Hydrologic Process Identification For Western Oregon

Prepared for

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1.0 INTRODUCTION

The purpose of this project is to determine the hydrologic processes which produce peak flows throughout western Oregon. The identification of peak flow seasons and generating processes in western Oregon can provide some basic information about the types of flood events occurring in a watershed. The analysis of peak flows and changes in their magnitude is often undertaken to assess land use impacts on aquatic resources. Peak flow increases in response to land use activities may alter the channel geometry which could have potential negative impacts on habitat.

Several distinct types of peak flow generating processes such as rainstorms, winter and spring rain-on-snow events, and spring snowmelt can occur in a watershed and are produced by a combination of antecedent climatic variables such as temperature, precipitation, snowpack, wind, solar radiation, etc. Winter peak flows are generally produced by rainfall or rain-on-snow events and show a distinct large spike in the hydrograph during a period of relatively low flow (MacDonald and Hoffman 1995). Spring peak flows are produced during the snowmelt period initiated by increased solar radiation and occur over a sustained period of time (up to several weeks). The spring rain-on-snow process can cause a quick spike on the already elevated high flow portion of the hydrograph (sustained by spring snowmelt).

The information summarized in this document can be used by hydrologists and other analysts in the watershed assessment process developed under the Oregon Governor's Watershed Enhancement Board as well as other hydrologic analyses. Analysts conducting watershed studies should understand which types of hydrologic processes are producing peak flows in their watershed prior to selecting appropriate analysis tools. For instance, a major assumption in the hydrologic change module of Washington State's watershed analysis methodology is that the most significant long-term cumulative effects from timber harvest on public resources are caused by the alteration of hydrologic parameters during late fall and winter rain-on-snow events. While this may be applicable to portions of western Washington and Oregon, different processes may be more active in other parts of the Pacific Northwest. The identification of which processes are present is an important aspect in evaluating how land use and management practices affect peak flows.

1.1 Description of Study Area

Western Oregon encompasses a large area including two mountain ranges and two major river valleys. The climatologic and hydrologic patterns differ across this large area and can be better understood when the landscape is divided into smaller spatial units. Several spatial classification systems are currently available which have divided this report's study area into regions of similar characteristics. Two of these systems will be discussed in this report: physiographic regions used by the U.S.

Geological Survey (USGS) (Harris, 1979) and ecoregions as delineated in Pater, et. al. (1997).

Physiographic areas are identified based on meteorologic and hydrologic patterns. For the purpose of estimating the magnitude and frequency of floods in western Oregon, the USGS (Harris, 1979) identified four principal physiographic areas (Map 1), which cover the study area for this report:

1. Coast Region
   Along the western slope of the coast region, average annual precipitation mostly ranges between 60 and 80 inches with a few areas in the coastal mountains receiving up to 200 inches.
2. Willamette Region
   Average annual precipitation mostly ranges between 40 and 80 inches with a few areas in the western foothills nearing 110 inches.
3. Rogue-Umpqua Region
   Average annual precipitation mostly ranges between 20 and 60 inches with a few areas nearing 80 inches.
4. High Cascades Region
   Average annual precipitation mostly ranges from less than 20 inches in the south to more than 100 inches in the north.

Ecoregions are defined as areas of general similarity in the type, quality, and quantity of environmental resources (e.g. geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology). As such they provide a spatial framework for ecosystem research, assessment, management, and monitoring. Pater, et. al. (1997) delineated a hierarchical set of ecoregions for Western Washington and Oregon that, while similar to the USGS physiographic regions, differ along the edges and boundaries. The Level III ecoregions Pater et. al. (1997) presents within the bounds of this report's study area are as follows:

1. Coast Range (Ecoregion 1)
   The coast range are low mountains covered by highly productive, rain-drenched coniferous forests.
2. Willamette Valley (Ecoregion 3)
   The Willamette River has a broad lowland valley characterized by rolling prairies, deciduous/ coniferous forests and extensive wetlands. Productive soils and temperate climate make this region well suited for agriculture.
3. Klamath Mountains (Ecoregion 78)
   This region is physically and biologically diverse with highly dissected folded mountains, foothills, terraces and floodplains. Summers are hot and dry. Mediterranean climate, vegetation, and land use are more similar to northern California's inland valleys than the Willamette Valley.
4. Cascades (Ecoregion 4)
   The cascades region is mountainous with steep ridges and river valleys resultant from alpine glaciation. The moist temperate climate supports a highly productive coniferous forest.

There is some overlap between the physiographic areas and the ecoregions. Physiographic region (1) Coast Region encompasses most of ecoregion 1 (Coast Range) and a small portion of ecoregion 78 (Klamath Mountains). Physiographic region (4) High Cascades contains the upper or higher elevations of ecoregion 4 (Cascades). Physiographic region (2) Willamette Valley contains all of ecoregion 3 (Willamette Valley), the lower portion of ecoregion 4, and the east slope of the Coast Range in ecoregion 1. Physiographic region (3) Rogue Umpqua contains most of ecoregion 78 (Klamath Mountains), the lower portion of ecoregion 4, and the east slope of the Coast Range in ecoregion 1 (Map 1).

Where possible we have discussed our results within the framework of these two systems. For the purpose of this investigation we have relied more heavily on the USGS regions since they are more specifically hydrologically based. The Level III Ecoregions in Pater (1997) help to understand the broader landscape issues. For ease in analysis and presentation, the study area, which encompasses all the lands in the state of Oregon west of the Cascade Mountain range, was also split into two contiguous regions using the political boundaries of the counties: approximately 16,880 mi^2 in Northwestern Oregon and 12,790 mi^2 in Southwestern Oregon. (Map 1). The Northwestern Oregon region (A) is bounded on the north by Washington state and extends to the southern border of Lane County; the Southwestern Oregon region (B) includes Douglas County south to the California border. Northwestern Oregon contains the northern half of physiographic areas 1 and 4 and all of 2; southwestern Oregon contains the southern half of physiographic areas 1 and 4 and all of 3.

