Exhibit D-4

Robert St. Clair

From:	Susan Logan <susie@susiestevens.com>
Sent:	Wednesday, October 18, 2023 12:51 PM
To:	Planning Group
Cc:	Jennifer Barrett
Subject:	"Revised Wetland Overlay Ordinance" notification, and resident concern regarding inaccurate map diagrams provided via City website
Attachments:	7th and Laurel Narrative_Final 2023-08-29 2.pdf; Screenshot CLOSE UP OF Urbsworks N. end Cannon Beach map and stream designation.pdf

Hello,

I am a resident of Cannon Beach, and my property is located on the north end of our town. While I am in support of efforts being addressed to secure appropriate wetland protections within our City, I am disturbed by the inaccuracy of the maps specifically provided on the City website, which are intended to support this proposed wetland revision. The "LWI stream sites" included in the maps (I assume, provided by "Urbsworks" ?) which represent the north end are inaccurate- *and should be corrected!*

Without the assurance of accurate recording of the streams that currently exist in our area, there is a high likelihood that important factual information related to these proposed revisions will be overlooked and/or dismissed.

Recently one of my neighbors and myself were informed of the results of a study which was contracted by the City, and conducted by "Windsor Engineering," in order to assess serious flooding events which occurred on our street (N. Laurel) in November of 2021, and again in January of 2022. The results of this study have been attached for your review- and for clarification of accurate stream bed representations - which should be implemented in this proposed "Revised Wetland Overlay Ordinance."

In addition to the Windsor Engineering study (which provides maps of the north end of Cannon Beach, included to assess the flooding on our N. Laurel street, on pp. 25-26 of the study), I have provided a close up view of one of the maps included by the "Urbsworks Team," who has been contracted by the City to assist this wetland revision ordinance. Note how the map that Urbsworks has presented indicates a stream bed originating on N. Laurel St. and suggesting that the stream origin begins just above the intersection of Laurel St (which is actually **N.** Laurel St.) and 7th St. In reality, the origin of that stream bed begins several lots upward on N. Laurel St. and as you will see from the Windsor Engineering study, it is recognized as a "tributary of the Logan Creek." In fact, that "tributary of Logan Creek" enters into a culvert just north of where your map suggests that the stream *begins.* A comparison of the maps provided by Windsor Engineering verses that of Urbsworks should provide the clarity (and corrections) which I hope to have addressed in this correspondence.

Exhibit D-4

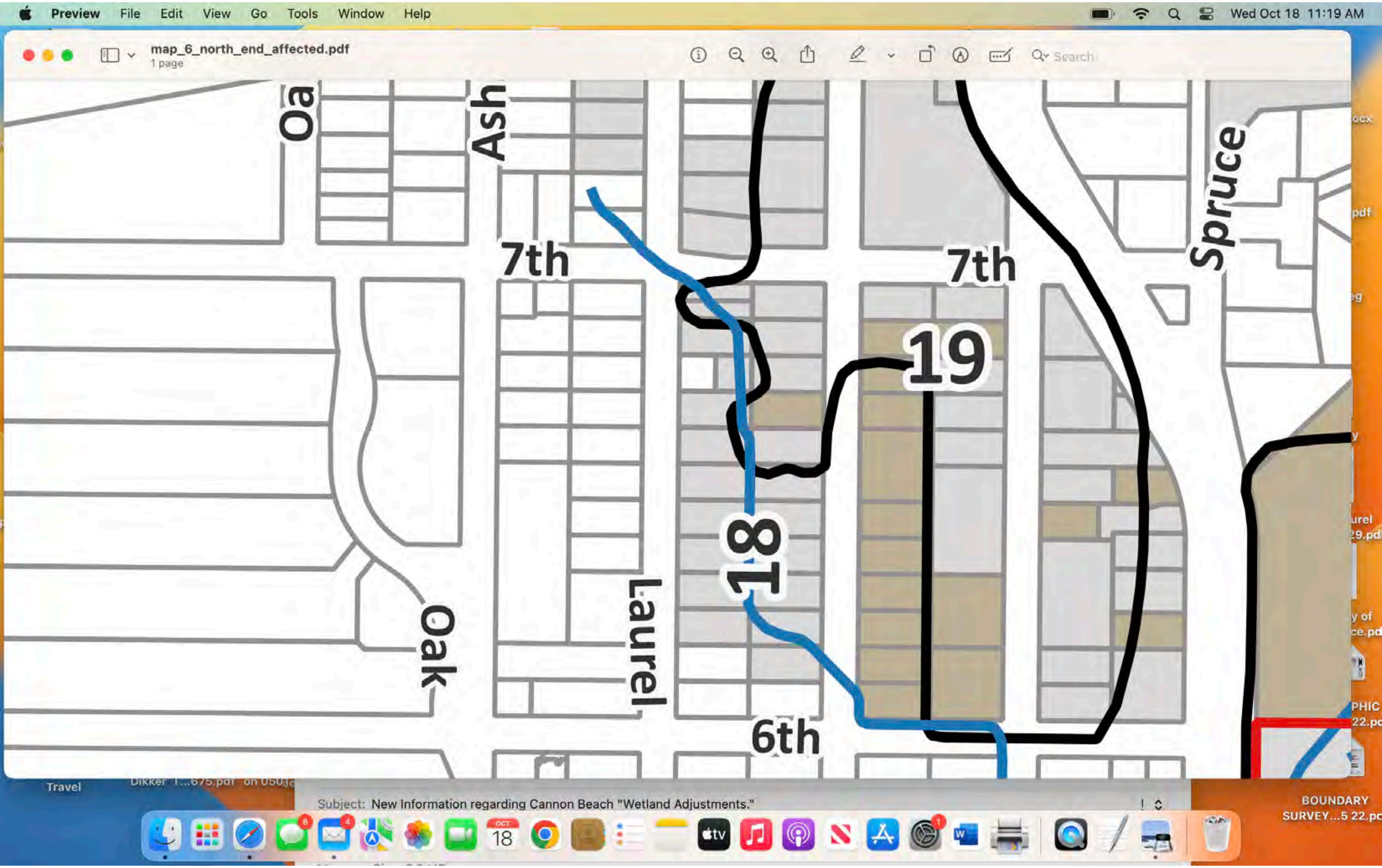
Preview File Edit View Go Tools Window Help
Wed Oct 18 11:19 AM
map_6_north_end_affected.pdf
1 page
Oa
Ash
7th
7th
Spruce
19
18
Oak
Laurel
6th
Subject: New Information regarding Cannon Beach "Wetland Adjustments."
BOUNDARY SURVEY...5 22.pdf
Travel

Exhibit D-4

Thank you for your time,

Susie Stevens Logan

Inaccurate "Urbsworks" map of N. End stream representation:

Exhibit D-4

CITY OF CANNON BEACH
7th & Laurel Intersection

Stormwater & Flooding Assessment
AUGUST 29, 2023

Submitted by
Windsor Engineers
Civil, Mechanical & Electrical Engineers
27300 NE 10th Avenue
Ridgefield, WA 98642
360.610.4931

Prepared for
City of Cannon Beach
163 E. Gower St.
PO Box 368
Cannon Beach, OR 97110
503.436.5068

Exhibit D-4

Table of Contents

Tables

Figures

1.0 PROJECT TEAM

Owner

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EIT
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Travis Tormanen
Professional Engineer
TTormanen@WindsorEngineers.com

2.0 CERTIFICATION

CERTIFICATE OF THE ENGINEER

Title: Stormwater & Flooding Assessment

Project: 7th & Laurel

This Assessment was initially completed as a draft document in February 2023. All data references in this assessment collected prior to that date. This current August 2023 final version of the assessment includes minor edits, but does not include any new data or findings.

This Assessment has been prepared under my supervision and meets the standard of care for similar documents within the engineering community.

Windsor Engineers

Reviewed By: Travis Tormanen, PE

Designed By: Dan Koistinen, EIT

3.0 REFERENCES

Clean Water Act. n.d. <https://www.epa.gov/laws-regulations/summary-clean-water-act>.

Oregon Department of Transportation Hydraulics Manual <https://www.oregon.gov/odot/GeoEnvironmental/Pages/Hydraulics-Manual.aspx>.

Nation Oceanic and Atmospheric Administration https://www.noaa.gov/

National Resources Conservation Service <https://www.nrcs.usda.gov/>

Exhibit D-4

4.0 PROJECT DESCRIPTION

4.1 General Project Description

Windsor Engineers (Windsor) has provided an assessment of flooding that occasionally occurs near the intersection of West 7th Street and North Laurel Street (7th and Laurel). Windsor was authorized to complete this assessment by Beery Elsner & Hammond LLP on November 30, 2022. It is our understanding that there have been localized flooding problems in the yards of at least two homes and that these have occurred during heavy rainfall events that happened at the same time as King Tide events occurred. One event occurred over November 4 and 5, 2021 and the other flooding occurred on January 6, 2022. Two local property owners contacted the City with concerns about the flooding.

This assessment analyzed several potential factors that may contribute to the flooding at the 7th and Laurel location:

- Unusually high tides (King Tides) and elevation
- Large rainfall events
- Undersized stormwater system
- Obstructions in the downstream drainage system
- Combination of several above

Figure 1: 7th & Laurel St. Drainage Basin

5.0 DRAINAGE BASIN CHARACTERISTICS

5.1 Drainage Characteristics

The unnamed stream that flows under the 7th and Laurel intersection is a tributary of Logan Creek. The unnamed stream flows into Logan Creek near the intersection of Ecola State Park Rd and East 5th Street. The stream enters a private conveyance system near the rear yard of 716 North Laurel and appears to connect to the City stormwater conveyance system that flows under the intersection of 7th and Laurel. There are no known as-builts of the private stormwater system.

The stream that flows into the private conveyance system is approximately 2 feet (ft) wide by 1 ft deep. This is based on site observation. The stream begins in the Ecola State Park to the north and drains approximately 54.38 acres in total, draining under the 7th and Laurel intersection (see the blue pin in Figure 1). The basin has several types of land covers. The area breakdowns were estimated by available Clatsop County Geographic Information System (GIS) data and the City of Cannon Beach (City) GIS information. The area breakdown is seen in Table 1, below.

Table 1: Basin Characteristics

Land Cover	Hydrologic Soil Group		Total	Modeled Land Cover
	A	B		
Residential	3.07	4.40	7.47	1/8-acre average lot size
Streets/Roadway	0.00	1.65	1.65	Impervious Area, paved parking, gravel road
Native Forest/Wood	0.00	45.26	45.26	Woods - Good Condition
		TOTAL	**54.38**	

5.2 Soil Characteristics

The National Resource Conservation Service (NRCS) web soil survey lists Class A and Class B hydrological soil groups as the primary soils in the delineated basin. Class A soils have low runoff potential when thoroughly wet and water is transmitted freely through the soil. Class B soils have moderately low runoff potential when thoroughly wet and water is transmitted unimpeded through the soil. Approximately 86.4 percent (%) of the basin soil is classified as Skipanon gravelly medial silt loam (58E) which is a Class B soil. The last significant soil type found in the basin area is Waldport Fine Sand (70C & 70D), a Class A soil type. The basin is approximately 8.4% Waldport Fine Sand. A small portion (approximately 4.4%) of the basin on the north side in Ecola State Park is classified as Klootchie Silt Loam, a Class B soil. See **Appendix D** for the NRCS Web Soil Survey. Most of the drainage basin is sloped with slopes ranging from 30% to 80% and small areas of flat. The basin also has a geologic hazard overlay and landslide susceptibility according to the Clatsop County GIS mapping.

The drainage basin area includes parts of the City of Cannon Beach residential areas to the native forests of Ecola State Park. The basin breakdown, as seen in Table 1, is primarily native vegetation and wooded area, at 45.26 acres. Approximately 1.65 acres of paved or gravel roads are within the drainage area. 7.47 acres of the basin are 1/8 acre lots (average) residential areas.

Exhibit D-4

6.0 ELEVATION AND TIDES

6.1 Important Elevations

Windsor researched the elevation of the unnamed tributary and Logan by authorizing Onion Peak Design to survey a few key locations associated with the 7th and Laurel intersection. Figure 2, below, highlights the elevation of the mouth of Logan Creek, the Logan Creek and 5th Street crossing, and the unnamed tributary crossing at the intersection of 7th Street and Laurel Street.

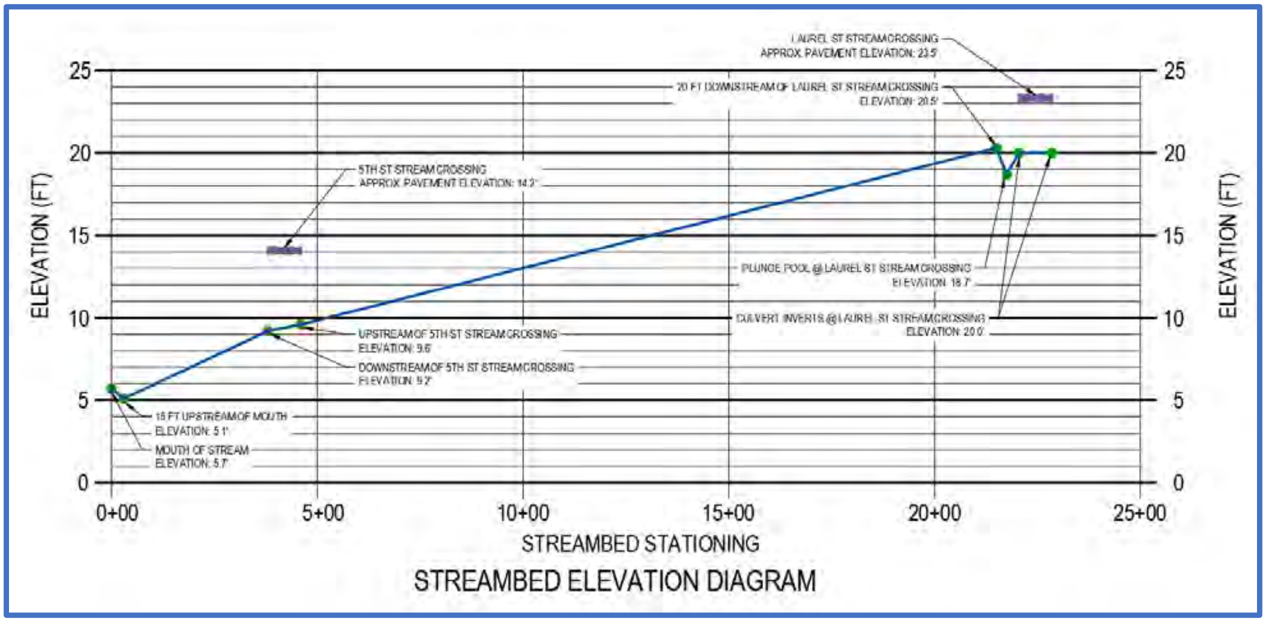

Figure 2: Streambed Elevation Diagram

6.2 Key Elevations

There are several key elevation differences shown on the diagram.

- Mouth of Logan Creek versus (vs) the storm system outlet at 7th & Laurel
  - 14.9 ft different
- 5th Street crossing vs the storm system outlet at 7th & Laurel
  - 5.8 ft different
- The elevation difference between the 5th Street crossing and the pavement at 7th & Laurel
  - 9.3 ft different

6.3 Tides

The National Oceanic and Atmospheric Administration (NOAA) defines a King Tide as a *popular, non-scientific term used to describe exceptionally high tides*. One possibility of flooding at 7th and Laurel could be exceptionally high tides: King Tides. There are two NOAA tidal stations near Cannon Beach. One station is located approximately 30 miles away in Garibaldi, OR on Tillamook Bay and the other is located approximately 26 miles away near Astoria, OR on the Columbia River. The tidal data from Garibaldi was observed due to the proximity and lack of influence from the Columbia River. The tidal data was selected for this analysis based on a set of criteria:

- Dates that rainfall was recorded to be above 1.50 inches over 24 hours in Cannon Beach during the months of November, December, and January of 2021 to present.
- Dates prior to and after rainfall events of 1.50 inches over 24 hours
- Dates where tidal fluctuations called “King Tides.”
- Dates of known flooding at the 7th and Laurel intersection.

Tidal fluctuations measurement data is presented in several ways. The height of the tide compared to a baseline is called a ”datum.” The two main datums selected for the analysis are the Mean Sea Level Datum, *the arithmetic mean of hourly heights observed over the National Tidal Datum Epoch (NOAA),* and Mean High Water Level Datum, *the average of all the high-water heights observed over the NOAA*. See **Appendix A** for all tidal data.

7.0 RAINFALL

7.1 Stormwater

Stormwater runoff is the precipitation that flows across the ground. The runoff may flow overland to nearby bodies of water including streams, lakes, rivers, and oceans, through infiltration into the ground, or evaporation into the atmosphere. Modern modeling software can analyze the amount of stormwater generated by the drainage basin based on rainfall events. Windsor analyzed the drainage basin for 7th and Laurel using a modeling software to compare Oregon State accepted design rainfall events to measure rainfall events of the dates flooding occurred.

7.2 Modeling Software

Windsor Engineers selected the single unit hydrograph software, WinTR-55, to model the drainage basin. WinTR-55 is released by the NRCS and is a single event, small runoff watershed hydraulic modeling software. The software can model both urban and rural areas. Inputs include land cover, design rainfall event, time of concentration, and other parameters. The output information flows in cubic feet per second (cfs) for associated rainfall events. WinTR-55 is accepted by the Oregon Department of Transportation (ODOT) Hydraulic Design Manual as an acceptable modeling software. See Section 12.10.1 of the ODOT Hydraulics Manual for more information on ODOT accepted modeling software. See **Appendix B** for a summary of the modeling with WinTR-55.

7.3 Rainfall Event

Design storms are hypothetical storm events where a depth of rainfall occurs for a return frequency (2-year [yr], 5-year, etc.), duration (24 hours), and timing distribution (IA). The design storm depths for Cannon Beach are estimated from rainfall maps called Isopluvial maps. Isopluvial maps for the State of Oregon are issued by two primary sources; the first is ODOT and the second is the NOAA. Table 2 shows the reoccurrence interval and design storm for the 7th and Laurel drainage system. See **Appendix C** for the Isopluvial maps.

Table 2: 7th & Laurel Drain Basin Analysis

NOAA		ODOT		Average
Return Frequency	**Inches per 24 hrs.**	**Return Frequency**	**Inches per 24 hrs.**	**Inches per 24 hrs.**
2 yr	3.8	2 yr	3.8	3.8
5 yr	4.5	-	-	4.5
10 yr	4.8	10 yr	4.6	4.7
25 yr	6.0	25 yr	6.0	6.0
50 yr	6.5	50 yr	6.5	6.5
100 yr	7.0	100 yr	7.0	7.0
-	-	500 yr	8.0	8.0
-	-	1000 yr	9.0	9.0

The City has been recording rainfall since the early 2000s. Due to the extensive records, the rainfall data is available for the dates flooding occurred near 7th and Laurel. Windsor went through the results of rainfall events in the months of November, December, and January for 2021 to analyze the rainfall events over 1.50 inches in a 24-hour period. See the results in Section 9.0 Conclusions.

Exhibit D-4

8.0 OREGON DEPARTMENT OF TRANSPORTATION (ODOT) AND OREGON PARKS AND RECREATION DEPARTMENT (OPRD)

8.1 Design Requirements

Windsor Engineers reached out to ODOT and OPRD for available information on the infrastructure in Ecola State Park and the surrounding areas. No records were found.

Another item to consider is the sizing of the stormwater conveyance system. The ODOT design manual has the following design storm sizing requirements.

Policy 3-9

Table 3-1 Design Recurrence Interval (Years)

Drainage Facility	Freeways	Highways Other Than Freeways	
		ADT[1] less than 750	ADT[1] greater than or equal to 750
Bridge Openings[2,4]	50	25	50
Bridge Scour	See Chapter 10	See Chapter 10	See Chapter 10
Bank Protection	50	25	50
Culverts[2,4]	50	25	50
Ditches, Inlets and Gutters	10	10	10
Depressed Roadways	50	25	50
Energy Dissipators[3]	50	25	50
Storage Facilities	See Chapter 12	See Chapter 12	See Chapter 12
Water Quality Facilities	See Chapter 14	See Chapter 14	See Chapter 14
Storm Drains	10	10	10
Storm Drain Outfalls from Sags	50	25	50
Temporary Drainage Facilities[5]	See Section 3.10	See Section 3.10	See Section 3.10
Channel Changes[2,4]	50	25	50

April 2014 ODOT Hydraulics Manual

Figure 3: ODOT Design Storm Sizing Table

9.0 CONCLUSIONS

9.1 Results of Analysis

Below are the results from the analyses of events that took place with the following criteria:

- Tides greater than the Mean High-Water Level (MHW).
- Recorded rainfalls above 1.50 inches in 24 hours.
- Events over the dates when flooding occurred.

Table 3: Design Storm Events for Cannon Beach

Date of Storm Event	Return Period	24-hr Rainfall Depth (in)	Peak Flow (cfs)	Height of Tide Above Mean High Water Level (MHW) (ft)
N/A	**2 yr**	3.80	2.55	**N/A**
N/A	**5 yr**	4.50	6.50	**N/A**
N/A	**10 yr**	4.80	8.53	**N/A**
N/A	**25 yr**	6.00	17.96	**N/A**
N/A	**50 yr**	6.50	22.40	**N/A**
N/A	**100 yr**	7.00	27.05	**N/A**
12/22/2021	**Less than 2 yr return period**	1.51	0.08	1.92
12/11/2021		1.59	0.12	1.13
12/18/2021		1.67	0.16	1.82
1/2/2022		1.75	0.21	3.36
11/12/2021		2.22	0.55	0.42
12/26/2022		3.00	1.34	3.11
11/11/2022		3.04	1.38	0.59
1/11/2022		3.11	1.47	0.82
11/4/2022	**Less than 10 yr return period**	4.65	8.78	3.05
[1]**1/6/2022**	**Greater than 10 yr return period**	4.96	11.13	2.27
[1]****11/11/2021 - 11/12/2022**	****Greater than 10 yr return period**	5.26	13.53	0.51
**Please note that this storm event took place over 24 to 48 hrs.				
[1]Dates that flooding occurred				

Several pieces of evidence became apparent when evaluating the results. Two flooding events occurred; one on January 6, 2022, and the other event was November 11-12, 2021. The January 6th flooding simultaneously had King Tides while the storm event in November of 2021 (that resulted in flooding) experienced tides that were only 0.51 ft higher than the mean high-water level. Three other events on November 4, 2022, January 2, 2022, and December 26, 2022, had larger tides than the January 6, 2022, flood event, but no flooding occurred at these times.

One other piece of information that supports the results that King Tides do not affect the 7th and Laurel intersection is **Figure 2: Streambed Elevation Diagram.** The diagram shows that the streambed elevations in the mouth of Logan Creek and the 7th and Laurel conveyance system are 14.9 ft different in elevation. Several blocks of residential housing between the mouth of Logan Creek and 7th and Laurel would experience flooding if water, due to high tides, was to stack up in elevation high enough to influence the 7th and Laurel intersection. Furthermore, no other reports of flooding downstream of 7th and Laurel are known in connection to the flood events.

Conclusion: based on the data available for the timeframes described in this report, it can be observed that flooding occurred with and without the presence of a King Tide, suggesting that a King Tide does not likely affect the water level at 7th and Laurel.

Looking at the results table leads to an additional conclusion. Flooding occurs when storm events are greater than a 10-year design storm for this drainage basin. While there is not a large sample size of events since 2021, Cannon Beach observed flooding on both occasions where storms were larger than 4.80 inches of rainfall in 24 hours (10-yr design storm). ODOT standards for storm inlets, ditches, and storm drains are to convey the 10-yr design storm. The empirical data suggests that the intersection is able to convey the 10-yr storm but that there have been system capacity issues for storms larger than this size.

In conclusion, the results of the analysis suggest that the cause of the flooding is a consequence of large rain fall events and a lack of ability for the unnamed tributary to convey events larger than the 10-year design storm. Additional data from future storms would be helpful to further analyze the connection in storm sizes and flood events.

9.2 Capacity Issues

The reason that the system appears to have capacity issues when storms greater than the 10-yr design storm occur is likely associated with a combination of the following.

- The downstream creek has fallen trees and other debris that prevent optimized drainage of the 7th & Laurel intersection area.
- The topography of the area may not be conducive to avoiding flooding in storms that are greater than the 10-yr design storm event.
- Private stormwater system improvements are not fully documented. It is unknown what design criteria were used in sizing any private pipelines, culverts, inlets, and screens and whether the sizing and configuration is appropriate to avoid flooding.
- It is possible that some of the public and/or private pipelines are partially plugged.

10.0 APPENDICES

Appendix A – Tidal Information

Appendix B – WinTR-55 Modeling

Appendix C – Isopluvial Maps

Appendix D – Soils Information

APPENDIX A

Tide Data from NOAA

Exhibit D-4

Tide Information

		Cannon Beach Records		NOAA Station 9437540 - Garibaldi, OR		
		Rain Fall Data		Tide Height (Ft)		
	Tide	Date	Inch / 24 hrs	Datum: STI	Datum: MSL	Datum: MHW
		11/4/2021	1.35	14.65	6.16	3.05
	king	11/5/2021	0.71	14.71	6.22	3.11
	king	11/6/2021	0.88	14.85	6.36	3.25
	king	11/7/2021	0.39	14.37	5.87	2.77
		11/11/2021	3.04	12.19	3.69	0.59
		11/12/2021	2.22	12.02	3.52	0.42
	king	12/3/2021	0.00	13.66	5.16	2.06
	king	12/4/2021	0.67	14.50	6	2.9
	king	12/5/2021	0.01	13.93	5.43	2.33
		12/6/2021	0.36	14.32	5.83	2.73
		12/7/2021	0.36	13.71	5.22	2.12
		12/11/2021	1.59	12.72	4.23	1.13
		12/18/2021	1.67	13.42	4.93	1.82
		12/22/2021	1.51	13.52	5.02	1.92
	king	1/1/2022	0.00	14.02	5.53	2.42
	king	1/2/2022	1.75	14.96	6.47	3.36
	king	1/3/2022	0.48	16.07	7.58	4.47
		1/4/2022	0.37	14.83	6.34	3.23
		1/5/2022	1.27	13.91	5.42	2.32
Flooded		1/6/2022	4.96	13.87	5.38	2.27
		1/7/2022	0.61	13.88	5.38	2.28
		1/8/2022	0.03	12.77	4.27	1.17
		1/9/2022	0.00	12.42	3.93	0.82
		1/10/2022	0.26	12.19	3.69	0.59
		1/11/2022	3.11	12.42	3.92	0.82
		1/12/2022	0.55	12.66	4.16	1.06
		11/3/2022	0.62	11.3	2.81	-0.29
		11/4/2022	4.65	12.62	4.12	1.02
		11/5/2022	0.36	13.16	4.67	1.57
		11/22/2022	0.48	13.68	5.19	2.09
		11/23/2022	0.1	13.56	5.07	1.97
	king	11/24/2022	0.00	13.86	5.37	2.26
	king	11/25/2022	0.11	13.79	5.29	2.19
	king	11/26/2022	0.00	13.22	4.72	1.62
	king	12/22/2022	0.13	14.01	5.51	2.41
	king	12/23/2022	0.11	14.61	6.11	3.01
	king	12/24/2022	1.22	14.64	6.15	3.04
		12/25/2022	1.41	14.5	6	2.9
		12/26/2022	3.00	14.71	6.22	3.11
		12/27/2022	1.12	15.29	6.8	3.69

APPENDIX B

WinTR-55 Modeling

Exhibit D-4

Summary of Results

7th and Laurel Design Basin				
Date of Storm Event	**Return Period**	**24-hr Rainfall Depth (in)**	**Peak Flow (cfs)**	**Height of Tide Above Mean High Water Level (MHW) (ft)**
N/A	**2-Yr**	3.80	2.55	**N/A**
N/A	**5-Yr**	4.50	6.50	**N/A**
N/A	**10-Yr**	4.80	8.53	**N/A**
N/A	**25-Yr**	6.00	17.96	**N/A**
N/A	**50-Yr**	6.50	22.40	**N/A**
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[1]** **11/11/2021 - 11/12/2022**	****Greater than 10 yr return period**	5.26	13.53	0.51

**Please note that this storm event took place over 24 to 48 hrs

[1]Dates that flooding occurred

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		11/5/2022	0.36	13.16	4.67	1.57
		11/22/2022	0.48	13.68	5.19	2.09
		11/23/2022	0.1	13.56	5.07	1.97
	king	11/24/2022	0.00	13.86	5.37	2.26
	king	11/25/2022	0.11	13.79	5.29	2.19
	king	11/26/2022	0.00	13.22	4.72	1.62
	king	12/22/2022	0.13	14.01	5.51	2.41
	king	12/23/2022	0.11	14.61	6.11	3.01
	king	12/24/2022	1.22	14.64	6.15	3.04
		12/25/2022	1.41	14.5	6	2.9
		12/26/2022	3.00	14.71	6.22	3.11
		12/27/2022	1.12	15.29	6.8	3.69

Exhibit D-4

Rainfall Information

No Data	king	1/20/2023	0.00
No Data	king	1/21/2023	0.29
No Data	king	1/22/2023	0.01

STND = Station Datum
MSL = Mean Sea Level
MHW = Mean High Water Level

Isopluvial Rainfall for 7th St and Laurel St

NOAA		ODOT		Average
Design Sto	In/24 hrs	Design Storm	In/24 hrs	Inch/24 hr
2 yr	3.8	2 yr	3.8	3.8
5 yr	4.5	-	-	4.5
10 yr	4.8	10 yr	4.6	4.7
25 yr	6.0	25 yr	6.0	6.0
50 yr	6.5	50 yr	6.5	6.5
100 yr	7.0	100 yr	7.0	7.0
		500 yr	8.0	8.0
		1000 yr	9.0	

Exhibit D-4

Summary of WinTR-55 Inputs and Outputs			
	Basin 1	**Units**	**Notes**
Rainfall Distribution:	24-hour Type 1-A		
Drainage Area:	54.38	acres	per client data
Impervious Acres	1.65	acres	rural road/streets
Residential Acres	7.47	acres	1/8 acre lots (avg)
Pervious Acres	45.26	acres	woods/forest
Percent Impervious	99.8%		
Hydrologic Soil Group:	A & B		per NRCS Web Soil Survey
Time of Concentration (Tc)	0.307		Win-TR 55 Output
Sheet Flow			
Length	100		
Slope	0.2		from contours
Surface Mannings n	Dense woods (0.80)		
Shallow Concentrated Flow			
Length	250	ft	
Slope	0.31	ft/ft	from contours
Surface Mannings n	Unpaved		
Channel Flow			
Length	2,000	ft	
Slope	0.134	ft/ft	from contours
n	0.035		Stream - rocks, pools, riffles
Avg width (ft)	2	ft	
Avg depth (ft)	0.75	ft	
Area (ft2)	1.5	ft2	
WP (ft)	3.5	ft	
Velocity (f/s)	8.8	f/s	
Pipe/channel Flow			
Length	250	ft	
Slope	0.04	ft/ft	from contours
n	0.014		Corrugated Plastic Pipe
Pipe Diameter (ft)	1	ft	assumed
Area (ft2)	0.8	ft2	
WP (ft)	3.1	ft	
Velocity (f/s)	8.7	f/s	
WinTR-55 Design Storm Flows			
Peak Runoff (Q) - 2-yr storm (3.68 in):	2.46	cfs	Win-TR 55 Output
Peak Runoff (Q) - 5-yr storm (4.5 in):	3.88	cfs	Win-TR 55 Output
Peak Runoff (Q) - 10-yr storm (5 in):	4.84	cfs	Win-TR 55 Output
Peak Runoff (Q) - 25-yr storm (6.5 in):	7.95	cfs	Win-TR 55 Output
Peak Runoff (Q) - 50-yr storm (7in):	9.03	cfs	Win-TR 55 Output
Peak Runoff (Q) - 100-yr storm (8 in):	11.26	cfs	Win-TR 55 Output
Peak Runoff (Q) - 100-yr storm (8 in):	11.26	cfs	Win-TR 55 Output
WinTR-55 Measured Rainfall Flows			
Peak Runoff (Q) - 12/22/2021 (1.51 in):	0.08	cfs	Win-TR 55 Output
Peak Runoff (Q) - 12/11/2021 (1.59 in):	0.12	cfs	Win-TR 55 Output
Peak Runoff (Q) - 12/18/2022 (1.67 in):	0.16	cfs	Win-TR 55 Output
Peak Runoff (Q) - 01/02/2022 (1.75 in):	0.21	cfs	Win-TR 55 Output
Peak Runoff (Q) - 11/12/2021 (2.22 in):	0.55	cfs	Win-TR 55 Output
Peak Runoff (Q) - 12/26/2022 (3.00 in):	1.34	cfs	Win-TR 55 Output
Peak Runoff (Q) - 11/11/2022 (3.04 in):	1.38	cfs	Win-TR 55 Output
Peak Runoff (Q) - 01/11/2022 (3.11 in):	1.47	cfs	Win-TR 55 Output
Peak Runoff (Q) - 11/04/2022 (4.65 in):	8.78	cfs	Win-TR 55 Output
Peak Runoff (Q) - 01/06/2022 (4.96 in):	11.13	cfs	Win-TR 55 Output

Basin Characteristics

Basin Characteristics				
Land Cover	**Hydrologic Soil Group**		**Total**	**Modeled Land Cover**
	A	**B**		
Residential	3.07	4.40	7.47	1/8 acre average lot size
Streets/Roadway	0.00	1.65	1.65	Impervious Area, Paved parking lots/roofs/driveways
Native Forest/Wood	0.00	45.26	45.26	Woods-grass combination - Fair Condition
		TOTAL	54.38	

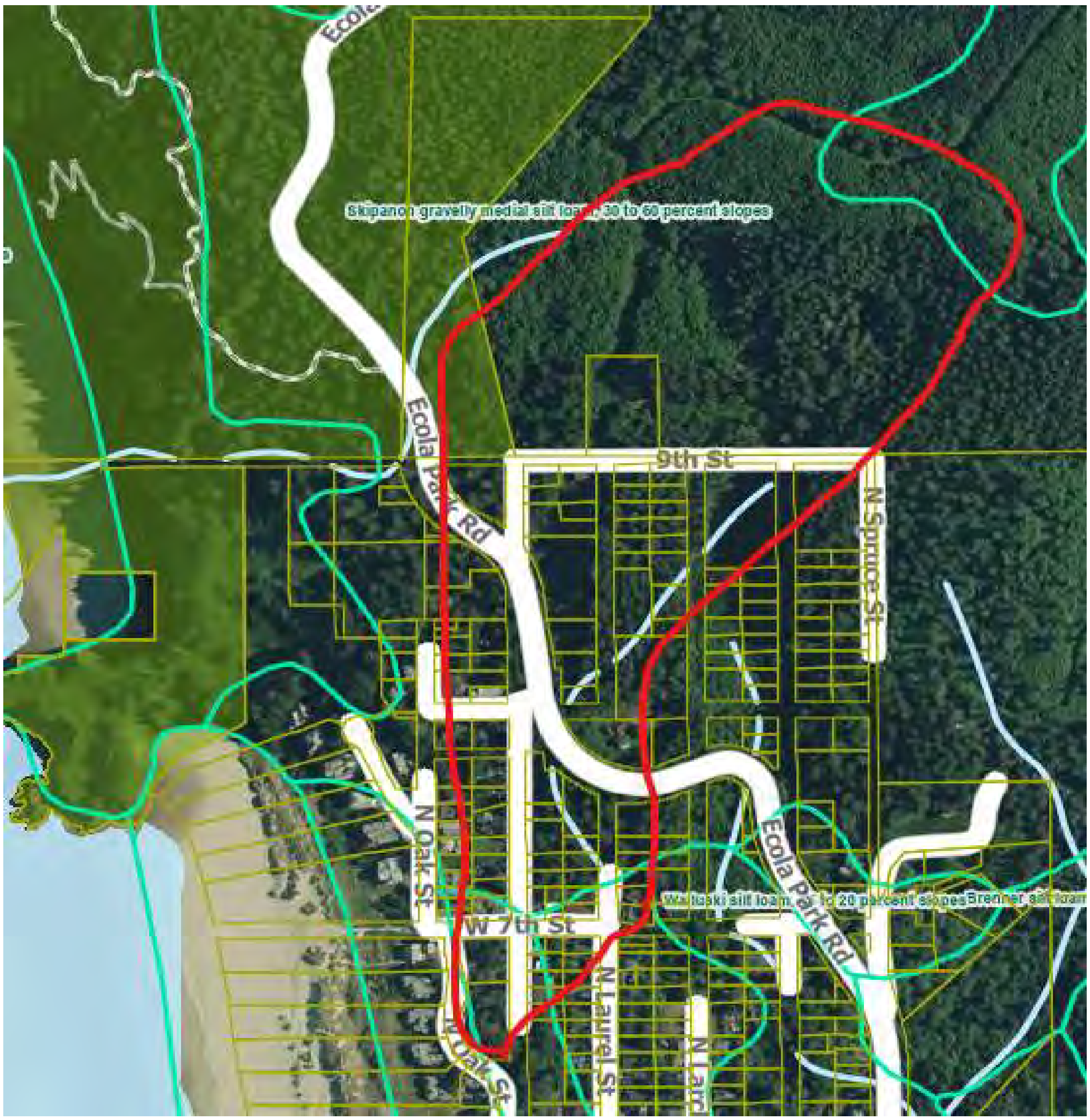


Exhibit D-4

WinTR-55 T.O.

Time of Concentration Details

Sub-area Name: Laurel St — Rename — Clear

2-Year Rainfall (in): 3.8

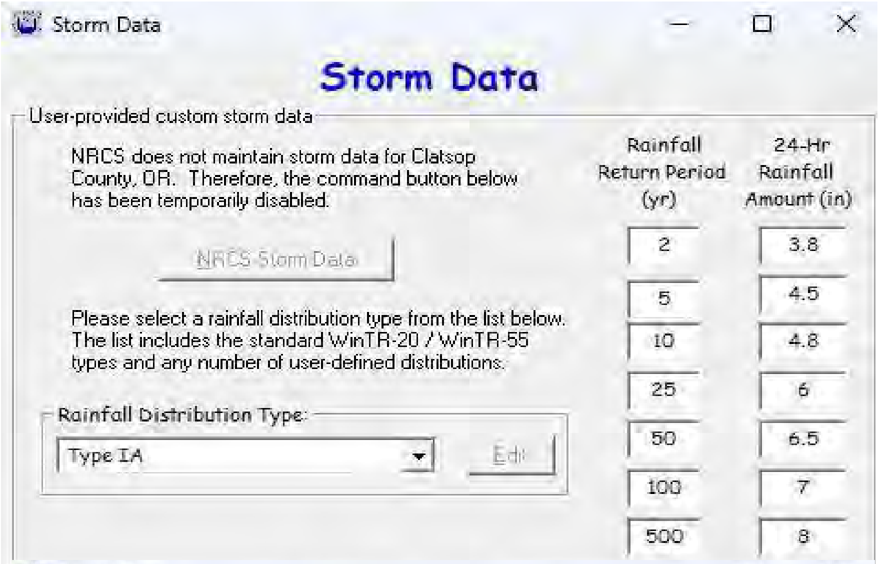
Time of Concentration Details

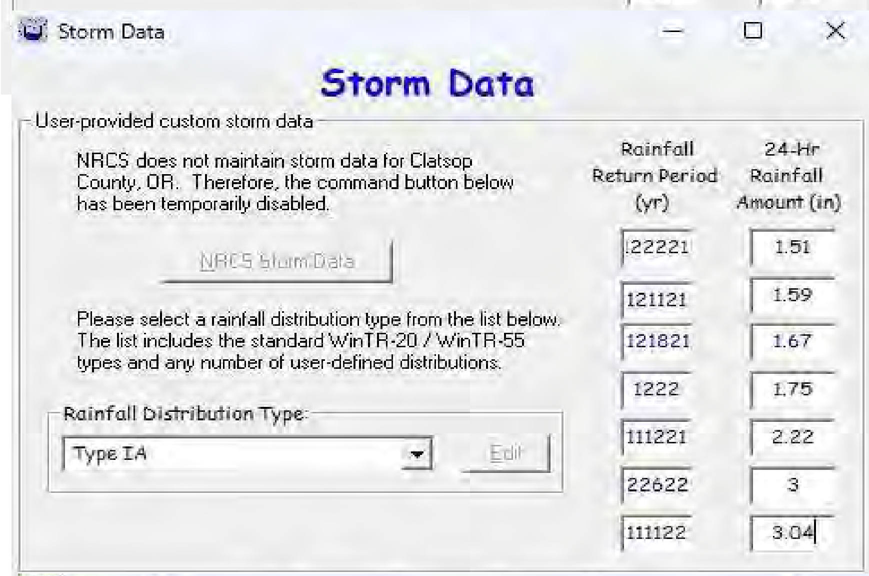
Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.2000	Woods, Dense (0.80)					0.228
Shallow Concentrated	200	0.3100	Unpaved					0.006
Shallow Concentrated								
Channel	2000	0.1340		0.035	1.50	3.50	8.818	0.063
Channel	250	0.0400		0.014	0.80	3.10	8.681	0.008
Total	2,550						2.3224	0.305

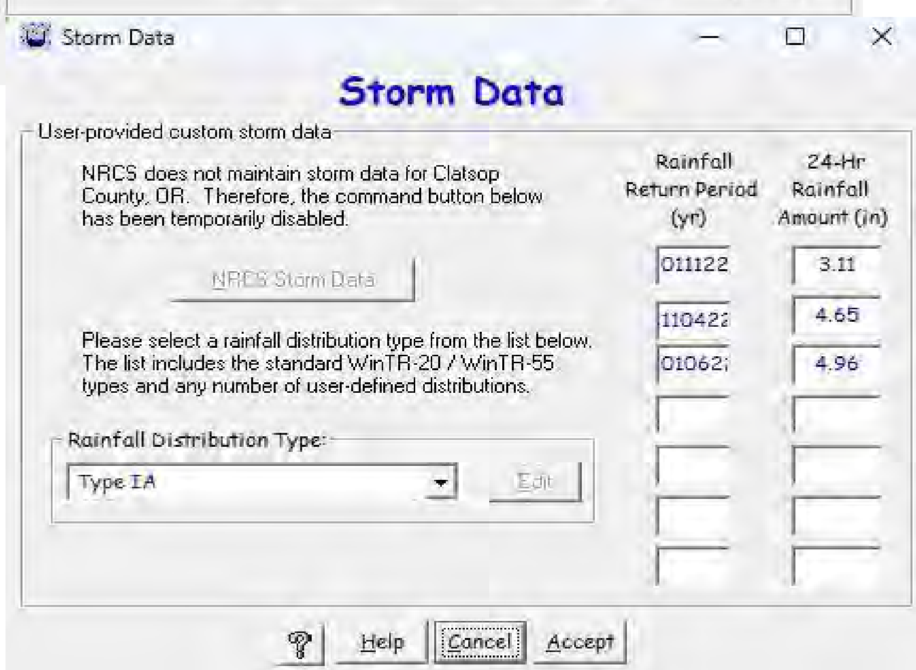
Help — Cancel — Accept

Exhibit D-4

WinTR-55 Rainfall Info

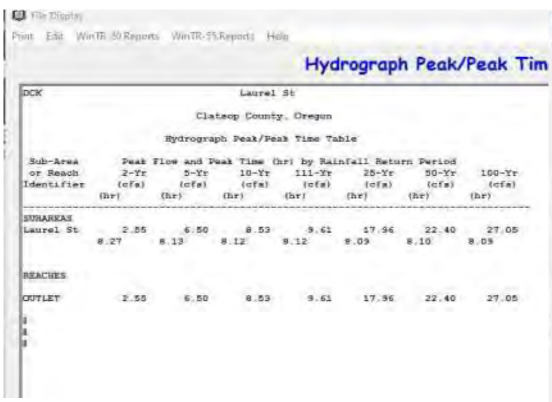






WinTR-55 Results

WinTR-55 Peak Runoff		
Return Period	**24-hr Rainfall Depth (in)**	**Peak Flow (cfs)**
2-Yr	3.80	2.55
5-Yr	4.50	6.50
10-Yr	4.80	8.53
25-Yr	6.00	17.96
50-Yr	6.50	22.40
100-Yr	7.00	27.05
12/22/2021	1.51	0.08
12/11/2021	1.59	0.12
12/18/2021	1.67	0.16
1/2/2022	1.75	0.21
11/12/2021	2.22	0.55
12/26/2022	3.00	1.34
11/11/2022	3.04	1.38
1/11/2022	3.11	1.47
11/4/2022	4.65	8.78
1/6/2022	4.96	11.13
11/11/2021 - 11/12/2021	5.26	13.53



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File Display
Print  Edit  WinTR-20 Reports  WinTR-55 Reports  Help
Hydrograph Peak/Peak Tim

DCK                              Laurel St

                          Clatsop County, Oregon

                      Hydrograph Peak/Peak Time Table

 Sub-Area       Peak Flow and Peak Time (hr) by Rainfall Return Period
 or Reach       2-Yr      5-Yr     10-Yr     111-Yr     25-Yr     50-Yr    100-Yr
Identifier      (cfs)     (cfs)     (cfs)     (cfs)     (cfs)     (cfs)     (cfs)
              (hr)      (hr)      (hr)      (hr)      (hr)      (hr)      (hr)
------------------------------------------------------------------------------
SUBAREAS
Laurel St       2.55      6.50      8.53      9.61     17.96     22.40     27.05
              8.27      8.13      8.12      8.12      8.09      8.10      8.09


REACHES

OUTLET          2.55      6.50      8.53      9.61     17.96     22.40     27.05
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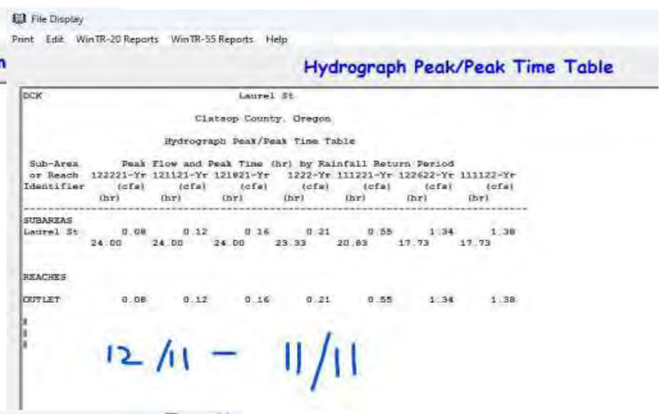

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File Display
Print  Edit  WinTR-20 Reports  WinTR-55 Reports  Help
Hydrograph Peak/Peak Time Table

DCK                              Laurel St

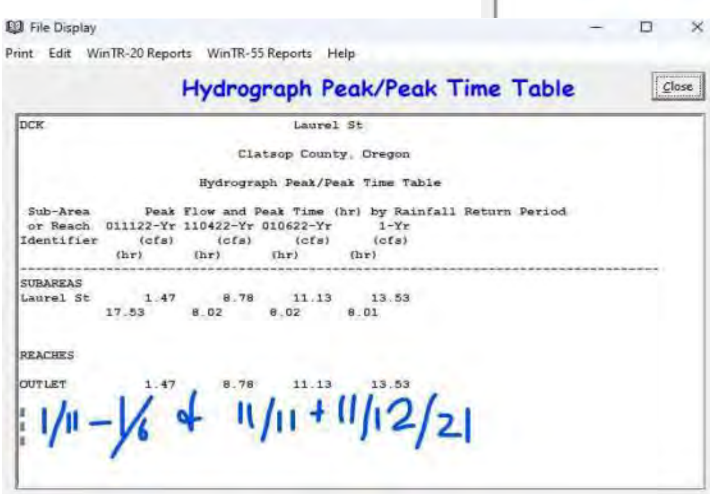
                          Clatsop County, Oregon

                      Hydrograph Peak/Peak Time Table

 Sub-Area       Peak Flow and Peak Time (hr) by Rainfall Return Period
 or Reach  122221-Yr 121121-Yr 121021-Yr   1222-Yr 111221-Yr 122622-Yr 111122-Yr
Identifier      (cfs)     (cfs)     (cfs)     (cfs)     (cfs)     (cfs)     (cfs)
              (hr)      (hr)      (hr)      (hr)      (hr)      (hr)      (hr)
------------------------------------------------------------------------------
SUBAREAS
Laurel St       0.08      0.12      0.16      0.21      0.55      1.34      1.38
             24.00     24.00     24.00     23.33     20.83     17.73     17.73


REACHES

OUTLET          0.08      0.12      0.16      0.21      0.55      1.34      1.38
```

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File Display
Print  Edit  WinTR-20 Reports  WinTR-55 Reports  Help
Hydrograph Peak/Peak Time Table                                   Close

DCK                              Laurel St

                          Clatsop County, Oregon

                      Hydrograph Peak/Peak Time Table

 Sub-Area       Peak Flow and Peak Time (hr) by Rainfall Return Period
 or Reach  011122-Yr 110422-Yr 010622-Yr      1-Yr
Identifier      (cfs)     (cfs)     (cfs)     (cfs)
              (hr)      (hr)      (hr)      (hr)
-------------------------------------------------------------------------
SUBAREAS
Laurel St       1.47      8.78     11.13     13.53
             17.53      8.02      8.02      8.01


REACHES

OUTLET          1.47      8.78     11.13     13.53
```

APPENDIX C

Isopluvial Maps

NOAA ATLAS 2

Precipitation-Frequency Atlas of the Western United States

J. F. Miller, R. H. Frederick, and R. J. Tracey

Volume X–Oregon

U.S. DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

NATIONAL WEATHER SERVICE
George P. Cressman, Director
Silver Spring, Maryland – 1973

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Stock Number 0317-00151

Prepared for U.S. Department of Agriculture, Soil Conservation Service, Engineering Division

Exhibit D-4

NOAA ATLAS 2

Precipitation Frequency Atlas of the Western United States

Volume	I.	Montana
Volume	II.	Wyoming
Volume	III.	Colorado
Volume	IV.	New Mexico
Volume	V.	Idaho
Volume	VI.	Utah
Volume	VII.	Nevada
Volume	VIII.	Arizona
Volume	IX.	Washington
Volume	X.	Oregon
Volume	XI.	California

UDC 551.577.36(084.4)(795)

551.5	Meteorology
.577	Precipitation
.36	Frequencies
(084.4)	Atlases
(795)	Oregon

Exhibit D-4

Contents

List of Illustrations

List of Tables

Abstract

Each volume of this Atlas contains precipitation-frequency maps for 6- and 24-hr durations for return periods from 2 to 100 yrs for one of the 11 western states (west of about 103° W.). Also included are methods and nomograms for estimating values for durations other than 6 and 24 hrs. This new series of maps differs from previous publications through greater attention to the relation between topography and precipitation-frequency values. This relation is studied objectively through the use of multiple regression screening techniques which develop equations used to assist in interpolating values between stations in regions of sparse data. The maps were drawn on a scale of 1:1,000,000 and reduced to 1:2,000,000 for publication.

In addition to the maps, each volume includes a historical review of precipitation-frequency studies, a discussion of the data handling and analysis methods, a section on the use and interpretation of the maps, and a section outlining information pertinent to the precipitation-frequency regime in the individual state. This state section includes a discussion of the importance of snow in the precipitation-frequency analysis and formulas and nomograms for obtaining values for 1-, 2-, 3-, and 12-hr durations.

Preface

Previous precipitation-frequency studies for the 11 western states have considered topography in only a general sense despite the numerous mountain ranges present. As a result, variation in precipitation-frequency values is greater than was portrayed in these studies. In this Atlas, the relation between precipitation-frequency values and topography has been considered both objectively and subjectively.

This work has been supported and financed by the Soil Conservation Service, Department of Agriculture, to provide material for use in developing planning and design criteria for the Watershed Protection and Flood Prevention program (P.L. 566, 83d Congress and as amended).

Each volume of the Atlas can be considered to consist of three parts. The first part contains several sections giving a historical review of the field, a discussion of the approach and methods used in the development of the precipitation-frequency maps, and a discussion of how to interpret and use the maps. This section outlines the general background information and is applicable to all states. The second part of the Atlas contains a discussion of items pertinent to the individual state. Included in this section are methods and nomograms designed to estimate precipitation-frequency values for durations other than 6 and 24 hrs. These procedures were developed for broad geographic regions; the ones applicable to a particular state are included in the appropriate volume. The last part contains the maps for the 6- and 24-hr durations for return periods of 2, 5, 10, 25, 50, and 100 yrs.

Coordination with the Soil Conservation Service was maintained through Kenneth M. Kent, Chief, Hydrology Branch, Engineering Division, and through his successor, Robert E. Rallison. The work was done in the Special Studies Branch, Water Management Information Division, Office of Hydrology, National Weather Service. Hugo V. Goodyear, Chief of the Branch (since retired) made many contributions to the preparation of the final manuscript. Overall direction and guidance was furnished by William E. Hiatt, Associate Director (Hydrology), National Weather Service, his successor, Max A. Kohler, and Joseph Paulhus, former Chief, Water Management Information Division. Data tabulations, computations and many other assisting duties were done by the Branch meteorological technicians.

Introduction

Objective

Although generalized maps of precipitation-frequency values have been available for many years, the construction of isopluvial lines in mountainous regions has been done considering topography and its effect on precipitation in a general sense only. Investigations for this Atlas were undertaken to depict more accurately variations in the precipitation-frequency regime in mountainous regions of the 11 conterminous states west of approximately 103° W. These investigations are intended to provide material for use in developing planning and design criteria for the Watershed Protection and Flood Prevention programs.

Primary emphasis has been placed on developing generalized maps for precipitation of 6- and 24-hr duration and for return periods of 2 to 100 yrs. Procedures also have been developed to estimate values for 1-hr duration. Values for other durations can be estimated from the 1-, 6-, and 24-hr duration values.

Historical Review

The first generalized study of the precipitation-frequency regime for the United States was prepared in the early 1930's by David L. Yarnell (1935). Yarnell's publication contains a series of generalized rainfall maps for durations of 5 min to 24 hrs for return periods of 2 to 100 yrs. Yarnell's study served as a basic source of frequency data for economic and engineering design until the middle 1950's. The maps were based on data from about 200 first-order Weather Bureau stations equipped with recording precipitation gages. In 1940, about 5 yrs after Yarnell's study was published, a hydrologic network of recording gages, supported largely by the U.S. Army Corps of Engineers, was installed. This was done to supplement the Weather Bureau recording-gage network and the network of a relatively large number of nonrecording gages maintained by private individuals in cooperation with the Weather Bureau, for a long period of years. The additional recording gages have subsequently increased the amount of short-duration (1- to 24-hr) precipitation data by a factor of about 20.

Weather Bureau Technical Paper No. 24, published in two parts, (U.S. Weather Bureau 1953–54a) was prepared for the Corps of Engineers, in connection with its military construction program. This Technical Paper contained the results of the first investigation of precipitation-frequency information for an extensive region of the increased hydrologic data network. The results showed the importance of the additional data for defining the short-duration rainfall-frequency regime in a mountainous region of the western United States. In many instances, the differences between the values given in Technical Paper No. 24 and those given by Yarnell reach a factor of three, with Yarnell's figures generally higher. Results from these two studies in the United States were then used to prepare similar reports for the coastal regions of North Africa (U.S. Weather Bureau 1954b) and for several Arctic regions (U.S. Weather Bureau 1955a) where recording-gage data were lacking. These reports were also prepared in cooperation with the Corps of Engineers to support its military construction program.

In 1955, the Weather Bureau and the Soil Conservation Service began a cooperative effort to define the depth-area-duration precipitation-frequency regime in the entire United States. *Weather Bureau Technical Paper* No. 25 (U.S. Weather Bureau 1955b), partly a byproduct of previous work done for the Corps of Engineers, was the first study published under the sponsorship of the Soil Conservation Service; it contains a series of precipitation intensity-duration-frequency curves for about 200 first-order Weather Bureau stations. This was followed by *Weather Bureau Technical Paper* No. 28 (U.S. Weather Bureau 1956) which was an expansion of information contained in Technical Paper No. 24 to longer return periods and durations. The five parts of *Weather Bureau Technical Paper* No. 29 (U.S. Weather Bureau 1957–60), for the region east of longitude 90° W., were published next. This Technical Paper included seasonal variation on a frequency basis and area-depth curves so that the point-frequency values could be transformed to areal-frequency values.

In the next study, *Weather Bureau Technical Paper* No. 40 (U.S. Weather Bureau 1961), the results of previous Weather Bureau investigations of the precipitation-frequency regime of the conterminous United States were combined into a single publication. Investigations by the Weather Bureau during the 1950's had not covered the region between longitudes 90° and 105° W. Technical Paper No. 40 contained the results of an investigation for this region, and was the first such study of the midwestern plains region since Yarnell's work of the early 1930's. Topography was considered only in a general sense in this and earlier studies.

Technical Paper No. 40 has been accepted as the standard source for precipitation-frequency information in the United States for the past decade. Results presented in that publication are most reliable in relatively flat plains. While the averages of point values over relatively large mountainous regions are reliable, the variations within such regions are not adequately defined. In the largest of these regions, the western United States, topography plays a significant role in the incidence and distribution of precipitation. Consequently, the variations in precipitation-frequency values are actually greater than portrayed in the region. Investigations reported herein were made using currently available longer records and the maximum number of stations possible (consistent with the constraints explained in the section on Basic Data).

Approach

The approach used for this Atlas is basically the same as that used for Technical Paper No. 40, in which simplified relations between duration and return period were used to determine numerous combinations of return periods and durations from several generalized key maps. For this Atlas, relations were developed between precipitation-frequency values and meteorologic and topographic factors at observing sites. These were used to aid in interpolating values between stations on the key maps.

The key maps developed in this study were for 2- and 100-yr return periods for 6- and 24-hr durations. The initial map developed was for the 2-yr return period for the 24-hr duration. This return period was selected because values for shorter return periods can be estimated with greater reliability than for longer return periods. The 24-hr duration was selected because this permitted use of data from both recording and nonrecording gages. Also, because an extensive nonrecording-gage network was in existence for many years before the recording-gage network was established in 1940, the period of record available for 24-hr observations is much longer than that for the 6-hr duration. The second map developed was for the 100-yr return period for the 24-hr duration. In the development of this map the advantage of maximum sample size and length of record was retained at the expense of some decrease in reliability of computed values. The 6-hr maps for the 2- and 100-yr return periods followed. For the 6-hr duration, the sample size was materially smaller in both numbers and length of record because only recording-gage data could be used. After these four maps were completed, values for intermediate return periods were computed for a grid of about 47,000 points, and appropriate maps were prepared.

In previous studies, topography was considered only in a general sense and the isopluvials were drawn by interpolating subjectively between the individual stations. In preparing this Atlas, multiple linear regression equations were developed for each of many regions of the western United States as an aid to estimating the precipitation-frequency values at each of about 47,000 grid points. These equations related topographic and climatologic factors to the variations in the precipitation-frequency values. Isopluvials were smoothed subjectively between values in adjoining regions. The subjective smoothing was based upon experience in analyzing precipitation-frequency maps; the amount of smoothing was rarely greater than the standard error of estimate for the equations in the adjoining regions.

Analysis

Basic Data

Station location. Frequency analysis of precipitation data requires a relatively long and stable station record. In analyzing a mean annual or a seasonal precipitation map, it is possible to use double-mass curve analysis to evaluate the effects of changes in station location or exposure. Within limits, the effects of differing locations on the annual precipitation values can be eliminated by use of relations determined from the double-mass curve analysis (Weiss and Wilson 1953). However, no technique for evaluation and modification of a series of extreme precipitation values has been developed. Therefore, it was necessary to ensure that the data used in this Atlas represented, as nearly as possible, observations taken from a single location.

