2010 Northwest Floods December 10 – 14, 2010

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December 10 – 14, 2010

Introduction

Heavy rains concentrated over the weekend of December 11-12, 2010 caused significant flooding across Western Washington. Heaviest observed 48 hour point precipitation values ranged between 6 to near 13 inches (see Figure 1).

Storm Damage

Several houses were inundated along the South Fork Stillaguamish near Granite Falls. According to local papers, approximately 230 homes along the Stillaguamish were issued a voluntary evacuation. Other damage included numerous road closures due to excess water, landslides, and property flooding. Amtrak's Cascades train route was shut down for 48 hours north and south of Seattle as a result of landslides.



Figure 1. December 11-12, 2010 heaviest 48 hour western Washington precipitation observations.

Meteorological Summary

Early December, NWRFC QPF grids and forecast discussions reflected the potential for a mid Pacific pattern to result in hydrologically active weather for the Pacific Northwest. The following text is an excerpt from the December 3rd NWRFC Hydro-Meteorological Discussion (PDXHMDPTR):

....6-10 DAY OUTLOOK....Dec 08 - Dec 12...

Latest longrange guidance tends to be inconsistent at this point...but there are some indications that our western tier could be hit by a very wet and warm day 8-10. The potential for this to occur is supported somewhat by recent trends in mid-pacific tropical convection resembling an MJO signal...and if this activity more fully entrains into the late period storm track taking aim at us...a very wet warm late period event into our westside is more likely. Thursday December 9, 2010 a large central Pacific area of enhanced subtropical convection and high precipitable water shifted east of the International Date Line (Figure 3). Subsequent imagery confirmed the feature's northeastward drift two days before western Washington was inundated with heavy warm rain.



Figure 3. Water vapor image - December 9, 2010. Large area of subtropical convection and high precipitable water in yellow.



Figure 4. Visible satellite imagery - Saturday December 11, 2010.

December 11, 2010, the central Pacific feature transformed into a conveyor band of moist subtropical air (~325 miles wide) reaching from Hawaii to the northern panhandle of Idaho (Figure 4). This pattern largely held in place through Sunday December 12, 2010.

Within this conveyor band, heavy rain began to train in first along the Olympic Peninsula and north Oregon Coast December 11, 2010. In general, the heaviest precipitation pivoted northward around the Olympic Peninsula with its tail jumping from the north Oregon coast quickly through the central Washington Cascades to the north Washington Cascades. The heaviest precipitation pattern sagged south again as storm expired and shifted east.

Figure 5 illustrates the 310K isentropic surface lift efficiency and moisture convergence (via moisture transport magnitude vectors) over western Washington for the Sunday 00-06Z December 12, 2010 forecast (made from the Saturday 12Z GFS solution). In Figure 5 an inverted 450 dekameter isentropic ridge across western Washington correlates well with the area of heaviest 24hour precipitation for Saturday December 11, 2010 (see Figure 6).



Figure 5. GFS 310K isentropic surface with moisture transport vectors valid for the 00-06Z period on December 12, 2010 (Saturday evening).

Figures 6 and 7 show 24 hour (12Z-12Z) QPE totals for December 11 and 12, 2010. Western Washington as hardest hit in the Northwest with 4 plus inch (darker orange to purple color scale) daily precipitation totals on both Saturday and Sunday of this unusually wet second weekend in December 2010.



Figure 6. Saturday, December 11, 2010 12Z-12Z 24 hour observed precipitation. Source: http://water.weather.gov/precip



Figure 7. Sunday, December 12, 2010 12Z-12Z 24 hour observed precipitation. Source: http://water.weather.gov/precip

The subtropical warmth of this system is revealed by the 8,000 to 12,000 plus foot freezing levels reported across western Washington and western Oregon during the peak heavy rain over the weekend of December 11-12, 2010. Seattle-Tacoma International Airport reached 55 degrees Sunday morning December 12, 2010 (8 degrees higher than the 00Z temperature from Saturday afternoon). At 55 degrees, Seattle-Tacoma International Airport was 9 degrees above the normal daily high temperature prior to sunrise Sunday morning. Many locations in western Washington and western Oregon experienced similar temperature patterns, supporting both typing precipitation as rain as well as melting pre-existing headwater snow packs.