2.0 METHODS OF HYDROLOGIC ANALYSIS

2.1 Data Collection

In order to identify the hydrologic processes present in Western Oregon, all available data from streamflow, climate, snow course and SNOTEL stations located within or near the study area were identified and summarized. The information was organized by location in either the Northwest Oregon region (A) or the Southwest Oregon region (B). U.S. Geological Survey (USGS) streamflow station information for gages located in the two regions was obtained from HYDRODATA (Hydrosphere, 1996) and the USGS web site. Climate station data were acquired from CLIMATEDATA (Hydrosphere 1996) and the Desert Research Institute, Western Regional Climate Center in Reno, Nevada. Snow course and SNOTEL station information was obtained from the Natural Resources Conservation Service (NRCS).

Numerous streamflow and climate stations are located in western Oregon (Table 1 and Map 1), however, significantly fewer snow course and SNOTEL sites exist. Summary tables listing each of the streamflow, climate and snow stations are located in Appendix I, *Background Data Tables for Northwestern Oregon* (**A**) *and Southwestern Oregon* (**B**). To facilitate presentation, the information is reported according to the County in which the collection sites are located with additional cross-reference to USGS physiographic region. Streamflow records which reported regulated flows for canals, diversions or mine drainage tributaries were not included in the summary tables. The list is otherwise comprehensive including all the continuous streamflow recording gages as well as annual peak flow stations maintained by the USGS.

Table 1: Number of Streamflow, Climate, and Snow Stations in Study Areas

Type of Data Collection Station	***Northwestern Oregon***	***Southwestern Oregon***	***Total***
Streamflow	280	169	449
Climate (precipitation, temperature)	106	67	173
SNOTEL	21	8	29
Snow Course	11	33	44

2.2 Stream Gage Selection

Since it was not feasible to analyze peak flows at all 449 streamflow stations, selection criteria were developed and systematically applied to reduce the number of stream gages to a manageable size for further analysis. The criteria used in this study are similar to those used in MacDonald and Hoffman (1995) and are as follows:

1) the streamflow station must have at least ten years of continuous data;
2) the gage must be located in a drainage basin smaller than 150 square miles; and,
3) the watershed must not have large lakes or regulation which would affect peak flows.

At least ten years of continuous streamflow or annual peak flow data were required to represent an adequate sample size for flood frequency analysis. There were some gage records, which indicated a sufficient period of record to meet the criteria, however when actually examining the data, the records had missing dates, flows, or both. If the missing information reduced the record to an unusable point (i.e. less than 10 years of record), these gage records were eliminated from further analysis. The focus of the analysis was on basins less than 150 mi^2 since “larger basins incorporate more spatial and temporal variability in meteorologic conditions which makes it more difficult to ascribe a specific peak flow to a particular cause” (MacDonald and Hoffman, 1995). Since large lakes and diversions complicate the analysis of how peak flows relate to climatic conditions, watersheds with these features were excluded from this study.

MacDonald and Hoffman (1995) also used a criteria focused on overlapping SNOTEL and streamflow records. This criteria was not applied in this study due to the sparse distribution of SNOTEL sites. The SNOTEL sites in western Oregon are mostly situated along the west slope of the Cascade Range; only 2 were situated in the Coast Range (in Washington County) and 3 were located in the Klamath Mountains near the California border. This sparse distribution of sites in the coastal range, Willamette valley and Klamath Mountains prevented any detailed analysis of coincident streamflow gage records and snow records. Snow course data, while available in some areas, are insufficient to analyze in conjunction with streamflow data since snowpack is measured once or twice per month and no continuous measurement of precipitation is available at these sites.

Of the 449 streamflow gaging stations, 211 met the criteria stated above: 131 streamflow stations meeting the established criteria were located in the Northwest Oregon (A) section, while 80 were located in the Southwest Oregon (B) portion of the study area (Map 1). These gages are shaded in gray in the streamflow gage list located in Appendix I.

2.3 Hydrologic Process Identification Methods

Identification of Dominant Season of Peak Flow Occurrence

The dominant season of peak flow occurrence was determined by analyzing the annual peak flow series for each gage which met the criteria. A graphical illustration of the monthly peak flow distribution was generated for each gage (Appendix II). Peak flows were then classified by season; winter, spring, summer, fall, or unknown. In some instances, the peak flow rate and the year were recorded while the month was not; the season of the peak flow was, therefore, unknown. The seasons were defined as explained below.

Rain-on-snow events generally occur during the late fall and winter season or in the springtime. For purposes of this report, the late fall/winter season will be referred to as *Winter* covering the period from November 1 to March 20; early fall (*Fall*) covers the period from September 21 until November 1. Winter rain-on-snow events can begin to occur in November when a shallow snowpack may have developed. It is rare for this to occur as early as October. The first day of spring, March 20, was selected as the cutoff date between the winter and spring seasons; therefore, the *Spring* season ranges from March 21 until June 20 and *Summer* ranges from June 21 through September 20.

Identification of Specific Type of Hydrologic Process

Once the dominant season of peak flow occurrence was identified, further analysis can be conducted to determine which specific types of hydrologic process are active (e.g. winter rainstorm, winter rain-on-snow, spring rain-on-snow events or spring snowmelt peaks). In most cases, to determine the dominant hydrologic process, the annual maximum flows can be associated with nearby snowmelt and climatic data for overlapping periods of record.

In some regions, this comparison is a straightforward exercise. In other regions such as western Oregon, difficulties in discerning the dominant process can arise particularly due to the spatial relationship of the available SNOTEL data. For instance, snowpack along most of the Coast Range is not monitored, therefore, rainstorms cannot be easily distinguished from rain-on-snow events. As one moves inland snowpack is monitored to some extent, however there are not enough stations to discern local patterns and data are not available for all months; several of the stations did not report a long-term average for January, while February and March data occurred more frequently at these stations. In addition, the amount of snow recorded in western Oregon tends to be minimal until one reaches the High Cascades Region. Because of these issues, it was necessary to develop some assumptions or a procedure by which to systematically assign a likelihood that one process was responsible for generating the peak flows.

