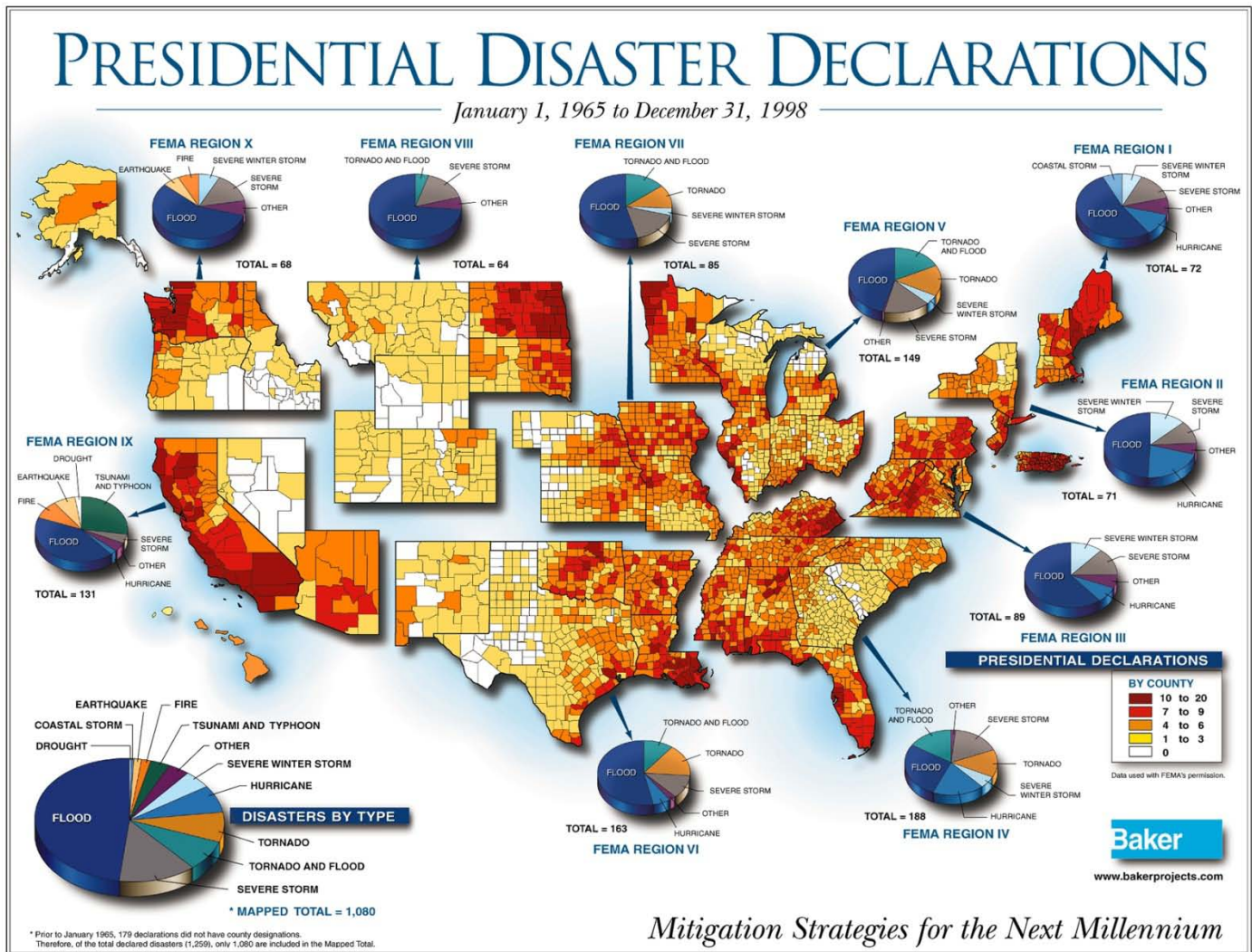


Western Washington river flooding

Western Washington is one of the most flood prone regions in the United States. The figure below shows that western Washington counties are among the Nation's "leaders" with respect to Presidential disaster declarations, and flooding accounts for more than half of these.

