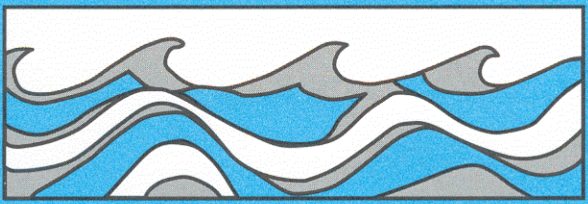
University of Washington
Department of Civil and Environmental Engineering

A PRELIMINARY EXAMINATION OF RELATIONSHIPS BETWEEN CATCHMENT CHARACTERISTICS AND VOLUMES OF INFREQUENT LARGE FLOODS

James B. Balocki
Stephen J. Burges



Water Resources Series
Technical Report No.130
August 1991

Seattle, Washington
98195

Department of Civil Engineering
University of Washington
Seattle, Washington 98195

A PRELIMINARY EXAMINATION OF RELATIONSHIPS BETWEEN CATCHMENT CHARACTERISTICS AND VOLUMES OF INFREQUENT LARGE FLOODS

James B. Balocki
Stephen J. Burges

Water Resources Series
Technical Report No. 130

August 1991

Department of Civil Engineering
University of Washington
Seattle, Washington 98195

A Preliminary Examination of Relationships Between Catchment Characteristics and Volumes of Infrequent Large Floods

by

James B. Balocki

and

Stephen J. Burges

Water Resources Series
Technical Report No. 130

August 1991

ABSTRACT

Design floods are used to consider relevant hydrologic and economic factors in the evaluation of operation, or changes in operation, of flood damage mitigation. The design hydrograph, which relates flood volume and frequency in a catchment of concern, is commonly used to estimate design floods of various duration. Constructing a design hydrograph is accomplished using flood volumes, often extrapolated beyond observed records, from flood volume-duration-frequency curves. An assessment of the existence of coincident and similar frequency flood volume relationships, required to construct design hydrographs, was conducted using flood flow data from seven Pacific Northwest river catchments. These catchments were influenced minimally by engineered facilities or farming or sivicultural practices. Coincident occurrence of large return period flood volumes, for flood durations important to decision making, held true for all seven basins. Flood volume-frequency-duration for the largest two or three flood volumes is strongly related in three catchments, moderately related in three others, and unrelated in the seventh. No link is apparent for any of the seven catchments between its physical features and flood volume coincidence or frequency. These results indicate that the flood hydrograph frequency record for each catchment should be evaluated prior to using assumed nested volume relationships to derive a design flood hydrograph having a given exceedance frequency. A general method for evaluating the validity of extrapolated design flood hydrographs for low exceedance probabilities is given.

ACKNOWLDEGEMENTS

This report was prepared from the first author's Master of Science in Civil Engineering thesis. We appreciate comments as the work evolved from Professor Charles Jahren and Larry Merkle, Chief, Hydraulics and Hydrology Branch, Seattle District, U.S. Army Corps of Engineers. The work was undertaken during the first author's secondment to the University of Washington by the U.S. Army Corps of Engineers for his graduate studies. He expresses his gratitude for this opportunity. To his wife, Marie, go his heartfelt thanks for her support and encouragement. Kim Hartsoch used her extensive skills to bring the report to its final form.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

Page

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

CHAPTER 1 INTRODUCTION

A scheme for relating flood volume frequencies of different durations and constructing a design flood hydrograph is presented and explored. The purpose of the work is twofold. First, it examines assumptions made in professional practice for constructing a theoretical design flood hydrograph. Secondly, it shows how such hydrographs can be constructed and used for evaluating the operations, or proposed changes in operations, for a single, multi-purpose, reservoir. Low exceedance probability (high return period) floods are needed to determine possible benefits for such facilities when they are operated for flood damage mitigation.

One approach for obtaining an estimate of a high return period flood hydrograph is to select relevant volumes from flood volume-duration-frequency curves. For a given return period (or recurrence interval), flow volumes for different durations are combined to construct the design flood hydrograph. Design hydrographs constructed in this manner require extrapolation beyond the observed record. The hope is that the respective extrapolated flood volumes of specific durations and design return period correspond to the same flood (Beard, 1975).

The terms ***probability of exceedance***, P, and ***return period*** ,T, are used throughout this report. They are reciprocals:

$$P = \frac{1}{T} \qquad (1)$$

Both terms express probability of a particular event occurring. A specific magnitude flood has equal likelihood of occurring in any year; i.e. events are assumed to be *independent* of one another.

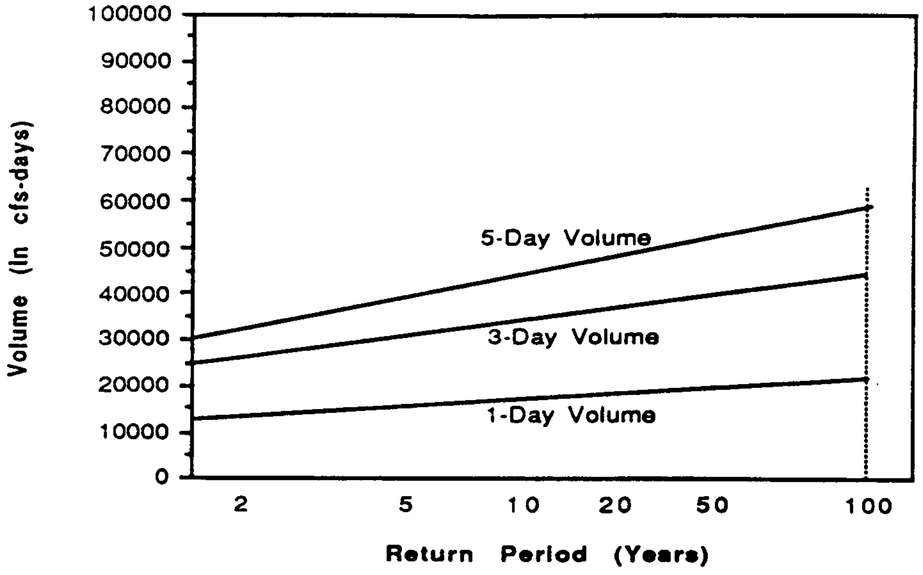
If an extremely long record of streamflow was available, the problem of choosing a "design hydrograph" or a suite of low exceedance probability design hydrographs (typically $P = 0.04$ and smaller), is relatively simple. The record would be scanned and several large volume flood hydrographs, corresponding to low values of P, selected for use in system operation investigations. For the situation faced in practice where records are too short for this to be done, an alternative is needed. A relatively data rich stream gauge record may extend for fifty to eighty years. This constitutes a short record and design hydrographs are obtained from extrapolation of theoretical distributions estimated from the observed record.

Consider the hypothetical case of an extremely long hydrological record from which the annual series (the largest quantity in a year) of 1-, 3-, and 5-day flood volumes has been extracted. When plotted on an extreme value type I (EVI) cumulative probability page, where the probability scale is distorted to cause the information to plot as a straight line, the information is as shown in Figure 1.1 (a). The 100-yr (P = 0.01) quantities for 1-, 3-, and 5-day volumes are obtained by reading the ordinate corresponding to the intersection of the dashed vertical line through T = 100 with the corresponding EVI curves. The average 3-day and 5-day hydrographs for this circumstance are shown in Figure 1.1 (b). Also shown is the 100-yr hydrograph that is contained in the record. In this case the 1-, 3-, and 5-day 100-yr flood volumes occurred around day 6.

We do not have the luxury of the actual hydrograph in Figure 1.1 (b). If the usual short historical record shows that the m th largest 1-, 2-, 3-,.. n-day flood all occur during the same flood (i.e. at the same time of year and in the same year) we refer to this situation as *nested or coincident*. In such circumstances we attempt to construct estimated hydrographs by extrapolation and have no means for determining if the time distribution of the flow volumes is correct or is a good representation of nature. In Figure 1.1 (b), the 1-day flood is the same as the actual flood in the absence of any estimation errors. If we had the 3-day volume and the 1-day volume (Figure 1.1 (a)) we approximate the 3-day design hydrograph with the actual 1-day volume and distribute the difference between the 3-day and 1-day volumes equally in time around the 1-day volume. Extending the hydrograph beyond a 3-day duration is done in like fashion. The difference between the 5-day volume and the 3-day volume is distributed equally and assigned symmetrically in time. If there was information to support some other temporal distribution, that information could be used instead of the symmetric assumption. From Figure 1.1 (b), it is clear that the most complete information is contained in the actual hydrograph (which we are unlikely to have) and the maximum ignorance situation is for use of average duration hydrographs. For example, if a 5-day duration situation was important for decision making, the average 5-day flood hydrograph (the horizontal line between days 4 and 8 at approximately 11,000 cfs) has little resemblance to the actual situation. The design hydrograph construction scheme described above is intermediate between the maximum ignorance case and complete knowledge. To test the utility of the suggested scheme requires examination of flow records from a variety of hydro-climatological regimes.

Design hydrographs are routed through the reservoir under investigation to determine release rates and storage pool elevations and corresponding damages. Benefits are assumed to be damages avoided by the presence and operation of the flood damage mitigation component of the structure. The time distribution of flow influences all such benefits. The validity of conservatism introduced into analyses by choosing different possible time distributions of flow volumes, particularly delaying the peak flow condition to times when a given flood facility may be almost full, cannot be determined unequivocally.

Based on literature searches we conducted and enquiries made to colleagues concerned with the class of design and operation problems discussed here, we are unaware of any current or earlier relevant published work. The concept of a *balanced hydrograph*, which depends on scaling of observed hydrographs, is discussed. Beard (U.S. Army Corps of Engineers, 1975) and Cudworth (1989) detail how to construct and use a balanced hydrograph. The work that follows examines the viability of the general approach we have described as well as some aspects of balanced flood hydrograph principles.



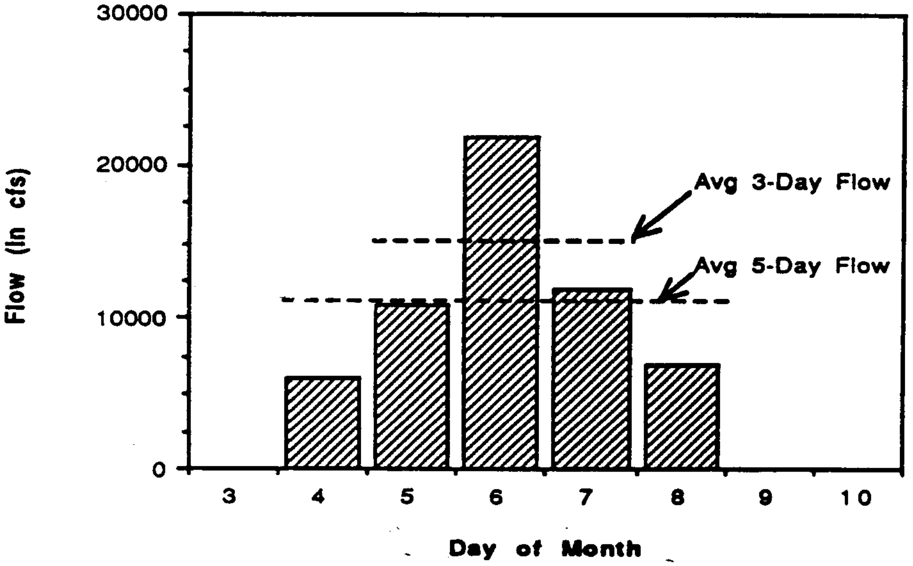


Figure 1.1 (a) Hypothetical Extreme Value Type I plots of 1-, 3-, and 5-day flow volumes, (b) Comparison of average hydrographs of different durations with hypothetical actual 100-yr hydrograph.

This work is exploratory. Flood hydrographs of seven Pacific Northwest catchments were examined for their *nested* and *coincidental* occurrence. The seven catchments were selected because they do not contain any engineered storage or flood mitigation facilities; the hydrological significance of any changes in agricultural and silvicultural practices during the period of investigation was minimal. For illustrative purposes, N was chosen to be 3, 5, and 10 days. Nesting was determined by checking if the 1-day volume for a given year occurs in the same period of days as the n-day volume. Coincidental occurrence was determined by examining the flow volume data to determine if each n-day volume component of a nested hydrograph occurs with the same frequency. For example, the largest 10-day volume in a particular year may not contain the largest 5-day volume or occur at the same general time of year.

Complete examination of this issue would be a major undertaking. The seven catchments, located in Washington and Oregon states, ranged from approximately 40 to 3,700 square miles. They comprise areas with differing dominant hydrologic mechanisms: each catchment produced rainfall only, mixed rainfall and snow melt, or snow melt runoff floods. A great deal of what is learned here may be only of regional interest; the hope is that this preliminary investigation may provoke interest in examining other hydro-climatic regions of the world.

The work that follows is divided into three chapters. Chapter 2 describes pertinent physical and hydrologic characteristics of the seven river basins. Chapter 3 presents a method for analyzing flood flow data from daily stream flow records. Chapter 4 provides summary findings and the conclusions.

CHAPTER 2 GENERAL CATCHMENT CHARACTERISTICS

Seven catchments located in the Pacific Northwest (Figure 2.1), each of which has distinctive climatic and physical characteristics, are examined. A summary of general characteristics for each catchment is presented in Table 2.1.

One characteristic shared by all seven river systems is the general Pacific Northwest climate. The Pacific Ocean and jet stream play dominant roles in the regional climatic conditions. During winter months, low pressure storm centers originating in the Gulf of Alaska move southeasterly carrying cool air masses. These storms move onshore in British Columbia and Washington yielding precipitation which lasts for several days to two weeks (Hemstrom, 1986). Less frequently, storm systems originating in the tropics carry warm, moist air masses into the region from the southwest. These tropical systems also move across the area in several days; however, rainfall is generally more intense from their storms.

During summer months, atmospheric high pressure ridges develop off the Washington-Oregon coast. These systems block the path of approaching low pressure centers causing them to take a more northerly path, usually through British Columbia. Additionally, summer low pressure systems are generally weaker, bringing less rainfall, when they come ashore. As a result, summers are typically warm and dry. Similar high pressure ridges can develop in autumn and may persist into January but they occur less frequently than in summertime. When high atmospheric pressure ridges form in winter, the region experiences cold temperatures and clear skies (Hemstrom, 1986).

The major climatological differences in the seven catchments are caused by topographical features and distance of each from the Pacific coast. The mesoscale-climate for each catchment is described more fully below.

2.1 WILLAPA RIVER AND GRAYS RIVER (130 AND 40 MI^2)

The Willapa and Grays River catchments are located in Pacific County and Wahkiakum County in southwestern Washington State (Figure 2.2). To the west, the region is bounded by the Pacific Ocean. The Willapa River flows into Willapa Bay, a small, semi-sheltered coastal inlet. To the south lies the Columbia River into which waters from the Grays River flow. To the east and north lie the Willapa Hills, a small coastal mountain range. The maximum elevation is 2,419 feet and the median elevation is 641 feet (Williams and Pearson, 1985).

The Willapa River flows generally northwest for approximately 30 miles (Allan Cartography, 1987). Its headwaters are on Walville Peak and Huckleberry Ridge in the Willapa Hills. It is joined by Mill Creek, Ward Creek, and Wilson Creek, as it flows toward the Pacific Ocean. The gauge used for this study is located in the town of Willapa, Washington at an elevation of 3.57 feet above the National Geodetic Vertical Datum of 1929 (USGS, 1964).

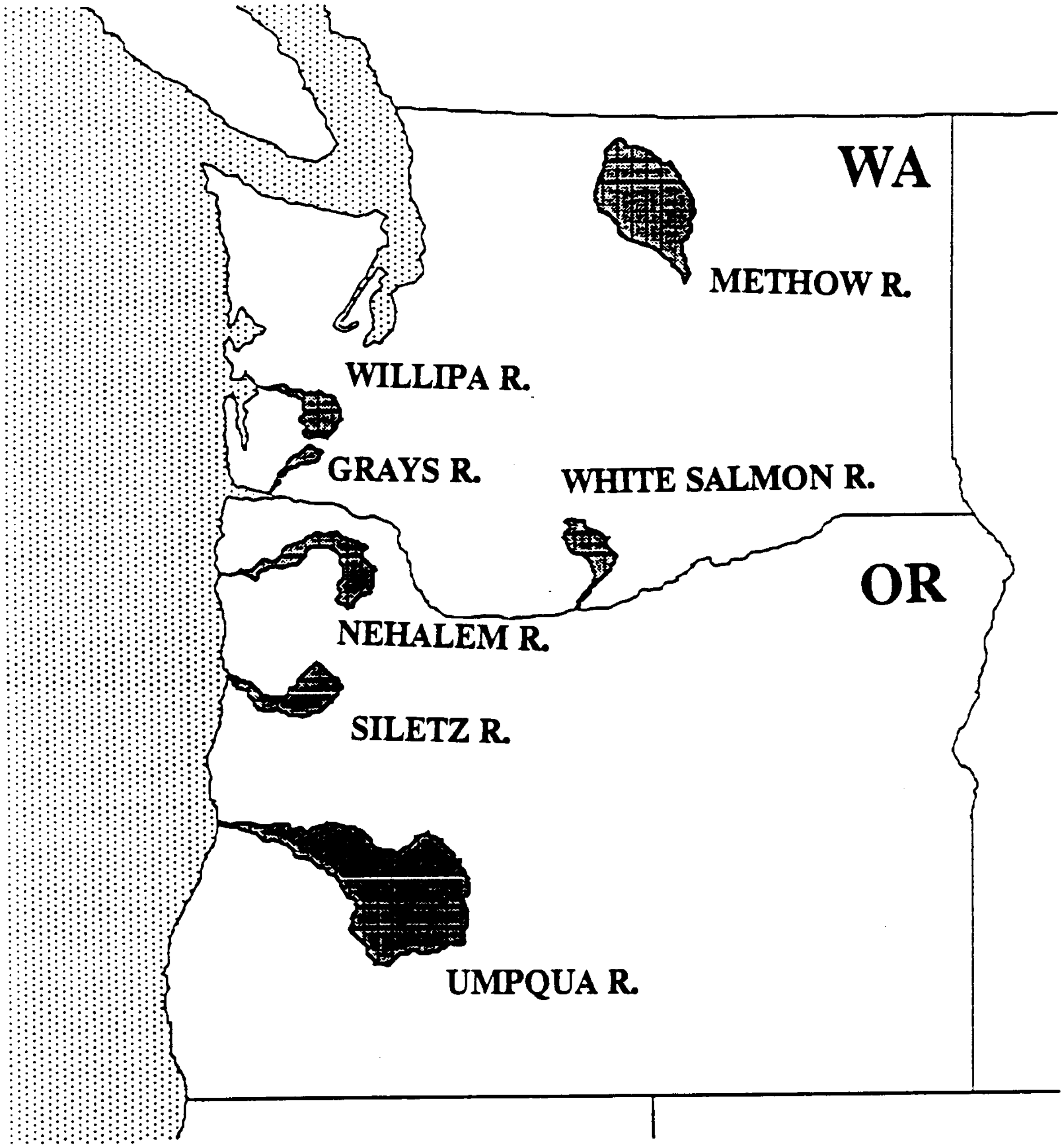


Figure 2.1 General area map showing the approximate location of seven river catchments examined.

Table 2.1 Summary of river characteristics for seven river systems in Washington and Oregon. (Williams and Pearson, 1985; Friday and Miller, 1984)

River	**USGS Station Number**	**Basin Area** (Sq. Mi.)	**Average Basin Elev.** (Ft.)	**Average River Slope** (Ft./Mi.)	**Lake Area** (%)	**Forest Area** (%)	**Precip.** (In.)[1]	**Snow** (In.)[2]	**Stream Flow Record**	**Major Flow Medium**	**Diversion or Flow Regulation**
Willapa	12013500	130	641	16	0	84	87	30	Good	Rainfall	Domestic use and irrigation diverts small amount, no regulation
Grays	14249500	40	1,350	142	0	90	116	50	Excellent	Rainfall	None
Methow	12449500	1,301	5,180	72	0.13	76	35	140	Good[3]	Snow melt, rainfall	Large portion of flow diverted for irrigation, no regulation.
White Salmon	14123500	386	3,220	93	0.26	86	66	130	Excellent[4]	Snow melt, rainfall[5]	Irrigation for 4,500 acres; low and medium flow regulated by power plant

Table 2.1 (Continued). Summary of river characteristics for seven river systems in Washington and Oregon. (Williams and Pearson, 1985; Friday and Miller, 1984)

River	USGS Station Number	Basin Area (Sq. Mi.)	Average Basin Elev. (Ft.)	Average River Slope (Ft./Mi.)	Lake Area (%)	Forest Area (%)	Precip. (In.)[1]	Snow (In.)[2]	Stream Flow Record	Major Flow Medium	Diversion or Flow Regulation
Umpqua	14321000	3,680	2,480	8	0.25	86	47	N/A	Excellent[6]	Snow melt, rainfall	Irrigation diversion, no regulation
Siletz	14305500	202	1,260	42	0.29	57	118	16	Good	Rainfall	Small irrigation diversion, minor regulation from log pond
Nehalem	14301000	667	1,180	6	0.01	80	82	8	Fair	Rainfall	Domestic use and irrigation diversion, no regulation

Notes: 1. Determined from low elevation precipitation stations.
2. Water equivalent is not available.
3. During periods of ice effect, records are "fair".
4. During periods of no gauge height, records are "good".
5. Augmented by melt from the Avalanche Glacier on Mount Adams.
6. Estimated daily discharge records are "fair".
N/A - information not available.

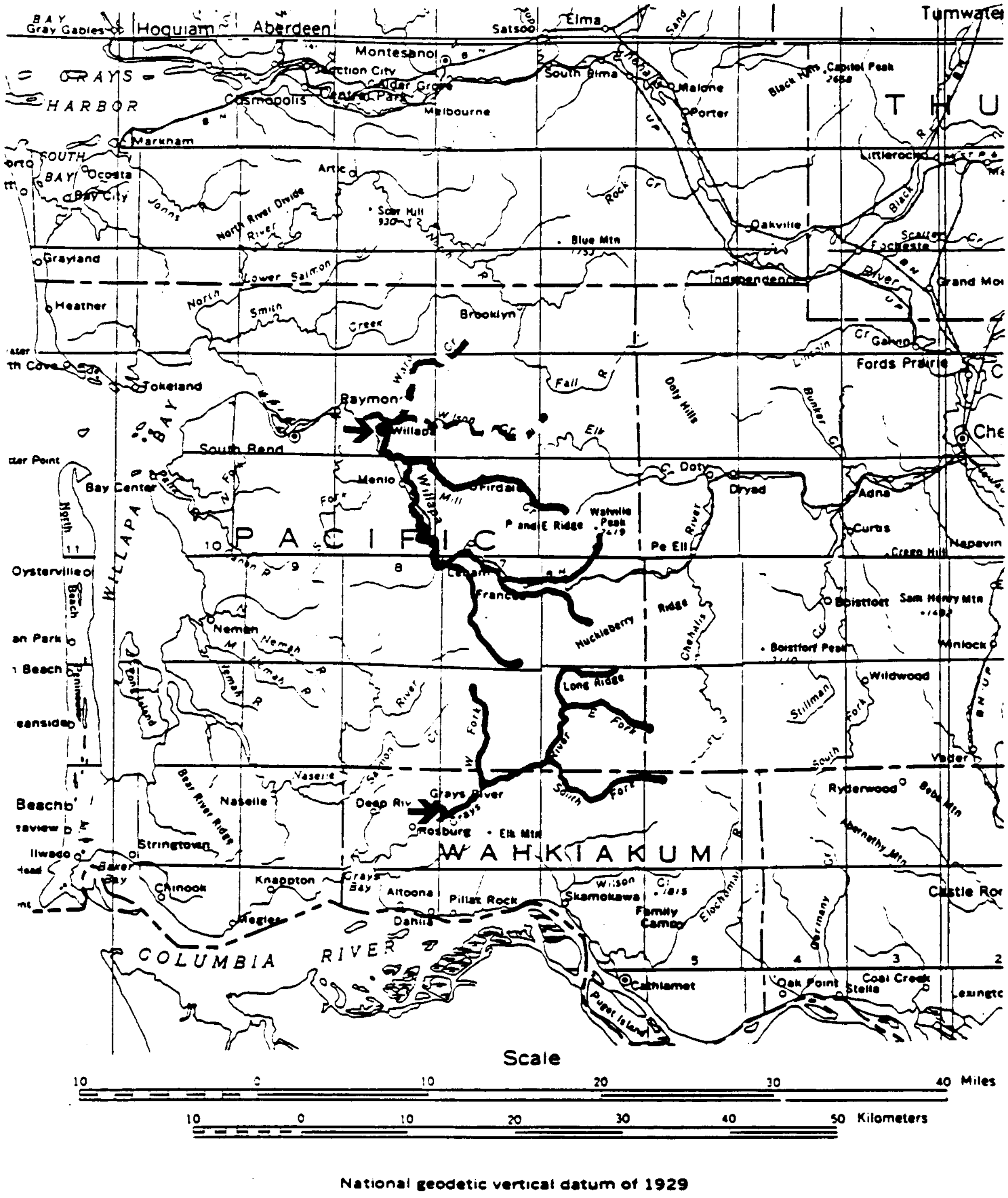


Figure 2.2 Plan view showing locations of principal channels of the Willapa and Grays River basins, stream gauges, and towns. Scale approximately 1 : 600,000 (USGS, 1979).

The Grays River flows to the southwest for approximately 15 miles (Allan Cartography, 1987). It begins on the south slopes of the Willapa Hills. The river is joined by its East, South, and West Forks, respectively, as it flows toward the Columbia River. The gauge for this study is located just northwest of the town of Grays River and above the South Fork at an elevation of 350 feet, estimated from USGS topographic map (USGS, 1964).

2.1.1 TOPOGRAPHY

The Willapa and Grays River basins comprise coastal lowlands and hills. Most of the region's terrain is hilly. The Willapa Hills are the major topographic feature in the region. Elevations in the catchments range from nearly sea level to 2,419 feet on Walville Peak (Allan Cartography, 1987). Slopes in the area vary from 0 to 5 percent in the lowlands and river valleys to 90 percent in the upper reaches of both catchments (Pringle, 1986).

2.1.2 WEATHER

The primary influences upon local weather patterns in the Willapa and Grays River catchments are the Pacific Ocean, Olympic Mountains, and Willapa Hills. The summer months are usually dry, but cool. Winter months are persistently wet and mild throughout the region. Spatial variability of precipitation from the coastal area to the Willapa Hills is evident but not pronounced. Precipitation ranges from 65 to 75 inches annually near the coast to 100 inches per year in the Willapa Hills (Pringle, 1986). Typically, more than 75 percent of annual rainfall occurs between October and March each year (Pringle, 1986). Figure 2.3 (recorded at Naselle, Washington) and Figure 2.4 (recorded at the Grays River Hatchery, Washington), show typical precipitation patterns.

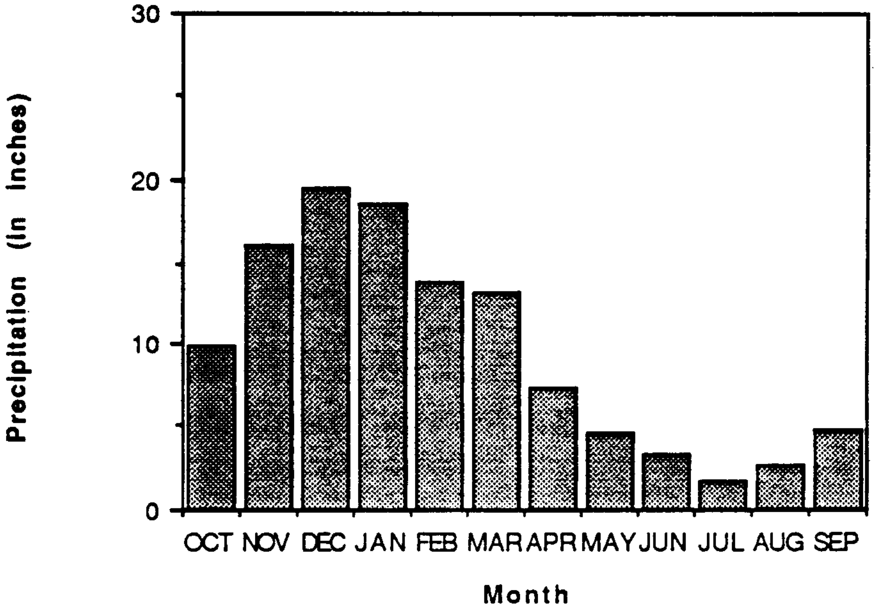


Figure 2.3 Mean monthly precipitation recorded at Naselle, Washington (station number 5774), elevation 50 feet. Recorded from 1948 through 1988; mean annual precipitation is 113.6 inches (EarthInfo, Inc., 1988).

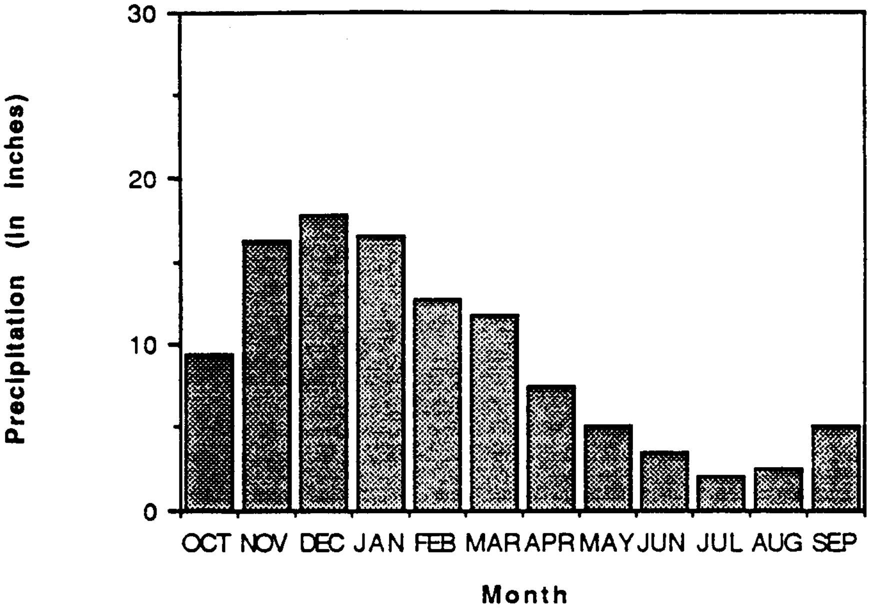


Figure 2.4 Mean monthly precipitation recorded at the Grays River Hatchery, Washington (station number 3333), elevation 100 feet. Recorded from 1962 through 1988; mean annual precipitation is 109.5 inches (EarthInfo, Inc., 1988).

Despite mild temperatures, snowfall occurs several times during winter months. Annual seasonal snowfall varies throughout the catchment, from 6 to 10 inches (Pringle, 1986). In coastal areas, snow usually melts before it reaches the ground. In the Willapa Hills, some accumulation occurs. Accumulated snow melts typically in 1 to 3 days; snowmelt has minimal influence on riverine flooding.

2.1.3 VEGETATION

Timber harvesting and processing are major activities in the Willapa and Grays River catchments. Logging operations have been ongoing in the region since the 1880's (Pringle, 1986). Aerial photographs reveal that a significant percentage of both catchments remain forested today, either with old growth or post-harvest regrowth trees.

Forests cover in excess of 80 percent of the catchment area and are among the highest quality coniferous forests in the world; forests in the Willapa Hills area are the densest in the contiguous United States (Franklin and Dryness, 1988). The area is also characterized by a well developed shrub layer, extensive matting, and organic litter on the forest floor (Franklin and Dryness, 1988). In lower reaches of the Willapa River, a small flood plain exists where vegetal cover is limited to grasses and annual crops.