In general, throughout the region studied, the majority of annual peak flows occur in the winter season. Since winter is the dominant season, the hydrologic process question comes down to discerning rainfall events from rain-on-snow events. The USGS physiographic regions, delineated for the purpose of flood frequency analyses (Map 1), can be applied as a first screen for distinguishing between hydrologic processes. In general, region 1 peak flows are mostly rain-dominated with rain-on-snow events occuring under rare conditions (large, infrequent floods), region 2 and 3 have more probability of experiencing some rain-on-snow events, and region 4 has significantly higher occurrence of rain-on-snow events. Regression analysis was conducted to define more specifically within these physiographic regions the existence of areas with higher probability for rain-on-snow events by using elevation to estimate the snowpack available for melting. Through the use of regression analysis, assumptions were made to extrapolate the available snow data and assign which process was generating peak flows.

Snow water equivalent versus elevation equations were used to determine the elevation above which a snowpack developed under average conditions. Since the monthly snowpack data reflect snow water equivalent for the 1st day of the month, it is often more representative of the month prior. Therefore, February 1st data were selected to represent average January conditions; January was the month in which most of the annual peaks occurred. January 1st data reflects December conditions, the month which ranked second highest for peak flow occurrence. Consequently, regional snow water equivalent versus elevation relationships were computed for the months of January and February; one equation for each month for the northwest area (A) and one for the southwest area (B) (Table 2). Smaller regions were not used due to the limited distribution of snow stations.

A log-log regression equation was fit to the January data from all of the snow course and SNOTEL data available within each area (25 sites reported long-term averages (1961-1990) in Northwest Oregon; 21 stations reported January data in Southwest Oregon). These relationships (Figures 1 and 2) suggest that on January 1st in an average year very little snow water equivalent is available to be melted below 2000 feet in elevation in Northwest Oregon or below 3000 feet in Southwest Oregon. Regression analysis of the February snow data (27 sites in northwest and 28 in southwest) resulted in a linear relationship of best fit for both the northwest and southwest areas (Figures 3 and 4).

Table 2: Snow Water Equivalent as a Function of Elevation by Month and Region

Region	January Equation	February Equation
Northwest Oregon	$Log(SWE_{Jan})=2.83Log(Elev)-9.26$ $r^2 = 0.77$	$SWE_{Feb} = 0.009*Elev-21.66$ $r^2 = 0.71$
Southwest Oregon	$Log(SWE_{Jan}) =3.97*Log(Elev)-13.84$ $r^2 = 0.77$	$SWE_{Feb}= 0.006*Elev-19.53$ $r^2 = 0.80$

The February 1st average snowpack is minimal below approximately 2300 feet and 3300 feet in northwestern and southwestern Oregon respectively. These estimated snowlines (shaded areas on Map 1) were assumed to apply across the region and were used to categorize the winter peak flows by hydrologic process. Winter peak flows occurring in basins below the regional snowline were assumed to be predominantly rain generated; winter peak flows occurring in basins with mean basin elevation above the regional snowline were assumed to have more frequent rain-on-snow events.

