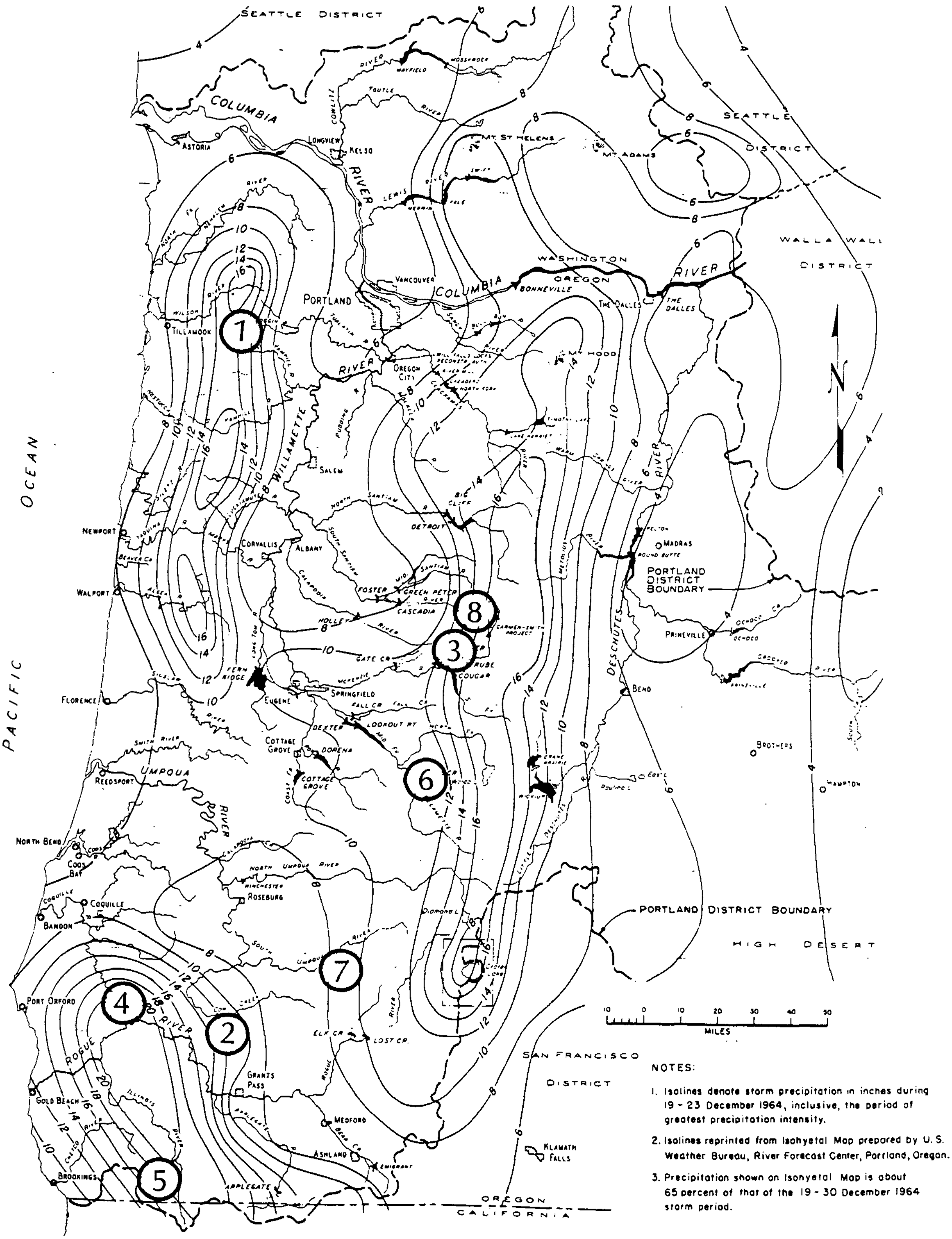


Figure 5.2. Location Map for Oregon Watersheds

5.5 APPROACH TO MODEL DEVELOPMENT

The primary objective of this investigation is to develop a rain-on-snow hydrograph model which can be applied in a consistent manner to mountainous watersheds where recorded historical flood data are not available for model calibration. A lag and route procedure has been selected as a method that is compatible with limited site data which are commonly available. An outline of procedures which will be implemented to assess whether a lag and route hydrograph model can be applied for extreme rain-on-snow floods is as follows:

(i) examine methods for estimating travel time of a water particle through the basin.

(ii) tabulate storage coefficients derived from analysis of recorded extreme rain-on-snow flood hydrographs.

(iii) apply lag and route procedure for a rainfall-only event on Mann Creek to examine whether the fast runoff contribution to flood peaks in mountainous regions can be simulated using one storage coefficient.

(iv) apply lag and route procedure for rain-on-snow event on Mann Creek to examine whether the model can be adopted for rain-on-snow, and compare the storage coefficient to that on the same basin for rainfall-only.

(v) apply lag and route procedure for rain-on-snow event on Lookout Creek to undertake a second application of the model, and to assess storage coefficients during more extreme flood events.

It is generally recognized (e.g. Loague and Freeze, 1985) that hydrograph procedures can ultimately be modified to reproduce any recorded hydrograph through a sequence of reassigning parameter values in the model. However, while such exercises are sometimes classified as model calibration, they are more an exercise in curve fitting for a single event and results cannot always be extrapolated to other runoff events even on the same basin.

Acceptability of lag and route procedures to extreme rain-on-snow events will be judged on simulation results of only the initial application of the model. Even though a better fit between recorded and simulated events could be achieved through additional model modifications for each event, such a process is not possible in field application to ungauged watersheds where recorded data are not available for calibration.

5.6 LAG AND ROUTE HYDROLOGIC MODEL

5.6.1 Procedures for Computation

Implementation of lag and route hydrograph procedures requires the time-area response characteristics and the storage coefficient for the basin. Calculations proceed in two steps. First, water inputs onto each sub-area delineated by isochrones are "lagged" to the watershed outlet based on water particle travel times through the basin. Water inputs can be varied across the basin by specifying different amounts for each sub-area. Second, at the basin outlet lagged flows are "routed" through a reservoir whose storage characteristics represent those governing the fast component of runoff through the basin. Calculations required for hydrograph development are described in this section, and procedures for estimating travel time and storage characteristics of the basin are presented in subsequent sections.

Lagged flows at the basin outlet are calculated as follows:

$$I_i = \frac{B}{t}(R_i A_1 + R_{i-1} A_2 + \cdots + R_{i-n+1} A_n) \qquad \text{.......... (5.8)}$$

where I_i = lagged discharge (inflow to reservoir) after i time increments; B = constant which varies with units; t = time increment for calculations; R_i = water input during ith time increment; A_n = drainage area of the sub-area into which the basin is divided by isochrones. For example, for a watershed divided into three sub-areas by isochrones at half-hour intervals, a time increment for calculation equal to a half-hour, and water inputs in mm and areas in km^2, Eqn. 5.8 would be written as follows:

$$I_i = 0.556(R_i A_1 + R_{i-1} A_2 + R_{i-2} A_3) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5.9)$$

Lagged flows are routed through a reservoir at the basin outlet to produce the simulated flood hydrograph for the watershed. These calculations are undertaken by combining the characteristic equation for a linear reservoir:

$$S = KQ \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5.10)$$

and the continuity equation:

$$I - Q = \frac{\Delta S}{\Delta t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5.11)$$

where S = reservoir storage; K = storage coefficient; Q = reservoir outflow; and I = reservoir inflow.

Eqns. 5.10 and 5.11 can be combined and rearranged to yield:

$$Q_{i+1} = (I_i + I_{i+1})\frac{\Delta t}{2K + \Delta t} + Q_i\left(\frac{2K - \Delta t}{2K + \Delta t}\right) \qquad \ldots\ldots\ldots\ldots (5.12)$$

where i and i+1 refer to successive time increments.

Eqns. 5.9 and 5.12 are used in this study to produce "lagged" and "routed" flows, respectively, once the time-area runoff characteristics and storage coefficient are estimated for the basin.

5.6.2 **Travel Time**

Travel time of a water particle which contributes to the fast component of runoff is determined by flow velocities occurring prior to channelization and those occurring after runoff concentrates sufficiently to form channels. Examination of topographic maps in mountainous regions shows channels are evident through a large portion of most drainage basins.

Travel time through a basin is not constant for all runoff events. This feature is referred to as a non-linear characteristic of basin response. In contrast, unit-hydrograph and lag and route procedures assume linear basin response. Nevertheless, they have still been applied successfully in many instances of engineering planning and design. One explanation for success of linear hydrologic models is their application for a given design condition where basin response can be approximated as linear over a limited range. A similar philosophy is adopted in this study for application of lag and route procedures to the special case of extreme rain-on-snow floods. Accordingly, methods proposed and tested in this investigation should not be extrapolated for application to other runoff conditions.

Estimates of velocities for channelized flow will be based on Manning's equation, and non-channelized velocities will be based on empirical and theoretical overland flow velocities. Travel time of a water particle in channelized flow can be estimated from Manning's equation:

$$\bar{V} = \frac{1}{n} y^{0.67} S^{0.5} \qquad \text{.......................... (5.1)}$$

and

$$t = L/\bar{V} \qquad \text{.......................... (5.2)}$$

where $\bar{V}$ = mean velocity; y = depth; S = slope; n = Manning roughness coefficient; t = time; and L = channel length. Solution of Eqn. 5.1 is shown graphically on Figure 5.3 for three typical mountain slopes and a range of channel depths and Manning's n values. For comparison, overland flow velocity estimates proposed by the Soil Conservation Service (1974) are also included on Figure 5.3.

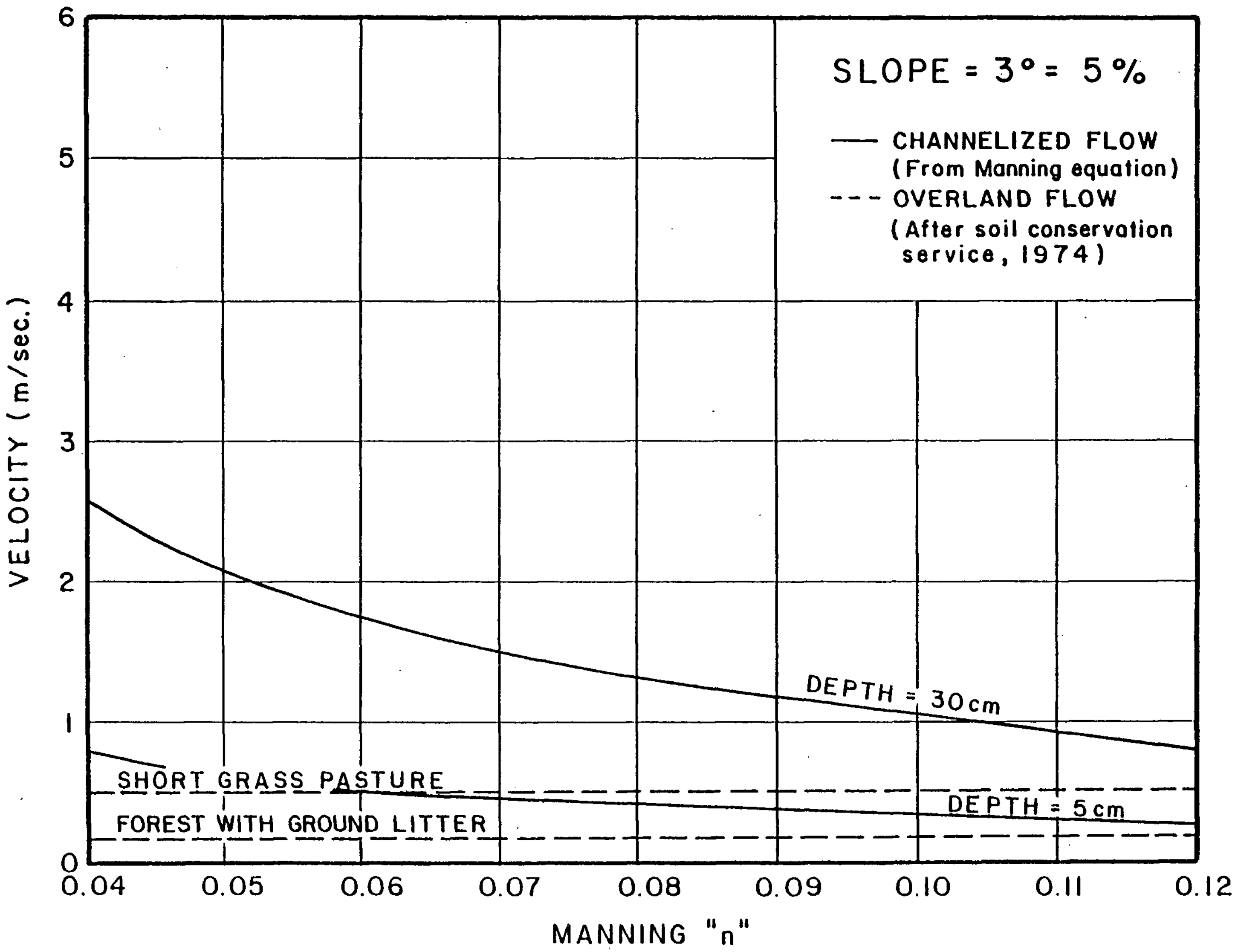


Figure 5.3(a) Comparison of Wide Channelized and Overland Flow Velocities

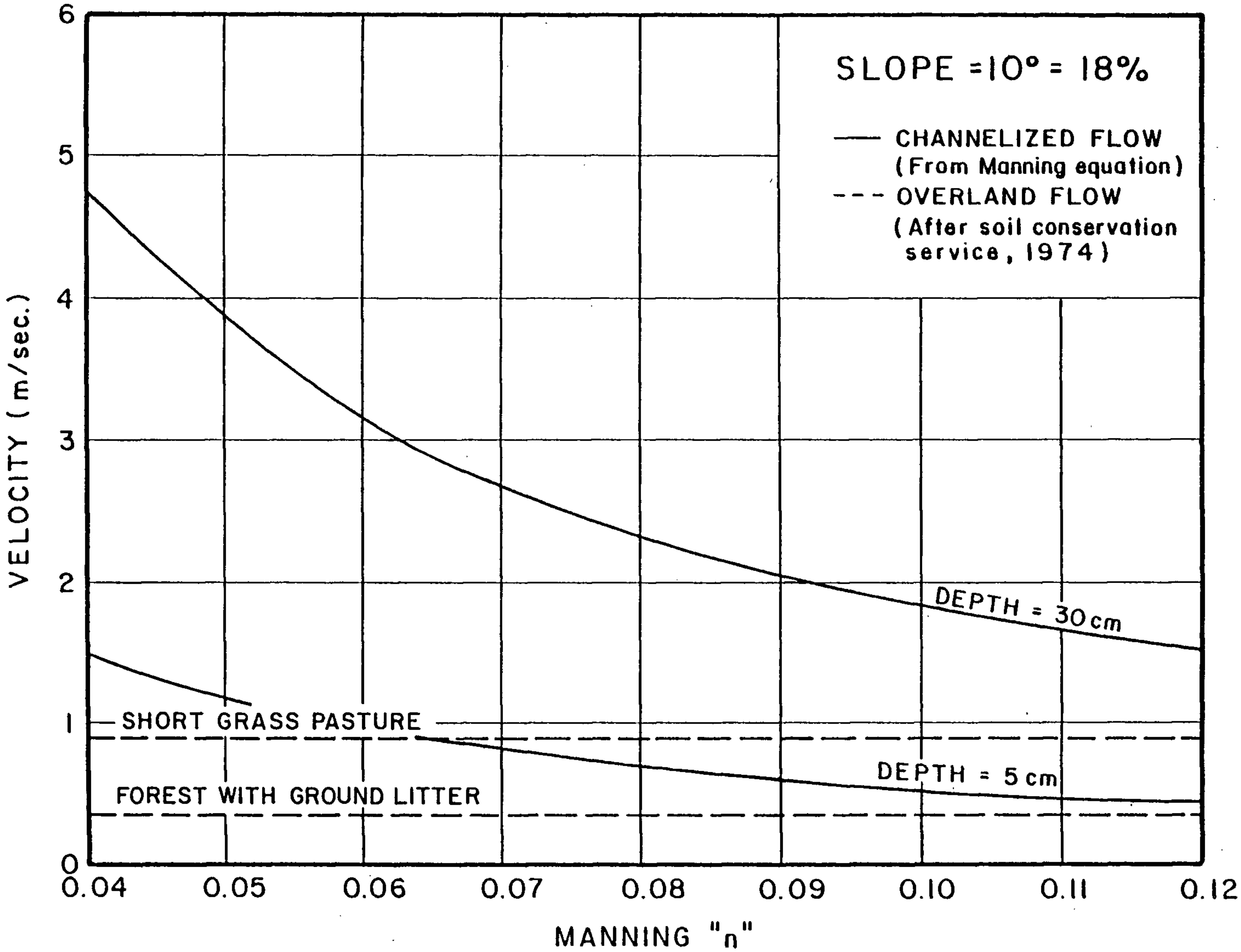


Figure 5.3(b) Comparison of Wide Channelized and Overland Flow Velocities

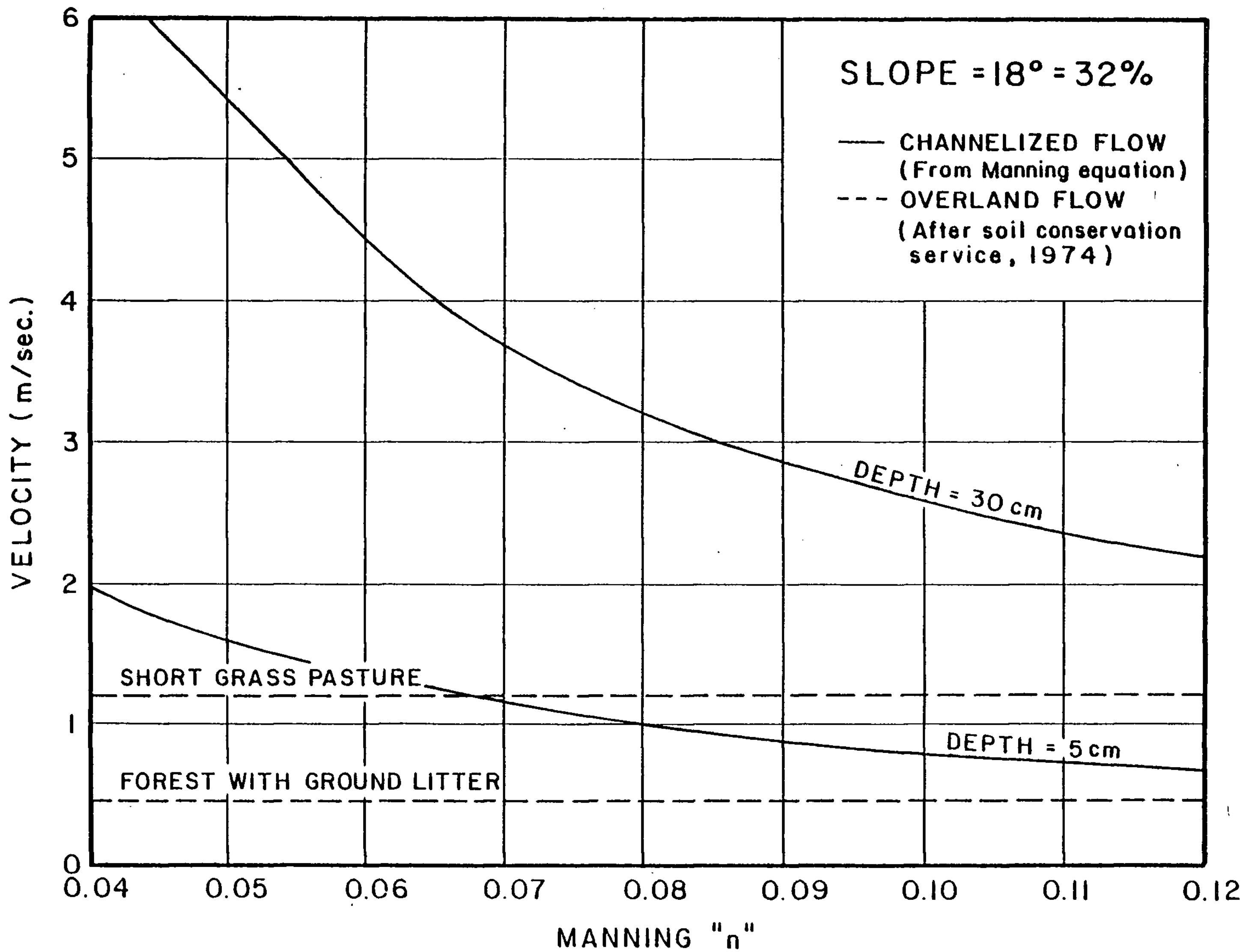


Figure 5.3(c) Comparison of Wide Channelized and Overland Flow Velocities

One method for estimating overland flow velocities has been developed by the Soil Conservation Service (1974) for use in hydrograph analysis. Velocity estimates for a range of hillside slopes and for different ground covers are shown graphically on Figure 5.4. Examination of Figure 5.4 shows these results represent linear basin response as velocity estimates do not vary with magnitude of the rainfall event. Overland flow velocities estimated by the Soil Conservation are also included with open channel flow curves on Figure 5.3 for comparison.

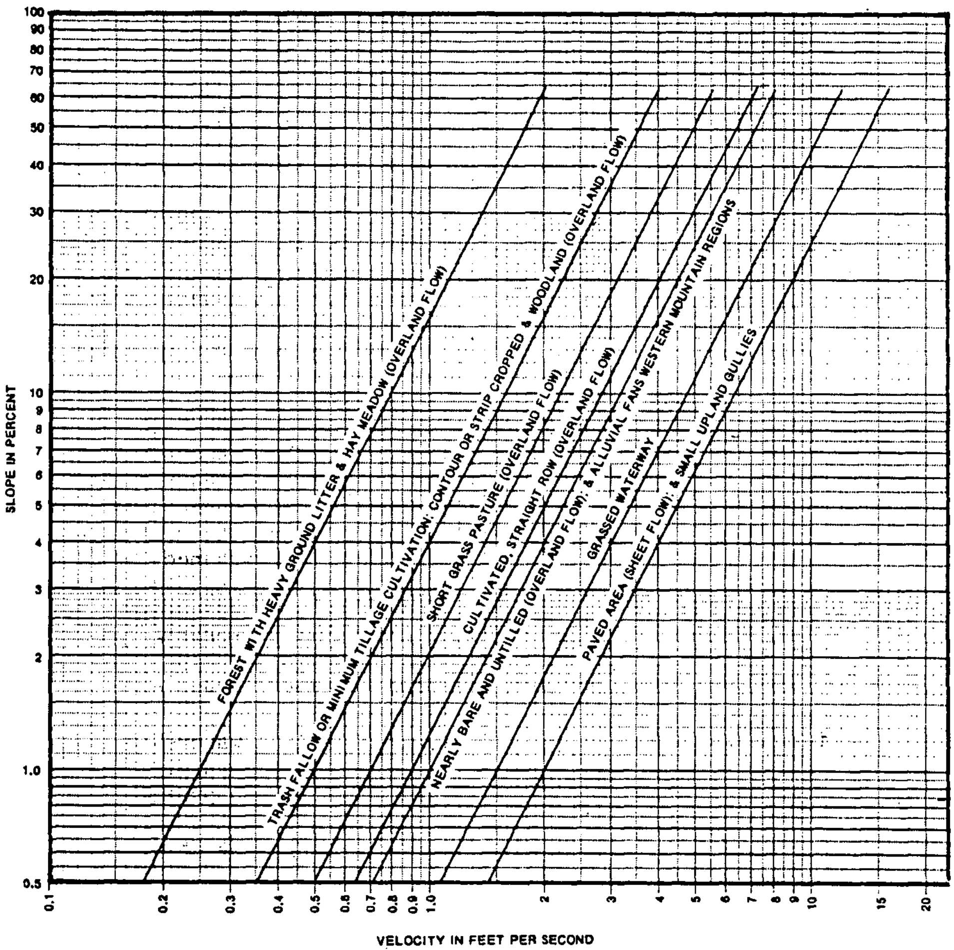


Figure 5.4. Overland Flow Velocities (after Soil Conservation Service, 1974)

Physically-based representations of the overland flow component of basin runoff have been proposed which demonstrate non-linear basin response for variations in rainfall intensity (Henderson and Wooding, 1965). The conceptualization of runoff, termed kinematic-overland flow, has been developed for the idealized case of flow over a plane surface. Results of analysis show velocity and depth increases in the downslope direction where for distance L:

$$y_L = \left(\frac{niL}{\sqrt{S}}\right)^{0.6} \qquad (5.3)$$

$$V_L = \frac{(iL)^{0.4}}{(\sqrt{S}n)^{0.6}} \qquad (5.4)$$

$$\bar{V} = 0.73\frac{(iL)^{0.4}}{(\sqrt{S}n)^{0.6}} \qquad (5.5)$$

where y_L = depth at distance L; V_L = velocity at distance L; $\bar{V}$ = mean water particle velocity over distance L; n = Manning roughness coefficient; i = rainfall intensity; and S = slope.

Based on kinematic-overland flow, mean water particle velocity varies with rainfall intensity and slope length. For illustration, mean water particle velocities for slope length = 100 m and rainfall intensity = 12 mm/hr, estimated as the maximum hourly intensity occurring in the coastal region for a 24-hour rainfall of 150 mm, range from 0.04 - 0.08 m/s for a 3° slope, 0.06 - 0.12 m/s for a 10° slope, and 0.08 to 0.15 m/s for an 18° slope. Comparison to results in Figure 5.3 shows mean velocities calculated for the idealized case of overland flow on a plane surface are less than empirical overland flow velocity estimates provided by the Soil Conservation Service. Empirical results presented by the Soil Conservation Service for overland flow are adopted for this study because these results have received widespread application in engineering studies and because Henderson (1966) cautions the application of kinematic flow on a watershed scale to rural catchments.

Travel time for application of lag and route procedures to rain-on-snow floods will be estimated from channelized flow velocities based on Manning's equation and on empirical overland flow velocities from the Soil Conservation Service. This procedure is particularly attractive for ungauged watersheds because the response of each basin can be estimated based on hydraulic principles and empirical results rather than having to rely on equations developed for other basins and regions. As proposed in Chapter 4, this approach to estimating travel time through a drainage basin considers that an internal drainage network has formed within the snowpack and delay between inputs at the snow surface and transmission to the snowpack base is minimal.

5.6.3 **Storage Coefficient**

The lag and route procedure simulates storage characteristics of a watershed by a single linear reservoir located at the basin outlet. The storage coefficient can be estimated from analysis of recorded flood hydrographs where the recession portion of the fast runoff component is approximated by:

$$Q_t = Q_0\, e^{(-t/K)} \qquad \text{.......................... (5.6)}$$

where Qt = discharge at time t; Qo = discharge at t=o; and K = storage coefficient. Taking logarithms of Eqn. 5.6 and rearranging terms yeilds:

$$\ln Q_t = \left(-\frac{1}{K}\right) t + \ln Q_0 \qquad \text{.......................... (5.7)}$$

which shows that the storage coefficient for a basin can be estimated from the slope on a graph plotting ln Q versus time.

For illustration a flood hydrograph from Lookout Creek in Oregon is shown on Figure 5.5 on graphs with natural and with semi-log scales. The hydrograph plotted at natural scales illustrates the fast response and relatively large magnitude of this extreme flood compared to winter flow preceding the storm. The slope of the recession portion of the hydrograph on semi-log scales illustrates storage characteristics of the basin.

Clark (1945) envisioned that the storage coefficient be estimated from the recession curve of a hydrograph after cessation of a pulse of rain. While this approximation is relatively straightforward in concept, appropriate recorded hydrographs may not be available. It is more likely that

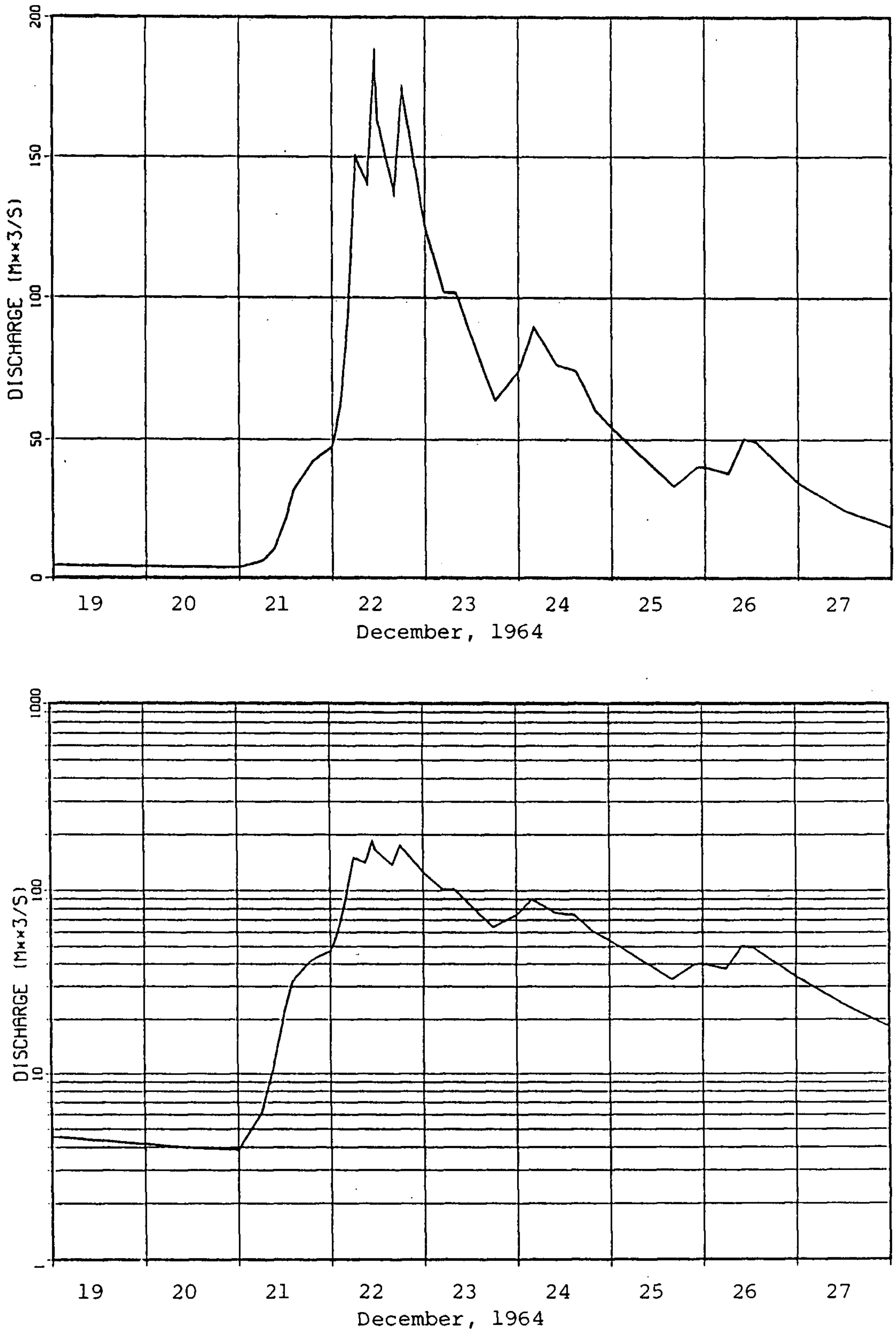


Figure 5.5. Rain-On-Snow Flood Hydrograph on Lookout Creek

a flood peak results from intense rainfall within a longer duration storm and that lower intensity rain may still be occurring during hydrograph recession. Similarly, for rain-on-snow events snowmelt continues to add water inputs to the snowpack even after rainfall has ceased.

For instances when low intensity rain or snowmelt is still occurring during hydrograph recession, storage coefficients may be overestimated because recession flows would result from both water release from storage and additional water inputs to the basin. Even under these circumstances, however, storage coefficients measured from recorded hydrographs would be more representative of a basin when peak water inputs are much larger than those occurring during hydrograph recession. This is especially true for extreme rain-on-snow when peak rainfall intensities are much larger than snowmelt rates.

Recession curves for flood hydrographs from seven drainage basins in Oregon which experienced extreme rain-on-snow floods in December 1964 and one from Mann Creek in the Willamette Basin Snow Laboratory for a less extreme event in February 1951 were analyzed to estimate storage coefficients for use in the lag and route hydrograph procedure. The storage coefficient for each hydrograph was calculated from the slope of the recession curve plotted on semi-log graph paper. Results for each drainage basin are summarized in Table 5.2

TABLE 5.2

STORAGE COEFFICIENTS FOR RAIN-ON-SNOW EVENTS

Station*	Drainage Area (km^2)	Date of Flood	Storage Coefficient** (h)
1. Nestucca River	16.0	December 22, 1964	13
2. Grave Creek	57.3	December 22, 1964	6
3. Lookout Creek	62.4	December 22, 1964	20
4. S. Fork Coquille R.	105	December 22, 1964	17
5. W. Fork Illinois R.	110	December 22, 1964	10
6. Hills Creek	137	December 22, 1964	15
7. Elk Creek	141	December 22, 1964	7
8.a Mann Creek	13.0	February 7, 1951	50
8.b Mann Creek	(rainfall only)	November 1, 1950	19 & 25

* See Table 5.1 and Figure 5.2 for station location.
** For single linear reservoir: storage = storage coefficient x discharge

Examination of results in Table 5.2 shows estimated storage coefficients are in a relatively narrow range for seven drainage basins in Oregon during an extreme rain-on-snow event in December 1964. No attempt is made in this study to develop functional relationships between storage coefficients and basin characteristics, land use or geometry. Storage coefficients included in Table 5.2 are presented as preliminary estimates for use when lag and route procedures are applied to rain-on-snow floods in the Pacific Northwest. A recommended follow-up study to this investigation is one which examines storage coefficients from recorded rain-on-snow hydrographs throughout the coastal region of Oregon, Washington, British Columbia and Alaska.

Comparison of the storage coefficient estimated for the rain-on-snow flood on Mann Creek with those from Oregon in December 1964 shows the Mann Creek value is much larger. One possible explanation for this difference can be proposed based on physical aspects of water flow through snow. The Mann Creek flood of February 1951 was not an extreme flood and, therefore, an internal snowmelt drainage network may not have been very extensive and water percolation through the snowpack could control much of the runoff process. For the extreme rain-on-snow events in Oregon an internal drainage network, as described in Chapter 4.2, may have provided the dominant routing mechanism. In the latter case, the storage characteristics of a basin during extreme rain-on-snow events may approach that for rainfall when no snowcover is present.

5.7 ANALYSIS OF FLOOD HYDROGRAPHS ON MANN CREEK

5.7.1 Basin Location

The Mann Creek basin is located in the Cascade Mountains in Oregon and forms part of the Willamette Basin Snow Laboratory (WBSL) established by the Cooperative Snow Investigations program of the Corps of Engineers and Weather Bureau. The basin has a drainage area of 13 km^2 and extends from a continuously recording streamflow gauge at elevation 759 m to mountain peaks as high as elevation 1596 m. Basin location and topography are shown on Figure 5.6 at a scale of 1:48 000. Reference numbers included on Figure 5.6 represent locations for hydrometeorological instruments that were established for the WBSL research program.

5.7.2 Rainfall Flood of October 28, 1950 to November 2, 1950

5.7.2.1 Hydrometeorological Data

A summary of hydrometeorological data is available in the WBSL Hydrometeorological Log 1949-51 (U.S. Army Corps of Engineers, 1952) for two periods of intense rainfall from October 28 - November 2, 1950. This rainfall produced the largest flood recorded on Mann Creek during the two-year period and occurred prior to snow accumulation in the basin.

Hourly rainfall data recorded at three gauges across the 13 km^2 basin are available from the WBSL Hydrometeorological Log. A summary of these data is included in Table 5.3.

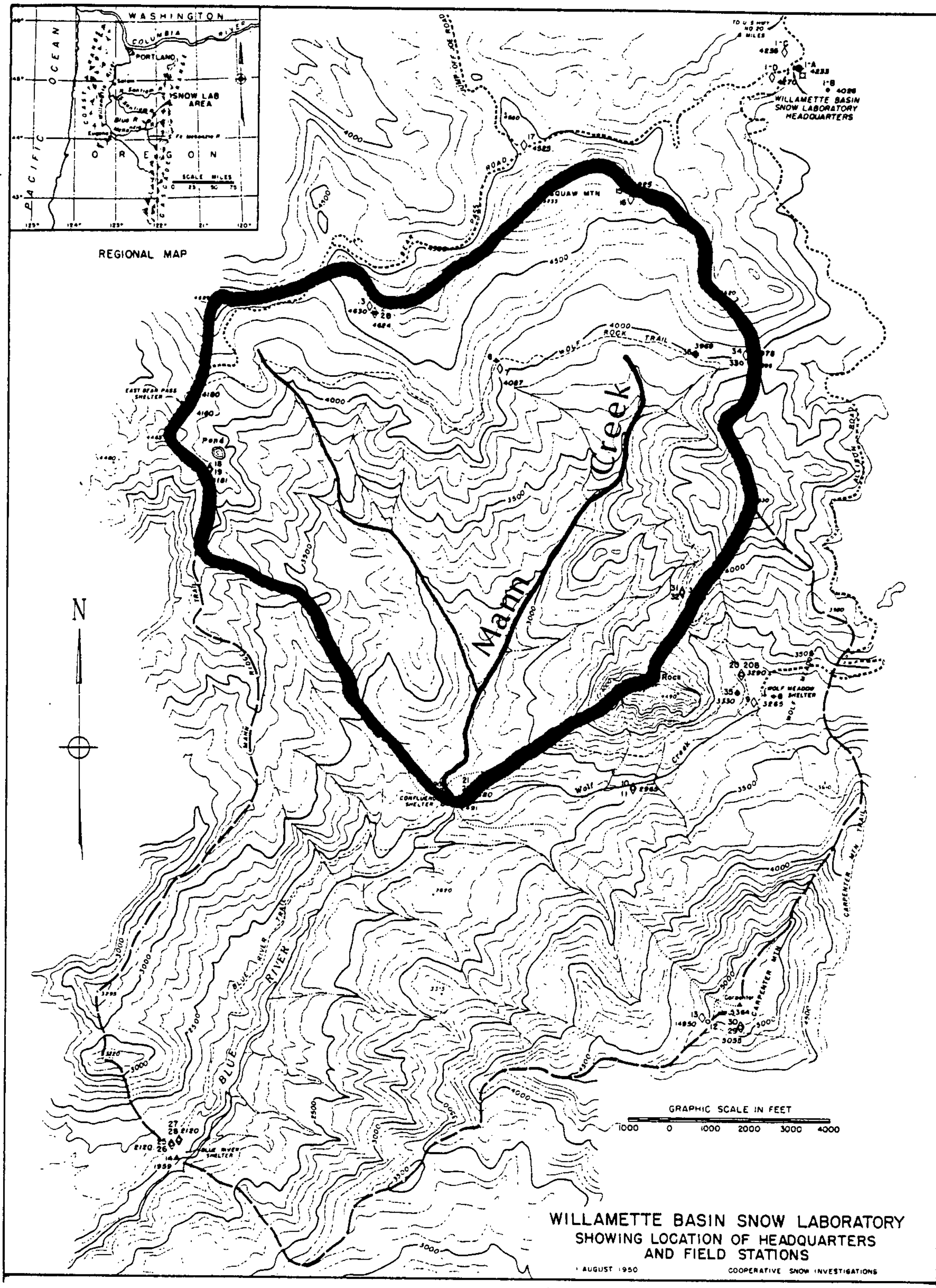


Figure 5.6. Mann Creek Topography

TABLE 5.3

MANN CREEK RAINFALL DATA: OCTOBER 28 - NOVEMBER 2, 1950

Station Number*	Elevation (m)	General Location	Daily Rainfall (mm) October 28	29	30	31	November 1	2
21	817	Basin outlet	107	48	13	9	78	15
8	994	Near South-eastern Boundary	102	48	18	13	99	4
2	1409	Northwestern Boundary	100	39	19	23	93	11

* See Figure 5.6 for gauge locations.