2.1.4 SOILS

The soils in Pacific and Wahkiakum Counties are diverse and were influenced by many factors. In the lowlands, marine sediment was deposited as the region's coastline shifted and sea level changed through time (Pringle, 1986). Large quantities of clay, silt, and sand were deposited, their origin thought to be from a volcanic mountain range to the east. These sediments hardened and have since eroded to yield the current soils in low lying regions.

Soils in uplands have been formed from volcanic (probably basalt) and sedimentary parents. The "general soils mapping units" as described by the United States Soil Conservation Service for the Willapa River catchment (Pringle, 1986) are presented in Table 2.2. The Grays River basin soils are displayed in Table 2.3.

Table 2.2 Soils in the Willapa River basin and selected physical characteristics (Pringle, 1986; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Bunker-Knappton	Uplands	0.6 to 6.0	.16 to .24	N/A	GM, MH, ML, OH, OL	B
Buckpeak Centralia	Siltstone and Sandstone Uplands	0.6 to 2.0	.12 to .21	15 to 35	CL, ML	B
Zenker-Elochman	Sandstone Uplands	0.6 to 2.0	.14 to .24	N/A	ML, MH, OH, OL	B
Willapa-Newskah	Marine Terraces	0.6 to 20.0	.11 to .24	N/A	MH, ML, OH, OL, SM	B, C

Table 2.3 Soils in the Grays River basin and selected physical characteristics (Pringle, 1986; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Lates-Murnen	Mountains	0.6 to 2.0	.12 to .22	N/A	MH, ML, OH, OL	B, C
Bunker-Knappton	Uplands	0.6 to 2.0	.16 to .24	N/A	GM, MH, ML, OH, OL	B
Lytell-Astoria	Siltstone Uplands	0.6 to 2.0	.19 to .24	N/A	MH, ML, OH, OL	B
Grehlem-Rennie	Flood Plains	0.06 to 2.0	.14 to .21	15 to 55	CH, CL	B, D
Ocosta	Flood Plains and Deltas	<0.06 to 2.0	.14 to .21	30 to 60	CH, CL, MH	D

The Unified Soil Classification system is given in Das (1990). Description of USDA Hydrologic Groups may be found in Pringle (1986) or any soil survey published by the Soil Conservation Service.

2.2 METHOW RIVER BASIN (1,301 MI^2)

The Methow River catchment is located within Okanogan County in north central Washington State (Figure 2.5). To the north is the Canada-United States border (49th parallel). To the west the basin is bounded by the crest of the northern Cascade Mountain Range. The Methow River joins the Columbia River near Pateros, Washington.

The Methow River flows generally southeasterly for 60 miles (Walters, 1974). In upper reaches of the basin, the river is formed by the confluence of the West Fork Methow River and Robinson Creek. Downstream the Lost, Chewack, and Twisp Rivers, respectively, join the Methow River as it flows toward the Columbia River.

The stream gauge used is located at Twisp, Washington (elevation 1,580 feet, estimated from USGS topographic map) (USGS, 1961). Records for this gauge include the period from 1921 through 1962 during which time (1948) the largest recorded flood (peak and volume) in the region occurred (Paulsen, 1949).

2.2.1 TOPOGRAPHY

The Methow River basin can best be characterized as mountainous. The Cascade mountain peaks range from 7,000 to 9,000 feet along the catchment's western boundary (Walters, 1974). Gentle relief occurs near the river and on river terraces in lower reaches of the region. Slopes in the region are quite steep, notably in the upper sections of the catchment.

2.2.2 WEATHER

The Methow River basin lies in the eastern precipitation shadow of the Cascade Mountains whose orographic features cause great areal variation in precipitation throughout the catchment. Pacific Ocean moisture patterns affect this basin in the same seasonal manner as in the Washington-Oregon coastal regions (Figures 2.6 and 2.7). The basin averages approximately 32 inches of precipitation per year. However, a range of 15 to in excess of 80 inches fall annually within 30 miles of each other (Walters, 1974). The largest depth of precipitation falls in upper reaches of the basin as snowfall during the winter and rainfall during late spring and summer months. Approximately 75 percent of yearly precipitation falls between October and March (Pacific Northwest River Basins Commission, 1971).

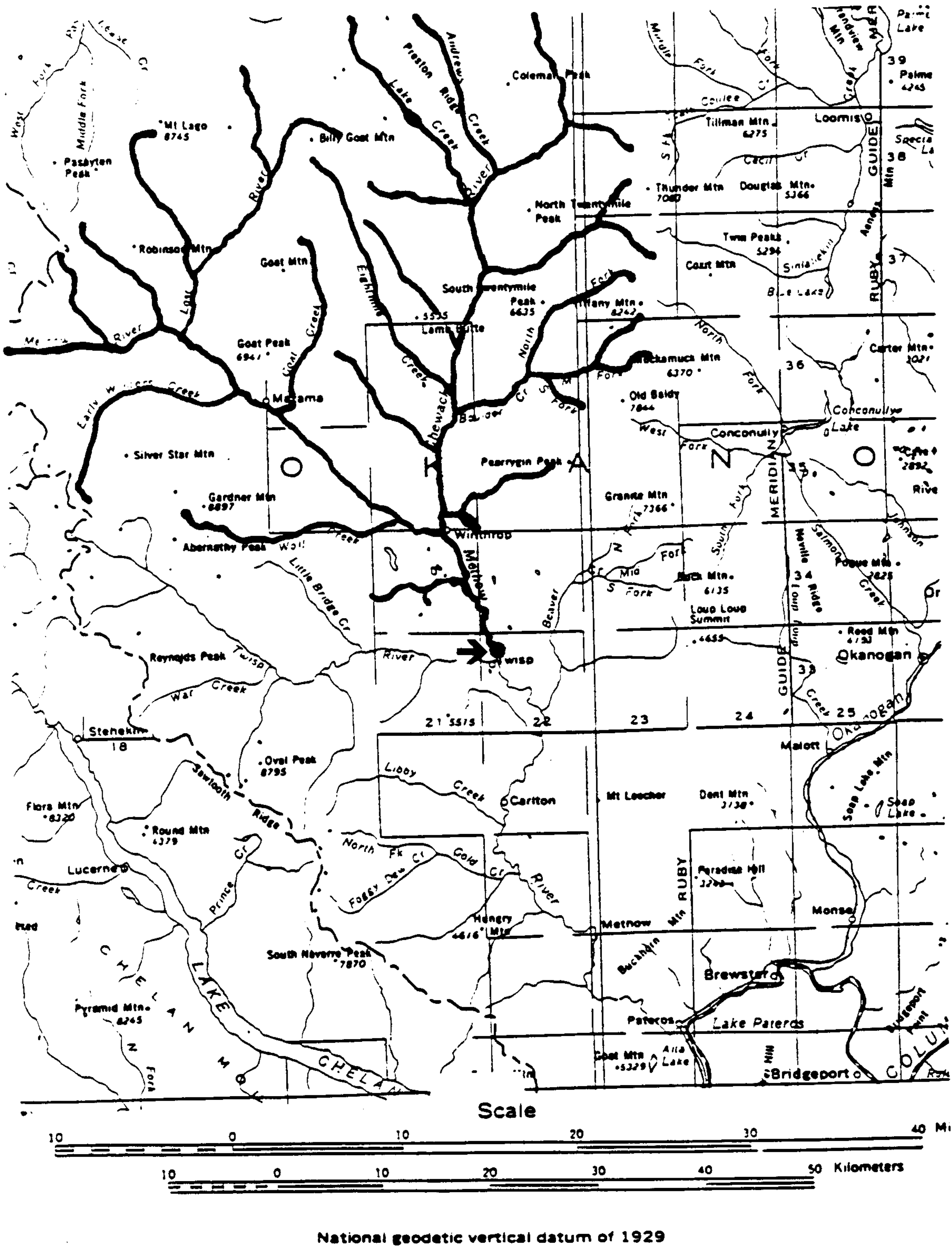


Figure 2.5 Plan view showing locations of principal channels of the Methow River basin, stream gauge, and towns. Scale approximately 1 : 600,000 (USGS, 1979).

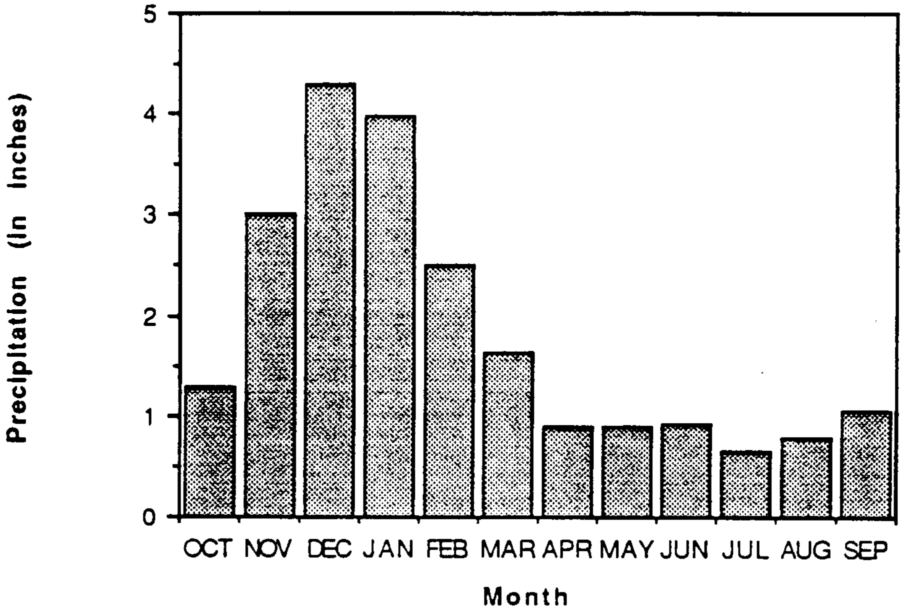


Figure 2.6 Mean monthly precipitation recorded at Mazama, Washington (station number 5133), elevation 2,170 feet. Recorded from 1950 through 1988, mean annual precipitation is 21.6 inches (EarthInfo, Inc., 1988).

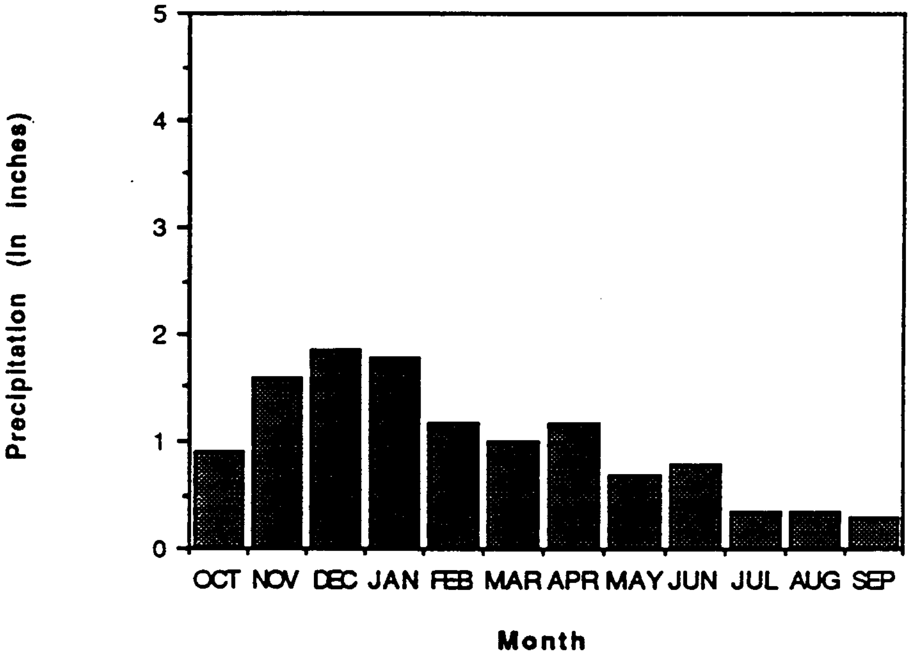


Figure 2.7 Mean monthly precipitation recorded at Methow, Washington (station number 5326), elevation 1,170 feet. Recorded from 1970 through 1988, mean annual precipitation is 13.3 inches (EarthInfo, Inc., 1988).

Snowfall in the upper reaches of the Methow River catchment exceeds 100 inches depth each year (Donaldson and Rusch, 1975). The equivalent water content of the snow varies; water content data are not generally available. Snowmelt dominates flood flow production in this basin. The extreme floods of design significance occur in late spring and early summer months.

2.2.3 VEGETATION

A significant portion of the area is preserved as National Forest wilderness area and reserved from timber harvest. The densest stands of timber are located in the upper reaches of the basin. Douglas fir (pseudotsuga menziesii), spruce (picea), and lodgepole pine (pinus contorta) are most common throughout the basin (Walters, 1974). Forests in the region extend from the Cascades or local ridges to meet range or crop lands on the valley floors.

A small area of agricultural and grazing land is located in the lower portions of the catchment close to the Methow River. Sparse stands of ponderosa pine (pinus ponderosa) grow in this location. Perennial grasses and shrubs dominate the landscape. Crop land is devoted primarily to apple and pear orchards and cereal crops such as wheat. Most of these lands are typified by shallow to moderately deep soils with overly sorted sand, gravel, and cobbles (Pacific Northwest River Basins Commission, 1970).

2.2.4 SOILS

The soils in Okanogan County were influenced heavily by ancient glaciation. Advancing and receding glaciers left U-shaped valleys, rounded mountain tops and glacial outwash terraces (Lenfesty, 1980). Soils in the wooded and range areas were formed from glacial till and outwash mixed with volcanic ash in the surface layer (Lenfesty, 1980). The predominant soil types found in the Methow Valley are presented in Table 2.4; 25 percent of the catchment (higher elevations) has not been mapped by the United States Soil Conservation Service.

Table 2.4 Soils in the Methow River basin and selected physical characteristics (Lenfesty, 1980; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Newbon-Conconully	Dissected Uplands	0.6 to 6.0	.08 to .18	N/A	GM, SM, ML	B
Kartar-Dinkleman-Springdale	Plains and Terraces	2.0 to 6.0	.02 to .13	N/A	GM, GP, GP-GM, SM	B
Owhi-Winthrop	Plains and Terrace	2.0 to > 20.0	.02 to .14	N/A	GM, GP, GP-GM, SM, SP-SM	A, B

2.3 WHITE SALMON RIVER (386 MI^2)

The White Salmon River catchment is located within Skamania and Klickitat Counties in south central Washington State (Figure 2.8). To the south, the river flows directly into the Columbia River (between the Dalles and Bonneville Dams) downstream from the town of White Salmon, Washington and upstream from the town of Hood River, Oregon. The White Salmon River originates on the southern slopes of Mount Adams and is fed by the Avalanche Glacier.

The White Salmon River flows generally to the south for 35 miles (Allan Cartography, 1987). It is joined approximately 15 miles from its origin by Trout Lake Creek and Gochen Creek. Gochen Creek also has its origins on the slopes of Mount Adams, however it is not glacially fed. Finally, Rattlesnake Creek joins the White Salmon River shortly before it reaches the Columbia River. The gauge used is located at Underwood, Washington at an elevation of 112.96 feet vertical datum of 1929 (USGS, 1964).

2.3.1 TOPOGRAPHY

The White Salmon basin is the most rugged of those evaluated. Elevations range from 12,307 feet on Mount Adams, at the catchment's northern boundary, to almost sea level through the Columbia Gorge; foothills and plateaus ranging from 700 to 5,000 feet are prevalent through the majority of the basin (Pacific Northwest River Basins Commission, 1971). Slopes in the White Salmon basin are steep, (in excess of 100 percent) especially in higher elevation portions of the catchment. Rolling hills and gentler slopes (0 to 15 percent) occur near the Columbia River (SCS, 1990).

2.3.2 WEATHER

The White Salmon River catchment is located on the eastern slope of the Cascade Mountains and drains to the Columbia Gorge. Orographic features cause a significant variation in precipitation within the catchment (Figures 2.9 and 2.10). The basin averages in excess of 60 inches of precipitation per year. The observed average rainfall at Underwood, Washington is 47 inches per year; the station at Trout Lake, Washington reports in excess of 90 inches yearly (Phillips, 1964). The largest volume of precipitation reaches the upper portion of the catchment as snowfall in winter months and rainfall from May through September. Approximately 87 percent of annual precipitation falls between October and March (Pacific Northwest River Basins Commission, 1971).

Snowfall accumulation in the northern portion of the catchment may exceed 250 inches per year (Phillips, 1964). Snowmelt runoff due to late winter or early spring storms leads to some flooding in the basin. The annual snowfall at the Mount Adams Ranger Station (elevation 1,960 feet) is nearly 126 inches (EarthInfo, Inc., 1988).

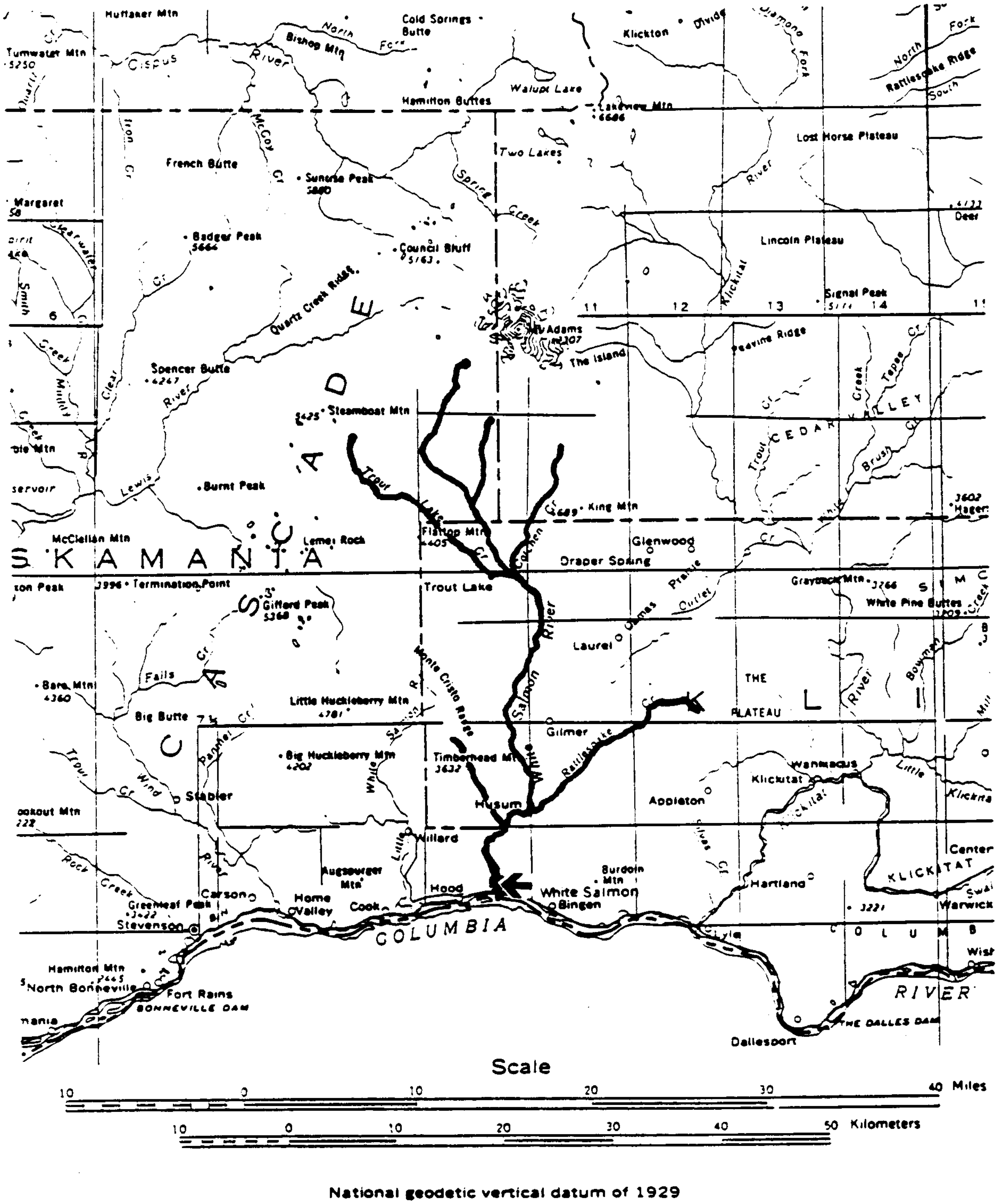


Figure 2.8 Plan view showing locations of principal channels of the White Salmon River basin, stream gauge, and towns. Scale approximately 1 : 600,000 (USGS, 1979).

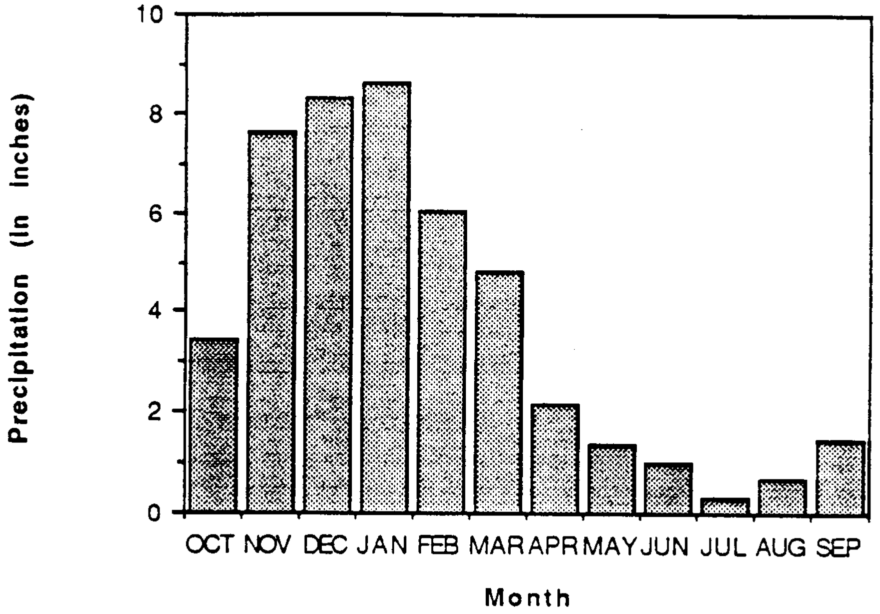


Figure 2.9 Mean monthly precipitation recorded at Mount Adams Ranger Station, Washington (station number 5659), elevation 1,960 feet. Recorded from 1948 through 1988; mean annual precipitation is 44.8 inches (EarthInfo Inc., 1988).

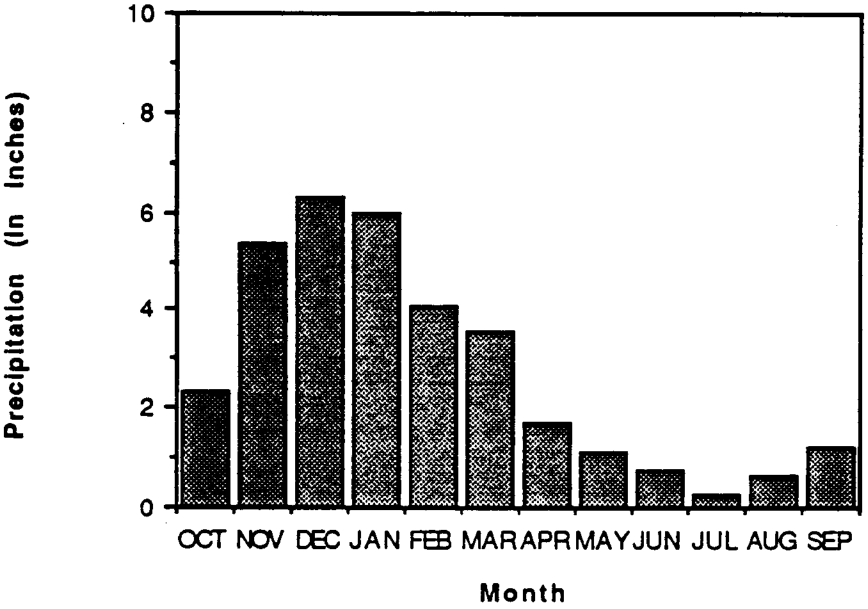


Figure 2.10 Mean monthly precipitation recorded at Appleton, Washington (station number 217), elevation 2,340 feet. Recorded from 1959 through 1988; mean annual precipitation is 33.4 inches (EarthInfo, Inc., 1988).

2.3.3 VEGETATION

Forest cover dominates the White Salmon River basin. Most of the land in the region is public and controlled by the United States Forest Service and other state and local agencies (Pacific Northwest River Basins Commission, 1970). The Gifford Pinchot National Forest comprises approximately 25 percent of the basin.

The oldest, densest stands of trees are found in the northwestern portions of the catchment. Timber cutting and harvest in the region are ongoing. Ponderosa pine (pinus ponderosa), Douglas fir (pseudotsuga menziesii), lodgepole pine (pinus contorta), and fir-spruce (abies-picea) varieties are all common in the forested areas (Pacific Northwest River Basins Commission, 1970). Much of the region classified as forested has lesser density than a coastal forest. These areas are suitable for grazing because they contain fewer trees and more perennial grasses (poa, carex, festuca and others) and shrubs such as, sagebrush (artemisia), and wheatgrass (agropyron).

Two localized regions of agricultural and grazing land are also located in the catchment. The first is located in the vicinity of the confluence of the White Salmon River and Trout Lake Creek. A second area exists adjacent to the Columbia River and extends several miles north along both banks of the White Salmon River. Fruit orchards are located principally at lower elevations close to the Columbia River, while grains or hay are grown in higher elevation fields (Pacific Northwest River Basins Commission, 1970). These two regions comprise approximately 15 percent of total catchment area. Most of these farmed areas are located on gravelly, sandy terraces.

2.3.4 SOILS

The soils in Skamania and Klickitat Counties have been influenced by a large number of volcanic eruptions. Local pyroclastic flows and water transport and deposition of ash and alluvium have contributed to soil formation in the area. Floods in the Columbia River Gorge have left large deposits of silt. These floods pushed lacusturine deposits approximately one mile up the White Salmon River channel from the Columbia River (Haagen, 1990).

The United States Soil Conservation Service survey in Skamania County was completed but not yet published when this report was prepared. The Klickitat study is ongoing; information presented here is intended to provide only a general background. The predominant soils found in the White Salmon River basin are described in Table 2.5.

Table 2.5 Soils in the White Salmon River basin and selected physical characteristics (SCS, 1990; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Samania-Washougal-Pilchuck	Floodplains, River Terraces, and Escarpments	0.6 to 6.0	.05 to .17	0 to 15	GM, ML, SM	B, C
McElroy-Underwood-Undusk	Mountains and Terraces	0.6 to 2.0	.05 to .21	10 to 35	CL, GM, GM-GC, ML, SC, SM, SM-SC	B
Kingtain-McElroy-Timberhead	Mountains	0.6 to 2.0	.05 to .20	10 to 20	GM, ML, SM	B
Guler-Trouter-Pinbit	Floodplains and Terraces	0.6 to 6.0	.06 to .24	N/A	GM, ML, SM	B, C
Glen- Segidal-Flotag	Floodplains and Terraces	0.6 to 6.0	.11 to .25	10 to 18	GM, ML, SM	B, D

2.4 UMPQUA RIVER (3,680 MI^2)

The Umpqua River is located within Douglas County in southwestern Oregon (Figure 2.11). The eastern basin boundary is on the western slopes of the Cascade Mountain Range. To the north lies the Willamette Valley, separated from the Umpqua basin by the Calapooya Range. The Rogue River lies to the south, separated from the Umpqua River by the Rogue River Range. The Umpqua River empties into the Pacific Ocean at the western most boundary of the catchment.

The Umpqua River flows generally northwesterly for 111 miles (Hayes and Herring, 1960). A large, complex network of rivers, creeks, and streams form the system. The basin is divided into two major sub-basins --north and south -- from which flow the North and South Umpqua Rivers, respectively. In the south basin, Jackson Creek, Elk Creek, Myrtle Creek, and Cow Creek join the river. In the north basin, Clearwater River, Steamboat Creek, and Little River join the river. The drainage densities and broad drainage network features differ in the two sub-basins. This is obvious from perusal of Figure 2.11. The confluence of the North and South Umpqua Rivers is located approximately 10 miles northwest of Roseburg, Oregon. Calapooya Creek and Elk Creek join the Umpqua River main stem just above the gauge.

The gauge used is located at Elkton, Oregon, approximately 30 miles inland from the coast, at an elevation of 90.42 feet vertical datum of 1929 (Friday and Miller, 1984). The record for this gauge extends back

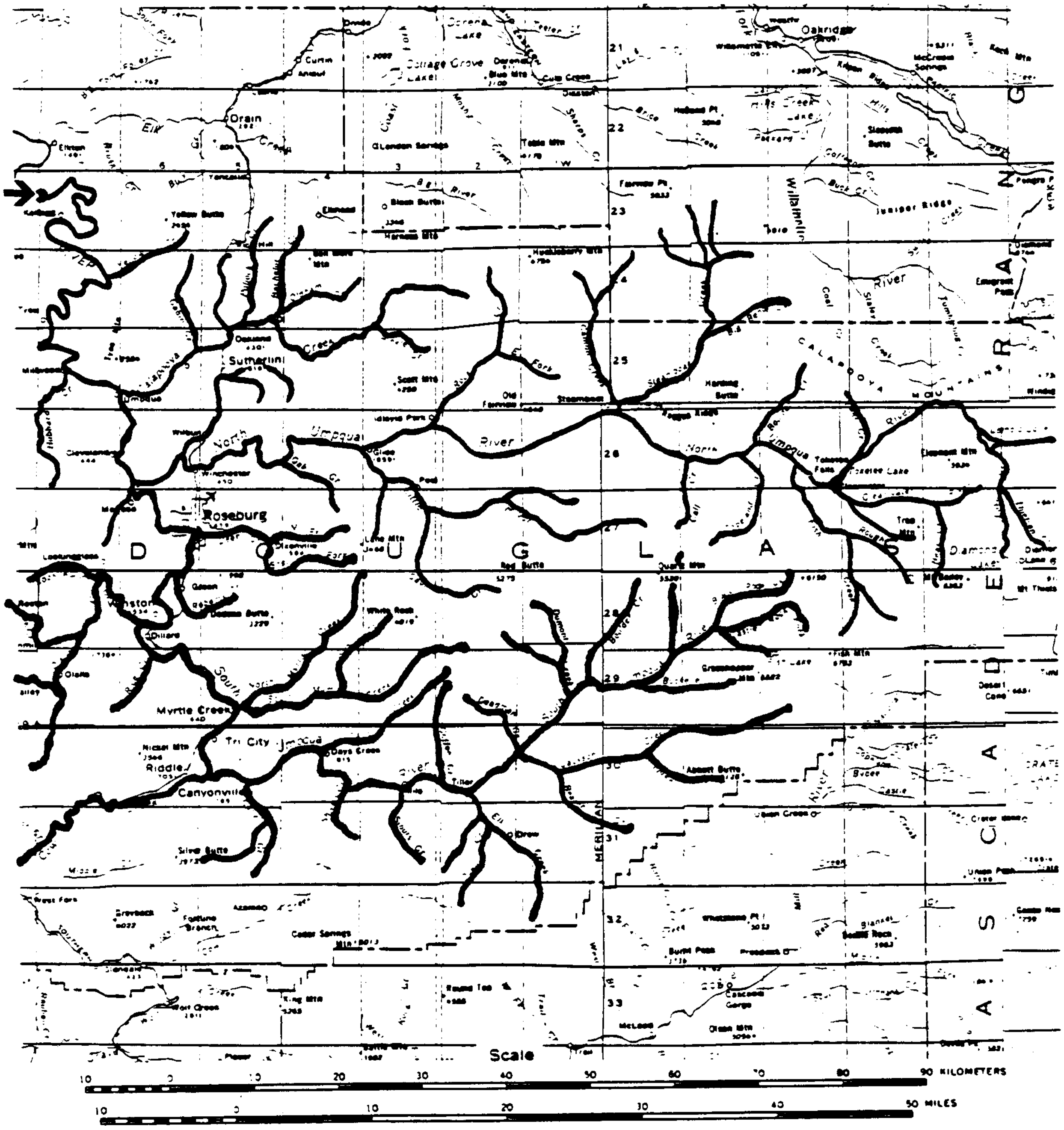


Figure 2.11 Plan view showing locations of principal channels of the Umpqua River basin, stream gauge, and towns. Scale approximately 1 : 800,000 (USGS, 1979).

to 1905 and captures flow information for a drainage area of 3,683 square miles (Hayes and Herring, 1960; Friday and Miller, 1984).