Figure 1

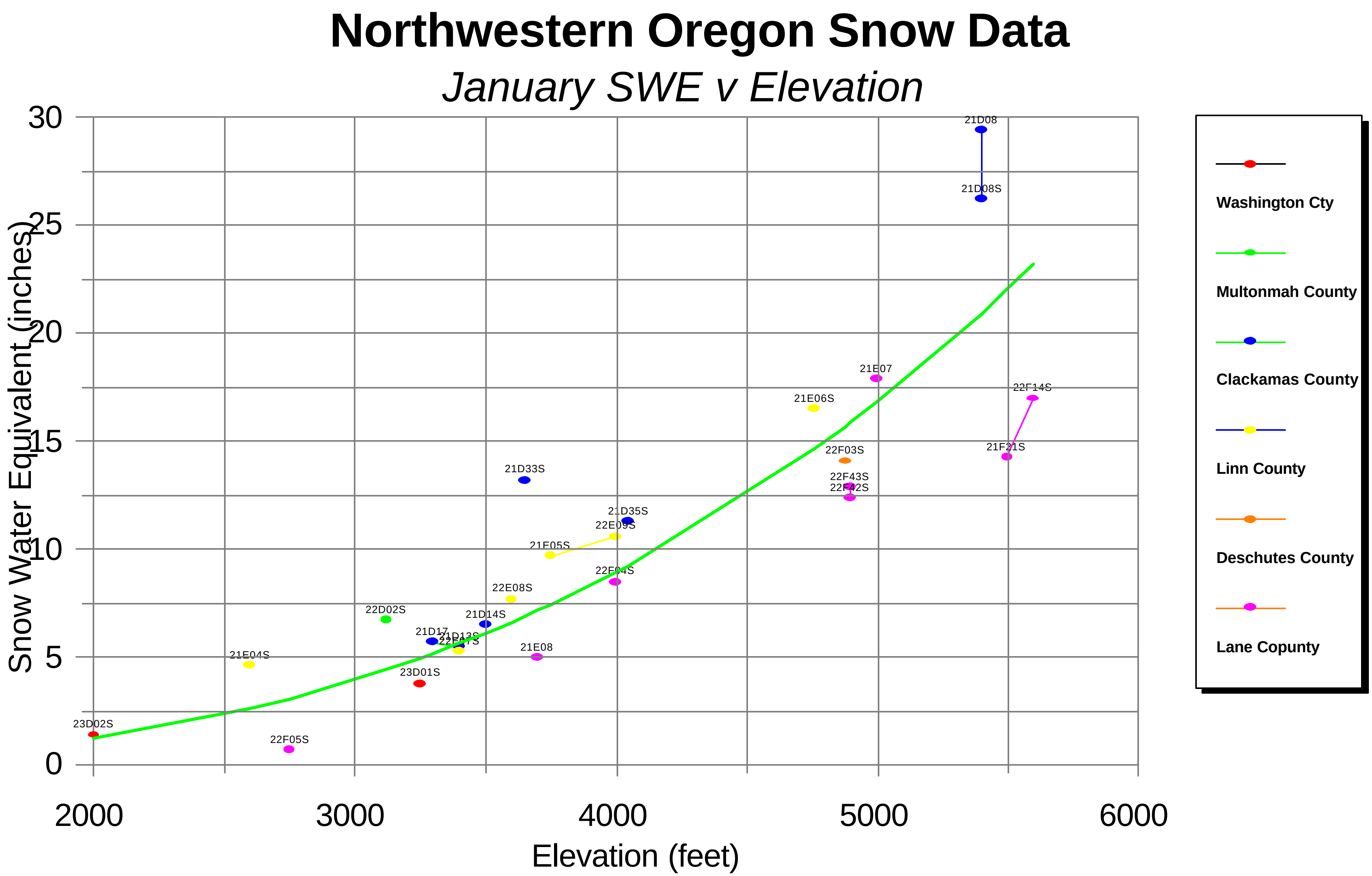