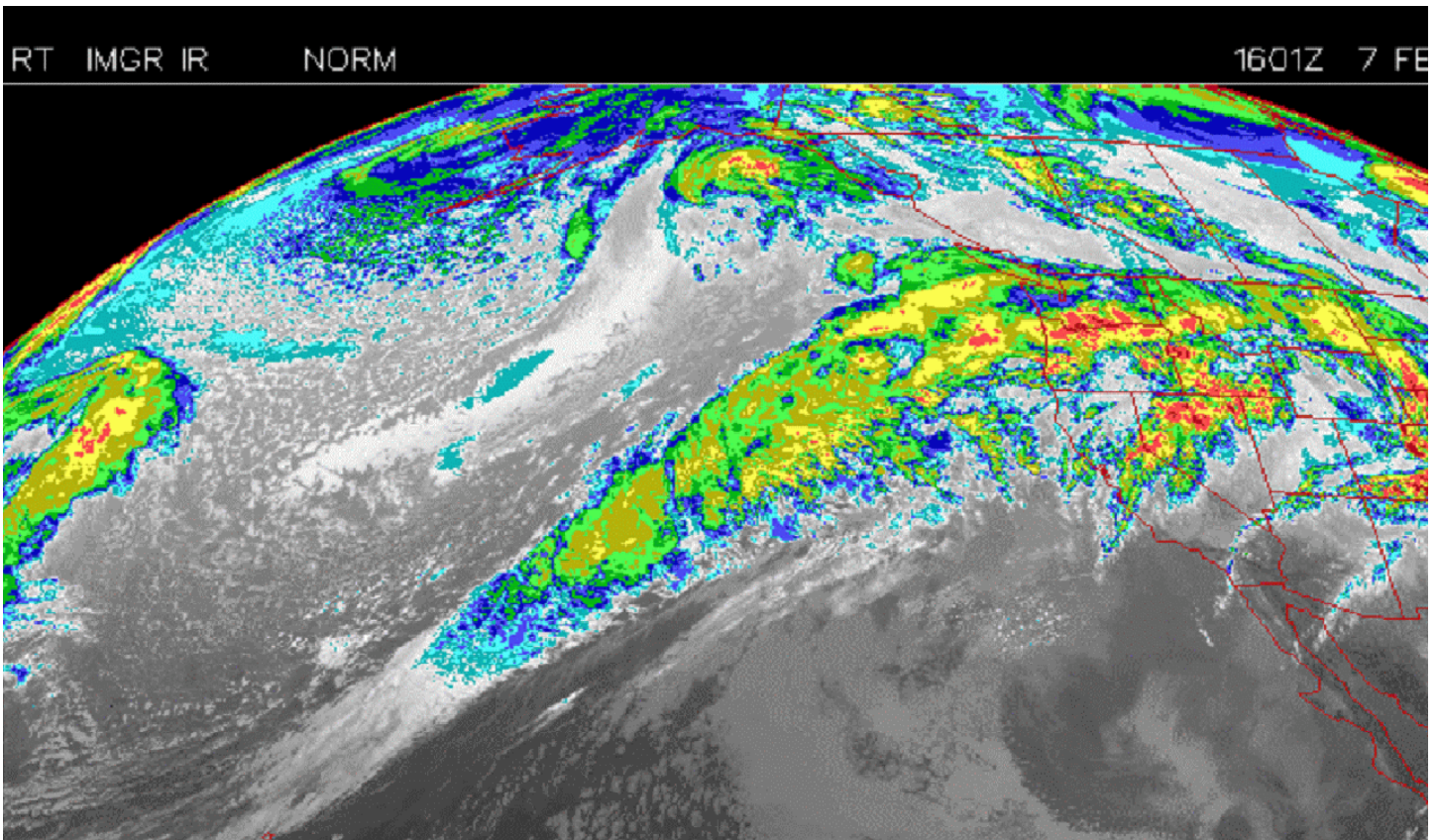


Mitigation Strategies for the Next Millennium

Presidential Disaster Declarations for the period 1965 to 1998. (Source: FEMA)

Virtually all significant river floods in western Washington are the result of heavy rainfall episodes. Almost all of these rain episodes occur when a band of strong winds in the upper atmosphere (the jet stream) extends from the sub-tropical North Pacific Ocean into the Pacific Northwest, bringing an unusually warm air mass and an enormous quantity of moisture. The jet stream often originates near Hawaii – hence the pattern has become known as the “Pineapple Express.” Most recently the scientific community has labeled these airstreams “Atmospheric Rivers.”

