The Northwest's
Great Storms and Floods of
November 1995 and February 1996

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After nearly thirty years of moderate storms and flooding the coastal regions of the Pacific Northwest sustained two major floods within a four month period. These were indeed great floods in that the flood-producing storms were noted for their differences in intensity and in duration. Typically floods during the winter period, November through March, are rain induced and are limited to the area from the coast to the Cascade Mountains. The intensity of these storms negated this generality. A wide geographical area of the Northwest was enveloped by these storms: coastal basins of both Washington and Oregon, interior basins in Puget Sound and the Willamette Valley, and in the Columbia Basin as far east as Idaho and Montana. The November storm had the characteristic of a shorter duration and greater intensity whereas the February storm with a lower intensity had its effects intensified by frozen ground, a snowpack essentially to sea level, and precipitation of unusual duration. This resulted in floods of generally greater magnitude in the latter storm although the short term intensity of rainfall was greater in the former. This report discusses the storms and flood effects, along with reservoir operation to mitigate flood effects.

I. BASIN DESCRIPTION

The geographical area covered by this report is the entire Pacific Northwest, including the coastal streams of Washington and Oregon and the Columbia River basin and its tributaries (Figure 1). The coastal drainages of Oregon and Washington, including Puget Sound, covers 37,100 sq mi (96,000 sq km), and the Columbia Basin covers another 259,000 sq mi (671,000 sq km) for a total area of 296,100 sq mi (766,900 sq km).

The dominate physiographic features of the Northwest are the Pacific Ocean, the mountain ranges and the Columbia River Basin. The Pacific Ocean affects the region because it is the source of virtually all moisture entering the basin. The region is traversed by three major mountain ranges, the Coast Range, the Cascade Range, and the Rocky Mountains, crossing the region in a roughly north-south direction. As storms cross the Northwest from the west, the mountains, in effect, remove moisture from the storms, the air is cooled as it rises over the mountains, and the moisture condenses and falls as either rain or snow. An indicator of this is the higher rainfall in the mountains than in the adjacent valleys. The Coast Range (excluding the Olympic Mountains), with a few peaks that extend over 3000 ft (915 m), generally lie within 20 miles (30 km) of the Pacific Ocean. The Olympic Mountains, which are an extension of the Coastal Range but with a different geological history, have peaks over 7000 ft (2130 m). The 60 mile (100 km) wide Puget Sound/Willamette Valley trench, which extends from British Columbia to southern Oregon, separates the Coastal and Cascade Ranges. The Cascade Mountains, a volcanic range with several peaks over 10,000 ft (3050 m), has an average crest elevation near 6000 ft (1830 m). East of the Cascade Range is the Columbia River basin that drains the remainder of the Northwest. It is bordered on the east by the Continental Divide in the Rocky Mountains, on the south by the low divide into the Great Basins of Utah and Nevada, and on the north by the Monashee (a range within the Rockies) and Cascade Mountains in British Columbia.

The Columbia River is the largest river in the Pacific Northwest and, with a length of 1214 mi (1953 km), is the 15th longest in North America. From its source in Columbia Lake at an elevation of 2650 ft (809 m) in Canada's Selkirk Mountains it first flows northwestward through eastern British Columbia, then turns southward toward the United States. It crosses the US-Canadian border north of Spokane, WA, then flows southward across central Washington where it is joined by the Snake River.

The Columbia then turns westward, where it forms the border between Washington and Oregon as it flows through the Gorge in the Cascade Mountains and on to the Pacific Ocean near Astoria, OR.

The major tributaries to the Columbia are the Kootenai and Flathead/Pend Oreille rivers draining southeastern British Columbia, western Montana, and northern Idaho, the Snake River draining western Wyoming, most of Idaho and eastern Oregon, and the Willamette River of western Oregon (Figure 2). Other maps show the coastal basins of Washington, including Puget Sound (Figure 3), and the coastal drainages of Oregon (Figure 4).

The climate of the region ranges from continental arid in parts of the interior basin to alpine in the mountainous regions to maritime rainforest in coastal areas. In parts of eastern Washington, eastern Oregon, and the Snake River basin precipitation averages from less than eight inches (over 200 mm) annually to more than 200 inches (5,100 mm) annual in the rain forests of the coastal mountains.

II. NOVEMBER 1995 STORM

A. METEOROLOGY

November began with an atmospheric low pressure system fixed in the Gulf of Alaska that circulated Arctic air around its center. This airmass picked up moisture and heat as it moved over the relatively warm waters, and then was expelled the modified air in the form of weather fronts. The weather systems were propelled by a zonal (westerly) jet stream into the northern part of the Columbia Basin producing normal amounts of rain and snowfall. With this more northerly track the storm produced some snow along the US Canadian border but missed southern Idaho and Oregon, which remained relatively dry. This weather pattern continued through the first week of November when the Gulf low drifted to the southwest where it remained until early December. In this more southerly position over tropical water the airmass flowing through the low picked up additional heat and moisture before being propelled northeastward toward the Pacific Northwest by the steering jet stream. By the last three days of November this jet stream was sending a steady stream of warm, moist air from near Hawaii (thus the nickname Pineapple Express) into western Washington and western Oregon, producing heavy precipitation that resulted in major flooding. This warm rainfall also penetrated areas east of the Cascade Mountains, extending as far east as central Idaho and western Montana, resulting in snowmelt that added more flow to the already rain-swollen rivers. Daily weather maps prepared by the NOAA's Climate Prediction Center for the period 27 November through 2 December, Figures 5, Figure 6, Figure 7, Figure 8, Figure 9, and Figure 10, show the progression of the surface frontal weather systems and the upper air flow patterns.

A map of storm precipitation prepared by NOAA's Climate Prediction Center, Figure 11, shows that the maximum amount of rainfall center (16" isopleth) for the 12-day storm was located in the Washington Cascades with a secondary high in the far northwestern corner of Oregon. The greatest precipitation, expressed in percentage of normal, is in northern Idaho and western Montana with over 200% of normal while having only 4-plus inches of rainfall. These maps are bases on observations from NWS weather stations and do not include special hydro-meteorology gages operated by other federal water resource gages. The rainfall tables below show that the rainfall centers are generally higher than those reported on the map.

Heavy rains from these storms produced record rainfall throughout much of Washington prior to the storm to bring the soil moisture to near saturation. This heave antecedent rainfall is illustrated by Hanson Dam which received 26.81 inches of rain during the month, easily exceeding the previous November total of 24.10 inches set in 1991. Of this new record, 55% (14.91") fell prior to the flood period and 45% (11.9") during the flood. Single day precipitation totals of 5 to 6 inches fell on a few locations in the Washington Cascades and northwest Oregon. A two-day total of 11.1 inches was measured in the Cascade Mountains at Hyak, WA, for 28-29 November. Samples of precipitation totals for the period 27-30 November range up to 12.9 inches.

4-DAY STORM RAINFALL

River	Station	Rainfall	River	Station	Rainfall
Nooksack	Glacier	5.5"	Wynoochee	Wynoochee Dam	12.5"
Skagit	Marblemount	7.5"	McKenzie	Belknap Springs	4.8"
Sauk	Darrington	5.7"	McKenzie	Leaburg	4.1"
Stillaguamish	Verlot	5.9"	Sandy	Government Camp	9.2"
Skykomish	Skykomish	11.1"	Columbia	Astoria	8.1"
Snoqualmie	Snoqualmie	12.9"	Wilson	Tillamook	9.8"
Green	Hanson Dam	11.9"	Youngs	Seaside	7.7"
White	Mud Mtn	6.0"	Siuslaw	Florence	5.6"

B. SNOWMELT

Prior to the Thanksgiving storm, the warmer-than-normal temperatures in the storm area limited the snowpack accumulation mainly to higher elevations. This was especially true for much of the Cascades and westward. During the storm the freezing level, typically between 3000 and 5000 ft this time of year, was high enough to cause snowmelt up to 10,000 ft, near the top of the highest volcanic mountain peaks. But since the snowpack did not cover a significant portion of the basins it was only a minor contributing factor to the major flood events in the western basins. Northern Idaho and western Montana basins had larger snowpacks so their snowmelt contribution was larger than in the western basins.

C. HYDROLOGY

This section describes the flood area hydrology beginning in northern Puget Sound and progressing southward into western Oregon, then into the basins east of the Cascades. In the following tables the sites shown in **bold** experienced new stage or discharge records and those in *italics* are subject to upstream flood control operation. The unregulated discharges are those that would have occurred had the storage not been used. The recurrence interval (RI) is a calculation of the frequency of occurrence of the storm. For example, a storm with a RI of 6 can be expected to reoccur on the average one every six years; or there is a 17% chance of this storm occurring in any one year. Only the more significant events will be discussed in this report.