Recorded streamflow on Mann Creek for the storm period is available in the Hydrometeorological Log in two-hour increments. Flood hydrographs are shown on Figure 5.7.

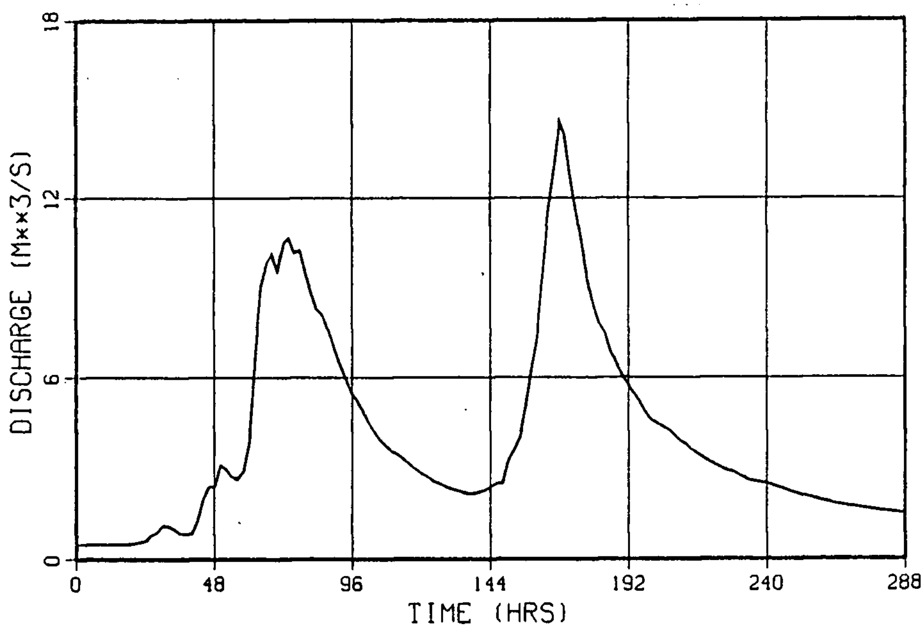


Figure 5.7 Recorded Hydrograph on Mann Creek: Oct. 27-Nov. 6, 1950

5.7.2.2 **Travel Time and Storage Coefficient**

Travel time of a water particle through the watershed is estimated based on results presented in Chapter 5.6.2 for channelized and overland flow velocities. The procedure adopted for this study is to estimate flow velocities in watercourses identified on a 1:50 000 scale topography map based on Manning's equation for open channel flow, and across other segments of the basin on estimates for overland flow velocities. One goal in developing these procedures is to provide a method which can be applied in a consistant manner on any ungauged watershed where only a topographic map is available to guide the analysis.

Assessment of the time-area runoff characteristics of the basin proceeded as follows:

(i) transects were drawn on the topographic map from the basin outlet to locations along the watershed boundary.

(ii) sections along each transect were designated as having either channelized or overland flow based on the criterion noted above.

(iii) slopes were measured along each transect.

(iv) travel times for overland flow were estimated for measured slopes and velocities proposed by the Soil Conservation Service (1974) for forests with ground litter.

(v) travel times for channelized flow in this mountainous stream were estimated for measured slopes and Mannings "n" equal to 0.07. Selection of Manning's n in upper reaches of mountainous watersheds requires judgement because n varies with relative roughness between the channel bed and banks and the flow depth. Mannings "n" adopted in this study is based on values provided by Chow (1959b). This particular exercise highlights the important role that site photos or a site visit can play in actual application of flood hydrograph procedures.

(vi) points were identified along each transect in half-hour increments and lines connecting points of equal travel time to the basin outlet, called isochrones, were drawn. Results for Mann Creek are shown on Figure 5.8 where isochrones illustrate the time-are runoff characteristics for the basin.

The storage coefficient for Mann Creek basin during the October 28 - November 2, 1950 rainfall event was estimated from the slope of recession curves on a semi-log plot of the recorded flood hydrographs. This graph is shown on Figure 5.9 where the recession constant for the fast runoff component on the first peak is estimated at 25-hours and on the second peak at 19-hours.

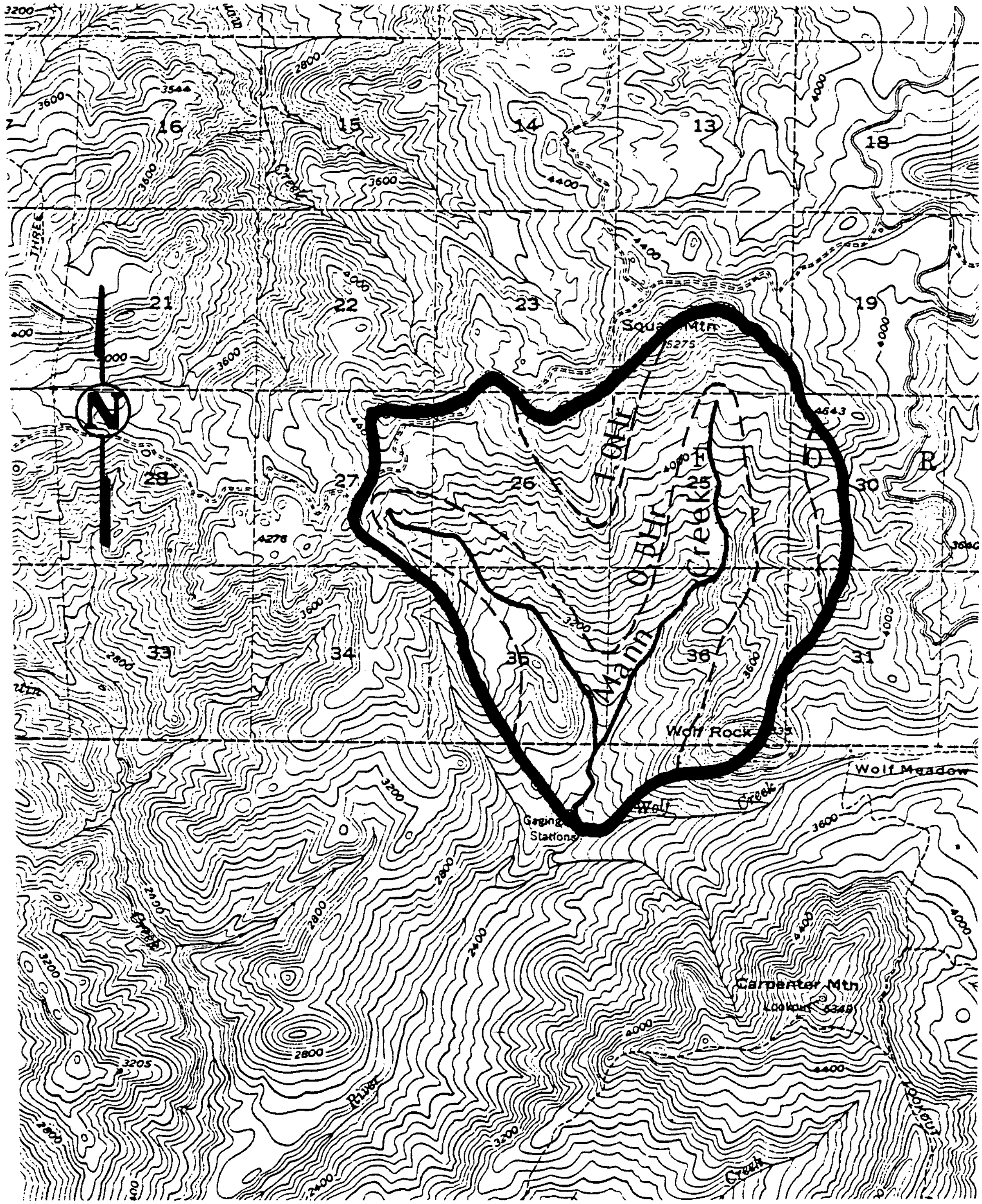


Figure 5.8. Mann Creek Time-Area Graph

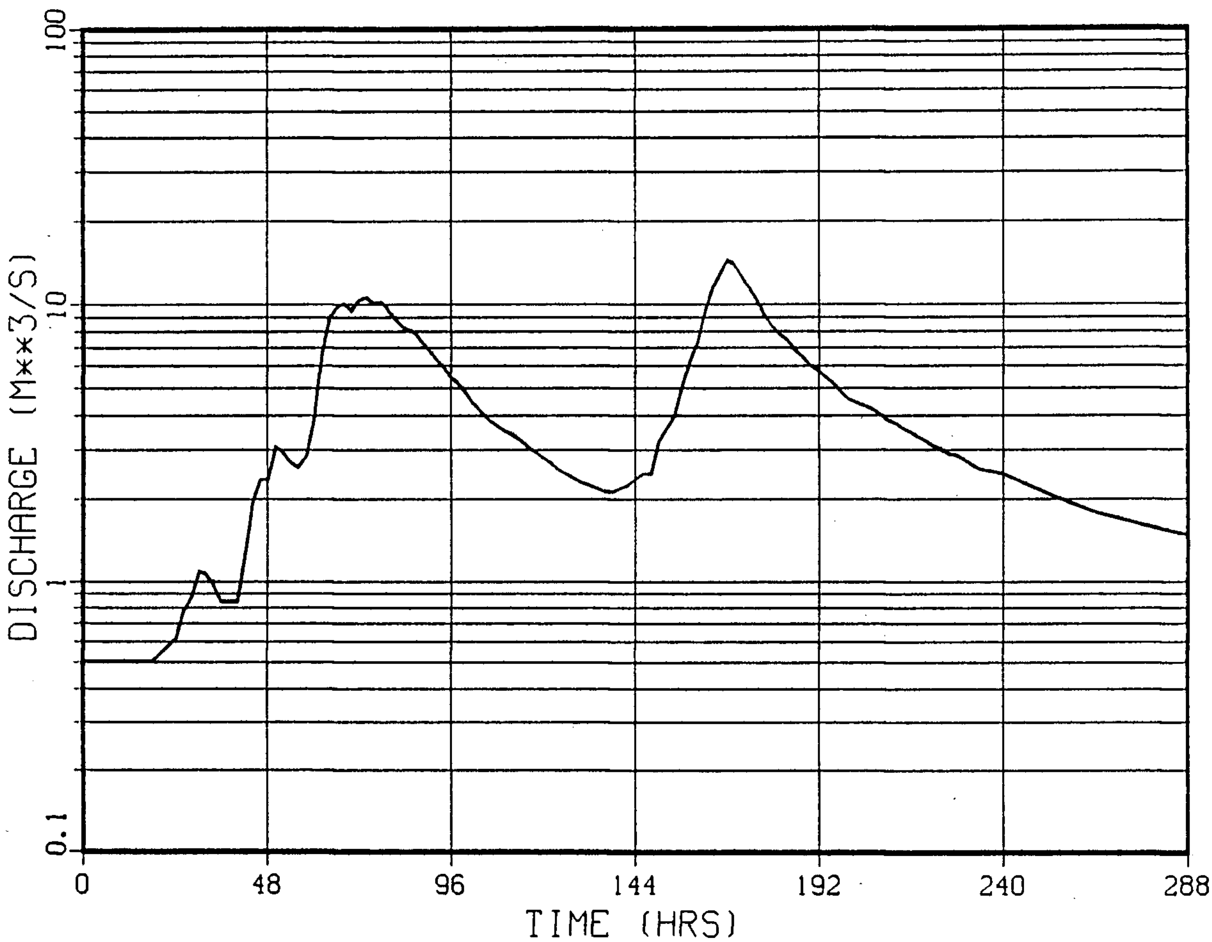


Figure 5.9. Semi-Log Plot of Mann Creek Hydrograph, October 27 - November 7, 1950

5.7.2.3 Application of Lag and Route Hydrologic Model

The primary purpose of applying the lag and route hydrograph procedure to a rainfall-only flood event, prior to examining rain-on-snow flood hydrographs, is to assess whether the fast runoff contribution to flood peaks in mountainous regions can be simulated using a single storage constant. Even though lag and route procedures are accepted as standard engineering practice for rainfall events (U.S. Army Corps of Engineers, 1973), application to a coastal mountain basin was still undertaken in this study for confirmation. Application of the lag and route hydrologic model for the rainfall-induced flood of October 28 - November 2, 1950 on Mann Creek proceeded as follows:

i) hourly rainfall data were obtained from the Hydrometeorological Log. As shown in Table 5.3 rainfall was fairly uniform over the 13 km^2 basin for this event.

ii) comparison of rainfall and recorded streamflow for the first hydrograph peak indicated that about 73 percent of rainfall occurred in the fast runoff component. To account for losses, the Soil Conservation Service (1974) curve number approach to estimating direct runoff was applied to recorded rainfall for the basin; a curve number of 80 was selected because this value represented the observed rainfall and runoff.

iii) the lag and route hydrograph model was applied to the Mann Creek basin using estimated effective rainfall as input, the time-area graph for runoff response characteristics shown on Figure 5.8, and a storage coefficient of 23 hours.

Results of the initial analysis are shown on Figure 5.10. Preliminary examination of flood hydrographs shows the lag and route procedure simulated the first runoff peak but underestimated the second. Comparison of rainfall and recorded streamflow for the second hydrograph peak indicated that recorded runoff is greater than rainfall over the basin. More detailed review of rainfall from all gauges on or near the basin provided no evidence to suggest errors in recorded data. Alternatively, it is reasonable to suppose that published streamflow for this high flow period may be in error since the flood event was the largest recorded on Mann Creek. Therefore, flow estimates would be based on extrapolation of an existing stage-discharge rating curve for the gauge site.

Results of the initial application of a lag and route hydrologic model show that the fast runoff component contributing to flood hydrographs for rainfall events in mountainous regions can be simulated using a single storage coefficient and with travel time for a water particle estimated from channelized and overland flow considerations. Application of lag and route procedures to Mann Creek demonstrates how flood peaks can be estimated with limited site information.

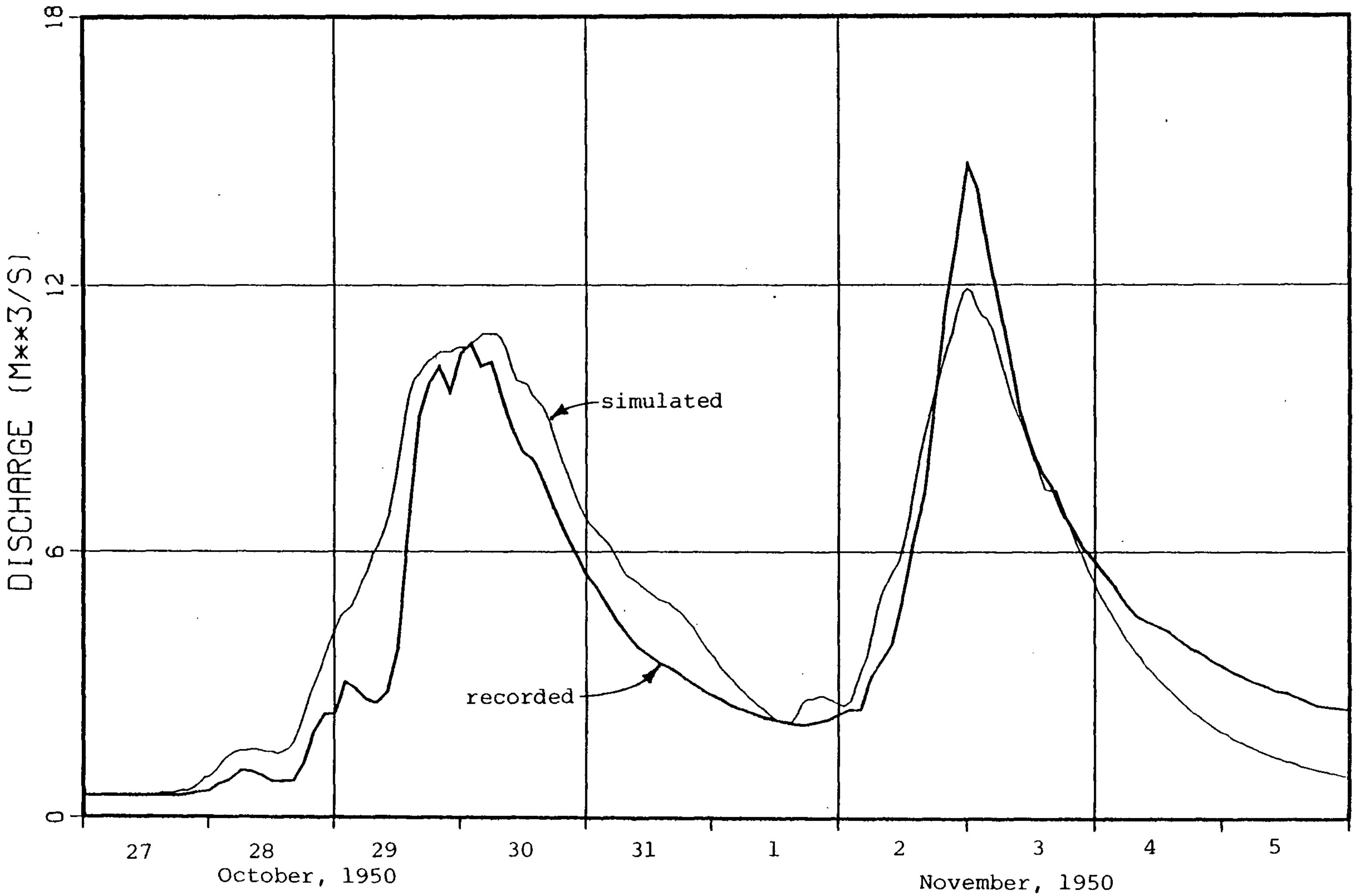


Figure 5.10. Simulated Rainfall Hydrograph on Mann Creek

5.7.3 Rain-On-Snow Flood of February 3 - 8, 1951

5.7.3.1 Hydrometoerological Data

A special research note (U.S. Army Corps of Engineers, 1955) documents and analyzes snowmelt for a rain-on-snow flood on Mann Creek in February 1951. During the February 3-8, 1951 flood event, a snowpack existed over the entire basin and precipitation occurred as rain throughout the watershed. The WBSL Hydrometeorological Log contains climatological data recorded by instruments across the basin. A listing of climatological stations referenced in this study and their general location is included in Table 5.4.

TABLE 5.4

MANN CREEK CLIMATOLOGICAL STATIONS

Station Number*	Elevation (m)	General Location	Climatological Data
21,22	817	basin outlet	precip., air temp., snow
11	902	near southeastern boundary	snowcourse
8	994	near southeastern boundary	precip., air temp.
20B	997	near southeastern boundary	snowcourse
32	1125	eastern boundary	snowcourse
34	1213	northeastern boundary	snowcourse
2,2B	1409	northwestern boundary	precip, air temp., snow

* see Figure 5.6 for gauge locations

An overview of hydrologic conditions during the rain-on-snow event on Mann Creek is provided in Tables 5.5, 5.6 and 5.7 which summarize daily rainfall, air temperature and snowcourse data, respectively.

TABLE 5.5

MANN CREEK RAINFALL DATA: FEBRUARY 3-8, 1951

Station Number	Elevation (m)	Daily Rainfall (mm) 3	4	5	6	7	8
21	817	6	39	17	14	55	0
8	994	8	50	18	-	-	3
2	1409	9	43	14	-	-	0

TABLE 5.6

MANN CREEK AIR TEMPERATURE DATA: FEBRUARY 3-8, 1951

Station Number	Elevation (m)	Mean Daily Air Temperature (°C) 3	4	5	6	7	8
21	817	0.6	0.6	2.2	1.1	3.3	3.3
8	994	-0.6	-0.6	0.6	0.0	2.2	1.7
2	1409	-1.7	0.0	0.6	2.2	2.2	3.3

MEAN = (max. + min.) /2

TABLE 5.7

MANN CREEK SNOWCOURSE DATA: FEBRUARY, 1951

Station Number	Elevation (m)	Date	Snow Depth (mm)	Water Equivalent (mm)
22	817	Feb. 2	762	267
11	902	Feb. 2	780	254
20B	997	Feb. 3	820	348
32	1125	Feb. 3	1288	503
34	1213	Feb. 2	2192	800
2B	1409	Feb. 1	2286	782

Estimates for basin averaged snowmelt and rainfall during the storm period are provided in the research note published by the U.S. Army Corps of Engineers (1955). A summary of these estimates is included in Table 5.8.

TABLE 5.8

SNOWMELT AND RAINFALL ESTIMATES

From	To	Length (hrs)	Snowmelt (mm)	Rainfall (mm)
Feb. 3 (HR 17)	Feb. 5 (HR 18)	50	25	58
Feb. 5 (HR 19)	Feb. 6 (HR 18)	24	12	20
Feb. 6 (HR 19)	Feb. 7 (HR 24)	30	18	42
Feb. 8 (HR 1)	Feb. 9 (HR 6)	30	22	0

Recorded streamflow on Mann Creek for the storm period is available in the Hydrometeorological Log in two-hour increments. The flood hydrograph for February 3-8, 1951 is shown on Figure 5.11.

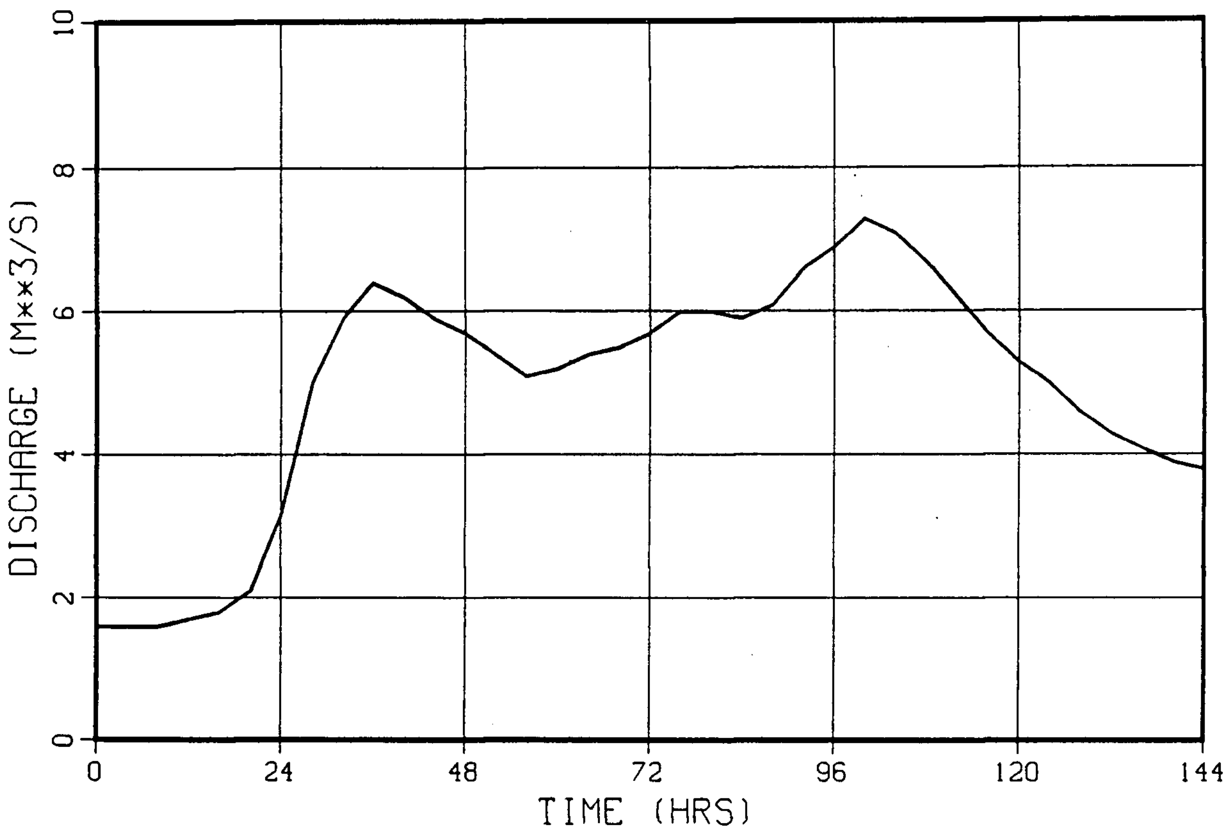


Figure 5.11. Recorded Hydrograph on Mann Creek: February 3-8, 1951

5.7.3.2 **Travel Time and Storage Coefficient**

Analysis of travel time of a water particle through the Mann Creek basin for the rain-on-snow event of February 3-8, 1951 considers that an internal network has formed within the snowpack and delay between water inputs at the snow surface and transmission to the snowpack base is minimal. For this case the time-area runoff characteristics for the basin shown previously on Figure 5.8 for rainfall-only is adopted for analysis of the rain-on-snow event.

The storage coefficient for Mann Creek basin during the February 3-8, 1951 rain-on-snow event is estimated from the slope of the recession curve on a semi-log plot of the recorded flood hydrograph. This graph is shown on Figure 5.12 where the recession constant for the fast runoff component is estimated at 50 hours.

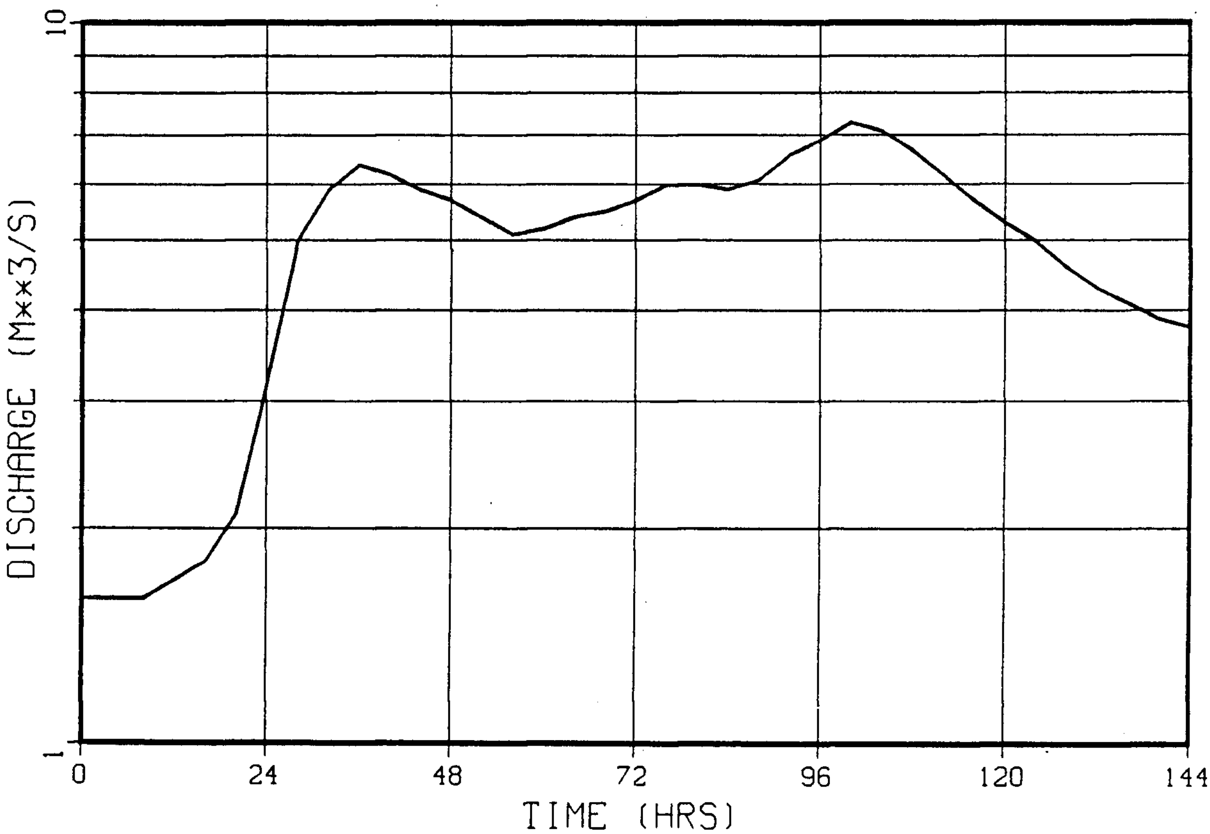


Figure 5.12. Semi-Log Plot of Rain-on-Snow Hydrograph on Mann Creek

5.7.3.3 **Application of Lag and Route Hydrograph Model**

Lag and route hydrograph procedures are applied to Mann Creek for the February 3-8, 1951 flood event to examine whether the model can be adopted for rain-on-snow and to compare basin storage characteristics to those for a rainfall-only runoff event on the same watershed. Application of the lag and route hydrograph model to the rain-on-snow flood of February 3-8, 1951 proceeded as follows:

i) hourly rainfall data were obtained from the Hydrometeorological Log. As indicated in Table 5.5 rainfall was fairly uniform over the basin.

ii) snowmelt estimates provided by the U.S. Army Corps of Engineers (1955) were added to hourly rainfall data to produce the total input to the basin.

iii) detailed water balance calculations undertaken by the U.S. Army Corps of Engineers (1955) concluded that approximately all rain and snowmelt water inputs to the basin occurred in the fast component of runoff contributing to the flood hydrograph. Accordingly, no losses to groundwater were extracted from rain and snowmelt water inputs to the lag and route hydrograph model.

iv) a basin storage coefficient equal to 50 hours was applied for routing basin runoff through a single linear reservoir.

v) the lag and route hydrograph model was applied with the above input conditions and time-area runoff characteristics similar to those for rainfall-only.

Results of applying the lag and route hydrological model to the February 3-8, 1951 rain-on-snow flood on Mann Creek are shown on Figure 5.13. Results of hydrograph analysis indicate that rain-on-snow floods can be simulated using conventional lag and route procedures with water input to the basin taken as the sum of rainfall and snowmelt and with no losses to groundwater.

Comparison of storage coefficients on Mann Creek for the October 1950 rainfall flood and the February 1951 rain-on-snow event shows the coefficients differed by a factor of two. Even though evidence presented in Chapter 4 suggests basin response characteristics for rain-on-snow floods could approach conditions which exist in the absence of a snowpack, this does not occur on Mann Creek. Perhaps because the rain-on-snow flood is not a very extreme event, an internal drainage network did not form sufficiently to produce more terrain controlled runoff.

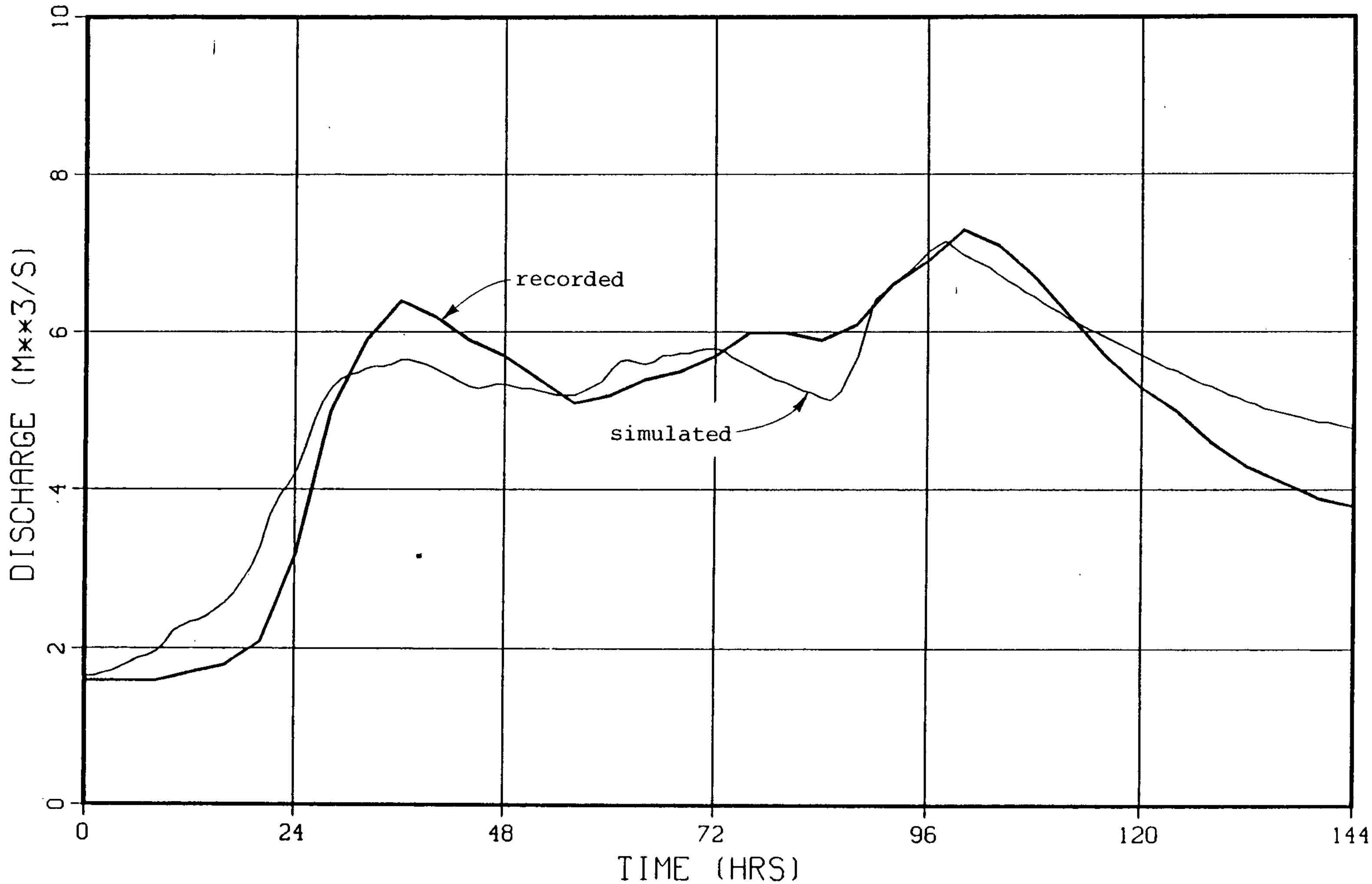


Figure 5.13. Simulated Rain-on-Snow Hydrograph on Mann Creek, February 3-8, 1951

5.8 ANALYSIS OF FLOOD HYDROGRAPH ON LOOKOUT CREEK

5.8.1 Basin Location

The Lookout Creek basin is located in the Cascade Mountains in Oregon approximately 10 km south of Mann Creek. Lookout Creek has a drainage area of 62.4 km^2 and extends from a continuously recording streamflow gauge at elevation 420 m to mountain peaks as high as elevation 1631 m. Basin topography is shown on Figure 5.14 at a scale of 1:62 500.

5.8.2 Rain-On-Snow Flood of December 21-24, 1964

5.8.2.1 Hydrometeorological Data

An extreme rain-on-snow flood event occurred on Lookout Creek and throughout the Coastal and Cascade Mountains in Oregon from December 21-24, 1964. During the flood event on Lookout Creek a snowpack existed over the entire basin and precipitation occurred as rain throughout the watershed. Climatological data are not measured directly within the drainage basin as was the case for research undertaken on Mann Creek. Therefore, climatological data for Lookout Creek must be inferred from recorded data at regional stations.

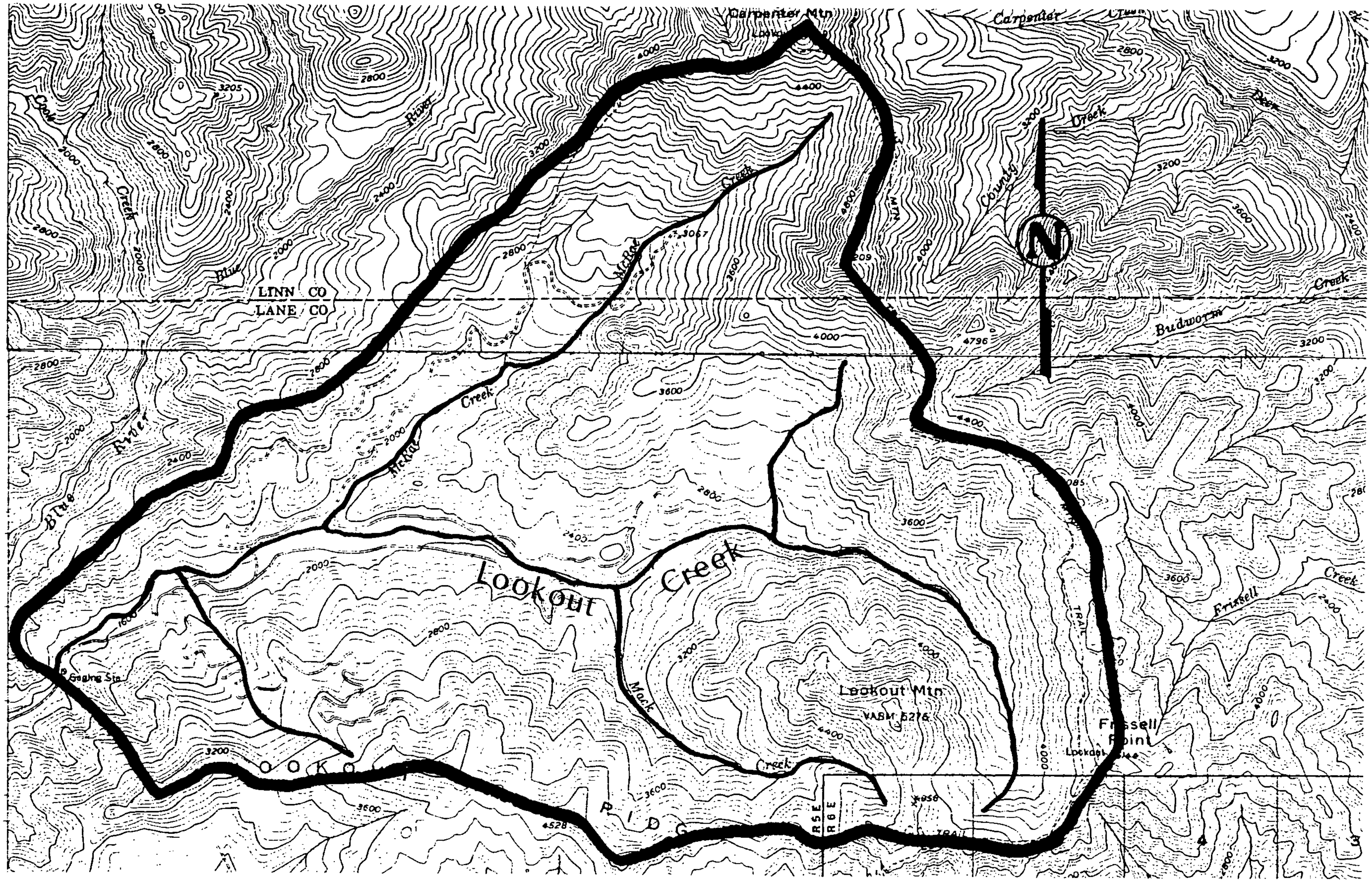


Figure 5.14. Lookout Creek Topography

Estimates of rainfall over the Lookout Creek basin require recorded rainfall from a local station and an assessment of rainfall variation with elevation. Hourly rainfall data are available for the storm period from a local station at McKenzie Bridge located approximately 3.5 km south of the watershed boundary. A summary of daily rainfall recorded at McKenzie Bridge is included in Table 5.9.

