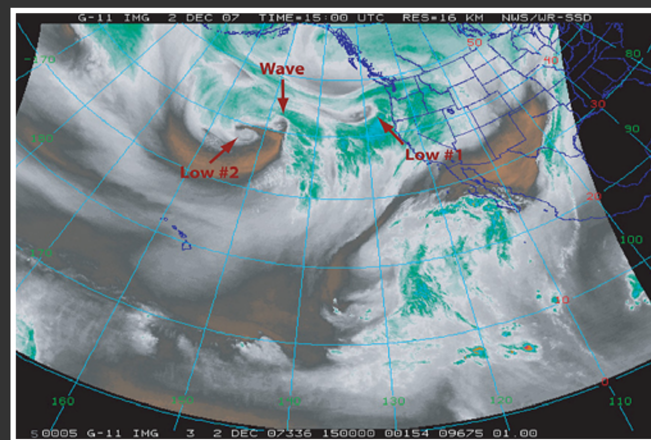
December 1-4, 2007
Storm Events Summary



Prepared for:
Weyerhaeuser Western Timberlands

Maryanne Reiter, Hydrologist,
Weyerhaeuser Company
February 8, 2008

Weyerhaeuser

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Introduction

This report was prepared for Weyerhaeuser Western Timberlands in order to characterize the magnitude of the December 1-4, 2007 storm event in southwest Washington and northwest Oregon. This report focuses on the storm in the vicinity of Weyerhaeuser ownership in northwest Oregon and southwest Washington.

The brief synopsis of the early December 2007 storm events provided by the National Weather Service of Seattle on December 19, 2007 said it well: "The December 1-3 storm offered nearly every winter season hazard … snow … strong winds … heavy rainfall … major flooding … landslides … avalanches and high coastal surf and coastal flooding."[1] The public service announcement went on to describe the closing of I-5, 100,000 coastal residents without power, landslides, the Chehalis, Elwa and Skokomish Rivers cresting at new, all-time records, the state of emergency declared by the governor and disaster areas declared by the president of the United States. This brief narrative gives a sense of the magnitude of the event, while the following sections give more detail on each of the three storms: the snow, the wind and the rain with its subsequent flooding.

The Storm Set-up

The wind and rain portion of the storm began as a typical mid-latitude storm in the mid-Pacific. But a major infusion of moisture from two decaying typhoons (Hagibis and Mitag) caused the storm to grow in size and intensify. The first part of the storm brought wind; the second part brought not just hurricane force wind but abundant moisture as well. This storm grew so large that it reached a diameter of several thousand miles. As it grew in size and strength, the storm was able to incorporate abundant moisture from the tropics.[2]

The Snow

The first in a series of storms in early December brought heavy snow to the mountains and lighter low elevation snow throughout the region due to the arctic air over the area. While only about 1" of snow fell around Seattle, higher elevations of the Cascades received well over a foot of snow. This heavy snow resulted in avalanches in the Washington Cascade Mountains.

On December 2, the snow changed over to rain as temperatures and winds increased.[3] The second phase of the storm, with mild, subtropical air, caused temperatures across the region to jump from near freezing to more than 60 °F (in some areas) in just a few hours. The warm temperatures caused much of the new snow to melt. Snowmelt (inches of water content) amounts ranged from 1-3" for areas below 4,000 ft which was minimal compared to the extremely high rainfall amounts in some areas. This estimate was based on data from Snotel sites[4] (Table 1) in the Oregon Coast Range and in the Cascades of southwest Washington and modeled amounts of changes in snow water equivalent (SWE)[5], i.e., inches of water contained in the snow, from the National Operational Hydrologic Remote Sensing Center (Figures 1A and 1B).

Table 1. Daily snow water equivalent (SWE) for Snotel stations in the southwest Washington/ northwest Oregon vicinity.

	Daily snow water equivalent (in)					
Dec 2007 day	Mowich (3150 ft)	Swift Cr (3770 ft)	June Lake (3340 ft)	Sheep Canyon (4030 ft)	Seine Cr, OR (2060 ft)	Saddle Mtn, OR (3110 ft)*
1	1	6.2	3.4	3.9	0.2	2.1
2	1.3	7.5	5.1	5.1	0.9	3.7
3	1.4	12.7	10.8	8.4	1.5	8.1
4	0.4	10.5	7.5	6.6	0.2	0
SWE (in) change	-1	-2.2	-3.3	-1.8	-1.3	-8.1

*The Saddle Mountain Snotel site lost 8.1 in of SWE, which seems suspicious since it went from 8.1 to 0 in 1 day as compared to the lower elevation Seine Creek site which still had 0.2 in on Dec 4.

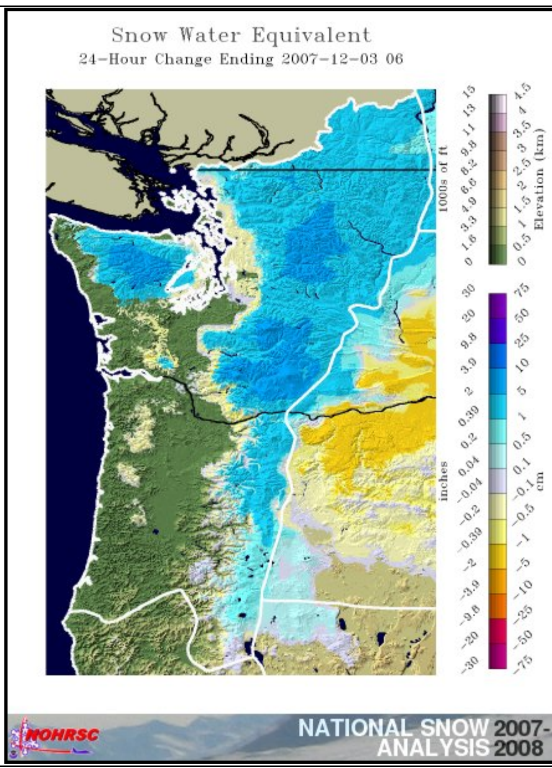

Figure 1A

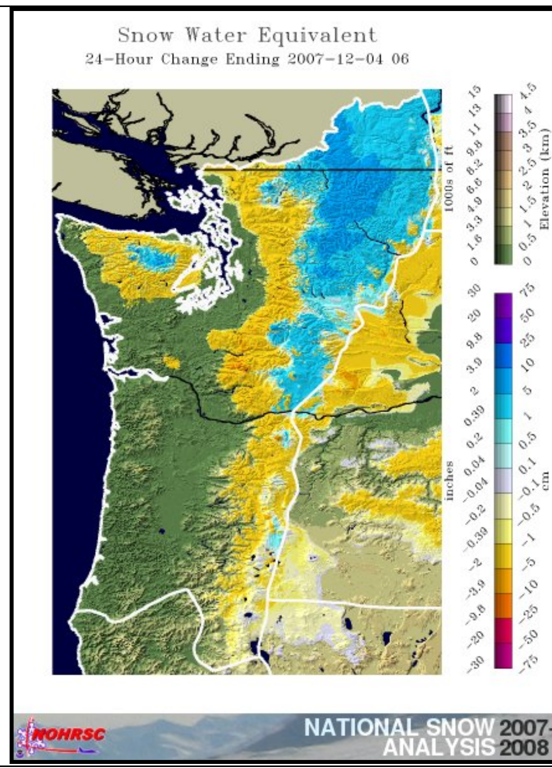

Figure 1B

Figure 1A and B. Figure 1A Modeled change in snow water equivalent (SWE) from December 3, 2007 and 1B from December 4, 2007. These figures are from the National Operational Hydrologic Remote Sensing Center (http://www.nohrsc.nws.gov/ accessed 1/28/2008).