As the event develops the freezing level over western Washington typically climbs to 9,000 feet or above, meaning that even in the mountains essentially all the precipitation falls as rain (rather than snow) and is available for quick runoff. The heavy rain event usually lasts around 24 to 36 hours, and rainfall amounts of 3 to 6 inches in the mountains and a half inch to 3 inches across the lowlands are common. Such an event would usually cause minor to moderate flooding on the flood-prone rivers in



Infrared satellite image of a pineapple express from February 7, 1996

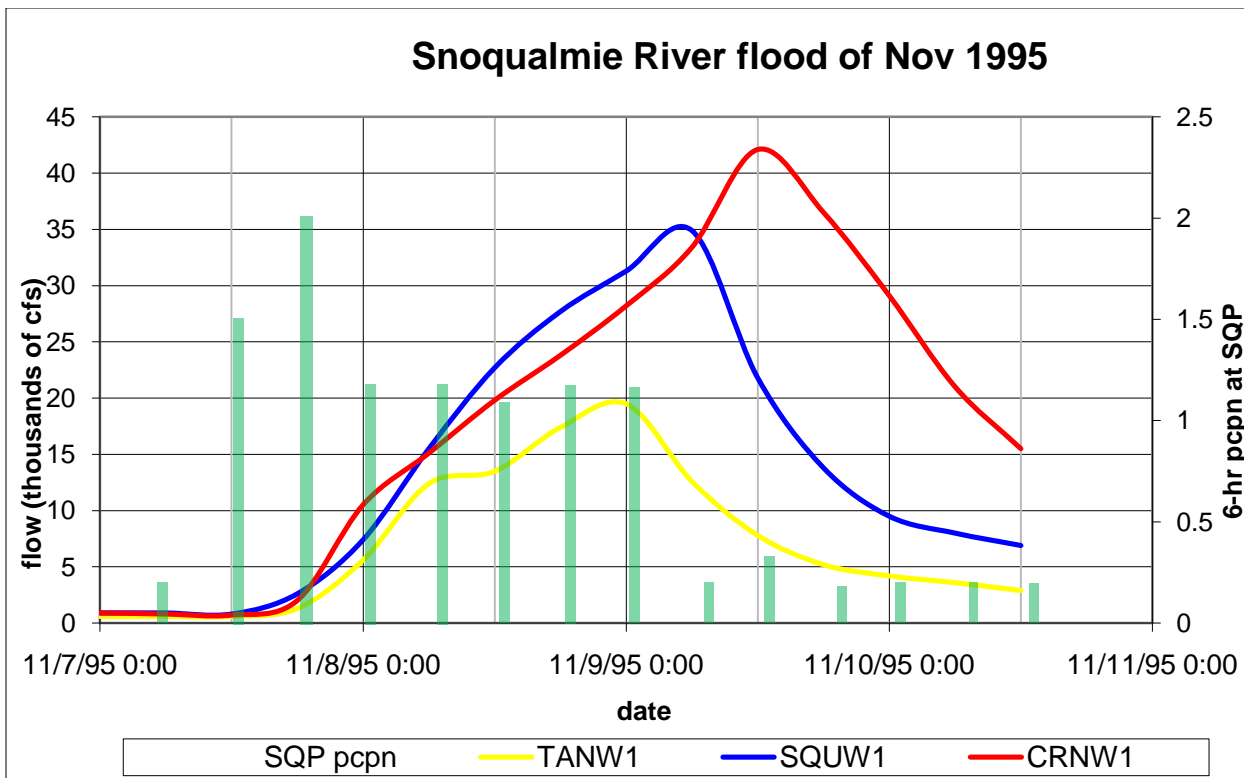
western Washington. These events are fairly common – it is rare to go through a cool season without at least one such event, and more than one is not uncommon. Indeed the most flood-prone rivers in western Washington, like the Snoqualmie River and several others flowing off the west slopes of the Cascades and out of the Olympics, usually flood at least once per year.

Occasionally an event will continue for several days with a series of waves sustaining the heavy rainfall. Rainfall amounts during prolonged events can exceed 20 inches, and not surprisingly these produce our most severe floods.

River flooding in western Washington occurs between the months of October and April, but floods are most common in the autumn and especially November.

