2023 Gage Master Plan

Chehalis River Basin Flood Warning System

JUNE 2023

CHEHALIS RIVER BASIN
FLOOD AUTHORITY

WEST CONSULTANTS
WATER | ENVIRONMENTAL | SEDIMENTATION | TECHNOLOGY

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List of Acronyms

ASOS.............................Automated Surface Observing System
AWOS............................Automated Weather Observing System
CoCoRaHS....................Community Collaborative Rain, Hail and Snow Network
COOP............................Cooperative Observer Network
CORPSCON .................U.S. Army Corps of Engineers Conversion Software
DCP...............................Data Collection Platform
Ecology..........................Washington State Department of Ecology
FAA ....Federal Aviation Administration
FEMA.............................Federal Emergency Management Agency
GARR ....Gage-Adjusted Radar Rainfall
HADS.............................Hydro-meteorological Automated Data System
LIDAR............................Light Detection and Ranging
METAR..........................Meteorological Aerodrome Report
NASA ....National Aeronautics and Space Administration
NAVD 88........................North American Vertical Datum of 1988
NESDIS ....National Environmental Satellite Data and Information Service
NEXRAD........................Next Generation Radar
NGVD 29 ....National Geodetic Vertical Datum of 1929
NLCD.............................National Land Cover Dataset
NOAA ....National Oceanic and Atmospheric Administration
NWRFC ....Northwest River Forecast Center
NWIS ....National Water Information System
NWS ....National Weather Service
RAWS............................Remote Automated Weather Stations
SCADA ....Supervisory Control and Data Acquisition
USGS ............................U.S. Geological Survey
VERTCON.....................North American Vertical Datum Conversion
WSDOT ....Washington State Department of Transportation

Executive Summary

The Chehalis River Basin Flood Authority operates a flood warning system that includes automatically reporting rain, stream, weather, and other sensors at 14 sites owned and operated by the authority. Three additional sites include webcams for visual monitoring of water conditions. The primary purposes of the network are:

1. Flood threat recognition,
2. Support for NWS weather and river forecasting,
3. Decision support for emergency response, and
4. Long term data records for water resources management.

The data also support environmental analyses, fisheries, and recreational activities in the Chehalis River Basin.

The Chehalis River Basin Flood Authority Flood Warning System leverages data from a much larger network of more than 100 monitoring stations in the region operated by a variety of federal, state, and local agencies. A core philosophy of the Flood Authority's approach is to leverage monitoring stations owned, operated, and professionally maintained by other agencies. This "gap-filling" approach serves to minimize the capital and operating costs of a much larger system in favor of a more manageable network to meet needs specific to the Chehalis Basin that are not met by the regional network. Thus, the Flood Authority has access to large volumes of useful regional data at a fraction of the cost required to build the entire network from scratch. Other agency networks include but not limited to:

1. United States Geological Survey.
2. National Weather Service
3. Washington Department of Ecology
4. United State Army Corps of Engineers.
5. National Oceanic and Atmospheric Administration
6. Thurston County
7. City of Aberdeen
8. TransAlta

Agency data along with data from the Flood Authority's monitoring stations are shared back to these agencies and the public through its data management system, known as Contrail. One of the key objectives of the flood warning system is to organize and present these data in visually appealing ways to better communicate developing flood threats in the basin.

Numerous projects were successfully completed by the Flood Authority since the 2017 Gage Master Plan to enhance the Flood Warning System. Eight recommendations were made in the 2017 Master Plan. Seven of the eight recommendations were funded and completed. In addition to the projects suggested in the 2017 plan, three additional projects were funded and completed. Brief descriptions of each of the projects are listed in Section 2 of the following report.

Current Gage Inventory

Currently, a total of 272 sensors from 102 gaging sites report data to the Flood Authority's website. Table 0-1 and Table 0-2 summarize the current inventory of hydro-meteorological sensors reporting to the website.

Table 0-1. Hydro-meteorological sensors inventories

	Gage Type	Total
Precipitation	Rain Accumulation	38
	Rain Increment	32
Stream	Discharge	34
	Stage	63
Temperature	Water Temperature	6
	Air Temperature	35
Battery	Voltage	14
Meteorological	Dew Point	1
	Pressure	4
	Relative Humidity	6
	Solar Radiation	5
Tidal/Ocean	Tide Prediction	2
	Tide Elevation	2
	Tide Residual	2
Wind	Direction	13
	Speed/Velocity	13
	Gust	2
Total Sensors		**272**
Total Gaging Sites		**102**

Table 0-2. Key hydro-meteorological sensors in Contrail

Gage type	City of Aberdeen	Flood Authority	WSDOE	USGS	METAR	TransAlta	TIDES	Total
Precipitation	0	55	0	1	5	0	0	61
Stage	1	6	4	37	0	2	2	52
Air Temp	0	20	2	0	5	0	2	29
Total	**1**	**81**	**6**	**38**	**10**	**2**	**4**	**142**

Recommendations

The 2023 Gage Master Plan recommendations are presented as critical updates, relatively low-cost enhancements, important upgrades, strategic initiatives, and issues on the horizon. These recommendations form an outline of the path forward for the next five years to support continued success of the Flood Warning System. Recommendations are derived from experience operating and maintaining the Flood Warning System since 2010, feedback from user surveys, technology advancements, and from lessons learned during recent flood events. The recommendations are discussed in more detail in Section 4.

- **Critical Updates** – Updates needing completion as soon as possible.
  - Relocate the Chehalis River below Thrash Creek Gage
- **Low-Cost Enhancements** - "Low-hanging fruit" that are quickly and inexpensively achievable.
  - Add new sensor data from existing gages,
  - Standardize Flood Alert Messaging,
  - Implement Forecast High Water Alerts,
  - Improve Website User Interface,
  - Improve Inundation Maps,
  - Add Website Training,
  - Develop a Post-Flood Action Plan,
  - Add QR Code Stickers to Highly Visible Gages linked to the FWS website,
  - Leverage Office of Chehalis Basin Public Relations Resources for Social Media and Messaging, and
  - Introduce Citizen Science for some applications.
- **Important Upgrades** – Key upgrades critical for long-term system performance and success.
  - Upgrade to Contrail Server,
  - Verify Rating Curves at Chehalis River (CENW1) and Skookumchuck River (CTAW1),
  - Develop a Data Agent between Ecology and Contrail,
  - Investigate Water Level Discrepancies at Skookumchuck Reservoir,
  - Investigate Feasibility of Adding Gap-Filling Rain Gages,
  - Improve Transient Snowpack Monitoring,
  - Develop Inundation Maps for Bucoda, and
  - Explore Ways to Communicate Uncertainty in Inundation Maps
- **Strategic Initiatives** – Recommendations that require cooperation and, potentially, joint funding by regional stakeholders which include various local regional, state, and/or federal agencies.
  - Improve Forecasting on the Lower Chehalis River (Primarily a National Weather Service function)

- Install Flow Gaging Sensor on the Lower Chehalis River to Support Modeling and Forecasting (Expensive gage to install, operate, and maintain. USGS is the logical lead agency with potential funding from a variety of other agency stakeholders.)
- Improved Flow Forecasts for Skookumchuck Reservoir near Bucoda (Primarily a National Weather Service function)

- **Tasks on the Horizon** – Upcoming events that may trigger work projects.
    - Skookumchuck River at Centralia Bridge Replacement
    - Develop Capital Investment Strategy for Gage Obsolescence and Technology Change

National Recognition

It is important to acknowledge the collective efforts of the Flood Authority, the Office of the Chehalis Basin, support staff and contractors. Through these efforts, the Chehalis River Basin Flood Warning System has achieved a high level of performance and operational excellence since its inception in 2010. The system has been recognized nationally on two different occasions in the past four years. In 2019, the Association of State Flood Plain Managers (ASFPM) recognized the Flood Warning System was a major component in the floodplain management program in the Chehalis Basin. The Flood Authority received the 2019 ASFPM James Lee Witt Local Award for Excellence in Floodplain Management. Most recently, the Chehalis River Basin Flood Warning System was recognized by the National Hydrologic Warning Council (NHWC) who presented the Flood Authority with its 2023 Operational Excellence Award. This award is given to an organization that has developed and/or maintained an exceptional hydrologic warning system. Specifically, the NHWC Award recognized the Flood Warning System for its exceptional performance during major flooding in the Basin in early 2022.

The recommendations provided in the 2023 Gage Master Plan are intended to promote continued operational success while maintaining the core philosophy of maximizing leverage of regional resources with targeted gap filling projects by the flood authority.

1. Background

1.1. Purpose and Scope

Prior floods in the Chehalis River Basin and the potential for future flood events motivate improved flood mitigation strategies. The Chehalis River Basin Early Flood Warning System (Flood Warning System), operated by the Chehalis River Basin Flood Authority (Flood Authority), was developed to improve community flood preparedness in the basin. The system consists of gages operated by various agencies and a means to disseminate information to the public. This report discusses the Chehalis River basin, describes how the Flood Warning System operates, assesses the current state of the system, and identifies unmet flood mitigation needs related to hydrologic forecasting and warning.

1.2. Chehalis Basin Strategy

1.2.1. Chehalis River Basin Flood Authority

The Flood Authority was formed in April of 2008, by an inter-local agreement among Lewis, Grays Harbor, and Thurston counties; the cities of Aberdeen, Centralia, Chehalis, and Montesano; the towns of Bucoda, and Pe Ell; and the Confederated Tribes of the Chehalis Reservation. It was established as a response to extreme damage and flooding that occurred in the Chehalis River basin and adjoining areas during December of 2007. The main goals stated in the agreement were to

- Create a basin flood control district,
- Inform state and federal funding sources of project options and the needs of the basin communities,
- Work with the State of Washington to develop policy for flood control projects, and
- Seek funding for the basin governments to identify, study, and permit projects for localized problems.

Lewis County was the designated lead agency and granted various powers and responsibilities over the agreement. Since the time of the agreement, the Cities of Oakville, Cosmopolis, and Napavine have been added and the Confederated Tribes of the Chehalis Reservation have withdrawn.

Currently, the Flood Authority conducts board meetings open to the public, seeks stake holder input, permits projects, funds and commissions studies, and actively engages State and Federal agencies to facilitate supplementary funding. In addition, the Flood Authority operates the Flood Warning System, which this study supports.

1.2.2. Washington State Office of Chehalis Basin

In 2016, the Washington Legislature created the Office of the Chehalis Basin (OCB) within Ecology and established the Chehalis Basin Board. The OCB administers funding and works closely with the Board to implement the Chehalis Basin Strategy while the Board provides long-term oversight of the Strategy. The Board is responsible for developing budget recommendations to the Governor's office to implement the strategy. The board members represent agricultural, environmental, and economic interests in the basin and include representatives from the Flood Authority, the Confederated Tribes of the Chehalis Reservation, and the Quinalt Indian Nation, as well as non-voting members from State agencies such as DFW, DNR, WSDOT, Ecology, and the Washington State Conservation Commission.

1.3. Chehalis River Basin

1.3.1. Location

The Chehalis River Basin encompasses about 2,660 square miles in southwestern Washington. The basin covers large portions of Lewis, Grays Harbor, Thurston, and Mason counties and the entire Chehalis Indian Reservation. An estimated 144,000 residents live in the basin. The largest municipalities in the basin include Centralia and Aberdeen. Other smaller cities and communities are scattered throughout the basin as shown in Figure 1.1.

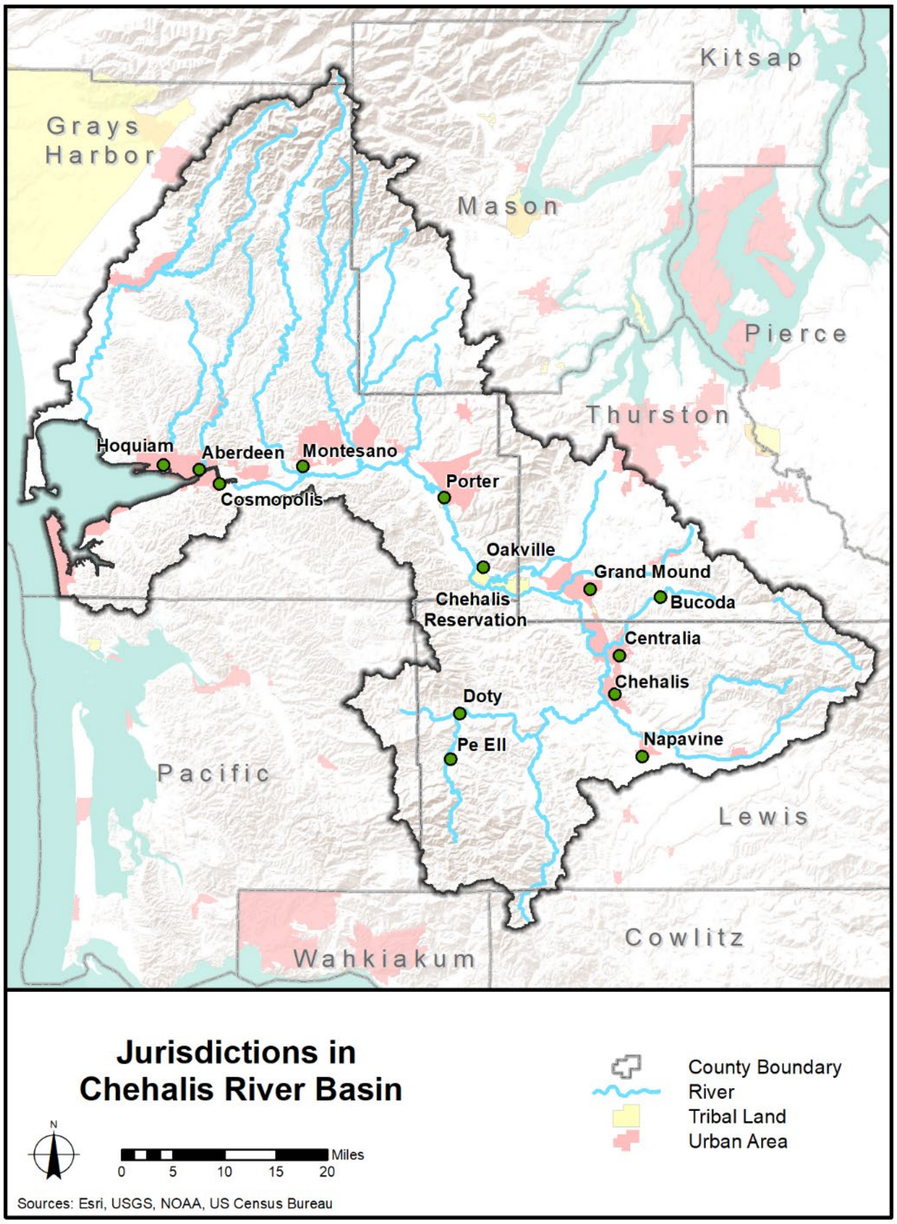

Figure 1.1. Jurisdictions in the Chehalis Basin

1.3.2. Land Cover

The Chehalis Basin is mountainous with low-lying river valleys. Most of the developed land is in the river valleys as seen in Figure 1.2. The mountainous areas are dominated by heavily logged coniferous forest. These forests are made up of tracts of land that have been clear-cut and replanted throughout the last 150 years, resulting in a patchwork of unpaved roads and forest with trees at various ages. The low-lying areas are dominated by farms, riparian habitat, and urban development.

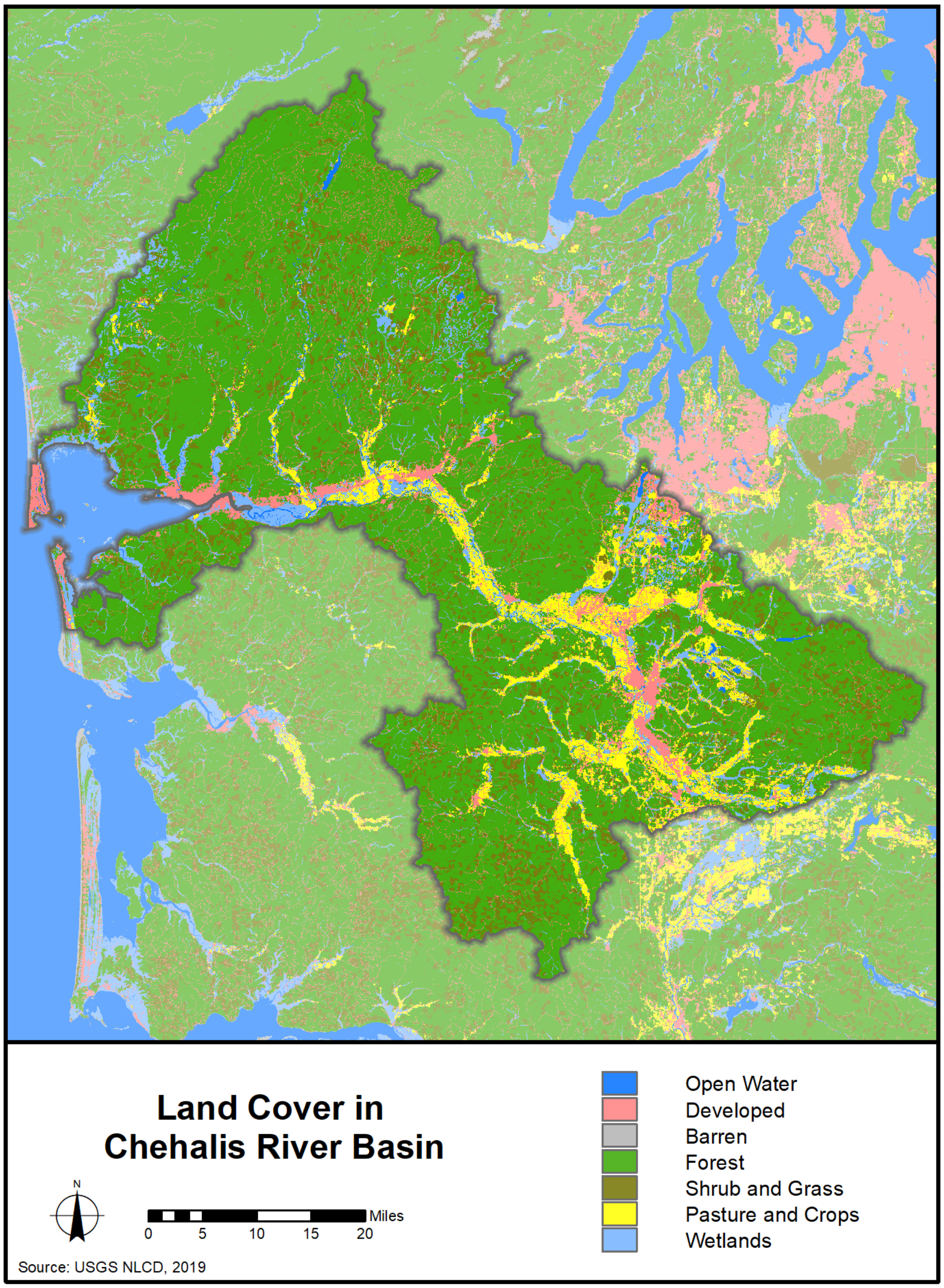

Figure 1.2. NLCD (2019) land cover classification in the Chehalis Basin

1.3.3. Climate

Most of the basin is within the Köppen Warm-Summer Mediterranean (Csb) zone while the headwaters of the northern tributaries lie within the Oceanic (Cfb) zone. Temperatures in the basin are seasonal and mild. Precipitation in the Chehalis Basin is high and variable, ranging between approximately 50 and 150 inches per year. Figure 1.3 shows the spatial distribution of annual rainfall in the Chehalis River basin with green indicating less than 45-75 inches of rain annually and red areas indicating over 125 inches of rain annually. Figure 1.4 illustrates how the temperature and precipitation changes seasonally. The spatial distribution of rainfall is heavily influenced by the topography. Most storms originate to the west over the Pacific Ocean. As this moisture is carried inland and onto mountainous terrain by prevailing winds, it uplifts, cools, then condenses, resulting in orographically enhanced precipitation.

Headwaters in the northern Chehalis basin, originating in streams flowing from the southern Olympic Mountains, reach as high as 5000 feet. The elevation and orientation of the southern Olympics cause orographic precipitation resulting in high rainfall in the northern portion of the basin, as moist air meets the southern portion of the Olympic Range.

The southern basin lacks the same magnitude of orographic enhancement of precipitation as seen in the North. It receives less rainfall due to its lower elevations and orientation of watersheds. The southern basin is lower, mostly under 3000 feet. A rain shadow effect can be seen (Figure 1.3), with much of the rain originating from the Pacific, falling as orographic rain in the Willapa Hills outside of the basin.

There is a strong seasonal signal in the temporal distribution of rainfall. The rainy season is from November through March, which brings more than twice the rainfall that occurs during the rest of the year. Snow is only common in the highest elevations of the basin and only typical between December and February. On occasion, the snow level can drop below 6000 ft.

Atmospheric River events pose the largest risk to flooding in the Chehalis River. These atmospheric features carry large volumes of moisture from the tropics, often transporting the water equivalent to 15-20 times the flow of the Mississippi River. Their linear appearance in imagery generated from satellite water vapor data inspired the term, atmospheric river (Figure 1.5). These extreme precipitation events tend to occur during the rainy season and are the primary cause of major flood events in the Chehalis River basin.

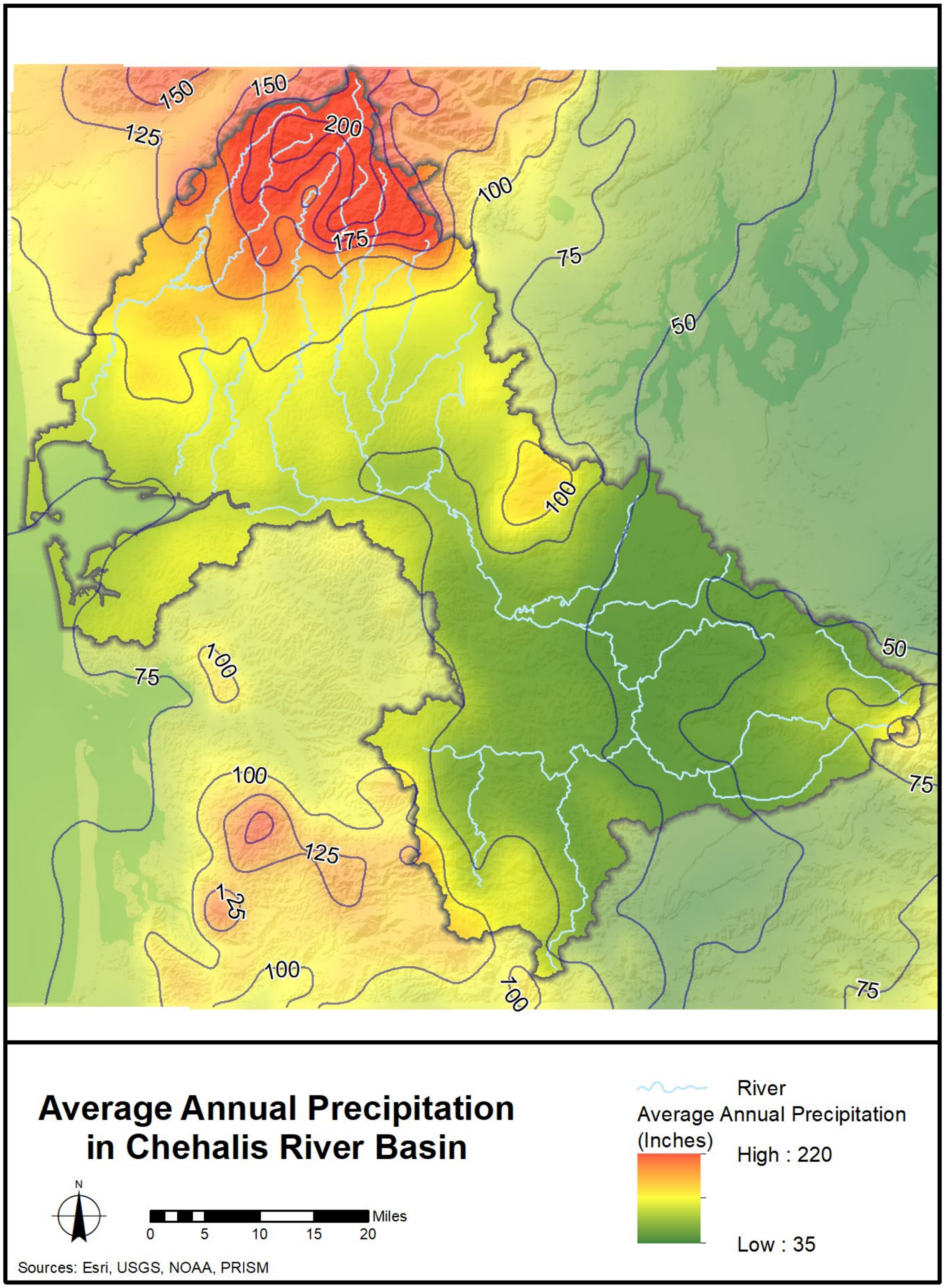

Figure 1.3. Average annual precipitation in the Chehalis Basin.

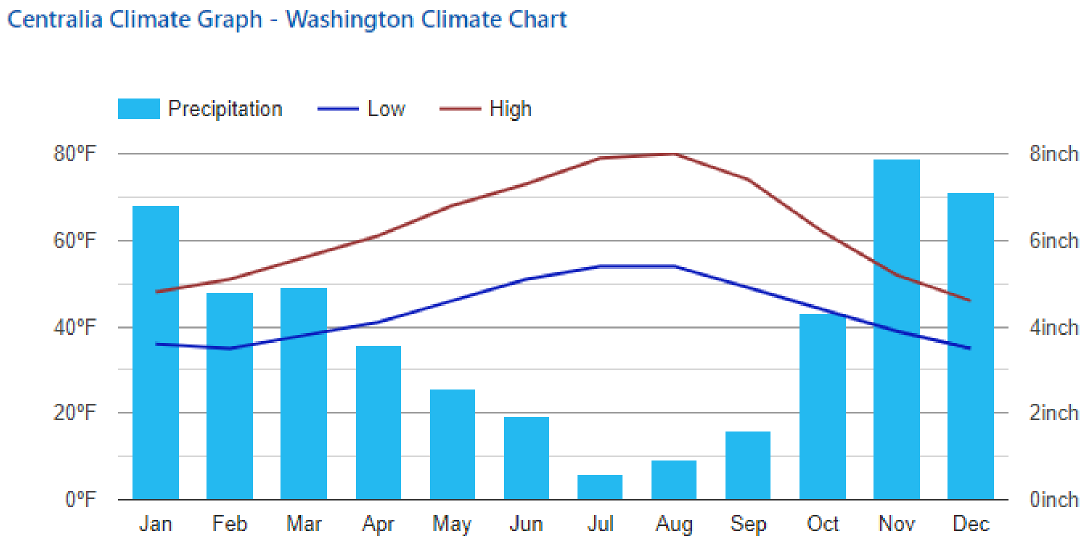

Figure 1.4. Climate data for Centralia, WA (Source: www.usclimatedata.com)

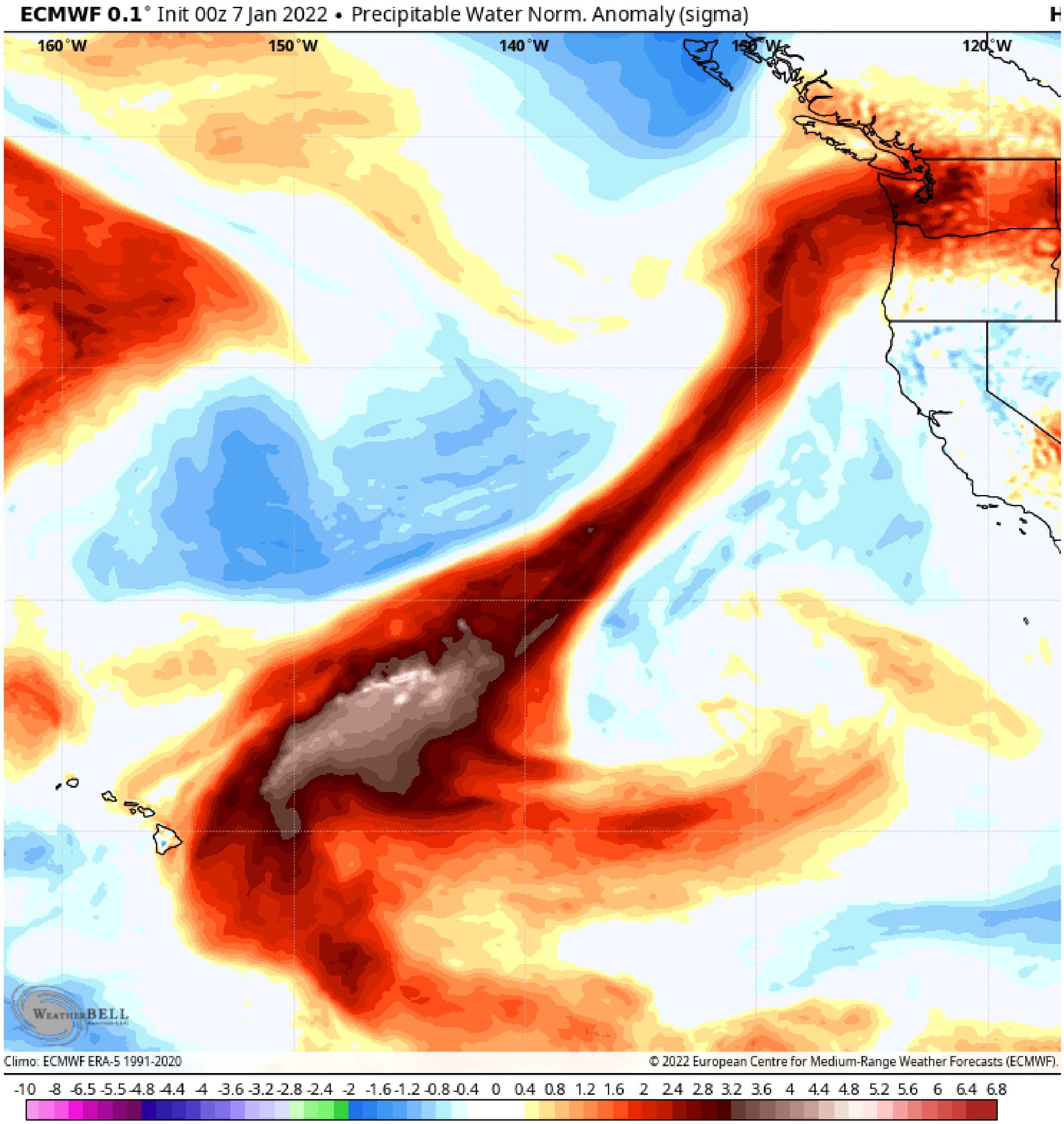

Figure 1.5. Atmospheric River directed toward Washington State, January 7, 2022.

1.3.4. Hydrology

The Chehalis River Basin is the second largest watershed in the State of Washington. It is bounded on the north by the Olympic Mountains, on the south by Cowlitz River Basin, on the west by the Pacific Ocean, and on the east by the Deschutes River Basin. The Chehalis River originates in southwestern Lewis County, at the confluence of the East Fork Chehalis River and the West Fork Chehalis River. It flows approximately 125 miles in a north-northwesterly direction to Grays Harbor, an estuary of the Pacific

Ocean. Several tributaries join the Chehalis River along its route to Grays Harbor. These tributaries are listed in Table 1-1 along with other major rivers that empty into Grays Harbor.