The Wind

On Friday, November 30, the National Weather Service issued a marine weather statement warning of possible hurricane force winds on Sunday and Monday. Later that day they issued a gale warning; then on Saturday December 1 at 2:48 p.m. they issued a hurricane wind warning for the first time… "HURRICANE FORCE WIND WARNING IN EFFECT FROM SUNDAY EVENING THROUGH MONDAY MORNING..."[6]

The coasts of Oregon and Washington, from approximately Newport to Hoquiam received the strongest wind since the Columbus Day wind storm of 1962. Some areas of Washington may have received even stronger winds (Oregon Climate Service, The Great Coastal Gale). Figure 2 shows the location of peak wind gusts along the coast.

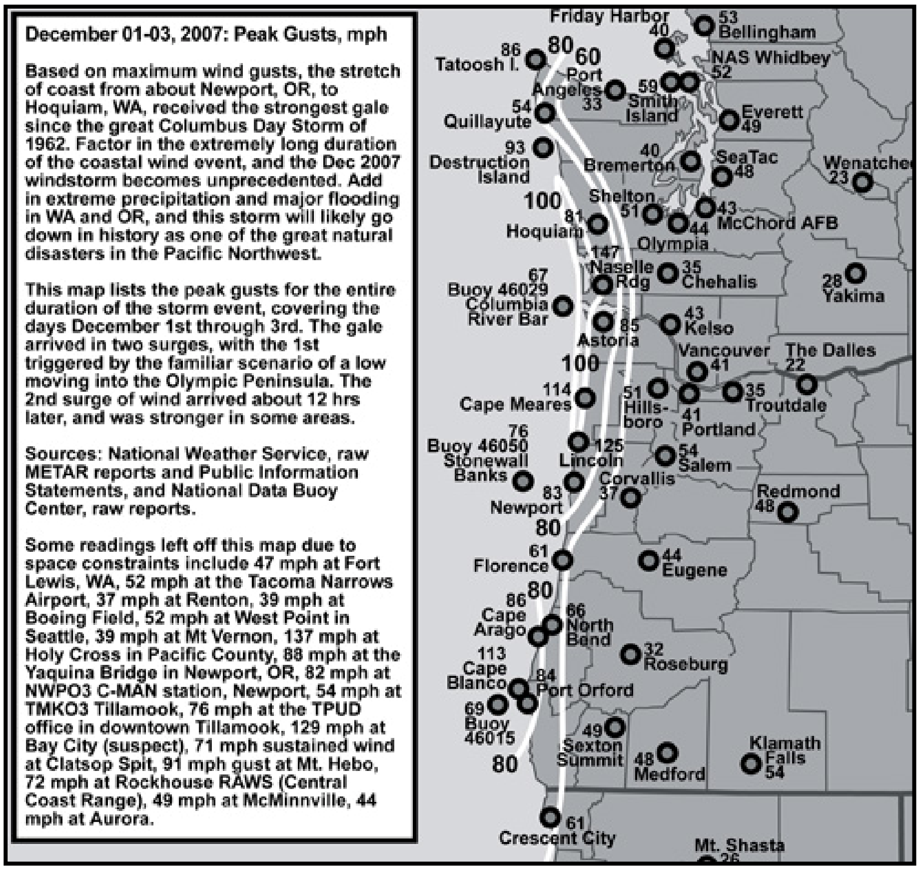

Figure 2. Peak wind gust along the Oregon and Washington coasts. Figure developed by Wolf Read and available on the Oregon Climate Service webpage, The Great Coastal Gale: http://www.ocs.oregonstate.edu/index.html

While the December wind storm was not as strong or as extensive as the Columbus Day storm of 1962, it had a much longer duration, increasing the potential for damage. Figure 3 illustrates both the high wind speeds and the duration of the wind for Clatsop Spit in Oregon. During the storm at this site, winds in excess of 40 mph lasted from Dec 2nd through 4th.

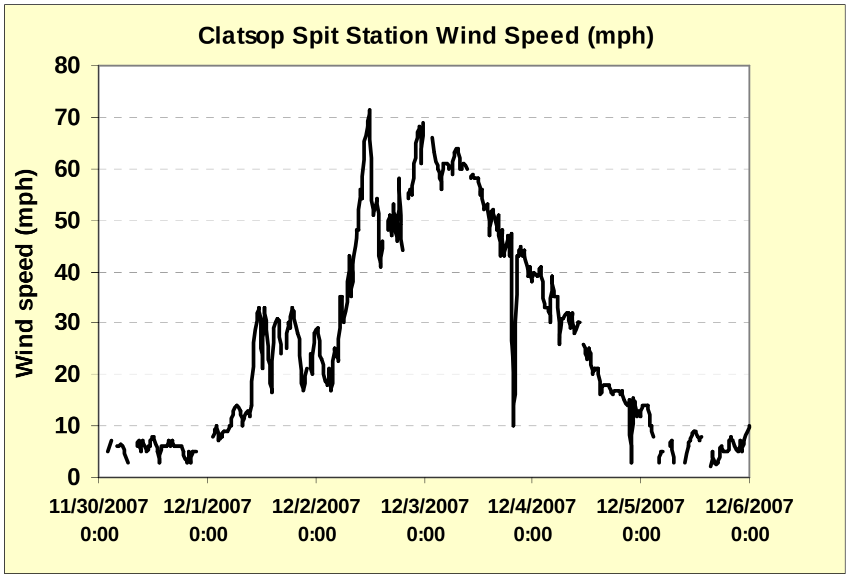

Figure 3. Half hour wind speeds (mph) for the Clatsop Spit weather station, Oregon.

Wolf Read, who researches wind events especially as they relate to tree damage, said: "The storm had Category 1 hurricane force winds, and that doesn't happen very often. The potential for tree damage is incredible. Such storms --mid-latitude cyclones -- have a reach far beyond that of a typical hurricane … and can cause damage into the hundreds of millions, even billions, of dollars."[7] Wind that can lead to windthrow is generally classified as either endemic or catastrophic.[8] Endemic winds are normal peak winds with return intervals less than five years (Wolf Read pers. comm). Windthrow from endemic winds are influenced strongly by site factors and silvicultural practices. Catastrophic winds, according to Dr. Steve Mitchell of UBC, "results from winds with longer return periods and unlike endemic windthrow, is influenced strongly by wind speed, wind direction and local topographic features." Because catastrophic winds, such as occurred in early December 2007, overwhelm site conditions, it is hard to predict the effect they will have on stands since they overwhelm any forest management practice.

The duration of this wind event was important for understanding the level of damage. According to the article on the Great Coastal Gale (OCS 2007); "Trees under heavy wind stress may build up an accumulation of microfractures in the trunk or undergo a series of small root breaks that could lead to catastrophic failure given enough time. Swathing of forests usually takes time. A given opening in a stand gradually widens as each surge of wind topples trees freshly exposed by the loss of their neighbors. The duration of the coastal gale likely explains the extent of windthrow more than the maximum wind speeds." Figure 4 shows an example of swaths of downed forest stands.

Figure 4. Weyerhaeuser photograph showing patchiness of blowdown.