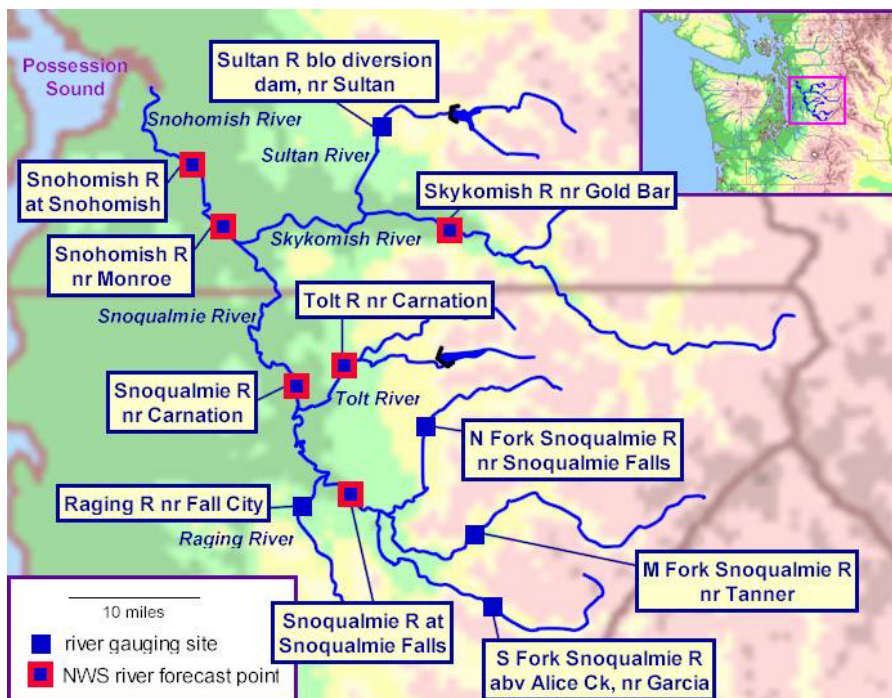
Western Washington is made up of many relatively small drainage basins that flow off the west slopes of the Cascades or out of the Olympic mountains. The short, steep nature of these rivers causes flood events here to develop rapidly. In addition to the rapid onset, the flood waves move downstream quickly so the floods have a relatively short life cycle.

The example below, from a flood on the Snoqualmie River, shows a typical flood on a western Washington river. The flood-producing rain occurred over a 42-hour period; in this case the green columns on the graph show the 6-hour precipitation amounts at the Snoqualmie Pass rain gauge, which reported a storm-total of almost 10 inches. The river responded dramatically, with the flow increasing from a base flow of around 2,000 cubic feet per second to more than 40,000 cfs at the Snoqualmie River near Carnation gauge (shown by the red trace on the graph). This was a rise of more than 15 feet in around 36 hours.



Hydrograph of a typical western Washington flood on the Snoqualmie River

The flood crest moved downstream quickly. The yellow trace shows the Middle Fork Snoqualmie River near Tanner, a gauge in the upper part of the basin (lower right on the map below), which crested almost simultaneously with the end of heavy rain. The crest moved downstream past the Snoqualmie R at Snoqualmie Falls (blue trace) within 6 hours and the Snoqualmie R near Carnation another 6 hours later. The flood crest would reach the confluence with the Snohomish River a few hours later. The total travel time for the crest to move from the upper part of the basin to the mouth of the Snohomish River at Puget Sound is around 36 hours.