Long-term median flows at USGS stream gaging locations in the Chehalis River Basin are listed in Table 1-3. Note that the headwaters of the river have an average flow of 93 cfs while the flow at Porter is 2,020 cfs. The Satsop River contributes the largest flow, 1,030 cfs, to the Chehalis River in comparison to the other tributaries which have a median flow ranging from 137 cfs to 269 cfs.

Table 1-1. Tributaries to the Chehalis River and Grays Harbor

	Confluence Location	Subbasin Area	Tributary Length	Minimum Elevation	Maximum Elevation	Mean Annual Precipitation
	Chehalis RM	*sq. mi.*	*mi.*	*ft NAVD88*	*ft NAVD88*	*in*
Chehalis River Tributaries						
Wynoochee River	11.3	196	61	8	5,030	130
Satsop River	18.3	302	6	15	3,960	116
Cloquallum Creek	23.1	68	18	24	1,590	86
Black River	44.2	138	24	79	2,660	56
Scatter Creek	51.3	42	19	111	1,480	49
Skookumchuck	62.9	189	32	156	3830	54
Newaukum River	69.4	159	10	160	3,820	60
South Fork Chehalis	81.2	125	25	201	3,140	67
Elk Creek	92.3	58	13	303	2,420	79
Grays Harbor Tributaries						
Humptulips River	-	247	26	0	4,470	131
Hoquiam River	-	91	24[1]	0	924	93
Wishkah River	-	103	33	0	1,650	109

[1] Length measured along the East Fork Hoquiam River

Table 1-2. Median annual flow at USGS gaging stations in the Chehalis River Basin.

USGS Station Number	Station Name	Median Annual Flow (cfs)
Chehalis River		
12019310	Chehalis River above Mahaffey Creek Near Pe Ell, WA	93
12020000	Chehalis River near Doty, WA	230
12027500	Chehalis River near Grand Mound, WA	1,220
12031000	Chehalis River at Porter, WA	2,020
Chehalis River Tributaries		
12020525	Elk Creek Below Deer Creek near Doty, WA	158
12024000	South Fork Newaukum River near Onalaska, WA	144
12025000	Newaukum River near Chehalis, WA	269
12025700	Skookumchuck River near Vail, WA	137
12026150	Skookumchuck River Bl Bldy Run Cr near Centralia, WA	191
12026400	Skookumchuck River near Bucoda, WA	228
12035000	Satsop River near Satsop, WA	1,030

The Chehalis River basin is primarily a rain dominated watershed and most streamflow in the basin is maintained by groundwater recharge during the dry season and rainfall at other times. Snow-dominated regions include the Southern Olympic and Cascade Foothills while rain-snow transitional headwaters occur in the Black Hills and Willapa Hills (Figure 1.6).

Reservoirs are limited to Skookumchuck Reservoir and Wynoochee Lake. The reservoirs have a capacity of 69,405 and 34,800 acre-feet, respectively. The Skookumchuck Dam is a run-of-river dam that was built in 1970. The reservoir is used for water supply and environmental flow requirements. In 1990, a small powerhouse was constructed to produce hydropower from the reservoir. The Washington Department of Fish and Wildlife uses a portion of the water for a fish-rearing facility downstream of the dam. (TransAlta, 2017). The reservoir also provides water downstream to the Centralia Coal Plant, Washington State's largest baseload power source, which is essential for keeping the west-coast electrical grid stable. Wynoochee Lake is a multipurpose reservoir owned by the City of Aberdeen; used for water supply, recreation, flood control, and hydroelectric power generation. It is located on the Wynoochee River with a drainage area of 41 square miles. The reservoir's maximum discharge of 25,500 cfs occurred in 1968. It has 35,000 acre-feet of flood control storage (USACE, 2017).

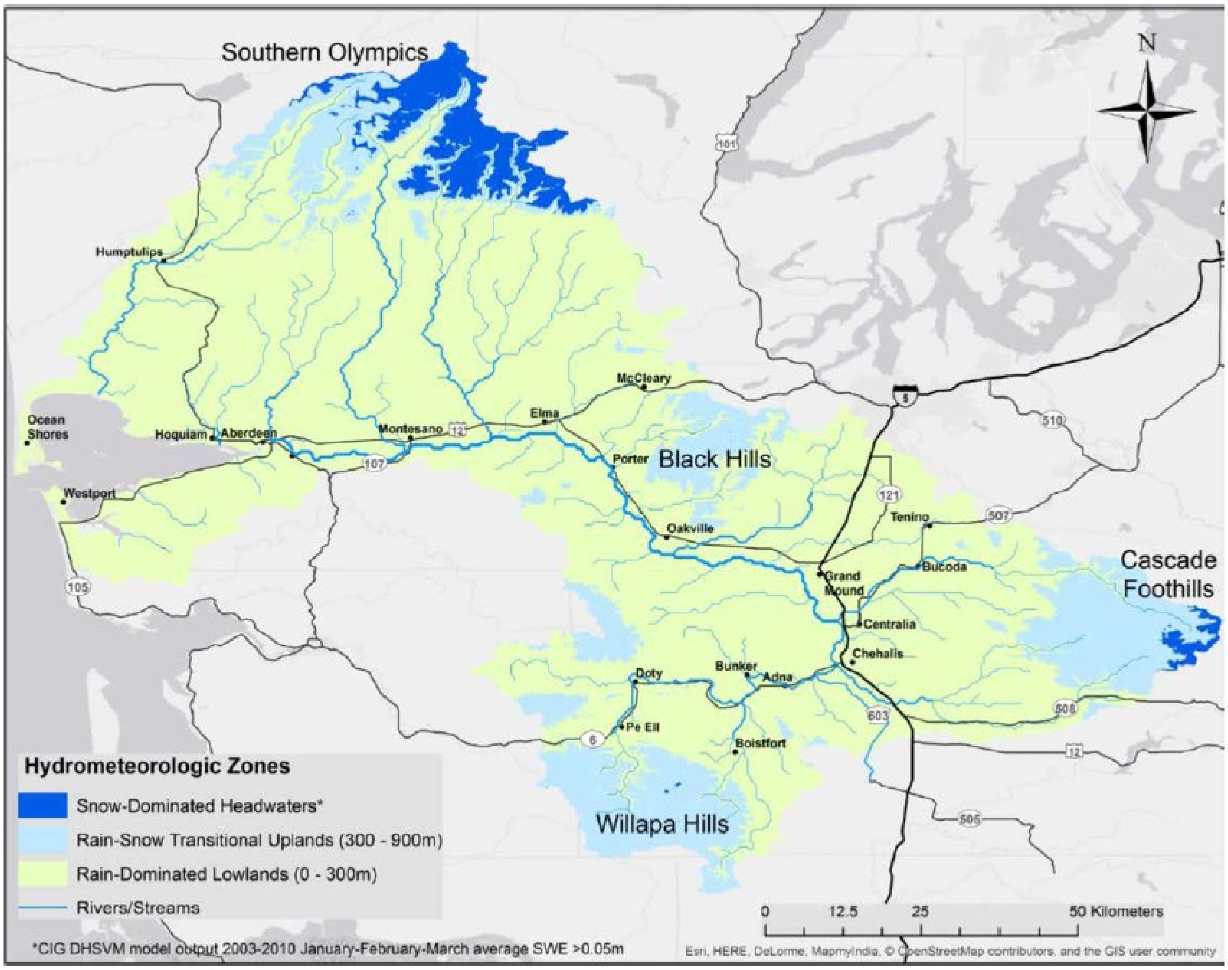

Figure 1.6. Hydro-meteorologic zones in the Chehalis Basin

1.4. Historical Flooding

Extreme rainfall events in the Chehalis River Basin are primarily a result of atmospheric rivers originating in the equatorial Pacific, causing increased flood risk from late-fall through mid-winter. The flood risk is exceptionally high in low-lying river valleys, where rivers sometimes spill over their banks multiple times in a single year. Most floods are minor, causing minimal damage. Although occasionally they can be significant resulting in loss of life and property. The last five major floods are presented in detail in Appendix B.

Flood stage is defined as the water surface level which begins to impact property of commerce and is not necessarily the same as bankfull stage. The NWS maintains flood categories of river stage heights at various gages. These categories characterize flood severity to effectively communicate the impact of flooding as shown in Table 1-3. Minor flooding causes minimal or no property damage, but possibly some public threat or inconvenience. Moderate flooding causes some inundation (flooding) of structures and roads near streams. Some localized evacuations may be necessary. Major flooding is extensive inundation of structures and roads with significant evacuations of people and/or property. Flood stages for selected stations in the Chehalis Basin are list in Table 1-4.

Table 1-3. NWS flood stage categories

NWS Flood Severity	Flooding Effects
Minor Flooding	Minimal or no property damage, but possibly some public threat or inconvenience.
Moderate Flooding	Some inundation of structures and roads near streams. Some evacuations of people and/or transfer of property to higher elevations.
Major Flooding	Extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.

Table 1-4. NWS flood stages for rivers in the Chehalis Basin

NWS Station Name	USGS Station Number	Station Name	Flood Stage (ft NAVD88)
Chehalis River			
DOTW1	12020000	Chehalis River near Doty, WA	318.0
CENW1	12025500	Chehalis River near Centralia	168.5
CGMW1	12027500	Chehalis River near Grand Mound, WA	141.0
CRPW1	12031000	Chehalis River at Porter, WA	48.0
Chehalis River Tributaries			
NEWW1	12025000	Newaukum River near Chehalis, WA	202.5
BCDW1	12026400	Skookumchuck River near Bucoda, WA	211.5
CTAW1	12026600	Skookumchuck River near Centralia	189.0
SATW1	12035000	Satsop River near Satsop, WA	38.0
MNSW1	12037400	Wynoochee River near Montesano	42.5

Figure 1.7 shows the daily mean stage during the flood season (November through March) for the entire historical USGS gage record (1930-2023) for the Chehalis River at Ground Mound while Table 1-5. Number of days above flood stage at Chehalis River at Ground Mound. lists the total number of days during each category. The colors match the NWS flood categories to visualize the flood category more easily. Note that most of the flooding occurs from December through February. Figure 1.7 aids in visualizing the frequency, duration, and intensity of flood events in the basin. Major floods tend to occur between late November and early February. The highest frequency of flooding occurs in December and January. Most floods last one to three days. Table 1-7 lists the total number of days during each category.

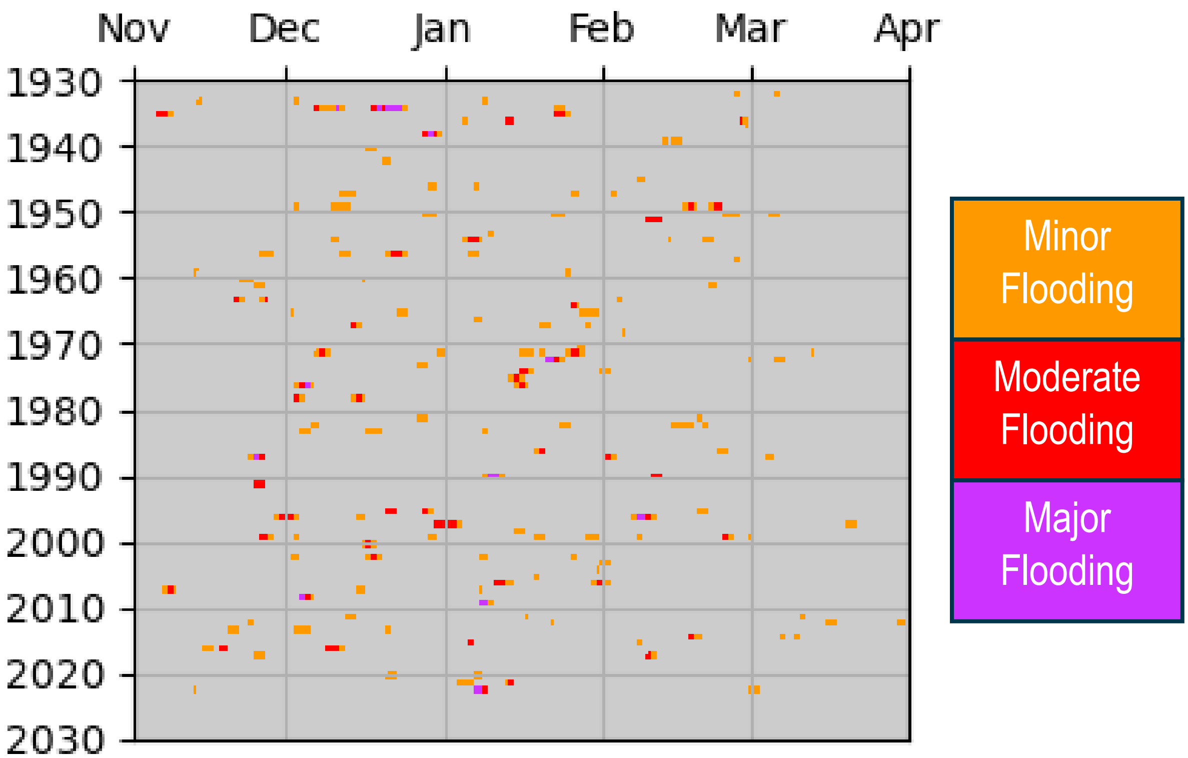

Figure 1.7. Historical flood events for the Chehalis River at Ground Mound during the wet season (November - March).

Table 1-5. Number of days above flood stage at Chehalis River at Ground Mound

Nov - Mar		Days above flood stage: Minor	Days above flood stage: Moderate	Days above flood stage: Major	Nov - Mar		Days above flood stage: Minor	Days above flood stage: Moderate	Days above flood stage: Major
1931	1932	2			1977	1978	3	2	
1932	1933	3			1978	1979			
1933	1934	7	3	5	1979	1980			
1934	1935	2	4		1980	1981	3		
1935	1936	2	3		1981	1982	9		
1936	1937	2			1982	1983	6		
1937	1938	1	2	1	1983	1984			
1938	1939	3			1984	1985			
1939	1940	2			1985	1986	3	1	
1940	1941				1986	1987	4	2	1
1941	1942	2			1987	1988			
1942	1943				1988	1989			
1943	1944				1989	1990	2	2	2
1944	1945	2			1990	1991	2	3	
1945	1946	3			1991	1992			
1946	1947	6			1992	1993			
1947	1948				1993	1994			
1948	1949	8	3		1994	1995	3	3	
1949	1950	11			1995	1996	7	5	2
1950	1951		3		1996	1997	3	5	
1951	1952				1997	1998	2		
1952	1953	1			1998	1999	12	3	
1953	1954	7	2		1999	2000	2	1	
1954	1955				2000	2001			
1955	1956	9	2		2001	2002	7	1	
1956	1957	1			2002	2003	2		
1957	1958				2003	2004	1		
1958	1959	2			2004	2005	1		
1959	1960	4			2005	2006	4	4	
1960	1961	4			2006	2007	5	1	
1961	1962				2007	2008	1	1	1
1962	1963	3	2		2008	2009	1		2
1963	1964	1	1		2009	2010			
1964	1965	7			2010	2011	4		
1965	1966	2			2011	2012	6		
1966	1967	4	1		2012	2013	6		
1967	1968	1			2013	2014	4	1	
1968	1969				2014	2015	1	1	
1969	1970	2			2015	2016	3	5	
1970	1971	11	3		2016	2017	3	1	
1971	1972	4	1	2	2017	2018			
1972	1973	2			2018	2019			
1973	1974	3	2		2019	2020	4		
1974	1975	2	1		2020	2021	4	1	
1975	1976	4	2	1	2021	2022	3	1	2
1976	1977				2022	2023			

1.5. Chehalis River Basin Flood Warning System (FWS)

The Flood Warning System was created by the Flood Authority as a tool to inform the public of imminent danger during a flood and to maximize flood awareness. It includes publicly accessible, Internet-based flood data collection; a webpage interface; and an automated email alert system. Rain, stream, reservoir, wind, and air temperature information are collected, displayed, and used in near real-time. Most of the data in the basin is transmitted from field sites using the Geostationary Operation Environmental Satellite Data Collection System (GOES DCS – Appendix D) Internet users access current data along with the latest NWS river forecasts for the basin, local traffic conditions, and other flood-preparedness information. Flood inundation maps (Figure 1.8. Example inundation map available on Contrail.) show the public and government officials where flooding is expected at each forecasted river stage. Automated email alerts are sent to participants as specified high-water levels are reached. The web features of the Flood Warning System are provided, through an online interface referred to as Contrail (Appendix E). The following chapter will describe the gage data currently used in the Flood Warning System.

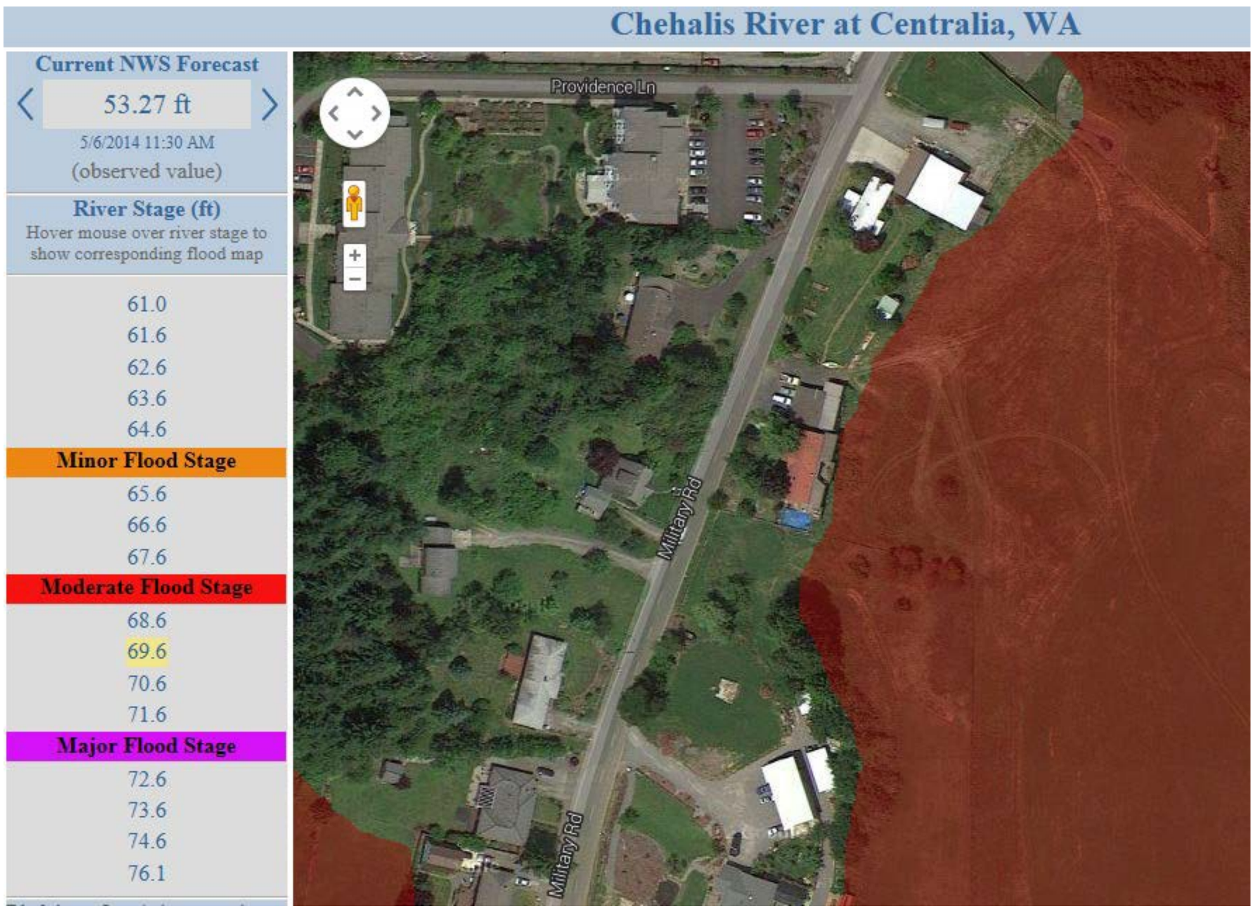

Figure 1.8. Example inundation map available on Contrail.

2. Completed Recommendations from the 2017 Gage Master Plan

Numerous successful projects have been completed since the 2017 Gage Master Plan to enhance the Flood Warning System. Eight recommendations were made in the 2017 Master Plan. Seven of the eight recommendations were funded and completed. In addition to the projects suggested in the gage master plan three additional projects were funded and completed since 2017. Brief descriptions of each of the projects are listed in the subsections below.

2.1. Add Additional HADS, USGS, and METAR Precipitation Gages

The 2017 Gage Master Plan identified 19 precipitation gages which could be added to Contrail to provide additional precipitation data in the Chehalis basin (Table 2-1). All 19 of these gage sites have been connected to Contrail, bringing the total number of precipitation gages in the system to 40.

Table 2-1. Precipitation gages added to Contrail

Site ID	Site Name	Contrail Data System
EKMW1	ELK MEADOWS RAIN GAGE NEAR MONTESANO 20N	HADS
BKBW1	BLACK KNOB	HADS/RAWS
MIPW1	MINOT PEAK	HADS/RAWS
HUFW1	HUMPTULLIPS	HADS/RAWS
TILW1	TILTON RIVER ABOVE BEAR CANYON CREEK NEAR CINEBAR 4SE	HADS
DOTW1	CHEHALIS RIVER NEAR DOTY 1S	HADS
SKOW1	NORTH FORK SKOKOMISH RIVER BELOW STAIRCASE RAPIDS NEAR HOODSPORT 11NW	HADS
CRWW1	CHEHALIS RIVER AT WASTEWATER TREATMENT PLANT AT CHEHALIS 1W	HADS
NFFW1	NORTH FORK NEWAUKUM RIVER ABOVE BEAR CREEK NEAR FOREST NEAR ONALASKA 7NW	HADS
SCW1	SOUTH FORK CHEHALIS RIVER AT WILDWOOD NEAR RYDERWOOD 6NW	HADS
ABNW1	ABERNTHY MOUNTAIN	HADS/RAWS
KCLS	CHEHALIS-CENTRALIA AIRPORT	METAR
BCDW1	SKOOKUMCHUCK RIVER NEAR BUCODA 3SW	HADS
KMMW1	KM MOUNTAIN ALERT	HADS
SFNW1	SOUTH FORK NEWAUKUM RIVER NEAR ONALASKA 1E	USGS
CLSW1	CHEHALIS	HADS/RAWS
HKFW1	HUCKLEBERRY RIDGE	HADS/RAWS
12035380	WYNOOCHEE LAKE NEAR GRISDALE, WA	USGS
471541123425300	ABERDEEN RESERVOIR NEAR GRISDALE, WA	USGS

2.2. Add Ecology Measurements to the Flood Warning System

The Washington Department of Ecology maintains several stream gages within the Chehalis River Basin (Ecology, 2023). In 2017 there were six Ecology gages (Bunker Creek, Dillenbaugh Creek, Newaukum near Chehalis, Salzer Creek, South Fork Chehalis River, and Stearns Creek) that were not included in HADS and were not available for use in the FWS. As of early 2023, four of the gages (Newaukum near Chehalis, Salzer Creek, South Fork Chehalis River and Stearns Creek) have been added to HADS and subsequently added to the Flood Authority’s Contrail website. Three sites measure stage data in NAVD 88, three of the sites provide air temperature, and one provides precipitation. As of the writing of this report the following gages are available on Ecology's website, but are not in HADS:

- Bunker Creek @ Ceres Hill Rd (Ecology ID: 23I070, NESDIS ID: 3005D7F6)
    - Parameters: Stage, discharge, air temperature.
- Dillenbaugh Creek at Riverside Dr (Ecology ID: 23L070, NESDIS ID 30001BFA)
    - Parameters: Stage, discharge, air temperature.
- South Fork Newaukum River @ Middle Fork Rd. (Ecology ID: 23B200, NESDIS ID: 3009B38C)
    - Parameters: Stage, discharge, air temperature.
- South Fork Newaukum River @ North Fork Rd (Ecology ID: 23B190, NESDIS: 300B231A)
    - Parameters: Stage, discharge, air temperature.

2.3. National Weather Service Flood River Gages Near Centralia

The two National Weather Service (NWS) owned stream gages near Centralia, WA, the Chehalis River near Centralia (CENW1) and Skookumchuck River at Centralia (CTAW1), are critical components of the Flood Warning System. In addition to being in the most populous region of the Chehalis River Basin, these gages support NWS river forecasts and are among the most requested locations for flood or high-water alerts. Both gages have been in operation for many decades. Recent performance had degraded via electro-mechanical failures of outmoded monitoring and telemetry equipment. On-going sediment buildup in the stilling wells contributed to delayed and erroneous stage readings.

In 2017, the Flood Authority engaged WEST Consultants to upgrade the equipment at these two locations. Figure 2.1 and Figure 2.2 show the recently installed gages on the Chehalis and Skookumchuck Rivers. The outdated equipment was replaced by electronic stage sensors and the data is now recorded onsite by data loggers. Near real-time data is now transmitted using the National Environmental Satellite Data and Information Service (NESDIS) GOES system. The accuracy and reliability of the gages has improved drastically since the equipment upgrades. It should be noted that the North Pearl Street bridge, where the Skookumchuck River gage is located is scheduled to be replaced soon. It is going out for advertisement in 2024 (D. Noyes, personal communication, December 19, 2018). Prior to the work occurring, the gage will need to be removed temporarily and then reinstalled when construction is finished.

Figure 2.1. Skookumchuck River at Centralia upgraded gage house with bubbler sensor and satellite telemetry.

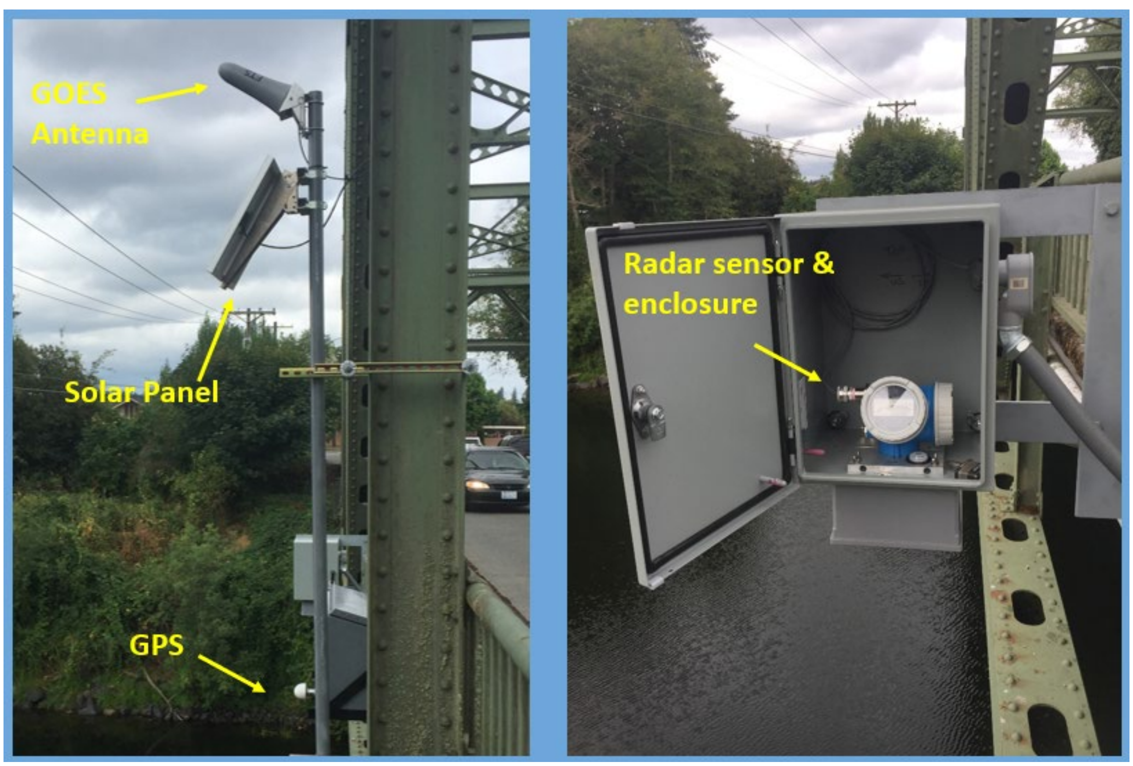

Figure 2.2. Chehalis River at Centralia upgraded gage with radar sensor and satellite telemetry.

2.4. Survey Gages to NAVD 88

In 2018, the Flood Authority, USGS, and Ecology updated the water level datum for stream gages in the basin to NAVD 88 to provide consistent and meaningful water level elevations across the basin. The updated datum was surveyed at each gage using common survey methods including RTK GNSS and differential levels (Figure 2.3).

Figure 2.3. Skookumchuck at Centralia being surveyed to NAVD 88. Photo courtesy of USGS.

2.5. Outreach and Education for Datum Change

Gage datums are deeply embedded in day-to-day usage by local users. In some cases, the same datum has been in use for 50 – 100 years or more. They are engrained in emergency action plans, indicators for recreational users, navigation, pump operations, and many more riverine activities. When the Flood Authority cooperated with the USGS to update gage datums throughout the basin to provide consistency and to correct datum errors, a significant outreach effort was conducted to promote a smooth transition. The outreach activities included:

- Developed and distributed outreach flyers,
- Created social media postings,
- Sent email notifications to stakeholders,
- Sent notifications to federal, state, and local agencies,

- Provided notification at public meetings,
- Described changes at emergency preparedness meetings,
- Sent notices to Chambers of Commerce,
- Contributed to newspaper articles,
- Provided content for radio/TV distribution, and
- Posted information on relevant websites.

The outreach program was successful as no significant issues were observed due to the datum changes through subsequent wet seasons.

2.6. Upgrade GOES DCS

The GOES DCS is the backbone of data transmissions from the field in the Chehalis Basin. The majority of USGS, Ecology, and Flood Authority gages collect data with sensors in the field. The sensor data are recorded at the site in a data logger and then transmitted via satellite at a routine interval (typically once per hour). In June of 2009, NOAA adopted the current set of certification standards for GOES DCP transmitters which included requirements for Version 2.0 transmitters. The deadline to transition satellite transmitters over to GOES Version 2 (CS2) is May 31, 2026.

The Flood Authority and Ecology have completed the switch to CS2 transmitters. USGS has completed the transition at almost 40% of their gages (R.E. Rader, personal communication, January 11, 2023).

2.7. Add City of Aberdeen Stream Gage

The City of Aberdeen monitors water levels at the Wishkah River at Aberdeen. The gage consists of a submersible pressure transducer installed on a pier of the East Heron St. Bridge. The water level sensor is measured and transmitted by the City's SCADA system. Historically, the sensor was reporting values in an unverified datum that required a (-) 0.7 ft offset to convert the data to MLLW. In 2021, the City started pushing the data from the gage to Contrail's FTP site so that the data could be displayed online. A site has been created on the FWS website for this data:

https://chehalis.onerain.com/site/?site_id=24336&site=5bab9276-a4b9-4846-a3b9-571a01dc4ce6

In September of 2022, the City installed two staff gages near the pressure transducer, one in the MLLW datum and one in the NAVD 88 datum. The sensor was adjusted to match the NAVD 88 datum. The MLLW datum staff gage is installed nearby as an example of how two different datums can be used to describe the same water level. A new webcam was also installed to provide a visual confirmation of water level at the site (Figure 2.4).