The Rain

The rain component of the storm was characterized by three "surges" of moisture, or "storms within a storm." The most significant of the three surges arrived December 3 with near record high temperatures and moist tropical air which led to record rainfall in many areas of southwestern Washington and northwestern Oregon.[9] The most intense rainfall amounts were generally west of I-5 in the Willapa Hills and Kitsap Peninsula area of Washington. In Oregon, the most intense rainfall was in the higher elevations of the Oregon Coast Range. Figure 5 shows the rainfall pattern as recorded by the Multi-satellite Precipitation Analysis (MPA) at NASA Goddard Space Flight Center.[10]

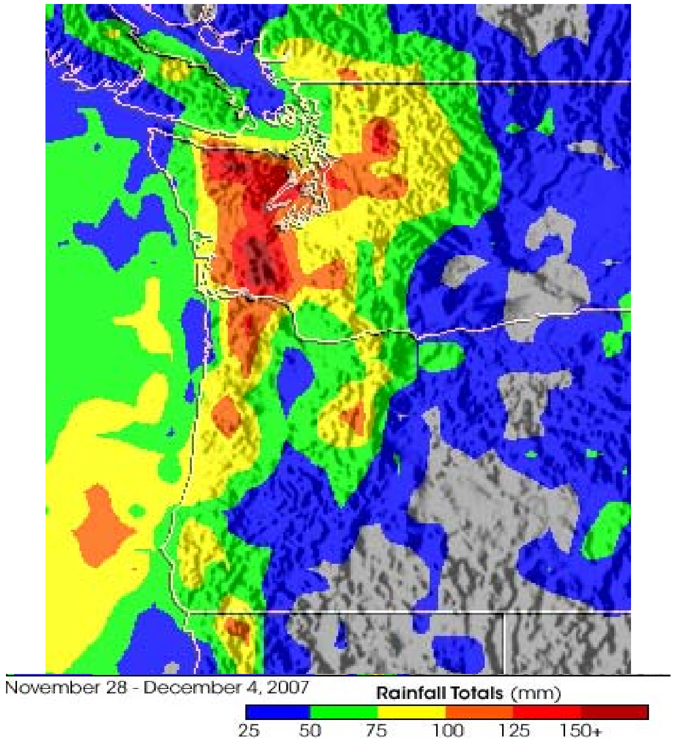

Figure 5. NASA satellite derived image of late November-early December 2007 rainfall pattern.

The storm set several one-day (midnight to midnight) total precipitation records and ranked within the top 5 rainfall totals for several stations. Table 2 shows the station name along with the period of record and the one day amount with its rank in the record. The most impressive records that were broken were for Bremerton and Elma since their rainfall records go back to the late 1800s.

Table 2. Daily rainfall amounts for selected weather stations in southwest Washington with period of record and rank of December 3rd daily rainfall amount.[11]

Station	Year records began	One-day precipitation amount (in)	Rank
Aberdeen	1891	5.21	5
Bremerton	1899	7.50	1
Cushman Powerhouse	1973	7.00	3
Elma	1896	4.77	1
Kalama Hatchery	1967	4.00	1
National Weather Service Seattle	1986	4.15	1
Sea-Tac Airport	1948	3.77	2
Shelton	1999	5.79	2
Wauna 3W (Kitsap Peninsula)	1938	4.42	2

Storm total precipitation

The measured rainfall amounts followed the pattern shown in the NASA satellite image with northwest Oregon and southwest Washington and the northern Olympic Peninsula having the highest rainfall amounts. For Weyerhaeuser ownership, the greatest amount of precipitation fell in the headwaters of the Chehalis River and Stillman Creek basin. Figure 6 shows measured amounts of rainfall in the hardest hit storm area. For the National Weather Service rain gage at Frances, which is in the high landslide impact area, there was 14.1 inches of rain, most of which fell in just over 48 hours while the previous record storm event for that area, observed in February 1996, was 10.3 inches of rain in a 100-hour period.

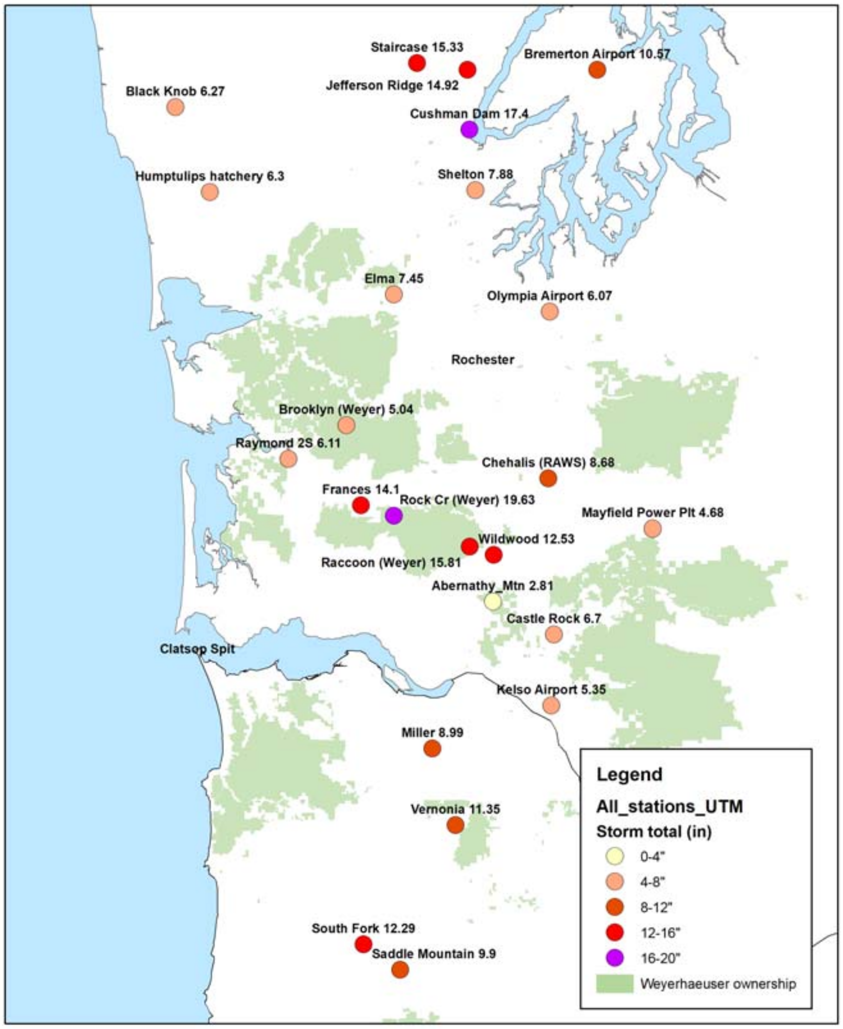

Figure 6. Rainfall totals for northwest Oregon and southwest Washington with Weyerhaeuser ownership indicated.

Rainfall intensity

While total storm precipitation amount is an important metric for assessing the magnitude of the storm, precipitation intensity is critical to understanding processes such as landslide initiation.[12] For this storm, single-day intensities were quite significant. Because this was a relatively short duration storm (most of the rain fell within 48 hours), maximum 24-hour precipitation amounts were 70-90% of the storm total amount. Table 3 shows observed values of maximum 24-hour precipitation values for stations in northwest Oregon and southwest Washington. The highest maximum 24-hour amounts were for the Weyerhaeuser rain gages located in the Upper Chehalis and Stillman basins. The next highest amounts were found in the southern Kitsap Peninsula. George Taylor of the Oregon Climate Service developed storm isopleths[13] for these maximum 24-hour precipitation values as well as some additional stations (Figure 7).