Precipitation Forecast Verification

Western Washington precipitation forecast values are a result of coordination between the Hydrologic Prediction Center, NOAA (HPC), Seattle WFO, and the NWRFC. Final coordinated NWRFC precipitation values are incorporated into the NWRFC river forecast models. The following precipitation verification section relates observed gridded precipitation (QPE) to forecast gridded precipitation (QPF) for the period of December 10-14, 2010.

Long Term Forecast

The heaviest precipitation days of December 11 and 12 were well identified in QPF produced in advance of the storm. Even 9 and 10 days out, QPF values of more than 5 times the normal were projected through parts of western Washington and Oregon (Figure 8, 9).



Figure 8. Day 9 24hour QPF for December 11.



Figure 9. Day 10 24hour QPF for December 12.

Solutions were fairly consistent as the days approached the event. Beginning December 6th, five days prior to the event, solutions converged on a widespread multi-day western Washington and Oregon precipitation event (Figure 10).

Short Term Forecast

QPF values trended toward observed amounts for the most part in the short term.

December 10, 2010

Friday was the lightest precipitation day as the storm system began to impact the Northwest U.S. and Southern British Columbia. This was fairly well forecasted in advance, however, QPF maximums on December 8th trended south, heavier through the western Oregon mountains. For the December 9th and 10th forecasts, QPF trended north again, closer to the QPE values west of the Cascades (Figure 10).

December 11, 2010

A substantial increase in QPF occurred between December 10 and December 11 (Figure 10). This QPF increase significantly improves the precipitation outlook for the northern Puget Sound valley area, and moves the Olympic Peninsula QPF in the right direction. The QPF amounts, however, fall well under the QPE analysis for the majority of the Olympic Peninsula and in some areas of the higher elevations of the north Cascades. The QPF



Figure 10. Day 1-5 QPF compared to Observed Precipitation December 11-12, 2010.

created a positive bias (over-forecasting) through southwest Washington (Figure 11).

December 12, 2010 Sunday was another strong precipitation day, with the precipitation focus moving a little farther north, mainly through the Olympic Peninsula and northern Cascades. Like Saturday, the forecast trend was to place precipitation farther south through the central Oregon Cascades and Coastal Mountains. In the end, the precipitation came in strong through much of Coastal western Washington and extreme northwestern Oregon, the Olympic Mountains, and central and northern Cascades, but not very strong through southwest Oregon. By the day 1 forecast, there were some significant under-forecast bias errors through western Washington. There were also some high over-forecast biases over the central western Oregon Mountains (Figure 11).



Figure 11: NWRFC 24 Hour QPF Day 1-2 forecasts for December 11, 2010.

Precipitation Verification Summary

The December 10-14, 2010, QPF event was well advertised by the NWRFC 10 days in advance.

Overall, forecasts trended well to the eventual observed solutions up until 1 day out. For December 10, 11, and 13, QPF's were generally increased for western Washington 24 hours ahead of the event day. The QPF increase helped at times in some areas, day 1 changes overall tended to increase bias.

The valley area south of Puget Sound was consistently over-forecasted for the event. This is thought to have happened because the storm moved more quickly than expected from South to North and again as the event sagged south from North to South.

Hydrologic Summary

Heavy rains mid December caused flooding in Western Washington from the Washington Cascades to the Olympic Peninsula and from the Washington/Oregon border to Canada. The Nooksack, Skagit, Stillaguamish, Skykomish, Snoqualmie, Tolt, Green, Elwha, Skokomish, Satsop, and Chehalis Rivers overtopped their banks and inundated adjacent land. Major Flood levels occurred in the Lower Stillaguamish, the Snoqualmie River Basin near Carnation, and the Skokomish River on the Olympic Peninsula. Record flooding occurred in the Lower Stillaguamish. Figure 12 displays western Washington river basins where flooding occurred December 10-14, 2010.