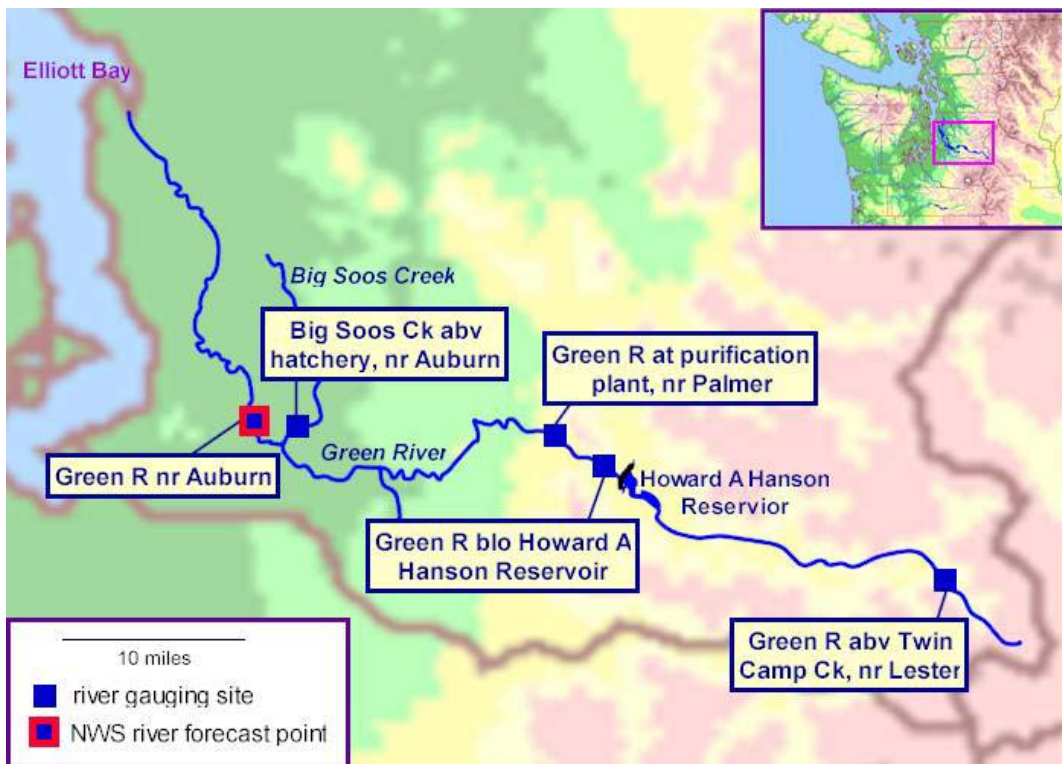


Map of the Snoqualmie / Skykomish / Snohomish River basin

As suggested by the satellite image of a pineapple express shown above these are relatively large scale events, and it is not unusual for a dozen or more rivers in western Washington to flood simultaneously. Of particular concern this year, of course, is the Green River which drains a relatively less wet section of the Washington Cascades west slopes. An event that causes the Green River to flood will also cause many of the other rivers in western Washington to flood as well.