Table 3. Maximum 24-hour storm amounts for stations in northwest Oregon and southwest Washington.

Station Name	Station ID	Elevation (ft)	Station Type	State	24hr maximum precipitation (in)
Rock Cr (Weyer)	Geoppt2	1424	Weyerhaeuser EF	WA	14.35
Raccoon (Weyer)	Geoppt3	1086	Weyerhaeuser EF	WA	13.85
Cushman Dam	CPHW1	76	COOPA	WA	13.10
Staircase	SKOW1	762	HADS	WA	12.09
Jefferson Ridge	JEFW1	2200	RAWS	WA	10.73
Frances	FRAW	230	NWS	WA	9.70
South Fork	SFKO3	2257	RAWS	OR	9.49
Wildwood	SCWW1	370	NWS	WA	9.29
Cedar	CDFO3	2220	RAWS	OR	9.18
Vernonia	USGS	755	USGS	OR	8.31
Rye Mountain	BDFO3	2000	RAWS	OR	7.29
Shelton	KSHN	269	NWS/FAA	WA	6.42
Miller	MLLO3	1031	RAWS	OR	6.40
Chehalis (RAWS)	CLSW1	262	RAWS	WA	5.38
Black Knob	BKBW1	588	RAWS	WA	5.17
Elma	ELAW1	70	COOPABC	WA	4.77
Humptulips Hatchery	HTUW1	140	COOPA	WA	4.71
Castle Rock	TR950	213	RAWS	WA	3.85
Rochester	CW5186	151	APRSWXNET/CWOP	WA	3.83
Olympia Airport	KOLM	203	NWS/FAA	WA	3.80
Raymond_2_S	RYMW1	30	COOPABC	WA	3.70
Brooklyn (Weyer)	Geoppt1	1020	Weyerhaeuser EF	WA	3.55
Kelso Airport	KKLS	20	NWS/FAA	WA	3.03
Abernathy Mtn	ABNW1	2000	RAWS	WA	1.65

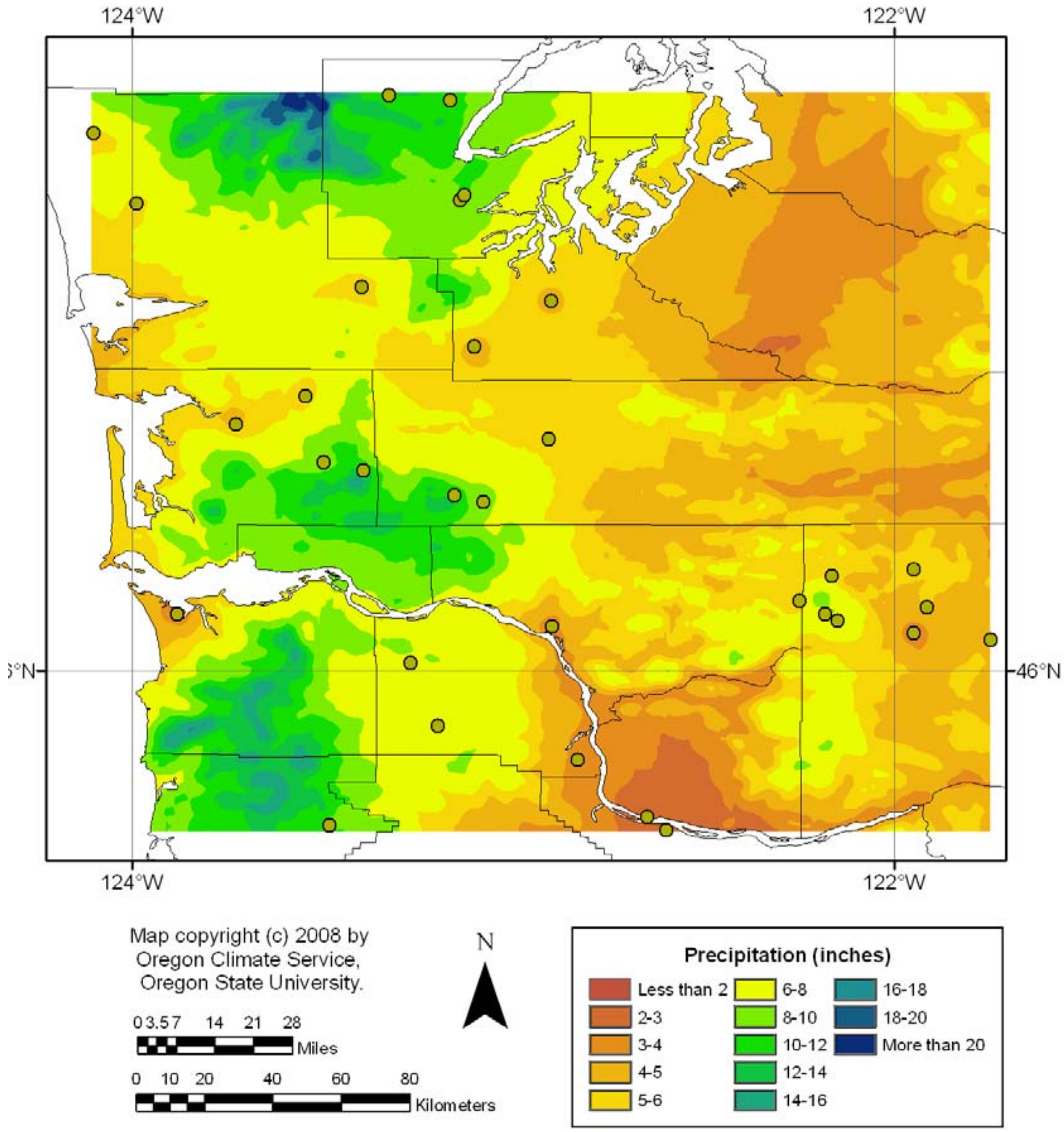

Figure 7. Isopleths for the maximum 24-hour precipitation that fell during the December 1-4, 2007 storm. The dark yellow circles indicate the location of climate stations.

While the preceding figure shows that maximum 24-hour amounts during the storm were estimated to be the highest in areas of northwest Oregon and the Olympic Peninsula, it is important to understand how the rainfall intensities compared to historical rainfall intensities. For the December storm, 24-hour rainfall intensities were up to 140% of the estimated 100-year 24-hour storm in northwest Oregon, southwest Washington and the Kitsap Peninsula (Figure 8) based on the recent Washington State Department of Transportation (WSDOT) analysis.[14] Areas east of I-5 in both Oregon and Washington generally had maximum 24-hour precipitation amounts that were less than the estimated 100-year 24-hour amounts.