2.4.1 TOPOGRAPHY

The Cascade Mountains, along the catchment's eastern boundary, range in elevation from 5,000 to 9,000 feet (Allan Cartography, 1987). The terrain is rugged. Canyons are steep-sided and valleys in the mountains are typically less than a mile wide at the floor (Emmer and Muckleston, 1971). Approximately 20 percent of the North Umpqua basin lies at elevations above 5,000 feet, while 3 percent of the South Umpqua basin is above this elevation. These steep slopes in the upper reaches of the basin give way to gentle, rolling hills and pasture land in the area between the towns of Roseburg and Elkton. Approximately 20 percent of the land above the gauge is of this type.

2.4.2 WEATHER

Weather patterns in the Umpqua region are heavily affected by the topography of the larger surrounding region. The Coastal Mountain Range and Cascade Range influence precipitation patterns throughout the basin. Substantial differences in annual average precipitation are common within short distances because of the rapid changes from river valleys to mountain peaks. Average annual rainfall in the basin ranges from approximately 30 inches at Riddle, Oregon to 54 inches at Elkton, Oregon, only 20 miles apart (EarthInfo, Inc., 1988). In a more general sense, approximately 30 inches per year of precipitation occur in the interior valley, increasing with elevation to 80 inches annually in the Cascade Mountains (Hayes and Herring, 1960). Approximately 80 percent of annual rainfall occurs between October and March (Figure 2.12).

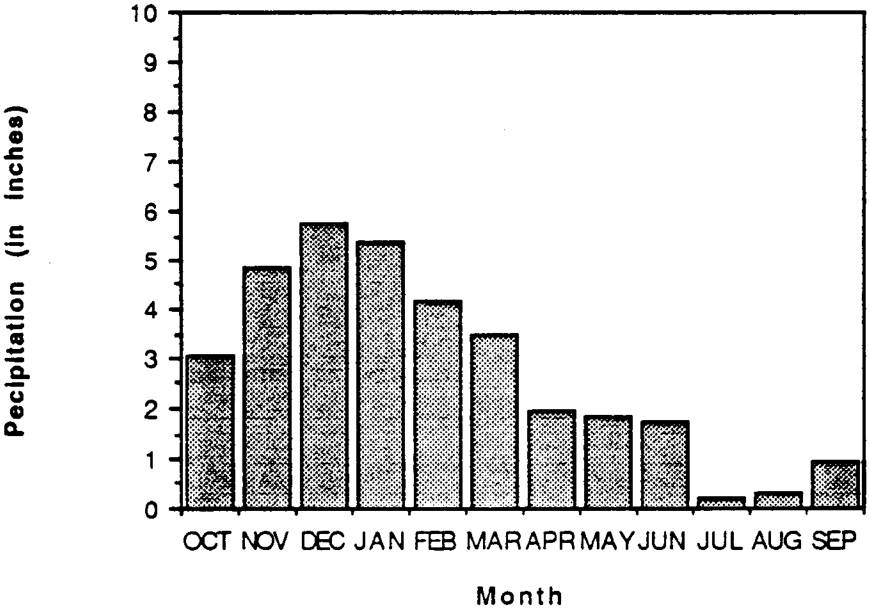


Figure 2.12 Mean monthly precipitation recorded at Roseburg, Oregon (station number 7326), elevation 510 feet. Recorded from 1931 through 1965; mean annual precipitation is 33.8 inches (EarthInfo, Inc., 1988).

Snowfall accumulates at higher elevations in the basin. Most of the area which supports prolonged snow pack is located in the North Umpqua basin. Average snowfall recorded at Toketee Falls, Oregon, elevation 2,060 feet, is 48.5 inches annually (EarthInfo, Inc., 1988). Snowfall totals are larger at higher elevations in the catchment. The water equivalents of the measured snow depths are generally unavailable. Snowmelt contributes to flood flow in the autumn and winter when warm (rain producing) weather systems move over the catchment. Spring melt does not contribute to regular flooding.

2.4.3 VEGETATION

The forest is principally douglas fir in the north and it changes to mixed pine in the south (Richlen, 1973). The catchment is mainly forested with some small meadows. Much of the land is owned by the United States Forest Service and other government agencies. A small portion of the catchment, in the Crater Lake area, is protected from commercial timber harvest (Pacific Northwest River Basins Commission, Fig. 44, 1970). The most thickly forested areas are found at higher elevations where timber harvesting access is limited. Douglas fir (pseudotsuga menziesii), ponderosa pine (pinus ponderosa), sugar pine (pinus lambertiana), grand fir (abies grandis), cedar (cedrus), lodgepole pine (pinus contorta), and some hardwood varieties (acer and others) are found in these areas of the basin (Hayes and Herring, 1960; Richlen, 1973).

Most of the range and crop land in the basin is located in low mountains and foothills in river reaches between Canyonville and Elkton. The footslopes, fans, or terraces of these hills are typically used for crops or grazing (Pacific Northwest River Basins Commission, 1970). Crops include fruit, cereal, and grains. Trees and prairie grasses grow on range land located adjacent to the river.

2.4.4 SOILS

The soils that formed in Douglas County were influenced by a variety of factors. Basalt flows and volcanic activity in the Cascade Mountains laid much of the parent material. At higher elevations this is still exposed and soils are thin. Granites and basalts have weathered and decomposed to form the rolling hills. Upper portions of the basin contain sandstone or basalt bedrock. There is evidence of some glacial lacusturine deposits in upper regions of the basin. Table 2.6 presents the major soils of the Umpqua River basin.

Table 2.6 Soils in the Umpqua River basin and selected physical characteristics (SCS, 1986; USACERL, 1990; Richlen, 1973; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Malabon-Coburg-Salem	Floodplains and Terraces	0.2 to > 20.0	.02 to .20	0 to 45	CL, CL-ML, GM, GM-GC, GP, GP-GM, ML, SM, SP, SP-SM	B,C
Medford-Takilma-Newburg	Floodplains and Terraces	0.2 to 20.0	.03 to .18	0 to 45	CL, CL-ML, GC, GM, GP-GM, GW, GW-GM, ML, SC	B
Oakland-Bateman-Sutherlin	Forested Uplands	< 0.06 to 0.6	.11 to .21	18 to 45	CH, CL, CL-ML, GC, ML	C
Jory-Nekia	Forested Uplands	0.2 to 2.0	.11 to .21	18 to 60	CH, CL, GC, MH, ML	C
Bellpine-Nekia-Hazelair	Forested Uplands	< 0.06 to 2.0	.09 to .21	18 to 70	CH, CL, GC, MH, ML	C, D
Klickitat-Kinney-Harrington	Forested Mountain Uplands	0.6 to 6.0	.05 to .16	10 to 33	CL, GC, GM, GM-GC, ML, SC	B
Kinzel-Keel-Hummington	Forested Mountain Uplands	0.6 to 6.0	.10 to .50	5 to 20	GM, MH, ML, SM	B, C
Siskiyou-Lettia-Clawson	Mountains and Hills	0.2 to 6.0	.07 to .17	8 to 35	CL, ML, SC, SC-SM, SM	B, C
Beekman-Josephine-Vannoy	Mountains and Hills	0.2 to 2.0	.05 to .19	12 to 35	CL, CL-ML, GC, GM, ML, SC, SM	B, C
Pearsoll-Dubakella-Cornutt	Mountains and Hills	< 0.06 to 2.0	.04 to .18	15 to 60	CH, CL, CL-ML, GC, GM, GM-GC, ML, SC, SC-SM, SM	C, D
Freezener-Geppert-Straight	Mountains and Hills	0.2 to 2.0	.03 to .21	0 to 45	CL, CL-ML, GM, GM-GC, GP, GP-GM, ML, SC, SC-SM, SM	B, C
Lastance-Talapus	High Mountains	0.6 to 6.0	.06 to .18	5 to 18	GM, GP-GM, GW-GM, SM	B

2.5 SILETZ RIVER (202 MI^2)

The Siletz River is located in Lincoln and Polk Counties in Western Oregon (Figure 2.13). The river flows to the Pacific Ocean at the basin's west boundary. To the east and north lie the mountains of the Coast Range. The Yaquina River basin to the south, is separated from the Siletz River Basin by only a few small foothills.

The Siletz River flows initially in a southerly direction until it reaches Logsden, Oregon. There it turns west until it reaches Siletz, Oregon, where it turns to the northwest. The river starts on Stott Mountain and Sugarloaf Mountain approximately 20 miles east of the Pacific coast. The South Fork originates at Valsetz Lake and flows northwest until it joins the main stem. Gravel Creek enters below this confluence and a major tributary, Rock Creek, enters further downstream.

The stream gauge used is located at Siletz, Oregon, elevation 102.32 feet, vertical datum of 1929, approximately 15 miles upstream from the Pacific Ocean (Friday, 1984). The gauge has a relatively long period of record, from 1905 with a break between 1912 and 1924.

2.5.1 TOPOGRAPHY

The Siletz River basin is typical of many Oregon and Washington coastal rivers. The western portion of the catchment is characterized by dissected marine terraces extending up to 2 miles inland (SCS, 1990). East of the terraces the region is dominated by steep mountainous terrain which rises from near sea level to just over 3,400 feet on Sugarloaf Mountain (Allan Cartography, 1987). Most of the higher elevations are found in the northeastern portion of the catchment. Primarily the basin lies in coastal lowlands, meandering northward almost 20 miles along the base of the Coast Range. The Siletz River has generally narrow stream valleys with active flood plains and several distinct levels of older flood plain terraces (SCS, 1990).

2.5.2 WEATHER

The Siletz basin experiences typical North Pacific coastal precipitation patterns (Figures 2.14 and 2.15). Orographic effects are pronounced in the region with the dominant storms moving inland from the ocean. The Coastal Mountain Range has a significant impact on precipitation patterns. Mountainous areas in the northwest part of the catchment experience up to 200 inches of rainfall annually; lowlands nearer the coast receive 70 inches of precipitation per year (Hemstrom, 1986). An estimated 30 to 50 inches of rain falls annually on the ocean just west of the basin (SCS, 1990).

Fog occurs frequently in the summer months along the coast. Fog "drip" provides measurable precipitation at stations in the basin. Fog and drizzle over the coastline account for a larger number of rainy days

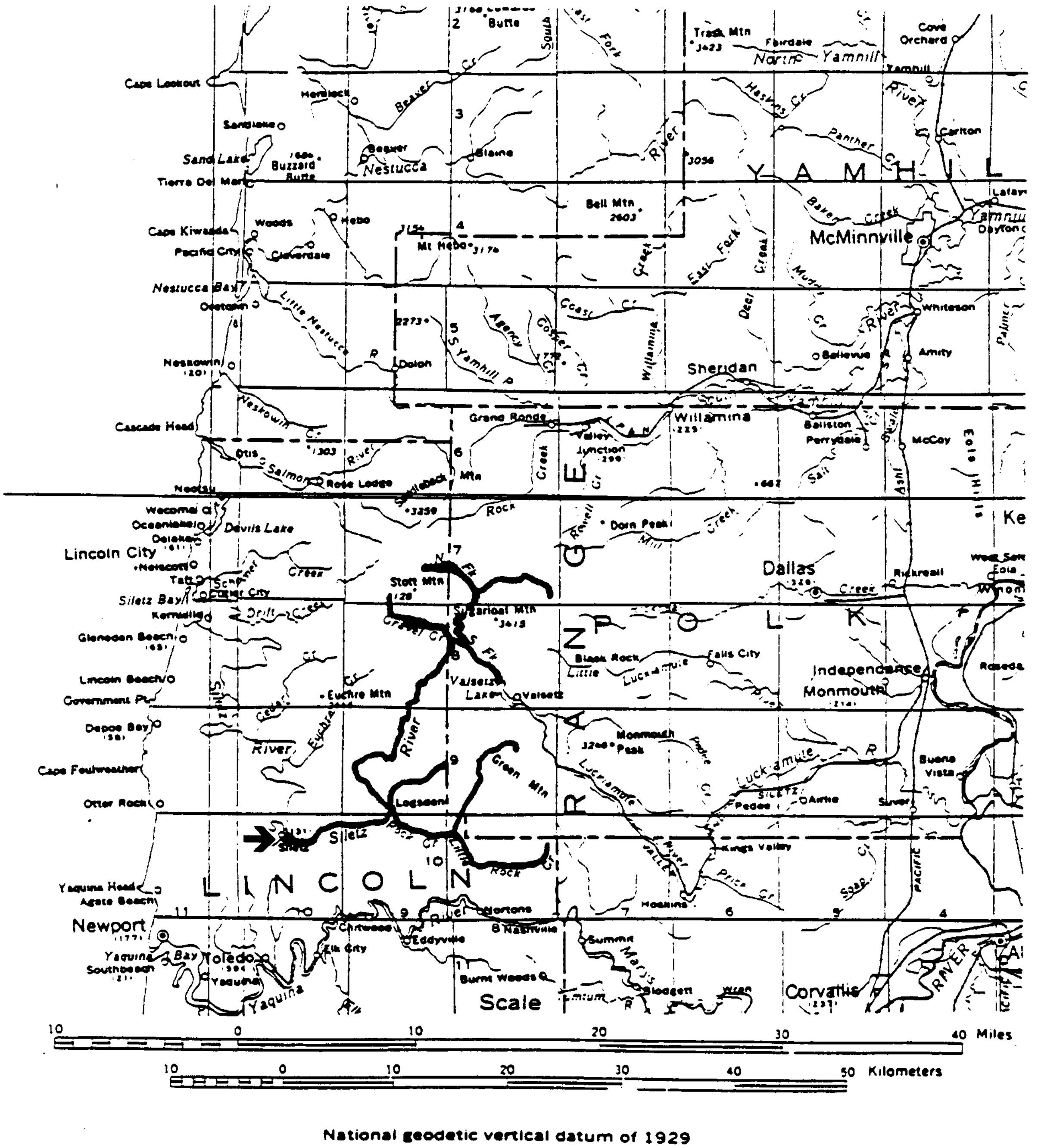


Figure 2.13 Plan view showing locations of principal channels of the Siletz River basin, stream gauge, and towns. Scale approximately 1 : 600,000 (USGS, 1979).

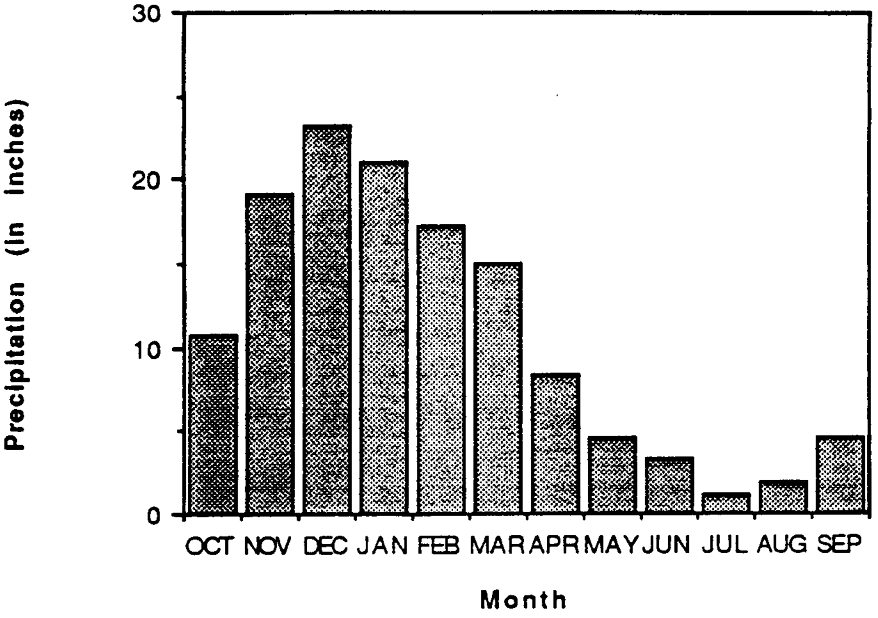


Figure 2.14 Mean monthly precipitation recorded at Valsetz, Oregon (station number 8833), elevation 1,160 feet. Recorded from 1936 through 1986; mean annual precipitation 129.1 inches (EarthInfo, Inc., 1988).

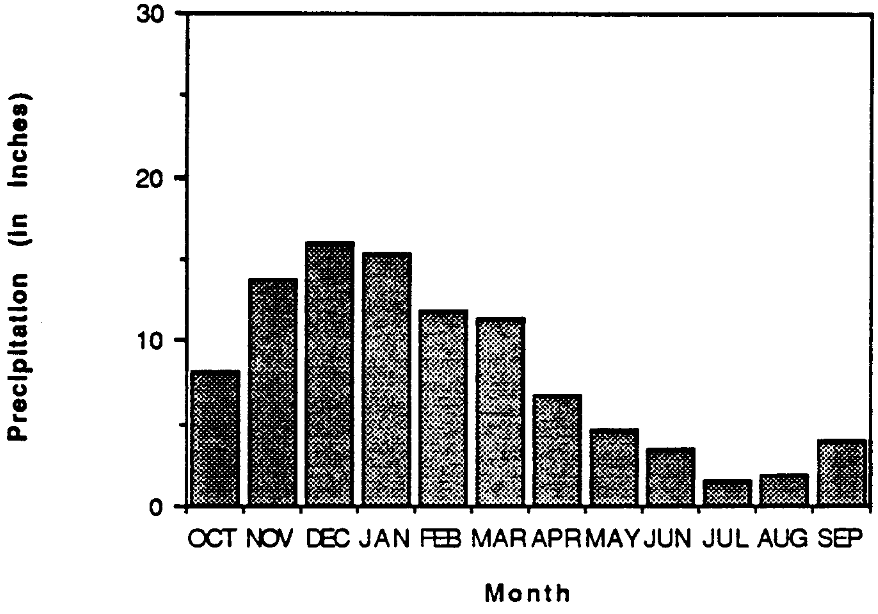


Figure 2.15 Mean monthly precipitation recorded at Otis, Oregon (station number 6366), elevation 150 feet. Recorded from 1948 through 1988; mean annual precipitation is 97.9 inches (EarthInfo, Inc., 1988).

than at higher elevations where twice as much precipitation is recorded; 48 percent of yearly rainfall occurs from November to January (SCS, 1990).

Snowfall is uncommon at lower elevations in the catchment. Measurable snow falls, on average, once per year or once every other year near sea level (SCS, 1990). Higher elevations in the Coast Range receive snow more frequently. Valsetz, at 1,160 feet averages over 26 inches of snowfall annually and receives an inch or more on 6 days each year (SCS, 1990; EarthInfo Inc., 1988). Snowmelt is not a significant contributor to flood flows.

2.5.3 VEGETATION

Forest and understory cover in the Siletz River basin are dense and dominate the region. Approximately 90 percent of the area is classified as commercial forest land (SCS, 1990).

A Sitka spruce (picea sitchensis) zone is located in the coastal and lower river reaches of the basin. Salmonberry (rubus spectabilis) and salal (gaultheria shallon) are commonly found understory vegetation (Hemstrom, 1986). Further inland, where soils are well-drained, Douglas fir (pseudotsuga menziesii) are likely to be found on steeper slopes and western red cedar (cedrus rubrua) on valley floors. Red alder (alnus rubra) and big leaf maple (acer macrophyllum) are the major hardwood species found in the basin. Vine maple (acer circinatum), salal and salmonberry dominate shrub growth (Hemstrom, 1986).

At lower elevations, several extremely small areas of crop and rangeland are located adjacent to the river. These areas are dedicated to grazing and forage production; hay and pasture lands are closest to the river. Strawberries, blueberries, Christmas trees, and vegetables are grown on the terraced areas (SCS, 1990).

2.5.4 SOILS

The Lincoln and Polk County soils were heavily influenced by a maritime climate, volcanic activity, and deposition of sediment from runoff. At higher elevations, and in the Siletz River Gorge, there are basalt formations, indicative of subsurface volcanic activity. At lower elevations the soils overlay sedimentary bedrock where siltstones and sandstones are abundant. These sedimentary rocks were likely formed from river or marine deposition of sediments (Thorson, 1990; Hemstrom, 1986). The general soils found within the Siletz region are summarized in Table 2.7.

Table 2.7 Soils in the Siletz River basin and selected physical characteristics (Shipman, 1990; SCS, 1986; USACERL, 1990; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Bandon-Coquille-Nehalem	Coastal Fog Belt	0.06 to 20.0	.05 to .21	3 to 65	CL, CL-ML, MH, ML, SC, SM	C, D
Templeton-Salander-Svenson	Coastal Fog Belt	0.6 to 2.0	.20 to .45	10 to 35	CL, GM, MH, OL, OH	G
Klistan-Hemcross-Harslow	Coastal Mountain Uplands	0.6 to 6.0	.05 to .45	12 to 27	GM, GP-GM, MH, SM	B, C
Valsetz-Luckiamute	Coastal Mountain Uplands	0.6 to 6.0	.06 to .25	20 to 35	GC, GM, GM-GC, MH, SM	C, D

2.6 NEHALEM RIVER (667 MI^2)

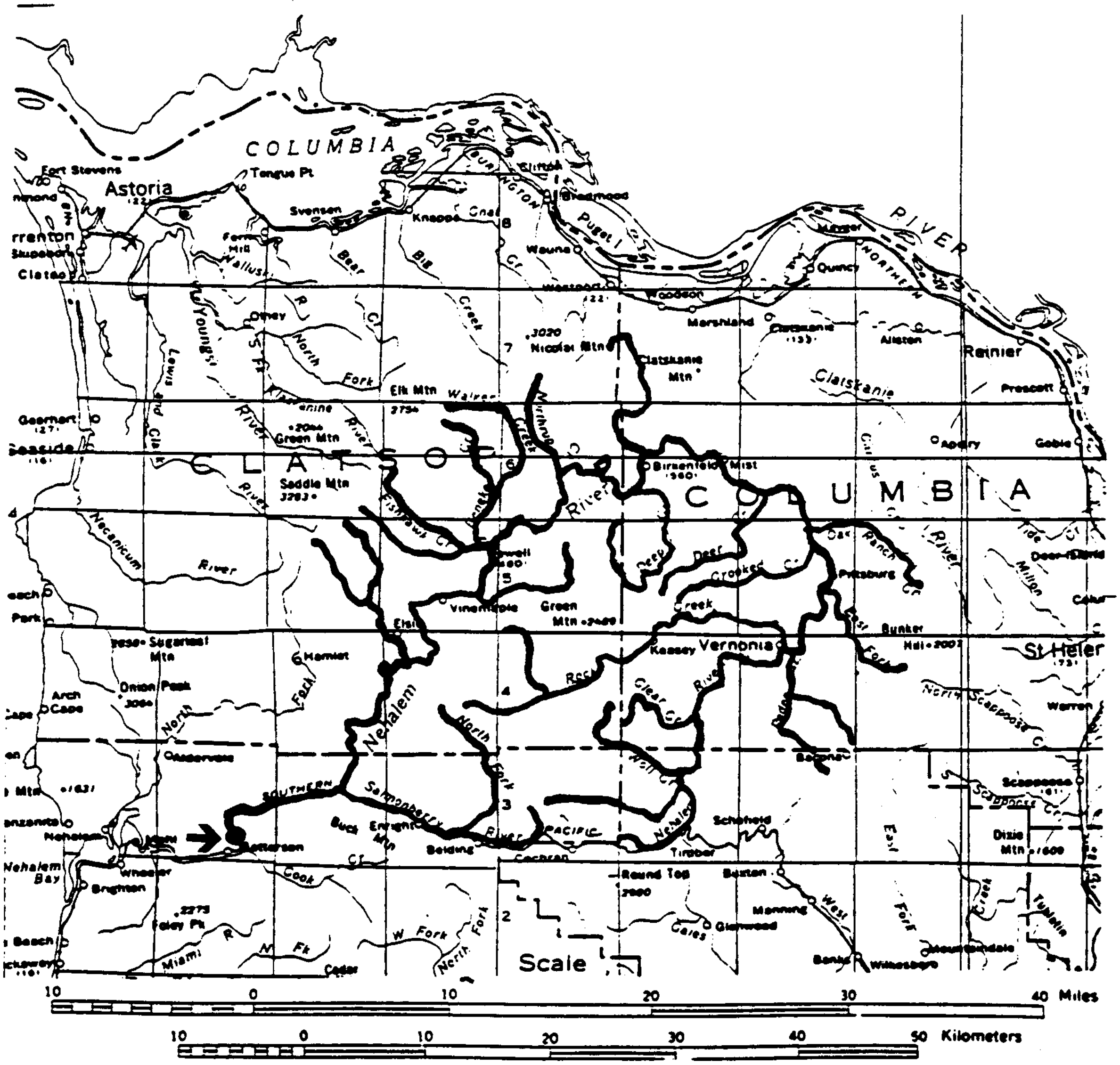
The Nehalem River system is located in Tillamook, Clatsop, and Columbia Counties in the northwest corner of Oregon (Figure 2.16). The Columbia River is the major river immediately to the north. To the south are the mountains and foothills of the Coast Range. The Nehalem River empties into the Pacific Ocean to the west.

Initially, the Nehalem River flows eastward, originating on the leeward or dry side of the Coast Range near Cochran, Oregon (Figure 2.16). It turns north, flowing toward the Columbia River and is joined by Wolf, Clear, Rock, Pebble, Crooked, Oak Ranch, and Deer Creeks, respectively. At its northernmost point, the Nehalem River comes to within 15 miles of the Columbia. It then turns west and is joined by Deep, Northrup, Fishawk, and Cook Creeks and the Salmonberry River before it drains into the Pacific Ocean.

The stream gauge used is located near Foss, Oregon approximately 8 miles inland from the coast, at an elevation of 32.60 feet vertical datum of 1929 (Friday and Miller, 1984). This gauge has been in operation since 1940.

2.6.1 TOPOGRAPHY

The Nehalem River basin is typical of a Pacific Northwest coastal catchment except for its circuitous path. The catchment is characterized by steep mountains, terraces, and a wide river valley. It winds down, around, and through the Coast Range. It turns west through a gap in the mountains where elevations on either



National geodetic vertical datum of 1929

Figure 2.16 Plan view showing locations of principal channels of the Nehalem River basin, stream gauge, and towns. Scale approximately 1 : 600,000 (USGS, 1979).

side range between 2,500 feet and 3,000 feet (USGS, 1987). At Jewell Junction, its character changes. The river has cut through basalt to form a canyon with vertical sides and flows as rapids and waterfalls through parts of this section (Smith and Shipman, 1988). For most of the catchment the terrain is mostly rolling hills, with gentle, wide valley floors.

2.6.2 WEATHER

The Nehalem River basin experiences a typical maritime coastal climate. The Coast Range has an influences rainfall patterns in the catchment. Rainfall for "wet" and "dry" locations is illustrated in Figures 2.17, and 2.18, respectively. Mountains in the southeast portion of the basin receive in excess of 100 inches of rain annually (Hemstrom, 1986). The "dry" side of the Coast Range experiences precipitation on the order of 40 to 50 inches per year (EarthInfo., 1988).

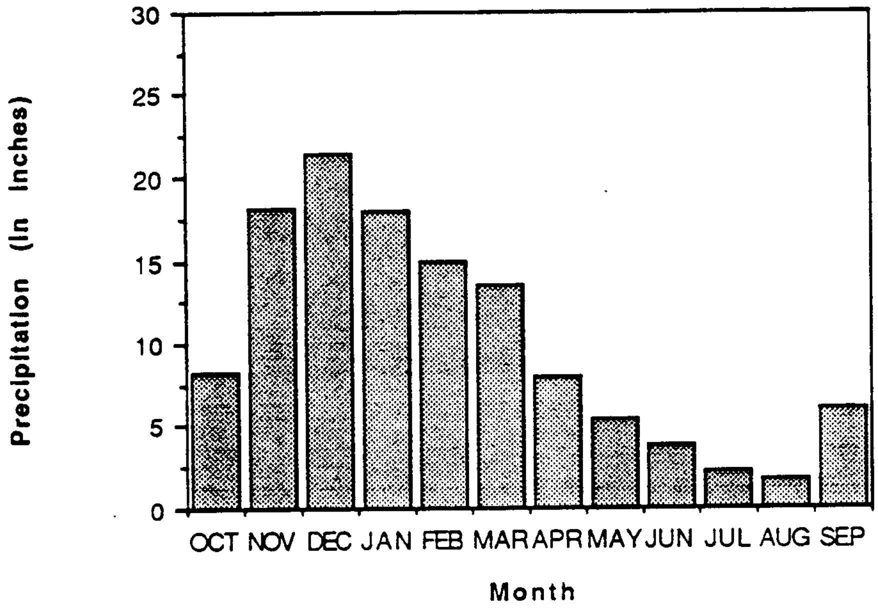


Figure 2.17 Mean monthly precipitation recorded at Nehalem, Oregon (station number 5971), elevation 140 feet. Recorded from 1969 through 1988; mean annual precipitation is 121.9 inches (EarthInfo, Inc., 1988).

Generally, the pattern of annual precipitation in the catchment is heavy on the coast, increases with elevation in the Coast Range, and drops significantly on the eastern side of the crest of the Coast Range. The lower Nehalem River is located in the "fog belt" region of Oregon (SCS, 1990). Fog is a frequent phenomenon in summer months. Fog 'drip' provides measurable moisture to the basin. The bulk of yearly rainfall occurs in the winter months, between October and March.

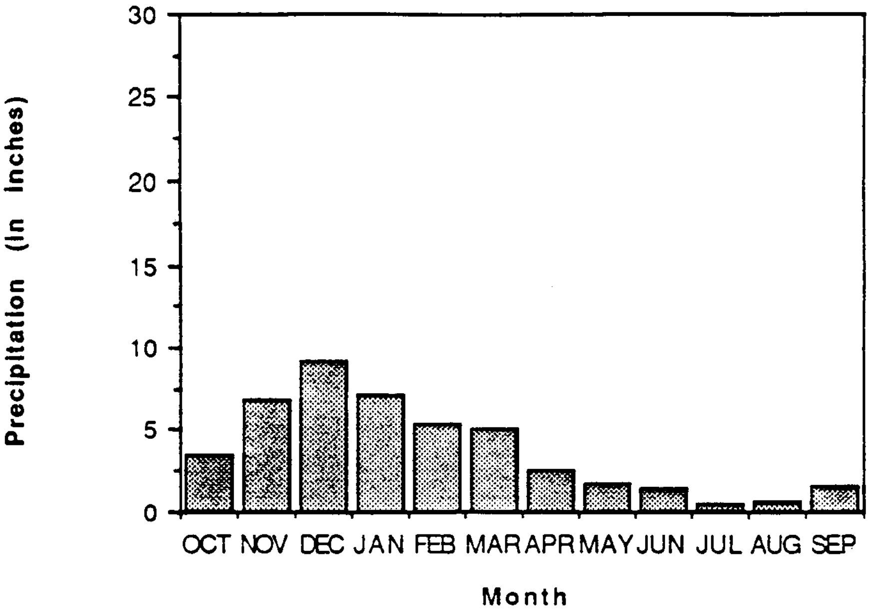


Figure 2.18 Mean monthly precipitation recorded at Forest Grove, Oregon (station number 2997), elevation 180 feet. Recorded from 1928 through 1988; mean annual precipitation is 45.4 inches (EarthInfo, Inc., 1988)

Snow falls occasionally in the catchment. The average annual total is less than 3 inches at Nehalem; however, as elevation increases, totals increase (EarthInfo, Inc., 1988). Accumulation occurs typically in the higher elevations of the Coast Range. Snow is present on vegetation and the ground for brief periods and has minimal influence on floods.