Map of western Washington and its rivers

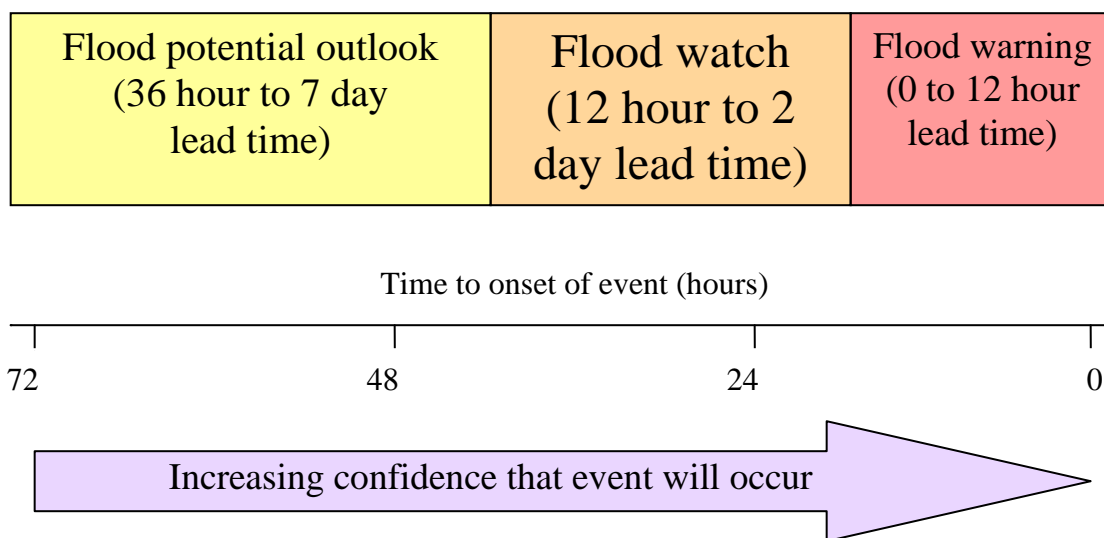


Map of the Green River basin and its river gauging network

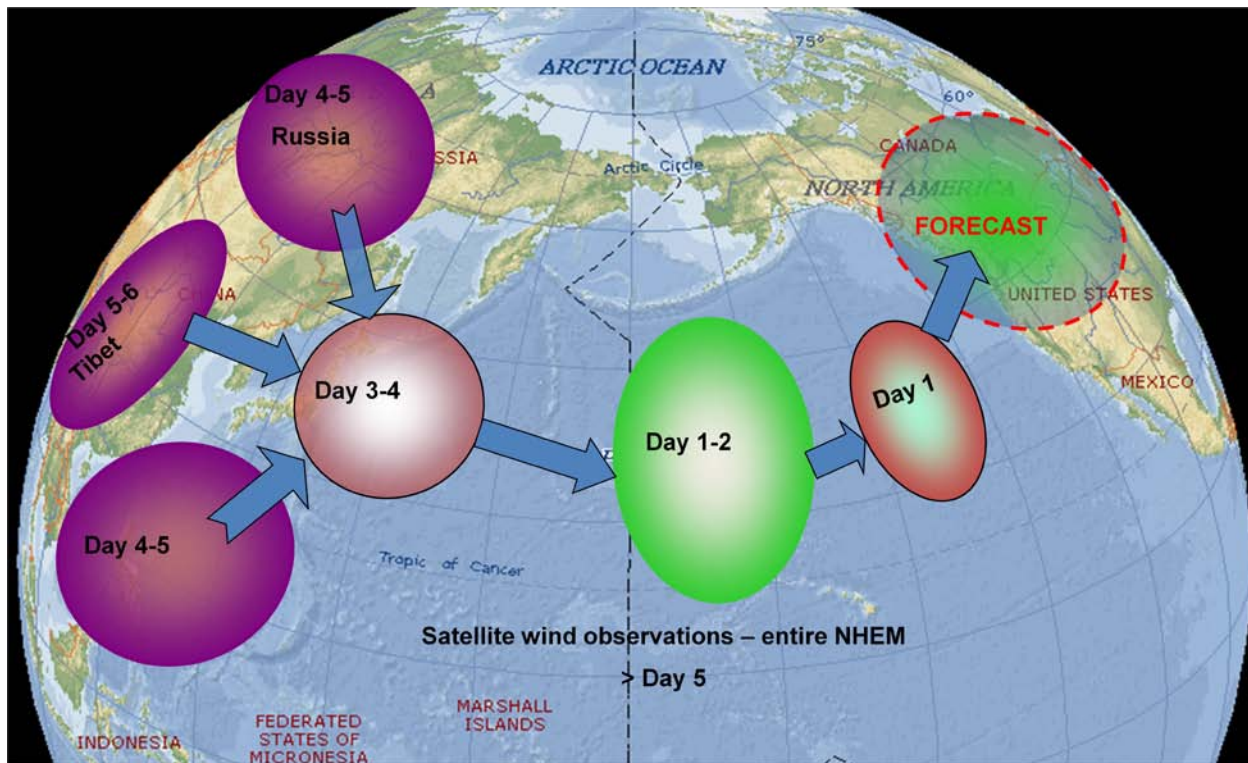
Forecasting and warning for river flooding

The rapid response of the rivers makes the forecasting and warning of floods very challenging. Notice that in the Skykomish River event, significant rain had not even begun 36 hours prior to the river reaching flood stage.

The National Weather Service issues a series of products in the lead-up to an event, progressing from a **flood potential outlook** to a **flood watch** and eventually to a **flood warning**. This sequence of products reflects not only the approaching onset of the event, but also increasing confidence in its occurrence and greater certainty with respect to timing and location. This is illustrated in the figure below.



To meet its goal of lead times for events, the National Weather Service needs to issue flood potential outlooks and flood watches well before significant precipitation has begun. In fact the storm bringing the potential for flooding would still be well offshore in the Pacific Ocean or even eastern Asia. Therefore the assessment of the potential for flooding depends upon accurate weather forecasting models several days ahead of the event. The issuance of a flood warning, which we strive to issue 12 hours ahead of a river reaching flood stage, depends upon accurate forecasts of how much rain will fall for how long over specific river basins. It is widely acknowledged that these quantitative precipitation forecasts are one of the most difficult tasks in weather forecasting.



A global perspective of the river forecasting and flood warning challenge

Let's take a closer look at the NWS products issued during the lead-up to a flooding episode and the type of forecasting tools available for use at each stage of the event.

