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REGIONAL PRECIPITATION-FREQUENCY ANALYSIS AND SPATIAL MAPPING OF PRECIPITATION FOR 24-HOUR AND 2-HOUR DURATIONS IN WESTERN WASHINGTON

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Planning and Capital Program Management

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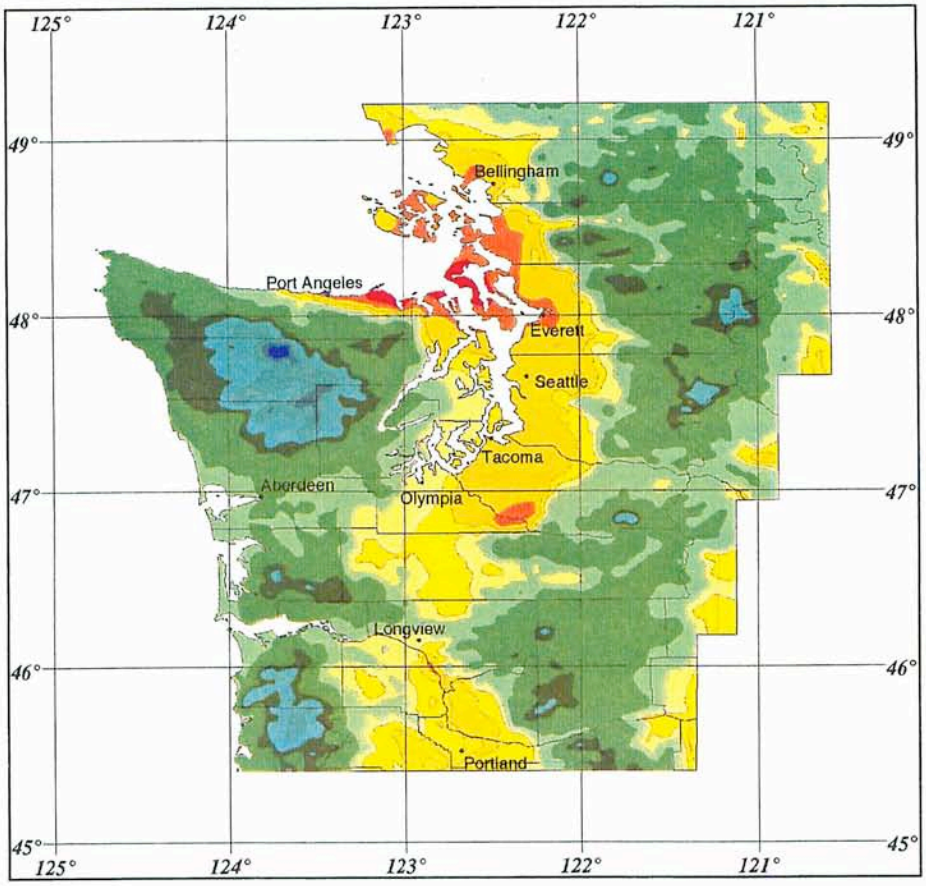

10-Year 24-Hour Precipitation

Washington State Department of Transportation

March 2002

MGS Engineering Consultants, Inc.

Oregon Climate Service

REGIONAL PRECIPITATION-FREQUENCY ANALYSIS AND SPATIAL MAPPING OF PRECIPITATION FOR 24-HOUR AND 2-HOUR DURATIONS IN WESTERN WASHINGTON

Prepared for:

Washington State Department of Transportation

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EXECUTIVE SUMMARY

Regional frequency analyses were conducted for precipitation annual maxima in western Washington for durations of 24-hours and 2-hours. A total of 430 precipitation gages in Washington, southern British Columbia and northern Oregon were included in the study representing 15,124 and 4,797 station-years of record for the 24-hour and 2-hour durations, respectively. A regional analysis methodology was utilized that pools data from climatologically similar areas to increase the dataset and improve the reliability of precipitation-frequency estimates. The regional analysis methodology included L-moment statistics, and an index-flood type approach for scaling the annual maxima data. L-moment statistics were used to: characterize the variability, skewness and kurtosis of the data; measure heterogeneity in proposed homogeneous sub-regions; and assist in identification of an appropriate regional probability distribution.

It was found that the study area could be described by seven climatic regions. These seven climatic regions were geographic areas that had similar topographic and climatological characteristics and were subjected to similar meteorological conditions during storm events. This included three coastal regions, two interior lowland regions and two Cascade Mountain regions. In particular, the need was recognized to distinguish between windward and leeward areas in both mountain and lowland areas. Separate regional analyses were conducted for each of the seven climatic regions for each of the two durations. Within each climatic region, precipitation gages were assigned to groups where the gage sites had similar magnitudes of mean annual precipitation. A total of 32 sub-regions were formed by this process and were found to be acceptably homogeneous. Predictor equations were then developed to describe the variability of the L-moment ratios, L-Cv and L-Skewness, between the sub-regions and within and/or across climatic region boundaries. The sub-region L-moment ratio plots for L-Skewness and L-Kurtosis revealed the data to be near or slightly more kurtotic than the Generalized Extreme Value distribution. The four-parameter Kappa distribution was chosen to describe the regional magnitude-frequency relationship for both the 24-hour and 2-hour durations.

Spatial mapping techniques were employed for mapping of the precipitation-frequency information. This included spatial mapping of at-site means, L-moment ratio values of L-Cv and L-Skewness, and mapping of precipitation for selected recurrence intervals at both the 24-hour and 2-hour durations. Procedures were employed to minimize differences between mapped values and observed station values in a manner that was consistent with the regional behavior of the data and also recognized uncertainties due to natural sampling variability.

Color-shaded isopluvial maps were developed for the 2-year, 10-year, 25-year, 50-year, and 100-year precipitation at both the 24-hour and 2-hour durations. An isopluvial map was also developed for 6-month, 24-hour precipitation, which is useful for water-quality treatment design applications. Electronic gridded datasets were provided for WSDOT use in creation of GIS applications that utilize precipitation-frequency information.

A catalog of extreme storms was assembled that lists precipitation events in western Washington that exceeded a 20-year return period. The information from the storm catalog was used to conduct seasonality analyses. The seasonality analyses were used to identify the frequency of occurrence of extreme storms by month. In particular, the seasonality analyses identified those months that were the most likely and least likely for an extreme event to occur. This information is useful in rainfall-runoff modeling and can be used by WSDOT staff in conducting hydrologic analyses throughout western Washington.

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OVERVIEW

This report documents the findings of regional precipitation-frequency analyses of 24-hour and 2-hour precipitation annual maxima for western Washington. It also describes the procedures used for spatial mapping of the precipitation-frequency estimates for selected recurrence intervals.

This study is an update of the information contained in the precipitation-frequency atlas published by the National Weather Service in 1973 (NOAA Atlas 2[16]). Data collection for the NWS study ended in 1966, and this study includes the 34-years of record collected since 1966. These additional data provide a precipitation database with more than double the record length than was available in the original NWS study.

Since the original study, major advances have been made in the methods for statistical analysis of precipitation annual maxima, and for spatial mapping of precipitation in complex terrain. Specifically, L-Moment statistical analysis techniques[7,9] conducted within a regional framework have greatly improved the reliability of precipitation magnitude-frequency estimates, particularly for rare storm events. Development of the PRISM model[3] incorporating digital terrain data has also improved the spatial mapping of precipitation and increased the reliability of estimating precipitation in the broad areas between precipitation measurement stations. These methodologies are particularly effective in areas with high topographic and climatic variability such as in western Washington, where mean annual precipitation varies from less than 20-inches to over 200-inches. Both of these methodologies have been utilized in conducting the precipitation-frequency analyses and in developing the isopluvial maps for selected recurrence intervals.

STUDY AREA

While western Washington is the area of interest, the study area was expanded to provide additional data in border areas. Accordingly, the study area included areas in southwestern British Columbia, northwestern Oregon, and areas in the Cascade Mountains in eastern Washington (Figure 1). Specifically, the study area is bounded on the North at latitude 49°30′ N, bounded to the south by latitude 45°00′ N, and bounded to the east by the contour line of 20-inches mean annual precipitation, approximately longitude 120°00′ W. Addition of precipitation stations in the boundary areas also provided data from areas climatologically similar to data-sparse areas in Washington such as the windward and leeward faces of the Olympic Mountains, Willapa Hills, and the Cascade Mountains.

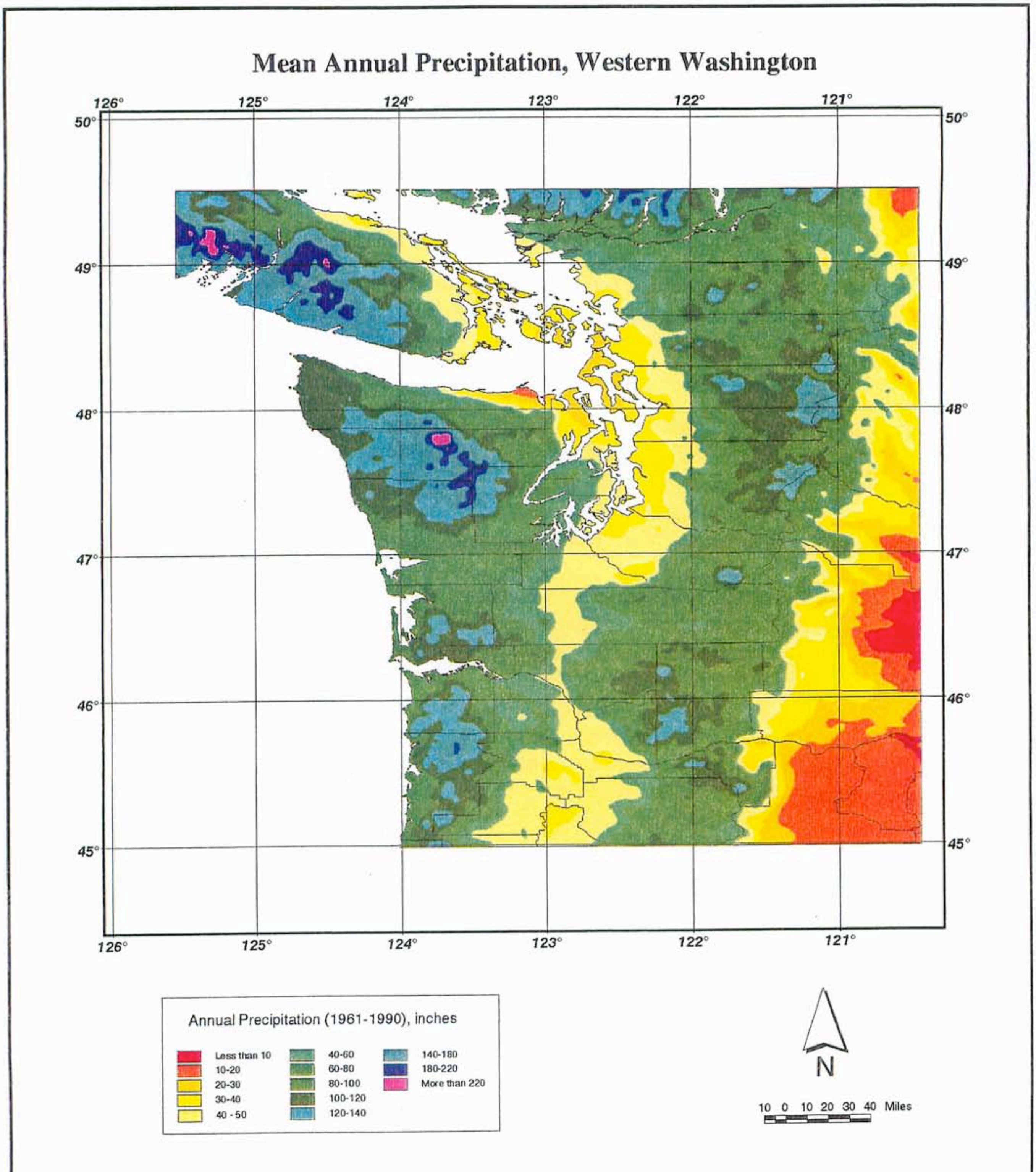

Figure 1 – Mean Annual Precipitation[20,21] for Western Washington Study Area

CLIMATIC AND METEOROLOGIC CHARACTERISTICS OF STUDY AREA

Annual Precipitation

Mean annual precipitation within the study area varies dramatically from the coast to the eastern slopes of the Cascade Mountains (Figure 1). Mean Annual Precipitation[20] (MAP) ranges from a high of over 240-inches in the Olympic Mountains, to a low near 18-inches in the Olympic rain shadow area near Sequim, and to 20-inches in the foothills of the Cascades in eastern Washington.

Weather Systems and Sources of Atmospheric Moisture

In general, two ingredients are needed for precipitation to occur, a source of atmospheric moisture and a meteorological mechanism to release that moisture. There is also a greater potential for extreme precipitation events when the source of moisture originates in areas with warmer temperatures and higher dewpoints. There are three generalized geographic areas that are sources of atmospheric moisture to the study area and have differing characteristic temperatures and dewpoints. These source areas include: the Gulf of Alaska; the Pacific Ocean north of the Canadian border; and the Pacific Ocean from as far south as latitude 20°N near the Hawaiian Islands.

Storm systems[16,18,19] moving in a southeasterly direction out of the Gulf of Alaska primarily affect northern portions of the study area and generally contain cooler temperatures and dewpoints. Storm systems originating over the Pacific Ocean are the most common and those that originate from southerly latitudes near the Hawaiian Islands have been responsible for many of the largest long-duration precipitation events experienced in the winter months. Synoptic-scale cyclonic weather systems and associated fronts generally provide the mechanism for producing precipitation annual maxima at the 24-hour and longer durations. Precipitation is enhanced in mountain areas as atmospheric moisture is lifted over the Olympic, Coastal and Cascade Mountains. This orographic component of precipitation has the greatest effect at 24-hour and longer time scales, and can significantly enhance the total accumulation of precipitation over several days. Precipitation annual maxima at the 24-hour duration occur predominately in the fall and winter seasons in western Washington.

Precipitation annual maxima at the 2-hour duration may occur as a result of several different storm mechanisms. They may occur due to low-to-moderate convective activity associated with a large-scale synoptic weather system in the fall or winter season. In this case, the 2-hour annual maxima are embedded within a much longer duration storm event. They may also occur due to more intense convective activity that may, or may not, be associated with an organized weather system. In this latter case, the 2-hour annual maxima are often associated with "thunderstorms" in the spring and summer, which are short-duration localized storm events with limited areal coverage.

DATA SOURCES

A precipitation annual maximum is the greatest precipitation amount in a 12-month period for a specified duration at a given measurement site. The water-year, October 1st to September 30th is the 12-month period used for determining precipitation annual maxima for the 24-hour and 2-hour durations for these analyses.

Precipitation annual maxima and associated storm dates were obtained from precipitation records from a variety of sources. The majority of the data were obtained from the electronic files of the National Climatic Data Center (NCDC). Data for southwestern British Columbia were obtained from the Canadian Atmospheric Environment Services Agency (AES). Data from Snotel gages in mountains areas were obtained from electronic files from the Natural Resources Conservation Service (NRCS). Several counties in Washington also provided data for urban areas, including: King, Kitsap, Snohomish, Thurston and Clark Counties.

Precipitation Gage Types, Methods of Measurement and Reporting

Precipitation is measured by a variety of devices and reported by a number of different agencies in the United States and Canada. Descriptions of the gage types and reporting methods are summarized below.

Daily Gages – Daily gages in US and Canada are standardized devices comprised of simple vertical cylinders open to the atmosphere. A variety of shields for protection from the wind are used in both countries, with shields being more common now than in the past. Precipitation is measured once each day at a specified time and represents the precipitation for the previous 24-hours.

Automated Gages – Automated gages such as weighing buckets, Fisher-Porter tipping buckets, and other types of tipping buckets can provide information about precipitation intensity on various time scales. The standards in both the US and Canada are for reporting on either hourly or 15-minute intervals. Weighing bucket gages with paper strip charts came on-line around 1940-1945 in the US and many were installed in Canada in the 1950's and 1960's. Tipping bucket gages and automated reporting systems were installed at many sites beginning in the 1970's. These gages are often given the generic term hourly gages to distinguish them from daily gages.

Snotel Gages – Snotel gages are a type of automated gage commonly used in mountain areas. They have external heating systems and are designed for cold weather operation. Precipitation that falls as snow is converted to liquid water for measurement. Snotel gages typically report precipitation on a daily basis on a midnight-to-midnight reporting schedule.

Number of Gages and Gage Types

The number of gages and gage types used in the regional analyses are summarized in Tables 1a,b. Both daily and hourly precipitation gages are co-located at many NCDC sites in the US. This occurred at 61 stations in Washington and Oregon. To avoid duplication, the record from the gage with the longest record was utilized in the analyses for the 24-hour duration. When both the daily and hourly records were of similar length, the record from the hourly gage was selected. The precipitation station networks are shown in Figures 2a,b for the 24-hour and 2-hour durations, respectively.

Table 1a – Number and Type of Gages Utilized for Analyses of 24-Hour Annual Maxima

STATION LOCATION	DAILY GAGE	HOURLY GAGE	SNOTEL GAGE
British Columbia	56	6	0
Washington	146	78	44
Oregon	44	31	11
Municipal Gages	14	0	0
TOTAL	**260**	**115**	**55**

61 NCDC stations have co-located daily and hourly gages

Table 1b – Number and Type of Gages Utilized for Analyses of 2-Hour Annual Maxima

STATION LOCATION	DAILY GAGE	HOURLY GAGE	SNOTEL GAGE
British Columbia	0	24	0
Washington	0	78	0
Oregon	0	31	0
Municipal Gages	0	3	0
TOTAL	**0**	**146**	**0**

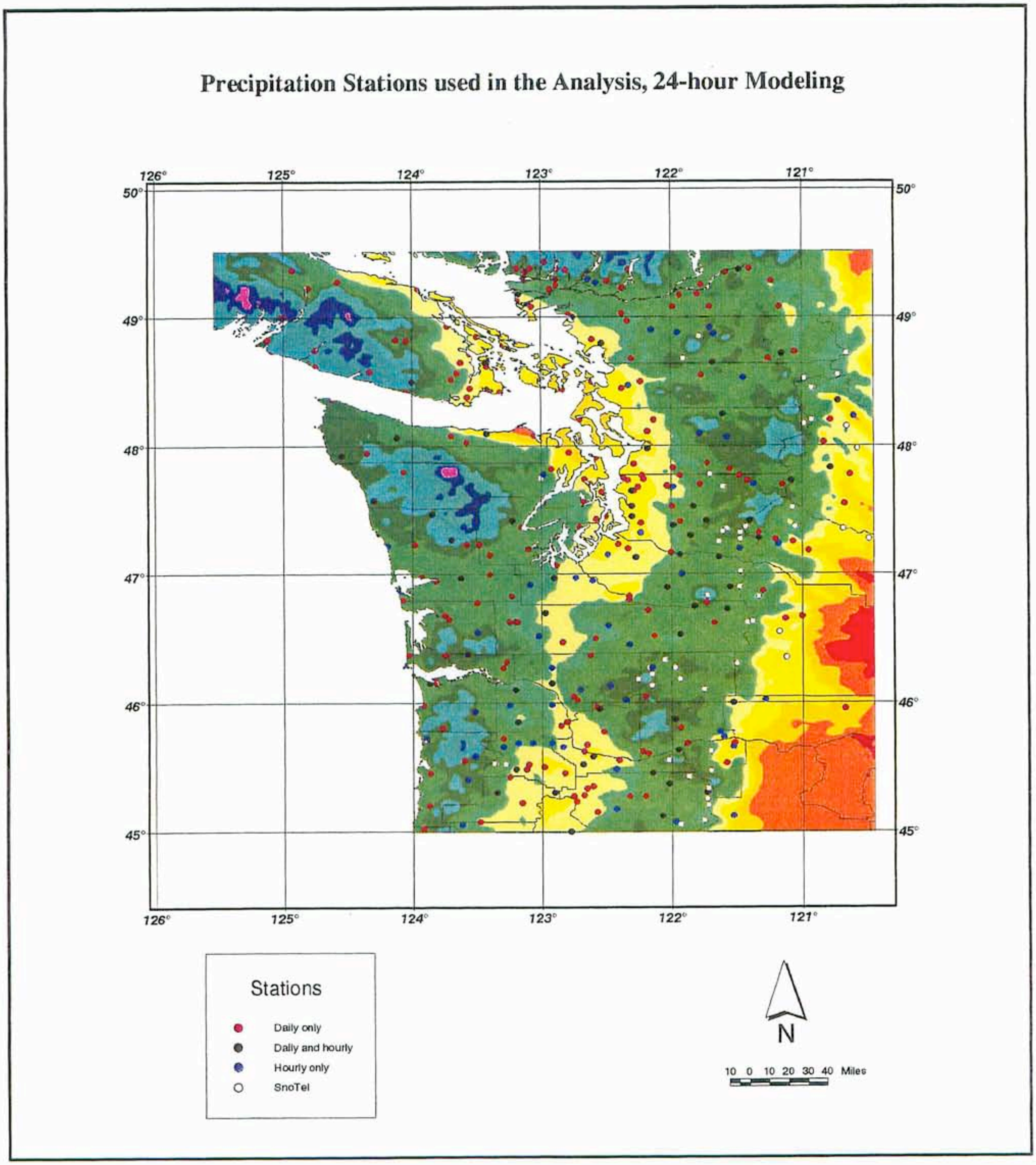

Figure 2a – Precipitation Gaging Network for Analysis of 24-Hour Annual Maxima

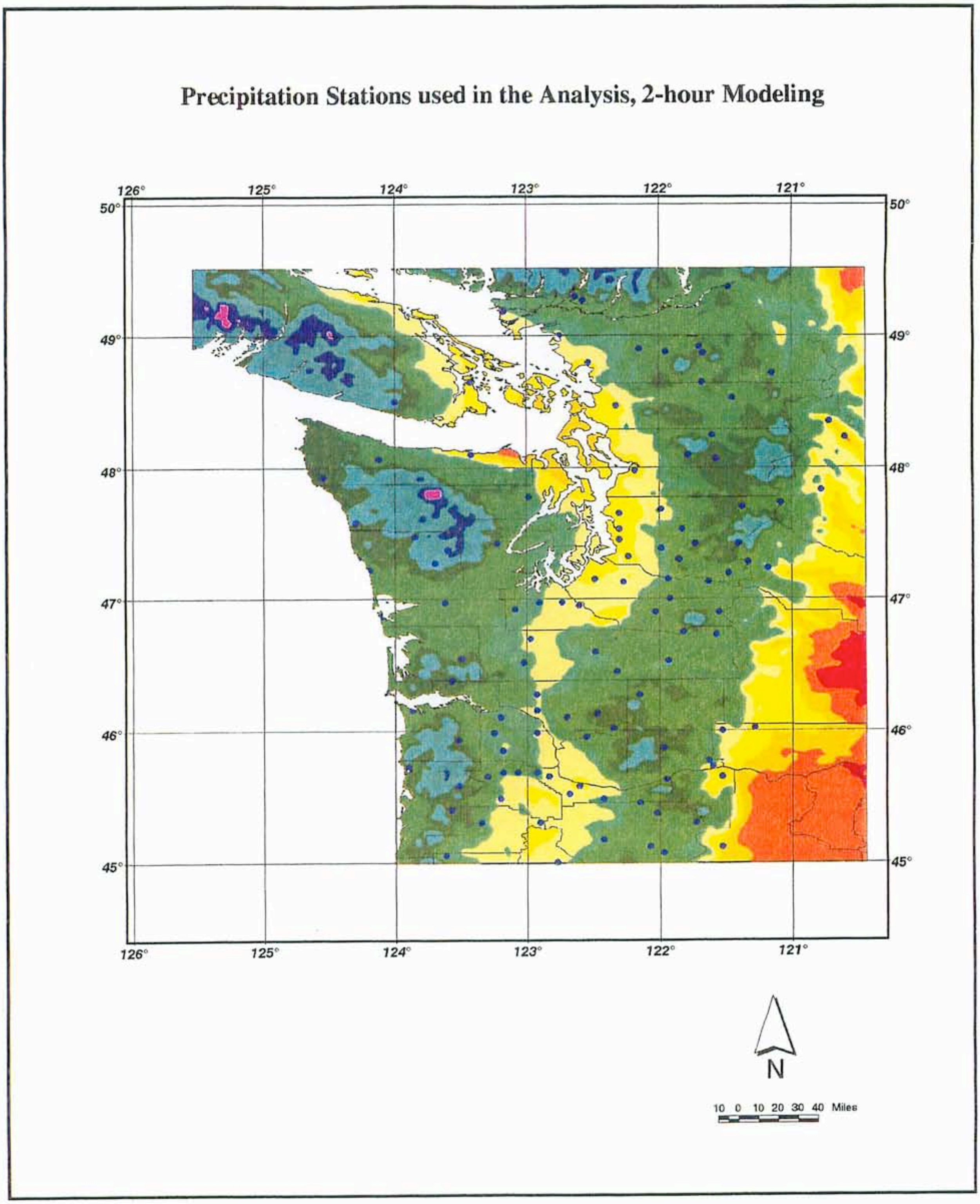

Figure 2b – Precipitation Gaging Network for Analysis of 2-Hour Annual Maxima

DATA SCREENING AND QUALITY CHECKING

Extensive efforts were made in screening and quality checking the annual maxima data. Quality checking was needed to eliminate false annual maxima associated with a variety of data measurement, reporting, and transcription errors, particularly incomplete reporting during some years. The record for all sites and climatic-years was checked for completeness. In addition, all records were scanned for anomalously small or large precipitation amounts and the Hosking and Wallis[9,10] measure of discordancy [9,10] was also used to identify gages whose sample statistics were markedly different from the majority of gages in a given region. Suspicious gages and data were checked to verify the validity of records. Nearby sites were also checked to corroborate the magnitude and date of occurrence of any anomalously small or large precipitation annual maxima. Data that were clearly erroneous were removed from the datasets.

Stationarity and Serial Independence

Two underlying assumptions inherent in frequency analyses are the data are stationary over the period of observation and prediction, and the data at a given site (gage) are serially independent. As part of the data screening process, standard statistical tests for stationarity and serial independence were conducted. Inter-station correlation analyses were also conducted to assess the relative amount of correlation between annual maxima data at nearby gages.

To meet the stationarity criterion, the data must be free from trends during the period of observation. For each duration, this was confirmed by standard linear regression techniques where the station data were first rescaled by division by the at-site mean and then regressed against the year of occurrence minus 1900. This approach allowed comparisons to be made among all gages and to interpret the relative magnitude of any trend over the past century. The average values of the slope parameter were +0.20%, and +0.15% for the 24-hour, and 2-hour durations, respectively. The regression results for the collective group of gages were tested against a null hypothesis of zero slope (stationarity). The null hypothesis could not be rejected at the 5% level and the data at both durations were accepted as stationary.

To confirm independence of the annual maxima data, serial correlation coefficients were computed for the data at each gage for each duration. The regression results for the collective group of gages at each duration were tested against a null hypothesis of zero serial correlation (independence). The null hypothesis could not be rejected at the 5% level. As expected, the annual maxima data were found to be serially independent.

REGIONAL FREQUENCY ANALYSIS METHODOLOGY

The cornerstone of a regional frequency analysis is that data from sites within a homogeneous region can be pooled to improve the reliability of the magnitude-frequency estimates for all sites. A homogeneous region may be a geographic area delineated on a map or it may be a collection of sites having similar characteristics pertinent to the phenomenon being investigated.

Early in the study it was recognized that the climatic and topographic diversity in the study area would likely preclude the use of large geographic areas that would meet statistical criteria for homogeneity. It was decided to employ climatic/geographic regions that had basic similarities in the climatic and topographic setting. It was anticipated that these regions might require further sub-division to meet homogeneity criteria for use in regional frequency analysis.

Description of Climatic/Geographic Regions
Identification of climatologically similar regions meant delineating geographic areas that had similar climatological and topographical characteristics. To assist in this effort, a literature review was conducted to examine region designations utilized in prior studies. This included a review of NOAA Atlas 2[16], studies of extreme precipitation in the Pacific Northwest (NWS[18,19]), and prior regional frequency analyses conducted in coastal mountain areas (Schaefer[23,25,26]).

Based on information in those studies and the spatial characteristics of mean annual precipitation, seven climatic/geographic regions were identified (Figure 3). In particular, the map of mean annual precipitation (Figure 1) developed by Daly using the PRISM[3] model provided the basic mapping information for delineating the boundaries of the climatic regions. This map is based on the 1961-1990 time period, which is the most recent NOAA 30-year decadal-based climate tracking period. The magnitude and gradient of mean annual precipitation were the primary measures used to define the boundaries between the regions. Those regions include:

Coastal Lowlands (Region 5) – The lowlands along the west coast of Washington, Oregon and Vancouver Island that are open to the Pacific Ocean. The eastern boundary is either a generalized contour line of 1,000 feet elevation, or the ridgeline of mean annual precipitation that separates the coastal lowlands from the interior lowlands, such as within the Aberdeen-Montesano gap.

Coastal Mountains West (Region 151) – The windward faces of the Olympic Mountains, Willapa Hills, Black Hills, Coastal Mountains in Oregon, and Vancouver Island Mountains in British Columbia above a generalized contour line of 1,000 feet elevation. These areas are bounded to the west by the 1,000 feet contour line, and bounded to the east by the ridgeline of mean annual precipitation near the crestline of the mountain barrier.

Coastal Mountains East (Region 142) – The leeward faces of the Olympic Mountains, Willapa Hills, Black Hills, Coastal Mountains in Oregon, and Vancouver Island Mountains in British Columbia above a generalized contour line of 1,000 feet elevation. These areas are bounded to the west by the ridgeline of mean annual precipitation near the crestline of the mountain barrier, and bounded to the east by the 1,000 feet contour line.

Interior Lowlands West (Region 32) – The interior lowlands below a generalized contour line of 1,000 feet elevation bounded to the east by the trough-line of mean annual precipitation through the Strait of Juan De Fuca, Puget Sound Lowlands and Willamette Valley. This is a zone of low orography where mean annual precipitation generally decreases from west to east.

Interior Lowlands East (Region 31) – The interior lowlands below a generalized contour line of 1,000 feet elevation bounded to the west by the trough-line of mean annual precipitation through the Strait of Juan De Fuca, Puget Sound Lowlands and Willamette Valley. This is a zone of low orography where mean annual precipitation generally increases from west to east.

Cascade Mountains West (Region 15) – The windward face of the Cascade Mountains in Washington, Oregon, and British Columbia above a generalized contour line of 1,000 feet elevation. This region is bounded to the east by the ridgeline of mean annual precipitation near the Cascade crest.

Cascade Mountains East (Region 14) – The leeward face of the Cascade Mountains in Washington, Oregon, and British Columbia above the 20-inch isopluvial of mean annual precipitation. This region is bounded to the west by the ridgeline of mean annual precipitation near the Cascade crest.

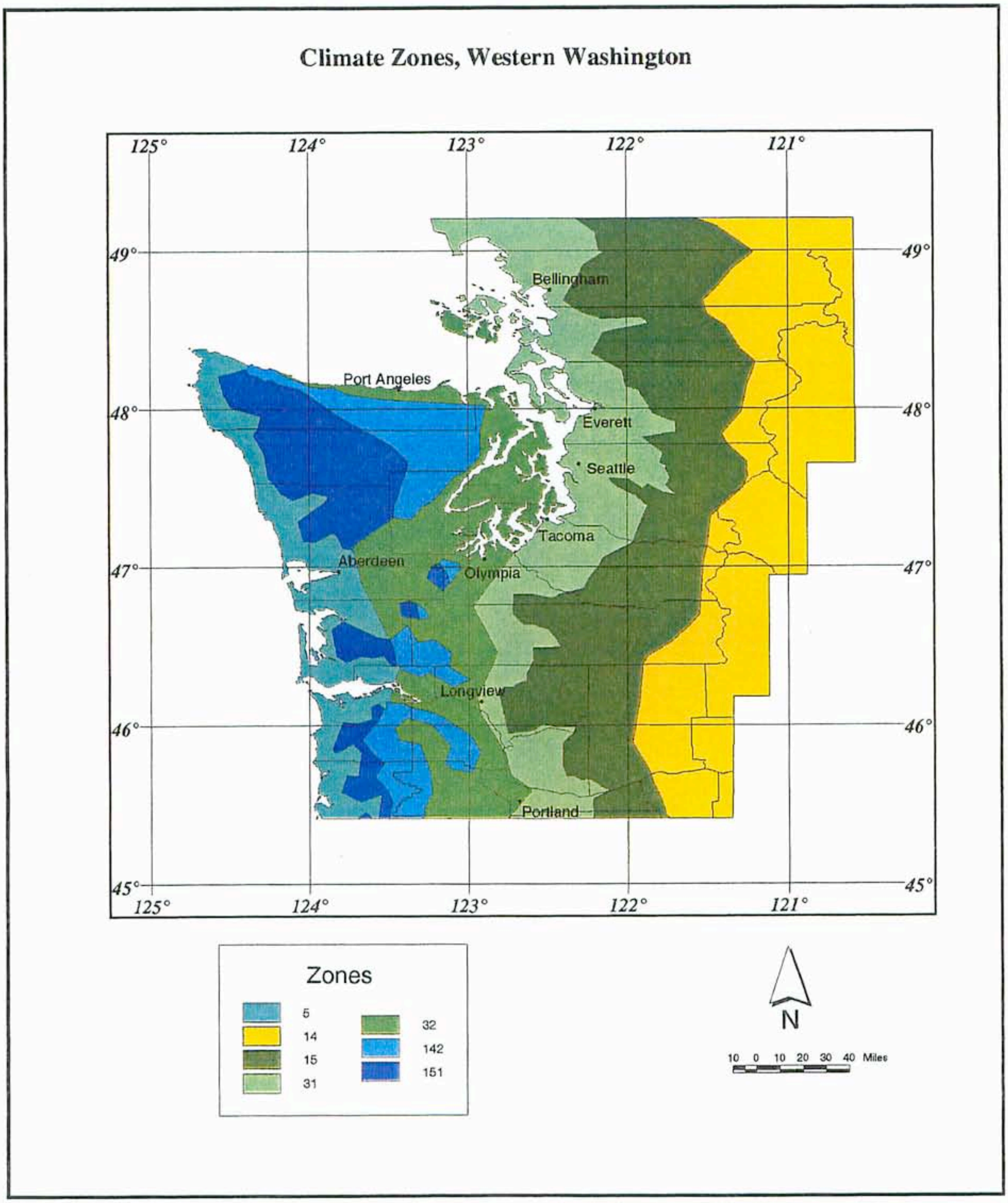

Figure 3 – Delineation of Climatic Regions for Western Washington Study Area

REGIONAL GROWTH CURVE

Implicit in the definition of a homogeneous region is the condition that all sites can be described by one probability distribution having common distribution parameters after the site data are rescaled by their at-site mean. Thus, all sites have a common regional magnitude-frequency curve (regional growth curve, Figure 4) that becomes site-specific after scaling by the at-site mean of the data from the specific site of interest. Thus,

$$Q_i\,(F) \;=\; \hat{\mu}_i\; q(F) \tag{1}$$

where $Q_i\,(F)$ is the at-site inverse Cumulative Distribution Function (CDF), $\hat{\mu}_i$ is the estimate of the population at-site mean, and $q\,(F)$ is the regional growth curve, regional inverse CDF. This is often called an index-flood approach to regional frequency analyses and was first proposed by Dalrymple[2] and expanded by Wallis[30,31].