TABLE 5.9

RAINFALL AT MCKENZIE BRIDGE: DECEMBER 21-24, 1964

Gauge Location				Elevation	December Precipitation (mm)			
Latitude		Longitude		(m)	21	22	23	24
44	10	122	10	419	84	95	70	32

Hourly precipitation data are not available for the storm period at any regional stations at higher elevations than McKenzie Bridge and, therefore, elevation effects on storm rainfall cannot be assessed directly. Alternatively, comparison of precipitation recorded for the storm period to that for the entire month of December at lower elevation stations indicates precipitation varied in a similar manner between stations for both storm and longer duration monthly data. This result suggests that December monthly precipitation data recorded at stations higher in elevation than McKenzie Bridge could be used as an indicator of rainfall variation with elevation during the storm period. These results are shown in Table 5.10 and a plot of December precipitation versus elevation is shown on Figure 5.15.

TABLE 5.10

RAINFALL NEAR LOOKOUT CREEK BASIN

Station	Location Latitude		Location Longitude		Elev. (m)	Precipitation (mm) Dec. 21-26	Precipitation (mm) Dec.	Storm:Month
Marcola	44	10	122	51	162	255	535	0.48
Leaburg	44	06	122	41	206	-	512	-
Cascadia State Park	44	24	122	29	259	233	519	0.45
McKenzie Bridge	44	10	122	10	419	323	684	0.47
Belnap Springs	44	18	122	02	656	-	762	-
Santiam Pass	44	25	121	52	1448	-	882	-

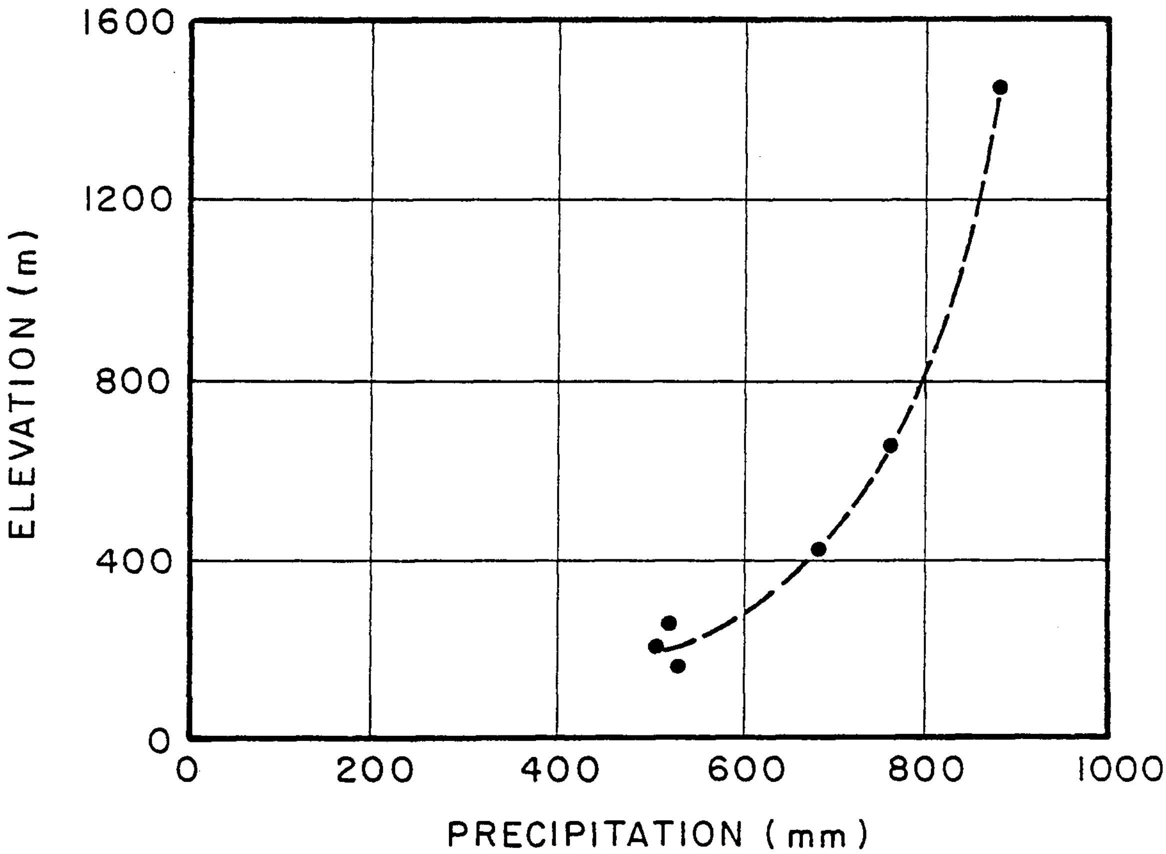


Figure 5.15. December 1964 Precipitation

Examination of recorded rainfall intensity data throughout the coastal region of Oregon (U.S. Army Corps of Engineers, 1966) showed the time distribution of storm rainfall had a similar pattern over large areas. Time distributions of precipitaiton recorded at McKenzie Bridge and at Cascadia located approximately 40 km to the northwest at elevation 259 m are shown on Figure 5.16.

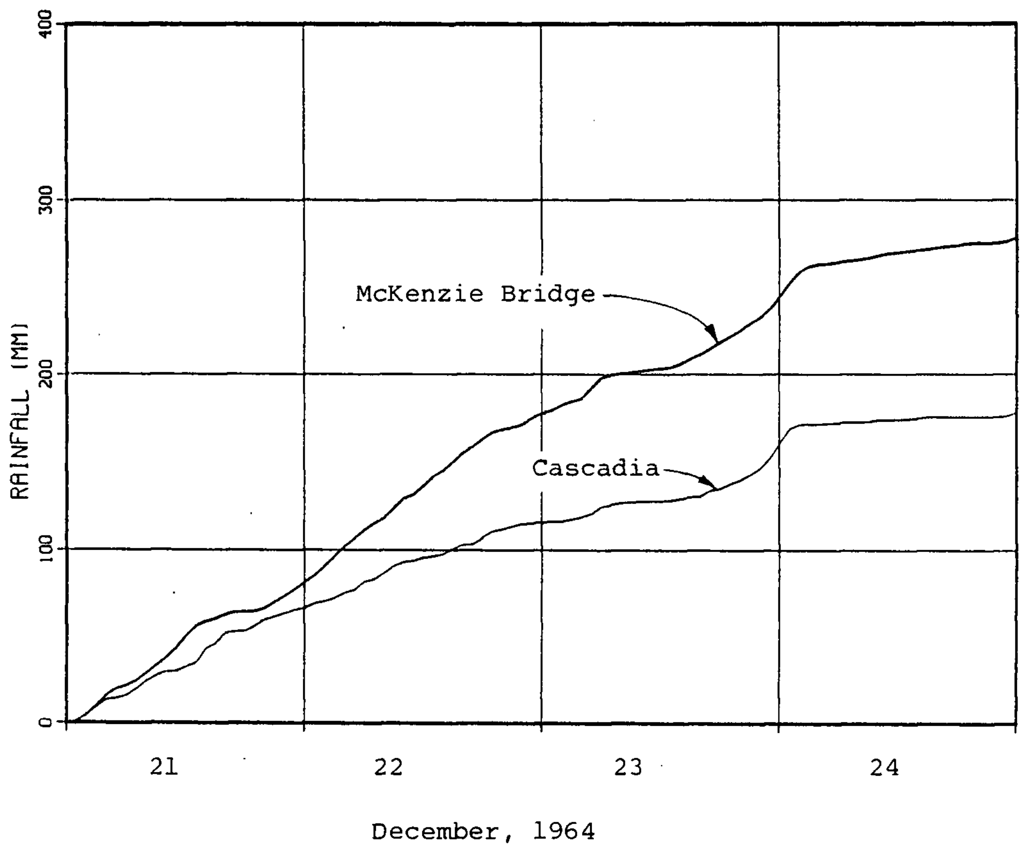


Figure 5.16. Time Distribution of Rainfall

A summary of air temperature recorded at McKenzie Bridge and at Santiam Pass located approximately 10 km northwest of Lookout Creek basin is included in Table 5.11 for the storm period. These data illustrate the relatively high temperatures which occurred during days with the largest rainfall.

TABLE 5.11

AIR TEMPERATURE (°C) NEAR LOOKOUT CREEK BASIN

Day	McKenzie Bridge (Elev. 419 m) Min.	Max.	Mean	Santiam Pass (Elev. 1448 m) Min.	Max.	Mean
Dec. 20	0	2	1.1	-4	-3	-3.6
Dec. 21	0	10	5.0	-3	6	1.1
Dec. 22	4	12	8.3	3	8	5.6
Dec. 23	7	11	8.3	0	6	3.1
Dec. 24	7	9	7.8	1	4	2.2
Dec. 25	0	7	3.3	-2	2	0.0

mean = (min + max)/2

Using air temperatures and precipitation for McKenzie Bridge and Santiam Pass, daily snowmelt estimates based on the U.S. Army Corps of Engineers equation for rain-on-snow (Eqn. 4.3) are presented in Table 5.12.

TABLE 5.12

SNOWMELT ESTIMATES FOR LOOKOUT CREEK

Day	Daily Snowmelt (mm) McKenzie Bridge (Elev. 419 m)	Santiam Pass (Elev. 1448 m)
Dec. 21	24	7
Dec. 22	39	29
Dec. 23	37	15
Dec. 24	31	10

The depletion of snowpack during the December storm period along the Cascade Range is evident from snow depth data compiled by the U.S. Army Corps of Engineers (1966) and the U.S. Weather Bureau (1965a). These data are included in Table 5.13. Corresponding water equivalent for the snow depths are not available.

TABLE 5.13

SNOW DEPTHS IN CASCADE RANGE: DECEMBER 1964

Station	Elevation (m)	Snow Depth (cm) Dec. 20	21	22	23	24	25
McKenzie Bridge	419	3	5	0	0	0	0
Belnap Springs	656	39	30	15	0	0	3
Government Camp	1189	140	114	51	15	10	25
Santiam Pass	1448	218	188	127	117	109	122
Odell Lake	1461	163	132	86	71	61	76
Crater Lake	1974	208	229	213	173	168	188

Recorded streamflow on Lookout Creek is available in a special publication compiled for the storm period by the U.S. Geological Survey (Waananen et al., 1971) to document flood flows throughout the region. The rain-on-snow flood hydrograph for December 21-24, 1964 is shown on Figure 5.17.

5.8.2.2 **Travel Time and Storage Coefficient**

Travel time of a water particle through the Lookout Creek basin for the extreme rain-on-snow flood of December 21-24, 1964 is undertaken considering that an internal drainage network has formed within the snowpack. For this case, delay between water inputs at the snow surface and transmission to the snowpack base is minimal. This assessment is consistent with observations and research studies by snow hydrologists for snowpack response to inputs of liquid water.

Travel time of a water particle through the watershed is based on estimates for channelized and overland flow velocities presented in Chapter 5.6.2. Flow velocities in watercourses identified on a 1:62 500 scale topography map are based on Manning's equation for open channel flow, and across other segments of the basin on estimates for overland flow. Travel time from various points in the Lookout Creek watershed to the basin outlet was determined based on slope, estimated roughness and whether or not flow was considered to be channelized. Details of the procedure are outlined for Mann Creek in Chapter 5.7.2.2. Results for Lookout Creek are shown on Figure 5.18 where isochrones illustrate the time-area runoff characteristics for the basin.

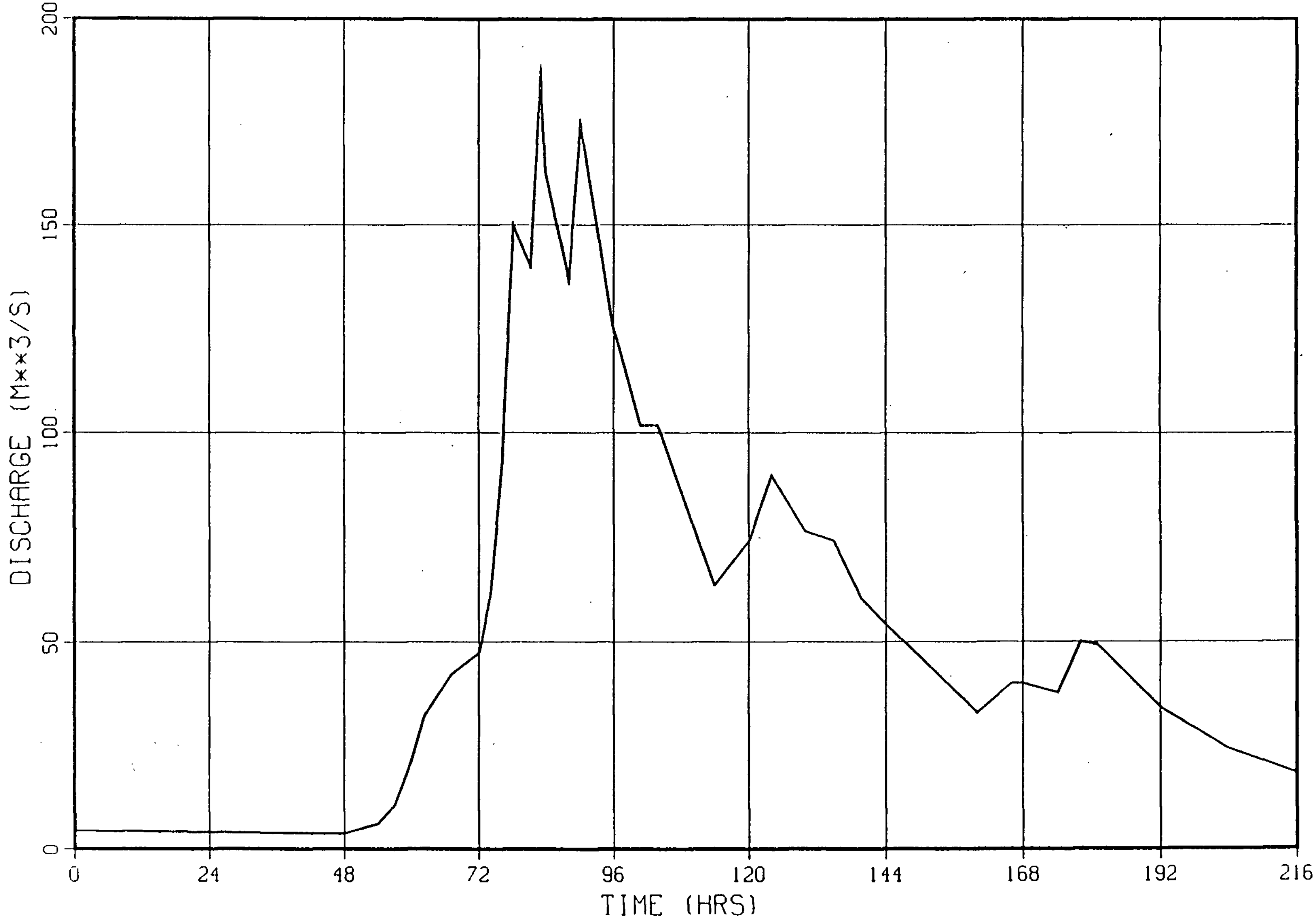


Figure 5.17. Rain-on-Snow Flood Hydrograph on Lookout Creek: December 19-27, 1964

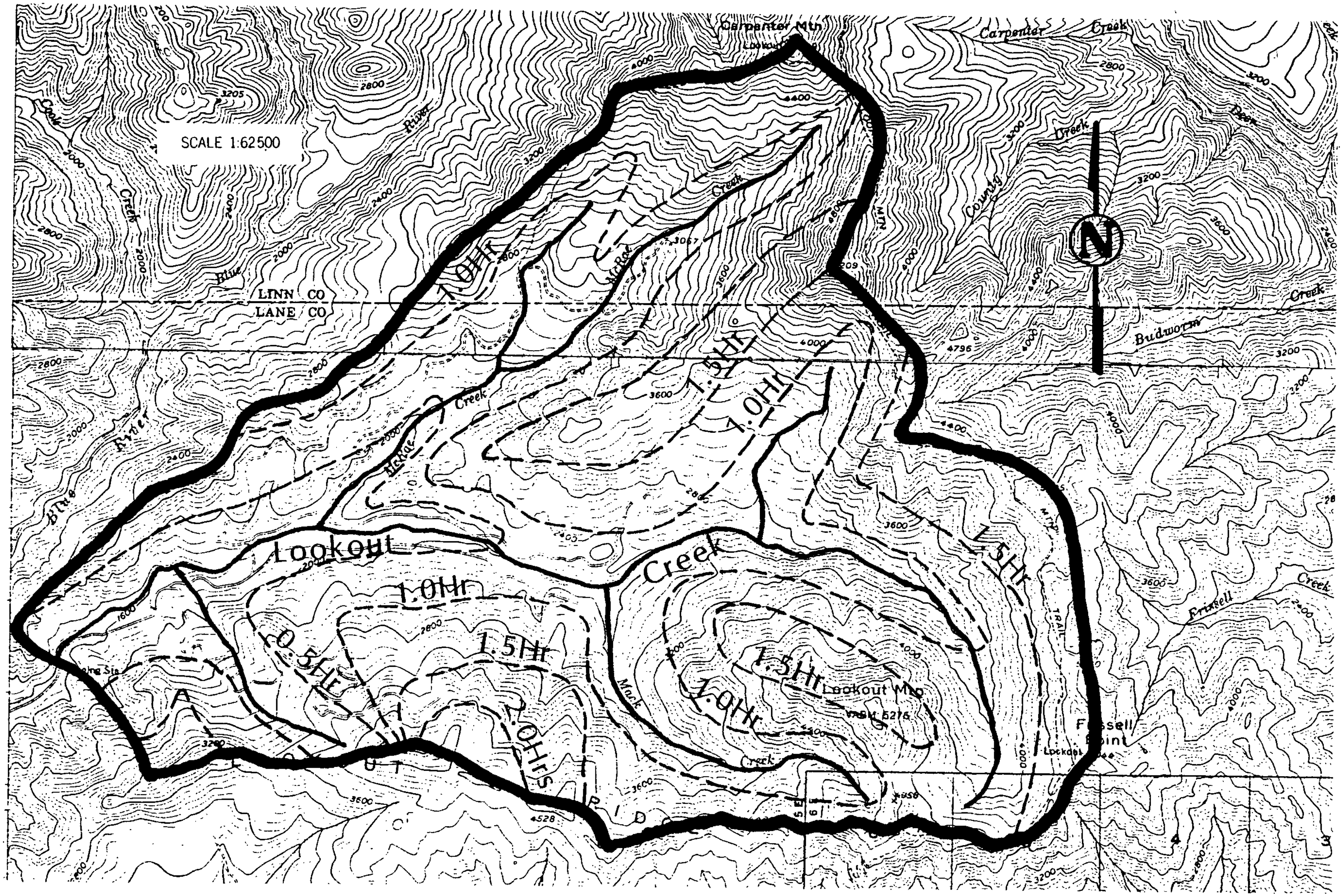


Figure 5.18. Lookout Creek Time-Area Graph

The storage coefficient for Lookout Creek during the December 21-24, 1964 rain-on-snow event was estimated from the recession curve slope on a semi-log plot of the recorded flood hydrograph. This graph is shown on Figure 5.19 where the recession constant for the fast runoff component is estimated at 20 hours.

5.8.2.3 **Application of Lag and Route Hydrograph Model**

Lag and route hydrograph procedures are applied to Lookout Creek for the December 21-24, 1964 flood event to undertake a second application of the model for rain-on-snow, and to analyze a more extreme flood than which occurred on Mann Creek. Application of the lag and route hydrograph model to the rain-on-snow flood of December 21-24, 1964 proceeded as follows:

i) hourly rainfall across the watershed was estimated based on recorded data at McKenzie Bridge and on the variation in rainfall with elevation shown on Figure 5.15.

ii) daily snowmelt was estimated from the U.S. Army Corps of Engineers equation (Eqn. 4.3) for rain-on-snow using recorded rainfall and air temperature data. Eqn. 4.3 was applied to Lookout Creek because it was developed from snow research studies in this region and because wind data are not available for use in other empirical formulas developed for snowmelt. Hourly distribution of daily snowmelt was

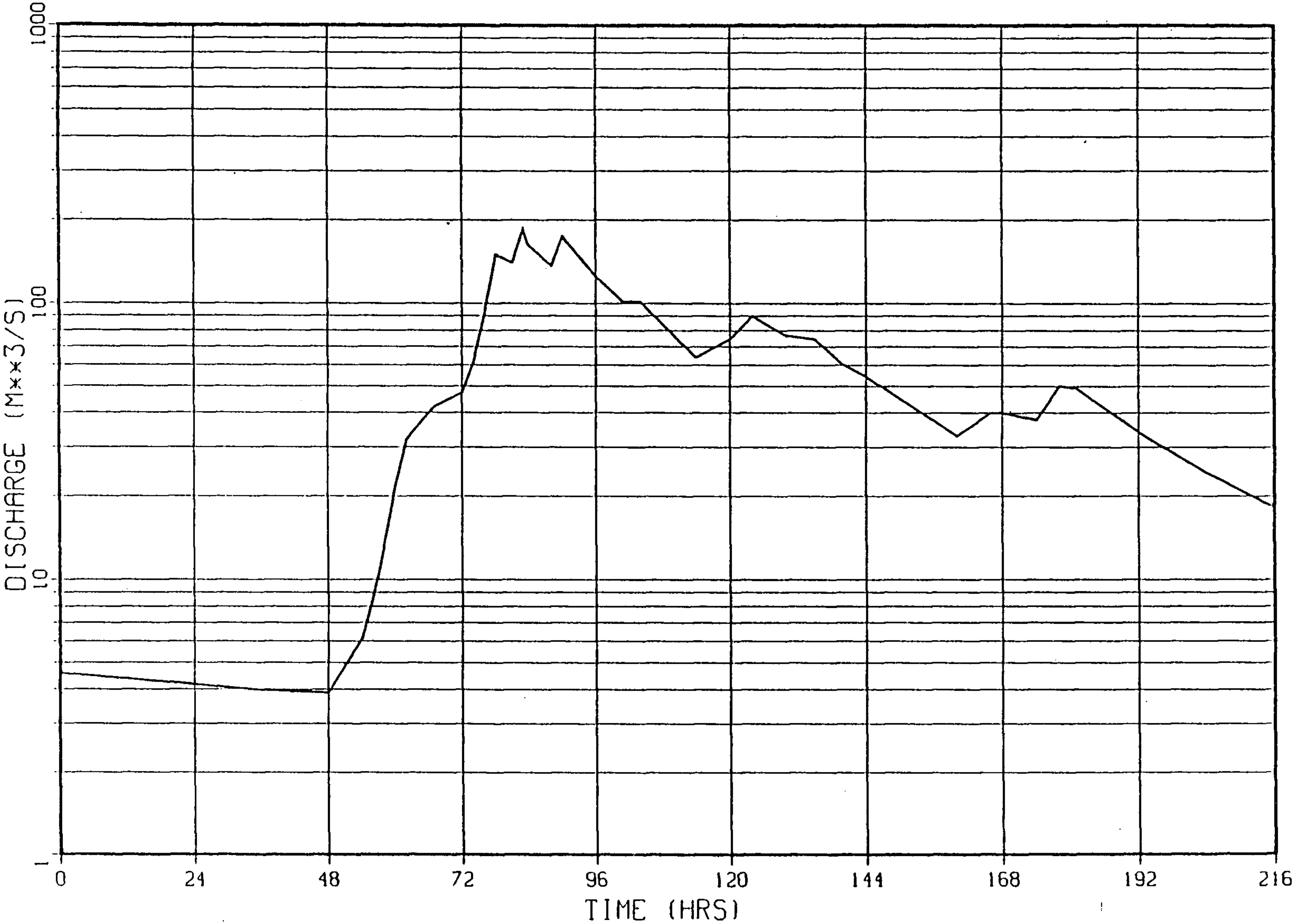


Figure 5.19. Semi-Log Plot of Rain-on-Snow Flood Hydrograph on Lookout Creek: December 19-27, 1964

simulated by a sine curve as proposed by Colbeck and Davidson (1973) during research studies in the northern Cascade Mountains in Washington state.

iii) hourly rainfall and snowmelt were added to produce the total hourly water input to the basin.

iv) no losses to groundwater were considered for water inputs to the Lookout Creek basin. This assessment was based on results of analysis of the rain-on-snow event on Mann Creek.

v) the lag and route hydrograph model was applied to the Lookout Creek basin with the above input data, the time-area graph for runoff response characteristics shown on Figure 5.18, and a storage coefficient of 20 hours.

Results of initial analysis are shown on Figure 5.20a. Preliminary examination of the simulated flood hydrograph shows the recorded flood peak is approximately 80 percent greater than that estimated by the model. Further comparison of simulated and flood hydrographs indicates that about 75 mm more runoff occurred on December 22 than was predicted based on recorded rainfall and snowmelt estimates.

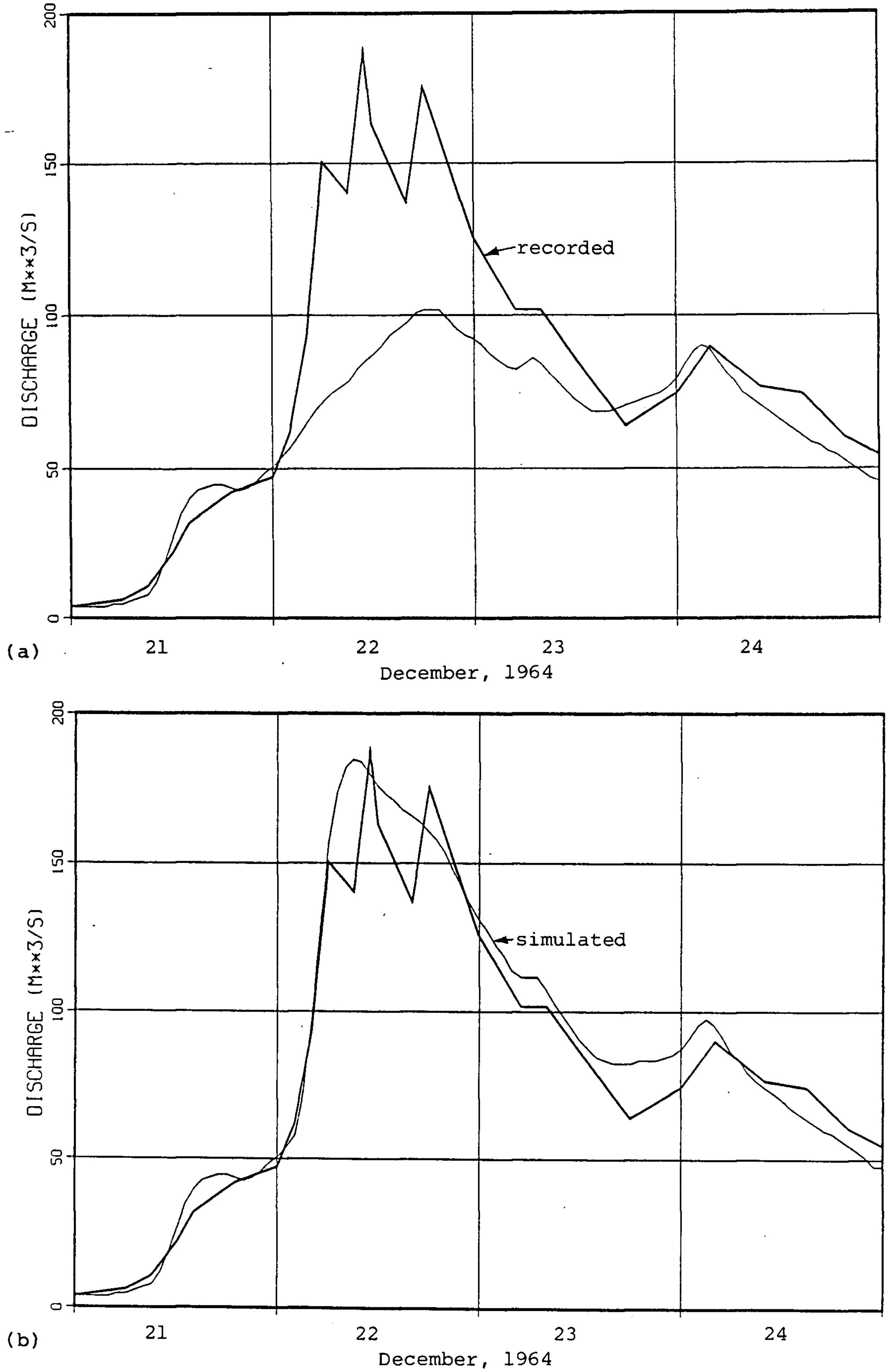


Figure 5.20. Simulated Rain-on-Snow Flood Hydrograph on Lookout Creek

Three possible explanations for the difference between recorded and simulated flood hydrographs are as follows:

i) since the December 21-24 flood event was the largest on record on Lookout Creek, streamflow estimates would be based on extrapolation of an existing stage-discharge curve. However, other basins in the coastal region of Oregon also experienced peak floods with similar unit discharges during this storm event. Therefore, the difference between recorded and simulated flows appears too great to be the result of measurement error alone.

ii) snow metamorphism causes an increase in snow grain sizes, and water percolation through coarse grained snow is faster than through more finely grained new snow. Since new snow fell on the basin prior to the December 21-24 flood, snow metamorphism would have occurred during the storm period. However, for this process to yield an additional 75 mm of runoff on December 22, water from snowmelt on previous days would have had to be in transit through the snowpack. Examination of recorded air temperature data prior to the storm suggests melt rates of the required magnitude would not occur.

iii) field measurements obtained by Beaudry and Golding (1983) showed that snow trapped by the forest canopy affects melt from a forested site. Even though some snow which occurred prior to the extreme rainfall could have been held by the canopy, it is unlikely that this potential source of melt could account for an additional 75 mm.

iv) initial snowmelt estimates using Eqn. 4.3 may be too low for the case of extreme rainfall combined with relatively high temperatures. Examination of snow depth data in Table 5.13 suggests melt rates were much greater than those predicted by the Corps of Engineers melt equation. Even though water equivalent data are not available, very conservative assumptions for snow density yield greater melt rates than those initially estimated for the basin. Calculations are shown in Table 5.14 for two reasonable estimates of snowpack density.

TABLE 5.14

SNOW DEPTHS AT SANTIAM PASS (Elev. 1448 m)

Dec. 18 snow depth (cm)	Dec. 18 water equiv. (mm)	Dec. 18-20 new snow (cm)	Dec. 18-20 water equiv. (mm)	Dec. 20 water equiv. (mm)	Dec. 22 snow depth (cm)	Dec. 22 water equiv. (mm)	Dec. 20-22 snow melt (mm)
137	453 (33%)	81	81 (10%)	534	127	419 (33%)	115
137	548 (40%)	81	162 (20%)	710	127	508 (40%)	202

Available evidence suggests that extreme rainfall combined with relatively high temperatures on Lookout Creek produced greater snowmelt than that predicted by the Corps of Engineers temperature-index equation developed in this region. Results from the lag and route hydrograph model are shown again on Figure 5.20b with water input on December 22 increased by 75 mm to correspond with recorded runoff. Even though climatic data for Lookout Creek are not as extensive as for a fully instrumented research watershed, available regional data indicates an increase in snowmelt more accurately represents basin conditions during the December flood.

Results of hydrograph analysis indicate that extreme rain-on-snow floods can be simulated using conventional lag and route procedures with water input to the basin taken as the sum of rainfall and snowmelt. However, results also indicate the importance of correctly estimating input rainfall and snowmelt to the hydrograph model. Estimation of input data on ungauged watersheds is often more difficult than estimating a storage coefficient and travel times for basin response.

5.9 DISCUSSION OF RESULTS

The primary goal of this study is to develop hydrograph procedures for estimation of extreme floods on ungauged watersheds where data are not available for model calibration. This goal is achieved by combining results from each of the Chapters presented in this thesis. Study components include assessment of flood producing mechanisms in the coastal region; analysis of rainfall characteristics for input to a hydrograph model; examination of the role of a snowpack during extreme floods; and application of a hydrograph model. To illustrate the continuity between study components, an overview of results from previous Chapters is included below with results from this Chapter.

The initial task required in the development of hydrograph procedures in the coastal region is to establish the flood producing mechanism which must be simulated. Floods in the coastal region are generally either snowmelt-induced in spring and summer or rainfall-induced in fall and winter. Rainfall-induced floods can result from rainfall-only or a combination of rain and snowmelt. In Chapter 2, historical flood records, flood frequency analyses, and atmospheric processes which affect climate in the coastal region are examined. It is shown that extreme floods on most basins in the coastal region are generated from rain-on-snow events.

In Chapter 3, development of hydrograph procedures for extreme rain-on-snow floods is initiated by analyzing characteristics of storm rainfall for input to a model. Estimation of input data to a hydrograph model is sometimes more difficult on an ungauged watershed than assessment of the response characteristics of the basin. Assessment of storm rainfall in coastal B.C. is especially difficult because the existing gauge network is relatively sparce and there is difficulty in transposing data in mountainous terrain because rainfall can vary over short distances in plan and elevation.

Because of the difficulty in estimating storm rainfall for hydrograph analysis in the mountainous coastal region, analysis is undertaken to investigate whether regional characteristics of storm rainfall can be identified even when the magnitude of rainfall varies between stations. Analyses undertaken in Chapter 3 show that regional rainfall characteristics can be identified for multi-storm intensity data available from Atmospheric Environment Service and for single storm distributions developed as part of this study. In practice, these results can be used to set limits on the range of hourly intensities that need to be considered by a design engineer in the absence of site data.

The next step in developing hydrograph procedures for rain-on-snow floods is to assess the role of a snowpack with regard to its effect on runoff response from the basin. This assessment is undertaken in Chapter 4 to establish the routing mechanism which must be simulated by a hydrograph model. Examination of available literature in snow hydrology conducted in this study suggests that development of an internal drainage network within the snowpack, not water percolation, is the dominant routing mechanism during extreme rain-on-snow floods.

Chapter 5 examines the application of a hydrograph model to extreme rain-on-snow floods. Procedures are developed for hydrograph analysis based on the assessment of snowpack routing characteristics in Chapter 4. The assessment of snowpack response to extreme rainfall is critical because once the routing mechanism is established then any model capable of simulating the runoff process can be applied. For reasons discussed in Sections 5.1 and 5.3, this study develops procedures for application of a lag and route hydrograph model to extreme rain-on-snow floods.

Preliminary results from application of a lag and route model on Mann and Lookout Creeks suggest that this hydrograph procedure can be applied to estimate extreme rain-on-snow floods when the following methodology is adopted:

(i) estimate travel time through the basin based on channelized and overland flow considerations, without any additional time increment for water transmission through the snowpack.

(ii) select the storage coefficient which simulates basin response.

(iii) specify water inputs to the basin as the sum of rainfall and snowmelt.

(iv) consider there are no water losses to groundwater.

It can be concluded from examination of the above methods that rain-on-snow produces the most extreme flood peaks on a basin because of the relatively large water inputs available for runoff, rather than because of changes in basin response characteristics that can be attributed to a snowpack. Once an internal drainage network forms, the major role of a snowpack is to contribute snowmelt. Also, during extreme events most rainfall and snowmelt inputs to the basin occur in the fast component of runoff that produces the flood peak because losses to groundwater are relatively small in comparison.

One topic for additional research in the development of lag and route hydrograph procedures is to examine methods for estimating storage coefficients for use on ungauged watersheds. Two questions arise for selection of a storage coefficient for extreme rain-on-snow floods. First, how does the storage coefficient for rain-on-snow floods compare on the same basin with rainfall-only floods; and secondly, can storage coefficients be estimated from physical characteristics of the basin which can be readily identified on topographic maps. These concerns are discussed below based on snowpack response to inputs of liquid water and results from application in this study of the lag and route model, and an outline for a follow-up study to this investigation is presented.

Snow hydrologists have concluded (Colbeck et al., 1979) that development of flow channels during snow metamorphism causes a snowcovered watershed to undergo a transition from snow-controlled to terrain-controlled water movement. This conclusion suggests that during snow metamorphism and channel development, basin response would also undergo a transition and approach runoff characteristics that exist in the absence of a snowpack. This occurrence is not evident for Mann Creek where basin storage coefficients were 23 and 50 hours for a rainfall-only and rain-on-snow flood, respectively. However, the rain-on-snow flood on Mann Creek is not a very extreme event and perhaps runoff is still partly snow-controlled. It is worth noting that the basin storage coefficient of 20 hours on Lookout Creek during the December 1964 flood is similar to that on Mann Creek for rainfall-only. In addition, six other mountainous watersheds in Oregon ranging in drainage area from 16 to 141 km^2 had storage coefficients of 6 to 20 hours during the extreme rain-on-snow flood in December 1964. These storage coefficent values may signify that sufficient channel development had occurred during the extreme event such that basin response approached conditions similar to rainfall-only.

Further assessment of storage coefficients can be undertaken by examining the recession curves of recorded extreme rain-on-snow floods from throughout the coastal hydrologic region in Oregon, Washington, British Columbia and Alaska. Analysis can be undertaken to develop functional relationships between storage coefficients calculated from recorded hydrographs and basin characteristics such as basin length, slope and drainage area. A similar approach has been adopted for unit hydrograph procedures for rainfall floods where data from various researchers have been combined (Watt and Chow, 1985) to produce a relationship between basin lag and basin length and slope. Until further research is undertaken, it is recommended that storage coefficients calculated in this study from recorded extreme rain-on-snow floods be adopted for use with lag and route hydrograph procedures.

A second topic for further research based on the results of this study is a re-examination of snowmelt equations. Preliminary evidence from application of lag and route hydrograph procedures to Lookout Creek suggests that during this extreme rain-on-snow event, snowmelt was much greater than predicted by the Corps of Engineers equation developed in this region for forested areas. It is likely that temperature-index equations, such as developed by the Corps of Engineers, will continue to be applied to ungauged mountainous watersheds because estimates of wind and other climatic data are seldom available for use in alternative melt equations. Since input data to a hydrograph model are very important, snowmelt occurring during the special case of extreme rain-on-snow is highlighted as an important topic for further analysis in the development of procedures for estimating extreme rain-on-snow floods.