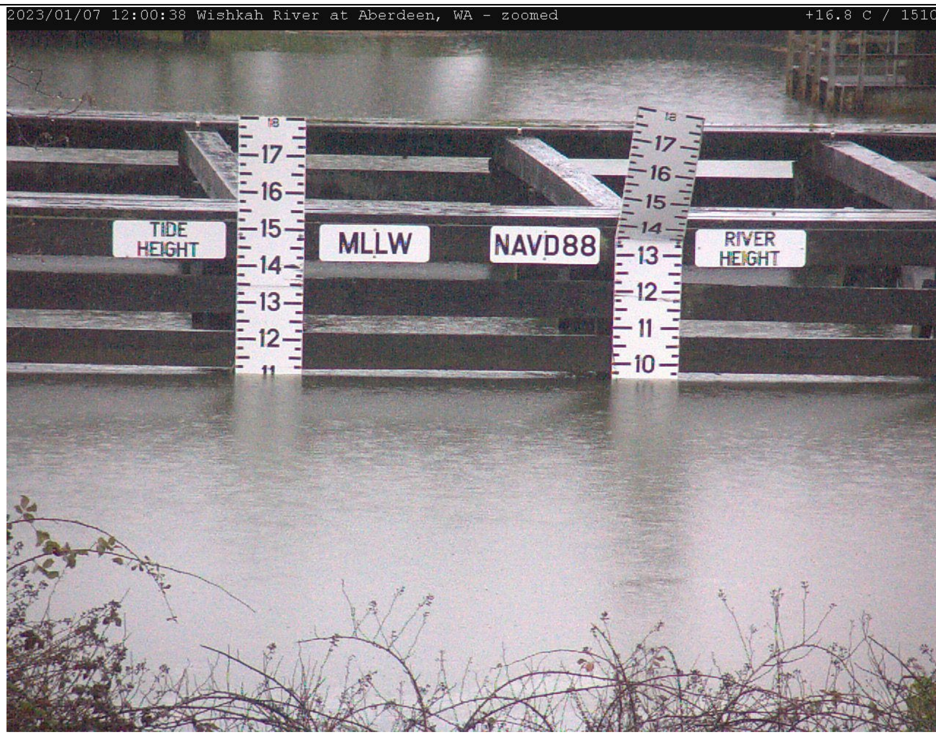

Figure 2.4. MLLW and NAVD 88 staff gages installed at Wishkah River at Aberdeen gage.

2.8. Gage-Adjusted Radar Rainfall

The 2017 Gage Inventory recommended implementing Gage Adjusted Radar Rainfall (GARR) to estimate the full spatial distribution of real-time precipitation. Rainfall during events often exhibits significant spatial variation, however, FWS precipitation observations are limited to single point locations. GARR estimates the spatial distribution of rainfall by using point precipitation measurements to calibrate NEXRAD radar observations and develop a map of rainfall over a larger area.

While GARR would provide some benefit to improving the forecasting capabilities of the FWS, much of this benefit can be obtained by adding more gages to the system. It was determined that additional gages were a most cost-effective route to improving the FWS and the GARR recommendation was not implemented.

2.9. NWRFC River Forecast Alarm Capabilities Added to Contrail

The NWRFC provides river stage forecasts for nine locations in the Chehalis River Basin:

- Chehalis River near Doty
- Newaukum River near Chehalis
- Chehalis River at Centralia
- Skookumchuck River at Centralia
- Skookumchuck River near Bucoda
- Chehalis River near Grand Mound
- Chehalis River at Porter
- Satsop River near Satsop
- Wynoochee River near Montesano

WEST has developed a method to trigger email alarms from forecast stages in the future, giving interested parties potentially days of notice for when flooding is forecasted. These alerts are not currently open to the public but incorporating them into the official FWS alerts is recommended in Section 4.2.4.

3. Flood Warning System Gage Inventory

Flood monitoring in the Chehalis River Basin begins with precipitation, air temperature, and streamflow measurement. The number, placement, and quality of gages used for monitoring is of particular importance to any Flood Warning System. In 2017, the first Gage Inventory and Master Plan (WEST, 2017) was performed to determine the resources available for the Flood Warning System both within and immediately outside the Chehalis Basin (Figure 3.1). Since the 2017 Gage Inventory, numerous improvements and additions have been made to the FWS. This section updates the inventory of hydro-metrological gages within the Chehalis River Basin that was performed in 2017. This inventory is a means to assess the current state of the system and identify unmet flood mitigation needs. Appendix C has been included as a background to describe hydro-metrological measurements and the types of instruments used to make them.

For this inventory, a gage is defined as a unique hydro-metrological measurement taken at a unique location. Hydro-metrological measurements include measurements of stream height (stage), discharge, rainfall, air temperature, relative humidity, pressure, wind, and other weather-related measurements. A database of all gages in the inventory was created along with this report. A description of the database and methods used to create the database can be found in Appendix H. The full database is electronically provided to the Flood Authority in a Microsoft Excel workbook.

The remainder of this section will describe the inventory with the intent of giving an overview of gages currently connected to the Flood Warning System and other hydro-metrological gages in the vicinity of the Chehalis River Basin. It will also provide an indication of the quality of the data in various networks and whether or not any particular gage can be added to the Flood Warning System. The inventory is separated into two parts. The first part includes hydro-metrological gages currently in the Flood Warning System and available through Contrail. The second part includes a census of other known hydro-metrological gages in the vicinity of the basin. Each part will first introduce the gages by their data source, then display the gages by type (Stream, Precipitation, or other Meteorological).

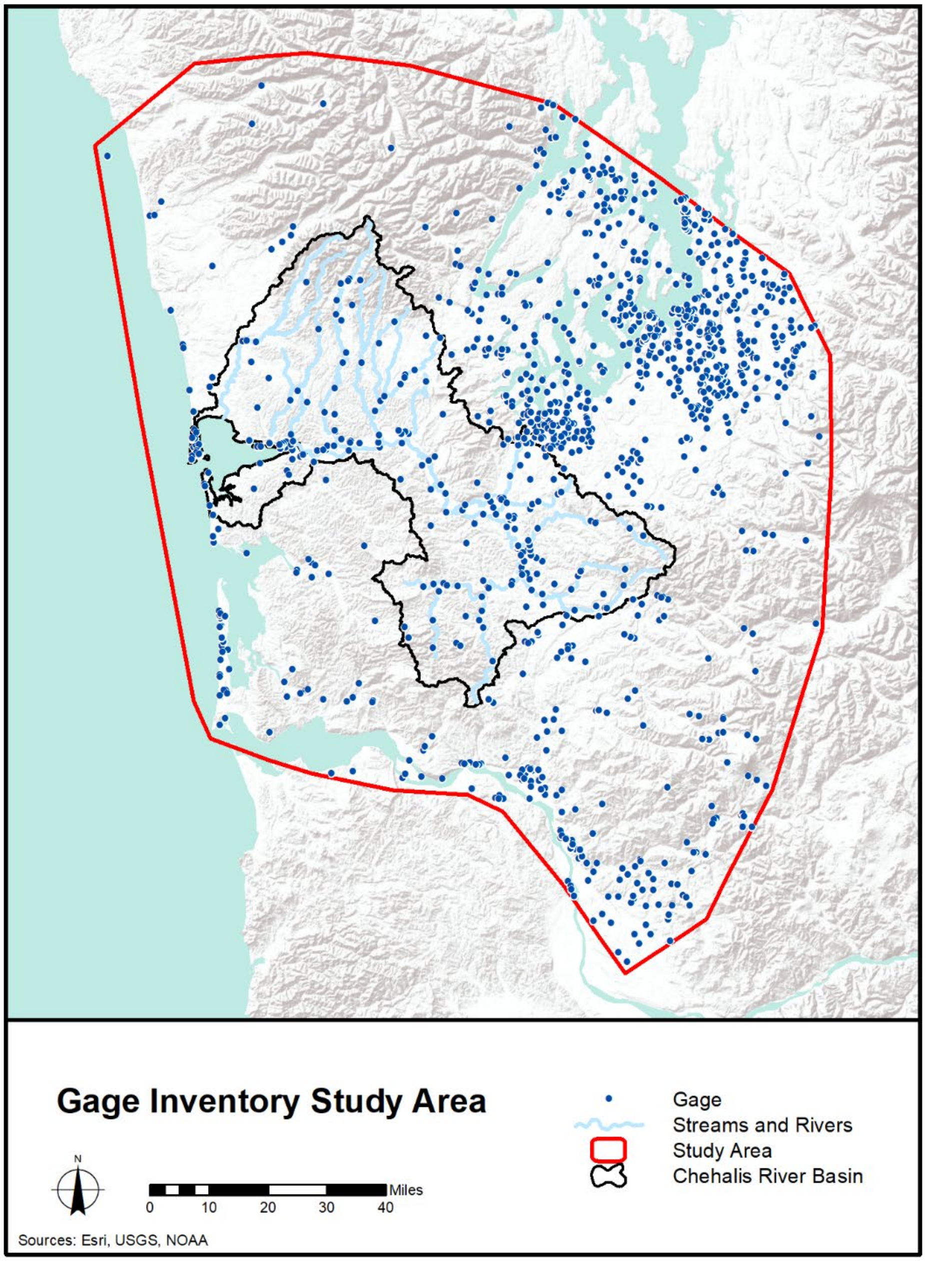

Figure 3.1. Study area for gage inventory.

3.1. Summary of Gage Updates since 2017 Master Plan

In addition to the recommendations that were identified in the previous Master Plan and discussed in Section 2, the following gage additions and enhancements were completed.

3.1.1. Webcam Installations

In 2019 the Flood Authority purchased three webcams and components to install in the basin. The webcams take pictures and transfer those images to Contrail's server every 15 minutes. The webcams provide valuable information via pictures that can be used to assess field conditions and verify electronic sensor readings. The webcam installation at the Wynoochee River at Montesano is shown in Figure 3.2. There is a dedicated webcam dashboard on the Flood Authority website:

https://chehalis.onerain.com/dashboard/?dashboard=4a77124f-3311-4f07-963f-a3f302bf8335

The webcam locations are currently:

- Chehalis River at Centralia
- Wishkah River at Aberdeen
- Wynoochee River at Montesano

Figure 3.2. Webcam installed at the Wynoochee River at Montesano WWTP.

3.1.2. Precipitation Gage Relocations

WEST installed 10 real-time precipitation gages (see e.g., Figure 3.3) for the Flood Authority in 2011 and 2012. These gages, placed in areas previously lacking high quality, real-time data, provide important precipitation and temperature data used to improve river forecasts at NWS forecast points and inform residents of the Chehalis River Basin of developing flood threats. The original gage locations were selected in consultation with the NWS to fill gage network gaps identified during post-event reviews of the 2007 and 2009 floods. Timber growth over the past decade at several gage locations has reached a point where precipitation data was being affected.

In 2021 and 2022, WEST relocated six of the precipitation gages to new locations. The new locations (except for Mason FD13) are on timberland and will need to be relocated again in 10-12 years once tree growth obstructs the equipment. The new locations are:

- Doty Hills
- Mason FD13
- Newaukum River Foothills
- Skookumchuck
- Weathermax
- Willapa Hills

Figure 3.3. New precipitation gage at Willapa Hills.

3.1.3. Thurston County Gages

Thurston County operates a network of gages that provide data useful to the Flood Warning System. In 2019, ten gages were added to the FWS from Thurston County. Four of the gages monitor water level and water temperature, while the remaining six monitor air temperature and precipitation. The gages use cellular telemetry to transmit data from the field to Thurston County where it is then packaged and sent to the Flood Warning System via FTP transfer. The names of the gages and parameters collected at each gage are listed below:

Table 3-1. Thurston County gages

Name	Stage	Precipitation	Water Temperature	Air Temperature
Black River at 110th Ave. SW	X		X	
Bucoda		X		X
Grand Mound		X		X
LIttlerock 128th Ave.		X		X
Praire Creek at Old Highway 99	X		X	
Rainier Fire Station		X		X
Rochester Drop Box		X		X
Salmon Creek at Littlerock Rd.	X		X	
Scatter Creek at James Rd.	X		X	
Tenino		X		X

3.1.4. China Creek Gage

In 2022, a flow control structure (FCS) was completed at China Creek at Chehalis to provide flood relief for businesses and residents of Chehalis. After the structure was completed the Flood Authority installed a gaging station upstream of the FCS to monitor water levels and precipitation. The new gage is available online at:

https://chehalis.onerain.com/dashboard/?dashboard=5d781908-a334-4c8d-99f0-f821e4848520

Currently there is one warning stage identified for the gage at 187.00 ft NAVD 88. This is 1.76 ft below the elevation of the weir crest when water starts spilling over the structure. The gage has a bubbler water level sensor measuring stage every 15 minutes. It also has a tipping bucket rain gage to measure precipitation at the same interval. Once per hour the gage transmits its data via GOES DCS to HADS where it is then available to be ingested into the FWS.

In addition to the gage installed upstream of the FCS, two staff gage only sites (no sensors, data loggers, or telemetry) were installed farther downstream on China Creek at Eubanks Glass (between W Pine St. And W. Main St.) and at Tiki Tap House (downstream of Railroad Ave.). The downstream gages will be used by the City to assess when flooding issues occur and will help correlate those water levels to water levels at the FCS. Based on observations over several high flow events, the warning level at the FCS can be fine-tuned.

Figure 3.4. China Creek flow control structure with important elevations.

Figure 3.5. China Creek staff gage at Tiki Tap House.

Figure 3.6. China Creek staff gage at Eubanks Glass.

3.2. Hydro-Metrological Data Systems and Networks in the Flood Warning System

Several hydro-metrological gages are currently connected through Contrail. Data available in Contrail is part of Contrail data systems. Contrail data systems are defined as sources of data, including online databases, which have been programmatically connected to Contrail through the internet. Typically, gages on the ground can automatically report data via land-based radio telemetry, hard wired telemetry, satellite radio, direct internet connection, or cellular telemetry. The data are then entered into databases, which can then be accessed by Contrail data systems in near real-time. The current data systems in Contrail are USGS, HADS, Tides, METAR, City of Aberdeen, Forecast Data, Thurston County, and TransAlta. Systems report monitoring data, through their respective databases systems, to Contrail. A background of each data system is provided below, followed by a list of gages within Contrail.

3.2.1. Hydro-Meteorological Automated Data System

The Hydro-meteorological Automated Data System (HADS) is a real-time data acquisition and data distribution system operated by the NWS Office of Dissemination (NOAA, 2023a). HADS receives data from various systems such as the GOES DCS (for more information regarding GOES, see Appendix D). Several agencies provide HADS with raw data feeds through GOES telemetry. The NWS provides gage owners a downlink to access their data via HADS and Contrail can be set up to access this HADS data.

Some of the public agencies that share data with HADS in the vicinity of the Chehalis River Basin include the USGS, the NWS, the Flood Authority, and the WA Department of Ecology.

3.2.1.1 Flood Authority

The Flood Authority owns 17 stations in all. Fourteen of the gages owned by the Flood Authority collect precipitation, air temperature, and/or stream water level data and transmit via the GOES DCS. Battery voltage at each site is also reported to support gage maintenance. The three remaining stations are webcams that collect pictures and transmit via cellular modem. Lewis County also publishes real time flood stages for its monitored rivers through its Emergency Management Department. See table below for list of gages owned and operated by the Flood Authority:

Table 3-2. Flood Authority-owned gages

Gage Name	Telemetry	Parameters
Beeville Rain Gage	GOES DCS	Precip, Air Temp
Cedar Creek Rain Gage	GOES DCS	Precip, Air Temp
Chehalis River at Centralia	GOES DCS	Stage
Chehalis River at Centralia Webcam	Cellular	Images
Chehalis River below Thrash Creek	GOES DCS	Stage
China Creek at Centralia	GOES DCS	Stage, Precip
Doty Hills Rain Gage	GOES DCS	Precip, Air Temp
Mason FD13	GOES DCS	Precip, Air Temp
Newaukum River Foothills	GOES DCS	Precip, Air Temp
Riverside Rain Gage	GOES DCS	Precip, Air Temp
Skookumchuck Rain Gage	GOES DCS	Precip, Air Temp
Skookumchuck River at Centralia	GOES DCS	Stage
Weathermax Ridge Rain Gage	GOES DCS	Precip, Air Temp
West Fork Satsop River	GOES DCS	Stage
Willapa Hills	GOES DCS	Precip, Air Temp
Wishkah River at Aberdeen Webcam	Cellular	Images
Wynoochee River at Montesano WWTP	Cellular	Images

Many of the gages were installed more than 10 years ago and the equipment (sensors, data loggers, satellite transmitters, and antennas) at the gages is naturally aging. Repairs to equipment have been taken care of as needed over the years, but there has been an uptick in the number and cost of repairs in the last few years. Some equipment and components are reaching the end of their expected lifespans (10-15 years).

3.2.1.2 Washington State Department of Ecology

The Washington State Department of Ecology (Ecology) is Washington's environmental protection agency. The department is also the state coordinating agency providing technical assistance to local governments in implementing the National Flood Insurance Program, which is part of the Federal Emergency Management Agency (FEMA). Ecology's Environmental Monitoring Program maintains a gaging network that produces near real-time stream data throughout Washington (Ecology, 2023). Seven of these gages are connected to the FWS through HADS. There are six ecology gaging sites within the Chehalis basin that could be added to the FWS through HADS, though one site would need to be upgraded with telemetry equipment.

Table 3-3. Washington State Department of Ecology stream gage sites in the Chehalis Basin

Station Name	Station ID	In FWS?	Status	Parameters
Wishkah River near Nisson	22D110	Yes	Active/Telemetered	Discharge, stage, air temp
Chehalis River at Centralia	23A120	Yes	Active/Telemetered	Water temp, Dissolved oxygen, pH, conductivity
Newaukum River near Chehalis	23B070	Yes	Active/Telemetered	Rainfall, Water temp, Turbidity, Dissolved oxygen, pH, conductivity
Black River at Highway 12	23E060	Yes	Active/Telemetered	Discharge, stage, water temp, air temp, dissolved oxygen, pH, conductivity
Salzer Creek at Airport Road	23H060	Yes	Active/Telemetered	Discharge, stage, water temp, air temp
Stearns Creek at Twin Oaks Road	23J070	Yes	Acitve/Telemetered	Discharge, stage, water temp, air temp
South Fork Chehalis River at the Highway 6 bridge	23K060	Yes	Active/Telemetered	Discharge, stage, water temp, air temp, dissolved oxygen, pH, conductivity
Chehalis River above Pe Ell	23A190	No	Active/Telemetered	Water temp, Air temp, Dissolved Oxygen, pH, conductivity
South Fork Newaukum River at Jorgensen Road	23B120	No	Active/Telemetered	Water temp, Turbidity
South Fork Newaukum River at North Fork Road (Scheer property)	23B190	No	Active/Telemetered	Discharge, stage, water temp, air temp, turbidity
South Fork Newaukum River at Middle Fork Road bridge	23B200	No	Active/Telemetered	Discharge, stage, water temp, air temp, turbidity
North Fork Newaukum River at Forest Road	23C070	No	Active/Non-telemetered	Discharge, stage
Bunker Creek at the Ceres Hill Road bridge	23I070	No	Active/Telemetered	Discharge, stage, water temp, air temp

3.2.1.3 USGS NWIS

The USGS National Water Information System (NWIS) is an application that supports the acquisition, processing, and long-term storage of water data. It is a system included in Contrail, so all gages in the USGS NWIS can be added to the Flood Warning System.

Nationally, USGS surface-water data includes more than 850,000 station years of time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall.

The data are collected by automatic recorders and manual field measurements at installations across the nation. (USGS, 2023)

Data are collected by field personnel or relayed through telephones or satellites to offices where they are stored and processed. The data relayed through GOES (Appendix D) are processed automatically in near real time.

There are currently 38 USGS stream gages connected through Contrail. Of these, 34 have rating curves which allow for the calculation of discharge from gage height. The majority of the other affiliated water level gages do not calculate flow. Rating curves are relevant to the Flood Warning System because NWS forecasts are converted from discharge to stage using rating curves. An accurate rating curve results in better estimation of stage at a forecast point.

The USGS cooperates with other entities for funding. Table 3-2 lists the primary contributors for funding of USGS gages near Chehalis River Basin.

Table 3-4. List of USGS partners in the Chehalis Basin

USGS Partners in the Chehalis River Basin
Chehalis River Basin Flood Authority
Skookumchuck Dam, LLC
Thurston County
Tacoma Public Utilities
Grays Harbor County
Mason County
City of Tacoma
Squaxin Island Tribe
Pierce County
US Army Corps of Engineers
National Weather Service
The Chehalis Tribe
TransAlta
Washington Department of Ecology
Lewis County

To maintain the utility of the FWS, continued funding of the USGS stream gages within the Chehalis River Basin is important. Table 3-3 shows a summary of funding sources for the 16 USGS stream gages within the Chehalis River Basin. Gage funding comes from four distinct levels, including Federal funding provided by the U.S government, Washington state funding, funding from local sources including towns and private entities, and funding provided by Tribal groups. Federal sources contribute the majority of gage funding in the basin, with State and Local sources providing roughly equal amounts, and Tribal sources contributing the remaining portion.

An exact breakdown of the funding at each stream gage was not provided by the USGS, however may be accessible through a Freedom of Information Act (FOIA) request.

Table 3-5. USGS stream gage funding sources

Partner Type	FY23 Funding ($)
Federal	139,325
State	86,010
Local	76,908
Tribal	5,303
	307,546

3.2.2. NOAA Tides

The National Oceanic and Atmospheric Administration (NOAA) provides a vast collection of oceanographic and meteorological data via tidesandcurrents.noaa.gov (NOAA, 2023b). The Tides agent in Contrail gathers tide elevations, predictions, air and water temperatures, air pressure, and wind speed, direction, and gust at two locations near the basin and makes the data available on the Flood Authority website.

3.2.3. METAR

The Meteorological Aerodrome Report (METAR) system is generated from gages used in the Aviation Routine Weather Report. The gage networks used to generate this report are the Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS). They are highly accurate sensors located at airports. The data is provided as a partnership between the NWS and the Federal Aviation Administration (FAA). There are four of these sites currently in Contrail, each with several variables, including Precipitation and Other Metrological data.

3.2.4. City of Aberdeen

The City of Aberdeen provides data from a water level sensor they operate via their SCADA system. The measurements are collected on a City computer and then transferred to Contrail via an FTP server where Contrail's Universal Agent is used to process the data every 30 minutes.

3.2.5. Forecast Data

The National Weather Service (NWS) provides river flood stage forecasts at several locations within the Chehalis Basin. The forecast predictions are the number of hours until flood stage is reached. Nine of these river stage forecasts are connected to Contrail via a Python script that checks the forecasts every five minutes.

3.2.6. Thurston County

Thurston County provides data for 10 of their gages via FTP transfer with Contrail. The gages communicate with Thurston County via cellular modem and then the data is packaged up by the County and sent to Contrail's FTP site. Contrail's Universal Agent is used to process the data and update the sites. The gages are a mix of precipitation and water level monitoring sites (Thurston County, 2023).

3.2.7. TransAlta

TransAlta is a power company operating the Centralia Coal power plant in the Chehalis River Basin. It operates the Skookumchuck Dam in Thurston County, WA to store water for power generation. The stage at the outlet from the dam is monitored with pressure transducers. There are two pressure transducers; one is located at the spillway and the other is located just outside the spillway. The pressure transducer at the spillway is referred to as the narrow band sensor and gives more precise measurements of water level in the spillway. The pressure transducer located just outside the spillway is referred to as the wide band sensor and is accurate for higher ranges of water levels. The data from the sensors are measured with TransAlta's SCADA system and then transferred via FTP to Contrail.

The Centralia Coal Plant plans to cease operations at the end 2025.TransAlta states that the dam will remain in place and the water level sensors will continue to be maintained and operational.

3.3. Current FWS Hydro-Metrological Gage Inventory by Type

This section describes the current types of gages included within the FWS. Three categories of monitoring gages are defined in this section:

1. Stream Measurement Sites,
2. Precipitation Measurement Sites, and
3. Other metrological measurement sites.

3.3.2. Stream Measurements

The Flood Warning System is currently connected to 61 stream measurement sites within the basin (Figure 3.7). A gage at each site measures stage height, which it reports through telemetry. Additionally, 34 of the sites have rating curves, which allow for estimated discharges to be reported. Most of the gages report through USGS, with several exceptions. The exceptions include ten gages reporting through HADS and four gages owned by Thurston County. Other exceptions are a site on the Wishkah River operated by the City of Aberdeen as well as a gage at the outlet of the Skookumchuck Reservoir owned by TransAlta.

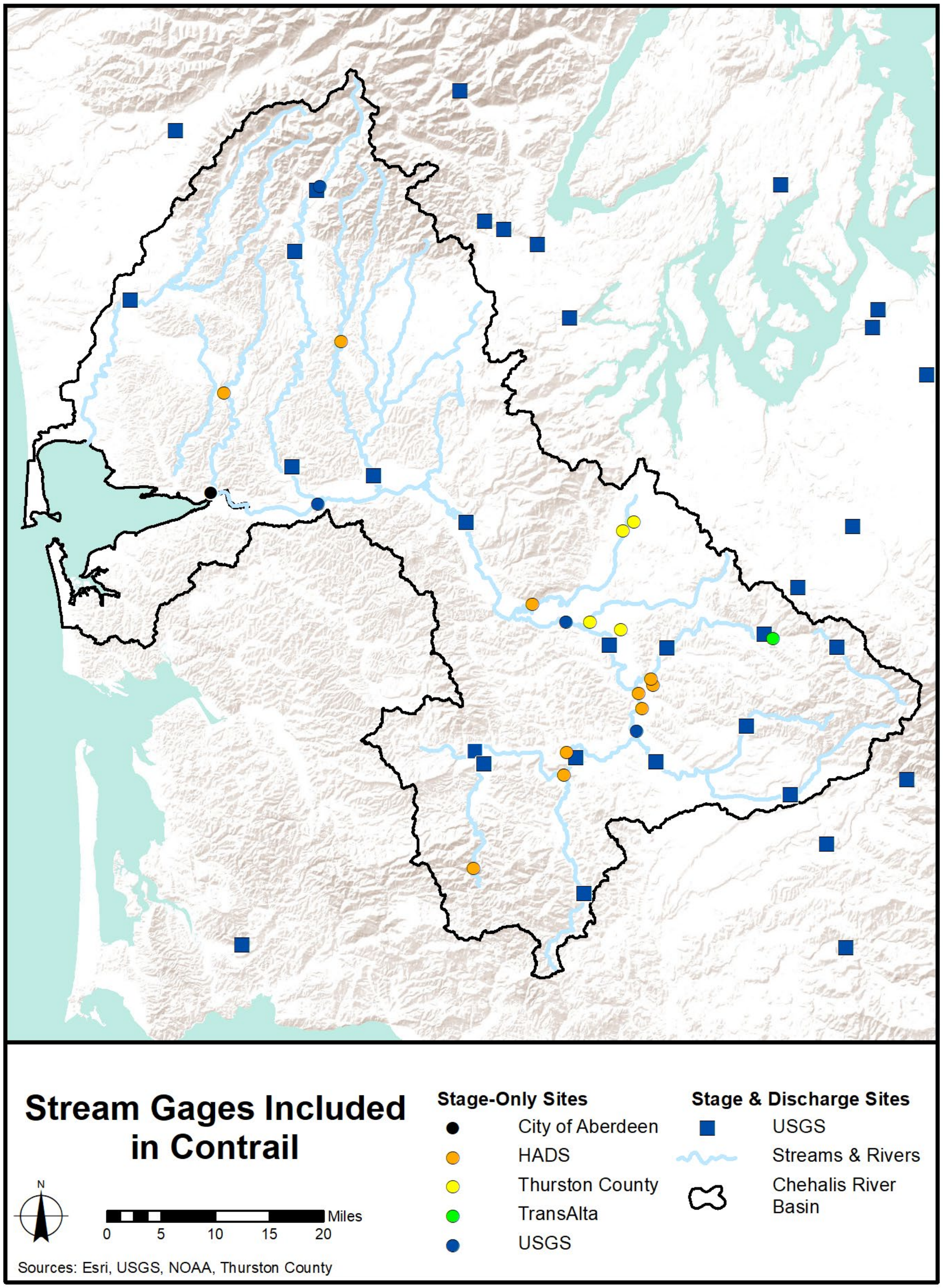

Figure 3.7. Stream measurement sites included in Contrail.

3.3.3. Precipitation Measurements

The flood alert system is currently connected to 42 precipitation measurement sites that automatically report data from tipping bucket gages in and around the basin (Figure 3.8). There are 27 sites that report precipitation data through HADS. Measurements taken at five local airports report through METAR. Four USGS measurement sites report precipitation. Finally, Thurston County operates six precipitation gage sites which are connected to Contrail.

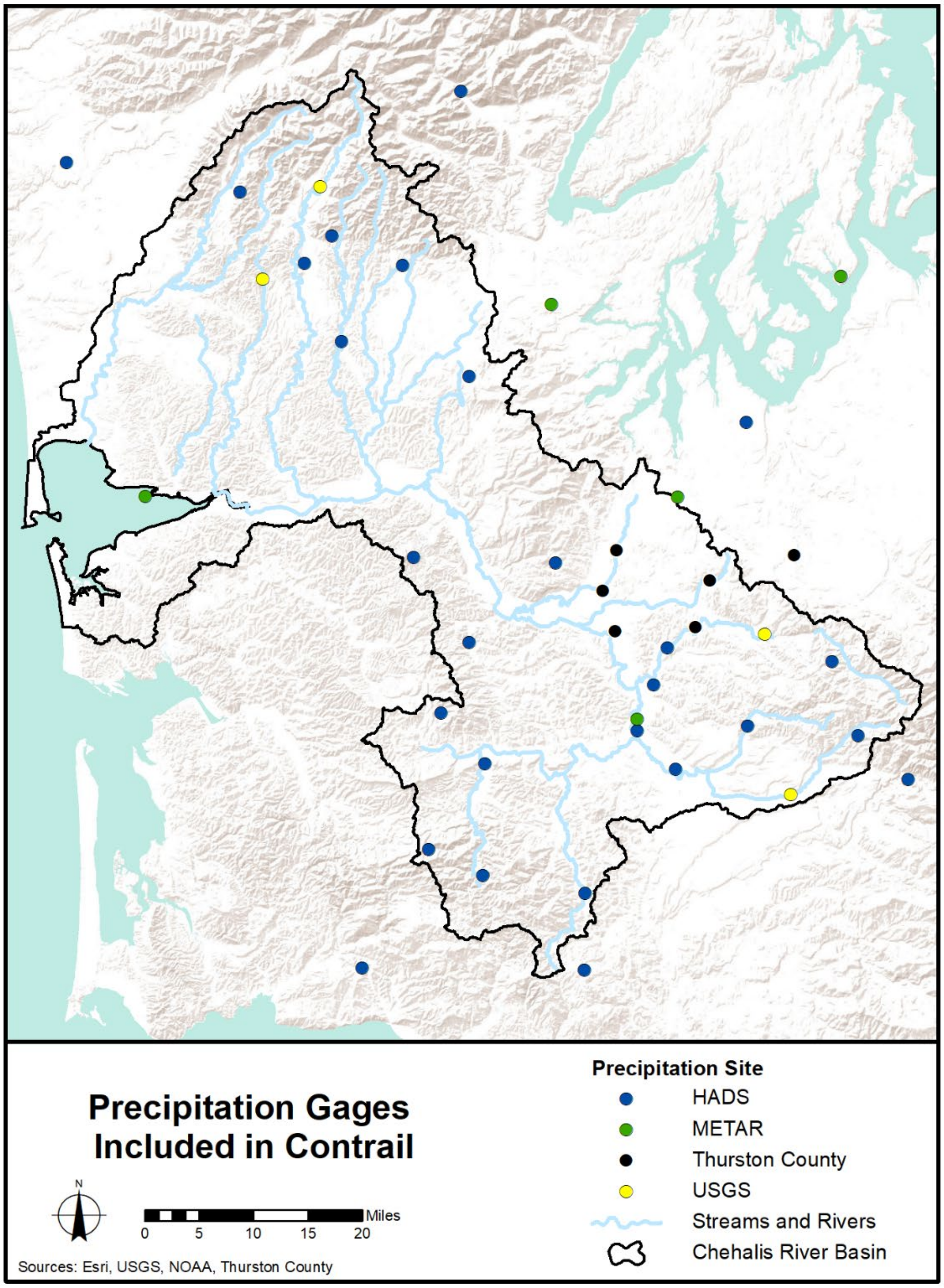

Figure 3.8. Precipitation gages included in Contrail.

