II. HYDROMETEOROLOGY

Observations: *Meteorology* *Climatology* *Snowpack* *SWSI* *Streamflow* *Flood Events*
Forecasts: *Runoff Volume* *Long Range Peaks* *Daily Streamflows*

A. OBSERVATIONS

With the Pacific Northwest's highly diverse hydrologic conditions, both areally and seasonally, information on weather, snowpacks, and streamflows played a pivotal role in the effective operation of the dams and reservoirs to meet the needs of the region's people, industry, and natural resources. This chapter summarizes these conditions, first generally in describing the overall conditions throughout the year and then some unique conditions that had a pronounced effect on the region. The chapter concludes with summaries of forecasts and peak streamflow conditions.

1. Meteorology

This year's weather was influenced by the peak and waning effects of the strongest and longest-lasting El Niño to occur this century. El Niño's effect on the water temperature of the tropical and northern Pacific Ocean were sufficient to move the storm-steering, upper level atmospheric weather systems, and their jet streams, away from their typical seasonal positions. During most summers a high pressure system resides in the Gulf of Alaska blocking storms from entering the Northwest while in the winter the Gulf is dominated by a large low pressure system that, with its counter-clockwise circulation, steers storms into the Northwest. This year, however, the high and low pressure systems were less intense and generally located west of their typical positions which frequently allowed the jet stream to split, with one branch of the jet directing storms into central British Columbia and the other branch directing storms into central and southern California. This left the Northwest relatively warm and dry, except for a few short periods when the split flow pattern broke down as seen in charts 1-4 in Appendix D.

The 1998 water year was preceded with three months of highly variable weather including the effects of a waning tropical storm. July was very wet with from one and one-half times to more than twice the normal monthly rainfall which included a rare summer flood in northeastern Puget Sound. August weather was nearly as dramatic but on the lower end of the spectrum, with half the normal rainfall, even with the passage of the remnants of tropical storm *Ignacio*. September was another wet month with most storms going into the northern basins resulting in warm weather and no snow, preserving the wet soil moisture conditions to greet the new water year.

In keeping with the unusual weather that preceded the water year, October began with the passage of former tropical storm *Ginger*, which made its presence known with heavy rainfall and cooler temperatures in coastal basins. It was followed by a series of winter-like storms and then just before mid-month warm weather returned for a ten-day stay which was then followed by three vigorous, but fast moving, storms that struck the western basins with heavy rains, including widespread but minor flooding in western Washington, and heavy snowfall in the Rockies. November and December saw another adjustment in the weather pattern: basin temperatures averaging 2.1°F above normal and average monthly precipitation ranging from half to two-thirds of normal. Although the average basin-wide November precipitation was very low, western Washington received enough rainfall after mid-month to raise some streams above their flood stage. A strong high pressure ridge formed over the Northwest at the beginning of December followed at mid-month by a Gulf of Alaska low pressure storm system that displaced the ridge and sent storms into the Northwest, producing record daily rainfalls at some westside stations and snow in the Portland area. On the 27th the remnants of super-typhoon *Paka* (which devastated Guam) invaded western Washington delivering heavy showers and bringing some streams close to flood stage. January saw another major change in the weather patterns, producing above normal temperatures for most of the month, and a constant barrage of storms which produced steady snowfall in the mountains. The exception was during January 10-14 when an Arctic airmass moved across the basin that resulted in low elevation snowfall in western basins and an ice storm near the mouth of the Columbia Gorge east of Portland. As El Niño circulation of warmer air returned following this brief chill, the intensity of storms in western Washington increased producing minor flooding near month's end. February saw yet another change in the weather patterns with the split flow directing most storm energy away from the coastal areas of Washington and Oregon, into northern California and Nevada and then northward into eastern Oregon, western Idaho and Montana. Basin temperatures averaged above normal while the precipitation above Grand Coulee was less than half of normal, and northwestern Washington received above normal rainfall. March saw the beginning of the seasonal transition of weather patterns to the spring scenario. During the first week western Idaho and the Oregon Cascades experienced weakening storms that continued to produce snow at higher elevations. The third weekend of March saw a strong storm move over southwest Oregon producing a flash flood on the Illinois River, an uncontrolled tributary to the Rogue River. Snowmelt also began in March with the central Snake Basin experiencing a brief hot spell that resulting in minor flooding in Idaho's Weiser Basin and in small basins in Oregon's Blue Mountains. In keeping with transitional weather patterns, a snowstorm concluded the month in these same basins. Snow accumulation continued for the first three weeks of April as low-pressure systems, with cold air from Alaska and plenty of moisture from the mid-Pacific, dominated the Pacific Northwest's weather. Warm temperatures and an unusually strong thermal low engulfed the region in 80-90°F weather dominated during April's last week initiating a fast snowmelt which resulted in minor flooding in eastern Idaho. By May 3, this thermal low had been pushed out of the Columbia Basin and replaced by cooler and wetter Aleutian air that brought back the wet cycle. This upper atmospheric trough, extending from Alaska to the Oregon coast, helped guide a series of fronts into the region for the rest of May and June, resulting in well-above normal monthly rainfall throughout the Northwest. One storm at the end of May produced extreme rainfall over the Deschutes River basin that flooded the central Oregon town of Prineville. See Section 6 for more details.