All flood control reservoirs were placed on flood operation status, both Corps-owned and Section 7, and generally were operated according to their flood control requirements. In some cases, the reservoirs were above their rule curves from high inflows stored during mid-November storms, but were drafting as quickly as possible when this storm began.

In the main flood areas the streamflows, prior to the flood, were generally above normal, the result of heavy antecedent rainfall. For example, Wilson River at Tillamook average October flow was 113% of normal, the Chehalis River at Grand Mound was 128%, and the Skykomish River at Gold Bar was 256%. The changes in average monthly streamflow from October to November also reflected the enormity of the November flow: in the Snake Basin it varied from minus 5% to plus 26%whereas on the Wilson River it was 708% and the Chehalis River was 498%. [The Gold Bar gage

PUGET SOUND FLOOD EVENTS

River	Station	Damage Zero	Damage Major	Observed Flood Stage	Observed Flood Disch	RI	Unreg Disch
Nooksack	Deming	12.0	15.1	14.82	50.e		
Nooksack	Ferndale			22.05	47.2	25	
Skagit	*Marblemount*			*13.73*	*62.3*	*75*	
Sauk	Sauk	10.0	13.0	16.03	73.2	25	
Skagit	***Concrete***	***28.0***	***32.3***	***41.47***	***160.0***	***<50***	***209***
Skagit	*Mt Vernon*	*28.0*	*30.1*	*37.32*	*135.0*	*12*	*160-170*
NF Stillaguamish	Arlington			14.7	34.1	10	
SF Stillaguamish	Granite Falls	14.0	18.0	14.20	17.35	3	
Stillaguamish	Arlington	16.0	19.0	17.4	49.2	18	
Skykomish	Gold Bar	15.0	19.0	19.5	74.e	≥10	
Snoqualmie	Snoqualmie Fls		50.2	9.0			
Tolt	Carnation		11.1	11.19	11.4	10	
Snoqualmie	Carnation	54.0	58.0	60.30	62.4	20	
Snohomish	Monroe	14.0	17.0	24.10	130.8	40	
Snohomish	Snohomish	25.0	29.0	33.1			
Cedar	Cedar Falls			11.25	6.03	40R	
Cedar	Landsburg	5.0	7.4	7.43	6.57	≤25	8.6e
Cedar	Renton	10.8	12.0	16.02	8.17	20R	10.1
Issaquah	Issaquah			12.1	2.08	5	
Green	*Auburn*	*63.5*	*65.0*	*62.51*	*10.6*	*6*	*20.0*
Puyallup	*Electron*			*12.7*			
Puyallup	Orting	10.0	10.2	10.42	11.1	10	
Carbon	Fairfax			15.08	10.1	20	
Puyallup	**Alderton**			**58.35**	**38.7**		
Greenwater	*Greenwater*			*7.98*	*5.66*	*30*	
Puyallup	*Puyallup*	*30.3*	*31.0*	*25.55*	*36.4*	*8*	*54.0*
Nisqually	National	10.0		11.33	16.0	50	
Nisqually	LeGrande			11.59	24.3	50R	
Nisqually	McKenna	12.0		12.48	23.2e	11	25.0e
NF Skokomish	Hoodsport	15.0		6.72	5.26	<5	
Dungeness	Sequim			6.85	3.96	5	
Elwha	Port Angeles	20.0	21.2	21.43	21.4	<10	

was destroyed in the flood so no percentages increase was available for that site.] This storm event also produced substantial streamflow rises on the northern Oregon coast and in the Willamette valley, but their relatively low flow prior to this event prevented any serious flooding.

The rise in the flows for this flood generally began on November 27 with the peak flows occurring on November 29 and 30. The Skagit, Puyallup, Cowlitz, Stehekin, and Wenatchee rivers, all with headwater in the Cascades, received the brunt of the storm and had flows equal to or exceeding their 100-year flood, or set new flow records.

1. North Puget Sound Basins. Nooksack River flows responded quickly to two heavy rain-pulses on November 28 and 29, producing a double peaked hydrograph (Figure 12). Although the peak stages at Deming did not reach the major damage stage, it was above the zero damage stage for 32 hours. Downstream on Ferndale the peak stage of 22.05 ft was equivalent to a 25-year flood.

Flood control in the Skagit River Basin is provided by the Ross Project, owned by Seattle City Light, and the Baker River Project, owned by Puget Sound Energy. The operation of these Section 7 projects combine to regulate the downstream river flow as measured at the Concrete and Mt Vernon gages. The Ross and Upper Baker projects together control the runoff from 44% and 39% of basin above the Concrete (Figure 13a) and Mt Vernon (Figure 13b), respectively. Both projects stored significant amounts of runoff during the storm. Ross pool rose from 1595.2 ft before the storm to a maximum of 1602.38 ft, 0.12 ft from full pool. Some spillway operation at Ross was required to keep the lake below full pool. Upper Baker rose from 707.68 ft prior to the storm to a maximum of 719.2 ft, 4.8 ft from full pool. No spillway operation was required at Upper Baker. The results of these operations was that the discharge at Concrete, WA, was reduced from 209 kcfs to 159 kcfs, and the Mt Vernon discharge was reduced from 160-170 kcfs to 139 kcfs. Note that the Skagit River at Concrete, even with the use of upstream flood control, set a new all time flow record at Concrete. These flows corresponded to new crest-stage records at Concrete and Mt Vernon of 41.6 ft, 5.5 ft less than the highest forecast by the National Weather Service, but 0.5 ft greater than its record stage of November 1949. The Mt Vernon gage reached a crest of 37.39 ft, approximately 2.5 ft less than the highest forecast crest but a scant 0.02 ft greater than the record flood of November 1990.

The evacuation of the stored flood waters, to prepare for storing future storms, began after the passage of the flood crests. Drafting of Upper Baker prolonged the time for the Skagit River at Concrete to recede below zero damage and kept Mt Vernon hovering about 0.5 ft above major damage, but well below peak stage, for an extra one-half day. The drafting of Ross Reservoir kept the Concrete gage above zero damage for about three-fourths day and at Mt Vernon above zero damage for about one day. These effects were acceptable consequences as prescribed in the reservoir regulation manual for each project and because Concrete was kept below 90 kcfs and below 31.0 ft during the recession as required from the field.

The South Fork and the North Fork Stillaguamish rivers both had runoff hydrographs with three peaks within 30 hours in direct response to the three weather systems that comprised this flood system. The return interval on these peaks were estimated at 3 to 18 years.

Peak flows in this basin had return intervals generally between 10 and 25 years. The North Fork Snoqualmie River near Snoqualmie Falls, WA, peaked at about 13.8 kcfs. This was slightly less than a 25-year flood but still higher than the 1990 flood peak of 12.1 kcfs. The Skykomish River near Gold Bar (Figure 14a) was destroyed early on November 29, prior to the peak, so the peak was determined from high water marks. At the key index station Snoqualmie R near Carnation (Figure 14b) the river remained above the major flood stage for 44 hours and above zero damage in excess of three and one half days.

2. South Puget Sound Basins. Chester Morse Lake, a water supply project for the Seattle Water Department, by virtue of its low lake elevation at the beginning of this runoff event was able to informally store some of the runoff and reduce the flood peak (Figure 15a). The regulated peaks at Cedar River near Landsburg and Renton gages (Figure 15) were near the 20 year recurrence interval.

Flood control in the Green River Basin is provided by the Corps' Howard A. Hanson Dam which controls the runoff from the upper 50% of the basin. Hanson Dam's typical winter operation is to remain near empty pool, passing inflow until flows reach a specified level and then begin storing so that the flows at the Green River near Auburn control point do not exceed 12,000 cfs. The pool was at 1089.9 ft prior to the storm and filled to a maximum of 1168 ft, using 51,600 af, or 49% of the total available flood control space (Figure 16a). This storage reduced the Auburn flows from an unregulated peak estimated at 20,000 cfs to 10,600 cfs during the peak of the storm and 11,200 cfs during the storm recession and pool evacuation.

Flood control in the Puyallup River Basin is provided by the Corps' Mud Mountain Dam on the White River, a tributary to the Puyallup River, and controls the runoff from 42% of the White River basin. Mud Mountain's normal winter operation is to maintain its pool near empty until flows reach a specified level and then begin storing so that the flows at the Puyallup River near Puyallup control point do not exceed 45,000 cfs. The pool was near 943 ft prior to the storm and filled to a maximum of 1161.8 ft, using 63,100 af, or 60% of the total available flood control space (Figure 16b). This pool was 11.8 ft higher than the previous maximum set during a test pool in August 1974. This storage reduced the Puyallup flows from an unregulated peak estimated at 54,000 cfs to 36,400 cfs during the peak of the storm.