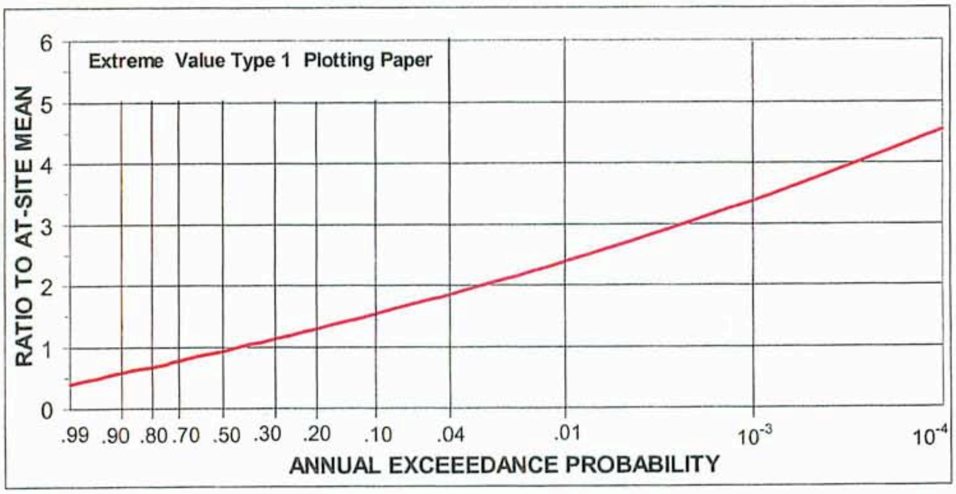

Figure 4 – Example of Regional Growth Curve

FORMING HOMOGENEOUS SUB-REGIONS

It was anticipated that the climatic regions defined here would require sub-division to meet homogeneity criteria. The methodology used herein for forming and testing proposed homogeneous sub-regions follows the procedures recommended by Hosking and Wallis[9,10].

The basic approach is to propose homogeneous sub-regions (grouping of sites/gages) based on the similarity of the physical/meteorological characteristics of the sites. L-moments (Hosking[7,9], Appendix E) are then used to estimate the variability and skewness of the pooled regional data and to test for heterogeneity as a basis for accepting or rejecting the proposed sub-region formulation.

In general, proposed homogeneous sub-regions can be formed by utilizing some measure(s) of physical and/or climatological characteristics for assigning sites/gages to sub-regions. Candidates for physical features[16,18,19] include such measures as: site elevation; elevation averaged over some grid size; localized topographic slope; macro topographic slope averaged over some grid size; distance from the coast or source of moisture; distance to sheltering mountains or ridgelines; and latitude or longitude. Candidate climatological characteristics include such measures as: mean annual precipitation; precipitation during a given season; seasonality of extreme storms; and seasonal temperature/dewpoint indices.

A review of the topographic and climatological characteristics in each region shows that the seven climatic regions already had similarities regarding several of the physical and climatological measures listed above. As such, only one additional measure, mean annual precipitation (MAP) was needed for grouping of sites/gages into homogeneous sub-regions within a given climatic region. Homogeneous sub-regions were therefore formed with gages/sites within a small range of MAP.

Heterogeneity Measures of Proposed Homogeneous Sub-Regions

Heterogeneity measures have been developed by Hosking and Wallis[9,10] as indicators of the amount of heterogeneity in the L-moment ratios for a collection of sites/gages. The statistics H1 and H2 measure the relative variability of observed L-Cv and L-Skewness sample statistics, respectively, for gages/sites in a sub-region. Specifically, these measures compare the observed variability to that expected from a large sample drawn from a homogeneous region from the Kappa distribution[12] having weighted average L-moment ratios that were observed in the sub-region. Initial recommendations from Hosking and Wallis[9,10] were that regions with H1 and H2 values less than 1.00 were acceptably homogeneous. Values of H1 and H2 between 1.00 and 2.00 were possibly heterogeneous. Values greater than 2.00 indicated definite heterogeneity and that redefinition of the region and/or reassignment of sites/gages should be considered.

These heterogeneity criteria measure statistical heterogeneity from known distributions and do not account for variability that arises from other sources. Most cooperative precipitation measurement networks include gages operated by various organizations and individuals that provide a varied level of quality control. Therefore, precipitation measurements often contain additional variability due to: gages being moved during the many years of operation; frequent change of operators and level of diligence in timely measurement; missing data arising from inconsistent reporting; lack of attention to measurement precision; and localized site and wind condition changes over time due to building construction or growth of trees in the vicinity of the gage. Recognizing this additional variability, Wallis[29] has suggested that for precipitation annual maxima, H1 values less than 2.00 may be considered acceptably homogeneous and H1 values greater than 3.00 would be indicative of heterogeneity. Both the H1 and H2 measures will be used later to assess the relative heterogeneity in proposed sub-regions.

Acceptance of Proposed Homogeneous Sub-Regions

When a proposed sub-region is found to satisfy homogeneity criteria, the regional L-moment ratios are then used to conduct goodness-of-fit tests (Hosking and Wallis[9,10]) to assist in selecting a suitable probability distribution, and to estimate the parameters of the regional distribution. Examples of this type of approach are described by Schaefer in his study of Washington State[23], southern British Columbia[25], and the Sierra Mountains in California[26]. The basic approach adapted to this study is summarized below:

Adopted Methodology

1) Form proposed homogeneous sub-regions by assigning gages within a climatic region to groups within a small range of mean annual precipitation;
2) Compute L-moment sample statistics for gages within the proposed homogeneous sub-regions;
3) Use L-moment heterogeneity criteria to test proposed homogeneous sub-regions;
4) Develop a mathematical predictor for describing the behavior of regional L-Cv and L-skewness values with mean annual precipitation across the climatic region;
5) Conduct goodness-of-fit tests to identify a suitable probability distribution for regional growth curve;
6) Solve for the distribution parameters of the selected probability distribution for each sub-region using the regional values of L-Cv and L-skewness (from Step 4).

Systematic Variation of L-Cv and L-Skewness with Mean Annual Precipitation

As described previously, climatic regions were comprised of numerous homogeneous sub-regions. A mathematical relationship was therefore needed to link the sub-regions and provide estimation of L-moment ratios L-Cv and L-Skewness across a climatic region. The relationships were developed in a manner to provide continuity with adjacent climatic regions. This approach had the additional benefit of eliminating or minimizing discontinuities at the boundaries between the climatic regions. Recognizing that the sub-regions were formed as groupings of gages within a small range of mean annual precipitation (MAP), it was found that MAP was a suitable explanatory variable. The predictor equations took the general forms:

$$L\text{-}Moment\ Ratios = \alpha\, e^{-\beta(MAP)} + \delta \qquad (2a)$$

$$L\text{-}Moment\ Ratios = \alpha + \beta(LN[MAP]) \qquad (2b)$$

where: alpha (α), beta (β), and delta (δ) are parameters specific to a given climatic region or group of climatic regions, and delta is a limiting value at large values of mean annual precipitation.

ANALYSES OF 24-HOUR DURATION ANNUAL MAXIMA

Homogeneous sub-regions were formed as collections of gages within small ranges of mean annual precipitation (MAP) within each of the climatic regions. The range of MAP was chosen so that about 8 to 12 gages, 400 to 500 station-years of record, were included in each sub-region with each gage having at least 15 years of record. This resulted in a total of 32 sub-regions for the 24-hour duration (Table 2). Record lengths at precipitation measurement stations varied from a minimum of 15-years to over 100-years, with nearly 50% of the stations having record lengths in excess of 50-years. Figure 5 depicts the number of stations within various ranges of record length.

Table 2 – Number of Sub-Regions, Gages and Station-Years of Record for 24-Hour Duration Annual Maxima

CLIMATIC REGION	NUMBER OF SUB-REGIONS	DAILY GAGES	HOURLY GAGES	SNOTEL GAGES	STATION-YEARS OF RECORD
5	3	18	9	0	1,328
151	2	8	6	0	715
142	3	20	6	1	1,263
32	6	39	17	0	2,838
31	7	45	16	0	3,474
15	6	24	28	19	2,925
14	5	28	13	22	2,581
TOTAL	**32**	**182**	**95**	**42**	**15,124**

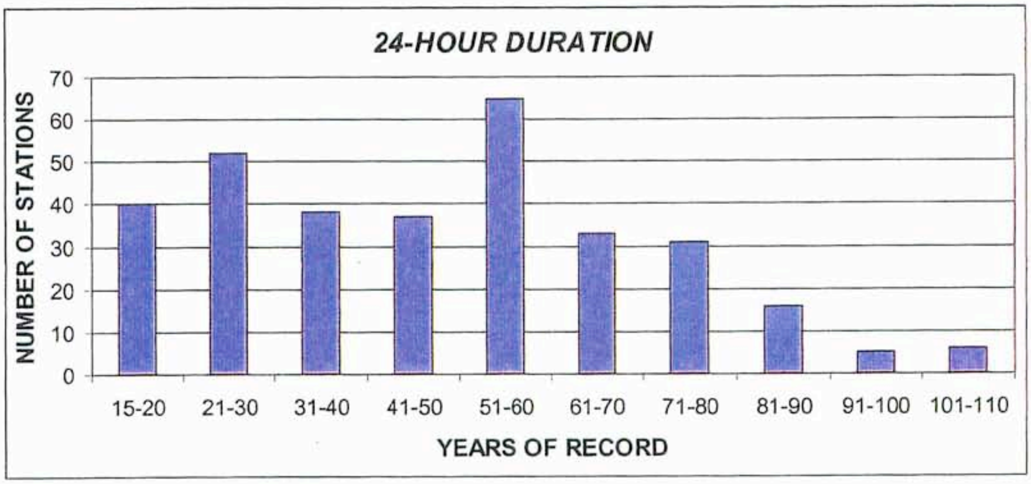

Figure 5 – Histogram of Record Lengths at Stations for 24-Hour Annual Maxima

Regional Solutions for L-Moment Ratios, L-Cv and L-Skewness

Regional predictor equations for L-moment ratios were developed for groupings of sub-regions in the climatic regions using forms of the regression equations shown in Equations 2a and 2b. It was found that a single predictor equation could often be developed applicable to adjacent climatic regions (Tables 3a,b). For those climatic regions where an exponential decay predictor equation was appropriate (Equation 2a), delta values were first estimated based on regional L-moment ratio values computed from those sub-regions with the largest sub-region values of mean annual precipitation.

For the case of climatic regions 15 and 14, where the boundary is near the crest of the Cascade Mountains, sub-region L-moment ratio values were also computed for gages near the Cascade crest. The sub-region and boundary L-moment ratio values were used to assist in estimation of the delta parameter, which provided continuity between mountain regions 15 and 14.

A least squares solution was used to determine the alpha and beta parameters. Standardized root mean square error (RMSE) was also computed for the predictor equation for each region(s) to provide a measure of the goodness-of-fit of the predictor equation. The resultant predictor equations for L-Cv are listed in Tables 3a,b and graphically depicted in Figures 6a,b,c,d.

Few precipitation gages exist at high elevations in the Olympic Mountains. Extrapolation is required in this area to provide L-moment ratio values applicable to locations with mean annual precipitation exceeding about 140-inches. The regression parameters for high mountain areas in region 142, on the leeward face of the Olympic Mountains, were based on the behavior of L-moment ratio values for gages with the greatest mean annual precipitation on the windward face of the Olympics. This approach provided continuity across the crest of the Olympics for very high values of mean annual precipitation as seen in Figures 5a,b and 6a,b.

Table 3a – Predictor Equations for L-Cv for 24-Hour Annual Maxima

$L\text{-}Cv = \alpha + \beta * LN(MAP)$				
REGIONS	APPLICABILITY	ALPHA	BETA	STANDARDIZED RMSE
5 - 151	ALL	0.0925	0.0130	5.3%
32 - 142	MAP $\geq$ 75-inches	0.0925	0.0130	3.2%
31 - 15	MAP $\geq$ 60-inches	0.1276	0.0054	3.5%

Table 3b – Predictor Equations for L-Cv for 24-Hour Annual Maxima

$L\text{-}Cv = \alpha * EXP[-\beta * MAP] + \delta$					
REGIONS	APPLICABILITY	ALPHA	BETA	DELTA	STANDARDIZED RMSE
32 - 142	MAP < 75-inches	0.2500	0.0845	0.1480	3.2%
31 - 15	MAP < 60-inches	0.2500	0.0845	0.1480	3.5%
14	ALL	0.1100	0.0330	0.1550	3.3%

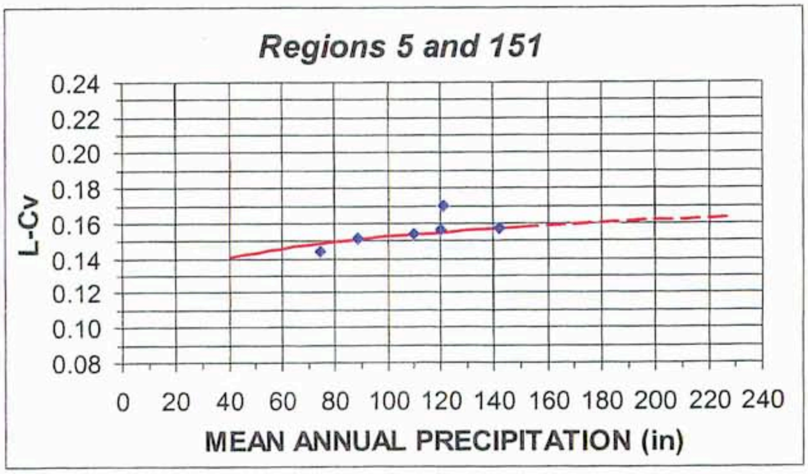

Figure 6a – Predictor Equation Solutions of Observed L-Cv for Climatic Regions 5 and 151 for 24-Hour Duration

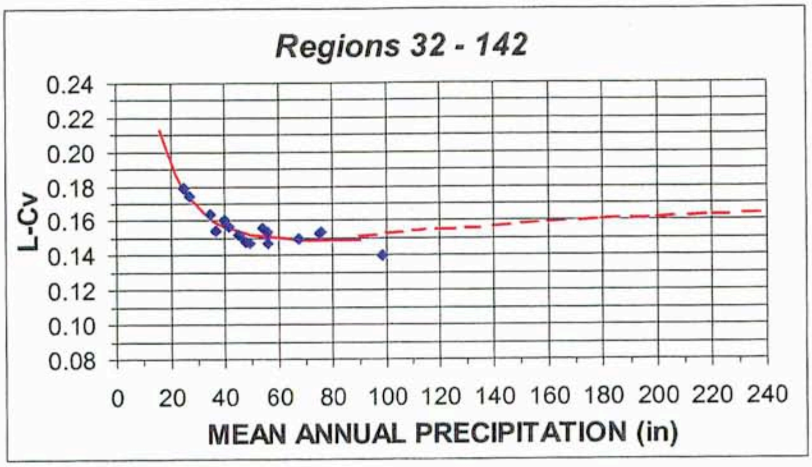

Figure 6b – Predictor Equation Solutions of Observed L-Cv for Climatic Regions 32 and 142 for 24-Hour Duration

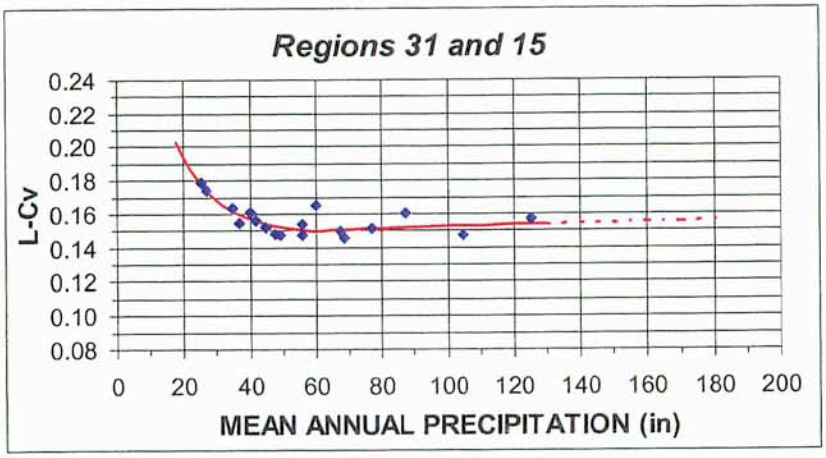

Figure 6c – Predictor Equation Solutions of Observed L-Cv for Climatic Regions 31 and 15 for 24-Hour Duration

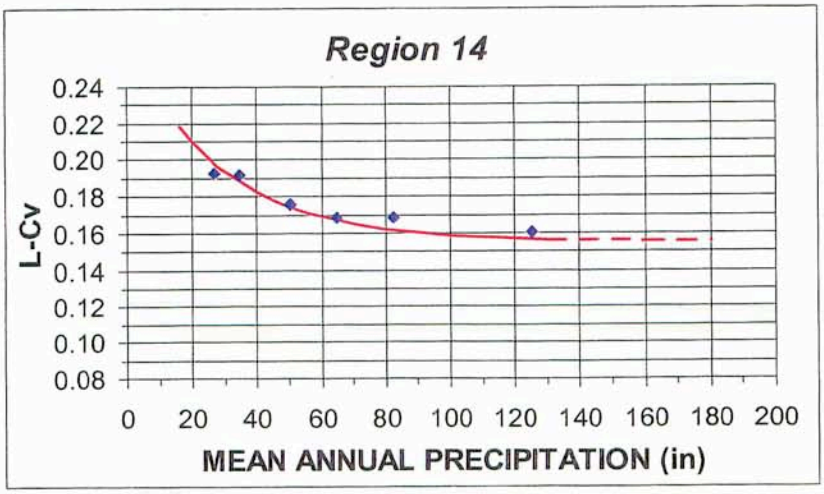

Figure 6d – Predictor Equation Solution of Observed L-Cv for Climatic Region 14 for 24-Hour Duration

Skewness measures are highly variable for the record lengths commonly available for precipitation-frequency analysis. This greater sampling variability is exhibited in larger RMSE values for the predictor equations for L-Skewness (Tables 4a,b). Regional predictor equations for L-Skewness were developed in the same manner as that described above for L-Cv. The predictor equations for L-Skewness are listed in Tables 4a,b and graphically depicted in Figures 7a,b,c,d.

Table 4a – Predictor Equations for L-Skewness for 24-Hour Annual Maxima

L-Skewness = $\alpha + \beta$ * LN (MAP)				
REGIONS	**APPLICABILITY**	**ALPHA**	**BETA**	**STANDARDIZED RMSE**
5 - 151	MAP < 150-inches	0.0930	0.0130	13.7%
5 - 151	MAP ≥ 150-inches	0.1580	0.0000	13.7%
32 - 142	70-inches ≤ MAP < 150-inches	0.0930	0.0130	14.2%
32 - 142	MAP ≥ 150-inches	0.1580	0.0000	14.2%

Table 4b – Predictor Equations for L-Skewness for 24-Hour Annual Maxima

L-Skewness = α * EXP [-β * MAP] + δ					
REGIONS	**APPLICABILITY**	**ALPHA**	**BETA**	**DELTA**	**STANDARDIZED RMSE**
32 - 142	MAP < 70-inches	0.1500	0.0400	0.1400	14.2%
31 - 15	ALL	0.1300	0.0400	0.1580	9.8%
14	ALL	0.1300	0.0400	0.1580	10.5%

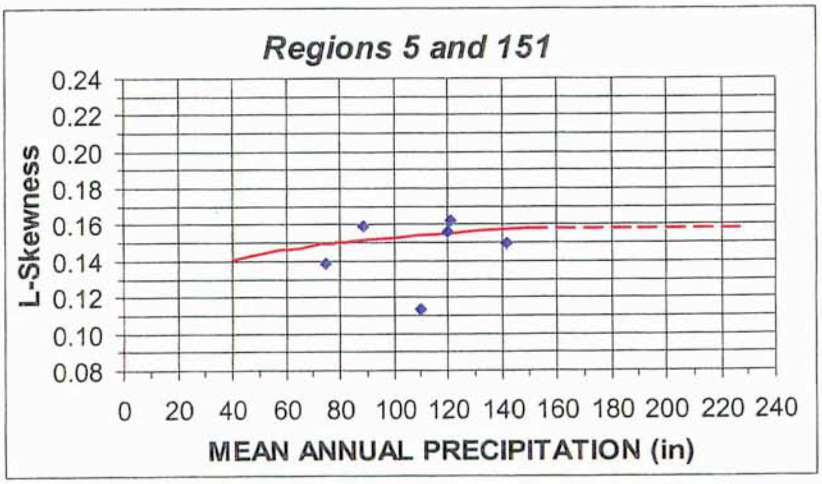

Figure 7a – Predictor Equation Solutions of Observed L-Skewness for Climatic Regions 5 and 151 for 24-Hour Duration

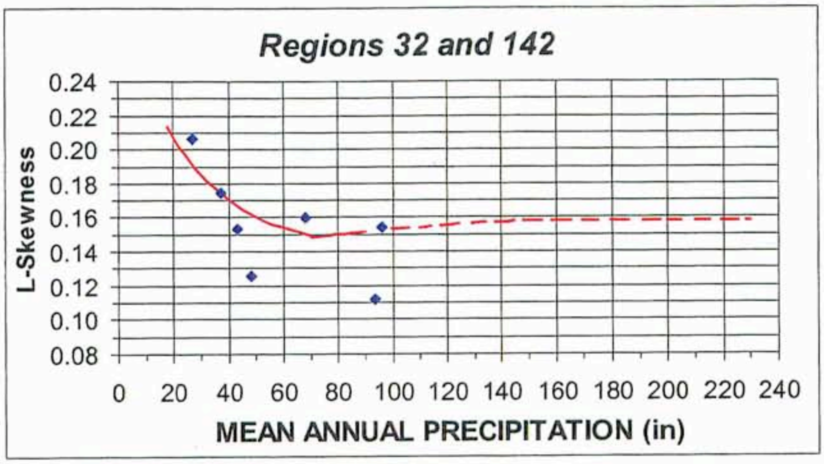

Figure 7b – Predictor Equation Solutions of Observed L-Skewness for Climatic Regions 142 and 32 for 24-Hour Duration

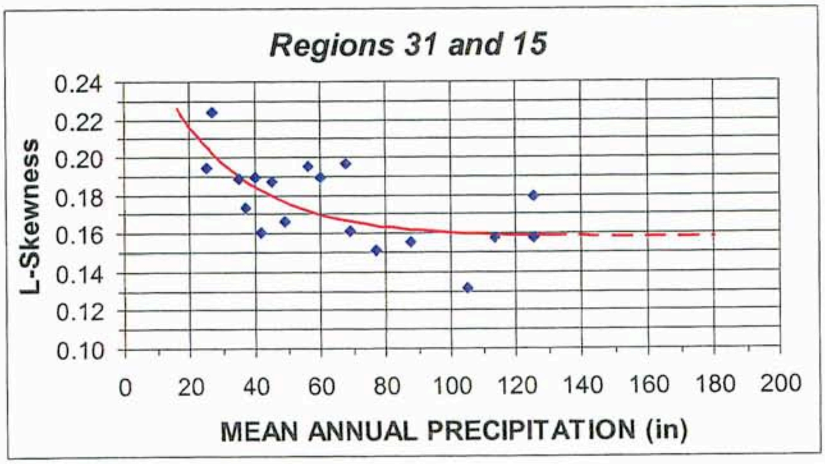

Figure 7c – Predictor Equation Solutions of Observed L-Skewness for Climatic Regions 31 and 15 for 24-Hour Duration

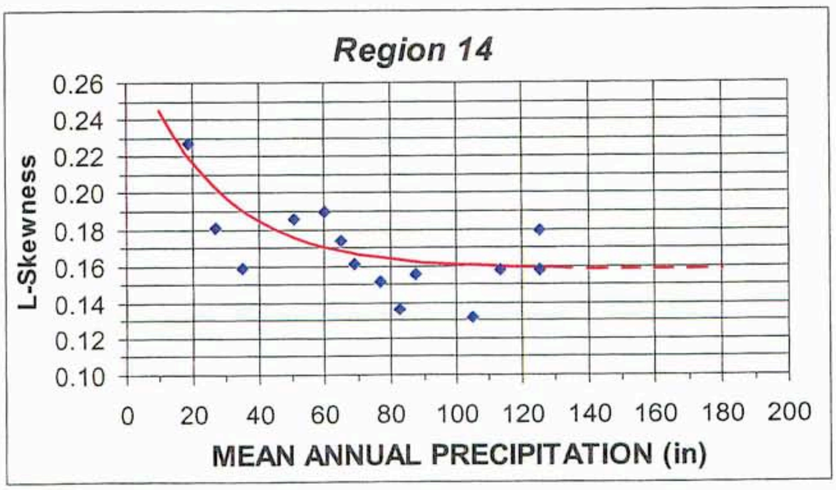

Figure 7d – Predictor Equation Solutions of Observed L-Skewness for Climatic Region 14 for 24-Hour Duration

Heterogeneity Measures, 24-Hour Duration

Heterogeneity measures H1 and H2 (Hosking and Wallis[9,10]) were used to judge the relative heterogeneity in the proposed sub-regions for L-Cv and L-Skewness, respectively. Computation of H1 and H2 values for the various sub-regions indicated the majority of sub-regions were acceptably homogeneous (Table 5). In those cases where computed heterogeneity measures exceeded acceptance criteria, the excursions were generally of a minor amount. Only one sub-region on the windward face of the Olympics had large excursions beyond the acceptance criteria. In summary, mean annual precipitation was an excellent explanatory variable for describing the variability of L-Cv and L-Skewness across the study area.

Table 5 – Results of Heterogeneity and Goodness-of-Fit Tests for 24-Hour Duration

CLIMATIC REGIONS	NUMBER OF SUB-REGIONS	HOMOGENEOUS SUB-REGIONS H1 ≤ 2.00	HOMOGENEOUS SUB-REGIONS H2 ≤ 1.00	SUB-REGIONS ACCEPTING GEV DISTRIBUTION
5 - 151	5	3	4	5
142 - 32	9	6	7	8
31 -15	13	13	11	13
14	5	4	4	3
TOTAL	**32**	**26**	**26**	**29**

Identification of Regional Probability Distribution, 24-Hour Duration

One of the primary tasks in the regional analyses was to identify the best probability distribution for describing the behavior of the annual maxima data. Accordingly, a goodness-of-fit test statistic (Hosking and Wallis[9,10]) was computed for each sub-region for use in identifying the best three-parameter distribution. Using the L-moment based test statistic, the Generalized Extreme Value (GEV) distribution[9,27] was identified most frequently as the best three-parameter probability model (Table 5).

A plot of regional L-Skewness and L-Kurtosis values for the 32 sub-regions at the 24-hour duration in shown in Figure 8. Nearness to the GEV distribution is clearly evident and consistent with the goodness-of-fit test results listed in Table 5.

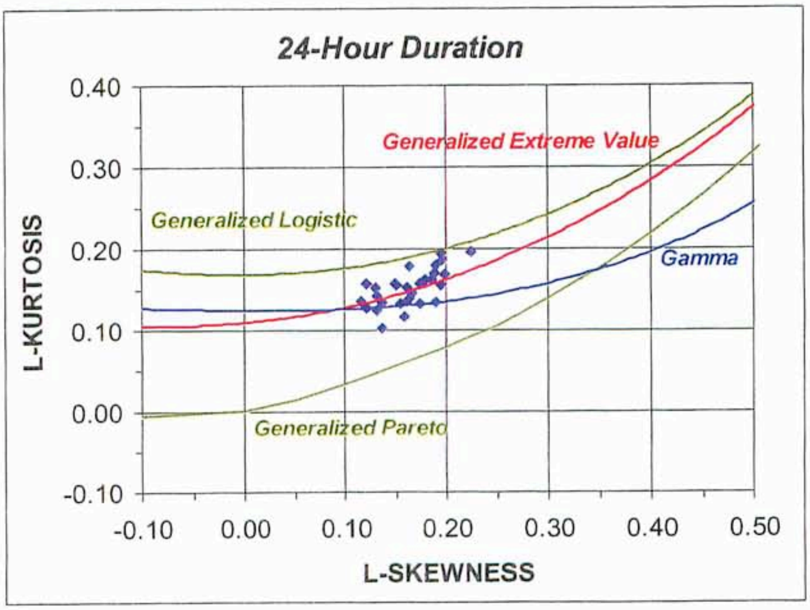

Figure 8 – L-Moment Ratio Plot for Sub-Regions for 24-Hour Duration

The GEV is a very suitable distribution for estimation of precipitation quantiles out to the 500-year recurrence interval. If quantile estimates are desired for events more extreme than the 500-year recurrence interval, it would be worthwhile to refine the selection of the regional probability distribution. Given this consideration, it was decided to utilize the four-parameter Kappa[9,12] distribution, which can mimic the GEV and produce a variety of regional growth curves immediately around the GEV. The inverse form of the Kappa distribution is:

$$q(F) = \xi + \frac{\alpha}{\kappa}\left\{1-\left(\frac{1-F^{h}}{h}\right)^{\kappa}\right\} \tag{3}$$

where: ξ, α, κ, and h are location, scale and shape parameters respectively.

An h value of zero leads to the GEV distribution, an h value of 1 produces the Generalized Pareto (GP) and an h value of -1 produces the Generalized Logistic (GL) distribution. Thus, positive values of h produce regional growth curves that are flatter than the GEV, and negative values of h produce steeper regional growth curves. Minor adjustments of h near a zero value (GEV) allow fine-tuning of the regional growth curves. This minor adjustment of the h value only becomes important for the estimation of very rare quantiles.

To solve for an appropriate h value, a hierarchical approach (Fiorentino[4]) was taken wherein the shape parameter h was computed as the average value from the group of sub-region solutions. An average value of -0.057 was computed with a standard error of estimation of approximately $\pm$ 0.045. Based on this information, a nominal h value of -0.05 was adopted. This produces a regional growth curve slightly steeper than the GEV for very rare events and essentially matches the GEV out to the 100-year recurrence interval.

ANALYSES OF 2-HOUR DURATION ANNUAL MAXIMA

As in the analysis of 24-hour annual maxima, homogeneous sub-regions at the 2-hour duration were formed as collections of gages within small ranges of mean annual precipitation (MAP) within each of the climatic regions. The range of MAP was chosen so that about 6 to 10 gages, 200 to 350 station-years of record, were included in each sub-region with each gage having at least 15-years of record. This resulted in a total of 15 sub-regions for the 2-hour duration (Table 6). Record lengths at precipitation measurement stations varied from a minimum of 15-years to near 60-years, with nearly 50% of the stations having record lengths in excess of 40-years. Figure 9 depicts the number of stations within various ranges of record length.

Table 6 – Number of Sub-Regions, Gages and Station-Years of Record for 2-Hour Duration Annual Maxima

CLIMATIC REGIONS	NUMBER OF SUB-REGIONS	DAILY GAGES	HOURLY GAGES	SNOTEL GAGES	STATION-YEARS OF RECORD
5 - 151	2	0	19	0	721
142 - 32	4	0	27	0	1,101
31 - 15	7	0	63	0	2,424
14	2	0	15	0	551
TOTAL	**15**	**0**	**124**	**0**	**4,797**

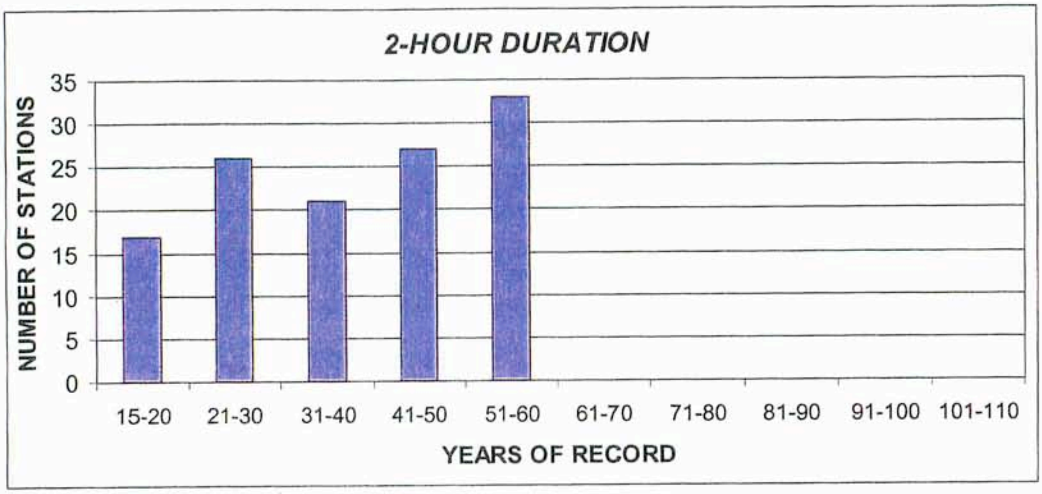

Figure 9 – Histogram of Station Record Lengths for 2-Hour Annual Maxima

Regional Solutions for L-Moment Ratios, L-Cv and L-Skewness

Regional predictor equations for L-moment ratios at the 2-hour duration were developed in the same manner as that for the 24-hour duration. The resultant predictor equations for L-Cv are listed in Table 7 and graphically depicted in Figures 10a,b,c. The predictor equation for L-Skewness is listed in Table 8 and graphically depicted in Figure 11.