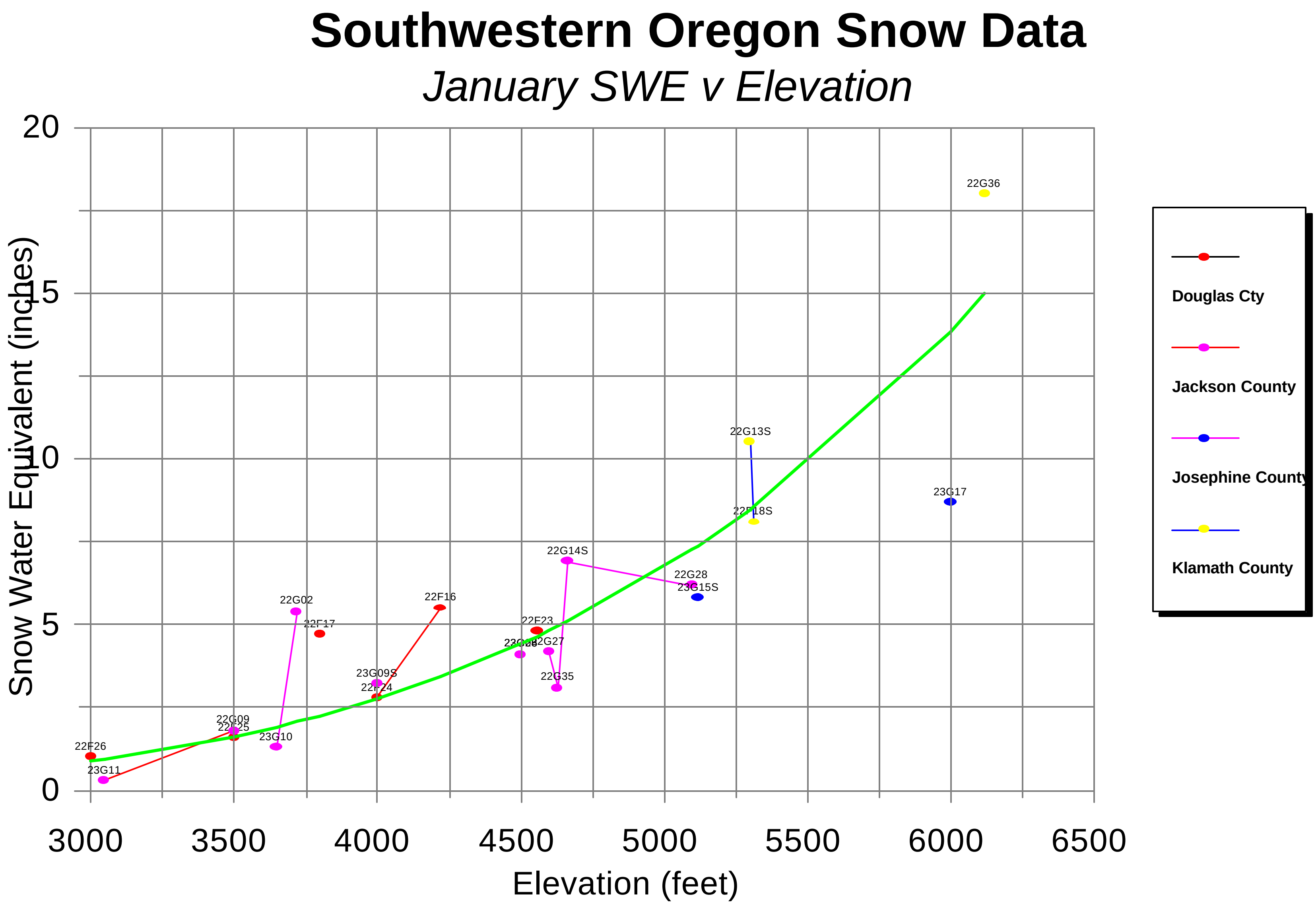
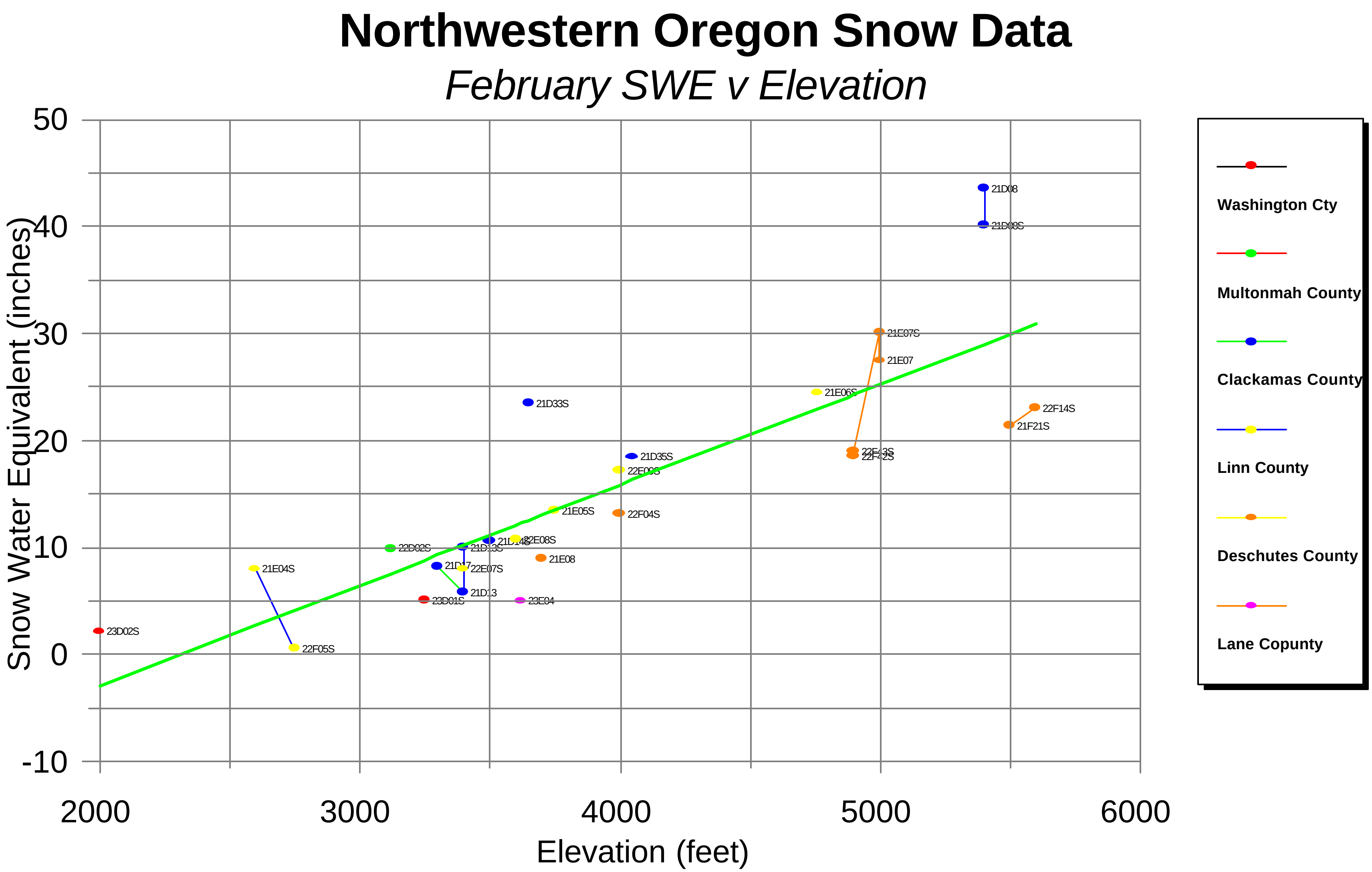