COASTAL BASINS FLOOD EVENTS

		Damage		Observed Flood			Unreg
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**	**Disch**
Queets	Clearwater			23.21	87.9	<10	
Quinault	Quinault Lake			16.49	34.8	<10	
Chehalis	Centralia	65.0	68.5	68.5	34.8	6	36.4
Skookumchuck	Pearl St	85.0	89.0	85.17	7.5	12	5.72
Chehalis	Grand Mound			16.88	36.4	5	
Satsop	Satsop	34.0	38.0	34.27	29.4	<5	
Wynoochee	*Black Creek*	*15.5*	*20.0*	*16.11*	*17.7*	*5*	*25.1e*
Klickitat	Pitt	9.0		8.58	7.28	2	
White Salmon	Underwood			7.34	4.93	>2	
EF Lewis	Heisson			20.35	11.70	5	
Cowlitz	Packwood	10.5	12.0	10.72	33.3	25	
Cowlitz	*Castle Rock*	*23.0*		*31.57*	*127.0*	*>100*	
Willapa	*Willapa*			*21.05*	*9.15*		
Naselle	*Naselle*			*14.67*	*7.22*	*<10*	
Nehalem	Foss	13.0	17.0	18.60	32	<5	
Wilson	Tillamook	13.0		15.29	23.51	5	

Recurrence intervals of the flood peaks in this basins were near 50-year. The Nisqually River at National, WA, peaked at a flow rate of about 16.0 kcfs, the highest since 1977 when the flow peaked at 17.1 kcfs.

3. Coastal Basins Events. The rivers that drain the Olympic Peninsula on the east, north, and west generally had recurrence intervals of less than 10-years. The Elwha River at McDonald Bridge began recording 100 years ago; and the previous high flow was a century ago in 1897!

On the Chehalis, Willapa, and Naselle rivers, that drain this area, the Chehalis is by far the largest. Preliminary estimates of the flood peaks from the Chehalis were overestimated; recurrence intervals of near five-years were found to be more correct.

Near the downstream end of the Chehalis Basin is the Wynoochee River, on which flood control is provided by Wynoochee Dam, a Section 7 project, which is owned by the City of Aberdeen and operated by Tacoma City Light and which controls the runoff from 26% of the Wynoochee Basin.

Wynoochee's normal winter operation is to maintain its pool to remain at minimum flood control pool until flows reach a specified level and then begin storing so that the flows at the Wynoochee River above Black Creek near Montesano control point do not exceed 15,000 cfs. The pool was at 774.3 ft prior to the storm and filled to a maximum of 784.5 ft, using 63,100 af, or 33% of the total available flood controls space (Figure 17). This storage reduced the Black Creek gage flows from an unregulated peak estimated at 25,000 cfs to 17,600 cfs during the peak of the storm. Else where in the Chehalis Basin (Figure 18a), the Centralia gage climbed to its major damage stage it did not exceed the peak of record. The Satsop River just reached its zero damage stage (Figure 18b).

The Willapa and Naselle rivers, with headwaters in the Willapa Mountains adjacent to that of the Chehalis River, had estimated return intervals of 15 and 10 years, respectively. These peak flows were well short of the current record holder of November 1990.

On the Oregon coast the perennial flood-prone Nehalem, Wilson, Nestucca, and Siletz rivers again had flood peaks three to four feet above their flood stages but were only rated as five-year or less recurrence intervals and are not included in further discussion.

4. Cowlitz River Basin. Flood control in the Cowlitz River Basin is provided by Mossyrock and Mayfield dams, a Section 7 project owned by Tacoma City Light, which controls the runoff from 47% of the basin that headwaters on the south side of Mt Rainier and the north side of Mt St Helens. Mossyrock's normal winter operation is to maintain its pool to remain at minimum flood control pool until flows reach a specified level and then begin storing so that the flows at the Cowlitz River at Castle Rock control point do not exceed 70.0 kcfs. The Mossyrock pool was near 762.0 ft prior to the storm and filled to a maximum of 773.6 ft, using 130 kaf, or 36% of the total available flood control space (Figure 19). This storage reduced the Castle Rock gage flows to 68.4 kcfs during the peak of the storm. Record flows were observed on the Cowlitz River with severe flooding experienced near Toledo and Castle Rock, WA. At the Castle Rock gage the river crested over 8 ft above flood stage (Figure 19). Depending upon the location the recurrence interval for peak flows in the Cowlitz Basin ranged from 10 to 75 years.

For the Corps' Sediment Retention Structure, which was designed to store sediment and not water, this was the second of five peak discharges during the winter months, and second only to the February 1996 high water event (Figure 20).

5. Other Coastal Columbia. Three small Washington basins technically in the Columbia drainage but generally thought of as coastal basins are the Lewis, White Salmon, and Klickitat. The flood event on the Lewis was rated as a five year flood whereas the White Salmon and Klickitat were both listed as two year events. The Sandy River flood crest was high (preliminarily listed at between 25 and 50 years) but considerably below the record levels of November 1990.

6. Willamette River Basin. The storm significantly affected only the northern most portion of the basin. The more southerly (upstream) projects generally stored between 14 and 18% of their capacity during this event whereas the downstream projects used 43% of their storage. Two rivers, both in the northern portion of the basin, exceeded their flood stage. The Clackamas, with no flood control projects exceeded the flood stage at Estacada by more than three feet. Scoggins Dam, a Section 7 project on a tributary to the Tualatin River, controls runoff from less than six percent of the Tualatin Basin reduced its discharge to 10 cfs, minimum flow, and still was unable to hold the Farmington gage below flood stage; it peaked nearly three feet above flood stage. The only flood protection for these areas would be dikes or sandbagging. On the Pudding and Luckiamute rivers flood crests were high but considerably below the record levels of November 1990. Although above their flood stage, these events were rated at a five year recurrence interval or less and are not discussed in this report.

7. Columbia River At Vancouver. For the first time since 1989 the Columba River crested above its 16.0 ft flood stage at Vancouver, WA, reaching a maximum of 18.02 ft.

8. Eastside Events. East of the Cascades, high water events and operations to mitigate for these events extended from the Cascade Mountains to the Continental Divide. Bureau of Reclamation reservoirs in the Yakima Basin are operated informally for flood control. This means that flood control activities, although not specifically authorized as a purpose for the projects, are included in the project operating plan, to the extent that it does not infringe upon the authorized purposes, *ie*, irrigation. The basin projects were near 35% of capacity at the beginning of the storm and stored as much as possible, with one project having to initiate spill during the storm. Even with this storage,

EASTSIDE FLOOD EVENTS

		Damage		**Observed Flood**		
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**
Coeur d'Alene	Cataldo	43.0		45.88	34.1	
Coeur d'Alene	Enaville	72.0		71.37	24.9	
St Joe	Calder	13.0	16.0	14.55	32.5	
St Joe	St Maries	32.5	38.0	36.4		
Stehekin	Stehekin			29.58	21.0	>100
Entiat	Ardenvoir	7.5	8.0	6.68	3.32	5
Wenatchee	Peshastin	10.8	15.8	17.89	41.3	>100
American	Nile			76.75	2.68	>10
Naches	*Naches*	*16.5*	*18.0*	*19.1*		
Yakima	*Cle Elum*	*6.9*	*12.0*	*8.7*		
Yakima	*Parker*	*9.4*	*12.0*	*13.9*		
Yakima	*Kiona*	*13.0*	*17.4*	*16.0*		
Clearwater	Orofino	17.0	20.0	16.8	80.0	
NF Clearwater	Canyon RS			17.58	37.5	
Clearwater	Peck			17.95	76.0	

the Yakima River at the Parker gage rose to a peak of 13.9 ft, 1.9 ft above major flood stage, and remained above flood stage (9.4 ft) for more than four days.

In eastern basins, both Pend Oreille Lake behind Albeni Falls Dam and Dworshak Dam stored significant amounts of runoff to reduce downstream flows. The former stored 329 kaf, raising the lake surface 3.73 ft to 2055.62 ft while Dworshak stored 426 kaf, raising its lake level 37.14 ft to 1537.86 ft.

Farther east of the Cascades, rises to near flood stages were observed on the Okanogan, Pend Oreille, Spokane, Clearwater, Umatilla, and Grande Ronde river systems. The St Joe River at Calder rose to a foot above flood stage and was one of the few rivers to actually exceed flood stage in this region. Lesser rises were noted in the Flathead, Clark Fork, and Kootenai basins. Libby Dam on the Kootenai River in western Montana, despite its remote location from the main highwater events, reduced its discharge from 20.0 kcfs to 4.0 kcfs, minimum discharge, to reduce river stages in the Vancouver/Portland area (Figure 21).