In conclusion, study components presented in this thesis examine the characteristics of extreme floods in the coastal hydrologic region; provide regional characteristics of storm rainfall for estimating input data to a hydrograph model; and examine the application of lag and route procedures to extreme rain-on-snow floods. It is hoped that extreme rain-on-snow events will be analyzed further in British Columbia as data becomes available. Recently installed Data Collection Platforms (DCP's) by B.C. Hydro and the B.C. Ministry of Highways provide a source of rainfall and streamflow data at high elevations which has previously been unavailable.

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APPENDIX I

MAXIMUM FLOODS ON RECORD IN COASTAL BRITISH COLUMBIA AND SOUTHEAST ALASKA

TABLE 1.1

MAXIMUM FLOODS ON RECORD IN COASTAL BRITISH COLUMBIA

Station Number	Station	Drainage Area(A) (sq km)	Flood Regimes: Spring/ Summer	Flood Regimes: Fall/ Winter	Maximum Daily Discharge on Record: No. of Years of Record	Date	Discharge(Q) m^3/s	Q/A $(m^3/s)/km^2$	Maximum Instantaneous Discharge on Record: No. of Years of Record	Date	Peak Discharge(Q_p) m^3/s	Daily Discharge(Q) m^3/s	$\frac{Q_p}{Q}$
08MH104	Anderson Creek at the mouth	27.2		X	17	17 Dec 1971	17.2	0.63	NA				
08FB006	Atnarko River near the mouth	2430	X	X	18	24 Jan 1968	289	0.12	18	29 Jan 1968	340	289	1.18
08DC006	Bear River above Bitter Creek	350	X	X	16	8 Oct 1974	225	0.64	15	8 Oct 1974	271	225	1.20
08FB007	Bella Coola River above Burnt Creek Bridge	3730	X	X	18	23 Jan 1968	703	0.19	17	23 Jan 1968	828	703	1.18
08FB002	Bella Coola near HagensBorg	4040	X	X	21	24 Jan 1968	963	0.24	NA				
08HA016	Bings Creek near the mouth	15.5		X	19	14 Jan 1968	14.8	0.95	NA				
08HD001	Campbell River at outlet of Campbell Lake	1400		X	38	16 Nov 1939	858	0.61	NA				
08HB048	Carnation Creek at the mouth	10.1		X	10	26 Dec 1980	21.6	2.14	10	23 Jan 1982	50.0	13.7	3.65
08GA060	Chapman Creek above Sechelt Diversion	64.5		X	13	31 Oct 1981	78.8	1.22	13	31 Oct 1981	148	78.8	1.88
08GA046	Chapman Creek near Wilson Creek	71.5		X	11	13 Oct 1962	193	2.70	NA				
08GA024	Cheakamus River near Mons	287	X	X	23	19 Oct 1940	197	0.69	21	19 Oct 1940	257	197	1.30
08HA001	Cheakamus River near Westholme	355		X	30	26 Dec 1980	457	1.29	NA				
08MH103	Chilliwack River above Slesse Creek	645	X	X	20	26 Dec 1980	262	0.41	20	26 Dec 1980	387	262	1.48
08EG012	Exchamsiks River near Terrace	370		X	21	15 Oct 1974	572	1.55	20	1 Nov 1978	864	530	1.63
08CG006	Forrest Kerr Creek above 460 m contour	311	X	X	11	8 Sep 1981	254	0.82	11	8 Sep 1981	262	254	1.03
08HB003	Haslam Creek near Cassidy	95.6		X	13	4 Nov 1955	65.1	0.68	5	29 Jan 1960	64.6	45.0	1.44
08FF002	Hirsch Creek Near the mouth	347		X	17	15 Oct 1974	566	1.63	17	15 Oct 1974	807	566	1.43
08CG001	Iskut River below Johnson River	9350	X	X	24	15 Oct 1961	6880	0.74	20	15 Oct 1961	7930	6880	1.15
08CG004	Iskut River above Snippaker Creek	7230	X	X	16	9 Sep 1981	2080	0.29	16	9 Oct 1974	2520	2000	1.26
08MH108	Jacobs Creek above Jacobs Lake	12.2		X	14	19 Jan 1968	19.8	1.62	14	17 Sep 1968	24.6	5.4	4.52

TABLE 1.1

MAXIMUM FLOODS ON RECORD IN COASTAL BRITISH COLUMBIA

Station Number	Station	Drainage Area(A) (sq km)	Flood Regimes: Spring/Summer	Flood Regimes: Fall/Winter	Maximum Daily Discharge on Record: No. of Years of Record	Date	Discharge(Q) m^3/s	Q/A $(m^3/s)/km^2$	Maximum Instantaneous Discharge on Record: No. of Years of Record	Date	Peak Discharge(Q_p) m^3/s	Daily Discharge(Q) m^3/s	$\frac{Q_p}{Q}$
08MH076	Kanaka Creek near Webster Corners	47.7		X	23	14 Dec 1979	86.2	1.81	22	14 Dec 1979	146	86.2	1.69
08FE003	Kemano River above Powerhouse Tailrace	583		X	10	15 Oct 1974	646	1.11	10	15 Oct 1974	889	646	1.38
08EB004	Kispiox River near Hazelton	1870	X	X	18	2 Nov 1978	595	0.32	2	2 Nov 1978	702	595	1.18
08FF001	Kitimat River below Hirsch Creek	1990		X	19	1 Nov 1978	2410	1.21	19	1 Nov 1978	3000	2410	1.24
08EF004	Kitseguecla River near Skeena Crossing	728	X	X	12	2 June1964	269	0.37	12	24 Oct 1966	603	229	2.63
08EG006	Kitsumkalum River near Terrace	2180	X	X	22	3 June 1936	883	0.41	18	3 June 1936	883	883	1.00
08HF001	Koksih River at Beaver Cove	290		X	14	31 Jan 1935	334	1.15	NA				
08HF003	Koksih River below Bonanza Creek	269		X	13	6 Feb 1963	134	0.50	11	5 Dec 1962	164	128	1.28
08HA003	Koksilah River at Cowichan Station	209		X	26	14 Dec 1979	212	1.01	NA				
08HB029	Little Qualicum River near Qualicum Beach	237		X	22	27 Dec 1980	166	0.70	21	27 Dec 1980	213	166	1.28
08HB004	Little Qualicum River at outlet of Cameron Lake	135		X	32	16 Jan 1961	189	1.40	NA				
08FF003	Little Wedeene River below Bowbyes Creek	188		X	17	1 Nov 1978	274	1.46	16	1 Nov 1978	382	274	1.39
08GA061	Mackay Creek at Montroyal Boulevard	3.63		X	10	31 Oct 1981	9.25	2.55	10	31 Oct 1981	16.2	9.25	1.75
08MH020	Mahood Creek near Sullivan	34.4		X	24	19 Jan 1968	28.3	0.82	NA				
08MH018	Mahood Creek near Newton	18.4		X	22	19 Jan 1968	25.0	1.36	NA				
08GA054	Mamquam River above Mashiter Creek	334		X	15	26 Dec 1980	270	0.81	15	26 Dec 1980	369	270	1.37
08GA057	Mashiter Creek near Squamish	38.9		X	10	26 Dec 1980	53.5	1.38	10	3 Nov 1975	121	44.2	2.74
08GD007	Mosley Creek near Dumbell Lake	1550	X		12	1 Sep 1967	254	0.16	7	1 Sep 1967	311	254	1.22
08MH129	Murray Creek at 216 Street Langley	26.2		X	14	3 Dec 1982	19.7	1.33	12	23 Jan 1982	49.2	14.0	3.51
08FC002	Nascall River near Ocean Falls	383		X	12	25 Oct 1947	886	2.31	5	25 Oct 1947	923	886	1.04

TABLE I.1

MAXIMUM FLOODS ON RECORD IN COASTAL BRITISH COLUMBIA

Station Number	Station	Drainage Area(A) (sq km)	Flood Regimes: Spring/ Summer	Flood Regimes: Fall/ Winter	Maximum Daily Discharge on Record: No. of Years of Record	Date	Discharge(Q) m^3/s	Q/A $(m^3/s)/km^2$	Maximum Instantaneous Discharge on Record: No. of Years of Record	Date	Peak Discharge(Q_p) m^3/s	Daily Discharge(Q) m^3/s	$\frac{Qp}{Q}$
08DB001	Nass River above Shumal Creek	19200	X	X	45	15 Oct 1961	9460	0.49	16	9 Oct 1974	8920	7670	1.16
08MH105	Nicomekl River below Murray Creek	64.5		X	17	19 Jan 1968	28.3	0.44	12	26 Dec 1972	35.4	21.9	1.62
08HF002	Nimpkish River near Englewood	1760		X	11	31 Dec 1926	1270	0.72	NA				
08GA052	Noons Creek near Port Moody	6.99		X	15	19 Nov 1962	17.6	2.52	NA				
08MH058	Norrish Creek near Dewdney	117		X	21	26 Nov 1963	214	1.83	21	26 Nov 1963	399	214	1.86
08MH006	North Alouette River at 232nd Street	37.3		X	25	23 Dec 1963	76.2	2.04	14	26 Dec 1980	118	64.6	1.83
08FB005	Nusatsum River near Hagensborg	269	X	X	17	27 Sep 1973	190	0.71	15	7 Nov 1978	206	120	1.72
080B002	Pallant Creek near Queen Charlotte	76.7		X	11	8 Oct 1974	93.4	1.22	11	15 Oct 1974	126	69.4	1.82
08GA023	Rubble Creek near Garibaldi	74.1		X	11	4 June 1955	48.1	0.65	NA				
08FB004	Salloomt River near Hagensborg	161		X	18	16 Dec 1980	141	0.88	17	16 Dec 1980	241	141	1.71
08HA010	San Juan River near Port Renfrew	580		X	23	26 Dec 1982	862	1.49	23	26 Dec 1982	1160	862	1.35
08HB014	Sarita River near Bamfield	162		X	31	29 Jan 1960	677	4.18	NA				
08MH056	Slesse Creek near Vedder Crossing	162	X	X	24	29 Apr 1959	72.2	0.45	22	7 Nov 1978	212	49.6	4.27
08GA064	Stawamus River Below Ray Creek	40.4		X	11	26 Dec 1980	64.4	1.59	11	26 Dec 1980	113	64.4	1.75
08MH029	Sumas River near Huntingdon	149		X	30	15 Feb 1982	47.4	0.32	27	15 Feb 1982	49.2	47.4	1.04

TABLE I.1

MAXIMUM FLOODS ON RECORD IN COASTAL BRITISH COLUMBIA

Station Number	Station	Drainage Area(A) (sq km)	Flood Regimes: Spring/ Summer	Flood Regimes: Fall/ Winter	Maximum Daily Discharge on Record: No. of Years of Record	Maximum Daily Discharge on Record: Date	Maximum Daily Discharge on Record: Discharge(Q) m^3/s	Maximum Daily Discharge on Record: Q/A $(m^3/s)/km^2$	Maximum Instantaneous Discharge on Record: No. of Years of Record	Maximum Instantaneous Discharge on Record: Date	Maximum Instantaneous Discharge on Record: Peak Discharge(Q_p) m^3/s	Maximum Instantaneous Discharge on Record: Daily Discharge(Q) m^3/s	$\frac{Qp}{Q}$
08MH033	Sweltzer River at Cultus Lake	65.0		X	10	12 Feb 1951	25.8	0.40	NA				
08HB024	Tsable River near Fanny Bay	113		x	23	15 Jan 1964	261	2.31	NA				
08HC002	Ucona River at the Mouth	185		x	23	19 Nov 1962	549	2.97	23	19 Nov 1962	1080	549	1.97
08DD001	Unuk River near Stewart	1480	X	X	17	8 Oct 1974	1000	0.68	16	9 Oct 1979	1230	591	2.08
08MH098	West Creek near Fort Langley	11.4		X	20	23 Dec 1963	12.8	1.12	12	26 Dec 1980	24.1	16.2	1.49
08OA002	Yakoun River near Port Clements	477		X	22	28 Nov 1963	612	1.28	15	27 Dec 1979	374	315	1.19
08MH097	Yorkson Creek near Walnut Grove	5.96		X	19	30 Jan 1965	5.10	0.86	NA				
08HE006	Zeballos River near Zeballos	181		X	22	13 Nov 1975	728	4.02	18	13 Nov 1975	1180	728	1.62
08EG011	Zymagotitz River near Terrace	376	X	X	23	15 Oct 1974	382	1.02	23	15 Oct 1974	549	382	1.44
08EF005	Zymoetz River above O.K. Creek	2980	X	X	20	1 Nov 1978	1980	0.66	20	1 Nov 1978	3140	1980	1.59
08EF003	Zymoetz River near Terrace	3080	X	X	13	31 Oct 1961	1050	0.34	NA				

TABLE 1.2

MAXIMUM FLOODS ON RECORD IN SOUTHEAST ALASKA

Station Number	Station	Drainage Area(A) (sq km)	Maximum Daily Discharge on Record: No. of Years of Record	Maximum Daily Discharge on Record: Water Year (Oct.-Sept.)	Maximum Daily Discharge on Record: Discharge(Q) m^3/s	Q/A $(m^3/s)/km^2$	Maximum Instantaneous Discharge on Record: No. of Years of Record	Date	Peak Discharge(Q_p) m^3/s	Daily Discharge(Q) m^3/s	$\frac{Q_p}{Q}$
15010000	Davis River near Hyder	207	10	1937	295	1.43	10	12 Nov 1936	552	295	1.87
15011500	Red River near Metlakatla	117	15	1977	240	2.05	15	3 Nov 1976	351	240	1.46
15012000	Winstanley Creek near Ketchikan	40.1	28	1962	80.1	2.00	30	30 Jan 1962	117	80.1	1.46
15022000	Harding River near Wrangell	175	31	1962	323	1.85	31	14 Oct 1961	425	323	1.32
15026000	Cascade Creek near Petersburg	59.6	38	1920	69.7	1.17	35	11 Sept 1947	92.7	56.6	1.64
1503100	Long River above Long Lake near Juneau	21.5	10	1968	42.5	1.98	10	28 Sept 1968	100	42.5	2.35
15034000	Long River near Juneau	84.2	32	1957	128	1.52	NA				
15036000	Speel River near Juneau	585	16	1961	898	1.54	17	27 Sept 1918	1008	566	1.81
15040000	Dorothy Creek near Juneau	39.4	35	1950	47.9	1.22	37	3 Nov 1949	50.4	47.9	1.05
15044000	Carlson Creek near Juneau	62.9	10	1954	98.8	1.57	10	12 Aug 1961	144	82.1	1.75
15048000	Sheep Creek near Juneau	11.8	29	1948	16.0	1.36	30	8 Sept 1948	23.8	16.0	1.49
15050000	Gold Creek at Juneau	25.3	38	1961	51.8	2.05	39	6 Sept 1981	76.5	27.8	2.75
15052000	Lemon Creek near Juneau	31.3	20	1961	75.3	2.41	22	13 Aug 1961	95.4	75.3	1.27
15052500	Mendenhall River near Auke Bay	220	17	1981	388	1.76	17	8 Sept 1981	481	388	1.24
15052800	Montana Creek near Auke Bay	40.1	10	1970	38.2	0.95	10	23 Aug 1966	54.4	25.5	2.13
15053800	Lake Creek at Auke Bay	6.5	10	1966	14.0	2.15	10	23 Aug 1966	27.8	14.0	1.99
15054000	Auke Creek at Auke Bay	10.3	13	1970	5.9	0.57	NA				
15056100	Skagway River at Skagway	376	19	1967	275	0.73	19	7 Sept 1981	464	237	1.96
15056200	West Creek near Skagway	112	15	1967	201	1.79	16	15 Sept 1967	278	201	1.38
15059500	Whipple Creek near Ward Cove	13.7	12	1969	23.9	1.74	12	19 Nov 1968	80.1	23.9	3.35
15060000	Perseverance Creek near Wacker	7.3	30	1950	13.5	1.85	31	18 Oct 1964	19.3	10.1	1.91
15068000	Mahoney Creek near Ketchikan	14.8	22	1923	43.0	2.91	22	2 Feb 1954	71.6	30.9	2.32
15070000	Falls Creek near Ketchikan	94.5	28	1959	110	1.16	28	1 Nov 1917	158	51.0	3.10
15072000	Fish Creek near Ketchikan	83.1	64	1920	149	1.79	63	15 Oct 1961	153	125	1.22
15074000	Ella Creek near ketchikan	51.0	22	1955	41.3	0.81	22	7 Dec 1930	48.7	40.2	1.21
15076000	Manzanita Creek near Ketchikan	87.8	30	1962	110	1.25	30	14 Oct 1961	165	110	1.50
15078000	Grace Creek near Ketchikan	78.2	16	1965	85.2	1.09	16	4 Sept 1966	113	79.6	1.42
15080000	Orchard Creek near Bell Island	153	12	1920	164	1.07	11	1 Nov 1917	201	62.3	3.23

TABLE 1.2

MAXIMUM FLOODS ON RECORD IN SOUTHEAST ALASKA

Station Number	Station	Drainage Area(A) (sq km)	Maximum Daily Discharge on Record: No. of Years of Record	Maximum Daily Discharge on Record: Water Year (Oct.-Sept.)	Maximum Daily Discharge on Record: Discharge(Q) m^3/s	Q/A $(m^3/s)/km^2$	Maximum Instantaneous Discharge on Record: No. of Years of Record	Maximum Instantaneous Discharge on Record: Date	Maximum Instantaneous Discharge on Record: Peak Discharge(Q_p) m^3/s	Maximum Instantaneous Discharge on Record: Daily Discharge(Q) m^3/s	$\frac{Qp}{Q}$
15081500	Stanley Creek near Craig	134	17	1973	239	1.78	17	18 Oct 1964	442	143	3.09
15085100	Old Tom Creek near Kasaan	15.3	32	1952	19.0	1.24	32	21 Nov 1979	31.4	15.4	2.04
15085600	Indian Creek near Hollis	22.8	15	1963	60.3	2.64	13	13 Oct 1961	170	46.7	3.64
15085700	Harris River near Hollis	74.3	14	1962	145	1.95	15	5 Dec 1959	250	144	1.74
15085800	Maybeso Creek at Hollis	39.1	14	1963	85.0	2.17	14	14 Oct 1961	107	61.4	1.74
15086600	Big Creek near Point Baker	29.0	18	1966	38.5	1.33	18	3 Sept 1966	41.1	38.5	1.07
15088000	Sawmill Creek near Sitka	101	26	1952	141	1.40	20	14 Sept 1952	181	141	1.28
15093400	Sashin Creek near Big Port Walter	9.6	14	1977	36.8	3.83	14	2 Nov 1976	75.0	36.8	2.04
15094000	Deer Lake Outlet near Port Alexander	19.2	16	1963	26.7	1.39	16	14 Dec 1962	31.7	26.7	1.19
15098000	Baranof River at Baranof	82.9	29	1922	103	1.24	25	6 Oct 1972	255	70.8	3.60
15010000	Takatz Creek near Baranof	45.3	18	1968	45.6	1.01	18	28 Sept 1968	49.6	45.6	1.09
15102000	Hasselborg Creek near Angoon	146	17	1954	62.9	0.43	17	23 Oct 1953	68.0	62.9	1.08
15106920	Kadashan River above Hook Creek near Tenakee	26.4	12	1973	25.5	0.97	12	15 Sept 1976	52.4	16.1	3.25
15106940	Hook Creek above Tr near Tenakee	11.6	13	1979	20.2	1.74	13	15 Sept 1976	36.5	9.1	4.01
15106960	Hook Creek near Tenakee	20.7	13	1979	25.6	1.24	13	5 Oct 1979	43.0	25.6	1.68
15106980	Tonalite Creek near Tenakee	37.6	14	1979	64.3	1.71	14	9 Oct 1979	102	40.8	2.50
15107000	Kadashan River near Tenakee	97.6	15	1979	127	1.30	NA				
15108000	Pavlof River near Tenakee	62.9	24	1979	95.4	1.52	24	30 Oct 1978	131	95.4	1.37
15109000	Fish Creek near Auke Bay	35.2	20	1960	33.1	0.94	20	2 Oct 1961	60.0	18.1	3.31

APPENDIX II

DEPTH-DURATION-FREQUENCY DATA FOR THE BRITISH COLUMBIA COASTAL REGION

TABLE II. 1

DEPTH-DURATION-FREQUENCY DATA FOR ABBOTSFORD A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.8	18.7	22.6	27.6	31.3	35.0
2 HR	18.5	24.8	29.1	34.4	38.4	42.3
6 HR	35.6	40.3	43.5	47.5	50.5	53.4
12 HR	49.2	58.3	64.3	72.0	77.6	83.3
24 HR	61.7	77.8	88.3	101.8	111.6	121.4

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.21	0.24	0.26	0.27	0.28	0.29
2 HR	0.30	0.32	0.33	0.34	0.34	0.35
6 HR	0.58	0.52	0.49	0.47	0.45	0.44
12 HR	0.80	0.75	0.73	0.71	0.70	0.69
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.56	0.83	1.00	1.22	1.38	1.54
2 HR	0.64	0.85	1.00	1.18	1.32	1.45
6 HR	0.82	0.93	1.00	1.09	1.16	1.23
12 HR	0.76	0.91	1.00	1.12	1.21	1.29
24 HR	0.70	0.88	1.00	1.15	1.26	1.37

TABLE II. 2

DEPTH-DURATION-FREQUENCY DATA FOR AGASSIZ CDA

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.8	13.1	14.6	16.5	17.9	19.3
2 HR	16.3	18.6	20.2	22.1	23.5	25.0
6 HR	32.5	36.3	38.8	42.0	44.4	46.7
12 HR	50.0	57.2	62.0	68.2	72.7	77.2
24 HR	73.0	88.6	98.9	111.8	121.4	131.0

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.15	0.15	0.15	0.15	0.15	0.15
2 HR	0.22	0.21	0.20	0.20	0.19	0.19
6 HR	0.45	0.41	0.39	0.38	0.37	0.36
12 HR	0.69	0.65	0.63	0.61	0.60	0.59
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.74	0.90	1.00	1.13	1.23	1.32
2 HR	0.81	0.92	1.00	1.10	1.17	1.24
6 HR	0.84	0.94	1.00	1.08	1.14	1.20
12 HR	0.81	0.92	1.00	1.10	1.17	1.24
24 HR	0.74	0.90	1.00	1.13	1.23	1.33

TABLE II. 3

DEPTH-DURATION-FREQUENCY DATA FOR ALOUETTE LAKE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.3	14.4	15.8	17.6	18.9	20.3
2 HR	20.2	24.1	26.7	30.0	32.4	34.9
6 HR	44.9	49.1	51.8	55.4	58.0	60.5
12 HR	70.0	81.7	89.6	99.5	106.8	114.1
24 HR	97.7	117.6	130.8	147.6	159.8	172.1

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.12	0.12	0.12	0.12	0.12
2 HR	0.21	0.20	0.20	0.20	0.20	0.20
6 HR	0.46	0.42	0.40	0.38	0.36	0.35
12 HR	0.72	0.69	0.69	0.67	0.67	0.66
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.77	0.91	1.00	1.11	1.20	1.28
2 HR	0.76	0.90	1.00	1.12	1.21	1.31
6 HR	0.87	0.95	1.00	1.07	1.12	1.17
12 HR	0.78	0.91	1.00	1.11	1.19	1.27
24 HR	0.75	0.90	1.00	1.13	1.22	1.32

TABLE II. 4

DEPTH-DURATION-FREQUENCY DATA FOR ALTA LAKE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	7.0	8.2	9.0	10.0	10.8	11.5
2 HR	11.0	12.6	13.6	14.9	15.9	16.8
6 HR	20.0	23.4	25.7	28.6	30.7	32.8
12 HR	29.5	36.5	41.0	46.9	51.2	55.6
24 HR	43.0	56.2	64.8	75.8	84.0	92.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.16	0.15	0.14	0.13	0.13	0.13
2 HR	0.26	0.22	0.21	0.20	0.19	0.18
6 HR	0.47	0.42	0.40	0.38	0.36	0.36
12 HR	0.69	0.65	0.63	0.62	0.61	0.60
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.78	0.91	1.00	1.11	1.19	1.28
2 HR	0.81	0.92	1.00	1.10	1.17	1.24
6 HR	0.78	0.91	1.00	1.11	1.19	1.28
12 HR	0.72	0.89	1.00	1.14	1.25	1.35
24 HR	0.66	0.87	1.00	1.17	1.30	1.42

TABLE II. 5

DEPTH-DURATION-FREQUENCY DATA FOR BEAR CREEK

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	23.7	36.4	44.8	55.4	63.3	71.1
2 HR	35.4	48.1	56.6	67.3	75.2	83.1
6 HR	63.8	82.0	94.1	109.3	120.5	131.8
12 HR	88.9	120.6	141.5	168.0	187.6	207.0
24 HR	141.8	205.2	247.2	300.2	339.4	378.5

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.17	0.18	0.18	0.18	0.19	0.19
2 HR	0.25	0.23	0.23	0.22	0.22	0.22
6 HR	0.45	0.40	0.38	0.36	0.36	0.35
12 HR	0.63	0.59	0.57	0.56	0.55	0.55
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.53	0.81	1.00	1.24	1.41	1.59
2 HR	0.62	0.85	1.00	1.19	1.33	1.47
6 HR	0.68	0.87	1.00	1.16	1.28	1.40
12 HR	0.63	0.85	1.00	1.19	1.33	1.46
24 HR	0.57	0.83	1.00	1.21	1.37	1.53

TABLE II. 6

DEPTH-DURATION-FREQUENCY DATA FOR BELLA COOLA BC HYDRO

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.6	13.0	14.6	16.6	18.1	19.6
2 HR	17.4	22.3	25.6	29.7	32.7	35.7
6 HR	36.7	47.7	55.0	64.2	71.0	77.8
12 HR	59.6	76.8	88.2	102.6	113.3	123.8
24 HR	88.3	113.8	130.6	151.9	167.5	183.1

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.12	0.11	0.11	0.11	0.11	0.11
2 HR	0.20	0.20	0.20	0.20	0.20	0.19
6 HR	0.42	0.42	0.42	0.42	0.42	0.42
12 HR	0.68	0.68	0.68	0.68	0.68	0.68
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.73	0.89	1.00	1.14	1.24	1.34
2 HR	0.68	0.87	1.00	1.16	1.28	1.40
6 HR	0.67	0.87	1.00	1.17	1.29	1.41
12 HR	0.68	0.87	1.00	1.16	1.28	1.40
24 HR	0.68	0.87	1.00	1.16	1.28	1.40

TABLE II. 7

DEPTH-DURATION-FREQUENCY DATA FOR BUNTZEN LAKE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	14.5	18.6	21.3	24.8	27.3	29.8
2 HR	23.1	28.6	32.3	36.9	40.3	43.7
6 HR	50.0	61.0	68.4	77.6	84.5	91.3
12 HR	75.4	99.1	115.0	134.8	149.5	164.3
24 HR	111.4	151.0	177.4	210.5	235.2	259.7

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.12	0.12	0.12	0.12	0.11
2 HR	0.21	0.19	0.18	0.18	0.17	0.17
6 HR	0.45	0.40	0.39	0.37	0.36	0.35
12 HR	0.68	0.66	0.65	0.64	0.64	0.63
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.68	0.87	1.00	1.16	1.28	1.40
2 HR	0.72	0.89	1.00	1.14	1.25	1.35
6 HR	0.73	0.89	1.00	1.14	1.24	1.34
12 HR	0.66	0.86	1.00	1.17	1.30	1.43
24 HR	0.63	0.85	1.00	1.19	1.33	1.46

TABLE II. 8

DEPTH-DURATION-FREQUENCY DATA FOR BURNABY MTN BCHPA

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.0	13.3	14.8	16.7	18.1	19.5
2 HR	17.8	20.1	21.5	23.4	24.8	26.2
6 HR	37.4	42.7	46.3	50.7	54.0	57.2
12 HR	54.4	63.8	70.1	77.9	83.8	89.6
24 HR	75.1	89.8	99.6	111.8	121.0	129.8

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.15	0.15	0.15	0.15	0.15	0.15
2 HR	0.24	0.22	0.22	0.21	0.21	0.20
6 HR	0.50	0.48	0.46	0.45	0.45	0.44
12 HR	0.72	0.71	0.70	0.70	0.69	0.69
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.75	0.90	1.00	1.13	1.22	1.32
2 HR	0.83	0.93	1.00	1.09	1.15	1.22
6 HR	0.81	0.92	1.00	1.10	1.17	1.24
12 HR	0.78	0.91	1.00	1.11	1.20	1.28
24 HR	0.75	0.90	1.00	1.12	1.21	1.30

TABLE II. 9

DEPTH-DURATION-FREQUENCY DATA FOR CAMPBELL RIVER BCFS

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.7	13.9	15.9	18.6	20.6	22.5
2 HR	15.9	19.0	21.2	23.8	25.8	27.8
6 HR	30.8	37.0	41.2	46.3	50.2	54.0
12 HR	41.3	48.5	53.3	59.3	63.8	68.3
24 HR	54.0	65.3	73.0	82.6	89.8	96.7

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.20	0.21	0.22	0.23	0.23	0.23
2 HR	0.29	0.29	0.29	0.29	0.29	0.29
6 HR	0.57	0.57	0.56	0.56	0.56	0.56
12 HR	0.76	0.74	0.73	0.72	0.71	0.71
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.67	0.87	1.00	1.17	1.29	1.41
2 HR	0.75	0.90	1.00	1.13	1.22	1.31
6 HR	0.75	0.90	1.00	1.13	1.22	1.31
12 HR	0.77	0.91	1.00	1.11	1.20	1.28
24 HR	0.74	0.89	1.00	1.13	1.23	1.33

TABLE II.10

DEPTH-DURATION-FREQUENCY DATA FOR CAMPBELL RIVER BCHPA

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	13.1	18.5	22.0	26.5	29.8	33.1
2 HR	17.9	22.8	26.1	30.3	33.4	36.4
6 HR	32.5	37.0	40.0	43.8	46.6	49.4
12 HR	43.9	48.8	52.2	56.4	59.5	62.6
24 HR	60.0	69.8	76.3	84.5	90.7	96.7

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.22	0.26	0.29	0.31	0.33	0.34
2 HR	0.30	0.33	0.34	0.36	0.37	0.38
6 HR	0.54	0.53	0.52	0.52	0.51	0.51
12 HR	0.73	0.70	0.68	0.67	0.66	0.65
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.60	0.84	1.00	1.20	1.35	1.50
2 HR	0.68	0.87	1.00	1.16	1.28	1.39
6 HR	0.81	0.93	1.00	1.09	1.16	1.24
12 HR	0.84	0.94	1.00	1.08	1.14	1.20
24 HR	0.79	0.92	1.00	1.11	1.19	1.27

TABLE II.11

DEPTH-DURATION-FREQUENCY DATA FOR CARNATION CREEK CDF

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	11.8	14.8	16.7	19.2	21.1	22.9
2 HR	19.8	24.5	27.6	31.5	34.4	37.3
6 HR	43.9	56.3	64.7	75.2	82.9	90.7
12 HR	64.7	83.2	95.4	110.8	122.3	133.7
24 HR	91.9	119.0	137.3	159.8	176.9	193.7

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.13	0.12	0.12	0.12	0.12	0.12
2 HR	0.22	0.21	0.20	0.20	0.19	0.19
6 HR	0.48	0.47	0.47	0.47	0.47	0.47
12 HR	0.70	0.70	0.69	0.69	0.69	0.69
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.70	0.88	1.00	1.15	1.26	1.37
2 HR	0.72	0.89	1.00	1.14	1.25	1.35
6 HR	0.68	0.87	1.00	1.16	1.28	1.40
12 HR	0.68	0.87	1.00	1.16	1.28	1.40
24 HR	0.67	0.87	1.00	1.16	1.29	1.41

TABLE II.12

DEPTH-DURATION-FREQUENCY DATA FOR CHILLIWACK MICROWAVE

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	10.0	12.8	14.6	17.0	18.7	20.4
2 HR	14.0	16.8	18.6	21.0	22.7	24.4
6 HR	27.1	31.7	34.9	38.8	41.7	44.6
12 HR	39.8	46.8	51.5	57.4	61.7	66.0
24 HR	55.2	66.5	73.9	83.5	90.5	97.4

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.18	0.19	0.20	0.20	0.21	0.21
2 HR	0.25	0.25	0.25	0.25	0.25	0.25
6 HR	0.49	0.48	0.47	0.46	0.46	0.46
12 HR	0.72	0.70	0.70	0.69	0.68	0.68
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.68	0.87	1.00	1.16	1.28	1.39
2 HR	0.75	0.90	1.00	1.13	1.22	1.31
6 HR	0.78	0.91	1.00	1.11	1.20	1.28
12 HR	0.77	0.91	1.00	1.11	1.20	1.28
24 HR	0.75	0.90	1.00	1.13	1.22	1.32

TABLE II.13

DEPTH-DURATION-FREQUENCY DATA FOR CLOWHOM FALLS

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.5	13.2	15.0	17.3	18.9	20.6
2 HR	15.9	18.9	21.0	23.5	25.4	27.3
6 HR	33.1	39.2	43.3	48.5	52.3	56.0
12 HR	52.3	60.2	65.5	72.1	77.0	82.0
24 HR	78.0	92.9	102.7	115.2	124.3	133.4

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.14	0.15	0.15	0.15	0.15
2 HR	0.20	0.20	0.20	0.20	0.20	0.20
6 HR	0.42	0.42	0.42	0.42	0.42	0.42
12 HR	0.67	0.65	0.64	0.63	0.62	0.61
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.70	0.88	1.00	1.15	1.26	1.38
2 HR	0.76	0.90	1.00	1.12	1.21	1.30
6 HR	0.76	0.91	1.00	1.12	1.21	1.29
12 HR	0.80	0.92	1.00	1.10	1.18	1.25
24 HR	0.76	0.90	1.00	1.12	1.21	1.30

TABLE II.14

DEPTH-DURATION-FREQUENCY DATA FOR COMOX A

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	9.8	12.4	14.1	16.3	17.9	19.6
2 HR	14.3	17.5	19.7	22.4	24.4	26.4
6 HR	28.1	33.1	36.2	40.3	43.4	46.4
12 HR	41.2	48.2	52.9	58.8	63.2	67.6
24 HR	58.1	69.4	77.0	86.4	93.6	100.6

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.17	0.18	0.18	0.19	0.19	0.19
2 HR	0.25	0.25	0.26	0.26	0.26	0.26
6 HR	0.48	0.48	0.47	0.47	0.46	0.46
12 HR	0.71	0.70	0.69	0.68	0.68	0.67
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.69	0.88	1.00	1.15	1.27	1.38
2 HR	0.73	0.89	1.00	1.14	1.24	1.34
6 HR	0.78	0.91	1.00	1.11	1.20	1.28
12 HR	0.78	0.91	1.00	1.11	1.20	1.28
24 HR	0.75	0.90	1.00	1.12	1.21	1.31

TABLE II.15

DEPTH-DURATION-FREQUENCY DATA FOR COQUITLAM LAKE

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	14.5	16.6	17.9	19.6	20.9	22.1
2 HR	22.7	25.3	27.1	29.3	30.9	32.5
6 HR	55.2	63.5	69.1	76.1	81.4	86.5
12 HR	92.9	110.8	122.6	137.5	148.6	159.6
24 HR	143.8	174.5	194.6	220.3	239.3	258.2

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.10	0.09	0.09	0.09	0.09	0.09
2 HR	0.16	0.15	0.14	0.13	0.13	0.13
6 HR	0.38	0.36	0.36	0.35	0.34	0.34
12 HR	0.65	0.63	0.63	0.62	0.62	0.62
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.81	0.93	1.00	1.09	1.16	1.23
2 HR	0.84	0.94	1.00	1.08	1.14	1.20
6 HR	0.80	0.92	1.00	1.10	1.18	1.25
12 HR	0.76	0.90	1.00	1.12	1.21	1.30
24 HR	0.74	0.90	1.00	1.13	1.23	1.33

TABLE II.16

DEPTH-DURATION-FREQUENCY DATA FOR COURTENAY PUNTLEDGE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	9.6	12.1	13.7	15.9	17.4	19.0
2 HR	14.5	17.3	19.3	21.7	23.5	25.3
6 HR	30.6	36.6	40.6	45.6	49.3	53.0
12 HR	45.5	56.3	63.4	72.4	79.1	85.7
24 HR	66.2	84.5	96.7	112.1	123.4	134.6

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.14	0.14	0.14	0.14	0.14	0.14
2 HR	0.22	0.21	0.20	0.19	0.19	0.19
6 HR	0.46	0.43	0.42	0.41	0.40	0.39
12 HR	0.69	0.67	0.66	0.65	0.64	0.64
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.70	0.88	1.00	1.15	1.27	1.38
2 HR	0.75	0.90	1.00	1.13	1.22	1.31
6 HR	0.75	0.90	1.00	1.12	1.21	1.31
12 HR	0.72	0.89	1.00	1.14	1.25	1.35
24 HR	0.68	0.87	1.00	1.16	1.28	1.39

TABLE II.17

DEPTH-DURATION-FREQUENCY DATA FOR DAISY LAKE DAM

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	9.9	14.0	16.6	20.1	22.6	25.1
2 HR	15.5	20.6	23.9	28.1	31.3	34.4
6 HR	32.1	39.5	44.4	50.6	55.2	59.8
12 HR	47.5	55.3	60.6	67.1	72.0	76.8
24 HR	66.2	78.7	87.1	97.7	105.4	113.0

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.15	0.18	0.19	0.21	0.21	0.22
2 HR	0.23	0.26	0.27	0.29	0.30	0.30
6 HR	0.48	0.50	0.51	0.52	0.52	0.53
12 HR	0.72	0.70	0.70	0.69	0.68	0.68
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.60	0.84	1.00	1.20	1.36	1.51
2 HR	0.65	0.86	1.00	1.18	1.31	1.44
6 HR	0.72	0.89	1.00	1.14	1.24	1.35
12 HR	0.78	0.91	1.00	1.11	1.19	1.27
24 HR	0.76	0.90	1.00	1.12	1.21	1.30

TABLE II.18

DEPTH-DURATION-FREQUENCY DATA FOR ESTEVAN POINT

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	18.3	22.4	25.1	28.5	31.0	33.5
2 HR	28.0	35.6	40.7	47.0	51.8	56.4
6 HR	61.6	73.9	82.0	92.3	99.9	107.5
12 HR	90.1	106.4	117.2	130.8	140.9	150.8
24 HR	131.0	168.2	193.0	223.9	247.2	270.0

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.14	0.13	0.13	0.13	0.13	0.12
2 HR	0.21	0.21	0.21	0.21	0.21	0.21
6 HR	0.47	0.44	0.43	0.41	0.40	0.40
12 HR	0.69	0.63	0.61	0.58	0.57	0.56
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.73	0.89	1.00	1.14	1.24	1.34
2 HR	0.69	0.88	1.00	1.16	1.27	1.39
6 HR	0.75	0.90	1.00	1.13	1.22	1.31
12 HR	0.77	0.91	1.00	1.12	1.20	1.29
24 HR	0.68	0.87	1.00	1.16	1.28	1.40