Figure 12. Western Washington Flood Basins December 10-14, 2010.

Hydrographs are provided by river basin to show the relative magnitude of the event at all locations where flood level was exceeded. The heaviest 24 hour precipitation period occurred on December 11th. This is coincidental with river rises in Western Washington from the Cascades to the Olympic Peninsula December 12th and 13th. The following hydrographs are ordered from north to south.

Nooksack River

Flooding occurred on the South Fork and main stem portions of the Nooksack River in Northwest Washington (Figures 13-15).



Figure 13. Flood Graph for SF Nooksack at Saxon Bridge.



Figure 14. Flood Graph for Nooksack at North Cedarville.



Figure 15. Flood Hydrograph for Nooksack at Ferndale.

Skagit River

Water storage in the upper Skagit River basin is a combination of Ross, Upper Baker, and Lake Shannon Reservoirs. When natural flow at Concrete is forecasted above 90k, the Corps of Engineers regulates the system reservoirs. The COE took control of regulation on the Skagit on December 12th. Lake Shannon is the lower most project on the Skagit River. The Skagit River at Concrete and Mount Vernon reached moderate flood levels December 13th (Figures 16-18).



Figure 16. Lake Shannon Discharges



Figure 17. Flood Hydrograph for Skagit nr Concrete.



Figure 18. Flood Hydrograph for Skagit nr Mt Vernon.

Stillaguamish River

The Stillaguamish River exceeded major flood along its north and south fork sections. The combined flows pushed the main stem Stillaguamish also to Major Flood level. The Stillaguamish River near the town of Arlington surpassed record flood by 0.1' on December 13th (Figures 19-21).







Figure 20. Flood Graph SF Stillaguamish nr Granite Falls.



Figure 21. Flood Graph for Stillaguamish nr Arlington.

Snohomish Basin

Heavy precipitation pushed the Tolt River briefly above Major Flood while the nearby Snoqualmie River near the Falls peaked just above Moderate Flood Flow. The upstream Snoqualmie flows combined with the flooding Skykomish River propelled the lower Snohomish to flood December 12-14 (Figures 22-27).





Figure 22. Flood Hydrograph for Tolt River nr Carnation.



Figure 24. Flood Hydrograph for Snoqualmie nr Carnation.





Figure 23. Flood Graph for Snoqualmie nr Snoqualmie Falls.



Figure 25. Flood Hydrograph for Skykomish nr Gold Bar.



Figure 27. Flood Hydrograph for Snohomish at Snohomish.

Green River

The Howard Hanson reservoir, located 43 miles southwest of Seattle, Washington, in the headwaters of the Green River is owned and operated by the Corps of Engineers (COE). The COE and NWRFC work together to get current regulation into the NWRFC hydrologic model. Final COE discharges are incorporated into NWRFC forecasts prior to forecast issuance.

Inflow into Howard Hanson Reservoir peaked on December 13th 19Z at approximately 7,700cfs and reached a pool elevation of 1097.32 feet on the 14th at 23Z (Figures 28-29).

The Green River natural flow combined with discharges from Howard Hanson pushed flows at Auburn to flood levels for 12hours on December 14, 2010 (Figure 30). Reports of damage include a few road closures and flooded fields between Howard Hanson Reservoir and the town of Auburn.





Figure 28. Inflow Graph for Howard Hanson Reservoir.





Figure 30. Flood Hydrograph for the Green River near Auburn.

Olympics

The Olympics experienced the heaviest rains for the event. Precipitation 48 hour totals along the Olympic Peninsula area generally ranged between 10 and 13 inches for December 11 and 12, 2010 (12Z-12Z). Primed from the recent flood event on December 8, the Skokomish River near Potlatch soared to major flood levels on December 12th. The mid December precipitation event also stretched in to the Elwha basin north of the Skokomish. The intense rains forced a flood peak on the Elwha River at McDonald Bridge December 12.

The Skokomish River reached flood levels five times between October 1, 2010 and December 12, 2010.





Figure 31. Flood Hydrograph for Skokomish nr Potlatch.