D. EMERGENCY OPERATIONS

Seattle District had over 60 personnel deployed to the field to assist state and local governments in flood fight efforts. An equal number of District personnel were involved in EOC operations, reservoir control, and support activities. The Corps distributed 200,000 sandbags, of which 90,000 bags went to Skagit county. Estimated expenditures for hiring of equipment, sandbags, and personnel costs in $900,000.

E. DAMAGES

The following counties in Washington state were declared eligible for federal disaster aid: Chelan, Clallum, Clark, Cowlitz, Grays Harbor, Island, Jefferson, King, Kittitas, Lewis, Mason, Pacific, Pierce, Skagit, Snohomish, Thurston, Wakiakum, Whatcom, and Yakima.

Damages and damages prevented from this flood were not computed because of the occurrence of an even greater flood in February 1996. However, there are some general indications of the amount of damages sustained from this flood. Damages in the Seattle District portion of Washington State were estimated to be $200-250 million. Nineteen counties in Washington were declared to be eligible for Federal disaster relief.

III. FEBRUARY 1996 STORM

A. METEOROLOGY

November and December were very wet months and flooding occurred throughout Oregon and Washington. Most of northwest Oregon received at least 125% of normal precipitation for the first four months of the water year (October-January) 1996. The table below compares observed and normal precipitation totals during this 4-month period at selected Northwest stations and basins.

This rainfall, plus mean monthly temperatures up 6°F above normal, brought the soil moisture to the saturation point especially west of the Cascades. By mid-January the snow-water equivalent at the high elevation SNOTEL sites in the Willamette drainage was only 29% of normal. Then, after mid-month, a combination of Arctic air to the north and tropical moisture to the south caused heavy snowfall over the Cascades. This brought the average snowpack up to 112% of normal across Oregon

Location	Observed (Inches)	Normal (Inches)	Percent of normal
Laurel Mountain	108.66	59.10	184
Portland 27.46 19.50		141	
Eugene	41.55	28.13	148
Government Camp	71.42	46.16	155
Willamette Basin	44.56	32.06	139
SW Washington Cascades	52.11	37.76	138
NW Washington Cascades	62.44	46.25	135
E Slopes Washington Cascades	33.10	22.85	145

at elevations where snowpacks normally accumulate. Then in late January a change in the weather pattern from southwesterly to northerly flow aloft which brought bitterly cold temperatures across the Northwest, causing ice formation on rivers in northern Idaho and Montana. This produced snowfall even on the valley floors and then froze the already saturated ground and snow. Figures 22, Figure 23, Figure 24, Figure 25, Figure 26, and Figure 27 are a series of weather maps that shows the cold weather ending on February 4, when Portland's high was 24°F and the low was 20°F, and the beginning of the southwest flow at the guiding 500 mb level. By February 5, the weather patterns had shifted as a strong front moved into the region raising Astoria's minimum temperature from 34°F to 42°F and raising Portland's minimum temperature by 7°F. The Pineapple Express had begun! This caused very heavy rain concentrated over northwest Oregon and fell on snowpacks that had grown to 200% to 300% of normal in some valleys. This resulted in rapid snowmelt that quickly entered and swelled the streams and rivers. This weather system remained in this position for four days as wave after wave of tropical moist air flowed into the Northwest. Air temperatures rose into the mid-50's where they remained through the 8th when the upper air pattern (500 mb) began shifting northward over cooler waters, the rains gave way to drier cooler air that produced three days of sunshine in which to begin assessing flood damages and begin the seemingly impossible cleanup.

During the storm, temperatures at the surface rose from below freezing to over 50°F in 24 hours and the freezing level, which had been at the surface, rose to and generally remained above 8,000 ft for the four days. The snowpack melted completely below 3,000 ft and suffered significant losses above the 3000 ft level. By February 9, weather stations were reporting minimum daily temperatures in the 30s and 40s, effectively stopping all snowmelt.

The table below shows four day total precipitation for selected northwestern Oregon and Washington locations, as well as the all-time four day records which are shown in **bold**. The most spectacular rainfall, but for a different four days, was at Laurel Mountain in the Coast Range where four-day total was 27.88 inches (8.20", 7.90", 7.05", and 4.73" for February 6-9, respectively). Other notable rainfall amounts include 4.24 inches in 24-hours ending 10 pm February 8 at Toledo, Lewis county, WA, 4.4 inches in 24-hours ending 6 am February 9, and at SeaTac Airport 3.06 inches, a daily record for February 8, and a total of 5.75 inches, four times normal, for the period February 1-8. Figure 28 shows the four day total storm rainfall to be greater than 16 inches in the Washington Cascades and on the Oregon Coast. Actual observed values were over 11 inches in the Oregon Cascades, over 14 inches in the Washington Cascades, and 9 inches on the Oregon coast.

		FOUR-DAY TOTAL		
		1996	**Previous Record**	
	Site	**(inches)**	**(inches)**	**Year**
Willamette Valley	**Corvallis**	**8.10**	**7.84**	**1974**
	Eugene	9.14	10.30	1964
	Hillsboro	**6.70**	**5.91**	**1974**
	Hood River	7.50	8.67	1964
	Oregon City	**7.51**	**7.29**	**1964**
	Portland Airport	**7.00**	**5.10**	**1994**
	Salem	8.18	8.69	1937
Cascade Mountains	Government Camp	11.30	13.84	1964
Oregon Coast	**Astoria**	**8.88**	**8.24**	**1975**
	Newport	9.81	10.17	1965
Puget Sound	Howard Hanson Dam 14.62			
	Mud Mountain	7.39		

B. SNOWPACK

The snowpack played a critical role in producing runoff. In mid-January, the snow water equivalent for high-elevation sites in the Willamette drainage was only 29% of normal. Then, unusually high amounts of snow fell in the middle and high elevations of the Cascades and Coast Range (in many locations, several feet per day were reported for many days). By January 31 the average snowpack for the Willamette drainage had risen to 112% of normal. With the arrival of the Pineapple Express temperatures rose from below freezing before the storm to over 50°F in the Willamette Valley and the free air freezing level rose to over 10,000 ft during the storm. The warm temperatures, winds, and rains preceded to prime the snowpack during the 5th and 6th. An example of the contribution of snowmelt to the storm runoff was the snowpack at Marion Forks in the Oregon Cascades which was reduced by more than one half during the storm; amounting to more than half of the runoff from that location. Another example of Oregon snowmelt was Government Camp on the side of Mt Hood where the snowpack went from 88 inches on the 5th to 30 inches on the 9th.

In the Puget Sound basin above Mud Mountain and Howard Hanson dams the snowpack had been below normal at 79% on February 5th, with a density of 25 to 30%, well below the normal of 45% which is typical at this time of year. By the next day, the snowpack had risen to 86% and the density increased to 30-35%. By the 7th, with a rising freezing level, the snowpack increased to 88% and the runoff began to rise rapidly, especially from the lower elevations. The Green River snowpack got as high as 89% before being exceeded by the melt rate and by the storm's end was 65-70% of normal. As a result, the snowpack actually helped in reducing streamflows by absorbing a greater than normal amount rainfall to prime the snowpack at higher elevations. As the heavy rains continued in the basins the snow on the ground at Hanson Dam was reduced from 12 inches on the 6th to 3 inches in just 24 hours. The remaining low level snow was removed quickly on the following day. The snowpack above Hanson Dam was reduced from a peak of 89% of normal to near 70% of normal after the storms.

Demonstrations of the storm centering along the Columbia is seen in the SNOTEL losses. In Washington the more northerly basins (Tolt and Cedar) and the eastside Naches Basin had lower rainfall, SWE loss, and total runoff than the southwestern basins. In Oregon, the southwestern SNOTEL stations, Holland Meadows, King Mountain, McKenzie, Quartz Peak, and Salt Creek Falls, all had lower losses than the northern basins. The following table summarize the snow water equivalent (SWE) and rainfall at sites in Oregon and Washington.