2.6.3 VEGETATION

The Nehalem River basin is characterized by dense forest and understory vegetation. Roughly 25 to 35 percent of the region is owned as public land by the State of Oregon, the remainder being privately held (Pacific Northwest River Basins Commission, Fig. 42, 1970). Timber harvesting is permitted throughout the entire basin.

The western fog belt area of the basin, where summers are cool and moist, contains mostly Sitka spruce (picea sitchensis), western hemlock (tsuga heterophylla), and red alder (alnus rubra). Understory growth is also abundant. In eastern portions of the catchment, where summers are warm and moist, Douglas fir (pseudotsuga menziesii), western red cedar (cedrus rubra), western hemlock, and red alder are common.

Several small crop growing regions are located adjacent to the Nehalem River. While high soil acidity limits the variety of crops which can be grown, woody plants including blueberries, cranberries, holly, and some flowers grow well in these soils (Pacific Northwest River Basins Commission, 1970).

2.6.4 SOILS

The soils in Tillamook, Clatsop and Columbia Counties were predominantly influenced by the maritime climate and associated hillslope and channel flow production. Much of the area is comprised of marine sediments which have been lifted and pierced by basalt intrusion and flow (SCS, 1990). Except for the highest elevations, the catchment overlies sedimentary siltstone and sandstone. Soils in these regions were formed by marine or ocean activity and alluvial deposition. The upper elevations in the catchment contain basalts, likely of submarine origin. Extensive lifting in this region has caused mixing of the sedimentary and basaltic materials (Smith and Shipman, 1988).

It appears that most of these soils came from the same parent material. Their differences are due to differing climatic conditions where weathering and erosion took place (Thorson, 1990). The predominant soils in the Nehalem River basin are displayed in Table 2.8.

Table 2.8 Soils in the Nehalem River basin and selected physical characteristics (Thorson, 1990; SCS, 1986; USACERL, 1990; Das, 1990).

Soil	Location	Permeability (In./Hr.)	Water Capacity (In./In.)	Percent Clay	Unified Soil Class	USDA Hydrologic Group
Bandon-Coquille-Nehalem	Coastal Fog Belt	0.06 to 20.0	.05 to .17	5 to 65	CL, CL-ML, MH, ML, SC, SM	C, D
Templeton-Salander-Svenson	Coastal Fog Belt	0.6 to 2.0	.20 to .45	10 to 35	CL, GM, MH, ML, OL, OH	B
Murtip-Tolany- Caterl	Coastal Mountain Uplands	0.6 to 2.0	.16 to .45	12 to 27	GM, GP-GM, MH, ML, SM	B
Digger-Bohannon-Preacher	Coastal Mountain Uplands	0.6 to 6.0	.07 to .35	7 to 35	CL-ML, GM, MH, ML, SC-SM, SM	B, C
Klistan-Hemcross-Harslow	Coastal Mountain Uplands	0.6 to 6.0	.05 to .45	12 to 27	GM, GP-GM, MH, SM	B, C
Eilersten-Kirkendall	Floodplains and Terraces	0.6 to 2.0	.16 to .21	15 to 35	CL, CL-ML, ML	C

2.7 SUMMARY

The preceding sections provide both general and specific information about topography, weather, vegetation, and soils in each of seven river catchments. The descriptions have been included for completeness and to give a summary of catchment features. The seven catchments vary in size by almost two orders of magnitude (40 to 3680 square miles) and represent a range of flood flow production processes. The physical, climatological, and weather characteristics combine to yield different hydrologic behavior for each catchment. Considerably more information than we have included here is needed to describe flood flow production for particular storms or snowmelt situations. If the n-day floods are nested and have common return periods for these seven catchments, it is likely that similar relationships would be found in other hydro-climatic regions.

The flood flow volume records at the gauge location for each of these catchments are examined in Chapter 3. Each flow record is analyzed using the approach described in Chapter 1.

CHAPTER 3 ANALYSIS OF FLOOD VOLUME-DURATION INFORMATION

The continuous time series of daily flow volumes for each of the seven river systems described above was used to examine flood volumes of differing duration. United States Geological Survey stream flow records were read from "Hydrodata"; a compact disc published by EarthInfo, Inc. (formerly U.S. West Optical Publishing) containing United States Geological Survey annual instantaneous maxima (peak) and daily average flow records.

The first step in the process was to compute annual maximum 1-, 3-, 5-, and 10-day flow volumes. Daily flow values were systematically searched to find the largest 3, 5, and 10 day flood volumes (hereafter the term "n-day" shall be used to represent events associated with multiple time periods involved, such as 3, 5, and 10-day) from each year of record. Each maximum value was indexed by day of the water year in which the event occurred. Table 3.1 is a sample of such a summary. A FORTRAN computer program which was written for this purpose is available from the authors.

Table 3.1 Example annual maximum n-day flood volumes (cfs-days) and the first day of the n-day period, for the Willapa River, Washington. Complete summaries are given in Appendix A.

Year	Day	1-Day Volume	Day	3-Day Volume	Day	5-Day Volume	Day	10-Day Volume
1949	145	10,000	144	26,610	144	25,650	139	43,800
1950	89	7,460	112	18,120	112	24,190	147	34,940
1951	132	8,790	132	21,740	130	28,600	127	38,200

In the above table, the following tables, and Appendix A, the "first day" corresponds to the day of the United States water year which starts on October 1 of the year preceding the calendar year for which the water year is defined. For example, water year 1975 is from October 1, 1974 to September 30, 1975. The water year day corresponding to the first day of the calendar month is given in Appendix B for non leap years.

The n-day floods from each year were examined to determine if they occurred during the same time period. The primary interest was to determine if, for the entire period of record for a selected river, the largest flood volumes from each year were nested (that is they all occurred within the same period of time). The hypothesis was that the largest annual n-day volumes from each year would occur within the same 10 day period, since 10 days was the largest flooding duration examined.

The second step was to rank order the series of n-day volumes for each catchment. For example, all of the 5-day volumes were ranked independently from other durations. Return period and probability of exceedance were computed for each catchment's ordered series using Cunnane's (1978) scheme. For example, the Mth largest 5-day volume was assigned return period

$$T_{M,5} = \frac{N + 1 - 2\alpha}{M - \alpha} \qquad (2)$$

where: $\alpha = 0.40$ and N = total number of 5-day volumes. Table 3.2 shows an example of such a ranking summary. A second FORTRAN computer program (available from the authors) was used for this purpose.

Table 3.2 Example rank ordered maximum annual flood volumes (cfs-days), for the Willapa River, Washington, record length of 35 years. Complete summaries are given in Appendix A.

1-Day		**3-Day**		**5-Day**		**10-Day**			
Year	Volume	Year	Volume	Year	Volume	Year	Volume	Return Period	Probability of Exceedance
1967	10,100	1976	26,120	1976	36,510	1954	46,340	58.7	0.017
1949	10,000	1951	21,740	1951	28,600	1976	45,530	22.0	0.046
1987	9,760	1949	20,610	1982	28,300	1982	45,200	13.5	0.074

A balanced flood is one: ". . . of equal severity for all possible critical durations of project design." (Beard, 1975). 'Equal severity' means equal probability of exceedance or return period for critical duration floods. The critical flood durations for a particular project are not known apriori. They may depend upon many factors including the magnitude of a particular flood, the river's storage capacity, any reservoir storage capacity, and reservoir release rates. de Ormijina and Maidment (1988) have suggested a method for determining a catchment's critical duration flood. The concern here with duration is only to the extent that a particular duration remains an issue for flood damage mitigation.

When the objective is to design and operate facilities to contain river flow within a channel, flow rates in excess of the bank-full rate must be stored or diverted via manmade means. The bank-full flow rate for alluvial channels occurs with a return period of approximately 1.58 years when the annual maximum flood volumes are plotted to an extreme value type I distribution (Dury, 1969). Consequently, we chose the 1-day flood flow rate associated with a theoretical extreme value type I return period of 1.6 years as the bank-full flow rate. The 3-, 5-, and 10-day natural bank-full volumes were calculated by multiplying the selected 1-day rate by the number of days of interest (3, 5, or 10). The resultant n-day bank-full volumes were plotted as overlaying horizontal lines on an extreme value type I plot of annual n-day flood volumes calculated above.

A basin which produces flood volumes greater than or nearly the same as the theoretical bank-full volumes requires mitigation measures to avoid flooding. The duration of excess flow volume dictates the flood duration time period to be considered.

The hydrographs for years in which the six largest 1-day flood volumes occurred were examined and return periods for each of the n-day volumes compared. Large magnitude floods of critical duration should display a similar probability of exceedance or return period if the assumptions of a balanced flood are valid. Finally, coincidental occurrence of n-day volumes for the six largest 1-day flood volumes was examined.

The reason for examining the six largest floods was arbitrary. There is little point in, and certainly no basis for, constructing theoretical flood frequency distributions when there are fewer than 25 to 30 observations. This is a pragmatic observation rather than some arbitrary hard and fast rule. Whenever a cumulative distribution is constructed it is for the more commonly occurring phenomena. We are usually in the awkward position of extrapolating beyond the largest observed data to estimate design floods. For a record containing 30 annual floods, the sixth largest has an approximate return period of five years. Few, if any flood damage mitigation measures are considered for return periods of this magnitude and smaller.

3.1 WILLAPA RIVER CATCHMENT (130 mi^2)

The Willapa catchment (USGS Station Number 12013500, -- records "good", rating curve extrapolated beyond 7,300 cfs) has 35 years of record, from 1949 until 1988. No records were kept from 1 December 1954 to 31 March 1961. In sixteen of thirty-five years, n-day volumes were not produced by the same flood generation weather system.

In six cases, 1-day flood volumes did not occur within the same time frame as the 3-, 5-, and 10-day volumes for the same return period. In these cases, however, the 3-, 5-, and 10- day volumes were nested. In four other cases the 10-day volumes occurred at a different time from 1-, 3-, and 5-day volumes, which occurred coincidentally. In four other years, more than two flood production systems were involved. Finally, in two water years 5-day volumes occurred partially outside the period which contained the 10-day volume.

The Willapa River bank-full flow rate is approximately 6,130 cfs for a 1.6 year return period. Theoretical bank-full volumes for 1-, 3-, 5-, and 10-days are shown together with flood data, displayed using an extreme value type I probability scale, in Figure 3.1.

Inspection of Figure 3.1 reveals that in the Willapa catchment critical flood durations are from 1 to 3 days. The largest recorded 5-day volume exceeds the theoretical 5-day bank-full volume. Observed 10-day volumes are all less than the theoretical within-channel 10-day bank-full volume. Consequently, the primary

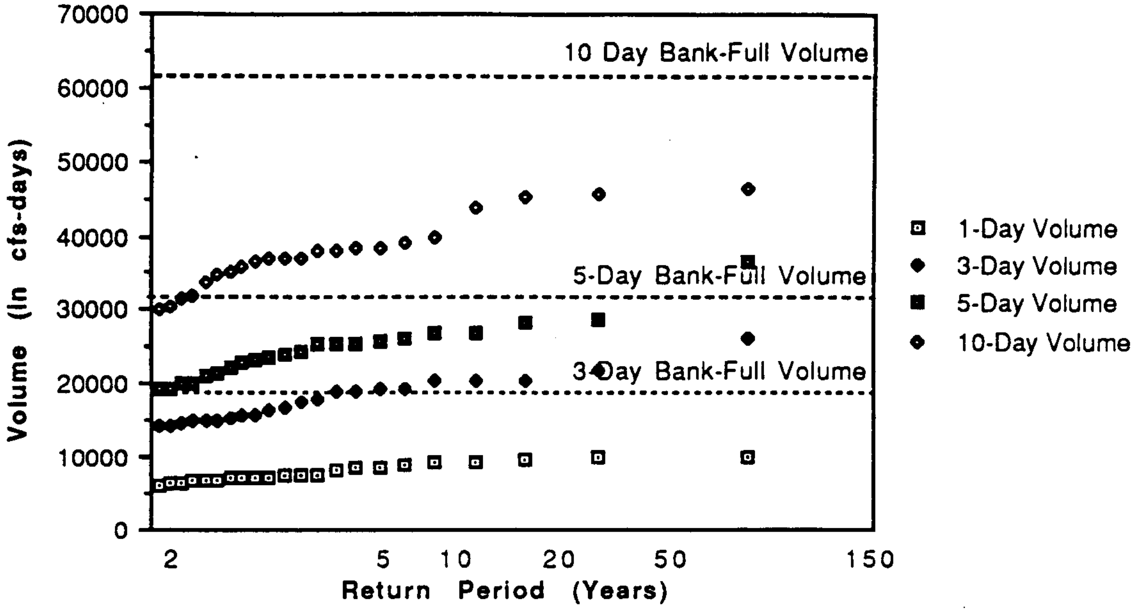


Figure 3.1 Bank-full and rank-ordered observed volumes, Willapa River, Washington.

focus of evaluation is on the frequency relationship between 1- and 3-day flood volumes. The return period for n-day volumes of years in which the six largest 1-day floods occurred is presented in Table 3.3. These results are also presented graphically in Figure 3.2.

Table 3.3 Return period (years) associated with n-day flood volume (cfsd) for the six largest 1-day flood volumes on the Willapa River, Washington.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1967	58.7	4.1	2.6	3.0
1949	22.0	13.5	4.6	9.8
1987	13.5	5.3	3.3	2.3
1971	9.8	9.8	4.1	2.6
1963	7.6	2.8	1.9	2.8
1976	6.3	58.7	58.7	22.0

The six largest 1-day flood volumes occurred in 1949, 1951, 1963, 1967, 1971, and 1987. In water years 1949, 1971 and 1976 the n-day volume return periods are closely related between two n-day volumes in each year. For example, the 3- and 5-day flood volumes in 1976 have the same return period.

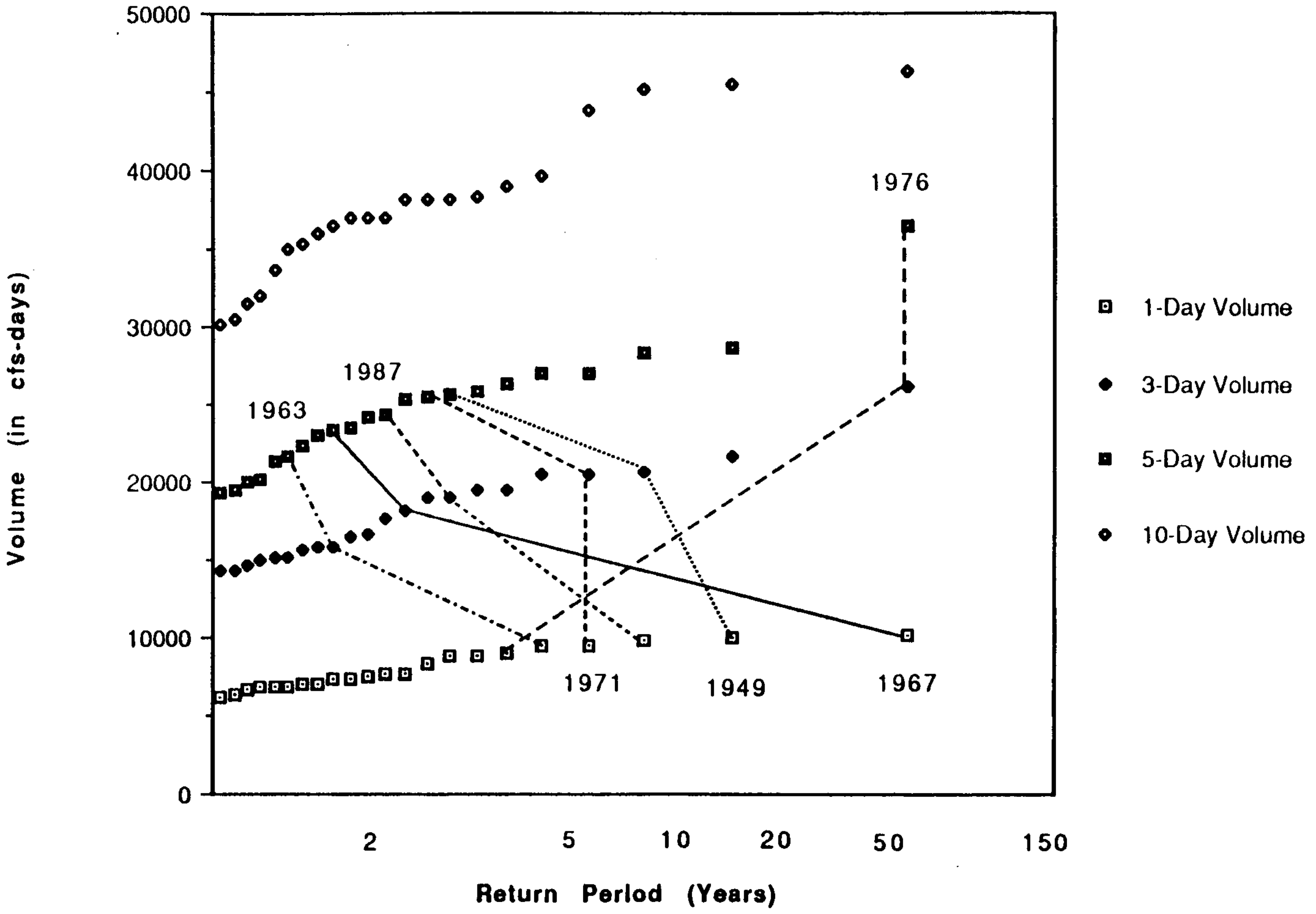


Figure 3.2 Relationship of 1-, 3-, and 5-day flow volumes for the six largest 1-day flood volumes on the Willapa River, Washington.

In 1967 the flood volume dropped from the largest 1-day flood of record in the basin to just over a bank-full condition for the 3-day volume and less than bank-full at 5 days. In 1963 the fourth largest 1-day flood volume in the basin dropped to flowing less than bank-full in 3 days and remained so for the 5-day duration.

In 1976 the 1-day flood was the sixth largest in the record; the 3- and 5- day flood volumes were the largest. Inspection of Figure 3.2 shows that there is no relationship between return period and n-day flood volumes on the Willapa River.

A design flood, whose volumes, at critical durations, have equal return periods (or probability of exceedance) can not be developed using the procedures in Figure 1.1 for the Willapa River at the stream gauge location. For this catchment, the assumption of nested and balanced hydrographs for design, and particularly those obtained from extrapolating theoretical n-day volume distributions, is invalid.

3.2 GRAYS RIVER CATCHMENT (40 mi^2)

The Grays River basin (USGS Station Number 14249500 -- records "good", rating curve extrapolated beyond 3,900 cfs) has 21 years of recorded stream flow from 1956 through 1976. In ten of those years the n-day flood volumes were not nested. In two cases the 1-day flood volume did not occur at the same time of year as 3-, 5-, and 10-day volumes; however, the latter all overlapped. In two other cases the opposite was true: 10-day volumes were produced independently from 1-, 3-, and 5-day volumes; the shorter duration floods in those years were nested. In two other cases the 5-day volumes started within the 10-day volume time frame but they extended past the end of the longer flood. Finally, in four cases n-day volumes were recorded at three or more different times of the year, or else the 3- or 5-day volume occurred outside the time frame of the 10-day volume.

The Grays River bank-full flow is approximately 3,030 cfs with an associated return period of 1.6 years. Theoretical n-day volumes are shown on an extreme value plot in Figure 3.3.

Inspection of Figure 3.3 indicates that critical flood durations in the Grays River basin, are 1 to 3 days. One 5-day volume exceeds the theoretical bank-full volume. Recorded 10-day volumes are all below the theoretical bank-full volume and therefore are not of critical duration. The major emphasis in this evaluation is frequency relationship between 1- and 3-day duration flood volumes. Return periods associated with n-day volumes in years when the six largest 1-day flood volumes occurred are displayed in Table 3.4 and depicted graphically in Figure 3.4.

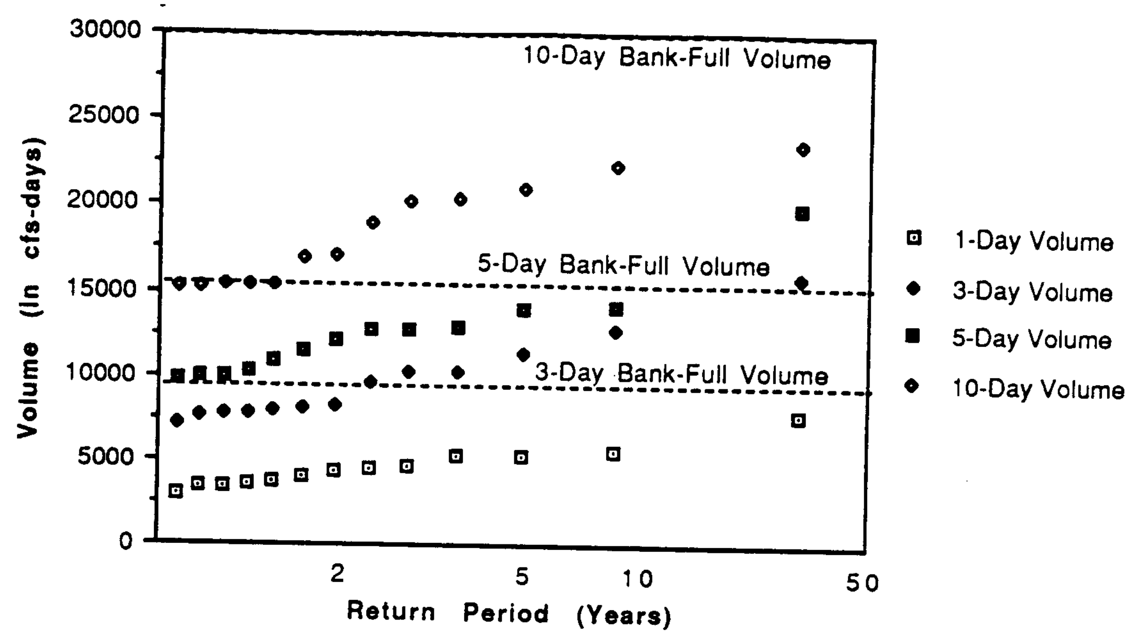


Figure 3.3 Bank-full and rank-ordered observed flow volumes, Grays River, Washington.

Table 3.4 Return period (years) associated with n-day volume for six largest 1-day flood volumes (cfsd) on the Grays River, Washington.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1972	35.3	35.3	35.3	35.3
1963	13.2	13.2	13.2	4.6
1967	8.2	4.6	3.8	2.8
1971	5.9	8.2	8.2	8.2
1961	4.6	3.8	4.6	3.8
1965	3.8	5.9	5.9	5.9

The six largest recorded 1-day flood volumes in this catchment occurred in 1961, 1963, 1965, 1967, 1971, and 1972. In all of these water years the return period associated with the 1-, 3-, and 5-day flood volumes are related. This can be seen in Figure 3.4 by the strong vertical tendency of lines on the extreme value plot for each of the six years examined. In years in which the six largest 1-day flood volumes occurred, the critical n-day volumes occurred coincidentally within the same 5 day time period.

In this instance, the assumption that balanced hydrographs can be developed from the theoretical distributions of data and extrapolated for a larger return period appears to be valid.

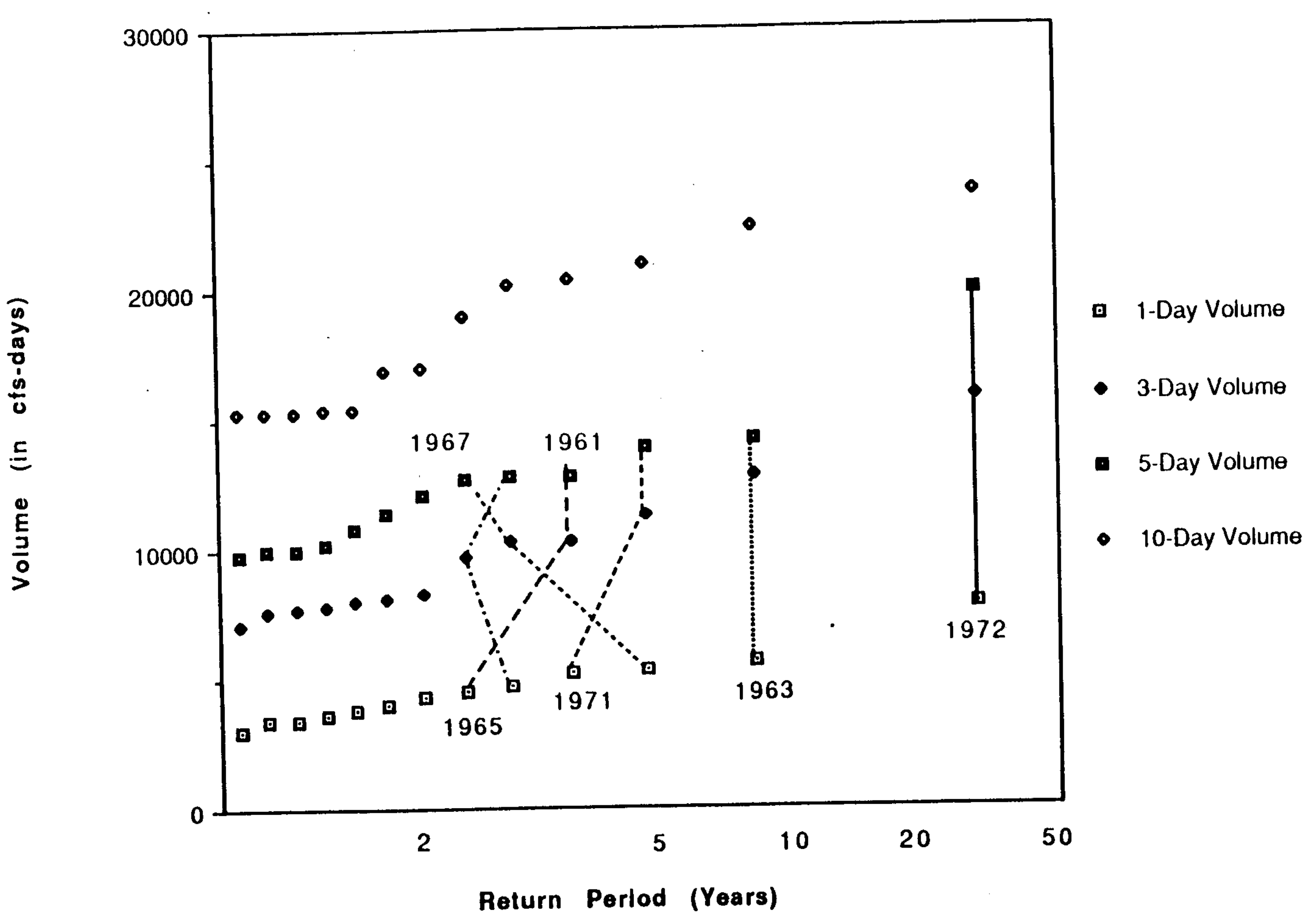


Figure 3.4 Relationship of 1-, 3-, and 5-day flow volumes for the six largest 1-day flood volumes on the Grays River, Washington.

3.3 METHOW RIVER CATCHMENT (1,301 mi^2)

The Methow River (USGS Station Number 12449500 -- records "good" except for periods of ice effect; rating curve extrapolated above 18,000 cfs) has 40 years of flow records, from 1919 through 1962. The gauge was not operating in water years 1930 through 1933. In five of those forty years n-day volumes did not occur coincidentally. In one case, the 5-day flood volume started within the same time window as the 10-day volume but it extended beyond the end of that period. In another case, the single day flood volume was the result of a separate storm system and did not coincide with any of the 3-, 5-, and 10-day volumes. In another instance, the 10-day volume resulted from a separate storm than that which lead to the 1-, 3-, and 5-day volumes. In another case the 1- and 10-day volumes occurred at a different time than the 3- and 5-day volumes. In the final case, 1- and 3- day volumes occurred separately from 5- and 10-day volumes.

The Methow River bank-full flow rate is approximately 9,880 cfs for a 1.6 year return period. Bank-full volumes are compared with observed annual volumes in Figure 3.5.

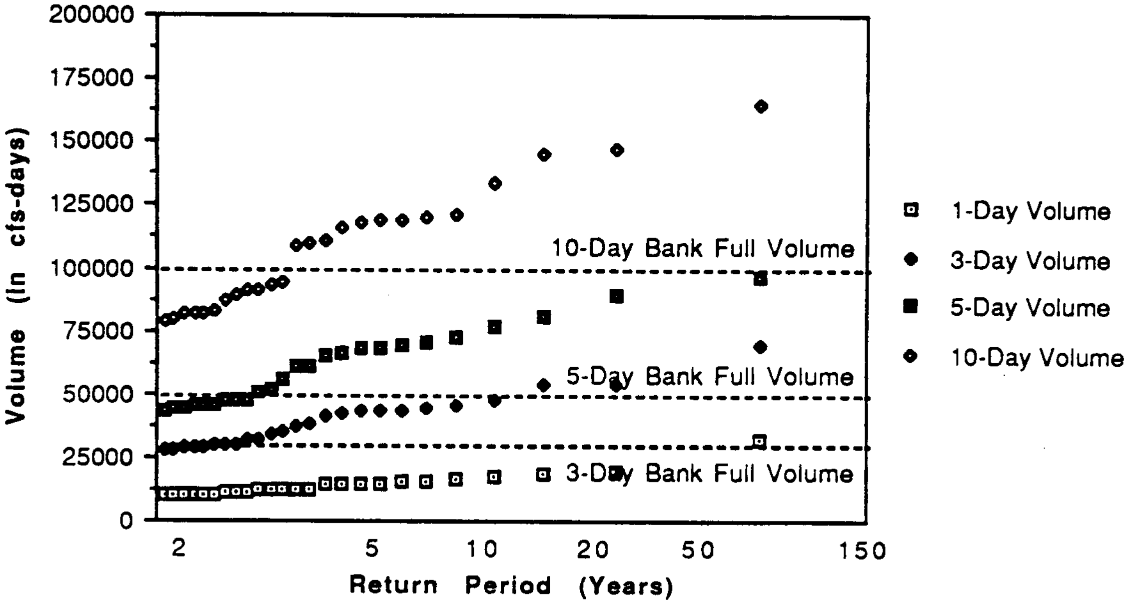


Figure 3.5 Bank-full and rank-ordered observed flow volumes, Methow River, Washington.

Flood durations up to and including 10 days in the Methow catchment are critical relative to our bank-full flow criterion. Thus, the focus of evaluation for this basin is on the frequency relationship between 1-, 3-, 5-, and 10-day flood volumes. The return periods for n-day volumes of years in which the six largest 1-day floods occurred are displayed in Table 3.5 and presented graphically in Figure 3.6.

Table 3.5 Return period (years) associated with n-day flood volume (cfsd) for the six largest 1-day flood volumes on the Methow River, Washington.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1948	67.0	67.0	67.0	15.5
1942	25.1	25.1	15.5	8.7
1950	15.5	15.5	25.1	67.0
1957	11.2	7.2	3.8	3.5
1956	8.7	11.2	11.2	25.1
1955	7.2	8.7	7.2	4.2

The assumptions of nesting and similar frequency are weak for n-day volumes in this catchment. It is clear, however, from Figure 3.6 that 1-, 3-, and probably 5-day volumes can be treated as nested (within measurement accuracy limits) for the largest three or four 1-day floods.