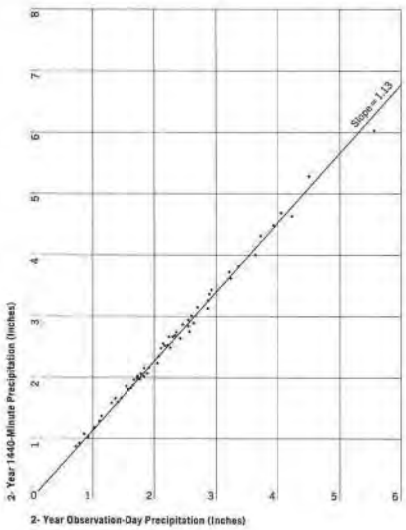
Official records of station locations (latitude, longitude, and elevation) were examined to determine physical moves. The criterion was adopted that if a move at any station changed the elevation 100 ft or more or changed the horizontal location 5 mi or more, its data were treated as though they came from separate stations. In some cases, a station retained the same name but investigation indicated that it had been moved beyond acceptable limits. In such cases, the records for the station were terminated and new records were started. In other cases, published sources indicated location changes beyond acceptable limits, but subsequent inspection of records indicated these changes were corrections to reported values of elevation, latitude, or longitude rather than actual physical moves. Thus, the observations for the station actually were continuous at one location. Occasionally, a lesser move resulted in a significant difference in exposure, such as from the windward to the lee side of a mountain range. Data from stations such as these also were treated as data from separate stations.

Types of data. The primary data used in this Atlas can be divided into two categories. First, there are data from recording gages; these data are published for clock-hour intervals. These data were processed to obtain maximum 6- and 24-consecutive clock-hour amounts for each month of record. The time interval selected did not have to start at a particular hour; for example, the 6-hr interval might be from 1 to 7 a.m., or from 3 to 9 p.m.; the 24-hr interval might be from 4 a.m. on one day to 4 a.m. on the following day, or from 2 p.m. on one day to 2 p.m. on the next. Second, there is the large amount of data from nonrecording gages. At these gages, observations are usually made once each day at a given time for each station. At observation time, the amount of precipitation that fell in the preceding 24-hr interval is measured; this precipitation may have fallen during any part or all of the 24-hr period. These data are commonly referred to as observation-day amounts.

A subset of data in the first category is the recording-gage data from the long-record first-order Weather Bureau (now National Weather Service) stations. There are approximately 200 such stations in the entire country (about 50 in the western United States). Maximum values for each year of record from these stations have been tabulated for the various durations to the nearest minute. The maximum 6-hr amount recorded each year is for a period of 360 consecutive minutes, regardless of the time beginning; for example, such a period might begin at 2:03 p.m. or at 3:59 p.m. Similarly, data for the 24-hr duration are for a 1,440-min period. These amounts are commonly referred to as *n*-minute amounts.

Exhibit D-4

Figure 1. *Relation between 2-yr 1,440-min precipitation and 2-yr observation-day precipitation.*



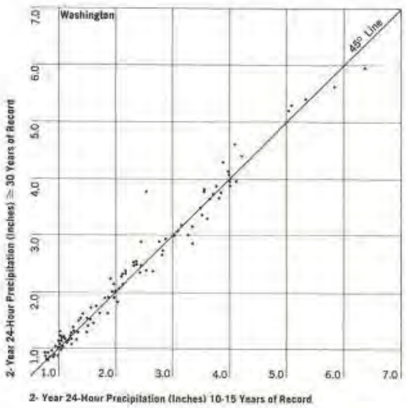


Figure 2. *Test of 2-yr 24-hr precipitation values from short- and long-record stations for the State of Washington.*

Fixed- versus true-interval precipitation values. The continuous clock-hour and observation-day data from most stations are available for intervals fixed by arbitrary clock intervals. Because the time of occurrence of precipitation is a random phenomenon, straddling often occurs; for example, part of the maximum precipitation may start in one time interval and end in the succeeding time interval. Seldom does maximum precipitation for a specified duration occur within a mandatory measurement interval. For this reason, it was necessary to use relations between fixed-time intervals (of actual occurrence) and the 360- and 1,440-min periods to make maximum use of available data.

These relations have been investigated in previous studies (U.S. Weather Bureau 1954a, 1956, 1957–60). It was found that on the average 1.13 times a statistical value for a particular return period, based on a series of annual maximum observation-day (fixed-interval) amounts, was equivalent to a statistical value for the same return period obtained from a series of 1,440-min (true-interval) values. The ratio of statistical values computed from a series of six consecutive clock-hour measurements to those from a series of 360-min observations is 1.02; a similar ratio of statistical values computed from 24 consecutive clock-hour amounts to those from 1,440 min values is 1.01.

These ratios (for example, *n*-year 1,440-min precipitation equals 1.13 times *n*-year observation-day precipitation) are not built on a causal relation. They are average index ratios because the distributions of observation-day, *n*-hour, and *n*-minute precipitation are irregular and unpredictable. For example, the annual maxima of the two series for the same year do not necessarily come from the same storm. Graphical comparison of the values for the 2-yr return period based on observation-day and 1,440-min precipitation data is shown in figure 1.

The frequency and amount of straddling that occur can be investigated on probability considerations as well as empirically. The time axis can be represented by a straight line separated into uniform time intervals by an evenly spaced series of points. These intervals can represent individual hours, 6- or 24-hr periods, an observation day, and so forth. The maximum precipitation for any duration can be assumed to occur at a uniform rate in a time unit exactly equal to one of the fixed intervals, but without regard to the location of the fixed intervals. This time unit may fall at random with respect to the fixed intervals and will, in general, overlap two adjacent intervals. Using probability theory, Weiss (1964) confirmed the empirical values used.

Data sources. The primary data sources used were *Climatological Data for the United States by Sections* (National Climatic Center 1897–1970) and *Hourly Precipitation Data* (National Climatic Center 1940–70). In California, it was possible to increase the data sample 15 to 20 percent by using unpublished data from gages maintained by the State, local agencies, private corporations, or individuals (California, Department of Water Resources 1900–69). Published data are routinely of high quality because of periodic checks of observing sites and observation techniques and the quality-control procedures used in the publication process. The quality of unpublished data must be checked by a review of the inspection records of the organization maintaining the gage and by a careful screening of the data.

Length and period of record. In preparing generalized maps of precipitation-frequency values, a uniform period of record several times the length of the return period desired and computed at a relatively dense network of stations (for sampling all data and topographic extremes) is the ideal. In practical work, compromises are necessary.

The use of a nonuniform record period, especially when the period is short, may result in unrealistic relations between stations. For instance, if data taken during a short-record period at one station were taken during a relatively dry period, while data from the neighboring station were taken during a relatively wet period, the interstation relation would not be valid. Because the objective of this investigation is to define the geographic variation in mountainous regions, it is desirable to minimize other causes of variation. Use of a standard base period would minimize the above variation. This is common practice in the preparation of mean annual precipitation maps and also can be applied to the preparation of precipitation-frequency maps for shorter return periods.

Determination of precipitation-frequency values is usually based upon the longest record available. These values are assumed to be reasonably representative of the values that would be obtained if the entire record were known. The use of a short-record base period requires testing to determine if the data provide unbiased results representative of values that would be obtained from use of a long-record base period. For most regions covered in this study, the most recent 15-yr period immediately preceding the period when the maps for this Atlas were developed was used to compute precipitation values for the 2-yr return period. At locations with at least 30 years of data, the 2-yr values from the 15-yr base period were compared with the 2-yr values computed using the total record. If the differences between the two series were small and randomly distributed, the 15-yr base period was adopted for all stations. Figure 2 shows the result of such a test for the 24-hr duration values for stations in Washington. The same test was made for the rest of the western states.

In most of California and Nevada, the values computed from the 15-yr base period data showed significant differences and some bias to values based upon the total record. In this region, it was necessary to use values based on the longest record possible for each station in preparation of the 2-yr maps. Stations without data during all or most of the more recent years were identified on the working maps.

To make use of data from the maximum number of stations, data from stations with 10 to 14 yrs of record were used in preparing the 2-yr maps. Such stations also were suitably identified on the working maps so that the analyst could use judgment in his interpretation of such values.

While a 15-yr record provides data several times the length of the return period for 2-yr maps, it provides only a small fraction of the length of the 100-yr return period. During a 15-yr period, some stations may experience precipitation amounts equivalent to a return period of 50, 100, or more years. However, the probability of having a 100-yr value in any preselected 15-yr period is only 0.14. Similarly, the probability of *not* having a true 15-yr return period value in any preselected 15-yr period is about 0.09. Thus, in a given 15-yr period, the probability that a station has received its true 100-yr value is not greatly different from the probability that its neighboring station has *not* experienced its true 15-yr value. While, admittedly, this would be an extreme case, this example shows the importance of using as long a record as possible when preparing precipitation-frequency maps for long return periods. In this study, records for as long as possible for each station (without violating the 100-ft or 5-mi criterion) were used to compute the 100-yr return period values. The length of record and a confidence band to indicate the range of values likely to be experienced at each station were included in the plotting model. With this information, the analyst could more effectively evaluate the reliability of each data point.

Published and unpublished data from approximately 3,300 stations were used in this study. The number of stations grouped by length of record and state are shown in table 1. Many recording gages were established at sites where nonrecording gages had been located for many years. In table 1, the first column for each state shows the number of stations with recording-gage data. The second column for each state shows the total period of record for which observation-day data were available for each of these stations. The total record includes both recording and nonrecording data for the recording-gage station. (Note: The total number of stations in columns 1 and 2 are equal.) The third column for each state shows the number of stations with nonrecording-gage data only.

Figure 3 shows the location of the 1,030 recording stations used in this study. The length of record indicated is for the longest available record and includes the period where only a nonrecording gage may have been located at the particular station. Figure 4 shows the location of the 2,292 nonrecording gages that, together with the recording gages, were used to provide data to define the 24-hr isopluvial pattern. A few additional stations with records of less than 10yrs were used to provide guidance for estimating the precipitation pattern in extremely mountainous regions where no other data were available. Most of the data were for observation days. Empirical adjustments were used to convert statistical analyses of these data to the equivalent of 1,440-min data.

Table 1. *Number of precipitation stations by length and type of record in each Western State*

Years of record	Arizona RGR	Arizona TR	Arizona NR	New Mexico RGR	New Mexico TR	New Mexico NR	Colorado RGR	Colorado TR	Colorado NR	Utah RGR	Utah TR	Utah NR	Wyoming RGR	Wyoming TR	Wyoming NR
10-14	6	5	38	29	10	33	18	18	28	13	8	20	23	16	31
15-19	9	8	28	8	16	34	14	11	29	2	0	11	2	1	11
20-24	23	12	30	34	12	36	52	36	31	18	9	16	31	20	14
25-29		1	15		7	15		3	15		2	7		3	7
30-34		1	9		3	15		3	7		1	7		1	8
35-39		2	10		3	11		0	9		4	4		2	6
40-44		6	53		2	16		2	10		1	9		1	8
45-49		0	1		4	16		0	10		0	5		3	8
50-54		1	1		5	13		4	12		2	13		2	6
55-59		1	4		8	14		2	7		1	3		5	8
60-64		0	1		1	3		0	6		2	14		0	5
65-69		1	1		0	4		1	8		3	4		2	2
70-74								4	6						
75-79															
80-84															
85-89															
90-94															
Number:															
By type	38		191	71		210	84		178	33		113	56		114
Total stns		229			281			262			146			170	
Percent:															
By type	3.7		8.3	6.9		9.2	8.2		7.8	3.2		4.9	5.4		5.0
Total stns		6.9			8.4			7.9			4.4			5.1	

Years of record	Montana RGR	Montana TR	Montana NR	Idaho RGR	Idaho TR	Idaho NR	Washington RGR	Washington TR	Washington NR	Oregon RGR	Oregon TR	Oregon NR	Nevada RGR	Nevada TR	Nevada NR
10-14	29	22	78	19	18	10	31	20	19	26	19	33	11	6	10
15-19	5	3	19	2	1	7	4	2	13	3	3	13	6	5	5
20-24	59	50	23	3	2	5	15	14	21	15	15	29	6	7	6
25-29		2	15	16	10	11	37	25	8	50	36	30	15	5	4
30-34		2	14		2	7		1	19		3	25		3	3
35-39		2	9		1	4		4	19		4	11		1	3
40-44		1	8		0	10		4	12		0	9		0	2
45-49		1	5		0	15		3	8		1	4		5	3
50-54		5	11		1	14		4	15		2	10		2	4
55-59		1	9		4	8		0	9		4	6		0	5
60-64		4	3		0	6		3	4		1	2		1	2
65-69		0	1		1	3		7	8		3	7		3	2
70-74								0	1		3	1			
75-79															
80-84															
85-89															
90-94															
Number:															
By type	93		195	40		100	87		156	94		180	38		49
Total stns		288			140			243			274			87	
Percent:															
By type	9.0		8.5	3.9		4.4	8.4		6.8	9.1		7.9	3.7		2.1
Total stns		8.6			4.2			7.3			8.2			2.6	

Years of record	California RGR	California TR	California NR	Total RGR	Total TR	Total NR	Total Stns.	Percent RGR	Percent TR	Percent NR	Percent Total
10-14	98	95	209	303	237	509	812	29.4	23.0	22.2	24.4
15-19	37	35	92	92	85	262	354	8.9	8.3	11.4	10.6
20-24	47	42	132	303	219	343	646	29.4	21.3	15.0	19.4
25-29	140	114	97	258	208	224	482	25.0	20.2	9.8	14.5
30-34	53	54	59	53	74	173	226	5.1	7.2	7.6	6.8
35-39	14	18	43	14	41	129	143	1.4	4.0	5.6	4.3
40-44	5	15	70	5	32	207	212	0.5	3.1	9.0	6.4
45-49	0	2	16	0	19	91	91	0.0	1.8	4.0	2.7
50-54	0	1	13	0	29	112	112	0.0	2.8	4.9	3.4
55-59	0	3	13	0	29	86	86	0.0	2.8	3.8	2.6
60-64	1	6	13	1	18	59	60	0.1	1.7	2.6	1.8
65-69	0	2	19	0	23	59	59	0.0	2.2	2.6	1.8
70-74	0	8	21	0	15	29	29	0.0	1.5	1.3	0.9
75-79	0	0	4	0	0	4	4	0.0	0.0	0.2	0.1
80-84	1	1	4	1	1	4	5	0.1	0.1	0.2	0.2
85-89		0	0		0	0	0	0.0	0.0	0.0	0.0
90-94		0	1		0	1	1	0.0	0.0	0.0	0.0+
Number:											
By type	396		806	1,030		2,292	3,322				
Total stns		1,202			3,322						
Percent:											
By type	38.4		35.1								
Total stns		36.1									

Note: RGR = stations having recording-gage record.
TR = stations having recording gage for part of the record; total record includes both recording- and nonrecording-gage record.
NR = stations having only nonrecording-gage record.

Data tabulations. The maximum observed 24-hr (and 1- and 6-hr for recording gages) precipitation amount for each month was tabulated for each station. The maximum amount for each year of record was determined from these maximum monthly amounts. In the tabulations, data for some stations were missing or of questionable reliability for all or part of one or more years. For each such case, the data were evaluated individually to obtain the maximum length of record for the station. For instance, if data for a few months were missing, the maximum amount recorded for the remainder of the year was used to determine the maximum yearly amount if it appeared reasonable when compared with other years and with the maxima for that year at surrounding stations. This could result in an underestimation of the accepted amount, but it is felt that such errors are small and of little consequence.

Every effort was made to keep spurious data to a minimum. Reports of unusually large amounts at a station, or of large amounts at one station surrounded by stations reporting little or no precipitation, were examined to determine whether these large amounts were meteorologically reasonable. Cool season data were examined to ascertain if unusually large amounts were depth of snow rather than its water equivalent. However, not all large amounts were examined, nor could conclusive determinations be made regarding all of the large amounts that were examined. It is believed that most of the spurious data have been corrected.

Frequency Analysis

Two types of series. There are two methods of selecting data for analysis of extreme values. The first method produces the annual series. This method selects the largest single event that occurred within each year of record. In the annual series, year may be calendar year, water year, or any other consecutive 12-mo period. The limiting factor is that one, and only one, piece of datum is accepted for each year. The second method of selecting data produces the partial-duration series. This method recognizes that large amounts are not calendar bound and that more than one large event may occur in the time unit used as a year. In a partial-duration series, the largest *N* events are used regardless of how many occur in the same year; the only restriction is that independence of individual events be maintained. The number of events used is at least equal to the number of years of record.

One requirement in the preparation of this Atlas is that the results be expressed in terms of partial-duration frequencies. To avoid the laborious processing of partial-duration data, the annual series data were collected and analyzed and the resulting statistics were transformed to partial-duration statistics.

Conversion factors between annual and partial-duration series. Table 2 gives the empirical factors used to multiply partial-duration series analysis values to obtain the equivalent annual series analysis values. It is based on a sample of about 200 widely scattered first-order Weather Bureau stations. Only about one-fourth of these stations are in the western United States. The factors used in table 2 were taken from *Weather Bureau Technical Paper* No. 40. Reciprocals of these factors were used to convert the statistics of the annual series to those of the partial-duration series.

These relations have also been investigated by Langbein (1949) and Chow (1950) with equivalent results. The quality of the relation between the mean of the partial-duration series and that of the annual series data for 6- and 24-hr durations is shown in figure 5. The means for both series are equivalent to the 2.3-yr return period. Tests for samples of from 10 to 50 yrs of record length indicate that the factors of table 2 are independent of the record length.

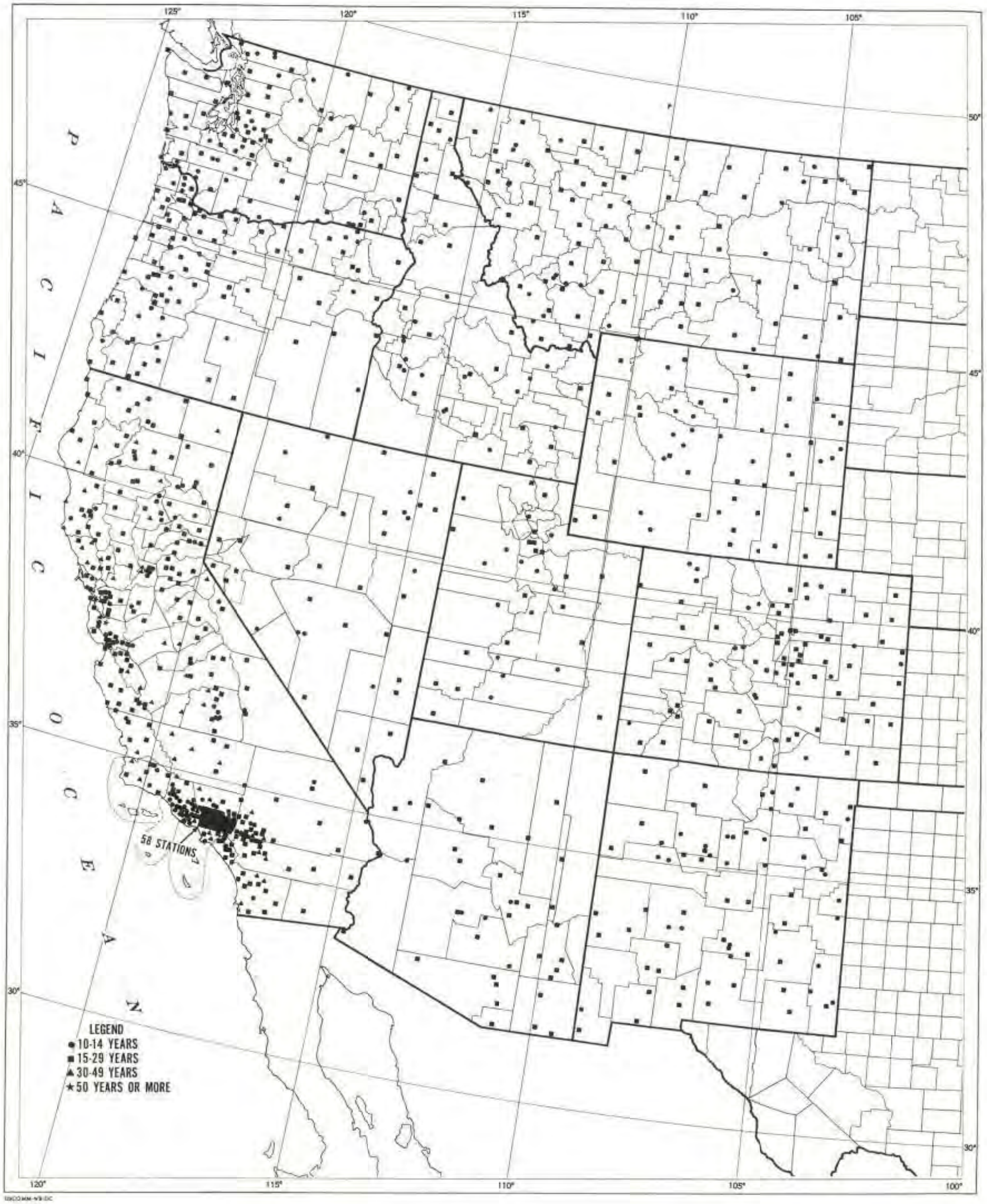
Return period	Conversion factor
2-yr	0.88
5-yr	0.96
10-yr	0.99

Table 2. *Empirical factors for converting partial-duration series to annual series*

Frequency distribution. The frequency distribution used was the Fisher-Tippett Type I distribution; the fitting procedure was that developed by Gumbel (1958). This distribution and fitting procedure were used by the National Weather Service in previous studies of short-duration precipitation values (U.S. Weather Bureau 1953, 1954a, 1954b, 1955a, 1955b, 1956, 1957–60, and 1961). Studies by Hershfield and Kohler (1960) and Hershfield (1962) have demonstrated the applicability of this distribution to precipitation extremes. The distribution was fitted by the method of moments. The 2-yr value measures the first moment, the central tendency of the distribution. The relation of the 2-yr to the 100-yr value is a measure of the second moment, the dispersion of the distribution. The 2-yr and 100-yr precipitation can be used for estimating values for other return periods.

The return-period diagram, figure 6, taken from *Weather Bureau Technical Paper* No. 40, is based on data from National Weather Service stations having long records. The spacing of the vertical lines on the diagram is partly empirical and partly theoretical. From 1- to 10-yr return periods, it is entirely empirical, based on freehand curves drawn through plottings of partial-duration series data. For 20-yr and longer return periods, reliance was placed on the Gumbel procedure for fitting annual series data to the Fisher-Tippett Type I distribution. The transition was smoothed subjectively between the 10- and 20-yr return periods. If

Exhibit D-4



precipitation values for return periods between 2 and 100 yrs are desired, it is necessary to obtain the 2- and 100-yr values from this series of generalized precipitation-frequency maps. These values are then plotted on the appropriate verticals and connected with a straight line. The precipitation values for the intermediate return periods are determined by reading values where the straight line intersects the appropriate verticals. If the rainfall values are then converted to the annual series by applying the factors of table 2 and plotted on either Gumbel or log-normal graph paper, the points will very nearly approximate a straight line.

Isopluvial Maps

Methodology. The factors considered to determine the sequence of preparation of the basic isopluvial maps for this series of generalized precipitation-frequency maps were (1) availability of data, (2) reliability of estimates for the return period, and (3) range of durations and return periods. Because of the large amount of data for the 24-hr duration and the relatively small standard error associated with the 2-yr values, a map showing such data was selected for preparation as the basic map for this series. The second map was prepared for the 24-hr duration and 100 yrs, the longest return period of interest. Next, the 2-yr 6-hr and the 100-yr 6-hr precipitation maps were prepared. These four key maps envelop the range of durations and return periods required and provide the data to be used for obtaining values for four intermediate return period maps at each duration.

Development of relations for interpolating precipitation-frequency values. The adequacy of the basic data network for determining precipitation-frequency values varies from place to place within the western United States. The greatest station density occurs along the Pacific coast west of the Cascade and Sierra Nevada Ranges (figs. 3 and 4). The lowest densities are in the intermountain plateau—between the Cascade-Sierra Nevada ranges and the Continental Divide—particularly in Nevada and in the Salmon River Mountains of Idaho. Even within particular regions, the stations are not evenly distributed. Most of the stations are located in the coastal plains, the river valleys, the western portion of the Great Plains, and the lower foothills of the mountains. Relatively few stations are located on steep slopes or on crests of mountains, in sparsely populated areas, or in areas where access is difficult.

It is desirable, therefore, to develop relations that can be used in interpolating precipitation-frequency values between stations in regions where data are relatively scarce. A preferred method is to relate variations in precipitation-frequency directly to variations in topographic factors; this is done when an adequate relation can be developed. The primary advantage of this procedure is that topographic factors can be determined at any point in a region. Topographic maps can be prepared from aerial photographs or surveys, or by other methods that do not require observations taken at a fixed point over a period of time. Among topographic factors frequently considered are: (1) elevation of the station, either the actual elevation or some effective elevation (an average elevation determined along a circle of a given radius around the station); (2) slope of the terrain near the station, both in the small and large scales; (3) distances from both major and minor barriers; (4) distances and directions from moisture sources; and (5) roughness of the terrain in the vicinity of the station.

Figure 3. *Geographic distribution of stations with recording gages. Symbols indicate total length of record available.*

Exhibit D-4

It has not been possible to develop such relations for all regions. Hence, it also was necessary to develop relations that included climatological or meteorological factors. The factors selected for use must be available at locations where precipitation data for durations of between 1 and 24 hrs are not available. Otherwise, they would not provide additional information needed for use in interpolating between locations with frequency values. An example of such a factor is normal annual precipitation. In the construction of such a map, data from snow courses, adjusted short records, and storage gages that give weekly, seasonal, or annual accumulations of precipitation can be used. Such records do not yield the short-duration precipitation amounts necessary for this study. Thus, normal annual precipitation data, particularly because it provides greater areal coverage in mountainous regions, might be of definite use in developing the patterns of the precipitation-frequency maps.

Several other meteorologic factors can be used in combination with normal annual precipitation data and topographic factors to interpolate short-duration precipitation-frequency values at intermediate points. Examples of such factors are: (1) number of thunderstorm days, (2) number of days or hours with precipitation above a threshold value, (3) percentage frequencies of various wind directions and speeds, and (4) percentage frequencies of class intervals of relative humidity. Since these factors can be obtained only where there are recording meteorological gages or where there are observers to record the data they do not supplement the available short-duration precipitation-frequency values by providing data at additional sites.

It would have been desirable to develop a single equation, utilizing physiographic factors, to interpolate between locations with short-duration precipitation-frequency values for the western United States. Such an equation could not be developed, so relations for interpolating the precipitation-frequency values were developed for each of several smaller regions considered to be meteorologically homogeneous. The extent of each region was determined from consideration of the weather situations that could be expected to produce large precipitation amounts. Among the questions asked and answered were: What is the source and from what direction does moisture for major storms come and are there major orographic barriers that influence the precipitation process? Figure 7 shows some of the principal paths of moisture inflow for the western United States and the major orographic barriers to such inflow.

The regions selected for their homogeneity normally are river basins or combinations of river basins. The river basins selected were usually bounded by major orographic barriers that significantly influence the precipitation regime. The size of these regions varied, partly because of meteorologic and topographic considerations and partly because of the availability of data. Some regions included more variability in topographic and meteorologic factors than was ideal. Efforts made to reduce the size of the regions were not successful because sample sizes decreased to less than acceptable limits.

After the geographic regions were selected, various topographic factors that could cause variation of precipitation-frequency values within limited regions such as slope, elevation, roughness, and orientation were examined. Individual precipitation-frequency values and exposures around the stations were examined to gain insight into topographic factors that could be im-

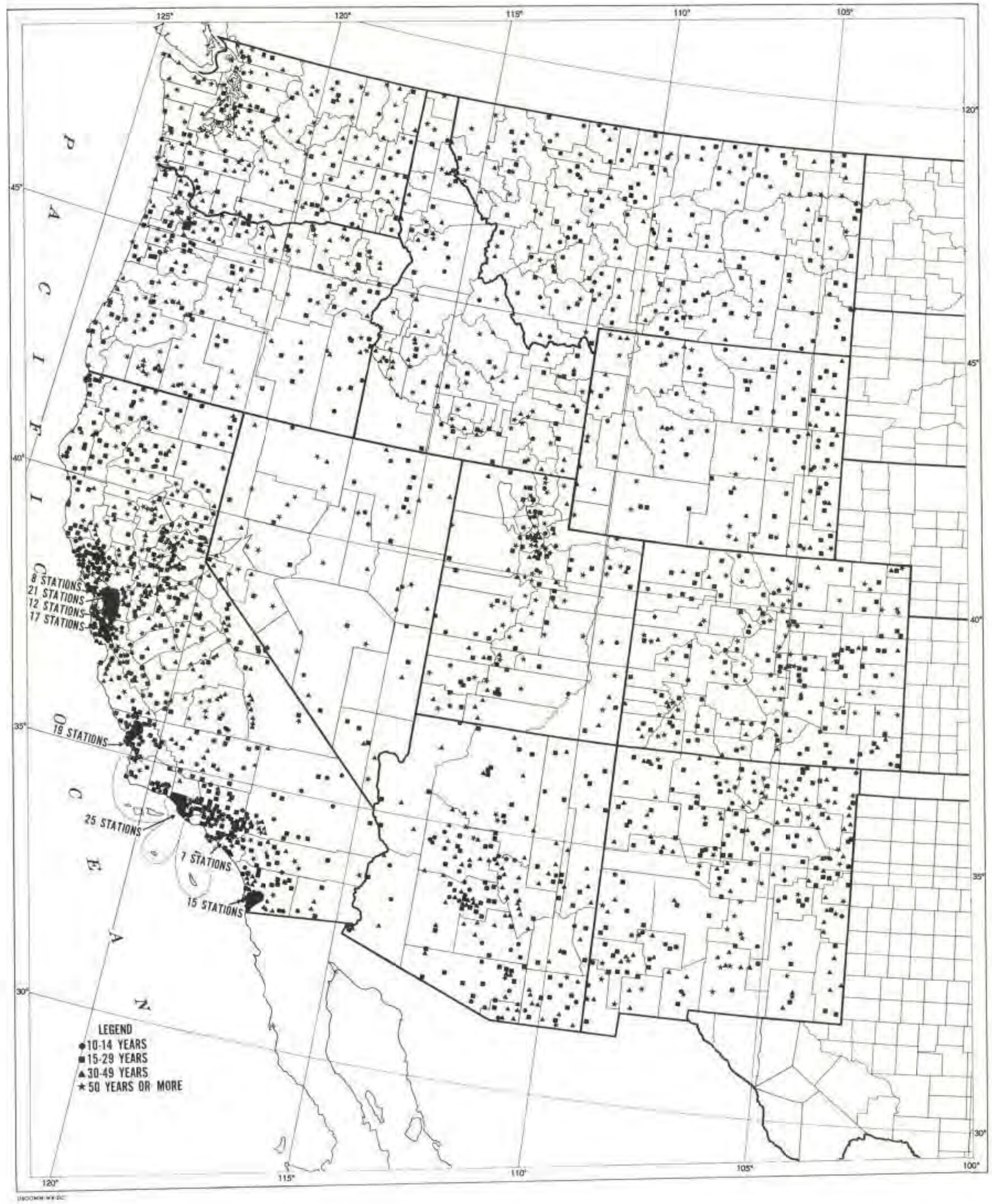
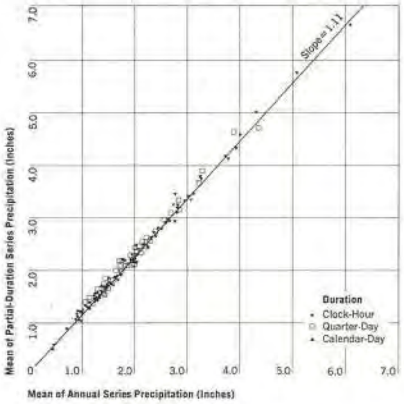


Figure 4. *Geographic distribution of stations with nonrecording gages. Symbols indicate total length of record available.*

Figure 5. *Relation between annual and partial-duration series.*



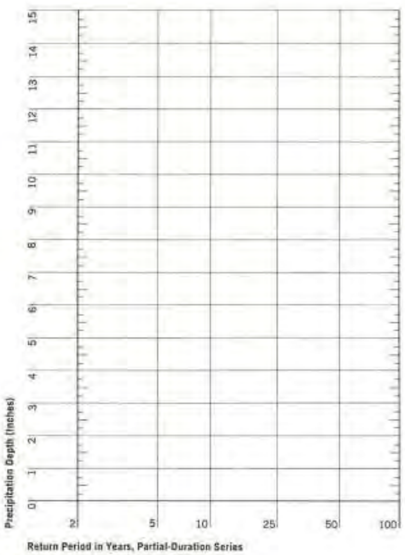


Figure 6. *Precipitation depth versus return period for partial-duration series.*

Figure 7. *Principal paths of moisture inflow in the western United States for storms producing large precipitation amounts. Toned areas are major orographic barriers.*

portant. Next, an examination was made of factors that combined topographic and meteorologic considerations, such as distance and direction to moisture sources. Each factor considered was a measure of some physical reality, and each was understandably related to variation in the precipitation-frequency regime.

Finally, various climatological and meteorological factors that could be indexes of variation of the precipitation-frequency values were considered. The procedure used for developing interpolating equations was a multiple-regression screening technique. This process was done by computer using a least-squares technique. The computer program was capable of accepting a total of 174 independent variables for as many locations as data were available. The number of variables screened for the various relations ranged between 60 and 100. This does not mean that 60 or more completely different factors could be identified. For example, several factors might involve different measures of slope. Moreover, these measures of slope might be over different distances or have different orientations. In each instance, the practice was to permit the computer to select the most critical of the various measures of each factor.

Although the computer program treated each variable as linear during the regression analysis, it was possible through internal computations to use logarithms, powers, roots, reciprocals, or combinations of any or all of the factors. The computer program selected the single variable most highly correlated with the precipitation-frequency value under investigation. The next step was to select the variable that, combined with the variable already selected, would explain the greatest variation in the precipitation-frequency values. The third, fourth, fifth, and further variables were selected in a similar manner. The program continued to select

Region of applicability[1]	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Gila, Williams, and lower Colorado River Basins (1)	0.84	86	1.86	0.21
Little Colorado, San Juan, and Virgin River Basins, except higher elevations of south-facing slopes (2)[2]	0.81	105	1.36	0.20
Higher elevations of south-facing slopes of Little Colorado, San Juan, and Virgin River Basins (2)[2]	0.93	41	1.31	0.13
Rio Grande Basin north of El Paso, Tex. (3)	0.77	110	1.35	0.18
Crest of Continental Divide and Sangre de Cristo Mountains to generalized 7,000-ft contour from southern Wyoming to southern tip of Sangre de Cristo Mountains (4)	0.83	122	1.43	0.22
Upper Colorado and Gunnison River Basins and Green River Basin below confluence of Green and Yampa Rivers (5)	0.79	69	1.12	0.13
Yampa River Basin, Green River Basin above confluence of Green and Yampa Rivers, and Bear River Basin east of Wasatch Mountains (6)	0.83	29	1.03	0.08
Mountains of central Utah (7)	0.85	86	1.35	0.18
Western Utah and Nevada, except Snake and Virgin River Basins and spillover zone east of Sierra Nevada Crest (8)[3]	0.71	79	1.03	0.13
Western Utah and Nevada, except Snake and Virgin River Basins and spillover zone east of Sierra Nevada crest (8)[3]	0.71	55	1.04	0.15
Big Horn River Basin above Saint Xavier and minor portions of North Platte, Powder, Tongue, and Yellowstone River Basins (9)	0.78	55	1.25	0.21
Upper Missouri River Basin above Holter Dam, Mont.; Snake River Basin above Alpine, Wyo.; and upper Yellowstone River Basin above Springdale, Mont. (10)	0.76	57	1.19	0.16
From generalized 4,000-ft contour on east to crests of Crazy and Little Belt Mountains and Lewis Range on west (11)	0.80	52	1.67	0.26
West of Continental Divide, but east of Bitteroot Range and Cabinet and Selkirk Mountains (12)	0.85	44	1.36	0.12
Mountainous region of eastern Washington and Oregon and of Idaho west of Bitteroot Range crest and Continental Divide, and north of southern boundary of Snake River Basin—excluding Snake River Valley below a generalized 5,000-ft contour (13)	0.78	147	1.44	0.24
Orographic region east of crest of Cascade Range and west of Snake River Basin (14)	0.90	115	1.75	0.35
Western slopes of Coast Ranges, Olympic Mountains, and Cascade Range (15)	0.87	125	3.69	0.48
Eel River Basin; southern portion of Klamath River Basin; and Cottonwood, Elder, Thomas, and Gladstone Creeks (16)	0.91	39	4.19	0.50
Russian River, Cache and Putah Creeks, and coastal drainages west of Russian River (17)	0.84	63	5.31	0.78
Santa Cruz Mountains and La Panza, Santa Lucia, and Coast Ranges (18)	0.95	55	4.32	0.45
Diablo, Gabilan, and Temblor Ranges (19)	0.82	58	2.21	0.35
San Rafael, San Bernardino, Santa Monica, and San Gabriel Mountains (20)	0.88	149	3.98	0.59
Santa Ana, Santa Rosa, Coyote, and other extreme southern coastal mountains (21)	0.88	34	2.44	0.33
Northern Sierra Nevada north of Mokelumne River Basin (22)	0.92	84	4.56	0.53
Southern Sierra Nevada south of Consumnes River Basin (23)	0.88	61	3.43	0.53
Southeastern desert region of California (24)	0.89	41	1.07	0.16
Spillover zone east of Sierra Nevada crest (25)	0.94	41	2.05	0.27
Spillover zone east of crest of coastal mountains of southern California (26)	0.97	10	2.08	0.15

[1] Numbers in parentheses refer to geographic regions shown in figure 8.
[2] Two different equations were used in region 2. See text for explanation.
[3] Two different equations were used in region 8. See text for explanation.

Table 3. *Statistical parameters for relations used for interstation interpolation of 2-yr 24-hr precipitation values*

Exhibit D-4

variables until the variance explained by an additional variable was less than some preselected amount or until a fixed number of variables was selected. Final equations did not contain more than five independent variables.

In the development of these equations, data from all stations with daily or hourly observations were considered. The data sample used was not completely adequate. First, it did not include for each factor the full range of values that occur within the region. Application of the equation, therefore, required unavoidable extrapolation. Second, the number of data points used to develop these equations was occasionally less than desirable. Nevertheless, the equations provided the best available method of developing preliminary estimates of frequency values in regions lacking adequate data.

Relations for interpolating between 24-hr precipitation-frequency data points. Figure 8 shows generalized boundaries of the regions used to develop relations for interpolation between locations with 2-yr 24-hr precipitation values. Topographic maps show recognizable topographic barriers chosen as the boundary lines of most regions. For example, the boundary separating regions 3 and 4 from those to the west is the Continental Divide. The boundary separating region 15 from 14 is the crest of the Cascade Range. A few of the boundaries between adjoining regions may appear somewhat arbitrary, but examination of detailed topographic maps will show a physical basis for each.

In areas where topographic variation is gradual and where there are no large differences in elevations or slopes over short distances, precipitation-frequency values at a station usually are representative of a much larger area than are such values in a mountainous region. Within the western United States, some rather extensive regions met this criteria. Within these regions, there were also numerous stations with suitable records. The lack of topographic controls means only there is limited variation in precipitation-frequency values, and this variation is such that it can be depicted using the numerous station data points. No equations for interpolating between stations were developed for such regions (shown shaded in fig. 8).

The equations developed for interpolating between locations with 2-yr 24-hr precipitation values in regions of sparse data were not all equally reliable. On the average, the 28 equations developed for estimating the 2-yr 24-hr precipitation values at intermediate points in western United States explained about 70 percent of the variance. The standard error of estimate averaged about 13 percent of the average station value for 2-yr 24-hr precipitation. The correlation coefficient, the number of stations used, the average 2-yr precipitation value, and the standard error of estimate for each equation used to estimate 2-yr 24-hr precipitation values are shown in table 3.

The equation that explained the least variance, only slightly over one-half, was for western Utah and most of Nevada (region 8, fig. 8). This is a region with diverse topography and no well-defined orographic barrier. It is also a region where a wide variety of storms produce large precipitation amounts. The equation developed for the coastal mountains of California (region 18, fig. 8) explained the greatest portion of the variance, about 90 percent. The region consists primarily of mountain ranges oriented north-northwest to south-southeast; within this region, large precipitation amounts generally result from one storm type.

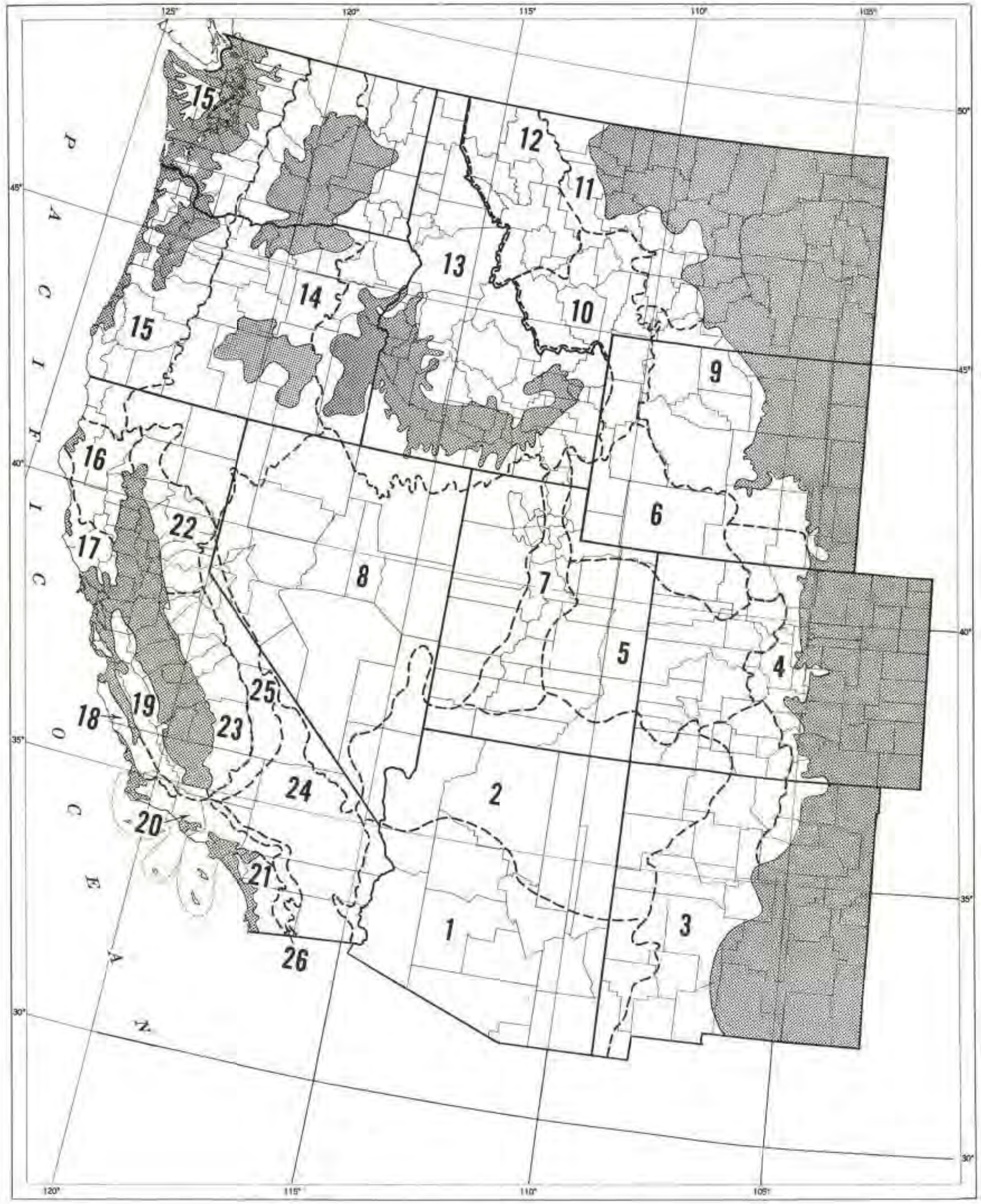


Figure 8. *Regions used to develop statistical parameters for interstation interpolation of 2-yr 24-hr precipitation values.*

Table 4. *Factors most useful in relations for interstation interpolation for 2-yr 24-hr precipitation values*

Factors (by category)	Number of equations using factor	Percent of equations using factor	Number of times each factor used	Percent of total number of times each factor used
Slope	18	64	37	42
Normal annual precipitation	15	54	15	17
Barrier to airflow	10	36	11	12
Elevation	10	36	10	11
Distance to moisture	9	32	9	10
Location (latitude or longitude)	4	14	5	6
Roughness	2	7	2	2

Two equations were developed for region 8 (fig. 8), which includes western Utah and Nevada except for the Snake and Virgin River Basins and a spillover zone east of the Sierra Nevada. The two relations had nearly equal correlation coefficients and standard error of estimates. The first equation was developed using normal annual precipitation, the second topographic factors only. The equation using normal annual precipitation data was developed during preparation of maps for Utah because reliable normal annual precipitation maps were available. Investigations continued, and a relation that gave about equally reliable results was obtained during the development of the maps for Nevada. Values computed using both equations for points near the Nevada-Utah border showed results that did not differ greatly. The second equation was then used to prepare the maps for Nevada.

Table 4 shows the factors, grouped in general categories, found most useful in depicting variations in the 2-yr 24-hr precipitation values for the western United States. The first and second columns show the number and percent of equations in which each factor was used. The total for the second column is larger than 100 percent because several factors were used in the equations developed for each region. The third column shows the total number of times each factor was used, and the fourth what percentage each factor used was of the total number of factors. For example, of the 89 different factors used in the 28 equations, 37 were some measure of slope; the use of the slope factor represents 42 percent of the total number of factors used.

The single most important factor considered was slope, a topographic factor. Measurement of slope varied from region to region. In some regions, slope was measured directly by dividing the difference in height between two points by the distance between the points. In the Cascade and Coast Ranges of Washington and Oregon, the difference between the station elevation and the average elevation at a distance of 20 miles in the western quadrant proved to be the most significant factor. A less direct measure was used in north-central Wyoming and south-central Montana, where the greatest change in elevation between the station and the lowest point within 20 miles was used and the distance between the station and such a point was not involved. In several portions of California, a more complicated method was used. A path 5 miles wide was oriented along the prevailing direction of moist airflow. At 1-mi intervals along this path, the average height was measured. The difference in height between adjoining lines indicated whether there was an upslope or a downslope in this particular segment. The summation of the upslopes and downslopes, separately, was an indirect measurement of slope. A combination of these upslopes and downslopes, each divided by the distance between the station and the center of the area included between two adjoining lines, was a direct measurement of slope.

The second most important topographic factor was found to be the barrier to moist airflow; this factor is actually a combination of meteorology and topography. In selecting a barrier, the first consideration was the direction of moist air inflow. The barrier had to be normal, or nearly normal, to this direction. The barrier range, or ranges, had to be sufficiently massive to cause a significant disruption in the airflow. Barriers of limited lateral extent that would permit air to flow around as easily as over were not considered. A generalized crest line was drawn along the significant barrier, and measurements of barrier height or distances or directions to this barrier were then made from the station to this generalized crestline. The orientation of barriers to moist airflow was determined as appropriate for each region. For example, along the Pacific coast, a westerly direction of moist airflow was used; in Colorado and New Mexico, a southeasterly airflow was appropriate. The direction selected was determined from an examination of the moist air inflow in storms that produce large precipitation amounts in these regions. In some regions, the distance behind the barrier was important. In others, the height of the barrier proved to be more significant.

The distance to the principal moisture source, a combination of topographic and meteorologic influences, was another important factor. In northeastern New Mexico, central Colorado, and southeastern Wyoming (region 4, fig. 8), examination of a topographic map and consideration of the moist air inflow in storms that produced large precipitation amounts (fig. 7), made it evident that the general moist airflow was from the Gulf of Mexico. Distance to moisture was therefore measured in that direction.

Another topographic factor used frequently was the elevation of the station, either the actual station elevation or, preferably, where narrow valleys and ridges predominate in the area the average elevation around the station at some distance (effective elevation). Elevation alone usually correlated rather poorly with precipitation-frequency values. In many regions, the simple correlation between elevation and precipitation-frequency values was not statistically significant at either the 0.01 or 0.05 level. It was not elevation alone but a combination of elevation with other factors, such as slope, height of intervening barriers, and distance to moisture source, that was significant.

Normal annual precipitation was used in many of these index relations. However, the policy adopted was that normal annual precipitation was not used if an equally reliable relation could be derived solely on the basis of topographic factors, even though normals could have been used in almost every region. The one exception was the southeastern desert regions of California, where normal annual precipitation did not correlate well with precipitation-frequency values. Normal annual precipitation maps are most exact at points where data are available. Isopleths used to arrive at estimates in areas where data are not available are only as accurate as the standard error of estimate of the relation used in the interpolation and as the skill of the analyst will permit. Therefore, where estimates of normal annual precipitation (or other climatological factors) are used to develop precipitation-frequency maps, the error incorporated in development of the normal annual precipitation map is combined with the standard error of estimate of the relation for precipitation-frequency maps. Normal annual precipitation maps were, however, helpful and were used. Storage-gage and snow-course data, streamflow data, and vegetation maps are useful for drawing accurate normal annual or seasonal precipitation maps in regions where lack of short-duration precipitation data decreases the reliability of relations between frequency values and topographic factors. Normal annual precipitation was used as a factor where topographic factors could not be quantified to estimate the precipitation-frequency values with sufficient accuracy.

Table 5 shows the statistical parameters of the interpolating equations used to estimate the 100-yr 24-hr precipitation values. The equations were developed for the same regions as those for the 2-yr return period, with one exception (fig. 9). This was in Arizona where data from the Gila, Williams, and lower Colorado Basins were combined with data from the San Juan, Little Colorado, and Virgin River Basins. In regions relatively unaffected by orography, equations were developed that related the 2-yr 24-hr precipitation values to those for the 100-yr return period. These equations were developed as an additional aid for interpolating between stations in these regions because of the relatively few stations with long records available. Although the longest record stations were generally within the nonorographic regions, most states had less than 20 percent of the stations within these regions with 50 or more years of record. Equations for these regions provided an objective method of providing space-averaged ratios between 100-yr 24-hr precipitation values and 2-yr 24-hr precipitation values.

As with the relations for estimating the values for the 2-yr return period, the equations did not all have the same degree of reliability. The orographic region for which the equation accounted for the least variance (not quite one-half of the variation) was the region including the Yampa River Basin, the Green River Basin above the confluence of the Green and Yampa Rivers, and the Bear River Basin east of the Wasatch Mountains (region 5, fig. 9). For several regions in California, over 90 percent of the variance was accounted for by the equations. The equation developed for the San Rafael, San Bernardino, Santa Monica, and San Gabriel Mountains (region 20, fig. 9) accounted for the greatest amount of the variation. On the average, the 35 equations developed to interpolate the 100-yr 24-hr precipitation values in this portion of the United States accounted for about 75 percent of the variance, and the standard error of estimate averaged about 12 percent of the average station value.

There was one region (region 7, fig. 9) for which two equations were developed. In the preparation of frequency maps for Utah, basins that were wholly or partly within Utah were investigated. One region extended westward from Utah to include most of Nevada. Within this region, a relation was developed that accounted for about 60 percent of the variance. During subsequent investigations, a superior relation was developed when frequency maps for Nevada were prepared. The newly developed equation accounted for about 80 percent of the variance.

Table 6 shows the factors found most useful for interpolating variations in the 100-yr 24-hr precipitation values in sparse-data areas of the western United States. This table is in the same format as table 4. The definitions of the variables—slope, distance to moisture, elevation, etc.—are the same as those for table 4. Again, slope is the most important topographic factor. The next most important topographic factor was elevation. In the equations, the 2-yr 24-hr precipitation values were used in interpolation. In table 6, it can be seen that the 2-yr 24-hr precipitation value was the most important variable. However, this may be misleading because about one-fourth of the regions for which equations were developed were considered nonorographic. In such regions, the use of the 2-yr 24-hr precipitation value in an equation was similar to using an average 100- to 2-yr ratio. Frequently, these equations included a location factor that reflected the variation of such a ratio over the region. As with other meteorological or climatological factors—for example, normal annual precipitation—it would have been preferable to avoid the use of precipitation-frequency values in the equations. However, this was not always possible.

Relations for estimating the 6-hr precipitation-frequency values. Data from both recording and nonrecording gages can be incorporated in equations for estimating precipitation-frequency values for the 24-hr duration. For durations of less than 24 hrs, only data from recording gages can be used. This frequently reduces the number of data points within a particular region by one-half or more. The effect of topography on precipitation-frequency values decreases as the duration decreases. Thus, there is less variability in the precipitation-frequency values for the 6-hr duration. For these reasons, larger regions are used to develop interpolation equations for 6-hr duration maps. Figure 10 shows the regions used to develop the equations for estimating 2-yr 6-hr precipitation values. The regions used for developing relations for the 100-yr return period were the same with one exception; the region south of the Snake, Bear, Yampa, and North Platte River Basins (region 1, fig. 10). This region was divided approximately along the Arizona-Utah and the New Mexico-Colorado boundary lines into Regions 1A and 1B.

The equation for the northern Sierra Nevada region of California (region 7, fig. 10) accounted for the least amount of variation—about 60 percent—in the 2-yr 6-hr precipitation values (table 7). The equation for the coastal mountains of California (region 6, fig. 10) accounted for over 90 percent of the variation and was the most reliable equation developed. On the average, the equations accounted for over 80 percent of the variations and had a standard error of estimate of about 11 percent of the average 2-yr 6-hr precipitation values.

For the 100-yr 6-hr precipitation values, the equation for the coastal mountains of California (region 6, fig. 10) accounted for the greatest amount of variation in these values (table 8). In this region, over 90 percent of the variation in the data sample was accounted for. The equation for the northern Great Basin (region 3, fig. 10) accounted for the least variation. In this region, the equation accounted for about 60 percent of the variation. On the average, the equations accounted for over 80 percent of the variation with a standard error of estimate of about 14 percent of the

Exhibit D-4

Region of applicability[1]	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Gila, Williams, San Juan, Little Colorado, and Virgin River Basins (1)	0.80	148	3.98	0.59
Rio Grande Basin north of El Paso, Tex. (2)	0.78	110	3.26	0.48
Crest of Continental Divide and Sangre de Cristo Mountains to generalized 7,000-ft contour from southern Wyoming to southern tip of Sangre de Cristo Mountains (3)	0.91	69	3.28	0.38
Upper Colorado and Gunnison River Basins and Green River Basin below confluence of Green and Yampa Rivers (4)	0.79	53	2.57	0.31
Yampa River Basin, Green River Basin above confluence of Green and Yampa Rivers, and Bear River east of Wasatch Mountains (5)	0.68	27	2.41	0.30
Mountains of central Utah (6)	0.88	65	2.84	0.25
Western Utah and Nevada, except Snake and Virgin River Basins and spillover zone east of Sierra Nevada crest (7)[2]	0.77	64	2.50	0.29
Western Utah and Nevada, except Snake and Virgin River Basins and spillover zone east of Sierra Nevada crest (7)[2]	0.90	55	2.42	0.22
Big Horn River Basin above Saint Xavier and minor portions of North Platte, Powder, Tongue, and Yellowstone River Basins (8)	0.94	47	3.10	0.31
Upper Missouri River Basin above Holter Dam, Mont.; Snake River Basin above Alpine, Wyo.; and upper Yellowstone River Basin above Springdale, Mont. (9)	0.88	48	2.68	0.34
From generalized 4,000-ft contour on the east to crests of Crazy and Little Belt Mountains and Lewis Range on the west (10)	0.85	41	3.71	0.44
West of Continental Divide, but east of Bitteroot Range and Cabinet and Selkirk Mountains (11)	0.90	37	2.87	0.20
Mountainous region of eastern Washington and Oregon and of Idaho west of Bitteroot Range crest and Continental Divide, and north of southern boundary of Snake River Basin—excluding Snake River Valley below a generalized 5,000-ft contour (12)	0.87	99	2.74	0.32
Orographic region east of crest of Cascade Range and west of Snake River Basin (13)	0.92	115	3.76	0.61
Western slopes of Coast Ranges, Olympic Mountains, and Cascade Range (14)	0.80	119	7.09	1.13
Spillover zone east of crest of Sierra Nevada (15)	0.91	28	5.39	0.75
Eel River Basin; southern portion of Klamath River Basin; and Cottonwood, Elder, Thomas, and Gladstone Creeks (16)	0.85	26	8.34	1.42
Russian River, Cache and Putah Creeks, and coastal drainages west of Russian River (17)	0.88	35	10.17	1.24
Santa Cruz Mountains and La Panza, Santa Lucia, and Coast Ranges (18)	0.96	26	10.90	1.25
Diablo, Gabilan, and Temblor Ranges (19)	0.97	29	5.26	0.48
San Rafael, San Bernardino, Santa Monica, and San Gabriel Mountains (20)	0.98	68	11.72	0.97
Santa Ana, Santa Rosa, Coyote, and other extreme southern coastal mountains (21)	0.87	29	6.74	1.06
Northern Sierra Nevada north of Mokelumne River Basin (22)	0.96	65	9.74	1.01
Southern Sierra Nevada south of Consumnes River Basin (23)	0.89	42	8.14	1.29
Southeastern desert region of California (24)	0.93	41	3.37	0.47
Spillover zone east of crest of coastal mountains of southern California (25)	0.98	10	6.20	0.50
New Mexico east of Rio Grande Basin (26)	0.66	136	5.28	0.88
Colorado east of generalized 7,000-ft contour, and southeastern Wyoming east of generalized 7,000-ft contour and south of North Platte River Basin (27)	0.82	119	4.73	0.52
Eastern Wyoming and southeastern Montana east of generalized 6,000- to 5,000-ft contour and south of generalized 4,000-ft contour in vicinity of Wyoming-Montana border (28)	0.83	66	4.08	0.45
Montana east and north of generalized 4,000-ft contour (29)	0.76	83	3.86	0.42
Snake River Valley below 5,000 ft (30)	0.85	48	2.25	0.21
Coastal Plain, Puget Sound region, and Williamette Valley below 1,000 ft (31)	0.94	146	5.47	0.62
Nonorographic region east of crest of Cascade Range (32)	0.71	50	2.07	0.25
Sacramento and San Joaquin River Valleys of California below 1,000 ft (33)	0.94	102	4.07	0.51
Coastal lowlands of California (34)	0.87	180	6.65	1.03

[1] Numbers in parentheses refer to geographic regions shown in figure 9.
[2] Two different equations were used in region 7. See text for explanation.

Table 5. *Statistical parameters for relations used for interstation interpolation of 100-yr 24-hr precipiation values*

average 100-yr 6-hr precipitation values.

The factors used most frequently in the equations for estimating the 2-yr 6-hr precipitation values are listed in table 9; those for the 100-yr 6-hr precipitation values are given in table 10. The format and definitions of variables of tables 9 and 10 are the same as those of table 4. For the 2-yr return period, the factor used most frequently was a measurement of slope. Most equations, however, related variations in the 6-hr precipitation values to variations in the 24-hr values. For the 100-yr return period, slope and elevation were equally important topographic factors. As with the 100-yr 24-hr and 2-yr 6-hr maps, precipitation-frequency values were used in the equations for some regions.

Typical multiple linear regression equations. It is beyond the scope of this publication to present all the equations used for estimating precipitation-frequency values for this Atlas. However, it is useful to discuss in some detail two equations used to estimate the 2-yr 24-hr precipitation values. The factors used and the accuracy of the results obtained are typical of other equations developed.