Table 7 – Predictor Equations for L-Cv for 2-Hour Annual Maxima

$L\text{-}Cv = \alpha * EXP[-\beta * MAP] + \delta$					
REGIONS	**APPLICABILITY**	**ALPHA**	**BETA**	**DELTA**	**STANDARDIZED RMSE**
5 - 151	ALL	0.0850	0.0200	0.1200	4.6%
142 - 32	ALL	0.0500	0.0250	0.1200	7.9%
31 - 15	ALL	0.0850	0.0200	0.1200	4.6%
14	ALL	0.0850	0.0200	0.1200	1.9%

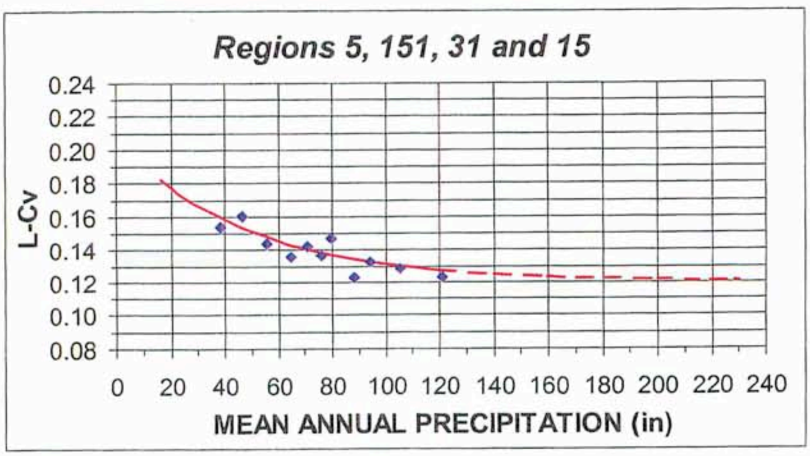

Figure 10a – Predictor Equation Solutions of Observed L-Cv for Climatic Regions 5, 151, 31 and 15 for 2-Hour Duration

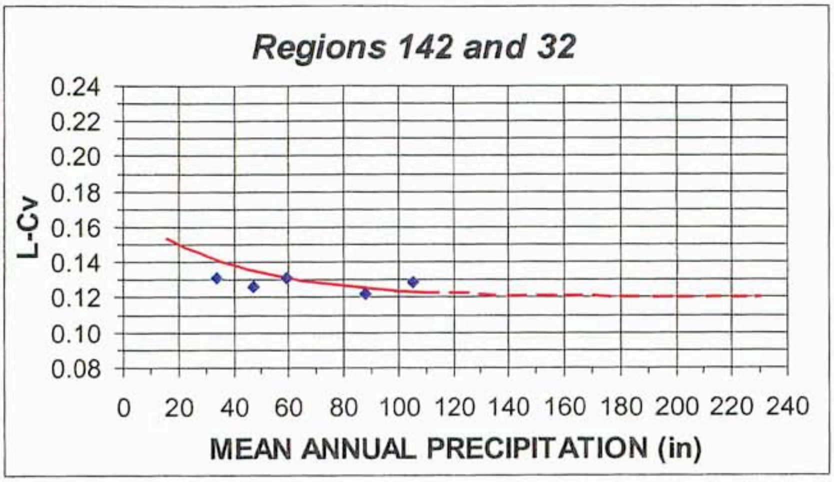

Figure 10b – Predictor Equation Solutions of Observed L-Cv
for Climatic Regions 142 and 32 for 2-Hour Duration

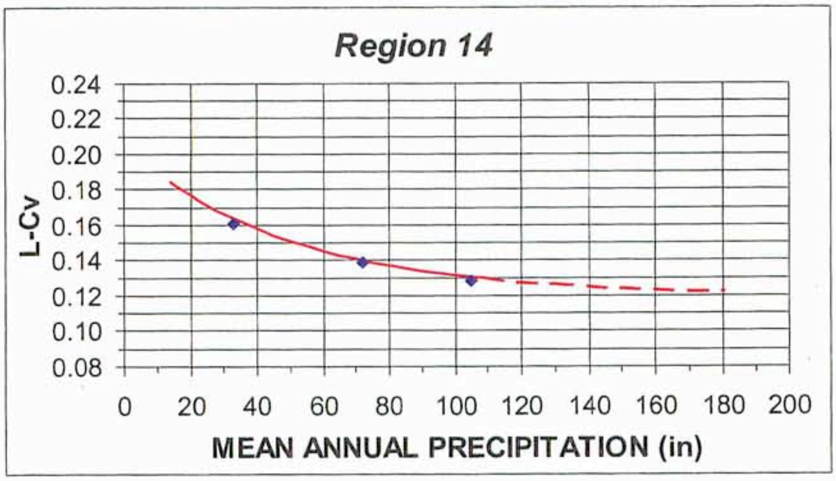

Figure 10c – Predictor Equation Solution of Observed L-Cv
for Climatic Region 14 for 2-Hour Duration

Table 8 – Predictor Equations for L-Skewness for 2-Hour Annual Maxima

*L-Skewness = α * EXP [-β * MAP] + δ*					
REGIONS	**APPLICABILITY**	**ALPHA**	**BETA**	**DELTA**	**STANDARDIZED RMSE**
ALL	ALL	0.1800	0.0250	0.1700	15.7%

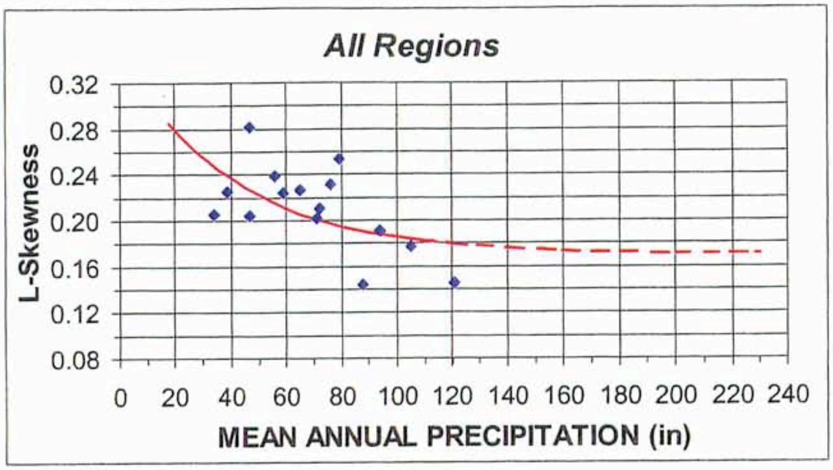

Figure 11 – Predictor Equation Solutions of Observed L-Skewness for All Climatic Regions for 2-Hour Duration

The suitability of the general form of the L-moment predictor equation (Equation 2a) is not as apparent in Figure 11 as was the case for other climatic regions. The naturally high variability of sample L-skewness values makes it more difficult to discern the underlying behavior of the data. However, the general form of the solution curve is consistent with behavior seen at the 24-hour duration and the behavior seen in other regional precipitation studies where the L-skewness values converge to some limiting value for sites with very high mean annual precipitation.

Heterogeneity Measures, 2-Hour Duration

Heterogeneity measures H1 and H2 (Hosking and Wallis[9,10]) were used to judge the relative heterogeneity in the proposed sub-regions for L-Cv and L-Skewness, respectively. Computation of H1 and H2 values for the various sub-regions indicated the majority of sub-regions were acceptably homogeneous (Table 9). In those cases where computed heterogeneity measures exceeded acceptance criteria, the excursions were generally of a minor amount. Only one sub-region on the windward face of the Olympics had large excursions beyond the acceptance criteria. In summary, mean annual precipitation was an excellent explanatory variable for describing the variability of L-Cv and L-Skewness across the study area.

Table 9 – Results of Heterogeneity and Goodness-of-Fit Tests for 2-Hour Duration

CLIMATIC REGIONS	NUMBER OF SUB-REGIONS	HOMOGENEOUS SUB-REGIONS H1 $\le$ 2.00	HOMOGENEOUS SUB-REGIONS H2 $\le$ 1.00	SUB-REGIONS ACCEPTING GEV DISTRIBUTION
5 - 151	2	1	1	2
142 - 32	4	4	2	4
31 -15	7	5	7	6
14	2	2	2	1
TOTAL	15	12	12	13

Identification of Regional Probability Distribution, 2-Hour Duration

The Generalized Extreme Value (GEV) distribution was identified most frequently as the best three-parameter probability model (Table 9) using the L-moment based test statistic for goodness-of-fit. A plot of regional L-Skewness and L-Kurtosis values for the 15 sub-regions at the 2-hour duration in shown in Figure 12. It is seen that the majority of data pairs plot nearest the GEV distribution, with the centroid being slightly above, slightly more kurtotic, than the GEV distribution.

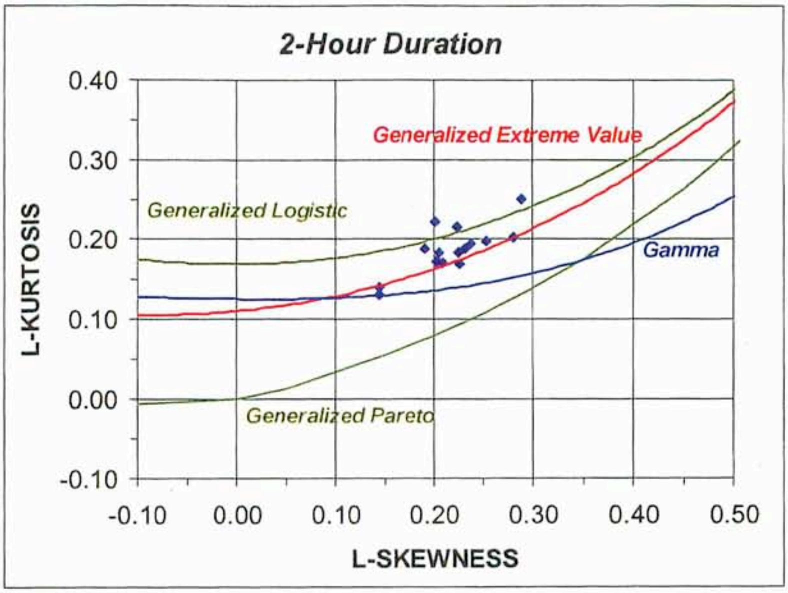

Figure 12 – L-Moment Ratio Plot for Sub-Regions for 2-Hour Duration

As was the case for the 24-hour duration, the GEV is a suitable distribution for estimation of precipitation quantiles out to the 500-year recurrence interval. If quantile estimates are desired for events more extreme than the 500-year recurrence interval, it would be worthwhile to utilize the four-parameter Kappa distribution and to refine the selection of the h parameter. To solve for an appropriate h value, a hierarchical approach (Fiorentino[4]) was taken wherein the shape parameter h was computed as the median value from the group of sub-region solutions. A median value of -0.150 was computed with a standard error of estimation of approximately $\pm$ 0.093. Based on this information, a nominal h value of -0.15 was adopted. This produces a regional growth curve slightly steeper than the GEV for very rare events and essentially matches the GEV distribution up to the 100-year recurrence interval.

PRECIPITATION MAGNITUDE-FREQUENCY ESTIMATES FOR GAGED SITES

The first step in developing a site-specific precipitation magnitude-frequency curve is to compute the regional growth curve. The findings described in the previous sections provide the information necessary for developing the regional growth curve for the 24-hour and 2-hour durations. Specifically, the first three parameters of the Kappa distribution (ξ, α, and κ) are solved (Hosking and Wallis[9,12]) using a mean of unity and the applicable regional values of L-Cv and L-Skewness as indicated in Tables 3a,b and 4a,b. The fourth parameter (h) of the Kappa distribution is set to the regional average value applicable to the selected duration. Equation 3 is then used to describe the regional growth curve. The site-specific precipitation-frequency curve is obtained by scaling the regional growth curve by the at-site mean.

For gaged sites, the at-site mean ($\hat{\mu}$) can be computed from the gage mean ($\bar{x}$) based on the correction factors (C_{nop}) in Table 10. A correction factor (Weiss[32]) is needed to adjust the gage sample mean to account for precipitation measurement and reporting on a fixed time interval rather than on the desired continuous basis. The at-site mean is computed from the gage mean as:

$$\hat{\mu} = C_{nop}(\bar{x}) \qquad (4)$$

Table 10 – Correction Factors (C_{nop}) to Adjust Gage Sample Statistics

GAGE TYPE	DURATION	
	2-Hour	24-Hour
Daily Gage Snotel Gage	n/a	1.13
Automated Gage Hourly Reporting	1.04	1.00
Automated Gage 15-Minute Reporting	1.00	1.00

This procedure can be explained by an example using an existing gaged site. The Seattle-Tacoma Airport gage is located in the Interior Lowlands West, climatic Region 31. The mean annual precipitation for the site is 37.9-inches. For the 24-hour duration, the regional value of L-Cv is 0.159, which is obtained from Equation 2a and parameter values from Table 3b. The regional value of L-Skewness is 0.187, which is obtained from Equation 2a and parameter values from Table 4b. The regional value of the *h* parameter is -0.05 for the 24-hour duration. Using a mean value of unity, the solution for the four parameters of the Kappa distribution[12,15], yields:

$\xi = 0.8716$, $\alpha = 0.2166$, $\kappa = -0.0394$, and $h = -0.05$.

Use of Equation 3 yields the regional growth curve depicted in Figure 13a. Seattle-Tacoma Airport has an hourly gage with a gage mean of 2.10-inches for the 24-hour duration for 60-years of record. Use of Equation 4 with a correction factor of 1.00 yields an at-site mean value of 2.10-inches for the 24-hour duration. The at-site precipitation magnitude-frequency curve is obtained by scaling the regional growth curve by the at-site mean and is depicted in Figure 13b. The observed 24-hour annual maxima for the Seattle-Tacoma Airport site for the period from 1940-2000 are also depicted in Figure 12b for a comparison of the regional solution and the sample data.

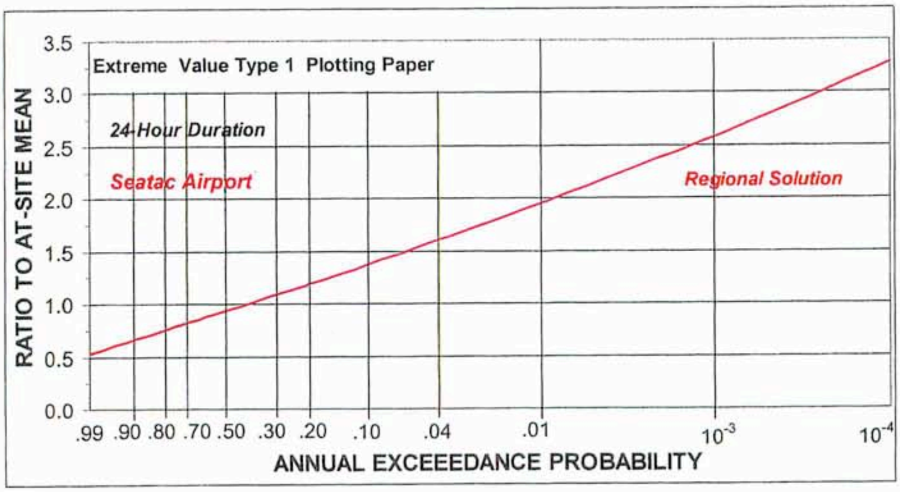

Figure 13a – Regional Growth Curve for Seattle-Tacoma Airport for 24-Hour Duration

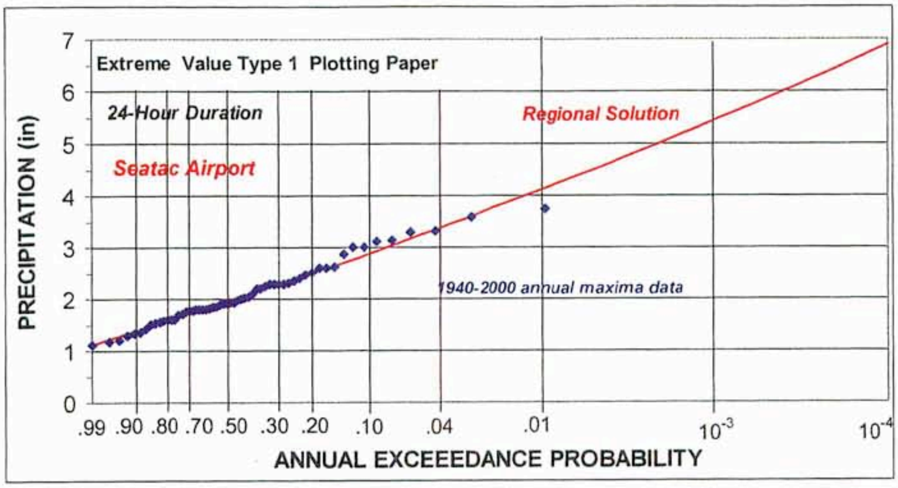

Figure 13b – Precipitation Magnitude-Frequency Curve for Seattle-Tacoma Airport for 24-Hour Duration

SPATIAL MAPPING OF PRECIPITATION-FREQUENCY INFORMATION

Products from the PRISM model[3] operated by Oregon Climate Service were used in conducting spatial mapping of precipitation for selected recurrence intervals. Gridded datasets and isopluvial maps were prepared for the 2-year, 10-year, 25-year, 50-year and 100-year recurrence intervals for the 24-hour and 2-hour durations. A gridded dataset and isopluvial map was also prepared for the 6-month (twice/year) recurrence interval for the 24-hour duration, which is needed for some water quality applications. Precipitation estimates for the 6-month and 2-year recurrence intervals were converted from annual maxima to partial duration series equivalents using the conversion developed by Langbein[15,27]. This was done to improve the frequency estimates for common events and to be consistent with past mapping products produced by the National Weather Service[16].

The spatial mapping of precipitation for selected recurrence intervals is dependent upon the production of two key components in addition to the regional precipitation-frequency information. The first component required is the spatial mapping of at-site means (station mean values, also called mean annual maxima). Grid-cell values of at-site means are used to scale dimensionless magnitude-frequency relationships to obtain precipitation estimates for the recurrence interval of interest. The second component required is the spatial mapping of regional statistical parameters. This provides L-moment ratio statistics applicable to each grid-cell in the study area domain, which are used to determine the probability distribution parameters for describing the magnitude-frequency relationship applicable to each grid-cell. Thus, the spatial mapping of at-site means and the spatial mapping of regional statistical parameters are the primary work products needed for isopluvial mapping.

Mean Annual Precipitation

The gridded dataset of mean annual precipitation provides a basis for spatial mapping of both at-site means and L-moment statistics and is therefore an important element of this project. An analysis of mean annual precipitation for the period from 1961 to 1990 has been completed for the study area by Oregon Climate Service using the PRISM model[3,20]. The resultant map has been utilized in this study and provides digital values of mean annual precipitation on a gridded latitude-longitude system with a nominal resolution of 1.25 minutes per grid-cell for the study area (about 1.4 mi^2). This resolution yields a study area domain that is a matrix of 216 rows by 336 columns, 72,576 grid-cells.

SPATIAL MAPPING OF AT-SITE MEANS

Spatial mapping of at-site means encompasses a number of separate tasks that address the spatial behavior of at-site means and seeks to minimize differences between mapped values and sample values computed at precipitation measurement stations. This typically involves first developing relationships between at-site means computed at precipitation measurement stations and climatic/physiographic factors. These relationships are then used to populate the grid-cells in the study area domain with the values predicted from the regression equation based on the climatic/physiographic factors representative of each grid-cell. Residuals are then computed for each of the station at-site means that quantify the magnitude of difference between mapped values and station values. This allows analyses to be conducted of the residuals to identify if there is a coherent spatial pattern to the magnitude and sign of the residuals. When coherent residual patterns are encountered, they are used to adjust the original estimates. Lastly, standard bias and root mean square error measures are computed to quantify the overall goodness-of-fit of the mapped values relative to the observations at the gages. The completed maps of the at-site means for the 24-hour and 2-hour durations are shown in Figures 14a,b, respectively.

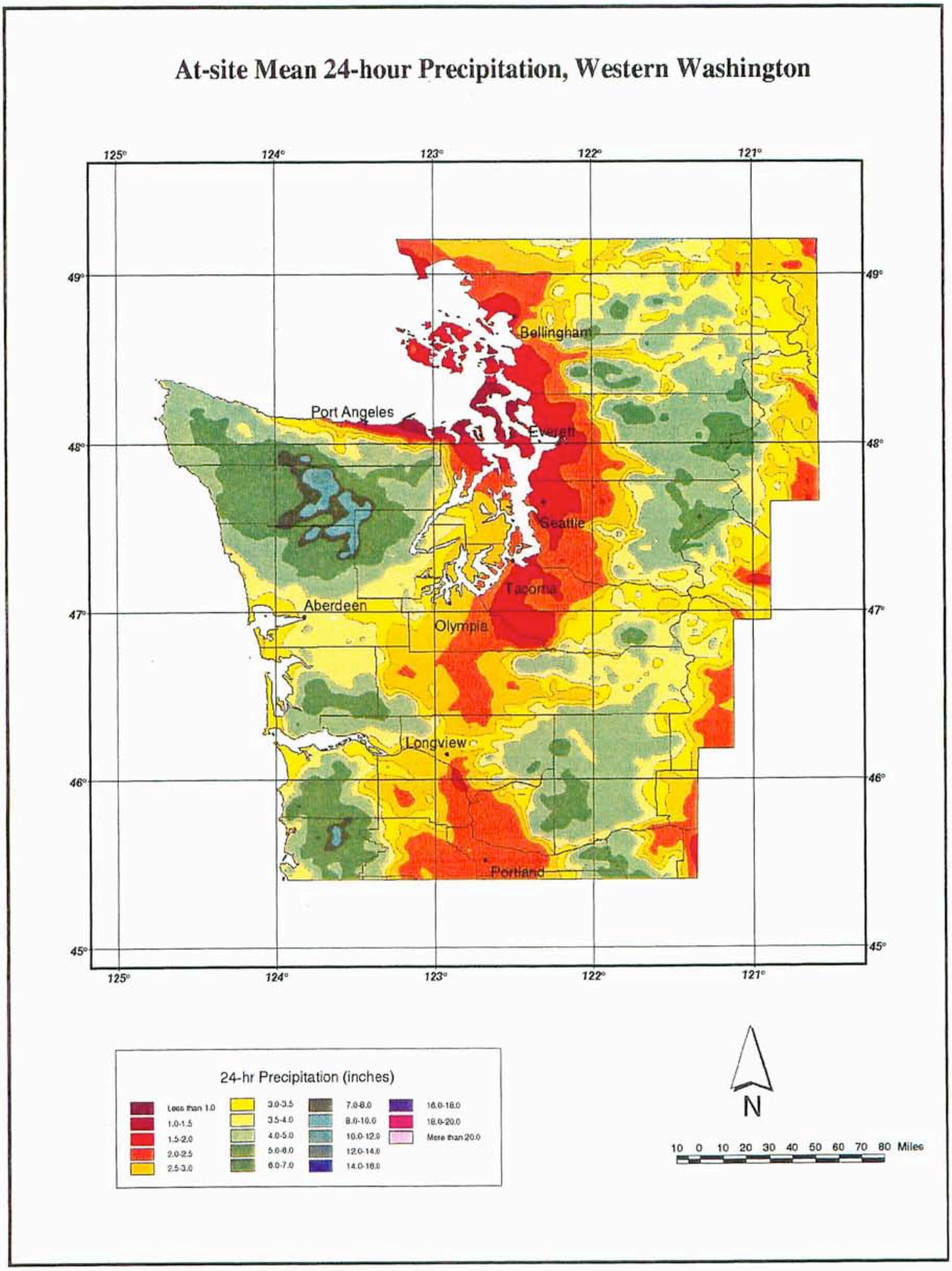

Figure 14a – Map of At-Site Means for 24-Hour Duration for Western Washington

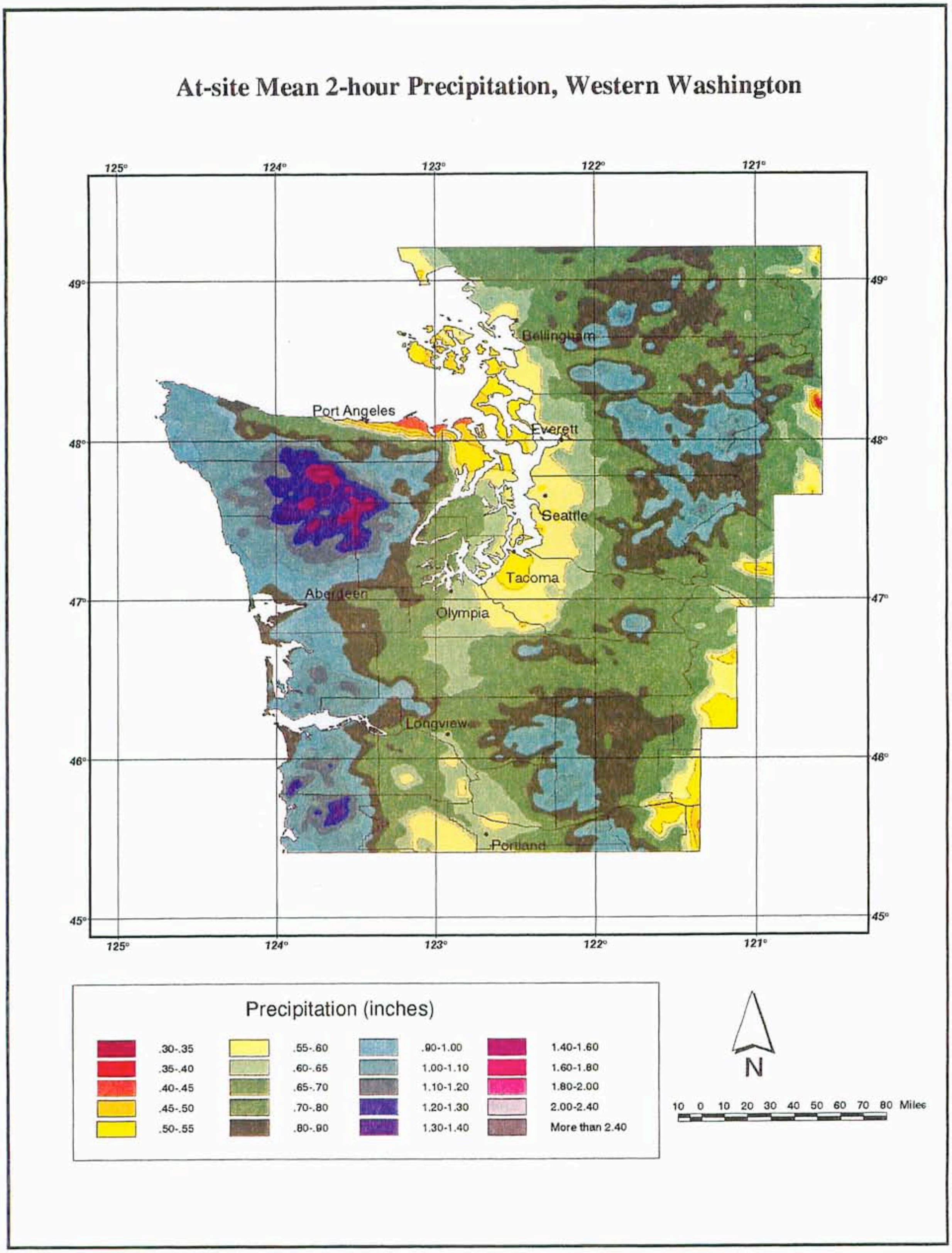

Figure 14b – Map of At-Site Means for 2-Hour Duration for Western Washington

Quantitative Assessment of Success Achieved in Spatial Mapping of At-Site Means

A quantitative measure was needed to assess the relative success of the spatial mapping procedures in capturing the spatial behavior of the at-site means. This is a difficult task in all studies of this type because the true values of the at-site means are unknown. The logical standard for comparison is the station sample value of at-site mean. However, sample values of the station at-site mean will differ from the true population values due to sampling variability, and other natural and man-related variability associated with precipitation measurement and recording.

We chose to approach this problem by framing the question as - how do the observed station values compare with the final mapped values? Given this question, the bias and root mean square error (RMSE) computations can be expressed in standardized units using the mapped values as the predicted value. This equates to computing bias and RMSE for the standardized residuals (SR_2) as:

$$SR_2 = (S - P_2) / P_2 \qquad (5)$$

where: S is the observed station value of the at-site mean (in); and P_2 is the mapped value of the station at-site-mean (in).

The computed standardized residuals are listed in Tables 11a,b. It is seen that the final mapped values of the at-site means are nearly unbiased. If the RMSE values for the stations are representative of the at-site mean maps taken as a whole, then the final maps of at-site means have a standard error of estimate that is near 5%. The RMSE of the final mapped values are generally similar in magnitude to that expected from natural sampling variability and, thus, are as low as can reasonably be expected.

Table 11a –Bias and Root Mean Square Error of Standardized Residuals for Final Mapped Values of At-Site Means for 24-Hour Duration

REGION	FINAL MAPPED VALUES	
	Bias	***RMSE***
COASTAL AREAS		
Region 5	+1.04%	5.26%
Region 151	-0. 68%	2.92%
Region 142	-1.47%	5.07%
INTERIOR LOWLAND AREAS		
Region 32	+0. 56%	6.63%
Region 31	+0.41%	4.42%
CASCADE MOUNTAIN AREAS		
Region 15	+0.02%	4.01%
Region 14	+0.17%	6.27%
ALL REGIONS	+0.18%	5.21%

Table 11b – Bias and Root Mean Square Error of Standardized Residuals for Final Mapped Values of At-Site Means for 2-Hour Duration

REGION	FINAL MAPPED VALUES	
	Bias	***RMSE***
COASTAL AREAS		
Region 5	+0.61%	1.55%
Region 151	-1.58%	5.77%
Region 142	+2.75%	5.57%
INTERIOR LOWLAND AREAS		
Region 32	+0. 35%	3.66%
Region 31	+0.24%	2.95%
CASCADE MOUNTAIN AREAS		
Region 15	+0.55%	4.12%
Region 14	-0.85%	4.70%
ALL REGIONS	+0.21%	3.96%

SPATIAL MAPPING OF REGIONAL L-MOMENT STATISTICAL PARAMETERS

In order to compute precipitation estimates for the selected recurrence intervals, the appropriate value of L-Cv and L-skewness must be obtained for each grid-cell. This was accomplished by populating the grid-cells in the study area domain utilizing the functional relationships for L-Cv and L-skewness (Tables 3a,b and 4a,b) developed in the regional precipitation-frequency analysis.

A smoothing filter was then employed along regional boundaries to provide a smooth transition of L-moment ratio values across boundaries. In general, these were minor adjustments with changes of only a few percent, as particular care had previously been taken in the precipitation-frequency study to minimize differences at regional boundaries.

Separate gridded data files were prepared for L-Cv and L-skewness for each of the two durations, and are included as electronic files with this report (Appendix A).

PRODUCTION OF ISOPLUVIAL MAPS

Production of the isopluvial maps was accomplished by incorporation of the information described in the prior sections. For each grid-cell, the applicable value of the at-site mean and L-moment ratios L-Cv and L-skewness were used to solve the distribution parameters for the four-parameter Kappa distribution[9,12]. The distribution parameters were then used with Equation 3 to compute the expected value of the precipitation for the desired recurrence interval. This procedure was repeated for each grid-cell until the domain for the study area was populated. The resultant precipitation field was then contoured to yield isopluvials for selected values of precipitation.

An example of an isopluvial map produced by this process is depicted in Figure 15, which shows a color-shaded map of 24-hour 100-year precipitation. Isopluvial maps for the other selected recurrence intervals for the 24-hour and 2-hour durations are contained in Appendix B.

Precipitation Magnitude-Frequency Estimates for Moderate to Large Size Watersheds
The precipitation magnitude-frequency information contained in the gridded datasets and depicted on the isopluvial maps corresponds to 10-mi^2 and 1-mi^2 precipitation for the 24-hour and 2-hour durations, respectively. Estimation of precipitation volumes for larger watersheds for a selected recurrence interval requires the application of areal reduction factors[16,18,19]. Areal reduction factors would be obtained from analyses of historical storms. The topic of areal reduction factors, depth-area-duration analyses, and estimation of precipitation for moderate to large size watersheds is beyond the scope of this report. It is mentioned here to alert the reader that precipitation values from the gridded datasets and isopluvial maps need to be scaled by areal reduction factors to obtain estimates of precipitation volumes for moderate to large watersheds.

Uncertainty Bounds for 100-Year Values
The accuracy of estimation of 100-year precipitation annual maxima at a given location is dependent upon the success obtained in estimating the at-site mean, and L-moment ratios L-Cv and L-skewness, and the similarity between the chosen probability model (Kappa distribution) and the actual model mother-nature is using, which is unknown.

In general, uncertainties associated with the estimation of L-moment ratios L-Cv and L-skewness result in standard errors of estimation of about 5% at the 100-year recurrence interval. These relatively low levels of uncertainty are attributable to the very large datasets that were used to estimate the L-moment ratios and identify a suitable probability model. Interaction of these standard errors of estimation with that due to estimation of the at-site mean (Tables 11a,b) yield the standard errors of estimation shown in Table 12. The range in standard errors of estimation for a given duration is primarily due to the region-to-region variation of the standard errors for estimation of the at-site mean for the recurrence intervals cited in Table 12.

The values in Table 12 should be considered approximate as detailed studies for computation of uncertainty bounds have not been conducted. Further, these values represent regional averages. Values applicable to a given location may be somewhat smaller or larger than that indicated in Table 12.