After the first week in July, typical summer weather circulation patterns moved into their ususal position and became stationary producing hot wet weather for the remainder of the water year. Periodically small disturbances passed over the basin producing above normal rainfall in some smaller basins. August was very dry and September saw an increase in rainfall in the Snake Basin. Monthly precipitation in subbasins is shown in Table 1 and Table 2.

2. Climatology

The average of the mean daily air temperatures at 30-station were used to determine the average monthly basin temperature which was then compared to the 1961-90 normal temperature for the basin (Table 3). This year the monthly basin temperature departures from normal varied from a cool 1.5°F below normal during June to a high of 5.2°F above normal in September. Only October and June had mean basin temperatures that were below normal. January had the station with the relatively warmest with +11.3°F of normal and June had the lowest with -7.0°F. The extended time (10 month s) of above normal temperatures was indicative of the warm airflow over the basin that is attributed to the El Niño ocean warming. Overall the year averaged 1.9°F above normal.

Although precipitation varied widely over the Northwest was for the year, Figure 6, it averaged 101% of normal for the basin above The Dalles while individual sub-basins averaged between 85% and 136% of normal. The wettest were generally in southern and eastern sub-basins while the drier were in the north. This pattern was in line with the redirection of the storms away from the coastal Northwest and directing them into California, through Nevada and into Idaho. Basinwide, the wettest month was May which had 16 of the 27 sub-basins with more than 200% of their normal monthly precipitation, 10 had more than 300% of normal and the Upper Deschutes-Crooked River sub-basin had over 500% of its normal rainfall. This latter amount was the result of extreme rainfall which resulted in the flooding of Prineville, Oregon.

The driest month was August which had many sub-basins with single-digit percentages of their normal monthly rainfall and a maximum of 81% in the Upper Snake.

The cumulative precipitation indices in the four major basins of the Columbia drainage, Figure 7, shows the excess precipitation in January and spring kept the year totals near normal. Figure 8, the history of these indices for WY77-98, shows the near normal totals of the four basins and that all were significantly lower than last year with the Willamette Basin having the greatest reduction. The slightly above normal totals in the Snake Basin is attributed to El Niño currents rerouting storms from their typically westerly direction to a path from the southwest into California, Nevada, and Idaho.

3. Snowpack

Snowpack measurements begin with the first snowfall at SNOTEL sites. These early season snowpack, however, are highly variable so in this report they begin with the January 1 readings. Two points of reference are to compare the observed snowpack to the long-term normal snowpack. One is to compare the observed value to the normal for that date. Second is to compare the observed snowpack to the normal peak annual snowpack which usually occurs near April 1 as seen in Figure 9.

This years snowpack appeared to have followed the pattern of the 1994 El Niño year snowpack, although this January's heavy precipitation, was not duplicated in 1994. The below normal accumulation and rapid April snowmelt were very similar. The variability of early season snowpacks was demonstrated in November and December as warm weather and heavy rainfall would melt away the first snowfalls of the season.

On January 1, 1998, the average basin snowpack was 73% of its normal value for that date, a stark contrast from the 174% observed the previous year. This average snowpack was 32% of its normal seasonal peak, 14% below its normal value. The wettest snowpacks was in the Wallowa Mountains in northeastern Oregon (91% of normal), and the driest was 55% in the Boise/Payette and John Day sub-basins. Above normal precipitation during January aided the snowpack by producing 30% of the annual snowpack so that on February 1 nearly all sub-basins reported snowpack increases at rates greater than normal resulting in the Columbia Basin average of 90% of normal on February 1, the equivalent 61% of the typical April peak snowpack, compared to a normal year with 69%. The greatest increase was in the Kootenay sub-basin, where the snowpack increased 23% from the previous month's value of 85%, and the British Columbia snowpacks increased 7% to 94%. This was a major increase since together these two sub-basins account for 41% of the normal runoff for the Columbia River at The Dalles, Oregon. The Northwest had less than normal snowfall during February, which resulted in a Columbia Basin snowpack on March 1 that was 84% of normal for that date, and 71% of its normal April peak (14% below its normal). In British Columbia the snowpack was at 86% of its normal and the Kootenai drainage decreased to the mid 70%'s. These decreases were offset by a few small rises in sub-basins in eastern Oregon and southwestern Idaho. During March the average snow accumulation for the basin was near or slightly below that of February so that on April 1, which is generally considered the time of maximum snowpack, before the beginning of the snowmelt season, the basin-wide average snowpack was 83% of normal, Figure 10. There was, however, a north-south gradient in the March snowpack with British Columbia and the Kootenai Basin increasing 2-3%, the Pend Oreille with no change, and decreases in the drainages from Spokane southward.