3.4 White Salmon Catchment (386 mi^2)

The White Salmon River basin (USGS Station Number 14123500 -- records "excellent", rating curve extrapolated above 6,000 cfs) has 70 years of stream flow records from 1931 through 1987. No records were kept in 1914 or from water year 1931 through 1934. Twenty-one of those seventy years had n-day floods whose volumes did not occur coincidentally. In over half of those, (12 cases) 10-day flood volumes occurred at different times of the year than the 1-, 3-, and 5-day volumes (which did occur within the same 5 day period). In three cases, the 1- and 3-day volumes occurred at different times from 5- and 10-day volumes but the 1- and 5-day volumes were nested within 3- and 10-day volumes, respectively.

The White Salmon River bank-full flow rate is approximately 3,330 cfs for a return period of 1.6 years. The n-day bank-full volumes are shown in Figure 3.7.

Figure 3.7 shows that floods of up to 10 days duration are critical in the White Salmon catchment. Therefore, emphasis of analysis for this basin is on frequency relationships between 1-, 3-, 5-, and 10-day flood volumes. N-day volumes and associated return periods from the six largest 1-day flood years are presented in Table 3.6 and displayed in Figure 3.8.

The six largest 1-day flood volumes occurred in 1918, 1965, 1974, 1978, 1981, and 1982. The display in Figure 3.8 indicates that the assumption of similar frequency and nested flood volumes, considering flow volume measurement uncertainty, for the largest floods may be valid.

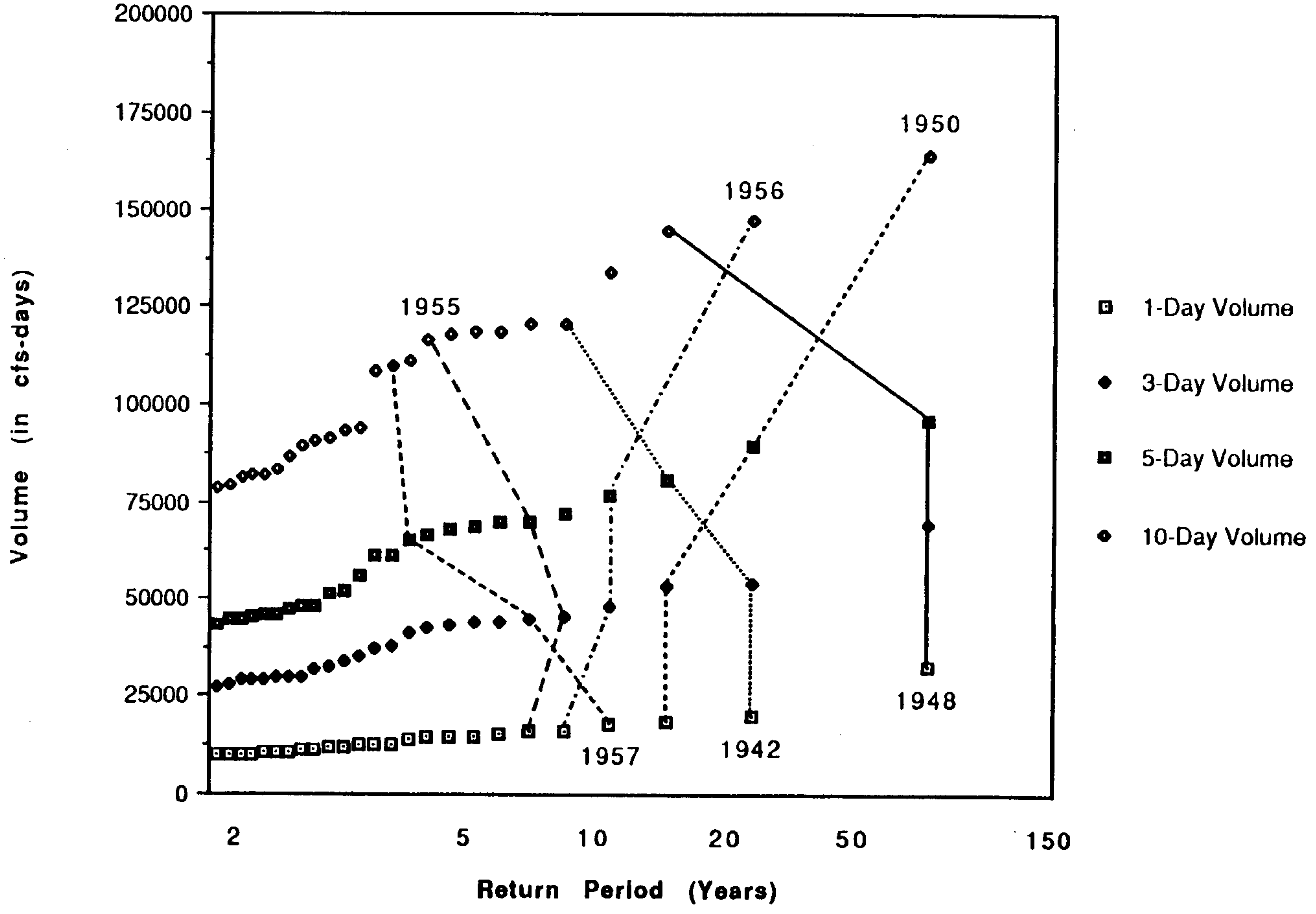


Figure 3.6 Relationship of 1-, 3-, 5-, and 10-day flow volumes for the six largest 1-day flood volumes on the Methow River, Washington.

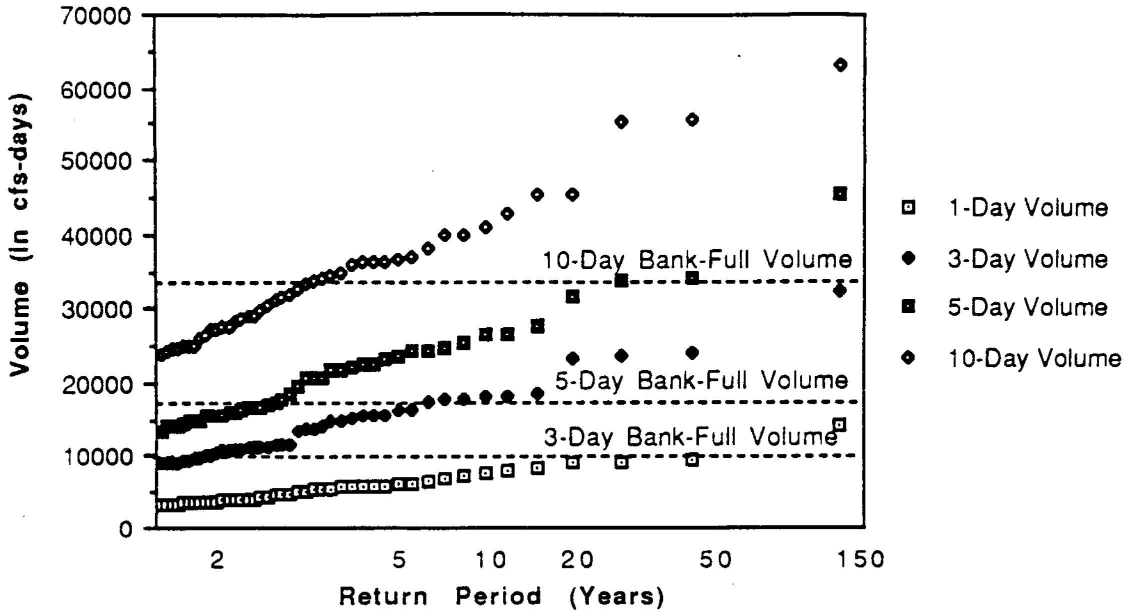


Figure 3.7 Bank-full and rank-ordered observed flow volumes, White Salmon River, Washington.

Table 3.6 Return period (years) associated with n-day flood volume (cfsd) for the six largest 1-day flood volumes on the White Salmon River, Washington.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1974	117.0	117.0	117.0	117.0
1982	43.9	43.9	27.0	43.9
1918	27.0	19.5	43.9	27.0
1978	19.5	27.0	19.5	15.3
1981	15.3	15.3	6.6	6.0
1965	12.5	12.5	8.2	4.0

3.5 Umpqua River Catchment (3,680 mi^2)

The Umpqua basin (USGS Station Number 14321000 -- records "excellent") has 81 years of continuous stream flow records from 1906 through 1986. Twenty-four of those eighty-one years have n-day flood volumes which do not display a nested characteristic. In one-third of those cases (8 years) 10-day flood volumes occurred at a different period of time than 1-, 3-, and 5-day volumes (which all occurred together). In six other cases where the 1-day flood volume occurred separately from 3-, 5-, and 10-day volumes, the latter three volumes were nested. In four other cases the 1- and 3-day volumes were nested but occurred at different times than the 5- and 10-day volumes. In three other cases 5-day volumes initially began within 10-day volumes but extended past

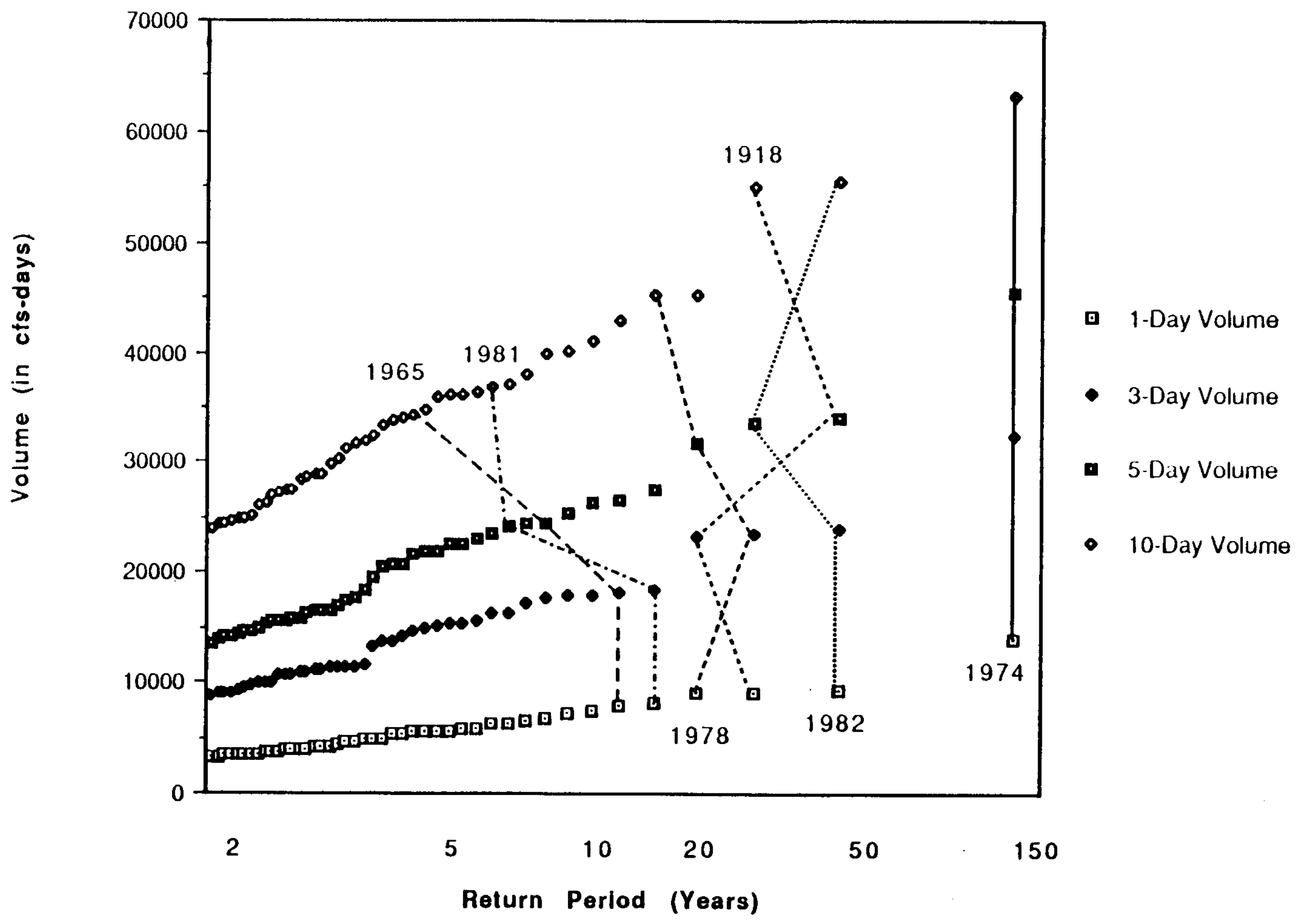


Figure 3.8 Relationship of 1-, 3-, 5-, and 10-day flow volumes for the six largest 1-day flood volumes on the White Salmon River, Washington.

them. In the remaining three cases either 3- or 5-day volumes occurred at separate times from the other n-day volumes.

The Umpqua River bank-full flow rate is approximately 69,200 cfs for a 1.6 year return period. Theoretical bank-full volumes for the catchment are shown in Figure 3.9.

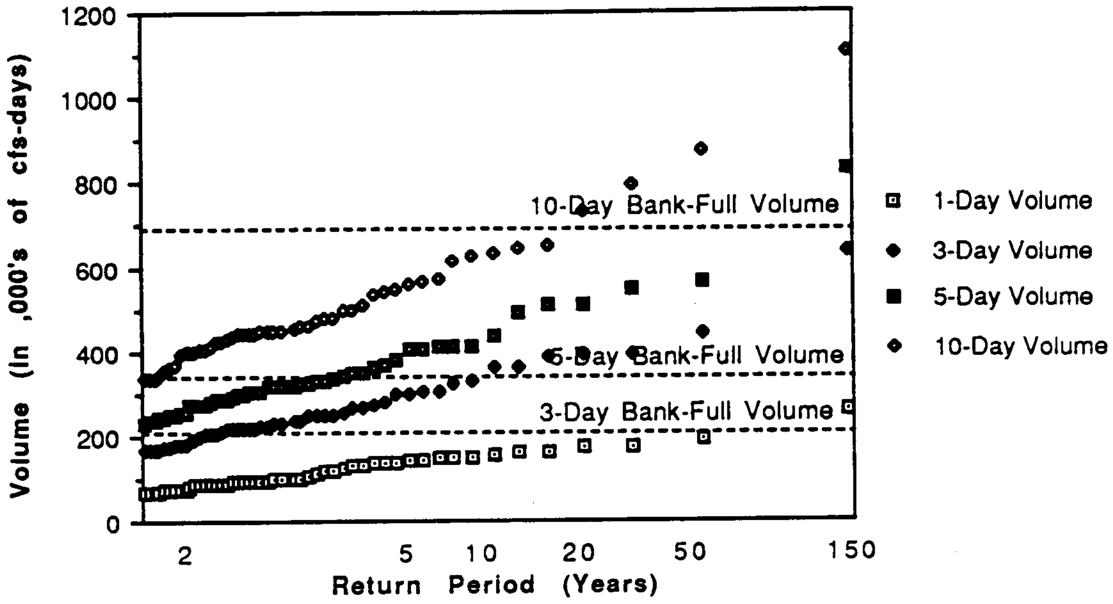


Figure 3.9 Bank-full and rank-ordered observed flow volumes, Umpqua River, Oregon.

Comparison of observed and calculated volumes (Figure 3.9) shows that flood durations up to and including 10 days in length are critical in the Umpqua catchment. Therefore, the focus of analysis in the basin is on frequency changes between 1-, 3-, 5-, and 10-day flood volumes. Return periods associated with n-day volumes for the six largest 1-day floods are presented in Table 3.7 and shown in Figure 3.10.

The six largest 1-day flood volumes occurred in 1943, 1951, 1954, 1956, 1965, and 1974 (Figure 3.10). The largest 1-day flood, in 1965, displays perfect nesting.

Years when the six largest 1-day flood flow volumes occurred have only one instance (1954) in which the n-day volumes are not nested. The 1-, 3-, and 5-day volumes were recorded beginning on the 23rd or 24th of November 1953. The 10-day volume was recorded from 23 January through 1 February 1954. The assumption of nesting and similar frequency for design purposes is satisfied moderately well for the largest four floods.

Table 3.7 Return period (years) associated with n-day flood volume (cfsd) for the six largest 1-day flood volumes on the Umpqua River, Oregon.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1965	135.3	135.3	135.3	135.3
1974	50.8	50.8	50.8	22.6
1956	31.2	31.2	31.2	50.8
1954	22.6	6.4	4.9	2.4
1943	17.6	22.6	22.6	31.2
1951	14.5	14.5	9.4	4.9

3.6 Siletz River Catchment (202 mi^2)

The Siletz River (USGS Station Number 14305500 -- records "excellent", rating curve extrapolated beyond 15,000 cfs) has 71 years of stream flow records, from 1906 to 1987. No records were kept from 1 May 1912 through 31 December 1923. In thirty of those seventy years, n-day flood volumes did not occur at coincident times. In nearly one-third of those cases (nine years), 1-day volumes occurred at a different time from 3-, 5-, and 10-day volumes (which all occurred coincidentally). In seven cases the 10-day flow volume occurred separately from the 1-, 3-, and 5-day volumes which were nested. In four cases the 1- and 3-day volumes occurred together but at different times than the 5- and 10-day volumes which occurred coincidentally. In three other cases the 3-day volumes occurred separately from 1-, 5-, and 10-day volumes (which were coincident). In the remaining eight cases, single occurrences of a particular n-day volume, or several n-day volumes, occurred separately from the major flood peak recorded that year.

The Siletz River bank-full flow rate is approximately 14,700 cfs for a 1.6 year return period. The bank-full n-day volumes are displayed in Figure 3.11.

Inspection of Figure 3.11 shows that flood durations of 1-, 3-, and 5-days are critical in the Siletz catchment. Return periods associated with the six largest 1-day flood years are given in Table 3.8 and displayed in Figure 3.12.

The six largest 1-day flood volumes occurred in 1908, 1928, 1934, 1938, 1949, and 1965. In four of these water years: 1934, 1938, 1949, and 1965, the return period associated with each n-day volume is similar, as seen in Figure 3.12.

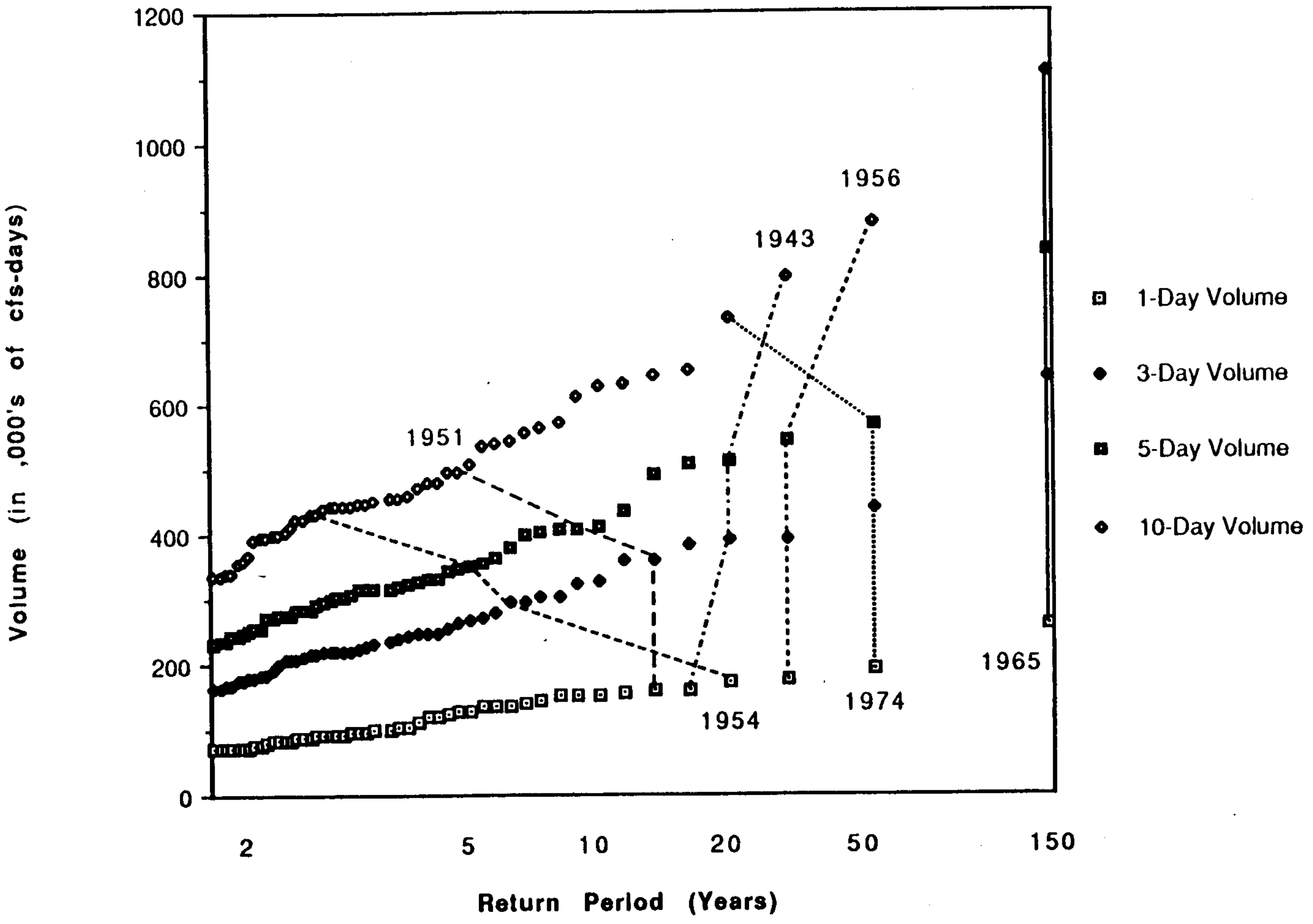


Figure 3.10 Relationship of 1-, 3-, 5-, and 10-day flow volumes for the six largest 1-day flood volumes on the Umpqua River, Oregon.

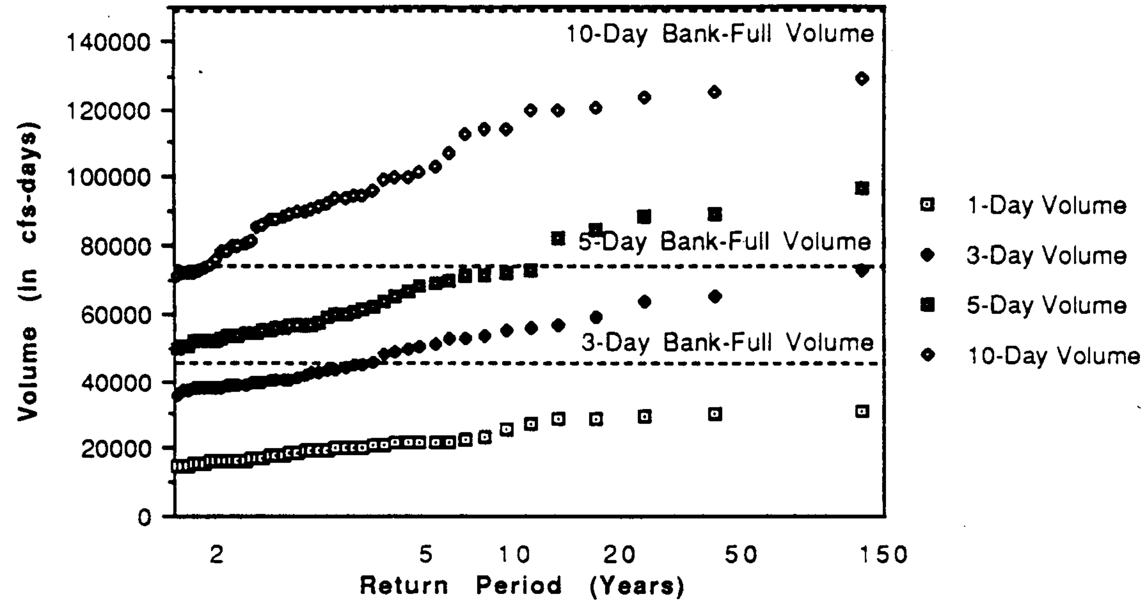


Figure 3.11 Bank-full and rank-ordered observed flow volumes, Siletz River, Oregon.

Table 3.8 Return period (years) associated with n-day flood volume (cfsd) for the six largest 1-day flood volumes on the Siletz River, Oregon.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1928	118.7	6.7	6.1	4.9
1938	44.5	118.7	118.7	10.8
1965	27.4	44.5	44.5	15.5
1908	19.8	10.8	5.6	3.6
1934	15.5	12.7	19.8	44.5
1949	12.7	9.4	9.4	12.7

The nested and similar frequency assumptions appear to be far from valid here. The flatness of the 1-day flow volume frequency curve for the largest floods suggests that uncertainties in the data could lead to a reordering of the 1-day flood volumes. (We did not have an opportunity to examine the raw gauge records or to discuss gauging history at the site with USGS personnel to assess the overall accuracy of the reported flow data). If the 1928 flood is deleted from the analysis, a strong frequency relationship appears to hold for the remaining largest two floods.

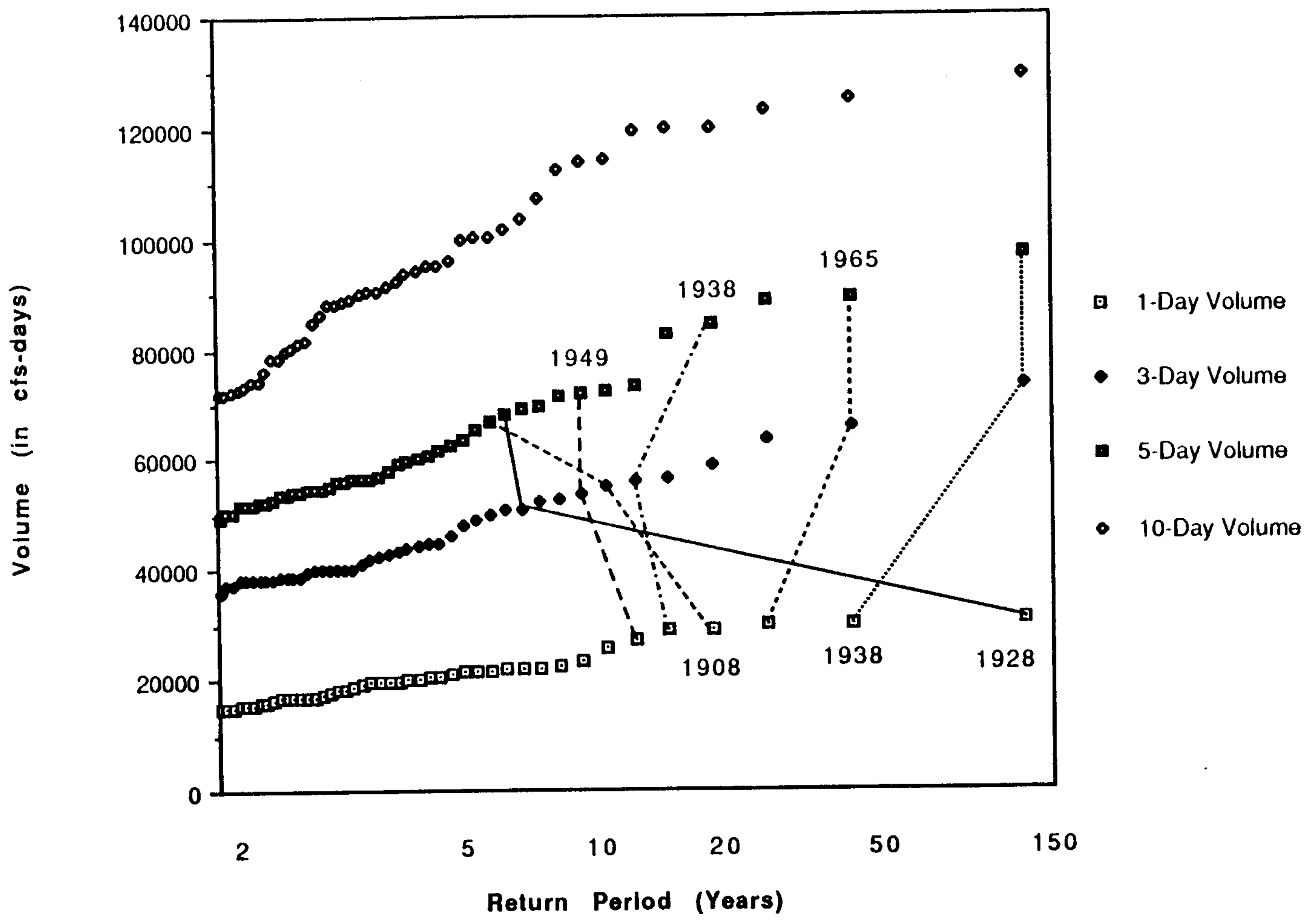


Figure 3.12 Relationship of 1-, 3-, 5-, and 10-day flow volumes for the six largest 1-day flood volumes on the Siletz River, Oregon.

3.7 NEHALEM RIVER CATCHMENT (667 MI2)

The Nehalem River (USGS Station Number 14301000 -- records "excellent") has 48 continuous years of stream flow records from 1940 to 1987. Eighteen of those forty-eight years have n-day flood volumes which did not occur at the same time of year. In eight cases the 10-day flood volume occurred at a different time of the year than the 1-, 3-, and 5-day volumes which occurred coincidentally. In three cases the 5-day volumes began initially within the 10-day volumes but extended beyond them. In two other cases the 1- and 3-day volumes occurred separately from the 5-, and 10-day flood volumes. For those cases the 1- and 3-day volumes and 5- and 10-day volumes, respectively, occurred together. In the remaining five cases n-day volumes occurred separately.

The Nehalem River bank-full flow rate is approximately 22,200 cfs for a 1.6 year return period. Bank-full n-day volumes are shown with observed n-day volumes in Figure 3.13.

Figure 3.13 reveals that flood durations of 1-, 3-, and 5-days are critical in the Nehalem catchment. Return periods associated with the six largest 1-day flood years are shown in Table 3.9 and depicted graphically in Figure 3.14.

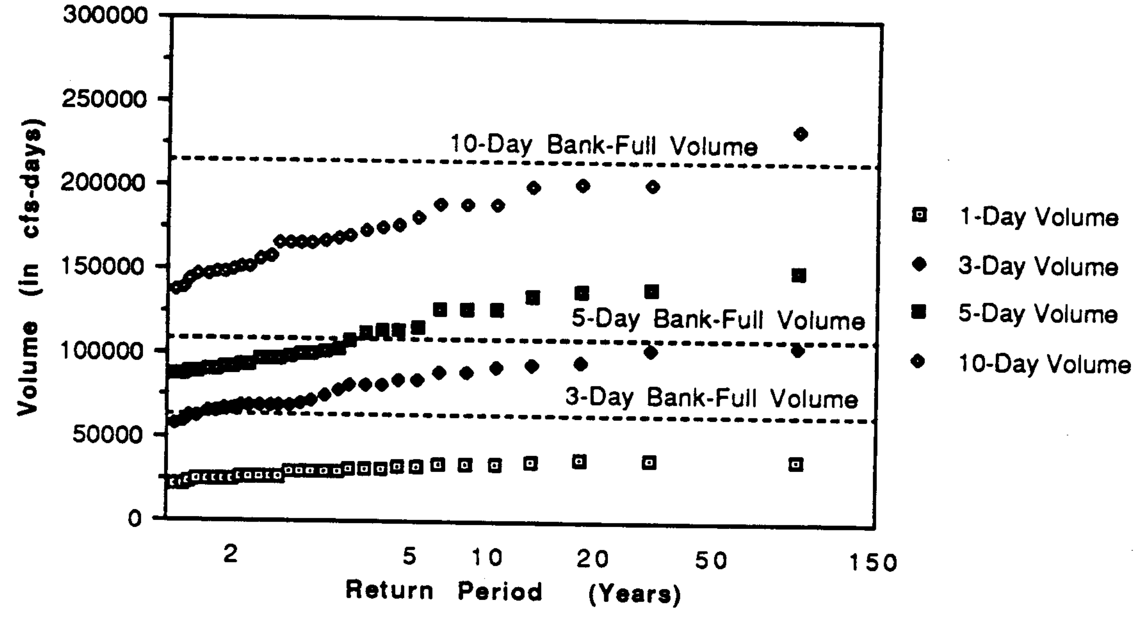


Figure 3.13 Bank-full and rank-ordered observed flow volumes, Nehalem River, Oregon.