Table 12 – Range of Standard Errors of Estimation for Selected Recurrence Intervals

DURATION	STANDARD ERROR OF ESTIMATION FOR PRECIPITATION	
	10-YEAR	100-YEAR
2-HOUR	4% - 7%	6% - 9%
24-HOUR	5% - 8%	7% - 10%

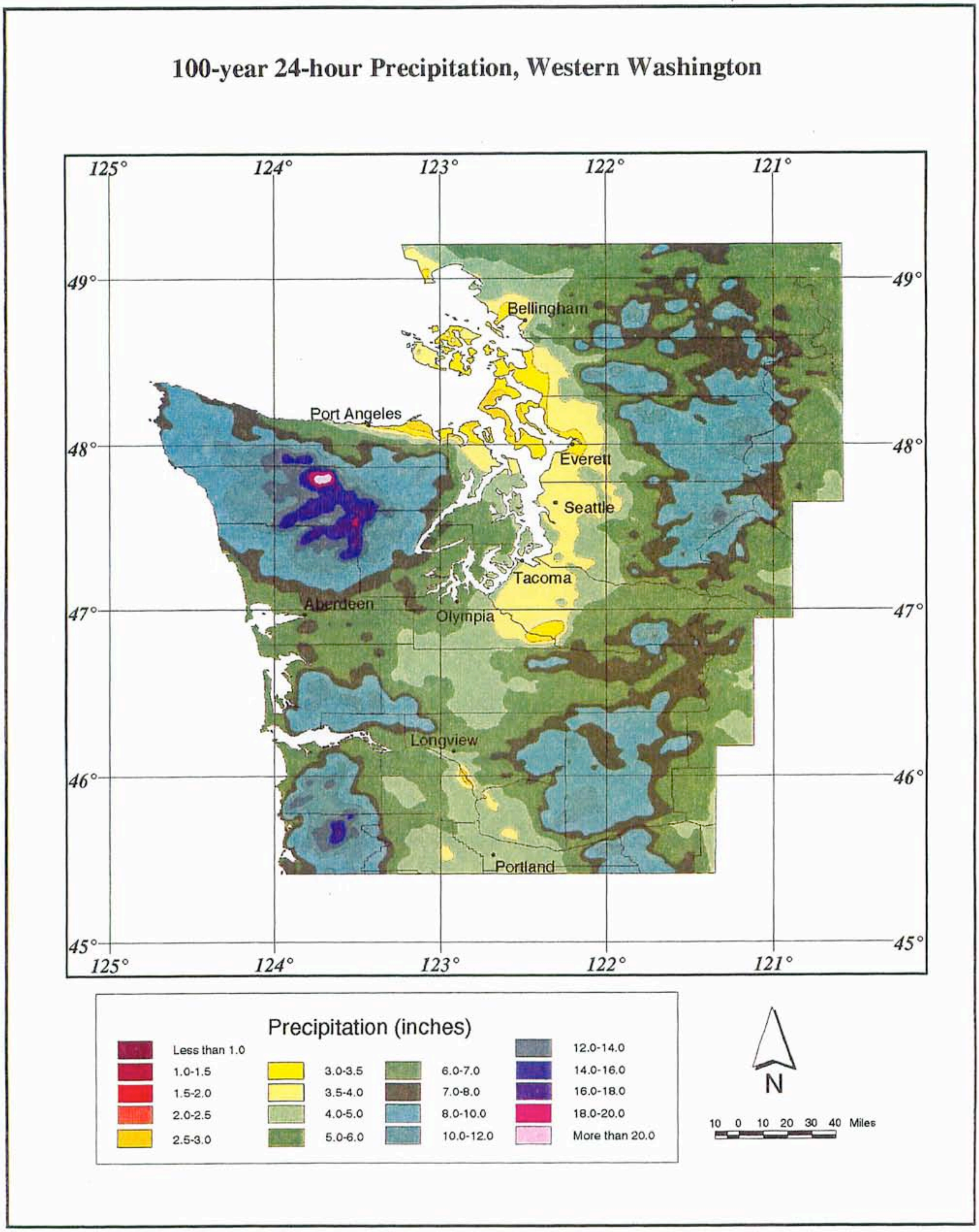

Figure 15 – Isopluvial Map of 24-Hour Precipitation for 100-Year Recurrence Interval for Western Washington

ELECTRONIC FILES

LISTING AT-SITE AND REGIONAL PARAMETERS FOR ALL GAGED SITES

Appendix A includes station catalogs for the stations/gages used in the study. It also references a compact disc (CD) containing ASCII text files and Excel spreadsheets listing the precipitation estimates for selected recurrence intervals. Specifically, the files contain the station identification number, station name, type of gage, climatic region number, latitude, longitude, elevation, mean annual precipitation, sample value of at-site mean, mapped value of at-site mean, regional values of L-Cv, L-skewness, *h* parameter for the Kappa distribution, and estimated 6-month, 2-year, 10-year, 25-year, 50-year, 100-year, and 500-year precipitation.

SEASONALITY OF EXTREME STORMS

The seasonality of extreme storms can be a valuable tool for application of the precipitation-frequency information in rainfall-runoff modeling. Specifically, information on the seasonality of storms is helpful in decision-making for setting watershed conditions antecedent to the storm. The seasonality of extreme storms was investigated by constructing frequency histograms of the storm dates for rare 24-hour and 2-hour precipitation amounts for each of the seven climatic regions. Extreme storms were taken to be precipitation amounts with annual exceedance probabilities less than 0.05 (rarer than a 20-year event). Precipitation amounts/gages with duplicate storm dates (generally dates within 7 calendar days) were removed before constructing the frequency histograms for each climatic region. The results of the seasonality analyses are discussed briefly below and additional frequency histograms are presented in Appendix C.

Well-defined seasonal patterns are apparent for the 24-hour and 2-hour durations. In western Washington, storms which are extreme at the 24-hour duration occur predominantly in the fall and winter months (Figure 16). These storms are the result of synoptic scale cyclonic weather systems and associated fronts. These storms remain organized and penetrate a considerable distance inland from the coast, as the eastern slopes of the Cascade Mountains also exhibit a distinctive fall-winter seasonal pattern.

Storms which are extreme at the 2-hour duration exhibit greater seasonal variability. In lowland areas, storms that are extreme at the 2-hour duration occur both in the warm season and in the fall and winter period (Figure 17a). Some of these events are localized events having limited areal coverage with precipitation occurring over a relatively short period of time. Other events are embedded in longer duration cool season storm events and are associated with large-scale weather systems having more widespread areal coverage. As the precipitation amounts become more rare and increase in magnitude, there is a greater likelihood that they are associated with a localized event and have temporal characteristics of a thunderstorm. These more rare events are more likely to occur in the warm season as a result of convective storm activity. (Figure 17b).

In coastal and mountain areas, the seasonality of extreme 2-hour storms covers the period from late-spring through winter. Moderately large 2-hour precipitation amounts are often embedded within longer duration storms associated with large-scale weather systems. For these sites, there is a greater percentage of storms at the 2-hour duration that occur in the fall and winter period (Figure 18).

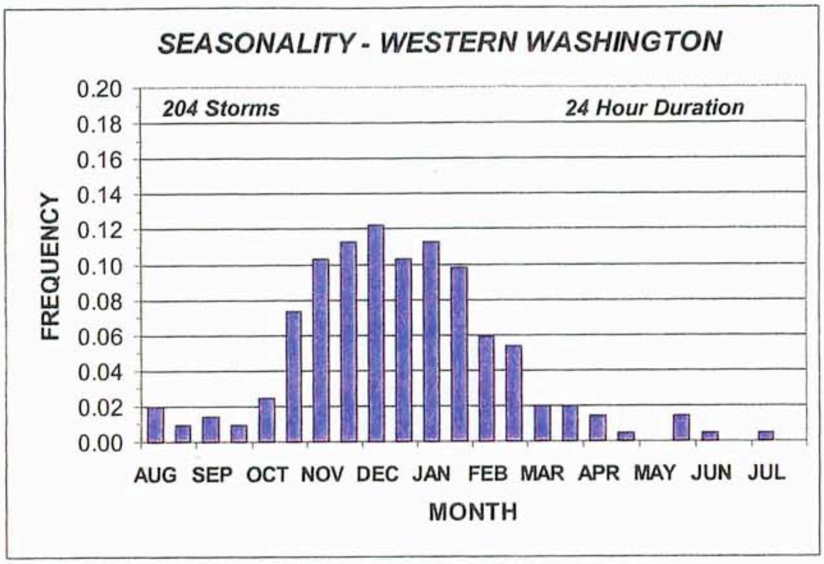

Figure 16 – Seasonality of Extreme Storms for All Climatic Regions for 24-Hour Duration

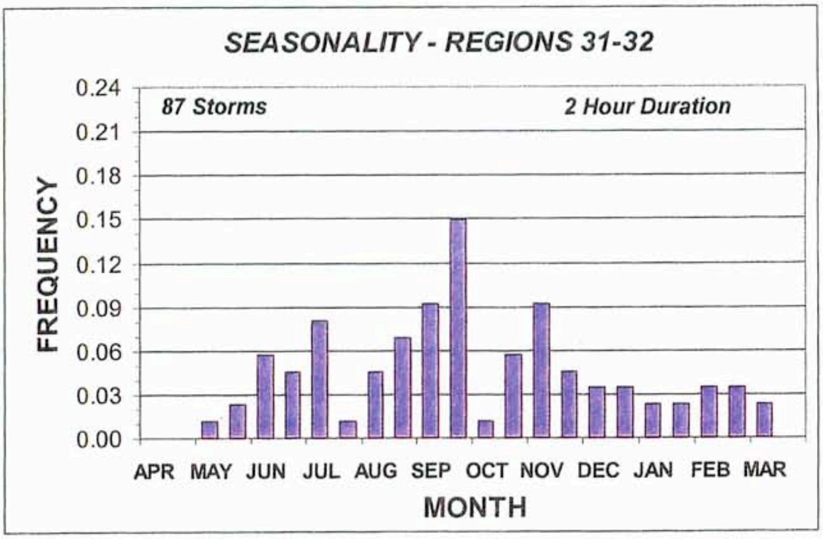

Figure 17a – Seasonality of Extreme Storms in Lowland Climatic Regions 31 and 32 for 2-Hour Duration

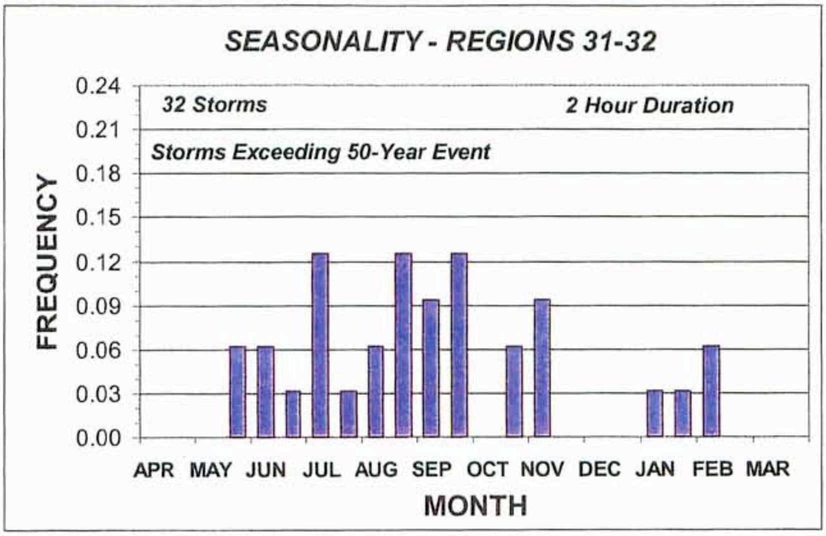

Figure 17b – Seasonality of Extreme Storms that Exceed 50-Year Event in Lowland Climatic Regions 31 and 32 for 2-Hour Duration

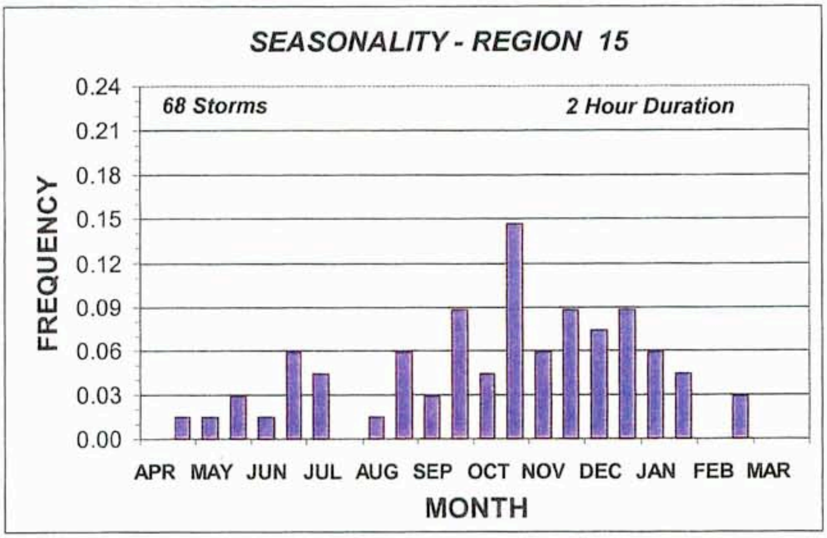

Figure 18 – Seasonality of Extreme Storms for Climatic Region 15 Windward Face of Cascade Mountains for 2-Hour Duration

CATALOG OF EXTREME STORMS

A catalog of extreme storms is contained in Appendix D. The catalog lists those storm events at the 24-hour and 2-hour durations where the annual exceedance probabilities were less than 0.05 (rarer than a 20-year event). These are the same storm events/storm dates as used in the seasonality analysis. The temporal patterns from these storms would be logical candidates for single event rainfall-runoff modeling of extreme storms.

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Appendix A

STATION CATALOGS

AND

ELECTRONIC FILES OF PROJECT DELIVERABLES

OVERVIEW

This appendix includes station catalogs for the stations/gages used in the study for analysis of precipitation annual maxima at the 24-hour and 2-hour durations. These listings include the station identification number, station name, type of gage, climatic region number, latitude, longitude, elevation, and mean annual precipitation. A compact disc (CD) is also included as part of this appendix that contains electronic files for all of the project deliverables. Two items of particular interest are: a listing of precipitation magnitude-frequency estimates for each of the stations for the 6-month, 2-year, 10-year, 25-year, 50-year, 100-year, and 500-year recurrence intervals; and gridded datasets of precipitation-frequency values for the recurrence intervals listed above, that can be imported into GIS software ..

The CD contains files with the following contents:

- catalog of stations
- precipitation annual maxima for all gages
- catalog of extreme storms
- gridded datasets for 24-hour and 2-hour mean annual maxima (at-site means)
- gridded datasets of L-moment ratios L-Cv and L-Skewness for 24-hour and 2-hour durations
- gridded datasets of precipitation estimates for selected recurrence intervals
- precipitation magnitude-frequency estimates for selected recurrence intervals for each station
- final report and supporting graphics

Table A1 – Station Catalog of Gages Used in Analyses of Precipitation Annual Maxima at 24-Hour Duration

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
1100030	ABBOTSFORD A	BC	49.0333	122.3667	190	1944	1996	53	31	DY	57.8
45-0008	ABERDEEN	WA	46.9500	123.8167	10	1897	2000	104	5	DY	83.5
45-0013	ABERDEEN 20 NNE	WA	47.2667	123.7000	435	1931	2000	70	151	DY	131.0
45-0013	ABERDEEN 20 NNE	WA	47.2667	123.7000	435	1940	2000	61	151	HR	131.0
1100120	AGASSIZ CDA	BC	49.2500	121.7667	49	1889	1995	107	14	DY	67.6
1030180	ALBERNI BEAVER CREEK	BC	49.3667	124.9333	298	1894	1959	66	142	DY	97.2
45-0094	ALDER DAM CAMP	WA	46.8000	122.3167	1300	1948	1954	7	15	DY	50.2
SN-0564	ALDERWOOD WATER DIST	WA	47.8600	122.2839	620	1988	2000	13	31	DY	40.2
1020270	ALERT BAY	BC	50.5833	126.9333	193	1924	1994	71	142	DY	67.5
1100360	ALOUETTE LAKE	BC	49.2833	122.4833	383	1924	1982	59	15	DY	102.5
1100370	ALOUETTE POWER HOUSE	BC	49.3667	122.3167	298	1935	1949	15	15	DY	109.3
21B48S	ALPINE MEADOWS	WA	47.7833	121.7000	3500	1995	1999	5	15	DY	101.5
45-0176	ANACORTES	WA	48.5000	122.6000	20	1897	2000	104	31	DY	27.2
45-0242	ARIEL DAM	WA	45.9667	122.5667	220	1934	1972	39	31	DY	67.3
45-0257	ARLINGTON	WA	48.2000	122.1333	100	1936	2000	65	31	DY	47.0
35-0318	ASTOR EXPERIMENT STN	OR	46.1500	123.8167	49	1948	1973	26	5	DY	83.0
35-0324	ASTORIA	OR	46.1833	123.8333	200	1948	1960	13	5	DY	80.7
35-0328	ASTORIA AP PORT OF	OR	46.1500	123.8667	9	1953	2000	48	5	DY	77.3
35-0328	ASTORIA AP PORT OF	OR	46.1500	123.8667	9	1953	2000	48	5	HR	77.3
45-0324	AUBURN	WA	47.3167	122.2333	79	1954	1977	24	31	HR	38.5
35-0343	AURORA	OR	45.2333	122.7333	72	1951	1969	19	31	DY	40.7
45-0400	BALDY MOUNTAIN	WA	46.1000	122.7000	2190	1983	1989	7	15	HR	90.2
1030605	BAMFIELD EAST	BC	48.8333	125.1167	13	1959	1995	37	5	DY	115.2
45-0456	BARING	WA	47.7667	121.4833	760	1970	2000	31	15	DY	103.2
45-0482	BATTLE GROUND	WA	45.7667	122.5167	284	1930	2000	71	31	DY	50.3
1010720	BEAR CREEK	BC	48.5000	124.0000	1151	1910	1996	87	151	DY	122.5
35-0571	BEAR SPRINGS RS	OR	45.1167	121.5333	3360	1961	2000	40	14	HR	28.5
35-0595	BEAVERTON 2 SSW	OR	45.4500	122.8167	270	1973	2000	28	32	DY	40.2
45-0587	BELLINGHAM 3 SSW	WA	48.7167	122.5167	15	1911	2000	90	31	DY	38.0
45-0574	BELLINGHAM CAA AP	WA	48.8000	122.5333	147	1941	1952	12	31	HR	39.4
45-0574	BELLINGHAM FCWOS AP	WA	48.8000	122.5333	149	1950	2000	51	31	DY	39.4
45-0729	BLAINE	WA	49.0000	122.7500	60	1941	2000	60	31	DY	45.6
45-0729	BLAINE	WA	49.0000	122.7500	60	1941	2000	60	31	HR	45.6
21D33S	BLAZED ALDER	OR	45.4167	121.8667	3650	1981	2000	20	15	DY	114.6
20B02S	BLEWETT PASS	WA	47.3500	120.6833	4270	1982	1999	18	14	DY	33.4
1020885	BLIND CHANNEL	BC	50.4167	125.5000	9	1956	1993	38	142	DY	92.4
KI-04U	BOEING CREEK	WA	47.7508	122.3593	450	1990	2000	11	31	DY	37.8
35-0897	BONNEVILLE DAM	OR	45.6333	121.9500	62	1948	2000	53	15	DY	78.1
35-0897	BONNEVILLE DAM	OR	45.6333	121.9500	62	1940	2000	61	15	HR	78.1
45-0826	BOTHELL 2 N	WA	47.7667	122.2167	112	1948	1959	12	31	DY	39.0
45-0872	BREMERTON	WA	47.5667	122.6667	110	1899	2000	102	32	DY	51.9
35-1028	BRIGHTWOOD	OR	45.3667	122.0167	1070	1959	1982	24	15	DY	89.9
35-1033	BRIGHTWOOD 1 WNW	OR	45.3833	122.0333	978	1971	2000	30	15	HR	79.1
45-0917	BROOKLYN	WA	46.7833	123.5000	190	1928	1974	47	32	DY	81.3
45-0945	BUCKLEY 1 NE	WA	47.1667	122.0000	685	1913	2000	88	31	DY	50.5
45-0969	BUMPING LAKE	WA	46.8667	121.3000	3442	1910	1967	58	14	DY	51.7
21C38S	BUMPING RIDGE	WA	46.8167	121.3333	4600	1979	1999	21	14	DY	50.4
1101140	BUNTZEN LAKE	BC	49.3833	122.8667	32	1924	1983	60	15	DY	131.7
45-0986	BURLINGTON	WA	48.4667	122.3167	30	1941	2000	60	31	HR	36.5
1101200	BURQUITLAM VANCOUVER	BC	49.2500	122.8833	400	1926	1995	70	31	DY	69.0
35-1222	BUXTON	OR	45.6833	123.1833	355	1948	2000	53	32	HR	55.2
35-1227	BUXTON MOUNTAINDALE	OR	45.6833	123.0667	360	1948	1975	28	32	HR	53.5
1021230	CAMERON LAKE	BC	49.2833	124.5833	633	1924	1986	63	32	DY	66.8
45-1064	CAMP GRISDALE	WA	47.3667	123.6000	820	1956	1986	31	151	HR	166.4
35-1329	CANBY 2 NE	OR	45.2833	122.6667	89	1948	1979	32	31	DY	42.8
TH-1168	CAPITOL FOREST	WA	46.9215	123.0900	450	1995	2000	6	142	HR	80.0
1031402	CARMANAH POINT	BC	48.6167	124.7500	124	1968	1995	28	5	DY	120.0
45-1146	CARNATION 4 NW	WA	47.6833	121.9833	50	1941	2000	60	31	HR	49.0
45-1160	CARSON FISH HATCHERY	WA	45.8667	121.9667	1134	1977	2000	24	14	DY	102.0
45-1160	CARSON FISH HATCHERY	WA	45.8667	121.9667	1134	1977	2000	24	14	HR	102.0
35-1407	CASCADE LOCKS	OR	45.6833	121.8833	102	1948	1954	7	15	DY	89.1
45-1191	CASTLE ROCK 2 NW	WA	46.2667	122.9167	39	1954	1978	25	31	HR	47.7
45-1205	CATHLAMET 6 NE	WA	46.2667	123.3000	180	1959	2000	42	142	DY	77.3
45-1207	CATHLAMET 9 NE	WA	46.3167	123.2667	479	1948	1959	12	142	DY	80.9
45-1233	CEDAR LAKE	WA	47.4167	121.7333	1560	1931	2000	70	15	DY	106.9
45-1233	CEDAR LAKE	WA	47.4167	121.7333	1560	1953	2000	48	15	HR	106.9
45-1276	CENTRALIA	WA	46.7167	122.9500	185	1902	2000	99	31	DY	46.2
45-1277	CENTRALIA 1 W	WA	46.7000	122.9667	185	1941	2000	60	31	HR	46.1
1021480	CHATHAM POINT	BC	50.3333	125.4333	75	1958	1995	38	142	DY	86.3
1011500	CHEMAINUS	BC	48.9333	123.7333	246	1919	1995	77	32	DY	44.5
35-1552	CHERRY GROVE 2 S	OR	45.4167	123.2500	781	1948	1983	36	32	DY	54.3
1101530	CHILLIWACK	BC	49.1667	121.9333	19	1879	1995	117	14	DY	70.7

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
1101N65	CHILLIWACK R HATCHER	BC	49.0833	121.7000	698	1961	1995	35	15	DY	62.6
45-1414	CHIMACUM 4 S	WA	47.9500	122.7833	140	1944	2000	57	32	DY	29.2
45-1426	CHIWAWA RIVER	WA	48.0333	120.8333	2713	1935	1958	24	14	DY	35.9
45-1457	CINEBAR 2 E	WA	46.6000	122.4833	1040	1941	2000	60	15	HR	57.9
21D13S	CLACKAMAS LAKE	OR	45.0833	121.7500	3400	1981	2000	20	14	DY	56.5
45-1465	CLALLAM BAY 1 NNE	WA	48.2667	124.2500	30	1928	1976	49	142	DY	83.4
35-1643	CLATSKANIE	OR	46.1000	123.2000	22	1948	2000	53	32	DY	52.3
35-1643	CLATSKANIE	OR	46.1000	123.2000	22	1954	2000	47	32	HR	52.3
45-1504	CLE ELUM	WA	47.1833	120.9500	1920	1901	2000	100	14	DY	26.8
21D12S	CLEAR LAKE	OR	45.2000	121.7167	3500	1981	2000	20	14	DY	55.1
45-1484	CLEARBROOK	WA	48.9667	122.3333	64	1903	2000	98	31	DY	51.2
45-1496	CLEARWATER	WA	47.5833	124.3000	80	1931	2000	70	5	DY	117.6
45-1496	CLEARWATER	WA	47.5833	124.3000	80	1943	2000	58	5	HR	117.6
35-1682	CLOVERDALE	OR	45.2000	123.8833	12	1948	2000	53	5	DY	98.5
35-1735	COLTON	OR	45.1667	122.4167	680	1948	2000	53	31	HR	58.9
1021830	COMOX A	BC	49.7167	124.9000	79	1944	1996	53	142	DY	48.6
45-1679	CONCRETE PPL FISH ST	WA	48.5500	121.7667	195	1925	2000	76	15	DY	63.7
1101890	COQUITLAM LAKE	BC	49.3667	122.8000	528	1924	1982	59	15	DY	111.5
21B13S	CORRAL PASS	WA	47.0167	121.4667	6000	1982	1999	18	14	DY	70.1
45-1759	COUGAR 4 SW	WA	46.0167	122.3500	520	1941	2000	60	15	HR	67.1
45-1760	COUGAR 6 E	WA	46.0500	122.2000	659	1930	2000	71	15	DY	121.1
21B42S	COUGAR MOUNTAIN	WA	47.2500	121.6333	3200	1982	1999	18	15	DY	89.6
45-1783	COUPEVILLE 1 S	WA	48.2000	122.7000	50	1916	2000	85	31	DY	22.4
1012010	COWICHAN BAY CHERRY	BC	48.7167	123.5500	3	1913	1995	83	32	DY	41.5
1012040	COWICHAN LAKE FOREST	BC	48.8333	124.1333	580	1931	1995	65	142	DY	84.3
1102220	CULTUS LAKE	BC	49.0833	121.9833	150	1931	1994	64	14	DY	65.2
45-1934	CUSHMAN DAM	WA	47.4167	123.2167	760	1931	1973	43	142	DY	97.0
45-1934	CUSHMAN DAM	WA	47.4167	123.2167	760	1941	2000	60	142	HR	97.0
45-1939	CUSHMAN PWR HOUSE 2	WA	47.3667	123.1500	21	1973	2000	28	32	DY	67.3
45-1992	DARRINGTON RANGER ST	WA	48.2500	121.6000	550	1931	2000	70	15	DY	73.6
45-1992	DARRINGTON RANGER ST	WA	48.2500	121.6000	550	1941	2000	60	15	HR	73.6
45-2157	DIABLO DAM	WA	48.7167	121.1500	891	1931	2000	70	14	DY	69.1
45-2157	DIABLO DAM	WA	48.7167	121.1500	891	1944	2000	57	14	HR	69.1
35-2325	DILLEY 1 S	OR	45.4833	123.1167	165	1948	2000	53	32	DY	45.5
35-2348	DIXIE MOUNTAIN	OR	45.6833	122.9167	1430	1976	2000	25	32	HR	66.9
45-2220	DOTY 3 E	WA	46.6333	123.2000	260	1958	2000	43	32	DY	55.2
45-2253	DRYAD	WA	46.6333	123.2500	310	1937	1978	42	32	DY	56.3
45-2309	DUVALL 3NE	WA	47.7666	121.9333	813	1932	1954	23	31	DY	57.9
35-2493	EAGLE CREEK 9 SE	OR	45.2667	122.2000	926	1973	2000	28	15	DY	68.8
KI-14U	EAST FK ISSAQUAH CRK	WA	47.5327	121.9873	520	1988	2000	13	15	DY	79.3
45-2384	EASTON	WA	47.2333	121.1833	2170	1941	2000	60	14	HR	49.5
TH-1938	EATON CREEK	WA	46.9742	122.7300	264	1992	2000	9	31	HR	45.0
21A32S	ELBOW LAKE	WA	48.6833	121.9000	3200	1996	1999	4	15	DY	97.7
45-2493	ELECTRON HEADWORKS	WA	46.9000	122.0333	1730	1948	1980	33	15	DY	69.6
45-2493	ELECTRON HEADWORKS	WA	46.9000	122.0333	1730	1943	1980	38	15	HR	69.6
45-2500	ELK MOUNTAIN	WA	46.1333	122.4667	4480	1983	1990	8	15	HR	118.4
45-2531	ELMA	WA	47.0000	123.4000	70	1928	2000	73	32	DY	67.2
45-2548	ELWHA R S	WA	48.0333	123.5833	360	1943	2000	58	142	DY	56.3
1012700	ESQUIMALT	BC	48.4333	123.4167	45	1872	1950	79	32	DY	35.0
35-2693	ESTACADA 2 SE	OR	45.2667	122.3167	450	1948	2000	53	31	DY	62.6
35-2697	ESTACADA 24 SE	OR	45.0667	121.9667	2200	1948	2000	53	15	HR	72.2
KI-18U	EVANS CREEK	WA	47.6873	122.0305	150	1989	2000	12	31	DY	49.8
45-2675	EVERETT	WA	47.9833	122.1833	60	1930	2000	71	31	DY	37.4
45-2675	EVERETT	WA	47.9833	122.1833	60	1941	2000	60	31	HR	37.4
21B04S	FISH LAKE	WA	47.5167	121.0667	3371	1982	1999	18	14	DY	74.5
35-2997	FOREST GROVE	OR	45.5167	123.1000	180	1928	2000	73	32	DY	43.6
45-2914	FORKS 1 E	WA	47.9500	124.3500	350	1928	2000	73	151	DY	122.0
45-2984	FRANCES	WA	46.5500	123.5000	231	1941	2000	60	142	HR	97.8
45-3160	GLACIER R S	WA	48.8833	121.9500	935	1935	1983	49	15	DY	65.5
45-3160	GLACIER R S	WA	48.8833	121.9500	935	1971	2000	30	15	HR	65.5
45-3177	GLENOMA	WA	46.5167	122.1333	840	1906	2000	95	15	DY	68.0
45-3183	GLENWOOD	WA	46.0167	121.2833	1896	1941	2000	60	14	HR	34.7
35-3318	GLENWOOD 2 WNW	OR	45.6500	123.3000	644	1948	2000	53	142	HR	65.8
35-3340	GOBLE 3 SW	OR	45.9833	122.9167	530	1948	2000	53	32	HR	48.3
1033232	GOLD RIVER TOWNSITE	BC	49.7833	126.0500	383	1966	1995	30	142	DY	121.8
1013240	GOLDSTREAM LAKE	BC	48.4500	123.5500	1505	1894	1953	60	142	DY	43.7
35-3402	GOVERNMENT CAMP	OR	45.3000	121.7333	3980	1951	2000	50	15	DY	72.6
35-3402	GOVERNMENT CAMP	OR	45.3000	121.7333	3980	1955	2000	46	15	HR	72.6
35-3421	GRAND RONDE TREE FAR	OR	45.0500	123.6167	395	1948	2000	53	5	HR	56.1
45-3284	GRAPEVIEW 3 SW	WA	47.3000	122.8667	51	1931	1995	65	32	DY	53.1
45-3320	GRAYLAND	WA	46.8000	124.0833	10	1948	2000	53	5	DY	77.5
45-3333	GRAYS RIVER HATCHERY	WA	46.3833	123.5667	100	1962	2000	39	5	DY	107.4
45-3333	GRAYS RIVER HATCHERY	WA	46.3833	123.5667	100	1954	2000	47	5	HR	107.4
21C10S	GREEN LAKE	WA	46.5500	121.1667	6000	1983	1999	17	14	DY	38.4
21D01S	GREENPOINT	OR	45.6167	121.7000	3200	1980	2000	21	14	DY	57.6
45-3357	GREENWATER	WA	47.1333	121.6333	1730	1939	1981	43	15	DY	61.6
45-3357	GREENWATER	WA	47.1333	121.6333	1730	1940	1999	60	15	HR	61.6

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
35-3521	GRESHAM	OR	45.4833	122.4167	310	1948	2000	53	31	HR	53.0
45-3386	GROTTO	WA	47.7333	121.4167	850	1948	1970	23	15	DY	110.0
20B11S	GROUSE CAMP	WA	47.2667	120.4833	5380	1983	1999	17	14	DY	30.1
1103332	HANEY UBC RF ADMIN	BC	49.2667	122.5667	469	1962	1996	35	15	HR	88.0
KP-24	HANSVILLE-HOOD CANAL	WA	47.9064	122.5686	230	1982	2000	19	32	DY	30.1
20A05S	HARTS PASS	WA	48.7167	120.6500	6500	1982	1999	18	14	DY	54.2
20A05S	HARTS PASS 2	WA	48.7167	120.6500	6500	1991	1994	4	14	DY	54.2
35-3705	HASKINS DAM	OR	45.3000	123.3500	756	1948	2000	53	142	DY	72.6
35-3705	HASKINS DAM	OR	45.3000	123.3500	756	1948	2000	53	142	HR	72.6
35-3770	HEADWORKS PTLD WTR B	OR	45.4500	122.1500	748	1931	2000	70	15	DY	75.6
35-3770	HEADWORKS PTLD WTR B	OR	45.4500	122.1500	748	1976	2000	25	15	HR	75.6
35-3908	HILLSBORO	OR	45.5000	122.9833	160	1948	2000	53	32	DY	38.8
45-3730	HOLDEN VILLAGE	WA	48.2000	120.7833	3220	1938	2000	63	14	DY	44.5
KP-25	HOLLY BEACH	WA	47.5578	122.9775	15	1991	2000	10	32	DY	56.4
1103510	HOLLYBURN RIDGE	BC	49.3833	123.1833	3051	1954	1995	42	15	DY	112.1
35-4003	HOOD RIVER EXP STN	OR	45.6833	121.5167	500	1928	2000	73	14	DY	29.8
35-4008	HOOD RIVER TUCKER BR	OR	45.6500	121.5333	383	1941	2000	60	14	HR	30.6
1113540	HOPE A	BC	49.3667	121.4833	127	1934	1995	62	14	DY	66.8
1113540	HOPE A	BC	49.3667	121.4833	127	1947	1991	45	14	S6	66.8
1113550	HOPE KAWKAWA LAKE	BC	49.3833	121.4000	498	1910	1977	68	14	DY	62.5
1113581	HOPE SLIDE	BC	49.2833	121.2333	2211	1975	1995	21	14	DY	56.1
45-3807	HOQUIAM FCWOS AP	WA	46.9833	123.9333	12	1943	2000	58	5	DY	73.6
45-3826	HUMPTULIPS SALMON HA	WA	47.2333	123.9833	140	1987	2000	14	151	DY	93.1
45-3909	INDEX	WA	47.8167	121.5500	531	1935	1956	22	15	DY	101.5
1103660	IOCO REFINERY	BC	49.3000	122.8833	173	1916	1995	80	31	DY	73.1
1013720	JAMES ISLAND	BC	48.6000	123.3500	177	1914	1978	65	32	DY	31.9
35-4276	JEWELL WILDLIFE MEAD	OR	45.9333	123.5167	570	1954	2000	47	142	HR	94.5
1013754	JORDAN RIVER DIVERSI	BC	48.5000	124.0000	1289	1973	1996	24	151	HR	122.5
22C09S	JUNE LAKE	WA	46.1333	122.1500	3340	1983	1999	17	15	DY	111.0
45-4085	KALAMA 5 ENE	WA	46.0500	122.7500	902	1948	1967	20	15	DY	59.1
45-4084	KALAMA FALLS HATCHER	WA	46.0167	122.7167	312	1968	2000	33	15	DY	64.0
45-4169	KENT	WA	47.4000	122.2333	30	1912	2000	89	31	DY	38.7
45-4187	KEYPORT TORPEDO STN	WA	47.7000	122.6167	39	1915	1958	44	32	DY	44.2
45-4201	KID VALLEY	WA	46.3667	122.6167	689	1941	1980	40	15	DY	70.2
1034170	KILDONAN	BC	49.0000	125.0000	9	1937	1976	40	151	DY	172.7
45-4360	LA GRANDE	WA	46.8333	122.3167	961	1954	1983	30	15	DY	44.9
1104468	LADNER	BC	49.0833	123.0667	29	1878	1934	57	31	DY	44.1
1104488	LAIDLAW	BC	49.3500	121.5833	88	1977	1995	19	14	DY	80.5
45-4394	LAKE CLE ELUM	WA	47.2500	121.0667	2260	1909	1977	69	14	DY	38.9
1014493	LAKE COWICHAN	BC	48.8167	124.0500	590	1924	1995	72	142	DY	101.8
45-4406	LAKE KACHESS	WA	47.2667	121.2000	2270	1908	1977	70	14	DY	57.2
45-4414	LAKE KEECHELUS	WA	47.3167	121.3333	2480	1908	1977	70	14	DY	74.3
45-4438	LAKE SUTHERLAND	WA	48.0833	123.7000	570	1929	1976	48	142	DY	59.9
45-4446	LAKE WENATCHEE	WA	47.8333	120.7833	2005	1914	2000	87	14	DY	38.1
45-4446	LAKE WENATCHEE	WA	47.8333	120.7833	2005	1971	2000	30	14	HR	38.1
45-4454	LAKE WHATCOM	WA	48.6833	122.3000	322	1944	1954	11	15	DY	57.5
45-4486	LANDSBURG	WA	47.3833	121.9833	535	1931	2000	70	31	DY	56.0
45-4486	LANDSBURG	WA	47.3833	121.9833	535	1954	2000	47	31	HR	56.0
45-4572	LEAVENWORTH 3 S	WA	47.5500	120.6667	1128	1914	2000	87	14	DY	28.1
35-4824	LEES CAMP	OR	45.5833	123.5167	655	1948	2000	53	151	HR	113.6
45-4634	LESTER	WA	47.2000	121.4833	1630	1948	1975	28	15	HR	80.4
21C26S	LONE PINE	WA	46.2667	121.9667	3800	1982	1999	18	15	DY	92.2
45-4748	LONG BEACH EXP STN	WA	46.3667	124.0333	30	1953	2000	48	5	DY	82.6
45-4764	LONGMIRE RAINIER NPS	WA	46.7500	121.8167	2762	1909	2000	92	15	DY	84.7
45-4764	LONGMIRE RAINIER NPS	WA	46.7500	121.8167	2762	1979	2000	22	15	HR	84.7
45-4769	LONGVIEW	WA	46.1500	122.9167	12	1931	2000	70	31	DY	46.1
45-4769	LONGVIEW	WA	46.1500	122.9167	12	1954	2000	47	31	HR	46.1
21C39S	LOST HORSE	WA	46.3500	121.1167	5000	1991	1999	9	14	DY	34.6
45-4849	LUCERNE 1 N	WA	48.2333	120.6000	1200	1942	1989	48	14	HR	22.6
20A23S	LYMAN LAKE	WA	48.2000	120.9167	5900	1980	1999	20	14	DY	84.8
45-4999	MARBLEMOUNT RANGER S	WA	48.5333	121.4500	348	1941	2000	60	15	HR	69.8
45-5028	MARIETTA 3 NNW	WA	48.8333	122.6000	20	1914	1958	45	31	DY	41.2
45-5080	MATLOCK 3 W	WA	47.2333	123.4833	340	1945	1985	41	32	DY	101.3
45-5086	MATLOCK 8 S	WA	47.1500	123.4000	110	1986	2000	15	32	DY	94.3
45-5110	MAYFIELD POWER PLANT	WA	46.5000	122.5833	280	1980	2000	21	31	DY	56.7
45-5128	MAZAMA 6 SE	WA	48.5333	120.3333	1962	1948	1977	30	14	DY	23.3
45-5149	MC CHORD AFB	WA	47.1500	122.4833	290	1941	1979	39	31	HR	39.8
45-5224	MC MILLIN RESERVOIR	WA	47.1333	122.2667	579	1941	2000	60	31	DY	41.5
45-5224	MC MILLIN RESERVOIR	WA	47.1333	122.2667	579	1941	2000	60	31	HR	41.5
35-5384	MC MINNVILLE	OR	45.2167	123.1500	155	1928	2000	73	32	DY	41.6
21B59S	MEADOWS PASS	WA	47.2667	121.4667	3500	1994	1999	6	14	DY	105.0
45-5305	MERWIN DAM	WA	45.9500	122.5500	224	1934	2000	67	31	DY	67.4
45-5305	MERWIN DAM	WA	45.9500	122.5500	224	1983	1988	6	31	HR	67.4
1015105	METCHOSIN	BC	48.3833	123.5667	400	1915	1995	81	32	DY	39.9
45-5425	MINERAL 1 SW	WA	46.7167	122.1833	1470	1935	1980	46	15	DY	84.3
20A40S	MINERS RIDGE	WA	48.1667	120.9833	6200	1989	1999	11	14	DY	95.0
20A39S	MIRROR LAKE	WA	48.1500	120.6500	5600	1983	1988	6	14	DY	46.0