SNOW LOSS

Site	Basin	Elev (ft)	Precip (In)	SWE loss (In)	Total (In)
Alpine Meadows, WA	Tolt	3500	12.4	1.8	14.2
Cougar Mtn, WA	Cedar	3200	9.4	2.4	11.8
June Lake, WA	Lewis	3340	31.2	8.5	39.7
Morse Lake, WA	Naches	5400	10.4	3.1	13.5
Paradise, WA	Nisqually	5120	15.7	3.5	19.2
Sheep Canyon, WA	Cowlitz	4030	18.2	6.1	24.3
Skookum Cr, WA	Green	3920	13.8	5.2	19.0
Spirit Lake,WA	Cowlitz	3120	NA	8.1	NA
Blazed Alder, OR	Willamette	3650	18.3	1.8	20.1
Daly Lake, OR	Santiam	3360	10.1	6.1	16.2
Greenpoint, OR	Hood	3200	9.2	2.2	11.4
Hogg Pass, OR	Santiam	3500	9.7	5.1	14.8
Holland Meadows, OR	Willamette	4900	3.9	6.9	10.8
Jump-Off-Joe, OR	Santiam	3500	9.8	2.4	12.2

King Mtn, OR	Umpqua	4000	3.0	8.9	11.9
Little Meadows, OR	Santiam	4000	17.6	9.9	27.5
Marion Forks, OR	Santiam	2600	11.1	12.2	23.3
McKenzie, OR	McKenzie	4800	10.8	3.1	13.9
Mt Hood, OR	Sandy	5400	11.3	3.4	14.7
New Crescent, OR	Deschutes	4800	2.4	3.4	5.8
Ochoco Meadows, OR	Crooked	5200	1.3	2.9	4.2
North Fork, OR	Bull Run	3120	12.1	8.5	20.6
Peavine Ridge, OR	Clackamas	3500	10.6	5.5	16.1
Quartz Peak, OR	Klamath	5700	1.4	4.5	5.9
Red Hill, OR	Hood	4400	14.5	5.4	19.9
Saddle Mtn, OR	Tualatin	3250	20.4	14.0	34.4
Salt Creek Falls, OR	Willamette	4000	10.2	3.0	13.2
Seine Creek, OR	Tualatin	2000	14.0	8.0	22.0
Three Creeks, OR	Deschutes	5650	6.5	2.4	8.9

C. HYDROLOGY

This flood event was extensive, extending from coastal basins of Oregon and Washington to the Continental Divide and from the mid-Willamette Valley to British Columbia, with the greatest intensity in the vicinity of the Oregon-Washington border. River flood stages in Oregon were comparable in magnitude to the one hundred year flood of December 1964, which was the largest in Oregon since flood control reservoirs were built in the basin between the 1940s and 1960s. Of the 26 Oregon rivers that reached flood stage, six were new floods of record. In Washington, the floods were comparable to those of February 1990 and November 1959, with at least six rivers setting new record peak flows.

1. West of Cascade Mountains. The area most extensively affected by the high water was an west of the Cascades and centered along the Columbia River. This region extends from the Stillaguamish River southward through Puget Sound, Portland, and Vancouver, to the middle portion of the Willamette Valley, plus the northern coastal basins in Oregon and all coastal basins in south-western Washington State.

Streams in northwestern Oregon rose quickly on the 6th and 7th, reaching flood stage in many locations. At Vida on the McKenzie River, the flow jumped from 4,000 cfs on the 5th to over 20,000 cfs on the 6th. With the forecast for rivers to rise above their flood stages, action was quickly taken to reduce outflows on the twelve Willamette Basin flood control reservoirs, which control the runoff from only 27% of the basin. At the beginning of this flood event the Willamette reservoirs had 92 percent of their flood control capacity still available. (The reservoirs were drafting waters stored from storms earlier in the winter.) By the end of the flood event 77% of the total flood storage space had been used, with four dams using 90% or more of their space. Even though Detroit Reservoir (Figure 29a) stored nearly 252 kaf and Green Peter and Foster dams stored over 500 kaf the Santiam River at Jefferson exceeded its major flood stage by over 3 ft (Figure 29b).

Corps Dam	Percent of Flood Control Space Used	Corps Dam	Percent of Flood Control Space Used
Hills Creek	68	Cougar	68
Lookout Point	53	Blue River	91
Fall Creek	60	Fern Ridge	74

Cottage Grove	54	Green Peter	90
Dorena	87	Foster	94
		Detroit	94

Storage in the upper Willamette projects was sufficient to hold the Willamette River at Harrisburg gage near flood stage (Figure 30a). Controlled flows on the Willamette River at Salem (Figure 30b) beached 242 kcfs (uncontrolled 404 kcfs) and in Portland Harbor the controlled flow was 365 kcfs, as the river crested at 28.6 ft, roughly five inches below the top of the sea wall protecting downtown Portland (Figure 31a). There was flooding along the Willamette, however, all the way from Salem to the mouth of the Willamette, including in the industrial areas north of the downtown Portland. In the metropolitan area the perennial flood areas, Johnson Creek and Tualatin River, both flooded to their respective mouths. The latter flooded from Dilley, near Scoggins Dam at the headwaters, to its mouth near West Linn. On the lower Tualatin River the diversion gate to fill Lake Oswego failed, releasing a torrent into the lake causing potentially catastrophic overflow of the outlet dam. The lake outlet sustained only minimal damage although waterfront residents suffered significant losses. Other major and minor tributaries throughout the Willamette Basin jumped their banks, including the Clackamas, Mohawk, Luckiamute, Marys, Yamhill, Pudding, and Mollala rivers.

The Corps of Engineers also coordinated the flood control operation of 50 other dams throughout the Columbia River Basin to keep the Willamette River from flooding downtown Portland (due to the backwater effects of the high slows on the Columbia River) and to keep the Columbia River from flooding Vancouver (Figure 31b). British Columbia Hydro cooperated in the flood fight by respond-ing when asked to reduce Keenleyside Dam releases from 92 kcfs to 15 kcfs over four days so the

WILLAMETTE VALLEY FLOOD EVENTS

		Damage		**Observed Flood**			**Unreg**
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**	**Disch**
Lookout Cr	Blue River				9.58	>100	
Mohawk	Springfield	15.0		22.2	12.6		
McKenzie	*Vida*	*11.0*	*14.0*		*32.5*	*33*	*60.2*
Willamette	*Harrisburg*	*14.0*	*17.0*	*14.8*	*77.7*		
Luckiamute	Suver	27.0		33.0	24.8		
Marys	Philomath	20.0		20.8	10.0		
Willamette	*Corvallis*	*20.0*	*27.0*	*23.5*	*114.8*		
Willamette	*Albany*	*25.0*		*30.0*	*127.0*	*17*	*205.0*
North Santiam	Detroit				23.3	>50	
North Santiam	*Mehama*	*11.0*	*13.5*	*13.4*	*51.4*		*102.0*
South Santiam	*Cascadia*				*31.0*	*<100*	
South Santiam	*Waterloo*	*12.0*		*12.9*	*29.2*		*98.0*
Santiam	*Jefferson*	*15.0*	*20.0*	*23.2*	*169.2*	*>25*	
Willamette	*Salem*	*28.0*	*33.0*	*35.0*	*242.0*	*91*	*404.0*
South Yamhill	**Whiteson**	**38.0**	**42.0**	**47.5**	**47.4**		
Molalla	Canby	13.0		14.6	32.0		
Pudding	**Aurora**	**22.0**		**30.5**	**30.0**		
Tualatin	*Dilley*	*17.0*		*19.0*	*9.4*	*10*	
Tualatin	***Farmington***	***32.0***	***34.0***	***37.2***	***36.0***		

Tualatin	***West Linn***	***13.5***	***15.0***	***18.3***	***25.6***	***>50***
Clackamas	Three Lynx	12.0			46.8	50
Clackamas	Estacada	10.0		17.4	80.0	100
Johnson Cr	Sycamore	11.0		14.2	2.37	25
Willamette	Portland	18.0	25.0	28.8	365.0	200
Columbia	Vancouver	16.0		27.2	820.0	182

OREGON COASTAL FLOOD EVENTS

		Damage		Observed Flood			Unreg
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**	**Disch**
Nehalem	**Foss**	**14.0**	**17.0**	**27.4**	**69.0**	**>100**	
Wilson	Tillamook	13.0		18.1	51.e	>100	
Nestucca	Beaver	18.0		18.2	20.0		
Siletz	Siletz	16.0		24.5	28.5	10	
Alsea	Tidewater	18.0		23.9	32.0		
Siuslaw	**Mapleton**	**18.0**		**27.5**	**47.0**		

US Bureau of Reclamation could reduce its releases from Grand Coulee Dam from 135 kcfs to 50 kcfs. During this flow reduction Coulee's storage went from 80 to 91% of capacity. Other project discharge reductions included Brownlee on the Snake River where outflows were cut from 25 kcfs to 15 kcfs, Duncan in British Columbia cut outflows from 800 cfs to 100 cfs, Libby from 18 kcfs to 4 kcfs, Hungry Horse from 9.2 kcfs to 145 cfs, Kerr from 15 kcfs to 10 kcfs, and Albeni Falls from 28 kcfs to 20 kcfs, increasing its storage from 57 to 86% of capacity. These regulations alone reduced the Columbia River stage at Vancouver by a preliminary estimate of 1.8 feet. This Columbia Basin storage, along with the Willamette storage, also reduced the Willamette River peak in Portland by 2.92 ft, according to the Corps' UNET computer model, to an observed crest of 28.6 ft (Figure 32a).