Figure 32. Flood Hydrograph for Elwha at McDonald Bridge.

Chehalis

The headwaters of the Chehalis eluded flood during the mid December event. Combined flows, however, from the Chehalis headwaters and Skookumchuck River tributary totaled to flood on December 14, 2010 along the lower portions of the Chehalis River. (Figures 33,34).





Figure 33. Flood Hydrograph for Chehalis nr Grand Mound.

Figure 34. Flood Hydrograph for Chehalis at Porter.

Large runoff from the south slopes of the Olympics Mountains caused the Satsop River to reach moderate flood stage on December 13, 2010 (Figure 35).



Figure 35. Flood Hydrograph for Satsop near Satsop.

River Forecast Verification

NWRFC products are analyzed for forecast lead time to actual river flood stage and peak.

Lead Time

NWRFC flood forecast lead time for the December event is outlined in Table 1. Long flood lead times of greater than 10 days occurred in the Chehalis Basin. The average forecast lead time for the western Washington sites that reached flood mid December is 2.8 days. The shortest lead time occurred on the Green River at Auburn where a flood declaration was issued 10 minutes in advance of flood.

	DEC 10-14 EVENT Record Floods are Red								
							Observed	Forecasted	
Forecast	Peak	Time of Peak					Time of FS	Time of FS	Flood Forecast
Group	HG (ft)	date time (z)	BF	FS	MF	RF	date time (z)	date time (z)	(day.hr)
NW_WASH							1		
nssw1	8.13	12/12/2010 22:15	6.7	8.	9.5	none	12/12/2010 19:00	12/11/2010 17:50	1.01
nrkw1	148.07	12/13/2010 04:15	144.8	146.5	none	149.61	12/12/2010 16:15	12/08/2010 17:16	3.23
nksw1	20.5	12/14/2010 00:30	17.	19.	none	31.23	12/13/2010 09:15	12/11/2010 17:50	1.15
argw1	15.56	12/13/2010 01:15	10.7	13.	none	15.2	12/12/2010 15:30	12/09/2010 17:07	2.22
gflw1*	18.5	12/12/2010 21:00	12.9	14.	none	22.82	12/12/2010 12:45	12/09/2010 17:07	2.19
arlw1	21.16	12/13/2010 02:39	none	14.	19.	21.06	12/12/2010 14:24	12/09/2010 17:07	2.21
SKAGIT									
conw1	30.99	12/13/2010 06:15	none	28.	32.5	42.21	12/12/2010 23:00	12/11/2010 18:59	1.04
mvew1	29.91	12/13/2010 23:30	27.7	28.	30.	37.37	12/13/2010 08:30	12/11/2010 18:59	1.13
SNOHOMISH									
glbw1	17.54	12/13/2010 00:45	none	15.	19.	23.94	12/12/2010 17:30	12/11/2010 19:33	0.21
squw1	15.86	12/13/2010 03:00	12.2	13.	17.7	21.55	12/12/2010 17:15	12/11/2010 18:25	0.23
tolw1	10.3	12/12/2010 21:15	7.74	9.04	10.3	13.04	12/12/2010 09:45	12/09/2010 17:29	2.16
crnw1	58.78	12/13/2010 17:00	51.	54.	58.	62.31	12/12/2010 20:15	12/03/2010 18:03	9.02
mrow1	16.55	12/13/2010 10:00	14.	15.	17.	25.30	12/13/2010 02:30	12/11/2010 18:25	1.08
snaw1	27.59	12/13/2010 20:00	23.	25.	29.	33.50	12/13/2010 00:00	12/11/2010 18:25	1.05
GREEN									
aubw1	62.12	12/13/2010 21:00	60.7	61.7	64.6	69.75	12/13/2010 14:00	12/13/2010 14:10	10 minutes
OLYMPICS									
srpw1	18.05	12/12/2010 21:30	none	16.5	17.5	18.16	12/12/2010 09:00	12/08/2010 16:39	3.16
elww1	20.89	12/12/2010 22:15	18.	20.	23.	24.65	12/12/2010 18:30	12/10/2010 17:06	1.24
CHEHALIS									
cgmw1	14.2	12/14/2010 07:45	11.3	14.	17.	20.23	12/13/2010 19:30	12/03/2010 18:06	10.01
crpw1	21.07	12/14/2010 23:30	none	21.	none	26.05	12/14/2010 19:45	12/03/2010 18:06	11.01
satw1	36.84	12/13/2010 02:30	none	34.	38.	38.90	12/12/2010 16:45	12/10/2010 17:08	1.23

 Table 1. Flood Lead Time for December 10-14 Event.