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
35-5629	MIST 1 SE	OR	45.9833	123.2500	500	1948	1958	11	32	HR	54.8
45-5488	MOCLIPS	WA	47.2167	124.2000	120	1942	1957	16	5	HR	91.9
35-5677	MOLALLA	OR	45.1500	122.5667	400	1948	1977	30	31	DY	48.1
45-5525	MONROE	WA	47.8333	121.9833	120	1929	2000	72	31	DY	49.6
45-5549	MONTESANO 1 S	WA	46.9667	123.6167	25	1948	1953	6	32	DY	77.1
45-5549	MONTESANO 1 S	WA	46.9667	123.6167	25	1954	2000	47	32	HR	77.1
21C17S	MORSE LAKE	WA	46.9000	121.4833	5400	1979	1999	21	14	DY	76.5
45-5659	MOUNT ADAMS RANGER S	WA	46.0000	121.5333	1960	1925	2000	76	14	DY	42.4
45-5659	MOUNT ADAMS RANGER S	WA	46.0000	121.5333	1960	1971	2000	30	14	HR	42.4
45-5663	MOUNT BAKER LODGE	WA	48.8667	121.6667	4150	1948	1983	36	15	HR	81.1
23B06S	MOUNT CRAG	WA	47.7500	123.0000	4050	1990	1999	10	142	DY	71.9
21B21S	MOUNT GARDNER	WA	47.3500	121.5667	3000	1994	1999	6	15	DY	102.0
45-5678	MOUNT VERNON 3 WNW	WA	48.4500	122.3667	14	1956	2000	45	31	DY	33.8
21D08S	MT HOOD TEST SITE	OR	45.3333	121.7167	5400	1981	2000	20	15	DY	116.7
45-5704	MUD MOUNTAIN DAM	WA	47.1500	121.9333	1308	1939	2000	62	15	DY	61.3
45-5704	MUD MOUNTAIN DAM	WA	47.1500	121.9333	1308	1940	2000	61	15	HR	61.3
21D35S	MUD RIDGE	OR	45.2500	121.7333	3800	1979	2000	22	14	DY	62.0
1105658	N VANC GROUSE MTN RE	BC	49.3833	123.0833	3700	1971	1995	25	15	DY	110.6
1105655	N VANCOUVER CAPILANO	BC	49.3500	123.1167	305	1955	1990	36	15	DY	88.3
35-6151	N WILLAMETTE EXP STN	OR	45.2667	122.7500	150	1963	2000	38	31	DY	40.1
1025C70	NANAIMO DEPARTURE BA	BC	49.2167	123.9500	26	1913	1992	80	32	DY	39.5
45-5774	NASELLE 2 ENE	WA	46.3667	123.7500	50	1930	2000	71	5	DY	115.0
45-5801	NEAH BAY 1 E	WA	48.3667	124.6167	10	1930	1987	58	5	DY	120.3
35-5969	NEHALEM	OR	45.7167	123.9000	75	1948	2000	53	5	HR	78.7
35-5971	NEHALEM 9 NE	OR	45.8000	123.7667	140	1969	2000	32	5	DY	109.4
1105550	NEW WESTMINSTER	BC	49.2167	122.9333	390	1874	1980	107	31	DY	63.8
45-5840	NEWHALEM	WA	48.6833	121.2500	525	1926	2000	75	14	DY	89.4
1035610	NITINAT LAKE	BC	48.7500	124.7500	26	1924	1952	29	151	DY	125.7
45-5876	NOOKSACK SALMON HATC	WA	48.9000	122.1500	410	1964	2000	37	15	HR	67.0
22D02S	NORTH FORK	OR	45.5500	122.0167	3120	1980	2000	21	15	DY	132.3
45-5932	NORTH HEAD WB	WA	46.3000	124.0833	210	1940	1953	14	5	HR	81.5
KI-51U	NORWAY	WA	47.7350	122.2083	180	1988	2000	13	31	DY	38.2
45-6011	OAKVILLE	WA	46.8333	123.2333	80	1948	1998	51	32	DY	56.9
KP-34	OLALLA	WA	47.4328	122.5731	345	1983	2000	18	32	DY	47.4
21B55S	OLALLIE MEADOWS	WA	47.3667	121.4333	3700	1982	1999	18	15	DY	110.2
45-6096	OLGA 2 SE	WA	48.6167	122.8000	80	1891	2000	110	31	DY	29.8
45-6114	OLYMPIA AIRPORT	WA	46.9667	122.9000	206	1948	2000	53	32	DY	50.7
45-6114	OLYMPIA AIRPORT	WA	46.9667	122.9000	206	1948	2000	53	32	HR	50.7
45-6109	OLYMPIA PRIEST PT PA	WA	47.0667	122.8833	30	1948	1956	9	32	DY	51.5
35-6334	OREGON CITY	OR	45.3500	122.6000	167	1948	2000	53	31	DY	47.4
35-6366	OTIS 2 NE	OR	45.0167	123.9167	150	1948	2000	53	5	DY	93.5
1035940	PACHENA POINT	BC	48.7167	125.1000	121	1924	1995	72	5	DY	127.1
45-6262	PACKWOOD	WA	46.6167	121.6667	1060	1926	2000	75	15	DY	63.3
45-6295	PALMER 3 ESE	WA	47.3000	121.8500	920	1931	2000	70	15	DY	87.9
45-6295	PALMER 3 ESE	WA	47.3000	121.8500	920	1941	2000	60	15	HR	87.9
21C35S	PARADISE	WA	46.8333	121.7167	5120	1981	1999	19	15	DY	184.7
20A12S	PARK CREEK RIDGE	WA	48.4500	120.9167	4600	1979	1999	21	14	DY	61.8
35-6466	PARKDALE 1 NNE	OR	45.5333	121.5833	1520	1928	2000	73	14	DY	34.6
21D14S	PEAVINE RIDGE	OR	45.0500	121.9333	3500	1982	2000	19	15	DY	67.1
1016120	PENDER ISLAND	BC	48.7667	123.3000	85	1924	1995	72	32	DY	32.3
21C33S	PIGTAIL PEAK	WA	46.6167	121.4167	5900	1982	1999	18	14	DY	77.1
1106180	PITT POLDER	BC	49.3000	122.6333	3	1964	1996	33	31	HR	85.3
45-6534	PLAIN	WA	47.7833	120.6333	1940	1939	2000	62	14	DY	30.0
22C01S	PLAINS OF ABRAHAM	WA	46.2167	122.1500	4400	1984	1987	4	15	DY	120.9
45-6584	POINT GRENVILLE	WA	47.3000	124.2833	100	1947	1980	34	5	DY	89.4
45-6584	POINT GRENVILLE	WA	47.3000	124.2833	100	1957	1977	21	5	HR	89.4
20B24S	POPE RIDGE	WA	47.9833	120.5667	3540	1982	1999	18	14	DY	36.9
1036205	PORT ALBERNI	BC	49.2333	124.8000	193	1917	1981	65	142	DY	81.7
1036240	PORT ALICE	BC	50.3833	127.4500	68	1924	1995	72	151	DY	148.5
45-6624	PORT ANGELES	WA	48.1000	123.4167	90	1948	2000	53	32	DY	33.5
45-6624	PORT ANGELES	WA	48.1000	123.4167	90	1941	2000	60	32	HR	33.5
1016335	PORT RENFREW	BC	48.5833	124.3333	39	1970	1995	26	151	DY	143.9
45-6678	PORT TOWNSEND	WA	48.1000	122.7500	100	1930	2000	71	32	DY	23.2
45-6678	PORT TOWNSEND	WA	48.1000	122.7500	100	1941	1970	30	32	HR	23.2
35-6751	PORTLAND INTL AIRPOR	OR	45.5833	122.6000	19	1942	2000	59	32	DY	38.1
35-6751	PORTLAND INTL AIRPOR	OR	45.5833	122.6000	19	1941	2000	60	32	HR	38.1
35-6749	PORTLAND KGW-TV	OR	45.5167	122.6833	160	1928	2000	73	32	DY	45.2
35-6749	PORTLAND KGW-TV	OR	45.5167	122.6833	160	1948	2000	53	32	HR	45.2
21C14S	POTATO HILL	WA	46.3000	121.5000	4500	1982	1999	18	14	DY	71.9
KP-15	POULSBO	WA	47.7355	122.6583	18	1988	2000	13	32	DY	43.4
45-6803	PUYALLUP 2 W EXP STN	WA	47.2000	122.3333	50	1914	1995	82	31	DY	40.6
1036570	QUATSINO	BC	50.5333	127.6500	26	1895	1995	101	142	DY	99.6
45-6846	QUILCENE 2 SW	WA	47.8167	122.9167	123	1936	2000	65	32	DY	48.6
45-6851	QUILCENE 5 SW DAM	WA	47.7833	122.9833	1028	1941	2000	60	142	HR	68.2
45-6858	QUILLAYUTE WSCMO AP	WA	47.9333	124.5500	179	1966	2000	35	5	DY	104.8
45-6858	QUILLAYUTE WSCMO AP	WA	47.9333	124.5500	179	1966	2000	35	5	HR	104.8
45-6864	QUINAULT RANGER STN	WA	47.4667	123.8500	220	1906	1977	72	151	DY	110.9

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
45-6864	QUINAULT RANGER STN	WA	47.4667	123.8500	220	1977	2000	24	151	HR	110.9
45-6887	RAINBOW FALLS PK 2 E	WA	46.6333	123.1833	280	1948	1963	16	32	DY	55.2
45-6892	RAINIER CARBON RIVER	WA	47.0000	121.9167	1735	1948	2000	53	15	HR	78.3
45-6896	RAINIER OHANAPECOSH	WA	46.7333	121.5667	1950	1948	2000	53	15	DY	75.5
45-6896	RAINIER OHANAPECOSH	WA	46.7333	121.5667	1950	1941	2000	60	15	HR	75.5
45-6898	RAINIER PARADISE RNG	WA	46.7833	121.7333	5427	1924	2000	77	15	DY	112.5
20A09S	RAINY PASS	WA	48.5500	120.7167	4780	1982	1999	18	14	DY	61.7
45-6909	RANDLE 1 E	WA	46.5333	121.9333	900	1930	2000	71	15	DY	56.9
45-6909	RANDLE 1 E	WA	46.5333	121.9333	900	1954	2000	47	15	HR	56.9
45-6914	RAYMOND 2 S	WA	46.6500	123.7167	30	1980	2000	21	5	DY	92.2
21D04S	RED HILL	OR	45.4667	121.7000	4400	1979	2000	22	14	DY	92.2
35-7127	REX 1 S	OR	45.3000	122.9000	515	1948	2000	53	32	DY	44.8
35-7127	REX 1 S	OR	45.3000	122.9000	515	1948	2000	53	32	HR	44.8
21B17S	REX RIVER	WA	47.3333	121.6000	4000	1996	1999	4	15	DY	100.8
45-7010	RICHARDSON 3 SE	WA	48.4333	122.8333	30	1949	1958	10	32	DY	27.2
45-7038	RIMROCK TIETON DAM	WA	46.6500	121.1333	2733	1917	1977	61	14	DY	24.4
1016780	RIVER JORDAN	BC	48.4167	124.0500	9	1908	1972	65	5	DY	119.7
1106865	ROSEDALE	BC	49.1833	121.8000	36	1967	1988	22	14	DY	65.1
45-7185	ROSS DAM	WA	48.7333	121.0500	1236	1960	2000	41	14	DY	60.4
1016940	SAANICHTON CDA	BC	48.6167	123.4167	200	1914	1995	82	32	DY	34.7
23D01S	SADDLE MOUNTAIN	OR	45.5333	123.3667	3250	1980	2000	21	142	DY	88.4
KP-12	SAKAI INTERMEDIATE SCH	WA	47.6445	122.5288	60	1991	2000	10	32	DY	43.2
19A02S	SALMON MEADOWS	WA	48.6667	119.8333	4500	1982	1999	18	99	DY	24.1
1016990	SALTSPRING ISLAND	BC	48.8500	123.5000	239	1893	1977	85	32	DY	39.0
45-7294	SAM HENRY MOUNTAIN	WA	46.5167	123.0167	1460	1983	1989	7	32	HR	58.8
45-7319	SAPPHO 8 E	WA	48.0667	124.1167	760	1948	1997	50	151	DY	91.2
45-7319	SAPPHO 8 E	WA	48.0667	124.1167	760	1940	1998	59	151	HR	91.2
21B51S	SASSE RIDGE	WA	47.3667	121.0500	4200	1984	1999	16	14	DY	60.6
45-7342	SATUS PASS 2 SSW	WA	45.9500	120.6667	2610	1956	2000	45	99	DY	22.5
35-7572	SAUVIES ISLAND	OR	45.6500	122.8333	40	1948	2000	53	32	HR	45.2
45-7379	SCENIC	WA	47.7000	121.1500	2221	1929	1970	42	14	DY	95.2
35-7586	SCOGGINS DAM 2	OR	45.4833	123.2000	360	1973	1985	13	32	DY	48.2
35-7586	SCOGGINS DAM 2	OR	45.4833	123.2000	360	1973	1985	13	32	HR	48.2
35-7641	SEASIDE	OR	45.9833	123.9167	10	1930	2000	71	5	DY	74.8
45-7459	SEATTLE JACKSON PARK	WA	47.7333	122.3333	370	1941	1986	46	31	DY	36.5
45-7470	SEATTLE SAND PT WSFO	WA	47.6833	122.2500	60	1948	2000	53	31	DY	37.5
45-7473	SEATTLE TACOMA AIRPO	WA	47.4500	122.3000	400	1948	2000	53	31	DY	37.9
45-7473	SEATTLE TACOMA AIRPO	WA	47.4500	122.3000	400	1941	2000	60	31	HR	37.9
45-7478	SEATTLE UNIV OF WASH	WA	47.6500	122.2833	95	1909	1983	75	31	DY	37.2
45-7458	SEATTLE URBAN SITE	WA	47.6500	122.3000	19	1948	1998	51	31	DY	37.0
45-7458	SEATTLE URBAN SITE	WA	47.6500	122.3000	19	1940	1998	59	31	HR	37.0
45-7483	SEATTLE WB AP	WA	47.5333	122.3000	10	1948	1965	18	31	DY	37.1
45-7483	SEATTLE WB AP	WA	47.5333	122.3000	10	1948	1967	20	31	HR	37.1
45-7507	SEDRO WOOLLEY	WA	48.5000	122.2333	60	1898	2000	103	31	DY	44.2
23D02S	SEINE CREEK	OR	45.5167	123.2833	2000	1981	2000	20	142	DY	60.0
45-7544	SEQUIM 2 E	WA	48.0833	123.0500	50	1916	2000	85	32	DY	17.3
1107200	SEYMOUR FALLS	BC	49.4333	122.9667	800	1927	1995	69	15	DY	138.0
1017230	SHAWNIGAN LAKE	BC	48.6500	123.6167	449	1911	1995	85	32	DY	45.9
22C10S	SHEEP CANYON	WA	46.1833	122.2500	4030	1981	1999	19	15	DY	113.2
45-7584	SHELTON	WA	47.2000	123.1000	22	1931	1999	69	32	DY	63.6
45-7604	SHUKSAN	WA	48.9167	121.7000	2031	1955	1974	20	15	HR	86.5
35-7823	SILVERTON	OR	45.0000	122.7667	408	1962	2000	39	31	DY	45.0
35-7823	SILVERTON	OR	45.0000	122.7667	408	1962	2000	39	31	HR	45.0
45-7657	SILVERTON	WA	48.0667	121.5667	1475	1941	1988	48	15	HR	104.4
45-7690	SKAGIT POWER PLANT	WA	48.6833	121.2500	531	1931	1959	29	14	DY	89.4
1117410	SKAGIT RIVER	BC	49.0833	121.1667	1689	1936	1955	20	14	DY	59.5
45-7696	SKAMANIA FISH HATCHE	WA	45.6167	122.2167	440	1965	2000	36	15	DY	81.9
21B60S	SKOOKUM CREEK	WA	47.6833	121.6000	3920	1996	1999	4	15	DY	94.7
45-7709	SKYKOMISH 1 ENE	WA	47.7000	121.3667	1030	1941	2000	60	15	HR	98.3
SN-7124	SMOKEY POINT FIRE STN	WA	48.1136	122.1847	100	1991	2000	10	31	DY	40.9
45-7773	SNOQUALMIE FALLS	WA	47.5333	121.8333	440	1931	2000	70	31	DY	69.0
45-7773	SNOQUALMIE FALLS	WA	47.5333	121.8333	440	1954	2000	47	31	HR	69.0
45-7781	SNOQUALMIE PASS	WA	47.4167	121.4000	3020	1931	1972	42	15	DY	100.0
45-7781	SNOQUALMIE PASS	WA	47.4167	121.4000	3020	1941	2000	60	15	HR	100.0
45-7871	SO OLYMPIC TREE FARM	WA	47.2333	123.5833	580	1945	1956	12	151	DY	115.5
1017560	SOOKE LAKE	BC	48.5167	123.7000	567	1903	1966	64	142	DY	59.5
1017563	SOOKE LAKE NORTH	BC	48.5667	123.6500	757	1966	1995	30	142	DY	57.4
21C20S	SPENCER MEADOW	WA	46.1833	121.9333	3400	1982	1999	18	15	DY	89.6
22C12S	SPIRIT LAKE	WA	46.2667	122.1667	3120	1986	1999	14	15	DY	88.1
45-7919	SPIRIT LAKE R S	WA	46.2667	122.1500	3240	1941	1958	18	15	HR	87.7
45-7987	SPRUCE	WA	47.8000	124.0667	370	1927	1981	55	151	DY	132.6
35-7466	ST HELENS RFD	OR	45.8500	122.8000	100	1976	2000	25	32	DY	43.1
45-8009	STAMPEDE PASS	WA	47.2833	121.3333	3958	1944	2000	57	14	DY	89.0
21B10S	STAMPEDE PASS	WA	47.2833	121.3333	3860	1983	1999	17	14	DY	89.0
45-8009	STAMPEDE PASS	WA	47.2833	121.3333	3958	1943	2000	58	14	HR	89.0
45-8034	STARTUP 1 E	WA	47.8667	121.7167	170	1939	2000	62	31	DY	67.0
1107680	STAVE FALLS	BC	49.2333	122.3667	360	1909	1995	87	15	DY	89.3

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
45-8059	STEHEKIN 4 NW	WA	48.3500	120.7167	1270	1917	2000	84	14	DY	34.6
45-8059	STEHEKIN 4 NW	WA	48.3500	120.7167	1270	1976	2000	25	14	HR	34.6
45-8089	STEVENS PASS	WA	47.7333	121.0833	4070	1939	1994	56	14	DY	84.8
21B01S	STEVENS PASS	WA	47.7333	121.0833	4070	1981	1999	19	14	DY	84.8
45-8089	STEVENS PASS	WA	47.7333	121.0833	4070	1971	2000	30	14	HR	84.8
1107710	STEVESTON	BC	49.1333	123.1833	3	1896	1995	100	31	DY	45.0
45-8115	STOCKDILL RANCH	WA	48.3667	120.3333	2200	1922	1964	43	14	DY	29.8
22C08S	STRAWBERRY LANDING	WA	46.3333	122.0500	4800	1983	1989	7	15	DY	107.4
21C13S	SURPRISE LAKES	WA	46.1000	121.7500	4250	1981	1999	19	14	DY	90.5
45-8278	TACOMA 1	WA	47.2333	122.4000	25	1935	2000	66	31	DY	38.5
1037890	TAHSIS	BC	49.9167	126.6500	16	1952	1988	37	151	DY	149.3
45-8332	TATOOSH ISLAND WB	WA	48.3833	124.7333	100	1931	1966	36	5	DY	94.4
45-8332	TATOOSH ISLAND WB	WA	48.3833	124.7333	100	1940	1966	27	5	HR	94.4
35-8466	THREE LYNX	OR	45.1167	122.0667	1120	1931	2000	70	15	DY	72.0
35-8466	THREE LYNX	OR	45.1167	122.0667	1120	1971	2000	30	15	HR	72.0
20A07S	THUNDER BASIN	WA	48.5167	120.9833	4200	1988	1999	12	14	DY	99.2
45-8442	TIETON INTAKE	WA	46.6667	121.0000	2280	1920	1972	53	99	DY	20.0
35-8494	TILLAMOOK 1 W	OR	45.4500	123.8667	10	1948	2000	53	5	DY	88.3
35-8504	TILLAMOOK 12 ESE	OR	45.4000	123.5833	420	1949	2000	52	151	HR	112.5
35-8505	TILLAMOOK 13 ENE	OR	45.5500	123.6000	390	1970	1978	9	151	DY	117.6
35-8522	TIMBER	OR	45.7167	123.3000	940	1948	1976	29	142	DY	65.8
21B20S	TINKHAM CREEK	WA	47.3167	121.4667	3070	1994	1999	6	15	DY	114.3
45-8500	TOLEDO	WA	46.4667	122.8333	325	1950	2000	51	32	DY	44.1
45-8508	TOLT SOUTH FORK RESE	WA	47.7000	121.7833	1800	1963	2000	38	15	DY	77.5
20B25S	TROUGH	WA	47.2333	120.3167	5300	1979	1999	21	14	DY	28.1
35-8634	TROUTDALE SUBSTATION	OR	45.5500	122.4000	29	1948	2000	53	31	DY	45.6
45-8688	UNDERWOOD 4 W	WA	45.7333	121.6000	1260	1941	1962	22	14	HR	43.0
45-8715	UPPER BAKER DAM	WA	48.6500	121.6833	690	1960	2000	41	15	DY	77.6
45-8715	UPPER BAKER DAM	WA	48.6500	121.6833	690	1965	2000	36	15	HR	77.6
KI-25U	UPPER ISSAQUAH CREEK	WA	47.4123	121.9263	750	1988	2000	13	31	DY	66.7
20B07S	UPPER WHEELER	WA	47.2833	120.3667	4400	1982	1999	18	99	DY	28.3
45-8773	VANCOUVER 4 NNE	WA	45.6667	122.6500	210	1898	2000	103	31	DY	41.5
1108446	VANCOUVER HARBOUR CS	BC	49.3000	123.1167	3	1925	1995	71	31	DY	64.2
45-8778	VANCOUVER INTERSTATE	WA	45.6167	122.6667	2	1949	1959	11	31	DY	39.5
1108447	VANCOUVER INT'L A	BC	49.1833	123.1667	6	1937	1995	59	31	DY	50.2
1108447	VANCOUVER INT'L A	BC	49.1833	123.1667	6	1947	1995	49	31	S6	50.2
45-8802	VASHON ISLAND	WA	47.4500	122.5000	230	1915	1955	41	32	DY	43.5
45-8838	VERLOT	WA	48.1000	121.7833	975	1971	2000	30	15	HR	110.3
35-8884	VERNONIA 2	OR	45.8500	123.1833	625	1948	2000	53	32	DY	52.7
35-8884	VERNONIA 2	OR	45.8500	123.1833	625	1954	2000	47	32	HR	52.7
1018610	VICTORIA GONZALES HT	BC	48.4167	123.3167	229	1898	1995	98	32	DY	30.0
1018620	VICTORIA INT'L A	BC	48.6500	123.4333	62	1940	1996	57	32	DY	35.0
1018620	VICTORIA INT'L A	BC	48.6500	123.4333	62	1947	1995	49	32	S6	35.0
35-9051	WARREN	OR	45.8167	122.8500	79	1950	1976	27	32	DY	44.2
45-8999	WASHOUGAL 8 NE	WA	45.6000	122.1833	761	1950	1965	16	15	DY	72.0
45-9021	WAUNA 3 W	WA	47.3667	122.7000	17	1939	2000	62	32	DY	50.8
21A31S	WELLS CREEK	WA	48.8500	121.7833	4200	1996	1999	4	15	DY	99.1
35-9208	WEST LINN	OR	45.3333	122.6500	70	1948	1969	22	31	DY	47.6
45-9112	WESTPORT 2 S	WA	46.8667	124.1000	20	1940	2000	61	5	HR	76.2
21C28S	WHITE PASS E.S.	WA	46.6333	121.3833	4500	1981	1999	19	14	DY	77.5
45-9171	WHITE RIVER R S	WA	46.9000	121.5500	3500	1949	1976	28	15	DY	71.7
45-9171	WHITE RIVER R S	WA	46.9000	121.5500	3500	1944	1981	38	15	HR	71.7
1108910	WHITE ROCK CAMPBELL	BC	49.0167	122.7833	49	1929	1995	67	31	DY	48.8
35-9372	WILLAMINA	OR	45.0667	123.4833	230	1948	2000	53	32	DY	48.5
45-9291	WILLAPA HARBOR	WA	46.6833	123.7500	10	1910	1980	71	5	DY	88.1
45-9295	WILLARD FISH LAB	WA	45.7667	121.6333	770	1962	1976	15	14	HR	59.0
45-9342	WIND RIVER	WA	45.8000	121.9333	1150	1911	1977	67	15	DY	101.5
45-9358	WINTERS MOUNTAIN	WA	46.4500	122.3167	3650	1983	1989	7	15	HR	78.1
45-9376	WINTHROP 1 WSW	WA	48.4667	120.1833	1755	1906	2000	95	99	DY	13.7
45-9485	YELM	WA	46.9500	122.6000	351	1941	1979	39	31	HR	42.7

Table A2 – Station Catalog of Gages Used in Analyses of Precipitation Annual Maxima at 2-Hour Duration

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
1100030	ABBOTSFORD A	BC	49.0333	122.3667	190	1976	1996	21	31	HR	57.8
45-0013	ABERDEEN 20 NNE	WA	47.2667	123.7000	435	1940	2000	61	151	HR	131.0
1100120	AGASSIZ CDA	BC	49.2500	121.7667	49	1960	1990	31	14	HR	67.6
1030426	AMPHITRITE POINT	BC	48.9167	125.5500	88	1980	1996	17	5	HR	130.3
35-0328	ASTORIA AP PORT OF	OR	46.1500	123.8667	9	1953	2000	48	5	HR	77.3
45-0324	AUBURN	WA	47.3167	122.2333	79	1954	1977	24	31	HR	38.5
45-0400	BALDY MOUNTAIN	WA	46.1000	122.7000	2190	1983	1989	7	15	HR	90.2
35-0571	BEAR SPRINGS RS	OR	45.1167	121.5333	3360	1961	2000	40	14	HR	28.5
45-0574	BELLINGHAM CAA AP	WA	48.8000	122.5333	147	1941	1952	12	31	HR	39.4
45-0729	BLAINE	WA	49.0000	122.7500	60	1941	2000	60	31	HR	45.6
35-0897	BONNEVILLE DAM	OR	45.6333	121.9500	62	1940	2000	61	15	HR	78.1
35-1033	BRIGHTWOOD 1 WNW	OR	45.3833	122.0333	978	1971	2000	30	15	HR	79.1
1101140	BUNTZEN LAKE	BC	49.3833	122.8667	32	1969	1983	15	15	HR	131.7
45-0986	BURLINGTON	WA	48.4667	122.3167	30	1941	2000	60	31	HR	36.5
110JA54	BURNABY MTN BCHPA	BC	49.2833	122.9167	1525	1974	1992	19	15	HR	71.0
35-1222	BUXTON	OR	45.6833	123.1833	355	1948	2000	53	32	HR	55.2
35-1227	BUXTON MOUNTAINDALE	OR	45.6833	123.0667	360	1948	1975	28	32	HR	53.5
45-1064	CAMP GRISDALE	WA	47.3667	123.6000	820	1956	1986	31	151	HR	166.4
TH-1168	CAPITOL FOREST	WA	46.9215	123.0900	450	1995	2000	6	142	HR	80.0
45-1146	CARNATION 4 NW	WA	47.6833	121.9833	50	1941	2000	60	31	HR	49.0
1031413	CARNATION CREEK CDF	BC	48.9000	125.0000	200	1975	1986	12	5	HR	130.7
45-1160	CARSON FISH HATCHERY	WA	45.8667	121.9667	1134	1977	2000	24	14	HR	102.0
45-1191	CASTLE ROCK 2 NW	WA	46.2667	122.9167	39	1954	1978	25	31	HR	47.7
45-1233	CEDAR LAKE	WA	47.4167	121.7333	1560	1953	2000	48	15	HR	106.9
45-1277	CENTRALIA 1 W	WA	46.7000	122.9667	185	1941	2000	60	31	HR	46.1
45-1457	CINEBAR 2 E	WA	46.6000	122.4833	1040	1941	2000	60	15	HR	57.9
35-1643	CLATSKANIE	OR	46.1000	123.2000	22	1954	2000	47	32	HR	52.3
45-1496	CLEARWATER	WA	47.5833	124.3000	80	1943	2000	58	5	HR	117.6
35-1735	COLTON	OR	45.1667	122.4167	680	1948	2000	53	31	HR	58.9
1021830	COMOX A	BC	49.7167	124.9000	78	1962	1996	35	142	HR	48.6
1101890	COQUITLAM LAKE	BC	49.3667	122.8000	528	1970	1982	13	15	HR	111.5
45-1759	COUGAR 4 SW	WA	46.0167	122.3500	520	1941	2000	60	15	HR	67.1
1021990	COURTENAY PUNTLEDGE	BC	49.6833	125.0333	78	1964	1995	32	32	HR	53.7
45-1934	CUSHMAN DAM	WA	47.4167	123.2167	760	1941	2000	60	142	HR	97.0
45-1992	DARRINGTON RANGER ST	WA	48.2500	121.6000	550	1941	2000	60	15	HR	73.6
45-2157	DIABLO DAM	WA	48.7167	121.1500	891	1944	2000	57	14	HR	69.1
35-2348	DIXIE MOUNTAIN	OR	45.6833	122.9167	1430	1976	2000	25	32	HR	66.9
KI-14U	EAST FORK ISSAQUAH CK	WA	47.5327	121.9873	520	1988	2000	13	15	DY	79.3
45-2384	EASTON	WA	47.2333	121.1833	2170	1941	2000	60	14	HR	49.5
TH-1938	EATON CREEK	WA	46.9742	122.7300	264	1992	2000	9	31	HR	45.0
45-2493	ELECTRON HEADWORKS	WA	46.9000	122.0333	1730	1943	1980	38	15	HR	69.6
45-2500	ELK MOUNTAIN	WA	46.1333	122.4667	4480	1983	1990	8	15	HR	118.4
35-2697	ESTACADA 24 SE	OR	45.0667	121.9667	2200	1948	2000	53	15	HR	72.2
45-2675	EVERETT	WA	47.9833	122.1833	60	1941	2000	60	31	HR	37.4
45-2984	FRANCES	WA	46.5500	123.5000	231	1941	2000	60	142	HR	97.8
45-3160	GLACIER R S	WA	48.8833	121.9500	935	1971	2000	30	15	HR	65.5
45-3183	GLENWOOD	WA	46.0167	121.2833	1896	1941	2000	60	14	HR	34.7
35-3318	GLENWOOD 2 WNW	OR	45.6500	123.3000	644	1948	2000	53	142	HR	65.8
35-3340	GOBLE 3 SW	OR	45.9833	122.9167	530	1948	2000	53	32	HR	48.3
35-3402	GOVERNMENT CAMP	OR	45.3000	121.7333	3980	1955	2000	46	15	HR	72.6
35-3421	GRAND RONDE TREE FAR	OR	45.0500	123.6167	395	1948	2000	53	5	HR	56.1
45-3333	GRAYS RIVER HATCHERY	WA	46.3833	123.5667	100	1954	2000	47	5	HR	107.4
45-3357	GREENWATER	WA	47.1333	121.6333	1730	1940	1999	60	15	HR	61.6
35-3521	GRESHAM	OR	45.4833	122.4167	310	1948	2000	53	31	HR	53.0
1103328	HANEY MICROWAVE	BC	49.2000	122.5167	1049	1963	1984	22	15	HR	74.9
1103332	HANEY UBC RF ADMIN	BC	49.2667	122.5667	469	1962	1996	35	15	HR	88.0
35-3705	HASKINS DAM	OR	45.3000	123.3500	756	1948	2000	53	142	HR	72.6
35-3770	HEADWORKS PTLD WTR B	OR	45.4500	122.1500	748	1976	2000	25	15	HR	75.6
35-4008	HOOD RIVER TUCKER BR	OR	45.6500	121.5333	383	1941	2000	60	14	HR	30.6
1113540	HOPE A	BC	49.3667	121.4833	127	1963	1995	33	14	HR	66.8
35-4276	JEWELL WILDLIFE MEAD	OR	45.9333	123.5167	570	1954	2000	47	142	HR	94.5
1013754	JORDAN RIVER DIVERSI	BC	48.5000	124.0000	1289	1973	1996	24	151	HR	122.5
45-4446	LAKE WENATCHEE	WA	47.8333	120.7833	2005	1971	2000	30	14	HR	38.1
45-4486	LANDSBURG	WA	47.3833	121.9833	535	1954	2000	47	31	HR	56.0
1104555	LANGLEY LOCHIEL	BC	49.0500	122.5833	331	1971	1986	16	31	HR	59.6
35-4824	LEES CAMP	OR	45.5833	123.5167	655	1948	2000	53	151	HR	113.6
45-4634	LESTER	WA	47.2000	121.4833	1630	1948	1975	28	15	HR	80.4
45-4764	LONGMIRE RAINIER NPS	WA	46.7500	121.8167	2762	1979	2000	22	15	HR	84.7
45-4769	LONGVIEW	WA	46.1500	122.9167	12	1954	2000	47	31	HR	46.1
45-4849	LUCERNE 1 N	WA	48.2333	120.6000	1200	1942	1989	48	14	HR	22.6
45-4999	MARBLEMOUNT RANGER S	WA	48.5333	121.4500	348	1941	2000	60	15	HR	69.8
45-5149	MC CHORD AFB	WA	47.1500	122.4833	290	1941	1979	39	31	HR	39.8