TABLE II.19

DEPTH-DURATION-FREQUENCY DATA FOR HANEY MICROWAVE

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	12.6	15.6	17.5	19.9	21.8	23.6
2 HR	19.0	22.8	25.4	28.7	31.1	33.5
6 HR	37.2	42.6	46.2	50.7	54.0	57.4
12 HR	56.4	67.7	75.1	84.5	91.6	98.4
24 HR	78.7	97.0	109.0	124.3	135.6	146.9

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.16	0.16	0.16	0.16	0.16	0.16
2 HR	0.24	0.24	0.23	0.23	0.23	0.23
6 HR	0.47	0.44	0.42	0.41	0.40	0.39
12 HR	0.72	0.70	0.69	0.68	0.68	0.67
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.72	0.89	1.00	1.14	1.24	1.35
2 HR	0.75	0.90	1.00	1.13	1.22	1.32
6 HR	0.81	0.92	1.00	1.10	1.17	1.24
12 HR	0.75	0.90	1.00	1.12	1.22	1.31
24 HR	0.72	0.89	1.00	1.14	1.24	1.35

TABLE II.20

DEPTH-DURATION-FREQUENCY DATA FOR HANEY UBC RF ADMIN

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.8	14.3	16.0	18.1	19.6	21.2
2 HR	19.3	22.4	24.5	27.1	29.0	30.9
6 HR	39.2	45.1	49.1	54.1	57.8	61.5
12 HR	59.5	71.0	78.6	88.3	95.4	102.6
24 HR	89.3	111.8	126.7	145.4	159.4	173.3

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.13	0.13	0.12	0.12	0.12
2 HR	0.22	0.20	0.19	0.19	0.18	0.18
6 HR	0.44	0.40	0.39	0.37	0.36	0.35
12 HR	0.67	0.64	0.62	0.61	0.60	0.59
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.74	0.90	1.00	1.13	1.23	1.32
2 HR	0.79	0.92	1.00	1.11	1.19	1.26
6 HR	0.80	0.92	1.00	1.10	1.18	1.25
12 HR	0.76	0.90	1.00	1.12	1.21	1.31
24 HR	0.70	0.88	1.00	1.15	1.26	1.37

TABLE II.21

DEPTH-DURATION-FREQUENCY DATA FOR JORDAN RIVER DIVERSI

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	22.8	32.7	39.3	47.6	53.7	59.9
2 HR	35.0	44.2	50.3	58.0	63.6	69.3
6 HR	71.5	92.9	107.2	125.2	138.4	151.7
12 HR	104.4	142.9	168.5	200.6	224.5	248.3
24 HR	150.0	205.2	241.9	288.2	322.6	356.6

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.15	0.16	0.16	0.17	0.17	0.17
2 HR	0.23	0.22	0.21	0.20	0.20	0.19
6 HR	0.48	0.45	0.44	0.43	0.43	0.43
12 HR	0.70	0.70	0.70	0.70	0.70	0.70
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.58	0.83	1.00	1.21	1.37	1.52
2 HR	0.70	0.88	1.00	1.15	1.27	1.38
6 HR	0.67	0.87	1.00	1.17	1.29	1.41
12 HR	0.62	0.85	1.00	1.19	1.33	1.47
24 HR	0.62	0.85	1.00	1.19	1.33	1.47

TABLE II.22

DEPTH-DURATION-FREQUENCY DATA FOR JORDAN RIVER GEN STA

RAINFALL DATA FROM AES

DURATION	2	5	10	25	50	100
	RETURN PERIOD (YEARS)					
1 HR	10.6	12.3	13.4	14.8	15.9	16.9
2 HR	17.6	20.3	22.2	24.4	26.1	27.8
6 HR	37.4	44.6	49.3	55.4	59.8	64.3
12 HR	55.9	68.8	77.3	88.1	96.1	104.0
24 HR	75.4	99.1	115.0	134.9	149.8	164.4

DEPTH-DURATION RELATIONSHIPS

DURATION	2	5	10	25	50	100
	RETURN PERIOD (YEARS)					
1 HR	0.14	0.12	0.12	0.11	0.11	0.10
2 HR	0.23	0.21	0.19	0.18	0.17	0.17
6 HR	0.50	0.45	0.43	0.41	0.40	0.39
12 HR	0.74	0.69	0.67	0.65	0.64	0.63
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	2	5	10	25	50	100
	RETURN PERIOD (YEARS)					
1 HR	0.79	0.92	1.00	1.11	1.18	1.26
2 HR	0.80	0.92	1.00	1.10	1.18	1.26
6 HR	0.76	0.90	1.00	1.12	1.21	1.30
12 HR	0.72	0.89	1.00	1.14	1.24	1.35
24 HR	0.66	0.86	1.00	1.17	1.30	1.43

TABLE II.23

DEPTH-DURATION-FREQUENCY DATA FOR KITIMAT 2

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	11.9	14.5	16.2	18.4	20.0	21.6
2 HR	19.7	24.1	27.0	30.7	33.4	36.1
6 HR	44.5	57.5	66.2	77.2	85.3	93.4
12 HR	65.5	85.4	98.6	115.3	127.7	139.9
24 HR	88.8	109.7	123.6	141.1	154.3	167.0

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.13	0.13	0.13	0.13	0.13	0.13
2 HR	0.22	0.22	0.22	0.22	0.22	0.22
6 HR	0.50	0.52	0.54	0.55	0.55	0.56
12 HR	0.74	0.78	0.80	0.82	0.83	0.84
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.73	0.89	1.00	1.13	1.23	1.33
2 HR	0.73	0.89	1.00	1.14	1.24	1.34
6 HR	0.67	0.87	1.00	1.16	1.29	1.41
12 HR	0.66	0.87	1.00	1.17	1.29	1.42
24 HR	0.72	0.89	1.00	1.14	1.25	1.35

TABLE II.24

DEPTH-DURATION-FREQUENCY DATA FOR LADNER BCHPA

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	8.1	9.8	10.9	12.4	13.5	14.5
2 HR	12.5	14.0	15.0	16.2	17.1	18.1
6 HR	22.3	24.5	26.0	27.8	29.2	30.5
12 HR	31.6	38.3	42.7	48.2	52.4	56.5
24 HR	43.2	56.2	64.6	75.6	83.5	91.4

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.19	0.17	0.17	0.16	0.16	0.16
2 HR	0.29	0.25	0.23	0.21	0.21	0.20
6 HR	0.52	0.44	0.40	0.37	0.35	0.33
12 HR	0.73	0.68	0.66	0.64	0.63	0.62
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.74	0.90	1.00	1.13	1.23	1.33
2 HR	0.83	0.93	1.00	1.08	1.15	1.21
6 HR	0.86	0.94	1.00	1.07	1.12	1.18
12 HR	0.74	0.90	1.00	1.13	1.23	1.32
24 HR	0.67	0.87	1.00	1.17	1.29	1.42

TABLE II.25

DEPTH-DURATION-FREQUENCY DATA FOR LANGLEY LOCHIEL

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.4	14.6	16.7	19.4	21.4	23.4
2 HR	16.9	19.5	21.2	23.3	24.9	26.5
6 HR	31.4	37.3	41.2	46.1	49.8	53.4
12 HR	46.4	55.2	61.0	68.2	73.6	79.0
24 HR	61.2	75.6	85.2	97.2	106.3	115.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.19	0.19	0.20	0.20	0.20	0.20
2 HR	0.28	0.26	0.25	0.24	0.23	0.23
6 HR	0.51	0.49	0.48	0.47	0.47	0.46
12 HR	0.76	0.73	0.72	0.70	0.69	0.69
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.68	0.87	1.00	1.16	1.28	1.40
2 HR	0.80	0.92	1.00	1.10	1.18	1.25
6 HR	0.76	0.91	1.00	1.12	1.21	1.30
12 HR	0.76	0.91	1.00	1.12	1.21	1.30
24 HR	0.72	0.89	1.00	1.14	1.25	1.35

TABLE II.26

DEPTH-DURATION-FREQUENCY DATA FOR MISSION WEST ABBEY

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	13.7	17.8	20.6	24.1	26.6	29.2
2 HR	19.7	24.5	27.7	31.8	34.8	37.7
6 HR	35.3	40.6	44.1	48.5	51.7	55.0
12 HR	51.1	59.2	64.4	71.2	76.1	81.1
24 HR	72.5	85.4	94.1	105.1	113.0	121.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.19	0.21	0.22	0.23	0.24	0.24
2 HR	0.27	0.29	0.29	0.30	0.31	0.31
6 HR	0.49	0.48	0.47	0.46	0.46	0.45
12 HR	0.71	0.69	0.68	0.68	0.67	0.67
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.67	0.87	1.00	1.17	1.29	1.42
2 HR	0.71	0.88	1.00	1.15	1.25	1.36
6 HR	0.80	0.92	1.00	1.10	1.17	1.25
12 HR	0.79	0.92	1.00	1.10	1.18	1.26
24 HR	0.77	0.91	1.00	1.12	1.20	1.29

TABLE II.27

DEPTH-DURATION-FREQUENCY DATA FOR NANAIMO DEPARTURE BA

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	9.4	15.4	19.5	24.5	28.3	32.0
2 HR	13.2	20.0	24.6	30.3	34.6	38.9
6 HR	23.9	29.6	33.3	38.0	41.6	45.1
12 HR	33.6	40.1	44.4	49.8	53.9	57.8
24 HR	41.3	50.4	56.4	64.1	69.8	75.4

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.23	0.31	0.35	0.38	0.41	0.43
2 HR	0.32	0.40	0.44	0.47	0.50	0.52
6 HR	0.58	0.59	0.59	0.59	0.60	0.60
12 HR	0.81	0.80	0.79	0.78	0.77	0.77
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.48	0.79	1.00	1.26	1.45	1.65
2 HR	0.54	0.81	1.00	1.23	1.41	1.58
6 HR	0.72	0.89	1.00	1.14	1.25	1.35
12 HR	0.76	0.90	1.00	1.12	1.21	1.30
24 HR	0.73	0.89	1.00	1.14	1.24	1.34

TABLE II.28

DEPTH-DURATION-FREQUENCY DATA FOR N VANCOUVER LYNN CRE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	14.4	17.5	19.6	22.2	24.1	26.0
2 HR	23.2	28.2	31.5	35.6	38.7	41.8
6 HR	51.7	64.9	73.5	84.5	92.6	100.7
12 HR	80.8	103.8	119.0	138.4	152.6	166.9
24 HR	120.2	156.5	180.5	211.0	233.5	255.8

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.12	0.11	0.11	0.11	0.10	0.10
2 HR	0.19	0.18	0.17	0.17	0.17	0.16
6 HR	0.43	0.41	0.41	0.40	0.40	0.39
12 HR	0.67	0.66	0.66	0.66	0.65	0.65
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.74	0.90	1.00	1.13	1.23	1.33
2 HR	0.74	0.90	1.00	1.13	1.23	1.33
6 HR	0.70	0.88	1.00	1.15	1.26	1.37
12 HR	0.68	0.87	1.00	1.16	1.28	1.40
24 HR	0.67	0.87	1.00	1.17	1.29	1.42

TABLE II.29

DEPTH-DURATION-FREQUENCY DATA FOR PITT MEADOWS STP

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.5	17.5	20.9	25.1	28.2	31.3
2 HR	18.0	24.9	29.5	35.3	39.6	43.9
6 HR	38.0	45.6	50.7	57.1	61.8	66.5
12 HR	53.0	65.0	73.1	83.2	90.7	98.2
24 HR	67.7	85.7	97.4	112.6	123.8	134.9

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.19	0.20	0.21	0.22	0.23	0.23
2 HR	0.27	0.29	0.30	0.31	0.32	0.33
6 HR	0.56	0.53	0.52	0.51	0.50	0.49
12 HR	0.78	0.76	0.75	0.74	0.73	0.73
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.60	0.84	1.00	1.20	1.35	1.50
2 HR	0.61	0.84	1.00	1.20	1.34	1.49
6 HR	0.75	0.90	1.00	1.13	1.22	1.31
12 HR	0.73	0.89	1.00	1.14	1.24	1.34
24 HR	0.69	0.88	1.00	1.16	1.27	1.38

TABLE II.30

DEPTH-DURATION-FREQUENCY DATA FOR PITT POLDER

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.4	14.7	16.2	18.1	19.5	20.9
2 HR	18.9	22.9	25.4	28.7	31.2	33.6
6 HR	42.7	51.7	57.7	65.3	70.9	76.4
12 HR	67.3	80.3	88.9	99.8	107.9	115.9
24 HR	98.9	119.0	132.2	149.0	161.5	173.8

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.12	0.12	0.12	0.12	0.12
2 HR	0.19	0.19	0.19	0.19	0.19	0.19
6 HR	0.43	0.43	0.44	0.44	0.44	0.44
12 HR	0.68	0.67	0.67	0.67	0.67	0.67
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.77	0.91	1.00	1.12	1.21	1.29
2 HR	0.74	0.90	1.00	1.13	1.22	1.32
6 HR	0.74	0.90	1.00	1.13	1.23	1.32
12 HR	0.76	0.90	1.00	1.12	1.21	1.30
24 HR	0.75	0.90	1.00	1.13	1.22	1.31

TABLE II.31

DEPTH-DURATION-FREQUENCY DATA FOR PORT ALBERNI A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.2	15.2	17.9	21.2	23.7	26.2
2 HR	18.0	21.7	24.1	27.2	29.5	31.8
6 HR	37.9	42.4	45.3	49.0	51.8	54.5
12 HR	59.4	71.6	79.8	90.0	97.6	105.1
24 HR	87.1	108.5	122.9	140.9	154.3	167.5

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.14	0.15	0.15	0.15	0.16
2 HR	0.21	0.20	0.20	0.19	0.19	0.19
6 HR	0.44	0.39	0.37	0.35	0.34	0.33
12 HR	0.68	0.66	0.65	0.64	0.63	0.63
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.63	0.85	1.00	1.19	1.33	1.47
2 HR	0.75	0.90	1.00	1.13	1.22	1.32
6 HR	0.84	0.94	1.00	1.08	1.14	1.20
12 HR	0.74	0.90	1.00	1.13	1.22	1.32
24 HR	0.71	0.88	1.00	1.15	1.26	1.36

TABLE II.32

DEPTH-DURATION-FREQUENCY DATA FOR PORT COQUITLAM CITY

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.0	13.4	15.0	17.0	18.4	19.9
2 HR	17.1	18.7	19.7	21.0	22.0	23.0
6 HR	36.9	42.4	46.0	50.6	54.0	57.4
12 HR	56.3	65.9	72.4	80.4	86.4	92.4
24 HR	81.1	96.7	107.0	120.0	129.6	139.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.14	0.14	0.14	0.14	0.14	0.14
2 HR	0.21	0.19	0.18	0.18	0.17	0.17
6 HR	0.45	0.44	0.43	0.42	0.42	0.41
12 HR	0.69	0.68	0.68	0.67	0.67	0.66
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.74	0.90	1.00	1.13	1.23	1.33
2 HR	0.87	0.95	1.00	1.07	1.12	1.17
6 HR	0.80	0.92	1.00	1.10	1.17	1.25
12 HR	0.78	0.91	1.00	1.11	1.19	1.28
24 HR	0.76	0.90	1.00	1.12	1.21	1.30

TABLE II.33

DEPTH-DURATION-FREQUENCY DATA FOR PORT HARDY A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.0	11.2	12.1	13.1	13.8	14.6
2 HR	16.3	19.1	20.9	23.3	25.0	26.7
6 HR	37.2	44.2	49.0	54.8	59.2	63.6
12 HR	61.0	73.3	81.4	91.7	99.2	106.8
24 HR	89.5	116.6	134.6	157.4	174.2	190.8

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.11	0.10	0.09	0.08	0.08	0.08
2 HR	0.18	0.16	0.16	0.15	0.14	0.14
6 HR	0.42	0.38	0.36	0.35	0.34	0.33
12 HR	0.68	0.63	0.60	0.58	0.57	0.56
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.83	0.93	1.00	1.09	1.15	1.21
2 HR	0.78	0.91	1.00	1.11	1.19	1.28
6 HR	0.76	0.90	1.00	1.12	1.21	1.30
12 HR	0.75	0.90	1.00	1.13	1.22	1.31
24 HR	0.66	0.87	1.00	1.17	1.29	1.42

TABLE II.34

DEPTH-DURATION-FREQUENCY DATA FOR PORT MELLON

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	18.5	20.9	22.5	24.5	25.9	27.4
2 HR	30.4	33.9	36.1	39.0	41.1	43.2
6 HR	65.0	73.6	79.3	86.5	91.8	97.1
12 HR	98.9	119.2	132.6	149.5	162.1	174.7
24 HR	142.6	176.6	199.4	228.0	249.4	270.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.12	0.11	0.11	0.10	0.10
2 HR	0.21	0.19	0.18	0.17	0.16	0.16
6 HR	0.46	0.42	0.40	0.38	0.37	0.36
12 HR	0.69	0.67	0.66	0.66	0.65	0.65
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.82	0.93	1.00	1.09	1.16	1.22
2 HR	0.84	0.94	1.00	1.08	1.14	1.20
6 HR	0.82	0.93	1.00	1.09	1.16	1.22
12 HR	0.75	0.90	1.00	1.13	1.22	1.32
24 HR	0.71	0.89	1.00	1.14	1.25	1.35

TABLE II.35

DEPTH-DURATION-FREQUENCY DATA FOR PORT MOODY GULF OIL

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	10.6	13.2	15.0	17.2	18.8	20.4
2 HR	17.0	19.6	21.4	23.6	25.2	26.9
6 HR	38.3	44.3	48.4	53.5	57.2	61.0
12 HR	58.3	70.3	78.4	88.4	95.9	103.2
24 HR	84.5	105.4	119.0	136.3	149.0	161.8

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.13	0.13	0.13	0.13	0.13	0.13
2 HR	0.20	0.19	0.18	0.17	0.17	0.17
6 HR	0.45	0.42	0.41	0.39	0.38	0.38
12 HR	0.69	0.67	0.66	0.65	0.64	0.64
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.71	0.88	1.00	1.15	1.26	1.36
2 HR	0.79	0.92	1.00	1.10	1.18	1.26
6 HR	0.79	0.92	1.00	1.11	1.18	1.26
12 HR	0.74	0.90	1.00	1.13	1.22	1.32
24 HR	0.71	0.89	1.00	1.15	1.25	1.36

TABLE II.36

DEPTH-DURATION-FREQUENCY DATA FOR PORT RENFREW BCFP

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	20.6	28.5	33.7	40.4	45.3	50.1
2 HR	36.5	45.2	50.9	58.2	63.5	68.9
6 HR	80.0	96.0	106.7	120.1	130.0	139.9
12 HR	122.3	142.6	156.0	172.9	185.5	198.0
24 HR	168.0	197.3	217.0	241.4	259.7	277.9

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.12	0.14	0.16	0.17	0.17	0.18
2 HR	0.22	0.23	0.23	0.24	0.24	0.25
6 HR	0.48	0.49	0.49	0.50	0.50	0.50
12 HR	0.73	0.72	0.72	0.72	0.71	0.71
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.61	0.84	1.00	1.20	1.34	1.49
2 HR	0.72	0.89	1.00	1.14	1.25	1.35
6 HR	0.75	0.90	1.00	1.13	1.22	1.31
12 HR	0.78	0.91	1.00	1.11	1.19	1.27
24 HR	0.77	0.91	1.00	1.11	1.20	1.28

TABLE II.37

DEPTH-DURATION-FREQUENCY DATA FOR PRINCE RUPERT A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.3	14.3	15.7	17.4	18.6	19.8
2 HR	19.0	21.8	23.7	26.1	27.8	29.6
6 HR	39.1	49.3	56.0	64.6	70.9	77.2
12 HR	59.9	76.8	88.1	102.2	112.8	123.2
24 HR	89.5	112.3	127.7	146.6	161.0	175.0

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.14	0.13	0.12	0.12	0.12	0.11
2 HR	0.21	0.19	0.19	0.18	0.17	0.17
6 HR	0.44	0.44	0.44	0.44	0.44	0.44
12 HR	0.67	0.68	0.69	0.70	0.70	0.70
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.79	0.92	1.00	1.11	1.19	1.27
2 HR	0.80	0.92	1.00	1.10	1.17	1.25
6 HR	0.70	0.88	1.00	1.15	1.27	1.38
12 HR	0.68	0.87	1.00	1.16	1.28	1.40
24 HR	0.70	0.88	1.00	1.15	1.26	1.37

TABLE II.38

DEPTH-DURATION-FREQUENCY DATA FOR SAANICH DENSMORE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	7.6	8.8	9.6	10.7	11.5	12.2
2 HR	12.5	14.3	15.5	17.0	18.2	19.3
6 HR	26.4	30.4	33.0	36.4	38.8	41.2
12 HR	38.3	47.6	53.9	61.8	67.6	73.4
24 HR	49.4	67.0	78.5	93.1	103.9	115.0

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.15	0.13	0.12	0.11	0.11	0.11
2 HR	0.25	0.21	0.20	0.18	0.17	0.17
6 HR	0.53	0.45	0.42	0.39	0.37	0.36
12 HR	0.77	0.71	0.69	0.66	0.65	0.64
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.78	0.91	1.00	1.11	1.19	1.27
2 HR	0.80	0.92	1.00	1.10	1.17	1.24
6 HR	0.80	0.92	1.00	1.10	1.18	1.25
12 HR	0.71	0.88	1.00	1.15	1.25	1.36
24 HR	0.63	0.85	1.00	1.19	1.32	1.46

TABLE II.39

DEPTH-DURATION-FREQUENCY DATA FOR SANDSPIT A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.4	12.3	13.5	15.0	16.2	17.3
2 HR	16.2	19.0	20.9	23.2	25.0	26.8
6 HR	30.8	36.5	40.2	44.9	48.5	52.0
12 HR	40.0	46.4	50.8	56.2	60.1	64.2
24 HR	52.1	59.8	65.0	71.3	76.1	80.9

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.20	0.21	0.21	0.21	0.21	0.21
2 HR	0.31	0.32	0.32	0.33	0.33	0.33
6 HR	0.59	0.61	0.62	0.63	0.64	0.64
12 HR	0.77	0.78	0.78	0.79	0.79	0.79
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.77	0.91	1.00	1.11	1.20	1.28
2 HR	0.77	0.91	1.00	1.11	1.20	1.28
6 HR	0.77	0.91	1.00	1.12	1.21	1.29
12 HR	0.79	0.91	1.00	1.11	1.18	1.26
24 HR	0.80	0.92	1.00	1.10	1.17	1.24

TABLE II.40

DEPTH-DURATION-FREQUENCY DATA FOR SPRING ISLAND

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	15.4	18.7	20.9	23.7	25.7	27.8
2 HR	24.1	27.8	30.3	33.4	35.7	38.0
6 HR	51.5	61.5	68.0	76.4	82.5	88.6
12 HR	81.4	104.8	120.4	140.0	154.6	169.1
24 HR	121.7	156.7	179.8	209.0	230.9	252.5

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.13	0.12	0.12	0.11	0.11	0.11
2 HR	0.20	0.18	0.17	0.16	0.15	0.15
6 HR	0.42	0.39	0.38	0.37	0.36	0.35
12 HR	0.67	0.67	0.67	0.67	0.67	0.67
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.74	0.89	1.00	1.13	1.23	1.33
2 HR	0.80	0.92	1.00	1.10	1.18	1.25
6 HR	0.76	0.90	1.00	1.12	1.21	1.30
12 HR	0.68	0.87	1.00	1.16	1.28	1.40
24 HR	0.68	0.87	1.00	1.16	1.28	1.40

TABLE II.41

DEPTH-DURATION-FREQUENCY DATA FOR STAVE FALLS

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.0	13.6	14.7	16.0	17.0	18.0
2 HR	18.4	21.4	23.4	25.8	27.7	29.5
6 HR	40.4	49.6	55.7	63.5	69.2	74.9
12 HR	62.3	78.8	89.8	103.6	113.9	124.1
24 HR	83.8	106.3	121.4	140.4	154.3	168.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.14	0.13	0.12	0.11	0.11	0.11
2 HR	0.22	0.20	0.19	0.18	0.18	0.18
6 HR	0.48	0.47	0.46	0.45	0.45	0.45
12 HR	0.74	0.74	0.74	0.74	0.74	0.74
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.82	0.93	1.00	1.09	1.16	1.23
2 HR	0.79	0.92	1.00	1.11	1.18	1.26
6 HR	0.72	0.89	1.00	1.14	1.24	1.34
12 HR	0.69	0.88	1.00	1.15	1.27	1.38
24 HR	0.69	0.88	1.00	1.16	1.27	1.39

TABLE II.42

DEPTH-DURATION-FREQUENCY DATA FOR STRATHCONA DAM

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	12.1	17.5	21.1	25.6	28.9	32.3
2 HR	17.1	21.9	25.0	29.0	32.0	34.9
6 HR	31.4	38.6	43.5	49.6	54.1	58.5
12 HR	45.1	60.4	70.4	83.2	92.6	102.0
24 HR	61.7	88.1	105.4	127.4	143.8	160.1

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.20	0.20	0.20	0.20	0.20	0.20
2 HR	0.28	0.25	0.24	0.23	0.22	0.22
6 HR	0.51	0.44	0.41	0.39	0.38	0.37
12 HR	0.73	0.69	0.67	0.65	0.64	0.64
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.57	0.83	1.00	1.21	1.37	1.53
2 HR	0.68	0.87	1.00	1.16	1.28	1.39
6 HR	0.72	0.89	1.00	1.14	1.24	1.34
12 HR	0.64	0.86	1.00	1.18	1.32	1.45
24 HR	0.59	0.84	1.00	1.21	1.36	1.52

TABLE II.43

DEPTH-DURATION-FREQUENCY DATA FOR SURREY KWANTLEN PARK

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.1	14.5	16.8	19.7	21.8	24.0
2 HR	16.6	20.8	23.7	27.2	29.8	32.4
6 HR	32.6	39.1	43.4	48.8	52.8	56.8
12 HR	48.7	60.1	67.7	77.2	84.2	91.3
24 HR	67.9	89.3	103.4	121.4	134.9	148.1

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.16	0.16	0.16	0.16	0.16	0.16
2 HR	0.24	0.23	0.23	0.22	0.22	0.22
6 HR	0.48	0.44	0.42	0.40	0.39	0.38
12 HR	0.72	0.67	0.65	0.64	0.62	0.62
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.66	0.86	1.00	1.17	1.30	1.43
2 HR	0.70	0.88	1.00	1.15	1.26	1.37
6 HR	0.75	0.90	1.00	1.12	1.22	1.31
12 HR	0.72	0.89	1.00	1.14	1.24	1.35
24 HR	0.66	0.86	1.00	1.17	1.30	1.43

TABLE II.44

DEPTH-DURATION-FREQUENCY DATA FOR SURREY MUNICIPAL HAL

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	9.3	12.4	14.5	17.2	19.1	21.1
2 HR	13.6	17.2	19.6	22.6	24.8	27.0
6 HR	27.5	33.7	37.9	43.1	47.0	50.8
12 HR	40.3	49.6	55.7	63.4	69.1	74.8
24 HR	55.4	68.4	77.0	87.8	96.0	103.9

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.17	0.18	0.19	0.20	0.20	0.20
2 HR	0.25	0.25	0.25	0.26	0.26	0.26
6 HR	0.50	0.49	0.49	0.49	0.49	0.49
12 HR	0.73	0.72	0.72	0.72	0.72	0.72
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.64	0.86	1.00	1.18	1.32	1.45
2 HR	0.70	0.88	1.00	1.15	1.27	1.38
6 HR	0.73	0.89	1.00	1.14	1.24	1.34
12 HR	0.72	0.89	1.00	1.14	1.24	1.34
24 HR	0.72	0.89	1.00	1.14	1.25	1.35

TABLE II.45

DEPTH-DURATION-FREQUENCY DATA FOR TERRACE A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.1	13.6	15.8	18.7	20.8	22.9
2 HR	14.1	16.9	18.7	21.1	22.8	24.6
6 HR	25.8	32.6	37.1	42.8	47.0	51.1
12 HR	38.8	52.3	61.3	72.7	81.1	89.4
24 HR	55.7	79.4	95.3	115.2	129.8	144.5

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.18	0.17	0.17	0.16	0.16	0.16
2 HR	0.25	0.21	0.20	0.18	0.18	0.17
6 HR	0.46	0.41	0.39	0.37	0.36	0.35
12 HR	0.70	0.66	0.64	0.63	0.62	0.62
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.64	0.86	1.00	1.18	1.31	1.45
2 HR	0.75	0.90	1.00	1.13	1.22	1.31
6 HR	0.70	0.88	1.00	1.15	1.27	1.38
12 HR	0.63	0.85	1.00	1.19	1.32	1.46
24 HR	0.58	0.83	1.00	1.21	1.36	1.52

TABLE II.46

DEPTH-DURATION-FREQUENCY DATA FOR TERRACE PCC

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	7.7	12.0	14.9	18.5	21.2	23.9
2 HR	12.1	18.7	23.2	28.8	32.9	37.0
6 HR	22.3	31.6	37.7	45.5	51.4	57.1
12 HR	33.4	45.2	53.0	62.9	70.2	77.5
24 HR	43.9	58.8	68.6	81.1	90.2	99.4

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.18	0.20	0.22	0.23	0.24	0.24
2 HR	0.28	0.32	0.34	0.35	0.36	0.37
6 HR	0.51	0.54	0.55	0.56	0.57	0.57
12 HR	0.76	0.77	0.77	0.78	0.78	0.78
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.52	0.81	1.00	1.24	1.42	1.60
2 HR	0.52	0.81	1.00	1.24	1.42	1.60
6 HR	0.59	0.84	1.00	1.21	1.36	1.51
12 HR	0.63	0.85	1.00	1.19	1.32	1.46
24 HR	0.64	0.86	1.00	1.18	1.31	1.45

TABLE II.47

DEPTH-DURATION-FREQUENCY DATA FOR TOFINO A

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	17.8	20.7	22.7	25.1	26.9	28.7
2 HR	28.0	31.5	33.8	36.8	38.9	41.1
6 HR	60.4	69.5	75.5	83.2	88.8	94.4
12 HR	87.0	99.7	108.1	118.8	126.7	134.5
24 HR	128.2	157.0	176.4	200.6	218.6	236.6

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.14	0.13	0.13	0.13	0.12	0.12
2 HR	0.22	0.20	0.19	0.18	0.18	0.17
6 HR	0.47	0.44	0.43	0.41	0.41	0.40
12 HR	0.68	0.64	0.61	0.59	0.58	0.57
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.79	0.91	1.00	1.11	1.19	1.27
2 HR	0.83	0.93	1.00	1.09	1.15	1.22
6 HR	0.80	0.92	1.00	1.10	1.18	1.25
12 HR	0.80	0.92	1.00	1.10	1.17	1.24
24 HR	0.73	0.89	1.00	1.14	1.24	1.34

TABLE II.48

DEPTH-DURATION-FREQUENCY DATA FOR VANCOUVER HARBOUR

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	12.6	17.5	20.7	24.8	27.8	30.8
2 HR	17.5	22.7	26.1	30.5	33.7	36.9
6 HR	31.7	35.9	38.6	42.1	44.6	47.2
12 HR	45.0	51.6	56.0	61.6	65.6	69.7
24 HR	62.2	75.8	85.0	96.2	104.6	113.3

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.20	0.23	0.24	0.26	0.27	0.27
2 HR	0.28	0.30	0.31	0.32	0.32	0.33
6 HR	0.51	0.47	0.45	0.44	0.43	0.42
12 HR	0.72	0.68	0.66	0.64	0.63	0.62
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.61	0.84	1.00	1.20	1.34	1.49
2 HR	0.67	0.87	1.00	1.17	1.29	1.41
6 HR	0.82	0.93	1.00	1.09	1.16	1.22
12 HR	0.80	0.92	1.00	1.10	1.17	1.24
24 HR	0.73	0.89	1.00	1.13	1.23	1.33

TABLE II.49

DEPTH-DURATION-FREQUENCY DATA FOR VANCOUVER INT'L A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.1	12.7	14.4	16.6	18.3	19.9
2 HR	13.7	17.2	19.5	22.5	24.6	26.8
6 HR	25.7	30.4	33.5	37.4	40.3	43.3
12 HR	39.4	47.9	53.4	60.5	65.8	70.9
24 HR	52.8	66.5	75.4	86.6	95.0	103.4

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.19	0.19	0.19	0.19	0.19	0.19
2 HR	0.26	0.26	0.26	0.26	0.26	0.26
6 HR	0.49	0.46	0.45	0.43	0.42	0.42
12 HR	0.75	0.72	0.71	0.70	0.69	0.69
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.70	0.88	1.00	1.15	1.26	1.38
2 HR	0.70	0.88	1.00	1.15	1.26	1.37
6 HR	0.77	0.91	1.00	1.12	1.20	1.29
12 HR	0.74	0.90	1.00	1.13	1.23	1.33
24 HR	0.70	0.88	1.00	1.15	1.26	1.37

TABLE II.50

DEPTH-DURATION-FREQUENCY DATA FOR VANCOUVER KITSILANO

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	9.7	11.8	13.3	15.1	16.4	17.8
2 HR	14.3	17.3	19.3	21.7	23.6	25.4
6 HR	30.1	36.2	40.4	45.6	49.4	53.3
12 HR	45.6	55.3	61.7	69.7	75.7	81.6
24 HR	60.2	76.3	86.9	100.1	110.2	120.0

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.16	0.16	0.15	0.15	0.15	0.15
2 HR	0.24	0.23	0.22	0.22	0.21	0.21
6 HR	0.50	0.47	0.46	0.46	0.45	0.44
12 HR	0.76	0.72	0.71	0.70	0.69	0.68
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.73	0.89	1.00	1.14	1.24	1.34
2 HR	0.74	0.90	1.00	1.13	1.22	1.32
6 HR	0.74	0.90	1.00	1.13	1.22	1.32
12 HR	0.74	0.90	1.00	1.13	1.23	1.32
24 HR	0.69	0.88	1.00	1.15	1.27	1.38

TABLE II.51

DEPTH-DURATION-FREQUENCY DATA FOR VANCOUVER PMO

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	9.9	11.6	12.8	14.2	15.3	16.4
2 HR	15.6	18.1	19.7	21.8	23.3	24.8
6 HR	33.2	39.4	43.6	48.8	52.6	56.5
12 HR	50.0	62.6	71.0	81.6	89.4	97.2
24 HR	68.6	94.3	111.6	133.0	149.0	164.9

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.14	0.12	0.11	0.11	0.10	0.10
2 HR	0.23	0.19	0.18	0.16	0.16	0.15
6 HR	0.48	0.42	0.39	0.37	0.35	0.34
12 HR	0.73	0.66	0.64	0.61	0.60	0.59
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.77	0.91	1.00	1.11	1.20	1.28
2 HR	0.79	0.92	1.00	1.11	1.18	1.26
6 HR	0.76	0.90	1.00	1.12	1.21	1.30
12 HR	0.70	0.88	1.00	1.15	1.26	1.37
24 HR	0.62	0.85	1.00	1.19	1.34	1.48

TABLE II.52

DEPTH-DURATION-FREQUENCY DATA FOR VANCOUVER UBC

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	10.0	13.1	15.1	17.6	19.5	21.4
2 HR	14.0	16.8	18.7	21.1	22.8	24.6
6 HR	26.7	31.7	34.9	39.1	42.2	45.2
12 HR	42.1	52.0	58.4	66.7	72.8	79.0
24 HR	57.8	74.2	85.2	98.9	109.0	119.0

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.17	0.18	0.18	0.18	0.18	0.18
2 HR	0.24	0.23	0.22	0.21	0.21	0.21
6 HR	0.46	0.43	0.41	0.40	0.39	0.38
12 HR	0.73	0.70	0.69	0.67	0.67	0.66
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.66	0.87	1.00	1.17	1.29	1.42
2 HR	0.75	0.90	1.00	1.13	1.22	1.31
6 HR	0.76	0.91	1.00	1.12	1.21	1.30
12 HR	0.72	0.89	1.00	1.14	1.25	1.35
24 HR	0.68	0.87	1.00	1.16	1.28	1.40

TABLE II.53

DEPTH-DURATION-FREQUENCY DATA FOR VICTORIA GONZALES HT

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	7.2	9.1	10.4	12.0	13.2	14.4
2 HR	11.4	14.8	17.0	19.9	22.0	24.1
6 HR	22.9	30.4	35.3	41.6	46.2	50.8
12 HR	34.0	45.8	53.6	63.6	71.0	78.4
24 HR	45.1	63.8	76.3	91.9	103.7	115.2

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.16	0.14	0.14	0.13	0.13	0.13
2 HR	0.25	0.23	0.22	0.22	0.21	0.21
6 HR	0.51	0.48	0.46	0.45	0.45	0.44
12 HR	0.75	0.72	0.70	0.69	0.69	0.68
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.69	0.88	1.00	1.15	1.27	1.38
2 HR	0.67	0.87	1.00	1.17	1.29	1.42
6 HR	0.65	0.86	1.00	1.18	1.31	1.44
12 HR	0.63	0.85	1.00	1.19	1.32	1.46
24 HR	0.59	0.84	1.00	1.20	1.36	1.51

TABLE II.54

DEPTH-DURATION-FREQUENCY DATA FOR VICTORIA INT'L A

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	8.2	9.8	10.9	12.2	13.1	14.1
2 HR	12.6	14.7	16.1	17.9	19.2	20.5
6 HR	25.6	31.0	34.6	39.2	42.6	46.0
12 HR	38.0	47.0	53.0	60.6	66.2	71.8
24 HR	49.4	63.1	72.2	83.8	92.4	101.0

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.17	0.16	0.15	0.15	0.14	0.14
2 HR	0.25	0.23	0.22	0.21	0.21	0.20
6 HR	0.52	0.49	0.48	0.47	0.46	0.46
12 HR	0.77	0.75	0.73	0.72	0.72	0.71
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.76	0.90	1.00	1.12	1.21	1.30
2 HR	0.78	0.91	1.00	1.11	1.19	1.27
6 HR	0.74	0.90	1.00	1.13	1.23	1.33
12 HR	0.72	0.89	1.00	1.14	1.25	1.35
24 HR	0.68	0.87	1.00	1.16	1.28	1.40

TABLE II.55

DEPTH-DURATION-FREQUENCY DATA FOR VICTORIA MARINE

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	9.4	11.8	13.4	15.4	16.9	18.4
2 HR	15.4	18.8	21.1	24.0	26.1	28.2
6 HR	31.0	37.6	41.9	47.5	51.5	55.6
12 HR	45.8	55.6	62.0	70.3	76.3	82.4
24 HR	64.8	84.5	97.4	114.0	126.2	138.5

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.14	0.14	0.14	0.14	0.13	0.13
2 HR	0.24	0.22	0.22	0.21	0.21	0.20
6 HR	0.48	0.44	0.43	0.42	0.41	0.40
12 HR	0.71	0.66	0.64	0.62	0.60	0.60
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.70	0.88	1.00	1.15	1.26	1.37
2 HR	0.73	0.89	1.00	1.14	1.24	1.34
6 HR	0.74	0.90	1.00	1.13	1.23	1.33
12 HR	0.74	0.90	1.00	1.13	1.23	1.33
24 HR	0.67	0.87	1.00	1.17	1.30	1.42