Northwestern Oregon Snow Data
January SWE v Elevation
Snow Water Equivalent (inches)
Elevation (feet)
0
5
10
15
20
25
30
2000
3000
4000
5000
6000
21D08
21D08S
21E07
22F14S
21E06S
21F21S
22F03S
21D33S
22F43S
22F42S
21D35S
22E09S
21F05S
22F04S
22E08S
22D02S
21D14S
21D17
21D13S
22F47S
21E08
21E04S
23D01S
23D02S
22F05S
Washington Cty
Multonmah County
Clackamas County
Linn County
Deschutes County
Lane Copunty

Figure 2



Southwestern Oregon Snow Data
January SWE v Elevation
Snow Water Equivalent (inches)
0
5
10
15
20
3000
3500
4000
4500
5000
5500
6000
6500
Elevation (feet)
Douglas Cty
Jackson County
Josephine County
Klamath County

Figure 3

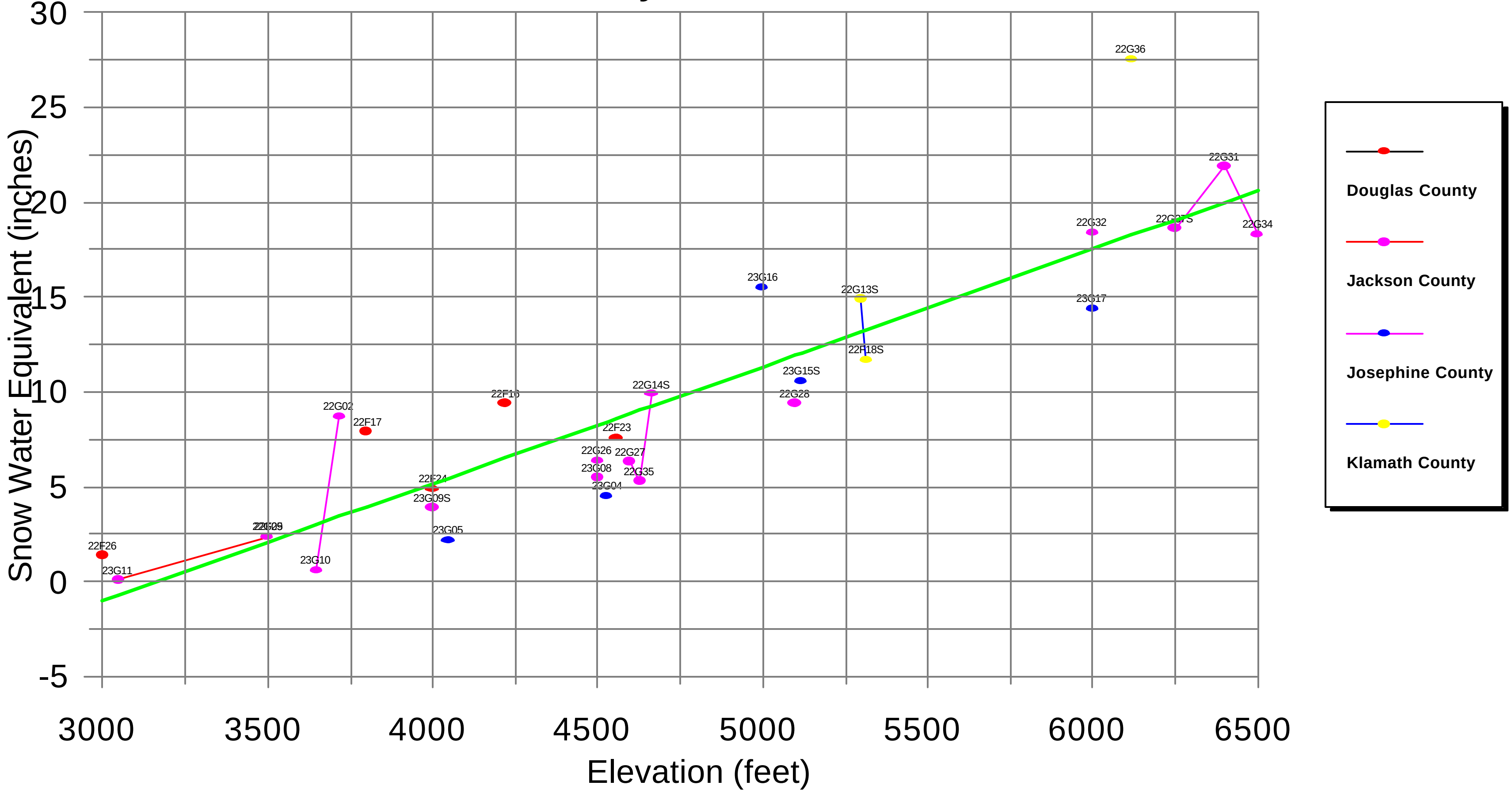


Northwestern Oregon Snow Data
February SWE v Elevation
Snow Water Equivalent (inches)
Elevation (feet)
50
40
30
20
10
0
-10
2000
3000
4000
5000
6000
21D08
21D08S
21E07S
21E07
21E06S
21D33S
22F14S
21F21S
21D35S
22E09S
22F04S
21E05S
22E08S
22D02S
21E08
21E04S
22E07S
23D01S
23E04
23D02S
22F05S
Washington Cty
Multonmah County
Clackamas County
Linn County
Deschutes County
Lane Copunty

Figure 4

Southwestern Oregon Snow Data

February SWE v Elevation



2.4 Hydrologic Information Map

Map 1 was generated for the western Oregon region (Boise Cascade Corporation, 1998) using Geographic Information Systems (GIS) technology. The locations of streamflow gages, climate stations, snow courses, SNOTEL sites are displayed on Map 1 along with county lines and the study area subregions, northwest and southwest Oregon. Physiographic regions adapted from USGS (1979) are also delineated.

The generation of physiographic regions for this study (displayed on Map 1) was accomplished by using the 4th order USGS hydrologic unit codes (HUC). The USES assigns levels to describe the relative sizes of watersheds and the 4th level HUC refers to major subbasins within larger river basins. For instance, the Middle Fork Willamette River has a 4th level designation and is encompassed within the Willamette River basin, a 3rd level HUC. The boundaries established by the 4th level HUC's are similar to those used in the USES 1979 document, however, exact duplication was not possible especially in the High Cascades Region. Most of the original physiographic boundaries followed hydrologic divides which is also the base of the HUC codes. The western boundary of the High Cascades region was delineated based on the interpretation of the grouped residuals associated with USGS regression analyses (personal communication Larry L. Hubbard 1998, USGS) and is therefore difficult to reproduce for use in this report. Consequently, the HUC codes were used to provide a reproducible means for delineating the western boundary of Region 4. Use of the HUC codes resulted in the delineation of a similar shaped but slightly wider area within the Region 4 bounds than that used by the USGS.

Two elevation bands are used on Map 1, each shaded a different tone of green, to illuminate the likelihood of the presence of a snowpack during winter storms. The average January snowlines discussed in the previous section are used to define the elevation bands; the 2300 to 3300 feet elevation band is shaded light green and the areas above 3300 feet elevation are shaded a darker green. In using this map one can assume that, throughout western Oregon, the tan areas (less than 2300 feet elevation) would not have snow available to melt during the winter storms, except during large floods (i.e. greater than 50-year recurrence interval).

3.0 FINDINGS

3.1 General Findings

The majority of western Oregon streams typically experiences peak flows during the winter months; about 80% of the annual peak flows recorded at the selected gages occurred in December or January. A small subregion emerged where peak flows occurred predominately in the spring (Table 3). There were six streamflow stations located in the southern portion of the High Cascades physiographic region, which indicated May was the primary peak flow month. These gages are situated above 3000 feet in elevation and on the west slope of the mountains, which hold Crater (6175 ft.) and Diamond (5182 feet) Lakes.

The general conclusions from this study are threefold:

1. In western Oregon most peak flows occur in the winter months;

2. As one moves inland from the coast toward the cascade crest, the probability for rain-on-snow influences increase; and
3. The area just west of the cascade crest experiences more peak flows due to spring snowmelt and a subregion emerged where spring peak flows dominate.

3.2 Detailed Findings - Coastal Region (Region 1)

In the Coastal region where maritime influences (warm, moist air masses) are significant, snowmelt is not a major factor in flooding (USGS, 1987). Most of the Coastal basins have a mean elevation lower than 2300 feet. Based on the snow equations generated for this study, the coastal basins have a low probability under average conditions of snowpack development
during the months in which peak flows occur (December and January). Therefore, most peak flows in both the northern and southern portions of the Coastal region are produced by rainfall.

Winter rain-on-snow events can happen and have happened in the Coastal region, however, they are rare and associated with very large storms (i.e. 50-100yr). There may be times when some snow is on the ground and melts on the rising limb of the hydrograph but has little or no effect on the maximum peak flow. Greenberg (1995) found in the Siletz watershed that the available snow was melted very early in the storm, prior to the peak of the hydrograph. In this case, the peak flow was generated by the rainstorm while the snowmelt simply caused the streams to begin rising earlier. Future hydrologic analyses of the coastal basins in Oregon should focus primarily on rainstorms as the peak flow generating process with less attention on snowmelt augmenting extreme events.