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[3,20] (in)
45-5224	MC MILLIN RESERVOIR	WA	47.1333	122.2667	579	1941	2000	60	31	HR	41.5
1045100	MERRY ISLAND	BC	49.4667	123.9167	26	1977	1996	20	31	HR	44.9
45-5305	MERWIN DAM	WA	45.9500	122.5500	224	1983	1988	6	31	HR	67.4
1105192	MISSION WEST ABBEY	BC	49.1500	122.2667	725	1962	1996	35	31	HR	73.1
35-5629	MIST 1 SE	OR	45.9833	123.2500	500	1948	1958	11	32	HR	54.8
45-5488	MOCLIPS	WA	47.2167	124.2000	120	1942	1957	16	5	HR	91.9
45-5549	MONTESANO 1 S	WA	46.9667	123.6167	25	1954	2000	47	32	HR	77.1
45-5659	MOUNT ADAMS RANGER S	WA	46.0000	121.5333	1960	1971	2000	30	14	HR	42.4
45-5663	MOUNT BAKER LODGE	WA	48.8667	121.6667	4150	1948	1983	36	15	HR	81.1
45-5704	MUD MOUNTAIN DAM	WA	47.1500	121.9333	1308	1940	2000	61	15	HR	61.3
1025370	NANAIMO A	BC	49.0500	123.8667	91	1985	1996	12	32	HR	44.4
10253G0	NANAIMO CITY YARD	BC	49.1833	123.9833	374	1979	1996	18	32	HR	42.1
35-5969	NEHALEM	OR	45.7167	123.9000	75	1948	2000	53	5	HR	78.7
45-5876	NOOKSACK SALMON HATC	WA	48.9000	122.1500	410	1964	2000	37	15	HR	67.0
1015628	NORTH COWICHAN	BC	48.8333	123.7167	150	1973	1995	23	32	HR	45.9
45-5932	NORTH HEAD WB	WA	46.3000	124.0833	210	1940	1953	14	5	HR	81.5
45-6114	OLYMPIA AIRPORT	WA	46.9667	122.9000	206	1948	2000	53	32	HR	50.7
45-6295	PALMER 3 ESE	WA	47.3000	121.8500	920	1941	2000	60	15	HR	87.9
110FAG9	PITT MEADOWS STP	BC	49.2167	122.6833	16	1974	1993	20	31	HR	70.2
1106180	PITT POLDER	BC	49.3000	122.6333	3	1964	1996	33	31	HR	85.3
45-6584	POINT GRENVILLE	WA	47.3000	124.2833	100	1957	1977	21	5	HR	89.4
1036206	PORT ALBERNI A	BC	49.2500	124.8333	6	1969	1995	27	142	HR	81.7
45-6624	PORT ANGELES	WA	48.1000	123.4167	90	1941	2000	60	32	HR	33.5
1106256	PORT COQUITLAM CITY	BC	49.2667	122.7833	22	1971	1990	20	31	HR	78.3
1046330	PORT MELLON	BC	49.5167	123.4833	26	1964	1975	12	15	HR	114.3
1106CL2	PORT MOODY GLENAYRE	BC	49.2833	122.8833	426	1970	1996	27	31	HR	71.0
45-6678	PORT TOWNSEND	WA	48.1000	122.7500	100	1941	1970	30	32	HR	23.2
35-6751	PORTLAND INTL AIRPOR	OR	45.5833	122.6000	19	1941	2000	60	32	HR	38.1
35-6749	PORTLAND KGW-TV	OR	45.5167	122.6833	160	1948	2000	53	32	HR	45.2
45-6851	QUILCENE 5 SW DAM	WA	47.7833	122.9833	1028	1941	2000	60	142	HR	68.2
45-6858	QUILLAYUTE WSCMO AP	WA	47.9333	124.5500	179	1966	2000	35	5	HR	104.8
45-6864	QUINAULT RANGER STN	WA	47.4667	123.8500	220	1977	2000	24	151	HR	110.9
45-6892	RAINIER CARBON RIVER	WA	47.0000	121.9167	1735	1948	2000	53	15	HR	78.3
45-6896	RAINIER OHANAPECOSH	WA	46.7333	121.5667	1950	1941	2000	60	15	HR	75.5
45-6909	RANDLE 1 E	WA	46.5333	121.9333	900	1954	2000	47	15	HR	56.9
35-7127	REX 1 S	OR	45.3000	122.9000	515	1948	2000	53	32	HR	44.8
1016942	SAANICH DENSMORE	BC	48.5000	123.4000	193	1963	1974	12	32	HR	34.8
45-7294	SAM HENRY MOUNTAIN	WA	46.5167	123.0167	1460	1983	1989	7	32	HR	58.8
45-7319	SAPPHO 8 E	WA	48.0667	124.1167	760	1940	1998	59	151	HR	91.2
35-7572	SAUVIES ISLAND	OR	45.6500	122.8333	40	1948	2000	53	32	HR	45.2
35-7586	SCOGGINS DAM 2	OR	45.4833	123.2000	360	1973	1985	13	32	HR	48.2
45-7473	SEATTLE TACOMA AIRPO	WA	47.4500	122.3000	400	1941	2000	60	31	HR	37.9
45-7458	SEATTLE URBAN SITE	WA	47.6500	122.3000	19	1940	1998	59	31	HR	37.0
45-7483	SEATTLE WB AP	WA	47.5333	122.3000	10	1948	1967	20	31	HR	37.1
45-7604	SHUKSAN	WA	48.9167	121.7000	2031	1955	1974	20	15	HR	86.5
35-7823	SILVERTON	OR	45.0000	122.7667	408	1962	2000	39	31	HR	45.0
45-7657	SILVERTON	WA	48.0667	121.5667	1475	1941	1988	48	15	HR	104.4
45-7709	SKYKOMISH 1 ENE	WA	47.7000	121.3667	1030	1941	2000	60	15	HR	98.3
45-7773	SNOQUALMIE FALLS	WA	47.5333	121.8333	440	1954	2000	47	31	HR	69.0
45-7781	SNOQUALMIE PASS	WA	47.4167	121.4000	3020	1941	2000	60	15	HR	100.0
45-7919	SPIRIT LAKE R S	WA	46.2667	122.1500	3240	1941	1958	18	15	HR	87.7
45-8009	STAMPEDE PASS	WA	47.2833	121.3333	3958	1943	2000	58	14	HR	89.0
45-8059	STEHEKIN 4 NW	WA	48.3500	120.7167	1270	1976	2000	25	14	HR	34.6
45-8089	STEVENS PASS	WA	47.7333	121.0833	4070	1971	2000	30	14	HR	84.8
1107873	SURREY KWANTLEN PARK	BC	49.2000	122.8667	305	1962	1996	35	31	HR	62.8
45-8332	TATOOSH ISLAND WB	WA	48.3833	124.7333	100	1940	1966	27	5	HR	94.4
35-8466	THREE LYNX	OR	45.1167	122.0667	1120	1971	2000	30	15	HR	72.0
35-8504	TILLAMOOK 12 ESE	OR	45.4000	123.5833	420	1949	2000	52	151	HR	112.5
1038205	TOFINO A	BC	49.0833	125.7667	78	1970	1996	27	5	HR	128.4
45-8688	UNDERWOOD 4 W	WA	45.7333	121.6000	1260	1941	1962	22	14	HR	43.0
45-8715	UPPER BAKER DAM	WA	48.6500	121.6833	690	1965	2000	36	15	HR	77.6
1108446	VANCOUVER HARBOUR CS	BC	49.3000	123.1167	3	1976	1995	20	31	HR	64.2
1108447	VANCOUVER INT'L A	BC	49.1833	123.1667	6	1960	1996	37	31	HR	50.2
1108487	VANCOUVER UBC	BC	49.2500	123.2500	285	1960	1990	31	31	HR	52.1
45-8838	VERLOT	WA	48.1000	121.7833	975	1971	2000	30	15	HR	110.3
35-8884	VERNONIA 2	OR	45.8500	123.1833	625	1954	2000	47	32	HR	52.7
1018610	VICTORIA GONZALES HT	BC	48.4167	123.3167	229	1960	1988	29	32	HR	30.0
1018620	VICTORIA INT'L A	BC	48.6500	123.4333	62	1964	1982	19	32	HR	35.0
45-9112	WESTPORT 2 S	WA	46.8667	124.1000	20	1940	2000	61	5	HR	76.2
45-9171	WHITE RIVER R S	WA	46.9000	121.5500	3500	1944	1981	38	15	HR	71.7
1108914	WHITE ROCK STP	BC	49.0167	122.7667	49	1964	1996	33	31	HR	48.8
45-9295	WILLARD FISH LAB	WA	45.7667	121.6333	770	1962	1976	15	14	HR	59.0
45-9358	WINTERS MOUNTAIN	WA	46.4500	122.3167	3650	1983	1989	7	15	HR	78.1
45-9485	YELM	WA	46.9500	122.6000	351	1941	1979	39	31	HR	42.7

Appendix B

ISOPLUVIAL MAPS

FOR SELECTED RECURRENCE INTERVALS

OVERVIEW

This appendix contains isopluvial maps of the 2-year, 10-year, 25-year, 50-year, and 100-year precipitation for the 24-hour and 2-hour durations. An isopluvial map for the 6-month recurrence interval (twice-year) is also depicted for the 24-hour duration. Estimates of precipitation for 6-month and 2-year recurrence intervals were made using standard conversions developed by Langbein[15,27] for conversion from annual maxima to partial duration series equivalents. Gridded datasets used to create these maps are contained on the Compact Disc (CD) described in Appendix A. Electronic files of the graphic images (jpeg files) contained in this appendix are also included on the CD.

6-month 24-hour Precipitation, Western Washington

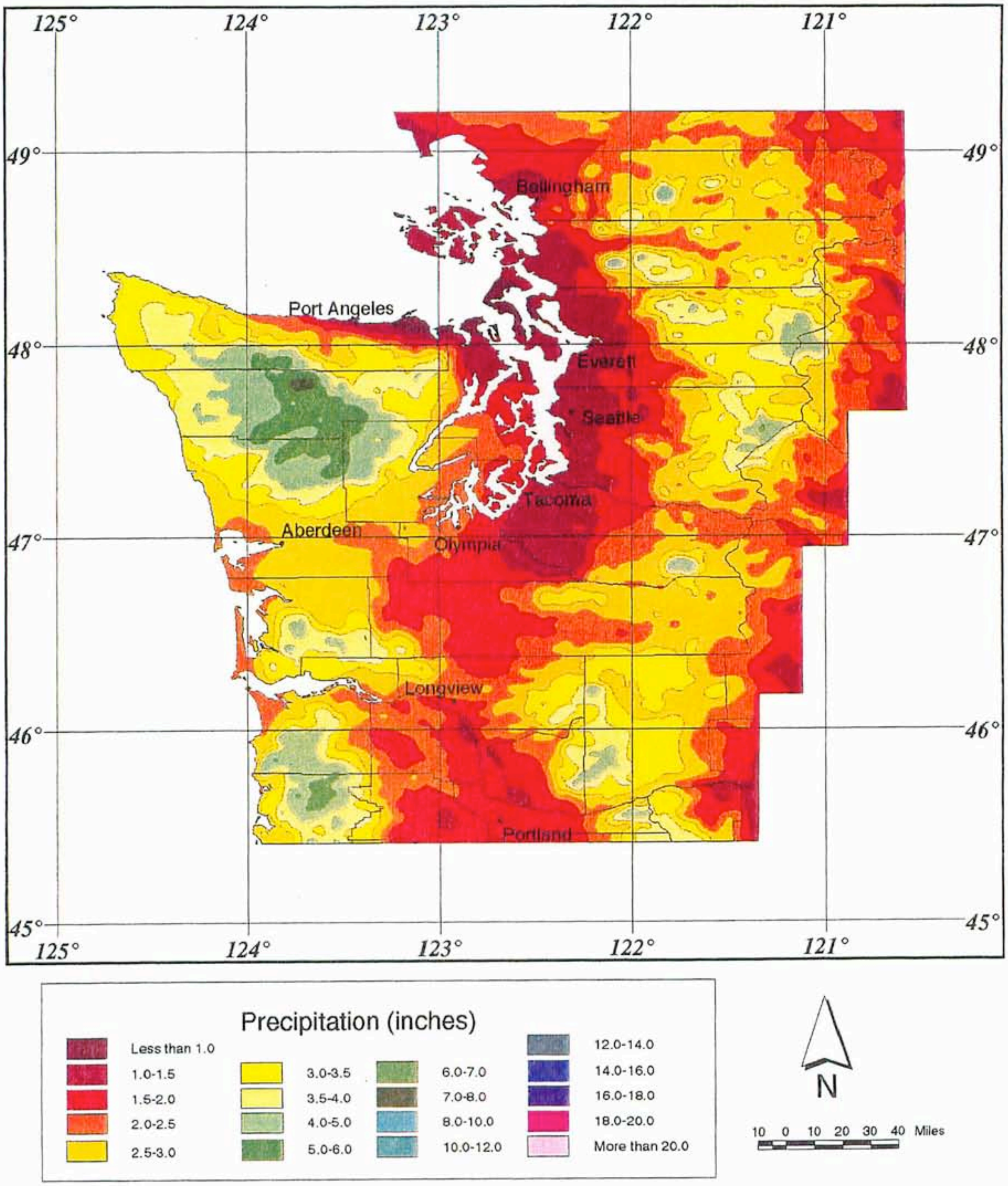

Figure B1 – Isopluvial Map of 24-Hour Precipitation for 6-Month Recurrence Interval for Western Washington

2-year 24-hour Precipitation, Western Washington

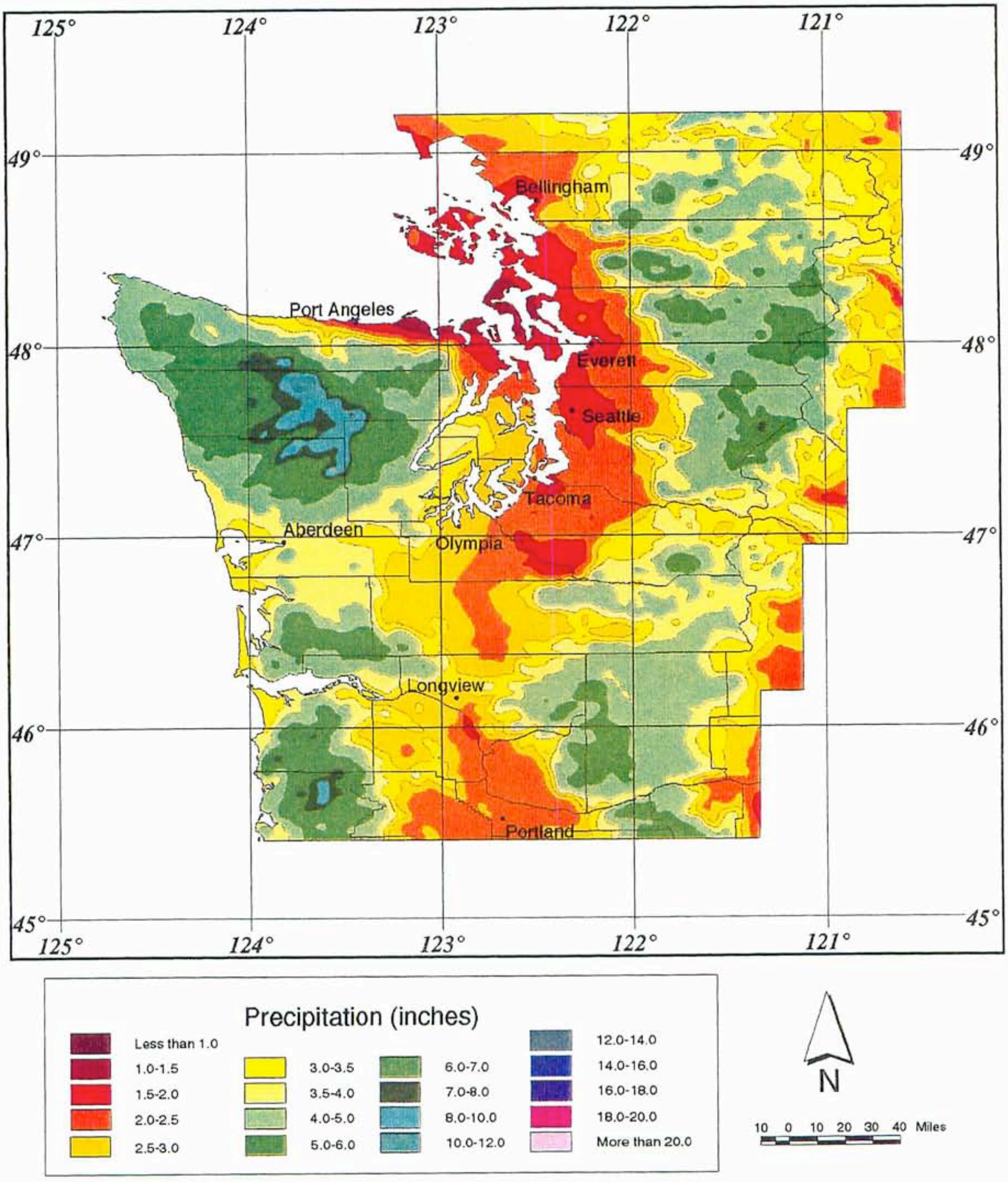

Figure B2 – Isopluvial Map of 24-Hour Precipitation for 2-Year Recurrence Interval for Western Washington

10-year 24-hour Precipitation, Western Washington

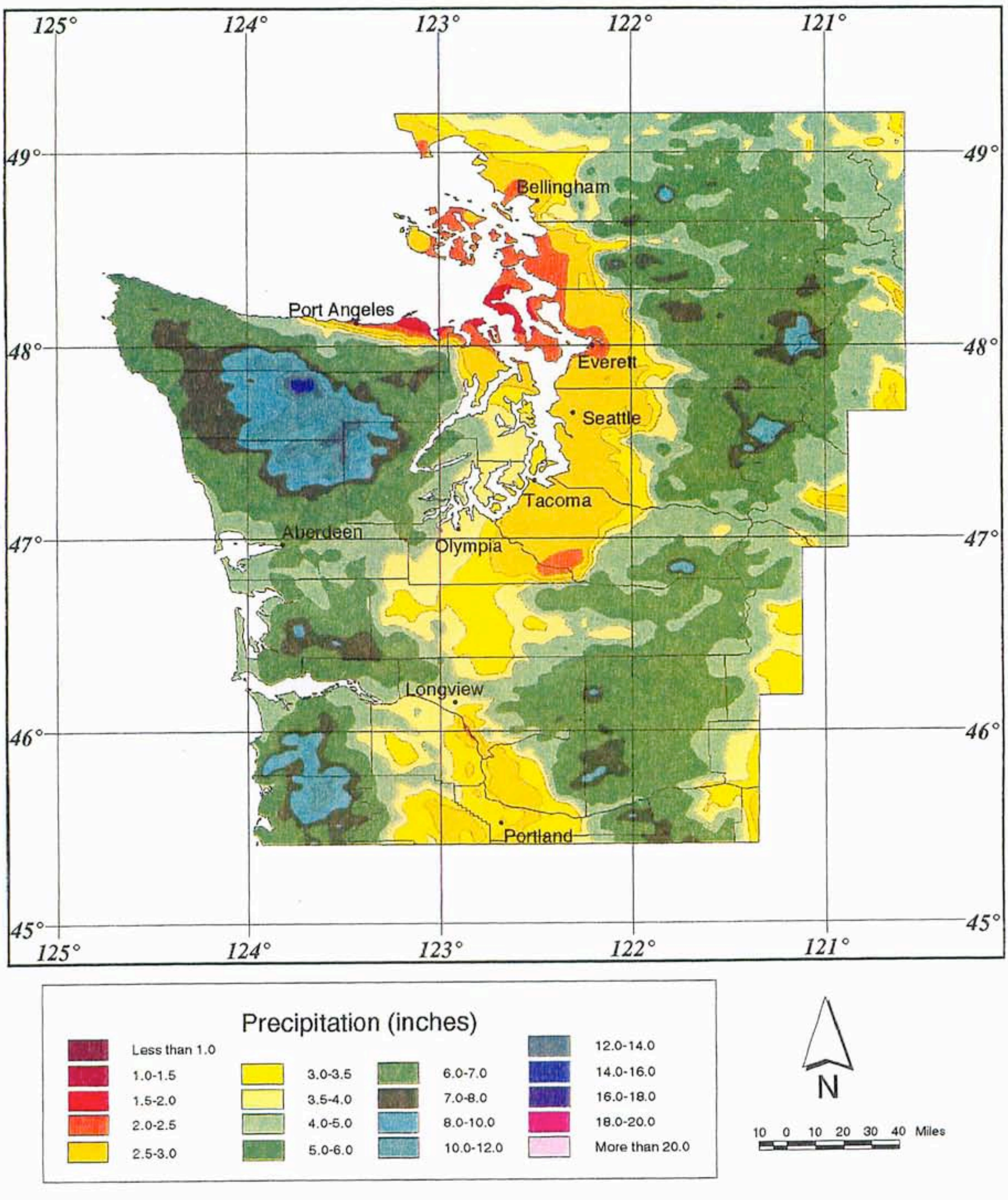

Figure B3 – Isopluvial Map of 24-Hour Precipitation for 10-Year Recurrence Interval for Western Washington

25-year 24-hour Precipitation, Western Washington

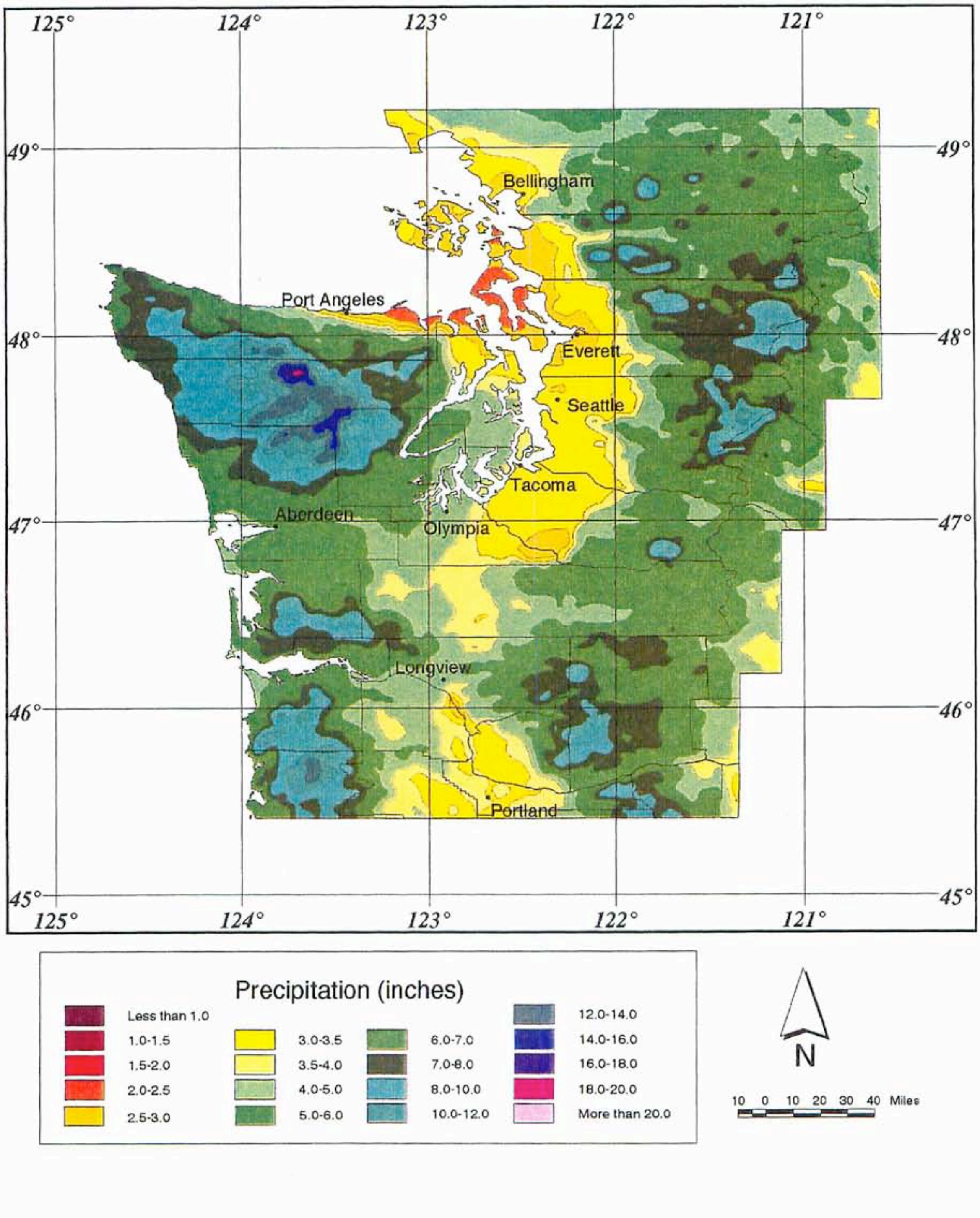

Figure B4 – Isopluvial Map of 24-Hour Precipitation for 25-Year Recurrence Interval for Western Washington

50-year 24-hour Precipitation, Western Washington

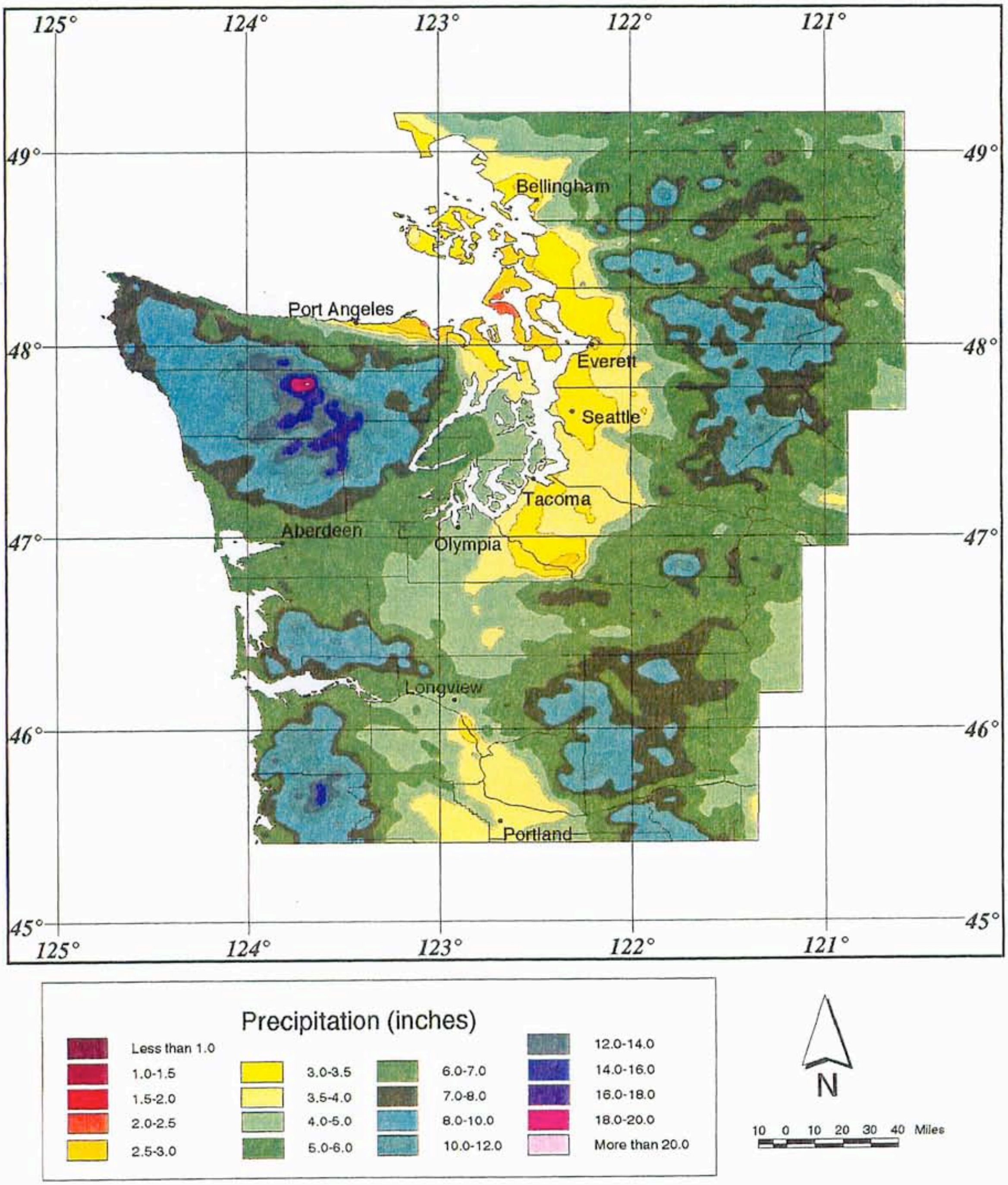

Figure B5 – Isopluvial Map of 24-Hour Precipitation for 50-Year Recurrence Interval for Western Washington

100-year 24-hour Precipitation, Western Washington

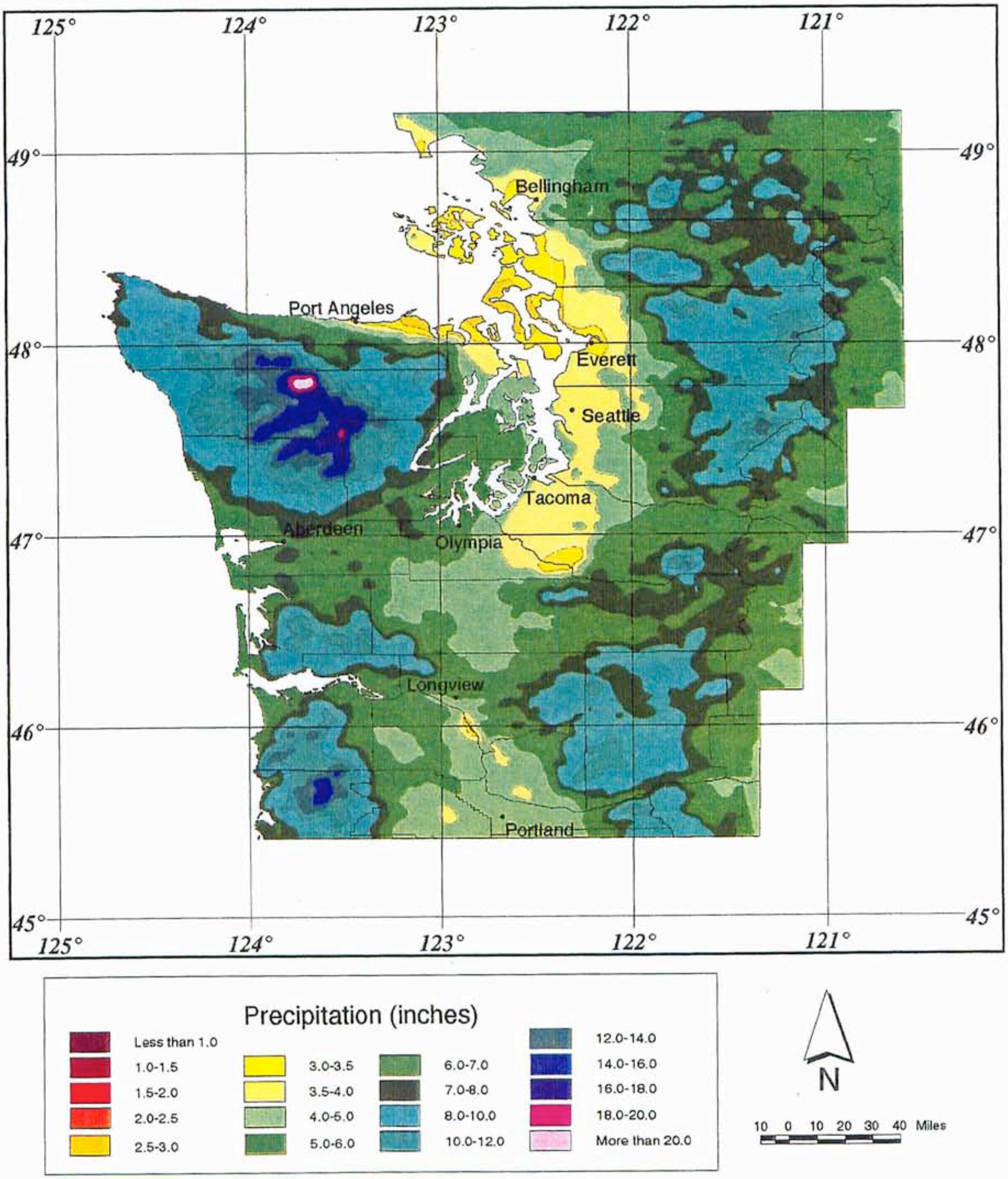

Figure B6 – Isopluvial Map of 24-Hour Precipitation for 100-Year Recurrence Interval for Western Washington