Table 3.9 Return period (years) associated with n-day flood volume (cfsd) for the six largest 1-day flood volumes on the Nehalem River, Oregon.

Year	1-Day Volume	3-Day Volume	5-Day Volume	10-Day Volume
1972	80.3	30.1	30.1	10.5
1974	30.1	80.3	80.3	18.5
1964	18.5	7.3	5.0	30.1
1956	13.4	10.5	7.3	5.6
1949	10.5	18.5	10.5	80.3
1967	8.6	4.2	4.2	2.7

The largest two 1-day flood volumes are statistically indistinguishable (Figure 3.14). Given this consideration, the assumption of nesting (1- to 5-day volumes) appears to be valid for the largest floods.

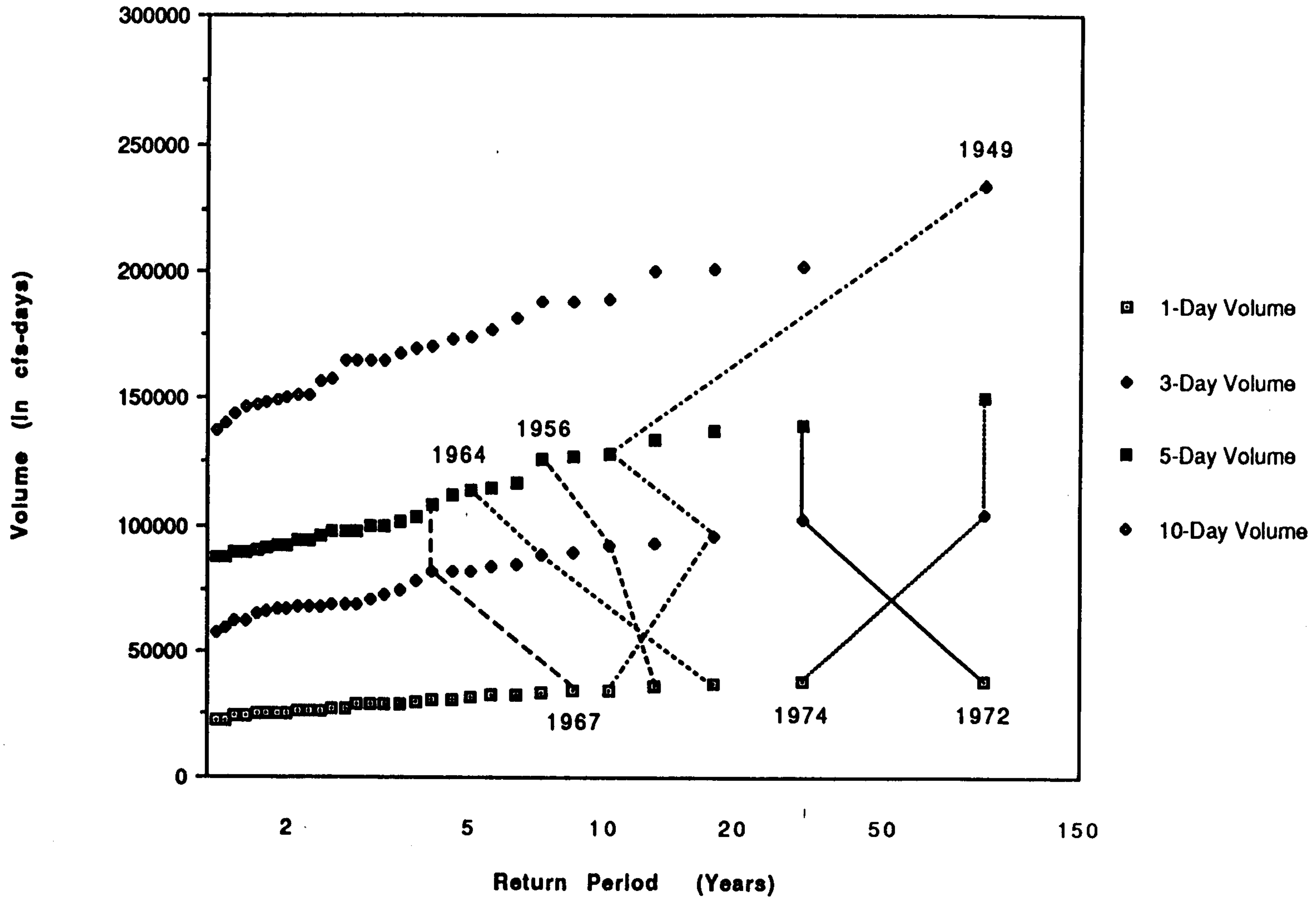


Figure 3.14 Relationship of 1-, 3-, 5-, and 10-day flow volumes for the six largest 1-day flood volumes on the Nehalem River, Oregon.

CHAPTER 4 SUMMARY, RECOMMENDED ANALYSIS SCHEME, AND CONCLUSIONS

4.1 SUMMARY

The focus of this work was to evaluate an approach used for determining high return period design flood hydrographs. There were two considerations: first, to determine if annual n-day flood volumes consistently occur at the same period of time each year (this concept is called nesting), and secondly, to determine if large critical n-day volumes, which are used to construct design hydrographs, occur with the same or similar return periods. Finally, any link with physical characteristics of a catchment for these considerations was examined.

4.1.1 NESTED FLOODS

Based on our empirical examination of flood records for seven catchments that do not contain flood modifying engineered structures, the assumption that the largest n-day flood volumes in each water year occur coincidentally is weak. Summary information for the seven river systems given in Table 4.1 indicates that between 52 and 88 percent of all annual n-day floods (1-, 3-, 5-, and 10-day duration) occur within a single 10 day period. This is not a strong relationship.

If the largest six 1-day flood volume years are considered, more frequent occurrence of nesting occurs. This stronger relationship is evident from the information in Table 4.2.

Table 4.1 Relationship of nested n-day flood volumes (1- to 10-days) for all records from seven river systems in Washington and Oregon.

River System	Number of Years of Record	Number of Years Nested	Percent of Years Nested
Willapa	35	19	54
Grays	21	11	52
Methow	40	35	88
White Salmon	70	49	70
Umpqua	81	56	70
Siletz	71	40	56
Nehalem	48	30	62

As flood volume magnitudes (and return periods) grow, nested *critical* n-day flood volumes are observed more frequently. Considering only the two largest 1-day flood years in seven river systems, critical n-day volumes were nested in every case. Therefore, it appears that critical n-day volumes for the highest return period observed floods may occur coincidentally in a wider variety of climatic and hydrologic regimes than examined here.

Table 4.2 Relationship of nested critical design duration n-day flood volumes for the six largest 1-day flood volumes from seven river systems in Washington and Oregon.

River System	Number of Years Nested	Percent of Years Nested
Willapa	6	100
Grays	6	100
Methow	5	83
White Salmon	4	67
Umpqua	5	83
Siletz	4	67
Nehalem	4	67

4.1.2 FREQUENCY RELATIONSHIP

The second hypothesis that large magnitude critical volumes occur with similar frequency, is true in some cases and false in others. Figures 3.2, 3.4, 3.6, 3.8, 3.10, 3.12, and 3.14 reveal a frequency relationship which holds strongly for the Grays, White Salmon, and Methow Rivers; and moderately on the Umpqua, Siletz, and Nehalem Rivers (each of these latter three has one year with a large frequency deviation). No relationship is evident on the Willapa River.

These observations suggest that universal application of design flood hydrographs which assume critical volumes of constant frequency may not be correct. Each catchment should be investigated, using the scheme presented here, or one similar to it, before constructing design flood hydrographs by extrapolation from the theoretical distributions fitted to extreme flow volume data.

4.1.3 PHYSICAL LINKS

There are no obvious relationships between the physical features of each catchment: topography, weather, vegetation, and soils; and either nested or constant frequency critical n-day volumes. For example, the Willapa and Grays Rivers are located in similar geologic and hydro-climatologic areas. Their soils, weather, and vegetation are similar. The Grays catchment is approximately one-third the area of the Willapa catchment. All critical duration volumes, from both rivers, are nested. However, the Grays River shows remarkable frequency stability of n-day flood volumes while the Willapa River displays none. The physical arrangement of these two catchments relative to the major storm paths for the region may account for what we have observed. Flood producing storms pass largely from downstream to upstream in the direction of the main river stem for the Grays River while they cross the main stem of the Willapa River orthogonally (Figure 2.1 and 2.2)

The lack of a consistent pattern of nesting in all river systems reinforces the need to study the observed flood behavior of a catchment before making any assumptions with respect to design flood hydrographs. We suggest the following approach be adopted when attempting to extrapolate and interpolate design hydrographs of low exceedance probability for a given catchment.

4.2 RECOMMENDED ANALYSIS SCHEME

Evaluation of a catchment for nested and constant frequency, and critical n-day volumes is straightforward. The procedure is:

1. Obtain daily flow volumes for the river of interest.
2. Compute and index the largest n-day volumes for each year of record. Selecting n depends upon catchment size and engineering design requirements.
3. Rank order each n-day series of volumes (for example, all 3-day volumes) from largest to smallest.
4. Compute and plot all ranked flood volumes with their associated return period or probability of exceedance. Cunnane's rank order probability with a = 0.4 is suitable.
5. Determine the catchment's critical n-day flow volumes. These depend upon the engineering problem or design criteria. Use of a theoretical bank-full flow, as explained earlier, may be appropriate.
6. Determine critical flood volume durations. This may be accomplished graphically. Plot observed flood volumes using a convenient display scheme (an extreme value type I scheme is appropriate) and superimpose critical volumes on the plot. Where several (2 or more) n-day volumes exceed a critical n-day volume, the duration, n, is judged critical. Repeat for all n.
7. Rank order all n-day flood volumes. An independent rank ordered list should be prepared for each series of flow volumes which are of critical duration. A computer program, such as included in Appendix B, is extremely helpful.
8. Determine the number of large floods to analyze - typically fewer than five. The 5 th largest flood in a series with 50 years of record has only an 11 year return period (using Cunnane's (1978) scheme with a = 0.4).
9. Evaluate the years from step 8, observing changes in return period as n increases from 1. This may be accomplished by direct numerical comparison or graphically. Plot observed flood data using a (linearized) extreme value type I distribution scale. Join n-day volumes for the year in which the largest (then 2 nd largest, etc.) 1-day volume occurred with a line. Large deviations from vertical on the plot indicate a lack of frequency relation, vertical lines mean a perfect relationship; i.e. all n-day floods of that year occurred with the same return period.
10. Check the evaluated (largest) floods for coincident occurrence of all n-day volumes (nesting). When n-day volumes are due to different flood production systems, the nesting relationship, and hence assumptions of a balanced hydrograph, are weak.

4.3 POSTSCRIPT

We have not specified how an analyst should construct theoretical flood volume distributions to describe the data displayed using the analysis scheme of Section 4.2. The largest two to six floods are of greatest importance for determining nesting preparatory to extrapolating any theoretical description of the observed data. Regional frequency techniques using robust fitting schemes may be more appropriate than widely used at-site methods. The emerging literature on regional methods and "L Moments" in particular should be explored. We recommend that the reader consult Hosking (1990) for details of L Moments and Potter and Lettenmaier (1990) for issues in regional flood frequency estimation.

4.4 CONCLUSIONS

Flood damage mitigation design and analysis are difficult tasks. The design flood hydrograph is one essential tool needed for determining benefits and costs from flood mitigation alternatives. This work has shown that constructing design hydrographs for high return periods, using volume-duration-frequency data, may provide adequate estimation of uncommon floods in some, but not all, cases.

Two components are essential for this procedure to work. First, all large flood n-day volumes must occur coincidentally, that is at the same time of year, and be nested. Nesting requires that the (n-1) days associated with the (n-1)-day volume fall within the n consecutive days of the n-day volume. This appears to be the case in all seven river systems for the years in which the two largest 1-day floods occurred. Second, all n-day volumes for a given year should occur with the same (or nearly the same) return period. This appears to be the case for the largest floods in six of the seven systems examined. The strength of this relationship varied by catchment.

The scheme we have described for obtaining design hydrographs will not work in every instance, as in the case of the Willapa River. A thorough analysis, using the steps outlined above, must be undertaken to evaluate both components of the procedure to determine its suitability for application.

REFERENCES

Allan Cartography. Oregon. Colorado Springs: Pikes Peak Lithography, Scale 1 : 500,000, 1987.

Allan Cartography. Washington. Colorado Springs: Pikes Peak Lithography, Scale 1 : 500,000, 1987.

Beard, Leo R. Hydrologic Engineering Methods for Water Resources Development. United States Army Corps of Engineers Hydrologic Engineering Center. Davis, California: United States Government Printing Office, 66 p., 1975.

Beard, Leo R. Personal Communication, 18 September 1990.

Beard, Leo R. "Practical Determination of Hypothetical Floods," Journal of Water Resources Planning and Management, Vol. 116, No. 3, 389-401, 1990.

Chow, Ven Te, ed. Handbook of Applied Hydrology, New York: McGraw-Hill, Section 25, 1964.

Cudworth, Aurthur G. Jr. Flood Hydrology Manual. United States Department of the Interior, Bureau of Reclamation. Denver: United States Government Printing Office, 243 p., 1989.

Cunnane, C. "Unbiased Plotting Positions - A Review," Journal of Hydrology, Vol 37, 205-222, 1978.

Das, Braja M. Principles of Foundation Engineering. 2nd ed. Boston: PWS-Kent Publishing, 731 p., 1990.

de Ormijina, Fidel Saen and Maidment, David R. "Frequency Analysis of Flood Hydrographs." Unpublished Paper, University of Texas, Austin, 33 p., 1988.

Donaldson, Wallace R. and Rusch, Charles. Washington Climate For Chelan, Douglas, and Okanogan Counties. Pullman, Washington: Agricultural Extension Service, 1975.

Dury, G. H. "Hydraulic Geometry." Water, Earth and Man. Richard J. Chorley ed., London: Methuen and Company, 588 p., 1969.

EarthInfo, Inc. (formerly U.S. West Optical Publishing). Climate Data Summary of the Day - Western Period of Record, Volume 1.2 (Optical Compact Disk). Denver, Colorado: EarthInfo, Inc. 1988.

EarthInfo, Inc. (formerly U.S. West Optical Publishing). Hydrodata USGS Daily Values - Western Period of Record, Volume 2.0 (Optical Compact Disk). Denver, Colorado: EarthInfo, Inc. 1988.

EarthInfo, Inc. (formerly U.S. West Optical Publishing). Hydrodata USGS Peak Values - United States Period of Record, Volume 1.2 (Optical Compact Disk). Denver, Colorado: EarthInfo, Inc. 1988.

Emmer, Rod E. and Muckleston, Keith W. A Compilation of Flood Abatement Projects in Oregon. Water Resources Research Institute. Corvallis, Oregon: Water Resource Research Institute, 112 p., 1971.

Feldman, Arlen. United States Army Corps of Engineers, Hydrologic Engineering Center. Davis, California: Personal Communication, 18 September 1990.

Franklin, Jerry F. and Dyrness, C. T. Natural Vegetation of Oregon and Washington. Corvallis, Oregon: Oregon State University Press, 452 p., 1988.

Friday, John and Miller, Suzanne J. Statistical Streamflow Data in Oregon. Vol. 2: Western Oregon. United States Department of the Interior, Geological Survey. Open File Report 84-454. Portland, Oregon: United States Government Printing Office, 250 p., 1984.

Gale Research Company. Climate Normals for the U.S. (Base 1951-80). 1st ed. Detroit: Gale Research, 712 p., 1983.

Haagen, Ed. United States Department of Agriculture, Soil Conservation Service. Goldendale, Washington: Personal Communication, 13 September 1990.

Harris, D. D., Hubbard, Larry L., and Hubbard, Lawrence E. Magnitude and Frequency of Floods in Western Oregon. United States Department of the Interior, Geological Survey. Open File Report 79-553. Portland, Oregon: United States Government Printing Office, 29 p.. 1987.

Hayes, G. L. and Herring, H. G. Some Water Problems and Hydrologic Characteristics of the Umpqua Basin. United States Department of Agriculture, Forest Service. Portland, Oregon: United States Government Printing Office, 22 p., 1960.

Hemstrom, Miles A. and Logan, Sheila E. Plant Association and Management Guide Suislaw National Forest. United States Department of Agriculture, Forest Service. Report Number R6-ECOL-220-1986a. Portland, Oregon: United States Government Printing Office, 121 p., 1986.

Hosking, J. R. M. "L-Moments: Analysis and Estimation of Distributions Using Linear Combinations of Order Statistics," Journal of the Royal Statistical Society. Series B52, 105-124, 1990.

Lenfesty Charles D. Soil Survey of Okanogan County Area, Washington. United States Department of Agriculture, Soil Conservation Service. Washington, D.C.: United States Government Printing Office, 162 p., 1980.

Loy, William G., et. al. Atlas of Oregon. Eugene, Oregon: University of Oregon Books, 215 p., 1976.

National Environment Research Council. Flood Studies Report. Vol. I. Hydrological Studies. London: White Friars Books, 550 p., 1975.

Oster, Eugene A. Flood Profiles in the Umpqua River Basin, Oregon: Part 2. United States Department of the Interior, Geological Survey. Open File Report 1973. Portland, Oregon: United States Government Printing Office, 113 p., 1973.

Pacific Northwest River Basins Commission. Columbia-North Pacific Region Comprehensive Framework Study, Appendix IV, Vols. 1 and 2, Land & Mineral Resources. Vancouver, Washington: 585 p., 1970.

Pacific Northwest River Basins Commission. Columbia-North Pacific Region Comprehensive Framework Study, Appendix VII, Flood Control. Vancouver, Washington: 396 p., 1971.

Pacific Northwest River Basins Commission. Columbia-North Pacific Region Comprehensive Framework Study, Appendix VIII, Vols. 1 and 2, Land Measures and Watershed Protection. Vancouver, Washington: 727 p., 1971.

Paulsen, C. G. Floods of May-June 1948 in Columbia River Basin. United States Department of Interior Geological Survey, Water Supply Paper 1080. Washington, D.C.: United States Government Printing Office, 1949.

Phillips, Earl L. and Donaldson, Wallace R. Washington Climate For These Counties: Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum. Pullman, Washington: Agricultural Extension Service, 1972.

Phillips, Earl L. Washington Climate For These Counties: Clark, Cowlitz, Lewis, Skamania, and Thurston. Pullman, Washington: Agricultural Extension Service, 42 p., 1964.

Pringle, Russell F. Soil Survey of Grays Harbor County Area, Pacific County, and Wahkiakum County, Washington. United States Department of Agriculture, Soil Conservation Service. Washington, D.C.: United States Government Printing Office, 295 p., 1986.

Potter, Kenneth, W., and Lettenmaier, Dennis, P. "A Comparison of Regional Flood Frequency Estimation Methods Using a Resampling Method". Water Resources Research, 26(3), 415-424, 1990.

Richlen, Ellsworth M. Soil Survey of the South Umpqua Area, Oregon. United States Department of Agriculture, Forest Service and Soil Conservation Service. Washington, D.C.: United States Goverment Printing Office, 66 p., 1973

Shipman, John. United States Department of Agriculture, Soil Conservation Service. Tillamook, Oregon: Personal Communication, 18 September 1990.

Smith, Phillip R. and Shipman, John A. Soil Survey of Clatsop County, Oregon. United States Department of Agriculture, Soil Conservation Service. Washington, D.C.: United States Government Printing Office, 1988.

Stephens, F. R. Soil and Watershed Characteristics of Southeast Alaska and Some Western Oregon Drainages. United States Department of Agriculture, Forest Service. Juneau, Alaska: United States Government Printing Office, 16 p., 1966.

Thorsen, Thor. United States Department of Agriculture, Soil Conservation Service, Portland, Oregon. Personal Communication, 13 September 1990.

United States Army Corps of Engineers, Construction Engineering Research Laboratory. "Environmental Technical Information System." (A Soils Information Computer Database), Champaign, Illinois, 1990.

United States Department of Agriculture Soil Conservation Service, General Soil Map State of Oregon. Washington, D.C.: United States Government Printing Office, Scale 1 : 250,000, 1986.

United States Department of Agriculture, Soil Conservation Service. "Soil Survey of Klickitat and Skamania County Area, Washington (Extract of Draft Report)". Goldendale, Washington: United States Government Printing Office, 1990.

United States Department of Agriculture, Soil Conservation Service. "Soil Survey of Lincoln County Area, Oregon (Extract of Draft Report)". Roseburg, Oregon: United States Government Printing Office, 1990.

United States Department of Commerce National Oceanic and Atmospheric Administration. Climatological Data Washington Annual Summary Washington. Vol. 92, No. 13. Raleigh, North Carolina: United States Government Printing Office, 33 p., 1988.

United States Department of the Interior, Geological Survey. Hydrologic Unit Map - 1974 State of Oregon. Reston, Virginia: United States Government Printing Office, Scale 1 : 500,000., 1976.

United States Department of the Interior, Geological Survey. Hydrologic Unit Map - 1974 State of Washington. Reston, Virginia: United States Government Printing Office, Scale 1 : 500,000, 1976.

United States Department of the Interior, Geological Survey. State of Washington. Reston, Virginia: United States Government Printing Office, Scale 1 : 500,000, 1979.

United States Department of the Interior, Geological Survey. Surface Water Records of Washington. Tacoma, Washington: United States Government Printing Office, 456 p., 1964.

United States Department of the Interior, Geological Survey. Surface Water Records of Washington. Tacoma, Washington: United States Government Printing Office, 419 p., 1961.

United States Water Resources Council. Guidelines for Determining Flood Flow Frequency Bulletin 17B. Washington, D.C.: United States Government Printing Office, 1981.

Walters, Kenneth L. and Nassar, E. G. Water in the Methow River Basin, Washington, Water Supply Bulletin 38., Olympia, Washinton: 73 p., 1974.

Williams, J. R. and Pearson, H. E. Streamflow Statistics and Drainage Basin Characteristics for the Southwestern And Eastern Regions, Washington. Vol. I. Southwestern Washington. United States Department of the Interior, Geological Survey. Open File Report 84-145-A. Tacoma, Washington: United States Goverment Printing Office, 424 p., 1985.

Williams, J. R. and Pearson, H. E. Streamflow Statistic and Drainage Basin Characteristics for the Southwestern And Eastern Regions, Washington. Vol. II. Eastern Washington. United States Department of the Interior, Geological Survey. Open File Report 84-145-B. Tacoma, Washington: United States Government Printing Office, 662 p., 1985.

APPENDIX A

SUMMARIES OF N-DAY FLOOD VOLUMES

The following pages contain summaries of n-day volumes and ranked n-day volumes for the seven catchments that have been described in the body of the report. The catchment data are given in the order the catchments are listed in the report.

The first page for each river contains, in chronological order, the annual instantaneous maximum (peak) flow, and the 1-, 3-, 5-, and 10-day volumes for each year of stream gauge record. The "Day" column preceding each volume indexes each event by day of the water year when the event began. For example, the 10-day volume on the Willapa River in 1949 began on day 139 (16 January, 1949) and lasted until day 148 (25 January, 1949).

The second page for each river contains the same 1-, 3-, 5-, and 10-day volumes but they are rank ordered from largest to smallest. Each volume is indexed by the water year in which it occurred. Return period (years) and probability of exceedance for each ranked event are computed using Cunnane's (1978) scheme. The reduced variate y of the extreme value type I (EVI) distribution is included to aid in plotting these data on a (linearized) extreme value type I graph scale. The first line of the Willapa River data indicates the largest n-day floods in the catchment occurred in: 1967 (1-day), 1976 (3- and 5-day), and 1954 (10-day). Finally, included but not used, are the mean, standard deviation, skew coefficient for each n-day set of flood data. The theoretical extreme value type I distribution quantile (flood volume magnitude) is provided for T = 2 and T = 200 year return periods to permit construction of an EVI distribution for each series.

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

WILLAPA RIVER NEAR WILLAPA, WASH.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1949	11400.	145	10000.	144	20610.	144	25650.	139	43800.
1950	8450.	89	7460.	112	18120.	112	24190.	147	34940.
1951	10300.	132	8790.	132	21740.	130	28600.	127	38200.
1952	6900.	127	5660.	126	11120.	123	17100.	119	29590.
1953	7690.	115	6640.	100	14270.	100	22270.	100	36070.
1954	8240.	98	6910.	96	19520.	95	27030.	136	46340.
1955	6270.	49	5670.	48	13150.	47	18120.	45	24000.
1961	N/A	123	1700.	121	3850.	119	5850.	218	8514.
1962	4650.	175	4050.	175	8800.	81	13670.	78	24730.
1963	11200.	51	9460.	50	16580.	50	20150.	50	36940.
1964	8300.	117	7340.	117	13320.	116	17380.	109	33740.
1965	6830.	62	5890.	61	14660.	119	19480.	55	30560.
1966	7100.	98	6130.	98	13690.	97	18530.	97	29540.
1967	11400.	74	10100.	73	18950.	72	23270.	66	37020.
1968	6520.	111	5560.	111	15090.	110	19310.	105	31490.
1969	5680.	134	4900.	132	10490.	131	16080.	131	23310.
1970	6460.	139	4850.	117	10400.	115	15790.	111	28600.
1971	10900.	68	9500.	67	20580.	66	25490.	107	36500.
1972	11100.	112	8770.	112	20460.	111	26960.	150	38140.
1973	7410.	87	6020.	82	14300.	83	21700.	80	38950.
1974	7920.	108	7010.	107	17700.	107	25850.	106	37080.
1975	6870.	135	5550.	135	11080.	104	15450.	98	25460.
1976	10500.	65	9060.	63	26120.	62	36510.	61	45530.
1977	6780.	159	5030.	158	13210.	158	17170.	157	22583.
1978	10700.	63	8300.	72	16740.	72	26280.	71	38400.
1979	7660.	156	5700.	155	11370.	155	14620.	148	27820.
1980	9160.	79	7330.	78	15840.	76	25400.	75	39740.
1981	8360.	139	6800.	139	15000.	139	23000.	137	32000.
1982	9780.	116	7600.	137	19000.	136	28300.	136	45200.
1983	9040.	65	7000.	64	15150.	61	21330.	76	30130.
1984	7230.	46	6300.	46	15910.	45	23580.	44	38240.
1985	N/A	59	4530.	59	10870.	58	15590.	55	21251.
1986	N/A	111	6880.	109	15600.	109	19980.	109	28200.
1987	N/A	55	9760.	54	19440.	52	24360.	51	35260.
1988	N/A	154	7700.	70	12110.	67	17150.	64	27880.

N/A - INFORMATION NOT AVAILABLE

```
                   RANKED N-DAY FLOOD VOLUMES
                    (VOLUMES IN CFS-DAYS)

---------------------------------------------------------------------
                WILLAPA RIVER NEAR WILLAPA, WASH.
---------------------------------------------------------------------

      ONE         THREE         FIVE          TEN     CUNNANE  REDUCED
      DAY          DAY          DAY           DAY    RET  PROB VARIATE
------------ ------------ ------------ ------------ ------------ ----
1967  10100. 1976  26120. 1976  36510. 1954  46340. 58.67  1.70  4.13
1949  10000. 1951  21740. 1951  28600. 1976  45530. 22.00  4.55  3.09
1987   9760. 1949  20610. 1982  28300. 1982  45200. 13.54  7.39  2.58
1971   9500. 1971  20580. 1954  27030. 1949  43800.  9.78 10.23  2.24
1963   9460. 1972  20460. 1972  26960. 1980  39740.  7.65 13.07  1.97
1976   9060. 1954  19520. 1978  26280. 1973  38950.  6.29 15.91  1.76
1951   8790. 1987  19440. 1974  25850. 1978  38400.  5.33 18.75  1.58
1972   8770. 1982  19000. 1949  25650. 1984  38240.  4.63 21.59  1.42
1978   8300. 1967  18950. 1971  25490. 1951  38200.  4.09 24.43  1.28
1988   7700. 1950  18120. 1980  25400. 1972  38140.  3.67 27.27  1.15
1982   7600. 1974  17700. 1987  24360. 1974  37080.  3.32 30.11  1.03
1950   7460. 1978  16740. 1950  24190. 1967  37020.  3.03 32.95  0.92
1964   7340. 1963  16580. 1984  23580. 1963  36940.  2.79 35.80  0.82
1980   7330. 1984  15910. 1967  23270. 1971  36500.  2.59 38.64  0.72
1974   7010. 1980  15840. 1981  23000. 1953  36070.  2.41 41.48  0.62
1983   7000. 1986  15600. 1953  22270. 1987  35260.  2.26 44.32  0.54
1954   6910. 1983  15150. 1973  21700. 1950  34940.  2.12 47.16  0.45
1986   6880. 1968  15090. 1983  21330. 1964  33740.  2.00 50.00  0.37
1981   6800. 1981  15000. 1963  20150. 1981  32000.  1.89 52.84  0.29
1953   6640. 1965  14660. 1986  19980. 1968  31490.  1.80 55.68  0.21
1984   6300. 1973  14300. 1965  19480. 1965  30560.  1.71 58.52  0.13
1966   6130. 1953  14270. 1968  19310. 1983  30130.  1.63 61.36  0.05
1973   6020. 1966  13690. 1966  18530. 1952  29590.  1.56 64.20 -0.03
1965   5890. 1964  13320. 1955  18120. 1966  29540.  1.49 67.05 -0.11
1979   5700. 1977  13210. 1964  17380. 1970  28600.  1.43 69.89 -0.18
1955   5670. 1955  13150. 1977  17170. 1986  28200.  1.38 72.73 -0.26
1952   5660. 1988  12110. 1988  17150. 1988  27880.  1.32 75.57 -0.34
1968   5560. 1979  11370. 1952  17100. 1979  27820.  1.28 78.41 -0.43
1975   5550. 1952  11120. 1969  16080. 1975  25460.  1.23 81.25 -0.52
1977   5030. 1975  11080. 1970  15790. 1962  24730.  1.19 84.09 -0.61
1969   4900. 1985  10870. 1985  15590. 1955  24000.  1.15 86.93 -0.71
1970   4850. 1969  10490. 1975  15450. 1969  23310.  1.11 89.77 -0.83
1985   4530. 1970  10400. 1979  14620. 1977  22583.  1.08 92.61 -0.96
1962   4050. 1962   8800. 1962  13670. 1985  21251.  1.05 95.45 -1.14
1961   1700. 1961   3850. 1961   5850. 1961   8514.  1.02 98.30 -1.42

MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

       ONE DAY      THREE DAY       FIVE DAY        TEN DAY
      --------      ---------      ---------      ---------
      6855.711      15281.141      21176.855      32735.656
      1880.443       4340.359       5659.195       7954.059
        -0.212         -0.026          0.011         -0.577


EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

       ONE DAY      THREE DAY       FIVE DAY        TEN DAY
      --------      ---------      ---------      ---------
      6551.754      14579.562      20262.102      31449.961
     13676.168      31023.828      41703.023      61585.402
```

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

GRAYS RIVER ABV SOUTH FK NR GRAYS RIVER, WASH.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1956	6360.	72	3450.	33	7790.	173	9840.	27	15278.
1957	7050.	70	3630.	70	8080.	70	10190.	70	15257.
1958	3730.	86	2300.	85	5720.	85	8410.	80	14718.
1959	5970.	43	4280.	42	7990.	115	10000.	42	15439.
1960	5230.	76	4010.	51	7710.	51	11440.	49	14715.
1961	5700.	144	4690.	143	9700.	142	12780.	47	19000.
1962	4480.	78	2100.	83	5800.	81	8900.	77	15300.
1963	8900.	50	5600.	50	12800.	50	14150.	50	20202.
1964	4910.	117	3380.	116	6590.	116	8508.	109	14467.
1965	5490.	61	4470.	61	10290.	60	12850.	55	20409.
1966	4800.	98	2740.	98	6740.	97	9310.	97	17039.
1967	8700.	74	5320.	73	10270.	71	12730.	67	16878.
1968	5400.	142	3030.	125	7100.	141	9970.	141	14940.
1969	3280.	64	2060.	64	4710.	64	6062.	64	10436.
1970	2760.	111	2120.	110	5030.	110	7970.	110	15340.
1971	6380.	67	5210.	66	11330.	66	13919.	109	21048.
1972	9280.	112	7810.	111	15850.	111	19860.	110	23688.
1973	5600.	82	3790.	82	8280.	81	12110.	79	22370.
1974	3670.	107	2700.	106	7590.	106	10820.	106	15387.
1975	3580.	135	2470.	105	5780.	104	8082.	104	12414.
1976	8320.	27	1340.	26	3552.	24	4435.	19	6401.