The first of these is the equation for the northern Coastal Mountains of California (region 16, fig. 8). This region includes the Eel River Basin, some southern portions of the Klamath River Basin, and the western portion of the Sacramento River Basin. This equation is

$$Y = 3.117 + 1.814(X_1) + 0.016(X_8) - 0.049(X_2), \quad (1)$$

where Y is the 2-yr 24-hr precipitation value in inches, and X_1 is the average elevation (in hundreds of feet) of the points on a 1-mile radius circle centered on the station and divided by the distance (in miles) to the coast. X_8 is the slope of the terrain near

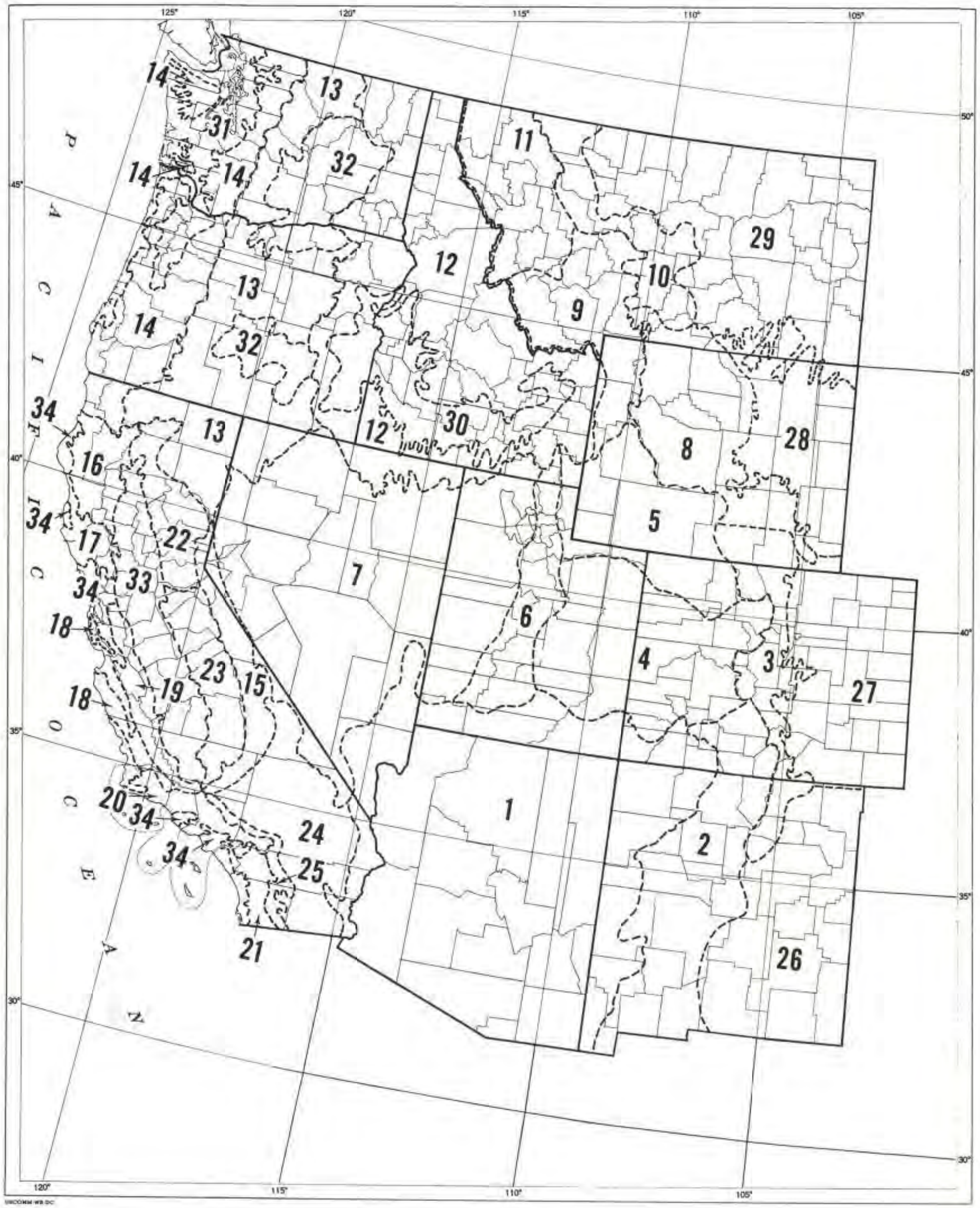
Table 6. *Factors most useful in relations for interstation interpolation for 100-yr 24-hr precipitation values*

Factors (by category)	Number of equations using factor	Percent of equations using factor	Number of times each factor used	Percent of total number of times each factor used
2-yr 24-hr precipitation	27	77	27	29
Slope	26	74	26	28
Elevation	20	57	20	22
Distance to moisture	6	17	6	7
Location (latitude or longitude)	5	14	6	7
Normal annual precipitation	4	11	4	4
Barrier to airflow	2	6	2	2
Roughness	1	3	1	1

Region of applicability[a]	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Arizona, New Mexico, extreme eastern California, Nevada south of the Snake River Basin, Utah south of the Snake and Bear River Basins, and Colorado south of the Yampa and North Platte River Basins (1a and 1b)	0.92	262	1.10	0.16
Montana and Wyoming east of a generalized crestline extending along the Continental Divide in northern Montana, the Crazy and Little Belt Mountains, the Absaroka Range, and the Continental Divide in southern Wyoming (2)	0.94	125	1.07	0.10
Region north of the southern boundaries of the Snake, Bear, and Yampa River Basins and between a generalized crestline of the Cascades and a generalized crestline extending along the Continental Divide in northern Montana, the Crazy and Little Belt Mountains, the Absaroka Range, and the Continental Divide in southern Wyoming and northern Colorado (3)	0.91	151	0.73	0.07
Orographic regions of western Washington, Oregon, and California from the crest of the Cascade Range to the Pacific Ocean extending southward to include the area drained by the Klamath and Salmon Rivers in northern California (4)	0.78	57	1.66	0.23
Nonorographic coastal lowlands of Washington and Oregon (5)	0.97	59	1.41	0.10
Coastal mountains of California from the Trinity River Basin in the north to the Mexican border (6)	0.97	87	1.85	0.16
Northern Sierra Nevada north of Mokelumne River Basin (7)	0.78	31	2.03	0.34
Southern Sierra Nevada south of Consumnes River Basin (8)	0.92	26	1.68	0.18
Spillover zone east of the crests of the Sierra Nevada and the coastal mountains of southern California and the southeastern desert region of California (9)	0.86	25	0.84	0.12
Coastal lowlands and San Joaquin and Sacramento Valleys of California (10)	0.95	73	1.37	0.11

[a] Numbers in parentheses refer to geographic regions shown in figure 10.

Table 7. *Statistical parameters for relations used for interstation interpolation of 2-yr 6-hr precipitation values*



the station (in hundreds of feet per mile). X_2 was computed by subtracting the average height along a 90° arc centered 10 miles southwest of the station (downwind for the most prevalent storm-wind direction) from the average height along a 90° arc centered 5 miles northeast of the station (upwind for the most prevalent storm-wind direction). X_3 is the average height (in hundreds of feet) of the final crest (measured along a 10° arc) divided by the distance (in miles) between the station and the final crest. The final crest was a generalized crestline that separated the Sacramento River Basin from basins to the west; it was drawn on a 1:1,000,000 World Aeronautical Chart. Distances to the east of this crest were considered negative.

The first factor, X_1, combines the measurements of the horizontal and vertical distances from moisture. It also measures the average slope between the station and the coast. The second factor, X_2, is a measure of the lift imparted to the airflow in the vicinity of the station—small-scale slope. The third factor, X_3, is a measure of large-scale lifting—large-scale slope. It can also be considered to represent the general distortion in the large-scale moist airflow caused by the major orographic barrier.

This equation explains about 84 percent of the variance in the 2-yr 24-hr precipitation values, with a standard error of estimate of 0.50 in. which is about 12 percent of the average 2-yr 24-hr precipitation value for stations in the region. Of the total variance, the first variable accounts for about 70 percent, the second, 9 percent, and the third, 4 percent. Other variables examined did not account for significant additional portions of the variance. The geographic distribution of the errors is shown in figure 11. The upper number at each station is the actual difference (in hundredths of inches) between the value computed from observed data and that estimated from the equation. The lower number is the error expressed in a percent of the 2-yr 24-hr precipitation value at the station. No discernible regional pattern in the errors was apparent. Although the factors used in this and the other equations have a physical meaning, the equation is a statistical relation of physical factors. There is no intention to imply a cause-and-effect relation. The requisite knowledge of the precipitation process is not yet available to develop equations that incorporate the dynamics of motion, condensation, and other factors to predict precipitation frequency.

The second illustrative equation was developed for the Big Horn River Basin, south of Saint Xavier, Mont. (region 9, fig. 8). Minor portions of the North Platte, Powder, Tongue, and Yellowstone River Basins were also included in this region. The equation is

$$Y = 1.497 + 0.027(X_4) + 0.002(X_5) - 0.023(X_6). \quad (2)$$

Y is the estimated 2-yr 24-hr precipitation value in inches. X_4 is the difference between the station elevation and the lowest elevation within 20 miles (in hundreds of feet). X_5 is the difference between the sum of the maximum heights within 40 miles along radials to the northwest, west, and southwest, and the sum of the maximum elevations within 40 miles along radials to the northeast, east, and southeast (in hundreds of feet). X_6 is the direction to the nearest point on the Continental Divide within the sector from southwest to north. If, however, there is a peak higher than 9,000 ft within this sector and it is closer to the station than is the Continental Divide, X_6 is the direction to this peak.

Figure 9. *Regions used to develop statistical parameters for interstation interpolation of 100-yr 24-hr precipitation values.*

All three variables are related to the effect of the ground slope in the vicinity of the station. The first two variables measure differences in height over small and medium distances and reflect the importance of the steepness of the slope in the precipitation process. Here, the moist airflow of large storms comes from an easterly direction, frequently associated with a cyclonic center south or southeast of the region, and ground elevation generally increases toward the west or northwest. The third variable relates the orientation of the ground slope and its effectiveness in the precipitation process to an optimum inflow direction. The total amount of the variance accounted for by this relation is about 60 percent, with a standard error of estimate of 0.21 in., or about 17 percent of the average 2-yr 24-hr precipitation value. The first variable accounts for about 41 percent of the variance; the second, 11 percent; and the last, 8 percent. The geographic distribution of the errors from this equation is shown in figure 12.

It would have been possible to include normal annual precipitation in this relation. This factor would have accounted for an additional 15 percent of the variance and a corresponding decrease in the standard error of estimate. Where this factor could be determined from data, the use of normal annual precipitation would have improved the results. As indicated earlier, the results would include some points for which short-duration precipitation data were not available. At points where such data were not available, any improvement would have been dependent on the ability to estimate normal annual precipitation. In using an equation with normal annual precipitation, the standard error of estimate incorporated in the procedure for preparing normal annual precipitation maps is combined with the standard error of estimate for the interpolating equation for 2-yr 24-hr precipitation values. When this combined error is greater than the standard error of estimate for an interpolating equation for 2-yr 24-hr precipitation that does not include normal annual precipitation, there is a loss of accuracy through use of the equation including normal annual precipitation. Within this particular region, the uncertainty in estimating normal annual precipitation at nondata points was sufficiently large and an equation developed using only topographic factors was sufficiently reliable that use of the equation containing normal annual precipitation for estimating the 2-yr 24-hr precipitation values was not justified.

Drawing of isopluvial lines on four key maps. In preparing the isopluvial maps, the computed precipitation-frequency values for all stations were plotted. In addition to the computed values, the width of the confidence band, computed according to standard statistical procedures, was plotted for the 100-yr return-period maps. Values estimated from the equations described in the preceding section were plotted for a latitude-longitude grid with 5-min grid points. The total number of grid points was approximately 47,000. Along the boundaries of each region, values were estimated by the equations applicable to each of the adjoining regions.

In the construction of isopluvial lines, the question arises as to how much the station and grid-point data should be smoothed for the most effective use of the maps. When drawing the isopluvial lines through the field of grid points and station data, the standard error of estimate for the various multiple regression equations and the confidence band about the station data must be considered. Also, smoothing between adjoining regions, where multiple regression equations give somewhat different values at the boundary

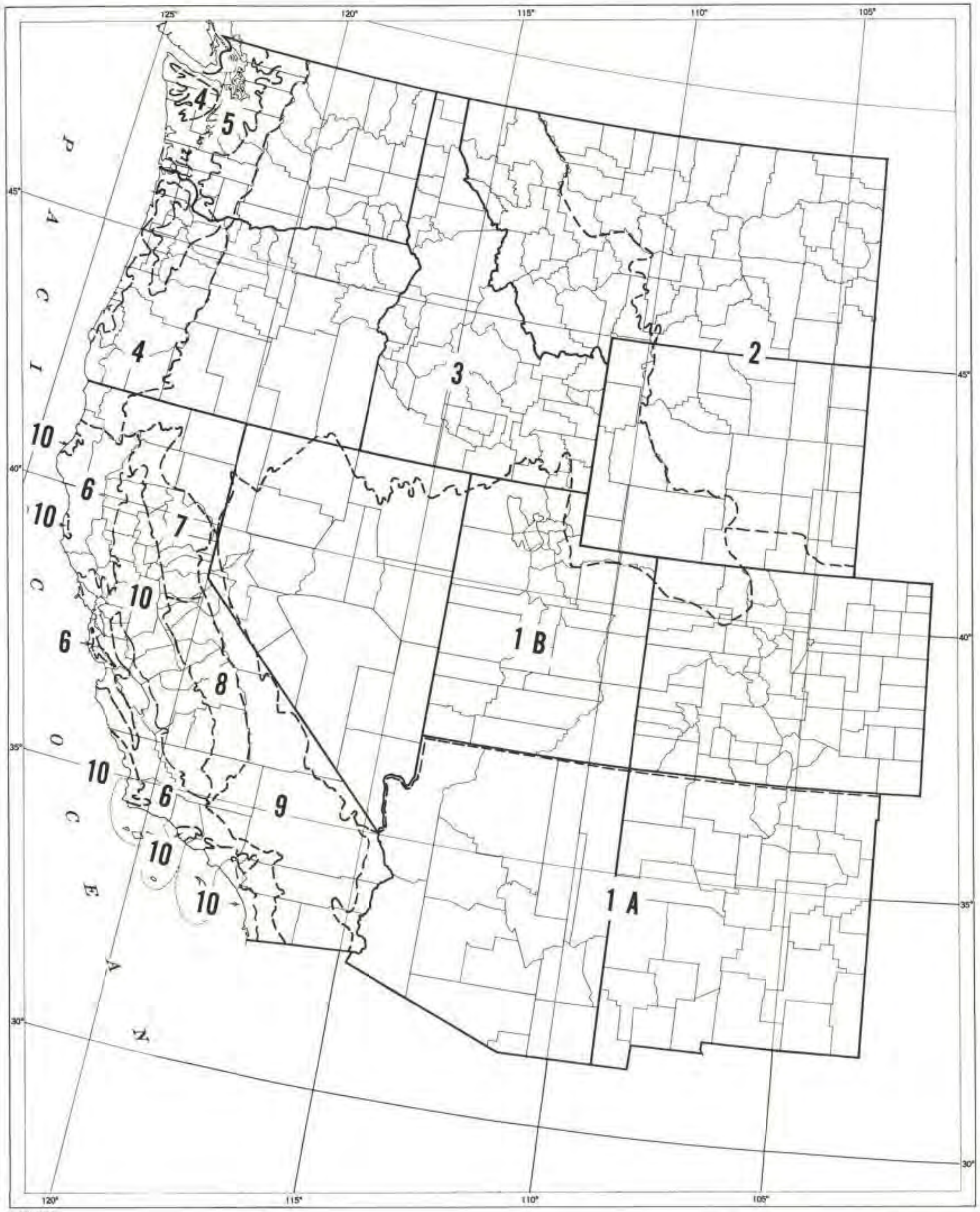


Figure 10. *Regions used to develop statistical parameters for interstation interpolation of 2-yr and 100-yr 6-hr precipitation values.*

Table 8. *Statistical parameters for relations used for interstation interpolation of 100-yr 6-hr precipitation values*

Region of applicability*	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Arizona, New Mexico, and lower Colorado River Basin in southeastern California (1a)	0.91	103	3.16	0.50
Nevada south of the Snake River Basin, Utah south of the Snake and Bear River Basins, and Colorado south of the Yampa and North Platte River Basins (1b)	0.91	144	2.34	0.47
Montana and Wyoming east of a generalized crestline extending along the Continental Divide in northern Montana, the Crazy and Little Belt Mountains, the Absaroka Range, and the Continental Divide in southern Wyoming (2)	0.92	110	2.62	0.31
Region north of the southern boundaries of the Snake, Bear, and Yampa River Basins and between a generalized crestline of the Cascades and a generalized crestline extending along the Continental Divide in northern Montana, the Crazy and Little Belt Mountains, the Absaroka Range, and the Continental Divide in southern Wyoming and northern Colorado (3)	0.79	120	1.62	0.22
Orographic regions of western Washington, Oregon, and California from the crest of the Cascade Range to the Pacific Ocean extending southward to include the area drained by the Klamath and Salmon Rivers in northern California (4)	0.89	57	2.98	0.33
Nonorographic coastal lowlands of Washington and Oregon (5)	0.91	59	2.49	0.31
Coastal mountains of California from the Trinity River Basin in the north to the Mexican border (6)	0.97	87	3.95	0.39
Northern Sierra Nevada north of Mokelumne River Basin (7)	0.93	31	3.81	0.45
Southern Sierra Nevada south of Consumnes River Basin (8)	0.93	26	3.87	0.50
Spillover zone east of the crests of the Sierra Nevada and the coastal mountains of southern California and the southeastern desert region of California (9)	0.84	25	2.29	0.36
Coastal lowlands and San Joaquin and Sacramento Valleys of California (10)	0.87	71	2.98	0.41

* Numbers in parentheses refer to geographic regions shown in figure 10.

Factors (by category)	Number of equations using factor	Percent of equations using factor	Number of times each factor used	Percent of total number of times each factor used
Slope	4	40	10	38
2-yr 24-hr precipitation	7	70	7	27
Location (latitude or longitude)	4	40	4	15
Elevation	3	30	3	12
Barrier to airflow	1	10	1	4
Distance to moisture	1	10	1	4

Table 9. *Factors most useful in relations for interstation interpolation of 2-yr 6-hr precipitation values*

Factors (by category)	Number of equations using factor	Percent of equations using factor	Number of times each factor used	Percent of total number of times each factor used
2-yr 6-hr precipitation	5	55	5	23
100-yr 24-hr precipitation	4	36	4	19
Elevation	4	36	4	19
Slope	4	36	4	19
2-yr 24-hr precipitation	1	9	1	5
Normal annual precipitation	1	9	1	5
Distance to moisture	1	9	1	5
Location	1	9	1	5

Table 10. *Factors most useful in relations for interstation interpolation for 100-yr 6-hr precipitation values*

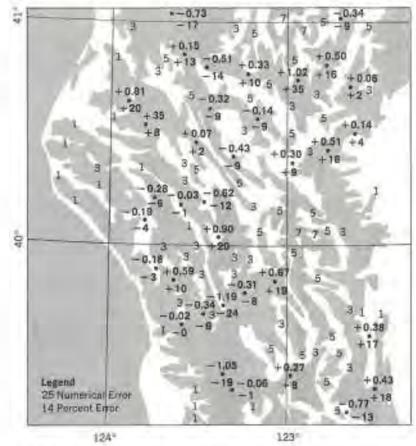
lines, must be considered separately. Isolines can be drawn to fit every point plotted on the map, although this would not allow for some of the random differences between adjoining grid points that result from errors in the multiple regression equation or sampling errors in station data. Also, the courseness of even a 5-min latitude-longitude grid is such that sometimes narrow ridges and valleys are missed. Because of these considerations, occasionally it was necessary to make additional computations for such locations. Some subjective smoothing must be used to make allowances for factors that could not be expressed quantitatively.

In analysis, smoothness and closeness of fit are basically inconsistent in that smoothing cannot be carried beyond a certain point without some sacrifice of closeness of fit and vice versa. As the isolines were drawn, the sampling error of the station values and the standard error of estimate were considered.

Additional working maps. Additional working maps were prepared showing the 100- to 2-yr ratios for the 6- and 24-hr durations and the 6- to 24-hr ratios for the 2- and 100-yr return periods. To minimize the exaggerated effect of an outlier (anomolous event) from a short record, only data from those stations with a minimum record length of 20 yrs for the 6- and 24-hr durations at the 100-yr return period were used in these working maps. Experience has shown that for long-record station data, the ratio of 6- to 24-hr values for the same return period and the 100- to 2-yr ratio for the same duration do not vary greatly over relatively large areas. The variation present is consistent with the variations in relations between meteorologic and topographic characteristics. Climatic factors that provide general guides on variations of precipitation-frequency values were examined and considered in a qualitative sense. Among these factors are the mean annual number of thunderstorm days (U.S. Weather Bureau 1952, 1947), normal monthly number of days above various threshold values (Environmental Science Services Administration, Weather Bureau, 1966), and mean number of days with rain (Environmental Science Services Administration, Environmental Data Service 1968).

Intermediate maps. The 47,000-point grid described earlier was also used in the analysis of the isopluvial patterns of the eight intermediate maps. These maps—for 5-, 10-, 25-, and 50-yr return periods for 6- and 24-hr durations were prepared primarily for the convenience of the user, because it is technically sufficient to provide two points of the frequency curve for a particular duration and to describe the method of interpolation. Four values, one from each of the four key maps, were read for each grid point. These four values were used in a computer program based on the return-period diagram (fig. 6) to compute values for eight additional maps. The key maps were used as underlays to maintain the basic isopluvial pattern on all maps.

Figure 11. *Geographic distribution of errors for equation used to interpolate 2-yr 24-hr precipitation values for the Eel River Basin; southern portion of Klamath River Basin; and Cottonwood, Elder, Thomas, and Gladstone Creeks, California.*



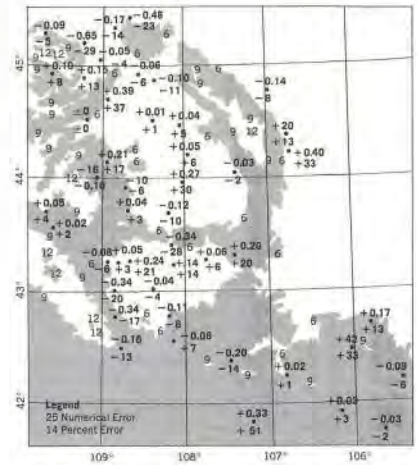


Figure 12. *Geographic distribution of errors for equation used to interpolate 2-yr 24-hr precipitation values for the Big Horn River Basin above Saint Xavier, Montana; minor portions of the North Platte, Powder, and Tongue River Basins in eastern Wyoming; and minor portions of the Yellowstone River Basin in northwestern Wyoming and southeastern Montana.*

Interpretation of Results

Season of Occurrence

The maps in this Atlas are based upon data for the entire year. In certain sections of the West, precipitation is highly seasonal. Thus, rainy season precipitation-frequency values approach the annual values. In sections where the greatest annual *n*-hour precipitation amount may be observed in any season, seasonal precipitation-frequency maps would differ from those presented in this Atlas. In no case could the seasonal value be greater than the annual value. However, the seasonal values would be a certain percent of the annual values, with the percent varying according to the frequency of large storms during the season under investigation. Generalizations about the seasonal distribution of large storms can be obtained from ESSA, *U.S. Weather Bureau Technical Paper* No. 57 (Environmental Science Services Administration, Weather Bureau, 1966). Currently, there is no convenient manner of applying this knowledge to the maps of this Atlas, other than subjectively.

Within Vs. Among Storms

Data for the various duration maps and diagrams in this Atlas were determined independently; that is, there was no requirement that the maximum 6- or 1-hr amount for a particular year be included within the maximum 24-hr amount for that year. The maps, therefore, represent an "among" storm distribution. In regions where winter-type storms predominate, the 6-hr value for a particular return period would more closely approximate the 6-hr value within the 24-hr storm for the same return period than would generally be the case in regions where convective storms predominate. In a study for the United States east of the Mississippi River, Miller (1971) showed that the ratio between the 2-yr 1-hr value computed from the maximum 1-hr amount within the 24-hr maximum and the 2-yr 1-hr value computed using maximum 1-hr amounts varied between 0.52 and 0.91. Studies have not been undertaken of this relation in the West, but a wide range in such ratios and similar ratios for the 6-hr duration could be expected.

Point Probabilities

The maps in this Atlas are derived from and depict point probabilities; the data points are independent of each other. Precipitation over a region is variable, even in large general area storms; neighboring stations do not necessarily experience maximum annual amounts from the same storm. Thus, the individual points on these maps express individual probabilities. That a point within a particular watershed may receive an amount equal to or greater than its 50- or 100-yr value on a particular day does not affect probabilities for any other point within that watershed. A second point within the watershed may experience an amount equal to or greater than its 50- or 100-yr value within the same storm or on the next day, within the next week or at any other time.

Areal Analysis

A value read from an isopluvial map in this Atlas is the value for that point and the amount for that particular duration which will be equaled or exceeded, on the average, once during the period indicated on the individual map. In hydrologic design, engineers are more concerned with the average depth of precipitation over an area than with the depth at a particular point. Depth-area curves were developed to meet this need. The depth-area curve is an attempt to relate the average of all point values for a given duration and frequency within a basin to the average depth over the basin for the same duration and frequency.

Generally, there are two types of depth-area relations. The first is the storm-centered relation; that is, the maximum precipitation occurring when the storm is centered on the area affected (fig. 13). The second type is the geographically fixed-area relation where the area is fixed and the storm is either centered over it or is displaced so only a portion of the storm affects the area (fig. 13). We can say that storm-centered rainfall data represent profiles of discrete storms, whereas the fixed-area data are statistical averages in which the maximum point values frequently come from different storms. At times, the maximum areal value for the network is from a storm that does not produce maximum point amounts. Each type of depth-area relation is useful, but each must be applied to appropriate data. Generally, the storm-centered relations are used for preparing estimates of probable maximum precipitation, while the geographically fixed relations are used for studies of precipitation-frequency values for basins.

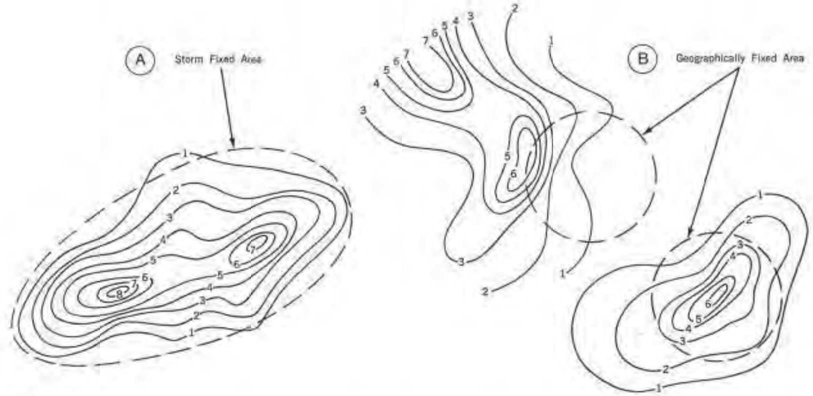
Dense networks of precipitation gages are required to furnish basic data used in developing depth-area relations for fixed areas. The criteria used in selecting dense networks for the determination of areal precipitation-frequencies by the National Weather Service have been:

1. A network should be composed entirely of recording gages. The use of nonrecording gages may greatly increase the number and density of stations within a network, but it involves the construction of mass curves and introduces additional subjectivity. Nonrecording gages are read at various hours, usually early morning, late afternoon, or midnight. Because of conflicting activities, a cooperative observer may not always be able to read his precipitation gage at the exact hour specified. In these cases, the exact time of the observation may not be available, so it is hard to relate the reported amounts to those of surrounding stations with the precision required for development of depth-area relations.
2. A minimum length of record should be established to ensure a reasonable estimate of the 2-yr areal precipitation.
3. Gage locations and exposures should remain consistent during the period of record analyzed.
4. Gages should be located so that there is at least one gage located within each 100 square-mile area.

The average depth-area curves in this Atlas (fig. 14) are for fixed areas and were developed from dense networks meeting the above criteria. The curves were first prepared for an earlier study (U.S. Weather Bureau 1957–60) and have since been rechecked against longer record data; no changes were needed. Application of these curves must be consistent with the manner in which they were developed. The following steps are used:

1. Estimate point values from a grid of many points over the basin of interest for the duration and return period required.
2. Compute an average of the point values obtained in step 1.
3. Use figure 14 to obtain an areal reduction factor required for the precipitation duration and size of area under consideration.
4. Multiply the average value obtained in step 2 by the ratio obtained in step 3. The value obtained in this step provides the areal value for the basin of interest for the duration and return period under consideration.

Figure 13. *Examples of (A) isohyetal pattern centered over basin as would be the case for storm-centered depth-area curves and (B) two possible occurrences of isohyetal patterns over a geographically fixed area as would be the case in development of curves for a geographically fixed area.*



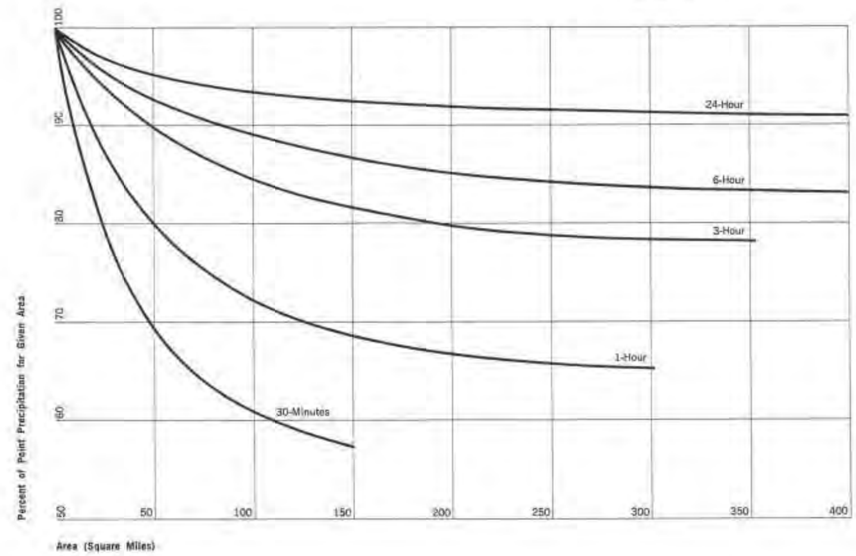


Figure 14. *Depth-Area curves.*

Data used to develop and validate the curves of figure 14 exhibited no systematic regional pattern. Duration turned out to be the major factor. The curves shown are based on data for the 2-yr return period. Within the accuracy of the data available, it could be shown that neither magnitude nor return period was a significant factor.

Importance of Snow in Estimating Frequency Values

The contribution of snow amounts to the precipitation-frequency values for durations of 24 hours or less has been investigated in most of the western United States. In many parts of this region, particularly at higher elevations, snow accounts for over 50 percent of the normal annual precipitation. Thus, the importance of snowfall to short-duration (6- to 24-hr) precipitation-frequency values is of interest for a more complete understanding of the precipitation-frequency regime.

Mean annual precipitation containing a high percentage of snow occurrences does not necessarily mean that snow contributed significantly to the annual series of maximum 6- or 24-hr precipitation amounts. This problem was investigated by tabulating two sets of data for all stations where snowfall observations were made routinely. The first set of data contained the greatest 24-hr (and 6-hr amounts at recording-gage stations) precipitation amount for each year, regardless of type of precipitation (water equivalent for snowfall amounts). The second series was restricted solely to rainfall events. In some cases, the second series contained amounts as low as the fifth highest for a particular year. Results of these investigations are reported in the section for each state.

Reliability of Results

The term "reliability" is used here as an indication of the degree of confidence that can be placed in the accuracy of the results obtained from the maps. The reliability of these results is influenced by the sampling errors in time and space, and by the manner in which the maps were constructed. Sampling errors in time and space result from: (1) the chance occurrence of an anomalous storm which has a disproportionate effect on the statistics for one station, but not on those for a nearby station, and (2) the geographic distribution of stations. In the relatively nonorographic regions (shown shaded on fig. 8), the occurrence of large precipitation events can be considered to be relatively random over a limited geographic area. Thus, a large precipitation event (especially of convective nature) at a station could just as easily have occurred at a neighboring station or between stations. Results from a generalized analysis based on space-averaging techniques are considered more nearly correct than results determined from an analysis of only individual station data. In the more mountainous regions, orography has greater control on the location and magnitude of the largest storms and simple space averaging between neighboring stations is inappropriate; consideration must be given to effects of the slopes of surrounding terrain, station elevations, the intervening barrier between station location and moisture source, etc.

The locations of the stations used in the analyses are shown in figures 3 and 4. This geographic network of stations does not reveal with complete accuracy the very detailed structure of the isopluvial patterns in the mountainous regions of the West. The multiple regression equations discussed earlier were used to help in interpolation between values computed for these stations. The standard error of estimate for these relations should be considered when using the precipitation-frequency values shown on the maps. In general, the accuracy of the estimates obtained from the maps of this Atlas varies from a minimum of about 10 percent for the shorter return periods in relatively nonorographic regions to 20 percent for the longer return periods in the more rugged orographic regions.

The values shown on these maps are in general agreement with those of *Weather Bureau Technical Paper* No. 40 (U.S. Weather Bureau 1961). Differences are found because of the greater attention paid to physiographic features in the present study. Even though the precipitation-frequency maps presented are prepared considering physiographic factors, only those of a major scale could be considered. There are some basins, therefore, that are more sheltered or exposed than a generalized topographic map would indicate. The map values may not be representative of the precipitation regimes in such basins.

The major centers of large precipitation-frequency values are located on the most exposed and steepest slopes of the mountains. Objective studies (such as the regression analysis previously discussed) and experience in precipitation-frequency analysis have indicated some general guidelines for the placement of isopluvial centers along crests and on slopes of mountain ranges. Two examples will serve to illustrate such guidelines. For an initial completely exposed orographic barrier, where the crest of the range was 3,000 to 4,000 ft. above the plains region to the windward of the mountain and the slope was on the order of 300 ft per mile, the largest isopluvial line should extend past the crest and include a little of the lee side of the mountain. Where the crest of the range was 8,000 to 10,000 ft above the plains region to the windward of the mountain range and the slope was on the order of 1,000 ft per mile, the isopluvial center would generally be about 4,000 to 6,000 ft above the plains region. For mountain ranges with crests and slopes having other combinations of these values, the placement of the highest precipitation-frequency values would depend upon the degree of exposure of the mountain range to moisture-bearing wind, the steepness of the slope, the height of the crest, and other orographic factors. In general, isopluvial centers for the longer return periods tend to be located at lower elevations than the centers for the shorter return periods. The distance downslope that the center is displaced depends on the exposure and steepness of the slope. Centers will be displaced less on a steep slope than on a gentle slope similarly exposed.

Exhibit D-4

Oregon

Discussion of Maps

Figures 19 through 30 present precipitation-frequency maps for Oregon for 6- and 24-hr durations for return periods of 2, 5, 10, 25, 50, and 100 yrs. The isopluvial maps represent the 360- and 1,440-min durations for the partial-duration series. Data were tabulated for clock and observation-day intervals for the annual series and were adjusted by the empirical factors given in the ANALYSIS section.

Isoline Interval. The isoline intervals selected were designed to provide a reasonably complete description of the isopluvial pattern in various regions of the state. For that portion of Oregon that extends from the eastern foothills of the Cascade Range westward to the coast, the isoline interval for the 24-hr duration is 0.5 in. for precipitation-frequency values below 8.0 in., with an interval of 1.0 in. above that value at the 2- and 5-yr return period. For the 10- through 100-yr return period, the 7-0-in. precipitation-frequency value separates the 0.5-in. and 1.0-in. intervals. At the 6-hr duration, the isoline interval in this part of the State is 0.1 in. below a precipitation-frequency value of 1.4 in. and 0.2 in. from 1.4 to 3.0 in. Above 3.0 in., the interval is 0.4 in. for 2- through 25-yr return periods and 0.5 in. for return periods of 50 and 100 yrs. For that portion of the state east of the eastern foothills of the Cascade Range, the isoline interval on the 24-hr precipitation-frequency maps is 0.2 in. for values up to 3.0 in. and 0.4 in. for values over 3.0 in. On the maps for the 6-hr duration, the interval is 0.1 in. for values to 1.6 in. on the 2- to 25-yr return periods and to 1.4 in. at the 50- and 100-yr return periods. From 1.6 in. (or 1.4 in. for the 50- and 100-yr maps) to 3.0 in., the isoline interval is 0.2 in. and above 3.0 in. the interval is 0.4 in. Dashed intermediate lines have been placed between widely separated isolines and in regions where a linear interpolation between the normal isopluvial interval would lead to erroneous interpolation. "Lows" that close within the boundaries of a particular map have been hatched on the low-valued side of the isoline.

Importance of snow in precipitation-frequency values. The maps in this Atlas represent frequency values of precipitation regardless of type. For many hydrologic purposes, precipitation falling as rain must be treated in a different manner from that falling as snow. The contribution of snow amounts to precipitation-frequency values in Oregon and the Pacific Northwest (roughly Idaho, Oregon, Washington, and small adjacent portions of California and Nevada) was investigated. In this area, there were 179 stations having 10 to 15 yrs of observations of snowfall as part of the precipitation observing program. Sixty-two of these stations are in Oregon. Table 11 shows the distribution of these stations by regions considered to be more meteorologically realistic than are state boundaries. For each of the 179 stations (56 of which were equipped with recording precipitation gages), two data series were formed as discussed under Interpretation of Results, Importance of Snow in Estimating Frequency Values.

A ratio was formed of the 2-yr 24-hr value for the series containing maximum annual events without regard to type of precipitation and the 2-yr 24-hr value for the series with snow occurrences eliminated. At more than 75 percent of the stations in the Pacific Northwest, this ratio showed differences between the two series to be 10 percent or less. A similar ratio for the 25-yr return period showed a difference as great as 10 percent at only about 5 percent of the stations. Further analysis was made for stations having ratios that showed the greatest difference between the two series.

Data from stations in the coastal plains region of Washington and Oregon (Region 31, fig. 9) showed that the maximum annual 24-hr event can contain snow, but such a case occurs only about 5 percent of the time. Less than half the stations within this region had any maximum annual event that included snow, and ratios for all durations and stations showed less than 10 percent difference between the two data series. Thus, snow was not considered to be of importance to precipitation-frequency values in this region.

Most of the mountainous portions of Oregon are included within Regions 13 and 14 of figure 9. In these regions, it is not unusual for the maximum annual event to include some snow or even to be composed of all or mostly snow. However, the areas where such events cause major differences between the series of all precipitation data regardless of type and the series composed exclusively of rain are relatively limited in extent. These areas are at the higher elevations of the Cascades and immediately to the lee of the crest of the Cascades. In this area of Washington and Oregon, data are available from about 20 stations ranging in elevation from 2,000 ft to over 6,500 ft. These data indicate that the 2-yr 24-hr values for a series containing only rain events would be 10 to 20 percent lower than the values presented on the precipitation-frequency maps in this Atlas at elevations of 2,000 to 4,000 ft, and the differences would range upward to 30 and possibly as much as 50 percent lower above 5,000 ft. The area to the lee of the crest of the Cascades would be limited to somewhat less than 50 mi in width; and in this narrow band, the rain-only series would be from 20 to as much as 35 percent less than the values presented on the 2-yr 24-hr map for Oregon.

Data from stations in the nonorographic regions east of the Cascades (Region 32, fig. 9) show snow to be of minor importance in the precipitation-frequency regime. Less than one maximum annual value out of every five will contain any snow, and 80 percent of the stations available for analysis showed differences of less than 10 percent in the two series of data tabulated.

The remainder of Oregon is included within Region 12, figure 9. Most of this region lies in Idaho. Analysis of the data for this region leads to the conclusion that snow is not an important factor in the precipitation-frequency regime. Ratios between 2-yr 24-hr values from the two series of data that were tabulated showed differences between the two series to be mostly small. It was found that maximum annual values that contained snow were most likely to be found in the lower two-thirds of the ranked data sample. This is discussed in more detail in NOAA Atlas 2, "Precipitation-Frequency Atlas of Western United States, Volume V—Idaho" (National Oceanic and Atmospheric Administration 1973).

The data analysis of the two series showed that the curves converge with increasing return period. At the 25-yr return period, only about 5 percent of the 179 stations showed differences greater than 10 percent between the two series. These stations were not concentrated in any region and did not show a geographic pattern. Generally, such differences result when one or a few of the larger values in the data series composed of all maximum annual events contains some snow, while the rain-only amount for that year is small and becomes a much lower ranked value in the exclusively rain series.

At the 6-hr duration, the data are restricted to stations with recording gages (12 recording precipitation-gage stations in Oregon). An analysis similar to that for the 24-hr duration showed that the ratio of the maximum annual series and the series without snow was lower at the 6-hr duration than at the 24-hr duration. This is meteorologically realistic since the portion of a 24-hr storm that contains snow is most likely to be of less intensity than is the maximum 6-hr period of that storm.

The conclusion was made that, except as previously noted, the elimination of amounts containing snow does not materially change the precipitation-frequency values on maps for Oregon. For the 24-hr duration where there are differences between results computed from the two series at the 2-yr return period, the differences would decrease to no more than half as large at the 25-yr recurrence interval and be negligible at the 100-yr recurrence interval.

In the selection of data for the series made up of amounts containing rain only, an observation was eliminated no matter how much snow was reported. Thus, an eliminated amount could have contained only a small portion of the precipitation as snow or it could have been all snow. In some cases, the amount of rain in a storm with little snow could have been greater than the value actually selected for that year since only a few stations report water content of snow (which would have enabled the tabulator to segregate such cases). Thus, the data could yield rain-only values actually less than the true amount but could not give results greater than the true amount. Therefore, the ratios compared tended to show maximum differences.

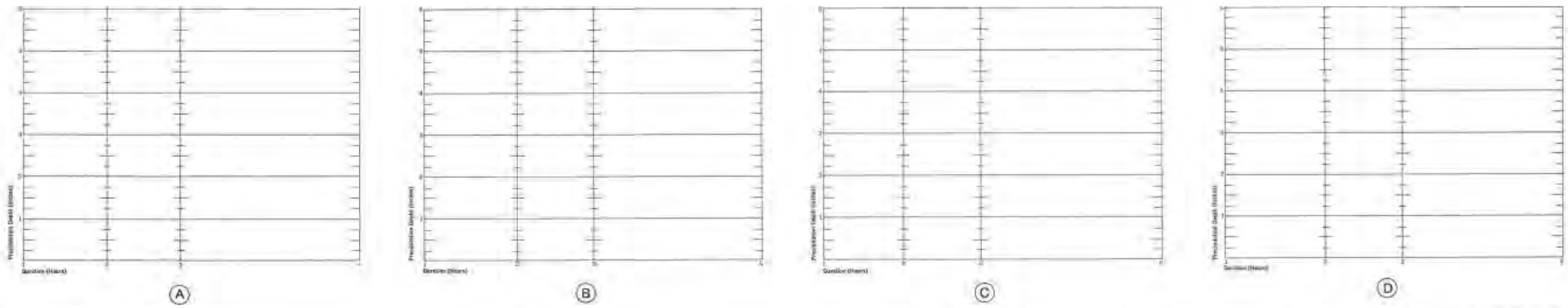


Figure 15. *Precipitation depth-duration diagram (1- to 6-hr).*
a. Mountainous regions of Washington and Oregon east of crest of Cascade Range and of Idaho and Montana west of Continental Divide and north of southern boundary of Snake River Basin (Region 1, fig. 18).
b. Nonorographic region east of crest of Cascade Range (Region 2, fig. 18).
c. Coastal plains, Puget Sound region, and Willamette Valley below 1,000 ft (Region 3, fig. 18). Olympic Mountains, western slopes of Cascade and Coast Ranges (Region 4 fig. 18).
d. Southeastern Oregon drained by the Quinn River (Region 5, fig. 18).

Exhibit D-4

Procedures for Estimating Values for Durations Other Than 6 and 24 Hrs

The isopluvial maps in this Atlas are for 6- and 24-hr durations. For many hydrologic purposes, values for other durations are necessary. Such values can be estimated using the 6- and 24-hr maps and the empirical methods outlined in the following sections. The procedures detailed below for obtaining 1-, 2-, and 3-hr estimates were developed specifically for this Atlas. The procedures for obtaining estimates for less than 1-hr duration and for 12-hr duration were adopted from *Weather Bureau Technical Paper* No. 40 (U.S. Weather Bureau 1961) only after investigation demonstrated their applicability to data from the area covered by this Atlas.

Procedures for estimating 1-hr (60-min) precipitation-frequency values. Multiple-regression screening techniques were used to develop equations for estimating 1-hr values. Factors considered in the screening process were restricted to those that could be determined easily from the maps of this Atlas or from generally available topographic maps.

The 11 western states were separated into several geographic regions. The regions were chosen on the basis of meteorological and climatological homogeneity and are generally combinations of river basins separated by prominent divides. Five of these geographic regions are partially within Oregon. For convenience and use as an overlay on the precipitation-frequency maps, the regions are outlined on figure 18. The first region includes the mountainous sections of eastern Oregon east of the crest of the Cascades (Region 1, fig. 18). This is part of a larger region that includes all the mountainous sections from the crest of the Cascades eastward to the Continental Divide and north of the southern boundary of the Snake River Basin. Region 2, figure 18, is the essentially nonorographic portions of eastern Oregon. There are three such nonorographic regions between the crest of the Cascades and the Continental Divide found to have similar relations between data for 1-, 6-, and 24-hr durations. One of these is completely within Oregon, whereas the other two extend partially into Oregon from Washington and Idaho. The coastal lowlands and nonorographic sections of western Washington and Oregon below 1,000-ft elevation make up another region (Region 3, fig. 18). This includes the Willamette Valley below 1,000 ft. The fourth region consists of the western slopes of the Cascade and the Coast Ranges of Oregon (Region 4, fig. 18). This region extends into Washington, where it also includes the Olympic Mountains. Region 5, figure 18, in southeastern Oregon is a small portion of a region that extends from central Utah through Nevada and into the desert regions of California. In Oregon, this is the area drained by the Quinn River. Equations to provide estimates for the 1-hr duration for the 2- and 100-yr return periods are shown in table 12. Also listed are the statistical parameters associated with each equation. The variable $[(X_1)(X_1/X_2)]$ or $[X_3)(X_3/X_4)]$ can be regarded as the 6-hr value times the slope of a line connecting the 6- and 24-hr values for the appropriate return period. The variable Y_2 appears in the right side of the 100-yr 1-hr equations for Regions 3 and 4. If the 2-yr 1-hr value is not required, the equation for Y_2 can be substituted and the second equation for Y_{100} shown in table 12 can be used.

Table 11. *Percent of snowfall stations in Pacific Northwest by regions*

Number of region in figure 9	Region	Percent of stations
12	Mountainous region of Idaho west of Bitterroot Range crest and Continental Divide and north of southern boundary of Snake River Basin—excluding Snake River Valley below a generalized 5,000-ft contour	30
13	Orographic region east of crest of Cascade Range and west of Snake River Basin	20
14	Olympic Mountains and western slopes of Coast and Cascade Ranges	14
30	Snake River Valley below 5,000 ft	13
31	Coastal Plain, Puget Sound region, and Willamette Valley below 1,000 ft	12
32	Nonorographic region east of crest of Cascade Range	11

As with any separation into regions, the boundary can only be regarded as the sharpest portion of a zone of transition between regions. These equations have been tested for boundary discontinuities by computing values using equations from both sides of the boundary. Differences were found to be mostly under 15 percent. However, it is suggested that when computing estimates along or within a few miles of a regional boundary computations be made using equations applicable to each region and that the average of such computations be adopted.

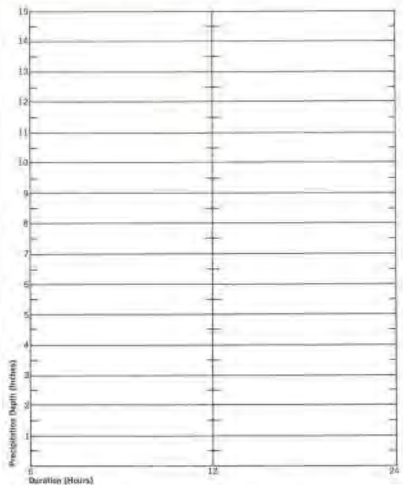


Figure 16. *Precipitation depth-duration diagram (6- to 24-hr).*

Estimates of 1-hr precipitation-frequency values for return periods between 2 and 100 yrs. The 1-hr values for the 2- and 100-yr return periods can be plotted on the nomogram of figure 6 to obtain values for return periods greater than 2 yrs or less than 100 yrs. Draw a straight line connecting the 2- and 100-yr values and read the desired return-period value from the nomogram.

Estimates for 2- and 3-hr (120- and 180-min) precipitation-frequency values. To obtain estimates of precipitation-frequency values for 2 or 3 hrs, plot the 1- and 6-hr values from the Atlas on the appropriate nomogram of figure 15. Draw a straight line connecting the 1- and 6-hr values, and read the 2- and 3-hr values from the nomogram. This nomogram is independent of return period. It was developed using data from the same regions used to develop the 1-hr equations.

The mathematical solution from the data used to develop figure 15 gives the following equations for estimating the 2- and 3-hr values:

For Region 1,	2-hr = 0.250 (6-hr) + 0.750 (1-hr)	(3)
figure 18	3-hr = 0.467 (6-hr) + 0.533 (1-hr)	(4)
For Region 2,	2-hr = 0.278 (6-hr) + 0.722 (1-hr)	(5)
figure 18	3-hr = 0.503 (6-hr) + 0.497 (1-hr)	(6)
For Regions 3	2-hr = 0.240 (6-hr) + 0.760 (1-hr)	(7)
and 4, figure 18	3-hr = 0.468 (6-hr) + 0.532 (1-hr)	(8)
For Region 5,	2-hr = 0.299 (6-hr) + 0.701 (1-hr)	(9)
figure 18	3-hr = 0.526 (6-hr) + 0.476 (1-hr)	(10)

Estimates for 12-hr (720-min) precipitation-frequency values. To obtain estimates for the 12-hr duration, plot values from the 6- and 24-hr maps on figure 16. Read the 12-hr estimates at the intersection of the line connecting these points with the 12-hr duration line of the nomogram.

Estimates for less than 1 hr. To obtain estimates for durations of less than 1 hr, apply the values in table 13 to the 1-hr value for the return period of interest.

Illustration of Use of Precipitation-Frequency Maps, Diagrams, and Equations

To illustrate the use of these maps, values were read from figures 19 to 30 for the point at 44°00′ N. and 118°00′ W. These values are shown in boldface type in table 14. The values read from the maps should be plotted on the return-period diagram of figure 6 because (1) not all points are as easy to locate on a series of maps as are latitude-longitude intersections, (2) there may be some slight registration differences in printing, and (3) precise interpolation between isolines is difficult. This has been done for the 24-hr values in table 14 (fig. 17a) and a line of best fit has been drawn subjectively. On this nomogram, the 2- and 25-yr values appear to be somewhat off the line. The value read from the maps is corrected (as shown by the strikeout in table 14); such corrected values are adopted in preference to the original readings.

The 2- and 100-yr 1-hr values for the point were computed from the equations applicable to Region 2, figure 18 (table 12) since the point is in the nonorographic region. The 2-yr 1-hr is estimated at 0.37 in. (latitude of 44° and longitude of 118° and the 2-yr 6- and 24-hr values from table 14); the estimated 100-yr 1-hr value is 1.07 in. (100-yr 6- and 24-hr values from table 14). By plotting these 1-hr values on figure 6 and connecting them with a straight line, one can obtain estimates for return periods of 5, 10, 25, and 50 yrs.

The 2- and 3-hr values can be estimated by using the proper nomogram of figure 15 or equations (5) and (6). The 1- and 6-hr values for the desired return period are obtained as above. Plot these points on the nomogram in figure 15 and connect them with a straight line. Read the estimates for 2 or 3 hrs at the intersections of the connecting line and the 2- and 3-hr vertical lines. An example is shown in figure 17b for the 2-yr return period. The 2-yr 2-hr (0.50 in.) and 2-yr 3-hr (0.55 in.) values are in italics in table 14 and compare closely with the values of 0.47 and 0.57, which would result from application of equations (5) and (6).

Table 12. *Equations for estimating 1-hr values in Oregon with statistical parameters for each equation*

Region of applicability*	Equation	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Mountainous regions of Washington and Oregon east of crest of Cascade Range and of Idaho and Montana west of Continental Divide and north of southern boundary of Snake River Basin (1)	$Y_2 = 0.019 + 0.711[(X_1)(X_1/X_2)] + 0.001Z$	0.82	98	0.40	0.031
	$Y_{100} = 0.338 + 0.670[(X_3)(X_3/X_4)] + 0.001Z$	.80	79	1.04	.141
Nonorographic region east of crest of Cascade Range (2)	$Y_2 = 0.077 + 0.715[(X_1)(X_1/X_2)] - 0.0004(X_5)(X_6)$	.86	30	0.35	.034
	$Y_{100} = 0.187 + 0.833[(X_3)(X_3/X_4)]$	.87	30	1.08	.161
Coastal plains, Puget Sound region, and Willamette Valley below 1,000 ft (3)	$Y_2 = 0.157 + 0.513[(X_1)(X_1/X_2)]$	.89	61	0.52	.050
	$Y_{100} = 0.324 + 0.752[(Y_2)(X_3/X_1)]$	.82	61	1.01	.113
	$Y_{100} = 0.324 + 0.118(X_3/X_1) + 0.386[(X_1)(X_3/X_2)]$				
Olympic Mountains, western slopes of Cascade and Coast Ranges (4)	$Y_2 = 0.160 + 0.520[(X_1)(X_1/X_2)]$	.86	70	0.54	.054
	$Y_{100} = 0.177 + 0.965[(Y_2)(X_3/X_1)]$	.74	66	1.10	.171
	$Y_{100} = 0.177 + 0.154(X_3/X_1) + 0.502[(X_1)(X_3/X_2)]$				
Southeastern Oregon drained by the Quinn River (5)	$Y_2 = 0.005 + 0.852[(X_1)(X_1/X_2)]$	.89	65	0.41	.047
	$Y_{100} = 0.322 + 0.789[(X_3)(X_3/X_4)]$	.87	65	1.25	.196

* Numbers in parentheses refer to geographic regions shown in figure 18. See text for more complete description.

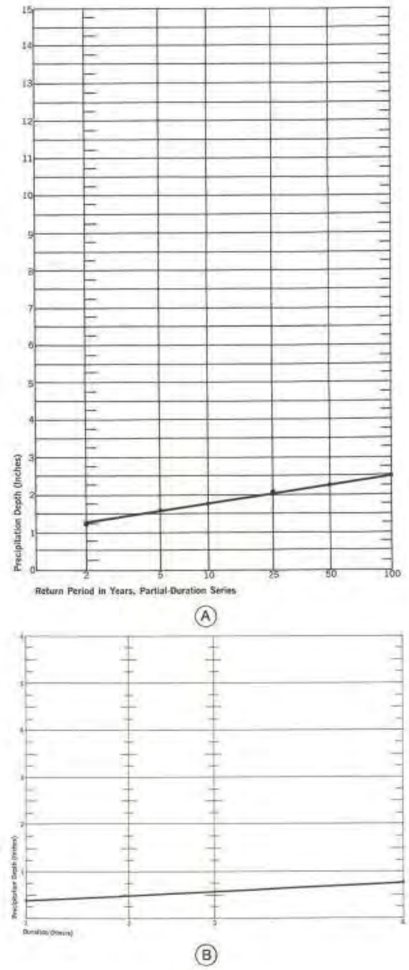
List of variables
- Y_2 = 2-yr 1-hr estimated value
- Y_{100} = 100-yr 1-hr estimated value
- X_1 = 2-yr 6-hr value from precipitation-frequency maps
- X_2 = 2-yr 24-hr value from precipitation-frequency maps
- X_3 = 100-yr 6-hr value from precipitation-frequency maps
- X_4 = 100-yr 24-hr value from precipitation-frequency maps
- X_5 = latitude (in decimals) minus 40°
- X_6 = longitude (in decimals) minus 100°
- Z = point elevation in hundreds of feet

Duration (min)	5	10	15	30
Ratio to 1-hr	0.29	0.45	0.57	0.79

(Adopted from *U.S. Weather Bureau Technical Paper* No. 40, 1961.)

Table 13. *Adjustment factors to obtain n-min estimates from 1-hr values*

Figure 17. *Illustration of use of precipitation-frequency diagrams using values from precipitation-frequency maps and relations.*



	1-hr	2-hr	3-hr	6-hr	24-hr
2-yr	*0.37*	*0.47*	*0.57*	0.74	1.26 ~~1.23~~
5-yr				0.95	1.56
10-yr				1.12	1.75
25-yr				1.34	2.02 ~~2.05~~
50-yr				1.49	2.25
100-yr	*1.07*			1.63	2.50

Table 14. *Precipitation data for depth-frequency atlas computation point 44°00′ N., 118°00′ W.*

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Exhibit D-4

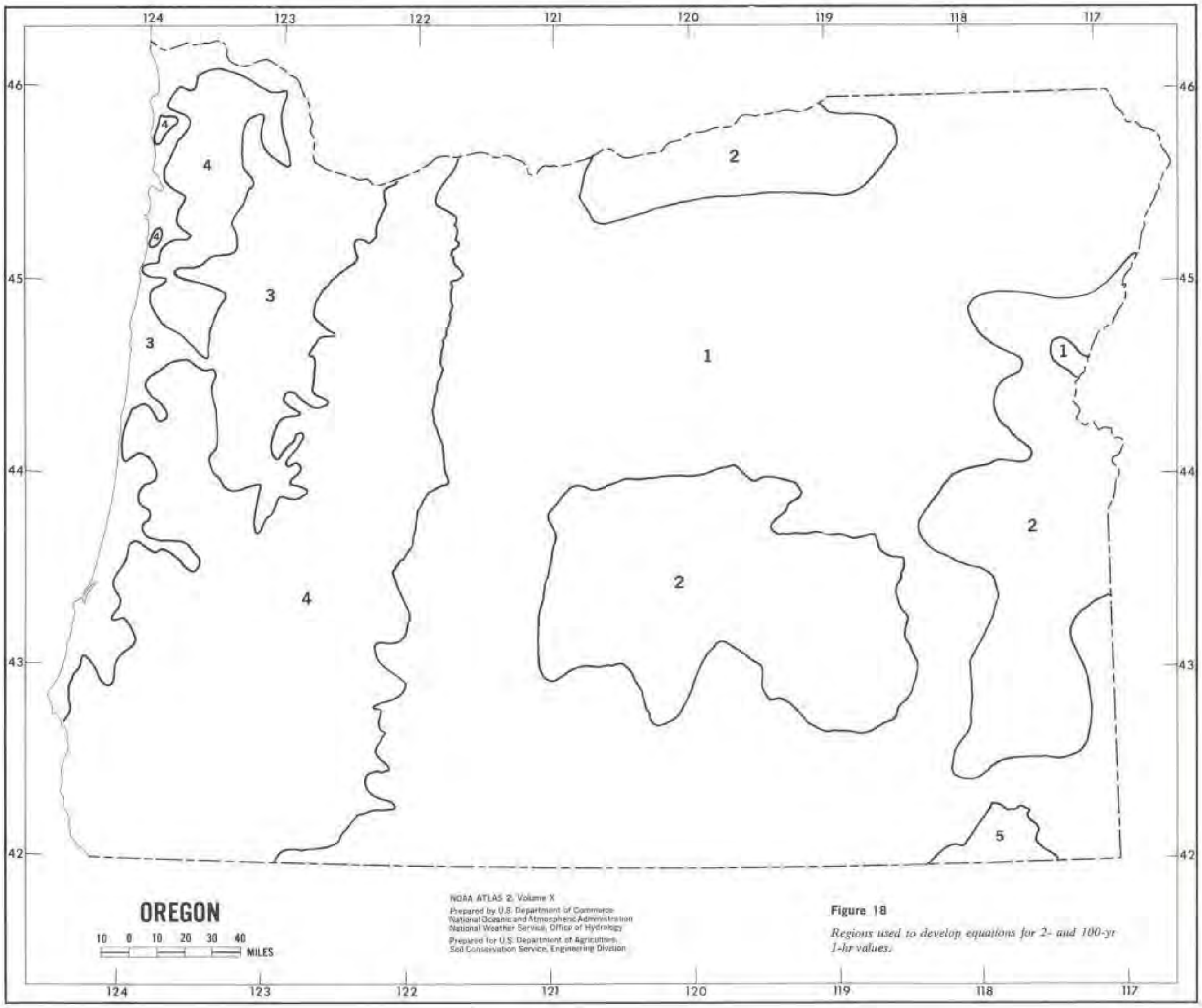

Figure 18

Regions used to develop equations for 2- and 100-yr 1-hr values.