TABLE II.56

DEPTH-DURATION-FREQUENCY DATA FOR VICTORIA SHELBOURNE

RAINFALL DATA FROM AES

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	8.0	9.6	10.8	12.2	13.2	14.2
2 HR	11.7	13.7	15.0	16.6	17.8	19.0
6 HR	23.8	27.3	29.6	32.6	34.8	37.0
12 HR	33.4	42.8	49.1	57.0	62.9	68.8
24 HR	44.9	61.7	73.0	87.1	97.4	108.0

DEPTH-DURATION RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.18	0.16	0.15	0.14	0.14	0.13
2 HR	0.26	0.22	0.21	0.19	0.18	0.18
6 HR	0.53	0.44	0.41	0.37	0.36	0.34
12 HR	0.74	0.69	0.67	0.65	0.65	0.64
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

DURATION	RETURN PERIOD (YEARS) 2	5	10	25	50	100
1 HR	0.74	0.90	1.00	1.13	1.23	1.32
2 HR	0.78	0.91	1.00	1.11	1.19	1.27
6 HR	0.80	0.92	1.00	1.10	1.17	1.25
12 HR	0.68	0.87	1.00	1.16	1.28	1.40
24 HR	0.62	0.85	1.00	1.19	1.34	1.48

TABLE II.57

DEPTH-DURATION-FREQUENCY DATA FOR VICTORIA U VIC

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	8.0	9.4	10.3	11.5	12.4	13.3
2 HR	12.4	14.5	15.9	17.6	18.9	20.1
6 HR	26.6	33.3	37.7	43.3	47.4	51.5
12 HR	40.0	49.8	56.3	64.6	70.7	76.7
24 HR	49.9	67.7	79.7	94.6	105.6	116.6

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.16	0.14	0.13	0.12	0.12	0.11
2 HR	0.25	0.21	0.20	0.19	0.18	0.17
6 HR	0.53	0.49	0.47	0.46	0.45	0.44
12 HR	0.80	0.74	0.71	0.68	0.67	0.66
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.77	0.91	1.00	1.12	1.20	1.29
2 HR	0.78	0.91	1.00	1.11	1.19	1.27
6 HR	0.71	0.88	1.00	1.15	1.26	1.37
12 HR	0.71	0.88	1.00	1.15	1.26	1.36
24 HR	0.63	0.85	1.00	1.19	1.33	1.46

TABLE II.58

DEPTH-DURATION-FREQUENCY DATA FOR WHITE ROCK STP

RAINFALL DATA FROM AES

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	11.7	19.6	24.9	31.5	36.4	41.2
2 HR	16.0	24.0	29.3	36.0	41.0	45.9
6 HR	27.8	35.3	40.3	46.6	51.2	55.9
12 HR	36.6	46.6	53.0	61.4	67.6	73.7
24 HR	50.4	64.8	74.4	86.6	95.5	104.6

DEPTH-DURATION RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.23	0.30	0.33	0.36	0.38	0.39
2 HR	0.32	0.37	0.39	0.42	0.43	0.44
6 HR	0.55	0.55	0.54	0.54	0.54	0.53
12 HR	0.73	0.72	0.71	0.71	0.71	0.70
24 HR	1.00	1.00	1.00	1.00	1.00	1.00

DEPTH-FREQUENCY RELATIONSHIPS

	RETURN PERIOD (YEARS)					
DURATION	2	5	10	25	50	100
1 HR	0.47	0.79	1.00	1.27	1.46	1.66
2 HR	0.55	0.82	1.00	1.23	1.40	1.57
6 HR	0.69	0.88	1.00	1.15	1.27	1.39
12 HR	0.69	0.88	1.00	1.16	1.27	1.39
24 HR	0.68	0.87	1.00	1.16	1.28	1.41

APPENDIX III

MAXIMUM 24-HOUR RAINFALL ON RECORD AT BRITISH COLUMBIA COASTAL STATIONS

TABLE III. 1
TIME DISTRIBUTION OF RAINFALL

ABBOTSFORD A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 16	19	2.3	2.3	2.
79 12 16	20	2.7	5.0	5.
79 12 16	21	1.7	6.7	7.
79 12 16	22	1.1	7.8	8.
79 12 16	23	1.7	9.5	10.
79 12 16	24	2.3	11.8	12.
79 12 17	1	2.9	14.7	15.
79 12 17	2	5.7	20.4	21.
79 12 17	3	7.5	27.9	28.
79 12 17	4	8.0	35.9	36.
79 12 17	5	6.8	42.7	43.
79 12 17	6	6.8	49.5	50.
79 12 17	7	10.3	59.8	61.
79 12 17	8	7.1	66.9	68.
79 12 17	9	2.6	69.5	70.
79 12 17	10	8.5	78.0	79.
79 12 17	11	5.9	83.9	85.
79 12 17	12	1.4	85.3	86.
79 12 17	13	3.3	88.6	90.
79 12 17	14	1.2	89.8	91.
79 12 17	15	1.6	91.4	93.
79 12 17	16	2.4	93.8	95.
79 12 17	17	3.1	96.9	98.
79 12 17	18	1.9	98.8	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	10.3	10.	18.1	79 8 17
2	17.4	18.	34.5	79 8 17
3	24.2	24.	35.7	79 8 17
4	31.9	32.	36.2	79 8 17
6	46.5	47.	46.5	79 12 17
8	57.6	58.	57.6	79 12 17
12	74.4	75.	74.4	79 12 16
24	98.8	100.	98.8	79 12 16

TABLE III. 2
TIME DISTRIBUTION OF RAINFALL

AGASSIZ CDA

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
75 12 1	21	1.8	1.8	2.
75 12 1	22	2.3	4.1	3.
75 12 1	23	6.4	10.5	9.
75 12 1	24	4.3	14.8	12.
75 12 2	1	3.6	18.4	15.
75 12 2	2	9.1	27.5	23.
75 12 2	3	6.6	34.1	29.
75 12 2	4	5.3	39.4	33.
75 12 2	5	4.8	44.2	37.
75 12 2	6	3.6	47.8	40.
75 12 2	7	4.6	52.4	44.
75 12 2	8	4.3	56.7	48.
75 12 2	9	5.1	61.8	52.
75 12 2	10	4.1	65.9	55.
75 12 2	11	3.8	69.7	58.
75 12 2	12	4.6	74.3	62.
75 12 2	13	3.3	77.6	65.
75 12 2	14	3.8	81.4	68.
75 12 2	15	4.6	86.0	72.
75 12 2	16	8.9	94.9	80.
75 12 2	17	8.9	103.8	87.
75 12 2	18	6.1	109.9	92.
75 12 2	19	5.6	115.5	97.
75 12 2	20	3.8	119.3	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	9.1	8.	16.6	79 10 27
2	17.8	15.	20.2	79 10 27
3	23.9	20.	24.4	62 2 3
4	29.5	25.	32.0	83 6 10
6	37.9	32.	39.6	79 12 9
8	45.8	38.	49.8	79 12 9
12	63.1	53.	63.8	80 12 25
24	119.3	100.	119.3	75 12 1

TABLE III. 3
TIME DISTRIBUTION OF RAINFALL

ALOUETTE LAKE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
81 10 30	23	4.8	4.8	3.
81 10 30	24	10.8	15.6	11.
81 10 31	1	2.0	17.6	13.
81 10 31	2	0.2	17.8	13.
81 10 31	3	0.2	18.0	13.
81 10 31	4	0.4	18.4	13.
81 10 31	5	10.0	28.4	20.
81 10 31	6	15.2	43.6	31.
81 10 31	7	9.6	53.2	38.
81 10 31	8	3.6	56.8	41.
81 10 31	9	2.6	59.4	43.
81 10 31	10	4.0	63.4	45.
81 10 31	11	2.8	66.2	47.
81 10 31	12	3.2	69.4	50.
81 10 31	13	8.8	78.2	56.
81 10 31	14	7.2	85.4	61.
81 10 31	15	10.8	96.2	69.
81 10 31	16	7.2	103.4	74.
81 10 31	17	5.2	108.6	78.
81 10 31	18	6.0	114.6	82.
81 10 31	19	5.6	120.2	86.
81 10 31	20	6.8	127.0	91.
81 10 31	21	6.4	133.4	96.
81 10 31	22	6.0	139.4	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	15.2	11.	18.4	79 9 4
2	25.2	18.	27.3	79 9 3
3	34.8	25.	34.8	81 10 31
4	38.4	28.	38.8	82 12 3
6	45.2	32.	54.3	80 12 25
8	57.6	41.	67.2	80 12 25
12	85.0	61.	96.6	80 12 25
24	139.4	100.	139.4	81 10 30

TABLE III. 4
TIME DISTRIBUTION OF RAINFALL

ALTA LAKE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
75 10 16	17	2.8	2.8	3.
75 10 16	18	3.3	6.1	8.
75 10 16	19	4.1	10.2	13.
75 10 16	20	3.8	14.0	17.
75 10 16	21	4.6	18.6	23.
75 10 16	22	4.6	23.2	29.
75 10 16	23	4.6	27.8	35.
75 10 16	24	3.6	31.4	39.
75 10 17	1	3.3	34.7	43.
75 10 17	2	4.1	38.8	48.
75 10 17	3	5.8	44.6	55.
75 10 17	4	4.6	49.2	61.
75 10 17	5	3.0	52.2	65.
75 10 17	6	3.0	55.2	69.
75 10 17	7	2.8	58.0	72.
75 10 17	8	3.0	61.0	76.
75 10 17	9	0.8	61.8	77.
75 10 17	10	2.5	64.3	80.
75 10 17	11	3.0	67.3	84.
75 10 17	12	2.8	70.1	87.
75 10 17	13	2.5	72.6	90.
75 10 17	14	2.8	75.4	94.
75 10 17	15	2.8	78.2	97.
75 10 17	16	2.3	80.5	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	5.8	7.	9.7	79 9 7
2	10.4	13.	15.7	78 7 26
3	14.5	18.	18.6	78 7 26
4	17.8	22.	24.1	78 7 26
6	26.0	32.	27.8	81 10 31
8	35.2	44.	35.2	75 10 16
12	49.4	61.	49.4	75 10 16
24	80.5	100.	80.5	75 10 16

TABLE III. 5
TIME DISTRIBUTION OF RAINFALL

BEAR CREEK

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 18	11	10.7	10.7	4.
68 1 18	12	12.2	22.9	8.
68 1 18	13	16.8	39.7	13.
68 1 18	14	12.4	52.1	17.
68 1 18	15	14.2	66.3	22.
68 1 18	16	11.7	78.0	26.
68 1 18	17	11.7	89.7	30.
68 1 18	18	11.9	101.6	34.
68 1 18	19	22.9	124.5	41.
68 1 18	20	10.7	135.2	45.
68 1 18	21	10.2	145.4	48.
68 1 18	22	20.8	166.2	55.
68 1 18	23	10.2	176.4	59.
68 1 18	24	7.4	183.8	61.
68 1 19	1	13.2	197.0	66.
68 1 19	2	18.0	215.0	72.
68 1 19	3	12.7	227.7	76.
68 1 19	4	8.6	236.3	79.
68 1 19	5	9.9	246.2	82.
68 1 19	6	11.2	257.4	86.
68 1 19	7	11.9	269.3	90.
68 1 19	8	8.9	278.2	93.
68 1 19	9	11.4	289.6	96.
68 1 19	10	10.9	300.5	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	22.9	8.	48.8	66 12 11
2	34.8	12.	56.4	67 12 10
3	46.5	15.	76.7	67 12 10
4	64.6	21.	90.4	67 12 10
6	88.2	29.	98.3	67 12 10
8	114.1	38.	114.1	68 1 18
12	166.2	55.	166.2	68 1 18
24	300.5	100.	300.5	68 1 18

TABLE III. 6
TIME DISTRIBUTION OF RAINFALL

BELLA COOLA HYDRO

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
75 10 30	24	9.1	9.1	7.
75 10 31	1	6.4	15.5	12.
75 10 31	2	3.0	18.5	14.
75 10 31	3	4.1	22.6	17.
75 10 31	4	2.5	25.1	19.
75 10 31	5	1.0	26.1	20.
75 10 31	6	4.3	30.4	23.
75 10 31	7	4.6	35.0	27.
75 10 31	8	4.3	39.3	30.
75 10 31	9	0.0	39.3	30.
75 10 31	10	4.1	43.4	33.
75 10 31	11	4.1	47.5	36.
75 10 31	12	2.8	50.3	38.
75 10 31	13	3.8	54.1	41.
75 10 31	14	3.6	57.7	44.
75 10 31	15	4.6	62.3	47.
75 10 31	16	5.6	67.9	52.
75 10 31	17	5.8	73.7	56.
75 10 31	18	5.8	79.5	61.
75 10 31	19	10.2	89.7	68.
75 10 31	20	13.2	102.9	78.
75 10 31	21	14.0	116.9	89.
75 10 31	22	7.6	124.5	95.
75 10 31	23	6.9	131.4	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	14.0	11.	15.0	76 10 27
2	27.2	21.	27.2	75 10 31
3	37.4	28.	37.4	75 10 31
4	45.0	34.	45.0	75 10 31
6	57.7	44.	57.7	75 10 31
8	69.1	53.	69.1	75 10 31
12	83.9	64.	91.3	71 11 18
24	131.4	100.	131.4	75 10 30

TABLE III. 7
TIME DISTRIBUTION OF RAINFALL

BUNTZEN LAKE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
81 10 30	21	7.7	7.7	3.
81 10 30	22	9.0	16.7	6.
81 10 30	23	0.5	17.2	7.
81 10 30	24	0.2	17.4	7.
81 10 31	1	2.4	19.8	8.
81 10 31	2	10.1	29.9	12.
81 10 31	3	15.3	45.2	17.
81 10 31	4	11.0	56.2	22.
81 10 31	5	8.8	65.0	25.
81 10 31	6	15.3	80.3	31.
81 10 31	7	13.1	93.4	36.
81 10 31	8	17.5	110.9	43.
81 10 31	9	13.1	124.0	48.
81 10 31	10	13.4	137.4	53.
81 10 31	11	11.7	149.1	58.
81 10 31	12	13.9	163.0	63.
81 10 31	13	13.0	176.0	68.
81 10 31	14	15.2	191.2	74.
81 10 31	15	11.7	202.9	78.
81 10 31	16	11.7	214.6	83.
81 10 31	17	11.9	226.5	87.
81 10 31	18	8.3	234.8	91.
81 10 31	19	15.8	250.6	97.
81 10 31	20	8.5	259.1	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	17.5	7.	27.7	79 6 30
2	30.6	12.	33.5	76 11 17
3	45.9	18.	45.9	81 10 31
4	59.0	23.	59.0	81 10 31
6	84.1	32.	84.1	81 10 31
8	111.0	43.	111.0	81 10 31
12	161.5	62.	161.5	81 10 31
24	259.1	100.	259.1	81 10 30

TABLE III. 8
TIME DISTRIBUTION OF RAINFALL

BURNABY MTN BCHPA

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 16	23	1.4	1.4	1.
79 12 16	24	1.6	3.0	2.
79 12 17	1	2.8	5.8	5.
79 12 17	2	2.4	8.2	7.
79 12 17	3	4.0	12.2	10.
79 12 17	4	4.8	17.0	14.
79 12 17	5	5.2	22.2	18.
79 12 17	6	4.8	27.0	22.
79 12 17	7	5.6	32.6	27.
79 12 17	8	6.0	38.6	32.
79 12 17	9	9.4	48.0	39.
79 12 17	10	7.6	55.6	45.
79 12 17	11	9.4	65.0	53.
79 12 17	12	9.6	74.6	61.
79 12 17	13	8.0	82.6	68.
79 12 17	14	6.8	89.4	73.
79 12 17	15	4.0	93.4	76.
79 12 17	16	8.8	102.2	84.
79 12 17	17	4.0	106.2	87.
79 12 17	18	3.4	109.6	90.
79 12 17	19	3.0	112.6	92.
79 12 17	20	3.6	116.2	95.
79 12 17	21	2.0	118.2	97.
79 12 17	22	4.0	122.2	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	9.6	8.	15.0	78 6 13
2	19.0	16.	21.9	77 11 28
3	27.0	22.	27.2	77 11 28
4	36.0	29.	36.0	79 12 17
6	50.8	42.	50.8	79 12 17
8	63.6	52.	63.6	79 12 17
12	85.2	70.	85.2	79 12 17
24	122.2	100.	122.2	79 12 16

TABLE III. 9
TIME DISTRIBUTION OF RAINFALL

CAMPBELL RIVER BCFS

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
69 11 6	20	0.3	0.3	0.
69 11 6	21	1.3	1.6	2.
69 11 6	22	3.3	4.9	6.
69 11 6	23	7.9	12.8	17.
69 11 6	24	3.0	15.8	21.
69 11 7	1	6.6	22.4	30.
69 11 7	2	7.4	29.8	40.
69 11 7	3	10.9	40.7	54.
69 11 7	4	9.7	50.4	67.
69 11 7	5	6.1	56.5	75.
69 11 7	6	3.6	60.1	80.
69 11 7	7	3.3	63.4	84.
69 11 7	8	2.0	65.4	87.
69 11 7	9	1.3	66.7	88.
69 11 7	10	1.3	68.0	90.
69 11 7	11	2.3	70.3	93.
69 11 7	12	2.0	72.3	96.
69 11 7	13	1.5	73.8	98.
69 11 7	14	0.5	74.3	99.
69 11 7	15	0.8	75.1	100.
69 11 7	16	0.3	75.4	100.
69 11 7	17	0.0	75.4	100.
69 11 7	18	0.0	75.4	100.
69 11 7	19	0.0	75.4	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	10.9	14.	12.7	75 8 26
2	20.6	27.	20.6	75 8 26
3	28.0	37.	28.5	75 11 14
4	34.6	46.	34.6	69 11 7
6	45.5	60.	45.5	69 11 6
8	55.2	73.	55.2	69 11 6
12	65.1	86.	65.1	69 11 6
24	75.4	100.	75.4	69 11 6

TABLE III.10
TIME DISTRIBUTION OF RAINFALL

CAMPBELL RIVER BCHPA

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 2 24	6	4.0	4.0	5.
79 2 24	7	4.4	8.4	11.
79 2 24	8	5.2	13.6	18.
79 2 24	9	4.5	18.1	23.
79 2 24	10	4.5	22.6	29.
79 2 24	11	2.7	25.3	33.
79 2 24	12	3.6	28.9	37.
79 2 24	13	4.5	33.4	43.
79 2 24	14	3.3	36.7	47.
79 2 24	15	4.5	41.2	53.
79 2 24	16	2.2	43.4	56.
79 2 24	17	4.1	47.5	61.
79 2 24	18	4.1	51.6	67.
79 2 24	19	3.6	55.2	71.
79 2 24	20	5.8	61.0	79.
79 2 24	21	5.0	66.0	85.
79 2 24	22	3.1	69.1	89.
79 2 24	23	1.6	70.7	91.
79 2 24	24	0.3	71.0	92.
79 2 25	1	1.1	72.1	93.
79 2 25	2	0.5	72.6	94.
79 2 25	3	1.6	74.2	96.
79 2 25	4	2.0	76.2	99.
79 2 25	5	1.1	77.3	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	5.8	8.	23.1	79 9 1
2	10.8	14.	25.9	77 12 12
3	14.4	19.	34.0	77 12 12
4	18.6	24.	35.8	77 12 12
6	25.7	33.	41.2	80 3 13
8	33.4	43.	47.0	80 3 13
12	47.9	62.	59.3	77 10 31
24	77.3	100.	77.3	79 2 24

TABLE III.11
TIME DISTRIBUTION OF RAINFALL

CARNATION CREEK

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
81 10 30	12	8.1	8.1	5.
81 10 30	13	9.0	17.1	11.
81 10 30	14	15.5	32.6	20.
81 10 30	15	4.5	37.1	23.
81 10 30	16	6.4	43.5	27.
81 10 30	17	6.2	49.7	31.
81 10 30	18	5.4	55.1	34.
81 10 30	19	4.9	60.0	37.
81 10 30	20	5.1	65.1	40.
81 10 30	21	1.5	66.6	41.
81 10 30	22	1.3	67.9	42.
81 10 30	23	2.4	70.3	43.
81 10 30	24	8.1	78.4	48.
81 10 31	1	4.7	83.1	51.
81 10 31	2	4.5	87.6	54.
81 10 31	3	1.9	89.5	55.
81 10 31	4	4.5	94.0	58.
81 10 31	5	10.7	104.7	64.
81 10 31	6	15.4	120.1	74.
81 10 31	7	9.4	129.5	80.
81 10 31	8	8.8	138.3	85.
81 10 31	9	7.9	146.2	90.
81 10 31	10	7.9	154.1	95.
81 10 31	11	8.3	162.4	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	15.5	10.	16.0	80 11 1
2	26.1	16.	26.4	77 2 11
3	35.5	22.	38.6	77 2 11
4	44.3	27.	50.8	77 2 11
6	60.1	37.	67.4	77 2 11
8	72.9	45.	83.9	77 2 11
12	92.1	57.	97.8	77 2 11
24	162.4	100.	162.4	81 10 30

TABLE III.12
TIME DISTRIBUTION OF RAINFALL

CHILLIWACK MICROWAVE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
66 10 18	21	3.0	3.0	4.
66 10 18	22	3.6	6.6	8.
66 10 18	23	3.3	9.9	12.
66 10 18	24	3.8	13.7	17.
66 10 19	1	3.0	16.7	20.
66 10 19	2	3.6	20.3	25.
66 10 19	3	3.0	23.3	29.
66 10 19	4	3.8	27.1	33.
66 10 19	5	3.8	30.9	38.
66 10 19	6	3.0	33.9	42.
66 10 19	7	3.3	37.2	46.
66 10 19	8	4.1	41.3	51.
66 10 19	9	5.1	46.4	57.
66 10 19	10	3.6	50.0	61.
66 10 19	11	4.3	54.3	67.
66 10 19	12	3.0	57.3	70.
66 10 19	13	2.8	60.1	74.
66 10 19	14	2.5	62.6	77.
66 10 19	15	2.8	65.4	80.
66 10 19	16	2.5	67.9	83.
66 10 19	17	3.3	71.2	87.
66 10 19	18	2.8	74.0	91.
66 10 19	19	3.3	77.3	95.
66 10 19	20	4.3	81.6	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	5.1	6.	18.0	66 1 6
2	9.2	11.	21.3	69 11 4
3	13.0	16.	24.9	63 10 21
4	17.1	21.	29.0	63 10 21
6	23.4	29.	39.4	63 10 21
8	31.0	38.	44.1	69 11 4
12	44.4	54.	58.0	69 11 4
24	81.6	100.	81.6	66 10 18

TABLE III.13
TIME DISTRIBUTION OF RAINFALL

CLOWHAM FALLS

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 2 24	12	3.0	3.0	3.
79 2 24	13	3.8	6.8	6.
79 2 24	14	3.2	10.0	9.
79 2 24	15	5.1	15.1	14.
79 2 24	16	5.1	20.2	18.
79 2 24	17	5.7	25.9	23.
79 2 24	18	6.2	32.1	29.
79 2 24	19	4.4	36.5	33.
79 2 24	20	3.8	40.3	36.
79 2 24	21	4.9	45.2	41.
79 2 24	22	6.8	52.0	47.
79 2 24	23	5.4	57.4	51.
79 2 24	24	6.8	64.2	58.
79 2 25	1	4.3	68.5	61.
79 2 25	2	4.2	72.7	65.
79 2 25	3	4.3	77.0	69.
79 2 25	4	3.0	80.0	72.
79 2 25	5	4.0	84.0	75.
79 2 25	6	4.3	88.3	79.
79 2 25	7	4.0	92.3	83.
79 2 25	8	3.5	95.8	86.
79 2 25	9	5.2	101.0	91.
79 2 25	10	5.8	106.8	96.
79 2 25	11	4.7	111.5	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	6.8	6.	20.1	75 8 28
2	12.2	11.	26.0	80 11 6
3	19.0	17.	32.2	78 11 7
4	23.9	21.	42.7	78 11 7
6	32.4	29.	54.2	78 11 7
8	44.0	39.	64.8	78 11 7
12	62.7	56.	72.3	78 11 7
24	111.5	100.	111.5	79 2 24

TABLE III.14
TIME DISTRIBUTION OF RAINFALL

COMOX A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
83 2 10	18	1.2	1.2	1.
83 2 10	19	3.2	4.4	5.
83 2 10	20	2.6	7.0	8.
83 2 10	21	2.5	9.5	11.
83 2 10	22	3.7	13.2	15.
83 2 10	23	1.6	14.8	17.
83 2 10	24	3.2	18.0	20.
83 2 11	1	7.3	25.3	28.
83 2 11	2	6.9	32.2	36.
83 2 11	3	5.9	38.1	43.
83 2 11	4	4.4	42.5	47.
83 2 11	5	5.7	48.2	54.
83 2 11	6	5.9	54.1	60.
83 2 11	7	5.1	59.2	66.
83 2 11	8	4.8	64.0	71.
83 2 11	9	3.0	67.0	75.
83 2 11	10	4.2	71.2	79.
83 2 11	11	3.8	75.0	84.
83 2 11	12	3.2	78.2	87.
83 2 11	13	3.0	81.2	91.
83 2 11	14	2.4	83.6	93.
83 2 11	15	2.2	85.8	96.
83 2 11	16	1.6	87.4	98.
83 2 11	17	2.2	89.6	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	7.3	8.	16.8	83 11 3
2	14.2	16.	24.8	83 11 3
3	20.1	22.	27.0	62 6 1
4	24.5	27.	32.0	81 11 14
6	36.1	40.	37.2	81 11 14
8	46.0	51.	46.0	83 2 11
12	60.2	67.	60.2	83 2 11
24	89.6	100.	89.6	83 2 10

TABLE III.15
TIME DISTRIBUTION OF RAINFALL

COQUITLAM LAKE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
81 10 30	21	7.6	7.6	3.
81 10 30	22	10.1	17.7	8.
81 10 30	23	0.8	18.5	8.
81 10 30	24	1.1	19.6	9.
81 10 31	1	1.3	20.9	9.
81 10 31	2	10.6	31.5	14.
81 10 31	3	10.6	42.1	19.
81 10 31	4	16.9	59.0	26.
81 10 31	5	10.6	69.6	31.
81 10 31	6	10.6	80.2	35.
81 10 31	7	11.8	92.0	41.
81 10 31	8	10.1	102.1	45.
81 10 31	9	11.7	113.8	50.
81 10 31	10	10.7	124.5	55.
81 10 31	11	10.7	135.2	60.
81 10 31	12	9.3	144.5	64.
81 10 31	13	9.8	154.3	68.
81 10 31	14	11.5	165.8	73.
81 10 31	15	9.8	175.6	77.
81 10 31	16	11.9	187.5	83.
81 10 31	17	9.3	196.8	87.
81 10 31	18	10.7	207.5	92.
81 10 31	19	10.6	218.1	96.
81 10 31	20	8.5	226.6	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	16.9	7.	16.9	81 10 31
2	27.5	12.	28.0	73 10 13
3	38.1	17.	39.1	77 11 13
4	49.9	22.	51.1	73 10 13
6	71.7	32.	71.7	81 10 31
8	93.1	41.	93.1	81 10 31
12	134.3	59.	134.3	81 10 31
24	226.6	100.	226.6	81 10 30

TABLE III.16
TIME DISTRIBUTION OF RAINFALL

COURTNEY PUNTLEDGE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 17	17	3.8	3.8	3.
68 1 17	18	5.1	8.9	7.
68 1 17	19	3.6	12.5	10.
68 1 17	20	2.3	14.8	12.
68 1 17	21	5.3	20.1	16.
68 1 17	22	5.8	25.9	21.
68 1 17	23	5.6	31.5	25.
68 1 17	24	4.8	36.3	29.
68 1 18	1	4.8	41.1	33.
68 1 18	2	7.9	49.0	39.
68 1 18	3	5.6	54.6	44.
68 1 18	4	6.9	61.5	49.
68 1 18	5	6.4	67.9	55.
68 1 18	6	7.6	75.5	61.
68 1 18	7	5.1	80.6	65.
68 1 18	8	3.6	84.2	68.
68 1 18	9	3.6	87.8	71.
68 1 18	10	6.6	94.4	76.
68 1 18	11	5.6	100.0	80.
68 1 18	12	4.1	104.1	84.
68 1 18	13	3.0	107.1	86.
68 1 18	14	5.1	112.2	90.
68 1 18	15	4.6	116.8	94.
68 1 18	16	7.6	124.4	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	7.9	6.	14.0	80 7 10
2	14.0	11.	23.8	80 7 10
3	20.9	17.	29.2	83 9 10
4	26.8	22.	36.4	83 9 10
6	39.5	32.	53.6	83 11 14
8	49.6	40.	64.0	83 11 14
12	69.4	56.	86.8	83 11 14
24	124.4	100.	124.4	68 1 17

TABLE III.17
TIME DISTRIBUTION OF RAINFALL

DAISY LAKE DAM

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
75 10 16	12	3.6	3.6	4.
75 10 16	13	2.8	6.4	7.
75 10 16	14	3.0	9.4	10.
75 10 16	15	3.6	13.0	13.
75 10 16	16	3.0	16.0	16.
75 10 16	17	3.6	19.6	20.
75 10 16	18	4.1	23.7	24.
75 10 16	19	4.3	28.0	29.
75 10 16	20	4.3	32.3	33.
75 10 16	21	5.1	37.4	38.
75 10 16	22	6.1	43.5	44.
75 10 16	23	4.6	48.1	49.
75 10 16	24	3.6	51.7	53.
75 10 17	1	4.1	55.8	57.
75 10 17	2	4.1	59.9	61.
75 10 17	3	7.1	67.0	69.
75 10 17	4	6.4	73.4	75.
75 10 17	5	4.8	78.2	80.
75 10 17	6	3.6	81.8	84.
75 10 17	7	3.6	85.4	87.
75 10 17	8	3.8	89.2	91.
75 10 17	9	3.3	92.5	95.
75 10 17	10	2.3	94.8	97.
75 10 17	11	3.0	97.8	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	7.1	7.	18.8	68 10 29
2	13.5	14.	27.9	69 4 4
3	18.3	19.	41.1	69 4 4
4	22.4	23.	46.2	69 4 4
6	30.1	31.	53.8	69 4 4
8	41.1	42.	57.3	69 4 4
12	58.6	60.	60.9	69 4 4
24	97.8	100.	97.8	75 10 16

TABLE III.18
TIME DISTRIBUTION OF RAINFALL

ESTAVAN POINT

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
78 11 6	2	3.4	3.4	2.
78 11 6	3	4.4	7.8	4.
78 11 6	4	7.2	15.0	7.
78 11 6	5	8.2	23.2	11.
78 11 6	6	7.2	30.4	14.
78 11 6	7	7.7	38.1	18.
78 11 6	8	11.4	49.5	24.
78 11 6	9	14.7	64.2	31.
78 11 6	10	13.9	78.1	37.
78 11 6	11	13.7	91.8	44.
78 11 6	12	8.7	100.5	48.
78 11 6	13	3.7	104.2	50.
78 11 6	14	1.4	105.6	50.
78 11 6	15	3.9	109.5	52.
78 11 6	16	3.7	113.2	54.
78 11 6	17	12.1	125.3	60.
78 11 6	18	15.9	141.2	67.
78 11 6	19	11.9	153.1	73.
78 11 6	20	12.4	165.5	79.
78 11 6	21	8.2	173.7	83.
78 11 6	22	15.9	189.6	90.
78 11 6	23	9.7	199.3	95.
78 11 6	24	6.9	206.2	98.
78 11 7	1	4.1	210.3	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	15.9	8.	27.7	71 11 2
2	28.6	14.	43.7	71 11 2
3	42.3	20.	56.7	71 11 2
4	53.7	26.	68.1	71 11 2
6	76.4	36.	80.1	71 11 2
8	93.0	44.	98.5	69 11 19
12	116.0	55.	131.3	69 11 19
24	210.3	100.	210.3	78 11 6

TABLE III.19
TIME DISTRIBUTION OF RAINFALL

HANEY MICROWAVE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 18	14	4.8	4.8	3.
68 1 18	15	6.6	11.4	8.
68 1 18	16	5.6	17.0	12.
68 1 18	17	5.8	22.8	16.
68 1 18	18	4.3	27.1	19.
68 1 18	19	3.6	30.7	22.
68 1 18	20	4.6	35.3	25.
68 1 18	21	4.6	39.9	28.
68 1 18	22	3.8	43.7	31.
68 1 18	23	3.0	46.7	33.
68 1 18	24	4.1	50.8	36.
68 1 19	1	4.6	55.4	39.
68 1 19	2	4.3	59.7	42.
68 1 19	3	6.6	66.3	47.
68 1 19	4	10.2	76.5	54.
68 1 19	5	8.9	85.4	60.
68 1 19	6	6.9	92.3	65.
68 1 19	7	6.9	99.2	70.
68 1 19	8	8.6	107.8	76.
68 1 19	9	6.6	114.4	80.
68 1 19	10	4.8	119.2	84.
68 1 19	11	9.4	128.6	90.
68 1 19	12	8.1	136.7	96.
68 1 19	13	5.6	142.3	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	10.2	7.	19.3	65 11 3
2	19.1	13.	27.9	69 1 1
3	26.0	18.	35.6	64 11 29
4	32.9	23.	40.7	64 11 29
6	48.1	34.	50.6	80 12 25
8	62.3	44.	63.0	80 12 25
12	86.9	61.	87.4	80 12 25
24	142.3	100.	142.3	68 1 18

TABLE III.20
TIME DISTRIBUTION OF RAINFALL

HANEY UBC

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 18	14	5.8	5.8	4.
68 1 18	15	5.6	11.4	8.
68 1 18	16	5.3	16.7	12.
68 1 18	17	5.3	22.0	16.
68 1 18	18	5.8	27.8	20.
68 1 18	19	3.6	31.4	23.
68 1 18	20	3.0	34.4	25.
68 1 18	21	4.1	38.5	28.
68 1 18	22	4.1	42.6	31.
68 1 18	23	5.6	48.2	35.
68 1 18	24	5.6	53.8	39.
68 1 19	1	5.6	59.4	43.
68 1 19	2	5.1	64.5	47.
68 1 19	3	6.9	71.4	52.
68 1 19	4	7.9	79.3	58.
68 1 19	5	5.8	85.1	62.
68 1 19	6	5.3	90.4	66.
68 1 19	7	6.9	97.3	71.
68 1 19	8	6.1	103.4	75.
68 1 19	9	6.9	110.3	80.
68 1 19	10	7.1	117.4	85.
68 1 19	11	6.4	123.8	90.
68 1 19	12	6.9	130.7	95.
68 1 19	13	7.1	137.8	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	7.9	6.	17.3	73 6 24
2	14.8	11.	29.1	83 7 11
3	20.6	15.	34.9	83 7 11
4	27.5	20.	40.7	83 7 11
6	40.5	29.	53.2	68 9 16
8	52.9	38.	63.3	68 9 16
12	78.4	57.	84.1	79 12 17
24	137.8	100.	137.8	68 1 18

TABLE III.21
TIME DISTRIBUTION OF RAINFALL

JORDAN RIVER DIVERSION

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 13	16	17.3	17.3	5.
79 12 13	17	11.2	28.5	8.
79 12 13	18	5.6	34.1	10.
79 12 13	19	6.6	40.7	12.
79 12 13	20	9.1	49.8	15.
79 12 13	21	11.7	61.5	18.
79 12 13	22	10.2	71.7	21.
79 12 13	23	11.7	83.4	24.
79 12 13	24	10.2	93.6	27.
79 12 14	1	13.5	107.1	31.
79 12 14	2	12.4	119.5	35.
79 12 14	3	18.0	137.5	40.
79 12 14	4	17.3	154.8	45.
79 12 14	5	15.7	170.5	50.
79 12 14	6	19.8	190.3	56.
79 12 14	7	18.5	208.8	61.
79 12 14	8	7.9	216.7	64.
79 12 14	9	14.7	231.4	68.
79 12 14	10	10.2	241.6	71.
79 12 14	11	15.2	256.8	75.
79 12 14	12	13.2	270.0	79.
79 12 14	13	21.3	291.3	85.
79 12 14	14	21.8	313.1	92.
79 12 14	15	27.9	341.0	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	27.9	8.	48.3	76 1 14
2	49.7	15.	55.8	80 1 12
3	71.0	21.	73.2	80 12 26
4	84.2	25.	97.6	80 12 26
6	109.6	32.	136.3	80 12 26
8	132.2	39.	172.9	80 12 26
12	203.5	60.	219.6	80 12 25
24	341.0	100.	341.0	79 12 13

TABLE III.22
TIME DISTRIBUTION OF RAINFALL

JORDAN RIVER GENERATING

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	4	1.3	1.3	1.
72 12 25	5	3.0	4.3	2.
72 12 25	6	4.1	8.4	5.
72 12 25	7	5.1	13.5	8.
72 12 25	8	15.0	28.5	16.
72 12 25	9	9.1	37.6	21.
72 12 25	10	8.4	46.0	26.
72 12 25	11	6.6	52.6	29.
72 12 25	12	5.1	57.7	32.
72 12 25	13	4.3	62.0	34.
72 12 25	14	6.9	68.9	38.
72 12 25	15	6.1	75.0	42.
72 12 25	16	3.6	78.6	44.
72 12 25	17	7.6	86.2	48.
72 12 25	18	15.7	101.9	57.
72 12 25	19	15.0	116.9	65.
72 12 25	20	13.5	130.4	72.
72 12 25	21	7.6	138.0	77.
72 12 25	22	9.9	147.9	82.
72 12 25	23	7.9	155.8	87.
72 12 25	24	12.2	168.0	93.
72 12 26	1	6.1	174.1	97.
72 12 26	2	3.3	177.4	99.
72 12 26	3	2.5	179.9	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	15.7	9.	15.7	72 12 25
2	30.7	17.	30.7	72 12 25
3	44.2	25.	44.2	72 12 25
4	51.8	29.	51.8	72 12 25
6	69.6	39.	69.6	72 12 25
8	89.4	50.	89.4	72 12 25
12	112.1	62.	112.1	72 12 25
24	179.9	100.	179.9	72 12 25

TABLE III.23
TIME DISTRIBUTION OF RAINFALL

KITIMAT

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
74 10 14	16	3.0	3.0	2.
74 10 14	17	2.5	5.5	4.
74 10 14	18	4.8	10.3	7.
74 10 14	19	5.6	15.9	11.
74 10 14	20	4.8	20.7	15.
74 10 14	21	4.6	25.3	18.
74 10 14	22	5.1	30.4	22.
74 10 14	23	5.8	36.2	26.
74 10 14	24	5.3	41.5	30.
74 10 15	1	7.4	48.9	35.
74 10 15	2	6.6	55.5	40.
74 10 15	3	7.6	63.1	46.
74 10 15	4	8.9	72.0	52.
74 10 15	5	10.2	82.2	59.
74 10 15	6	9.4	91.6	66.
74 10 15	7	7.9	99.5	72.
74 10 15	8	8.4	107.9	78.
74 10 15	9	7.6	115.5	83.
74 10 15	10	4.8	120.3	87.
74 10 15	11	3.0	123.3	89.
74 10 15	12	5.8	129.1	93.
74 10 15	13	3.6	132.7	96.
74 10 15	14	3.3	136.0	98.
74 10 15	15	2.5	138.5	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	10.2	7.	18.5	66 10 23
2	19.6	14.	33.5	66 10 23
3	28.5	21.	47.5	66 10 23
4	36.4	26.	60.5	66 10 23
6	52.4	38.	82.6	66 10 23
8	66.6	48.	102.7	66 10 23
12	90.2	65.	120.4	66 10 23
24	138.5	100.	138.5	74 10 14