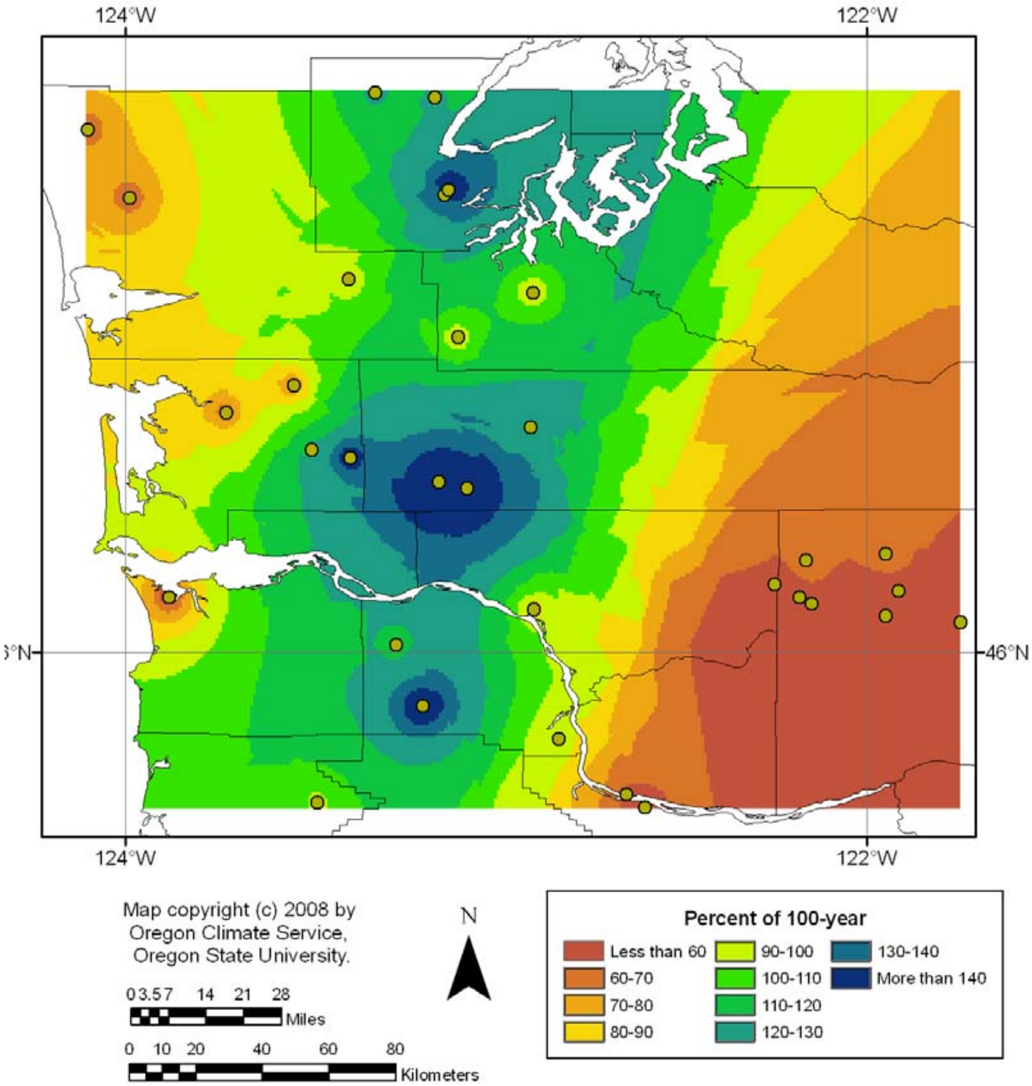

Figure 8. PRISM-derived isopleths for the percent of observed rainfall to estimated 100-year 24-hour rainfall. The dark yellow circles indicate the location of climate stations.

The Floods

The most intense flooding occurred where total storm rainfall amounts and intensities were highest (Figure 9). In Oregon, real-time stream gages on the Nehalem River near Foss and the Wilson River near Tillamook indicated the floods were approximately 25-year events.[15] On the Nehalem River near Vernonia, where rainfall exceeded the 100-year event, widespread flooding and landslides isolated the town for several days.[16] While there is a United States Geological Survey (USGS) gage there, it hasn't been in operation long enough for the establishment of flood return periods; however, residents indicated the flood was worse than the 1996 event. Though flooding was intense in the upper Nehalem, by the time the river reached the coast, it was not an extreme event. This could be due to the lower amounts of rainfall along the coast.

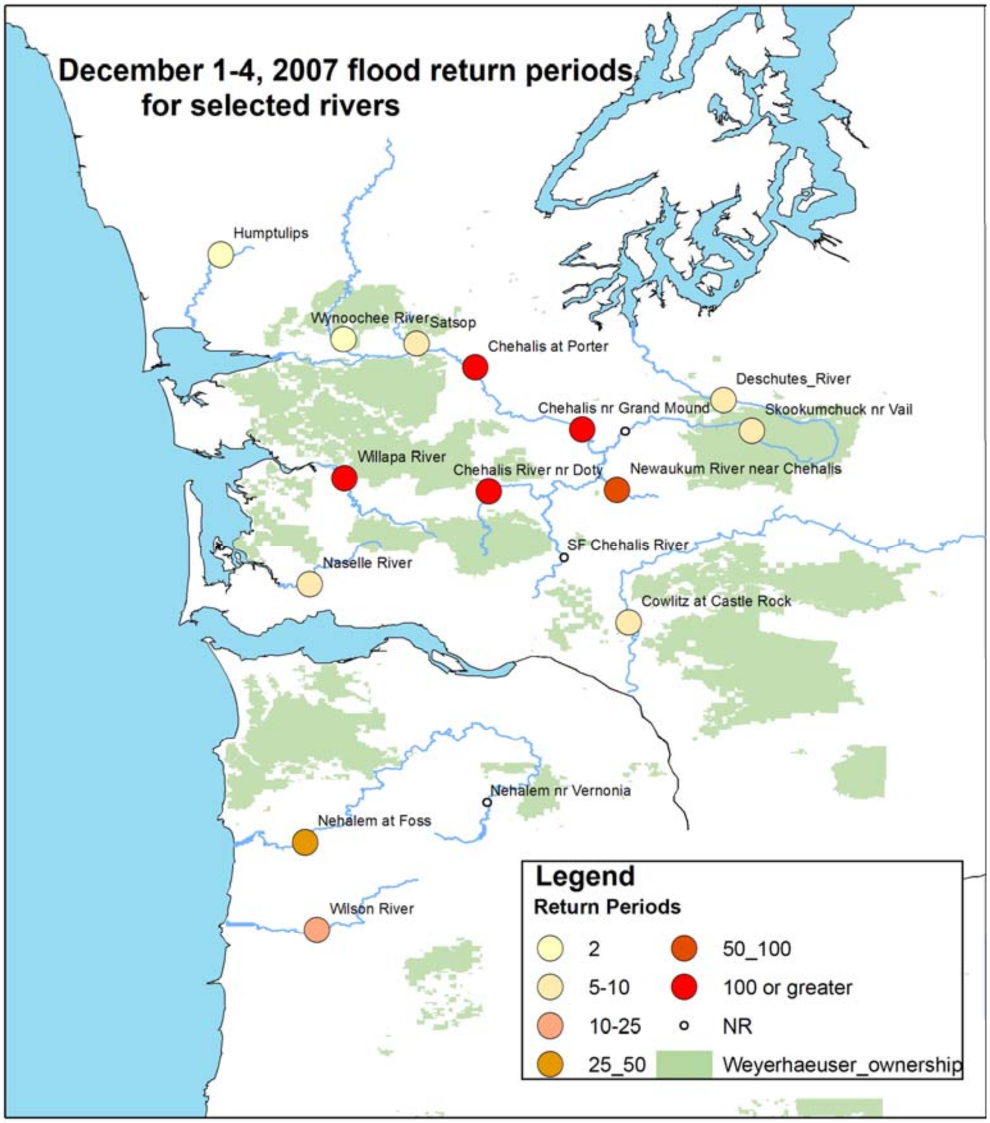

Figure 9. Estimated return periods for selected USGS gages in northwest Oregon and southwest Washington for the early December 2007 storm event. NR = not rated. The USGS indicates that their real-time data are provisional and subject to revision.