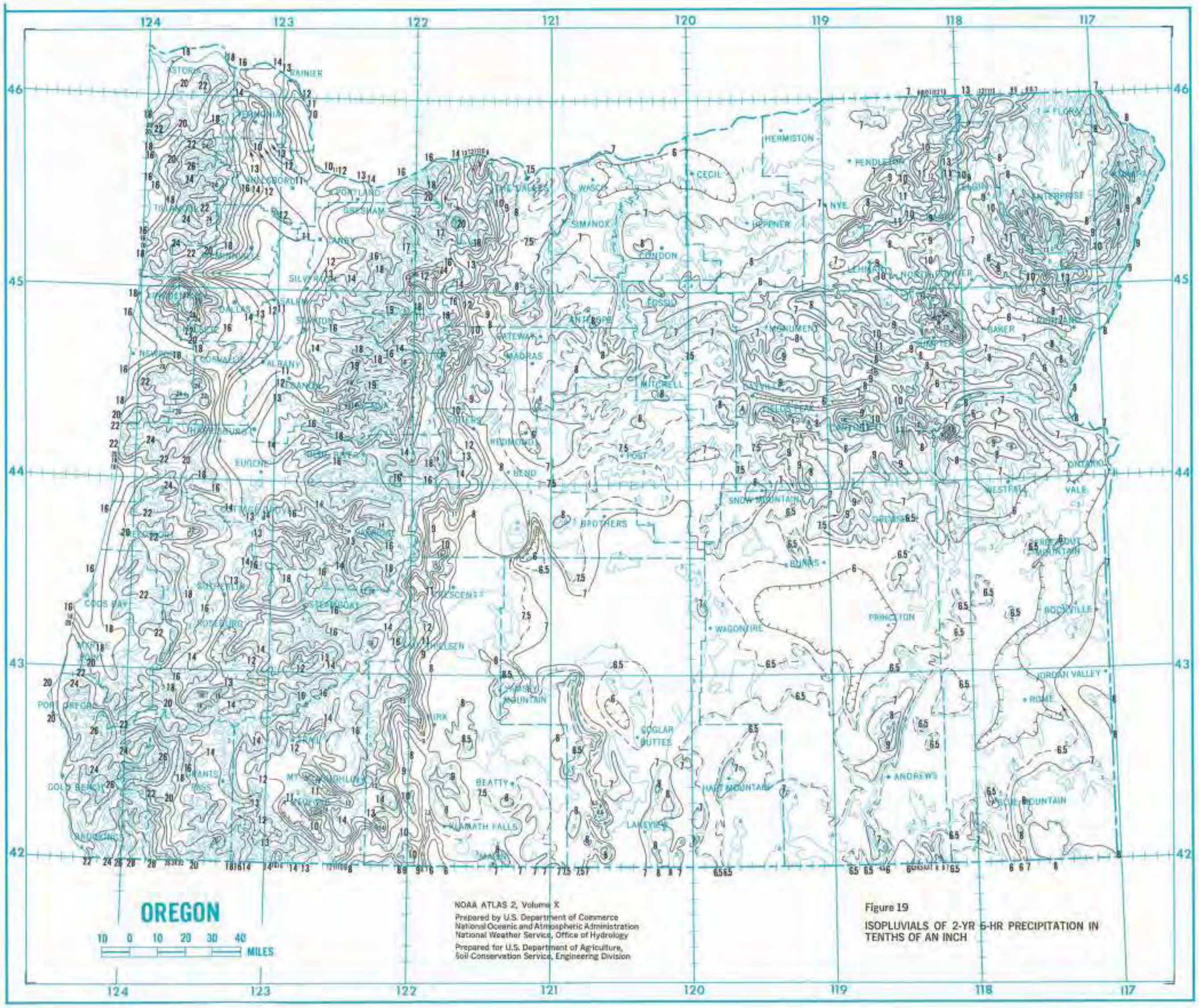

Figure 19

ISOPLUVIALS OF 2-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

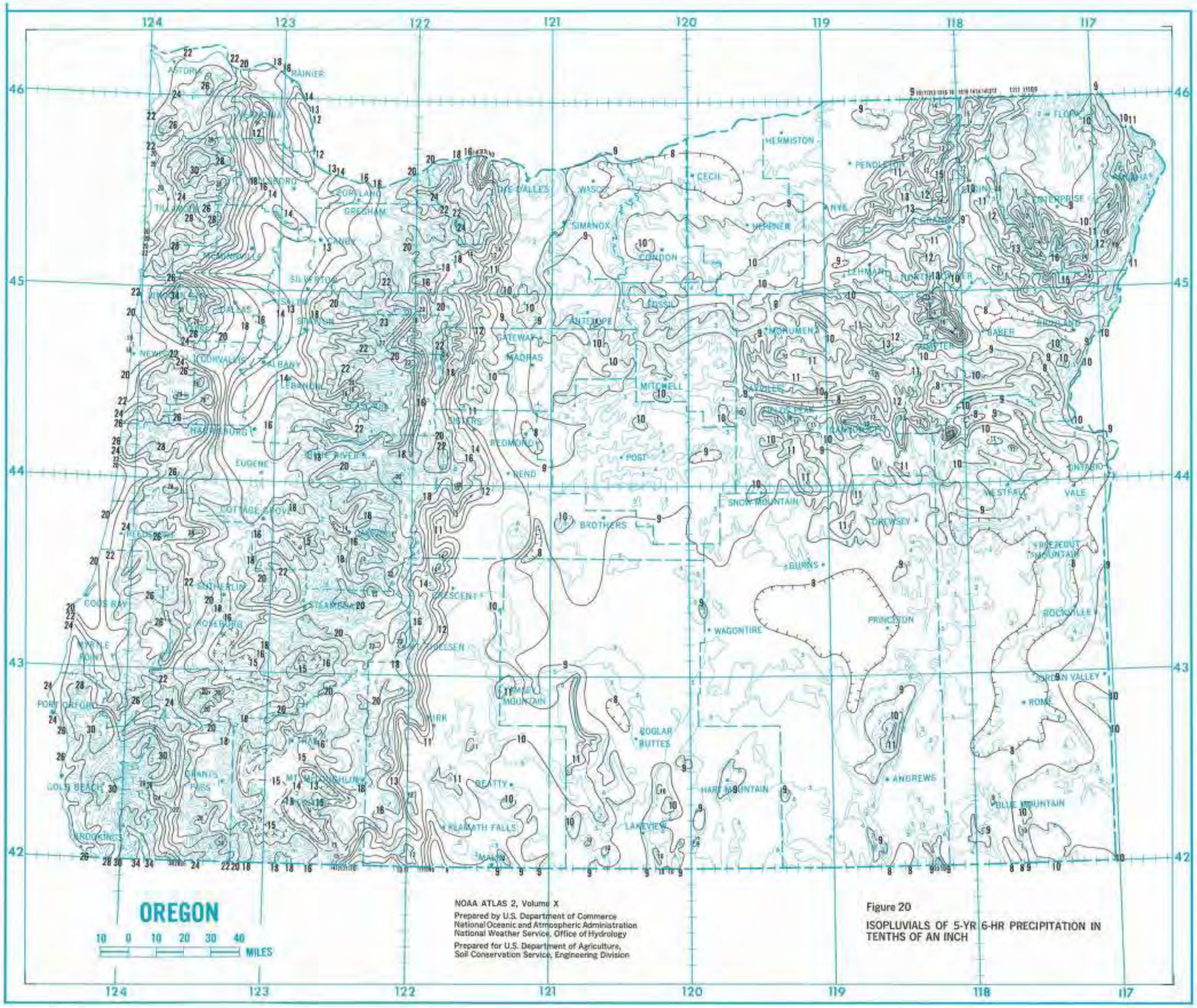

Figure 20

ISOPLUVIALS OF 5-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

23

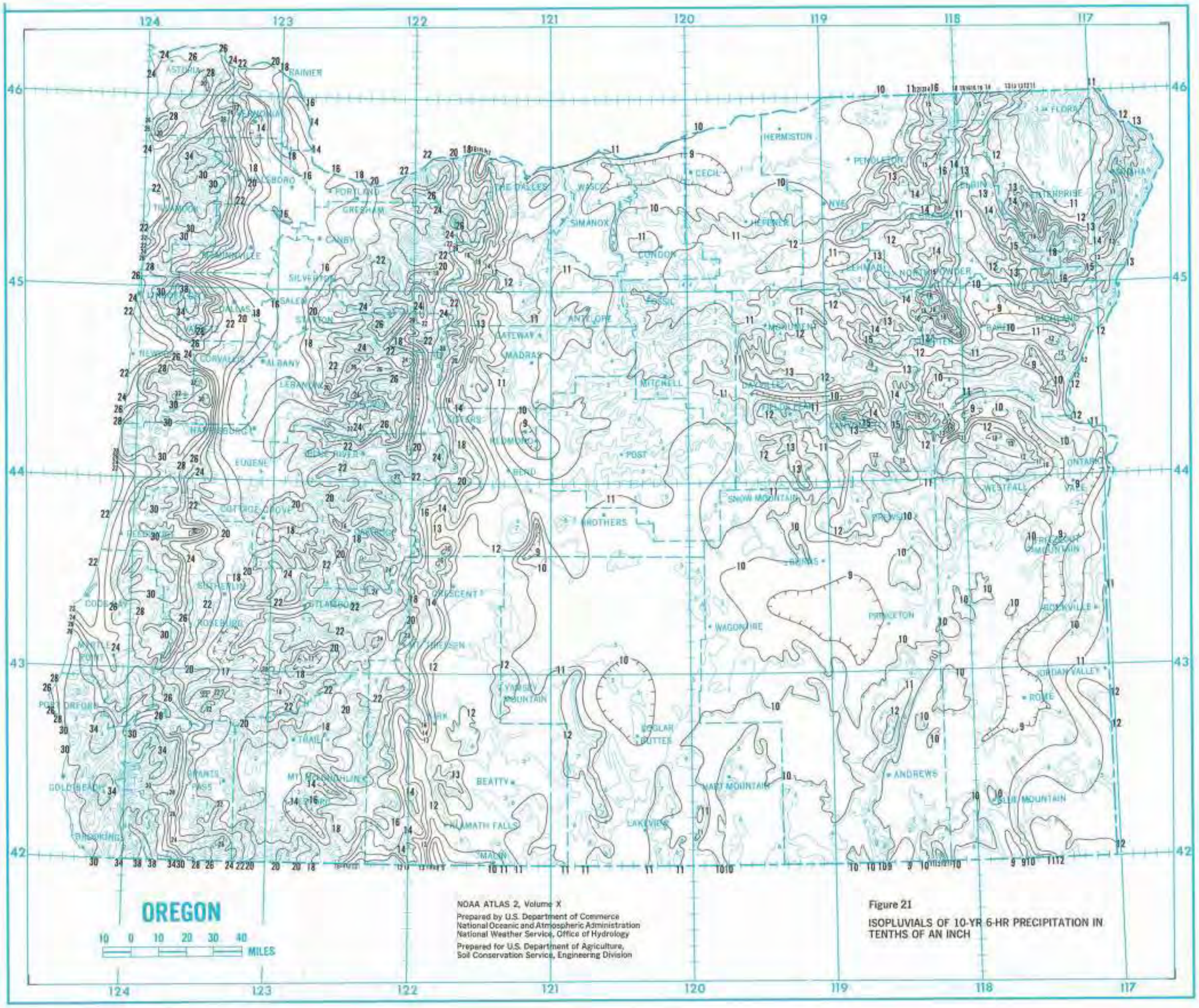

Figure 21

ISOPLUVIALS OF 10-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

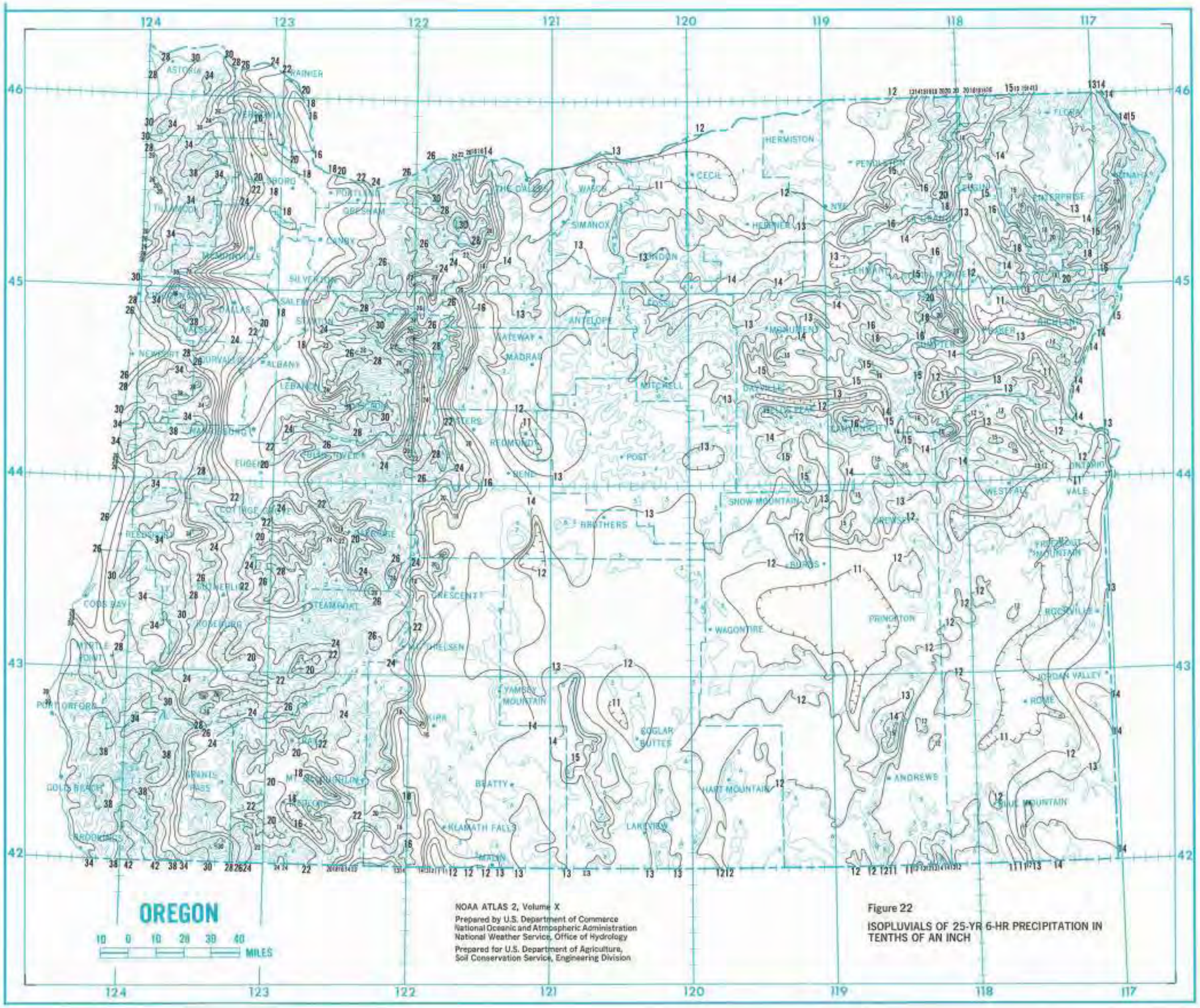

Figure 22

ISOPLUVIALS OF 25-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

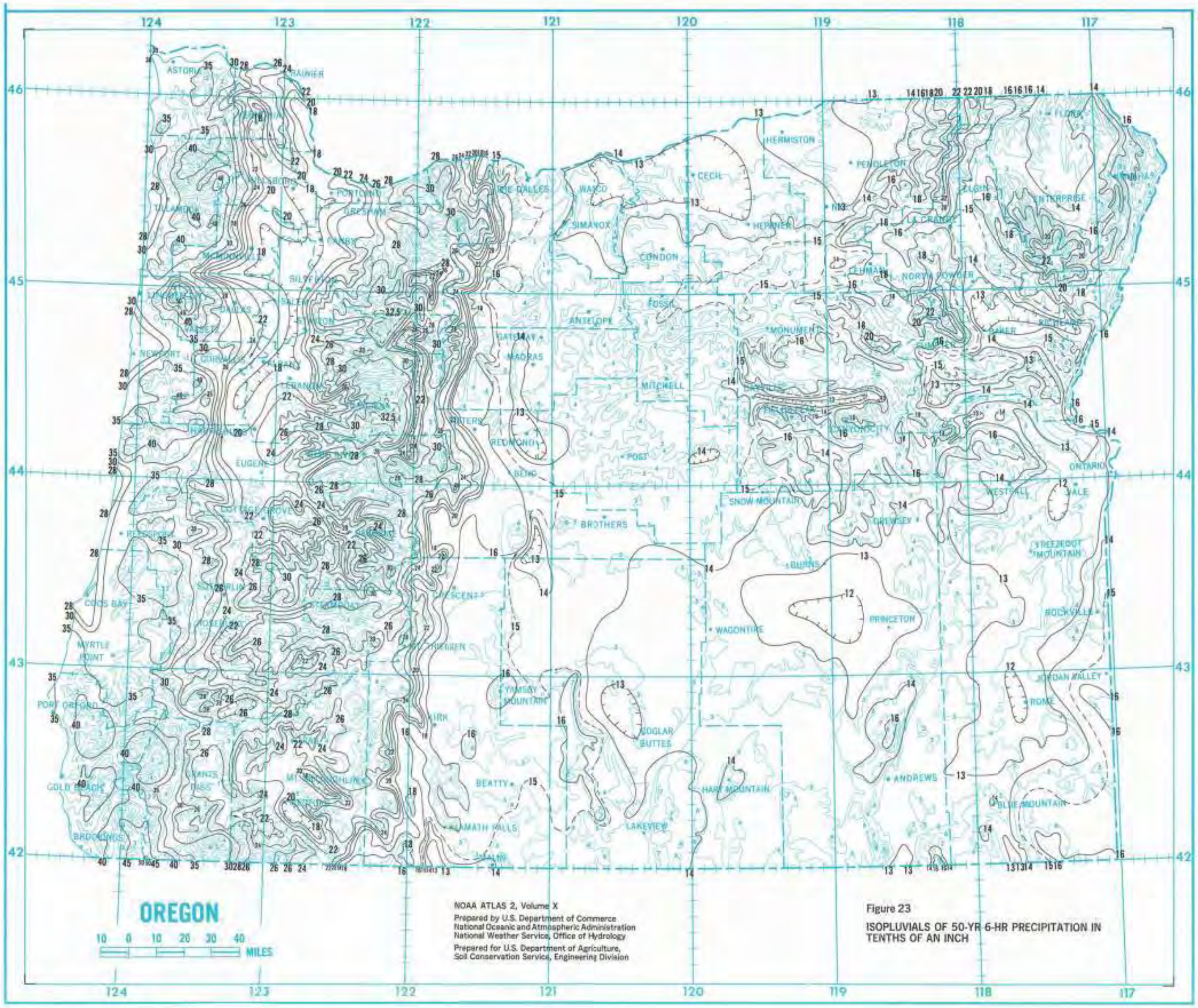

Figure 23
ISOPLUVIALS OF 50-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

29

Exhibit D-4

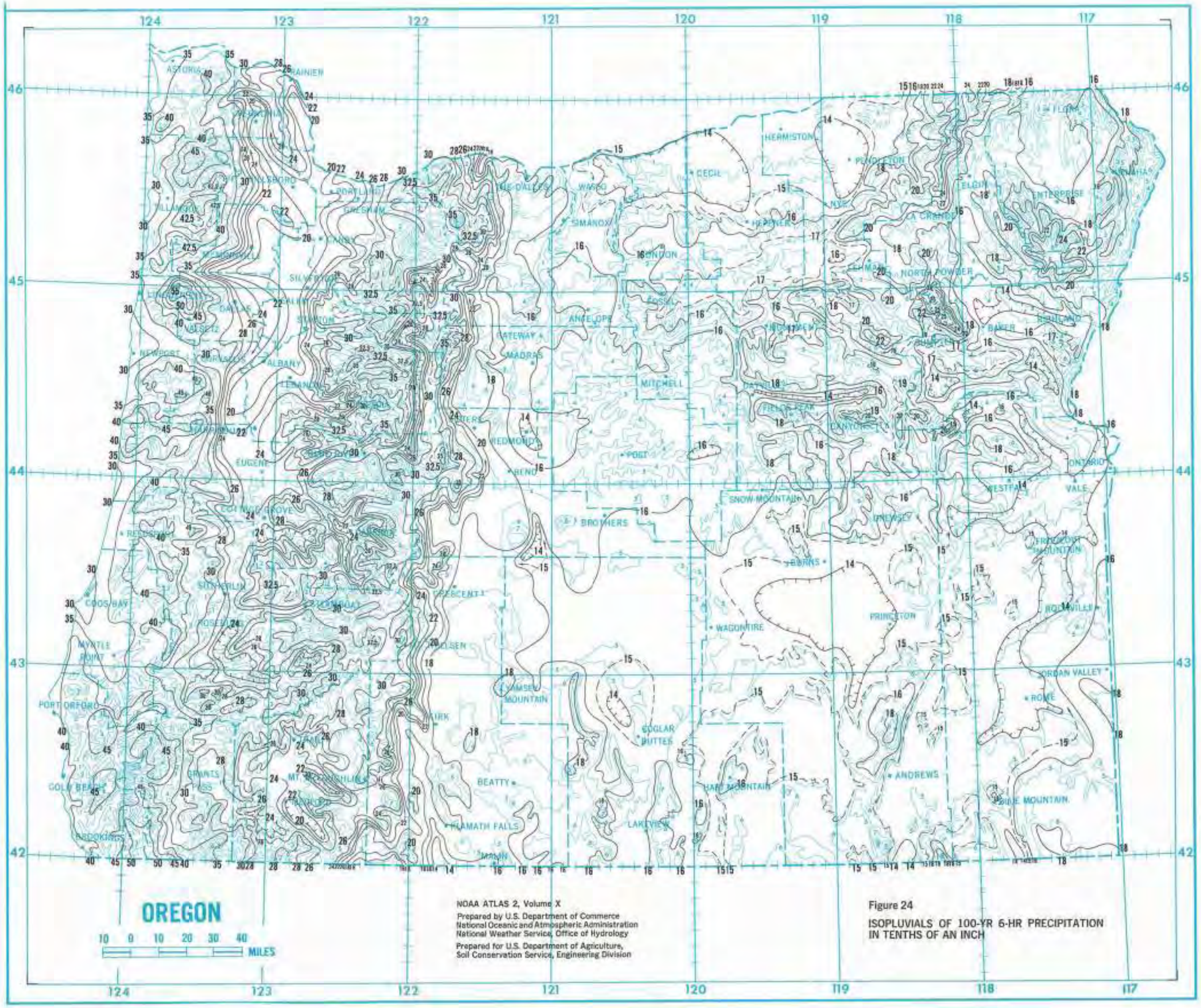

Figure 24

ISOPLUVIALS OF 100-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

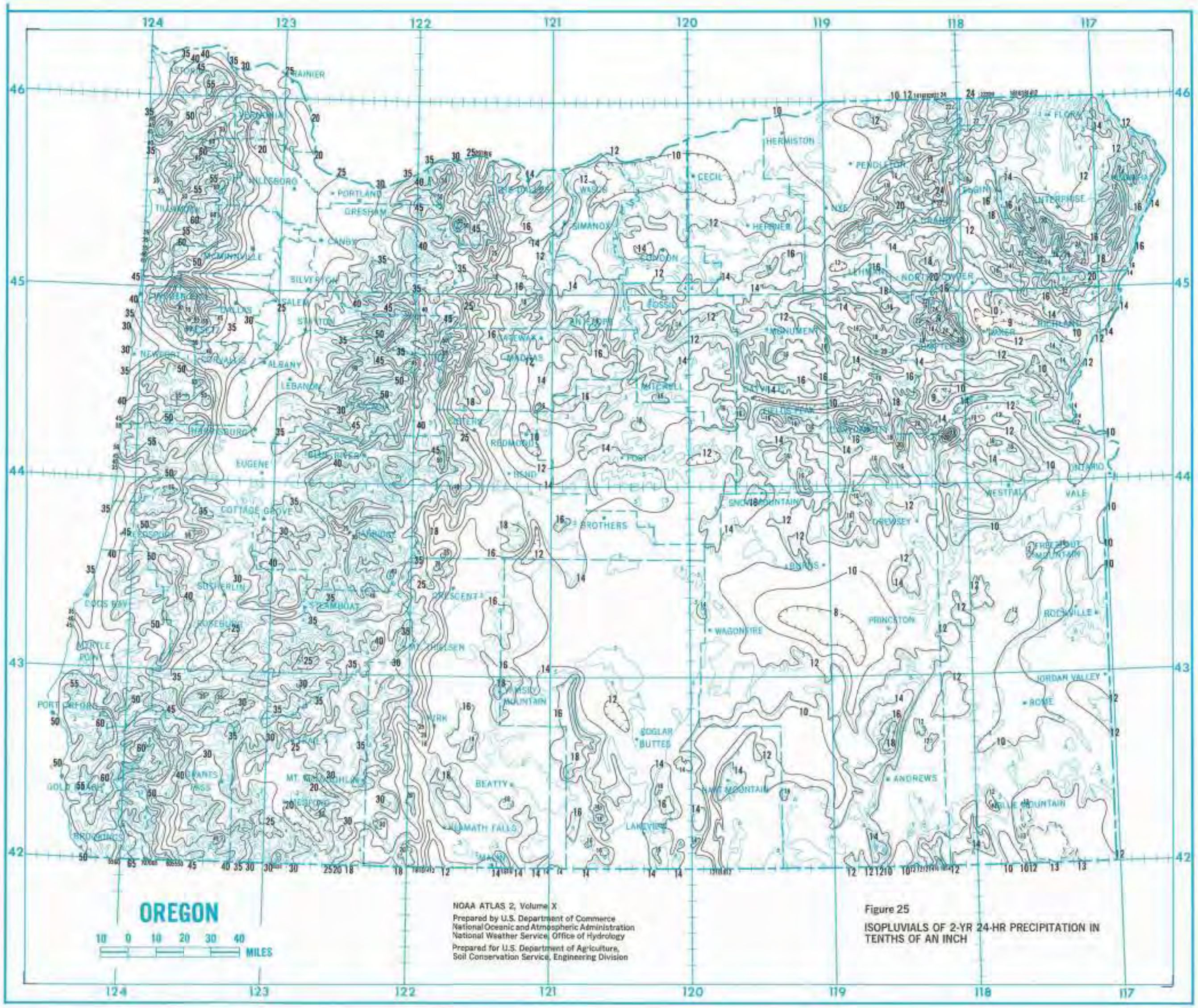

Figure 25

ISOPLUVIALS OF 2-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

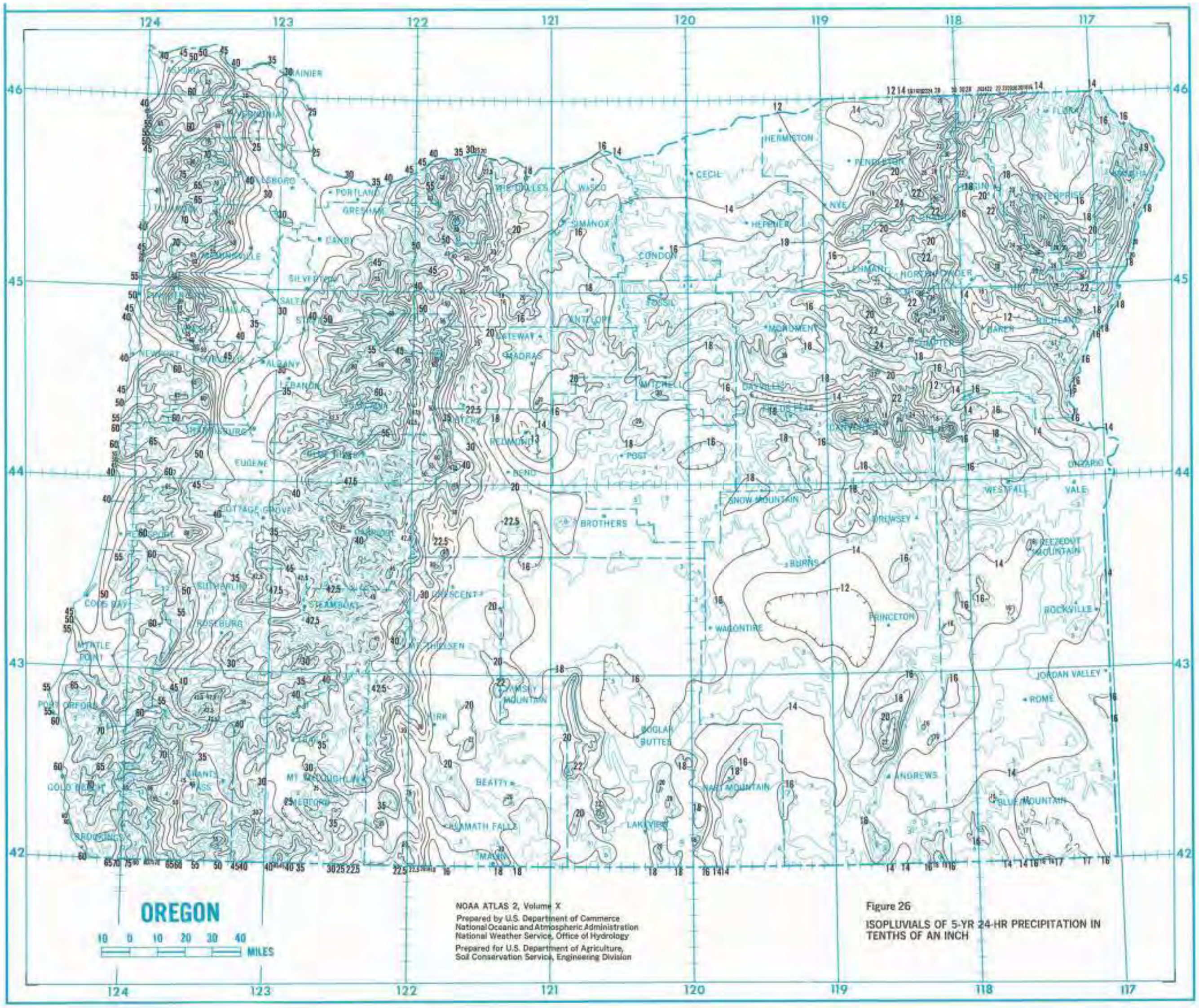

Figure 26

ISOPLUVIALS OF 5-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

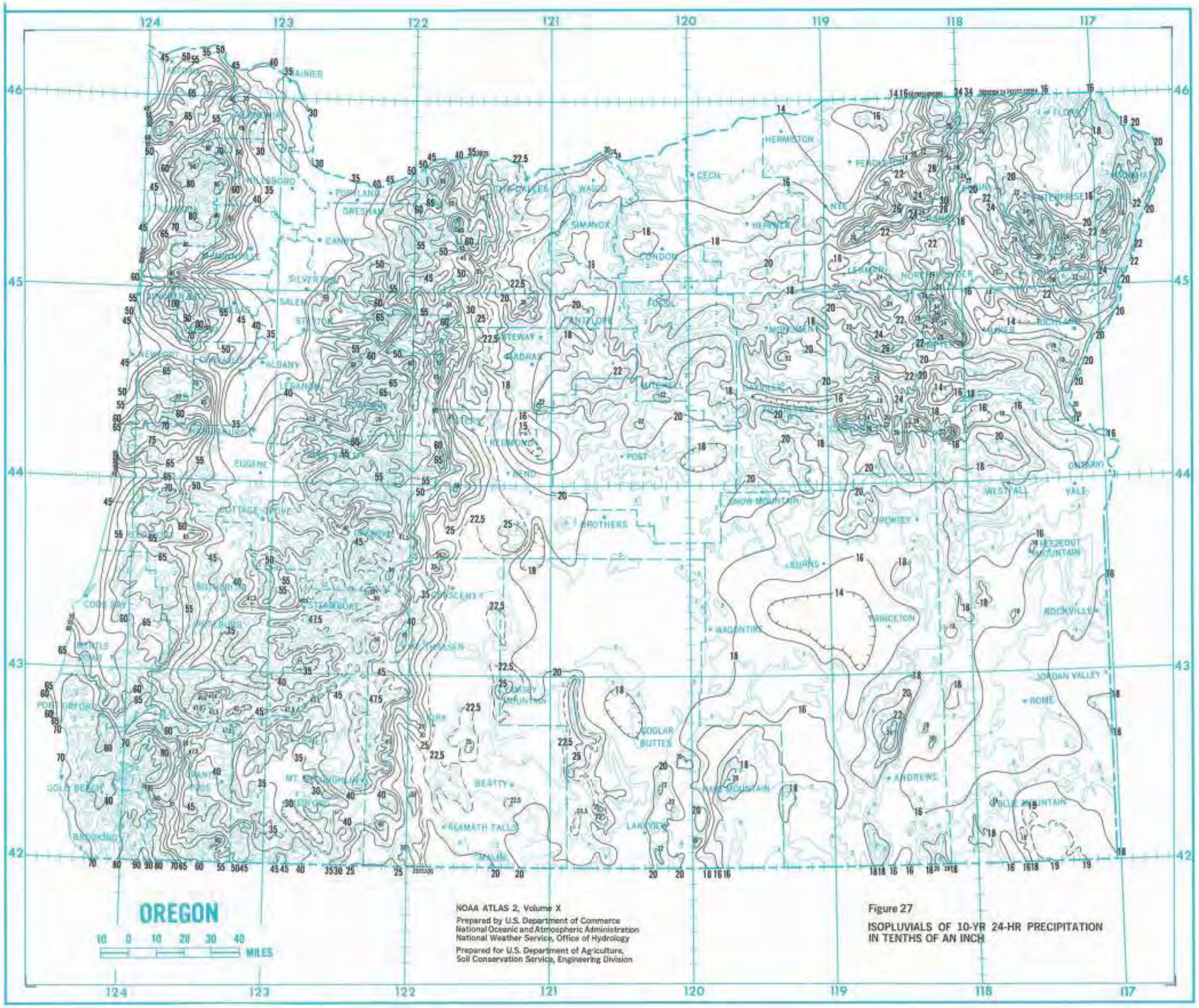

Figure 27

ISOPLUVIALS OF 10-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

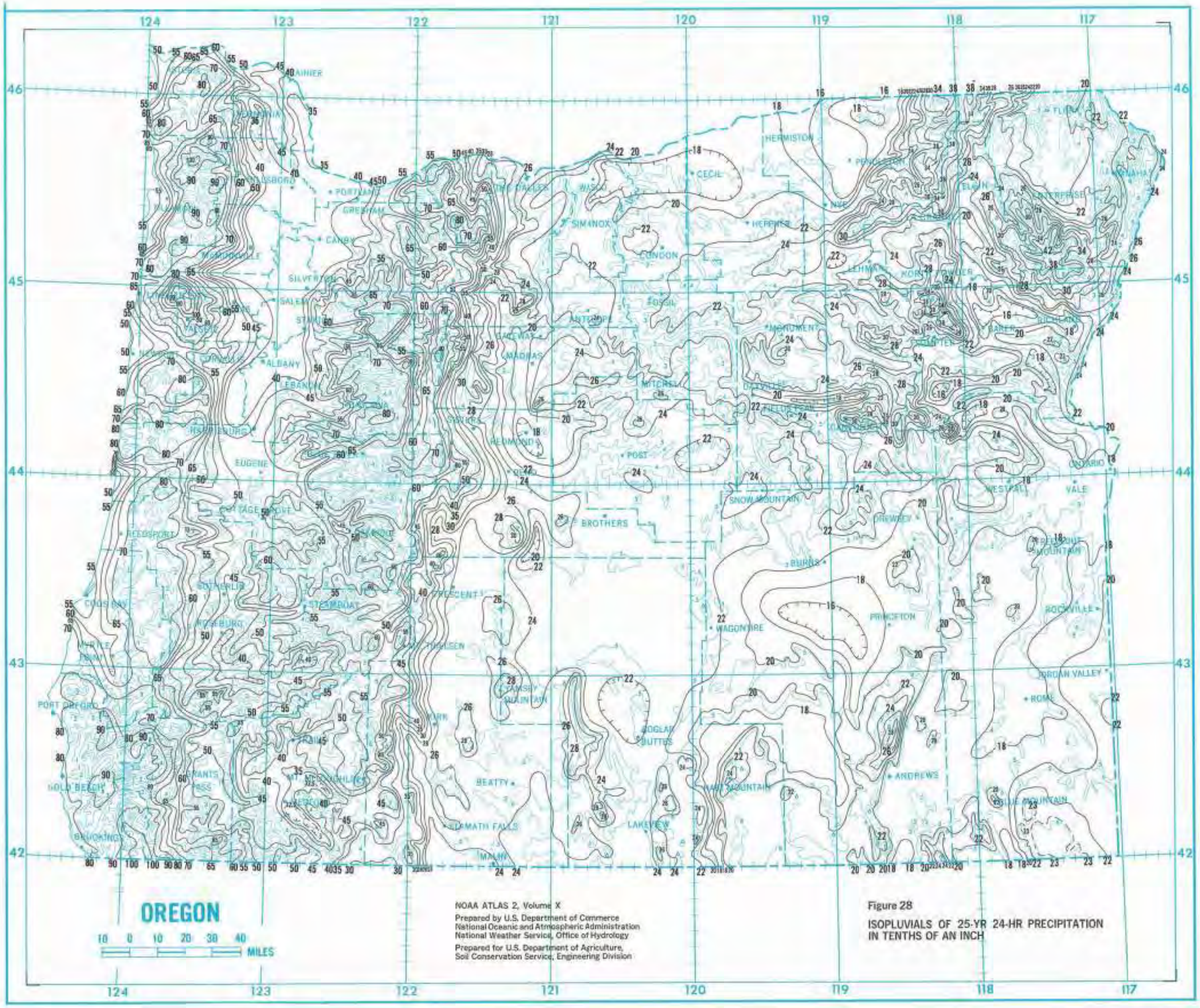

Figure 28

ISOPLUVIALS OF 25-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

39

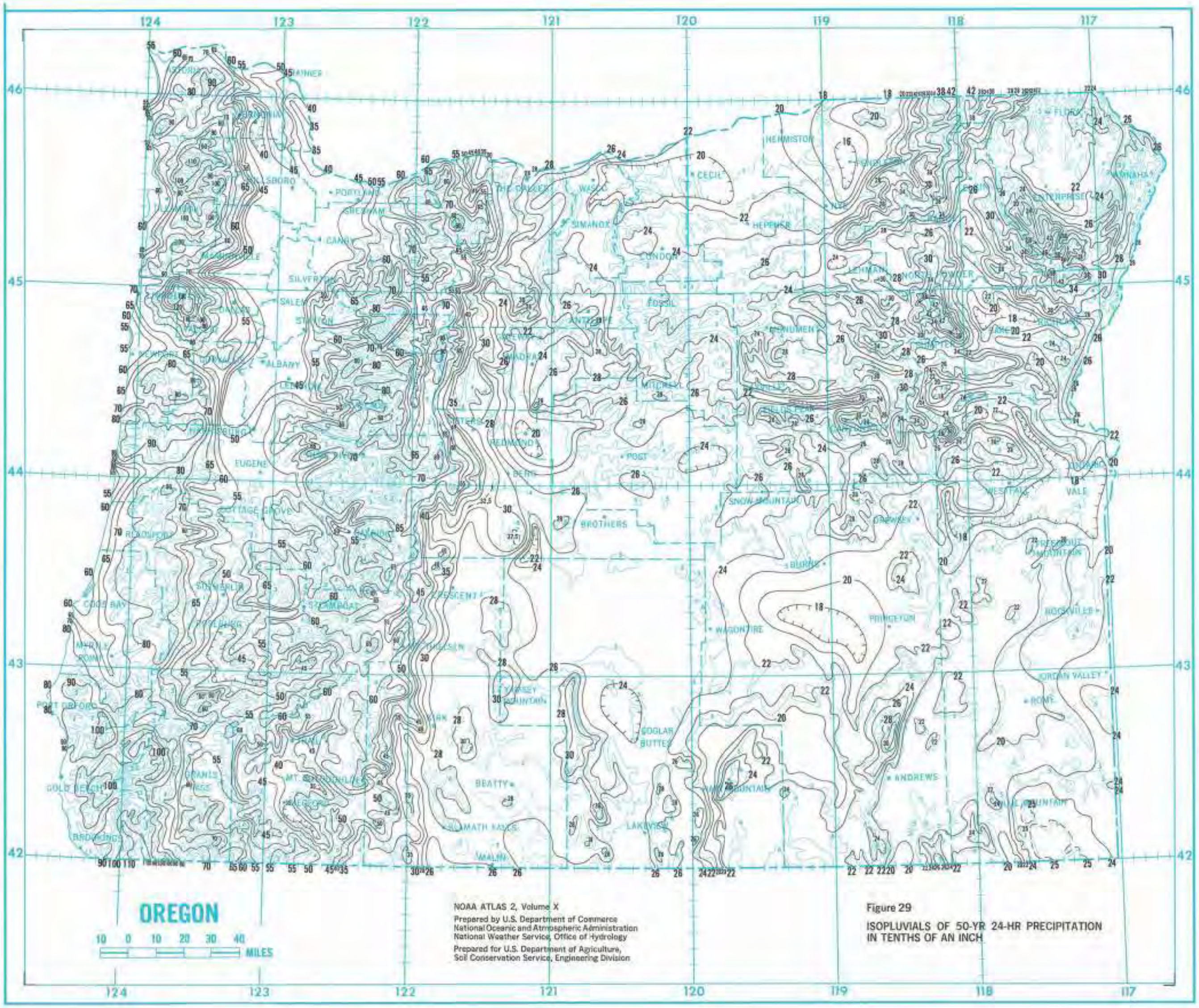

Figure 29

ISOPLUVIALS OF 50-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

41

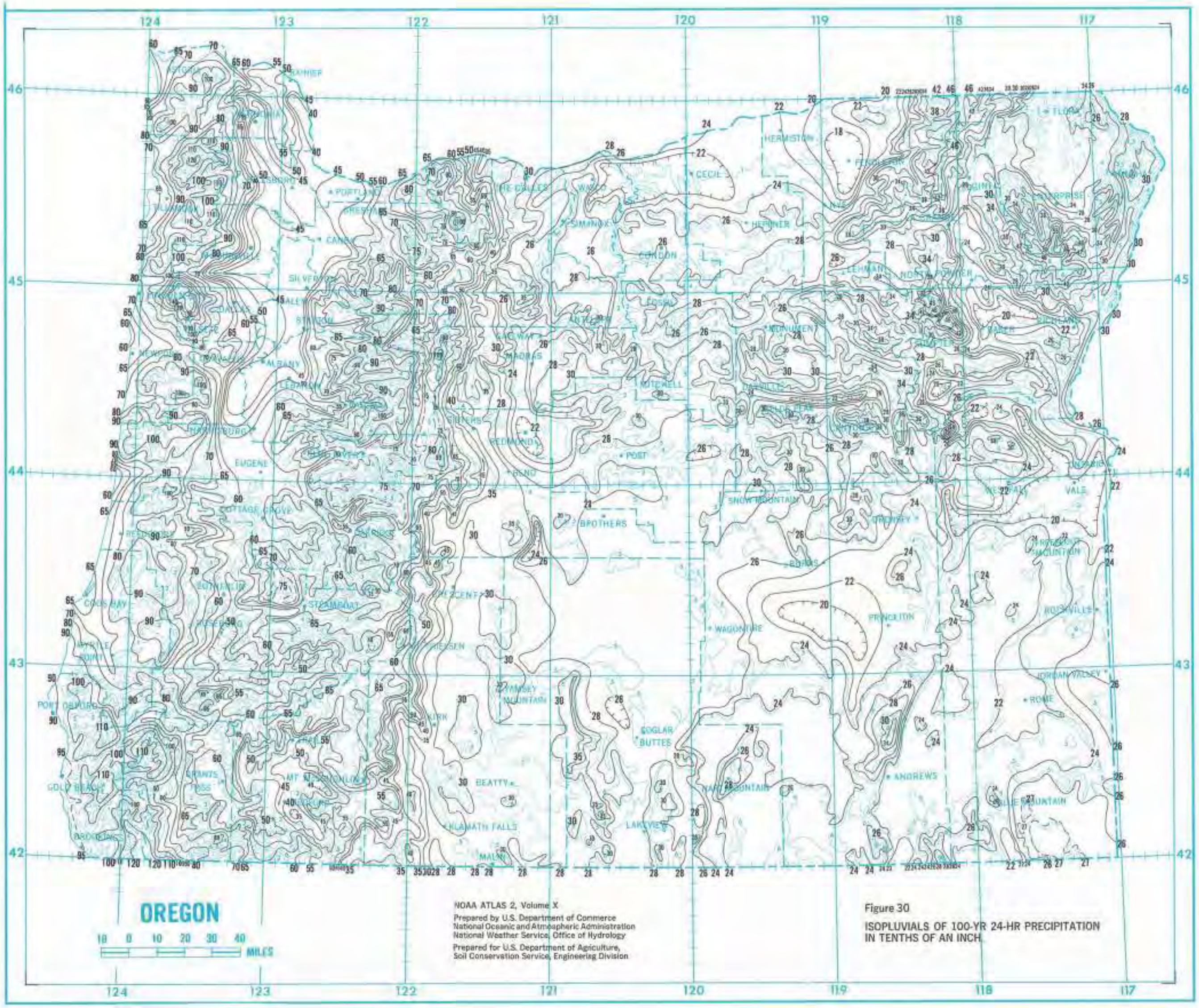

Figure 30

ISOPLUVIALS OF 100-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

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REGIONAL PRECIPITATION-FREQUENCY ANALYSIS AND SPATIAL MAPPING OF 24-HOUR PRECIPITATION FOR OREGON
Final Report

SPR 656

REGIONAL PRECIPITATION-FREQUENCY ANALYSIS AND SPATIAL MAPPING OF 24-HOUR PRECIPITATION FOR OREGON
Final Report

SPR 656

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January 2008

Exhibit D-4

Technical Report Documentation Page

1. Report No. OR-RD-FHWA-08-05	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Regional Precipitation-Frequency Analysis and Spatial Mapping of 24-Hour Precipitation for Oregon		5. Report Date January 2008 6. Performing Organization Code
7. Author(s) MG Schaefer Ph.D. P.E. (MGS Engineering Consultants) BL Barker P.E. (MGS Engineering Consultants) GH Taylor CCM (Oregon Climate Service) JR Wallis Ph.D. (Yale University)		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation Research Unit 200 Hawthorne Ave. SE, Suite B-240 Salem, OR 97301-5192		10. Work Unit No. (TRAIS) 11. Contract or Grant No. SPR 656
12. Sponsoring Agency Name and Address Oregon Department of Transportation Research Unit and Federal Highway Administration 200 Hawthorne Ave. SE, Suite B-240 400 Seventh Street, SW Salem, OR 97301-5192 Washington, DC 20590-0003		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

For this study regional frequency analyses were conducted for precipitation annual maxima in the state of Oregon for the 24-hour duration. A total of 693 precipitation gages in Oregon, southern Washington, western Idaho, northern California and northern Nevada were included in the study, representing 34,062 station-years of record. A regional analysis methodology was utilized that pooled 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.

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. 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 6-month, 2-year, 10-year, 25-year, 50-year, 100-year, 500-year, and 1000-year precipitation recurrence intervals. Electronic gridded datasets are available for use in creation of GIS applications that utilize precipitation-frequency information.

A catalog of extreme storms was assembled that lists precipitation events that exceeded a 20-year return period for the various climatic regions. The information from the storm catalog was also used to conduct seasonality analyses that identified the occurrence frequency 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 in conducting hydrologic analyses throughout the Oregon study area.

17. Key Words CLIMATE , PRECIPITATION-FREQUENCY, RAINFALL, SPATIAL MAPPING, 24-HOUR PRECIPITATION, OREGON, WASHINGTON, IDAHO, CALIFORNIA	18. Distribution Statement Copies available from NTIS, and online at http://www.oregon.gov/ODOT/TD/TP_RES/		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 114	22. Price

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
VOLUME				
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

ACKNOWLEDGEMENTS

The authors would like to acknowledge Chris Daly of the PRISM Group at OSU who provided the precipitation data layers which formed the basis for the spatial mapping. Cadee Hale of OCS and Joseph Smith of the PRISM Group were involved in collecting daily and hourly precipitation data.

DISCLAIMER

REGIONAL PRECIPITATION-FREQUENCY ANALYSIS AND SPATIAL MAPPING OF 24-HOUR PRECIPITATION FOR OREGON
Final Report

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Regional frequency analyses were conducted for precipitation annual maxima in Oregon State for the 24-hour duration. A total of 693 precipitation gages in Oregon, southern Washington, western Idaho, northern California and northern Nevada were included in the study, representing 34,062 station-years of record. A regional analysis methodology was utilized that pooled 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 17 climatic regions and two transition zones. The 17 climatic regions were geographic areas that had similar topographic and climatological characteristics and were subjected to similar meteorological conditions during storm events. Eight of the regions were in western Oregon, including windward and leeward mountain areas and interior lowlands. The other nine climatic regions were in eastern Oregon, comprising arid and semi-arid plains and mountain and inter-mountain areas. One transition zone was used near the crests of the Cascade and Klamath Mountains for spatial mapping of precipitation where precipitation characteristics changed rapidly over short distances. A second transition zone was used for spatial mapping of precipitation at the eastern foothills of the Cascade Mountains. Steep gradients in storm statistical measures were found along with a sharp change in the seasonality of storms in this eastern Cascade foothills area.

Separate regional analyses were conducted for each of the climatic regions. Within each climatic region, precipitation gages were assigned to groups where the gage sites had similar magnitudes of mean annual precipitation and latitude. A total of 68 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 the 24-hour precipitation annual maxima data.

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. 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 6-month, 2-year, 10-year, 25-year, 50-year, 100-year, 500-year, and 1000-year precipitation recurrence intervals. Electronic gridded datasets are available on a CD for use in creation of GIS applications that utilize precipitation-frequency information.

A catalog of extreme storms was assembled that lists precipitation events that exceeded a 20-year return period for the various climatic regions. The information from the storm catalog was also used to conduct seasonality analyses that identified the occurrence frequency 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 in conducting hydrologic analyses throughout the Oregon study area.

1.0 OVERVIEW

This report documents the findings of regional precipitation-frequency analyses of 24-hour precipitation annual maxima for the State of Oregon. It also describes the procedures used for spatial mapping of 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 (NWS) in 1973 (*Miller et al.*). Data collection for the NWS study ended in 1966, and this study includes the 40-years of precipitation records collected since. Additional data from sources not available in 1966 is also utilized. These additional data provide a precipitation database with more than double the record than was available in the original NWS study.

Since the original 1966 study, major advances have been made in methods for statistical analysis of precipitation annual maxima, and for spatial mapping of precipitation in complex terrain. Specifically, L-Moment statistical analysis techniques, conducted within a regional framework, have greatly improved the reliability of precipitation magnitude-frequency estimates, particularly for rare storm events (*Hosking 1990; Hosking and Wallis 1997)*. Development of the PRISM model 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 (*Daly 1994*) These methodologies are particularly effective in areas with high topographic and climatic variability that exist in Oregon. Both of these methodologies have been utilized in this study in conducting the precipitation-frequency analyses and in developing the isopluvial maps for selected recurrence intervals.

2.0 STUDY AREA

While the state of Oregon was the area of interest, the study area was expanded to provide additional data in border geographic areas. The Oregon study area included portions of southern Washington, western Idaho, northern California and northern Nevada (Figure 1). Specifically, the Oregon study area was bounded on the North by latitude 47°00′ N, to the south by latitude 41°00′ N, and to the east by latitude 116°00′ W. Addition of precipitation stations in the boundary areas also provided data from areas climatologically similar to data-sparse areas in Oregon such as locations in the Coastal Mountains, Cascade Mountains, Blue Mountains, Cabinet Mountains, and Klamath Mountains.

2.1 CLIMATIC AND METEOROLOGIC CHARACTERISTICS OF STUDY AREA

2.1.1 Annual Precipitation

Mean annual precipitation within the Oregon study area varies dramatically from the windward faces of the Coast Range and Cascade Mountains to the desert areas in central Oregon. Mean Annual Precipitation (MAP) ranges from a high of over 200-inches in the Coast Range, to a low near 6-inches in the inter-Mountain desert area in southeast Oregon (Figure 2.1) (*Oregon Climate Service 2000, 2005*).

2.1.2 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 four generalized geographic areas that are sources of atmospheric moisture to the study area. These four areas have differing characteristic temperatures and dew points (*Miller et al. 1973; National Weather Service 1966, 1994*). 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. The Gulf of Mexico is the fourth source of moisture that occasionally penetrates sufficiently north to be a source of precipitation in warm months.

Storm systems 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 (*Miller et al. 1973; National Weather Service 1966, 1994*). Storm systems originating over the Pacific Ocean are the most common, while those that originate from southerly latitudes, near the Hawaiian Islands, have been responsible for many of the largest long-duration precipitation

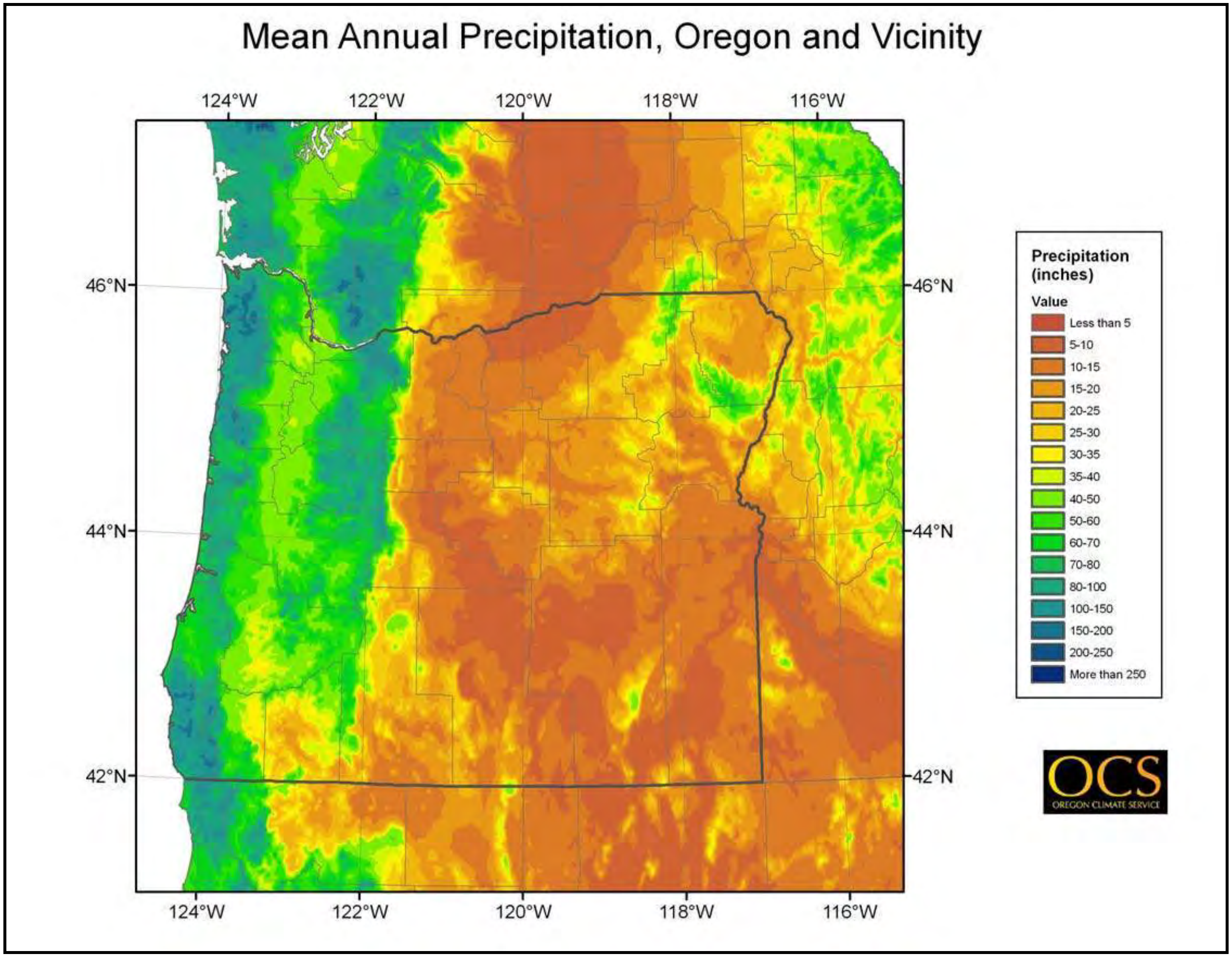

Figure 2.1: Mean Annual Precipitation for Oregon study area (*Oregon Climate Service 2000, 2005*).

totals experienced in the winter months. Synoptic-scale cyclonic weather systems, and associated fronts, generally provide the mechanism for producing precipitation annual maxima (the greatest precipitation amount in a 12-month period for a specified duration at a given measurement site) at 24-hour and longer durations. Precipitation is enhanced in mountain areas as atmospheric moisture is lifted over the Coastal, Cascade, Klamath and Blue 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 24-hour duration occur predominately in the fall and winter seasons in western Oregon and on east slopes of the Cascade and Klamath Mountains. Areas of eastern Oregon experience precipitation annual maxima at the 24-hour duration in both the fall and winter months as well as the spring and summer months. Additional information on the seasonality of precipitation annual maxima is presented in the discussion of climatic regions.

3.0 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. For the purpose of this study, the calendar year, January 1st through December 31st was used for determining 24-hour precipitation annual maxima.

Precipitation annual maxima and associated storm dates were obtained from precipitation records from a variety of sources. The majority of data were obtained from electronic files of the National Climatic Data Center (NCDC). Data from SNOTEL gages (see description in Section 3.1) located in mountain areas were obtained from electronic files of the Natural Resources Conservation Service (NRCS). Data were also obtained for precipitation gages operated by the State of California, whose electronic files were available through the California Data Exchange Center (CDEC).

3.1 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. Descriptions of the gage types and reporting methods are summarized below.