Along the Oregon coast the Nehalem and Wilson rivers, with their headwaters west of Portland and draining into the Pacific Ocean, suffered severe flooding (Figure 33). The four day rainfall total 27.88 inches at Laurel Mountain and 20.3 inches at Lees Camp were indicative of the rains that produced streamflows that exceeded the November 1995 flood peak by 8.8 ft, to a record peak of 27.4 ft. The towns of Vernonia and Tillamook were completely devastated by these floods. The Wilson River gage at Tillamook was knocked out of service at the beginning of the flood.

2. Puget Sound. The Puget Sound region has both informal flood control storage and formal flood control storage either by Federally owned dams or through Section 7 project agreements. The Nisqually River had informal flood control storage in Alder Dam which was quickly filled, and the project then passed its inflow producing 68 kcfs at McKenna 23 miles downstream. Upstream of Alder the gage at National recorded 20.1 kcfs. Both these gages not only eclipsed the November 1995 flows but also set all time records for these stations.

At the Corps' two flood storage projects, Mud Mountain and Howard Hanson dams, flood control operation was started when the first flood forecasts were issued by the NWS-River Forecast Center. Project discharges were reduced to minimum as the flows at the downstream control points increased toward their design levels. At Mud Mountain Dam this design level was 50 kcfs at the Puyallup gage, which is the capacity of the levees. The flows in the Puyallup River Basin, which are partially controlled by Mud Mountain, reached a critical point on the 8^{th} when the pool rose to the level where a transition to higher project discharges had to begin because of the ungated spillway. The project had been discharging minimum flows to keep the discharge at the Puyallup gage from exceeding the capacity of the levees. The pool was approaching the crest of the ungated spillway (1215 ft) even as the flows at the control point remained near capacity (Figure 34). With the forecast for the end to the rainfall and for cooler temperatures that would reduce the river flow, outflow from Mud Mountain was increased to slow the rate of filling of the reservoir. The amount of the increase in project discharge was calculated to be equal to the decreasing flow from the uncontrolled area thereby keeping the discharge at the Puyallup gage control point near its maximum design flow until reservoir drawdown was safely underway. Project inflow peaked at 29.7 kcfs as outflows were increased to 12 kcfs on the 9th, the reservoir level peaked at 1196.1 ft (84% of capacity), and the Puyallup gage flow was limited to 48.2 kcfs down from an unregulated peak of 76.0 kcfs (Figure 34). This unregulated peak would have been approximately 76.0 kcfs, 98% of the Project Design Flood, and 1.33 times the 1933 peak flood of record. This would have been a 150 year event and also the flood of record for this site. Without this regulation the Puyallup would have overtopped its levees, sending at least a foot of flood water into the highly industrialized portion of the valley between Tacoma and the town of Puyallup. While the dam operation minimized flood

WASHINGTON WESTSIDE FLOOD EVENTS

		Damage		Observed Flood			Unreg
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**	**Disch**
Nooksack	Deming	12.0	15.1	10.2	13.7	1	
Sauk	Sauk	10.0	13.0	14.4	58.0	10	
Skagit	***Concrete***	***28.0***	***32.3***	***32.1***	*88.9*	*4*	
Skagit	*Mt Vernon*	*28.0*	*30.1*	*29.3*	*75.6*	*3*	
NF Stillaguamish	Arlington			14.8	34.5	20	
SF Stillaguamish	Granite Falls	14.0	18.0	21.1	36.8	45	
Skykomish	Gold Bar	15.0	19.0	19.7	75.9	10	
Snoqualmie	Snoqualmie Falls				50.2		
Tolt	*Carnation*				*11.1*		
Snoqualmie	Carnation	54.0	58.0	59.98	59.3	15	
Snohomish	Monroe	14.0	17.0	21.5	98.5	10	
Snohomish	Snohomish	25.0	29.0	29.9			
Cedar	*Landsburg*	*5.0*	*7.4*	*6.78*	*5.72*		
Cedar	*Renton*	*11.1*	*12.4*	*16.0*	*8.0*	*20*	
Green	*Auburn*	*63.5*	*65.0*	*63.6*	*12.4*	*50*	*34.0*
Puyallup	Orting	10.0	10.2	11.19	18.0		
Puyallup	*Puyallup*	*30.3*	*31.0*	*29.77*	*48.2*	*150*	*76.0*
Nisqually	McKenna	12.0	12.5	24.7e	68.e		
Nisqually	National	10.0	11.3	12.2	20.1	100	
Skokomish	*Potlatch*	*15.0*		*16.4*	*24.0*	*10*	
Elwha	*Port Angeles*	*20.0*	*21.2*	*16.7*	*10.9*	*2*	
Chehalis	Centralia	65.0	68.5	74.3	61.0	150	
Skookumchuck	Pearl St	85.0	89.0	87.3	9.1	40	
Chehalis	Grand Mound			19.92	73.9		
Satsop	Satsop	34.0	38.0	33.5	25.1	2	
Wynoochee	*Black Creek*	*15.5*	*20.0*	*13.8*	*13.6*	*2*	
Willapa	Willapa			23.7	11.4		

Cowlitz	Packwood	10.5	12.0	10.6e	25.e
Cowlitz	*Castle Rock*	*23.0*		*29.1e*	*112.e*
Cowlitz	*Kelso*	*20.0*		*29.0*	*125.3*

damage in the lower Puyallup basin the high flows in the White River caused damage to homes and property located in the flood plain immediately below the dam. Federal levees and the project operation prevented serious flooding, even with peak river stages that were over major damage stage.

In the Green River Basin, adjacent to the White/Puyallup Basin, a similar operation, with some variations, was being conducted at Howard Hanson Dam. Outflow matched the increasing inflow to the point where the flow at the Auburn control point was forecast to reach its safe channel capacity of 12.0 kcfs. After that time the project outflow was regulated to keep the discharge at the Auburn gage at or below its capacity until drafting of the stored water was well underway (Figure 35). Hanson inflow peaked at 29.3 kcfs (a 30-year event), the reservoir peaked at 1183.2 ft (66% of the total flood control storage and an 80 year event). The local inflow between the dam and the Auburn gage was almost twice the previously know maximum, and the control point peaked at 12.4 kcfs or 63.6 ft, a 75-year event . Without the flood control operation the Auburn gage would have reached 34 kcfs and exceeded the November 1959 flood of record by nearly 4.0 kcfs.

The main tributaries to Lake Washington, Cedar River at Renton and Issaquah Creek near Issaquah, had peak flows near those of November 1995 but well below their floods of record. Flow from the Cedar River, the largest single tributary to the lake, exceeded its major flood level for more than seven consecutive days during this event (Figure 36) while Issaquah Creek peaked at 2.4 kcfs (Figure 36). Lake Washington was at 20.02 ft (winter draft level 20.00 ft) and rose to 20.45 ft, well below the 22.00 ft full lake level (Figure 37).

In northern Puget Sound, the Snohomish-Snoqualmie Basin also experienced high peak flows during this event. The Skykomish River gage destroyed during the flood two month earlier had not yet been rebuilt so the flood peak was estimated. The Snoqualmie River at Carnation spent 37 hours above major flood stage and 80 hours above zero damage stage (Figure 38a), with flows lower than those of November 1995 and the Monroe gage peaked 4.5 ft over its major flood stage (Figure 38b). Flows on the Stillaguamish River matched or exceeded their stages from November. The North Fork near Arlington (Figure 39b) matched the November flow while the South Fork near Granite Falls exceeded its November crest by nearly 7 ft, a 45-year flood (Figure 39a). This high water event on the mainstem Skagit and Nooksack rivers were 4-year or less events and will not be discussed in this report. Suffice it to say that the Sauk River near Sauk, a large tributary to the Skagit upstream of the Concrete gage had a 10-year crest, however it was nearly four feet below the flood of record.

In southern Puget Sound the Skokomish River suffered a three-peak high water event. The three peaks occurred on February 6, 7, and 8, with the latter being slightly higher than the first two. This peak was below the 16.80 ft of November 1990, and the 17.48 ft of December 1994, but above the 7.3 ft peak in November 29, 1995 (Figure 41b).

On the Chehalis River several gages broke their previous stages of record. At Grand Mound the peak stage of record was exceeded by over a half-foot (Figure 40), and downstream at Porter the previous record was exceeded by two feet. The Wynoochee and Satsop rivers did not have significant crest flows (2-year recurrence intervals). The Corps assumed control of Wynoochee Dam on February 7 for purposes of flood control. During this event the reservoir stored seven feet in the reservoir leaving 19 ft of flood storage unused (Figure 40). Peak inflow to the project was near 5000 cfs and outflow was reduced to 90 cfs (minimum flow) before being raised to 1200 cfs to draft the reservoir to minimum flood control level. The Satsop River had four flood crests in water year 1994 as well as the November 1995 crest that were greater than this flood.