In Washington, the worst flooding was in southwest part of the state, particularly on the Chehalis River where 5 new all-time records were set.[17] The Chehalis flooding resulted in closure of I-5 for several days. According to the USGS news release, about 30 gages recorded peak flows that ranked in the top five events with about 10 gages recording all time highs including the Elwa and Skokomish Rivers. Elsewhere in Washington, flooding was minor in northwestern counties and moderate in central sections of western Washington.

The Chehalis River near Doty (Station number 1202000) had a rapid rise in stage that went from about 3 ft to 30 ft in 17 hours with estimated discharge increasing from 500 cubic feet per second (cfs) to 51,100 cfs (according to the provisional data) in that time (Figure 10). The gage was damaged and stopped recording at 10:30 a.m. on December 3. As Larry Schick of the Army Corps of Engineers said shortly after the flood (December 7, 2007), "This is an extraordinarily rare event. A huge event. Double the previous record."[18] The USGS has subsequently done a field survey to determine the actually height and volume of the peak; Mr. Schick's estimates were rather good -- the reconstructed peak was estimated 63,100 cfs or 2.2 times the February 1996 peak. Figure 11 shows a picture of the USGS crew out surveying their gage with an indication of the height of the flood. In a press release dated February 5, 2008 the USGS stated, "A new record was set in peak streamflow in the upper watershed of the Chehalis River, according to preliminary calculations made after the December 3, 2007, storm event. The streamflow indicates a pattern resulting from a very intense rainstorm".[19] They also indicated that "At the Doty gaging station, floodwaters rose quickly—within a few hours—to reach the peak flow, then tapered off gradually, a typical pattern of streamflow during an intense rainstorm. The force of the moving water was great enough to scour out a 37,000-lb concrete anchor block at the Doty gaging station and move it from one side of the river to the other." In a recent news report, USGS researchers indicated this was a 500-year storm.[20]

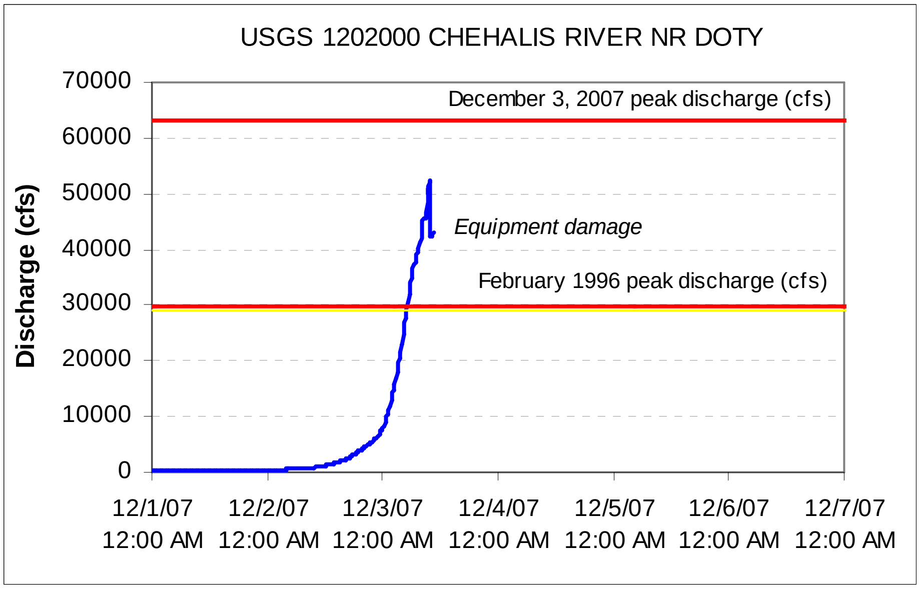

Figure 10. Flood hydrograph for the Chehalis River near Doty. The 63,100 cfs peak was announced by the USGS on February 5, 2008 in a press release.

Figure 11. USGS photograph of the water surface for the Chehalis River near Doty. Source is USGS Press release of February 5, 2008: New Peak Flow Record for the Chehalis Flood. http://wa.water.usgs.gov/news/2008/news.chehalis.newpeak.htm

As mentioned previously, the December 2007 peak flow for the Chehalis River near Doty was just over twice that of the February 1996 event, which had been the previous flood of record for that station. This station, which had been in operation since October of 1939, had never experienced such a massive event in its history (Figure 12).

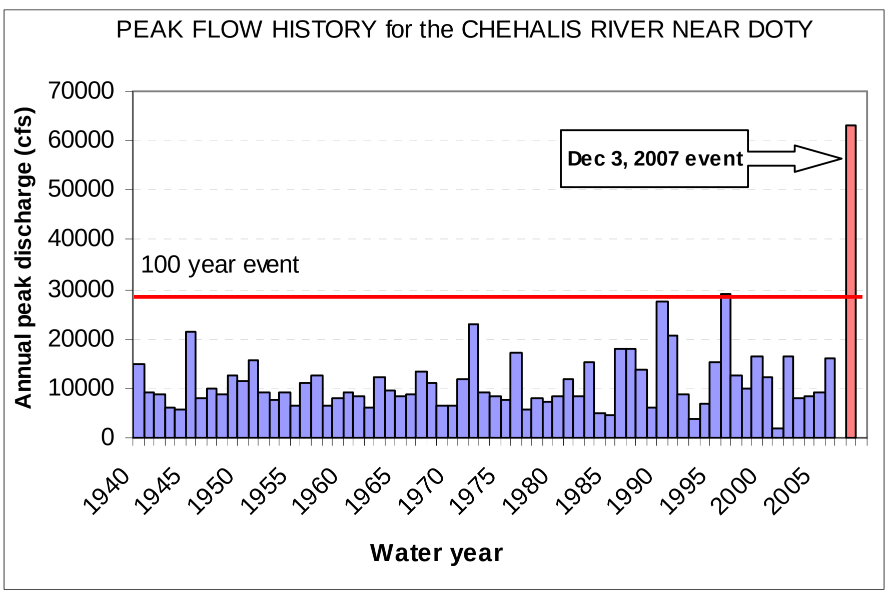

Figure 12. Peak flow (instantaneous annual maximum) history for the Chehalis River near Doty. The USGS indicates that their real-time data for the December 2007 event are provisional and subject to revision.

The South Fork of the Chehalis River (USGS Station 12020800) also saw a dramatic rise in stage during the December 2007 event (Figure 13). During this event the discharge rose to approximately twice the February 1996 maximum level (Figure 14). While the provisional data indicated that discharge reached to almost 18,000 cfs, a survey of the gage by the USGS indicated that due to the high sediment deposition at the site, the peak was actually somewhat less, at 12,200 cfs. Since the USGS gage on the South Fork of the Chehalis River only goes back to October of 1998 (they estimated the flood peak for February of 1996) no estimated recurrence interval is available due to the short time period.