*gflw1 - Gage outage near time of peak

Lead Time Services

NWRFC lead time services are based on forecast to observed river peak times. In general, flood forecast lead times were greatest for the Chehalis, Skokomish, and Snoqualmie River near Carnation. Little change in forecast heights occurred within 24hours of the

event. This is largely due to good knowledge of the weather pattern and good QPF. The peak stage forecast analysis follows per major river basin:

NW_Wash

In most cases, flood stage was advertised 2.5 days in advance of the mid December peak stage. Forecasts in general were fairly consistent 4 days in advance of the peak. Fluctuations in river forecasts within these 4 days are coincidental to QPF variances, as there was little to no snow contribution. Of note are the high flows in the SF Stillaguamish which peaked ~4 feet over flood stage. The peak at GFLW1 is somewhat in question as the gage stopped recording near the peak. The result downstream is a .1 foot above record flood classification on the Lower Stillaguamish near the town of Arlington.









25

20

15 15 10 **Stage (ft)**

0

Skagit Flood forecasts primarily went out 1.5 days prior to flood.



Snohomish

•

Lead Time (days)

11 10

Snohomish flood forecasts went out approximately 1.5 days in advance. Major Flood along the Tolt River at Carnation was noted 1 day out. Indications of flood on the Snoqualmie River at Carnation occurred as early at 9 days prior.





Green

The Green River basin is a combination of natural flow and releases from the COE Howard Hanson Reservoir upstream. For flood protection, the COE regulates Howard Hanson to maintain the Green River at Auburn to flows 12kcfs (63.49') and below. The NWS maintains a 9kcfs flood flow (61.66') at Auburn to represent the flooding potential between Auburn and the Reservoir. Reservoir discharges were increased just prior to the peak resulting in exceedance of NWS 9kcfs flood flow on December 13th.



Olympics

Skokomish River flood forecasts were issued immediately following the prior flood peak on Dec 9th (approximate 3day lead time). Event precipitation stretched north into the Elwha basin where flood notice was published ~2 days prior to peak.



Chehalis

Lower Chehalis River forecasts consistently indicated flood levels 5 days prior to the event.





Satsop

Satsop River flood forecasts were published approximately 3.5 days prior to flood peak.



Flood Peaks

An analysis of flood forecast peaks is displayed in Table 2. The NWRFC flood forecast peaks made within one day of river crests, during the mid December event, were within 2.5 feet of the observed peak. The average mean absolute error for all flood waters was .91 feet, one day prior to crest. The largest deviation of flood peaks occurred at locations with higher volumes of water near record. This is not surprising since these levels have never occurred before.

DEC 10-14 EV	Record Flood in Red Gage Outage	
Forecast Group	Peak HG (ft)	Day 1 - Flood Forecast Peak Mean Absolute Error (ft)
NW_WASH		
nssw1	8.13	.33
nrkw1	148.07	.31
nksw1	20.5	.79
argw1	15.56	1.15
gflw1*	18.5	2.41
arlw1	21.16	2.13
SKAGIT		
conw1	30.99	1.57
mvew1	29.91	.62
SNOHOMISH		
glbw1	17.54	.96
squw1	15.86	.44
tolw1	10.3	.40
crnw1	58.78	1.05
mrow1	16.55	1.60
snaw1	27.59	.90
GREEN		
aubw1	62.12	.45
OLYMPICS		
srpw1	18.05	.50
elww1	20.89	1.51
CHEHALIS		
cgmw1	14.2	.15
crpw1	21.07	.05
satw1	36.84	.93