Daily Gages

Daily gages in US are standardized devices comprised of simple vertical cylinders that are open to the atmosphere. A variety of shields for protection from the wind are used, 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 depth and intensity on various time scales. The standards in the US are for reporting on either hourly or 15-minute intervals. Weighing bucket gages with paper strip charts came into use in the early 1940'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 falling as snow is converted to liquid water for measurement. SNOTEL gages were first installed in the late 1970s and reported precipitation on a daily basis on a midnight-to-midnight reporting schedule. In the late 1990s, SNOTEL gages began reporting on an hourly schedule. The short record of hourly data currently available is insufficient for regional-frequency analysis and the SNOTEL data used in this study is equivalent to a daily gage with midnight to midnight reporting.

3.2 NUMBER OF GAGES AND GAGE TYPES

The number of gages and gage types used in the regional analyses are summarized in Table 3.1. Both daily and hourly precipitation gages were co-located at some precipitation measurement sites. In addition, sometimes there are clusters of gages located within short distances of each other. To avoid duplication of records when this occurred, only the gage with the longest record was utilized in analyses. When both daily and hourly records, with similar record lengths, were available at a given site, the record from the hourly gage was selected. This situation resulted in 156 gages/records in the study area being marked as duplicates. After these gages/records were removed, a total of 693 gages remained to be used in the study. The resultant precipitation station network is shown in Figure 3.1. The figure shows good spatial distribution that is representative of the diverse topographic and climatic characteristics in Oregon. Figure 3.2 depicts the range of record lengths for the 693 gages of various gage types.

Table 3.1: Number and Type of Gages Utilized for Analyses of 24-Hour Annual Maxima.

State	Precipitation Gage Type			Station-Years
	Daily	Hourly	Snotel	
Northern California	38	20	3	3,136
Western Idaho	34	9	9	2,903
Northern Nevada	12	6	10	1,124
Oregon	273	80	66	20,096
Southern Washington	99	19	15	6,803
Totals	**456**	**134**	**103**	**34,062**

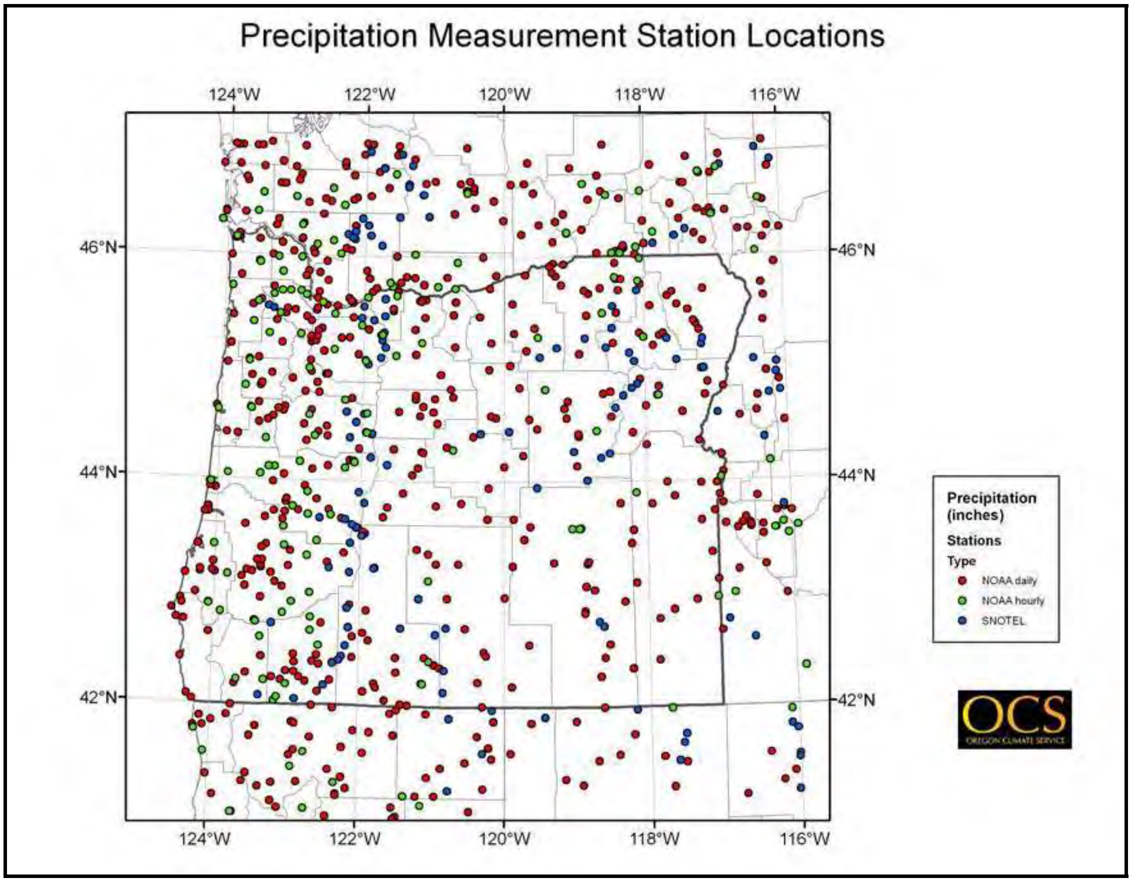

Figure 3.1: Precipitation Gaging Network for Oregon Study Area.

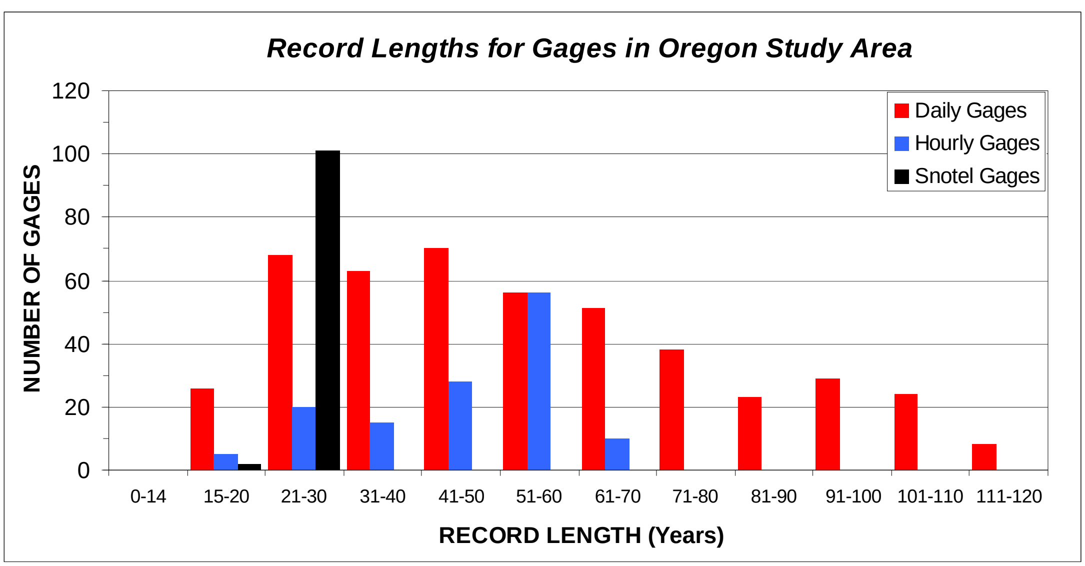

Figure 3.2: Record Lengths for Gages in Oregon Study Area.

4.0 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, transcription errors, and incomplete reporting during some years. The record for all sites and calendar-years was checked for completeness. In addition, all records were scanned for anomalously small or large precipitation amounts and the Hosking and Wallis measure of discordancy was used to identify gages whose sample statistics were markedly different from the majority of gages in a given climatic region (*Hosking and Wallis 1993, 1997*). Suspicious gages and data were checked to verify the validity of records. Nearby sites were also examined 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.

4.1 STATIONARITY AND SERIAL INDEPENDENCE

Two underlying assumptions inherent in frequency analyses were the data were stationary over the period of observation and use, and the data at a given site (gage) were serially independent. As part of the data screening process, standard statistical tests for stationarity and serial independence were conducted.

To meet the stationarity criterion, the data had to be free from trends during the period of observation. This was confirmed by standard linear regression techniques where the station data were first rescaled by division of 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 value of the slope parameter was -0.008 percent. 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 were accepted as stationary.

To confirm independence of the annual maxima data, a serial correlation coefficient was computed for the data at each gage. The regression results for the collective group of gages were tested against a null hypothesis of zero serial correlation (independence). The null hypothesis could not be rejected at the 5 percent level. The annual maxima data were found to be serially independent, consistent with the findings in Washington and California (*Schaefer and Barker 2000; Schaefer et al. 2002, 2006*).

5.0 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.

5.1 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 (*Miller et al. 1973*), studies of extreme precipitation in the Pacific Northwest (*NWS 1966, 1994*), and prior regional frequency analyses conducted in mountain areas (*Schaefer 1989, 1990, 1997; Schaefer and Barker 1997, 2000; Schaefer et al. 2002, 2006*). Each of the region designations utilized in these prior studies were based, to some extent, on the spatial distribution of mean annual precipitation and topographic characteristics, particularly the orientation of mountain ranges relative to common storm tracks.

This information was augmented by seasonality analyses of 24-hour precipitation annual maxima. Those analyses revealed winter storms to be the dominate events in western Oregon and in the Cascade and Klamath Mountains (Figure 5.1). Areas east of the eastern Cascade Foothills exhibited seasonality characteristics with a mixture of winter (Nov-Apr), spring-summer (May-Aug) and fall (Sep-Oct) annual maxima (Figures 5.1, 5.2, and 5.3).

Seventeen climatic regions and two transition zones (Figure 5.4) were identified based on information contained in the previously discussed precipitation studies; the spatial distribution of mean annual precipitation; and the seasonality characteristics of precipitation annual maxima. The magnitude and gradient of mean annual precipitation were the primary measures used to define the boundaries between the regions. The following sections contain descriptions of the climatic regions and progress from climatic regions nearest the Pacific coast eastward across the study area.

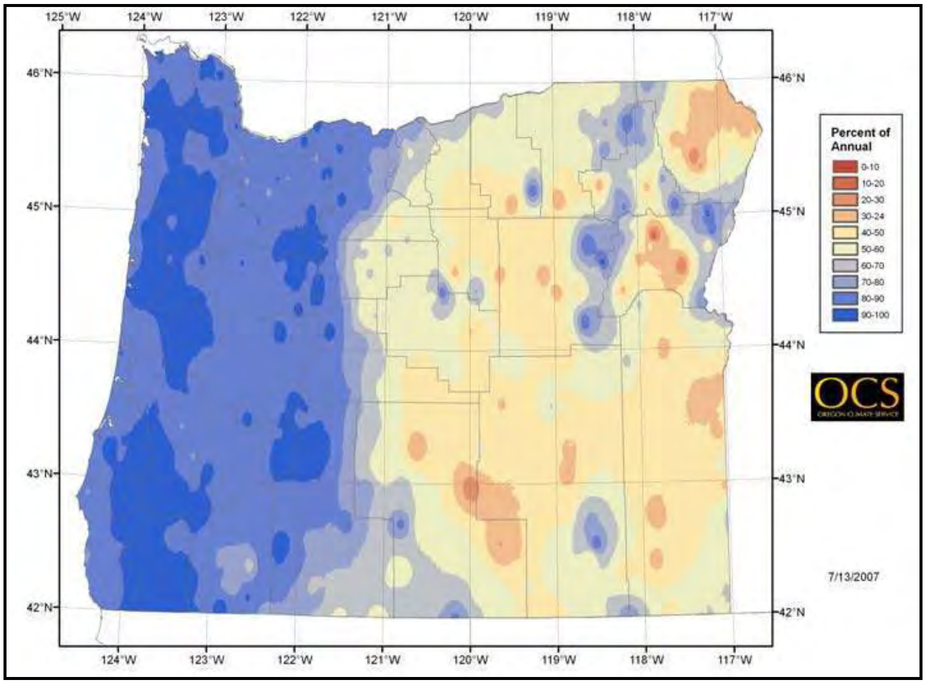

Figure 5.1: Frequency of Winter (November – April) 24-Hour Annual Maxima for Oregon Study Area.

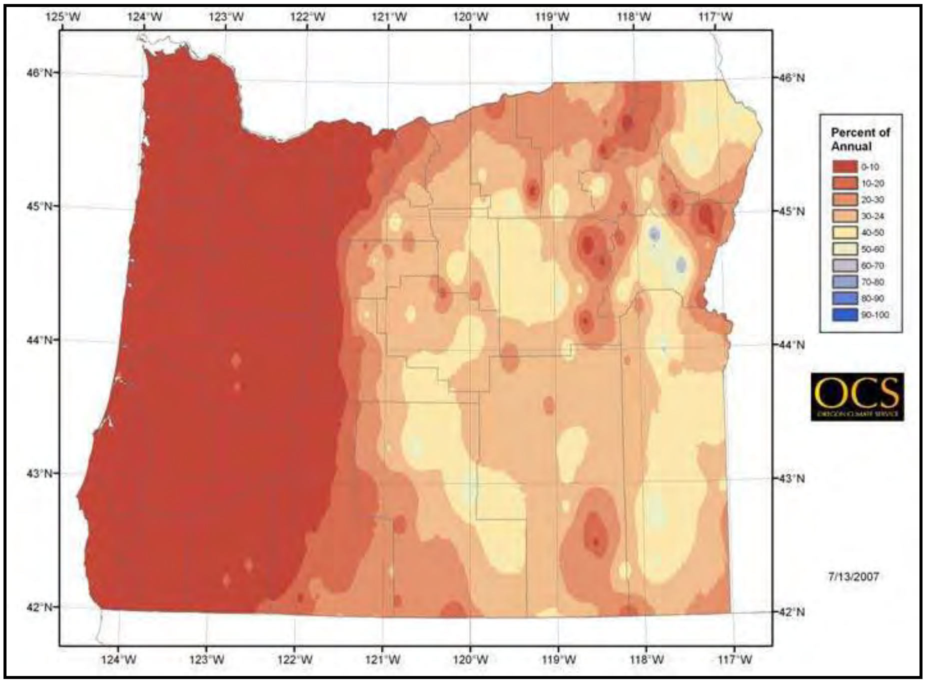

Figure 5.2: Frequency of Spring-Summer (May – August) 24-Hour Annual Maxima for Oregon Study Area.

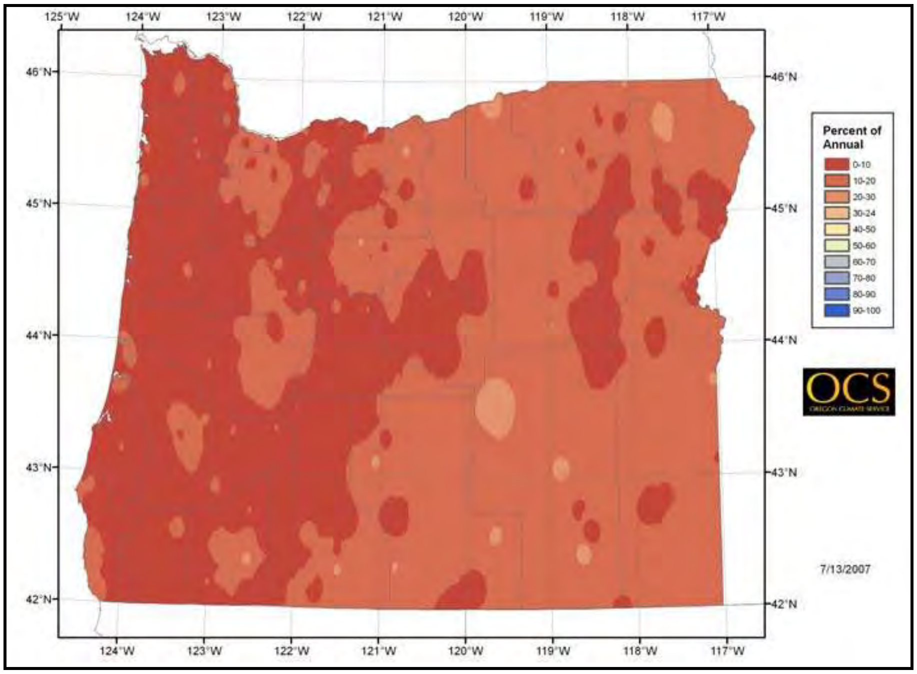

Figure 5.3: Frequency of Fall (September – October) 24-Hour Annual Maxima for Oregon Study Area.

Exhibit D-4

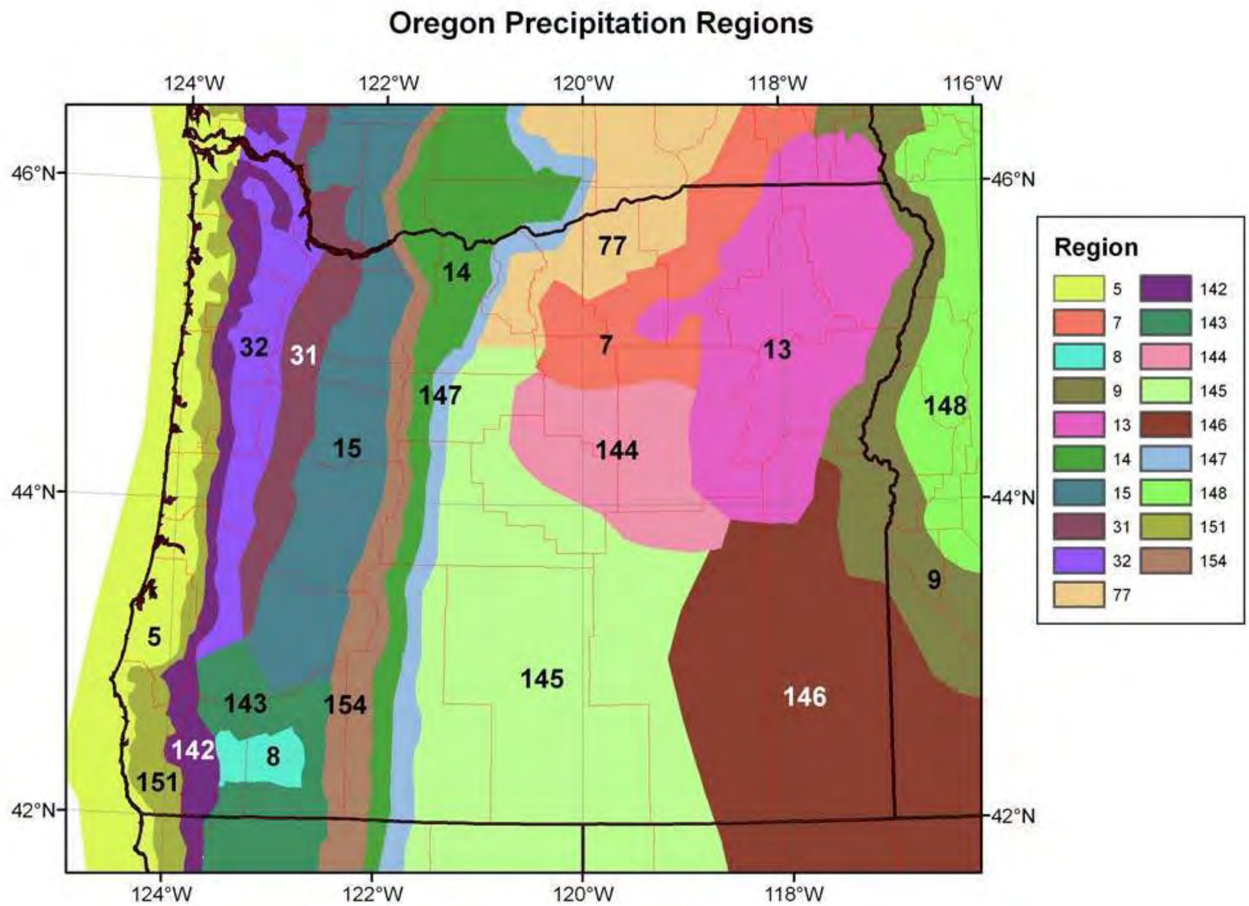

Figure 5.4: Delineation of Climatic Regions and Transition Zones for Oregon State and Surrounding Areas

5.2 CLIMATIC REGIONS FOR WESTERN OREGON STUDY AREA

Region 5 - Coastal Lowlands

This region includes the lowlands along the west coast of southern Washington, Oregon and northern California that are open to the Pacific Ocean. The eastern boundary is a generalized contour line of 1,000 feet elevation in the foothills of the coastal mountains.

Region 151 - Coastal Mountains West

This region includes the windward faces of the Coastal Mountains in southern Washington, Oregon and northern California 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 crest line of the Coastal Mountains.

Region 142 - Coastal Mountains East

This region includes the leeward faces of the Coastal Mountains in southern Washington, Oregon, and northern California 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 crest line of the mountain barrier, and bounded to the east by the 1,000 feet contour line.

Region 32 - Interior Lowlands West

The interior lowlands, primarily in the Willamette Valley, are below a generalized contour line of 1,000 feet elevation and are bounded to the east by the trough-line of mean annual precipitation through the Willamette Valley. This is a zone of low orography where mean annual precipitation generally decreases from west to east.

Region 31 - Interior Lowlands East

The interior lowlands, primarily in the Willamette Valley, are below a generalized contour line of 1,000 feet elevation and are bounded to the west by the trough-line of mean annual precipitation through the Willamette Valley. This is a zone of low orography where mean annual precipitation generally increases from west to east.

Region 15 - West Slopes of Cascade Mountains

This region is comprised of the windward faces of the Cascade Mountains in southern Washington, Oregon, and northern California, 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 that forms the boundary with Region 14.

Region 8 – Rogue Valley

This region is comprised of low elevation areas in southwestern Oregon between Medford and Grants Pass that reside in a rain-shadow created by the Coastal Mountains to the southwest.

Region 143 – Klamath Mountains and West Slope of Cascade Mountains

This region is comprised of the windward faces of the Klamath and Cascade Mountains in southern Oregon and northern California. This region is bounded to the west by the leeward faces of the Coastal Range (Region 142) and to the east by the ridgeline of mean annual precipitation near the Cascade crest.

5.3 CLIMATIC REGIONS FOR EASTERN OREGON STUDY AREA

Transition Zone 154 - Cascade Crest Transition Zone

This is a transition zone used for spatial smoothing of precipitation and is located near the crest of the Cascade Mountains between the west slopes of the Cascade Mountains (Regions 15 and 143) and the east slopes of the Cascade Mountains (Region 14). The transition zone has an average width of about six miles and the width varies with the steepness of the gradient of mean annual precipitation. This zone is wider where mean annual precipitation changes more slowly eastward of the Crest of the Cascade and Klamath Mountains. The transition narrows where there is a rapid drop-off of mean annual precipitation on the steeper leeward slopes of the Mountains.

Region 14 - East Slopes of Cascade and Klamath Mountains

This region is comprised of mountain areas on the east slopes of the Cascade and Klamath Mountains where precipitation annual maxima are produced predominately by winter storm events. This region is bounded to the west by the ridgeline of mean annual precipitation that generally parallels the crest line of the Cascade and Klamath Mountains. Region 14 is bounded to the east by the generalized contour line of 12-inches mean annual precipitation.

Transition Zone 147 - Cascade Foothills Transition Zone

This is a transition zone used for spatial smoothing of L-moment ratio statistics and precipitation in the eastern foothills of the Cascade Mountains. The transition zone is located between the east slopes of the Cascade Mountains (Region 14) and arid and semi-arid areas to the east. It also extends southward into the eastern Klamath Mountains. The transition zone has an average width of about 6 mile. The width varies with the steepness of the gradient of mean annual precipitation. The transition zone is narrower where there is a rapid drop-off of mean annual precipitation in the foothills of the Cascade Mountains.

Region 77 - Central Basin

The Central Basin region is comprised of the Columbia Basin and adjacent low elevation (non-orographic) areas in eastern Washington that extend into northern Oregon. It is bounded to the west by Region 14. The region is bounded to the northeast and southeast by the generalized (smoothed) contour line of 12-inches mean annual precipitation.

Region 7 – Pendleton-Palouse

This region is comprised of a mixture of lowland areas of low to moderate relief and extensive valley areas between mountain barriers. This includes areas near the Palouse, in southern Washington, and Pendleton, in northern Oregon. The region is bounded to the northwest by Region 77, which generally conforms to the contour line of 12-inches mean annual precipitation at the eastern edge of the Central Basin. It is bounded to the southeast by the Blue Mountains at the contour line of 22-inches mean annual precipitation.

Region 13 – Wallowa and Blue Mountains

This region is comprised of mountain areas in the northeastern part of Oregon where there is a significant orographic component to precipitation magnitudes. Mean annual precipitation ranges from a minimum of 22-inches to over 70-inches in the mountain areas. The western boundary of this region generally conforms to the contour line of 22-inches mean annual precipitation.

Region 9 – Snake River Canyon

This region is comprised of areas within and adjacent to the Snake River Canyon along the eastern border of Oregon.

Region 148 – Western Idaho Mountains

This region is comprised of mountain areas in western Idaho including the Selkirk, Clearwater and Salmon Mountains, where there is a significant orographic component to precipitation magnitudes. Mean annual precipitation ranges from a minimum of 22-inches to over 70-inches in these mountain areas. Region 9 forms the western boundary for this region.

Region 144 – Ochoco and Malheur

This region is comprised of mountain areas within the Ochoco and Malheur National Forests in central Oregon.

Region 145 – Fremont and Warner

This region is comprised of leeward slope mountain areas residing to the east of the Cascade Mountains in the Freemont National Forest and Warner Mountains. This region is bounded to the west by the crest line of mean annual precipitation in the Cascade Mountains (Regions 15 and 143) and bounded to the east by Climatic Region 146.

Region 146 –Pueblo and Crooked Creek Mountains

This region is a high desert intermountain area located in southeastern Oregon and northern Nevada. It is bounded to the west by the Fremont and Warner Region (Region 145).

5.4 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 within a homogeneous region have a common regional magnitude-frequency curve (regional growth curve, Figure 5.5) that becomes site-specific after scaling by the at-site mean of the data from the specific site of interest. Thus, the at-site inverse Cumulative Distribution Function (CDF) is calculated as follows:

$$Q_i(F) = \hat{\mu}_i \; q(F) \qquad \textbf{(5-1)}$$

In this equation; $Q_i(F)$ 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 (*1960*) and expanded by Wallis (*1980 and 1982*).

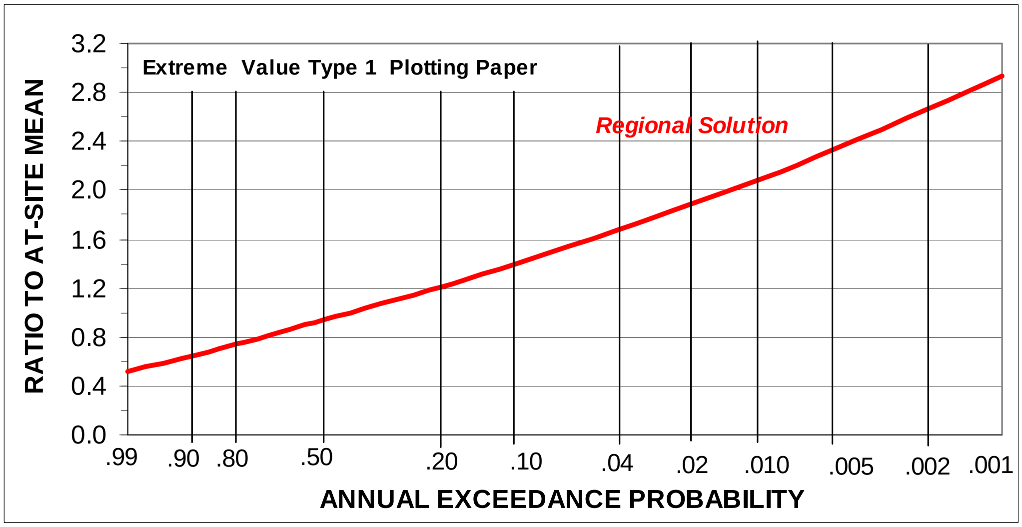

Figure 5.5: Example of Regional Growth Curve.

6.0 FORMING HOMOGENEOUS SUB-REGIONS

Identification and formation of homogeneous regions is an iterative process. It was anticipated that the climatic regions defined here would require further subdivision to meet homogeneity criteria. The methodology used herein for forming and testing proposed homogeneous sub-regions follows the procedures recommended by Hosking and Wallis (*1993, 1997*).

The basic approach was to propose homogeneous sub-regions (grouping of sites/gages) based on the similarity of the physical/meteorological characteristics of the sites. L-moment statistics were 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 (Appendix C) (*Hosking and Wallis 1993, 1997*).

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 included 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 (*Miller et al. 1973; NWS 1966, 1994*). Candidate climatological characteristics included 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 the Oregon study area showed that the 17 climatic regions already had similarities regarding several of the physical and climatological measures listed above. As such, only two measures, mean annual precipitation (MAP) and latitude were 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 small ranges of MAP and latitude.

6.1 HETEROGENEITY MEASURES OF PROPOSED HOMOGENEOUS SUB-REGIONS

Heterogeneity measures were developed by Hosking and Wallis as indicators of the amount of heterogeneity in the L-moment ratios for a collection of sites/gages (*1993, 1997*). 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 compared the observed variability to that expected from a large sample drawn from a homogeneous region of the Kappa distribution having weighted average L-moment ratios that were observed in the sub-region (*Hosking and Wallis 1997; Hosking 1988*). Initial recommendations from Hosking and Wallis were that: regions with H1 and H2 values less than 1.00 were acceptably homogeneous; values between 1.00 and 2.00 were possibly heterogeneous; and values greater than 2.00 indicated definite heterogeneity. When H1 and H2 values exceeded 2.00, Hosking and Wallis recommended that redefinition of the region and/or reassignment of sites/gages should be considered (*1993, 1997*)

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 the construction of building or the growth of trees in the vicinity of the gage. Recognizing this additional variability, Wallis 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 (*1997*). Both the H1 and H2 measures will be used later to assess the relative heterogeneity in proposed sub-regions.

6.2 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 to assist in selecting a suitable probability distribution, and to estimate the parameters of the regional distribution (*Hosking and Wallis 1993, 1997*). Examples of this type of approach are described for Washington State (*Schaefer 1990; Schaefer et al. 2002, 2006*), southern British Columbia (*Schaefer 1997*), and the Sierra Mountains in California (*Schaefer and Barker* 2000). The basic approach adapted to this study is summarized in adopted methodology 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 and a small range of latitude.
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 and latitude 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).

6.3 SYSTEMATIC VARIATION OF L-CV AND L-SKEWNESS WITH MEAN ANNUAL PRECIPITATION AND LATITUDE

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 an estimate of L-moment ratios, L-Cv and L-Skewness across climatic regions, and for the full study area. The predictor relationships were formulated to provide continuity with adjacent climatic regions. This approach had the 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) and latitude, it was found that MAP and latitude were suitable explanatory variables. Predictor equations for L-Cv and L-Skewness were obtained through regression analyses and took a variety of forms that included various combinations of 2nd order polynomials; linear and exponential formulations. Details about the predictor equations will be discussed in the sections that follow.

7.0 ANALYSES OF 24-HOUR PRECIPITATION ANNUAL MAXIMA

As described previously, homogeneous sub-regions were formed as collections of gages within small ranges of mean annual precipitation (MAP) and latitude within each of the climatic regions. The ranges of MAP and latitude were chosen so that about 7 to 15 gages, 350 to 750 station-years of record, were included in each sub-region. A minimum record length of 15-years was required to be included in the analysis. Record lengths at precipitation measurement stations varied from a minimum of 15-years to near 120-years; with nearly 50 percent of the stations having record lengths in excess of 50-years. Figure 3.2 depicts the number of stations within various ranges of record length.

As the analysis progressed, it was found that gages in adjoining climatic regions could often be grouped together with gages from the climatic region being analyzed. It was also found that resampling of gages in a region, or grouping of regions, was often required to separately evaluate the variation of L-Cv and L-Skewness with MAP and latitude. This approach resulted in the grouping of climatic regions as shown in Table 7.1 with a total of 68 sub-regions for the 24-hour duration.

Table 7.1: Number of Sub-Regions, Gages and Station-Years of Record for 24-Hour Duration Annual Maxima.

Study Area	Climatic Regions	Number Of Sub-Regions	Number Of Gages	Station-Years Of Record
Western Oregon	5, 151	7	60	3,227
	142, 32, 31, 15 (North of 43°N)	19	143	6,692
	142, 8, 143 (South of 43°N)	10	88	4,061
Eastern Oregon	154, 14, 147	11	102	4,632
	77, 7, 13, 144, 9, 148, 145, 146	21	327	16,427

7.1 REGIONAL SOLUTIONS FOR L-MOMENT RATIOS, L-CV AND L-SKEWNESS

Regional predictor equations for L-moment ratios were developed for groupings of climatic sub-regions using regression methods for various mathematical formulations with MAP and latitude as explanatory variables. Care was taken to select mathematical formulations that had the capability of minimizing discontinuities with adjoining climatic regions.

7.1.1 Spatial Variability of L-Cv

In western Oregon, latitude was found to explain the greatest proportion of variability in L-Cv, with MAP being of secondary importance. In examining the spatial variation of L-Cv over large areas of the west coast of North America, MAP was found to be an excellent explanatory variable for southern British Columbia and Washington State (*Schaefer 1997; Schaefer et al. 2002, 2006*). At the latitude of about 45°N, a combination of latitude and MAP provided the best predictors of L-Cv. Further south, on the west face of the Sierras, latitude was found to be the best predictor of L-Cv (*Schaefer and Barker 2000*). The change in correlation characteristics with MAP and latitude appeared to be associated with the frequency of storm tracks originating over the Pacific Ocean that affected different areas along the west coast. Areas in southern British Columbia and Washington were more centrally located relative to average storm tracks. Areas in southern Oregon and California were on the southerly end of the storm track, where there was greater variability in the number of large storms in any given year. The following relationships (Equations 7-1, 7-2, 7-3) provided the best predictors of spatial variation in L-Cv in the western portions of the Oregon study area. Figures 7.1 and 7.2 depict examples of the level-of-success of the predictor equations and a typical relationship of L-Cv with latitude (degrees Lat).

Regions 5, 151

$$L\text{-}C_v = 2.5883 - 0.1010 * Lat + 0.001039 * Lat * Lat + 0.08 * EXP(-0.060 * MAP) \qquad \textbf{(7-1)}$$

Regions 142, 32, 31, 15; North of 43°N

$$L\text{-}C_v = 9.2169 - 0.3948 * Lat + 0.004297 * Lat * Lat + 0.08 * EXP(-0.060 * MAP) \qquad \textbf{(7-2)}$$

Regions 142, 8, 143; South of 43°N

$$L\text{-}C_v = 0.08 * EXP(-0.040 * MAP) + 0.172 \qquad \textbf{(7-3)}$$

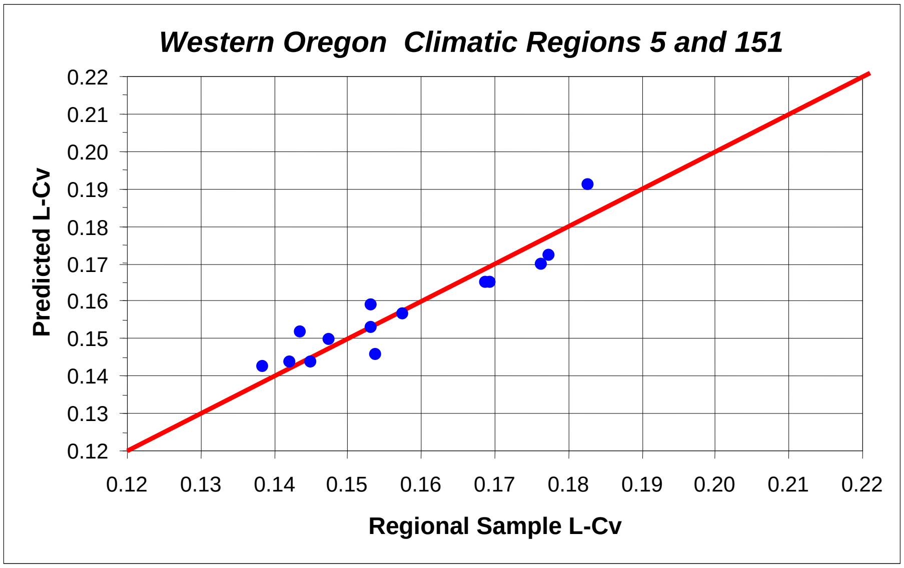

Figure 7.1: Comparison of Observed Regional Sample Values of L-Cv and Predicted L-Cv (Equation 7-1) for Climatic Regions 5 and 151.

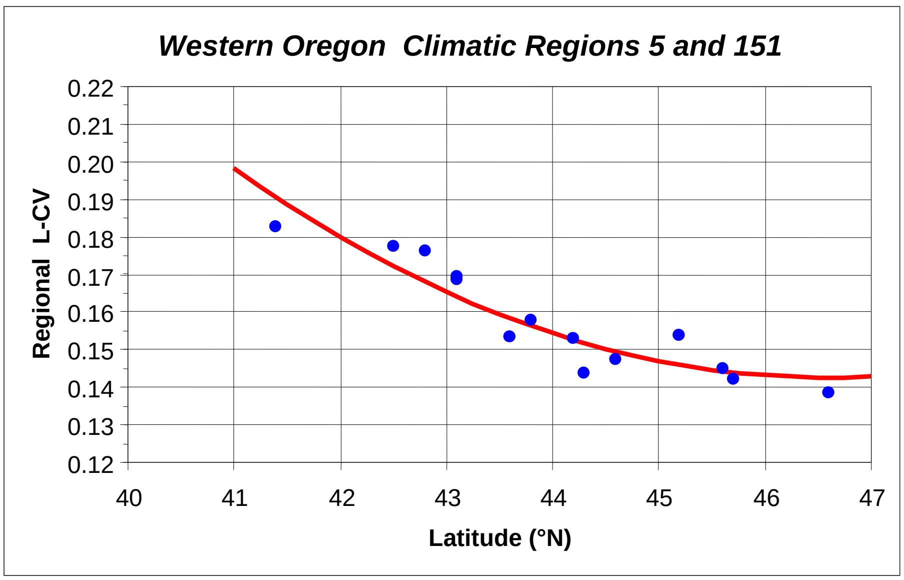

Figure 7.2: Relationship of Regional L-Cv with Latitude for Climatic Regions 5 and 151.

In eastern Oregon, MAP was found to be the primary factor in explaining spatial variation of L-Cv (Equations 7-4, 7-5). There was limited influence of latitude in the predictor equations for eastern Oregon. As indicated previously, the stronger correlation of latitude with L-Cv, in the western portion of the study area, appeared to be associated with the winter storm season that is dominant in that area. Conversely, precipitation annual maxima in eastern Oregon occurred across a wide range of seasons and the winter storm season is only a partial contributor. Figures 7.3 and 7.4 depict examples of the level-of-success of the predictor equations and a typical relationship of L-Cv with mean annual precipitation.

Regions 154, 14, 147

$L\text{-}C_v = 0.2195 - 0.00103*MAP + 0.00000036*MAP*MAP$; MAP < 92-inch **(7-4)**

$L\text{-}C_v = 0.155$; MAP ≥ 92-inch

Regions 77, 7, 13, 144, 9, 148, 145, 146

(7-5)

$L\text{-}C_v = 0.4071 - 0.0029*MAP + 0.0000268*MAP*MAP - 0.0041*Lat$; MAP < 55-inch

$L\text{-}C_v = 0.3288 - 0.0041*Lat$ MAP ≥ 55-inch

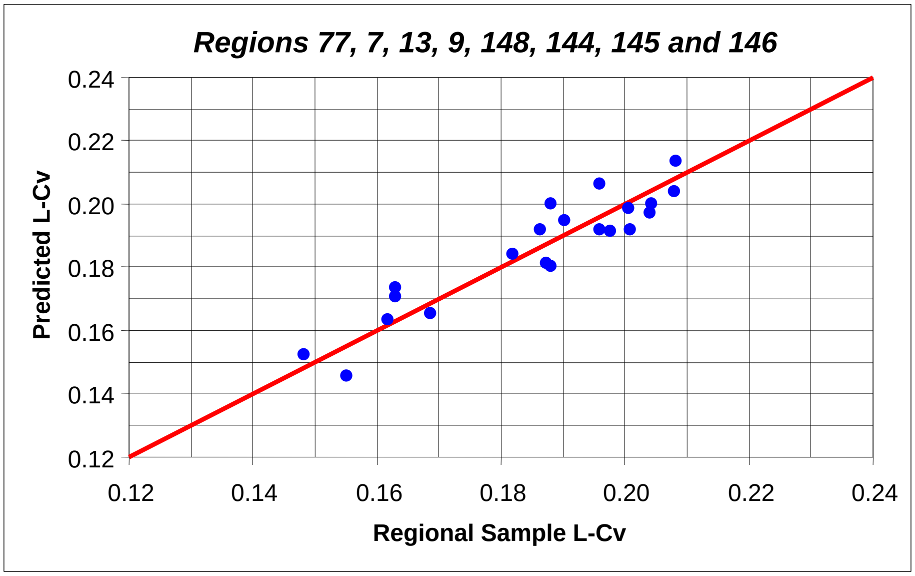

Figure 7.3: Comparison of Observed Regional Sample Values of L-Cv and Predicted L-Cv (Equation 7-1) for Climatic Regions 77, 7, 13, 9, 148, 144, 145, and 146.

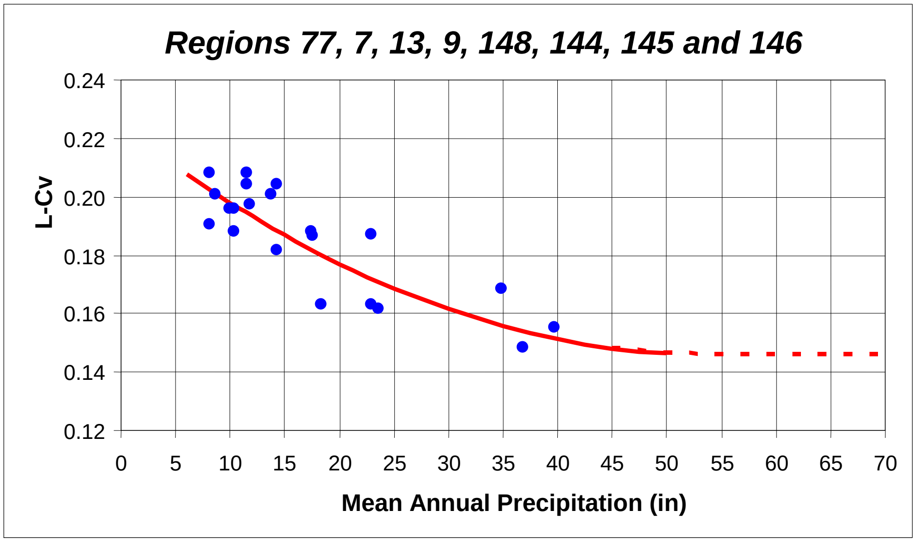

Figure 7.4: Relationship of Regional L-Cv with Mean Annual Precipitation for Climatic Regions 77, 7, 13, 9, 148, 144, 145, and 146.

Transition Zones

Transition zones were needed for mapping of L-Cv in several localized geographic areas. This was due to relatively steep gradients for L-Cv and/or moderate discontinuities in the predicted values of L-Cv at boundaries of adjacent climatic regions. Specifically, transition zones were used in the crest of the Cascade and Klamath Mountains (Transition Zone 154), and at the Foothills of the Cascade Mountains and eastern Klamath Mountains (Transition Zone 147). Transition Zone 147 delineated the break in the magnitudes of the variability measure L-Cv for the East Slopes of the Cascade Mountains relative to that in the arid and semi-arid regions further east (Figure 7.5). Review of Figures 5.1-5.3 also showed that a sharp change in storm seasonality accompanies this distinctive change in the magnitude of L-Cv at the Cascade foothills. Specifically, 24-hour precipitation annual maxima was predominately produced by winter storms on the east slopes of the Cascade Mountains. In areas further east, the 24-hour annual maxima were produced by a mixture of winter, spring and summer storms (Figures 5.1-5.3).

Figure 7.5 depicts the behavior of L-Cv across the eastern portion of the study area. This behavior of L-Cv, where there is an abrupt change at the foothills of the Cascade Mountains (Transition Zone 147), matched that observed in a prior study for eastern Washington (*Schaefer et al. 2006*). The figure depicts the relationship at latitude 44°N. There were very minor changes in L-Cv values to the north (smaller L-Cv) and to the south (larger L-Cv).

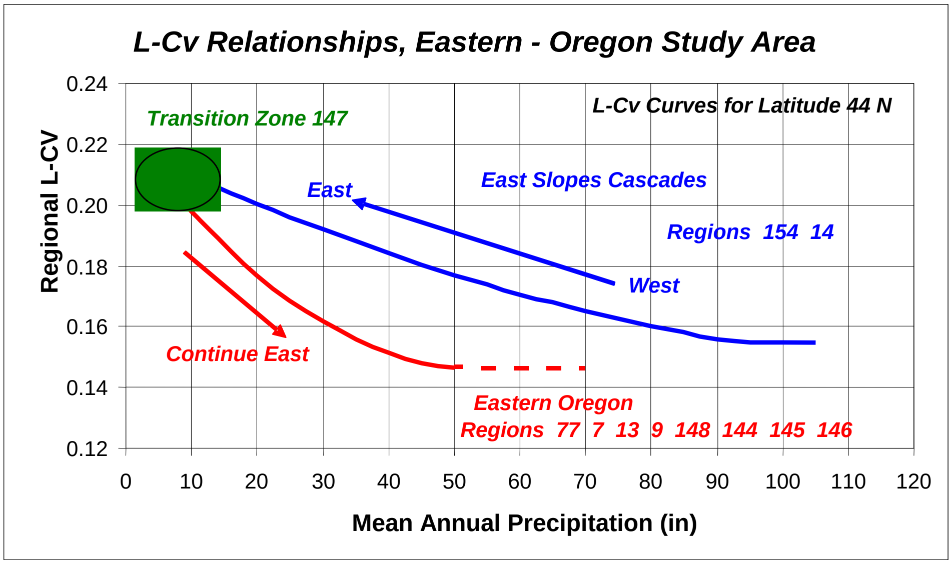

Figure 7.5: Behavior of L-Cv progressing eastward from the Crest of the Cascade Mountains, through the Eastern Foothills, and Across Eastern Oregon at Latitude 44°N.

7.1.2 Spatial Variability of L-Skewness

Skewness measures are highly variable for the record lengths commonly available for precipitation-frequency analysis. This greater sampling variability is exhibited in larger Root Mean Square Error (RMSE) values of the predictor equations for L-Skewness (Equations 7-6 and 7-7) (Table 7.2). Regional predictor equations for L-Skewness were developed in the same manner as that described above for L-Cv. Two predictor equations for L-Skewness were developed, one each, for the western and eastern portions of the study area. Homogeneous sub-regions, representing broad areas, were grouped for analysis to help reduce the effects of sampling variability and allow for a determination of the underlying behavior of L-Skewness. Figures 7.6 and 7.7 depict the predictor equations for L-Skewness for the western and eastern portions of the study area, respectively.

Regions 5, 151, 142, 3, 31, 15, 8 and 143

L-Skewness = 0.10*EXP(-0.024*MAP) + 0.3810 -0 .0050*Lat **(7-6)**

Regions 154, 14, 147, 77, 7, 13, 144, 9, 148, 145 and 1467

L-Skewness = 0.08*EXP(-0.018*MAP) + 0.2680 -0 .0025*Lat **(7-7)**

Table 7.2: Root Mean Square Error (RMSE) of Predictor Equations for L-Cv and L-Skewness for Oregon Study Area.

Study Area	Climatic Regions	Standardized RMSE Of L-Cv Predictor Equation (Percent)	Standardized Rmse Of L-Skewness Predictor Equation (Percent)
Western Oregon	5, 151	3.2	15
	142, 32, 31, 15 (North of 43°N)	5.9	
	142, 8, 143 (South of 43°N)	4.1	
Eastern Oregon	154, 14, 147	3.3	8.5
	77, 7, 13, 144, 9, 148, 145, 146	3.8	

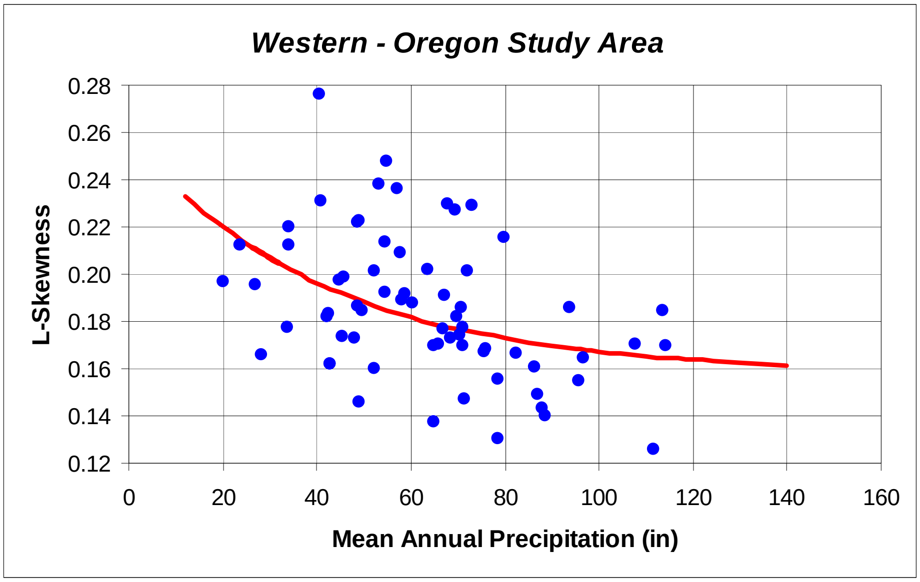

Figure 7.6: Relationship of Regional L-Skewness with Mean Annual Precipitation for Climatic Regions 5, 151, 142, 32, 31, 15, 8, and 143 in the Western Portion of Oregon Study Area.

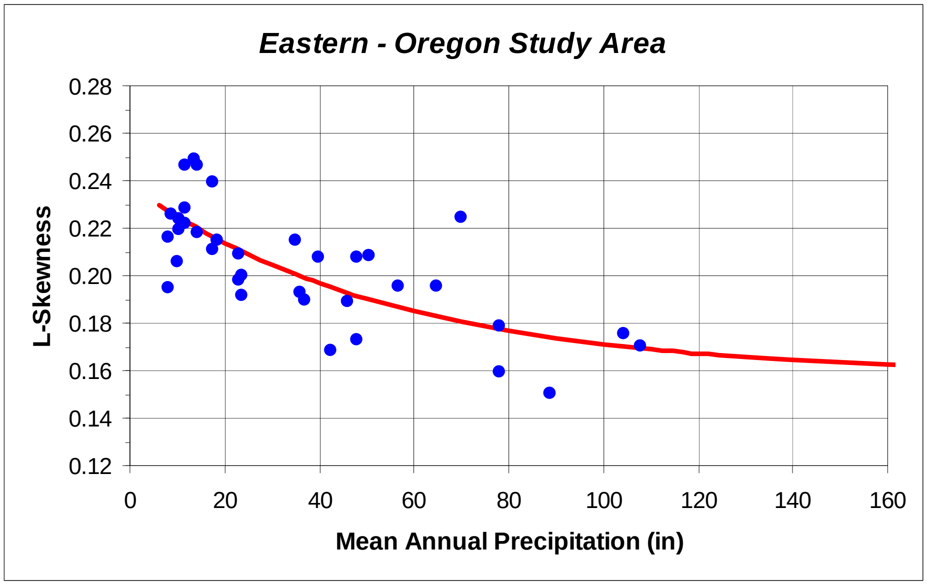

Figure 7.7: Relationship of Regional L-Skewness with Mean Annual Precipitation for Climatic Regions 154, 14, 77, 7, 13, 9, 148, 144, 145 and 146, in the Eastern Portion of Oregon Study Area.

7.2 HETEROGENEITY MEASURES, 24-HOUR DURATION

Heterogeneity measures H1 and H2 were used to judge the relative heterogeneity in the proposed sub-regions for L-Cv and L-Skewness, respectively (*Hosking and Wallis 1993, 1997*). Computation of H1 and H2 values for the various sub-regions indicated that nearly all sub-regions were acceptably homogeneous (Table 7.3). In those cases where computed heterogeneity measures exceeded acceptance criteria, the excursions were generally of a minor amount. In summary, small ranges of mean annual precipitation and latitude were excellent explanatory variables for grouping of stations/sites within climatic regions.

Table 7.3: Results of Heterogeneity and Goodness-of-Fit Tests for 24-Hour Duration.

Study Area	Climatic Regions	Number Of Sub-Regions	Homogeneous Sub-Regions H1 $\leq$ 2.00	Homogeneous Sub-Regions H2 $\leq$ 1.00	Sub-Regions Accepting GEV Distribution
Western Oregon	5, 151	7	6	7	5
	142, 32, 31, 15 (North of 43°N)	19	16	15	15
	142, 8, 143 (South of 43°N)	10	10	7	8
Eastern Oregon	154, 14, 147	11	10	7	6
	77, 7, 13, 144, 9, 148, 145, 146	21	18	17	18
Total		**68**	**60**	**53**	**52**

7.3 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 was computed for each sub-region for use in identifying the best three-parameter distribution (*Hosking and Wallis 1993, 1997*). Using the L-moment based test statistic, the Generalized Extreme Value (GEV) distribution was identified most frequently as the best three-parameter probability model (Table 7.3) (*Hosking and Wallis 1997; Schaefer et al. 2002, 2006*).

Plots of regional L-Skewness and L-Kurtosis values for 68 sub-regions in the western and eastern portions of the study area are shown in Figures 7.8 and 7.9. Nearness to the GEV distribution was clearly evident and consistent with the goodness-of-fit test results listed in Table 7.3.

The GEV was a suitable distribution for estimating 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 distribution, which can mimic the GEV and produce a variety of regional growth curves immediately around the GEV (*Hosking 1988; Hosking and Wallis 1997*). The inverse form of the Kappa distribution is shown in the following equation (7-8):

$$q(F) = \xi + \frac{\alpha}{\kappa}\left\{1-\left(\frac{1-F^h}{h}\right)^{\kappa}\right\} \qquad \textbf{(7-8)}$$

In this equation: ξ, α, κ, and h are location, scale, and shape parameters, respectively.

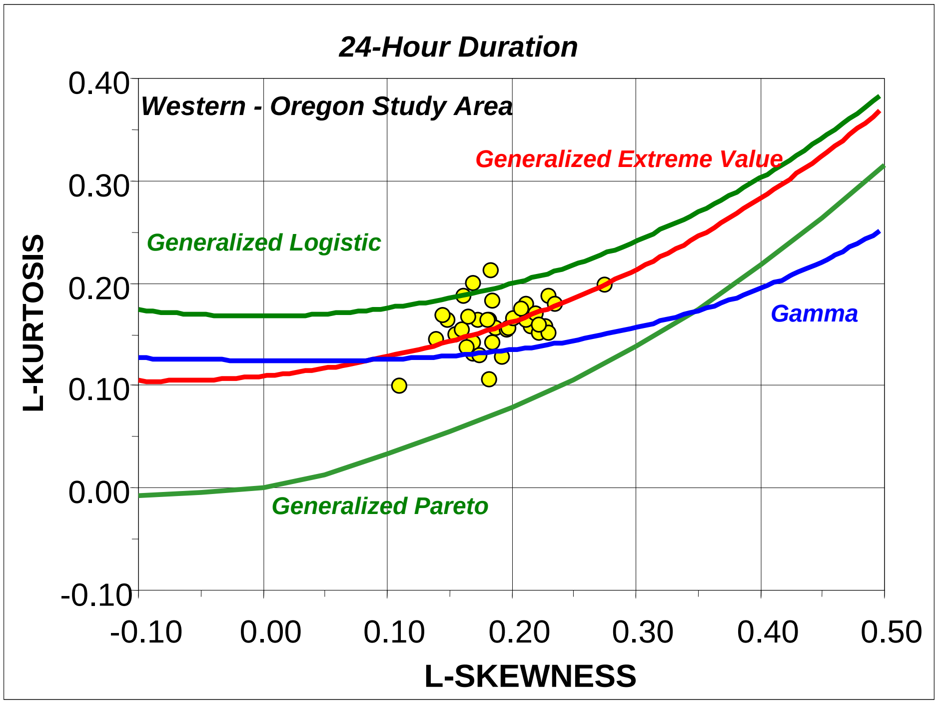

Figure 7.8: L-Moment Ratio Plot, for 24-Hour Duration, for Sub-Regions in Climatic Regions 5, 151, 142, 32, 31, 15, 8, and 143, in the Western Oregon Study Area.

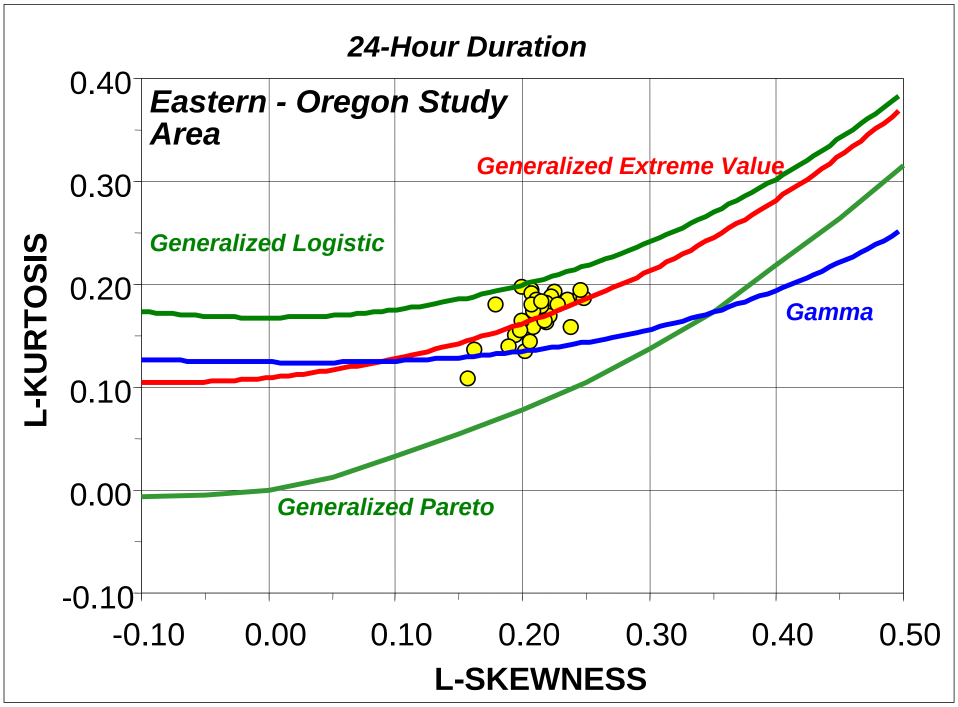

Figure 7.9: L-Moment Ratio Plot, for 24-Hour Duration, for Sub-Regions in Climatic Regions 154,14,147,77,7,13,9,148,144,145, and 146, in the Eastern Oregon Study Area.

Different distributions were produced with unique *h* values. The distributions were as follows: an *h* value of zero, led to the GEV distribution; an *h* value of one, produced the Generalized Pareto (GP) distribution; and an *h* value of -1, produced the Generalized Logistic (GL) distribution. Thus, positive values of *h* produced regional growth curves that were flatter than the GEV, and negative values of *h* produced 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 was taken wherein the shape parameter *h* was computed as the average value from the group of sub-region solutions (*Fiorentino et al. 1979*). An average *h* value of -0.038 was computed with a standard error of estimation of approximately ± 0.058 for the western portion of the study area. For the eastern portion of the study area, an average *h* value of -0.060 was computed with a standard error of estimation of approximately ± 0.042. These values compared with an *h* value of -0.05 that was found in the prior studies in Washington (*Schaefer et al. 2002, 2006*) and eastern British Columbia (*Schaefer 1997*). A nominal *h* value of -0.05 was adopted for the Oregon study area, which was consistent with the findings of prior studies and was well within one standard deviation of the sample average. Thus a regional growth curve was produced that was slightly steeper than the GEV, for very rare events, and essentially matched the GEV out through approximately the 500-year recurrence interval.