3.3.4. Other Meteorological Measurements

Each of the Lewis County gages, three METAR gages, and two NOAA Tides gages provide other meteorological parameters (Figure 3.9). These measurements include wind speed and direction, temperature, humidity, dew point, wave height, and solar radiation.

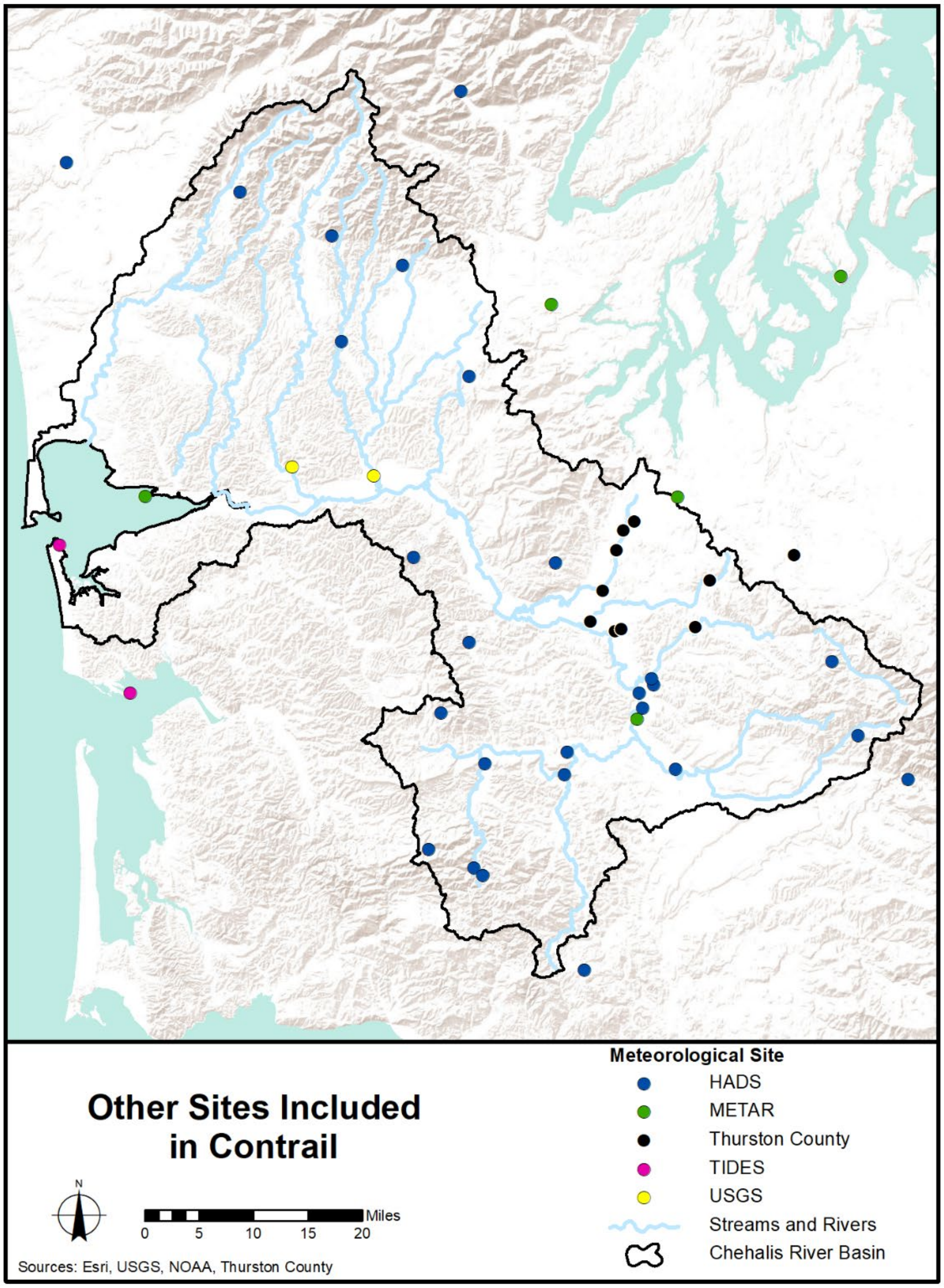

Figure 3.9. Other hydro-meteorological gages included in Contrail.

3.4. Rating Curves

Rating curves are commonly used at surface water gages to compute flow at the same interval that stage is being measured. The most common type of rating curve is the stage-discharge curve which is a relationship between the stage and the flow at a given location. The relationship must be developed over the range of water levels and flows experienced at a site. The conventional way to relate stage to discharge is by making discrete discharge measurements at various levels of stage. See Figure 3.10.

Discharge measurements are made by field personnel with wading, boat, or bridge equipment such as Acoustic Doppler Current Profilers (ADCPs), Acoustic Doppler Velocimeters (ADVs), and current meters. This method, while very accurate at sites with proper characteristics, can be time-consuming, expensive, and can put field personnel in situations where their safety is at risk. High flows are rare, and it may take many years to develop the upper portion of the curves. In addition, the shape of a river channel can change which may alter the relationship between the stage and the volume of water flowing (i.e., discharge) in the river at that stage.

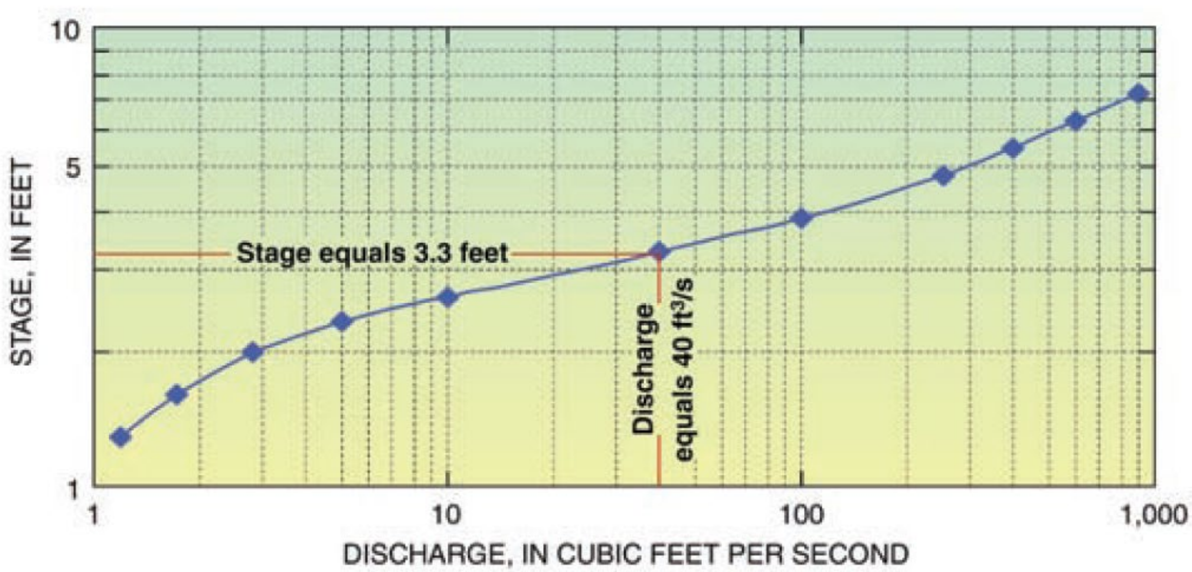

Figure 3.10. Example stage-discharge relationship.
(https://www.usgs.gov/media/images/usgs-stage-discharge-relation-example)

The relationship between stream stage and stream flow is critical for flood forecasting. Forecast models compute stream flow which must be converted to stage or elevations for the public to make meaningful flood responses. The conversion is also necessary to support inundation mapping, a powerful tool for visualizing potential community impacts of flooding.

Various options exist for developing ratings and calculating flow (in order of increasing accuracy and cost):

1. Synthetic Ratings – developed from surveying cross sections, hydraulic modeling, and calibration discharge measurements.

2. Surface Velocity Sensor Derived – requires installation of a surface velocity sensor, surveying a cross section at the gage, and making a few calibration measurements. This method would likely produce better results at medium and high flows than it would at very low flows.
3. Conventional stage-discharge relationship development – 8-10 discharge measurements per year are made and shift curves (temporary ratings) are applied as necessary.
4. Index-Velocity Method – requires installation of velocity sensor (usually under water), surveying a cross section, and making ongoing discharge measurements. It also requires a significant amount of office work to process and QA/QC the data.

In addition to development of the ratings, the maintenance of those ratings must also be considered. Most changes in rating curves are often found at the low end of the curve (low flows) but change is also possible at medium and high flows. Tracking changes to the rating curves requires discrete measurements of discharge made frequently enough to detect the changes, or in the case of synthetic curves and velocity measurements, surveying cross sections. However, if high flows are most important, and a larger range of uncertainty is acceptable, it may not be necessary to make regular discharge measurements or survey cross sections frequently if the method being used is producing acceptable results.

Most of the river gages operated by USGS and Ecology in the basin have established rating curves. The exceptions are:

- CHEHALIS RIVER AT WWTP AT CHEHALIS, WA (12025100)
- CHEHALIS RIVER NEAR ROCHESTER, WA (12028060)
- CHEHALIS RIVER NEAR MONTESANO, WA (12035100)

The Flood Authority operates the following gages without rating curves:

- CHEHALIS RIVER BELOW THRASH CREEK NEAR PE ELL, WA (D15080AC)
- CHINA CREEK ABOVE FCS AT CENTRALIA, WA (D1503DF0)
- WEST FORK SATSOP RIVER AT COUGAR SMITH ROAD NEAR SATSOP, WA (D1502054)

The six gages listed above were discussed with the NWS to determine what value a rating curve might add at the locations. According to the NWS, the gages on the Chehalis River would take priority over the other sites such as the West Fork Satsop River and China Creek. Specifically, the gages at Pe Ell and Montesano were listed as the two most important to calculate flow at.

The Flood Authority operates the Chehalis River at Centralia (CENW1) and the Skookumchuck River at Centralia (CTAW1) gages, both of which are critical gages due to their proximity to the population center of Centralia and because they serve as Northwest River Forecast Center forecast points (NWRFC, 2023). The ratings in use at the gages are synthetically developed without supporting discharge measurements. In 2017, the synthetic rating curves in use at each of the gages were compared to the most recently calibrated hydraulic model (2016). Differences of up to 2.0 and 1.5 feet were found at CENW1 and CTAW1 respectively. The results of the rating investigation were provided to NWS. The NWS rating curves are still in use and have not been updated to the 2016 model. NWS comments that improvements in ratings, especially those with flow measurements, would be welcome and would improve the accuracy of river modeling (B. Bower, personal communication, January 19, 2023). A recommendation is included in this document to check the accuracy of the ratings with flow measurements.

3.5. Measurements currently not included in the FWS

Additional hydro-metrological measurements are taken in and around the Chehalis River Basin by a variety of entities. The gages are divided into the following groups: Professional Near-Real Time with Systems Available in Contrail, Professional Near-Real Time System Not Currently Available in Contrail, Professional Not-Real-Time, and Citizen Scientist gages (Figure 3.11). A total of 3,029 gage sensors located within and near the Chehalis River Basin are included in the gage census.

3.5.1. Professional Near-Real-Time with Systems Available to Contrail

Real-time professional gages that are currently in Contrail include those in the HADS, USGS, METAR, and NOAA Tides systems. The HADS system contains those in a variety of networks including some gages in Ecology, although not all gages in the Ecology are included in HADS. Several gages that are part of the HADS system in the vicinity of the Chehalis Basin are not currently included in the Contrail (Figure 3.12). There are 72 HADS stations within 10 miles of the Chehalis Basin, and 37 gages that are part of the HADS system in the vicinity of the Chehalis Basin are not currently included in the Contrail (Figure 3.12). Because these gages are part of HADS, which is a system currently in Contrail, they can be easily added to Contrail. For gages reporting to other data systems listed below, additional coordination may be required.

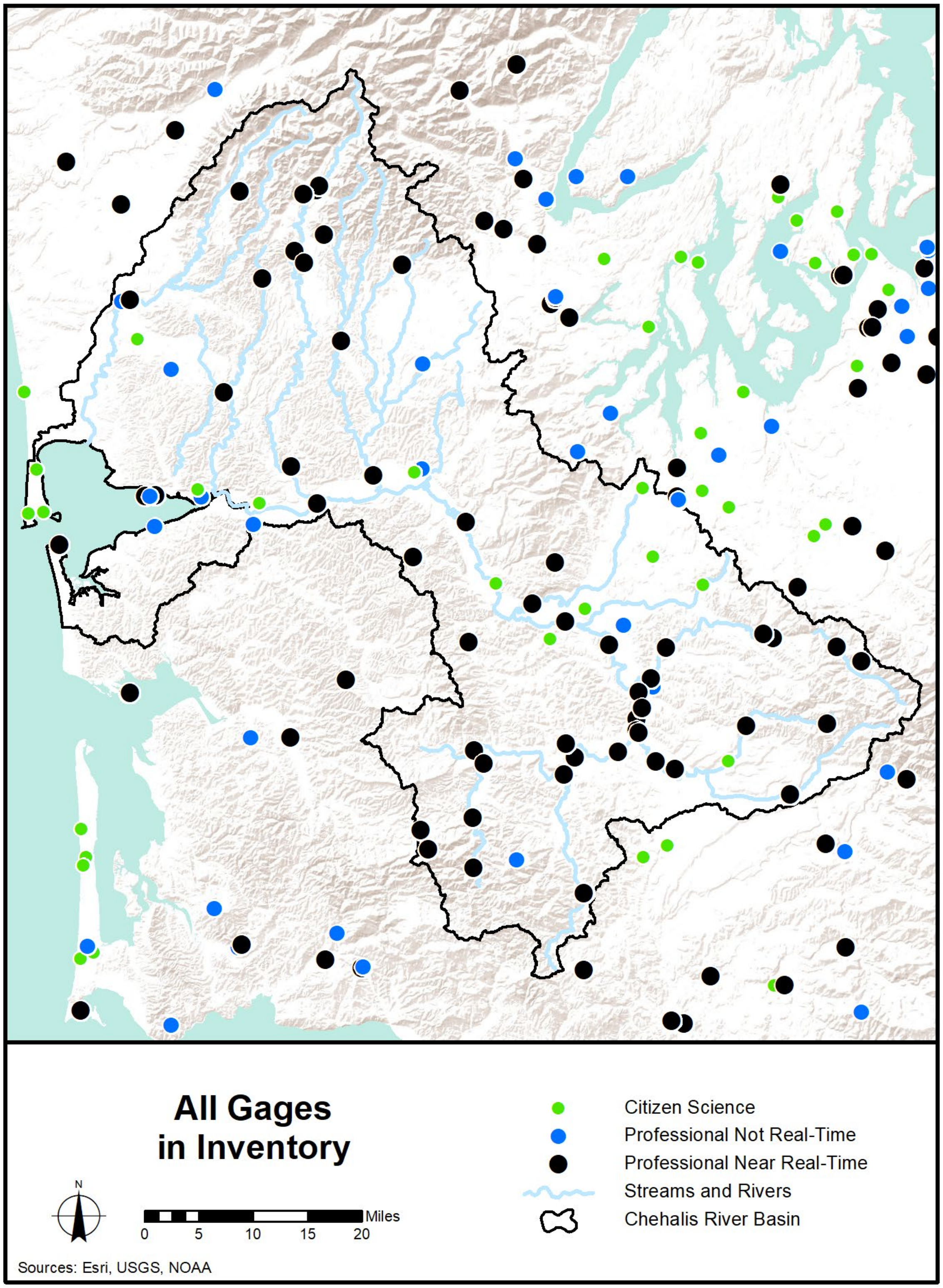

Figure 3.11. All gages in inventory by system type.

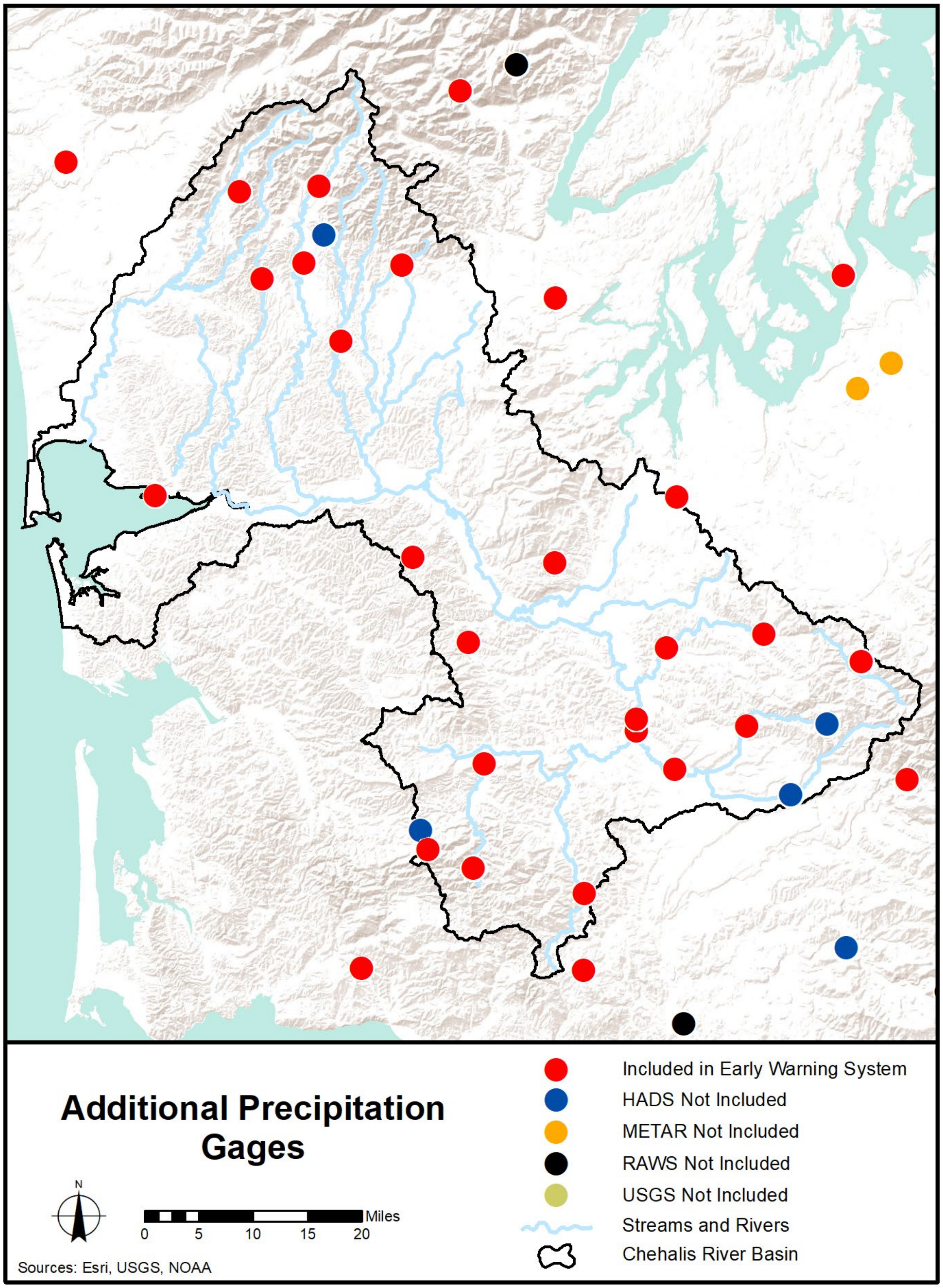

Figure 3.12. Precipitation gages included and not included in the FWS, by system.

3.5.1.1 Interagency Remote Automatic Weather Stations (RAWS)

RAWS is connected to the HADS data system and can be added to Contrail. It is of particular interest due to the number of precipitation gages it has in the vicinity of the basin. The gages in this network are mostly owned by wildland fire agencies. They utilize the GOES satellite network. The data is collected in real-time and is professionally maintained. Currently there are seven RAWS sites within a 10-mile buffer region around the Chehalis Basin. Six of these sites are already connected to the Chehalis Basin Contrail website. The seventh site, Elk Rock near Toutle, is approximately six miles southwest of the basin and could be added to provide further information to the FWS.

3.5.2. Professional Not-Real-Time

Networks that have professionally maintained gages, which do not transmit data in real-time, are listed in Table 34. The Cooperative Observer Network (COOP), Climate Reference Network (CRN), Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) are operated by a mix of regular citizens and professionals but are considered professional because there is quality control performed on the data. COOP and CRN are a mix of manual and automatic-recording gages. CoCoRaHS gages are all manually read gages.

Table 3-6. List of Professional Not-Real-Time networks.

Professional Not-Real-Time Networks	Number of Sensors
Cooperative Observer Network	68
Climate Reference Network	9
Community Collaborative Rain, Hail and Snow Network	61

3.5.3. Citizen Scientist Gages

Gages that are considered Citizen Scientist gages include those from the Automatic Position Reporting System WX NET/Citizen Weather Observer Program (APRSWXNET/CWOP, NWS 2023a). The gages are maintained by individual community members and vary in quality. APRSWXNET/CWOP has better quality control measures in place. Weather Underground also maintains a network of personal weather stations, however at some point since 2017 they have removed public access to the database of stations, which are now only visible on the Weather Underground website.

3.6. Summary

A summary of the inventory is provided below. It includes a summary of the 272 sensors currently in Contrail (Table 3-5) and of all 3,029 active sensors in the vicinity of the Chehalis River Basin (Table 3-6). The summary of gages currently in Contrail is categorized by its respective data system. The summary of all active gages in the vicinity of the Chehalis River Basin is categorized by its respective gage category described above. A database along with this report is provided electronically as an Excel Workbook. There are an additional 1,831 inactive sensors included in the database. A description of the database in described in Appendix H.

Table 3-7. Summary of gages in Contrail.

			HADS								
Gage Type		**City of Aberdeen**	**Flood Authority**	**WSDOE**	**USGS**	**METAR**	**NWS Flood Forecast**	**Thurston County**	**Trans Alta**	**TIDES**	**Total in FWS**
Precipitation	Accumulation	0	27	0	0	6	0	6	0	0	**38**
	Increment	0	28	0	0	0	0	0	0	0	**32**
Stream	Discharge	0	0	0		0		0	0	0	**34**
	Stage	1	6	4	9	4	9	4	2	0	**63**
Temperature	Water Temp.	0	0	0	0	4	0	4	0	2	**6**
	Air Temp.	0	20	2	0	6	0	6	0	2	**35**
Battery	Voltage	0	14	0	0	0	0	0	0	0	**14**
Meteorological	Dew Point	0	0	0	0	0	0	0	0	0	**1**
	Pressure	0	0	0	0	0	0	0	0	2	**4**
	Humidity	0	6	0	0	0	0	0	0	0	**6**
	Solar Radiation	0	5	0	0	0	0	0	0	0	**5**
Tidal/Ocean	Tide Prediction	0	0	0	0	0	0	0	0	2	**2**
	Tide Elevation	0	0	0	0	0	0	0	0	2	**2**
	Tide Residual	0	0	0	0	0	0	0	0	2	**2**
	Ocean Temp.	0	0	0	0	0	0	0	0	0	**0**
Wind	Direction	0	6	0	0	0	0	0	0	2	**13**
	Speed/Velocity	0	6	0	0	0	0	0	0	2	**13**
	Gust	0	0	0	0	0	0	0	0	2	**2**
Total Sensors		**1**	**118**	**6**	**75**	**9**	**9**	**20**	**2**	**18**	**272**
Total Gaging Sites		**1**	**31**	**4**	**39**	**9**	**9**	**10**	**1**	**2**	**102**

Table 3-8. Summary of gages in census.

Gage Type		Professional Near-Real-Time	Professional Not-Real-Time	Professional Total	Citizen Scientist	Total
Precipitation	Unspecified	39	61	100	0	**100**
	Accumulation	216	13	229	307	**536**
	Increment	22	0	22	0	**22**
Stream	Discharge	117	0	117	0	**117**
	Stage	134	0	134	0	**134**
Temperature	Water Temperature	63	0	63	6	**69**
	Air Temperature	233	28	261	124	**385**
Battery	Voltage	63	0	63	0	**63**
Meteorological	Dew Point	11	0	11	0	**11**
	Pressure	45	0	45	4	**49**
	Relative Humidity	83	0	83	122	**205**
	Solar Radiation	29	0	29	84	**113**
Tidal/Ocean	Tide Prediction	2	0	2	0	**2**
	Tide Elevation	2	0	2	0	**2**
	Tide Residual	2	0	2	0	**2**
	Ocean Temperature	0	0	0	0	**0**
Wind	Direction	94	0	94	124	**218**
	Speed/Velocity	91	1	92	124	**216**
	Gust	76	1	77	123	**200**
Other/Unspecified		370	57	427	158	**585**
Total		**1692**	**161**	**1853**	**1176**	**3029**

3.7. Non-Gage Data Available

Additional non-gage data exist in the Basin. These data include, but is not limited to, radar and SuomiNet GPS Water Vapor Sites. A brief description is provided for both.

3.7.1. Radar

Weather radars provide high temporal and spatial resolution rainfall information over large areas, which cannot always be obtained using gage only data. The Next-Generation Radar (NEXRAD) system is a network of 160 high-resolution S-band Doppler Weather Surveillance Radars (WSR-88D) operated by the NWS. The typical range of most radar products is 140 miles (230 km) from the radar site. However, mountains can block the lower elevation scans of the radar beam.

Figure 3.13 shows the NEXRAD system coverage of the Chehalis watershed. The map shown in this figure combines information for all NEXRAD radars and was developed by NOAA's Radar Operations Center. Coverage areas are classified based on radar beam coverage at specified altitudes from the ground. Figure 3.13 includes layers at 4,000 feet (best coverage), 6,000 feet (better coverage), and 10,000 feet (fair coverage). Depending on the type of cloud formation, radar beams that present fair or worse than fair coverage might overshoot rainfall.

As shown in Figure 3.13 the NEXRAD Langley Hill radar (KLGX) is in the northwest boundary of the watershed. Due to its proximity to the basin, this radar provides optimal radar coverage for the area of interest and has the potential to provide high quality rainfall estimates for the entire watershed. However, even when radar coverage is ideal, radar estimates are usually biased and should be corrected using gage data. The magnitude of bias in radar rainfall estimates depends on the physical characteristics of the region, the type of storm, the distance to the radar, and the maintenance and operation of the radar. A large literature review is available that describes methods to bias correct radar precipitation estimates using rain gage data (e.g., Krajewski and Smith, 2002 and Cunha et al., 2013).

Radar data can be brought into Contrail in near real-time. NWS NEXRAD data is collected, stored, and pre-processed by the NWS River Forecast Centers. Data from multiple radars are mosaicked to generate high-resolution products that cover large areas. However, the products provided by the NWS (available in real time) is not bias corrected. Several private companies have developed advanced computer routines that combine NWS weather radar mosaics with ground observations to produce highly accurate rainfall estimates with high temporal and spatial resolution in near real time (15-20 min delay). This process may prove more useful and cost effective than simply adding gages to the Flood Warming System since a very high-density rain gage network would be required to produce rainfall maps with similar resolution to weather radar rainfall products.

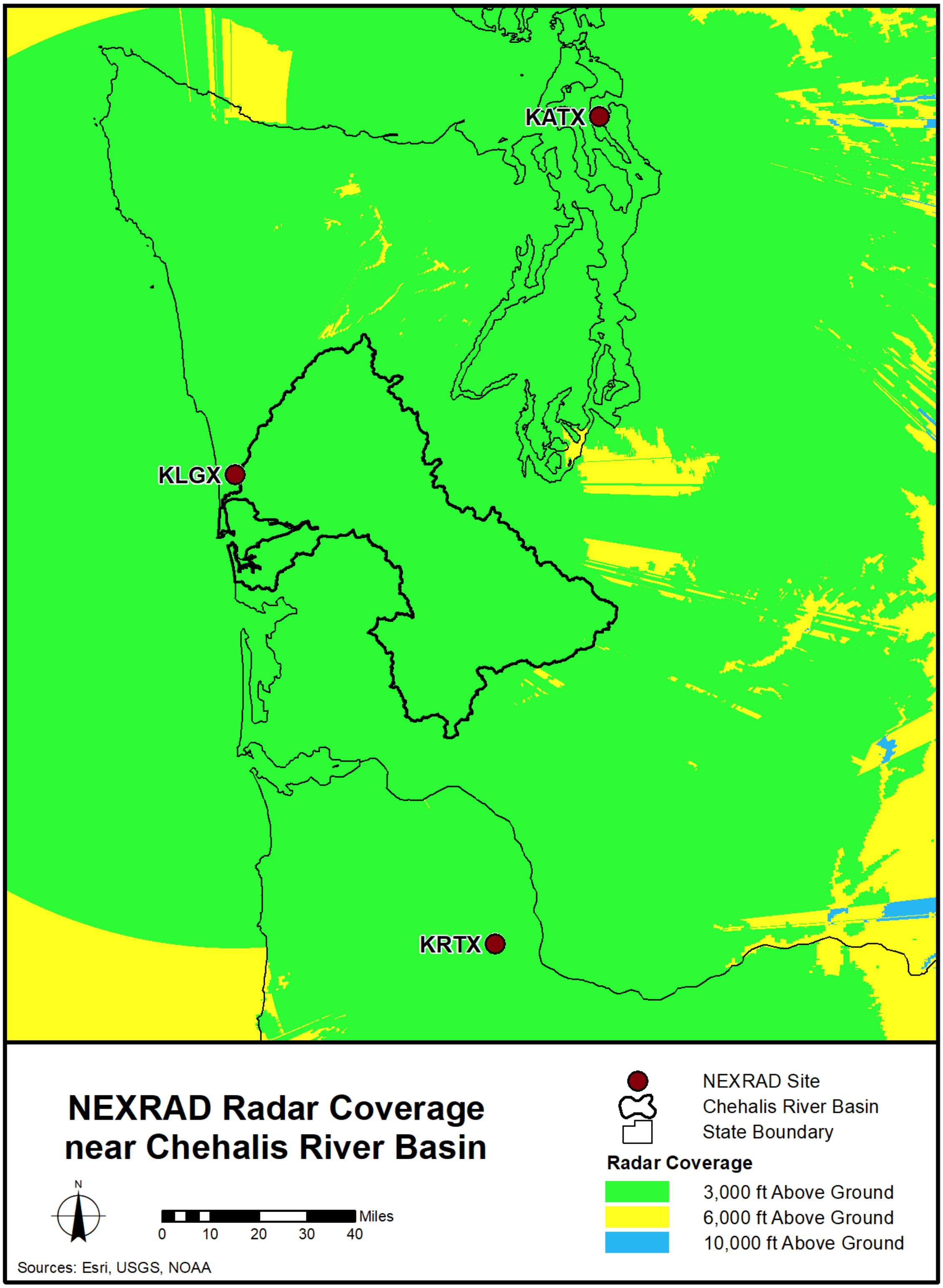

Figure 3.13. NEXRAD Radar Coverage in Chehalis Basin.