2-year 2-hour Precipitation, Western Washington

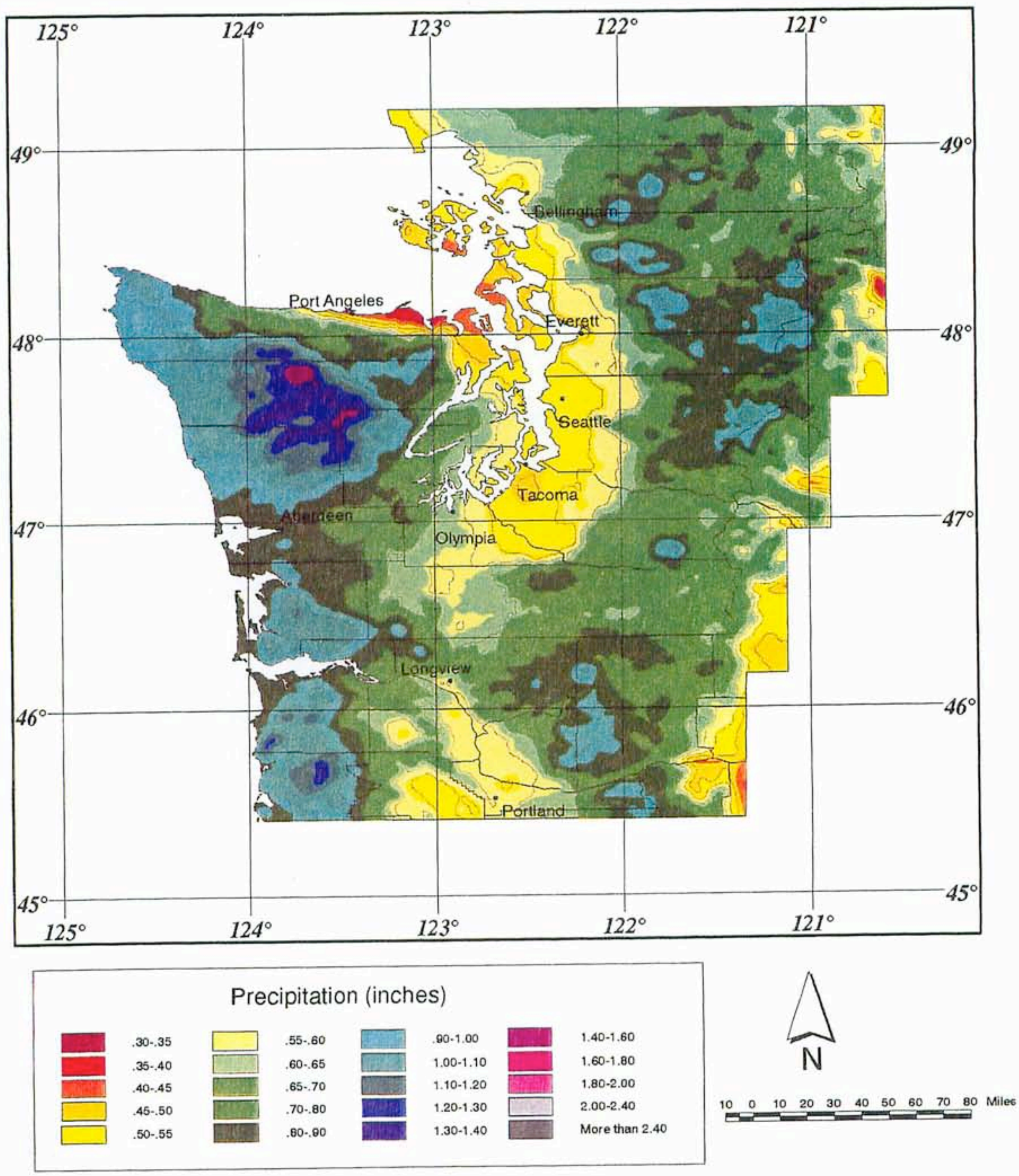

Figure B7 – Isopluvial Map of 2-Hour Precipitation for 2-Year Recurrence Interval for Western Washington

10-year 2-hour Precipitation, Western Washington

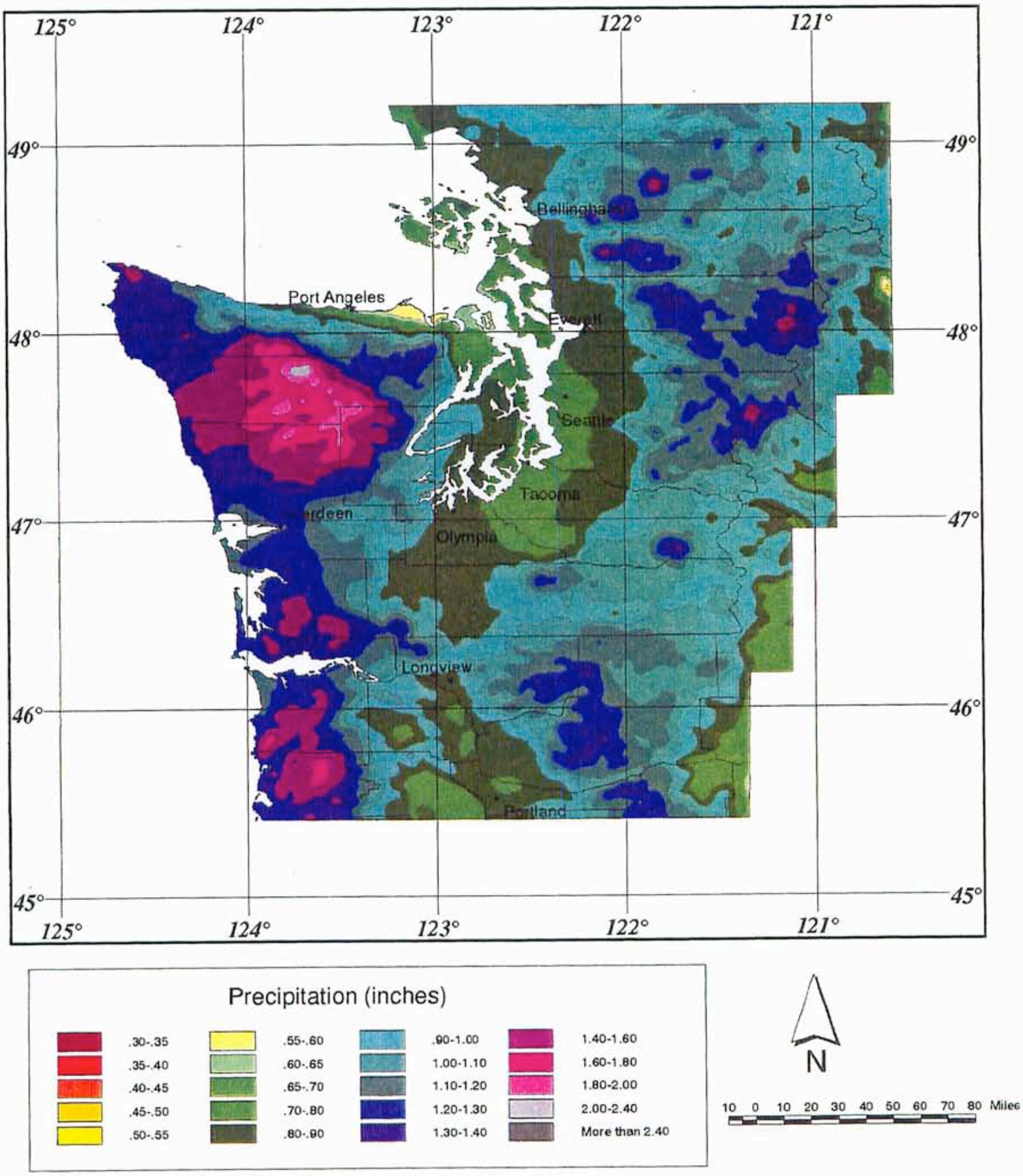

Figure B8 – Isopluvial Map of 2-Hour Precipitation for 10-Year Recurrence Interval for Western Washington

25-year 2-hour Precipitation, Western Washington

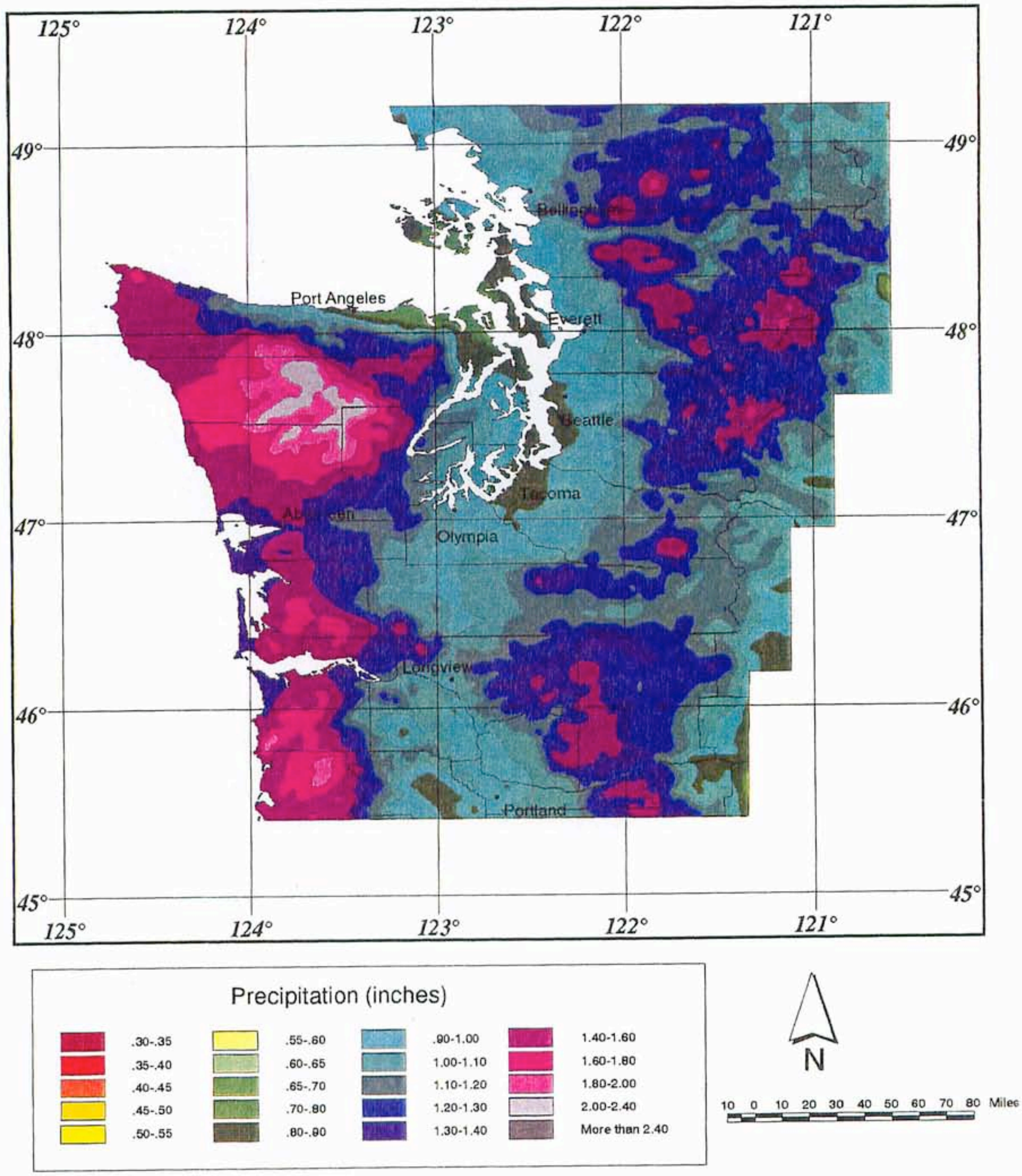

Figure B9 – Isopluvial Map of 2-Hour Precipitation for 25-Year Recurrence Interval for Western Washington

50-year 2-hour Precipitation, Western Washington

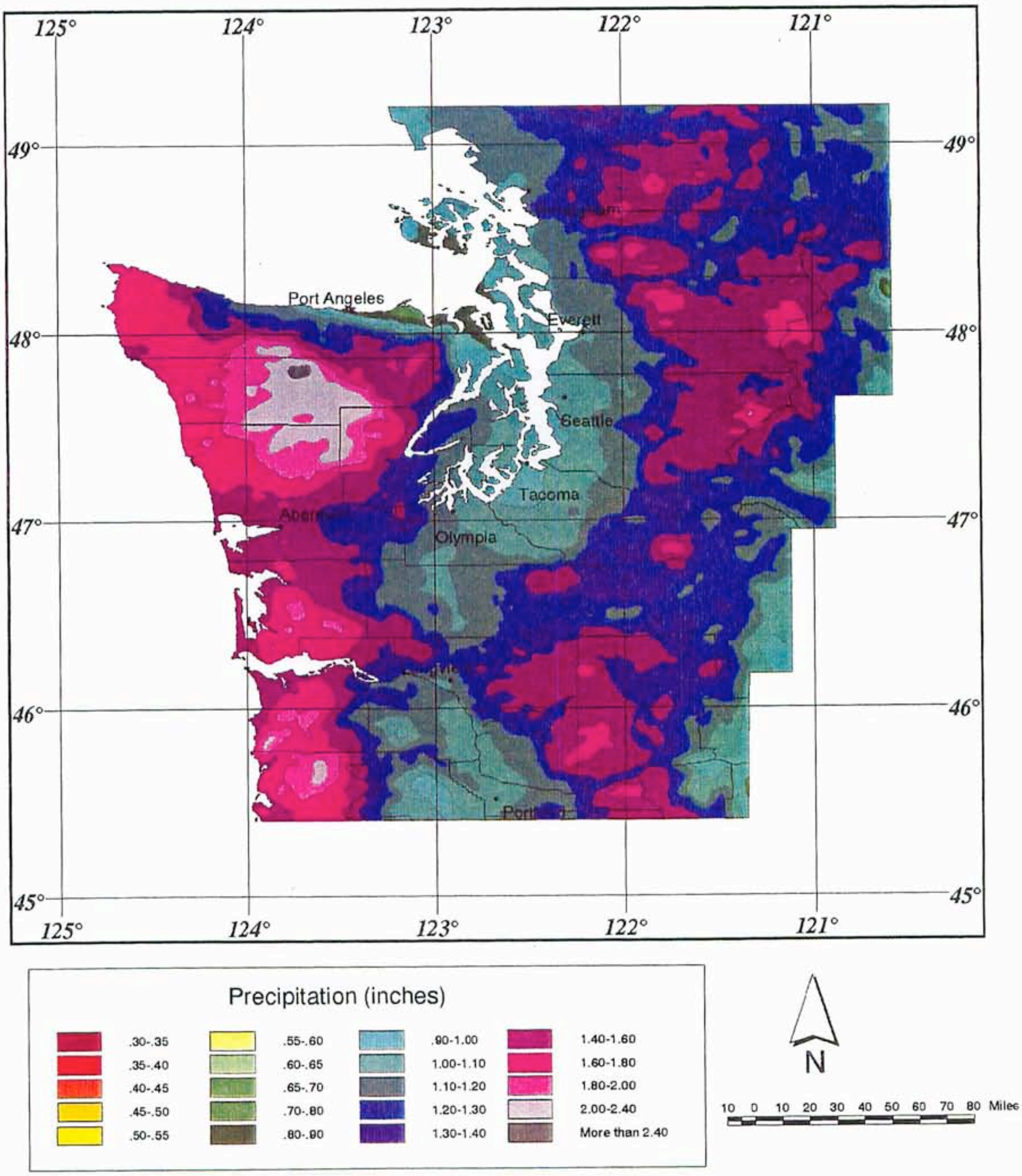

Figure B10 – Isopluvial Map of 2-Hour Precipitation for 50-Year Recurrence Interval for Western Washington

100-year 2-hour Precipitation, Western Washington

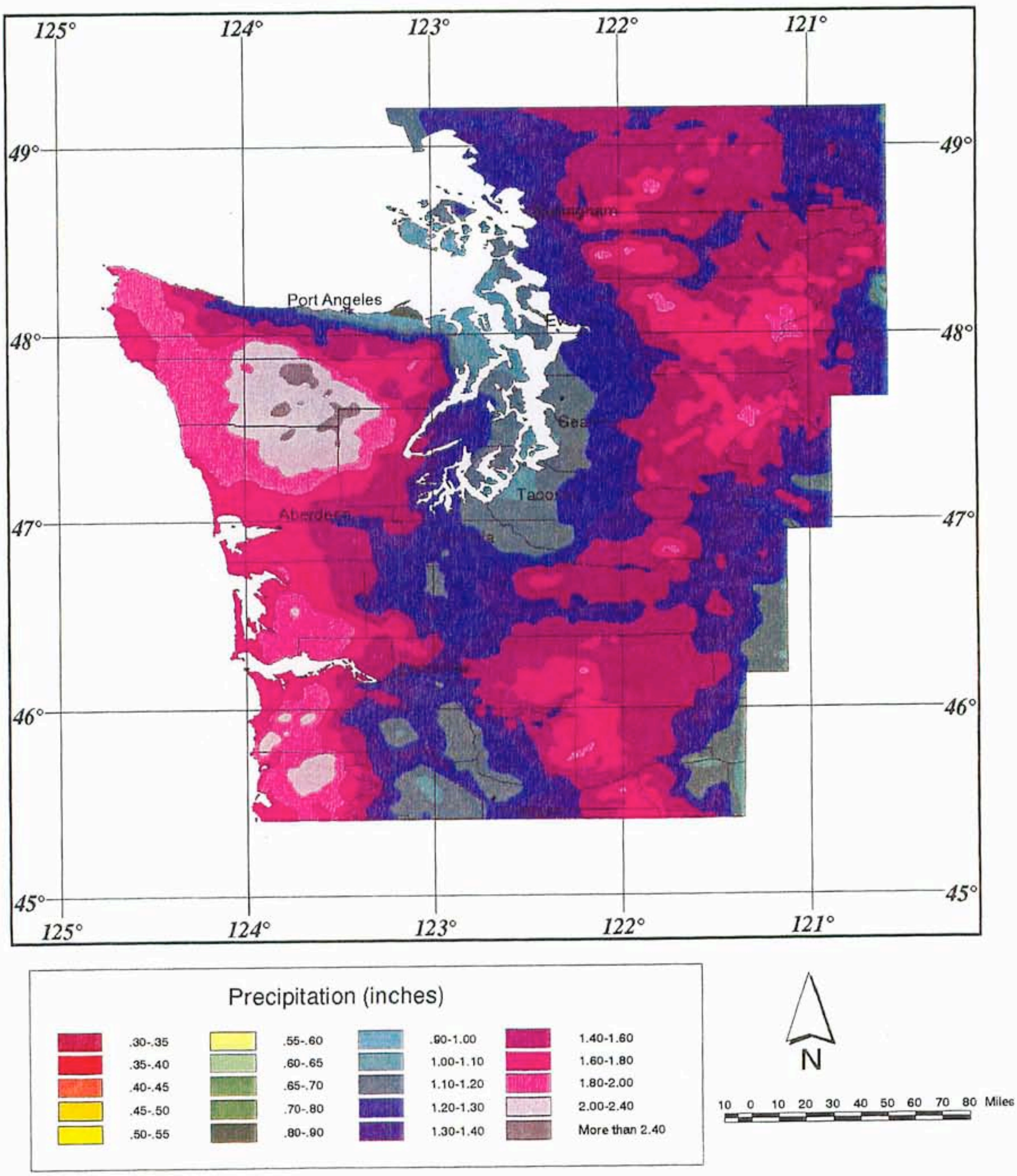

Figure B11 – Isopluvial Map of 2-Hour Precipitation for 100-Year Recurrence Interval for Western Washington

Appendix C

SEASONALITY OF

24-HOUR AND 2-HOUR EXTREME STORMS

OVERVIEW

The seasonality of extreme storms was investigated by constructing frequency histograms of the storm dates for rare 24-hour and 2-hour precipitation amounts for each of the seven climatic regions. Extreme storms were taken to be precipitation amounts with annual exceedance probabilities less than 0.05 (rarer than a 20-year event). Precipitation amounts/gages with duplicate storm dates (generally dates within 7 calendar days) were removed before constructing the frequency histograms for each climatic region.

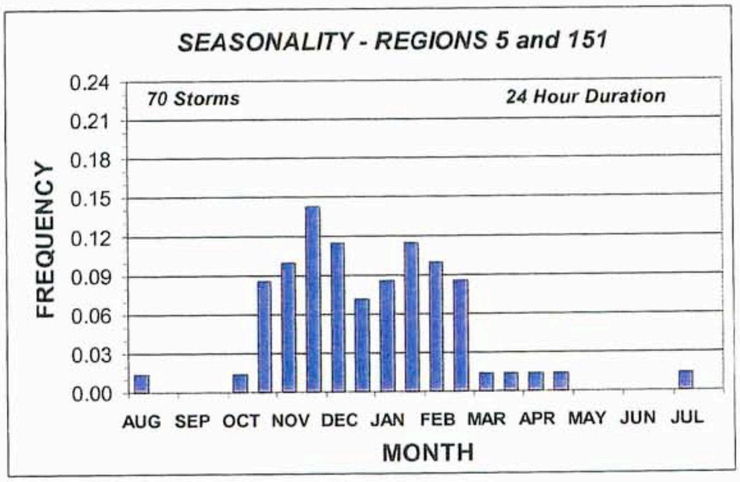

Figure C1 – Seasonality of Extreme Storms at 24-Hour Duration for Coastal Lowlands and Coastal Mountains West, Climatic Regions 5 and 151

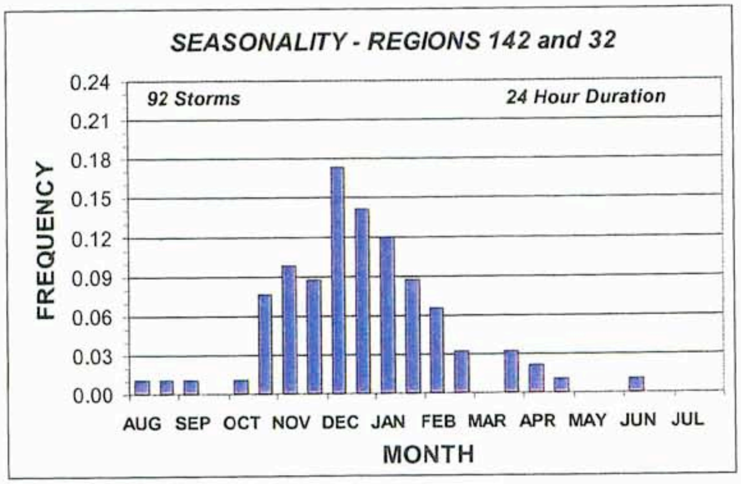

Figure C2 – Seasonality of Extreme Storms at 24-Hour Duration for Coastal Mountains East and Interior Lowlands West, Climatic Regions 142 and 32

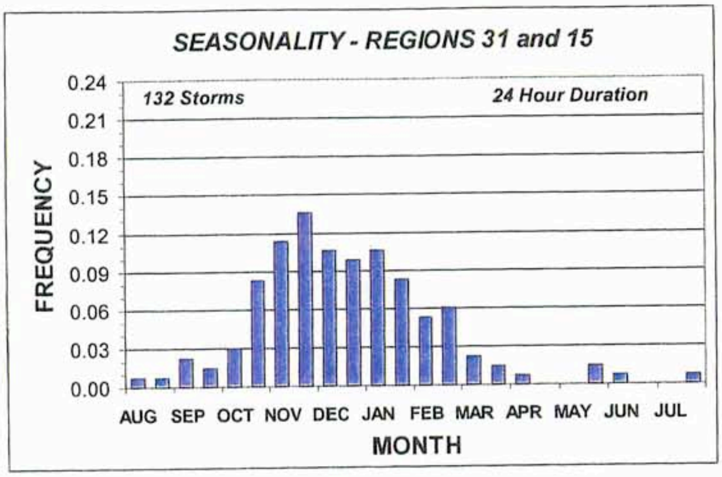

Figure C3 – Seasonality of Extreme Storms at 24-Hour Duration
for Interior Lowlands East and Cascade Mountains West, Climatic Regions 31 and 15

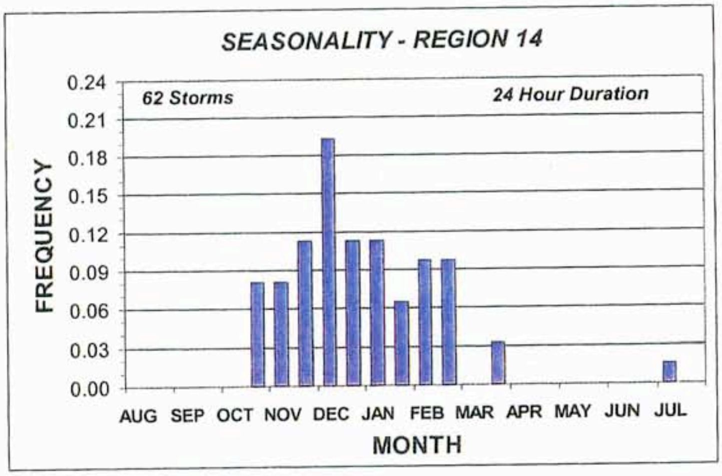

Figure C4 – Seasonality of Extreme Storms at 24-Hour Duration
for Cascade Mountains East, Climatic Region 14

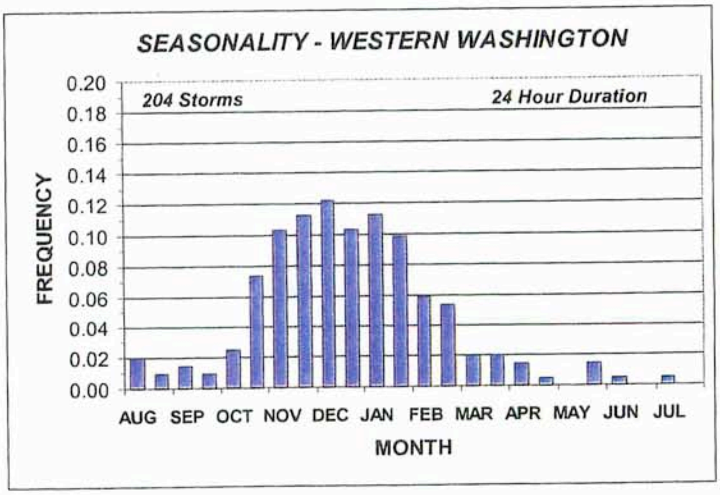

Figure C5 – Seasonality of Extreme Storms at 24-Hour Duration
for All Western Washington Climatic Regions

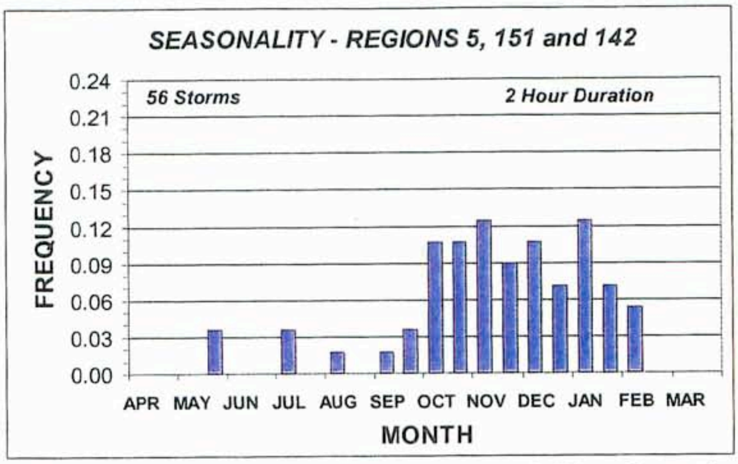

Figure C6 – Seasonality of Extreme Storms at 2-Hour Duration for Coastal Lowlands and Coastal Mountains, Climatic Regions 5, 151 and 142

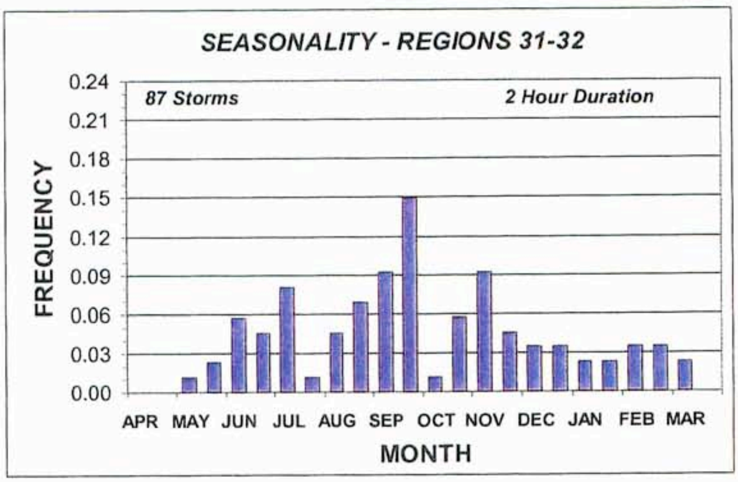

Figure C7 – Seasonality of Extreme Storms at 2-Hour Duration for Interior Lowlands East and West, Climatic Regions 31 and 32

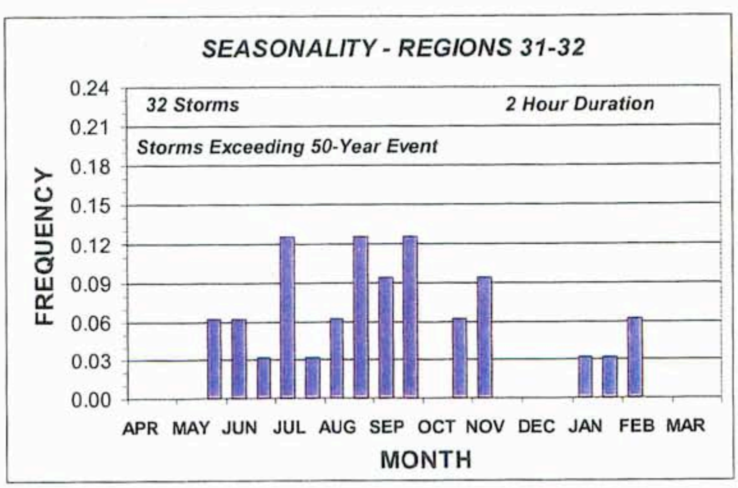

Figure C8 – Seasonality of Extreme Storms that Exceed 50-Year Event at 2-Hour Duration for Interior Lowlands East and West, Climatic Regions 31 and 32

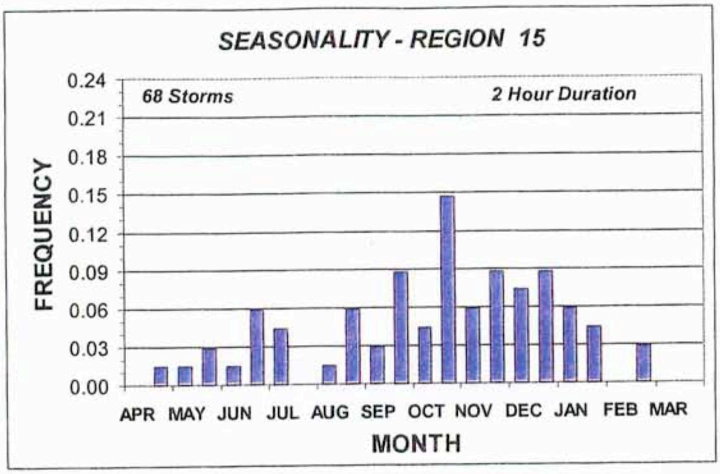

Figure C9 – Seasonality of Extreme Storms at 2-Hour Duration for Cascade Mountains West, Climatic Region 15

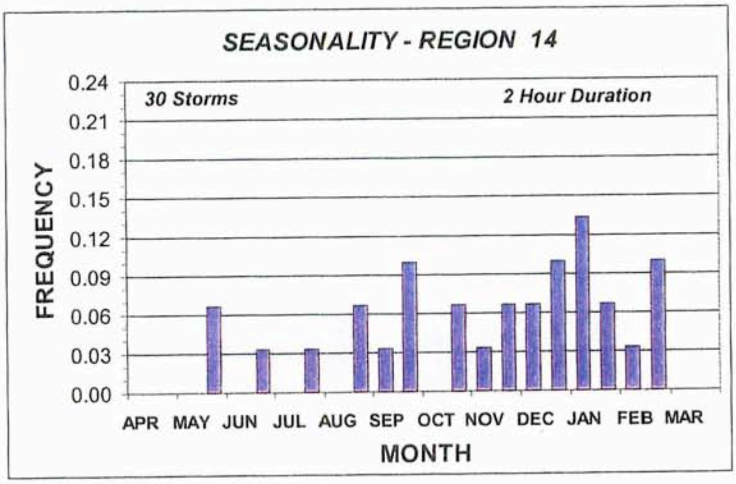

Figure C10 – Seasonality of Extreme Storms at 2-Hour Duration for Cascade Mountains East, Climatic Region 14

Appendix D

CATALOGS OF EXTREME STORMS

FOR 24-HOUR AND 2-HOUR DURATIONS

OVERVIEW

This appendix contains catalogs of the dates and locations of the occurrence of extreme storms. An extreme storm is deemed to occur when a recorded precipitation amount has exceeded a 20-year recurrence interval for that site. When numerous gages record precipitation amounts that exceed the 20-year threshold for a given storm date, the hourly gage with the rarest precipitation measurement is listed in the catalog. Hourly gages are listed because the primary application of the storm catalog is for identification of temporal storm patterns that would be useful in rainfall-runoff modeling of extreme events. Separate tables have been prepared, where the location, date and precipitation amount are listed for the various climatic regions.