During April the snowmelt began throughout the basin depleting the already below-normal snowpack at a greater-than-normal melt rate. On May 1 the snowpack for the Columbia Basin above The Dalles averaged 71% of the normal peak accumulation, about half of last year's value (141%). Meanwhile, small gains were seen in the snowpacks in the Upper Snake sub-basin in Wyoming, the Snake in eastern Oregon, the Washington North Cascades, and the Yakima basins. Snowmelt continued during May so that on June 1 the snowpacks below the 4000-ft elevation had melted and by July 1 only highest elevation sub-basins in the Upper Snake and British Columbia still had snowpacks.

4. Surface Water Supply Index

Category-score numerical methods have been developed to indicate the status of the overall surface water supply. The Surface Water Supply Index (SWSI) was developed by the NRCS and has been applied, with slight variations, in portions of the Pacific Northwest. Thus far, the SWSI has only been applied to basins in Oregon, Idaho, and Montana; but only the Oregon values are computed monthly. These indices include consideration of the status of the surface waters and reservoir contents of the basin, along with precipitation, snow, temperature, and other parameters. The index has a range of +4.1 (very ample supply of water) through 0.0 (normal supply), to -4.1 (very inadequate supply).

This water year saw a general increase in the SWSI in Oregon (Table 4). Nearly all basins started the year with near normal water supply. The exceptions were the Rogue/Umpqua (3.0) which was on the high or wet side. The largest changes occurred in the northern half of eastern Oregon from as low as -0.1 (normal) to 2.4 (moderately wet). (The Klamath, Lake County, and Harney areas do not contribute to the Columbia drainage or have flood control reservoirs and therefore are not germane to this report).

The effects of the water supply on the regulation of the specific reservoir projects are discussed in Chapter III, the effects on power generation, irrigation, recreation, fisheries, and other activities are discussed, by activity, in Chapter IV.

5. Streamflow

Streamflows in the Pacific Northwest were measured at approximately 900 gaging stations. To condense these data gages at 14 index locations, on both uncontrolled streams and controlled streams, were used to summarize the flows throughout the region. The gages with upstream reservoir storage had their discharges adjusted for the amount of storage. Mean monthly discharges for each of these index stations, as expressed as a percentage of their 1961-90 normal discharges, are shown in Table 5 and Table 6. This was an "average" discharge year as summarized by the 14 index stations. The highest annual discharge, in percent of normal, was at the Snake River at Weiser with 124% and the lowest was at the MF Flathead River near West Glacier with 80%.

At the start of the water year streamflows were above normal, a carryover from the preceding year which was very wet. In October, all the stations experienced mean monthly discharges that were above normal. The highest discharges, on the Wilson, Chehalis, and Skykomish rivers, were the result of flood producing storms. The other high runoff stations had lesser storms but no flooding. November flows were lower, ranging from 58% on the Umpqua River to 146% on the Clearwater River. Despite its low discharge, the Umpqua River had the largest percentage increase from the previous month. Streamflows decreases continued in December, resulting in monthly averages varying from 36% on the John Day River basin to 116% on the upper Snake River at Heise. Increased rainfall during January brought increased flow to all stations except on the MF Flathead River which decreased slightly. Flows ranged from 69% to 145 % with the Chehalis River being the lowest. In February only the Snake mainstem stations had 100% or more of normal discharge. March streamflow ranged from a high of 128% for the Snake River at Heise to a low of 90% on the Clearwater River and the Clark Fork. April streamflows west of the Cascades Mountains decreased while stations east of the Cascades increased. The greatest monthly increase was on the MF Flathead River (257%) while most stations had mean monthly flows remain in their normal range. The Wilson River had flows of only 53% of normal, the Chehalis River 62%, and the Spokane River 74%. May streamflows east of the Cascades increased by 100% or more while those on the westside had much lower gains or declines over April. The greatest increases were in the Salmon River of central Idaho with 233% and the Snake headwaters with 196%. These increases resulted from unseasonal rainfall which also caused wide spread flooding on small, uncontrolled streams throughout eastern Oregon (including the controlled Crooked River in Prineville), northeastern Washington and northwestern Montana. At most sites, June streamflows decreased from their previous month's values. The Umpqua River and Snake River at Weiser continued high with 200% and 166%, respectively. The lowest were the MF Flathead River with 62% of normal and the Clearwater River with 64%. July and August generally experienced decreasing flows that ranged from a high of 169% on the Chehalis River to a low of 53% on the Skykomish River. Streamflows in the Columbia Basin generally decreased during September, decreasing below the normal range for several of the index stations west of the Cascades and also on the MF Flathead River in western Montana. Figure 11 summarizes the Northwest mean annual adjusted flows for the four major basins in the Northwest, showing a considerable drop from, the last two years.