Other coastal basins in Washington sustained significant flood crests during this event. On the Willapa River this was the third high-water event in two years to exceed 10,000 cfs (Figure 41a). It was 3.4 ft below the record crest of December 1944 but above the 2.5 ft crest of November 1995.

3. Lower Columbia. Columbia River tributaries in the vicinity of Vancouver and Portland also experienced significant peak flows. On the Cowlitz River, flood control is provided by Tacoma City Light's Mossyrock Dam which was at elevation 736.49 ft on February 6. Over the next five days the reservoir inflow from the mainstem, as measured at the Cowlitz River near Kosmos gage (Figure 42a), had three high water events peaked at 103 kcfs, the Mossyrock outflow peaked at 45 kcfs and the pool peaked near 778 ft (Figure 42b). Mossyrock had stored nearly 42 ft of water,

COLUMBIA BASIN FLOOD EVENTS

		Damage		**Observed Flood**			**Unreg**
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**	**Disch**
Spokane	*Spokane*	*28.5*	*30.0*	*28.04*	*36.2*	*10*	
Hangman	Spokane	11.0		13.4e	15.0e	<25	
Coeur d'Alene	Cataldo	43.0		51.62	70.0	>65	
Coeur d'Alene	**Enaville**	**72.0**	**83**	**61.7**		**100**	
St Joe	Calder	13.0	16.0	15.22	39.2	25	
St Maries	**Santa**			**13.75**	**12.3**	**100**	
St Joe	St Maries	32.5	38.0	42		100	
Crab	*Irby*			*8.16*	*2.86*	*5*	
Yakima	*Cle Elum*	*6.9*	*10.0*	*9.0*	*18.0*	*20*	
Yakima	*Ellensburg*	*34.0*		*36.7*			
Yakima	Umtanum			38.77	28.0	50	
Naches	*Naches*	*16.5*	*18.0*	*22.5*			
American	***Nile***			***76.97***	***3.20***	***>25<50***	
Yakima	***Union Gap***			***95.39***	***53.***	***>100***	
Yakima	*Parker*	*9.4*	*12.0*	*16.2*	*57.5*	*100*	*77.3*
Yakima	*Kiona*	*13.0*	*17.4*	*17.90*	*47.9*	*75*	
Mill	**nr Walla Walla**			**20.43**	**4.93**	**>100**	
Mill	***at Walla Walla***			***6.94***	***4.22***	***>100***	
Touchet	Bolles			14.0	9.3	>75<100	
Walla Walla	**Touchet**			**20.58**			
Umatilla	Gibbon				6.2	>100	
Umatilla	Pendleton	7.8		11.0	13.0		
NF John Day	Monument	14.0		15.1	23.2		
John Day	Service Creek	11.5		14.0	26.0		
John Day	McDonald Fry				31.3	25	
Metolius	Grandview				8.43	>100	
Warm Springs	Kahneeta				24.8	100	
Deschutes	*Moody*	*8.0*		*12.0*	*79.0*	*>100*	
Columbia	*The Dalles*				*376.0*	*167*	*483.0*

Klickitat	**Glenwood**			**5.70**	**5.50**	**>100**
Klickitat	Pitt	9.0		17.90	51.0	>100
Hood	Tucker Bridge				23.3	25
White Salmon	***Underwood***			***14.94****	***20.1****	***>100***
Sandy	*Marmot*				*66.1*	*>100*
Sandy	***blw Bull Run***			***22.6***	***85.8***	***>100***
Columbia	Vancouver	16.0	27.2	27.2	820.0	

italics=upstream flood control storage **bold**=new all time record *flashboard failure

leaving 0.40 ft, or one percent of storage space available. On the Toutle River, a tributary to the Cowlitz below Mossyrock, the sediment retention structure (SRS), which was designed to reduce the volcanic sediment in the river below Mt St Helens, had three high water events this winter in which the water behind the structure rose above the crest of the ungated spillway (940 ft). The pool rose to 945 ft at a peak discharge of 5000 cfs (Figure 43b). These flows were combined to give a peak of 112 kcfs at Castle Rock and 125.3 kcfs at Kelso. These flows exceeded their flood stages by 6.1 ft and 9 ft, respectively, however levees prevented any serious flooding. At Castle Rock, flows exceeded 110 kcfs for eleven consecutive hours and exceeded 70 kcfs for 34 hours (Figure 43a).

On the Lewis River the power only dams of Swift, Yale, and Merwin had midnight lake elevations within 3 ft of full, suggesting they did fill during peak inflow: Swift filled 30 ft, Yale filled 12 ft, and Merwin filled 11 ft. The Klickitat, White Salmon, Hood, and Sandy river basins in the Columbia Gorge experienced extreme discharges, many of which were record-setters with recurrence intervals of 100-years or more. The Hood River had three flood peaks within 48 hours, with the highest at 23.3 kcfs (Figure 44b). None of these rivers has flood control storage projects. Conduit Dam, on the White Salmon River lost its three-foot high flashboards (initially reported in the press as a dam failure) in this 100-year event.

4. Mid-Columbia Basin. The storm carried over the Cascade crest to much of the Columbia basin. The Yakima basin informal flood control is provided by Tieton, Bumping Lake, Kachess, Keechelus, and Cle Elum reservoirs. The first two projects, on the Naches tributary, stored nearly 80 kaf (Figure 46a) and the latter three stored 100 kaf. The February peak at the Cle Elum gage was nearly as high as that in November (Figure 46b). This reduced the estimated peak unregulated flow at Parker from 77.3 kcfs to 57.5 kcfs, an estimated 100-year event. Even with the flood storage, the Yakima River at Parker gage still rose to more than four feet over its major flood stage (Figure 45).

At the Corps' Willow Creek dam at Heppner, OR, the project inflow rose to near 500 cfs, peak mean daily outflow 263 cfs, and the pool peaked at 2080.1 ft, storing 2.50 kaf (Figure 47a), or 26% of the flood control space. Prineville Reservoir on the Crooked River, a tributary to the Deschutes, had a peak inflow of 7.5 kcfs, outflow peaked at 2.8 kcfs and the reservoir stored 27.1 kaf (Figure 47b). This 100-year flow plus other 100-year flows from the Warm Springs and Metolius rivers produced a greater than 100-year storm on the Deschutes River at Moody near Biggs.

The storm effects also carried over to the eastern portions of the states and into Idaho and Montana where ice jams played a significant role in the damages. In Idaho, record and near record flows were observed in the Spokane River Basin (Figure 48b), including the St Joe, St Maries, and Coeur d'Alene (Figure 48a) drainages where ice jams were major factors in these floods and in the breaching of non-federal dikes. Farther south in the mid-Columbia region the Walla Walla, John Day, and Umatilla basins and in the Snake drainage the Clearwater, Palouse, and Touchet basins were all subjected to high or record-breaking flows. Near Walla Walla, WA, Mill Creek above the Corps' Mill Creek Reservoir (Lake Bennington) overflowed its banks and did major damage to many private homes. Diversions from Mill Creek (6360 af) into Lake Bennington just upstream of the city of Walla Walla raised the pool from 1191 ft to 1256.7 ft, more than 14 ft above the previous maximum. This operation reduced the natural peak of Mill Creek from and estimated 6.0 kcfs to 3.9 kcfs, the channel capacity within the city. Below town the only observed flood damage was minor and was about two miles below Walla Walla.

There were other Snake tributaries that suffered from this flood. The Touchet River broke its dikes in Waitsburg and Dayton, WA, causing extensive damage. In the Clearwater there were many landslides and washed out roads that hindered transportation and commerce. In the Palouse Basin the river caused excessive damage in the town of Potlatch, ID, where the river flowed out of its banks through the center of town.

In the Snake Basin inflow to Dworshak Reservoir on the North Fork Clearwater River in Idaho peaked on February 9 with a daily average of approximately 59.0 kcfs (the second highest of record). To assist in the downstream flood control operation, Dworshak outflow was reduced from 10.0 kcfs to 1.0 kcfs, storing 430 kaf during the peak of the flood event. This operation reduced the Clearwater River's portion of the peak flow into Lower Granite Reservoir by approximately 58.0 kcfs, from 138.0 kcfs (unregulated) to 80.0 kcfs (regulated). The observed peak average daily inflow into Lower Granite was approximately 180 kcfs while the unregulated peak average daily inflow was approximately 260 kcfs, or 45% of the standard project inflow.