8.0 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 provided the information necessary to develop the regional growth curve. Specifically, the first three parameters of the Kappa distribution (ξ, α, and κ) (*Hosking and Wallis 1997; Hosking 1988*) were solved using a mean of unity and the applicable regional values of L-Cv and L-Skewness, as indicated in Equations 7-1 through 7-7. The fourth parameter (*h*) of the Kappa distribution was set to the regional average value of -0.050, as discussed in the prior section. Equation 7-8 was then used to describe the regional growth curve. The site-specific precipitation-frequency curve was obtained by scaling the regional growth curve by the at-site mean.

$$\hat{\mu} = C_{nop} (\bar{x}) \qquad \textbf{(8-1)}$$

For gaged sites, the at-site mean ($\hat{\mu}$) could be computed from the gage mean ($\bar{x}$) using a correction factor. The correction factor accounted for the difference in sample statistics for precipitation measurement and reporting on a fixed time interval rather than on the desired 24-hour continuous basis. The correction factor (C_{nop}) varied with the length of the observational period (24-hours for daily gage). A correction factor of 1.13 was estimated from theoretical considerations of Weiss (*1964*) and has also been found in numerous studies (*Miller et al. 1973*). The value of 1.13 is commonly taken as a standard in humid environments subjected to numerous yearly storms and the typical duration of those storms approaches or exceeds the observational period.

In arid and semi-arid areas, there may be few noteworthy storms each year. The duration of these storms is also somewhat less than the length of the daily observational period. In these cases, it is possible that the correction factor for converting from maximum daily statistics, to maximum 24-hour precipitation statistics, is a value less than the conventional 1.13. Studies were previously conducted in Washington State to examine the magnitude of the correction factors (*Schaefer et al. 2006*). That study included precipitation stations sites in Oregon. The results of those analyses have been applied to the Oregon study area, and are listed in Table 8.1.

Table 8.1: Correction Factors (C_{nop}) Used to Adjust Gage Sample Statistics.

Climatic Regions	Gage Type	Correction Factors 24-Hour Duration
Western Oregon Study Area 5, 151, 32, 31, 15, 8, 143, 154	Daily and SNOTEL	1.13
East Slopes Cascade and Klamath Mountains 14, 147	Daily and SNOTEL	1.11
Eastern Oregon Study Area 77, 7, 13, 9, 148, 144, 145, 146	Daily and SNOTEL	1.08
All Regions	Automated/ Hourly Reporting	1.00
All Regions	Automated/ 15-Minute Reporting	1.00

8.1 EXAMPLES OF PRECIPITATION-FREQUENCY RELATIONSHIPS

The procedures for developing site-specific precipitation-frequency curves can be explained by using examples from existing gaged sites. The examples include a daily gauge from McMinnville, Oregon and an hourly gauge at the airport in Pendleton, Oregon.

8.1.1 24-hour Precipitation-Frequency Relationship: McMinnville, Oregon

The city of McMinnville, Oregon is located in Climatic Region 32 and has a daily gage. The mean annual precipitation for the site is 42.8-inches. The site is located at a latitude of 45.22º North. For the 24-hour duration, the regional value of L-Cv was 0.157, which was obtained from Equation 7-2. The regional value of L-Skewness was 0.191, which was obtained from Equation 7-6. The regional value of the h parameter was -0.05. Using a mean value of unity, the solution for the four distribution parameters of the Kappa distribution (*Hosking and Wallis 1997; Hosking 1988*), yields:

ξ= 0.8723, α= 0.2132, κ= -0.0450, and h= -0.05.

Application of Equation 7-8 yielded the regional growth curve depicted in Figure 8.1. McMinnville has a daily gage with a gage mean of 2.15-inches for 104-years of record. The precipitation-frequency curve for the daily gage was obtained by scaling (multiplying) the regional growth curve with the gage mean (Figure 8.2). The observed daily annual maxima for the McMinnville site, from 1894-2006, are also depicted in Figure 8.2 for a comparison with the regional solution. There is agreement between the historical data and that predicted by the regional solution.

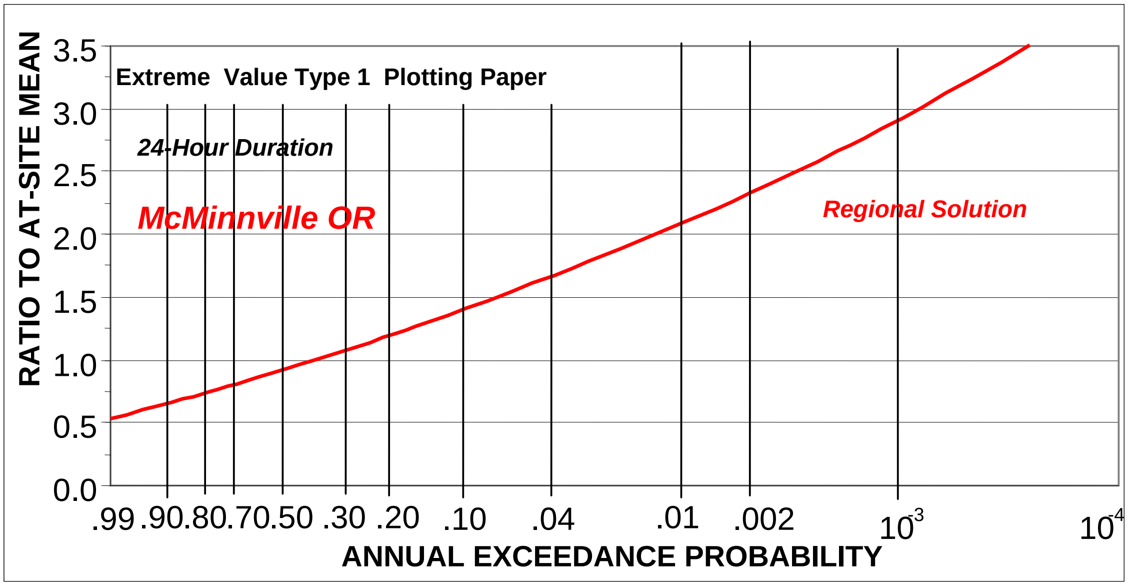

Figure 8.1: Regional Growth Curve for McMinnville, Oregon for 24-Hour Duration.

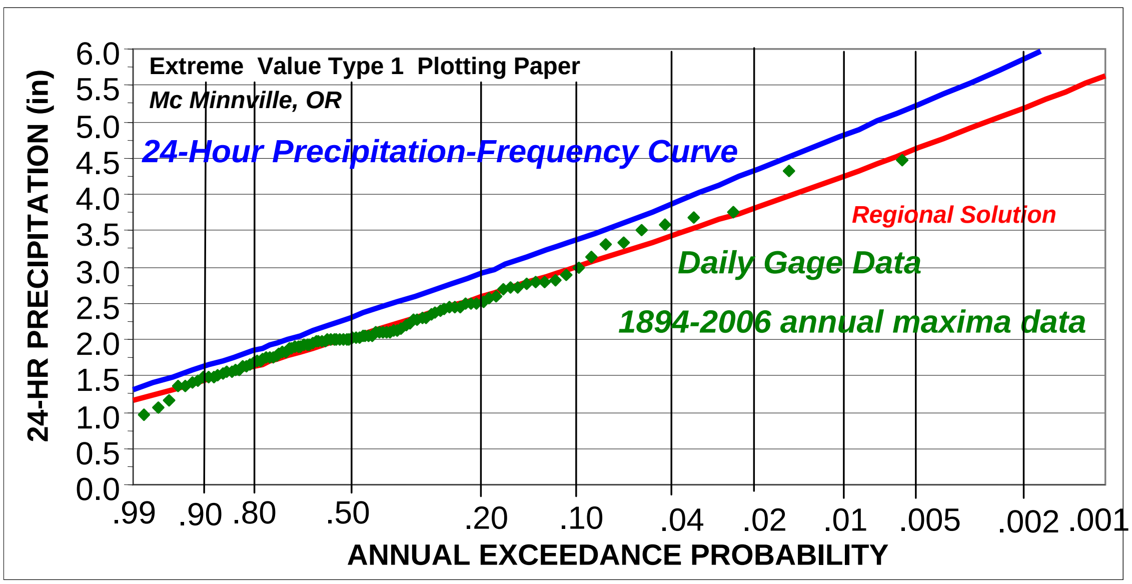

Figure 8.2: Precipitation Magnitude-Frequency Curve for McMinnville, Oregon for 24-Hour Duration.

Computation of the at-site precipitation-frequency curve (Figure 8.2) for the 24-hour duration required use of the correction factors listed in Table 8.1. Numerically, this is accomplished by multiplication of the distribution parameters for location (ξ) and scale (α) by the correction factor of 1.13 and reapplying Equation 7-8. The at-site precipitation-frequency curve for the 24-hour duration at McMinnville is shown as the blue curve in Figure 8.2. These types of computations for daily and SNOTEL gages (adjusting from a fixed daily observational period to a continuous 24-hour time-interval) are incorporated in the precipitation spatial mapping products that are described in later sections.

8.1.2 24-hour Precipitation-Frequency Relationship: Pendleton, Oregon

Another example of a 24-hour precipitation-frequency relationship is shown for the hourly gage at the Pendleton Airport in Oregon. The Pendleton Airport is located in eastern Oregon, in Climatic Region 7, at latitude 45.68°N. The mean annual precipitation is 13.0-inches. For the 24-hour duration, the station gage mean is 0.93-inches. The regional value of L-Cv was 0.187, which was obtained from Equation 7-5. The regional value of L-Skewness was 0.217, which was obtained from Equation 7-7. The regional value of the *h* parameter was -0.05. Using a mean value of unity, the solution for the four distribution parameters of the Kappa distribution (*Hosking and Wallis 1997; Hosking 1988*), yields:

$\xi = 0.8433$, $\alpha = 0.2437$, $\kappa = -0.0839$, and $h = -0.05$.

No corrections were required for hourly gages, and the at-site mean equaled the gage mean of 0.93-inches. Application of Equation 7-8, with the distribution parameters listed above, yielded the precipitation-frequency curve shown in Figure 8.3. The 24-hour annual maxima data for 1941-2006 have been plotted for comparison. There is good agreement between the regional solution for the precipitation-frequency relationship and the historical data.

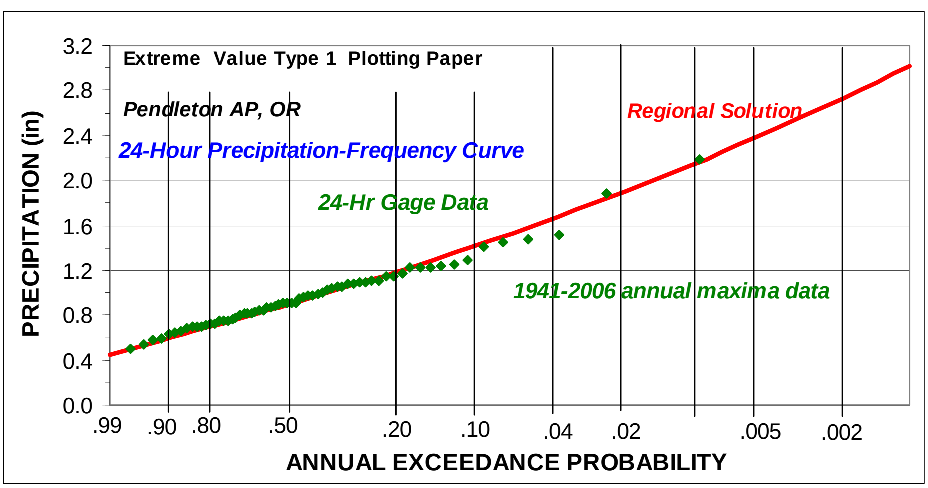

Figure 8.3: Precipitation Magnitude-Frequency Curve for 24-Hour Duration, for the Pendleton Airport in Oregon.

9.0 SPATIAL MAPPING OF PRECIPITATION-FREQUENCY INFORMATION

Products from the PRISM model (*Daly 1994*), 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 6-month, 2-year, 10-year, 25-year, 50-year, 100-year, 500-year and 1000-year recurrence intervals for the 24-hour duration. Precipitation estimates for the 6-month and 2-year recurrence intervals were converted from annual maxima to partial duration series equivalents (*Stedinger et al. 1992*) using the conversion developed by Langbein (*1949*). 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 (*Miller et al. 1973*).

The spatial mapping of precipitation for selected recurrence intervals is dependent upon the production of two key components. 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 L-Cv and L-Skewness 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.

9.1 MEAN ANNUAL PRECIPITATION

The gridded dataset of mean annual precipitation provided 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 1971 to 2000 has been completed for the study area by Oregon Climate Service using the PRISM model. The resultant map has been utilized in this study and has provided digital values of mean annual precipitation on a gridded latitude-longitude system with a nominal resolution of 0.50 minutes per grid-cell for the study area (about 0.23 mi^2). This resolution yields a study area domain that is a matrix of 840 rows by 1080 columns (907,200 grid-cells).

10.0 SPATIAL MAPPING OF AT-SITE MEANS

Spatial mapping of at-site means encompasses a number of separate tasks that address spatial behavior and seeks to minimize differences between mapped values and sample values computed at precipitation measurement stations. The first task involved developing relationships between at-site means, computed at precipitation measurement stations, and climatic/physiographic factors. An example of this type of relationship is depicted in Figure 10.1, where mean annual precipitation and latitude were used as explanatory variables. These relationships were then used to populate the grid-cells in the study area domain with the values predicted from the applicable regression equation based on the climatic and physiographic factors representative of each grid-cell. At-site mean values for grid-cells within transition zones 154 and 147 were computed as a weighted average of the at-site mean values in adjacent climatic regions in the same manner had the grid-cell been located in the adjoining regions. This provided continuity with at-site mean values at region boundaries and provided a smooth transition between adjoining regions. It should be noted that discontinuities in the transition zones prior to smoothing were relatively minor, typically less than 5 percent of the mapped value.

Residuals were then computed for each of the station at-site means that quantified the magnitude of difference between mapped values and station values. This allowed analyses to be conducted of the residuals to identify if there was a coherent spatial pattern to the magnitude and sign of the residuals. When coherent residual patterns were encountered, they were used to adjust the original estimates. Lastly, standard bias and root mean square error measures were computed to quantify the overall goodness-of-fit of the mapped values, relative to the observations at the gages. The map of the at-site means for the 24-hour duration is shown in Figure 10.2.

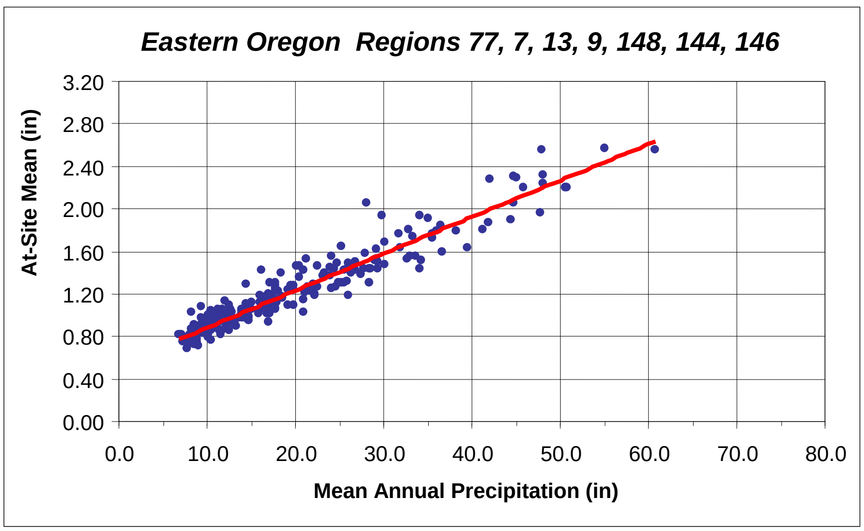

Figure 10.1: Example Relationship of Observed 24-Hour At-Site Mean with Mean Annual Precipitation for Eastern Oregon Study Area (Regions 77, 7, 13, 9, 148, 144, and 146).

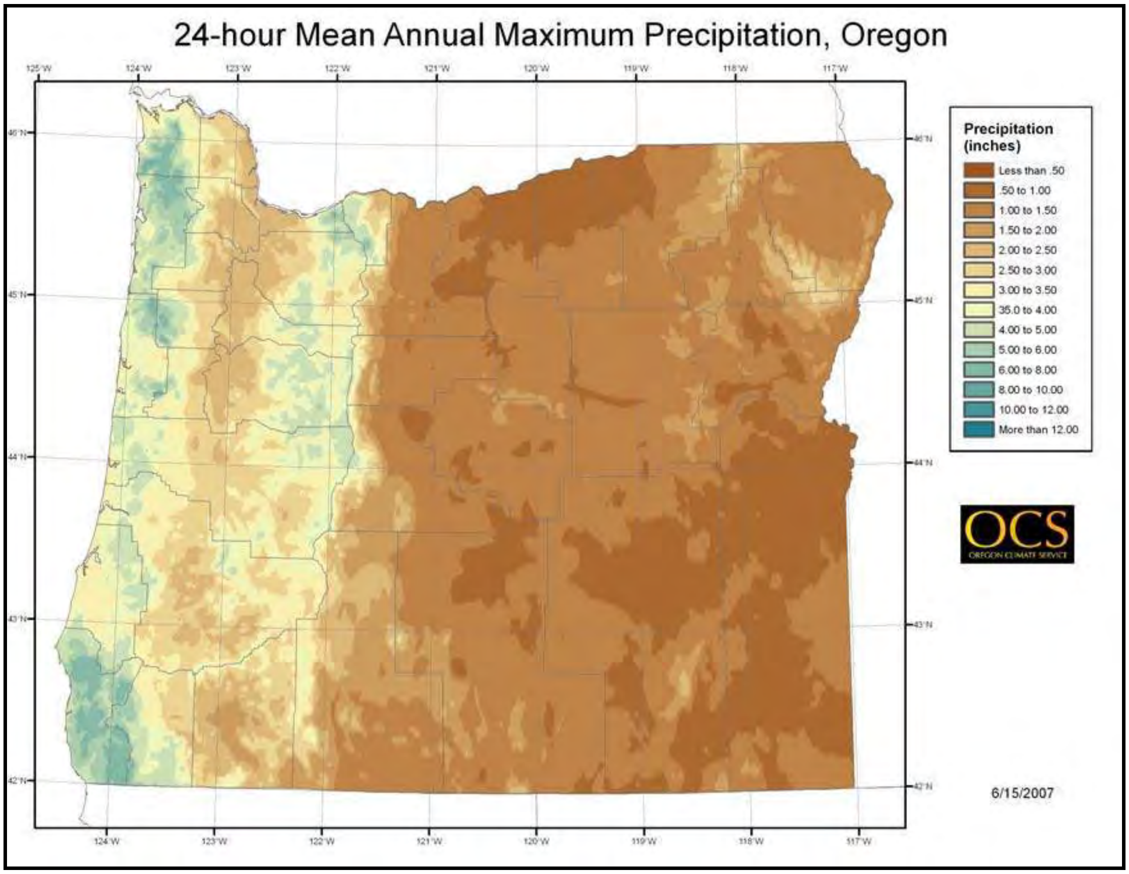

Figure 10.2: Map of At-Site Means for 24-Hour Duration for Oregon Study Area.

10.1 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 the at-site mean. However, station sample values of the 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.

This problem was approached 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 (*Helsel and Hirsch 1992*) were 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:

$$SR_2 = (S - P_2) / P_2 \tag{10-1}$$

In this equation: 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 Table 10.1 and a graphical example, comparing observed and mapped values, is shown in Figure 10.3. A review of Table 10.1 shows 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 percent. 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 10.1: Bias and Root Mean Square Error of Standardized Residuals for Final Mapped Values of Station At-Site Means for 24-Hour Duration.

Study Area	Climatic Regions	Final Mapped Values	
		Bias (%)	**RMSE (%)**
Western Oregon	Region 5 – Coastal Lowlands	0.0	3.7
	Region 151 – Windward Faces Coastal Mountains	-0.3	3.9
	Region 142 – Leeward Areas Coastal Mountains	1.6	5.0
	Region 32 – Interior Lowlands - West	-0.6	4.2
	Region 31 – Interior Lowlands - East	-0.3	4.6
	Region 15 – West Slopes of Cascade Mountains	-1.1	4.2
	Region 8 – Rogue Valley	-1.5	3.1
	Region 143 – Klamath Mountains and West Slopes Cascade Mountains	0.8	4.9
Eastern Oregon	Zone 154 – Transition Zone Crest Cascades and Klamath Mountains	-0.5	4.3
	Region 14 – East Slopes of Cascade Mountains	0.2	4.4
	Zone 147 – Transition Zone Cascade Foothills	0.1	4.3
	Region 77 – Central Basin	-0.9	2.8
	Region 7 – Pendleton-Palouse	0.2	2.6
	Region 13 – Wallowa and Blue Mountains	-0.6	4.0
	Region 9 – Snake River Canyon	-0.5	3.7
	Region 148 – Western Idaho Mountains	-1.3	3.1
	Region 144 – Ochoco and Malheur	-1.2	4.7
	Region 145 – Fremont and Warner	-1.0	4.9
	Region 146 – Pueblo and Crooked Creek Mountains	0.0	4.2
Weighted Averages for All Regions		**-0.4**	**4.1**

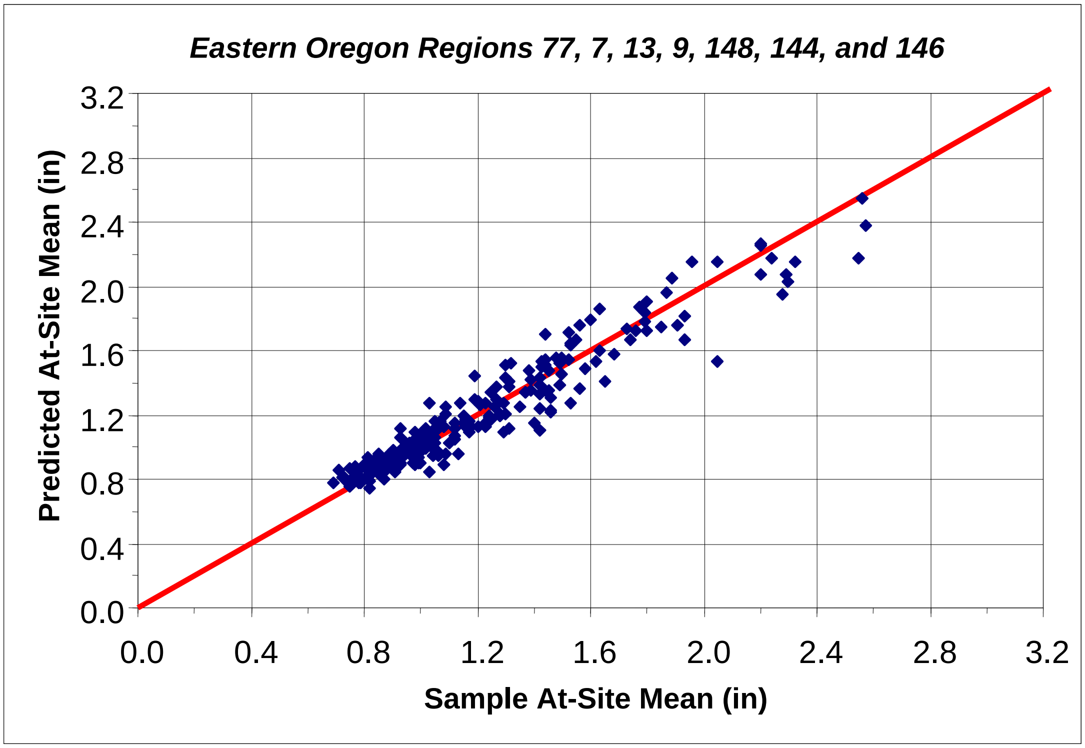

Figure 10.3: Comparison of Observed and Predicted Values of At-Site Means where Mean Annual Precipitation and Latitude were Used as Explanatory Variables for Climatic Regions 77, 7, 13, 9, 148, 144, 146 in Oregon Study Area).

11.0 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 had to be obtained for each grid-cell. This was accomplished by populating the grid-cells in the study area domain with the functional relationships for L-Cv and L-Skewness (Equations 7-1 through 7-7) that were developed in the regional precipitation-frequency analysis. Population of the grid-cells within transition zones 154 and 147 was accomplished as a weighted average of the L-moment ratio values. The weight factors were based on the nearness of a given grid-cell to the boundaries of the transition zone. This approach provided continuity at the region boundaries and a smooth transition between region boundaries within the transition zones. Discontinuities of L-Cv at L-Skewness in transition zones, prior to smoothing, were relatively minor; typically less than 5% of the mapped value.

Color-shaded maps of L-Cv and L-Skewness values are depicted in Figures 11.1 and 11.2. Separate gridded data files are included as electronic files with this report (Appendix A).

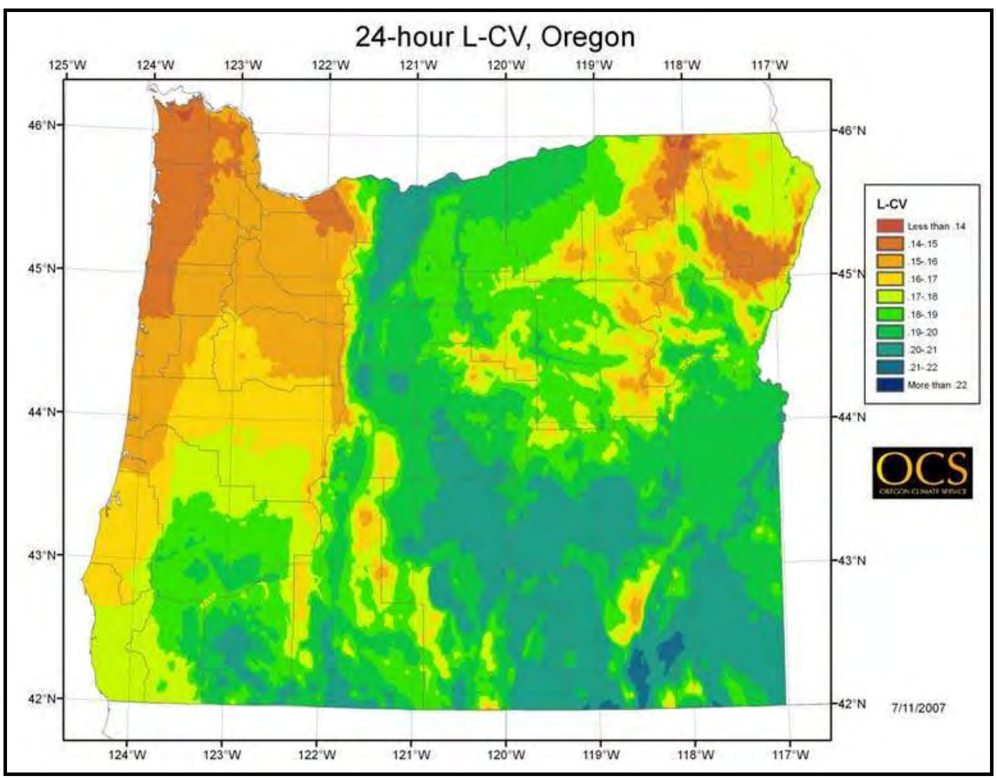

Figure 11.1: Oregon Variation of L-Cv for 24-Hour Precipitation Annual Maxima.

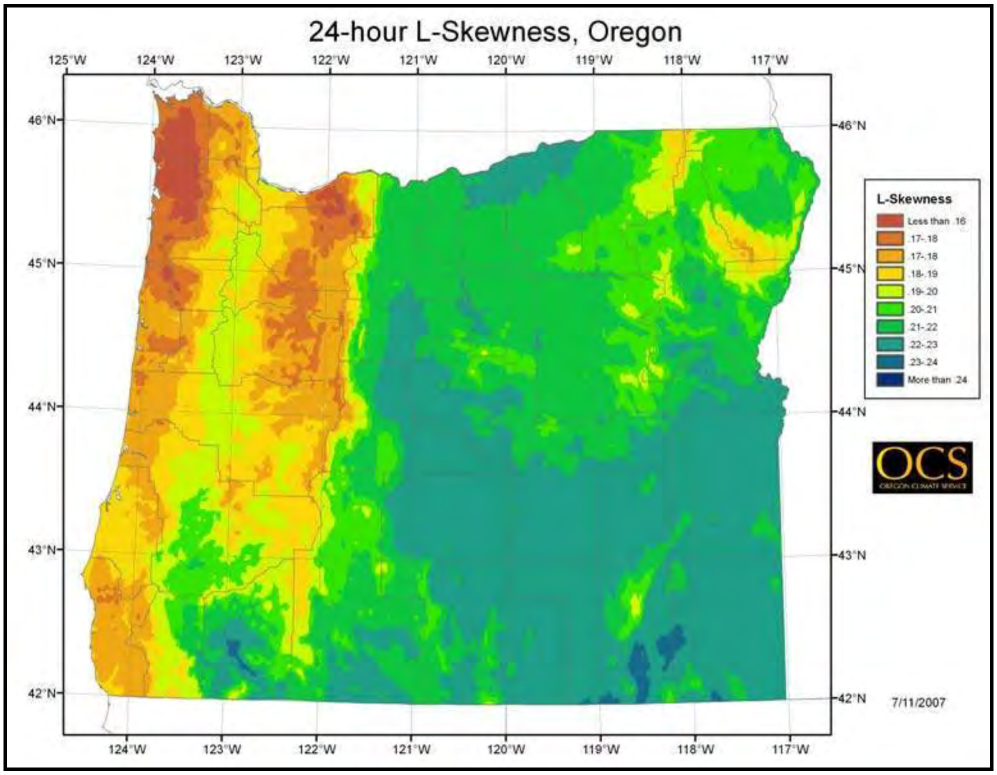

Figure 11.2: Oregon Variation of L-Skewness for 24-Hour Precipitation Annual Maxima.

12.0 PRODUCTION OF ISOPLUVIAL MAPS

The isopluvial maps were produced by incorporating the information described in 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 (*Hosking 1988; Hosking and Wallis 1997*). The distribution parameters were then used in Equation 7-8 to compute the expected value of 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.

12.1 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, corresponded to 10-mi^2 precipitation for the 24-hour duration. Estimation of precipitation volumes of larger watersheds for a selected recurrence interval require analysis of historical storms or application of areal reduction factors. Areal reduction factors would be obtained from analyses of historical storms from climatologically similar areas. The topics 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 adjusted in order to obtain estimates of precipitation volumes for moderate to large watersheds. Additional information on areal reduction factors can be found in articles by Bell (*1976*), Meyers and Zehr (*1980*), and Siriwardena and Weinmann (*1996*).

12.2 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 attained in estimating the at-site mean, and L-moment ratios; L-Cv and L-Skewness, as well as the similarity between the chosen probability model (Kappa distribution), and what actually is occurring in nature.

In general, uncertainties associated with estimating L-moment ratios; L-Cv and L-Skewness, resulted in standard errors of estimation of about 5 percent at the 100-year recurrence interval. These relatively low levels of uncertainty were attributable to very large datasets that were used to estimate the L-moment ratios and identify a suitable probability model. The interaction of these standard errors of estimation with errors due to estimation of the at-site mean (Table 10.1), yielded the standard errors of estimation that is shown in Table 12.1. The range in standard errors of estimation for a given duration was primarily due to the region-to-region variation of standard errors for the at-site mean estimates for recurrence intervals cited in Table 12.1.

Table 12.1 shows the range of standard errors of estimation for selected recurrence intervals. The values shown in Table 12.1 are approximate. Detailed studies that compute uncertainty bounds have not been conducted at this time. The values shown in the table represent regional averages. Values applicable to a given location may be somewhat smaller or larger than those indicated in Table 12.1.

Table 12.1: Range of Standard Errors of Estimation for Selected Recurrence Intervals.

Duration	10-Year	100-Year
24-Hour	4% to 7%	7% to 10%

12.3 ISOPLUVIAL MAPS

An example of an isopluvial map, which was produced by processes described in this chapter, is depicted in Figure 12.1. The figure shows a color-shaded map of 24-hour, 100-year precipitation. Isopluvial maps for the other selected recurrence intervals are contained as electronic files as part of Appendix B.

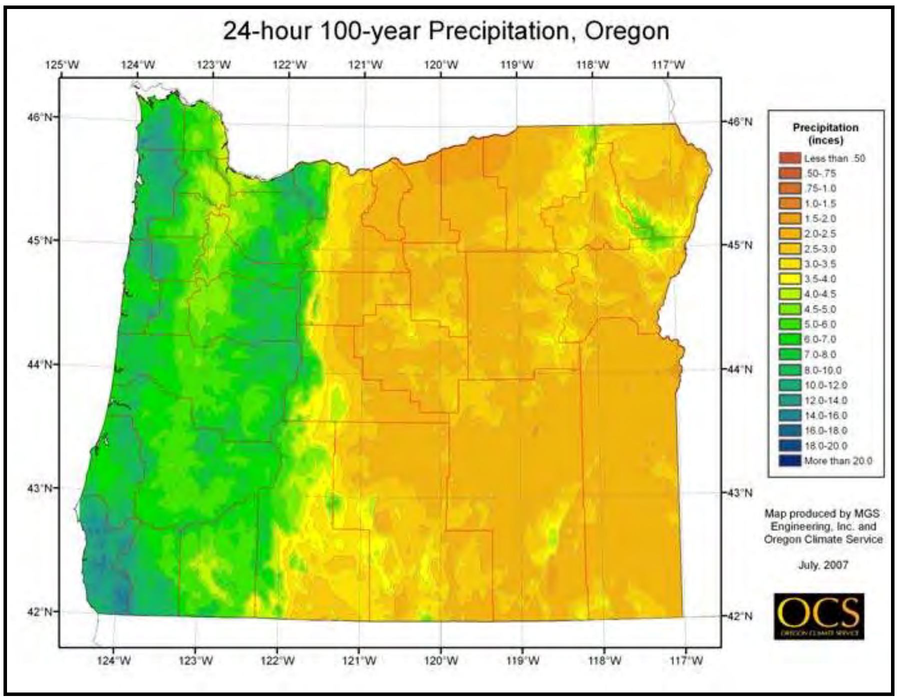

Figure 12.1: Isopluvial Map of 24-Hour Precipitation for 100-Year Recurrence Interval for the State of Oregon.

13.0 SEASONALITY OF EXTREME STORMS

The seasonality of extreme storms can be a valuable tool for application of precipitation-frequency information to rainfall-runoff modeling. Specifically, information on the seasonality of storms is helpful when 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 precipitation amounts for groupings of climatic regions. Storms characterized as extreme, were those where the precipitation amounts had annual exceedance probabilities of less than 0.05 (rarer than a 20-year event). Precipitation amounts/gages with duplicate storm dates (generally dates within about 3 calendar days) were removed before the frequency histograms were constructed for each climatic region. The results of the seasonality analyses are discussed below.

13.1 SEASONALITY OF 24-HOUR EXTREME EVENTS

Well-defined seasonal patterns were apparent for storms which were rare at the 24-hour duration in western Oregon and on the eastern slopes of the Cascade and Klamath Mountains (Figures 13.1-13.5). These storms were the result of synoptic scale cyclonic weather systems and associated fronts. These storms remain organized and would penetrate a considerable distance inland from the coast. There was a rapid transition in the seasonality of storms at the foothills of the Cascade and Klamath Mountains into eastern Oregon where arid, semi-arid, and humid climatic regions showed extreme storms occurring throughout the year (Figures 13.6-13.8).

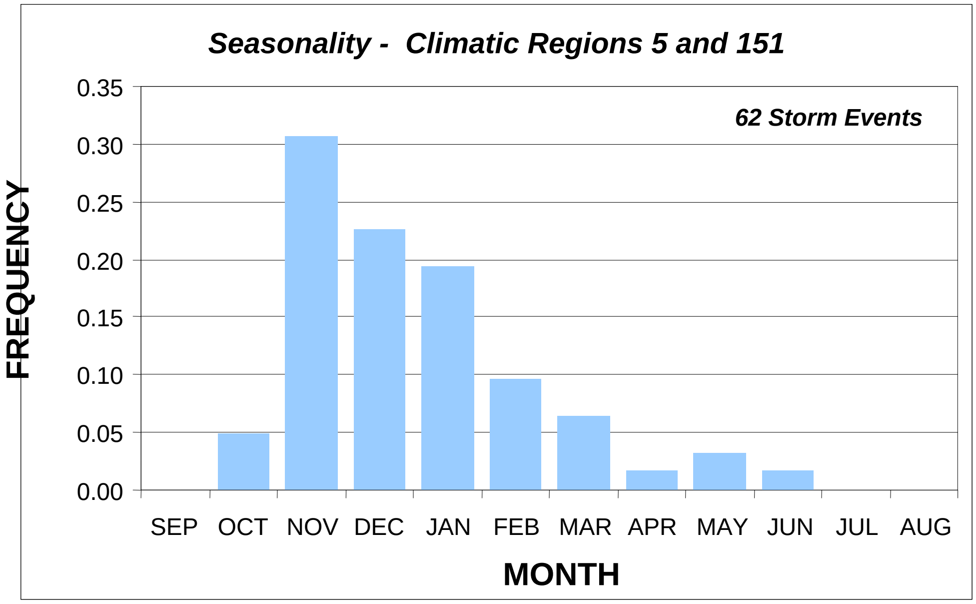

Figure 13.1: Seasonality of Extreme Storms in Climatic Regions 5 and 151 (Western Oregon – Coastal Lowlands and Windward Faces of the Coastal Mountains).

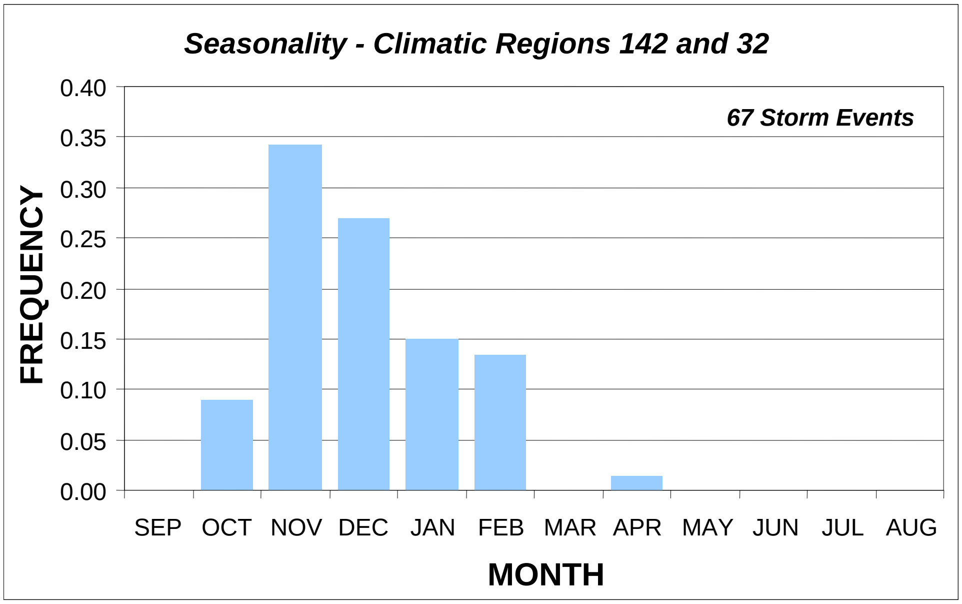

Figure 13.2: Seasonality of Extreme Storms in Climatic Regions 142 and 32 (Western Oregon – Leeward Faces of the Coastal Mountains and the Interior Lowlands to the West).

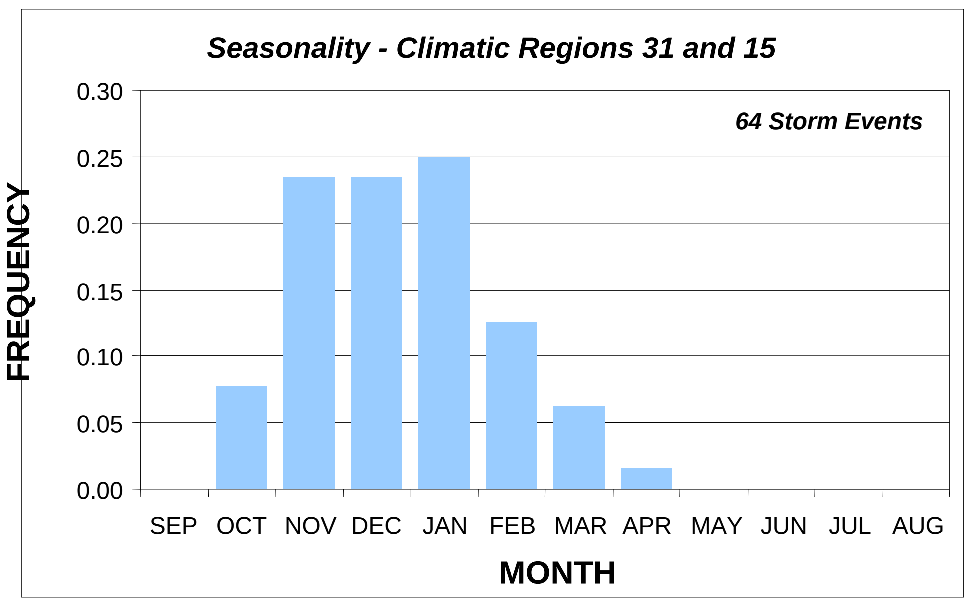

Figure 13.3: Seasonality of Extreme Storms in Climatic Regions 31 and 15 (Western Oregon -Interior Lowlands to the East and the Windward Faces of the Cascade Mountains).

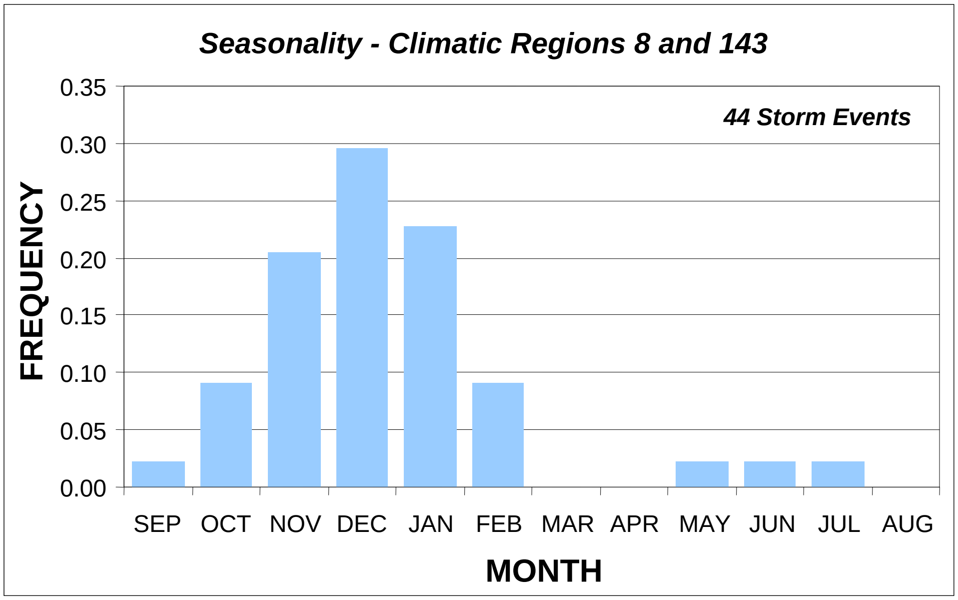

Figure 13.4: Seasonality of Extreme Storms in Climatic Regions 8 and 143 (Southwest Oregon – Rogue Valley and the Windward Faces of the Klamath Mountains).

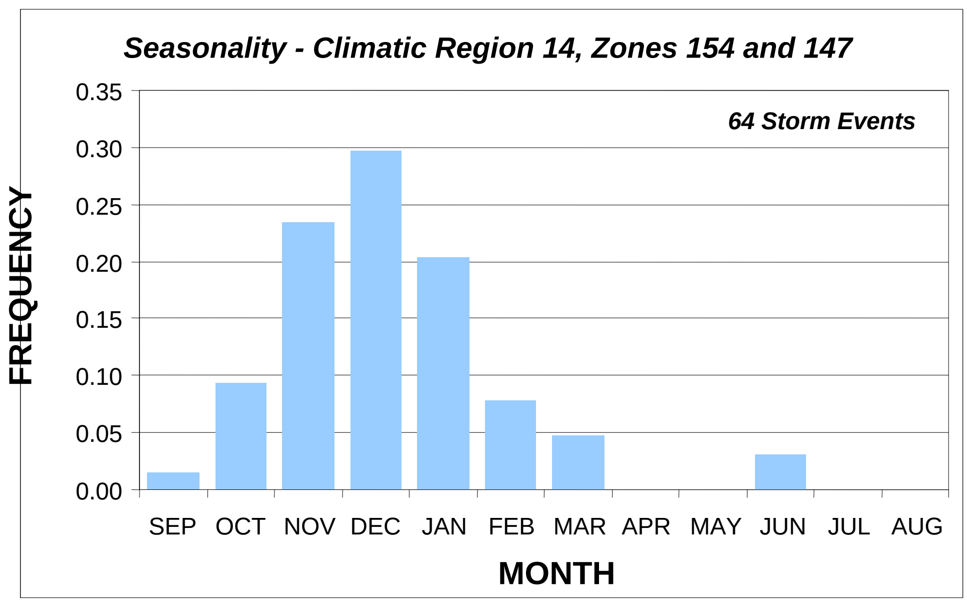

Figure 13.5: Seasonality of Extreme Storms in Climatic Region 14 and Transition Zones 154, and 147 (Eastern Oregon – Leeward Faces of the Cascade and Klamath Mountains).

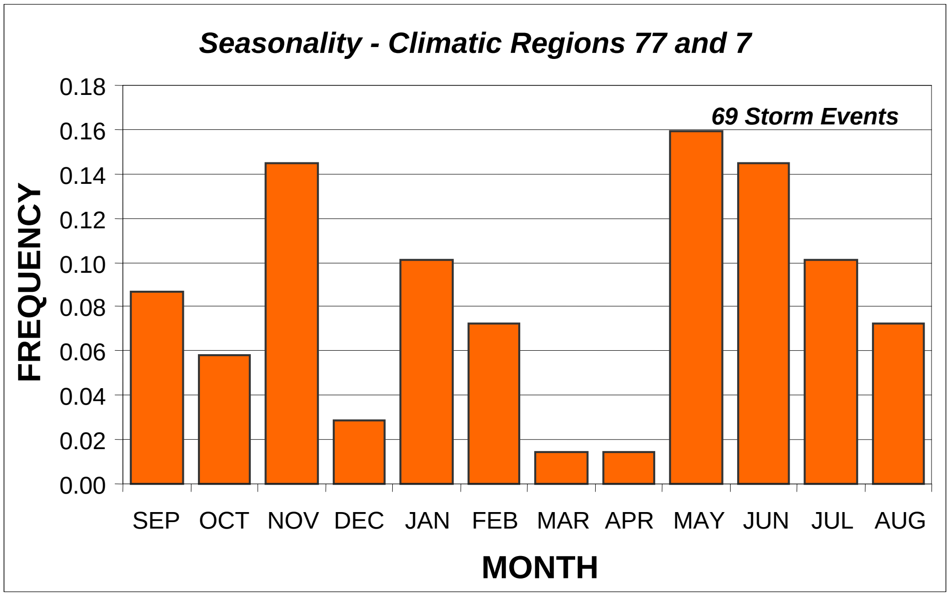

Figure 13.6: Seasonality of Extreme Storms in Climatic Regions 77 and 7 (Northeastern Oregon – Low Orographic Areas).

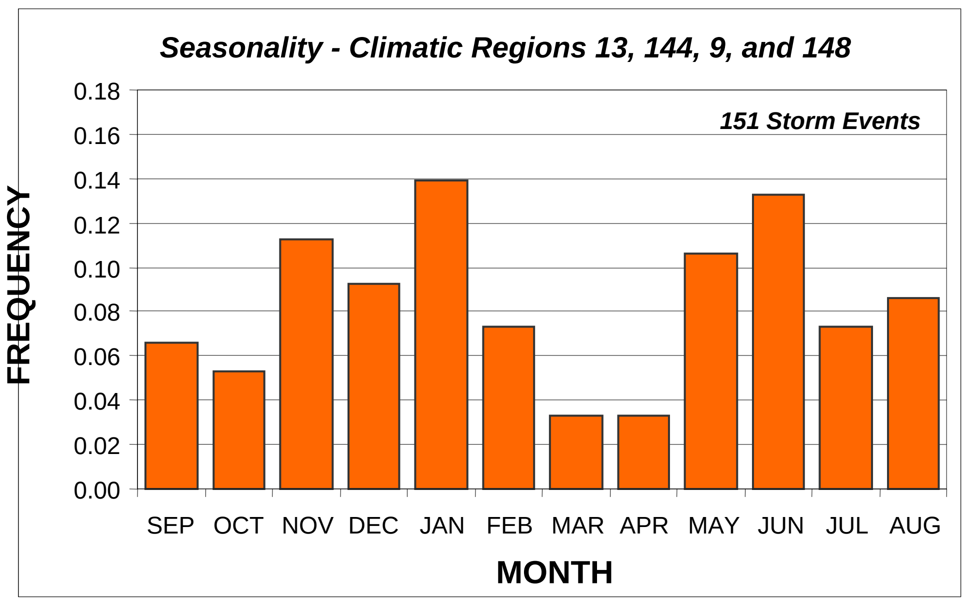

Figure 13.7: Seasonality of Extreme Storms in Climatic Regions 13, 144, 9, and 148 (Northeastern and Central Oregon – Mountainous Areas).

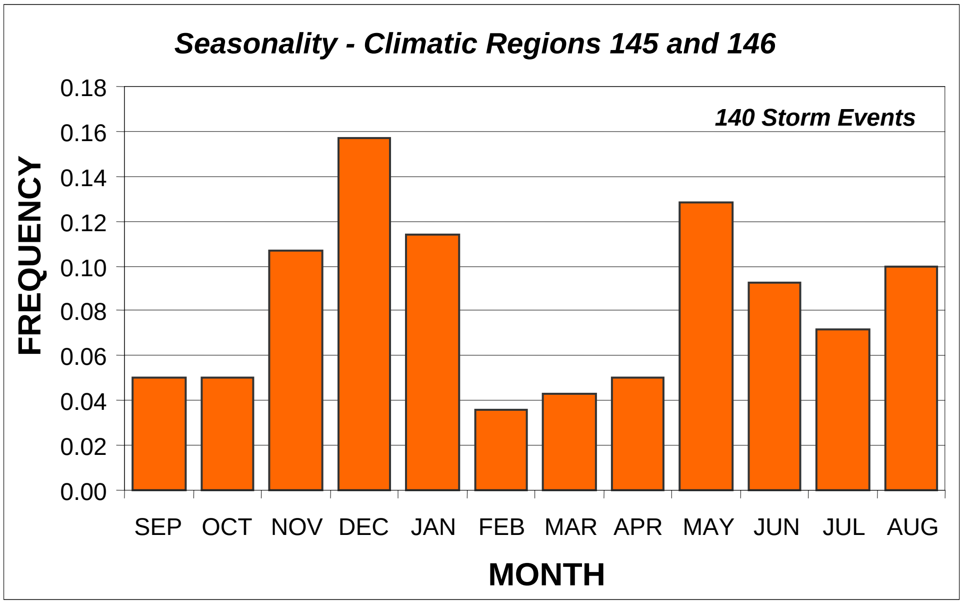

Figure 13.8: Seasonality of Extreme Storms in Climatic Regions 145 and 146 (Southeastern Oregon – Desert Mountain Areas).

14.0 SEASONALITY OF PRECIPITATION ANNUAL MAXIMA

Information on the seasonality of 24-hour annual maxima can be helpful early in the regional analysis for delineating climatic regions. Differences in the seasonality of annual maxima across a broad geographic area often indicate that there may also be systematic changes in L-Cv and L-Skewness across the area. Seasonality of annual maxima may be analyzed graphically, as depicted in the prior section. However, circular statistics are often more useful because they provide a quantitative measure of the differences in seasonality.

14.1 USE OF CIRCULAR STATISTICS FOR ASSESSING SEASONALITY OF 24-HOUR ANNUAL MAXIMA

Circular statistics are appropriate for seasonality analysis because of the continuous (circular) nature of the counting system for dates and months (*Fisher 1993*). For example, January (month 1) follows December (month 12). Arithmetic averaging of a group of numerical months or dates is not appropriate with conventional sample statistics because the counting system is circular not linear. Using circular statistics, the *average day of occurrence* is analogous to the arithmetic mean, and the *seasonality index* (*Dingman 2001*) is analogous to a standardized measure of variation. Specifically, values of the seasonality index range from zero to unity. Values near zero indicate a wide variation in the dates of occurrence. A seasonality index near unity indicates low variation in the dates of occurrence and strong clustering of dates.

Table 14.1 lists summary circular statistics for the various climatic regions. Review of values from the seasonality index, indicates that there are similar values for humid areas in western Oregon as there are on the eastern slopes of the Cascade Mountains. These relatively high values indicated strong clustering of 24-hour precipitation annual maxima in the fall and winter seasons. Graphics for seasonality of annual maxima for these climatic regions would be similar to that seen in Figures 13.1 through 13.5. By comparison, arid and semi-arid areas in the eastern portion of the study area had low seasonality index values, which indicated that the annual maxima occurred across a wide range of dates. These values were indicative of the wide variation in dates of annual maxima and would have a graphic depiction similar to that seen in Figures 13.6 through 13.8.

Review of Table 14.1 and Figures 2.1, 3.1, 3.2, 5.1-5.3 and 5.4 reveal that the seasonality index generally varies with mean annual precipitation (MAP). Climatic regions with larger MAP values tended to receive greater proportions of storms and annual maxima in the fall and winter seasons and had higher values of the seasonality index. This was true for regions in both the western and eastern portions of the study area, as mountain regions tended to have higher MAP and larger values of the seasonality index. Conversely, the driest climatic regions in the eastern portions of the study area had the lowest values of the seasonality index, with storms occurring throughout the year. The eastern Foothills of the Cascade Mountains (Zone 147) were a transition area where the annual maxima in the western areas were predominately fall-winter, and the frequency in eastern areas varied widely throughout the year. The value of the seasonality index in Transition Zone 147 was seen to be intermediate in magnitude between the wetter areas to the west and the drier areas to the east. The Rogue Valley (Region 8) was an interesting anomaly. The Rogue Valley exists in a rain-shadow that is down-slope from the Coastal Mountains and has generally low values of MAP. Yet the region has a high seasonality index because the annual maxima are caused by fall and winter storms. These findings are presented here as background information and as a supplement to the delineation of climatic regions presented earlier in this report. Equations for computation of circular statistics are presented in Appendix C.

Table 14.1: Summary of Circular Statistics for Seasonality of 24-Hour Annual Maxima for the Various Climatic Regions and Transition Zones.

Study Area	Region/Zone	Average Julian Day of Occurrence	Seasonality Index
Western Areas and East Slopes of the Cascade Mountains	Region 5 – Coastal Lowlands	362 (Dec)	0.697
	Region 151 – Windward Faces Coastal Mountains	360 (Dec)	0.764
	Region 142 – Leeward Areas Coastal Mountains	362 (Dec)	0.744
	Region 32 – Interior Lowlands - West	359 (Dec)	0.740
	Region 31 – Interior Lowlands - East	355 (Dec)	0.688
	Region 15 – West Slopes of Cascade Mountains	357 (Dec)	0.710
	Region 8 – Rogue Valley	353 (Dec)	0.695
	Region 143 – Klamath Mountains and West Slopes Cascade Mountains	358 (Dec)	0.730
	Zone 154 – Transition Zone Crest Cascades and Klamath Mountains	357 (Dec)	0.724
	Region 14 – East Slopes of Cascade Mountains	357 (Dec)	0.673
Eastern Areas	Zone 147 – Transition Zone Eastern Cascade Foothills	349 (Dec)	0.419
	Region 77 – Central Basin	338 (Dec)	0.178
	Region 7 – Pendleton-Palouse	043 (Feb)	0.159
	Region 13 – Wallowa and Blue Mountains	358 (Dec)	0.363
	Region 9 – Snake River Canyon	080 (Mar)	0.231
	Region 148 – Western Idaho Mountains	027 (Jan)	0.361
	Region 144 – Ochoco and Malheur	221 (Aug)	0.235
	Region 145 – Fremont and Warner	352 (Dec)	0.297
	Region 146 – Pueblo and Crooked Creek Mountains	107 (Apr)	0.289

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APPENDIX A

STATION CATALOG

OVERVIEW

This appendix includes a station catalog for the stations/gages used in the study for analysis of precipitation annual maxima at the 24-hour duration. This listing includes the station identification number, station name, type of gage, climatic region number, latitude, longitude, elevation, and mean annual precipitation. This appendix is also included as an electronic file on a compact disc (CD).