TABLE III.24
TIME DISTRIBUTION OF RAINFALL

LADNER BCHPA

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
67 10 6	24	0.5	0.5	1.
67 10 7	1	1.8	2.3	4.
67 10 7	2	3.8	6.1	9.
67 10 7	3	5.6	11.7	18.
67 10 7	4	4.6	16.3	25.
67 10 7	5	3.8	20.1	31.
67 10 7	6	3.3	23.4	36.
67 10 7	7	3.6	27.0	41.
67 10 7	8	2.5	29.5	45.
67 10 7	9	4.6	34.1	52.
67 10 7	10	2.8	36.9	57.
67 10 7	11	3.0	39.9	61.
67 10 7	12	0.8	40.7	62.
67 10 7	13	2.8	43.5	67.
67 10 7	14	3.8	47.3	72.
67 10 7	15	4.8	52.1	80.
67 10 7	16	3.8	55.9	86.
67 10 7	17	1.5	57.4	88.
67 10 7	18	3.0	60.4	92.
67 10 7	19	1.3	61.7	94.
67 10 7	20	2.3	64.0	98.
67 10 7	21	1.0	65.0	100.
67 10 7	22	0.3	65.3	100.
67 10 7	23	0.0	65.3	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	5.6	9.	12.7	69 4 17
2	10.2	16.	15.6	78 7 10
3	14.0	21.	19.1	78 7 10
4	17.8	27.	22.4	64 11 29
6	24.7	38.	27.0	64 11 29
8	31.8	49.	32.2	63 12 23
12	41.2	63.	41.2	67 10 7
24	65.3	100.	65.3	67 10 6

TABLE III.25
TIME DISTRIBUTION OF RAINFALL

LANGLEY LOCHIEL

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	5	1.3	1.3	1.
72 12 25	6	3.0	4.3	4.
72 12 25	7	3.0	7.3	7.
72 12 25	8	3.0	10.3	10.
72 12 25	9	2.0	12.3	12.
72 12 25	10	3.8	16.1	16.
72 12 25	11	5.1	21.2	21.
72 12 25	12	5.1	26.3	26.
72 12 25	13	3.3	29.6	29.
72 12 25	14	3.0	32.6	32.
72 12 25	15	2.8	35.4	35.
72 12 25	16	6.4	41.8	41.
72 12 25	17	7.6	49.4	49.
72 12 25	18	9.9	59.3	58.
72 12 25	19	9.4	68.7	68.
72 12 25	20	7.4	76.1	75.
72 12 25	21	4.3	80.4	79.
72 12 25	22	4.6	85.0	84.
72 12 25	23	3.3	88.3	87.
72 12 25	24	4.8	93.1	92.
72 12 26	1	3.0	96.1	95.
72 12 26	2	2.8	98.9	98.
72 12 26	3	1.5	100.4	99.
72 12 26	4	1.0	101.4	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	9.9	10.	17.3	73 10 6
2	19.3	19.	21.4	73 10 6
3	26.9	27.	26.9	72 12 25
4	34.3	34.	34.3	72 12 25
6	45.0	44.	45.0	72 12 25
8	52.9	52.	53.2	79 12 17
12	68.9	68.	68.9	72 12 25
24	101.4	100.	101.4	72 12 25

TABLE III.26
TIME DISTRIBUTION OF RAINFALL

MISSION WEST ABBEY

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 18	11	3.8	3.8	4.
68 1 18	12	3.6	7.4	7.
68 1 18	13	3.6	11.0	11.
68 1 18	14	4.3	15.3	15.
68 1 18	15	4.6	19.9	19.
68 1 18	16	4.8	24.7	24.
68 1 18	17	5.3	30.0	29.
68 1 18	18	4.8	34.8	34.
68 1 18	19	3.8	38.6	37.
68 1 18	20	3.6	42.2	41.
68 1 18	21	4.6	46.8	45.
68 1 18	22	3.0	49.8	48.
68 1 18	23	4.1	53.9	52.
68 1 18	24	5.3	59.2	57.
68 1 19	1	3.8	63.0	61.
68 1 19	2	3.3	66.3	64.
68 1 19	3	5.8	72.1	69.
68 1 19	4	5.8	77.9	75.
68 1 19	5	5.1	83.0	80.
68 1 19	6	3.8	86.8	84.
68 1 19	7	5.8	92.6	89.
68 1 19	8	4.6	97.2	94.
68 1 19	9	3.3	100.5	97.
68 1 19	10	3.3	103.8	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	5.8	6.	24.4	70 11 23
2	11.6	11.	31.6	81 9 27
3	16.7	16.	37.0	81 9 27
4	20.5	20.	40.6	81 9 27
6	30.9	30.	50.2	80 12 25
8	38.7	37.	66.8	80 12 25
12	55.0	53.	85.4	80 12 25
24	103.8	100.	103.8	68 1 18

TABLE III.27
TIME DISTRIBUTION OF RAINFALL

NANAIMO DEPARTURE BAY

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
83 2 10	21	3.6	3.6	5.
83 2 10	22	1.2	4.8	7.
83 2 10	23	4.0	8.8	13.
83 2 10	24	5.9	14.7	21.
83 2 11	1	5.1	19.8	29.
83 2 11	2	4.8	24.6	36.
83 2 11	3	4.0	28.6	41.
83 2 11	4	4.0	32.6	47.
83 2 11	5	4.0	36.6	53.
83 2 11	6	5.9	42.5	62.
83 2 11	7	5.9	48.4	70.
83 2 11	8	1.8	50.2	73.
83 2 11	9	0.4	50.6	73.
83 2 11	10	1.4	52.0	75.
83 2 11	11	0.4	52.4	76.
83 2 11	12	1.0	53.4	77.
83 2 11	13	1.0	54.4	79.
83 2 11	14	1.0	55.4	80.
83 2 11	15	1.6	57.0	83.
83 2 11	16	3.2	60.2	87.
83 2 11	17	2.4	62.6	91.
83 2 11	18	2.0	64.6	94.
83 2 11	19	2.4	67.0	97.
83 2 11	20	2.0	69.0	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	5.9	9.	28.4	72 8 21
2	11.8	17.	37.0	72 8 21
3	15.8	23.	37.0	72 8 21
4	19.8	29.	37.0	72 8 21
6	28.6	41.	37.6	75 2 12
8	39.6	57.	44.2	75 2 12
12	50.2	73.	50.4	83 2 10
24	69.0	100.	69.0	83 2 10

TABLE III.28
TIME DISTRIBUTION OF RAINFALL

NORTH VANC. LYNN CREEK

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
81 10 31	1	6.8	6.8	3.
81 10 31	2	13.6	20.4	8.
81 10 31	3	12.3	32.7	13.
81 10 31	4	10.0	42.7	17.
81 10 31	5	19.6	62.3	25.
81 10 31	6	13.8	76.1	30.
81 10 31	7	17.9	94.0	37.
81 10 31	8	16.8	110.8	44.
81 10 31	9	12.8	123.6	49.
81 10 31	10	14.0	137.6	55.
81 10 31	11	14.7	152.3	61.
81 10 31	12	11.5	163.8	65.
81 10 31	13	10.8	174.6	69.
81 10 31	14	10.0	184.6	73.
81 10 31	15	11.9	196.5	78.
81 10 31	16	9.1	205.6	82.
81 10 31	17	8.9	214.5	85.
81 10 31	18	5.7	220.2	88.
81 10 31	19	5.3	225.5	90.
81 10 31	20	2.1	227.6	91.
81 10 31	21	4.2	231.8	92.
81 10 31	22	6.1	237.9	95.
81 10 31	23	8.7	246.6	98.
81 10 31	24	4.7	251.3	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	19.6	8.	19.6	81 10 31
2	34.7	14.	34.7	81 10 31
3	51.3	20.	51.3	81 10 31
4	68.1	27.	68.1	81 10 31
6	94.9	38.	94.9	81 10 31
8	121.1	48.	121.1	81 10 31
12	167.8	67.	167.8	81 10 31
24	251.3	100.	251.3	81 10 31

TABLE III.29
TIME DISTRIBUTION OF RAINFALL

PITT MEADOWS STP

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 16	20	2.9	2.9	2.
79 12 16	21	1.5	4.4	4.
79 12 16	22	1.0	5.4	5.
79 12 16	23	2.1	7.5	6.
79 12 16	24	2.7	10.2	9.
79 12 17	1	2.1	12.3	10.
79 12 17	2	3.2	15.5	13.
79 12 17	3	5.1	20.6	18.
79 12 17	4	6.3	26.9	23.
79 12 17	5	6.3	33.2	28.
79 12 17	6	7.0	40.2	34.
79 12 17	7	8.0	48.2	41.
79 12 17	8	9.3	57.5	49.
79 12 17	9	7.8	65.3	56.
79 12 17	10	7.8	73.1	62.
79 12 17	11	9.3	82.4	70.
79 12 17	12	9.5	91.9	78.
79 12 17	13	8.3	100.2	85.
79 12 17	14	2.0	102.2	87.
79 12 17	15	4.1	106.3	91.
79 12 17	16	2.9	109.2	93.
79 12 17	17	2.5	111.7	95.
79 12 17	18	3.1	114.8	98.
79 12 17	19	2.5	117.3	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	9.5	8.	24.6	74 7 11
2	18.8	16.	37.6	74 7 11
3	27.1	23.	45.2	74 7 11
4	34.9	30.	51.0	74 7 11
6	52.0	44.	52.8	74 7 11
8	67.0	57.	67.0	79 12 17
12	87.9	75.	87.9	79 12 17
24	117.3	100.	117.3	79 12 16

TABLE III.30
TIME DISTRIBUTION OF RAINFALL

PITT POLDER

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 18	15	5.8	5.8	4.
68 1 18	16	6.1	11.9	8.
68 1 18	17	5.6	17.5	12.
68 1 18	18	5.6	23.1	16.
68 1 18	19	3.3	26.4	18.
68 1 18	20	3.6	30.0	21.
68 1 18	21	3.8	33.8	23.
68 1 18	22	5.1	38.9	27.
68 1 18	23	5.6	44.5	31.
68 1 18	24	6.1	50.6	35.
68 1 19	1	5.8	56.4	39.
68 1 19	2	5.8	62.2	43.
68 1 19	3	6.9	69.1	48.
68 1 19	4	8.1	77.2	53.
68 1 19	5	6.9	84.1	58.
68 1 19	6	5.6	89.7	62.
68 1 19	7	7.1	96.8	67.
68 1 19	8	8.1	104.9	73.
68 1 19	9	6.9	111.8	77.
68 1 19	10	8.1	119.9	83.
68 1 19	11	6.6	126.5	88.
68 1 19	12	6.9	133.4	92.
68 1 19	13	5.8	139.2	96.
68 1 19	14	5.1	144.3	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	8.1	6.	16.8	68 9 17
2	15.2	11.	30.3	68 9 17
3	23.1	16.	42.5	68 9 17
4	30.2	21.	51.9	68 9 16
6	43.7	30.	66.6	68 9 16
8	57.7	40.	78.6	68 9 16
12	82.8	57.	94.9	68 9 16
24	144.3	100.	144.3	68 1 18

TABLE III.31
TIME DISTRIBUTION OF RAINFALL

PORT ALBERNI A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
83 2 10	17	2.4	2.4	2.
83 2 10	18	4.8	7.2	5.
83 2 10	19	4.2	11.4	8.
83 2 10	20	4.4	15.8	11.
83 2 10	21	2.8	18.6	13.
83 2 10	22	5.0	23.6	16.
83 2 10	23	4.0	27.6	19.
83 2 10	24	5.7	33.3	23.
83 2 11	1	7.0	40.3	28.
83 2 11	2	8.8	49.1	34.
83 2 11	3	10.3	59.4	42.
83 2 11	4	6.6	66.0	46.
83 2 11	5	6.2	72.2	50.
83 2 11	6	6.4	78.6	55.
83 2 11	7	6.8	85.4	60.
83 2 11	8	7.2	92.6	65.
83 2 11	9	7.2	99.8	70.
83 2 11	10	8.9	108.7	76.
83 2 11	11	7.6	116.3	81.
83 2 11	12	6.3	122.6	86.
83 2 11	13	6.9	129.5	90.
83 2 11	14	5.0	134.5	94.
83 2 11	15	4.8	139.3	97.
83 2 11	16	3.8	143.1	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	10.3	7.	16.7	78 5 24
2	19.1	13.	29.1	78 5 24
3	26.1	18.	30.0	78 5 24
4	32.7	23.	35.3	73 10 27
6	45.3	32.	46.8	75 11 13
8	59.6	42.	60.2	79 12 17
12	89.3	62.	89.3	83 2 11
24	143.1	100.	143.1	83 2 10

TABLE III.32
TIME DISTRIBUTION OF RAINFALL

PORT COQUITLAM CITY YARD

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	3	0.5	0.5	0.
72 12 25	4	3.0	3.5	3.
72 12 25	5	5.1	8.6	7.
72 12 25	6	5.1	13.7	11.
72 12 25	7	5.3	19.0	15.
72 12 25	8	6.1	25.1	20.
72 12 25	9	7.6	32.7	26.
72 12 25	10	7.4	40.1	32.
72 12 25	11	6.6	46.7	38.
72 12 25	12	5.8	52.5	42.
72 12 25	13	5.3	57.8	46.
72 12 25	14	6.9	64.7	52.
72 12 25	15	6.1	70.8	57.
72 12 25	16	6.1	76.9	62.
72 12 25	17	6.1	83.0	67.
72 12 25	18	6.9	89.9	72.
72 12 25	19	5.6	95.5	77.
72 12 25	20	8.4	103.9	83.
72 12 25	21	8.9	112.8	91.
72 12 25	22	5.8	118.6	95.
72 12 25	23	3.3	121.9	98.
72 12 25	24	1.8	123.7	99.
72 12 26	1	0.5	124.2	100.
72 12 26	2	0.3	124.5	100.

DURATION	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	8.9	7.	12.0	82 7 3
2	17.3	14.	19.8	77 11 25
3	23.1	19.	28.1	79 12 17
4	29.8	24.	34.8	79 12 17
6	42.0	34.	49.8	79 12 17
8	55.0	44.	58.0	79 12 17
12	80.1	64.	80.1	72 12 25
24	124.5	100.	124.5	72 12 25

TABLE III.33
TIME DISTRIBUTION OF RAINFALL

PORT HARDY

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
80 12 9	19	5.0	5.0	3.
80 12 9	20	6.1	11.1	7.
80 12 9	21	6.3	17.4	11.
80 12 9	22	6.5	23.9	14.
80 12 9	23	6.1	30.0	18.
80 12 9	24	7.2	37.2	23.
80 12 10	1	7.0	44.2	27.
80 12 10	2	8.6	52.8	32.
80 12 10	3	7.7	60.5	37.
80 12 10	4	7.7	68.2	41.
80 12 10	5	6.5	74.7	45.
80 12 10	6	5.7	80.4	49.
80 12 10	7	5.0	85.4	52.
80 12 10	8	4.5	89.9	54.
80 12 10	9	4.3	94.2	57.
80 12 10	10	5.4	99.6	60.
80 12 10	11	4.9	104.5	63.
80 12 10	12	5.4	109.9	67.
80 12 10	13	6.3	116.2	70.
80 12 10	14	7.0	123.2	75.
80 12 10	15	9.9	133.1	81.
80 12 10	16	11.9	145.0	88.
80 12 10	17	12.8	157.8	96.
80 12 10	18	7.2	165.0	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	12.8	8.	12.9	80 6 8
2	24.7	15.	24.7	80 12 10
3	34.6	21.	34.6	80 12 10
4	41.8	25.	41.8	80 12 10
6	55.1	33.	55.1	80 12 10
8	65.4	40.	65.4	80 12 10
12	84.6	51.	85.4	80 12 10
24	165.0	100.	165.0	80 12 9

TABLE III.34
TIME DISTRIBUTION OF RAINFALL

PORT MELLON

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	1	0.5	0.5	0.
72 12 25	2	3.0	3.5	1.
72 12 25	3	10.4	13.9	6.
72 12 25	4	12.2	26.1	11.
72 12 25	5	15.0	41.1	17.
72 12 25	6	16.8	57.9	25.
72 12 25	7	11.9	69.8	30.
72 12 25	8	6.6	76.4	32.
72 12 25	9	11.9	88.3	37.
72 12 25	10	20.8	109.1	46.
72 12 25	11	11.2	120.3	51.
72 12 25	12	7.4	127.7	54.
72 12 25	13	8.9	136.6	58.
72 12 25	14	12.2	148.8	63.
72 12 25	15	9.4	158.2	67.
72 12 25	16	7.1	165.3	70.
72 12 25	17	10.2	175.5	74.
72 12 25	18	9.9	185.4	79.
72 12 25	19	11.4	196.8	83.
72 12 25	20	16.0	212.8	90.
72 12 25	21	12.2	225.0	95.
72 12 25	22	5.3	230.3	98.
72 12 25	23	3.0	233.3	99.
72 12 25	24	2.5	235.8	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	20.8	9.	20.8	72 12 25
2	32.7	14.	34.8	70 4 9
3	44.0	19.	44.7	70 4 9
4	55.9	24.	55.9	72 12 25
6	83.0	35.	83.0	72 12 25
8	106.4	45.	106.4	72 12 25
12	145.3	62.	145.3	72 12 25
24	235.8	100.	235.8	72 12 25

TABLE III.35
TIME DISTRIBUTION OF RAINFALL

PORT MOODY GULF OIL REF.

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	3	1.8	1.8	1.
72 12 25	4	4.3	6.1	4.
72 12 25	5	7.1	13.2	9.
72 12 25	6	7.4	20.6	14.
72 12 25	7	5.6	26.2	18.
72 12 25	8	6.6	32.8	23.
72 12 25	9	9.7	42.5	29.
72 12 25	10	8.4	50.9	35.
72 12 25	11	6.4	57.3	39.
72 12 25	12	7.9	65.2	45.
72 12 25	13	5.1	70.3	48.
72 12 25	14	5.1	75.4	52.
72 12 25	15	5.6	81.0	56.
72 12 25	16	7.9	88.9	61.
72 12 25	17	7.1	96.0	66.
72 12 25	18	6.4	102.4	71.
72 12 25	19	6.9	109.3	75.
72 12 25	20	9.4	118.7	82.
72 12 25	21	10.9	129.6	89.
72 12 25	22	8.4	138.0	95.
72 12 25	23	3.8	141.8	98.
72 12 25	24	2.3	144.1	99.
72 12 26	1	0.5	144.6	100.
72 12 26	2	0.5	145.1	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	10.9	8.	19.7	78 2 2
2	20.3	14.	21.8	78 2 2
3	28.7	20.	29.2	81 10 31
4	35.6	25.	36.3	71 10 25
6	49.1	34.	51.6	72 7 12
8	62.6	43.	67.3	72 7 12
12	87.1	60.	92.3	72 7 12
24	145.1	100.	145.1	72 12 25

TABLE III.36
TIME DISTRIBUTION OF RAINFALL

PORT RENFREW BCFS

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 13	5	13.6	13.6	5.
79 12 13	6	11.3	24.9	10.
79 12 13	7	10.4	35.3	14.
79 12 13	8	12.8	48.1	19.
79 12 13	9	14.0	62.1	25.
79 12 13	10	16.0	78.1	31.
79 12 13	11	14.8	92.9	37.
79 12 13	12	9.2	102.1	41.
79 12 13	13	5.2	107.3	43.
79 12 13	14	3.8	111.1	45.
79 12 13	15	4.2	115.3	46.
79 12 13	16	3.8	119.1	48.
79 12 13	17	6.2	125.3	50.
79 12 13	18	8.4	133.7	54.
79 12 13	19	10.8	144.5	58.
79 12 13	20	10.0	154.5	62.
79 12 13	21	12.0	166.5	67.
79 12 13	22	9.6	176.1	71.
79 12 13	23	12.0	188.1	76.
79 12 13	24	14.0	202.1	81.
79 12 14	1	14.0	216.1	87.
79 12 14	2	14.0	230.1	93.
79 12 14	3	8.0	238.1	96.
79 12 14	4	10.2	248.3	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	16.0	6.	43.7	77 11 1
2	30.8	12.	56.3	78 11 7
3	44.8	18.	78.1	78 11 7
4	57.6	23.	99.7	78 11 7
6	79.3	32.	117.6	78 11 7
8	102.1	41.	125.2	78 11 7
12	129.2	52.	153.6	75 10 16
24	248.3	100.	248.3	79 12 13

TABLE III.37
TIME DISTRIBUTION OF RAINFALL

PRINCE RUPERT A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
74 10 8	4	6.6	6.6	5.
74 10 8	5	8.9	15.5	11.
74 10 8	6	8.1	23.6	17.
74 10 8	7	5.3	28.9	21.
74 10 8	8	3.8	32.7	24.
74 10 8	9	2.5	35.2	26.
74 10 8	10	4.8	40.0	29.
74 10 8	11	3.0	43.0	32.
74 10 8	12	3.3	46.3	34.
74 10 8	13	4.6	50.9	37.
74 10 8	14	3.6	54.5	40.
74 10 8	15	2.8	57.3	42.
74 10 8	16	9.4	66.7	49.
74 10 8	17	4.8	71.5	53.
74 10 8	18	1.8	73.3	54.
74 10 8	19	1.8	75.1	55.
74 10 8	20	6.9	82.0	60.
74 10 8	21	7.1	89.1	66.
74 10 8	22	5.8	94.9	70.
74 10 8	23	8.4	103.3	76.
74 10 8	24	12.2	115.5	85.
74 10 9	1	9.9	125.4	92.
74 10 9	2	6.1	131.5	97.
74 10 9	3	4.3	135.8	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	12.2	9.	16.2	83 9 25
2	22.1	16.	24.7	76 10 26
3	30.5	22.	33.8	76 10 26
4	36.6	27.	42.8	76 10 26
6	50.3	37.	63.4	76 10 26
8	60.7	45.	80.6	76 10 26
12	78.5	58.	98.4	72 10 23
24	135.8	100.	135.8	74 10 8

TABLE III.38
TIME DISTRIBUTION OF RAINFALL

SAANICH DENSMORE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	3	1.3	1.3	1.
72 12 25	4	3.0	4.3	4.
72 12 25	5	4.1	8.4	9.
72 12 25	6	3.3	11.7	12.
72 12 25	7	4.6	16.3	17.
72 12 25	8	3.8	20.1	20.
72 12 25	9	2.5	22.6	23.
72 12 25	10	3.6	26.2	27.
72 12 25	11	3.8	30.0	30.
72 12 25	12	3.0	33.0	33.
72 12 25	13	3.8	36.8	37.
72 12 25	14	4.1	40.9	41.
72 12 25	15	4.6	45.5	46.
72 12 25	16	7.1	52.6	53.
72 12 25	17	4.8	57.4	58.
72 12 25	18	4.1	61.5	62.
72 12 25	19	4.3	65.8	67.
72 12 25	20	4.6	70.4	71.
72 12 25	21	4.3	74.7	76.
72 12 25	22	6.6	81.3	82.
72 12 25	23	7.6	88.9	90.
72 12 25	24	4.8	93.7	95.
72 12 26	1	3.6	97.3	99.
72 12 26	2	1.3	98.6	100.

DURATION	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	7.6	8.	9.4	72 2 16
2	14.2	14.	15.2	72 2 16
3	19.0	19.	20.9	65 10 5
4	23.3	24.	25.1	67 1 2
6	32.2	33.	32.2	64 9 30
8	43.4	44.	43.4	72 12 25
12	60.7	62.	60.7	72 12 25
24	98.6	100.	98.6	72 12 25

TABLE III.39
TIME DISTRIBUTION OF RAINFALL

SANDSPIT A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
78 10 31	16	2.9	2.9	4.
78 10 31	17	3.2	6.1	8.
78 10 31	18	1.7	7.8	10.
78 10 31	19	2.3	10.1	13.
78 10 31	20	1.5	11.6	15.
78 10 31	21	1.2	12.8	17.
78 10 31	22	2.1	14.9	20.
78 10 31	23	4.3	19.2	26.
78 10 31	24	4.3	23.5	31.
78 11 1	1	3.8	27.3	36.
78 11 1	2	1.6	28.9	39.
78 11 1	3	1.6	30.5	41.
78 11 1	4	3.1	33.6	45.
78 11 1	5	3.1	36.7	49.
78 11 1	6	2.6	39.3	52.
78 11 1	7	3.5	42.8	57.
78 11 1	8	4.3	47.1	63.
78 11 1	9	3.5	50.6	67.
78 11 1	10	3.1	53.7	72.
78 11 1	11	3.8	57.5	77.
78 11 1	12	3.5	61.0	81.
78 11 1	13	5.4	66.4	89.
78 11 1	14	4.8	71.2	95.
78 11 1	15	3.8	75.0	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	5.4	7.	12.7	75 10 5
2	10.2	14.	22.0	80 10 31
3	14.0	19.	32.3	80 10 31
4	17.5	23.	38.8	80 10 31
6	24.4	33.	42.8	80 10 31
8	32.2	43.	47.0	75 10 4
12	44.5	59.	51.8	79 11 20
24	75.0	100.	75.0	78 10 31

TABLE III.40
TIME DISTRIBUTION OF RAINFALL

SPRING ISLAND

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
78 11 6	2	3.8	3.8	2.
78 11 6	3	7.8	11.6	6.
78 11 6	4	0.4	12.0	6.
78 11 6	5	8.6	20.6	10.
78 11 6	6	8.8	29.4	15.
78 11 6	7	12.2	41.6	21.
78 11 6	8	12.8	54.4	27.
78 11 6	9	12.8	67.2	33.
78 11 6	10	13.8	81.0	40.
78 11 6	11	12.0	93.0	46.
78 11 6	12	13.6	106.6	53.
78 11 6	13	10.8	117.4	58.
78 11 6	14	8.6	126.0	63.
78 11 6	15	13.6	139.6	69.
78 11 6	16	12.0	151.6	75.
78 11 6	17	11.2	162.8	81.
78 11 6	18	12.6	175.4	87.
78 11 6	19	2.4	177.8	88.
78 11 6	20	4.0	181.8	90.
78 11 6	21	4.8	186.6	93.
78 11 6	22	3.4	190.0	94.
78 11 6	23	4.8	194.8	97.
78 11 6	24	2.4	197.2	98.
78 11 7	1	4.4	201.6	100.

DURATION	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL			
			MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	13.8	7.	22.6	79 9 4
2	26.6	13.	30.4	75 11 25
3	39.4	20.	40.6	78 10 22
4	52.2	26.	52.2	78 11 6
6	77.2	38.	77.2	78 11 6
8	98.0	49.	98.0	78 11 6
12	146.0	72.	146.0	78 11 6
24	201.6	100.	201.6	78 11 6

TABLE III.41
TIME DISTRIBUTION OF RAINFALL

STAVE FALLS

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
80 12 25	11	3.5	3.5	3.
80 12 25	12	0.6	4.1	3.
80 12 25	13	0.0	4.1	3.
80 12 25	14	0.0	4.1	3.
80 12 25	15	0.0	4.1	3.
80 12 25	16	0.0	4.1	3.
80 12 25	17	2.0	6.1	5.
80 12 25	18	1.4	7.5	6.
80 12 25	19	2.9	10.4	8.
80 12 25	20	3.1	13.5	10.
80 12 25	21	4.7	18.2	14.
80 12 25	22	7.1	25.3	19.
80 12 25	23	6.1	31.4	24.
80 12 25	24	10.6	42.0	32.
80 12 26	1	11.0	53.0	40.
80 12 26	2	10.8	63.8	48.
80 12 26	3	8.9	72.7	55.
80 12 26	4	12.8	85.5	64.
80 12 26	5	8.5	94.0	71.
80 12 26	6	7.7	101.7	77.
80 12 26	7	10.6	112.3	85.
80 12 26	8	9.7	122.0	92.
80 12 26	9	5.5	127.5	96.
80 12 26	10	5.3	132.8	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	12.8	10.	14.6	81 9 27
2	21.8	16.	25.5	81 9 27
3	32.5	24.	32.5	80 12 26
4	43.5	33.	43.5	80 12 26
6	62.6	47.	62.6	80 12 25
8	80.9	61.	80.9	80 12 25
12	109.3	82.	109.3	80 12 25
24	132.8	100.	132.8	80 12 25

TABLE III.42
TIME DISTRIBUTION OF RAINFALL

STRATHCONA DAM

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 17	17	5.1	5.1	3.
68 1 17	18	9.7	14.8	10.
68 1 17	19	7.6	22.4	14.
68 1 17	20	6.6	29.0	19.
68 1 17	21	12.7	41.7	27.
68 1 17	22	7.6	49.3	32.
68 1 17	23	9.1	58.4	38.
68 1 17	24	8.6	67.0	43.
68 1 18	1	8.1	75.1	48.
68 1 18	2	10.2	85.3	55.
68 1 18	3	7.1	92.4	60.
68 1 18	4	8.1	100.5	65.
68 1 18	5	4.1	104.6	67.
68 1 18	6	10.2	114.8	74.
68 1 18	7	3.6	118.4	76.
68 1 18	8	5.6	124.0	80.
68 1 18	9	4.1	128.1	83.
68 1 18	10	5.1	133.2	86.
68 1 18	11	4.1	137.3	88.
68 1 18	12	4.1	141.4	91.
68 1 18	13	1.8	143.2	92.
68 1 18	14	3.3	146.5	94.
68 1 18	15	3.6	150.1	97.
68 1 18	16	5.1	155.2	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	12.7	8.	23.9	69 2 7
2	20.3	13.	26.0	73 7 7
3	29.4	19.	29.4	68 1 17
4	38.0	24.	38.0	68 1 17
6	56.3	36.	56.3	68 1 17
8	71.5	46.	71.5	68 1 17
12	100.5	65.	100.5	68 1 17
24	155.2	100.	155.2	68 1 17

TABLE III.43
TIME DISTRIBUTION OF RAINFALL

SURREY KWANTLEN PARK

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
68 1 18	13	4.6	4.6	3.
68 1 18	14	6.1	10.7	8.
68 1 18	15	4.8	15.5	11.
68 1 18	16	7.9	23.4	17.
68 1 18	17	5.6	29.0	21.
68 1 18	18	7.4	36.4	26.
68 1 18	19	5.6	42.0	30.
68 1 18	20	5.6	47.6	34.
68 1 18	21	4.8	52.4	37.
68 1 18	22	5.1	57.5	41.
68 1 18	23	5.3	62.8	45.
68 1 18	24	3.8	66.6	48.
68 1 19	1	6.4	73.0	52.
68 1 19	2	4.6	77.6	55.
68 1 19	3	7.6	85.2	61.
68 1 19	4	10.4	95.6	68.
68 1 19	5	10.7	106.3	76.
68 1 19	6	5.8	112.1	80.
68 1 19	7	5.6	117.7	84.
68 1 19	8	6.4	124.1	89.
68 1 19	9	2.0	126.1	90.
68 1 19	10	4.6	130.7	93.
68 1 19	11	4.6	135.3	97.
68 1 19	12	4.8	140.1	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	10.7	8.	18.2	83 9 1
2	21.1	15.	28.2	62 2 3
3	28.7	20.	35.1	62 2 2
4	34.5	25.	37.1	62 2 2
6	46.5	33.	46.5	68 1 19
8	57.5	41.	57.5	68 1 19
12	77.3	55.	81.3	72 12 25
24	140.1	100.	140.1	68 1 18

TABLE III.44
TIME DISTRIBUTION OF RAINFALL

SURREY MUNICIPAL HALL

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	3	0.5	0.5	1.
72 12 25	4	0.8	1.3	1.
72 12 25	5	2.5	3.8	4.
72 12 25	6	4.3	8.1	9.
72 12 25	7	3.0	11.1	12.
72 12 25	8	3.3	14.4	15.
72 12 25	9	3.6	18.0	19.
72 12 25	10	4.3	22.3	23.
72 12 25	11	3.8	26.1	27.
72 12 25	12	3.8	29.9	31.
72 12 25	13	4.1	34.0	36.
72 12 25	14	4.1	38.1	40.
72 12 25	15	4.3	42.4	45.
72 12 25	16	5.6	48.0	51.
72 12 25	17	6.4	54.4	57.
72 12 25	18	8.4	62.8	66.
72 12 25	19	8.1	70.9	75.
72 12 25	20	7.1	78.0	82.
72 12 25	21	4.6	82.6	87.
72 12 25	22	3.3	85.9	90.
72 12 25	23	3.6	89.5	94.
72 12 25	24	3.0	92.5	97.
72 12 26	1	1.5	94.0	99.
72 12 26	2	1.0	95.0	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	8.4	9.	17.5	68 8 27
2	16.5	17.	21.5	81 7 29
3	23.6	25.	26.0	80 7 11
4	30.0	32.	31.6	80 7 11
6	40.2	42.	44.9	67 12 22
8	48.6	51.	56.6	67 12 21
12	64.6	68.	64.6	72 12 25
24	95.0	100.	95.0	72 12 25

TABLE III.45
TIME DISTRIBUTION OF RAINFALL

TERRACE A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
78 10 30	22	2.3	2.3	2.
78 10 30	23	3.6	5.9	5.
78 10 30	24	4.3	10.2	9.
78 10 31	1	5.3	15.5	13.
78 10 31	2	4.5	20.0	17.
78 10 31	3	5.5	25.5	22.
78 10 31	4	6.3	31.8	28.
78 10 31	5	8.1	39.9	35.
78 10 31	6	7.3	47.2	41.
78 10 31	7	7.5	54.7	47.
78 10 31	8	9.7	64.4	56.
78 10 31	9	6.5	70.9	61.
78 10 31	10	5.1	76.0	66.
78 10 31	11	4.1	80.1	69.
78 10 31	12	4.7	84.8	73.
78 10 31	13	4.7	89.5	77.
78 10 31	14	4.0	93.5	81.
78 10 31	15	3.8	97.3	84.
78 10 31	16	3.4	100.7	87.
78 10 31	17	3.4	104.1	90.
78 10 31	18	3.2	107.3	93.
78 10 31	19	2.8	110.1	95.
78 10 31	20	2.6	112.7	98.
78 10 31	21	2.8	115.5	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	9.7	8.	16.6	80 7 27
2	17.2	15.	19.2	80 7 27
3	24.5	21.	24.5	78 10 31
4	32.6	28.	32.6	78 10 31
6	45.4	39.	45.4	78 10 31
8	56.0	48.	56.0	78 10 31
12	74.6	65.	74.6	78 10 31
24	115.5	100.	115.5	78 10 30

TABLE III.46
TIME DISTRIBUTION OF RAINFALL

TERRACE PCC

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
74 10 14	15	2.0	2.0	2.
74 10 14	16	0.5	2.5	3.
74 10 14	17	0.8	3.3	4.
74 10 14	18	2.0	5.3	6.
74 10 14	19	1.8	7.1	9.
74 10 14	20	1.8	8.9	11.
74 10 14	21	2.8	11.7	14.
74 10 14	22	2.5	14.2	17.
74 10 14	23	3.3	17.5	21.
74 10 14	24	3.8	21.3	26.
74 10 15	1	3.8	25.1	30.
74 10 15	2	3.6	28.7	35.
74 10 15	3	4.6	33.3	40.
74 10 15	4	5.6	38.9	47.
74 10 15	5	5.1	44.0	53.
74 10 15	6	5.1	49.1	59.
74 10 15	7	6.6	55.7	67.
74 10 15	8	8.1	63.8	77.
74 10 15	9	5.1	68.9	83.
74 10 15	10	2.0	70.9	86.
74 10 15	11	4.8	75.7	91.
74 10 15	12	2.3	78.0	94.
74 10 15	13	2.5	80.5	97.
74 10 15	14	2.3	82.8	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	8.1	10.	19.1	80 9 19
2	14.7	18.	30.5	68 11 19
3	19.8	24.	41.9	68 11 19
4	24.9	30.	45.7	68 11 19
6	35.6	43.	50.2	68 11 19
8	43.8	53.	54.3	68 11 19
12	58.2	70.	62.9	68 11 19
24	82.8	100.	82.8	74 10 14

TABLE III.47
TIME DISTRIBUTION OF RAINFALL

TOFINO A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
80 12 9	18	7.5	7.5	4.
80 12 9	19	8.9	16.4	8.
80 12 9	20	9.5	25.9	12.
80 12 9	21	7.4	33.3	16.
80 12 9	22	9.7	43.0	21.
80 12 9	23	12.8	55.8	27.
80 12 9	24	10.8	66.6	32.
80 12 10	1	4.7	71.3	34.
80 12 10	2	1.6	72.9	35.
80 12 10	3	1.9	74.8	36.
80 12 10	4	3.1	77.9	37.
80 12 10	5	5.6	83.5	40.
80 12 10	6	6.0	89.5	43.
80 12 10	7	4.7	94.2	45.
80 12 10	8	7.9	102.1	49.
80 12 10	9	13.9	116.0	56.
80 12 10	10	15.1	131.1	63.
80 12 10	11	16.4	147.5	71.
80 12 10	12	17.3	164.8	79.
80 12 10	13	14.6	179.4	86.
80 12 10	14	5.8	185.2	89.
80 12 10	15	7.9	193.1	93.
80 12 10	16	8.3	201.4	97.
80 12 10	17	7.2	208.6	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	17.3	8.	21.4	77 10 25
2	33.7	16.	35.3	71 11 2
3	48.8	23.	48.8	80 12 10
4	63.4	30.	63.4	80 12 10
6	85.2	41.	85.2	80 12 10
8	99.3	48.	99.3	80 12 10
12	125.1	60.	125.1	80 12 10
24	208.6	100.	208.6	80 12 9

TABLE III.48
TIME DISTRIBUTION OF RAINFALL

VANCOUVER A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 16	20	3.2	3.2	3.
79 12 16	21	2.6	5.8	5.
79 12 16	22	1.8	7.6	6.
79 12 16	23	3.6	11.2	9.
79 12 16	24	3.6	14.8	12.
79 12 17	1	3.0	17.8	15.
79 12 17	2	5.2	23.0	19.
79 12 17	3	5.4	28.4	23.
79 12 17	4	5.7	34.1	28.
79 12 17	5	6.5	40.6	33.
79 12 17	6	5.9	46.5	38.
79 12 17	7	6.7	53.2	44.
79 12 17	8	9.9	63.1	52.
79 12 17	9	10.9	74.0	61.
79 12 17	10	13.1	87.1	72.
79 12 17	11	9.4	96.5	79.
79 12 17	12	3.2	99.7	82.
79 12 17	13	2.3	102.0	84.
79 12 17	14	2.5	104.5	86.
79 12 17	15	4.7	109.2	90.
79 12 17	16	3.5	112.7	93.
79 12 17	17	3.2	115.9	95.
79 12 17	18	1.8	117.7	97.
79 12 17	19	3.7	121.4	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	13.1	11.	23.1	81 6 13
2	24.0	20.	29.5	81 6 13
3	33.9	28.	34.0	81 6 13
4	43.3	36.	43.3	79 12 17
6	55.9	46.	55.9	79 12 17
8	68.1	56.	68.1	79 12 17
12	85.3	70.	85.3	79 12 16
24	121.4	100.	121.4	79 12 16