3.7.2. SuomiNet GPS Water Vapor Sites

SuomiNet is a real-time Global Positioning System (GPS) receiver-based system developed for atmospheric research. The network measures delays in GPS signals due to atmospheric water vapor which in turn is used to estimate water vapor in the atmosphere. It can be used to help bias correct radar data. These sensors are useful because current satellite-based water vapor sensing systems only work over the oceans (Figure 3.14), i.e., when water is the background. Land-based water vapor sensing helps track plumes of moisture after moving ashore from the Pacific. These real-time data have the potential to increase forecast rainfall accuracy. The sites are spread throughout the perimeter of the basin (Figure 3.15). The SuomiNet data can better inform rainfall forecast.

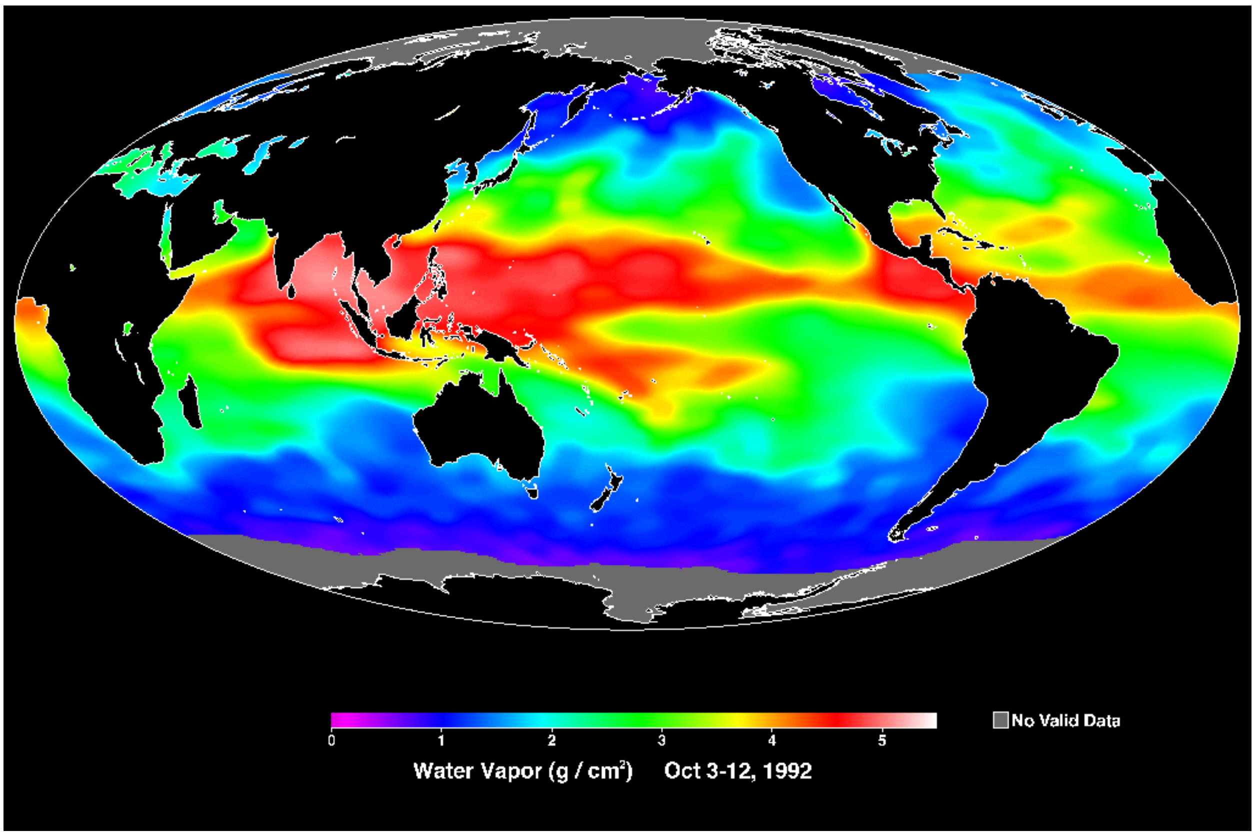

Figure 3.14. Satellite water vapor data.

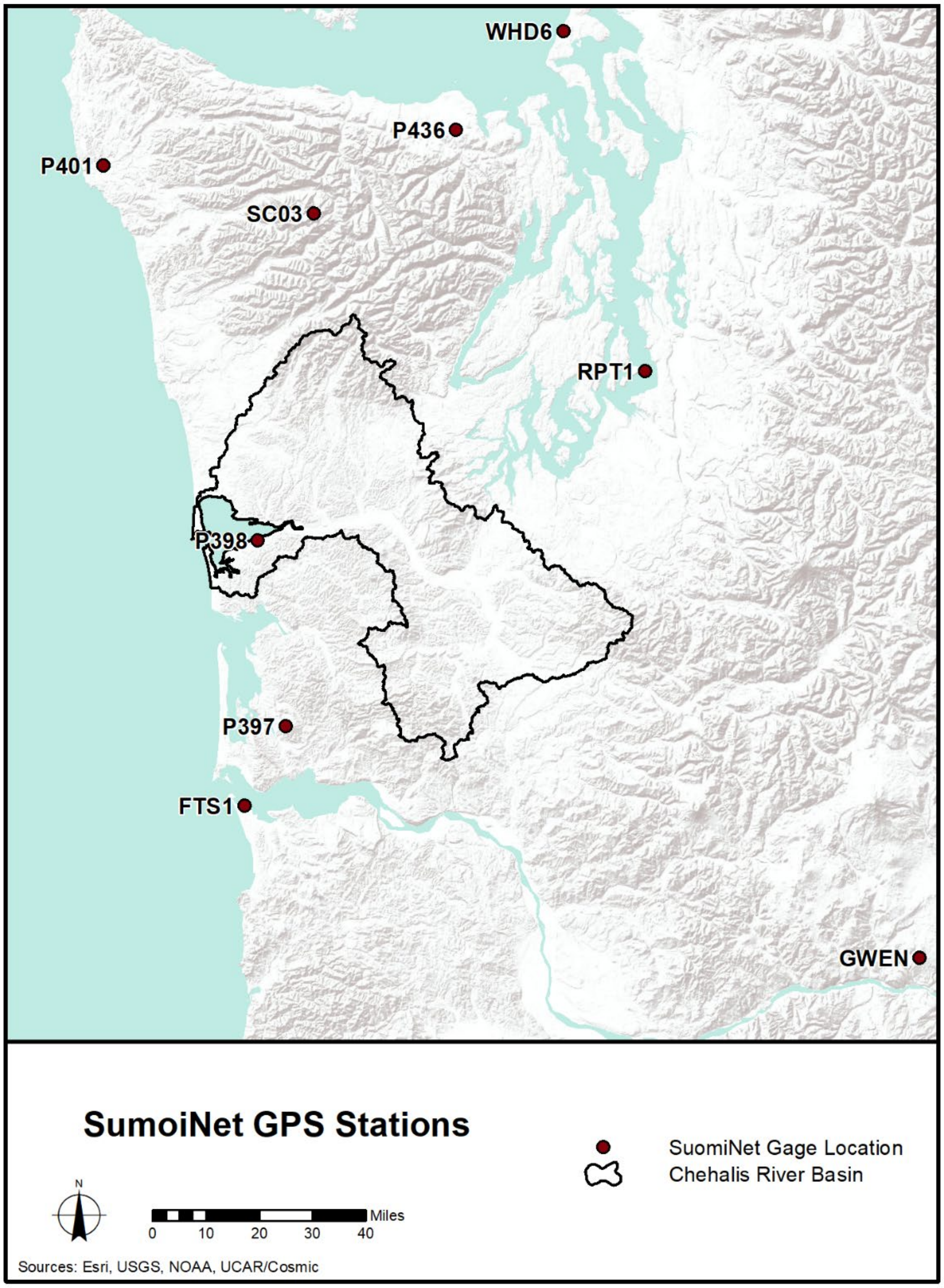

Figure 3.15. SumoiNet gages.

4. Recommendations

Several recommendations are presented under the following categories:

- Critical Updates – Updates needing completion ASAP.
- Low-Cost Enhancements - "Low-hanging fruit" that are quickly and inexpensively achievable.
- Important Upgrades – Key upgrades critical for long-term system performance and success.
- Strategic Initiatives – Recommendations that require cooperation and, potentially, joint funding by regional stakeholders which include various local regional, state, and/or federal agencies.
- Tasks on the Horizon – Upcoming events that may trigger work projects.

4.1. Critical Updates

4.1.1. Relocate the Chehalis River below Thrash Creek Gage

The Chehalis River below Thrash Creek near Pe Ell gage is the farthest upstream gage on the Chehalis River. It was originally a combination stream gage (water level) and precipitation gage with co-located sensors to make the most efficient use of a single data logger and GOES radio. The gage house (with the data logger, battery, GOES radio, etc.) and precipitation gage were installed at the top of a hill that had been recently harvested. The water level sensor is installed in conduit that runs all the way down a very steep hill into the Chehalis River approximately 150 ft upstream of a logging road bridge. Because the primary purpose of the gage is for flood warning, the water level sensor was not installed out in the deepest part of the channel, for fear it would get ripped out during a large event.

In 2021, the precipitation gage was removed and relocated to the Willapa Hills due to tree growth. The stream gage remains in its original location. Over the years the river has scoured the gage site and turned what was once a calm gage pool into a steep, high velocity riffle. Extending the water level sensor into this portion of the river is not ideal for long-term monitoring. Also, tree growth continues up at the gage house. Eventually the tree growth will cause power and communication problems as the trees block the solar panel and GOES satellite antenna.

Reconnaissance should be conducted to determine the best long-term gage location. The reconnaissance will help develop costs to move the existing equipment to a new location and possibly inform on whether new equipment needs to be purchased. For example, if the gage is to be moved to a bridge, then a radar sensor might be the best option for future water level monitoring. Reconnaissance will also help determine the best method for calculating flow at a new gaging location, which is recommending by the NWS.

Cost: $5,000 for reconnaissance.

4.2. Low-Cost Enhancements

4.2.1. Add Wynoochee River USGS Gages to Contrail

There are two USGS gages in the Wynoochee River basin that collect water level data and are available for use in Contrail:

1. BIG CREEK NEAR GRISDALE, WA (12035450)
2. SCHAFER CREEK NEAR GRISDALE, WA (12036400)

Cost: $500

4.2.2. Add Black River discharge to Contrail.

A request from a data user came in to add flow from the Ecology's Black River at Highway 12 (300AC212) gage to the FWS website. This can be accomplished by getting the most current rating curve from Ecology and creating a synthetic time series for discharge. The drawback of this method is that if there are changes to the rating curve by Ecology, those changes would not be automatically relayed to FWS data. Therefore, it is imperative that the current Ecology ratings curves are monitored to ensure that the most current Ecology ratings are updated to Contrail.

Cost: $500

4.2.3. Standardize Flood Alert Messaging

The current FWS alert emails are not standardized and could be improved in several ways. First, alert emails for all sites should be formatted the same way and contain the same information, including the location of the alert, the stage at which the alert was triggered, the stage considered 'flood stage', and the highest recorded stage at the site. The subject line for each alert email should contain the location and time of the alert to allow subscribers to understand what areas are under alert without opening the message. To keep alert subscribers aware of flood hazards, additional alert emails should be sent once per day for as long as the site remains at flood alert stage. If inundation maps exist for the site under alert, the email notifications should include a link to those maps so that users can understand what to expect at various flood stages. Currently FWS emails do not include any information on how to unsubscribe from alerts, but directions to do so should be added at the end of all FWS emails.

In addition to standardizing the emails, the alerts can be improved through providing links to other resources such as flood preparation tips from FEMA, county-wide flood hazard sites for Lewis, Thurston, and Grays Harbor. Local counties also provide sandbags for flood protection. Information on how to access these sandbags or other flood protection tools would be a valuable addition to the standardized flood alert emails. For alerts at tidally influenced sites, information on coastal flood warnings should be included.

Other possible avenues to improve the FWS notifications include setting up SMS alerts. The current FWS alerts are all distributed via email; however, SMS notifications would likely be seen more quickly by users. This should be investigated further as the current Contrail system (Contrail Web) does not support SMS notifications. Allowing users to sign themselves up for alerts would also improve the ease of use of the FWS and decrease the interval between a user asking to be added and when they are subscribed to FWS alerts. Contrail does not have a method to support self-signup without creating a user role for each subscriber, which adds a layer of unnecessary complexity. Other methods of self-sign-up should be investigated, such as purpose-built Python scripts or other automated tools.

Cost: $2,000 for alert standardization and notification improvements, $2,000 for reconnaissance into providing user-self sign-up

4.2.4. Implement Forecast High Water Alerts

As mentioned in Section 2.9, the NWRFC provides river stage forecasts for nine locations in the Chehalis River Basin:

- Chehalis River near Doty

- Newaukum River near Chehalis
- Chehalis River at Centralia
- Skookumchuck River at Centralia
- Skookumchuck River near Bucoda
- Chehalis River near Grand Mound
- Chehalis River at Porter
- Satsop River near Satsop
- Wynoochee River near Montesano

WEST has developed a method for bringing the stage forecasts into Contrail and sending email alerts when the NWRFC predicts that a flood stage will be reached. As a part of testing, these alerts have only been sent to WEST personnel and Scott Boettcher. Adding these alerts to the standard FWS alert suite would be a quick and low-cost method of improving the FWS. Users would receive an email alert when the location they have signed up for is forecasted to achieve flood stage. These alerts leverage existing infrastructure and increase the warning time that FWS users have.

Cost: $5,000

4.2.5. Improve Website User Interface

The Contrail website provides access to numerous resources and data feeds; however, it could be updated with several improvements. First, all sensor pages should include a statement that the data is provisional and has not been reviewed. Secondly, units across the site and sensor pages should be made consistent and obvious to the viewer. This will prevent confusion to users looking at multiple feeds and provide a better understanding of basin conditions. Similarly, the default map under the maps page should be set to 24-hour precipitation so that the map page experience is the same each time users access it. Additional dashboards should be created to allow users to view a summary of conditions within the basin or near their gage of interest. The USGS operates their own series of stage alerts at their stream gages. The FWS front page should include a link to information on signing up for custom stage alerts at USGS gages.

One major improvement for the FWS Contrail site would be to reorganize the homepage and navigation buttons. Several respondents to the January 2022 FWS performance survey noted that they had trouble finding the information they were looking for on the Contrail site. To mitigate these issues, links to the alert sites, maps, and dashboards should all include a large button. The landing page of the Contrail site should also include a brief description of the FWS as well as what information and resources is available on the website. Paired with the instructional video discussed in Section 4.2.7, these changes should lead to users accessing more information and utilizing the Contrail site more than in the past.

Cost: $10,000-$15,000

4.2.6. Improve Inundation Maps

The flood inundation maps accessible at chehalisriverflood.org are a valuable resource for property owners and other concerned parties. These maps provide information on what areas may be inundated at different flood levels and should be updated based on the most recent available data to provide the best resource to

users. Possible improvements to the inundation mapping effort would be to create depth maps that show the expected depth of flooding for a given flood stage.
Beyond updating and creating new maps, the performance of the inundation maps on different devices should be considered. Currently the maps are designed to be viewed on a desktop or laptop computer, however tablets and phones are a common method of access. The user experience of these maps when viewed on mobile devices should be reviewed and the maps and website should be updated to ensure they mesh well with all types of devices that are likely to be used.

Cost: $10,000-$15,000, assuming existing models are sufficient and available

4.2.7. Add Website Training

The Chehalis Basin Contrail site has many different maps, figures, and external resources; however, it may be confusing to someone without knowledge of floods. In the responses to the January 2022 FWS performance survey, several respondents asked for a tutorial on navigating the website, or otherwise left responses which indicated they were not familiar with all the information available on the website. To ensure that users can make the most of the information on the Contrail site, a short video introduction to the website could be created. This video would give a short background on the Chehalis Basin and the FWS, and demonstrate the different features included on the website. At the end of the video, contact information should be provided for users to reach out with any additional questions.

Cost: $5,000

4.2.8. Develop a Post-Flood Action Plan

A key part of the operation of a FWS is to make use of flood events to improve the system. To achieve this, a post flood action plan should be developed. This action plan would outline procedures that the Flood Authority and FWS team should perform during and after a flood, such as identifying and surveying high water marks. These high-water marks could be used to compare with or improve the inundation maps on the OneRain website. Observations made by first responders should be compared with existing inundation maps to identify problem areas where more focus should be spent.

Additionally, a post-event user survey would provide valuable input. A survey was distributed following the January 2022 floods to get feedback on the FWS from the community, and responses showed that the FWS was viewed positively by the community. A standard survey template would allow for faster distribution following a flood event. Using the same survey template also allows the FWS performance across flood events to be compared based on community responses.

Cost: $5,000-$8,000 to develop the post-flood action plan and survey, $3,000-$4,000 per year for review of survey responses and FWS performance

4.2.9. Add QR Code Stickers to Highly Visible Gages

Adding inexpensive QR code stickers (Figure 4.1) to highly visible gages could be an easy way to educate and inform local citizens about the Flood Warning System and its components. For example, a 6”x6” QR code sticker with a Flood Authority logo could be added to many of the sites that the Flood Authority operates, the most prominent of which are China Creek and the Chehalis and Skookumchuck gages in Centralia.

Figure 4.1. Example QR code sign from https://www.napnameplates.com/

Cost: $1,000 each including labor and installation

4.2.10. Leverage Office of Chehalis Basin Public Relations Resources for Social Media and Messaging

Much of the success of the FWS during the 2022 event was attributed to third party social media posts from The Chronicle and the Washington Department of Emergency Management. Continued exposure of the FWS through both traditional and social media is essential to maintaining public usage and support of the system. The Flood Authority is already pursuing public relations consultation. As part of their effort, a public relations coordination plan should be developed to prepare for future flood events. Social media templates can be prepared prior to the next major flood and allow a quick and efficient response to rising stages. Additional notices can be sent at the beginning and end of the flood season and include relevant FWS updates to remind users how the system works and to be prepared. Existing public relations resources such as those within the Washington State Department of Ecology should be leveraged where possible. Another avenue for increasing outreach is to add links to the FWS website and inundation maps on the websites of local governments such as towns and counties, as well as the Washington Department of Emergency Management and Washington Department of Ecology websites.

Cost: $TBD

4.2.11. Citizen Science

Citizen science approaches could be leveraged to improve rain and snow measurements within the Chehalis Basin. Existing programs like CoCoRaHS have dozens of participants within the basin that provide daily rain and snowfall measurements, however further outreach could be conducted. One possible avenue is to collaborate with local colleges and schools to set up rainfall gages that report to CoCoRaHS or an FWS-specific database. Manual measurement by residents within the basin would also be a cost-effective method of increasing snowfall and snowpack monitoring. CoCoRaHS maintains a pre-existing training package on maintaining and reading rain and snow gages which could be used directly or to guide the development of FWS-specific training materials.

Cost: $TBD

4.3. Important Upgrades

4.3.1. Upgrade to Contrail Server

Contrail, by OneRain, is a data collection and management system that is the backbone of the Chehalis River Basin Flood Warning System. Currently the FWS makes use of a Contrail Web subscription that has provided the required features over the years. However, there is an upgraded version offered by OneRain that would add more features and improve the user experience. Table 4-1 below summarizes the various options and features.

Table 4-1. Software options available from OneRain.

	Contrail Web	Contrail Server
Public Website	x	x
Data Exchange	x	x
Exclusive Server		x
Increased Customization		x
Hosted Server	x	x
Advanced Configuration		x
API Access		x
Custom Maps		x
Contrail Inventory Plus		x
Contrail Analytics		x
Discounted GARR		x
Spanish Language		x
One Time Cost	N/A	N/A
Annual Cost	$6,500	$15,000
Additional IT Cost	N/A	N/A

Contrail Web can be upgraded to Contrail Server for an additional cost of approximately $8,500 per year. Contrail Server provides the customer with their exclusive server hosted in a cloud service. It will also include a discount for GARR and provides free access to Contrail Inventory Plus and Contrail Analytics. Contrail Inventory Plus allows for notes and updates to be recorded about individual gages in the system as well as detailed tracking of equipment and sensors. Contrail Analytics provides access to a powerful toolset to analyze data and system performance. It allows for extended exports of data (Contrail Web is limited to data export of one year) as well as unique reports for rainfall intensity and sensor network performance.

Perhaps one of the most important features of Contrail Server is the ability to display the website with translation into Spanish language.

Cost: Additional Contrail subscription fee $8,500 per year

4.3.2. Verify Rating Curves at Chehalis River (CENW1) and Skookumchuck River (CTAW1)

CENW1 and CTAW1 are critical gage locations and NWRFC points. The ratings at each site are synthetic and have not been verified by discharge measurements. To verify the accuracy of the ratings, discharge measurements with an ADCP or current meter should be conducted at the following stages of each location:

- CENW1: 157 – 162 ft and greater than 169 ft.
- CTAW1: 178 – 182 ft. The upper end of the NWS rating agrees well with the modeled (2016) rating except for a deviation at stages greater than 190 ft which would make it difficult to obtain flow measurements.

If flow measurements are sufficiently close to the rating, then no more investigation is necessary. If measurements deviate significantly, then there should be a discussion about conducting more flow measurements or adding a velocity sensor to the sites to improve flow calculations.

Cost: $3,000 – $8,000

4.3.3. Develop a Data Agent between Ecology and Contrail

Creating a data agent between Contrail and Ecology would allow Contrail to access data directly from Ecology instead of being dependent on that data first being in HADS. Four sites that are available from Ecology that are not in HADS include:

- Bunker Creek @ Ceres Hill Rd (Ecology ID: 23I070, NESDIS ID: 3005D7F6)
- Dillenbaugh Creek at Riverside Dr (Ecology ID: 23L070, NESDIS ID: 30001BFA)
- South Fork Newaukum River @ Middle Fork Rd. (Ecology ID: 23B200, NESDIS ID: 3009B38C)
- South Fork Newaukum River @ North Fork Rd (Ecology ID: 23B190, NESDIS: 300B231A)

All four gages have stage, discharge, and air temperature parameters that would be valuable to users of the FWS website. The cost of the data agent is a one-time fee assuming Ecology doesn't make changes to how their data is provided. This would also allow Ecology flow values to populate on the FWS website. Currently there is at least one site that FWS users are interested in getting flow data from (Black River). The data agent would allow that flow data to come directly from Ecology and not require FWS staff to keep the rating up to date.

Cost: $5,000-$7,000 to develop the data agent.

4.3.4. Investigate Water Level Discrepancies at Skookumchuck Reservoir

TransAlta operates two pressure sensors at the spillway of Skookumchuck Dam. NWS relies on water level information from Skookumchuck Dam to make accurate predictions of flow downstream on the Skookumchuck River. There have been inconsistencies between the two sensors currently at the dam when water levels are high. For example, during peak stages during January 2022, the narrow band sensor was reporting water levels that were consistently 0.4 ft higher than the wide band sensor. It is assumed that the narrowband sensor is more accurate but water levels from two different sensors disagree that much can create confusion and uncertainty as to which sensor is accurate.

Cost: $1,500 more clearly present the TransAlta data on the Contrail Website.

4.3.5. Investigate Feasibility of Adding Gap-Filling Rain Gages

NWS has identified various locations where it would be advantageous to add precipitation gages. These areas include the west side of the Capitol State Forest and the hills between Winlock and Boisfort. The Newaukum Foothills already have a precipitation gage installed. These locations are primarily timberland, and if a precipitation gage were to be installed, it would have to be relocated every 10-12 years.

Cost: $15,000-$20,000 for reconnaissance and installation (per site) plus $5,000-$6,000 per year for maintenance (per site).

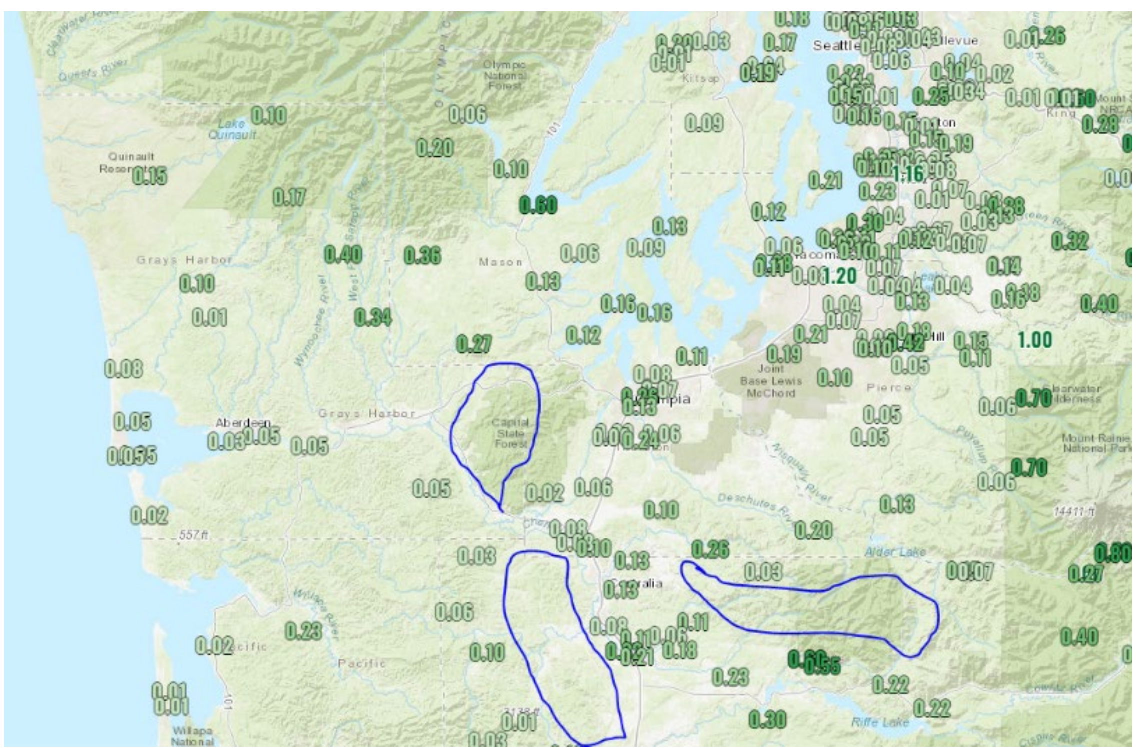

Figure 4.2. Locations identified by NWS for precipitation gages.

4.3.6. Improve Transient Snowpack Monitoring

Campbell Scientific makes an ultrasonic snow depth sensor (SnowVUE10) that could be tested out at one of the Flood Authority precipitation gages to measure transient snow depth. This sensor measures distance to a target within 0.2%. Campbell also makes a 2D multipoint, laser-based snowfall sensor (SDMS40) that could be added to an existing gage. A gage with maintained and flat ground around the site, such as Riverside or Cedar Creek would possibly be a good location to test this sensor. The sensors cost around $1,500-$4,000 and could be installed on an arm off the existing gage infrastructure. The benefit of installing this at an existing site is that the datalogger, telemetry, is already procured and installed. Minor changes would need to be made to the data logger program and the change data would need to be communicated to HADS, but after that is completed, the data could be available in Contrail. A major drawback of these sensors is that they do not account for SWE.

Cost: $1,500-$5,000 for equipment, $1,000 to install and program.

4.3.7. Develop Inundation Maps for Bucoda

In addition to these updates to the existing maps recommended in Section 4.2.6, an inundation map for the Skookumchuck River near Bucoda should be created and added to the website. This is a popular location for flood alert sign-ups and allowing users to view what the expected flood extents at different stages would allow them to respond appropriately when alerts go out.

Cost: $10,000-$15,000

4.3.8. Explore Ways to Communicate Uncertainty in Inundation Maps

One challenge faced in communicating flood risk to the public is ensuring that the uncertainty of the inundation area is clear and understandable. Methods for doing this should be investigated to ensure that the inundation maps are as helpful as possible without appearing exact. One way to achieve this would be to transition the edges of the inundation area from ‘flooding likely’ to ‘flooding possible’ zones, or by making the flood extent a gradient. If depth maps are produced, uncertainty could be communicated by using overlapping ranges should be used to avoid the maps being considered a guarantee of a certain depth of flooding. Another avenue is to work with the Office of the Chehalis Basin on outreach and educational campaigns within the community.

Cost: $5,000 to investigate

4.4. Strategic Initiatives

4.4.1. Improve Forecasting on the Lower Chehalis River

Currently, the NWS does not provide specific river forecasts in the lower Basin below Porter. The lower reaches of the Chehalis River are subject to compound flooding which includes riverine flooding from upstream areas combined with routine tidal influences, King Tides, and storm surges. The current NWS river forecast procedures in the Chehalis River Basin are incapable of accurately accounting for these complex issues, however the procedures needed to handle these issues exist within the NWS and are operational at other locations.

Improved river forecasts in the lower Basin would reduce uncertainty and increase time available to complete damage reduction tasks, further enhance the utility of many structural investments made in the past decade, and improve flood inundation mapping, one of the most popular and valuable tools provided by the FWS. The Flood Authority has begun discussion with the NWS (see Appendix G) regarding what resources would be required to improve NWS forecasting on this reach and should continue its cooperation with the NWS to further this goal.

4.4.2. Install Flow Gaging Sensor on the Lower Chehalis River to Support Modeling and Forecasting

If modeling moves forward on the lower reach of the Chehalis River, then it may be helpful, if not necessary, to have a stage and flow gaging station as far downstream as possible. The farthest downstream gage on the Chehalis River that computes flow is at Porter (USGS 12031000). USGS operates a stage-only gaging station on the Chehalis River at Montesano (12035100) that is heavily influenced by tides. It is anticipated that the new downstream flow gaging station would need to be located somewhere between Montesano and Aberdeen. A gaging station in this reach would certainly experience variable backwater from tides and would need to be a sophisticated index-velocity gage. An index-velocity gage not only measures water levels but also measures water velocity by using a side-looking or up-looking velocity sensor. In the case of the Chehalis River, it is anticipated that a side-looking device would work the best.