Table A-1.1: 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[4,20] (in)
450008	ABERDEEN	WA	46.966	-123.829	10	1891	2006	116	5	DY	83.2
350036	ADEL	OR	42.176	-119.896	4583	1956	2006	51	145	DY	10.8
20H13S	ADIN MTN	CA	41.250	-120.767	6200	1984	2006	23	145	Snotel	29.6
040029	ADIN RS	CA	41.200	-120.950	4193	1943	2006	64	145	DY	16.1
350041	ADRIAN	OR	43.733	-117.067	2231	1909	1972	64	9	DY	9.6
350078	ALBANY 1 N	OR	44.650	-123.100	210	1893	1963	71	32	DY	43.0
450094	ALDER DAM CAMP	WA	46.800	-122.317	1302	1917	1954	38	15	DY	47.8
350118	ALKALI LAKE	OR	42.969	-119.993	4332	1961	2006	46	145	DY	8.7
350126	ALLEGANY	OR	43.417	-124.017	50	1948	2006	59	5	HR	71.1
350145	ALSEA F H FALL CREEK	OR	44.404	-123.753	230	1954	2006	53	151	DY	87.5
040161	ALTURAS	CA	41.500	-120.533	4462	1905	2006	102	145	DY	12.2
450184	ANATONE	WA	46.133	-117.133	3573	1912	1981	70	13	DY	20.1
350188	ANDREWS 2 S	OR	42.433	-118.617	4104	1915	1942	28	146	DY	8.9
350189	ANDREWS WESTON MINE	OR	42.550	-118.550	4779	1969	1993	25	146	DY	17.8
17D02S	ANEROID LAKE #2	OR	45.214	-117.193	7300	1980	2006	27	13	Snotel	47.7
350197	ANTELOPE 6 SSW	OR	44.820	-120.753	3030	1924	2006	83	145	DY	13.8
350217	APPLEGATE	OR	42.245	-123.175	1282	1979	2006	28	8	DY	26.2
450217	APPLETON	WA	45.810	-121.282	2336	1959	2006	48	14	DY	33.7
19D02S	ARBUCKLE MTN	OR	45.191	-119.254	5400	1978	2006	29	13	Snotel	34.2
450242	ARIEL DAM	WA	45.950	-122.550	224	1930	1971	42	31	DY	73.6
350265	ARLINGTON	OR	45.721	-120.205	277	1893	2006	114	147	DY	9.1
350304	ASHLAND	OR	42.213	-122.714	1746	1892	2006	115	8	DY	20.2
350312	ASHWOOD 2 NE	OR	44.750	-120.717	2820	1945	2006	62	145	DY	13.7
450294	ASOTIN 14 SW	WA	46.201	-117.252	3500	1976	2006	31	13	DY	16.6
350318	ASTOR EXPERIMENT STN	OR	46.150	-123.817	49	1937	1973	37	5	DY	79.6
350324	ASTORIA	OR	46.183	-123.833	200	1892	1960	69	5	DY	77.8
350328	ASTORIA AP PORT OF	OR	46.150	-123.867	9	1953	2006	54	5	HR	71.7
350343	AURORA	OR	45.233	-122.749	98	1950	1969	20	31	DY	42.4
350356	AUSTIN 3 S	OR	44.575	-118.491	4213	1929	2006	78	13	DY	21.0
350409	BAKER #2	OR	44.767	-117.817	3467	1956	2006	51	13	HR	12.4
350412	BAKER CITY AIRPORT	OR	44.843	-117.809	3361	1943	2006	64	13	DY	10.7
350417	BAKER KBKR	OR	44.767	-117.833	3445	1928	1981	54	13	DY	12.2
350471	BANDON 2 NNE	OR	43.150	-124.402	20	1897	2006	110	5	DY	61.2
350501	BARNES STATION	OR	43.946	-120.217	3970	1961	2006	46	145	DY	13.6
450482	BATTLE GROUND	WA	45.779	-122.529	284	1928	2006	79	31	DY	52.5
260691	BATTLE MOUNTAIN 4 SE	NV	40.600	-116.883	4540	1948	2006	59	146	HR	9.1
16E11S	BEAR BASIN	ID	44.952	-116.143	5350	1981	2006	26	148	Snotel	36.7
16E10S	BEAR SADDLE	ID	44.604	-116.983	6180	1981	2006	26	9	Snotel	36.0
350571	BEAR SPRINGS RS	OR	45.117	-121.533	3360	1961	2006	46	14	HR	31.5
18D09S	BEAVER RESERVOIR	OR	45.145	-118.220	5150	1980	2006	27	13	Snotel	29.3
350595	BEAVERTON 2 SSW	OR	45.455	-122.820	270	1972	2006	35	32	DY	40.7
350631	BEECH CREEK	OR	44.567	-119.117	4715	1909	1949	41	144	DY	19.2

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
350652	BELKNAP SPRINGS 8 N	OR	44.287	-122.039	2152	1960	2006	47	15	DY	77.1
350673	BELLFOUNTAIN	OR	44.367	-123.350	322	1949	1977	29	32	HR	47.5
350694	BEND	OR	44.057	-121.285	3660	1901	2006	106	145	DY	11.7
350699	BEND 7 NE	OR	44.118	-121.211	3358	1991	2006	16	145	DY	10.3
450628	BENTON CITY 2 NW	WA	46.283	-119.500	679	1905	1964	60	77	DY	8.5
350723	BEULAH	OR	43.900	-118.150	3270	1948	2006	59	13	HR	11.9
450668	BICKLETON	WA	45.998	-120.301	3015	1927	2006	80	14	DY	13.9
040731	BIEBER	CA	41.117	-121.133	4125	1948	2006	59	145	HR	17.8
350753	BIG EDDY	OR	45.617	-121.117	131	1916	1957	42	14	DY	14.9
22G21S	BIG RED MOUNTAIN	OR	42.053	-122.855	6250	1980	2006	27	143	Snotel	54.5
23G15S	BIGELOW CAMP	OR	42.079	-123.344	5120	1980	2006	27	142	Snotel	65.0
22G13S	BILLIE CREEK DIVIDE	OR	42.407	-122.266	5300	1978	2006	29	154	Snotel	53.2
350773	BIRKENFELD 1 N	OR	46.000	-123.333	531	1939	1953	15	32	DY	73.5
350781	BLACKBUTTE 1 N	OR	43.583	-123.067	970	1948	2006	59	15	HR	58.9
21D33S	BLAZED ALDER	OR	45.428	-121.856	3650	1980	2006	27	15	Snotel	118.2
18E16S	BLUE MOUNTAIN SPRING	OR	44.248	-118.518	5900	1978	2006	29	13	Snotel	35.0
350853	BLY RANGER STN	OR	42.400	-121.033	4390	1949	2006	58	145	HR	14.5
350858	BOARDMAN	OR	45.840	-119.701	300	1971	2006	36	77	DY	8.5
101016	BOISE 3 E	ID	43.617	-116.117	3377	1972	2006	35	148	HR	19.9
101017	BOISE 7 N	ID	43.717	-116.200	3891	1973	2006	34	148	DY	17.8
101022	BOISE AIR TERMINAL	ID	43.567	-116.233	2814	1948	2006	59	148	HR	12.2
101018	BOISE LUCKY PEAK DAM	ID	43.517	-116.050	2840	1951	2006	56	148	HR	15.8
101022	BOISE WSFO AIRPORT	ID	43.567	-116.217	2858	1940	2006	67	148	DY	12.3
350897	BONNEVILLE DAM	OR	45.633	-121.950	62	1940	2006	67	154	HR	79.1
18E05S	BOURNE	OR	44.831	-118.188	5800	1978	2006	29	13	Snotel	34.3
18D20S	BOWMAN SPRINGS	OR	45.364	-118.467	4580	1978	2006	29	13	Snotel	28.4
351033	BRIGHTWOOD 1 WNW	OR	45.383	-122.033	978	1971	2000	30	15	HR	86.4
351055	BROOKINGS 2 SE	OR	42.030	-124.245	50	1912	2003	92	5	DY	71.9
450917	BROOKLYN	WA	46.783	-123.500	190	1927	1974	48	32	DY	82.2
351067	BROTHERS	OR	43.809	-120.600	4640	1959	2006	48	145	DY	9.2
101180	BROWNLEE DAM	ID	44.837	-116.898	1844	1966	2006	41	9	DY	17.1
16D09S	BRUNDAGE RESERVOIR	ID	45.043	-116.132	6300	1986	2006	21	148	Snotel	50.8
17H02S	BUCKSKIN LOWER	NV	41.751	-117.532	6700	1980	2006	27	146	Snotel	25.9
351124	BUENA VISTA STATION	OR	43.066	-118.868	4135	1957	2001	45	146	DY	9.8
450969	BUMPING LAKE	WA	46.867	-121.300	3442	1910	1967	58	14	DY	49.4
21C38S	BUMPING RIDGE	WA	46.810	-121.332	4600	1978	2006	29	154	Snotel	63.9
351149	BUNCOM 1 NNE	OR	42.183	-122.983	1949	1948	2006	59	143	HR	23.8
351174	BURNS JUNCTION	OR	42.777	-117.853	3930	1972	1999	28	146	DY	8.6
351175	BURNS MUNICIPAL AP	OR	43.583	-118.950	4140	1981	2006	26	145	HR	10.5
351176	BURNS WSO CITY	OR	43.583	-119.050	4141	1948	1981	34	145	HR	10.6
351207	BUTTE FALLS 1 SE	OR	42.533	-122.550	2500	1948	2006	59	143	HR	36.2
351222	BUXTON	OR	45.683	-123.183	355	1948	2006	59	32	HR	49.6
351227	BUXTON MOUNTAINDALE	OR	45.683	-123.067	360	1948	1975	28	32	HR	53.3
101380	CALDWELL 3 E	ID	43.667	-116.633	2421	1904	2006	103	9	DY	11.1
041316	CALLAHAN	CA	41.317	-122.800	3192	1943	2006	64	143	DY	22.2
101408	CAMBRIDGE	ID	44.573	-116.675	2650	1894	2006	113	148	DY	20.5
351324	CANARY	OR	43.917	-124.033	79	1932	1970	39	5	DY	84.5
351332	CANBY	OR	45.244	-122.686	94	1943	1966	24	31	DY	43.0
351329	CANBY 2 NE	OR	45.283	-122.667	89	1948	1979	32	31	DY	44.2
041476	CANBY RANGER STN	CA	41.450	-120.867	4310	1943	2006	64	145	DY	16.6
351352	CANYON CITY	OR	44.400	-118.950	3192	1938	1953	16	144	DY	15.4
351360	CAPE BLANCO	OR	42.833	-124.567	217	1952	1979	28	5	DY	76.4
451160	CARSON FISH HATCHERY	WA	45.868	-121.973	1134	1977	2006	30	154	DY	89.6
101514	CASCADE 1 NW	ID	44.523	-116.048	4896	1942	2006	65	148	DY	23.2
351407	CASCADE LOCKS	OR	45.683	-121.883	102	1894	1954	61	154	DY	78.7
351415	CASCADE SUMMIT	OR	43.583	-122.033	4843	1927	1947	21	154	DY	54.9

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
22F03S	CASCADE SUMMIT	OR	43.590	-122.060	4880	1980	2006	27	154	Snotel	60.3
351433	CASCADIA	OR	44.398	-122.486	860	1908	2006	99	15	DY	65.0
451189	CASTLE ROCK	WA	46.283	-122.900	112	1917	1941	25	31	DY	47.5
451191	CASTLE ROCK 2 NW	WA	46.267	-122.917	39	1954	1978	25	31	HR	47.7
451205	CATHLAMET 6 NE	WA	46.260	-123.299	180	1959	2006	48	32	DY	80.7
451207	CATHLAMET 9 NE	WA	46.317	-123.267	479	1937	1959	23	142	DY	87.2
351448	CAVE JUNCTION 1 WNW	OR	42.177	-123.675	1280	1962	2006	45	142	DY	61.8
041606	CECILVILLE	CA	41.142	-123.139	2310	1954	2003	50	143	DY	35.9
20H06S	CEDAR PASS	CA	41.583	-120.300	7100	1978	2006	29	145	Snotel	34.9
041614	CEDARVILLE	CA	41.534	-120.174	4670	1894	2006	113	145	DY	13.5
451257	CENTERVILLE 2 SW	WA	45.733	-120.950	1650	1941	1956	16	14	HR	16.1
451276	CENTRALIA	WA	46.720	-122.953	185	1902	2006	105	31	DY	46.5
351546	CHEMULT	OR	43.229	-121.789	4760	1937	2006	70	14	DY	27.1
21F22S	CHEMULT ALTERNATE	OR	43.226	-121.807	4760	1980	2006	27	14	Snotel	28.7
351552	CHERRY GROVE 2 S	OR	45.417	-123.250	781	1936	1983	48	32	DY	56.0
351571	CHILOQUIN 1 E	OR	42.583	-121.867	4193	1913	1979	67	14	DY	18.2
351574	CHILOQUIN 7 NW	OR	42.651	-121.948	4155	1980	2006	27	14	DY	20.6
451457	CINEBAR 2 E	WA	46.600	-122.483	1040	1941	2000	60	15	HR	65.9
21D13S	CLACKAMAS LAKE	OR	45.096	-121.753	3400	1980	2006	27	154	Snotel	55.3
451474	CLARKSTON HEIGHTS	WA	46.383	-117.083	1191	1937	1959	23	9	DY	14.6
351643	CLATSKANIE	OR	46.108	-123.206	22	1935	2006	72	32	DY	55.4
041799	CLEAR CREEK	CA	41.717	-123.450	981	1960	1977	18	143	DY	59.4
21D12S	CLEAR LAKE	OR	45.188	-121.691	3500	1980	2006	27	154	Snotel	50.8
041805	CLEAR LAKE DAM	CA	41.933	-121.067	4573	1907	1954	48	145	DY	15.0
351682	CLOVERDALE	OR	45.205	-123.893	187	1940	2006	67	5	DY	84.3
041886	COFFEE CREEK R S	CA	41.083	-122.700	2500	1961	2006	46	143	HR	53.7
22G24S	COLD SPRINGS CAMP	OR	42.533	-122.177	5880	1981	2006	26	154	Snotel	56.5
451586	COLFAX	WA	46.883	-117.350	1980	1892	1994	103	7	DY	19.8
351735	COLTON	OR	45.167	-122.417	680	1948	2006	59	31	HR	59.6
351765	CONDON	OR	45.233	-120.181	2840	1910	2006	97	7	DY	14.2
451690	CONNELL 1 W	WA	46.650	-118.867	1020	1960	2003	44	77	HR	8.8
451691	CONNELL 12 SE	WA	46.509	-118.788	1078	1951	2006	56	77	DY	10.2
041990	COPCO NO 1 DAM	CA	41.983	-122.333	2703	1959	2006	48	154	DY	20.7
351826	COPPER	OR	42.033	-123.133	1903	1948	1976	29	143	HR	28.6
351828	COPPER 4 NE	OR	42.067	-123.100	1820	1976	2006	31	143	HR	26.0
351836	COQUILLE CITY	OR	43.187	-124.203	23	1971	2006	36	5	DY	57.7
351852	CORNUCOPIA	OR	45.000	-117.200	4705	1909	1972	64	13	DY	48.1
351857	CORVALLIS	OR	44.566	-123.257	192	1936	1972	37	32	DY	43.5
351862	CORVALLIS STATE UNIV	OR	44.633	-123.189	225	1893	2006	114	32	DY	44.0
351877	CORVALLIS WATER BURE	OR	44.509	-123.458	592	1936	2006	71	32	DY	66.2
351897	COTTAGE GROVE 1 NNE	OR	43.808	-123.049	595	1916	2006	91	31	DY	45.4
351902	COTTAGE GROVE DAM	OR	43.718	-123.058	831	1943	2006	64	31	DY	49.6
102159	COTTONWOOD 2 WSW	ID	46.033	-116.383	3945	1948	2006	59	148	HR	22.5
451759	COUGAR 4 SW	WA	46.017	-122.350	520	1941	2006	66	15	HR	101.0
451760	COUGAR 6 E	WA	46.050	-122.200	659	1930	2006	77	15	DY	122.4
351914	COUGAR DAM	OR	44.117	-122.233	1260	1961	2006	46	15	HR	75.6
102187	COUNCIL	ID	44.750	-116.417	3153	1911	2006	96	148	DY	25.2
18D08S	COUNTY LINE	OR	45.191	-118.550	4800	1980	2006	27	13	Snotel	24.6
351926	COVE 1 E	OR	45.296	-117.790	3130	1917	2006	90	13	DY	22.6
102246	CRAIGMONT	ID	46.233	-116.467	3798	1980	1996	17	148	DY	22.3
351946	CRATER LAKE NPS HQ	OR	42.897	-122.133	6475	1919	2006	88	154	DY	66.6
042147	CRESCENT CITY 3 NNW	CA	41.796	-124.215	40	1893	2006	114	5	DY	64.9
042148	CRESCENT CITY 7 ENE	CA	41.800	-124.083	120	1953	2001	49	5	DY	82.9
042150	CRESCENT CITY MNTC S	CA	41.767	-124.200	49	1948	1984	37	5	HR	64.5
351978	CRESCENT LAKE JUNCTI	OR	43.533	-121.933	4764	1938	1973	36	14	DY	36.4
351998	CROW 6 ESE	OR	43.983	-123.233	502	1947	1968	22	31	DY	47.3

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
352010	CURTIN NEAR	OR	43.723	-123.209	400	1978	2006	29	31	DY	50.4
352112	DALLAS 2 NE	OR	44.946	-123.292	290	1935	2006	72	32	DY	49.4
451972	DALLESPORT 9 N	WA	45.750	-121.150	1923	1948	1980	33	14	DY	23.7
451968	DALLESPORT AP	WA	45.619	-121.167	235	1948	2006	59	14	DY	14.2
22E08S	DALY LAKE	OR	44.522	-122.087	3600	1980	2006	27	15	Snotel	88.3
042269	DANA 2 SE	CA	41.100	-121.517	3323	1959	1976	18	145	DY	29.4
352135	DANNER	OR	42.945	-117.339	4225	1929	2006	78	146	DY	12.3
042306	DAY	CA	41.200	-121.367	3650	1948	2006	59	145	HR	21.5
452030	DAYTON 1 WSW	WA	46.316	-118.001	1557	1893	2006	114	7	DY	19.8
452037	DAYTON 9 SE	WA	46.217	-117.850	2343	1940	1977	38	13	HR	32.7
352168	DAYVILLE	OR	44.467	-119.533	2362	1895	1978	84	144	DY	12.8
352173	DAYVILLE 8 NW	OR	44.556	-119.645	2260	1978	2006	29	144	DY	11.6
102444	DEER FLAT DAM	ID	43.576	-116.747	2510	1948	2006	59	9	DY	10.3
102451	DEER POINT	ID	43.750	-116.100	7156	1954	1970	17	148	DY	32.1
262229	DENIO	NV	41.990	-118.634	4190	1951	2006	56	146	DY	9.5
19E03S	DERR.	OR	44.446	-119.930	5670	1980	2006	27	144	Snotel	29.4
352277	DETROIT	OR	44.733	-122.150	1591	1909	1972	64	15	DY	81.2
352292	DETROIT DAM	OR	44.717	-122.250	1220	1955	2006	52	15	HR	89.3
352295	DEVILS FLAT	OR	42.817	-123.050	2030	1977	2006	30	143	HR	41.4
352305	DIAMOND 4 WNW	OR	43.033	-118.750	4163	1942	1957	16	146	DY	11.5
22F18S	DIAMOND LAKE	OR	43.188	-122.140	5315	1980	2006	27	154	Snotel	49.7
352325	DILLEY 1 S	OR	45.483	-123.124	165	1943	2006	64	32	DY	44.3
18H01S	DISASTER PEAK	NV	41.967	-118.189	6500	1980	2006	27	146	Snotel	21.0
20H12S	DISMAL SWAMP	CA	41.967	-120.167	7000	1980	2006	27	145	Snotel	49.1
352345	DISSTON 1 NE LAYING	OR	43.700	-122.733	1218	1948	2006	59	15	HR	56.6
452197	DIXIE 4 SE	WA	46.083	-118.100	2250	1940	2006	67	13	HR	39.6
352348	DIXIE MOUNTAIN	OR	45.683	-122.917	1430	1976	2006	31	32	HR	63.6
352370	DORA 2 W	OR	43.164	-123.996	95	1969	1999	31	5	DY	62.1
352371	DORAVILLE	OR	46.033	-123.033	751	1902	1936	35	32	DY	66.6
352374	DORENA DAM	OR	43.767	-122.950	820	1950	2006	57	31	HR	48.5
452220	DOTY 3 E	WA	46.633	-123.200	260	1958	2006	49	32	DY	55.5
352406	DRAIN	OR	43.666	-123.328	292	1902	2006	105	32	DY	48.1
352415	DREWSEY	OR	43.807	-118.376	3515	1970	2006	37	146	DY	10.7
452253	DRYAD	WA	46.633	-123.250	310	1937	1978	42	32	DY	55.8
352440	DUFUR	OR	45.455	-121.128	1330	1909	2006	98	14	DY	13.5
262394	DUFURRENA	NV	41.867	-119.017	4803	1959	2006	48	145	DY	7.3
042572	DUNSMUIR	CA	41.217	-122.267	2421	1906	1978	73	154	DY	59.5
042574	DUNSMUIR TREATMENT P	CA	41.200	-122.267	2170	1978	2006	29	154	DY	61.4
352482	DURKEE 3 NNW	OR	44.617	-117.483	2782	1948	1976	29	13	DY	11.6
102845	DWORSHAK FISH HATCHE	ID	46.500	-116.317	995	1967	2006	40	13	HR	25.5
352493	EAGLE CREEK 9 SE	OR	45.274	-122.202	926	1972	2006	35	15	DY	63.3
352564	ECHO	OR	45.750	-119.183	659	1903	1971	69	77	DY	10.6
18E03S	EILERTSON MEADOWS	OR	44.869	-118.114	5400	1980	2006	27	13	Snotel	30.2
452493	ELECTRON HEADWORKS	WA	46.900	-122.033	1732	1943	1980	38	15	DY	68.2
352597	ELGIN	OR	45.562	-117.920	2655	1937	2006	70	13	DY	24.0
16C20S	ELK BUTTE	ID	46.840	-116.123	5690	1982	2006	25	148	Snotel	60.8
102892	ELK RIVER 1 S	ID	46.783	-116.167	2913	1952	2006	55	148	DY	36.5
042749	ELK VALLEY	CA	41.987	-123.718	1705	1938	1976	39	142	DY	79.2
352633	ELKTON 3 SW	OR	43.595	-123.599	120	1936	2006	71	142	DY	52.5
452505	ELLENSBURG	WA	46.969	-120.540	1480	1893	2006	114	14	DY	9.2
452531	ELMA	WA	47.000	-123.400	70	1940	2006	67	32	DY	67.6
452542	ELTOPIA 8 WSW	WA	46.383	-119.150	700	1954	2006	53	77	DY	8.9
18D04S	EMIGRANT SPRINGS	OR	45.558	-118.454	3925	1980	2006	27	13	Snotel	35.5
102942	EMMETT 2 E	ID	43.854	-116.466	2390	1906	2006	101	148	DY	14.0
352678	ENTERPRISE 20 NNE	OR	45.708	-117.153	3280	1969	2006	38	13	DY	19.2
352672	ENTERPRISE R S	OR	45.426	-117.297	3815	1931	1981	51	13	DY	14.4

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
352693	ESTACADA 2 SE	OR	45.269	-122.319	450	1909	2006	98	31	DY	60.2
352697	ESTACADA 24 SE	OR	45.077	-121.971	2200	1920	1951	32	15	DY	57.9
352697	ESTACADA 24 SE	OR	45.067	-121.967	2200	1948	2006	59	15	HR	57.9
042899	ETNA	CA	41.450	-122.883	2950	1948	2006	59	143	HR	27.1
352706	EUGENE	OR	44.050	-123.083	390	1892	1945	54	31	DY	44.4
352709	EUGENE MAHLON SWEET	OR	44.117	-123.217	353	1948	2006	59	32	HR	44.5
352728	EULA	OR	43.833	-122.617	879	1923	1950	28	15	DY	55.4
042910	EUREKA WFO WOODLEY I	CA	40.800	-124.150	20	1948	2006	59	5	HR	40.6
352775	FAIRVIEW 4 NE	OR	43.259	-124.023	195	1974	2006	33	5	DY	69.7
352793	FALL RIVER HATCHERY	OR	43.767	-121.633	4304	1928	1942	15	14	DY	22.2
042964	FALL RIVER MILLS INT	CA	41.017	-121.467	3343	1923	2006	84	145	DY	21.0
352800	FALLS CITY 2 SSW	OR	44.836	-123.453	690	1896	1961	66	32	DY	73.5
352805	FALLS CITY NO 2	OR	44.858	-123.431	420	1961	2001	41	32	DY	66.2
16H08S	FAWN CREEK	NV	41.821	-116.101	7000	1980	2006	27	146	Snotel	31.7
352867	FERN RIDGE DAM	OR	44.117	-123.300	485	1948	2006	59	32	HR	44.5
18G02S	FISH CREEK	OR	42.711	-118.626	7900	1978	2006	29	146	Snotel	44.8
352928	FISH LAKE	OR	42.383	-122.350	4642	1918	1956	39	154	DY	45.0
22G14S	FISH LK.	OR	42.380	-122.349	4665	1980	2006	27	154	Snotel	45.3
352972	FLORENCE	OR	43.967	-124.100	12	1948	2006	59	5	HR	68.6
352974	FLOURNOY VALLEY	OR	43.191	-123.554	700	1978	1998	21	32	DY	45.0
355424	FORD EXPERIMENT S	OR	42.296	-122.870	1457	1937	2003	67	8	DY	20.9
352997	FOREST GROVE	OR	45.524	-123.103	197	1893	2006	114	32	DY	42.9
043157	FORT BIDWELL	CA	41.867	-120.150	4505	1911	2006	96	145	DY	18.2
043173	FORT DICK	CA	41.883	-124.133	59	1951	1988	38	5	DY	73.9
043176	FORT JONES 6 ESE	CA	41.583	-122.717	3323	1948	1977	30	143	HR	24.7
043182	FORT JONES RANGER ST	CA	41.600	-122.850	2723	1936	2006	71	143	DY	21.3
353038	FOSSIL	OR	44.999	-120.211	2650	1923	2006	84	7	DY	15.0
353047	FOSTER DAM	OR	44.400	-122.667	550	1970	2006	37	15	HR	54.1
22G12S	FOURMILE LAKE	OR	42.439	-122.229	6000	1978	2006	29	154	Snotel	52.0
452984	FRANCES	WA	46.550	-123.500	231	1941	2006	66	142	HR	96.8
353095	FREMONT 5 NW	OR	43.394	-121.212	4609	1909	1996	88	145	DY	12.5
353121	FRIEND	OR	45.350	-121.267	2441	1923	1976	54	14	DY	16.6
353193	GARDINER 1 N	OR	43.746	-124.122	30	1983	2006	24	5	DY	70.1
043357	GASQUET RANGER STN	CA	41.850	-123.967	384	1948	2006	59	151	DY	90.4
353232	GERBER DAM	OR	42.205	-121.131	4850	1925	1956	32	145	DY	18.6
353232	GERBER DAM	OR	42.200	-121.117	4850	1958	2006	49	145	HR	18.5
353250	GIBBON	OR	45.700	-118.367	1739	1972	1995	24	13	DY	28.0
353305	GLENDALE	OR	42.733	-123.417	1385	1950	2006	57	143	HR	40.3
453177	GLENOMA	WA	46.517	-122.133	840	1906	2004	99	15	DY	68.7
453183	GLENWOOD	WA	46.017	-121.283	1896	1941	2006	66	14	HR	32.3
353318	GLENWOOD 2 WNW	OR	45.650	-123.300	644	1948	2006	59	142	HR	61.7
353340	GOBLE 3 SW	OR	45.983	-122.917	530	1948	2006	59	32	HR	54.9
353356	GOLD BEACH RANGER ST	OR	42.404	-124.424	50	1948	2006	59	5	DY	77.9
18E08S	GOLD CENTER	OR	44.764	-118.312	5340	1980	2006	27	13	Snotel	26.1
453222	GOLDENDALE	WA	45.817	-120.817	1657	1906	2006	101	14	DY	16.6
353402	GOVERNMENT CAMP	OR	45.300	-121.733	3980	1955	2006	52	15	HR	88.9
353421	GRAND RONDE TREE FAR	OR	45.050	-123.617	395	1948	2006	59	5	HR	62.6
103760	GRAND VIEW	ID	42.983	-116.100	2362	1909	2006	98	9	DY	7.1
103771	GRANGEVILLE	ID	45.930	-116.115	3360	1922	2006	85	148	DY	23.9
353430	GRANITE 4 WSW	OR	44.800	-118.500	4944	1947	1967	21	13	DY	27.8
17H08S	GRANITE PEAK	NV	41.671	-117.566	7800	1980	2006	27	146	Snotel	34.1
353445	GRANTS PASS	OR	42.424	-123.324	930	1893	2006	114	8	DY	31.2
103811	GRASMERE 3 S	ID	42.333	-115.883	5140	1963	2006	44	146	HR	9.4
453320	GRAYLAND	WA	46.801	-124.086	10	1953	2006	54	5	DY	74.4
453333	GRAYS RIVER HATCHERY	WA	46.383	-123.567	100	1954	2006	53	5	HR	112.9
21C10S	GREEN LAKE	WA	46.548	-121.171	6000	1982	2006	25	14	Snotel	38.1

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
353509	GREEN SPRINGS POWER	OR	42.126	-122.545	2435	1960	2006	47	143	DY	23.3
21D01S	GREENPOINT	OR	45.622	-121.704	3200	1979	2006	28	14	Snotel	74.1
043614	GREENVIEW	CA	41.552	-122.907	2820	1943	2006	64	143	DY	23.2
353521	GRESHAM	OR	45.483	-122.417	310	1948	2006	59	31	HR	56.9
353542	GRIZZLY	OR	44.518	-120.939	3635	1934	2006	73	145	DY	13.3
353604	HALFWAY	OR	44.878	-117.113	2665	1936	2006	71	9	DY	21.3
453444	HANFORD A E C	WA	46.567	-119.583	722	1912	1944	33	77	DY	8.0
043761	HAPPY CAMP RANGER ST	CA	41.804	-123.376	1120	1914	2006	93	143	DY	50.8
353659	HARNEY BRANCH EXPERI	OR	43.583	-118.933	4144	1922	1954	33	145	DY	10.5
353666	HARPER	OR	43.867	-117.617	2513	1919	1975	57	146	DY	10.2
043791	HARRISON GULCH R S	CA	40.350	-122.950	2750	1949	2006	58	154	HR	37.1
353692	HART MOUNTAIN REFUGE	OR	42.548	-119.656	5616	1939	2006	68	145	DY	11.8
353705	HASKINS DAM	OR	45.300	-123.350	756	1948	2006	59	142	HR	75.1
043821	HAT CREEK RANGER STN	CA	40.800	-121.500	3353	1948	1975	28	145	HR	25.3
453546	HATTON 9 SE	WA	46.722	-118.651	1510	1905	2006	102	77	DY	10.2
353737	HAY CREEK	OR	44.950	-120.900	2943	1919	1944	26	145	DY	13.6
353770	HEADWORKS PTLD WTR B	OR	45.450	-122.154	748	1899	2006	108	15	DY	79.8
353827	HEPPNER	OR	45.365	-119.564	1885	1893	2006	114	7	DY	14.3
353830	HEPPNER 5 SSE	OR	45.283	-119.517	3240	1975	2006	32	7	HR	15.9
353847	HERMISTON 1 SE	OR	45.829	-119.264	640	1906	2006	101	77	DY	9.6
18D19S	HIGH RIDGE	OR	45.697	-118.105	4980	1978	2006	29	13	Snotel	48.1
353915	HILLS CREEK DAM	OR	43.700	-122.417	1247	1961	2006	46	15	HR	49.7
353908	HILLSBORO	OR	45.514	-122.990	160	1929	2003	75	32	DY	40.0
043987	HILTS SLASH DISPOSAL	CA	42.000	-122.617	2923	1939	1984	46	143	DY	24.1
21E06S	HOGG PASS	OR	44.421	-121.857	4760	1979	2006	28	154	Snotel	88.1
22F42S	HOLLAND MEADOWS	OR	43.669	-122.569	4900	1980	2006	27	15	Snotel	77.2
353971	HOLLEY	OR	44.353	-122.784	610	1940	2006	67	31	DY	50.7
104318	HOMEDALE 1 SE	ID	43.617	-116.917	2230	1990	2006	17	9	DY	9.1
353995	HONEYMAN STATE PARK	OR	43.929	-124.106	115	1971	2006	36	5	DY	71.1
354008	HOOD RIVER TUCKER BR	OR	45.650	-121.533	383	1941	2006	66	14	HR	32.0
044089	HOOPA	CA	41.033	-123.667	333	1948	2006	59	143	HR	55.3
453807	HOQUIAM BOWERMAN AP	WA	46.973	-123.930	12	1953	2006	54	5	DY	72.5
354060	HOWARD PRAIRIE DAM	OR	42.229	-122.381	4567	1960	2006	47	154	DY	32.6
354098	HUNTINGTON	OR	44.356	-117.255	2110	1901	2006	106	9	DY	14.0
044191	HYAMPOM	CA	40.600	-123.450	1275	1948	2006	59	143	HR	45.1
453883	ICE HARBOR DAM	WA	46.245	-118.879	368	1957	2006	50	77	DY	10.2
104450	IDAHO CITY 11 SW	ID	43.717	-116.000	5003	1948	1963	16	148	DY	28.1
044202	IDLEWILD HWY MNTNC S	CA	41.900	-123.767	1250	1959	1977	19	142	DY	78.7
354126	IDLEYLD PARK 4 NE	OR	43.371	-122.965	1080	1958	2006	49	15	DY	63.3
354133	ILLAHE	OR	42.629	-124.058	348	1938	2006	69	151	DY	82.7
354161	IONE 18 S	OR	45.318	-119.857	2130	1935	2006	72	77	DY	12.6
21F21S	IRISH TAYLOR	OR	43.804	-121.949	5500	1978	2006	29	154	Snotel	70.4
354175	IRONSIDE 2 W	OR	44.325	-117.996	3915	1955	2004	50	13	DY	12.4
16H02S	JACK CREEK UPPER	NV	41.547	-116.009	7250	1978	2006	29	146	Snotel	29.2
16H04S	JACKS PEAK	NV	41.517	-116.018	8420	1981	2006	26	146	Snotel	35.5
354216	JACKSONVILLE	OR	42.300	-122.983	1640	1893	1948	56	8	DY	24.0
044374	JESS VALLEY	CA	41.268	-120.295	5400	1948	2006	59	145	DY	18.0
354276	JEWELL WILDLIFE MEAD	OR	45.941	-123.528	570	1919	1943	25	142	DY	108.0
354276	JEWELL WILDLIFE MEAD	OR	45.933	-123.517	570	1954	2006	53	142	HR	102.6
354291	JOHN DAY	OR	44.423	-118.959	3063	1953	2006	54	144	DY	13.9
354321	JORDAN VALLEY	OR	42.967	-117.050	4390	1949	2006	58	146	HR	14.0
354329	JOSEPH	OR	45.346	-117.225	4260	1893	1954	62	13	DY	18.6
22E07S	JUMP OFF JOE	OR	44.386	-122.167	3500	1978	2006	29	15	Snotel	88.7
22C09S	JUNE LAKE	WA	46.148	-122.155	3340	1982	2006	25	15	Snotel	166.6
354357	JUNTURA 9 ENE	OR	43.800	-117.933	2830	1963	1996	34	146	DY	10.7
454077	KAHLOTUS 5 SSW	WA	46.583	-118.600	1552	1914	1996	83	77	DY	10.7

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
454085	KALAMA 5 ENE	WA	46.050	-122.750	902	1917	1967	51	15	DY	63.5
454084	KALAMA FALLS HATCHER	WA	46.016	-122.733	310	1967	2006	40	15	DY	69.1
104793	KAMIAH	ID	46.233	-116.017	1191	1913	2006	94	148	DY	24.1
454131	KELSO	WA	46.143	-122.916	20	1923	1953	31	31	DY	45.0
454154	KENNEWICK	WA	46.211	-119.101	390	1894	2006	113	77	DY	7.8
454159	KENNEWICK 10 SW	WA	46.133	-119.300	1503	1949	1974	26	77	DY	9.9
354403	KENO	OR	42.130	-121.930	4116	1927	2006	80	14	DY	20.0
354411	KENT	OR	45.197	-120.699	2598	1922	2004	83	77	DY	12.4
354420	KERBY	OR	42.217	-123.650	1270	1949	1967	19	142	HR	63.1
354426	KERBY 3 NNW	OR	42.217	-123.650	1210	1967	2006	40	142	HR	63.1
454201	KID VALLEY	WA	46.367	-122.617	689	1938	1980	43	15	DY	61.4
23G09S	KING MOUNTAIN	OR	42.724	-123.200	4000	1980	2006	27	142	Snotel	62.9
264236	KINGS RIVER VALLEY	NV	41.750	-118.233	423	1956	2006	51	146	DY	8.9
044577	KLAMATH	CA	41.567	-124.067	28	1948	2006	59	5	HR	73.5
354506	KLAMATH FALLS 2 SSW	OR	42.201	-121.781	4098	1898	2001	104	147	DY	13.9
354511	KLAMATH FALLS AG STA	OR	42.164	-121.755	4092	1948	2006	59	147	DY	12.5
044587	KNEELAND 10 SSE	CA	40.633	-123.900	2450	1954	2006	53	151	HR	62.8
454286	KOSMOS	WA	46.500	-122.183	781	1905	1965	61	15	DY	64.6
105038	KUNA 2 NNE	ID	43.517	-116.400	2690	1926	1996	71	9	DY	10.8
454328	LA CENTER	WA	45.850	-122.650	200	1896	1940	45	31	DY	48.3
354622	LA GRANDE	OR	45.317	-118.075	2755	1948	2006	59	13	DY	17.1
454360	LA GRANDE	WA	46.833	-122.317	961	1954	1983	30	15	DY	39.3
354620	LA GRANDE CAA AIRPOR	OR	45.283	-118.017	2707	1948	1966	19	13	HR	14.0
354603	LACOMB 1 WNW	OR	44.583	-122.750	650	1948	1987	40	31	HR	48.4
354606	LACOMB 3 NNE	OR	44.625	-122.719	520	1973	2006	34	31	DY	57.5
454338	LACROSSE	WA	46.816	-117.881	1450	1908	2006	99	7	DY	14.8
354632	LAKE 2 N	OR	43.267	-120.633	4366	1909	1978	70	145	DY	9.5
044675	LAKE CITY	CA	41.633	-120.217	4613	1929	1960	32	145	DY	21.4
354634	LAKE CREEK 2 S	OR	42.390	-122.626	1865	1955	1972	18	143	DY	26.0
354633	LAKE CREEK 3 NE	OR	42.450	-122.567	2400	1978	1995	18	143	DY	30.1
354635	LAKE CREEK 6 SE	OR	42.367	-122.533	1752	1917	1953	37	143	DY	30.2
18E18S	LAKE CREEK R.S.	OR	44.210	-118.638	5200	1981	2006	26	13	Snotel	25.5
354670	LAKEVIEW 2 NNW	OR	42.214	-120.364	4778	1893	2006	114	145	DY	15.8
17H07S	LAMANCE CREEK	NV	41.515	-117.631	6000	1980	2006	27	146	Snotel	29.8
354721	LANGLOIS #2	OR	42.924	-124.453	90	1956	2006	51	5	DY	74.8
105132	LAPWAI	ID	46.400	-116.800	889	1916	1938	23	9	DY	17.8
16H05S	LAUREL DRAW	NV	41.777	-116.028	6700	1979	2006	28	146	Snotel	26.0
354776	LAUREL MOUNTAIN	OR	44.923	-123.575	3589	1978	2006	29	142	DY	124.7
044838	LAVA BEDS NAT MONUME	CA	41.740	-121.507	4770	1959	2006	48	145	DY	14.6
354811	LEABURG 1 SW	OR	44.100	-122.688	675	1933	2006	74	15	DY	65.3
354824	LEES CAMP	OR	45.583	-123.517	655	1948	2006	59	151	HR	124.6
354835	LEMOLO LAKE 3 NNW	OR	43.360	-122.221	4077	1978	2006	29	154	DY	65.1
264527	LEONARD CREEK RANCH	NV	41.517	-118.719	4224	1954	2006	53	145	DY	9.6
105236	LEWISTON	ID	46.417	-117.017	810	1895	1955	61	9	DY	13.6
105241	LEWISTON AP	ID	46.367	-117.000	1436	1950	2006	57	9	HR	17.2
454679	LIND 3 NE	WA	46.998	-118.571	1630	1931	2006	76	77	DY	10.1
454702	LITTLE GOOSE DAM	WA	46.583	-118.033	702	1964	1979	16	77	HR	12.6
22E09S	LITTLE MEADOWS	OR	44.613	-122.226	4000	1980	2006	27	15	Snotel	111.8
354939	LITTLE RIVER	OR	43.233	-122.987	1060	1955	2006	52	15	DY	52.4
355008	LONDON	OR	43.650	-123.083	932	1947	1967	21	31	DY	52.4
21C26S	LONE PINE	WA	46.272	-121.964	3800	1981	2006	26	15	Snotel	100.8
454752	LONG BEACH 3 NNE	WA	46.383	-124.033	30	1953	1967	15	5	DY	78.3
454748	LONG BEACH EXP STN	WA	46.367	-124.033	30	1953	2006	54	5	DY	80.3
355020	LONG CREEK	OR	44.714	-119.101	3740	1957	2006	50	144	DY	16.6
454764	LONGMIRE RAINIER NPS	WA	46.750	-121.817	2762	1909	2006	98	15	DY	84.7
454769	LONGVIEW	WA	46.151	-122.916	12	1925	2006	82	31	DY	46.1

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
355026	LOOKINGGLASS	OR	43.181	-123.485	622	1978	2006	29	32	DY	39.4
045093	LOOKOUT 3 WSW	CA	41.200	-121.200	4183	1963	1977	15	145	DY	21.9
355050	LOOKOUT POINT DAM	OR	43.900	-122.750	712	1955	2006	52	15	HR	48.1
355055	LOST CREEK DAM	OR	42.667	-122.667	1580	1970	2006	37	143	HR	34.2
21C39S	LOST HORSE	WA	46.357	-121.081	5000	1990	2006	17	14	Snotel	34.9
264698	LOVELOCK	NV	40.183	-118.467	3975	1952	2006	55	145	HR	5.8
355080	LOWER HAY CREEK	OR	44.733	-120.975	1887	1938	2006	69	145	DY	11.1
454841	LOWER MONUMENTL DAM	WA	46.550	-118.533	460	1963	1979	17	77	HR	10.5
18D06S	LUCKY STRIKE	OR	45.275	-118.848	5050	1978	2006	29	13	Snotel	28.5
045231	MADELINE	CA	41.067	-120.483	5262	1908	1975	68	145	DY	14.7
19D03S	MADISON BUTTE	OR	45.105	-119.496	5250	1980	2006	27	13	Snotel	22.2
355139	MADRAS	OR	44.617	-121.001	3372	1920	2006	87	145	DY	10.7
355142	MADRAS 2 N	OR	44.666	-121.144	2414	1974	2006	33	145	DY	11.6
355160	MALHEUR BRANCH EXP S	OR	43.979	-117.025	2260	1942	2006	65	9	DY	10.2
355162	MALHEUR REFUGE HDQ	OR	43.266	-118.843	4109	1959	2006	48	146	DY	10.2
355170	MALIN	OR	42.017	-121.417	4052	1925	1946	22	145	DY	11.8
355174	MALIN 5 E	OR	42.008	-121.319	4627	1968	2006	39	145	DY	13.9
355206	MAPLETON 2 NNW	OR	44.050	-123.867	41	1975	2006	32	5	HR	83.6
355213	MARCOLA	OR	44.167	-122.867	545	1948	2006	59	31	HR	51.7
355218	MARIAL 7 N	OR	42.817	-123.900	2313	1956	1984	29	142	HR	90.8
21E04S	MARION FORKS	OR	44.594	-121.974	2600	1980	2006	27	15	Snotel	81.0
355221	MARION FRKS FISH HAT	OR	44.600	-121.933	2475	1948	2006	59	154	HR	77.2
355258	MASON DAM	OR	44.672	-117.994	3900	1969	2006	38	13	DY	17.0
455105	MAYFIELD	WA	46.483	-122.517	600	1893	1937	45	31	DY	59.7
455110	MAYFIELD POWER PLANT	WA	46.504	-122.594	280	1980	2006	27	31	DY	58.1
045449	MC CLOUD	CA	41.267	-122.133	3304	1909	2006	98	14	DY	51.4
355335	MC DERMITT 26 N	OR	42.411	-117.866	4464	1955	2006	52	146	DY	9.3
355357	MC KENZIE BRIDGE	OR	44.183	-122.167	1371	1954	1970	17	15	DY	76.4
355362	MC KENZIE BRIDGE R S	OR	44.178	-122.116	1478	1931	2006	76	15	DY	66.7
355384	MC MINNVILLE	OR	45.221	-123.162	98	1894	2006	113	32	DY	42.8
105708	MCCALL	ID	44.887	-116.105	5025	1905	2006	102	148	DY	27.4
264935	MCDERMITT	NV	41.983	-117.717	4527	1950	2006	57	146	HR	9.1
21E07S	MCKENZIE	OR	44.210	-121.873	4800	1981	2006	26	154	Snotel	95.7
355362	MCKENZIE BRIDGE RS	OR	44.167	-122.100	1478	1948	1975	28	15	HR	68.8
355375	MCKINLEY	OR	43.183	-124.033	141	1897	1944	48	5	DY	62.8
455231	MCNARY DAM	WA	45.941	-119.298	361	1954	2006	53	77	DY	8.5
355396	MEACHAM WSO AIRPORT	OR	45.500	-118.400	4050	1948	2006	59	13	DY	33.4
355429	MEDFORD INTL AP	OR	42.381	-122.872	1297	1928	2006	79	8	DY	18.4
355447	MEHAMA	OR	44.783	-122.617	620	1923	1966	44	15	DY	68.4
105841	MERIDIAN 1 SSW	ID	43.600	-116.400	2612	1911	1960	50	9	DY	11.4
355505	MERRILL 2 NW	OR	42.050	-121.633	4198	1949	1968	20	147	DY	12.0
455305	MERWIN DAM	WA	45.950	-122.550	224	1934	2006	73	31	DY	70.2
355515	METOLIUS 1 W	OR	44.583	-121.183	2503	1945	1993	49	145	DY	10.4
265105	MIDAS 4 SE	NV	41.200	-116.733	5203	1952	1969	18	146	DY	11.4
355545	MIKKALO 6 W	OR	45.467	-120.350	1550	1948	1994	47	77	DY	10.9
455377	MILL CREEK	WA	46.017	-118.117	2001	1915	1973	59	13	DY	45.8
455387	MILL CREEK DAM	WA	46.076	-118.274	1175	1948	2006	59	7	DY	19.6
355593	MILTON FREEWATER	OR	45.943	-118.409	970	1928	2006	79	7	DY	16.0
355610	MINAM 7 NE	OR	45.683	-117.600	3616	1955	1985	31	13	DY	26.9
455425	MINERAL 1 SW	WA	46.717	-122.183	1470	1935	1980	46	15	DY	82.5
355621	MIRA MONTE FARM	OR	45.267	-122.750	161	1893	1924	32	31	DY	42.4
355641	MITCHELL 2 NW	OR	44.583	-120.183	2645	1931	1994	64	144	DY	12.1
355656	MODOC ORCHARD	OR	42.450	-122.883	1220	1915	1966	52	8	DY	21.7
355677	MOLALLA	OR	45.150	-122.567	400	1935	1976	42	31	DY	45.0
355707	MONTGOMERY RANCH	OR	44.617	-121.483	1903	1930	1949	20	147	DY	16.1
355711	MONUMENT 2	OR	44.818	-119.419	1995	1961	2006	46	7	DY	14.8

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
355715	MONUMENT RANGER STN	OR	44.817	-119.417	1981	1948	2006	59	7	HR	14.8
355726	MORGAN 3 NE	OR	45.583	-119.883	951	1923	1979	57	77	DY	9.5
355734	MORO	OR	45.482	-120.724	1870	1917	2006	90	147	DY	11.6
21C17S	MORSE LAKE	WA	46.906	-121.483	5400	1978	2006	29	15	Snotel	83.9
106148	MOSCOW 5 NE	ID	46.783	-116.917	3000	1972	2006	35	148	HR	31.9
106152	MOSCOW U OF I	ID	46.733	-117.000	2631	1893	2006	114	148	DY	26.4
17D06S	MOSS SPRINGS	OR	45.272	-117.688	5850	1980	2006	27	13	Snotel	50.6
455656	MOTTINGER	WA	45.933	-119.150	312	1899	1946	48	77	DY	8.9
455659	MOUNT ADAMS RANGER S	WA	46.000	-121.540	1950	1924	2006	83	14	DY	42.6
355770	MOUNT ANGEL	OR	45.067	-122.750	489	1893	1926	34	31	DY	45.5
045941	MOUNT HEBRON RNG STN	CA	41.784	-122.045	4250	1942	2006	65	14	DY	12.6
045983	MOUNT SHASTA	CA	41.317	-122.300	3590	1948	2006	59	154	HR	41.7
455686	MOXEE	WA	46.583	-120.433	1001	1892	1945	54	77	DY	8.8
455688	MOXEE CITY 10 E	WA	46.500	-120.150	1550	1901	2006	106	77	DY	8.3
21D08S	MT HOOD TEST SITE	OR	45.321	-121.716	5400	1980	2006	27	154	Snotel	110.7
17D18S	MT. HOWARD	OR	45.265	-117.173	7910	1980	2006	27	13	Snotel	44.5
16G07S	MUD FLAT	ID	42.600	-116.559	5730	1980	2006	27	146	Snotel	17.8
21D35S	MUD RIDGE	OR	45.254	-121.737	3800	1978	2006	29	154	Snotel	71.5
355892	MYRTLE CREEK 12 ENE	OR	43.050	-123.067	1191	1955	1980	26	15	DY	41.2
355891	MYRTLE CREEK 8 NE	OR	43.091	-123.167	825	1980	2006	27	15	DY	39.9
356151	N WILLAMETTE EXP STN	OR	45.282	-122.752	98	1963	2006	44	31	DY	42.5
455736	NACHES HEIGHTS	WA	46.650	-120.633	1870	1910	1948	39	147	DY	11.1
106300	NAMPA 2 NW	ID	43.617	-116.583	2470	1946	1960	15	9	DY	10.6
106305	NAMPA SUGAR FACTORY	ID	43.600	-116.567	2470	1976	2006	31	9	DY	10.5
455774	NASELLE 2 ENE	WA	46.373	-123.753	50	1929	2006	78	5	DY	112.0
355969	NEHALEM	OR	45.717	-123.900	75	1948	2006	59	5	HR	99.4
355971	NEHALEM 9 NE	OR	45.814	-123.775	140	1969	2006	38	5	DY	119.8
21F10S	NEW CRESCENT LAKE	OR	43.512	-121.980	4800	1980	2006	27	154	Snotel	41.8
106388	NEW MEADOWS RANG S	ID	44.967	-116.283	3862	1905	2006	102	148	DY	24.7
356032	NEWPORT	OR	44.643	-124.056	122	1893	2006	114	5	DY	69.1
106424	NEZPERCE	ID	46.250	-116.200	3251	1948	2006	59	148	DY	21.8
356073	NORTH BEND FCWOS	OR	43.413	-124.244	6	1902	2006	105	5	DY	64.8
22D02S	NORTH FORK	OR	45.550	-122.003	3170	1979	2006	28	15	Snotel	143.2
356171	NOTI 2 ESE	OR	44.050	-123.417	449	1948	1984	37	32	HR	57.8
356179	NYSSA	OR	43.876	-116.990	2175	1937	2006	70	9	DY	10.5
356302	O O RANCH	OR	43.278	-119.311	4136	1950	2006	57	145	DY	10.2
046329	OAK KNOLL RANGER STN	CA	41.850	-122.883	1700	1972	2006	35	143	DY	24.7
046328	OAK KNOLL W C	CA	41.839	-122.850	1980	1943	2006	64	143	DY	25.3
356200	OAKLAND	OR	43.423	-123.300	430	1978	2006	29	31	DY	40.6
356213	OAKRIDGE FISH HATCHE	OR	43.743	-122.443	1275	1914	2006	93	15	DY	46.1
456011	OAKVILLE	WA	46.833	-123.233	80	1916	1997	82	32	DY	57.7
356238	OCHOCO DAM	OR	44.283	-120.717	3057	1949	2006	58	145	HR	11.8
20E02S	OCHOCO MEADOWS	OR	44.429	-120.331	5200	1980	2006	27	144	Snotel	29.0
356243	OCHOCO RANGER STATIO	OR	44.400	-120.433	3975	1909	2004	96	144	DY	16.2
356251	ODELL LAKE	OR	43.583	-122.050	4793	1948	1973	26	154	DY	58.9
356252	ODELL LAKE EAST	OR	43.549	-121.964	4800	1974	2006	33	154	DY	35.5
356254	ODELL LAKE WATER PAN	OR	43.583	-122.050	4793	1945	1959	15	154	DY	58.9
106586	OLA	ID	44.167	-116.267	3075	1948	2006	59	148	HR	23.3
356269	OLIVE LAKE	OR	44.783	-118.600	5945	1920	1947	28	13	DY	33.0
456114	OLYMPIA AIRPORT	WA	46.973	-122.903	188	1948	2006	59	32	DY	50.3
356294	ONTARIO KSRV	OR	44.033	-116.967	2145	1949	2006	58	9	HR	9.6
356334	OREGON CITY	OR	45.355	-122.605	167	1911	2006	96	31	DY	45.5
046498	ORICK PRAIRIE CREEK	CA	41.367	-124.017	160	1937	2006	70	151	DY	67.6
046508	ORLEANS	CA	41.309	-123.532	400	1903	2006	104	143	DY	52.9
106681	OROFINO	ID	46.483	-116.250	1030	1903	1981	79	148	DY	24.5
265818	OROVADA 4 WSW	NV	41.550	-117.833	429	1911	2006	96	146	DY	10.4

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
456215	OTHELLO 6 ESE	WA	46.789	-119.046	1190	1941	2002	62	77	DY	8.5
356366	OTIS 2 NE	OR	45.033	-123.924	150	1948	2006	59	5	DY	97.9
265869	OWYHEE	NV	41.950	-116.100	5397	1948	1975	28	146	HR	14.5
356405	OWYHEE DAM	OR	43.650	-117.247	2400	1935	2006	72	9	DY	9.9
356853	P RANCH REFUGE	OR	42.827	-118.888	4195	1942	2006	65	146	DY	12.8
456262	PACKWOOD	WA	46.609	-121.674	1060	1924	2006	83	15	DY	57.5
356426	PAISLEY	OR	42.692	-120.540	4360	1905	2006	102	145	DY	10.8
21C35S	PARADISE	WA	46.781	-121.747	5120	1980	2006	27	15	Snotel	115.9
266005	PARADISE VALLEY RANC	NV	41.500	-117.533	468	1894	2006	113	146	DY	11.2
356464	PARKDALE	OR	45.517	-121.583	1713	1912	1969	58	14	DY	41.6
356466	PARKDALE 1 NNE	OR	45.533	-121.583	1520	1928	2006	79	14	DY	37.7
456385	PARKWAY 6 S	WA	46.917	-121.533	3553	1943	1966	24	15	DY	56.3
106844	PARMA EXPERIMENT STN	ID	43.802	-116.944	2290	1922	2006	85	9	DY	10.0
456400	PASCO	WA	46.217	-119.100	350	1942	2003	62	77	HR	7.8
356500	PAULINA	OR	44.133	-119.997	3684	1961	2005	45	144	DY	11.7
106891	PAYETTE	ID	44.077	-116.929	2150	1892	2006	115	9	DY	10.8
21D14S	PEAVINE RIDGE	OR	45.041	-121.933	3500	1981	2006	26	15	Snotel	68.1
356532	PELTON DAM	OR	44.728	-121.251	1410	1958	2006	49	145	DY	10.9
356540	PENDLETON BR EXP STN	OR	45.721	-118.626	1487	1956	2006	51	7	DY	17.3
356541	PENDLETON DOWNTOWN	OR	45.670	-118.796	1040	1892	1936	45	7	DY	14.0
356541	PENDLETON DOWNTOWN	OR	45.670	-118.796	1040	1987	2006	20	7	DY	14.0
356546	PENDLETON E OR RGNL	OR	45.698	-118.855	1486	1928	2006	79	7	DY	13.0
456456	PEOLA	WA	46.333	-117.467	4003	1909	1936	28	9	DY	20.5
456477	PETERSONS RANCH	WA	46.050	-122.200	600	1927	1953	27	15	DY	122.4
356614	PHILOMATH 2 SE	OR	44.533	-123.333	220	1940	1972	33	32	DY	44.3
21C33S	PIGTAIL PEAK	WA	46.621	-121.386	5900	1981	2006	26	154	Snotel	72.7
356634	PILOT ROCK 1 SE	OR	45.476	-118.825	1720	1908	2006	99	7	DY	14.4
356636	PILOT ROCK 11 E	OR	45.500	-118.600	1920	1978	2006	29	13	HR	24.2
356655	PINE GROVE 5 ENE	OR	45.129	-121.256	2059	1969	1998	30	14	DY	17.7
046944	PIT RIVER P H 1	CA	41.000	-121.500	2880	1972	1996	25	145	DY	19.1
456553	PLEASANT VIEW	WA	46.517	-118.333	1670	1936	1979	44	77	DY	13.4
456610	POMEROY	WA	46.469	-117.589	1900	1929	2006	78	9	DY	17.6
356784	PORT ORFORD 2	OR	42.752	-124.501	42	1905	2006	102	5	DY	73.3
356795	PORT ORFORD 5 E	OR	42.739	-124.403	150	1971	2006	36	5	DY	122.7
356751	PORTLAND INTL AIRPOR	OR	45.583	-122.600	19	1941	2006	66	32	HR	38.4
356749	PORTLAND KGW-TV	OR	45.517	-122.683	160	1928	2006	79	32	DY	43.8
356761	PORTLAND WB CITY	OR	45.533	-122.667	200	1928	1973	46	32	DY	43.5
21C14S	POTATO HILL	WA	46.349	-121.514	4500	1981	2006	26	14	Snotel	66.3
107301	POTLATCH 1 SE	ID	46.900	-116.867	2592	1915	2006	92	148	DY	26.8
356820	POWERS	OR	42.889	-124.069	230	1932	2006	75	151	DY	59.8
356822	POWERS TELEMETERING	OR	42.883	-124.067	220	1971	2006	36	142	HR	58.1
356845	PRAIRIE CITY RS	OR	44.450	-118.700	3540	1949	2006	58	13	HR	17.7
456747	PRIEST RAPIDS DAM	WA	46.643	-119.910	460	1956	2006	51	77	DY	7.0
456753	PRINDLE 2 NW	WA	45.583	-122.167	249	1933	1949	17	31	DY	71.5
356883	PRINEVILLE	OR	44.307	-120.807	2915	1897	2006	110	145	DY	10.7
356907	PROSPECT 2 SW	OR	42.734	-122.516	2482	1905	2006	102	143	DY	41.7
456768	PROSSER	WA	46.200	-119.750	830	1913	2006	94	77	DY	8.6
456789	PULLMAN 2 NW	WA	46.750	-117.183	2545	1940	2006	67	13	HR	22.0
456784	PULLMAN EXP STN	WA	46.733	-117.167	2582	1893	1954	62	7	DY	21.4
20G06S	QUARTZ MOUNTAIN	OR	42.319	-120.825	5700	1980	2006	27	145	Snotel	21.8
356955	QUARTZVILLE 13 SW	OR	44.483	-122.500	820	1939	1962	24	15	DY	82.6
266504	QUINN RIVER CROSSING	NV	41.567	-118.433	409	1901	1951	51	146	DY	6.9
22F05S	RAILROAD OVERPASS	OR	43.659	-122.213	2750	1981	2006	26	15	Snotel	57.1
456887	RAINBOW FALLS PARK 2	WA	46.633	-123.183	279	1928	1963	36	32	DY	54.6
456892	RAINIER CARBON R ENT	WA	46.994	-121.911	1735	1926	1974	49	15	DY	71.9
456896	RAINIER OHANAPECOSH	WA	46.733	-121.567	1950	1941	2006	66	15	HR	76.9