Tables 7-10 show additional comparisons of WY98 modified streamflows and runoff with historical flows. These modified flows, which use a long term average (LTA) of 1928-89, were reduced to a common state of development. When expressed in percent, October was the wettest month at all four major sites, with modified flows ranging from 141% to198% of average. At the Columbia River at Grand Coulee, Table 7, summer (June through September) flows were below average with the modified discharges ranging from 74% to 84% of average while the wet months (October through March) averaged 126% of the long term average. On the Snake River at Lower Granite, Table 8, 11 of the 12 months had normal or higher flows with December flow only 6% below average. While the above Grand Coulee flows ranged from 74%-190%, a spread of 116%, the Snake basin range was from 94% to 141%, a spread of 47%. Also, the annual average modified discharge was greater than average during nine months at the Snake site (annual average of 110%) compared to the 98% at the Grand Coulee site. The Columbia River at The Dalles, Table 9, is the combination of the flows of the Grand Coulee and Snake sites, plus the flows produced from the eastern slopes of the Washington Cascades. The range of average monthly discharges, 82%-171%, had a spread of 89%. The Willamette River at Salem, Table 10, had the most volatile departures from long term averages: 51% to 198% of average, with four months with less than 80% and two months with more than 120% of average discharge. Without the three flood months of October, January and March , the wet season would have averaged 80% while the five dry months (May-September) averaged 115%; the opposite distribution of a typical year.

6. Flood Events

This water year there were numerous periods when above-flood stage flows occurred in the Northwest, albeit mostly on small uncontrolled streams and rivers. The information given here is covers only the less common events and is preliminary and subject to change.

a. WINTER FLOODS A series of winter storms produced several minor flood events each month from October through March with the Skokomish and Chehalis rivers in western Washington and the Tualatin River, west of Portland, flooding most frequently. During December and January minor flooding also occurred on the Snoqualmie River in Washington and the Nehalem and Pudding rivers in Oregon. During late March rain and snowmelt produced rises on many rivers east of the Cascades. The only river to exceed flood stage, however, was the Weiser River in Idaho, and that was due to a brief hot spell. The listing of flood peaks, Table 11, shows a sampling of the peak discharges and stages that exceeded their flood stages. Because of the drowning of two kayakers on the uncontrolled Illinois River in southwestern Oregon, the flood peaks in the adjacent basins are also included although all were below their respective flood stages.

b. SPRING FLOODS Spring flooding was limited to areas in Idaho, eastern Oregon, and eastern Washington. Most flooding involved small areas, except for those listed in Table 12. Early in May a brief warm spell resulted in minor snowmelt flooding on the Imnaha River in northeastern Oregon, the Naches River in eastern Washington, and on the Henrys Fork and the Portneuf rivers in Idaho. Two serious flood events took place during May. The first was on both the Weiser River and the main stem of the Snake River from the town of Weiser, Idaho, downstream to Anatone, Washington. The peak flow of 17.0 kcfs on the Weiser River near Weiser was exceeded only by the record January 1997 flood.