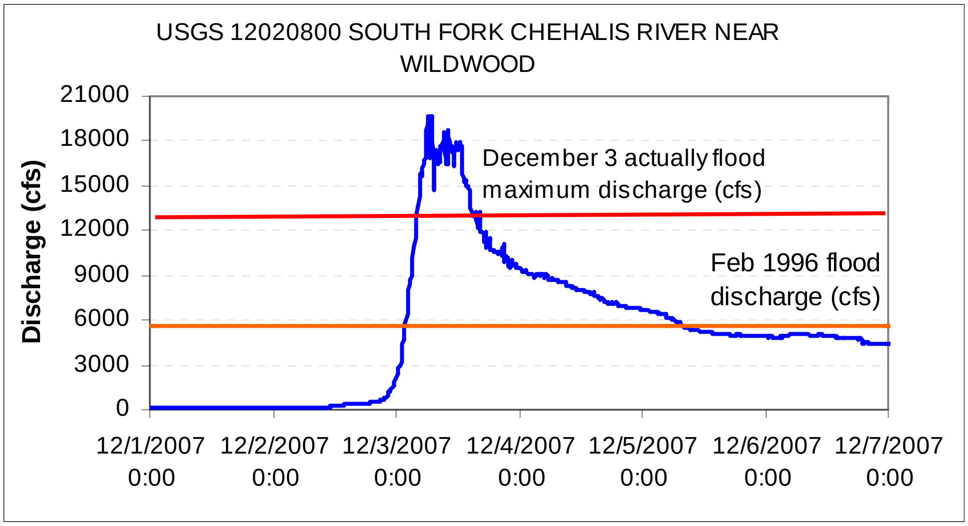

Figure 13. Flood hydrograph for the South Fork of Chehalis River near Wildwood. The USGS indicates that their real-time data for the December 2007 event are provisional and subject to revision.

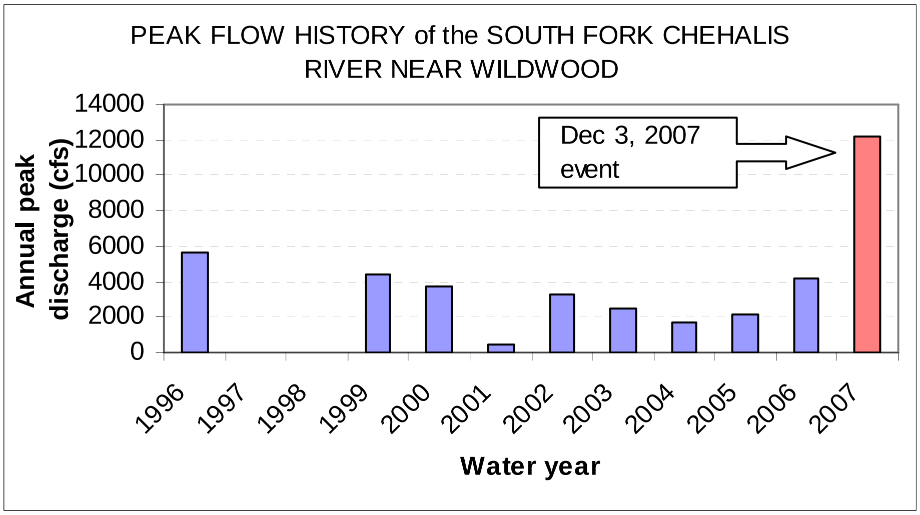

Figure 14. Peak flow (instantaneous annual maximum) history for the South Fork of the Chehalis River near Wildwood. The 12,200 cfs value was provided by Robert Kimbrough of the USGS, pers. comm.

As the flood surged downstream it destroyed the gage at Adna at 3 p.m. on December 3. In Centralia, the Chehalis River stage almost appeared to be leveling off when flood flows from the upper basin arrived around 7 p.m. on December 3, causing the stage to increase rapidly (Figure 15). Meanwhile, the Newaukum River near Chehalis, which joins the Chehalis just south of Centralia, was experiencing its peak at around 8 p.m. on the 3rd (Figure 16), contributing to the rise in stage though it only had a flow 13,000 cfs as compared to almost 75,000 cfs of combined flow coming out of the headwaters of the South Fork Chehalis River and the Chehalis River near Doty (this estimate does not even include the contribution of the Stillman Creek basin). The bulk of the flow from the Chehalis River, with some contribution from the Newaukum River, drove the Chehalis River at Centralia to its record height of 74.78 ft on 12/04/2007 which was 0.47 ft higher than the previous record stage for this station set on 02/09/1996. As the Chehalis River continued downstream it reached another peak of record at Grand Mound. By the time the flood surge reached Porter it had dissipated somewhat, with the Porter station not experiencing a flood of record.

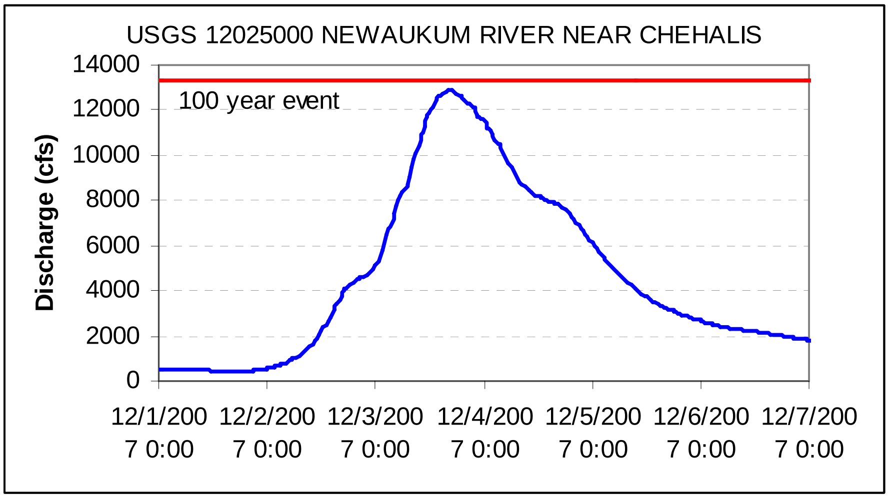

Figure 15. Flood hydrograph for the Newaukum River near Chehalis.

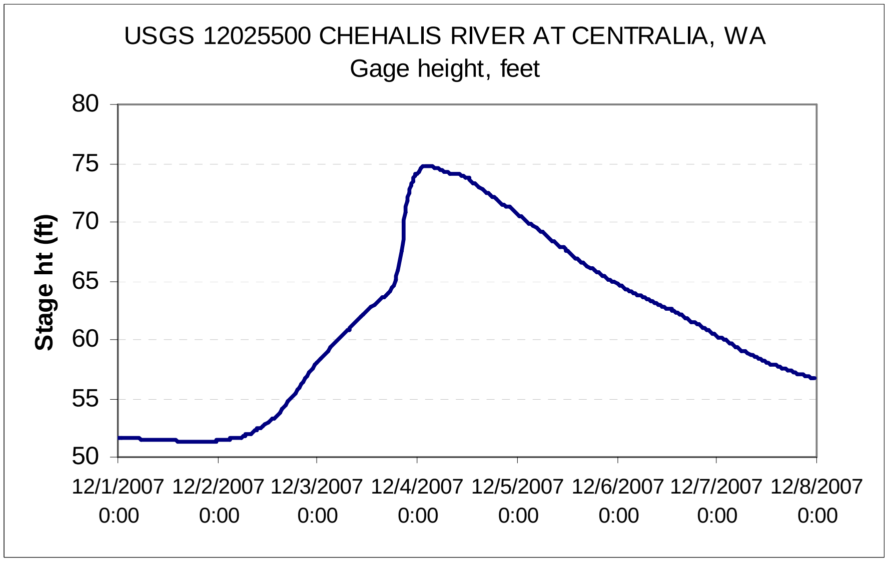

Figure 16. Flood stage for the Chehalis River near Centralia. This gage is operated by the NWS and does not have an associated recurrence interval.

The Willapa River also experienced a flood of record during this event (Figure 17). It crested at 15,100 cfs just above the previous record of 14,800 cfs set on December 20, 1994 (Figure 18) with a stream gage record going back to 1949.