3.3 Detailed Findings - Willamette Valley (Region 2)

The watersheds located in the interior region of northwestern Oregon, between the coastal mountains and the Cascade Mountains, tend to experience winter peak flows produced by either rainstorms or rain-on-snow events. The Willamette Valley tends to be wetter, warmer and generally lower in elevation than the southwestern interior valleys (Region 3). The orientation of a watershed and the mean basin elevation influence the extent of snowpack development in the basin and consequently the ability of snowmelt to augment peak flows generated from rainfall.

In general, rainstorms will be the primary producer of peak flows in the main corridor of Region 2 (the Willamette River and Tributaries Gallery Forest (3b) Ecoregion and the Prairie Terraces (3c) Ecoregion (Pater, 1997)). Near the eastern border of Region 2 (Valley Foothills (3d) Ecoregion (Pater, 1997)), the landscape becomes more mountaineous often above 2300 feet in elevation. Under average conditions, these foothills would have snow on the ground during the months in which the winter peak flows occur; rain-on-snow events would be expected to produce peak flows in these foothill basins.

The majority of snow data in the lower portion of Region 2 (Lane County) show less snow water equivalent for a given elevation than do stations in Clackamas, Linn, or Multnomah Counties (Figures 1 & 3). This indicates that the basins in eastern portions of Linn and Clackamas Counties, may have more snow available to melt during a rain-on-snow events than those in eastern Lane County. Lane

County is transitional, slightly drier than the rest of northwestern Oregon, exhibiting some of the southwestern Oregon characteristics.

Future analyses of watersheds in or near the Willamette Valley should focus on rainstorms and winter rain-on-snow processes as a function of mean basin elevation. The lowland watersheds will experience peak flows generated primarily from rainstorms while the upper tributaries and headwater basins will have snowmelt augmenting the peak flows.

3.4 Detailed Findings - Umpqua/Rogue Valley (Region 3)

Similar to the Willamette Valley, the Umpqua/Rogue watersheds are located in the interior region of western Oregon and tend to experience winter peak flows produced by either rainstorms or rain-on-snow events. Region 3 is nestled in between the Klamath Mountains and the Cascade Range and therefore local orographic effects play a major role in determining the snow cover. In addition to topography, the orientation of a watershed and mean basin elevation influence the extent of snowpack development in the basin. Low elevations and south-facing slopes tend to be drier while the north-facing and higher elevation slopes tend to be wetter.

The southwestern interior portion of the state is typically drier and colder than its northwestern counterpart. Dictated by its latitude, southwestern Oregon lies in a meteorological transition zone. Areas to the south (Northern California) are predominantly influenced by storms of subtropical origin while storms from the Pacific Ocean generate high streamflows in areas to the north (Northwestern Oregon). Oregon State Climatologist, George Taylor (personal communication, 1998), has found fairly strong correlations between climatic variables (precipitation, temperature, and snow) and El Nino events for northern Oregon (north of Roseburg, Oregon) up into British Columbia. The southern Oregon correlations, however, have not been as strong.

The majority of snow data in the lower portion of region 3 (Josephine and western Jackson Counties) show less snow water equivalent for a given elevation than do stations in Douglas County (Figures 2 & 4). This indicates that the eastern portions of Douglas County, watersheds in the upper Umpqua River basin (Umpqua Cascades (4f) Ecoregion (Pater, 1997)), may experience more rain-on-snow events than Rogue River tributaries (Inland Siskiyous (78e,d,f) Ecoregions (Pater, 1997)).

The upper watersheds in the Umpqua/Rogue Valley region are often above 3300 feet in elevation and under average conditions would have snow on the ground during the months in which the winter peak flows occur. Based on this we conclude that the winter peaks in the upper basins of the Umpqua/Rogue Valley region could often be attributed to rain-on-snow processes. Future analyses of watersheds in or near the Umpqua/Rogue Valley should focus on rainstorms and winter rain-on-snow processes as a function of mean basin elevation. The lowland watersheds will experience peak flows generated primarily from rainstorms while the upper tributaries and headwater basins will have snowmelt augmenting the peak flows.

3.5 Detailed Findings - High Cascades Region (Region 4)

The occurrence of spring snowmelt peak flows in addition to winter peak flows is notable in the High Cascades Region. This is particularly true for the southern portion of Region 4 where spring peak flows are frequently sound among the peak flow record. In the northern portion of Region 4, the streams experience some of their peak flows in the spring time, however, winter peak flows are more common.

High Cascades Region north

Investigation of the 16 streamflow stations in the northern portion of the High Cascades Region (north of Douglas County) showed that while a few of the annual peak flows may occur in springtime, winter is clearly the dominant season of peak flows at all the gages (Table 4). At 13 of the 16 stations, spring peak flows constituted less than 25% of the annual peak flow record. Two stations did show a higher percentage of peak flows occurring in the springtime: 44% at USGS station #14-208500, 27% at USGS station #14-145690, and 25% at USES #14-158250.

Much of the land in the northern portion of the High Cascades Region is above 2300 feet in elevation and under average conditions would have snow on the ground during the months in which winter peak flows occur. Based on this, winter peaks in the High Cascades Region are often attributed to rain-on-snow processes. Future analyses of watersheds in or near the northern half of region 4 should focus primarily on the winter rain-on-snow processes and to a lesser extent explore the factors which influence spring snowmelt.

High Cascades Region south

The southern portion of the High Cascades Region has a higher occurrence of spring snowmelt peak flows. The majority (13 of 17)of gages investigated in the south Region 4 reported spring peak flows accounting for greater than 25% of the annual peak flows on record (Table 4). At five stations, spring floods were more common (>50% of record) than winter floods. One station in Region 3, very close to the Region 4 border (14314500), was included in Table 4 because spring snowmelt peak flows were more common than winter peaks.