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
456898	RAINIER PARADISE RNG	WA	46.786	-121.743	5427	1917	2006	90	15	DY	128.2
456909	RANDLE 1 E	WA	46.533	-121.933	900	1930	2006	77	15	DY	62.4
456914	RAYMOND 2 S	WA	46.653	-123.730	30	1980	2006	27	5	DY	85.0
21D04S	RED HILL	OR	45.465	-121.704	4400	1978	2006	29	154	Snotel	108.9
357056	REDMOND 1 SSE	OR	44.263	-121.158	3042	1930	1989	60	145	DY	9.3
357062	REDMOND AIRPORT	OR	44.256	-121.139	3043	1948	2006	59	145	DY	8.9
047342	REDWOOD CREEK O'KANE	CA	40.900	-123.800	880	1975	2006	32	142	HR	60.9
357082	REEDSPORT	OR	43.700	-124.117	200	1937	1983	47	5	DY	73.1
357112	RESTON	OR	43.131	-123.620	890	1955	2004	50	32	DY	49.9
357127	REX 1 S	OR	45.300	-122.900	515	1948	2006	59	32	HR	45.0
107648	REYNOLDS	ID	43.206	-116.749	3930	1961	2006	46	9	DY	10.9
357160	RICHLAND	OR	44.766	-117.160	2215	1893	2006	114	9	DY	12.7
457015	RICHLAND	WA	46.312	-119.263	373	1944	2006	63	77	DY	7.8
357169	RIDDLE	OR	42.951	-123.357	680	1899	2006	108	143	DY	32.3
107706	RIGGINS RANGER STN	ID	45.417	-116.300	1801	1896	2006	111	148	DY	17.9
457038	RIMROCK TIETON DAM	WA	46.650	-121.133	2733	1917	1977	61	14	DY	25.6
354003	RIVER EXP STN	OR	45.685	-121.518	500	1893	2006	114	14	DY	30.7
357208	RIVERSIDE 7 SSW	OR	43.451	-118.224	3380	1897	2006	110	146	DY	10.1
22F43S	ROARING RIVER	OR	43.901	-122.031	4900	1980	2006	27	154	Snotel	70.9
357250	ROCK CREEK	OR	44.910	-118.073	4095	1920	2006	87	13	DY	21.1
18F01S	ROCK SPRINGS	OR	44.009	-118.838	5100	1980	2006	27	144	Snotel	17.7
357277	ROCKVILLE 5 N	OR	43.364	-117.114	3670	1963	2006	44	146	DY	12.5
357310	ROME 2 NW	OR	42.859	-117.657	3405	1950	2006	57	146	DY	8.5
357331	ROSEBURG KQEN	OR	43.213	-123.366	425	1965	2006	42	32	DY	33.7
357326	ROSEBURG WB AIRPORT	OR	43.233	-123.367	505	1931	1965	35	32	DY	34.1
357354	ROUND GROVE	OR	42.341	-120.889	4888	1920	1987	68	145	DY	18.7
047581	ROUND MOUNTAIN	CA	40.783	-121.933	2100	1970	2001	32	145	HR	65.0
357391	RUCH	OR	42.223	-123.047	1550	1963	2006	44	143	DY	25.0
267192	RYE PATCH DAM	NV	40.450	-118.300	4135	1948	2006	59	145	HR	8.6
23D01S	SADDLE MOUNTAIN	OR	45.545	-123.373	3250	1979	2006	28	142	Snotel	103.9
357444	SAGINAW	OR	43.833	-123.033	620	1941	1971	31	31	DY	48.1
357500	SALEM AP MCNARY FIEL	OR	44.905	-123.001	205	1892	2006	115	31	DY	41.1
22F04S	SALT CREEK FALLS	OR	43.612	-122.118	4000	1980	2006	27	154	Snotel	74.4
357533	SAND CREEK	OR	42.850	-121.900	4682	1929	1948	20	14	DY	32.6
21E05S	SANTIAM JCT.	OR	44.435	-121.945	3750	1978	2006	29	154	Snotel	77.3
357554	SANTIAM JUNCTION	OR	44.433	-121.933	3750	1948	2006	59	154	HR	76.5
357559	SANTIAM PASS	OR	44.417	-121.867	4754	1963	1985	23	154	DY	87.0
457327	SATSOP	WA	46.967	-123.533	39	1928	1947	20	32	DY	82.2
457342	SATUS PASS 2 SSW	WA	45.950	-120.667	2610	1956	2006	51	14	HR	21.2
357572	SAUVIES ISLAND	OR	45.650	-122.833	40	1948	2006	59	32	HR	41.5
048025	SAWYERS BAR RS	CA	41.302	-123.133	2169	1931	1988	58	143	DY	40.1
17D08S	SCHNEIDER MEADOWS	OR	45.001	-117.165	5400	1980	2006	27	13	Snotel	48.0
357631	SCOTTS MILLS 9 SE	OR	44.947	-122.525	2315	1956	2001	46	15	DY	82.9
357641	SEASIDE	OR	45.987	-123.924	10	1930	2006	77	5	DY	75.0
23D02S	SEINE CREEK	OR	45.526	-123.297	2000	1980	2006	27	142	Snotel	77.5
357675	SENECA	OR	44.138	-118.975	4660	1931	2006	76	144	DY	13.7
22G33S	SEVENMILE MARSH	OR	42.698	-122.142	6200	1980	2006	27	154	Snotel	63.8
357698	SEXTON SUMMIT	OR	42.600	-123.350	3832	1948	2006	59	143	HR	33.4
048135	SHASTA DAM	CA	40.700	-122.400	1075	1948	2006	59	154	HR	62.3
357736	SHEAVILLE 1 SE	OR	43.121	-117.039	4620	1931	2004	74	146	DY	16.1
22C10S	SHEEP CANYON	WA	46.193	-122.254	4030	1980	2006	27	15	Snotel	135.9
267443	SHELDON	NV	41.850	-119.633	6506	1933	1972	40	145	DY	12.7
19H05S	SHELDON	NV	41.904	-119.445	5860	1989	2006	18	145	Snotel	10.8
16C01S	SHERWIN	ID	46.950	-116.340	3200	1982	2006	25	148	Snotel	41.2
108412	SILVER CITY 5 W	ID	43.000	-116.817	6160	1983	2006	24	146	HR	26.0
21F12S	SILVER CREEK	OR	42.956	-121.181	5720	1980	2006	27	145	Snotel	26.1

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
357809	SILVER CREEK FALLS	OR	44.873	-122.648	1350	1938	2006	69	31	DY	78.3
357817	SILVER LAKE RANGER S	OR	43.117	-121.050	4382	1968	2006	39	145	HR	10.3
357823	SILVERTON	OR	45.000	-122.767	408	1962	2006	45	31	HR	47.6
18G01S	SILVIES	OR	42.753	-118.688	6900	1979	2006	28	146	Snotel	33.6
357857	SISTERS	OR	44.284	-121.549	3180	1958	2006	49	14	DY	14.2
357866	SITKUM 1 E	OR	43.150	-123.817	610	1976	2006	31	151	HR	80.1
457680	SIXPRONG	WA	45.833	-120.117	1102	1906	1943	38	147	DY	10.6
457696	SKAMANIA FISH HATCHE	WA	45.623	-122.218	440	1965	2006	42	31	DY	87.5
457727	SMYRNA	WA	46.837	-119.663	560	1951	2006	56	77	DY	7.9
19F01S	SNOW MOUNTAIN	OR	43.949	-119.540	6220	1979	2006	28	144	Snotel	28.4
357940	SOUTH DEER CREEK	OR	43.171	-123.225	690	1978	2006	29	15	DY	36.5
16G01S	SOUTH MTN.	ID	42.765	-116.901	6500	1980	2006	27	146	Snotel	32.8
21C20S	SPENCER MEADOW	WA	46.180	-121.926	3400	1981	2006	26	15	Snotel	104.2
22C12S	SPIRIT LAKE	WA	46.095	-121.763	3120	1985	2006	22	154	Snotel	98.6
457919	SPIRIT LAKE RANGER S	WA	46.267	-122.150	3241	1932	1956	25	15	DY	99.6
358007	SPRAGUE RIVER 2 SE	OR	42.431	-121.489	4483	1953	2001	49	145	DY	16.0
358009	SPRAY	OR	44.833	-119.783	1742	1958	1978	21	7	DY	15.0
358029	SQUAW BUTTE EXP STAT	OR	43.487	-119.721	4660	1937	2006	70	145	DY	11.8
16E05S	SQUAW FLAT	ID	44.771	-116.249	6240	1981	2006	26	148	Snotel	45.0
357466	ST HELENS RFD	OR	45.861	-122.810	100	1976	2006	31	31	DY	45.0
358034	STAFFORD	OR	45.417	-122.750	410	1896	1919	24	32	DY	42.4
358079	STARKEY	OR	45.233	-118.450	3402	1909	1948	40	13	DY	18.0
19E07S	STARR RIDGE	OR	44.265	-119.021	5300	1980	2006	27	144	Snotel	20.9
358095	STAYTON	OR	44.789	-122.815	425	1951	2006	56	31	DY	53.5
358102	STEAMBOAT RANGER STN	OR	43.333	-122.733	1200	1955	2006	52	15	HR	50.1
20G09S	STRAWBERRY	OR	42.126	-120.836	5760	1980	2006	27	145	Snotel	23.0
358173	SUMMER LAKE 1 S	OR	42.959	-120.790	4192	1957	2006	50	145	DY	12.8
20G02S	SUMMER RIM	OR	42.696	-120.802	7100	1978	2006	29	145	Snotel	28.3
358182	SUMMIT	OR	44.637	-123.579	746	1909	1995	87	142	DY	65.6
358182	SUMMIT	OR	44.633	-123.567	746	1971	2006	36	142	HR	66.7
358190	SUMMIT GUARD STN	OR	45.300	-121.750	3904	1895	1951	57	15	DY	86.0
22F14S	SUMMIT LAKE	OR	43.449	-122.138	5600	1978	2006	29	154	Snotel	73.4
358221	SUNDOWN RANCH	OR	44.950	-122.500	2402	1931	1955	25	15	DY	79.1
458207	SUNNYSIDE	WA	46.324	-120.010	747	1894	2006	113	77	DY	7.3
358245	SUNRISE VALLEY	OR	43.100	-118.167	3714	1913	1936	24	146	DY	14.1
358250	SUNTEX	OR	43.600	-119.633	4311	1961	1990	30	145	DY	9.4
21C13S	SURPRISE LAKES	WA	46.095	-121.763	4250	1980	2006	27	154	Snotel	98.6
048703	SUSANVILLE 1 WNW	CA	40.417	-120.667	4555	1952	2006	55	145	HR	15.6
358263	SUTHERLIN 12 ENE	OR	43.417	-123.050	960	1955	2006	52	15	HR	63.7
358260	SUTHERLIN 2 W	OR	43.396	-123.359	500	1978	2006	29	32	DY	40.9
108928	SWAN FALLS P H	ID	43.244	-116.378	2325	1935	2006	72	9	DY	8.5
358338	TALENT	OR	42.250	-122.800	1552	1913	1960	48	8	DY	19.2
21G03S	TAYLOR BUTTE	OR	42.691	-121.426	5100	1978	2006	29	145	Snotel	22.6
15H09S	TAYLOR CANYON	NV	41.229	-116.030	6200	1980	2006	27	146	Snotel	13.2
17D07S	TAYLOR GREEN	OR	45.077	-117.551	5740	1979	2006	28	13	Snotel	38.2
048873	TERMO 1 E	CA	40.867	-120.433	5300	1948	2000	53	145	HR	10.7
358407	THE DALLES	OR	45.607	-121.205	150	1893	2006	114	14	DY	14.5
358420	THE POPLARS	OR	43.264	-120.945	4310	1941	2006	66	145	DY	11.7
21E13S	THREE CREEKS MEADOW	OR	44.144	-121.641	5650	1980	2006	27	14	Snotel	43.1
358466	THREE LYNX	OR	45.125	-122.072	1120	1923	2006	84	15	DY	72.2
358481	TIDEWATER	OR	44.412	-123.902	50	1940	2002	63	5	DY	91.2
458442	TIETON INTAKE	WA	46.667	-121.000	2280	1920	1972	53	14	DY	21.0
358494	TILLAMOOK 1 W	OR	45.457	-123.873	10	1948	2006	59	5	DY	90.1
358504	TILLAMOOK 12 ESE	OR	45.400	-123.583	420	1949	2006	58	151	HR	121.4
358514	TILLER	OR	42.917	-122.933	1040	1971	2006	36	15	HR	41.5
358512	TILLER 15 ENE	OR	43.000	-122.683	2500	1956	2006	51	15	HR	42.1

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
358522	TIMBER	OR	45.717	-123.300	942	1924	1976	53	142	DY	66.5
18E09S	TIPTON	OR	44.656	-118.426	5150	1980	2006	27	13	Snotel	25.2
358536	TOKETEE FALLS	OR	43.275	-122.450	2060	1953	2006	54	15	DY	48.6
458500	TOLEDO	WA	46.469	-122.841	325	1948	2006	59	31	DY	44.7
358549	TOLLGATE	OR	45.783	-118.083	4892	1948	1963	16	13	HR	55.4
458540	TOUCHET	WA	46.033	-118.667	440	1905	1940	36	7	DY	11.7
17C05S	TOUCHET	WA	46.119	-117.851	5530	1980	2006	27	13	Snotel	55.0
458543	TOUCHET RIDGE	WA	46.117	-117.983	3602	1909	1943	35	13	DY	44.7
358588	TRAIL 12 NE	OR	42.783	-122.667	1850	1951	1970	20	143	HR	43.4
358634	TROUTDALE	OR	45.553	-122.389	33	1948	2006	59	31	DY	44.7
049053	TULELAKE	CA	41.967	-121.467	4042	1932	2006	75	145	DY	11.5
049056	TULELAKE 5 WSW	CA	41.933	-121.550	4042	1932	1957	26	145	DY	11.2
268346	TUSCARORA	NV	41.317	-116.233	6184	1957	2006	50	146	DY	14.2
268349	TUSCARORA ANDRAE RAN	NV	41.400	-116.083	5863	1888	1956	69	146	DY	16.7
358717	TYGH VALLEY	OR	45.233	-121.167	1115	1972	2006	35	14	HR	15.4
358726	UKIAH	OR	45.136	-118.934	3400	1922	2006	85	7	DY	17.0
358734	UMATILLA	OR	45.917	-119.350	269	1892	1965	74	77	DY	8.7
358740	UMPQUA	OR	43.700	-124.167	112	1915	1937	23	5	DY	71.5
458688	UNDERWOOD 4 W	WA	45.733	-121.600	1260	1941	1962	22	14	HR	37.5
358746	UNION EXPERIMENT STN	OR	45.208	-117.876	2765	1911	2006	96	13	DY	14.8
358780	UNITY	OR	44.436	-118.188	4031	1936	2006	71	13	DY	11.0
358788	UPPER OLALLA	OR	43.047	-123.581	860	1978	2006	29	32	DY	42.2
358790	UPPER STEAMBOAT CREE	OR	43.467	-122.600	1855	1957	2006	50	15	HR	45.5
358797	VALE	OR	43.981	-117.244	2240	1893	2006	114	9	DY	10.3
358812	VALLEY FALLS	OR	42.484	-120.282	4325	1910	1964	55	145	DY	13.2
358818	VALLEY FALLS 3 SSE	OR	42.450	-120.250	4583	1965	1983	19	145	DY	17.3
358833	VALSETZ	OR	44.833	-123.667	1155	1948	1987	40	142	HR	122.8
458773	VANCOUVER 4 NNE	WA	45.678	-122.652	210	1898	2006	109	31	DY	42.5
458778	VANCOUVER INTERSTATE	WA	45.621	-122.674	2	1902	1959	58	31	DY	40.0
358884	VERNONIA 2	OR	45.850	-123.183	625	1954	2006	53	32	HR	50.5
049390	VOLTA POWER HOUSE	CA	40.450	-121.850	2220	1948	2006	59	145	HR	35.4
358924	VOLTAGE 2 NW SOD HOU	OR	43.283	-118.833	4114	1937	1959	23	146	DY	10.2
268810	VYA	NV	41.583	-119.917	5663	1959	1980	22	145	DY	14.2
358948	WAGONTIRE	OR	43.250	-119.883	4727	1960	1986	27	145	DY	9.9
458903	WAHLUKE	WA	46.650	-119.717	420	1904	1944	41	77	DY	7.3
358985	WALLA WALLA 13 ESE	OR	45.983	-118.050	2400	1940	2006	67	13	HR	42.1
458926	WALLA WALLA 3 W	WA	46.050	-118.400	801	1931	1962	32	7	DY	16.9
458928	WALLA WALLA FAA AIRP	WA	46.100	-118.283	1166	1949	2006	58	7	DY	19.9
458931	WALLA WALLA WSO CITY	WA	46.033	-118.333	949	1940	1988	49	7	HR	18.1
358997	WALLOWA	OR	45.572	-117.531	2923	1903	2006	104	13	DY	17.5
458959	WAPATO	WA	46.435	-120.420	841	1915	2006	92	77	DY	8.1
359038	WARM SPRINGS AGENCY	OR	44.767	-121.250	1503	1902	1928	27	145	DY	10.1
359046	WARM SPRINGS RESERVO	OR	43.567	-118.200	3343	1927	1967	41	146	DY	9.3
359051	WARREN	OR	45.817	-122.850	79	1950	1976	27	32	DY	45.0
359068	WASCO	OR	45.597	-120.696	1264	1907	2006	100	147	DY	11.9
458999	WASHOUGAL 8 ENE	WA	45.600	-122.183	761	1950	1964	15	31	DY	82.9
359083	WATERLOO	OR	44.500	-122.819	437	1923	2006	84	31	DY	45.9
459024	WAWAWAI 2 NW	WA	46.650	-117.400	702	1928	1965	38	7	DY	18.4
049490	WEAVERVILLE	CA	40.733	-122.933	2040	1948	2006	59	143	HR	37.0
049498	WEED	CA	41.433	-122.383	3514	1943	1957	15	154	DY	29.1
049499	WEED FIRE DEPT	CA	41.433	-122.383	3590	1957	1989	33	154	DY	29.1
109638	WEISER 1 S	ID	44.233	-116.950	2123	1911	2006	96	9	DY	12.4
16D08S	WEST BRANCH	ID	45.072	-116.455	5560	1980	2006	27	148	Snotel	41.9
359208	WEST LINN	OR	45.333	-122.650	69	1938	1968	31	31	DY	47.5
359176	WESTFALL	OR	43.990	-117.719	3040	1962	2006	45	146	DY	10.8
359213	WESTON	OR	45.817	-118.417	1922	1953	2006	54	7	HR	18.6

STATION ID	STATION NAME	STATE	LAT	LONG	ELEV (ft)	YEAR START	YEAR END	YEARS OPEN	RGN	GAGE TYPE	PRISM MAP[4,20] (in)
359216	WESTON 2 SE	OR	45.800	-118.400	2103	1893	1954	62	7	DY	20.9
359219	WESTON 5 ESE	OR	45.800	-118.333	3202	1955	1982	28	13	DY	30.2
21C28S	WHITE PASS E.S.	WA	46.642	-121.381	4500	1980	2006	27	154	Snotel	52.5
459183	WHITE SALMON 4 NNE	WA	45.767	-121.483	2011	1911	1952	42	14	DY	32.8
459191	WHITE SWAN RANGER ST	WA	46.383	-120.717	971	1927	1981	55	147	DY	9.1
359290	WHITEHORSE RANCH	OR	42.337	-118.235	4380	1965	2006	42	146	DY	8.3
459200	WHITMAN MISSION	WA	46.033	-118.450	632	1963	2006	44	7	HR	14.5
359316	WICKIUP DAM	OR	43.682	-121.687	4358	1941	2006	66	14	DY	21.9
359324	WICOPEE	OR	43.667	-122.267	2881	1927	1954	28	15	DY	58.2
359372	WILLAMINA	OR	45.083	-123.489	385	1935	2006	72	32	DY	52.0
459291	WILLAPA HARBOR	WA	46.683	-123.750	10	1895	1979	85	5	DY	83.2
459295	WILLARD FISH LAB	WA	45.767	-121.633	770	1962	1976	15	14	HR	42.4
359390	WILLIAMS 1 NW	OR	42.217	-123.283	1450	1949	2006	58	143	HR	31.3
359398	WILLOW CREEK	OR	42.883	-124.433	249	1922	1951	30	5	DY	89.9
109846	WINCHESTER	ID	46.233	-116.617	3950	1939	2006	68	148	DY	24.9
359461	WINCHESTER	OR	43.283	-123.354	460	1950	2006	57	32	DY	35.8
459342	WIND RIVER	WA	45.800	-121.933	1150	1911	1977	67	15	DY	99.6
269171	WINNEMUCCA AIRPORT	NV	40.900	-117.800	4296	1948	2006	59	146	HR	8.5
18D21S	WOLF CREEK	OR	45.067	-118.152	5700	1978	2006	29	13	Snotel	29.2
459465	YAKIMA AIRPORT	WA	46.567	-120.533	1064	1940	2006	67	147	HR	8.4
359581	YAQUINA BAY	OR	44.617	-124.033	15	1966	2006	41	5	HR	68.5
359604	YONNA	OR	42.300	-121.483	4183	1907	1949	43	145	DY	15.6
049866	YREKA	CA	41.717	-122.633	2631	1893	2006	114	143	DY	19.2
359616	ZIGZAG RANGER STN	OR	45.350	-121.933	1385	1908	1953	46	15	DY	82.8

APPENDIX B

ISOPLUVIAL MAPS FOR SELECTED RECURRENCE INTERVALS

OVERVIEW

Isopluvial maps for 24-hour precipitation for recurrence intervals for the 6-month, 2-year, 10-year, 25-year, 50-year, 100-year, 500-year and 1,000-year are included as part of this appendix. Estimates of precipitation for 6-month and 2-year recurrence intervals were made using standard conversions developed by Langbein (*1949; Schaefer and Barker 2006*) for conversion from annual maxima to partial duration series equivalents. Gridded datasets used to create these maps are contained on the Compact Disc (CD) included with this report.

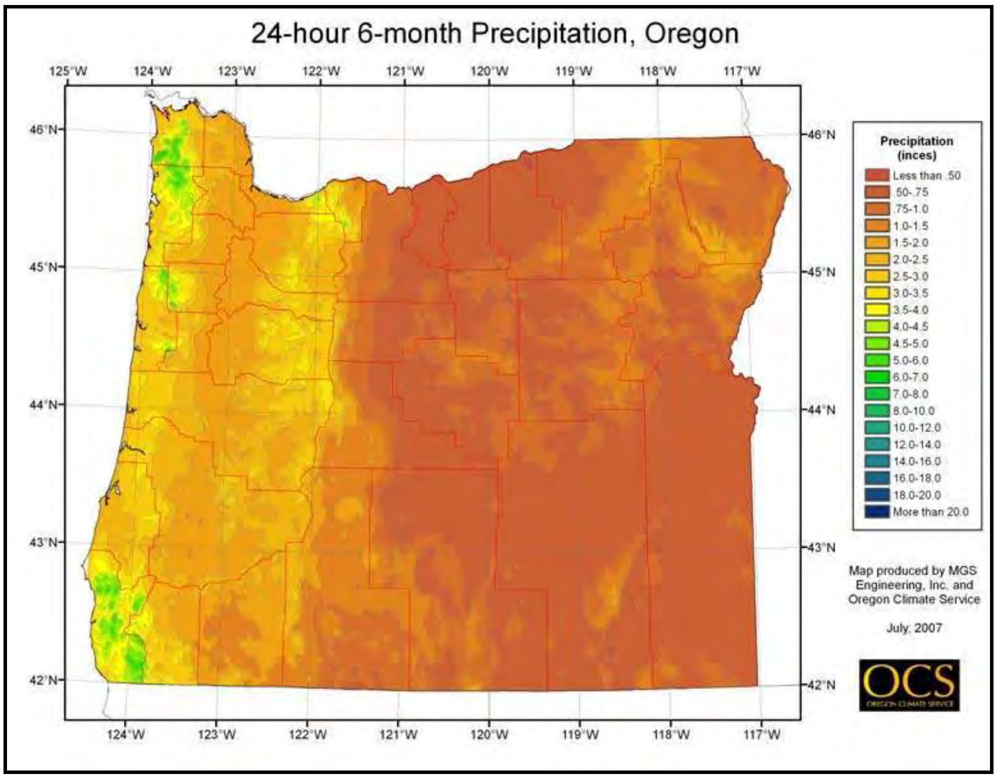


Figure B.1: Isopluvial Map of 24-Hour Precipitation for 6-Month Recurrence Interval for Oregon State.

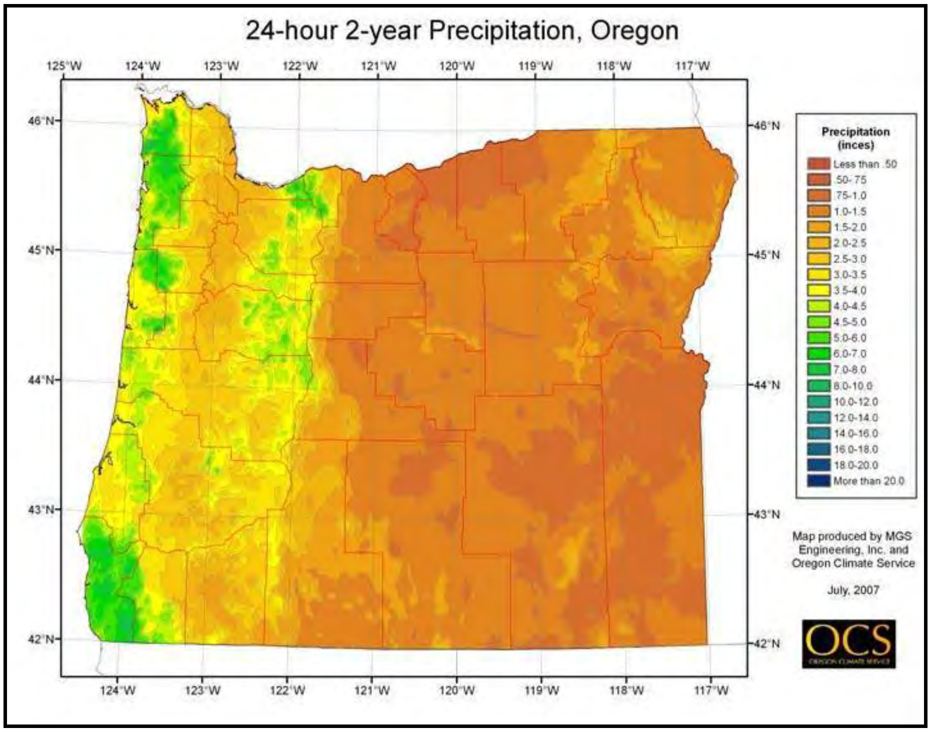


Figure B.2: Isopluvial Map of 24-Hour Precipitation for 2-Year Recurrence Interval for Oregon State.

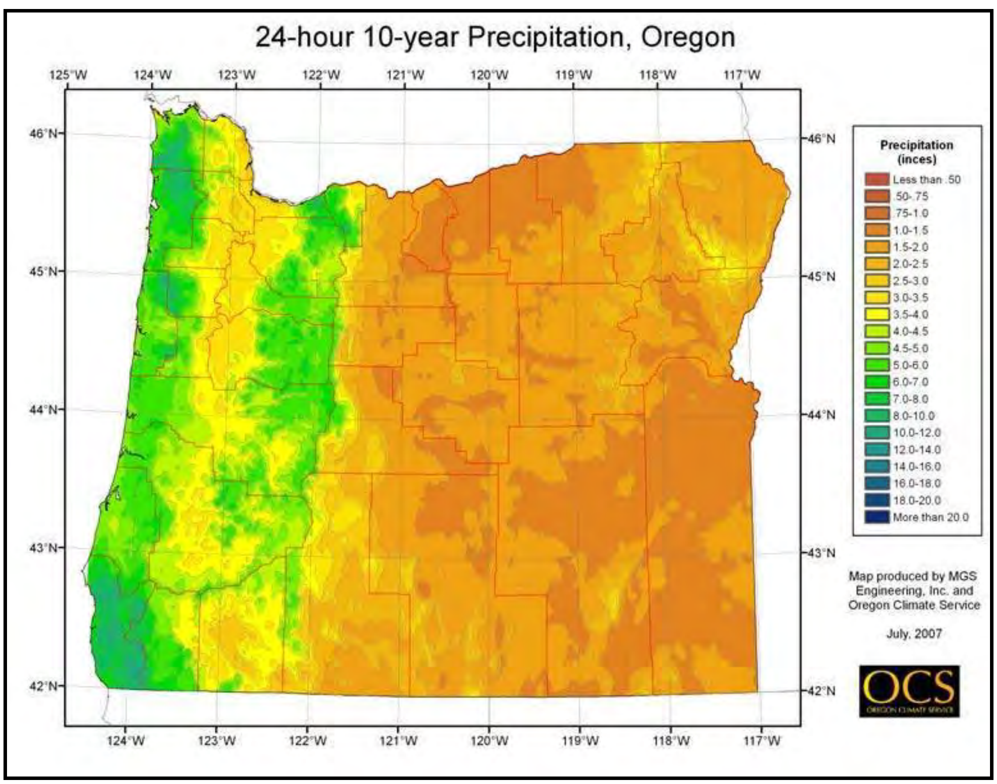


Figure B.3: Isopluvial Map of 24-Hour Precipitation for 10-Year Recurrence Interval for Oregon State.

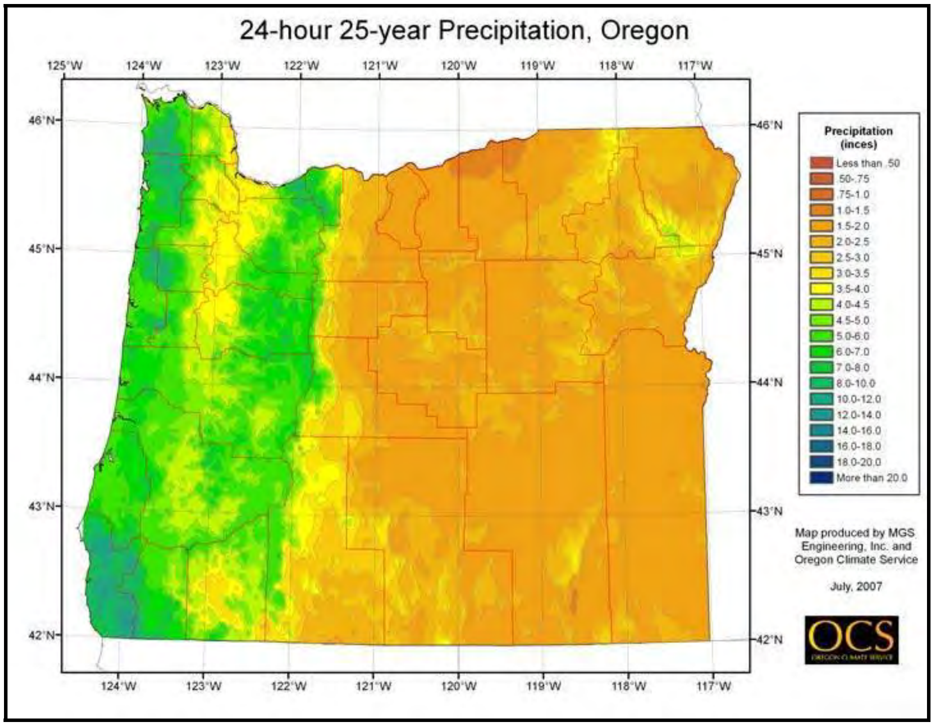


Figure B.4: Isopluvial Map of 24-Hour Precipitation for 25-Year Recurrence Interval for Oregon State.

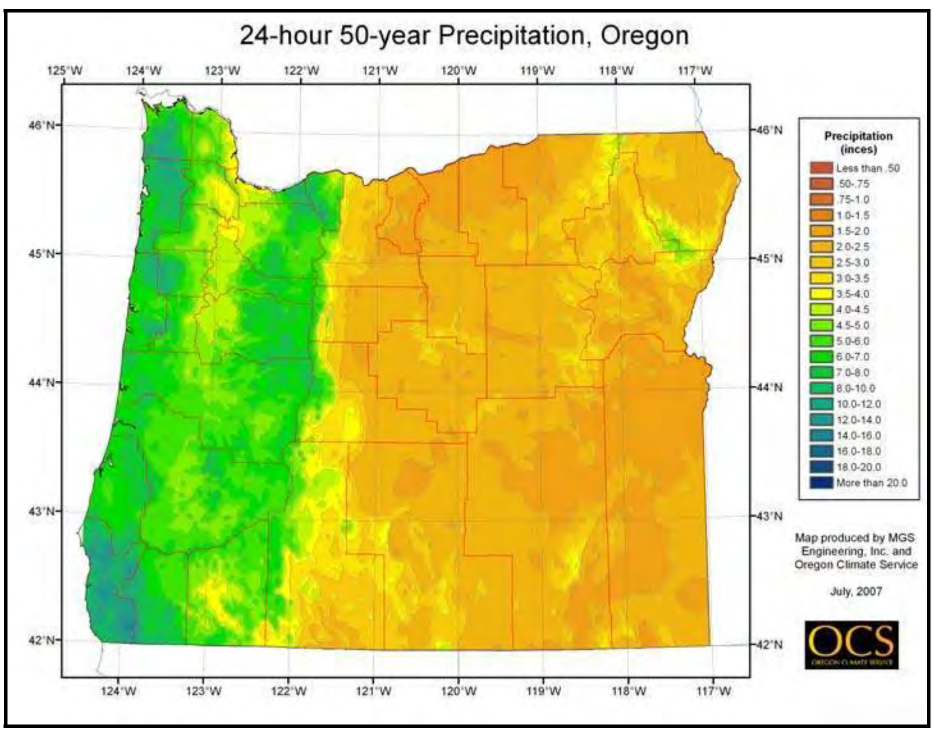


Figure B.5: Isopluvial Map of 24-Hour Precipitation for 50-Year Recurrence Interval for Oregon State.

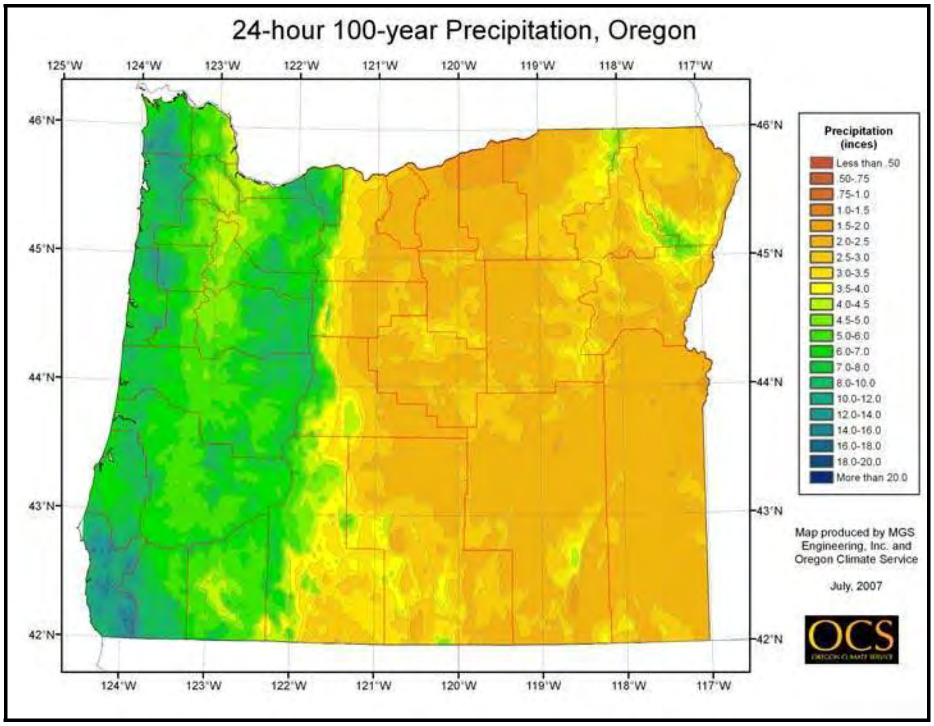


Figure B.6: Isopluvial Map of 24-Hour Precipitation for 100-Year Recurrence Interval for Oregon State.

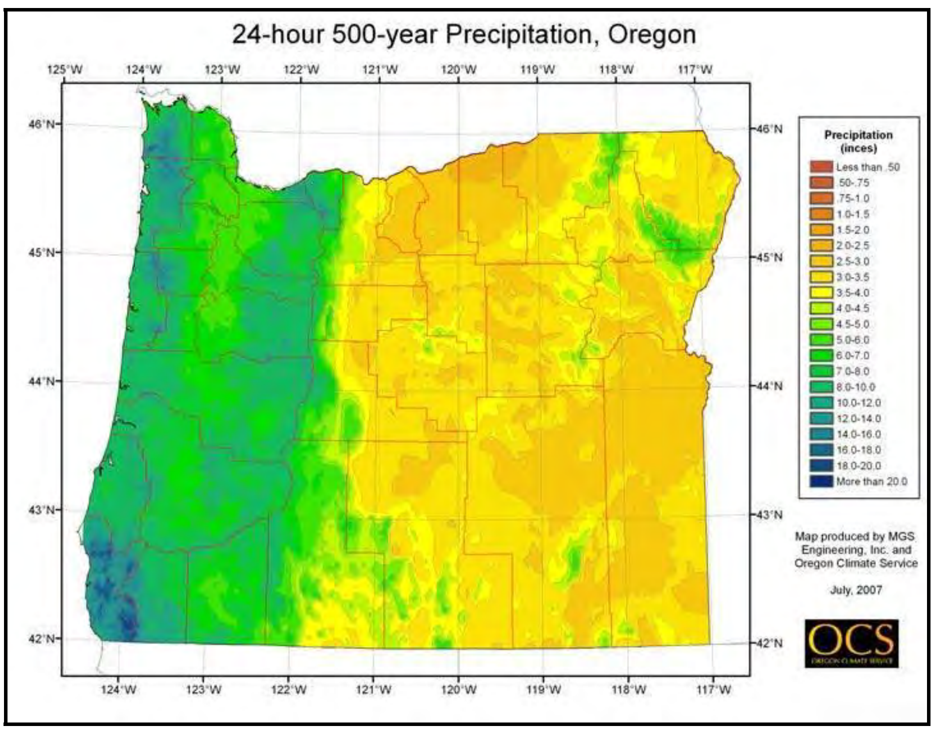


Figure B.7: Isopluvial Map of 24-Hour Precipitation for 500-Year Recurrence Interval for Oregon State.

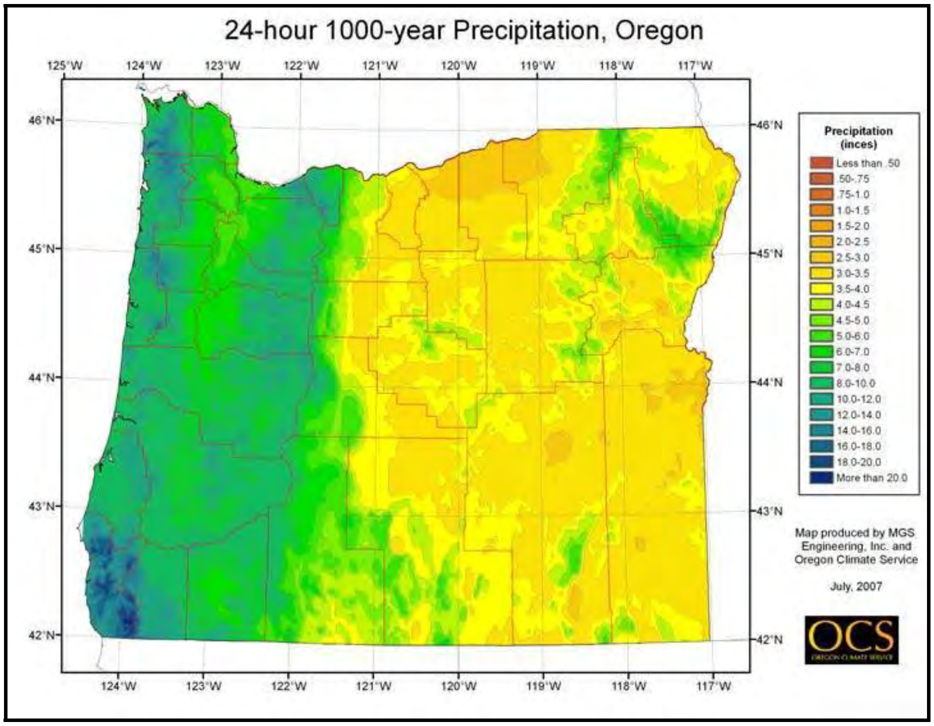


Figure B.7: Isopluvial Map of 24-Hour Precipitation for 1,000-Year Recurrence Interval for Oregon State.

APPENDIX C

L-MOMENT STATISTICS AND CIRCULAR 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 1986, 1990; Hosking and Wallis 1997*). 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:

$$\text{Mean} = L_1 \quad \text{(C1)}$$

Scale, L-Cv (t_2):

$$t_2 = L_2/L_1 \quad \text{(C2)}$$

L-Skewness (t_3):

$$t_3 = L_3/L_2 \quad \text{(C3)}$$

L-Kurtosis (t_4):

$$t_4 = L_4/L_2 \quad \text{(C4)}$$

where:

$$L_1 = \beta_0 \quad \text{(C5)}$$
$$L_2 = 2\beta_1 - \beta_0 \quad \text{(C6)}$$
$$L_3 = 6\beta_2 - 6\beta_1 + \beta_0 \quad \text{(C7)}$$
$$L_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0 \quad \text{(C8)}$$

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

$$\beta_0 = n^{-1} \sum_{j=1}^{n} x_j \quad \text{(C9)}$$

$$\beta_1 = n^{-1} \sum_{j=2}^{n} x_j\,[(j-1)/(n-1)] \quad \text{(C10)}$$

$$\beta_2 = n^{-1} \sum_{j=3}^{n} x_j\,[(j-1)(j-2)]/[(n-1)(n-2)] \quad \text{(C11)}$$

$$\beta_3 = n^{-1} \sum_{j=4}^{n} x_j\,[(j-1)(j-2)(j-3)]/[(n-1)(n-2)(n-3)] \quad \text{(C12)}$$

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:

$$n_R = \sum_{i=1}^{N} n_i \qquad (C13)$$

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

$$L_1^R = 1 \qquad (C14)$$

Regional L-Cv (t_2^R):

$$t_2^R = n_R^{-1} \sum_{i=1}^{N} n_i \; t_2^i \qquad (C15)$$

Regional L-Skewness (t_3^R):

$$t_3^R = n_R^{-1} \sum_{i=1}^{N} n_i \; t_3^i \qquad (C16)$$

Regional L-Kurtosis (t_4^R):

$$t_4^R = n_R^{-1} \sum_{i=1}^{N} n_i \; t_4^i \qquad (C17)$$

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 (*1995*, *1997*). These equations are valid for the range of regional L-moment ratios observed in the study area, where:

$$\text{bias } t_3^R = 4N(0.10 - t_4^R) / n_R \qquad (C18)$$

$$\text{bias } t_4^R = 4N(0.15 - t_4^R) / n_R \qquad (C19)$$

CIRCULAR STATISTICS

Circular statistics (*Fisher 1993*) are appropriate for analysis of data that are circular or directional in nature. Months of the year, days of the year (dates), and compass headings (wind direction) are all examples of circular data. For example, January (month 1) follows December (month 12). Arithmetic averaging of a group of numerical months or dates is not appropriate with conventional sample statistics because the counting system is circular not linear. In conducting the analysis of the seasonality of annual maxima or extreme storms, the Julian day of the year is used for describing the date of occurrence. The *average day of occurrence* is analogous to the arithmetic mean and the *seasonality index* (*Dingman 2001*) is analogous to a standardized measure of variation. Specifically, values of the seasonality index range from zero to unity, with values near zero indicating wide variation in the dates of occurrence. A seasonality index near unity indicates low variation in the dates of occurrence and strong clustering of dates. Circular statistics for dates of occurrence using Julian day-of-year are computed as follows:

Conversion of Julian day-of-year to compass direction (θ_i):

$$\theta_i = 360\ [\ J_i / Days_{total}] \qquad \text{(C20)}$$

Compute vectors for compass direction:

$$S = \sum_{i=1}^{n} P_i\ [sin(\theta_i)] \qquad \text{(C21a)}$$

$$C = \sum_{i=1}^{n} P_i\ [cos(\theta_i)] \qquad \text{(C21b)}$$

Compute Average Day-of-Occurrence (Julian day-of-year J_{mean}):

$$\theta_2 = ArcTan(S/C) \qquad \text{(C22a)}$$

$$\theta_m = \theta_2 \qquad if\ S>0\ and\ C>0 \qquad \text{(C22b)}$$

$$\theta_m = \theta_2 + 180^{o} \qquad if\ C<0 \qquad \text{(C22c)}$$

$$\theta_m = \theta_2 + 360^{o} \qquad if\ S<0\ and\ C>0 \qquad \text{(C22d)}$$

$$J_{mean} = 365\ \theta_m \qquad \text{(C22e)}$$

Compute Seasonality Index (*SI*):

$$SI = SQRT(S^2 + C^2)\ /\ P_{total} \qquad \text{(C23a)}$$

$$P_{total} = \sum_{i=1}^{n} P_i \qquad \text{(C23b)}$$

where:

J_i = Julian day-of-year for given date of interest; $Days_{total}$ is the total number of days in the current year; P_i is the precipitation value for a given date (J_i); n is the total number of precipitation and date pairs; and P_{total} is the sum of all precipitation values for the dataset.

APPENDIX D

SELECTED DEFINITIONS

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 (*Weiss 1964*).

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 such as the water-year, October 1st to September 30th. The calendar year was used as the annual period for this study of the State of Oregon.

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.

APPENDIX D

Soils Information

Exhibit D-4

United States Department of Agriculture

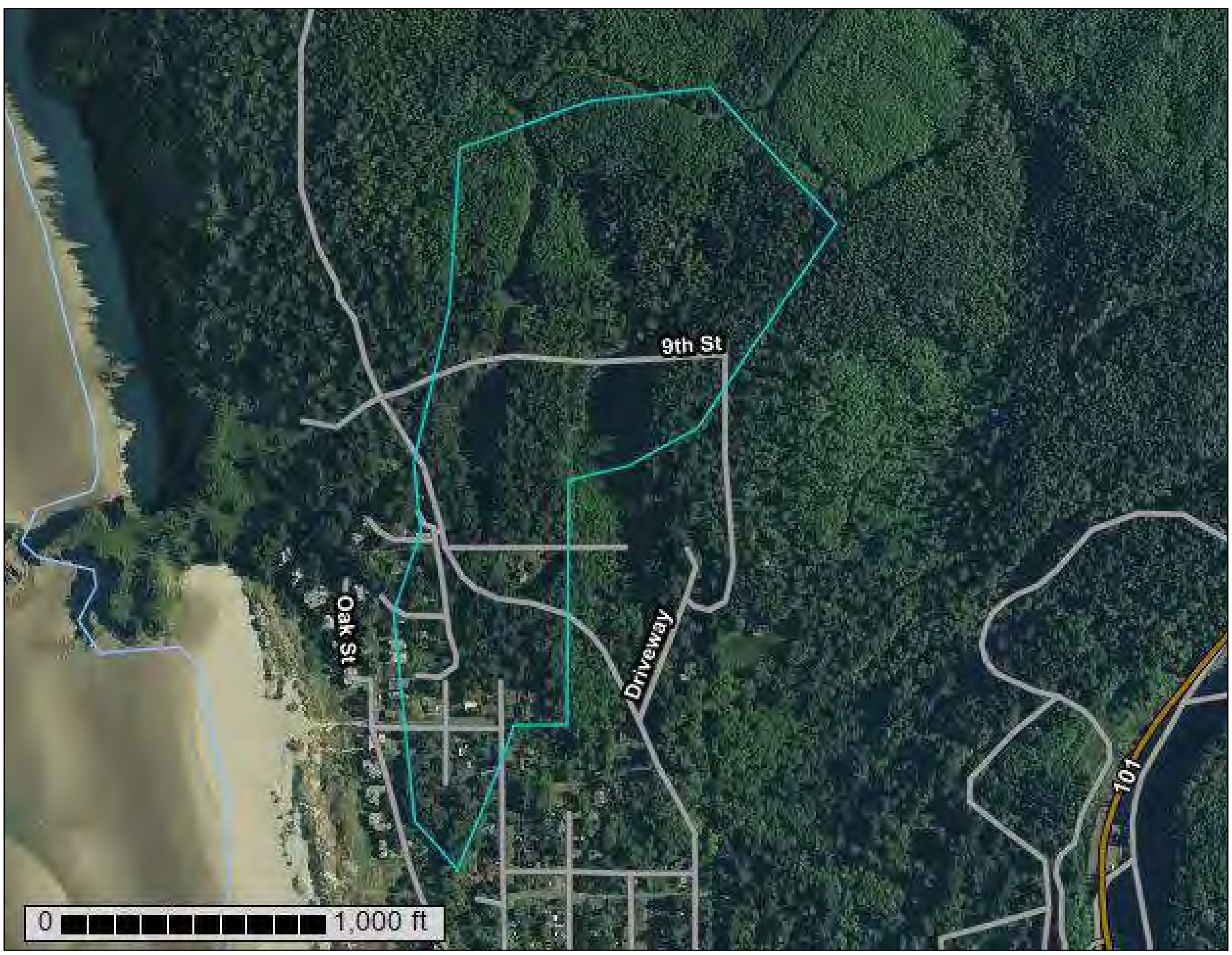
NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

Clatsop County, Oregon



February 2, 2023

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

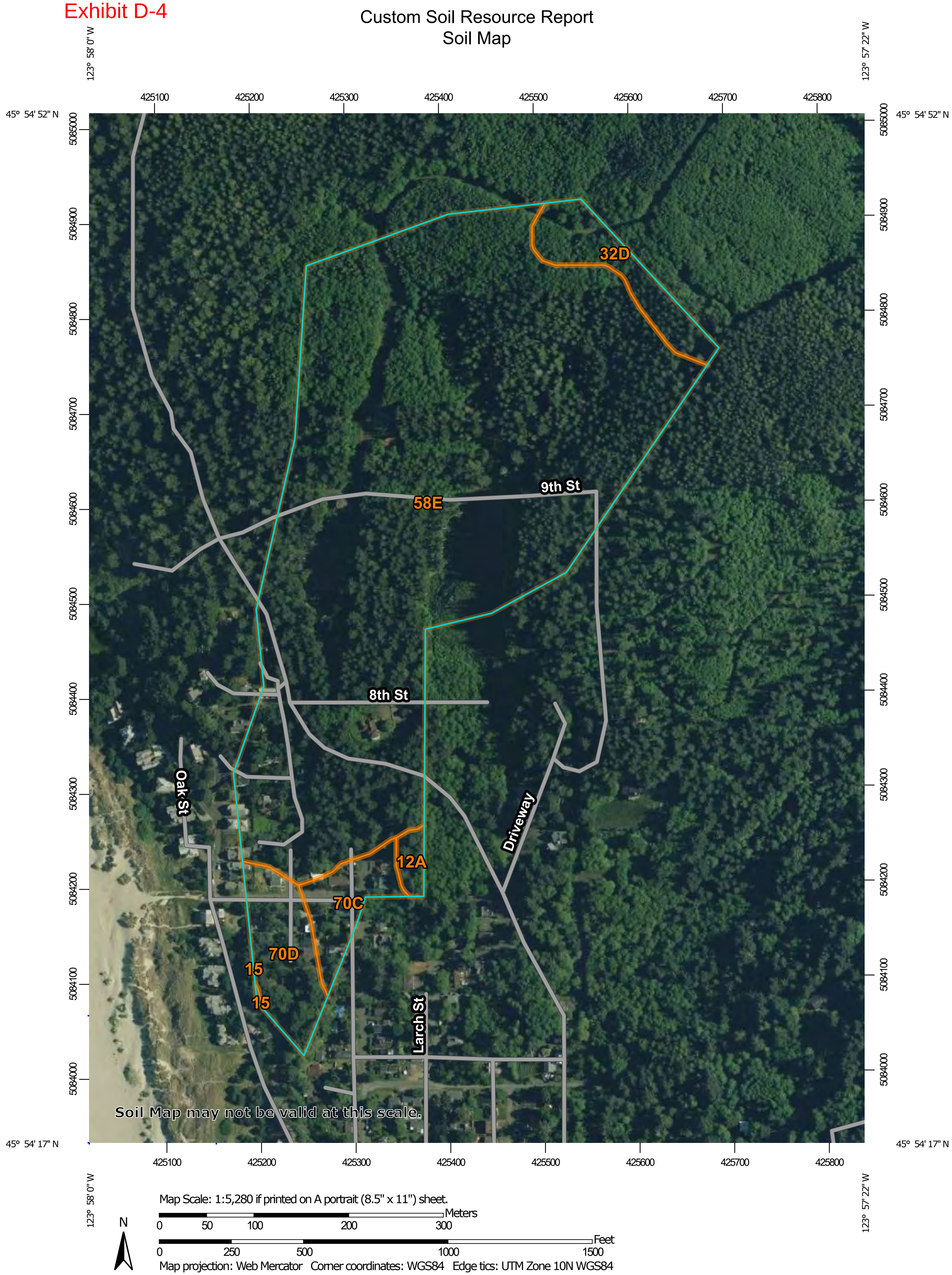
Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report
Soil Map



Map Scale: 1:5,280 if printed on A portrait (8.5" x 11") sheet.

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Clatsop County, Oregon
Survey Area Data: Version 21, Sep 8, 2022

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: May 28, 2020—Jun 22, 2020

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
12A	Coquille-Clatsop complex, protected, 0 to 1 percent slopes	0.5	0.8%
15	Dune land	0.0	0.0%
32D	Klootchie silt loam, 3 to 30 percent slopes	2.4	4.4%
58E	Skipanon gravelly medial silt loam, 30 to 60 percent slopes	47.2	86.4%
70C	Waldport fine sand, 3 to 15 percent slopes	1.8	3.4%
70D	Waldport fine sand, 15 to 30 percent slopes	2.7	5.0%
Totals for Area of Interest		**54.6**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Clatsop County, Oregon

12A—Coquille-Clatsop complex, protected, 0 to 1 percent slopes

Map Unit Setting

National map unit symbol: 219s
Elevation: 0 to 10 feet
Mean annual precipitation: 50 to 100 inches
Mean annual air temperature: 46 to 54 degrees F
Frost-free period: 165 to 245 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Coquille, protected, and similar soils: 60 percent
Clatsop, protected, and similar soils: 30 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Coquille, Protected

Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium

Typical profile

H1 - 0 to 6 inches: silt loam
H2 - 6 to 30 inches: silt loam
H3 - 30 to 60 inches: silty clay

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 to 24 inches
Frequency of flooding: NoneRare
Frequency of ponding: Frequent
Available water supply, 0 to 60 inches: High (about 10.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: C/D
Ecological site: R004AB200OR - Tidal Marsh and Estuary
Forage suitability group: Very Poorly Drained (G004AY019OR)
Other vegetative classification: Very Poorly Drained (G004AY019OR)
Hydric soil rating: Yes

Description of Clatsop, Protected

Setting

Landform: Flood plains

Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium

Typical profile

Oa - 0 to 6 inches: muck
H1 - 6 to 24 inches: silt loam
H2 - 24 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 to 24 inches
Frequency of flooding: NoneRare
Frequency of ponding: Frequent
Available water supply, 0 to 60 inches: Very high (about 12.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: C/D
Ecological site: R004AB200OR - Tidal Marsh and Estuary
Forage suitability group: Very Poorly Drained (G004AY019OR)
Other vegetative classification: Very Poorly Drained (G004AY019OR)
Hydric soil rating: Yes

Minor Components

Histosols

Percent of map unit: 3 percent
Landform: Flood plains
Hydric soil rating: Yes

Coquille, protected, very gravelly

Percent of map unit: 3 percent
Landform: Flood plains
Hydric soil rating: Yes

Coquille, protected, sandy substratum

Percent of map unit: 2 percent
Landform: Flood plains
Hydric soil rating: Yes

Psammaquents

Percent of map unit: 2 percent
Landform: Flood plains
Hydric soil rating: Yes

15—Dune land

Map Unit Setting

National map unit symbol: 219w
Elevation: 0 to 80 feet
Mean annual precipitation: 60 to 100 inches
Mean annual air temperature: 48 to 54 degrees F
Frost-free period: 180 to 300 days
Farmland classification: Not prime farmland

Map Unit Composition

Dune land: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Dune Land

Setting

Landform: Dunes
Parent material: Eolian sands

Typical profile

C - 0 to 60 inches: fine sand

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8
Hydric soil rating: No

Minor Components

Heceta

Percent of map unit: 15 percent
Landform: Interdunes
Hydric soil rating: Yes

32D—Klootchie silt loam, 3 to 30 percent slopes

Map Unit Setting

National map unit symbol: 21bq
Elevation: 50 to 1,800 feet
Mean annual precipitation: 70 to 130 inches
Mean annual air temperature: 45 to 52 degrees F

Frost-free period: 100 to 210 days
Farmland classification: Not prime farmland

Map Unit Composition

Klootchie and similar soils: 85 percent
Minor components: 3 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Klootchie

Setting

Landform: Mountain slopes
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Mountaintop
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Colluvium derived from basalt

Typical profile

Oi - 0 to 2 inches: slightly decomposed plant material
H1 - 2 to 14 inches: silt loam
H2 - 14 to 28 inches: silt loam
H3 - 28 to 45 inches: gravelly loam
H4 - 45 to 55 inches: weathered bedrock

Properties and qualities

Slope: 3 to 30 percent
Depth to restrictive feature: 40 to 60 inches to paralithic bedrock
Drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water supply, 0 to 60 inches: High (about 11.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: B
Ecological site: F004AB404WA - Coastal Upland Warm Forest
Hydric soil rating: No

Minor Components

Aquands

Percent of map unit: 3 percent
Landform: Mountains
Hydric soil rating: Yes

58E—Skipanon gravelly medial silt loam, 30 to 60 percent slopes

Map Unit Setting

National map unit symbol: 21cw
Elevation: 50 to 1,500 feet
Mean annual precipitation: 80 to 110 inches
Mean annual air temperature: 46 to 52 degrees F
Frost-free period: 120 to 210 days
Farmland classification: Not prime farmland

Map Unit Composition

Skipanon and similar soils: 80 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Skipanon

Setting

Landform: Mountain slopes, hillslopes
Landform position (two-dimensional): Backslope, footslope
Landform position (three-dimensional): Mountainflank, head slope, side slope
Down-slope shape: Concave, linear
Across-slope shape: Concave, linear
Parent material: Mass movement deposits derived from a mixture of igneous and sedimentary rock types overlying sedimentary rock

Typical profile

Oi - 0 to 2 inches: slightly decomposed plant material
A1 - 2 to 7 inches: gravelly medial silt loam
A2 - 7 to 15 inches: gravelly silt loam
Bw1 - 15 to 29 inches: gravelly clay loam
Bw2 - 29 to 44 inches: gravelly clay loam
C - 44 to 62 inches: paragravelly clay loam

Properties and qualities

Slope: 30 to 60 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water supply, 0 to 60 inches: High (about 10.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: B
Ecological site: F004AB404WA - Coastal Upland Warm Forest
Other vegetative classification: Sitka spruce/oxalis, swordfern-moist (902)

Hydric soil rating: No

70C—Waldport fine sand, 3 to 15 percent slopes

Map Unit Setting

National map unit symbol: 21dd
Elevation: 0 to 500 feet
Mean annual precipitation: 60 to 100 inches
Mean annual air temperature: 48 to 54 degrees F
Frost-free period: 180 to 260 days
Farmland classification: Not prime farmland

Map Unit Composition

Waldport and similar soils: 85 percent
Minor components: 7 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Waldport

Setting

Landform: Dunes
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed eolian sands

Typical profile

H1 - 0 to 3 inches: fine sand
H2 - 3 to 60 inches: fine sand

Properties and qualities

Slope: 3 to 15 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water supply, 0 to 60 inches: Low (about 3.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: A
Ecological site: F004AB202OR - Dune Forest
Hydric soil rating: No

Minor Components

Psammaquents

Percent of map unit: 7 percent
Landform: Interdunes
Hydric soil rating: Yes

70D—Waldport fine sand, 15 to 30 percent slopes

Map Unit Setting

National map unit symbol: 21df
Elevation: 0 to 500 feet
Mean annual precipitation: 60 to 100 inches
Mean annual air temperature: 48 to 54 degrees F
Frost-free period: 180 to 260 days
Farmland classification: Not prime farmland

Map Unit Composition

Waldport and similar soils: 85 percent
Minor components: 8 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Waldport

Setting

Landform: Dunes
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed eolian sands

Typical profile

H1 - 0 to 3 inches: fine sand
H2 - 3 to 60 inches: fine sand

Properties and qualities

Slope: 15 to 30 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water supply, 0 to 60 inches: Low (about 3.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7e
Hydrologic Soil Group: A
Ecological site: F004AB202OR - Dune Forest
Hydric soil rating: No

Minor Components

Psammaquents

Percent of map unit: 8 percent
Landform: Interdunes

Hydric soil rating: Yes

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