Index-velocity gaging stations require significant effort to plan, install, and operate. A detailed reconnaissance should be performed that would include bathymetric surveying as well as velocity mapping to determine the most appropriate location for the gaging station. The equipment costs are also much higher than a standard gaging station that only measures water levels due to the need to add a velocity sensor. Installation costs are also higher to install the velocity sensor appropriately. In fact, depending on the location of the gage and the infrastructure, or lack thereof, it may be necessary to engage the services of a diver to help with installation and maintenance.

Gaging in this reach benefits a large portion of the basin and multiple stakeholders, such as NWS, USGS, local governments, Office of the Chehalis Basin, and the tribes should be engaged to provide support and guidance to install this gage. Data at this location is critical to the flood forecasting and warning efforts in the lower basin. It is recommended that the Flood Authority actively engage the various stakeholders to determine the most appropriate funding mechanisms. The USGS experience with stream gaging, in general, and developing these types of monitoring systems makes them a logical choice to be lead agency in this effort with support from the Flood Authority.

Cost: $75,000 -$95,000 (reconnaissance and installation). $50,000-$60,000 per year for operation and maintenance.

4.4.3. Improved Flow Forecasts for Skookumchuck Reservoir near Bucoda

Skookumchuck Dam is a 190 ft high earth fill dam built in 1970 primarily for water supply and includes a small hydroelectric powerhouse. The dam and reservoir were not designed nor managed for flood control, but some flood control benefits are evident. For example, unusually low reservoir levels ahead of the 2007 flood reduced downstream flood damage that would otherwise have occurred.

The dam is located approximately 10 river miles upstream from the town of Bucoda. The timing and magnitude of potential flood producing reservoir outflows impacting Bucoda are highly uncertain and are significantly impacted by available reservoir storage. These uncertainties have a large impact on flood emergency response in the vicinity of Bucoda. Representatives from Bucoda requested forecast inundation maps like those developed for seven other locations within the flood warning system. However, the NWS does not currently provide river stage forecasts at Bucoda. The USGS operates a stream gage on the Skookumchuck River near Bucoda with data starting in 1967 which could be used to develop a river forecast point.

To further protect life and property in the vicinity of Bucoda, the Flood Authority sees a key need for improved inflow/outflow forecasts for Skookumchuck Reservoir and the development of river stage forecasts near the Town of Bucoda.

4.5. Tasks on the Horizon

4.5.1. Skookumchuck River at Centralia Bridge Replacement

The bridge over the Skookumchuck River at Centralia (N. Pearl St./SR 507) is scheduled to go out for construction bid in 2024. The bridge is aging and in need of replacement. The bridge is owned by the Washington State Department of Transportation and the Flood Authority should stay in touch with them about the construction timeline. The gage house and sensor at this location are installed at the downstream face of the bridge and the wire-weight gage is on the upstream face bridge rail. Prior to demolition/construction activities, the gage components will likely need to be removed. Depending on the construction timeline it might be desirable to install a temporary gage at the site. After construction, a permanent gage should be reinstalled at the bridge. For the permanent gage, a radar water level sensor should be considered to replace the aging bubbler.

4.5.2. Develop Capital Investment Strategy for Gage Obsolescence and Technology Change

Of the seventeen gages operated by the Flood Authority, ten of those gages have been operating in the field for almost twelve years. The sensors, data loggers, satellite transmitters, cables and antennas are currently working, but are aging. There is no exact timeline for when equipment will stop functioning but there has been a slight increase in equipment failures necessitating repairs in the last one to two years.

Gage obsolescence and technology changes are less about routine operations and maintenance but more about capital investments in the flood warning system. It is recommended to develop a capital investment strategy to address gage obsolescence, technology change, and other investment/re-investment issues.

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2023 Gage Master Plan Appendices

Chehalis River Flood Warning System

JUNE 2023

Prepared For:

Chehalis River Basin
Flood Authority

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Appendix A - High Flows at Major Gage in Chehalis

The ten largest flood crests at each USGS flood-monitoring gage location within the Chehalis Basin are listed in Table A.1 for the Chehalis River. Table A.2 is for the Skookumchuck River and Table A.3 includes crests for the Newaukum River.

Table A.1. Ten largest flood crests on the Chehalis River (ft NAVD88).

	Near Grand Mound (CGMW1)		Near Centralia (CENW1)		Near Porter (CRPW1)	
Rank	Date	Stage (ft)	Date	Stage (ft)	Date	Stage (ft)
1	12/4/2007	147.26	12/4/2007	178.10	12/5/2007	53.17
2	2/9/1996	147.01	2/9/1996	177.63	2/9/1996	52.33
3	1/10/1990	146.37	1/10/1990	176.82	1/8/2022	52.01
4	11/25/1986	145.44	1/8/2009	175.72	1/9/2009	51.76
5	12/29/1937	145.42	11/25/1986	175.31	1/11/1990	51.63
6	1/21/1972	145.24	1/21/1972	174.97	1/22/1972	50.99
7	1/7/2022	145.21	1/7/2022	174.93	1/27/1971	50.61
8	1/8/2009	145.21	11/25/1990	174.62	1/2/1997	50.54
9	11/25/1990	145.15	12/5/1975	174.49	12/5/1975	50.47
10	12/5/1975	144.76	1/26/1971	173.52	11/25/1986	50.47

Table A.2. Ten largest flood crests on the Skookumchuck River (ft NAVD88).

	Near Bucoda (BCDW1)		Near Centralia (CTAW1)	
Rank	Date	Stage (ft)	Date	Stage (ft)
1	2/8/1996	216.02	2/8/1996	191.03
2	1/7/2022	215.99	1/10/1990	190.86
3	1/8/2009	215.87	4/5/1991	190.44
4	1/10/1990	215.48	1/21/1972	190.36
5	11/25/1990	215.38	1/8/2009	190.34
6	1/21/1972	214.97	11/25/1990	190.26
7	4/5/1991	214.97	1/7/2022	190.18
8	12/30/1996	214.91	2/11/1990	190.14
9	12/9/2015	214.75	12/30/1996	189.93
10	2/11/1990	214.75	12/10/1953	189.76

Table A.3. Ten largest flood crests on the Newaukum River (ft NAVD88).

	Near Centralia (NEWW1)	
Rank	**Date**	**Stage (ft)**
1	1/6/2022	205.59
2	2/8/1996	205.48
3	1/7/2009	205.43
4	12/3/2007	205.39
5	1/5/2015	205.08
6	11/7/2006	204.94
7	3/1/2022	204.86
8	11/18/2015	204.73
9	11/24/1986	204.70
10	1/9/1990	204.69

Appendix B - Historic Flood events

B.1. December 2007 Event

A total of three storms moved through Washington starting on December 1, 2007. The first was a cold air mass from Alaska depositing snow in low elevations. The second system was warmer and wetter, depositing snow at higher elevations. The last storm originated in the tropics as an atmospheric river; it was much warmer, more intense, and lasted over 30 hrs. Exceptionally high rainfall fell in the Willapa hills above Doty. On December 4, 2007, the result was the largest flood in the history of the Chehalis River Basin (Figure B.1).The crest of the Chehalis River measured at Centralia was 74.8 feet, which is 10 feet over flood stage. (NWS, 2023b)

In all of western Washington, at least three people were killed and 130 people were rescued by helicopter. In the Chehalis River Basin, one person was killed, entire herds of livestock were lost; numerous homes and business were damaged or destroyed; and Interstate 5 was flooded damaged and closed for several days. The resulting rainfall also produced numerous landslides and debris flows adding to damage and injuries from flooding. A 20-mile stretch of I-5 was closed for four days. The total damage in the state of Washington was estimated at over $500 million. (NWS, 2023c) (OWSC, 2007).

Figure B.1. Aerial photograph of flooding during the 2007 Chehalis Flood.

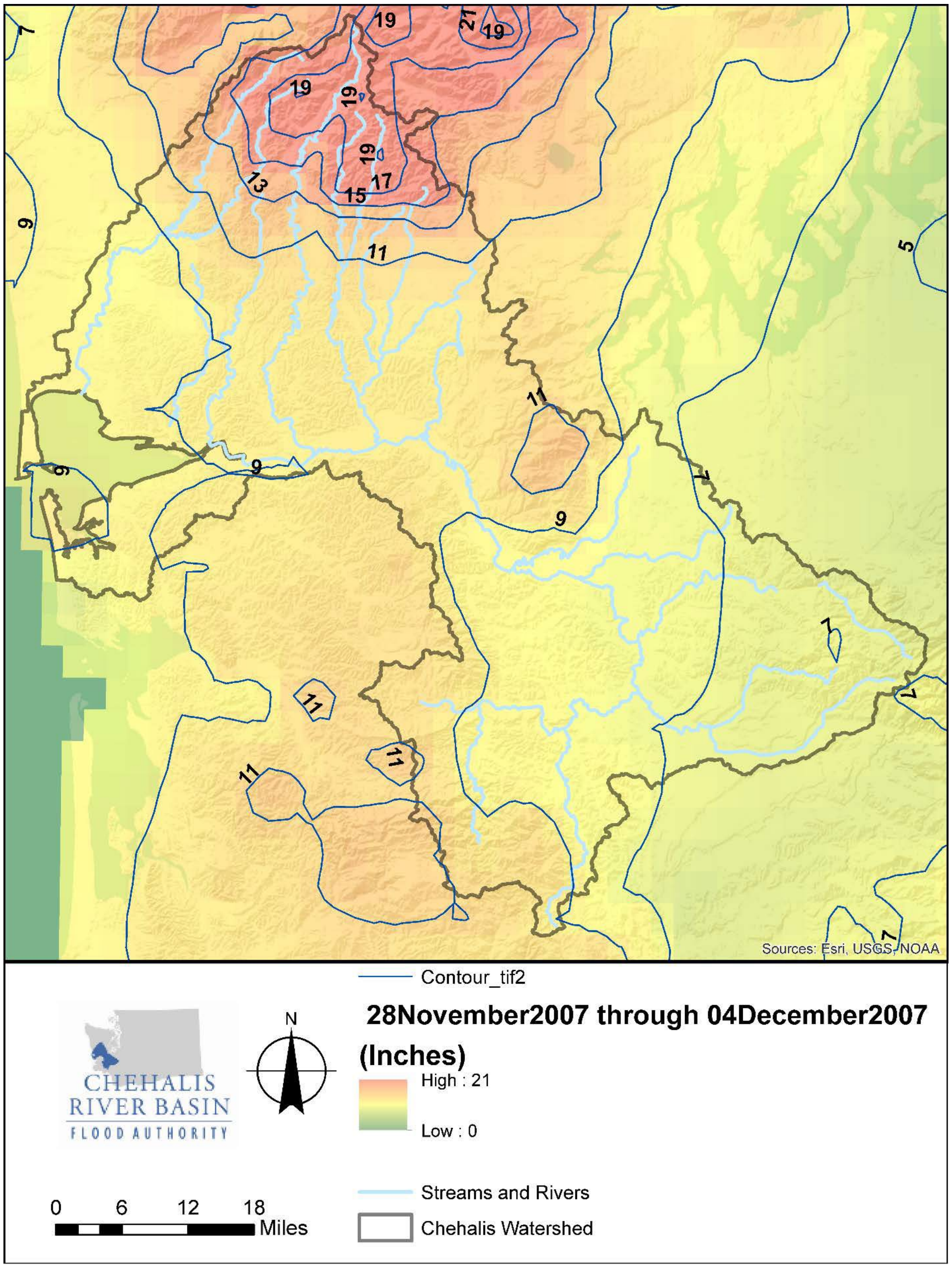

Figure B.2. PRISM accumulated precipitation resulting in the December 2007 flood.

B.2. January 2009 Event

Prior to January 6, 2009, the region was experiencing colder than normal temperature with snow levels below 6,000 ft. An atmospheric river (Figure B.3) brought high amounts of rainfall and warmer temperatures from January 6th through the 8. The combined snowmelt and high intensity rainfall resulted in severe flooding in the Chehalis River Basin (Figure B.4) and throughout western Washington. The saturated soil, due to continuous rain for several days prior to the atmospheric river event, contributed to the severity of the flood event. That, in combination with the heavy rainfall and lowland snow melt from the previous cold snap and heavy snow, led to landslides and mudslides and avalanches. Much more rain fell in the center of the basin near Chehalis than normally does in a large event, with three to eight inches of rain falling in the western Washington Counties (Figure B.2). The crest of the Chehalis River measured at Centralia was 72.4 feet on January 8th, seven feet above flood stage. The total damage was estimated at $72 million. (NWS, 2023c)

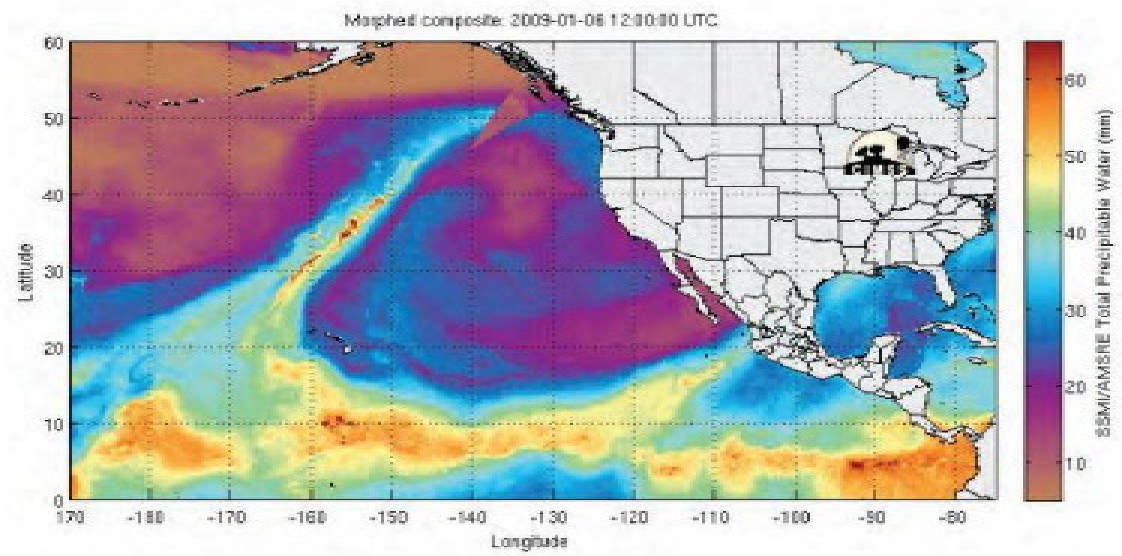

Figure B.3. Satellite image of atmospheric river, January 6, 2009 (USGS3, 2010)

Figure B.4. Aerial photograph of flooding during the 2009 Chehalis Flood

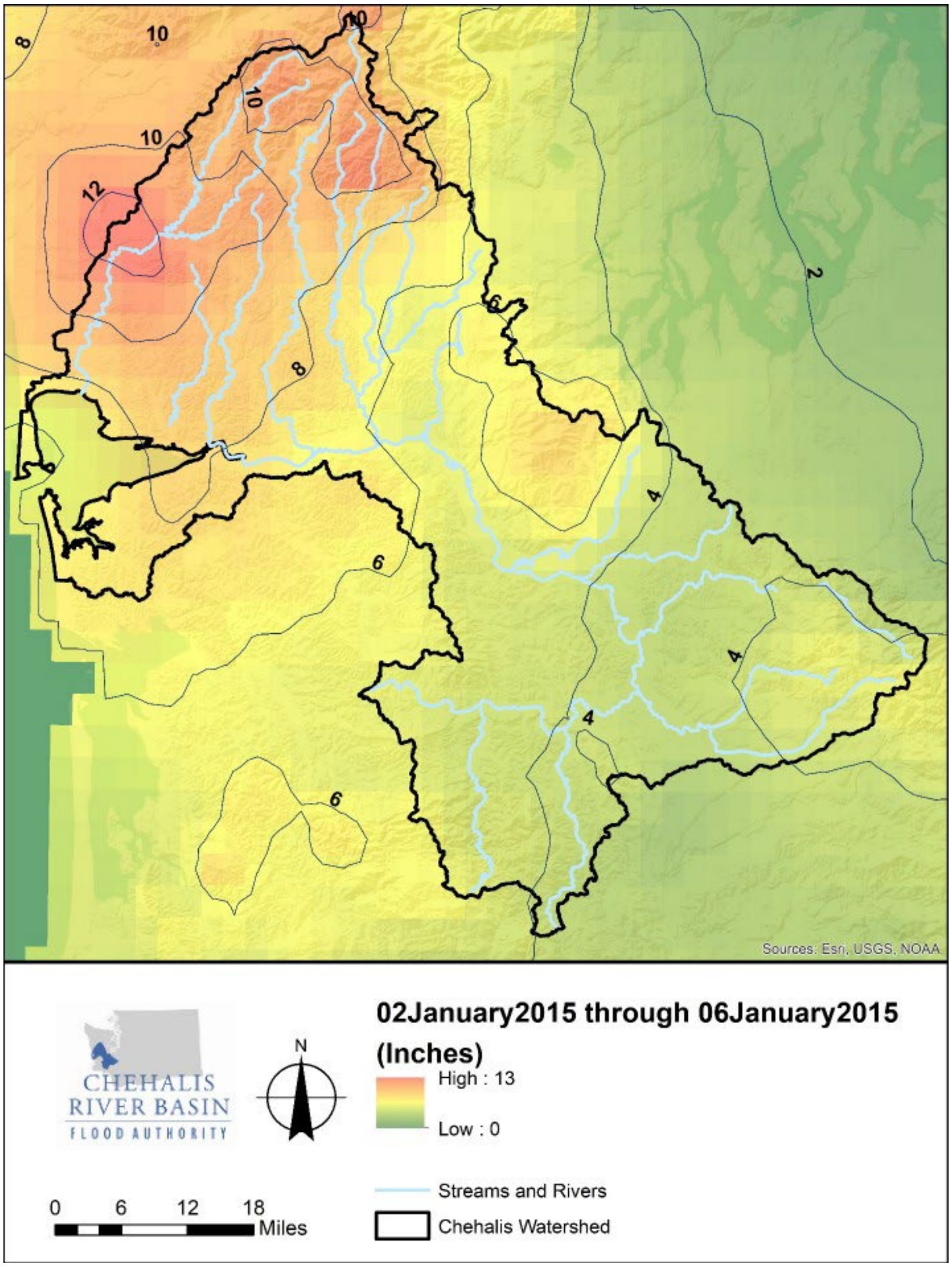

Figure B.5. PRISM accumulated precipitation resulting in the January 2009 flood.

B.3. February 1996 Event

The February 1996 flood was a rain on snow event affecting Western Washington and Oregon. Cold temperatures and wet weather prior to the event brought snow and ice to low levels. An atmospheric river delivered intense rainfall (Figure B.6) and warmer temperatures from February 4th through the 10th. The heavy rain and rapid snowmelt produced record flooding, mudslides, and avalanches. The crest of the Chehalis River measured at Centralia was 74.3 feet on February 9th, more than 9 feet above flood stage. At the time, this was the highest flood on record for the Chehalis River. Total damage was estimated at $120 Million throughout Washington. (NWS, 2023c)

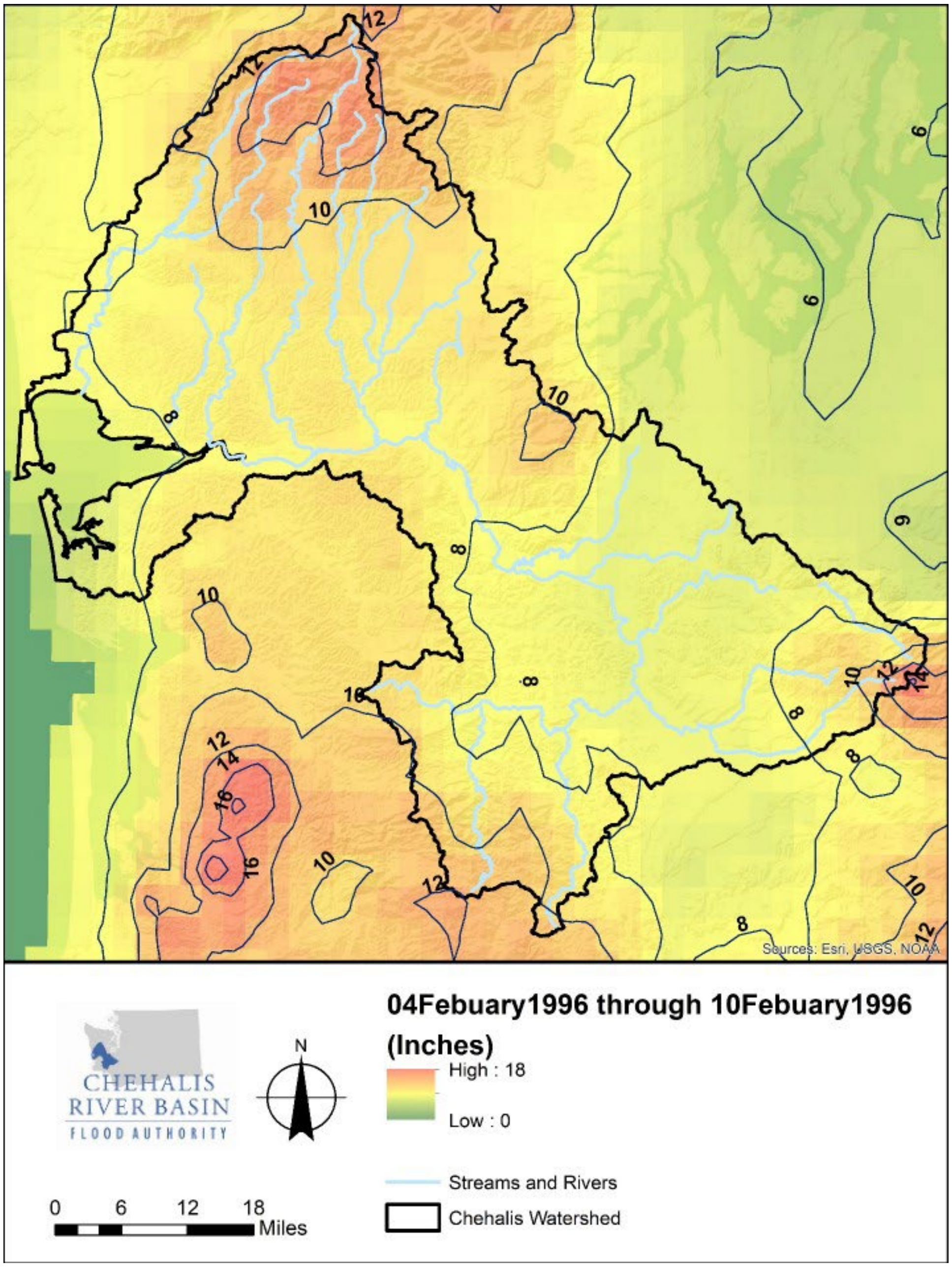

Figure B.6. PRISM accumulated precipitation resulting in the February 1996 flood.

B.4. January 2015 Event

In 2015, intense rain fell in western Washington from January 4th through the 5th. The Olympic Mountains and the coast received the heaviest precipitation in the Pacific Northwest: between 6" and 10" of precipitation, during the 24-hour period (Figure B.7). Temperatures were mild, with a majority of western Washington recording high temperatures well into the 50-degree range. Rain shadow effects by the Olympic Range were seen as the Seattle area received very little rain yet rainfall in the Hoquiam River and Wishkah River watersheds lead to flooding in the cities of Aberdeen and Hoquiam. Hoquiam received over seven inches of rain in two days as shown in the northwest quadrant of Figure B-5. (OWSC, 2015)

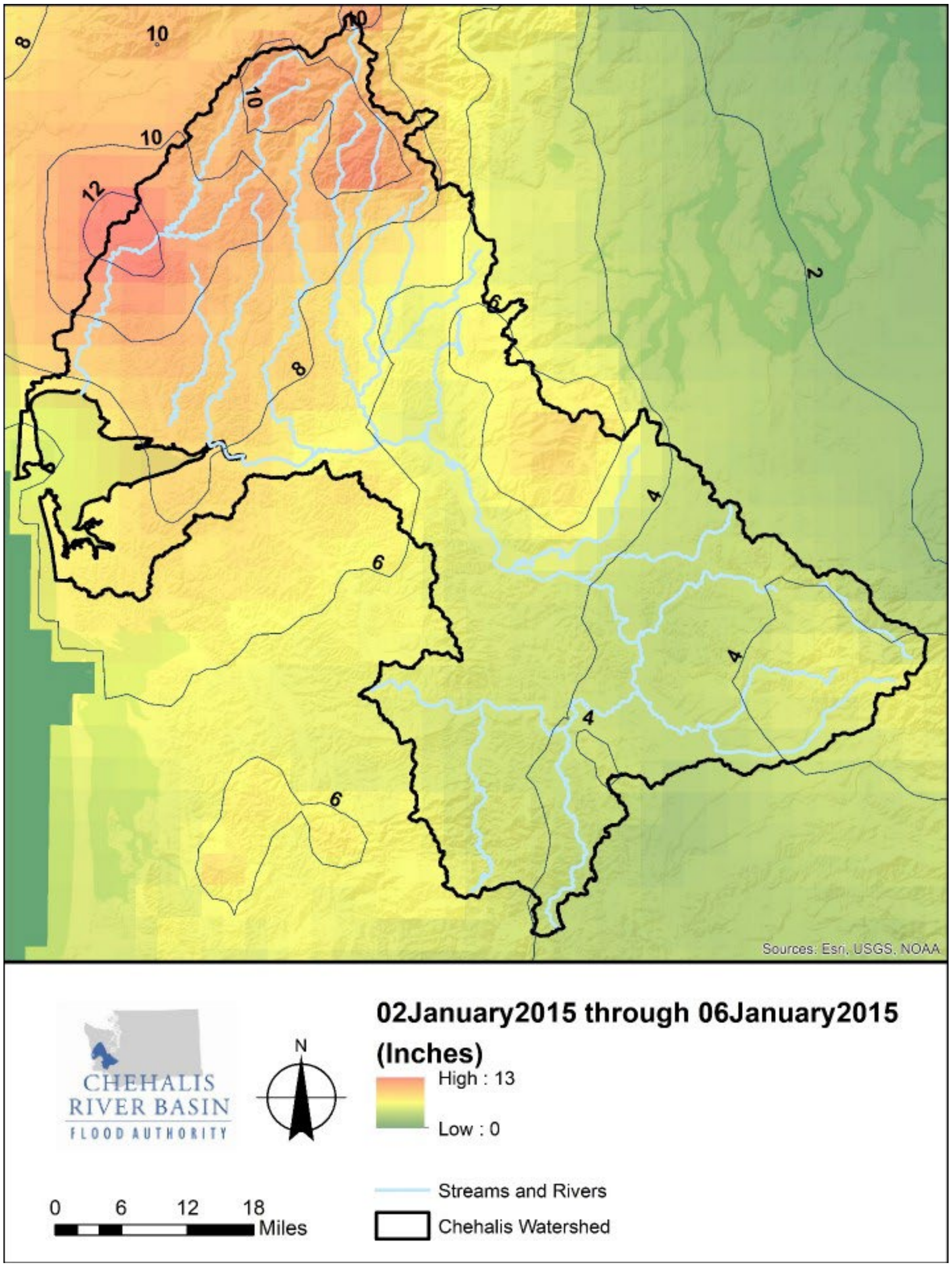

Figure B.7. PRISM accumulated precipitation resulting in the January 2015 flood.

B.5. January 2022 Event

B.5.1. January 2022 Flooding

Rain began falling in Washington's Chehalis River Basin on October 1, 2022, and continued without a significant break until mid-January 2023. Numerous atmospheric river events pummeled the region. Just shy of 87 inches of rain fell on the Beeville gauge during the period (Figure 1.8). The West Fork Satsop gage recorded 73.8 inches, Huckleberry Ridge reported 67.62 inches, while 57.75 inches fell at the

Newaukum-Weyco gage. During the 30-day period from mid-December to mid-January rainfall totals in the basin ranged from 12 to more than 40 inches.

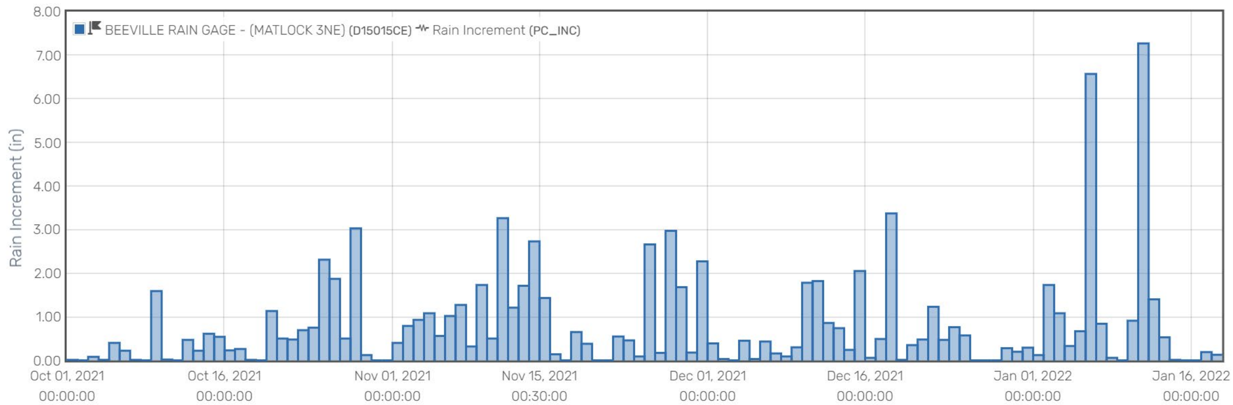

Figure 1.8. Daily precipitation reported at the Beeville gage from October 1, 2022, through January 18, 2023.

Cold temperatures from Christmas through New Year's Day caused snow to accumulate at abnormally low elevations in the basin. Precipitation gages in the Chehalis River Basin only measure rain or melting snow. Temperature sensors are available to indicate whether incoming precipitation was falling as snow or rain (Figure 1.9). Precipitation during the last week of December likely fell as snow and not recorded by the gages until temperatures warmed. Accumulated low elevation snow meant several additional inches of water were available for runoff when a Category 4 atmospheric river (See Figure 3) hit on January 6th with warmer temperatures and more heavy rain.

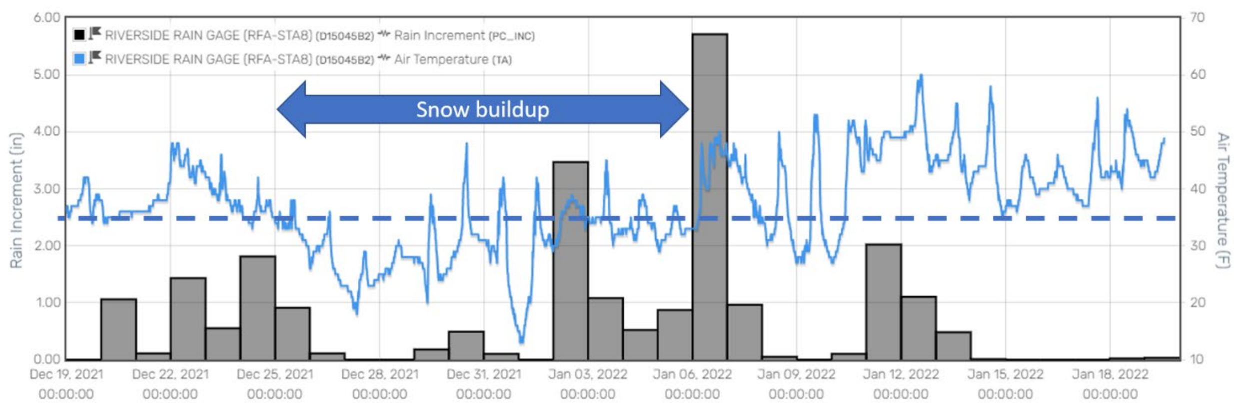

Figure 1.9. Daily rainfall with hourly temperatures at the Riverside gage.