While spring peak flows are more common in this region, only 7 of the 17 stations show spring peak flows responsible for producing any of the five largest floods on record and more often than not the largest floods occurred during the winter. This fact indicates that winter rain-on-snow events are probably responsible for producing the largest floods in this region, even at stations which showed spring as the dominant season.

Much of the land in the southern portion of the High Cascades Region is above 3300 feet in elevation and under average conditions would have snow on the ground during the months in which winter peak flows occur. Based on this we conclude that winter peaks in the High Cascades Region are often attributed to rain-on-snow processes. Future hydrologic analyses of watersheds located in or near the southern half of region 4 should focus on both the winter rain-on-snow processes and the spring snowmelt processes.

Table 3: Streamflow Stations Investigated in the High Cascades Region North

Station #	Station Name	County	# of peak flows within season (%)				Season in which 5 largest floods have occurred
			Fall	Winter	Spring	Summer	
High Cascades Region – North							
14207920	Poop Crk nr Big Bottom, Oregon	Clackamas	-	13 (76)	3 (16)	- 1 unknown	Winter
14208000	Clackamas R at Big Bottom, Oregon	Clackamas	-	42 (64)	8 (16)	-	4 Winter 1 Spring
14208500	Oak Grove Fork at Timothy Meadows, Oregon	Clackamas	-	9 (56)	7 (44)	-	4 Winter 1 Spring
14208850	East Fork Shellrock Cr nr Govt Camp, Oregon	Clackamas	1	9 (82)	1 (9)	-	Winter
14209100	Kink Cr nr Government Camp, Oregon	Clackamas	-	19	0	- 1 unknown	Winter
14178600	Short Cr at Breitenbush Hot Sprgs	Marion	-	12	0	-	Winter
14178700	E Humbug Crk nr Detroit, Oregon	Marion	-	16	0	-	Winter
14178800	Wind Crk nr Detroit, Oregon	Marion	-	23 (96)	1 (4)	-	Winter
14179000	Breitenbush R abv French Cr nr Detroit, Oregon	Marion	1	48 (87)	6 (11)	-	Winter
14158250	Hackleman Creek nr Upper Soda, Oregon	Linn	-	12 (75)	4 (25)	-	Winter
14158790	Smith R ab Smith Res nr Belknap Sprgs, Oregon	Linn	-	29 (85)	4 (11)	- 1 unknown	Winter
14144900	Hills Crk av Hills Cr Res, nr Oakridge, Oregon	Lane	-	22 (96)	1 (4)	-	Winter
14145690	Swamp Creek nr McCredie Springs, Oregon	Lane	-	8 (73)	3 (27)	-	Winter
14146000	Salt Crk nr Oakridge, Oregon	Lane	1	14 (74)	4 (21)	-	4 Winter 1 Fall
14146500	Salmon Crk nr Oakridge, Oregon	Lane	3	56 (82)	9 (13)	-	Winter
14158950	Twisty Cr nr Belknap Sprgs, OR	Lane	-	12 (92)	1 (8)	-	Winter

Table 4: Streamflow Stations Investigated in the High Cascades Region South

Station #	Station Name	County	# of peak flows within season (%)				Season in which 5 largest floods have occurred
			Fall	Winter	Spring	Summer	
High Cascades Region - South							
14312700	Thielsen Crk nr Diamond Lake, Oregon	Douglas	-	2 (17)	10 (83)	-	1 Winter 4 Spring
14314500	Clearwater R Ab Trap Cr nr T Falls, Oregon	Douglas*	1	23 (40)	33 (57)	1	4 Winter 1 Fall
14327490	National Crk nr Union Crk, Oregon	Douglas	-	6 (50)	6 (50)	-	Winter
14330500	S. Fk Rogue R ab Imhana Cr nr Prospect, Oregon	Jackson	-	11 (61)	7 (39)	-	Winter
14331000	Imnaha Crk nr Prospect, Oregon	Jackson	-	10 (56)	8 (44)	-	4 Winter 1 Spring
14332000	South Fk Rogue River nr Prospect, Oregon	Jackson	-	30 (70)	13 (30)	-	Winter
14333000	Middle Fk Rogue River nr Prospect, Oregon	Jackson	-	19 (63)	11 (37)	-	Winter
14333490	Elkhorn Creek nr Prospect, Oregon	Jackson	-	6 (55)	4 (36)	1	4 Winter 1 Spring
14333500	Red Blanket Creek nr Prospect, Oregon	Jackson	3	41 (75)	11 (20)	-	Winter
14335080	Fireline Crk nr Butte Falls, Oregon	Jackson	-	8 (67)	4 (33)	-	3 Winter 2 Spring
14339500	SF Little Butte Crk nr Big Elk Ranger Station, Oregon	Jackson	-	2 (9)	20 (91)	-	1 Winter 4 Spring
14341500	South Fork Little Butte Cr nr Lakecreek, Oregon	Jackson	-	47 (77)	14 (23)	-	Winter
14344500	NF Ltl Bute Cr Ab Intake Canl Lkecreek, Oregon	Jackson	-	8 (67)	4 (33)	-	Winter
14353000	W Fk Ashland Creek nr Ashland, Oregon	Jackson	-	18 (72)	5 (20)	-	4 Winter 1 Spring
14353500	East Fk Ashland Creek nr Ashland, Oregon	Jackson	3	16 (64)	6 (28)	-	Winter
14354400	Butler Creek near Ashland, Oregon	Jackson	-	11 (92)	1 (8)	-	Winter
11513000	Grizzley Creek nr Lilyglen, Oregon	Jackson	1	4 (40)	5 (50)	-	1 Winter 3 Spring 1 Fall

*****Station located in region 3 near border with most of the watershed in region 4-- exhibit region 4 characteristics

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Appendix I: Background Data Tables

Northwestern Oregon

Southwestern Oregon

Appendix II: Dominant Season of Peak Flow Occurrence for Selected Gages

Northwestern Oregon

Section IIA-1: Dominant Season of Peak Flow Occurrence for Selected Streamflow Gages

Southwestern Oregon

Section II B-1: Dominant Season of Peak Flow Occurrence for Selected Streamflow Gages