N/A - INFORMATION NOT AVAILABLE

```
                       RANKED N-DAY FLOOD VOLUMES
                         (VOLUMES IN CFS-DAYS)

------------------------------------------------------------------
               GRAYS RIVER ABV SOUTH FK NR GRAYS RIVER, WASH.
------------------------------------------------------------------

     ONE          THREE           FIVE          TEN        CUNNANE  REDUCED
     DAY           DAY            DAY           DAY       RET  PROB VARIATE
 -----------  -----------  -----------  -----------  -----------    ----
 1972   7810. 1972  15850. 1972  19860. 1972  23688. 35.33  2.83    3.62
 1963   5600. 1963  12800. 1963  14150. 1973  22370. 13.25  7.55    2.57
 1967   5320. 1971  11330. 1971  13919. 1971  21048.  8.15 12.26    2.05
 1971   5210. 1965  10290. 1965  12850. 1965  20409.  5.89 16.98    1.69
 1961   4690. 1967  10270. 1961  12780. 1963  20202.  4.61 21.70    1.41
 1965   4470. 1961   9700. 1967  12730. 1961  19000.  3.79 26.42    1.19
 1959   4280. 1973   8280. 1973  12110. 1966  17039.  3.21 31.13    0.99
 1960   4010. 1957   8080. 1960  11440. 1967  16878.  2.79 35.85    0.81
 1973   3790. 1959   7990. 1974  10820. 1959  15439.  2.47 40.57    0.65
 1957   3630. 1956   7790. 1957  10190. 1974  15387.  2.21 45.28    0.51
 1956   3450. 1960   7710. 1959  10000. 1970  15340.  2.00 50.00    0.37
 1964   3380. 1974   7590. 1968   9970. 1962  15300.  1.83 54.72    0.23
 1968   3030. 1968   7100. 1956   9840. 1956  15278.  1.68 59.43    0.10
 1966   2740. 1966   6740. 1966   9310. 1957  15257.  1.56 64.15   -0.03
 1974   2700. 1964   6590. 1962   8900. 1968  14940.  1.45 68.87   -0.16
 1975   2470. 1962   5800. 1964   8508. 1958  14718.  1.36 73.58   -0.29
 1958   2300. 1975   5780. 1958   8410. 1960  14715.  1.28 78.30   -0.43
 1970   2120. 1958   5720. 1975   8082. 1964  14467.  1.20 83.02   -0.58
 1962   2100. 1970   5030. 1970   7970. 1975  12414.  1.14 87.74   -0.75
 1969   2060. 1969   4710. 1969   6062. 1969  10436.  1.08 92.45   -0.96
 1976   1340. 1976   3552. 1976   4435. 1976   6401.  1.03 97.17   -1.29

 MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

          ONE DAY       THREE DAY        FIVE DAY         TEN DAY
         --------      ----------      ----------      ----------
         3642.857        8033.426       10587.426       16225.047
         1527.753        2899.812        3269.828        3984.071
            0.817           0.887           0.721          -0.224

 EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

          ONE DAY       THREE DAY        FIVE DAY         TEN DAY
         --------      ----------      ----------      ----------
         3398.344        7569.316       10064.098       15587.406
         9129.492       18447.555       22330.398       30533.086
```

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

METHOW RIVER AT TWISP, WASH.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1919	N/A	270	7210.	268	21630.	268	34130.	267	62780.
1920	4480.	266	4320.	259	12800.	259	20640.	259	39530.
1921	13600.	248	12700.	248	37300.	247	61500.	244	111270.
1922	12500.	247	12300.	246	35500.	245	56100.	243	93400.
1923	8420.	252	8420.	252	24640.	252	40660.	248	70750.
1924	10800.	229	10800.	229	28270.	226	44790.	225	82140.
1925	11400.	232	11400.	230	32500.	230	51230.	227	91400.
1926	3050.	212	3050.	211	8430.	211	13160.	209	23020.
1927	12400.	251	12400.	251	32300.	250	47910.	249	81970.
1928	10400.	234	10200.	234	30200.	233	47800.	231	91000.
1929	5010.	235	5010.	234	14500.	250	22960.	249	41420.
1934	15200.	206	14900.	206	43300.	205	68400.	203	118160.
1935	10400.	250	9840.	249	29260.	248	46110.	243	86920.
1936	12000.	247	9880.	246	22450.	244	32950.	244	56530.
1937	12300.	260	10900.	259	26960.	258	41080.	257	77140.
1938	13300.	239	12800.	237	38100.	236	61500.	234	108880.
1939	5020.	228	4800.	227	13610.	227	21010.	225	35660.
1940	9020.	238	8500.	236	24720.	235	37700.	231	64930.
1941	5240.	214	5020.	213	14530.	211	22940.	208	41250.
1942	21300.	238	20000.	237	54100.	236	80900.	234	120770.
1943	8890.	238	8320.	238	23110.	237	36410.	252	65880.
1944	5570.	229	5240.	244	14100.	242	23460.	241	42950.
1945	11700.	243	10700.	242	29220.	242	44810.	241	83170.
1946	10700.	239	10100.	238	29800.	236	47470.	231	89460.
1947	8920.	220	8700.	219	23470.	219	35880.	217	62830.
1948	40800.	242	32500.	241	69000.	239	96200.	237	144970.
1949	15500.	225	14700.	225	42500.	224	69900.	222	118750.
1950	19800.	260	18800.	259	53600.	257	89200.	256	164300.
1951	17600.	224	15600.	222	44000.	221	66800.	221	118800.
1952	10000.	232	9610.	231	27540.	230	43320.	230	78770.
1953	12700.	256	11500.	256	29830.	256	46030.	252	81390.
1954	12900.	231	12200.	231	33740.	230	51950.	229	93890.
1955	16600.	255	15700.	254	45100.	252	70100.	249	116530.
1956	17400.	234	16100.	232	47800.	233	76400.	231	147500.
1957	19000.	231	17900.	230	44500.	230	65340.	224	110170.
1958	15900.	237	14900.	236	43900.	235	72300.	232	134100.
1959	10700.	246	10200.	246	29230.	246	45310.	244	79660.
1960	11000.	248	9810.	247	27220.	247	41680.	247	74210.
1961	15000.	247	14200.	246	41600.	245	67900.	242	120450.
1962	6280.	240	6020.	239	17560.	238	27620.	237	48690.

N/A - INFORMATION NOT AVAILABLE

RANKED N-DAY FLOOD VOLUMES
(VOLUMES IN CFS-DAYS)

METHOW RIVER AT TWISP, WASH.

ONE DAY		THREE DAY		FIVE DAY		TEN DAY		CUNNANE		REDUCED VARIATE
								RET	PROB	
1948	32500.	1948	69000.	1948	96200.	1950	164300.	67.00	1.49	4.26
1942	20000.	1942	54100.	1950	89200.	1956	147500.	25.13	3.98	3.23
1950	18800.	1950	53600.	1942	80900.	1948	144970.	15.46	6.47	2.72
1957	17900.	1956	47800.	1956	76400.	1958	134100.	11.17	8.96	2.38
1956	16100.	1955	45100.	1958	72300.	1942	120770.	8.74	11.44	2.11
1955	15700.	1957	44500.	1955	70100.	1961	120450.	7.18	13.93	1.90
1951	15600.	1951	44000.	1949	69900.	1951	118800.	6.09	16.42	1.72
1958	14900.	1958	43900.	1934	68400.	1949	118750.	5.29	18.91	1.57
1934	14900.	1934	43300.	1961	67900.	1934	118160.	4.67	21.39	1.43
1949	14700.	1949	42500.	1951	66800.	1955	116530.	4.19	23.88	1.30
1961	14200.	1961	41600.	1957	65340.	1921	111270.	3.79	26.37	1.19
1938	12800.	1938	38100.	1938	61500.	1957	110170.	3.47	28.86	1.08
1921	12700.	1921	37300.	1921	61500.	1938	108880.	3.19	31.34	0.98
1927	12400.	1922	35500.	1922	56100.	1954	93890.	2.96	33.83	0.89
1922	12300.	1954	33740.	1954	51950.	1922	93400.	2.75	36.32	0.80
1954	12200.	1925	32500.	1925	51230.	1925	91400.	2.58	38.81	0.71
1953	11500.	1927	32300.	1927	47910.	1928	91000.	2.42	41.29	0.63
1925	11400.	1928	30200.	1928	47800.	1946	89460.	2.28	43.78	0.55
1937	10900.	1953	29830.	1946	47470.	1935	86920.	2.16	46.27	0.48
1924	10800.	1946	29800.	1935	46110.	1945	83170.	2.05	48.76	0.40
1945	10700.	1935	29260.	1953	46030.	1924	82140.	1.95	51.24	0.33
1928	10200.	1959	29230.	1959	45310.	1927	81970.	1.86	53.73	0.26
1959	10200.	1945	29220.	1945	44810.	1953	81390.	1.78	56.22	0.19
1946	10100.	1924	28270.	1924	44790.	1959	79660.	1.70	58.71	0.12
1936	9880.	1952	27540.	1952	43320.	1952	78770.	1.63	61.19	0.05
1935	9840.	1960	27220.	1960	41680.	1937	77140.	1.57	63.68	-0.01
1960	9810.	1937	26960.	1937	41080.	1960	74210.	1.51	66.17	-0.08
1952	9610.	1940	24720.	1923	40660.	1923	70750.	1.46	68.66	-0.15
1947	8700.	1923	24640.	1940	37700.	1943	65880.	1.41	71.14	-0.22
1940	8500.	1947	23470.	1943	36410.	1940	64930.	1.36	73.63	-0.29
1923	8420.	1943	23110.	1947	35880.	1947	62830.	1.31	76.12	-0.36
1943	8320.	1936	22450.	1919	34130.	1919	62780.	1.27	78.61	-0.43
1919	7210.	1919	21630.	1936	32950.	1936	56530.	1.23	81.09	-0.51
1962	6020.	1962	17560.	1962	27620.	1962	48690.	1.20	83.58	-0.59
1944	5240.	1941	14530.	1944	23460.	1944	42950.	1.16	86.07	-0.68
1941	5020.	1929	14500.	1929	22960.	1929	41420.	1.13	88.56	-0.78
1929	5010.	1944	14100.	1941	22940.	1941	41250.	1.10	91.04	-0.88
1939	4800.	1939	13610.	1939	21010.	1920	39530.	1.07	93.53	-1.01
1920	4320.	1920	12800.	1920	20640.	1939	35660.	1.04	96.02	-1.18
1926	3050.	1926	8430.	1926	13160.	1926	23020.	1.02	98.51	-1.45

```
MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

        ONE DAY      THREE DAY        FIVE DAY        TEN DAY
      ---------      ---------       ---------      ---------
      11431.250      31548.000       49288.750      86884.750
       5318.805      12977.379       19801.937      33360.664
          1.443          0.521           0.328          0.209

EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

        ONE DAY      THREE DAY        FIVE DAY        TEN DAY
      ---------      ---------       ---------      ---------
      10569.937      29446.480       46082.082      81482.375
      30758.234      78704.000      121243.187     208107.687
```

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

WHITE SALMON R NR UNDERWOOD, WASH.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1913	N/A	92	1590.	90	4670.	42	6680.	40	11943.
1915	N/A	189	3000.	188	7930.	187	11430.	185	19450.
1916	4100.	178	3570.	178	10110.	177	15950.	172	31730.
1917	2130.	252	2130.	251	6080.	240	10020.	239	19270.
1918	9700.	90	9200.	79	23330.	89	34120.	88	55040.
1919	5800.	115	5000.	114	11470.	114	16640.	110	28940.
1920	3820.	118	3240.	118	8200.	118	11530.	118	18130.
1921	4300.	169	4110.	168	11610.	167	17450.	167	29800.
1922	3930.	62	3330.	61	8800.	61	12580.	242	21860.
1923	6800.	99	6280.	98	17260.	98	23160.	95	33280.
1924	3060.	124	2850.	123	7760.	124	11970.	123	22660.
1925	5190.	126	4800.	126	13370.	124	20710.	121	34690.
1926	2780.	130	2550.	129	7010.	129	10500.	128	17100.
1927	4410.	144	4140.	143	11440.	143	17670.	141	28460.
1928	5320.	163	4390.	162	10750.	162	15720.	175	25150.
1929	2720.	236	1640.	235	4830.	233	7810.	230	14590.
1930	3220.	143	2990.	143	7800.	142	11860.	138	19910.
1935	N/A	182	1430.	181	4210.	180	6910.	180	9520.
1936	3490.	104	2540.	104	7030.	103	10940.	224	19280.
1937	4210.	197	3600.	196	9890.	195	14960.	195	24410.
1938	7300.	91	6280.	90	15740.	89	21930.	88	33750.
1939	2260.	138	1950.	138	4940.	138	7490.	172	12910.
1940	3920.	151	3160.	151	9160.	151	14690.	149	26150.
1941	1750.	111	1480.	110	3950.	110	6130.	111	11720.
1942	3790.	80	3290.	80	9070.	80	13280.	79	21250.
1943	6000.	182	4900.	182	13770.	180	20530.	178	36220.
1944	1720.	130	1270.	129	3700.	129	5732.	129	9894.
1945	3440.	131	2690.	131	7050.	131	10250.	223	18460.
1946	5280.	90	4270.	90	11120.	89	16610.	89	28860.
1947	6910.	74	6550.	73	17900.	73	27510.	72	40030.
1948	6430.	99	4610.	99	10770.	98	15450.	98	24530.
1949	7200.	140	3390.	226	8690.	224	14370.	221	27170.
1950	5260.	148	3780.	147	10960.	147	16640.	147	31980.
1951	6240.	134	5580.	133	15480.	132	23550.	131	38040.
1952	5900.	127	4710.	127	11300.	126	16300.	125	26470.
1953	7170.	111	5700.	110	15490.	109	22650.	108	37110.
1954	4410.	144	3680.	144	10020.	144	15740.	143	27650.
1955	2330.	254	2290.	254	6630.	252	10720.	249	19770.
1956	6420.	83	5450.	83	13790.	82	19550.	82	30420.
1957	4250.	160	3330.	159	9260.	159	14210.	158	24620.
1958	5130.	203	4030.	202	10920.	202	15840.	140	28740.
1959	4780.	104	3760.	104	9960.	103	14810.	102	24890.
1960	3790.	131	3070.	130	8830.	181	13060.	181	23710.
1961	6340.	133	5870.	133	16360.	133	24460.	132	40000.
1962	3070.	189	2390.	189	6910.	189	10580.	189	18940.

1963	5410.	51	3510.	127	8930.	127	13580.	126	22810.
1964	4990.	118	3550.	117	9460.	117	14010.	117	24110.
1965	9640.	84	8040.	84	18230.	83	24600.	119	34020.
1966	2650.	219	2490.	218	7210.	218	11790.	216	21090.
1967	4570.	122	4060.	120	11370.	120	17140.	119	27300.
1968	6930.	146	5700.	145	16330.	142	26600.	142	45340.
1969	4950.	99	3400.	99	8310.	98	12230.	223	22800.
1970	8000.	115	7170.	115	17820.	113	26430.	111	42920.
1971	4560.	112	4020.	110	11420.	109	18400.	109	31250.
1972	8360.	113	7500.	112	18040.	112	25510.	151	41000.
1973	8160.	82	5660.	82	14220.	82	20730.	80	32540.
1974	15300.	108	14000.	107	32440.	107	45510.	107	63230.
1975	4860.	117	3890.	117	10660.	116	15600.	110	27490.
1976	8250.	65	6750.	63	14840.	63	21790.	62	35830.
1977	1500.	216	1010.	215	2679.	248	4138.	212	7765.
1978	9980.	75	9080.	74	23580.	74	31640.	72	45270.
1979	2290.	158	1850.	157	5260.	156	8130.	212	14020.
1980	3280.	151	3180.	150	9190.	149	14230.	149	25040.
1981	10300.	87	8200.	86	18480.	86	24230.	83	36780.
1982	12400.	143	9300.	143	23970.	141	33570.	138	55640.
1983	5850.	100	5460.	98	15240.	98	22650.	159	36290.
1984	3260.	117	2770.	117	7670.	117	11610.	169	20150.
1985	N/A	251	2580.	250	7010.	250	10200.	249	17270.
1986	N/A	147	5810.	147	14710.	146	21970.	146	34340.
1987	N/A	165	2490.	164	7250.	163	11530.	161	20590.

N/A - INFORMATION NOT AVAILABLE

RANKED N-DAY FLOOD VOLUMES
(VOLUMES IN CFS-DAYS)

WHITE SALMON R NR UNDERWOOD, WASH.

	ONE DAY		THREE DAY		FIVE DAY		TEN DAY	CUNNANE		REDUCED
								RET	PROB	VARIATE
1974	14000.	1974	32440.	1974	45510.	1974	63230.	117.00	0.85	4.83
1982	9300.	1982	23970.	1918	34120.	1982	55640.	43.88	2.28	3.79
1918	9200.	1978	23580.	1982	33570.	1918	55040.	27.00	3.70	3.29
1978	9080.	1918	23330.	1978	31640.	1968	45340.	19.50	5.13	2.95
1981	8200.	1981	18480.	1947	27510.	1978	45270.	15.26	6.55	2.70
1965	8040.	1965	18230.	1968	26600.	1970	42920.	12.54	7.98	2.49
1972	7500.	1972	18040.	1970	26430.	1972	41000.	10.64	9.40	2.32
1970	7170.	1947	17900.	1972	25510.	1947	40030.	9.24	10.83	2.17
1976	6750.	1970	17820.	1965	24600.	1961	40000.	8.16	12.25	2.04
1947	6550.	1923	17260.	1961	24460.	1951	38040.	7.31	13.68	1.92
1923	6280.	1961	16360.	1981	24230.	1953	37110.	6.62	15.10	1.81
1938	6280.	1968	16330.	1951	23550.	1981	36780.	6.05	16.52	1.71
1961	5870.	1938	15740.	1923	23160.	1983	36290.	5.57	17.95	1.62
1986	5810.	1953	15490.	1983	22650.	1943	36220.	5.16	19.37	1.54
1968	5700.	1951	15480.	1953	22650.	1976	35830.	4.81	20.80	1.46
1953	5700.	1983	15240.	1986	21970.	1925	34690.	4.50	22.22	1.38
1973	5660.	1976	14840.	1938	21930.	1986	34340.	4.23	23.65	1.31
1951	5580.	1986	14710.	1976	21790.	1965	34020.	3.99	25.07	1.24
1983	5460.	1973	14220.	1973	20730.	1938	33750.	3.77	26.50	1.18
1956	5450.	1956	13790.	1925	20710.	1923	33280.	3.58	27.92	1.12
1919	5000.	1943	13770.	1943	20530.	1973	32540.	3.41	29.34	1.06
1943	4900.	1925	13370.	1956	19550.	1950	31980.	3.25	30.77	1.00
1925	4800.	1921	11610.	1971	18400.	1916	31730.	3.11	32.19	0.95
1952	4710.	1919	11470.	1927	17670.	1971	31250.	2.97	33.62	0.89
1948	4610.	1927	11440.	1921	17450.	1956	30420.	2.85	35.04	0.84
1928	4390.	1971	11420.	1967	17140.	1921	29800.	2.74	36.47	0.79
1946	4270.	1967	11370.	1950	16640.	1919	28940.	2.64	37.89	0.74
1927	4140.	1952	11300.	1919	16640.	1946	28860.	2.54	39.32	0.69
1921	4110.	1946	11120.	1946	16610.	1958	28740.	2.45	40.74	0.65
1967	4060.	1950	10960.	1952	16300.	1927	28460.	2.37	42.17	0.60
1958	4030.	1958	10920.	1916	15950.	1954	27650.	2.29	43.59	0.56
1971	4020.	1948	10770.	1958	15840.	1975	27490.	2.22	45.01	0.51
1975	3890.	1928	10750.	1954	15740.	1967	27300.	2.15	46.44	0.47
1950	3780.	1975	10660.	1928	15720.	1949	27170.	2.09	47.86	0.43
1959	3760.	1916	10110.	1975	15600.	1952	26470.	2.03	49.29	0.39
1954	3680.	1954	10020.	1948	15450.	1940	26150.	1.97	50.71	0.35
1937	3600.	1959	9960.	1937	14960.	1928	25150.	1.92	52.14	0.31
1916	3570.	1937	9890.	1959	14810.	1980	25040.	1.87	53.56	0.27
1964	3550.	1964	9460.	1940	14690.	1959	24890.	1.82	54.99	0.23
1963	3510.	1957	9260.	1949	14370.	1957	24620.	1.77	56.41	0.19
1969	3400.	1980	9190.	1980	14230.	1948	24530.	1.73	57.83	0.15
1949	3390.	1940	9160.	1957	14210.	1937	24410.	1.69	59.26	0.11
1922	3330.	1942	9070.	1964	14010.	1964	24110.	1.65	60.68	0.07
1957	3330.	1963	8930.	1963	13580.	1960	23710.	1.61	62.11	0.03

```
1942    3290. 1960    8830. 1942   13280. 1963   22810.   1.57 63.53 -0.01
1920    3240. 1922    8800. 1960   13060. 1969   22800.   1.54 64.96 -0.05
1980    3180. 1949    8690. 1922   12580. 1924   22660.   1.51 66.38 -0.09
1940    3160. 1969    8310. 1969   12230. 1922   21860.   1.47 67.81 -0.13
1960    3070. 1920    8200. 1924   11970. 1942   21250.   1.44 69.23 -0.16
1915    3000. 1915    7930. 1930   11860. 1966   21090.   1.42 70.66 -0.20
1930    2990. 1930    7800. 1966   11790. 1987   20590.   1.39 72.08 -0.24
1924    2850. 1924    7760. 1984   11610. 1984   20150.   1.36 73.50 -0.28
1984    2770. 1984    7670. 1987   11530. 1930   19910.   1.33 74.93 -0.33
1945    2690. 1987    7250. 1920   11530. 1955   19770.   1.31 76.35 -0.37
1985    2580. 1966    7210. 1915   11430. 1915   19450.   1.29 77.78 -0.41
1926    2550. 1945    7050. 1936   10940. 1936   19280.   1.26 79.20 -0.45
1936    2540. 1936    7030. 1955   10720. 1917   19270.   1.24 80.63 -0.50
1966    2490. 1985    7010. 1962   10580. 1962   18940.   1.22 82.05 -0.54
1987    2490. 1926    7010. 1926   10500. 1945   18460.   1.20 83.48 -0.59
1962    2390. 1962    6910. 1945   10250. 1920   18130.   1.18 84.90 -0.64
1955    2290. 1955    6630. 1985   10200. 1985   17270.   1.16 86.32 -0.69
1917    2130. 1917    6080. 1917   10020. 1926   17100.   1.14 87.75 -0.74
1939    1950. 1979    5260. 1979    8130. 1929   14590.   1.12 89.17 -0.80
1979    1850. 1939    4940. 1929    7810. 1979   14020.   1.10 90.60 -0.86
1929    1640. 1929    4830. 1939    7490. 1939   12910.   1.09 92.02 -0.93
1913    1590. 1913    4670. 1935    6910. 1913   11943.   1.07 93.45 -1.01
1941    1480. 1935    4210. 1913    6680. 1941   11720.   1.05 94.87 -1.09
1935    1430. 1941    3950. 1941    6130. 1944    9894.   1.04 96.30 -1.20
1944    1270. 1944    3700. 1944    5732. 1935    9520.   1.02 97.72 -1.34
1977    1010. 1977    2679. 1977    4138. 1977    7765.   1.01 99.15 -1.57

MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

          ONE DAY       THREE DAY        FIVE DAY          TEN DAY
         ---------      ---------       ---------        ---------
         4304.711       11280.555       16693.000        27619.742
         2292.692        5432.191        7513.254        10914.551
            1.462           1.219           1.104            0.775


EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

          ONE DAY       THREE DAY        FIVE DAY          TEN DAY
         ---------      ---------       ---------        ---------
         3931.405       10396.059       15469.656        25842.586
        12681.332       31127.715       44143.570        67497.312
```

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

UMPQUA RIVER NEAR ELKTON, OREG.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1906	61400.	109	61400.	108	134400.	144	191100.	143	317500.
1907	N/A	151	32800.	149	98400.	147	164000.	142	328000.
1908	106000.	87	84600.	87	206800.	85	300400.	84	423300.
1909	97200.	112	93000.	111	245800.	110	357600.	108	535900.
1910	144000.	54	138000.	53	247800.	52	323700.	51	445400.
1911	94300.	113	71300.	60	154900.	59	197100.	56	293900.
1912	109000.	105	99300.	140	207700.	103	274300.	99	446700.
1913	75800.	110	53300.	110	129700.	108	162800.	106	250800.
1914	67000.	118	57100.	117	158900.	115	243500.	112	403700.
1915	33100.	126	29100.	106	63900.	106	94100.	100	169000.
1916	116000.	130	111000.	129	218100.	129	302700.	129	442700.
1917	40300.	176	38700.	179	102900.	176	161100.	176	283600.
1918	67000.	105	58000.	105	137000.	105	199200.	104	324700.
1919	91000.	111	76000.	110	201000.	110	277200.	109	439000.
1920	53500.	70	45100.	80	95700.	80	140400.	80	228400.
1921	81000.	72	69200.	71	178400.	69	250600.	90	443400.
1922	76000.	61	64800.	61	167900.	61	271200.	58	401100.
1923	96000.	98	93500.	97	231900.	96	316100.	92	455400.
1924	39100.	68	37100.	68	80500.	129	107500.	125	193700.
1925	116000.	32	96500.	127	185700.	127	271900.	123	457400.
1926	67000.	128	60200.	128	142400.	128	196900.	127	299900.
1927	185000.	144	157000.	143	323500.	143	412000.	142	539200.
1928	67000.	179	61600.	179	131100.	179	185300.	179	341000.
1929	45400.	197	43600.	197	109000.	196	156000.	196	230700.
1930	62000.	80	57600.	79	120200.	77	170500.	74	267900.
1931	51000.	184	43600.	182	114100.	182	158000.	181	209400.
1932	104000.	171	92000.	170	228100.	169	307400.	169	433500.
1933	101000.	95	84600.	94	166500.	94	201800.	88	320800.
1934	53200.	116	45300.	115	102000.	113	147500.	111	213340.
1935	76600.	82	62800.	81	147800.	81	213600.	81	355500.
1936	111000.	105	87000.	104	236700.	103	350000.	102	545600.
1937	94000.	196	84500.	196	218100.	196	276200.	195	359900.
1938	119000.	130	104000.	129	215100.	167	293100.	167	479000.
1939	57300.	164	52800.	164	115000.	136	164400.	164	280600.
1940	83500.	152	73200.	151	164300.	151	230100.	149	324600.
1941	70400.	88	67100.	87	130400.	86	175600.	82	288000.
1942	74200.	80	70800.	79	175200.	78	257700.	77	397900.
1943	186000.	92	160000.	92	390000.	91	510700.	86	795800.
1944	52000.	36	41400.	35	71200.	129	94700.	126	155600.
1945	76500.	137	71500.	136	145800.	135	187000.	129	319900.
1946	179000.	90	152000.	89	303800.	89	365700.	89	564700.
1947	74000.	75	55800.	57	129500.	55	188500.	54	276100.
1948	154000.	99	142000.	98	303200.	97	378400.	93	571400.
1949	109000.	73	93800.	72	223700.	71	295400.	67	423800.
1950	78000.	114	77500.	113	208100.	111	333600.	110	470900.

1951	208000.	30	160000.	29	361100.	28	409300.	28	497800.
1952	72500.	125	66600.	125	158500.	123	234900.	84	392600.
1953	199000.	111	151000.	110	361000.	109	490800.	105	652800.
1954	195000.	54	173000.	54	295500.	53	346800.	115	430100.
1955	60400.	92	49900.	92	119600.	91	155800.	175	220400.
1956	218000.	83	176000.	82	393200.	83	546500.	80	879500.
1957	131000.	73	90000.	72	220000.	72	316000.	71	399000.
1958	131000.	82	120000.	81	264400.	80	330300.	81	507400.
1959	95200.	104	73600.	103	165700.	101	254900.	100	335200.
1960	91700.	132	85100.	131	191400.	130	244200.	126	336500.
1961	119000.	134	90000.	133	216000.	133	284000.	133	397000.
1962	176000.	54	140000.	54	280200.	54	327800.	54	450400.
1963	91300.	219	80600.	218	182000.	218	235200.	215	326400.
1964	138000.	112	123000.	111	238100.	110	316600.	110	442400.
1965	265000.	84	260000.	83	641000.	83	836000.	81	1108900.
1966	133000.	96	119000.	96	255900.	95	409100.	94	556800.
1967	82600.	121	63200.	120	165400.	119	232100.	113	332900.
1968	78300.	147	60000.	145	152900.	144	206200.	143	271730.
1969	85300.	105	70200.	104	154700.	103	213200.	99	314900.
1970	113000.	116	96300.	115	248100.	115	401900.	111	631200.
1971	201000.	110	150000.	109	385000.	108	508300.	107	644200.
1972	158000.	155	137000.	113	329100.	112	436600.	110	612800.
1973	35600.	105	30500.	105	78100.	105	119300.	79	192800.
1974	202000.	108	190000.	107	440000.	106	566000.	105	730600.
1975	80800.	98	66500.	98	135100.	98	196900.	170	338500.
1976	128000.	100	102000.	100	221900.	98	303400.	97	449300.
1977	13100.	161	12400.	160	30960.	160	45550.	155	72730.
1978	121000.	56	95500.	56	210800.	54	283100.	54	366400.
1979	92100.	104	60000.	103	112700.	103	142900.	130	243100.
1980	103000.	106	92100.	105	247300.	105	316700.	104	410600.
1981	86000.	65	72400.	64	175100.	64	212000.	63	257630.
1982	167000.	67	129000.	67	272400.	67	320900.	67	494500.
1983	156000.	141	129000.	141	269900.	141	342300.	136	478500.
1984	145000.	137	99800.	136	219000.	136	283100.	68	458600.
1985	N/A	59	64200.	59	178100.	59	248700.	56	333700.
1986	N/A	146	135000.	145	296400.	143	405000.	140	627900.