TABLE III.49
TIME DISTRIBUTION OF RAINFALL

VANCOUVER HARBOUR

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	2	0.5	0.5	1.
72 12 25	3	0.8	1.3	1.
72 12 25	4	3.3	4.6	5.
72 12 25	5	4.8	9.4	10.
72 12 25	6	4.6	14.0	15.
72 12 25	7	4.3	18.3	20.
72 12 25	8	4.1	22.4	24.
72 12 25	9	3.6	26.0	28.
72 12 25	10	4.3	30.3	33.
72 12 25	11	3.0	33.3	36.
72 12 25	12	3.0	36.3	39.
72 12 25	13	4.8	41.1	44.
72 12 25	14	4.6	45.7	49.
72 12 25	15	4.3	50.0	54.
72 12 25	16	6.4	56.4	61.
72 12 25	17	5.1	61.5	66.
72 12 25	18	7.4	68.9	74.
72 12 25	19	6.1	75.0	81.
72 12 25	20	5.3	80.3	86.
72 12 25	21	4.3	84.6	91.
72 12 25	22	4.3	88.9	96.
72 12 25	23	2.5	91.4	98.
72 12 25	24	1.5	92.9	100.
72 12 26	1	0.0	92.9	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	7.4	8.	15.0	62 2 3
2	13.5	15.	26.9	62 2 3
3	18.9	20.	32.2	62 2 2
4	25.0	27.	32.2	62 2 2
6	34.6	37.	40.3	79 12 17
8	44.0	47.	53.4	79 12 17
12	58.6	63.	67.4	79 12 16
24	92.9	100.	92.9	72 12 25

TABLE III.50
TIME DISTRIBUTION OF RAINFALL

VANCOUVER PMO

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	3	0.3	0.3	0.
72 12 25	4	2.0	2.3	2.
72 12 25	5	4.8	7.1	5.
72 12 25	6	9.7	16.8	12.
72 12 25	7	7.6	24.4	17.
72 12 25	8	5.3	29.7	21.
72 12 25	9	5.1	34.8	25.
72 12 25	10	8.4	43.2	31.
72 12 25	11	7.6	50.8	36.
72 12 25	12	5.6	56.4	40.
72 12 25	13	7.1	63.5	45.
72 12 25	14	5.6	69.1	49.
72 12 25	15	4.6	73.7	52.
72 12 25	16	5.3	79.0	56.
72 12 25	17	6.9	85.9	61.
72 12 25	18	8.1	94.0	66.
72 12 25	19	7.6	101.6	72.
72 12 25	20	6.1	107.7	76.
72 12 25	21	8.4	116.1	82.
72 12 25	22	9.4	125.5	89.
72 12 25	23	7.6	133.1	94.
72 12 25	24	6.1	139.2	98.
72 12 26	1	2.3	141.5	100.
72 12 26	2	0.0	141.5	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	9.7	7.	13.2	71 10 25
2	17.8	13.	20.6	71 10 25
3	25.4	18.	28.0	71 10 25
4	31.5	22.	35.4	71 10 25
6	47.2	33.	47.2	72 12 25
8	60.2	43.	60.2	72 12 25
12	82.8	59.	82.8	72 12 25
24	141.5	100.	141.5	72 12 25

TABLE III.51
TIME DISTRIBUTION OF RAINFALL

VANCOUVER UBC

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	2	0.3	0.3	0.
72 12 25	3	1.3	1.6	1.
72 12 25	4	4.1	5.7	5.
72 12 25	5	5.8	11.5	10.
72 12 25	6	6.9	18.4	16.
72 12 25	7	6.4	24.8	22.
72 12 25	8	4.1	28.9	25.
72 12 25	9	4.3	33.2	29.
72 12 25	10	5.1	38.3	34.
72 12 25	11	4.3	42.6	37.
72 12 25	12	4.1	46.7	41.
72 12 25	13	3.8	50.5	44.
72 12 25	14	5.1	55.6	49.
72 12 25	15	6.9	62.5	55.
72 12 25	16	8.1	70.6	62.
72 12 25	17	8.6	79.2	69.
72 12 25	18	7.4	86.6	76.
72 12 25	19	5.8	92.4	81.
72 12 25	20	5.8	98.2	86.
72 12 25	21	7.4	105.6	93.
72 12 25	22	5.6	111.2	98.
72 12 25	23	1.8	113.0	99.
72 12 25	24	1.0	114.0	100.
72 12 26	1	0.0	114.0	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	8.6	8.	16.4	79 9 8
2	16.7	15.	21.4	81 7 7
3	24.1	21.	27.3	81 7 6
4	31.0	27.	31.0	72 12 25
6	43.1	38.	43.1	72 12 25
8	55.6	49.	55.6	72 12 25
12	72.9	64.	72.9	72 12 25
24	114.0	100.	114.0	72 12 25

TABLE III.52
TIME DISTRIBUTION OF RAINFALL

VICTORIA GONZALES HEIGHTS

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 13	8	3.4	3.4	3.
79 12 13	9	5.0	8.4	8.
79 12 13	10	8.3	16.7	17.
79 12 13	11	6.9	23.6	24.
79 12 13	12	6.1	29.7	30.
79 12 13	13	4.5	34.2	34.
79 12 13	14	4.5	38.7	39.
79 12 13	15	3.8	42.5	42.
79 12 13	16	4.8	47.3	47.
79 12 13	17	4.0	51.3	51.
79 12 13	18	5.9	57.2	57.
79 12 13	19	6.1	63.3	63.
79 12 13	20	6.4	69.7	70.
79 12 13	21	5.6	75.3	75.
79 12 13	22	4.8	80.1	80.
79 12 13	23	5.4	85.5	85.
79 12 13	24	4.3	89.8	90.
79 12 14	1	1.6	91.4	91.
79 12 14	2	1.0	92.4	92.
79 12 14	3	0.3	92.7	93.
79 12 14	4	0.0	92.7	93.
79 12 14	5	0.3	93.0	93.
79 12 14	6	0.3	93.3	93.
79 12 14	7	6.9	100.2	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	8.3	8.	9.5	82 12 3
2	15.2	15.	18.6	82 12 3
3	21.3	21.	26.9	82 12 3
4	26.3	26.	35.0	82 12 3
6	35.3	35.	47.8	82 12 3
8	43.9	44.	58.9	82 12 3
12	66.9	67.	72.7	82 12 3
24	100.2	100.	100.2	79 12 13

TABLE III.53
TIME DISTRIBUTION OF RAINFALL

VICTORIA INT. A

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	2	1.3	1.3	1.
72 12 25	3	1.8	3.1	3.
72 12 25	4	3.6	6.7	7.
72 12 25	5	3.6	10.3	12.
72 12 25	6	2.3	12.6	14.
72 12 25	7	3.3	15.9	18.
72 12 25	8	1.3	17.2	19.
72 12 25	9	1.3	18.5	21.
72 12 25	10	1.8	20.3	23.
72 12 25	11	3.6	23.9	27.
72 12 25	12	2.0	25.9	29.
72 12 25	13	2.3	28.2	32.
72 12 25	14	2.5	30.7	34.
72 12 25	15	1.8	32.5	36.
72 12 25	16	5.6	38.1	43.
72 12 25	17	7.6	45.7	51.
72 12 25	18	4.6	50.3	56.
72 12 25	19	4.8	55.1	62.
72 12 25	20	5.1	60.2	67.
72 12 25	21	5.8	66.0	74.
72 12 25	22	6.9	72.9	82.
72 12 25	23	9.9	82.8	93.
72 12 25	24	4.3	87.1	97.
72 12 26	1	2.3	89.4	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	9.9	11.	11.9	74 11 9
2	16.8	19.	18.5	74 11 9
3	22.6	25.	23.3	74 11 9
4	27.7	31.	27.7	72 12 25
6	37.1	41.	38.2	80 11 21
8	50.3	56.	50.3	72 12 25
12	61.2	68.	61.2	72 12 25
24	89.4	100.	89.4	72 12 25

TABLE III.54
TIME DISTRIBUTION OF RAINFALL

VICTORIA MARINE RADIO

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D			HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72	3	4	22	1.0	1.0	1.
72	3	4	23	1.5	2.5	2.
72	3	4	24	3.6	6.1	6.
72	3	5	1	3.3	9.4	9.
72	3	5	2	5.3	14.7	14.
72	3	5	3	4.3	19.0	18.
72	3	5	4	6.9	25.9	24.
72	3	5	5	8.4	34.3	32.
72	3	5	6	6.9	41.2	38.
72	3	5	7	6.6	47.8	44.
72	3	5	8	10.7	58.5	54.
72	3	5	9	2.3	60.8	56.
72	3	5	10	1.3	62.1	58.
72	3	5	11	1.5	63.6	59.
72	3	5	12	5.1	68.7	64.
72	3	5	13	6.6	75.3	70.
72	3	5	14	4.8	80.1	74.
72	3	5	15	5.8	85.9	80.
72	3	5	16	6.6	92.5	86.
72	3	5	17	5.8	98.3	91.
72	3	5	18	5.3	103.6	96.
72	3	5	19	1.8	105.4	98.
72	3	5	20	1.0	106.4	99.
72	3	5	21	1.3	107.7	100.

DURATION	FOR INDICATED DURATION:					
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE		
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D		
1	10.7	10.	17.8	78	1	21
2	17.3	16.	24.8	78	1	21
3	24.2	22.	29.0	82	1	23
4	32.6	30.	35.7	82	1	23
6	43.8	41.	45.1	82	1	23
8	52.4	49.	53.3	82	1	23
12	66.9	62.	69.4	72	12	25
24	107.7	100.	107.7	72	3	4

TABLE III.55
TIME DISTRIBUTION OF RAINFALL

VICTORIA SHELBOURNE

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
72 12 25	4	1.3	1.3	1.
72 12 25	5	3.3	4.6	5.
72 12 25	6	1.5	6.1	7.
72 12 25	7	2.8	8.9	10.
72 12 25	8	3.6	12.5	14.
72 12 25	9	4.1	16.6	19.
72 12 25	10	3.3	19.9	23.
72 12 25	11	3.3	23.2	27.
72 12 25	12	2.8	26.0	30.
72 12 25	13	4.8	30.8	36.
72 12 25	14	3.8	34.6	40.
72 12 25	15	5.1	39.7	46.
72 12 25	16	5.6	45.3	52.
72 12 25	17	3.8	49.1	57.
72 12 25	18	2.8	51.9	60.
72 12 25	19	3.8	55.7	64.
72 12 25	20	4.6	60.3	70.
72 12 25	21	4.3	64.6	75.
72 12 25	22	5.6	70.2	81.
72 12 25	23	7.4	77.6	90.
72 12 25	24	5.3	82.9	96.
72 12 26	1	2.5	85.4	99.
72 12 26	2	0.8	86.2	99.
72 12 26	3	0.5	86.7	100.

DURATION (HOURS)	FOR INDICATED DURATION: MAX OCCURRING WITHIN MAX 24-HR RAINFALL (MM)	% OF 24-HR	MAXIMUM ON RECORD (MM)	DATE YR-M-D
1	7.4	9.	11.7	71 2 12
2	13.0	15.	14.7	71 2 12
3	18.3	21.	18.3	72 12 25
4	22.6	26.	22.6	72 12 25
6	31.0	36.	31.0	72 12 25
8	37.9	44.	37.9	72 12 25
12	56.9	66.	56.9	72 12 25
24	86.7	100.	86.7	72 12 25

TABLE III.56
TIME DISTRIBUTION OF RAINFALL

VICTORIA U. OF VICT.

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
79 12 13	4	0.8	0.8	1.
79 12 13	5	1.4	2.2	2.
79 12 13	6	2.4	4.6	5.
79 12 13	7	3.9	8.5	9.
79 12 13	8	3.3	11.8	13.
79 12 13	9	3.0	14.8	16.
79 12 13	10	6.4	21.2	23.
79 12 13	11	5.6	26.8	30.
79 12 13	12	5.0	31.8	35.
79 12 13	13	5.2	37.0	41.
79 12 13	14	3.8	40.8	45.
79 12 13	15	3.2	44.0	49.
79 12 13	16	4.2	48.2	53.
79 12 13	17	3.2	51.4	57.
79 12 13	18	4.8	56.2	62.
79 12 13	19	5.6	61.8	68.
79 12 13	20	5.6	67.4	74.
79 12 13	21	4.8	72.2	80.
79 12 13	22	4.6	76.8	85.
79 12 13	23	4.2	81.0	89.
79 12 13	24	4.0	85.0	94.
79 12 14	1	1.8	86.8	96.
79 12 14	2	3.0	89.8	99.
79 12 14	3	0.8	90.6	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	6.4	7.	9.9	81 11 14
2	12.0	13.	15.8	83 1 8
3	17.0	19.	21.4	74 12 20
4	22.2	25.	25.4	82 1 23
6	29.6	33.	37.8	82 1 23
8	37.0	41.	47.4	82 1 23
12	57.4	63.	57.4	79 12 13
24	90.6	100.	90.6	79 12 13

TABLE III.57
TIME DISTRIBUTION OF RAINFALL

WHITE ROCK STP

MAXIMUM 24-HOUR RAINFALL ON RECORD

DATE YR-M-D	HOUR	HOURLY RAIN (MM)	CUM. RAIN (MM)	PERCENT OF 24-HOUR RAINFALL
71 11 2	21	0.5	0.5	1.
71 11 2	22	0.3	0.8	1.
71 11 2	23	0.0	0.8	1.
71 11 2	24	0.3	1.1	1.
71 11 3	1	0.0	1.1	1.
71 11 3	2	0.0	1.1	1.
71 11 3	3	2.3	3.4	4.
71 11 3	4	3.3	6.7	8.
71 11 3	5	4.6	11.3	13.
71 11 3	6	4.8	16.1	19.
71 11 3	7	4.6	20.7	25.
71 11 3	8	4.8	25.5	30.
71 11 3	9	5.3	30.8	37.
71 11 3	10	4.8	35.6	42.
71 11 3	11	4.8	40.4	48.
71 11 3	12	6.4	46.8	56.
71 11 3	13	6.1	52.9	63.
71 11 3	14	7.6	60.5	72.
71 11 3	15	7.1	67.6	80.
71 11 3	16	6.4	74.0	88.
71 11 3	17	5.1	79.1	94.
71 11 3	18	2.3	81.4	97.
71 11 3	19	1.8	83.2	99.
71 11 3	20	1.0	84.2	100.

DURATION	FOR INDICATED DURATION:			
	MAX OCCURRING WITHIN MAX 24-HR RAINFALL		MAXIMUM ON RECORD	DATE
(HOURS)	(MM)	% OF 24-HR	(MM)	YR-M-D
1	7.6	9.	15.2	72 7 9
2	14.7	17.	24.3	72 7 9
3	21.1	25.	25.8	72 7 9
4	27.2	32.	27.7	78 11 3
6	38.7	46.	38.7	71 11 3
8	48.5	58.	48.5	71 11 3
12	67.8	81.	67.8	71 11 3
24	84.2	100.	84.2	71 11 2

APPENDIX IV

WATER PERCOLATION THROUGH SNOW

APPENDIX IV
WATER PERCOLATION THROUGH SNOW

IV.1 VERTICAL UNSATURATED FLOW

A physical model for vertical percolation of water through a homogeneous ripe snowpack has been developed by Colbeck (1971, 1972). Relationships derived by Colbeck and results of field studies undertaken to verify theoretical results are summarized in this section.

Development of the theory requires the following relationships between snowpack permeability and water saturation:

$$k_s = k_u S^3 \qquad \text{(IV..1)}$$

where S = saturation of the snowpack; k_u = intrinsic permeability in the unsaturated zone; and k_s = snowpack permeability at some value of S.

Also,

$$\phi_e = \phi(1 - S_i) \qquad \text{(IV.2)}$$

where Ø = total porosity of the snowpack; S_i = irreducible saturation; and $Ø_e$ = effective snowpack porosity.

Colbeck shows the vertical rate of movement of a water input, m, at the snow surface is given by:

$$\left(\frac{dz}{dt}\right)_m = \frac{3m^{0.67}}{\phi_e}\left(\frac{\rho g k_u}{\mu}\right)^{0.33} \qquad \text{(IV.3)}$$

where $(dz/dt)_m$ = speed of propagation of a wave with input rate m; p = density of water; g = acceleration due to gravity; and μ = viscosity of water.

Experiments have been conducted by Colbeck and Davidson (1973) on a small valley glacier in the Cascade Mountains in Washington State to compare theoretical and measured field results. Five holes were bored and flow measuring devices were installed at depths ranging from 1 m to 5 m. Results of the study are summarized on Figure IV.1 and show experimental data agreed with results derived from theoretical considerations. Similar results were also obtained by Colbeck and Anderson (1982) from experimental studies in Vermont and California, and by Jordan (1978) in British Columbia.

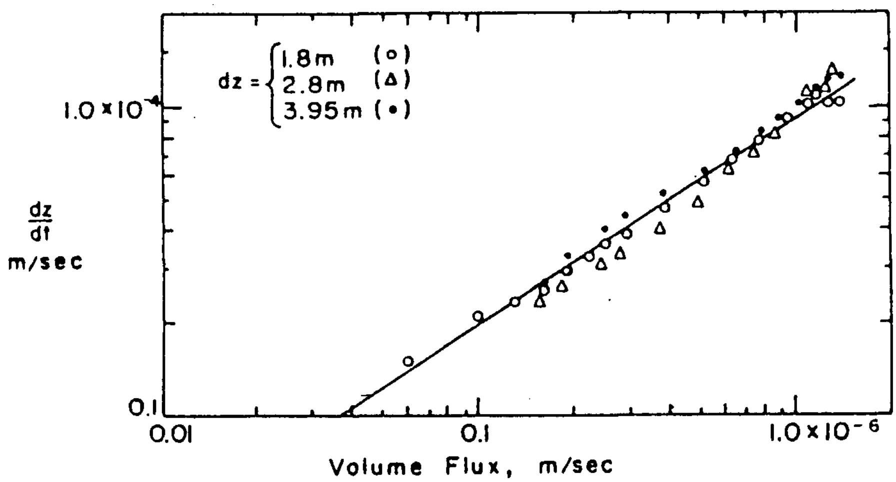

Figure IV.1 Wave Speed vs Influx Rate (after Colbeck and Davidson, 1973)

Eqn. IV.3 shows the rate of penetration of any input value is determined by the input rate at which it was generated. Therefore, a large input can overtake preceding smaller ones and form a shock front. Colbeck (1973) demonstrated analytical procedures for calculation of flux rates as a function of time at any snow depth for specified water inputs at the snow surface. This procedure was applied by Dunne et al. (1976) to predict snowmelt percolation characteristics in a subarctic snowpack.

Tucker and Colbeck (1977) developed a computer program to calculate flow at any depth for any input at the snow surface and snow properties. Plotted results are available for three snow surface input shapes over a 12-hour duration: double-peaked, sinusoidal and skewed. Flows at snow depths ranging from 1 m to 8 m are shown on Figure IV.2. Common features of the results of theoretical calculations for each surface input include the following:

i) a shock wave formed such that an instantaneous increase in flow occurred at depth.

ii) peak flow rates decreased with depth.

iii) differences in the shape of surface inputs disappears with increasing depth.

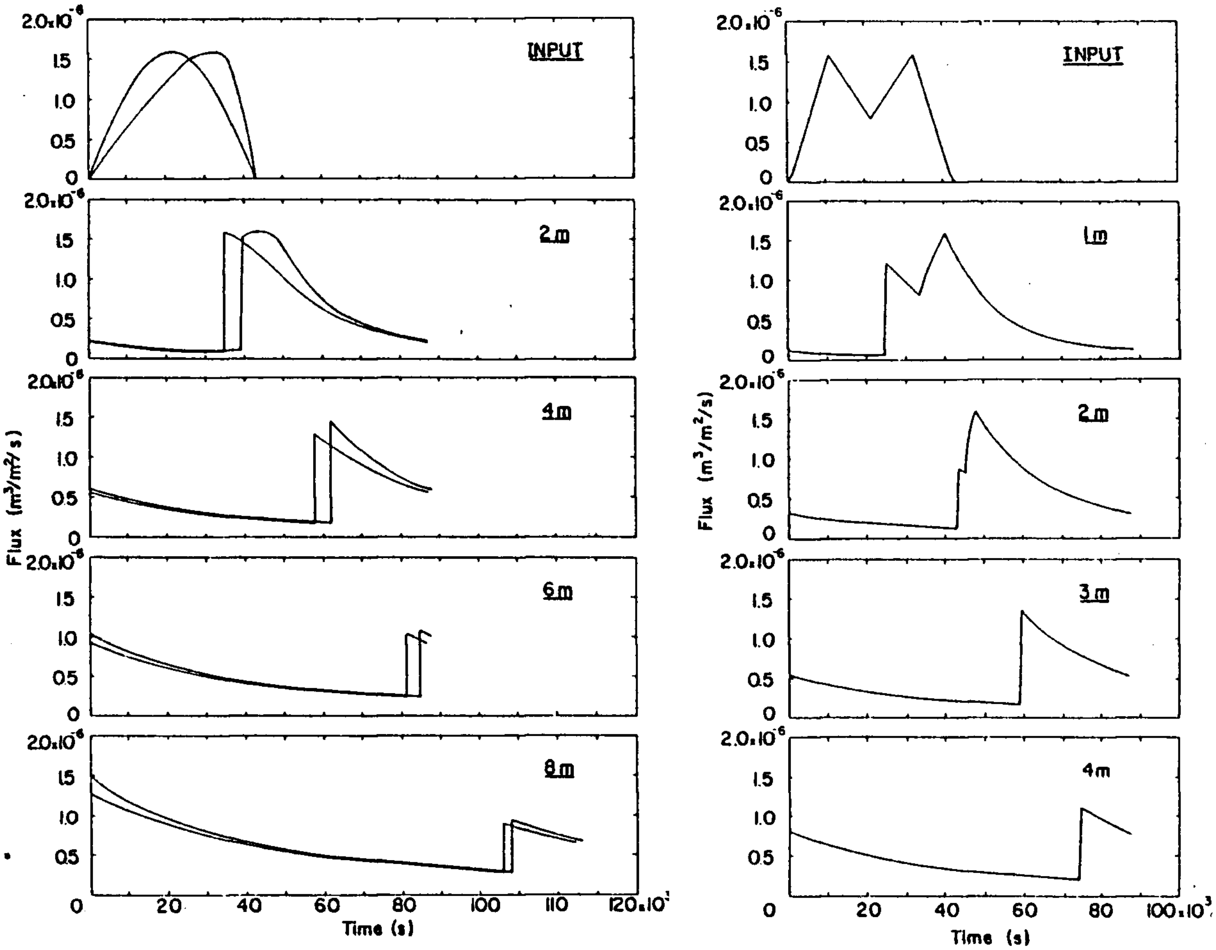

Figure IV.2. Water Percolation Through Snow (after Tucker and Colbeck, 1977)

In instances when a shock wave forms during vertical percolation, a rapid increase in snowpack outflow can be observed. However, it is important to also recognize that even in these cases, the peak outflow rate is less than the peak rate input at the snow surface.

Eqn. IV.3 can be simplified further by substituting

$$\alpha = \left(\frac{\rho g}{\mu}\right) = 5.46 \times 10^6 \ m^{-1}s^{-1}$$

$$\left(\frac{dz}{dt}\right)_m = \frac{3m^{0.67}(\alpha k_u)^{0.33}}{\phi_e} \quad \text{............ (IV.4)}$$

$$\left(\frac{dz}{dt}\right)_m = \frac{3m^{0.67}\left(5.46 \times 10^6\right)^{0.33} k_u^{0.33}}{\phi_e} \quad \text{............ (IV.4a)}$$

$$\left(\frac{dz}{dt}\right)_m = \frac{529m^{0.67} k_u^{0.33}}{\phi_e} \quad \text{............ (IV.4b)}$$

Colbeck and Anderson (1982) found the grouping $ku^{(1/3)}$ ϕe^{-1} to be more easily measured in experimental studies than either $ku^{(1/3)}$ or ϕe^{-1} alone, and a value for this grouping to be adequate for solution of Eqn. IV.4. Snowmelt analysis undertaken for undisturbed snow in California and Vermont yielded values for $ku^{(1/3)}$ ϕe^{-1} in a narrow band ranging from 0.00239 to 0.00301 with a mean value of 0.00270. Applying the mean value to Eqn. IV.4 yields the following relationship between percolation and water input rates to a ripe snowpack:

$$\left(\frac{dz}{dt}\right)_m = 1.43m^{0.67} \quad \text{............ (IV.5)}$$

Integration of Eqn. IV.5 with z=0 at the snow surface produces an equation describing depth of penetration into a snowpack with time for a constant input rate:

$$z = 1.43m^{0.67}t \qquad \text{............ (IV.6)}$$

Solution of Eqn. IV.6 is shown graphically on Figure IV.3 for a range of water inputs to a snowpack from rainfall and snowmelt. For illustration, consider snow depths of 1 to 2 m and typical rain and snowmelt inputs for the coastal region ranging from 5 to 20 mm/hr. Results presented on Figure IV.3 show that vertical percolation alone can add about 0.5 to 3 hours to the travel time of a water particle through the basin.

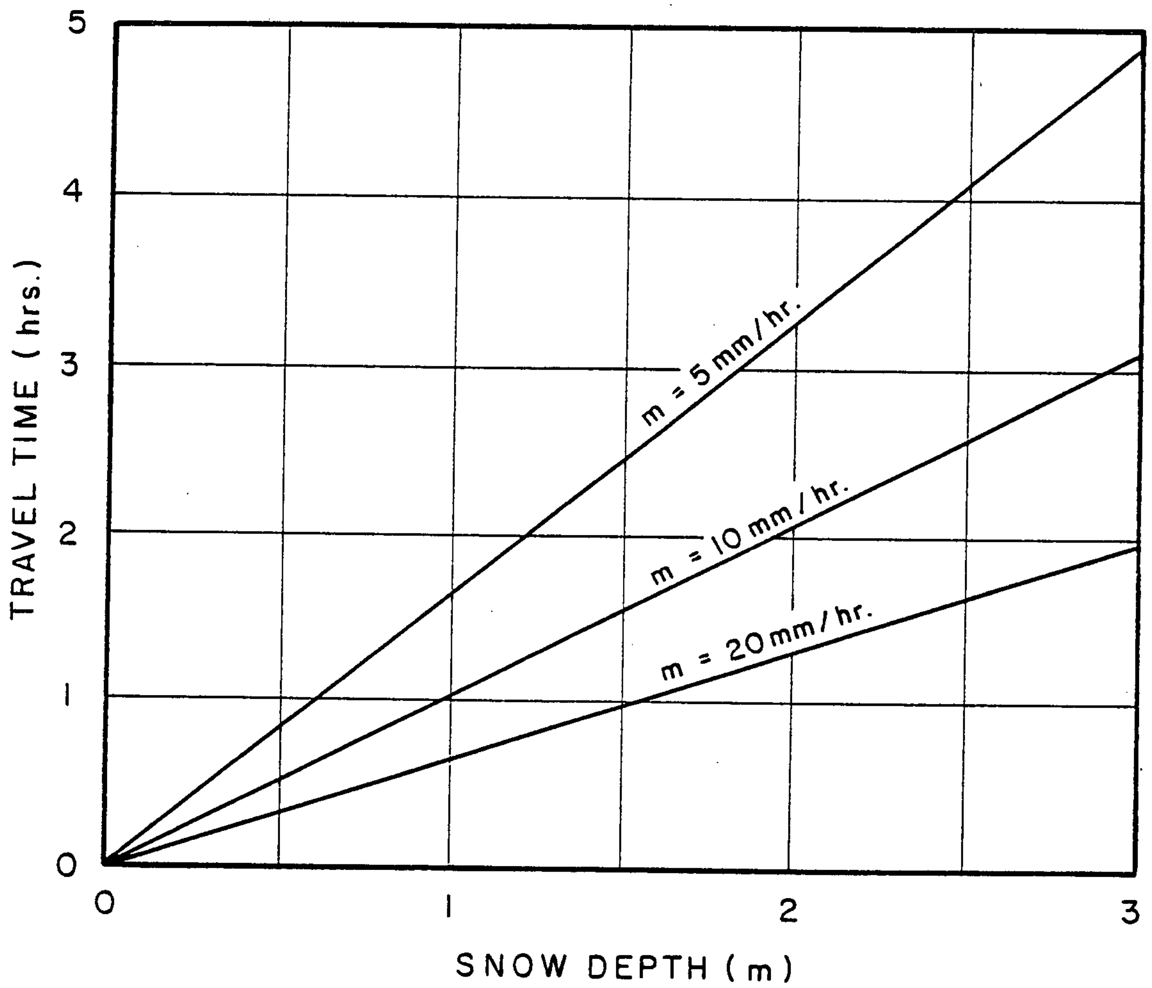

Figure IV.3. Percolation Rates for Vertical Unsaturated Flow

IV.2 BASAL SATURATED FLOW

The governing equations for water flow through saturated snow at the base of a snowpack have been developed by Colbeck (1974a). Colbeck envisioned a two-layer model for water flow through snow consisting of vertical flow through an unsaturated layer and downslope flow along a boundary in a saturated layer.

For constant slope and unit width, Colbeck expresses the continuity equation for the saturated layer as:

$$\alpha k_s \theta \left(\frac{\partial h}{\partial x}\right) + \phi \left(\frac{\partial h}{\partial t}\right) = I \qquad \text{............ (IV.7)}$$

where ks = intrinsic permeability of the saturated zone; θ = slope; h = saturated layer thickness; x = distance; t = time; and I = net input to saturated zone.

By considering a new coordinate system (x', t') which moves downslope at the wave speed in the saturated layer, Eqn. IV.7 can be simplified and solved directly to yield:

$$q\left(0, t'_L\right) = \frac{\alpha k_s \theta}{\phi} \int_{t'_0}^{t'_L} I\left(0, t'\right) dt' \qquad \text{....... (IV.8)}$$

where t_O' and t_L' are time limits for the period during which a parcel of water entering the saturated layer at the top of a slope moves to the base, and q $(0,t_L')$ is the unit discharge at the base of the slope. Eqn. IV.8 states that the outflow from the base of the slope is equivalent to the input to the saturated layer integrated over a preceding period equal to the time taken for water to travel along the slope length.

Experimental verification of equations developed for basal saturated flow has not been as extensive as that for vertical unsaturated flow. One study was undertaken by Dunne et al. (1976) in the Canadian subarctic. Snowmelt runoff was measured at seven hillslope plots ranging in area from 1335 to 2810 m^2 with downslope lengths between 37 m and 85 m.

Comparison was made between measured snowmelt runoff and values estimated using Eqn. IV.8. For example, a theoretical outflow hydrograph was calculated as follows: the input hydrograph to the saturated zone was estimated from surface melt and vertical unsaturated flow considerations; travel time along the hillslope was estimated; and outflow was calculated as the sum of inputs to the saturated zone for time increments equal to hillslope travel time. Dunne et al. concluded "the prediction of peak runoff was generally excellent" and "the prediction of the timing of runoff hydrographs was less satisfactory though still remarkably good". A summary of results for 20 hydrographs analyzed at these hillslope plots is shown on Figure IV.4.

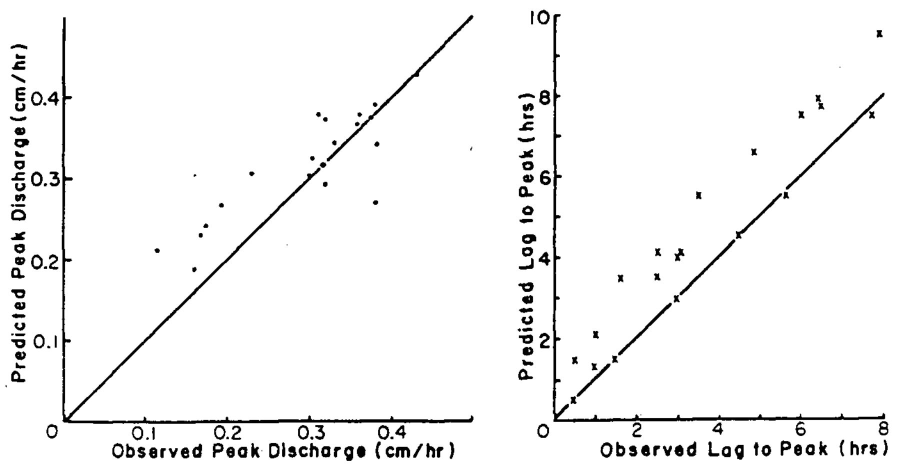

Figure IV.4 Comparison of Predicted and Observed Outflow Hydrographs (after Dunne et al., 1976)

Closer examination of results on Figure IV.4 for lag times shows in every instance observed lag times are less than predicted. These results contradict the conclusion that experimental results are especially good, particularly when one considers that data are from relatively small hillslope plots ranging in length from only 37 to 85 m. Extrapolation of results to a larger watershed scale suggests observed lag times would be much less than predicted by water percolcation theory. This observation supports further the concept of an internal drainage network as the dominant routing mechanism for hydrograph analysis on a watershed scale.

Examination of the special case of steady flow provides an opportunity to illustrate response characteristics that would occur if basal saturated flow existed under a snowpack. Colbeck (1974a) showed for steady flow:

flow depth $$h = Ix(\alpha k_s \theta)^{-1} \qquad \text{(IV.9)}$$

unit discharge $$q = \alpha k_s \theta h \qquad \text{(IV.10)}$$

travel time $$t = \phi_e x(\alpha k_s \theta)^{-1} \qquad \text{(IV.11)}$$

Even though the applicability of a steady-state solution to actual water runoff problems is limited, Eqn. IV.11 nevertheless allows for qualitative assessment of the time frame for basin response.

Colbeck (1974a) and Dunne et al. (1976) estimated ks is approximately equal to 5.1 x 10^{-9} m^2 for saturated flow through snow with grain sizes ranging from 1 mm to 2 mm. Experimental data presented by Colbeck and

Anderson (1982) indicates Øe is equal to about 0.46. Substituting these values into Eqn. IV.11 yields:

$$t = \frac{16.5x}{\theta} \qquad \text{............. (IV.12)}$$

Solution of Eqn. IV.12 is shown graphically on Figure IV.5 for mild and steep mountain slopes. Also included on Figure IV.5 for comparison are corresponding travel times estimated for overland flow through forests with heavy ground litter (Soil Conservation Service, 1974). Comparison of travel times shows basin response would be more rapid in instances where water is routed through the basin by overland or channelized flow than by saturated water percolation flow through snow. For illustration, consider saturataed flow along the base of a snowpack for a distance of 600 m and hillside slopes of 5 and 15 degrees. Results included on Figure IV.5 show that for basal percolation the travel time of a water particle ranges from about 10 to 30 hours. This time increment is in addition to the time required for vertical percolation through the snowpack.

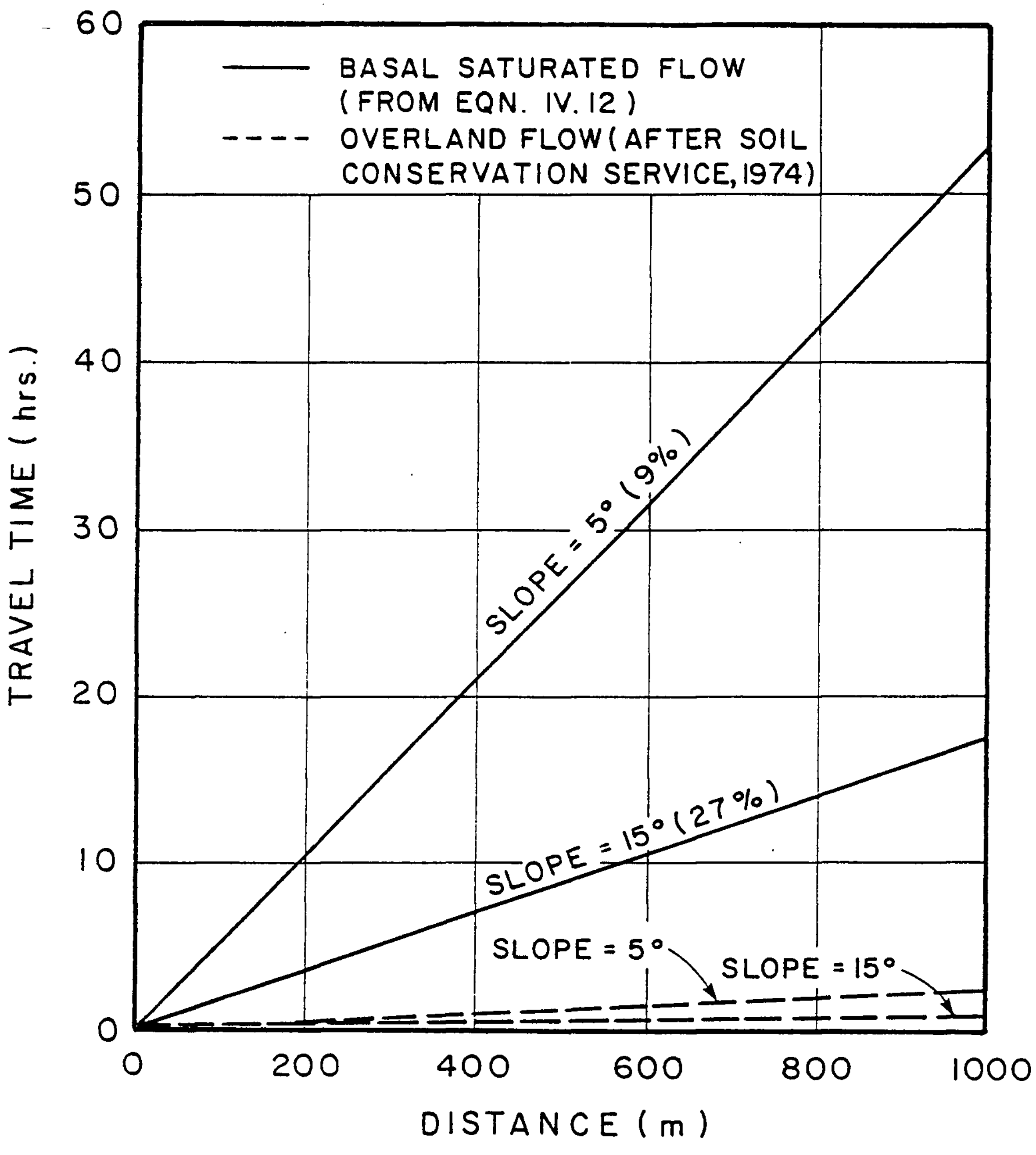

Figure IV.5. Travel Times for Basal Saturated Flow