The second major flood event occurred during the last week of May when eastern Oregon, eastern Washing ton and Idaho were subjected to a series of rainstorms that produced localized lowland and small stream flooding and numerous mudslides. During these events unseasonably heavy rains fell in central Oregon, with one report of was more than 7 inches in 48 hours that fell just north of Prineville. (Several meteorological stations set rainfall records for May and many sites received 200%-780% of their normal May rainfall.) At the time of this rainfall both Prineville and Ochoco reservoirs, a few miles upstream of the town of Prineville, were full and awaiting the beginning of the rain-delayed irrigation drawdown of the reservoirs. The reservoirs were operated to surcharge their storage with the unseasonable inflows, thereby reducing the flows downstream and in the town of Prineville. Although there were no stream gages on the river in Prineville, reports indicated that evacuation of people living below Ochoco dam began at 7:30 PM on Friday March 29, then shortly after midnight, early Saturday morning, the river started overflowing its banks in Prineville, by 3 AM road closures were beginning, and by late Saturday afternoon, all but one of the bridges in town were under flood waters and closed to traffic. The river continued to rise most of the day, inundating more than 20% of the town, including the town's Fire Department, and required the evacuation of 400 families. Ochoco Creek below Ochoco Dam crested at 3.7 ft about noon on Saturday May 30, the Crooked River near Post (Prineville Lake inflow) crested at 10.24 ft, when the river in town crested Saturday evening about 2100 cfs and then receded to 1600 cfs on Sunday. This river normally runs at 400 cfs at this time of the year. More details of the operation of Prineville and Ochoco dams during this event will be found in Chapter III, Section 33 of this report.

B. FORECASTS

River forecasts are prepared primarily by the Northwest River Forecast Center (NWRFC) under an agreement between the NWRFC, the Corps, and Bonneville and are fully coordinated with the Bureau of Reclamation. Under this Columbia River Forecasting Service (CRFS) agreement all major projects are assumed to be operated based on coordinated forecasts. This minimize unanticipated project operations due to the use of different flow forecasts. This agreement sets three main goals: (1) pool certain resources of the three participating agencies within the region; (2) avoid duplication of forecasts; and (3) increase the overall efficiency of operation. These forecasts are released monthly about the tenth of each month between January and June and are based on the basin hydrologic conditions on the first of each month plus normal weather assumed throughout the remainder of the forecast period.

In addition to these CRFS forecasts, the NWRFC also prepared forecasts which are distributed through the state NWS offices for public warning, for rivers in areas that were not affected by project regulations.

For forecast points located below flood control projects, outflow schedules are provided by the operating agency before the downstream flood warning is issued. The forecast area includes all of Oregon, Washington, Idaho, western Montana, western Wyoming, and the Columbia Basin portion of British Columbia. Distribution of all these forecasts was through CROHMS, by the Columbia Basin Telecommunications system (CBT), and the National Weather Service (NWS) web page (www.nwrfc.noaa.gov). The NWS AFOS system is used to transmit the forecasts to the state hydrologist offices in Seattle, Portland, Medford, Boise, Missoula, Pendleton, Pocatello, and Spokane for public release.

1. Runoff Volumes

Water supply volume forecasts issued on January 1, Table 13, indicated below normal runoff could be expected basin wide. By April 1, the volume forecasts were unchanged for the Columbia River above Priest Rapids, and on the lower Snake and lower Columbia rivers, while the volumes on the upper Snake River had increased by 10%. A wet spring following the April forecast, changed the water supply picture dramatically, especially on the Snake River and on the lower Columbia River tributaries below Grand Coulee. Final observed volumes were 5% to 10% higher than forecast on the Columbia River above Grand Coulee and as much as 30% to 60% higher than forecast at many of the Snake River forecast points. The wet spring not only brought additional runoff from rainfall, but also decreased diversions amounts to well below normal, allowing more water to remain in the river to flow downstream. Table 14 shows the monthly forecasts that were used for operations of several major projects. Table 15 shows the history of forecasting the January through July runoff of the Columbia River at The Dalles for the period 1970-98. This table lists the actual historical forecasts that were made at the time and do not include corrections or adjustments for improvements in forecast models, changes in the quality of data, number of data stations used or their locations that have occurred in recent years.

2. Long-Range Peak Flows

Spring peak flow forecasts, expressed as a range of stages or flows, are a product of volume forecasts which provide adjustments to these long-range predictions. The forecast stage or flow are expressed so there is a 67% chance that the peak discharge will fall within the forecast range. A comparison of this year's forecast and observed peaks for key sites is shown in Table 16. The majority of the peak flows in the upper Columbia, Pend Oreille, and on the lower Columbia tributaries fell within their expected ranges. Peak flows on the mainstem Snake and lower Columbia rivers were above their expected ranges due, in part, to the above normal spring rainfall.

3. Daily Streamflows

The forecasts of operational streamflow were prepared by the NWRFC. The three operating agencies, Reclamation, Bonneville, and the Corps, used these streamflow forecasts in their day-to-day reservoir project operation and energy production. Close and constant coordination was required between these agencies and the NWRFC because project operations were dependent upon forecasts and the forecasts must take into consideration the project operation. The results of water resource uses of these forecasts are described in the following two chapters of this report.