Table D1 - Catalog of Extreme Storms for Coastal Lowlands Climatic Region 5 for 24-Hour Duration

EXTREME STORMS AT 24-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-1496	CLEARWATER	5	52	47.6	124.3	1.66	8.41	12	1	1943
45-8332	TATOOSH ISLAND WB	5	25	48.4	124.7	1.66	5.33	10	23	1944
35-5969	NEHALEM	5	52	45.7	123.9	1.57	5.86	2	10	1949
45-5488	MOCLIPS	5	16	47.2	124.2	1.34	4.22	1	20	1950
45-3333	GRAYS RIVER HATCHERY	5	43	46.4	123.6	1.44	6.64	1	14	1958
45-6584	POINT GRENVILLE	5	19	47.3	124.3	1.44	5.15	11	20	1959
45-5549	MONTESANO 1 S	5	44	47.0	123.6	1.55	5.39	11	19	1962
35-5969	NEHALEM	5	52	45.7	123.9	1.59	5.94	1	28	1965
45-6858	QUILLAYUTE WSCMO AP	5	34	47.9	124.6	1.83	8.32	1	19	1968
45-1496	CLEARWATER	5	52	47.6	124.3	1.76	8.90	7	12	1972
45-6858	QUILLAYUTE WSCMO AP	5	34	47.9	124.6	1.49	6.76	12	26	1972
45-1496	CLEARWATER	5	52	47.6	124.3	1.84	9.30	2	13	1982
45-2984	FRANCES	5	56	46.6	123.5	1.52	6.20	3	3	1987
35-0328	ASTORIA AP PORT OF	5	48	46.2	123.9	1.70	5.14	1	9	1990
45-9112	WESTPORT 2 S	5	60	46.9	124.1	1.48	4.40	2	10	1990
45-9112	WESTPORT 2 S	5	60	46.9	124.1	1.78	5.30	11	24	1990
45-5549	MONTESANO 1 S	5	44	47.0	123.6	1.55	5.40	12	10	1993
45-3333	GRAYS RIVER HATCHERY	5	43	46.4	123.6	1.67	7.70	12	27	1994
45-2984	FRANCES	5	56	46.6	123.5	1.52	6.20	4	23	1996
35-0328	ASTORIA AP PORT OF	5	48	46.2	123.9	1.84	5.57	11	25	1998
45-2984	FRANCES	5	56	46.6	123.5	1.42	5.80	2	25	1999

Table D2 - Catalog of Extreme Storms for Coastal Mountains West Climatic Region 151 for 24-Hour Duration

EXTREME STORMS AT 24-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-7319	SAPPHO 8 E	151	57	48.1	124.1	1.87	8.15	11	3	1955
45-7319	SAPPHO 8 E	151	57	48.1	124.1	1.55	6.74	12	9	1956
45-1064	CAMP GRISDALE	151	27	47.4	123.6	1.72	10.68	11	19	1962
35-8504	TILLAMOOK 12 ESE	151	48	45.4	123.6	1.46	7.43	12	2	1977
45-7319	SAPPHO 8 E	151	57	48.1	124.1	1.47	6.40	1	24	1982
45-0013	ABERDEEN 20 NNE	151	59	47.3	123.7	1.58	9.00	2	13	1982
45-6864	QUINAULT RANGER STN	151	19	47.5	123.9	1.89	13.50	11	10	1990
45-7319	SAPPHO 8 E	151	57	48.1	124.1	1.47	6.40	11	8	1995

Table D3 - Catalog of Extreme Storms for Coastal Mountains East Climatic Region 142 for 24-Hour Duration

EXTREME STORMS AT 24-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
35-4276	JEWELL WILDLIFE MEAD	142	42	45.9	123.5	1.62	5.90	1	11	1972
35-3318	GLENWOOD 2 WNW	142	50	45.7	123.3	1.66	5.35	12	13	1977
35-3318	GLENWOOD 2 WNW	142	50	45.7	123.3	1.67	5.40	10	6	1981
45-6851	QUILCENE 5 SW DAM	142	55	47.8	123.0	1.87	7.90	10	22	1982
45-1934	CUSHMAN DAM	142	59	47.4	123.2	1.81	9.40	1	18	1986
35-3705	HASKINS DAM	142	49	45.3	123.4	1.43	5.60	4	5	1991
45-6851	QUILCENE 5 SW DAM	142	55	47.8	123.0	1.45	6.10	12	10	1993
45-1934	CUSHMAN DAM	142	59	47.4	123.2	1.58	8.20	12	20	1994
45-1934	CUSHMAN DAM	142	59	47.4	123.2	1.77	9.20	3	19	1997
45-6851	QUILCENE 5 SW DAM	142	55	47.8	123.0	1.75	7.40	1	29	1999

Table D4 - Catalog of Extreme Storms for Interior Lowlands West Climatic Region 32 for 24-Hour Duration

EXTREME STORMS AT 24-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-6678	PORT TOWNSEND	32	29	48.1	122.8	2.10	2.26	6	13	1946
45-6624	PORT ANGELES	32	57	48.1	123.4	1.85	3.26	2	16	1949
45-6114	OLYMPIA AIRPORT	32	46	47.0	122.9	1.76	4.93	2	9	1951
45-6624	PORT ANGELES	32	57	48.1	123.4	1.77	3.12	1	15	1961
35-1227	BUXTON MOUNTAINDALE	32	26	45.7	123.1	1.47	3.26	1	15	1974
35-1222	BUXTON	32	51	45.7	123.2	1.61	4.40	12	13	1977
35-8884	VERNONIA 2	32	45	45.9	123.2	1.72	4.00	10	6	1981
45-6624	PORT ANGELES	32	57	48.1	123.4	2.16	3.80	1	18	1986
35-1643	CLATSKANIE	32	43	46.1	123.2	1.57	4.30	1	9	1990
45-6114	OLYMPIA AIRPORT	32	46	47.0	122.9	2.10	5.90	11	24	1990
35-2348	DIXIE MOUNTAIN	32	22	45.7	122.9	1.39	4.00	4	5	1991
35-6749	PORTLAND KGW-TV	32	50	45.5	122.7	2.23	4.80	10	27	1994
35-6751	PORTLAND INTL AIRPOR	32	59	45.6	122.6	1.38	2.82	11	11	1995
35-1643	CLATSKANIE	32	43	46.1	123.2	1.72	4.70	2	8	1996
35-6749	PORTLAND KGW-TV	32	50	45.5	122.7	1.95	4.20	11	19	1996
35-2348	DIXIE MOUNTAIN	32	22	45.7	122.9	1.39	4.00	12	29	1996
35-1222	BUXTON	32	51	45.7	123.2	1.72	4.70	1	14	1998

Table D5 - Catalog of Extreme Storms for Interior Lowlands East Climatic Region 31 for 24-Hour Duration

EXTREME STORMS AT 24-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-1277	CENTRALIA 1 W	31	56	46.7	123.0	1.38	2.98	10	31	1942
45-0986	BURLINGTON	31	58	48.5	122.3	2.63	4.91	10	24	1945
45-0986	BURLINGTON	31	58	48.5	122.3	1.83	3.42	2	16	1949
45-9485	YELM	31	38	47.0	122.6	1.45	2.79	11	12	1949
45-5149	MC CHORD AFB	31	35	47.2	122.5	1.77	3.03	2	9	1951
45-0729	BLAINE	31	58	49.0	122.8	1.76	3.63	11	3	1955
45-0324	AUBURN	31	22	47.3	122.2	1.71	3.63	11	21	1959
45-4769	LONGVIEW	31	42	46.2	122.9	2.36	5.41	11	20	1962
45-2675	EVERETT	31	58	48.0	122.2	1.57	2.56	1	4	1967
45-0729	BLAINE	31	58	49.0	122.8	1.67	3.46	11	4	1971
45-7773	SNOQUALMIE FALLS	31	44	47.5	121.8	1.56	4.90	3	5	1972
45-4769	LONGVIEW	31	42	46.2	122.9	2.05	4.70	12	2	1977
45-7473	SEATTLE TACOMA AIRPO	31	60	47.5	122.3	1.78	3.74	10	6	1981
45-0729	BLAINE	31	58	49.0	122.8	1.60	3.30	12	30	1983
45-7458	SEATTLE URBAN SITE	31	49	47.7	122.3	2.18	4.48	1	18	1986
45-4769	LONGVIEW	31	42	46.2	122.9	2.05	4.70	2	23	1986
45-5224	MC MILLIN RESERVOIR	31	57	47.1	122.3	1.94	3.80	11	24	1986
45-7773	SNOQUALMIE FALLS	31	44	47.5	121.8	1.56	4.90	1	9	1990
45-0986	BURLINGTON	31	58	48.5	122.3	1.61	3.00	11	9	1990
45-1277	CENTRALIA 1 W	31	56	46.7	123.0	2.36	5.10	11	24	1990
45-1277	CENTRALIA 1 W	31	56	46.7	123.0	1.85	4.00	2	8	1996
45-2675	EVERETT	31	58	48.0	122.2	1.60	2.60	12	29	1996
45-5224	MC MILLIN RESERVOIR	31	57	47.1	122.3	1.84	3.60	11	25	1998

Table D6 - Catalog of Extreme Storms for Cascade Mountains West Climatic Region 15 for 24-Hour Duration

EXTREME STORMS AT 24-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-7919	SPIRIT LAKE R S	15	15	46.3	122.2	1.84	5.74	10	23	1943
35-0897	BONNEVILLE DAM	15	59	45.6	122.0	1.83	6.40	10	18	1947
45-9171	WHITE RIVER R S	15	32	46.9	121.6	1.41	4.04	2	17	1949
45-7657	SILVERTON	15	47	48.1	121.6	1.48	6.39	2	9	1951
45-4634	LESTER	15	23	47.2	121.5	1.63	4.69	12	9	1956
45-7781	SNOQUALMIE PASS	15	56	47.4	121.4	1.52	7.00	11	22	1959
45-7709	SKYKOMISH 1 ENE	15	57	47.7	121.4	1.80	7.70	12	15	1959
45-6896	RAINIER OHANAPECOSH	15	51	46.7	121.6	2.00	7.78	11	20	1962
1106180	PITT POLDER	15	30	49.3	122.6	1.46	5.68	1	18	1968
45-6295	PALMER 3 ESE	15	59	47.3	121.9	1.42	5.10	1	9	1971
45-6295	PALMER 3 ESE	15	59	47.3	121.9	1.37	4.90	11	4	1971
45-7604	SHUKSAN	15	14	48.9	121.7	1.32	4.45	12	26	1972
45-9171	WHITE RIVER R S	15	32	46.9	121.6	1.50	4.30	11	9	1973
35-2697	ESTACADA 24 SE	15	49	45.1	122.0	1.59	4.30	1	15	1974
45-1457	CINEBAR 2 E	15	46	46.6	122.5	2.20	6.80	12	2	1977
45-3160	GLACIER R S	15	25	48.9	122.0	1.80	5.90	12	14	1979
45-5663	MOUNT BAKER LODGE	15	23	48.9	121.7	1.32	5.20	2	26	1980
45-8715	UPPER BAKER DAM	15	33	48.7	121.7	1.41	5.80	11	21	1980
45-3357	GREENWATER	15	56	47.1	121.6	1.99	5.30	1	23	1982
45-8838	VERLOT	15	21	48.1	121.8	1.31	6.20	2	14	1982
45-7657	SILVERTON	15	47	48.1	121.6	1.78	7.70	12	3	1982
45-5876	NOOKSACK SALMON HAT	15	32	48.9	122.2	1.75	6.30	1	10	1983
45-3357	GREENWATER	15	56	47.1	121.6	1.69	4.50	1	24	1984
45-1992	DARRINGTON RGR STN	15	56	48.3	121.6	1.89	6.60	1	18	1986
45-4999	MARBLEMOUNT RGR STN	15	56	48.5	121.5	1.82	6.20	2	24	1986
45-5704	MUD MOUNTAIN DAM	15	61	47.2	121.9	1.81	4.20	11	24	1986
45-1457	CINEBAR 2 E	15	46	46.6	122.5	1.62	5.00	1	9	1990
45-5876	NOOKSACK SALMON HAT	15	32	48.9	122.2	1.86	6.70	2	10	1990
45-4999	MARBLEMOUNT RGR STN	15	56	48.5	121.5	1.82	6.20	11	10	1990
45-1233	CEDAR LAKE	15	45	47.4	121.7	1.74	6.40	11	24	1990
45-5704	MUD MOUNTAIN DAM	15	61	47.2	121.9	1.73	4.00	2	20	1991
45-1759	COUGAR 4 SW	15	59	46.0	122.4	1.45	6.40	10	31	1994
45-4764	LONGMIRE RAINIER NPS	15	22	46.8	121.8	1.68	6.40	11	28	1995
45-5704	MUD MOUNTAIN DAM	15	61	47.2	121.9	1.64	3.80	2	8	1996
35-0897	BONNEVILLE DAM	15	59	45.6	122.0	1.69	5.90	11	19	1996
35-0897	BONNEVILLE DAM	15	59	45.6	122.0	1.46	5.10	11	25	1999

Table D7 - Catalog of Extreme Storms for Coastal Lowlands Climatic Region 5 for 2-Hour Duration

EXTREME STORMS AT 2-HOUR DURATION

STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-5932	NORTH HEAD WB	5	13	46.3	124.1	1.42	1.13	11	13	1941
45-8332	TATOOSH ISLAND WB	5	25	48.4	124.7	1.75	1.53	10	10	1942
45-9112	WESTPORT 2 S	5	56	46.9	124.1	1.77	1.47	10	30	1950
45-5488	MOCLIPS	5	15	47.2	124.2	1.46	1.30	1	2	1951
35-5969	NEHALEM	5	52	45.7	123.9	1.40	1.23	1	21	1954
45-5549	MONTESANO 1 S	5	44	47.0	123.6	1.39	1.14	11	2	1955
45-6584	POINT GRENVILLE	5	19	47.3	124.3	1.42	1.33	11	20	1959
45-5549	MONTESANO 1 S	5	44	47.0	123.6	1.36	1.12	12	22	1961
35-0328	ASTORIA AP PORT OF	5	47	46.2	123.9	1.85	1.54	10	8	1962
45-1496	CLEARWATER	5	54	47.6	124.3	1.30	1.34	1	12	1966
45-6858	QUILLAYUTE WSCMO AP	5	34	47.9	124.6	1.34	1.22	10	1	1967
45-3333	GRAYS RIVER HATCHERY	5	42	46.4	123.6	1.27	1.30	12	10	1977
45-3333	GRAYS RIVER HATCHERY	5	42	46.4	123.6	1.47	1.50	11	6	1980
45-2984	FRANCES	5	58	46.6	123.5	1.76	1.50	12	15	1982
45-3333	GRAYS RIVER HATCHERY	5	42	46.4	123.6	1.27	1.30	2	13	1982
45-3333	GRAYS RIVER HATCHERY	5	42	46.4	123.6	1.27	1.30	10	26	1985
45-2984	FRANCES	5	58	46.6	123.5	1.53	1.30	1	14	1988
45-1496	CLEARWATER	5	54	47.6	124.3	1.35	1.40	10	21	1990
45-9112	WESTPORT 2 S	5	56	46.9	124.1	1.57	1.30	12	4	1990
45-6858	QUILLAYUTE WSCMO AP	5	34	47.9	124.6	1.41	1.29	8	6	1995
45-2984	FRANCES	5	58	46.6	123.5	1.65	1.40	9	29	1995
45-1496	CLEARWATER	5	54	47.6	124.3	1.35	1.40	10	25	1995
45-9112	WESTPORT 2 S	5	56	46.9	124.1	1.69	1.40	9	16	1997
35-0328	ASTORIA AP PORT OF	5	47	46.2	123.9	2.21	1.84	11	25	1998

Table D8 - Catalog of Extreme Storms for Coastal Mountains West Climatic Region 151 for 2-Hour Duration

EXTREME STORMS AT 2-HOUR DURATION

STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-7319	SAPPHO 8 E	151	58	48.1	124.1	2.40	1.92	2	2	1947
45-7319	SAPPHO 8 E	151	58	48.1	124.1	1.76	1.41	12	9	1956
45-1064	CAMP GRISDALE	151	28	47.4	123.6	1.75	2.00	11	20	1959
35-8504	TILLAMOOK 12 ESE	151	51	45.4	123.6	2.36	2.25	1	11	1972
45-0013	ABERDEEN 20 NNE	151	57	47.3	123.7	1.40	1.50	12	26	1975
45-7319	SAPPHO 8 E	151	58	48.1	124.1	1.62	1.30	11	8	1976
45-0013	ABERDEEN 20 NNE	151	57	47.3	123.7	2.33	2.50	5	28	1982
45-6864	QUINAULT RANGER STN	151	20	47.5	123.9	1.54	2.00	11	23	1986
45-0013	ABERDEEN 20 NNE	151	57	47.3	123.7	1.59	1.70	10	31	1994

Table D9 - Catalog of Extreme Storms for Coastal Mountains East Climatic Region 142 for 2-Hour Duration

EXTREME STORMS AT 2-HOUR DURATION

STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-6851	QUILCENE 5 SW DAM	142	58	47.8	123.0	1.63	1.35	12	1	1948
45-6851	QUILCENE 5 SW DAM	142	58	47.8	123.0	1.34	1.11	7	5	1957
45-1934	CUSHMAN DAM	142	59	47.4	123.2	1.50	1.50	12	25	1980
45-1934	CUSHMAN DAM	142	59	47.4	123.2	1.40	1.40	12	3	1982
45-1934	CUSHMAN DAM	142	59	47.4	123.2	1.70	1.70	1	18	1986
45-6851	QUILCENE 5 SW DAM	142	58	47.8	123.0	1.44	1.20	11	24	1998

Table D10 - Catalog of Extreme Storms for Interior Lowlands West Climatic Region 32 for 2-Hour Duration

EXTREME STORMS AT 2-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-6624	PORT ANGELES	32	58	48.1	123.4	1.41	0.72	9	27	1953
45-6114	OLYMPIA AIRPORT	32	47	47.0	122.9	1.53	0.97	12	9	1956
45-6678	PORT TOWNSEND	32	27	48.1	122.8	1.98	0.84	9	10	1967
45-6624	PORT ANGELES	32	58	48.1	123.4	1.57	0.80	11	3	1978
45-6624	PORT ANGELES	32	58	48.1	123.4	1.57	0.80	12	14	1984
45-6114	OLYMPIA AIRPORT	32	47	47.0	122.9	1.42	0.90	1	9	1990

Table D11 - Catalog of Extreme Storms for Interior Lowlands East Climatic Region 31 for 2-Hour Duration

EXTREME STORMS AT 2-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-2675	EVERETT	31	58	48.0	122.2	1.78	1.01	9	28	1944
45-5224	MC MILLIN RESERVOIR	31	55	47.1	122.3	1.91	1.10	7	8	1946
45-9485	YELM	31	39	47.0	122.6	1.39	0.72	11	22	1946
45-1277	CENTRALIA 1 W	31	58	46.7	123.0	1.93	1.15	10	28	1949
45-7473	SEATTLE TACOMA AIRPO	31	60	47.5	122.3	1.72	0.91	3	3	1950
45-7473	SEATTLE TACOMA AIRPO	31	60	47.5	122.3	1.82	0.96	6	29	1952
45-7773	SNOQUALMIE FALLS	31	45	47.5	121.8	1.35	0.95	6	14	1957
45-5149	MC CHORD AFB	31	37	47.2	122.5	1.49	0.71	7	14	1957
45-5224	MC MILLIN RESERVOIR	31	55	47.1	122.3	1.86	1.07	9	17	1957
45-2675	EVERETT	31	58	48.0	122.2	2.01	1.14	5	31	1958
45-0324	AUBURN	31	36	47.3	122.2	1.59	0.87	6	8	1959
45-5224	MC MILLIN RESERVOIR	31	55	47.1	122.3	2.75	1.58	8	26	1960
45-4769	LONGVIEW	31	43	46.2	122.9	1.74	1.07	11	19	1962
45-7773	SNOQUALMIE FALLS	31	45	47.5	121.8	1.62	1.14	9	19	1964
45-0986	BURLINGTON	31	58	48.5	122.3	2.18	1.28	8	12	1965
45-0324	AUBURN	31	36	47.3	122.2	1.28	0.70	9	17	1969
45-0324	AUBURN	31	36	47.3	122.2	1.28	0.70	2	28	1972
45-2675	EVERETT	31	58	48.0	122.2	1.75	0.99	9	22	1972
45-9485	YELM	31	39	47.0	122.6	1.45	0.75	12	21	1972
45-1191	CASTLE ROCK 2 NW	31	22	46.3	122.9	1.97	1.46	9	20	1973
45-1277	CENTRALIA 1 W	31	58	46.7	123.0	1.84	1.10	7	8	1974
45-0986	BURLINGTON	31	58	48.5	122.3	1.70	1.00	2	12	1975
45-7458	SEATTLE URBAN SITE	31	50	47.7	122.3	2.97	1.61	8	26	1977
45-1146	CARNATION 4 NW	31	59	47.7	122.0	2.01	1.20	9	20	1977
45-1277	CENTRALIA 1 W	31	58	46.7	123.0	1.51	0.90	9	3	1979
45-4486	LANDSBURG	31	45	47.4	122.0	1.48	0.90	7	11	1980
45-1277	CENTRALIA 1 W	31	58	46.7	123.0	1.51	0.90	3	3	1981
45-0729	BLAINE	31	58	49.0	122.8	1.90	1.10	2	15	1986
45-1146	CARNATION 4 NW	31	59	47.7	122.0	1.68	1.00	6	18	1986
45-0986	BURLINGTON	31	58	48.5	122.3	1.70	1.00	5	16	1988
45-1146	CARNATION 4 NW	31	59	47.7	122.0	1.68	1.00	9	19	1988
45-0729	BLAINE	31	58	49.0	122.8	2.24	1.30	8	15	1989
45-0729	BLAINE	31	58	49.0	122.8	2.07	1.20	6	11	1993
45-4486	LANDSBURG	31	45	47.4	122.0	1.48	0.90	9	10	1994
45-4769	LONGVIEW	31	43	46.2	122.9	1.62	1.00	11	11	1995
45-0986	BURLINGTON	31	58	48.5	122.3	1.70	1.00	6	21	1997
45-7458	SEATTLE URBAN SITE	31	50	47.7	122.3	1.53	0.83	11	23	1997
45-7473	SEATTLE TACOMA AIRPO	31	60	47.5	122.3	1.84	0.97	11	4	1998

Table D12 - Catalog of Extreme Storms for Cascade Mountains West Climatic Region 15 for 2-Hour Duration

EXTREME STORMS AT 2-HOUR DURATION										
STATION ID	STATION NAME	REGION	YEARS RECORD	LAT	LONG	RATIO TO MEAN	PRECIP (in)	MON	DAY	YEAR
45-1992	DARRINGTON RGR ST	15	54	48.3	121.6	1.47	1.01	11	3	1941
45-7781	SNOQUALMIE PASS	15	51	47.4	121.4	1.77	1.48	12	4	1941
45-7919	SPIRIT LAKE R S	15	16	46.3	122.2	1.84	1.18	10	24	1943
45-1759	COUGAR 4 SW	15	59	46.0	122.4	1.87	1.49	9	21	1944
45-7709	SKYKOMISH 1 ENE	15	56	47.7	121.4	2.26	1.78	5	25	1945
45-7781	SNOQUALMIE PASS	15	51	47.4	121.4	1.85	1.55	10	24	1945
45-1457	CINEBAR 2 E	15	45	46.6	122.5	1.44	1.00	4	17	1947
35-0897	BONNEVILLE DAM	15	56	45.6	122.0	2.23	1.68	10	19	1947
45-6295	PALMER 3 ESE	15	59	47.3	121.9	1.42	1.20	5	27	1948
45-2493	ELECTRON HEADWORKS	15	38	46.9	122.0	1.32	0.90	12	19	1948
45-5663	MOUNT BAKER LODGE	15	24	48.9	121.7	1.86	1.53	6	16	1949
45-2493	ELECTRON HEADWORKS	15	38	46.9	122.0	1.76	1.20	10	28	1949
45-9171	WHITE RIVER R S	15	34	46.9	121.6	1.77	1.17	2	16	1949
45-1457	CINEBAR 2 E	15	45	46.6	122.5	2.17	1.51	6	9	1953
45-6295	PALMER 3 ESE	15	59	47.3	121.9	1.36	1.15	6	30	1955
45-7604	SHUKSAN	15	14	48.9	121.7	1.28	0.82	11	9	1955
45-1759	COUGAR 4 SW	15	59	46.0	122.4	1.40	1.12	8	2	1956
35-0897	BONNEVILLE DAM	15	56	45.6	122.0	2.00	1.51	8	25	1956
45-4634	LESTER	15	23	47.2	121.5	1.70	1.05	12	9	1956
45-7657	SILVERTON	15	45	48.1	121.6	1.56	1.40	12	9	1956
45-6909	RANDLE 1 E	15	40	46.5	121.9	2.19	1.40	8	28	1957
45-6892	RAINIER CARBON RIVER	15	37	47.0	121.9	1.67	1.05	9	17	1957
45-6295	PALMER 3 ESE	15	59	47.3	121.9	1.62	1.37	9	26	1959
45-6896	RAINIER OHANAPECOSH	15	53	46.7	121.6	1.69	1.23	11	19	1962
45-8715	UPPER BAKER DAM	15	33	48.7	121.7	1.42	1.10	11	15	1970
35-0897	BONNEVILLE DAM	15	56	45.6	122.0	1.86	1.40	11	20	1970
45-4999	MARBLEMOUNT RGR ST	15	56	48.5	121.5	1.28	0.80	12	25	1972
45-9171	WHITE RIVER R S	15	34	46.9	121.6	1.81	1.20	5	10	1975
45-5704	MUD MOUNTAIN DAM	15	56	47.2	121.9	1.60	1.04	8	17	1975
45-1233	CEDAR LAKE	15	45	47.4	121.7	1.53	1.30	9	20	1977
45-3357	GREENWATER	15	54	47.1	121.6	1.71	1.13	12	1	1977
45-6909	RANDLE 1 E	15	40	46.5	121.9	1.88	1.20	6	28	1978
45-5704	MUD MOUNTAIN DAM	15	56	47.2	121.9	1.71	1.11	7	9	1979
45-7657	SILVERTON	15	45	48.1	121.6	2.01	1.80	9	30	1980
45-4764	LONGMIRE RAINIER NPS	15	21	46.8	121.8	1.82	1.30	1	12	1980
45-4999	MARBLEMOUNT RGR ST	15	56	48.5	121.5	1.43	0.90	8	30	1982
45-6892	RAINIER CARBON RIVER	15	37	47.0	121.9	1.28	0.80	9	15	1982
45-1992	DARRINGTON RGR ST	15	54	48.3	121.6	1.60	1.10	12	3	1982
45-3357	GREENWATER	15	54	47.1	121.6	1.52	1.00	1	23	1982
45-3357	GREENWATER	15	54	47.1	121.6	1.52	1.00	1	3	1984
45-1992	DARRINGTON RGR ST	15	54	48.3	121.6	1.45	1.00	9	5	1985
45-5876	NOOKSACK SALMON HAT	15	35	48.9	122.2	1.74	1.40	10	26	1986
45-6896	RAINIER OHANAPECOSH	15	53	46.7	121.6	1.65	1.20	1	18	1986
45-4999	MARBLEMOUNT RGR ST	15	56	48.5	121.5	1.28	0.80	2	23	1986
45-3357	GREENWATER	15	54	47.1	121.6	1.97	1.30	7	18	1987
45-6896	RAINIER OHANAPECOSH	15	53	46.7	121.6	1.51	1.10	12	30	1988
45-4999	MARBLEMOUNT RGR ST	15	56	48.5	121.5	1.28	0.80	11	9	1990
45-6896	RAINIER OHANAPECOSH	15	53	46.7	121.6	1.51	1.10	11	23	1990
45-3160	GLACIER R S	15	20	48.9	122.0	1.78	1.40	12	31	1990
45-1457	CINEBAR 2 E	15	45	46.6	122.5	1.44	1.00	1	9	1990
45-5876	NOOKSACK SALMON HAT	15	35	48.9	122.2	2.23	1.80	10	20	1992
45-1233	CEDAR LAKE	15	45	47.4	121.7	1.65	1.40	6	22	1993
KI-14U	EAST FORK ISSAQUAH C	15	12	47.5	122.0	1.64	1.08	7	4	1994
45-1759	COUGAR 4 SW	15	59	46.0	122.4	1.38	1.10	10	31	1994
45-8715	UPPER BAKER DAM	15	33	48.7	121.7	1.42	1.10	10	9	1995
45-4999	MARBLEMOUNT RGR ST	15	56	48.5	121.5	1.28	0.80	11	28	1995
45-8838	VERLOT	15	23	48.1	121.8	1.59	1.50	12	12	1995
45-1992	DARRINGTON RGR ST	15	54	48.3	121.6	1.45	1.00	12	27	1996
45-6896	RAINIER OHANAPECOSH	15	53	46.7	121.6	1.51	1.10	12	29	1996
45-4999	MARBLEMOUNT RGR ST	15	56	48.5	121.5	1.59	1.00	10	30	1997

Appendix E

L-MOMENT STATISTICS

L-MOMENT STATISTICS

L-moments are a dramatic improvement over conventional statistics for characterizing the variance and skewness of data, for describing the shape of a probability distribution, and for estimating the distribution parameters (Hosking[7,9,13]). They are particularly useful for describing environmental data that are often highly skewed. The at-site L-moment measure of location, and L-moment ratio measures of scale, skewness and kurtosis are:

Location, mean:

$$\text{Mean} = L_1 \qquad \text{(E1)}$$

Scale, L-Cv (t_2):

$$t_2 = L_2/L_1 \qquad \text{(E2)}$$

L-Skewness (t_3):

$$t_3 = L_3/L_2 \qquad \text{(E3)}$$

L-Kurtosis (t_4):

$$t_4 = L_4/L_2 \qquad \text{(E4)}$$

where:

$$L_1 = \beta_0 \qquad \text{(E5)}$$

$$L_2 = 2\beta_1 - \beta_0 \qquad \text{(E6)}$$

$$L_3 = 6\beta_2 - 6\beta_1 + \beta_0 \qquad \text{(E7)}$$

$$L_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0 \qquad \text{(E8)}$$

and where the at-site data are first ranked in ascending order from 1 to n ($x_{1:n}$) and:

$$\beta_0 = n^{-1} \sum_{j=1}^{n} x_j \qquad \text{(E9)}$$

$$\beta_1 = n^{-1} \sum_{j=2}^{n} x_j \, [(j-1)/(n-1)] \qquad \text{(E10)}$$

$$\beta_2 = n^{-1} \sum_{j=3}^{n} x_j \, [(j-1)(j-2)]/[(n-1)(n-2)] \qquad \text{(E11)}$$

$$\beta_3 = n^{-1} \sum_{j=4}^{n} x_j \, [(j-1)(j-2)(j-3)]/[(n-1)(n-2)(n-3)] \qquad \text{(E12)}$$

Regional L-moments ratios are obtained as weighted averages of the at-site L-moments ratios where the at-site values are weighted by record length. Specifically: n_i is the record length at site i of N sites: n_R is the total record length for the N sites in the region; t_2^i, t_3^i, t_4^i are L-moment ratios at site i ; and:

$$n_R = \sum_{i=1}^{N} n_i \qquad \text{(E13)}$$

Regional Mean (L_1^R) is unity using the index-flood procedure:

$$L_1^R = 1 \qquad \text{(E14)}$$

Regional L-Cv (t_2^R):

$$t_2^R = n_R^{-1} \sum_{i=1}^{N} n_i \; t_2^i \qquad \text{(E15)}$$

Regional L-Skewness (t_3^R):

$$t_3^R = n_R^{-1} \sum_{i=1}^{N} n_i \; t_3^i \qquad \text{(E16)}$$

Regional L-Kurtosis (t_4^R):

$$t_4^R = n_R^{-1} \sum_{i=1}^{N} n_i \; t_4^i \qquad \text{(E17)}$$

The regional L-moment ratios for L-Skewness (t_3^R) and L-Kurtosis (t_4^R) were corrected for bias based on bias correction equations provided by Hosking and Wallis[8,9]. These equations are valid for the range of regional L-moment ratios observed in the study area, where:

$$\text{bias } t_3^R = 4N(.10 - t_4^R)/\,n_R \qquad \text{(E18)}$$

$$\text{bias } t_4^R = 4N(.15 - t_4^R)/\,n_R \qquad \text{(E19)}$$

Appendix F

SELECTED DEFINITIONS

At-Site - the term at-site is used in various ways. It may be used to distinguish analyses/data at a specific site from regional analyses/data. It may be used in reference to a given gage/station or a specific geographic location. Observed at-site precipitation is synonymous with observed point rainfall.

At-Site Mean - the mean value of precipitation for a specified duration at a specific location. For a gaged site, it is based on the gaged record for the specified duration. At an ungaged site, it is based on a statistical relationship. Also see mean annual maxima.

Climatic Region - a geographic area that has similar physical and climatological characteristics.

Convective Precipitation - precipitation that results from lifting of atmospheric moisture due to vertical instability in the air column. The thunderstorm is one type of convective precipitation producing mechanism.

Convergence Precipitation - convergence is intended to encompass all precipitation producing mechanisms associated with the circulation of a cyclonic weather system.

Extreme Storm - a precipitation amount for a specified duration that has an annual exceedance probability less than 0.05; rarer than a 20-year event.

Gage Mean - the mean value computed from the annual maxima data at a precipitation gage for some specified duration. At-site mean values are determined from gage mean values using minor correction factors to adjust from fixed measurement intervals to true intervals. See Weiss[32].

Gaged Site - a geographic location where a precipitation gage is used to measure and record precipitation data. See also ungaged site.

Homogeneous sub-region - a collection of sites/gages with similar physical and/or climatic characteristics that can be described by a common regional growth curve.

Mean Annual Maxima (MAM) - the mean value of precipitation annual maxima for a specified duration at a specific location. It is the terminology commonly used in Canada as an alternate to at-site-mean.

Mean Annual Precipitation (MAP) - the average precipitation for a calendar year. (An example of an at-site-mean).

Orographic Precipitation - precipitation that occurs due to the lifting of atmospheric moisture over mountain barriers.

Precipitation Annual Maxima - the greatest precipitation amount in a 12-month period for a specified duration. The annual period may be a calendar year, or any other 12-month period. The water-year, October 1st to September 30th is the 12-month period used in these analyses.

Regional - the term regional is used in a generic manner to distinguish data/analyses for a group of sites/gages as opposed to individual at-site data/analyses. The term regional may be used in reference to homogeneous sub-regions or climatic regions.

Regional Growth Curve - a magnitude-frequency curve with a mean value of unity that is applicable to all sites within a homogeneous region.

Seasonality - frequency characteristics for the time of year (month) during which certain characteristics of precipitation have been observed to occur.

Station - refers to the weather station/collection site for precipitation. A particular station/location may contain any combination of daily, synoptic and automated gages. The term station and site are often used interchangeably.

Ungaged Site - a geographic location where no precipitation measurements are available.