N/A - INFORMATION NOT AVAILABLE

```
                     RANKED N-DAY FLOOD VOLUMES
                       (VOLUMES IN CFS-DAYS)

-------------------------------------------------------------------------
                   UMPQUA RIVER NEAR ELKTON, OREG.
-------------------------------------------------------------------------

      ONE          THREE            FIVE            TEN       CUNNANE  REDUCED
      DAY           DAY             DAY             DAY      RET  PROB VARIATE
  -----------  -----------  -----------  -----------  -----------   ----

1965 260000. 1965 641000. 1965 836000. 19651108900.135.33  0.74   4.97
1974 190000. 1974 440000. 1974 566000. 1956 879500. 50.75  1.97   3.94
1956 176000. 1956 393200. 1956 546500. 1943 795800. 31.23  3.20   3.44
1954 173000. 1943 390000. 1943 510700. 1974 730600. 22.56  4.43   3.10
1943 160000. 1971 385000. 1971 508300. 1953 652800. 17.65  5.67   2.85
1951 160000. 1951 361100. 1953 490800. 1971 644200. 14.50  6.90   2.65
1927 157000. 1953 361000. 1972 436600. 1970 631200. 12.30  8.13   2.47
1946 152000. 1972 329100. 1927 412000. 1986 627900. 10.68  9.36   2.32
1953 151000. 1927 323500. 1951 409300. 1972 612800.  9.44 10.59   2.19
1971 150000. 1946 303800. 1966 409100. 1948 571400.  8.46 11.82   2.08
1948 142000. 1948 303200. 1986 405000. 1946 564700.  7.66 13.05   1.97
1962 140000. 1986 296400. 1970 401900. 1966 556800.  7.00 14.29   1.87
1910 138000. 1954 295500. 1948 378400. 1936 545600.  6.44 15.52   1.78
1972 137000. 1962 280200. 1946 365700. 1927 539200.  5.97 16.75   1.70
1986 135000. 1982 272400. 1909 357600. 1909 535900.  5.56 17.98   1.62
1983 129000. 1983 269900. 1936 350000. 1958 507400.  5.21 19.21   1.55
1982 129000. 1958 264400. 1954 346800. 1951 497800.  4.89 20.44   1.48
1964 123000. 1966 255900. 1983 342300. 1982 494500.  4.61 21.67   1.41
1958 120000. 1970 248100. 1950 333600. 1938 479000.  4.37 22.91   1.35
1966 119000. 1910 247800. 1958 330300. 1983 478500.  4.14 24.14   1.29
1916 111000. 1980 247300. 1962 327800. 1950 470900.  3.94 25.37   1.23
1938 104000. 1909 245800. 1910 323700. 1984 458600.  3.76 26.60   1.17
1976 102000. 1964 238100. 1982 320900. 1925 457400.  3.59 27.83   1.12
1984  99800. 1936 236700. 1980 316700. 1923 455400.  3.44 29.06   1.07
1912  99300. 1923 231900. 1964 316600. 1962 450400.  3.30 30.30   1.02
1925  96500. 1932 228100. 1923 316100. 1976 449300.  3.17 31.53   0.97
1970  96300. 1949 223700. 1957 316000. 1912 446700.  3.05 32.76   0.92
1978  95500. 1976 221900. 1932 307400. 1910 445400.  2.94 33.99   0.88
1949  93800. 1957 220000. 1976 303400. 1921 443400.  2.84 35.22   0.83
1923  93500. 1984 219000. 1916 302700. 1916 442700.  2.74 36.45   0.79
1909  93000. 1916 218100. 1908 300400. 1964 442400.  2.65 37.68   0.75
1980  92100. 1937 218100. 1949 295400. 1919 439000.  2.57 38.92   0.71
1932  92000. 1961 216000. 1938 293100. 1932 433500.  2.49 40.15   0.67
1961  90000. 1938 215100. 1961 284000. 1954 430100.  2.42 41.38   0.63
1957  90000. 1978 210800. 1978 283100. 1949 423800.  2.35 42.61   0.59
1936  87000. 1950 208100. 1984 283100. 1908 423300.  2.28 43.84   0.55
1960  85100. 1912 207700. 1919 277200. 1980 410600.  2.22 45.07   0.51
1933  84600. 1908 206800. 1937 276200. 1914 403700.  2.16 46.31   0.48
1908  84600. 1919 201000. 1912 274300. 1922 401100.  2.10 47.54   0.44
1937  84500. 1960 191400. 1925 271900. 1957 399000.  2.05 48.77   0.40
1963  80600. 1925 185700. 1922 271200. 1942 397900.  2.00 50.00   0.37
1950  77500. 1963 182000. 1942 257700. 1961 397000.  1.95 51.23   0.33
1919  76000. 1921 178400. 1959 254900. 1952 392600.  1.91 52.46   0.30
1959  73600. 1985 178100. 1921 250600. 1978 366400.  1.86 53.69   0.26
```

```
1940  73200. 1942 175200. 1985 248700. 1937 359900.  1.82 54.93  0.23
1981  72400. 1981 175100. 1960 244200. 1935 355500.  1.78 56.16  0.19
1945  71500. 1922 167900. 1914 243500. 1928 341000.  1.74 57.39  0.16
1911  71300. 1933 166500. 1963 235200. 1975 338500.  1.71 58.62  0.12
1942  70800. 1959 165700. 1952 234900. 1960 336500.  1.67 59.85  0.09
1969  70200. 1967 165400. 1967 232100. 1959 335200.  1.64 61.08  0.06
1921  69200. 1940 164300. 1940 230100. 1985 333700.  1.60 62.32  0.02
1941  67100. 1914 158900. 1935 213600. 1967 332900.  1.57 63.55 -0.01
1952  66600. 1952 158500. 1969 213200. 1907 328000.  1.54 64.78 -0.04
1975  66500. 1911 154900. 1981 212000. 1963 326400.  1.51 66.01 -0.08
1922  64800. 1969 154700. 1968 206200. 1918 324700.  1.49 67.24 -0.11
1985  64200. 1968 152900. 1933 201800. 1940 324600.  1.46 68.47 -0.14
1967  63200. 1935 147800. 1918 199200. 1933 320800.  1.43 69.70 -0.18
1935  62800. 1945 145800. 1911 197100. 1945 319900.  1.41 70.94 -0.21
1928  61600. 1926 142400. 1975 196900. 1906 317500.  1.39 72.17 -0.25
1906  61400. 1918 137000. 1926 196900. 1969 314900.  1.36 73.40 -0.28
1926  60200. 1975 135100. 1906 191100. 1926 299900.  1.34 74.63 -0.32
1968  60000. 1906 134400. 1947 188500. 1911 293900.  1.32 75.86 -0.35
1979  60000. 1928 131100. 1945 187000. 1941 288000.  1.30 77.09 -0.39
1918  58000. 1941 130400. 1928 185300. 1917 283600.  1.28 78.33 -0.43
1930  57600. 1913 129700. 1941 175600. 1939 280600.  1.26 79.56 -0.46
1914  57100. 1947 129500. 1930 170500. 1947 276100.  1.24 80.79 -0.50
1947  55800. 1930 120200. 1939 164400. 1968 271730.  1.22 82.02 -0.54
1913  53300. 1955 119600. 1907 164000. 1930 267900.  1.20 83.25 -0.58
1939  52800. 1939 115000. 1913 162800. 1981 257630.  1.18 84.48 -0.62
1955  49900. 1931 114100. 1917 161100. 1913 250800.  1.17 85.71 -0.67
1934  45300. 1979 112700. 1931 158000. 1979 243100.  1.15 86.95 -0.71
1920  45100. 1929 109000. 1929 156000. 1929 230700.  1.13 88.18 -0.76
1931  43600. 1917 102900. 1955 155800. 1920 228400.  1.12 89.41 -0.81
1929  43600. 1934 102000. 1934 147500. 1955 220400.  1.10 90.64 -0.86
1944  41400. 1907  98400. 1979 142900. 1934 213340.  1.09 91.87 -0.92
1917  38700. 1920  95700. 1920 140400. 1931 209400.  1.07 93.10 -0.99
1924  37100. 1924  80500. 1973 119300. 1924 193700.  1.06 94.33 -1.06
1907  32800. 1973  78100. 1924 107500. 1973 192800.  1.05 95.57 -1.14
1973  30500. 1944  71200. 1944  94700. 1915 169000.  1.03 96.80 -1.24
1915  29100. 1915  63900. 1915  94100. 1944 155600.  1.02 98.03 -1.37
1977  12400. 1977  30960. 1977  45550. 1977  72730.  1.01 99.26 -1.60

MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

      ONE DAY      THREE DAY        FIVE DAY        TEN DAY
     --------      ---------       ---------       ---------
    89683.937     204058.750      276282.437      406719.187
    43400.266      97357.812      124061.375      166174.375
        1.096          1.410           1.388           1.276


EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

      ONE DAY      THREE DAY        FIVE DAY        TEN DAY
     --------      ---------       ---------       ---------
    82610.312     188190.937      256062.312      379635.312
   248407.937     560117.000      730001.312     1014454.250
```

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

SILETZ RIVER AT SILETZ, OREG.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1906	9980.	116	9400.	143	25510.	143	38690.	142	71300.
1907	24900.	128	22200.	45	50900.	44	72530.	38	123340.
1908	30600.	167	29000.	167	55180.	166	66820.	81	94000.
1909	18200.	89	8970.	88	23130.	87	32360.	83	47370.
1910	34600.	154	20300.	153	48200.	152	65310.	151	88180.
1911	25200.	52	21600.	110	52800.	110	61500.	110	73260.
1912	21600.	104	21600.	104	49900.	102	62380.	98	120100.
1924	N/A	124	8600.	124	20430.	124	31040.	123	55300.
1925	18800.	121	14400.	125	38700.	123	59340.	121	114040.
1926	16800.	147	15100.	128	38100.	127	52900.	124	69760.
1927	19500.	124	14100.	123	40000.	123	54800.	119	80290.
1928	30700.	56	30700.	55	51080.	55	68160.	55	99830.
1929	11200.	88	8900.	196	22020.	196	31560.	88	57230.
1930	11500.	131	11000.	130	27290.	128	39570.	125	66770.
1931	34100.	182	20000.	182	45980.	182	54520.	181	70680.
1932	21800.	110	21800.	110	39940.	110	48300.	169	66440.
1933	19800.	94	19800.	94	36120.	94	53700.	80	88050.
1934	28700.	67	28700.	81	56000.	80	84500.	79	124940.
1935	15000.	38	12600.	36	31580.	35	47900.	81	71880.
1936	19600.	96	19600.	96	38760.	94	56480.	96	103480.
1937	16100.	196	16100.	195	42200.	195	54840.	192	69190.
1938	30100.	88	30100.	88	73400.	88	97200.	87	114400.
1939	17800.	138	15000.	137	34060.	135	52340.	131	69910.
1940	21400.	129	17600.	76	38400.	129	52000.	128	76170.
1941	13200.	110	11900.	109	27790.	109	35240.	109	51270.
1942	25400.	80	21300.	79	44200.	78	56640.	77	81760.
1943	26500.	54	19400.	182	43340.	179	57750.	54	90270.
1944	12800.	64	9890.	64	23460.	63	31930.	62	41570.
1945	22400.	130	12700.	130	30960.	129	38670.	128	65650.
1946	21600.	89	17200.	89	38340.	88	48920.	89	81170.
1947	28000.	76	20200.	74	58800.	72	82710.	69	112460.
1948	21900.	145	16900.	144	34870.	144	42910.	93	67430.
1949	29000.	140	27200.	139	53700.	139	71760.	139	119430.
1950	16400.	114	13700.	112	38200.	112	54740.	111	74350.
1951	16600.	109	14000.	108	29340.	106	44140.	107	79800.
1952	19400.	127	14000.	125	37400.	123	60000.	122	85110.
1953	24600.	110	25800.	109	63400.	108	88500.	108	129110.
1954	21900.	53	19000.	53	42650.	67	54010.	64	86470.
1955	21200.	92	16600.	91	40230.	91	49700.	90	61450.
1956	22700.	96	19700.	56	40200.	95	52440.	50	78550.
1957	20900.	72	16700.	71	37180.	71	50510.	71	69870.
1958	22200.	80	16700.	80	40350.	80	51970.	80	92440.
1959	14200.	101	11700.	50	28070.	101	39090.	100	57540.
1960	14200.	132	12600.	130	30040.	130	44210.	129	67990.
1961	24400.	55	21900.	54	44740.	52	56900.	47	100190.

1962	20900.	53	14600.	80	33150.	79	43680.	78	64070.
1963	26300.	51	21100.	51	38820.	51	45180.	51	88880.
1964	19700.	117	18000.	116	38440.	116	50530.	110	89280.
1965	32200.	120	29900.	119	65600.	83	89000.	82	119940.
1966	19500.	160	16600.	96	34600.	95	51920.	89	78260.
1967	19100.	120	15400.	119	41200.	118	56000.	115	74130.
1968	18600.	142	15500.	142	35030.	142	53460.	141	72580.
1969	14500.	65	10900,	64	26720.	39	41190.	64	66300.
1970	17200.	111	13800.	110	38200.	110	55900.	110	107400.
1971	18100.	108	14100.	108	40100.	107	59550.	108	94190.
1972	31800.	112	23200.	111	56500.	110	73310.	104	101560.
1973	19700.	82	15400.	82	39600.	81	56420.	80	96130.
1974	20900.	108	18000.	107	45000.	106	60440.	40	91370.
1975	21500.	81	17000.	81	34790.	80	42940.	97	69910.
1976	23600.	65	18900.	63	42900.	62	69710.	61	100540.
1977	8630.	151	7840.	151	20340.	150	28780.	151	50270.
1978	23100.	56	20400.	74	52500.	74	71500.	70	95020.
1979	16600.	130	12435.	155	28643.	154	37842.	129	58243.
1980	14500.	104	12300.	103	34900.	103	47840.	100	72020.
1981	26500.	86	21900.	86	49070.	84	63510.	83	90510.
1982	21400.	115	16400.	115	38700.	140	54360.	137	95010.
1983	18300.	98	16100.	97	43800.	96	69000.	96	90650.
1984	11300.	136	9440.	135	22420.	48	30860.	47	55960.
1985	N/A	59	11000.	59	27320.	58	38950.	55	53280.
1986	N/A	146	14700.	145	33200.	145	45030.	139	72420.
1987	N/A	155	8560.	155	20200.	154	25780.	155	42320.

N/A - INFORMATION NOT AVAILABLE

RANKED N-DAY FLOOD VOLUMES
(VOLUMES IN CFS-DAYS)

SILETZ RIVER AT SILETZ, OREG.

ONE DAY		THREE DAY		FIVE DAY		TEN DAY		CUNNANE		REDUCED VARIATE
								RET	PROB	
1928	30700.	1938	73400.	1938	97200.	1953	129110.	118.67	0.84	4.84
1938	30100.	1965	65600.	1965	89000.	1934	124940.	44.50	2.25	3.81
1965	29900.	1953	63400.	1953	88500.	1907	123340.	27.38	3.65	3.31
1908	29000.	1947	58800.	1934	84500.	1912	120100.	19.78	5.06	2.97
1934	28700.	1972	56500.	1947	82710.	1965	119940.	15.48	6.46	2.71
1949	27200.	1934	56000.	1972	73310.	1949	119430.	12.71	7.87	2.51
1953	25800.	1908	55180.	1907	72530.	1938	114400.	10.79	9.27	2.34
1972	23200.	1949	53700.	1949	71760.	1925	114040.	9.37	10.67	2.19
1907	22200.	1911	52800.	1978	71500.	1947	112460.	8.28	12.08	2.05
1981	21900.	1978	52500.	1976	69710.	1970	107400.	7.42	13.48	1.94
1961	21900.	1928	51080.	1983	69000.	1936	103480.	6.72	14.89	1.83
1932	21800.	1907	50900.	1928	68160.	1972	101560.	6.14	16.29	1.73
1911	21600.	1912	49900.	1908	66820.	1976	100540.	5.65	17.70	1.64
1912	21600.	1981	49070.	1910	65310.	1961	100190.	5.24	19.10	1.55
1942	21300.	1910	48200.	1981	63510.	1928	99830.	4.88	20.51	1.47
1963	21100.	1931	45980.	1912	62380.	1973	96130.	4.56	21.91	1.40
1978	20400.	1974	45000.	1911	61500.	1978	95020.	4.29	23.31	1.33
1910	20300.	1961	44740.	1974	60440.	1982	95010.	4.05	24.72	1.26
1947	20200.	1942	44200.	1952	60000.	1971	94190.	3.83	26.12	1.20
1931	20000.	1983	43800.	1971	59550.	1908	94000.	3.63	27.53	1.13
1933	19800.	1943	43340.	1925	59340.	1958	92440.	3.46	28.93	1.08
1956	19700.	1976	42900.	1943	57750.	1974	91370.	3.30	30.34	1.02
1936	19600.	1954	42650.	1961	56900.	1983	90650.	3.15	31.74	0.96
1943	19400.	1937	42200.	1942	56640.	1981	90510.	3.02	33.15	0.91
1954	19000.	1967	41200.	1936	56480.	1943	90270.	2.89	34.55	0.86
1976	18900.	1958	40350.	1973	56420.	1964	89280.	2.78	35.96	0.81
1964	18000.	1955	40230.	1967	56000.	1963	88880.	2.68	37.36	0.76
1974	18000.	1956	40200.	1970	55900.	1910	88180.	2.58	38.76	0.71
1940	17600.	1971	40100.	1937	54840.	1933	88050.	2.49	40.17	0.67
1946	17200.	1927	40000.	1927	54800.	1954	86470.	2.41	41.57	0.62
1975	17000.	1932	39940.	1950	54740.	1952	85110.	2.33	42.98	0.58
1948	16900.	1973	39600.	1931	54520.	1942	81760.	2.25	44.38	0.53
1958	16700.	1963	38820.	1982	54360.	1946	81170.	2.18	45.79	0.49
1957	16700.	1936	38760.	1954	54010.	1927	80290.	2.12	47.19	0.45
1966	16600.	1982	38700.	1933	53700.	1951	79800.	2.06	48.60	0.41
1955	16600.	1925	38700.	1968	53460.	1956	78550.	2.00	50.00	0.37
1982	16400.	1964	38440.	1926	52900.	1966	78260.	1.95	51.40	0.33
1983	16100.	1940	38400.	1956	52440.	1940	76170.	1.89	52.81	0.29
1937	16100.	1946	38340.	1939	52340.	1950	74350.	1.84	54.21	0.25
1968	15500.	1970	38200.	1940	52000.	1967	74130.	1.80	55.62	0.21
1973	15400.	1950	38200.	1958	51970.	191	73260.	1.75	57.02	0.17
1967	15400.	1926	38100.	1966	51920.	1968	72580.	1.71	58.43	0.13
1926	15100.	1952	37400.	1964	50530.	1986	72420.	1.67	59.83	0.09
1939	15000.	1957	37180.	1957	50510.	1980	72020.	1.63	61.24	0.05

```
1986  14700. 1933  36120. 1955  49700. 1935  71880.  1.60 62.64  0.02
1962  14600. 1968  35030. 1946  48920. 1906  71300.  1.56 64.04 -0.02
1925  14400. 1980  34900. 1932  48300. 1931  70680.  1.53 65.45 -0.06
1971  14100. 1948  34870. 1935  47900. 1939  69910.  1.50 66.85 -0.10
1927  14100. 1975  34790. 1980  47840. 1975  69910.  1.47 68.26 -0.14
1951  14000. 1966  34600. 1963  45180. 1957  69870.  1.44 69.66 -0.18
1952  14000. 1939  34060. 1986  45030. 1926  69760.  1.41 71.07 -0.22
1970  13800. 1986  33200. 1960  44210. 1937  69190.  1.38 72.47 -0.26
1950  13700. 1962  33150. 1951  44140. 1960  67990.  1.35 73.88 -0.30
1945  12700. 1935  31580. 1962  43680. 1948  67430.  1.33 75.28 -0.34
1960  12600. 1945  30960. 1975  42940. 1930  66770.  1.30 76.69 -0.38
1935  12600. 1960  30040. 1948  42910. 1932  66440.  1.28 78.09 -0.42
1979  12435. 1951  29340. 1969  41190. 1969  66300.  1.26 79.49 -0.46
1980  12300. 1979  28643. 1930  39570. 1945  65650.  1.24 80.90 -0.51
1941  11900. 1959  28070. 1959  39090. 1962  64070.  1.22 82.30 -0.55
1959  11700. 1941  27790. 1985  38950. 1955  61450.  1.19 83.71 -0.60
1930  11000. 1985  27320. 1906  38690. 1979  58243.  1.17 85.11 -0.65
1985  11000. 1930  27290. 1945  38670. 1959  57540.  1.16 86.52 -0.70
1969  10900. 1969  26720. 1979  37842. 1929  57230.  1.14 87.92 -0.75
1944   9890. 1906  25510. 1941  35240. 1984  55960.  1.12 89.33 -0.81
1984   9440. 1944  23460. 1909  32360. 1924  55300.  1.10 90.73 -0.87
1906   9400. 1909  23130. 1944  31930. 1985  53280.  1.09 92.13 -0.94
1909   8970. 1984  22420. 1929  31560. 1941  51270.  1.07 93.54 -1.01
1929   8900. 1929  22020. 1924  31040. 1977  50270.  1.05 94.94 -1.10
1924   8600. 1924  20430. 1984  30860. 1909  47370.  1.04 96.35 -1.20
1987   8560. 1977  20340. 1977  28780. 1987  42320.  1.02 97.75 -1.34
1977   7840. 1987  20200. 1987  25780. 1944  41570.  1.01 99.16 -1.58
```

```
MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

       ONE DAY        THREE DAY         FIVE DAY          TEN DAY
      ---------       ---------        ----------        ---------
      17038.520       39277.223        53720.590        81690.562
       5551.527       11148.750        14877.070        21086.797
          0.593           0.545            0.588            0.331


EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

       ONE DAY        THREE DAY         FIVE DAY          TEN DAY
      --------        ---------        ---------        ---------
      16134.504       37461.750        51297.992        78256.750
      37323.758       80014.625       108081.250       158741.562
```

SUMMARY OF N-DAY FLOOD VOLUMES
(VOLUMES GIVEN IN CFS-DAYS)

NEHALEM RIVER NEAR FOSS, OREG.

WATER YEAR	PEAK FLOW	DAY	ONE DAY	DAY	THREE DAY	DAY	FIVE DAY	DAY	TEN DAY
1940	26700.	77	25100.	76	66000.	129	92100.	129	143050.
1941	19100.	110	17600.	109	44000.	109	60620.	109	87510.
1942	31100.	80	29300.	79	72400.	78	103100.	77	156740.
1943	25800.	183	24600.	182	62700.	181	87400.	127	148760.
1944	16000.	64	15500.	64	39700.	63	53500.	62	70020.
1945	30800.	130	26800.	130	67100.	130	84400.	165	117410.
1946	27400.	90	26100.	89	68400.	89	92500.	89	165100.
1947	35100.	74	32500.	73	84700.	72	127100.	69	182030.
1948	21900.	145	20500.	145	51100.	145	72370.	93	130270.
1949	36900.	145	34700.	145	95900.	144	127300.	139	234300.
1950	30800.	148	29900.	147	81800.	147	111900.	147	173210.
1951	22400.	109	20700.	132	57200.	131	85100.	107	136930.
1952	23700.	127	21900.	126	54200.	123	89400.	121	146870.
1953	22800.	111	20800.	110	55000.	109	84400.	108	151200.
1954	34700.	98	31200.	97	83800.	96	116100.	136	170900.
1955	19500.	92	18800.	92	47400.	91	67860.	90	93440.
1956	39300.	83	36000.	82	92200.	82	126200.	81	176900.
1957	23000.	149	19800.	148	51300.	147	74040.	146	99420.
1958	21200.	81	18100.	80	48800.	80	70400.	80	135600.
1959	21900.	102	20100.	101	53800.	101	84400.	100	126310.
1960	21600.	54	20000.	52	48900.	129	70700.	125	120230.
1961	30800.	56	26400.	55	69400.	52	96200.	49	165320.
1962	18400.	82	17700.	81	46900.	81	71500.	78	124620.
1963	35900.	126	30600.	126	78200.	125	99280.	51	147970.
1964	43200.	117	37100.	117	88300.	116	114100.	110	201890.
1965	40400.	84	34000.	83	93600.	83	137200.	116	188630.
1966	26800.	98	24800.	98	68100.	97	97500.	98	165300.
1967	38700.	74	34600.	74	81800.	73	107740.	66	165070.
1968	29900.	127	27000.	126	68000.	125	90440.	124	115710.
1969	19000.	134	17900.	134	45600.	98	65800.	65	113620.
1970	23500.	119	22600.	118	58100.	116	87700.	111	174500.
1971	35800.	68	33000.	117	81900.	115	114200.	109	200000.
1972	46900.	113	38200.	112	102800.	112	138900.	110	188940.
1973	31200.	83	24000.	82	62800.	82	94500.	81	169100.
1974	39400.	108	37800.	107	104000.	107	149700.	106	201060.
1975	26900.	106	26500.	105	68600.	105	97500.	99	150150.
1976	33900.	65	29000.	64	67400.	62	101900.	61	157440.
1977	14300.	160	13400.	159	35600.	159	50980.	153	79620.
1978	35200.	75	31300.	74	89100.	74	133600.	72	188570.
1979	18900.	130	17000.	130	40800.	130	57690.	129	100360.
1980	24400.	105	20699.	104	59632.	104	90988.	102	139514.
1981	34300.	87	29279.	86	74349.	85	99665.	83	150835.
1982	33600.	116	29300.	115	70700.	115	98100.	137	167800.
1983	33400.	65	24800.	77	65100.	77	94300.	76	146450.
1984	17200.	49	16500.	48	47500.	47	76400.	44	130040.
1985	N/A	60	17200.	59	49300.	58	71770.	55	104080.
1986	N/A	147	22200.	146	56300.	146	75390.	140	108930.
1987	N/A	155	25100.	154	69100.	153	89160.	154	123080.

N/A - INFORMATION NOT AVAILABLE

RANKED N-DAY FLOOD VOLUMES
(VOLUMES IN CFS-DAYS)

NEHALEM RIVER NEAR FOSS, OREG.

ONE DAY		THREE DAY		FIVE DAY		TEN DAY		CUNNANE RET	CUNNANE PROB	REDUCED VARIATE
1972	38200.	1974	104000.	1974	149700.	1949	234300.	80.33	1.24	4.45
1974	37800.	1972	102800.	1972	138900.	1964	201890.	30.13	3.32	3.41
1964	37100.	1949	95900.	1965	137200.	1974	201060.	18.54	5.39	2.91
1956	36000.	1965	93600.	1978	133600.	1971	200000.	13.39	7.47	2.57
1949	34700.	1956	92200.	1949	127300.	1972	188940.	10.48	9.54	2.31
1967	34600.	1978	89100.	1947	127100.	1965	188630.	8.61	11.62	2.10
1965	34000.	1964	88300.	1956	126200.	1978	188570.	7.30	13.69	1.92
1971	33000.	1947	84700.	1954	116100.	1947	182030.	6.34	15.77	1.77
1947	32500.	1954	83800.	1971	114200.	1956	176900.	5.60	17.84	1.63
1978	31300.	1971	81900.	1964	114100.	1970	174500.	5.02	19.92	1.51
1954	31200.	1950	81800.	1950	111900.	1950	173210.	4.55	21.99	1.40
1963	30600.	1967	81800.	1967	107740.	1954	170900.	4.16	24.07	1.29
1950	29900.	1963	78200.	1942	103100.	1973	169100.	3.83	26.14	1.20
1982	29300.	1981	74349.	1976	101900.	1982	167800.	3.54	28.22	1.11
1942	29300.	1942	72400.	1981	99665.	1961	165320.	3.30	30.29	1.02
1981	29279.	1982	70700.	1963	99280.	1966	165300.	3.09	32.37	0.94
1976	29000.	1961	69400.	1982	98100.	1946	165100.	2.90	34.44	0.86
1968	27000.	1987	69100.	1975	97500.	1967	165070.	2.74	36.51	0.79
1945	26800.	1975	68600.	1966	97500.	1976	157440.	2.59	38.59	0.72
1975	26500.	1946	68400.	1961	96200.	1942	156740.	2.46	40.66	0.65
1961	26400.	1966	68100.	1973	94500.	1953	151200.	2.34	42.74	0.58
1946	26100.	1968	68000.	1983	94300.	1981	150835.	2.23	44.81	0.52
1940	25100.	1976	67400.	1946	92500.	1975	150150.	2.13	46.89	0.46
1987	25100.	1945	67100.	1940	92100.	1943	148760.	2.04	48.96	0.40
1983	24800.	1940	66000.	1980	90988.	1963	147970.	1.96	51.04	0.34
1966	24800.	1983	65100.	1968	90440.	1952	146870.	1.88	53.11	0.28
1943	24600.	1973	62800.	1952	89400.	1983	146450.	1.81	55.19	0.22
1973	24000.	1943	62700.	1987	89160.	1940	143050.	1.75	57.26	0.16
1970	22600.	1980	59632.	1970	87700.	1980	139514.	1.69	59.34	0.11
1986	22200.	1970	58100.	1943	87400.	1951	136930.	1.63	61.41	0.05
1952	21900.	1951	57200.	1951	85100.	1958	135600.	1.58	63.49	-0.01
1953	20800.	1986	56300.	1945	84400.	1948	130270.	1.53	65.56	-0.06
1951	20700.	1953	55000.	1959	84400.	1984	130040.	1.48	67.63	-0.12
1980	20699.	1952	54200.	1953	84400.	1959	126310.	1.43	69.71	-0.18
1948	20500.	1959	53800.	1984	76400.	1962	124620.	1.39	71.78	-0.24
1959	20100.	1957	51300.	1986	75390.	1987	123080.	1.35	73.86	-0.30
1960	20000.	1948	51100.	1957	74040.	1960	120230.	1.32	75.93	-0.35
1957	19800.	1985	49300.	1948	72370.	1945	117410.	1.28	78.01	-0.42
1955	18800.	1960	48900.	1985	71770.	1968	115710.	1.25	80.08	-0.48
1958	18100.	1958	48800.	1962	71500.	1969	113620.	1.22	82.16	-0.55
1969	17900.	1984	47500.	1960	70700.	1986	108930.	1.19	84.23	-0.62
1962	17700.	1955	47400.	1958	70400.	1985	104080.	1.16	86.31	-0.69
1941	17600.	1962	46900.	1955	67860.	1979	100360.	1.13	88.38	-0.77
1985	17200.	1969	45600.	1969	65800.	1957	99420.	1.11	90.46	-0.86

```
1979  17000. 1941  44000. 1941  60620. 1955  93440.  1.08 92.53 -0.96
1984  16500. 1979  40800. 1979  57690. 1941  87510.  1.06 94.61 -1.08
1944  15500. 1944  39700. 1944  53500. 1977  79620.  1.03 96.68 -1.23
1977  13400. 1977  35600. 1977  50980. 1944  70020.  1.01 98.76 -1.49

MEAN STANDARD DEVIATION AND SKEW OF FLOOD DATA

           ONE DAY       THREE DAY        FIVE DAY        TEN DAY
          ---------     ----------      ----------      ----------
          25374.539     66028.750       93397.750      146558.312
           6597.055     17339.578       23234.715       35390.914
              0.236         0.360           0.402          -0.013

EXTREME VALUE TYPE I FOR TR=2 AND TR=200 YEARS

           ONE DAY       THREE DAY        FIVE DAY        TEN DAY
          --------      ----------      ----------      ----------
          24303.949      63214.840       89627.125      140814.937
          49397.477     129170.187      178006.125      275433.000
```

APPENDIX B

WATER YEAR TO CALENDAR YEAR CONVERSION

Table B.1 Conversion table from water year days to calendar year dates (non-leap year).

Water Year Day	Calendar Year Date
1	1 October
32	1 November
62	1 December
93	1 January
124	1 February
152	1 March
183	1 April
213	1 May
244	1 June
275	1 July
305	1 August
336	1 September