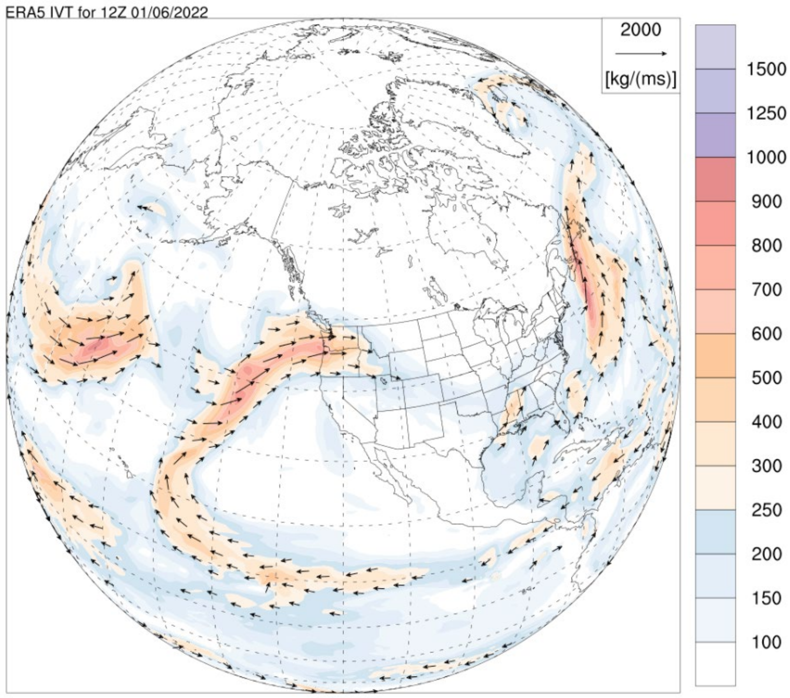

Figure 1.10. Atmospheric River shown as a plume of Integrated Water Vapor Transport striking the Pacific Northwest coast on January 6, 2023 (Source: CW3E)

Extremely wet antecedent conditions, significant snow on the ground, combined with a warming Category 4 atmospheric River were an ideal setup for flooding. Moderate to major flooding occurred with record stages on a major tributary, the Newaukum River at Chehalis, with near record flooding on another major tributary, the Skookumchuck River near Bucoda. Numerous other stations in the middle to lower Chehalis River Basin saw major and moderate flooding through January 9th.

Appendix C - Flood Monitoring Methods

C.1. Precipitation

Precipitation is measured using either a physical instrument, such as a rain gage, or remote methods like radar and satellite data collection. Rain gages measure and record the amount of rain that has fallen in a given time span. The frequency of the measurements depends on the purpose of the rain gage and the agency measuring the precipitation. Precipitation is commonly measured in 15-minute, 1-hour, and 24-hour increments. Three types of rain gages, as well as radar and satellite methods, are discussed in the following sections.

C.1.1. Physical Measurement

There are a variety of ways to physically measure precipitation, however a rain gage is the most common method. It collects falling precipitation and funnels it to a measurement device. The type of measuring device can vary.

C.1.1.1 Tipping Bucket

The tipping bucket was invented in 1662 and is still commonly used today. A tipping bucket gage catches precipitation in an open funnel, called the collector. Once collected (and, if necessary, melted by internal heating strips), the water is funneled to a mechanical device called the tipping bucket. The device contains two buckets, each on one side of a seesaw (Figure C.1). The bucket tips once it fills to a specified volume, often 0.01 inch of rainfall. Each tip empties the bucket and positions the other bucket under the funnel. A magnet measures each time the bucket moves past it while performing a “tip” and records the time of the bucket tip. Because the volume of the bucket is known, the number of bucket tips within a certain time frame can be translated to a rainfall rate. Often the recording device transmits the data electronically to a base station that collects, reports, and archives the data. A weather station in the Chehalis Basin that uses a tipping bucket rain gage is shown in Figure C.2. The data recording device as well as the satellite antenna are shown in the image as well.

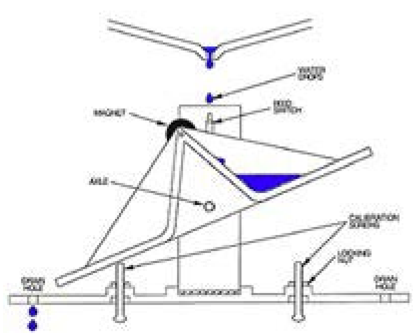

Figure C.1. Diagram of a tipping bucket precipitation gage (The Constructor, 2017)

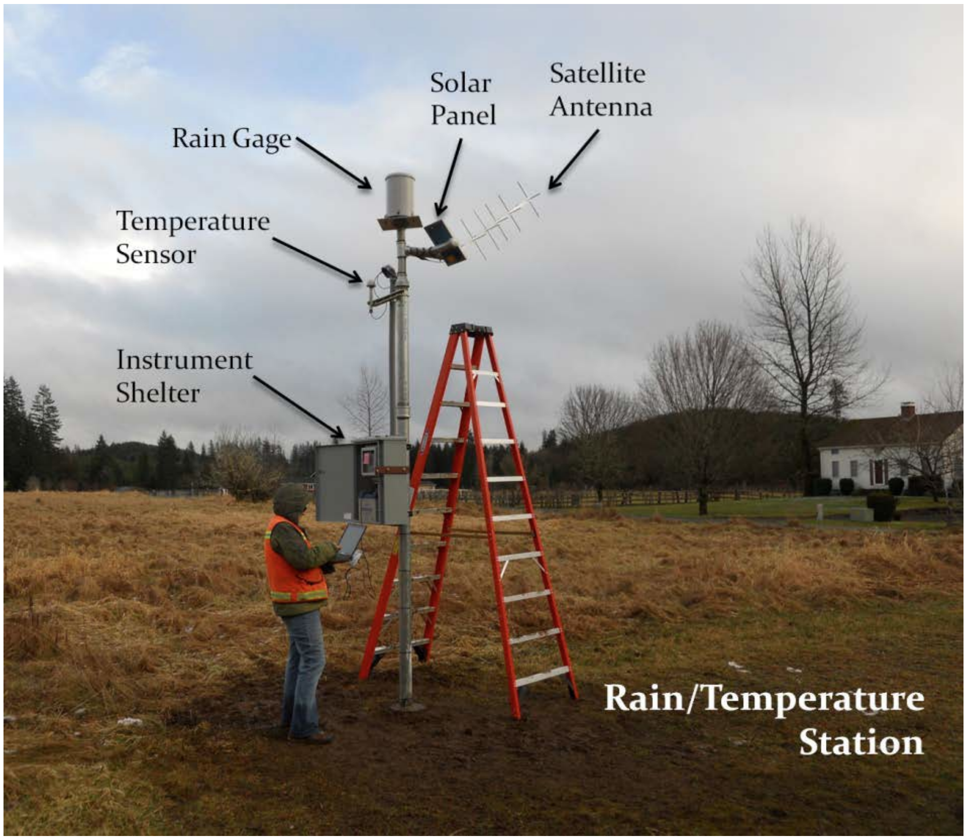

Figure C.2. A tipping bucket precipitation gage in the Chehalis River Basin FWS.

C.1.1.2 Weighing Bucket

A weighing bucket converts the weight of collected precipitation into the equivalent depth of accumulated water in conventional units of inches or millimeters. The rain travels through a funnel into a weighing bucket where the weight is converted and recorded by a recording device. Often the recording device transmits the data electronically to a base station that collects, reports, and archives the data. Figure C.3 shows a diagram of a typical weighing bucket gage.

In the winter, the funnel can be removed in order to measure snow accumulation. This type of gage does not underestimate intense rain like a tipping bucket might and it can measure all types of precipitation, not just rainfall.

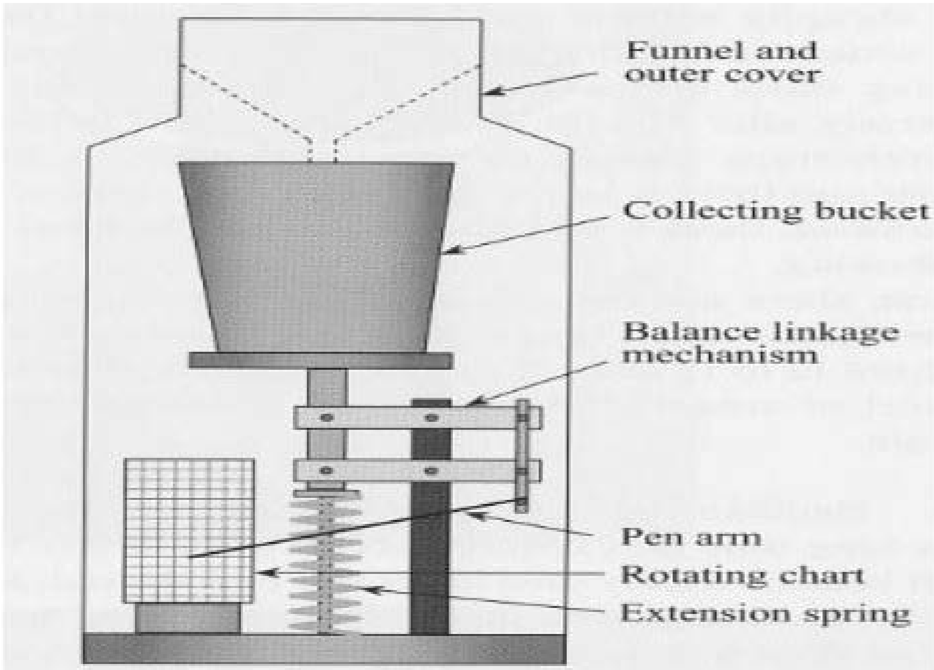

Figure C.3. Diagram of a weighing bucket precipitation gage (The Constructor, 2017).

C.1.1.3 Siphon Gage

A siphon rain gage is similar to a weighing bucket. Water is collected and funneled into a container. A float is at the bottom of the container, and it rises as the volume of rain collected in the container increases. The movement of the float is recorded. The relationship between the depth of the rain in the container and the volume of rainfall in the container is used to calculate the volume of rainfall. When the container is full, the siphon will drain out the water from the container. A siphon gage is often more accurate in high intensity rainfall events. (The Constructor, 2017)

C.1.1.4 Optical Rain Gage

An optical rain gage consists of a funnel that collects and channels precipitation into a single point. When enough water is collected to make a single uniform drop of known volume, it drips from the bottom of the funnel, falling into the path of a laser beam. The laser sensor is set at right angles to the water droplet path such that the dripping of the water droplet is detected. This break in the laser circuit allows an electrical signal to be recorded on an attached data recording instrument. The drops of water are counted, recorded, and converted into volume or intensity.

C.1.1.5 Limitations of Rain Gages

Rain gages are not effective in extreme storms with high winds or when located too close to protective structures. Winds can blow the rain away from the rain gage and distort the actual amount of rain that is falling. A rain gage should be located in an open area where there are no obstacles such as buildings or trees. These protective structures could intercept the rainfall and cause a bias in recorded rainfall.

Alternatively, water that has been collected in the tree canopy or on top of a building, may fall into the rain gage at a later time, causing inaccuracies in the readings.

C.1.2. Spatial Measurement

Physical precipitation measurements are point measurements, recording the rainfall in one location. Since rainfall intensities vary within a storm, sometimes it is more useful for flood prediction to collect the spatial distribution of rainfall data as well as rainfall intensity. Currently there are two ways in which to collect non-point rainfall data: radar or satellite.

C.1.2.1 Radar

Radar, which stands for Radio Detection and Ranging, has been used to detect precipitation since the 1940s. It allows meteorologists to study storms with more detail in space and time. Radar has high resolution and can detect motions toward and away from the radar as well as the location of the precipitation area. As the radar antenna rotates, it emits short bursts of radio waves that move through the atmosphere at the speed of light. The radar station measures the reflected waves as they bounce off the storm. This reflected signal is received by the radar during its listening period. Computers analyze the strength of the returned pulse, the time it took to travel to the object and back, and the phase shift of the radio wave. This process of emitting a signal, listening for any returned signal, then emitting the next signal, takes place very quickly, up to around 1,300 times each second.

The Next Generation Weather Radar (NEXRAD) system of radar is run by the NOAA and is the most recent and technologically updated radar system. It is currently made up of 160 stations throughout the United States and select overseas locations (Figure C.4). Computer processed data generates numerous meteorological products that are used and displayed by the NWS such as base reflectivity, composite reflectivity, base velocity, storm relative motion, one-hour precipitation, and storm total precipitation, all of which are described below.

NEXRAD Coverage Below 10,000 Feet AGL

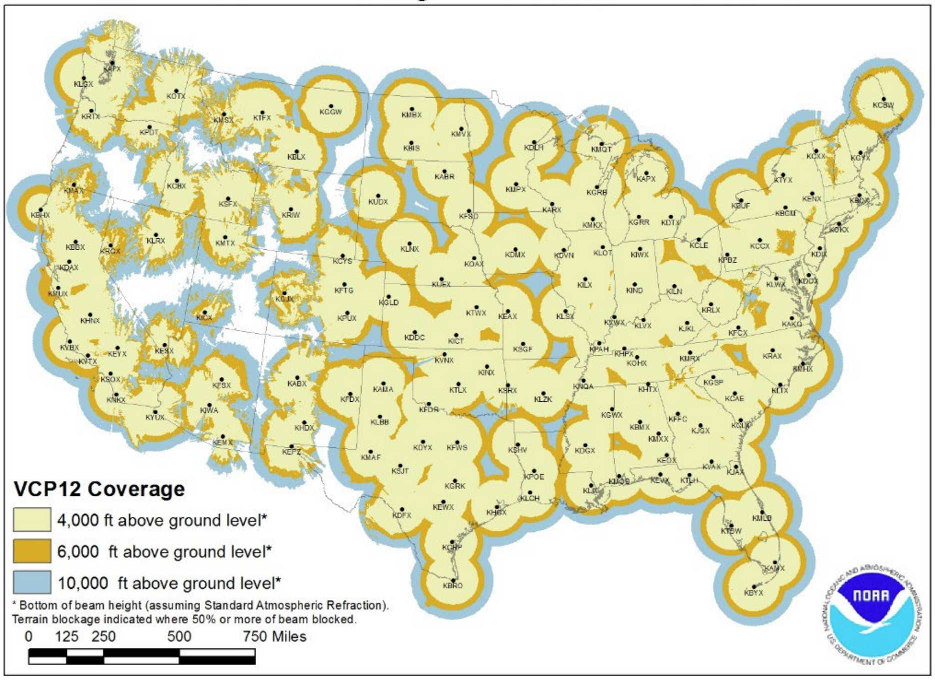

Figure C.4. NEXRAD radar coverage of the United States.

Base Reflectivity

Base Reflectivity is RADAR echo intensity (reflectivity) measured in dBZ (decibels of Z, where Z represents the energy reflected back to the radar). "Reflectivity" is the amount of transmitted power reflected off an object and returned to the radar receiver. Base Reflectivity images are used to detect precipitation, evaluate storm structure, locate atmospheric boundaries and determine hail potential.

Composite Reflectivity

Composite reflectivity displays the maximum echo intensity (reflectivity) from any elevation angle at every range from the radar. This product is used to reveal the highest reflectivity in all echoes. When compared with base reflectivity, the composite reflectivity can reveal important storm structure features and intensity trends of storms.

Base Velocity

Base velocity is an image of radial velocity representing the overall wind field. Green colors indicate wind moving toward the radar with red colors indicating wind moving away from the radar.

Storm Relative Motion

Storm relative motion is an image of the radial velocity of the wind relative to the storm's motion. The result is a picture of the wind as if the storms were stationary. This often unmasks storms that rotate (supercells) which can be a precursor to the formation of tornadoes. Green colors indicate wind moving toward the radar with red colors indicating wind moving away from the radar.

One-hour Precipitation

One-hour precipitation is an estimated one-hour precipitation accumulation. This product is used to assess rainfall intensities for flash flood warnings, urban flood statements, and special weather statements.

Storm Total Precipitation

Storm total precipitation is an estimated accumulated rainfall. It is used to locate flood potential over urban or rural areas, estimate total basin runoff and provide rainfall accumulations for the duration of the event. (NWS, 2023c)

Limitations

The maximum range for base velocity, storm relative motion, one-hour precipitation, and storm total precipitation is about 143 miles from the radar location (NWS, 2023c). The radar is also limited close in by its inability to scan directly overhead. Therefore, close to the radar, data are not available due to the radar's maximum tilt elevation of 19.5°. This area is commonly referred to as the radar's "Cone of Silence" and is illustrated in Figure C.4.

NEXRAD radar coverage for the United States is lacking in some of the West, however, western Washington is well covered as shown in Figure C.5.

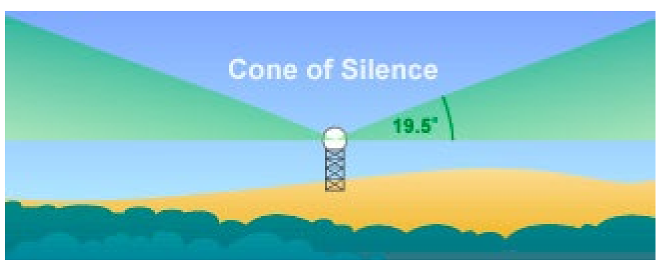

Figure C.5. Radar cone of silence.

C.1.2.2 Satellite Data

Satellites are man-made objects orbiting the earth and collecting information from space (Figure C.6). Satellites designed for weather data collection typically contain cameras and radar systems. The bird's-eye view that satellites have allows them to see large areas of Earth at one time. This ability means satellites can collect more data, more quickly, than instruments on the ground. Satellites measure the size and motion of clouds, ocean, land, and ice. They monitor and collect data that can be used for weather, climate, and environmental monitoring purposes such as precipitation, temperature, and humidity, among others. NOAA's Environmental Visualization Laboratory has the ability to capture images of severe storms (Figure C.7) giving the NWS the ability to predict the arrival of intense rain and severe storms, flood conditions, and mudslides.

Figure C.6. Satellite orbiting Earth. Photo by NASA.

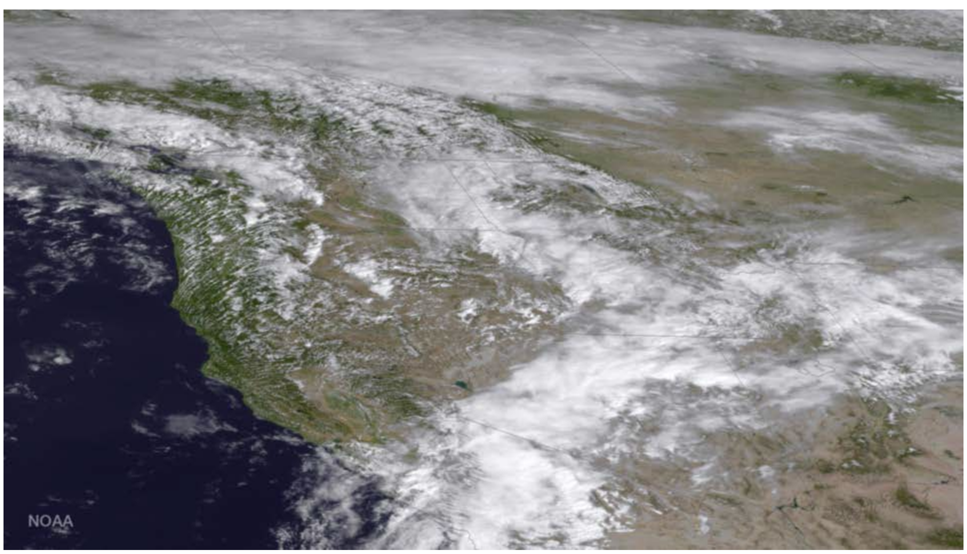

Figure C.7. Satellite image of a weather system.

C.1.3. Other Meteorological Variables

The sensors in a weather station, in addition to a rain gage can include:

- A thermometer measures air temperature.

- A hygrometer measures relative humidity. Relative humidity is the quantity or percentage of water vapor in the air. Humidity influences environmental factors and calculations used to predict precipitation, fog, dew point and heat index.
- A barometer measures atmospheric pressure. Changes in barometric pressure indicate changes in the weather pattern.
- A pyranometer measures solar radiation.
- An anemometer measures the wind speed and
- A wind vane measures the direction the wind is blowing.

Weather buoys collect weather and oceanography data in lakes and oceans. Weather buoys can be moored or drifting. Moored weather buoys are large and can be anywhere between 5 feet and 50 feet in diameter (NWS, 2023d). Drifting buoys are more common and are one foot to 18 inches in diameter (Lumpkin and Pazos, 2006).

C.2. Stream Level

There are many types of stream gaging stations that are used to measure water levels (also referred to as stage and gage height) in the Chehalis Basin. Stream gaging stations vary in complexity but in general terms can be separated into three categories; non-recording gaging stations, recording gaging stations, and real-time gaging stations.

A staff gage is the most common type of a non-recording stream gage. It is essentially a sturdy, long ruler that is installed in a vertical position in a body of water and used to determine water level. Instantaneous stage readings are obtained by manual observation of the point where the top of the water contacts the staff gage. This observation is a direct measurement of the water surface and not necessarily representative of water depth.

A recording station has a sensor that measures stage and a data logger that records information at specified time intervals, typically every 15 minutes. The data is retrieved manually at the gaging station during routine maintenance visits performed by trained technicians. Recording stream gaging stations typically have a staff gage that is used as a reference gage. Stage observations taken from the staff gage are compared to stage data measured by the stage sensor to ensure correct operation of the sensor.

Real-time gaging stations are the backbone of all Flood Warning Systems. Real-time stations are recording stations that have additional components that automatically transmit data from the station in near real-time to make it available to users. The term “near real-time” is important to understand because there is always lag time between the time a water level is measured and recorded at the field site and the time that data is made available for users. It is most common to transmit data from the field site via the GOES network, cellular phone networks, or other radio communication systems. All of these networks have their own unique lag times.

With the GOES network, data is typically transmitted at hourly intervals. However, Ecology transmits their stream level data every 3 hours. Real-time data allows users to see current conditions at a station and act accordingly.

C.2.1. Staff Gage

A staff gage (e.g., Figure C.8) is similar to a yard stick but with measurements displayed both to the nearest foot (one-foot intervals) and to the nearest tenth of a foot. They are installed in a vertical manner and used for measuring water levels in lakes, rivers, and reservoirs. Staff gages are easy to use because the height of the water can be quickly and easily read. Instantaneous water level (also called "stage") readings are obtained by manual observation of the point where the top of the water contacts the staff gage. This observation is a direct measurement of the water surface and not necessarily representative of water depth.

Staff gages are used for manual data recording, as when an agency staff person visits the site routinely to record the stage, and they are used to check the electronic measuring devices that may be installed in the stream. Staff gages are typically tied to a temporary benchmark or a known elevation so that a relationship can be formed between the discharge or pool of water and the stage measurement.

Figure C.8. Staff gage. Image from USGS.

C.2.2. Stilling Well

A stilling well dampens the rise and fall of waves and storm surges in rivers or reservoirs. It can be used in combination with a staff gage or an electronic stage sensor to measure the water level. The water level in the well can be measured and used to calculate flow or reservoir volume in the body of water. Figure C.9 illustrates one possible configuration of a stilling well. In this case, the stilling well is located outside the body of water with intakes that keep the water level equal to that in the stream. Other configurations might place the stilling well directly in the stream as shown in Figure C.10. A stilling well can be used as a recording station or a real-time station, depending on the equipment housed in the stilling well. The satellite antenna in Figure C.9 indicates that it is a real-time station. An outside reference gage, typically a staff gage, is read periodically to verify that the recorded gage heights from the stilling well are the same as the water levels in the stream.

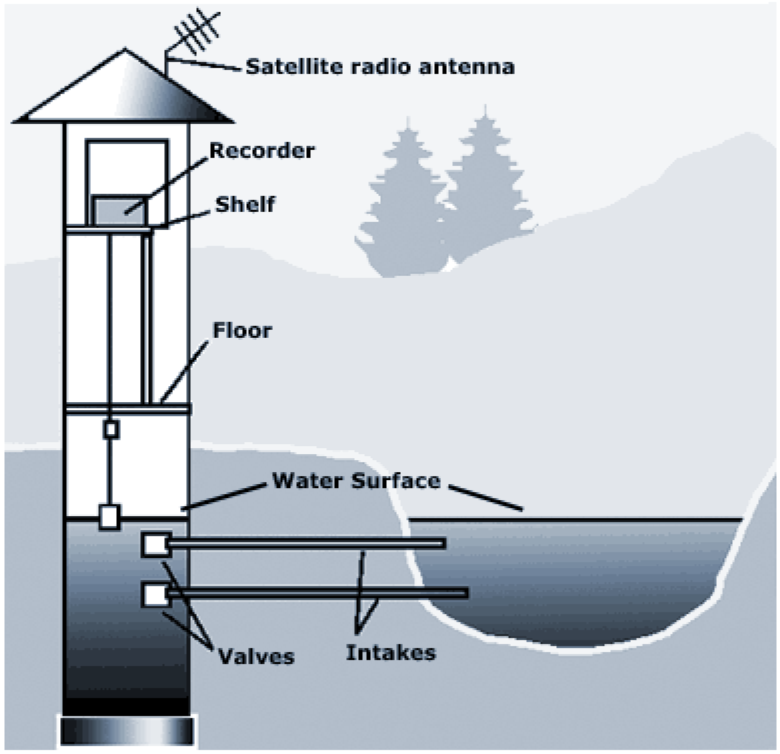

Figure C.9. Diagram of a stilling well at a stream gaging location.

Figure C.10. USGS stilling well attached to a bridge in a stream.

C.2.3. Bubbler

A bubbler system can be used in a recording gage or a real-time gaging station. It uses gas pressure to infer the stage of the stream. The stage is determined by measuring the pressure required to force a gas into a liquid at a point beneath the water surface. That pressure reading is converted into stage using a known relationship between water depth and pressure. Changes in the water level cause changes in the pressure required to release the gas into the stream channel. As the depth of water above the tube outlet increases, more pressure is required to push the gas bubbles through the tube. Data from the pressure transducer then is fed to a recorder, or data-collection platform. The measured pressure is directly related to the height of water over the tube outlet in the stream and the data recorder records the gage height and/or transmits it to a monitoring network. An outside reference gage, typically a staff gage, is read periodically to verify that the recorded gage heights from the bubble system are the same as the water levels in the stream.

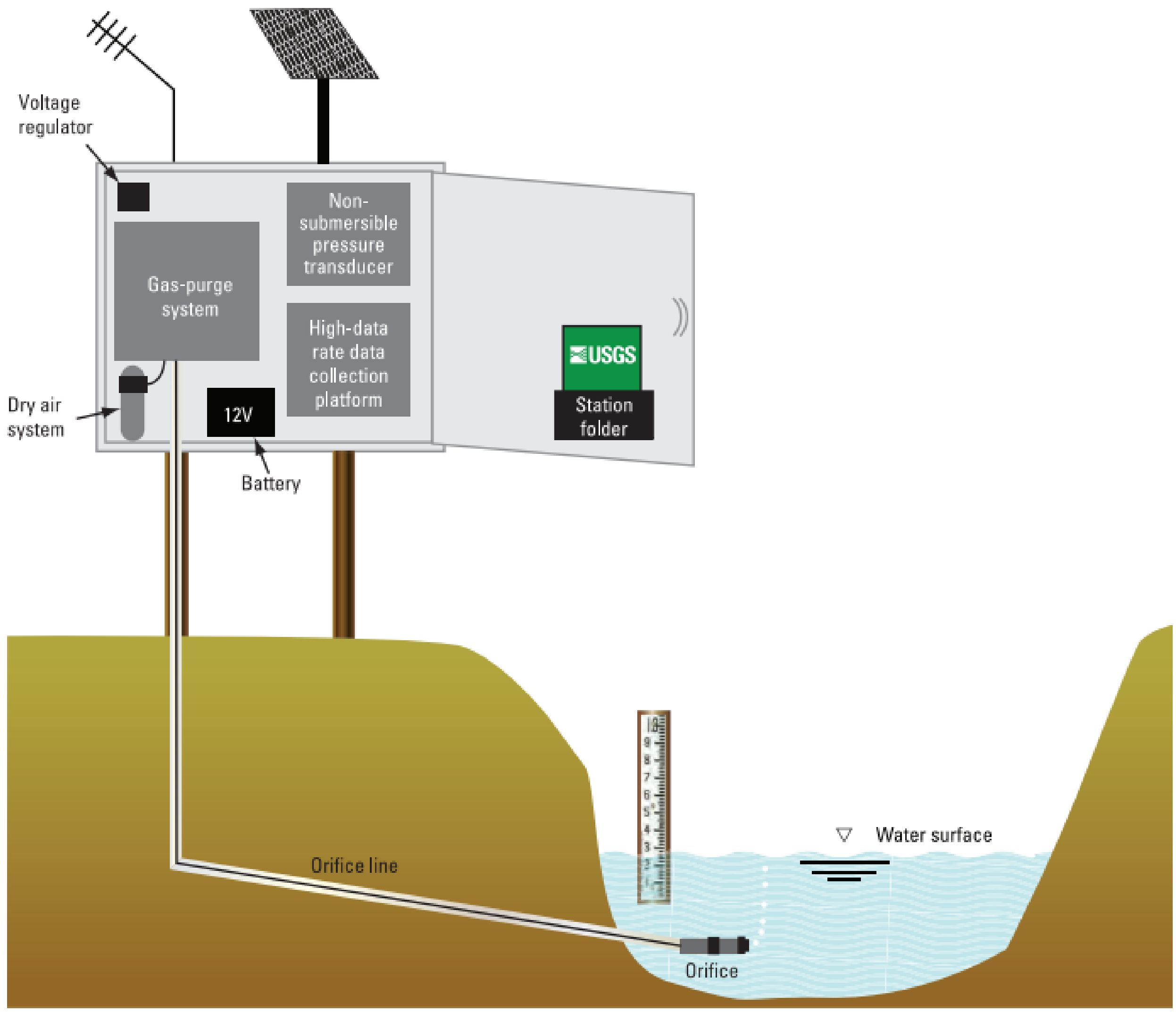

Figure C.11. Stream gage with bubbler system (Image by USGS).