SNAKE BASIN FLOOD EVENTS

		Damage		**Observed Flood**			**Unreg**
River	**Station**	**Zero**	**Major**	**Stage**	**Disch**	**RI**	**Disch**
Salmon	White Bird				15.32		
Grande Ronde	LeGrande	10.0		10.7	8.3		
Grande Ronde	**Troy**	**10.0**		**13.6**	**51.8**	**100**	
Snake	*Anatone*				*90.7*		
Clearwater	Orofino	17.0	20.0	14.93	62.6		
NF Clearwater	Canyon RS			16.32	30.8		
Clearwater	*Peck*				*58.9*		
Clearwater	*Spalding*	*18.0*	*19.4*	*16.34*	*91.6*		
Lapwai	**Lapwai**				**3.8**		
Snake	*Lower Granite*				*177.0*		*259.0*
Tucannon	Starbuck			7.30	5.58	20	
Palouse	Potlatch			22.15	14.6		
Palouse	Palouse			18.13	14.2		
SF Palouse	**Pullman**			**9.04**	**5.0**	**75**	
Palouse	**Colfax**			**21.70**	**23.9**	**>100**	
Palouse	Hooper			18.10	28.4	40	

5. Upper Columbia. The effects of the storm reached the eastern portions of the basin, although not with the intensity seen in the west. Even so, significant flooding occurred when the river discharge was stored behind ice jams, forcing water out of stream channels. Many communities were affected by this flooding, and numerous roads and highways were closed as a result of high water stages. Flood flows having a recurrence interval of generally less than 10 years were measured at a streamflow gaging station near Drummond, MT (Figure 49a) while other gages (Figure 49b and 49c) showed only minor rises. However, what under warmer temperatures would have been a moderate flood crest, instead approached record levels as a result of backwater from ice jams. For example, for nearly 100 years of record on the Blackfoot River near Bonner, MT, the stage during backwater conditions created by an ice jam downstream reached 16.0 ft, 5.1 ft higher than the highest previous record stage of June 1964. This produced a 57 kcfs peak on the Clark Fork at Thompson Falls Dam (Figure 50a) upstream of Albeni Falls Dam and below the confluence of the Flathead River and other major tributaries.

A combination of high inflows in November and December and the limited downstream river channel capacities prevented the full drafting of Pend Oreille Lake behind Albeni Falls Dam (Figure 50b). Consequently, when this February flood event began the lake was five feet above its normal winter elevation. On February 7 project inflow had averaged 31 kcfs, which is above normal for this time of the year. On the next day inflows to Lake Pend Oreille began to rise fairly dramatically to 51 kcfs, to 83.1 kcfs on the 9th and by the 10th it was up to 96.9 kcfs. As a result of the high flows and flooding problems region-wide, the level of Lake Pend Oreille was allowed to rise up to and even above 2060.0 ft, which is the normal upper limit for this time of year. As the inflow was peaking, project discharge was increased more rapidly than project criteria generally allowed to avoid flooding along the Pend Oreille River downstream of Albeni Falls Dam. The result of the operation was that although the lake level and project outflow rose quickly the downstream flood problems were avoided. The lake elevation peaked at 2060.38 ft, while the instantaneous inflows varied up to well over 100 kcfs during this flood event.

The operation of flood control projects described above have mainly served the local region, although the Willamette storage also served to reduce flows at Portland. Flood control projects away from the brunt of the main storm and flood area, played a significant role in reducing flows on the lower Columbia River and flooding from the Portland-Vancouver area downstream to the Columbia's mouth at the Pacific Ocean. On the Kootenai River in northwest Montana Libby outflow (Figure 51) was reduced from 19 kcfs to 4 kcfs to help reduce the peak flow at Vancouver. This reduction, along with reductions at other headwater projects, allowed Grand Coulee to reduce its discharge from near 135 kcfs to 50 kcfs. Added to this was the the mid-Columbia PUDs refraining from peaking generation to reduce surges of water moving toward Vancouver. Finally, the releases from the four Corps dams on the lower Columbia River were manipulated to take advantage of their limited flood storage capabilities. John Day reservoir was lowered 2.5 ft to create as much storage space as possible for the heavy runoff, going from 34% to 100% of the flood control storage during the peak of the runoff. All this operation reduced the Portland Harbor stage from 30.4 ft to 28.6 ft and the Vancouver stage from 29.0 ft to 27.2 ft. This observed stage was 0.5 feet below the 1994 flood, 3.8 ft below the infamous 1948 Vanport flood, and 8.4 ft below the historical flood of 1894. In terms of discharge, the observed flow of the Willamette River in Portland was 390 kcfs. When combined with the 420 kcfs discharge from Bonneville Dam plus the local inflow between Bonneville and the mouth of the Willamette, the combined flow was estimated to be 890 kcfs at the confluence.

D. DAMAGES

1. Observed. Damages from this series of floods extended over much of Oregon, Washington, and northern Idaho. Twenty six counties in Oregon, 24 in Washington, eight in Idaho, and the Yakima

Indian Nation were declared disaster areas and eligible for special Federal assistance. Damages included lost lives, damaged and destroyed property including buildings, houses, and equipment, sediment deposit on croplands and pastures, killed livestock, washed out roads and railroads, landslides, levee breaks, lost work due to river closure, etc. Some noteworthy facts about the damages are as follows.

-Eight lives were lost during this event, most were the result of having no respect for the power of moving water by trying to drive on flooded roads; seven in Oregon and one in Washington.

-Estimates of total damages for this February flood event are $3.2 billion.

- Over $1 million in cleanup and repair costs are estimated for the Le Grande powerhouse. The dam was overtopped the dam and the powerhouse was filled with three feet of mud and water. Fortunately, the project staff had sufficient time to protect or remove the most sensitive electrical equipment prior to flooding. “Numerous washouts” were reported on projects access roads.

-Mossyrock project also suffered “numerous washouts on access roads”. This, plus the removal and disposal of a forty-acre debris pile floating on the lake, will cost more than $1 million.

-The BPA had to purchase $5 million of outside energy to meet the region’s power needs. Because the vast amount of water being stored on the Columbia River was not available for hydroelectric power generation, much of the region’s hydro generation shifted to Walla Walla District’s Snake River Projects along with the out-of-region purchases.

-The Corps suffered $550k damage to the Moorings and $400k to Willamette locks due to overtopping.

-Debris removal at NPP reservoirs alone will amount to $350,000. Access roads to some projects washed out.

-Major damage areas included Portland, Lake Oswego, and Oregon City, OR; Tillamook and Vernonia, OR; Kalama and Woodland, WA; Clatskanie, OR; and Cowlitz County, WA. Major efforts were made in protecting the levees on the Puyallup River, saving the Marshland levee road on the Snohomish, and levee breaches and ice damages in western Montana and Idaho.

-Ice caused two major problems. First the jamming raised water levels resulting in overtopped dies. Second was the buildup of ice around docks on Lake Pend Oreille. With the flood’s rapid filling of the lake the ice frozen to the docks and their footings dislodged the footings and the docks floated away.

-Orofino, ID, despite its flood protection by Dworshak Dam on the NF Clearwater River, suffered considerable damage from Orofino Creek which, along with most other small streams in the area, exceeded its bank capacity causing many washouts and property damage.

-Other losses include those sustained by the navigation industry. Navigation was closed on the Columbia and Willamette rivers for several days near the flood peak, preventing ocean-going ships from moving to or from their berths and also prevented river barges use.

-In Tillamook County alone over 600 cattle were killed in the flood.

-More than 1 million sandbags total were used.

-Seattle District estimates that more than $850,000 and a half million sandbags have been used in flood fight activities there.

-In Walla Walla District, More than 70 NPW personnel assisted in the flood fight, providing some 120,000 sandbags to protect property.

-16,000 people were forced from their homes.

-In Oregon more than 750 roads were closed, including I-84 and I-5.

-In Washington 33 state and federal highways were closed.

-In Idaho two main highways, US 95 and US 12 were closed by washouts. Most secondary roads in north-central Idaho were blocked.

2. Prevented. In all, Corps projects and Section 7 projects in the Pacific Northwest were credited with preventing flood damages totaling more than $3.6 billion. Of this total $2,755.9 million were in Oregon, $729.3 million in Washington, $174.3 million in Idaho, and $8.0 million in Montana. In the Willamette Basin alone there was $1.1 billion damages prevented in Portland alone, $280 in the vicinity of Salem, and $500 million in the Vancouver, WA, area. Walla Walla District projects prevented an estimated $10-$12 million in flood damages, and in the Seattle District Mud Mountain Dam prevented about $118 thousand in damages, the Puyallup River levees $15 thousand, and Howard Hanson Dam $242 thousand. As a comparison Corps economists estimate the actual cost of Corps flood control projects in the Columbia and Snake river basins was about $520 million, or $2.77 billion in today’s dollars. That is a $2.77 billion investment saving $3.6 billion in just this flood alone.