Flood potential outlook – issued with 36 hours to several days lead time. The threatening storm will be still exiting the east part of Asia or over the northwest Pacific Ocean, and it will evolve dramatically before arriving in the Pacific Northwest.

Useful forecasting tools include

- Weather forecasting models
- Satellite
- Forecaster experience and climatology

Flood watch – issued with 12 hours to 2 days lead time. The threatening storm will be over the northeast Pacific or perhaps crossing the dateline. The storm could still undergo significant changes as it moves into the Pacific Northwest.

Useful forecasting tools again include

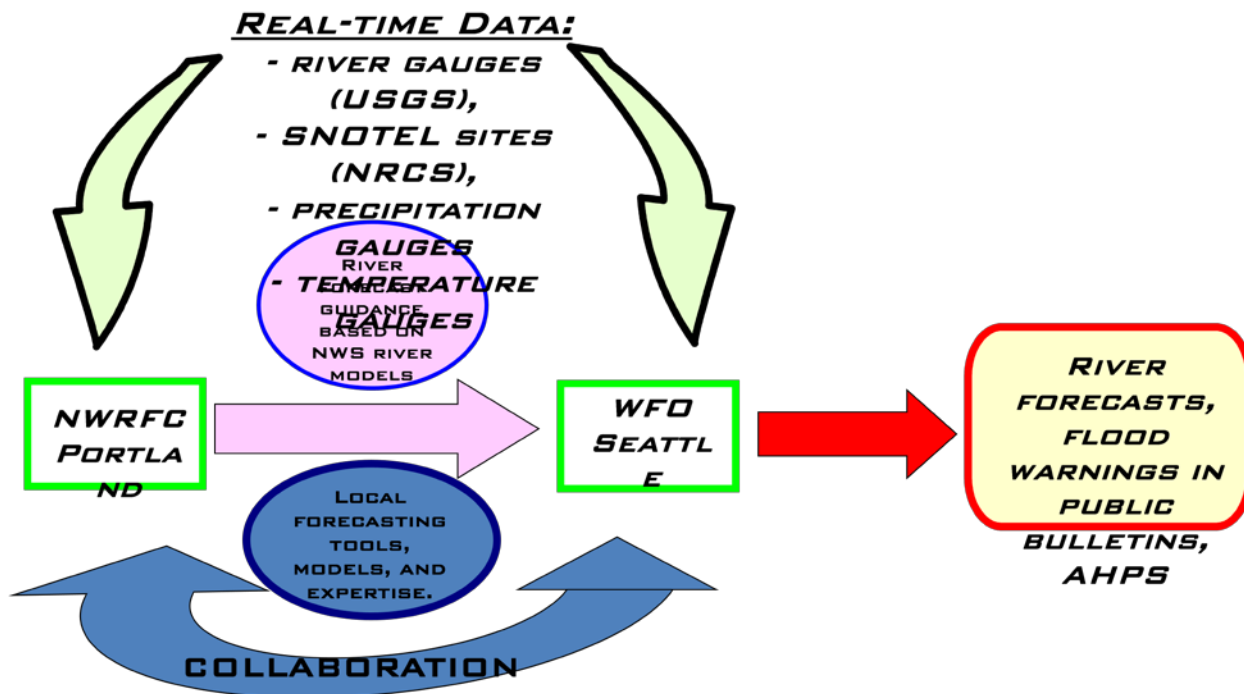
- Weather forecasting models, including quantitative precipitation forecasts
- River forecasting models
- Satellite
- Forecaster experience and climatology

Flood warning – issued with up to 12 hours lead time. The threatening storm will likely be starting to bring significant precipitation to the area, or at least be right at our doorstep. When we issue a flood warning it is for specific rivers and includes a forecast of the height and time of the flood crest.

Useful forecasting tools include

- Weather forecasting models, especially quantitative precipitation forecasts
- River forecasting models
- Satellite
- Radar
- Surface observation systems
- Buoy and ship reports
- Upper air observations from balloons and aircraft

The NWS forecast office in Seattle works with the NWS Northwest River Forecast Center in Portland to make river forecasts for western Washington. Essentially, it is the focus of the forecast office in Seattle to provide weather forecasts and meteorological expertise, make warning decisions, and issue the outlooks, watches and warnings. The River Forecast Center in Portland runs the hydrologic models, as well as providing hydrologic and meteorological expertise.



Schematic chart of the NWS river forecasting process