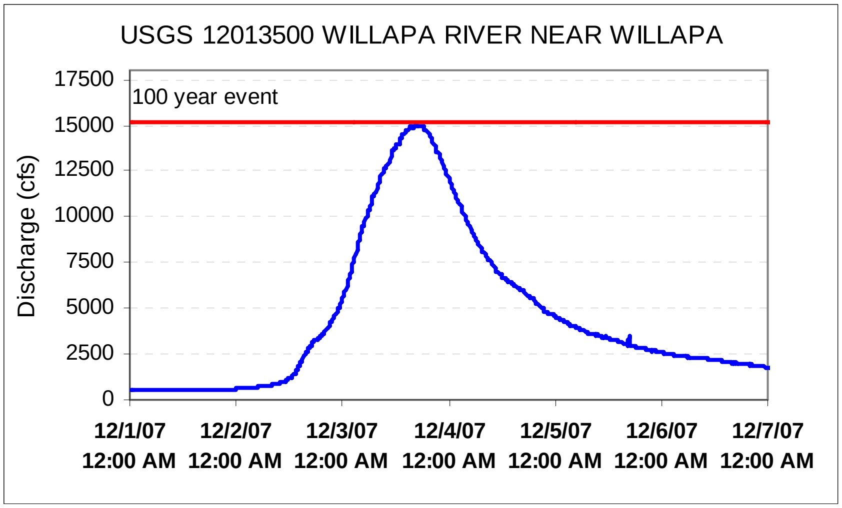

Figure 17. Flood hydrograph for the Willapa River near Willapa (USGS station number 12013500).

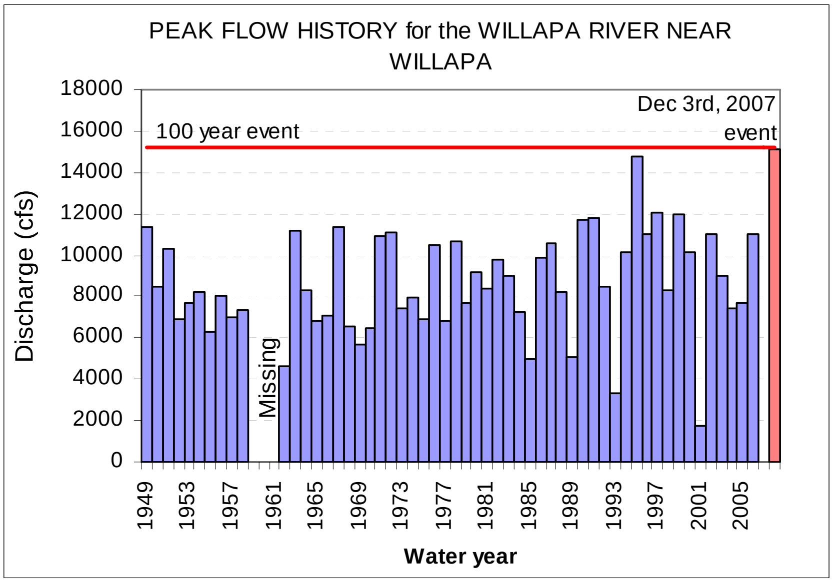

Figure 18. Peak flow history for the Willapa River near Willapa.

Summary

This storm produced concurrent extreme magnitude events; hurricane-strength winds along the coast and an estimated 500-year flood further inland in the upper Chehalis River basin. High winds impacted the coasts of Oregon and Washington from Newport to Hoquiam. This storm produced a maximum recorded wind gust of 147 mph and was the first ever hurricane force wind warning issued by NWS in the Pacific Northwest. While maximum speeds may have been higher in the 1962 Columbus Day storm, this event was of longer duration, which led to extensive damage. The rain portion of the storm produced not only high storm totals, but also 24-hour rainfall intensities that were up to 140% higher than the 100-year amounts for areas in southwest Washington. Two weather stations with records back to the late 1800s broke all-time records. This high rain led to extensive flooding with ten rivers in Washington exceeding their flood of record. In the Chehalis River basin 5 all-time high records were broken. For the stations in the upper Chehalis River, flood peaks were twice the previous flood of record and estimated to have a recurrence interval of 500-years. Either one of the events – the windstorm or the flooding, would have been notable individually, but taken together, they compounded the extreme nature of the storm.

Acknowledgments

This report would not have been possible without the invaluable contributions of data and discussion from several agency scientists: Brent Bower, National Weather Service; Larry Schick, U.S. Army Corps of Engineers; Bob Kimbrough, U.S. Geological Survey; Dr. Philip Mote, Office of the Washington State Climatologist; George Taylor, Oregon Climate Service and Wolf Read, a Masters candidate at UBC studying wind-tree interactions. I especially want to thank Brent and Larry for discussing skiing conditions as well as sharing information about the storm. In addition, I would like to thank all the Weyerhaeuser personnel for their important contributions to this report: Jim Ward for his foresight to install climate stations; Storm Beech for providing high quality data from those stations; Peter James for providing GIS support and to my manager, Brian Fransen, for his dedication to his team.

Endnotes

[1] NWS Public Service Announcement: http://www.wrh.noaa.gov/sew/get.php?sid=SEW&pil=PNS&version=2

[2] The Great Coastal Gale: http://www.ocs.oregonstate.edu/index.html

[3] Intense rainfall leads to record flooding around the state, Office of the Washington State Climatologist. http://www.climate.washington.edu/events/dec2007floods

[4] Snotel stands for "Snowpack Telemetry" which is a program operated by the Natural Resources Conservation Service.

[5] Snow water equivalent (SWE) is the depth of water in the snowpack, if the snowpack were melted (usually expressed in inches). The amount of SWE that comes from snow depends on the density of the snow. New snow ranges from about 5% when the air temperature is cold, to about 20% when the temperature near freezing. From the Natural Resources Conservation Service: http://www.nrcs.usda.gov/

[6] NWS marine warning as cited in The Great Coastal Gale: http://www.ocs.oregonstate.edu/index.html

[7] http://www.oregonlive.com/weather/index.ssf/2008/01/2007_weather_terrible_tempest.html

[8] Frequently asked questions regarding windthrow: http://farpoint.forestry.ubc.ca/fp/

[9] Intense rainfall leads to record flooding around the state, Office of the Washington State Climatologist. http://www.climate.washington.edu/events/dec2007floods

[10] Natural Hazards NASA Earth Observatory http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=14646

[11] Data from http://www.weather.gov/climate/xmacis.php?wfo=sew with some additional values provided by Brent Bower, Hydrologist, National Weather Service Seattle.

[12] Sidle, R.C., and Ochiai, H., 2006. Landslides. Water Resources Monograph, Am. Geophysical Union. Washington DC. 312 p.

[13] An isopleth is a line of equal or constant value of a given quantity, with respect to either space or time. An isopluvial is line drawn through geographical points having the same amount of precipitation falling in a specified period that is likely to be equaled or exceeded at a given return period or probability.

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[14] 100-year 24-hour isopluvials from WSDOT http://www.wsdot.wa.gov/mapsdata/geodatacatalog/ http://or.water.usgs.gov/index.html

[15]USGS Oregon District home page real-time data: http://or.water.usgs.gov/index.html. Return periods for gaged streams in Oregon were from: http://pubs.usgs.gov/sir/2005/5116/

[16] KATU News: Vernonia residents: worse than 1996: http://www.katu.com/news/12124361.html

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