C.2.4. Pressure Transducer

Pressure transducers monitor changes in pressure directly, without the use of a bubbler. The pressure from the water flowing above the transducer can be related to the water depth of the stream. Using a pressure transducer to measure stage is similar to using a bubbler system shown in Figure C.11, with the exception of the bubbles. Rather than using a tube that emits a gas into the stream or stilling well, a pressure transducer rests in the stream, usually affixed to something stationary, or it is secured to the inside of a stilling well. As the water rises in a stream, the pressure on the transducer increases and that pressure is measured by the sensor and converted into useful units such as feet. There are two types of pressure transducers: vented transducers that correct for barometric pressure and non-vented transducers. Wherever one or more non-vented pressure transducer gauges are installed at a site, there must also be an extra pressure transducer installed outside of the water, near the gaging station, to measure barometric pressure.

Figure C.12. Pressure transducer.

C.2.5. Radar

Radar water level sensors are a good option to measure water level if there is a structure in place over the body of water, such as a bridge or pier, where the sensor can be securely installed. Radar sensors use electromagnetic pulses to measure the distance between the sensor and water level by measuring the time it takes for the emitted waves to travel from the sensor to the water and back to the sensor. Lower water levels require longer travel times than do higher water levels. Perhaps the greatest advantage of radar sensors is that they are non-contact, meaning that there is no sensor installed underwater that can be damaged by the water or debris. Non-contact sensors often take less time to install and maintain than do their submersible counterparts.

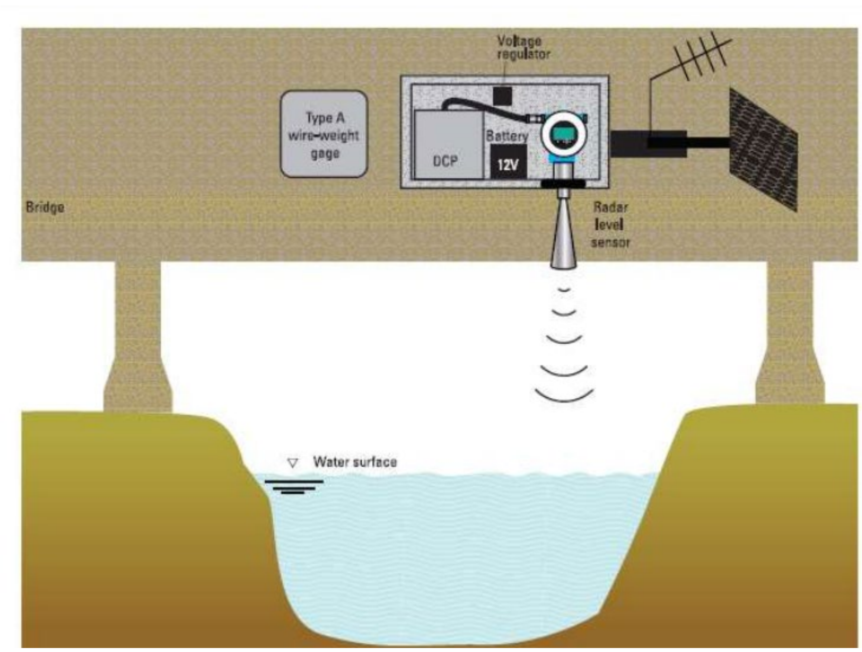

Figure C.13. Radar water level sensor (image by USGS).

Appendix D - Geostationary Operational Environmental Satellites (GOES)

The National Environmental Satellite, Data, and Information Service (NESDIS) of the U.S. Department of Commerce operates GOES that are part of a radio relay or data collection system (DCS). Data collection platforms (DCPs) measure environmental parameters (such as water level, air temperature, precipitation, etc.) and generally consist of a data logger, transmitter, power source, antenna, and various environmental sensors. DCPs (also known as gages, stations, or sites) measure sensors at a specified interval (typically every 15 minutes) and then transmit data at routine intervals (typically every hour) via the GOES DCS. The environmental data is sent up to the GOES East or West satellite where it is relayed back to a receiving station on Earth as shown in Figure D.1. Once it has been relayed back to Earth the environmental data is available for distribution (via various sources) and is typically hosted on a website.

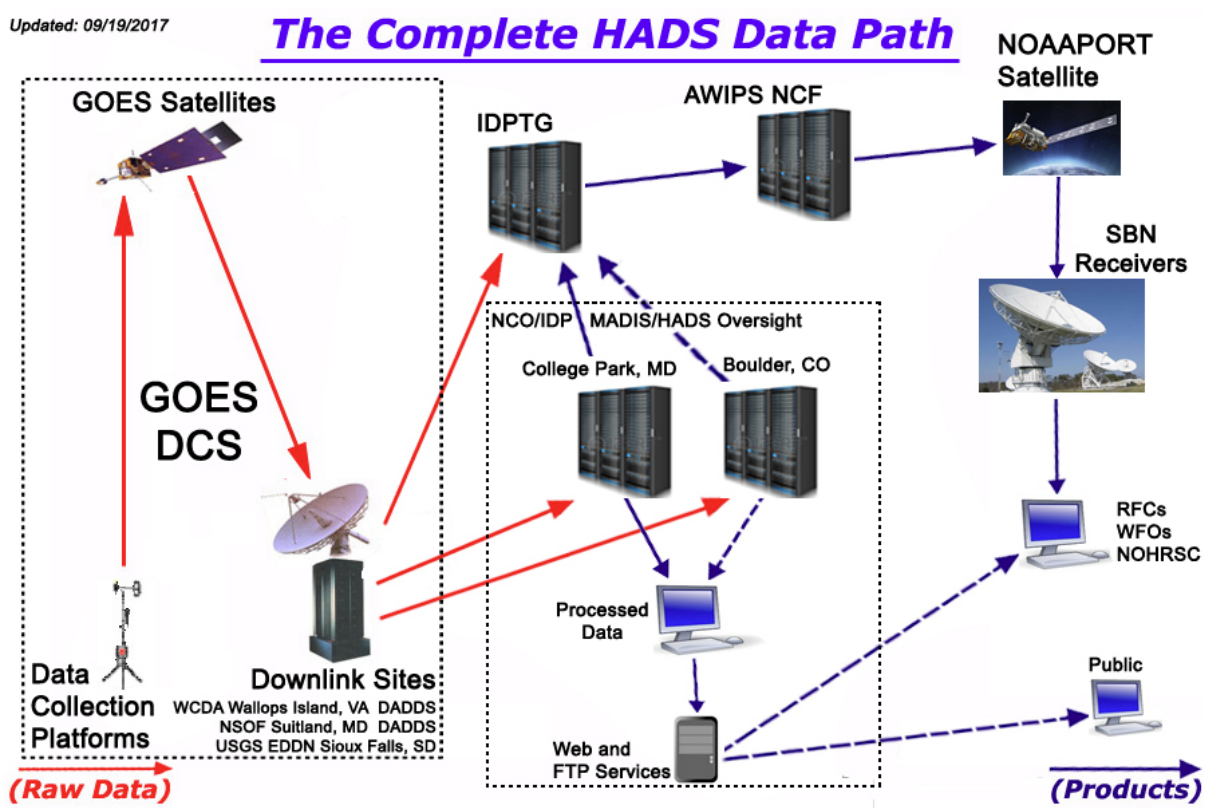

Figure D.1. Depiction of the GOES Data Transmission (from https://hads.ncep.noaa.gov/HADSdatapath.shtml)

DCPs are capable of operating in two distinct modes, self-timed and random. In self-timed mode, a DCP uplinks its data on a specifically assigned radio frequency, at specific time, on a specific GOES channel, and at defined time intervals. The vast majority of DCPs transmit on a one-hour cycle, but some transmit at 15-minute, 30-minute, 2-hour, 3-hour, and 4-hour cycles. Within each DCP's message, the actual interval of the data may be 2, 3, 5, 6, 10, 15, 20, 30 or 60 minutes. In random mode, also known as critical mode, a DCP will uplink a short message containing 1, 2 or 3 values of one or two 'critical' sensors. This occurs during extreme storms and floods and the threshold for this type of data transmission is dependent upon how the DCP has been programmed. Each station location will have a predetermined threshold for a flood threat. Typically, a random message is generated when a water level reaches and exceeds a predefined height or increases at a predefined rate. Random messages of precipitation data are typically generated when the rainfall rate for a defined time interval is met or exceeded.

D.1 Changes to the GOES DCS

In June of 2009, NOAA adopted the current set of certification standards for GOES DCP transmitters which included requirements for Version 2.0 transmitters. At a technical working group meeting in May of 2011, NOAA announced that three manufacturers had been certified to the new standard and that no Version 1.0 transmitters would be sold after May 31, 2012. Existing Version 1.0 transmitters will be supported until May 31, 2022. The Version 2.0 transition period ends on May 31, 2026. By 2026 there should be no more Version 1.0 transmitters operating in the field. Switching over to Version 2.0 transmitters doubles the channel capacity of the GOES DCS and allows users to take advantage of more frequent transmissions.

D.2 GOES DCS in the Chehalis River Basin

A majority of near real-time gages in the Chehalis River Basin use the GOES DCS to get data from field locations to a website where it is available to emergency managers, state and local officials, and the general public. Sites operated by USGS, Washington State Department of Ecology, the Flood Authority, and others all make use of the GOES DCS with GOES transmitters. The GOES DCS is used as the primary data transmission method for water level data in the Chehalis River Basin due to the large size, rugged terrain, and remote nature of the basin and because of the reliability and cost efficiency associated with the GOES system.

Appendix E - Contrail

Contrail is a data collection and management system. It manages the hydro-meteorological data and makes it available through a web interface. Real-time weather data is transmitted via GOES where it is relayed to HADS and made available through Contrail (Figure E.1). Contrail also has the ability to ingest data from other systems (USGS, METAR, NOAA Tides, FTP, etc). Users are able to access the data through the Contrail home page (Figure E.2). They are able to query individual gages to view graphs and tables of current and historical data. Links to river forecast points from the NWS are available (Figure E.3) and flood inundation maps are included to give the user reference (Figure E.4).

Site administrators (often flood managers) are able to design automated email alerts triggered by real-time measurements on the ground. These automated email alerts are referred to as *alarms* and are sent to a predetermined email list.

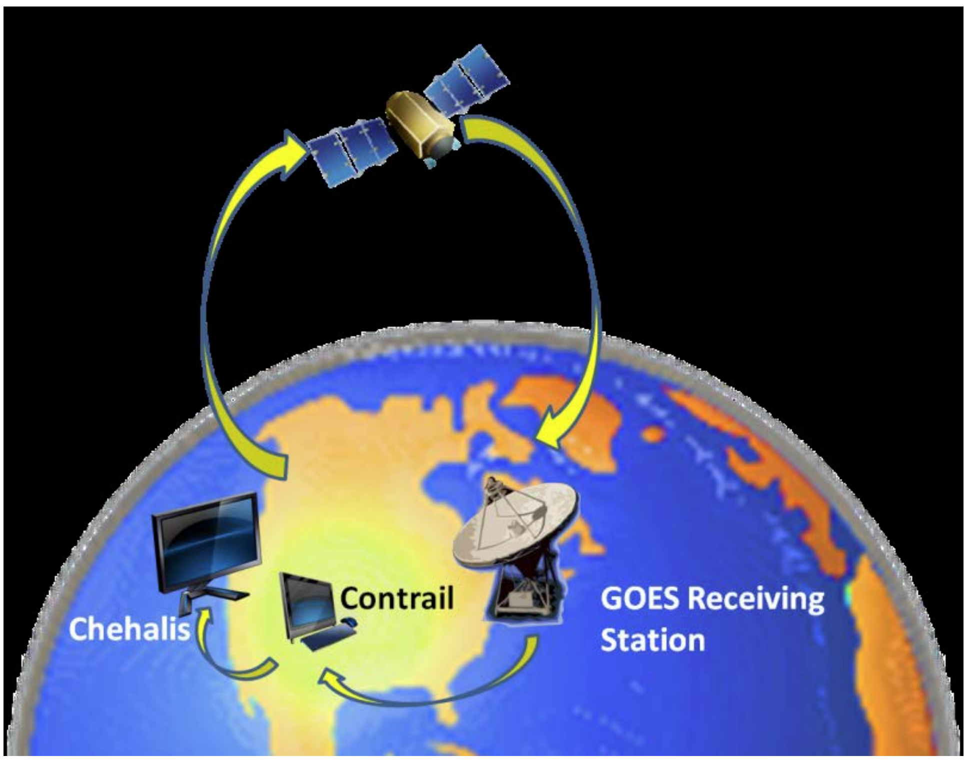

Figure E.1. Schematic of data collection and management through Contrail

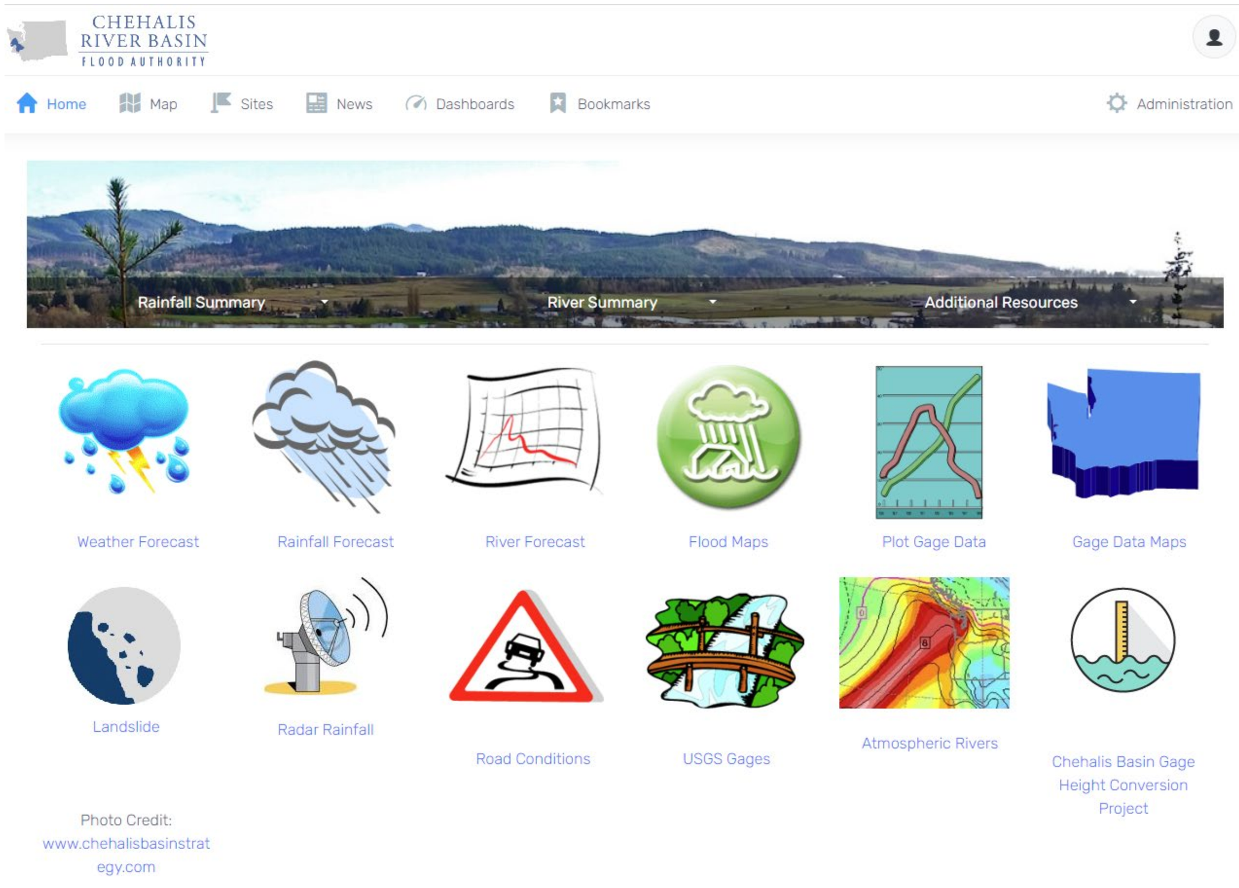

Figure E.2. The Contrail Home Page for the Chehalis River Basin Flood Authority.

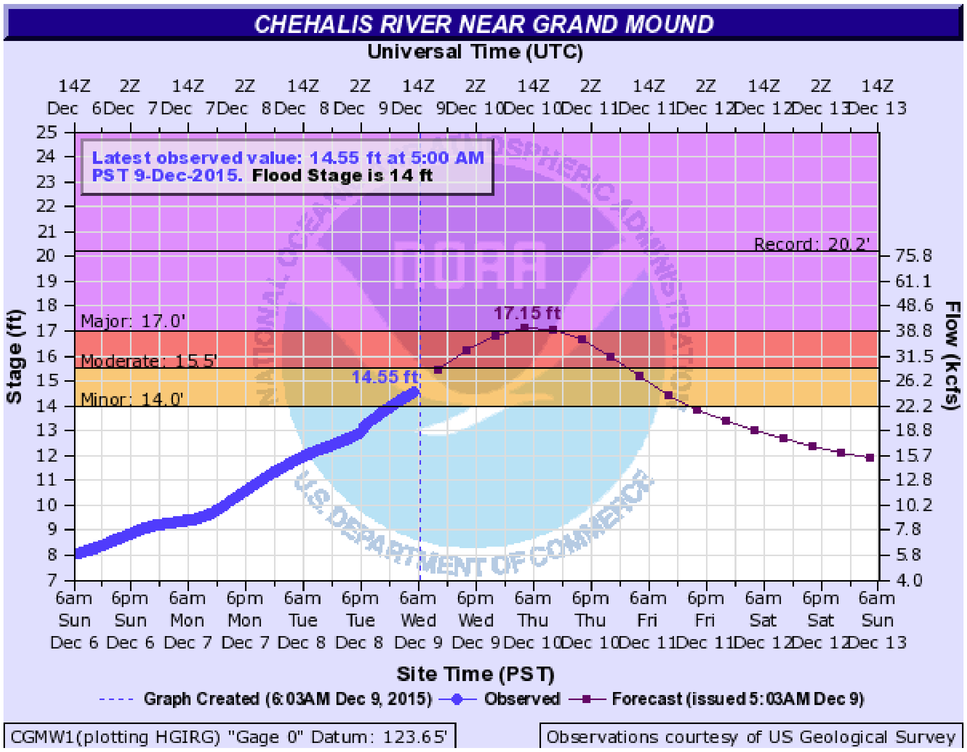

Figure E.3. Example of the National Weather Service River Forecast link.

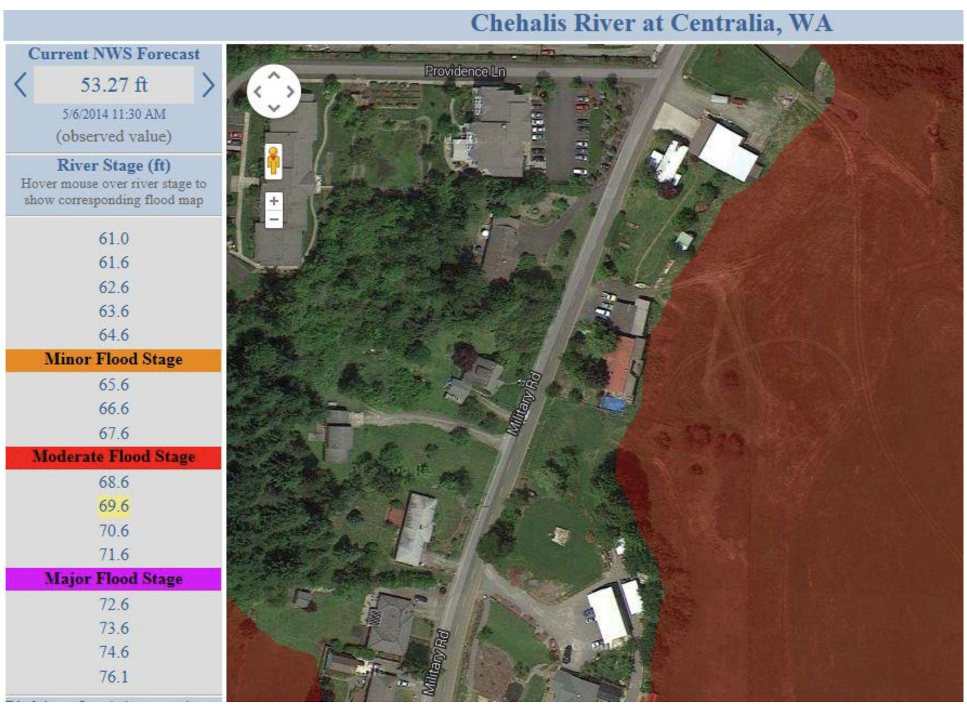

Figure E.4. Example of inundation maps available on Contrail.

E.1. Current Flood Warning System Alarms

E.1.1. Overview

Alarms are sent via email from the OneRain server to alarm recipients after a trigger is met. The trigger is defined within the OneRain site as an equation. When the height of a river at a particular site is greater than the desired trigger elevation and the site has not been in alarm for a certain period of time or the river stage has receded by a foot since the last alert, an alert email will be sent out. The time and stage recession checks prevent alarms from being spammed or triggered due to tidal activity. There are currently 13 alarms in the system (Figure E.5). Each is made to trigger at a predetermined river stage. There are no precipitation alarms.

E.2. Alarm Distribution and Frequency

Alarms are sent to a list of emails generated from requests made by public officials and members of the general public. The participants are able to request specific alarms. Figure E.6 shows the distribution of requested flood alerts. The requested alerts have been steadily increasing over the last few years. Figure E.7 shows the alarm stage height and frequency of each alarm. Note the high frequency of alarms at #11 Chehalis River near Montesano. This is a result of the tidal influence at that location.

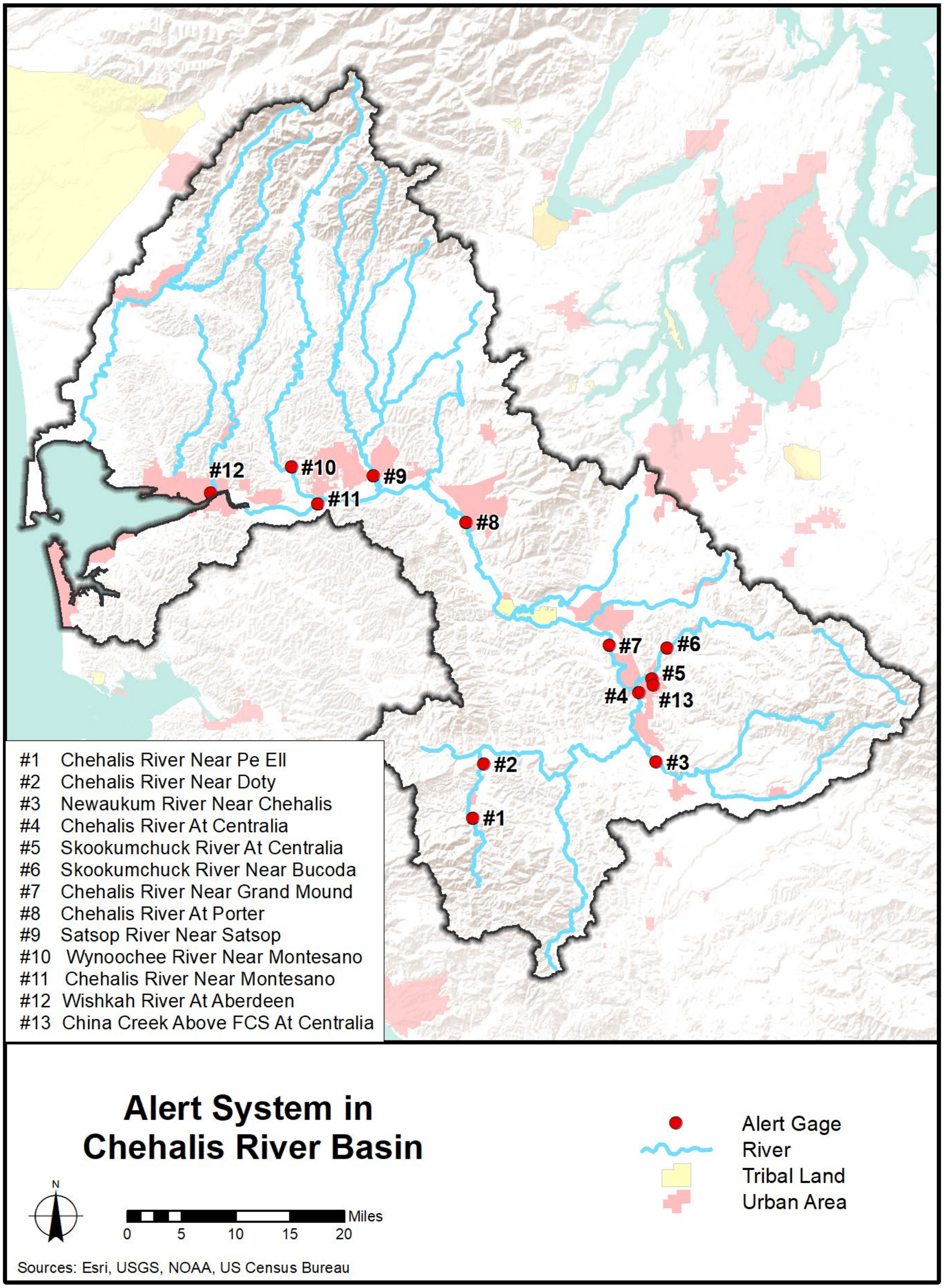
#12
#10
#9
#11
#8
#7
#6
#5
#4
#13
#3
#2
#1
#1 Chehalis River Near Pe Ell
#2 Chehalis River Near Doty
#3 Newaukum River Near Chehalis
#4 Chehalis River At Centralia
#5 Skookumchuck River At Centralia
#6 Skookumchuck River Near Bucoda
#7 Chehalis River Near Grand Mound
#8 Chehalis River At Porter
#9 Satsop River Near Satsop
#10 Wynoochee River Near Montesano
#11 Chehalis River Near Montesano
#12 Wishkah River At Aberdeen
#13 China Creek Above FCS At Centralia
Alert System in Chehalis River Basin
N
Miles
0 5 10 15 20
Alert Gage
River
Tribal Land
Urban Area
Sources: Esri, USGS, NOAA, US Census Bureau

Figure E.5. Alarms in the Chehalis River Basin Flood Warning System.

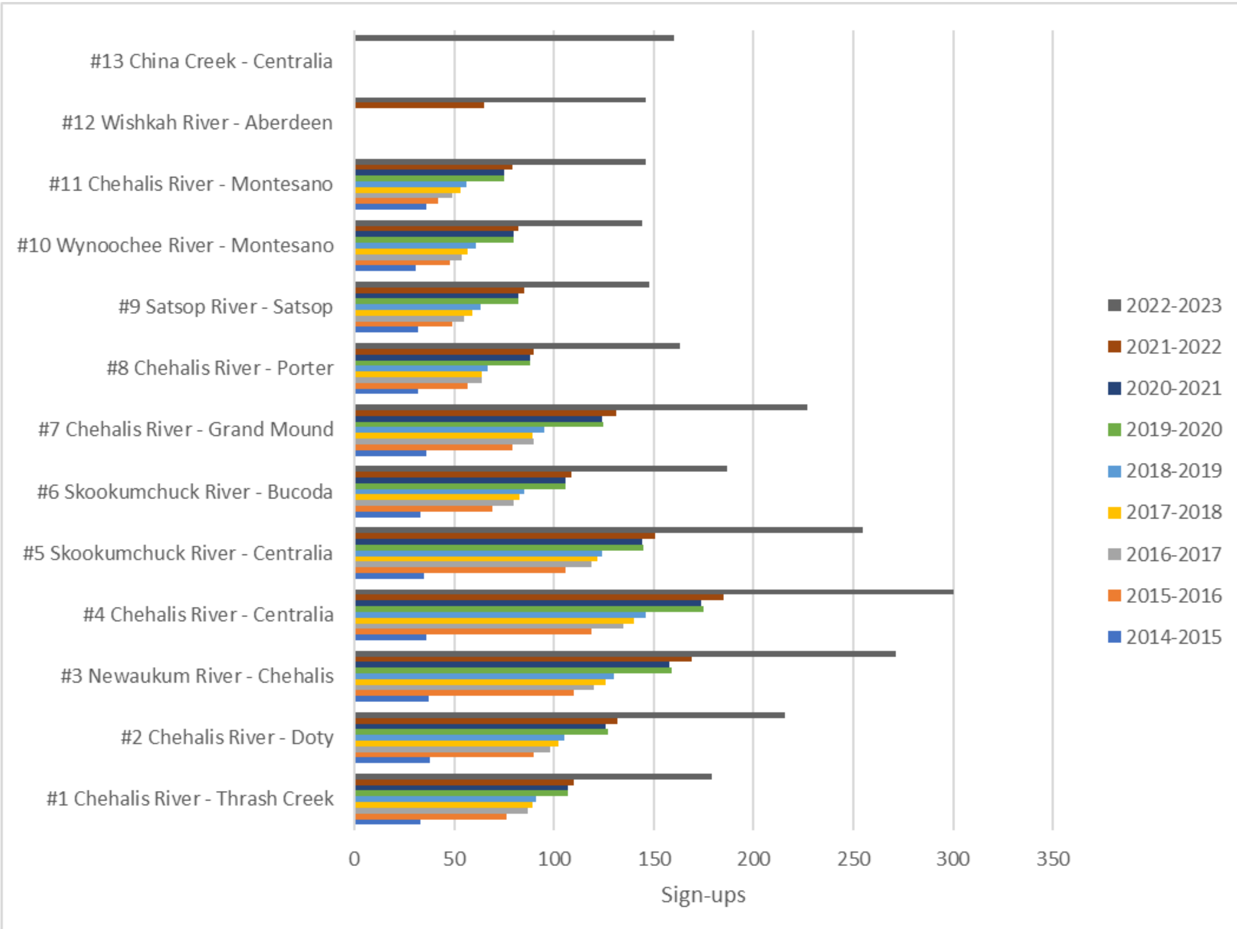

Figure E.6. Distribution of request flood alerts by site

Site Number	Site Name	Number of Alarms					
		2017-2018	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023
1	Chehalis River near Pe Ell	0	0	2	2	7	3
2	Chehalis River near Doty	1	0	2	3	3	0
3	Newaukum River near Chehalis	2	0	3	3	4	1
4	Chehalis River at Centralia	0	0	2	3	2	0
5	Skookumchuck River at Centralia	0	0	0	2	2	0
6	Skookumchuck River near Bucoda	4	0	2	3	3	0
7	Chehalis River near Grand Mound	2	0	2	3	6	6
8	Chehalis River at Porter	3	0	8	5	7	21
9	Satsop River near Satsop	2	5	3	4	5	2
10	Wynoochee River near Montesano	0	0	0	0	1	0
11	Chehalis River near Montesano	0	0	0	0	14	8
12	Wishkah River at Aberdeen	0	0	0	0	12	0
13	China Creek above FCS at Centralia	0	0	0	0	0	1

Figure E.7. Alarm stage heights and frequency of alarms.

Appendix F – Database Inventory Description

The Flood Warning System Inventory Database takes the form of an Excel Workbook. The information in the inventory was taken from several places. These include 1) data from Contrail, 2) the MesoWest API, 3) web lookups, email and over the phone contacts, 4) the Daily Global Historical Climatology Network (GHCND), and 5) the Master Station History Report (MSHR). The database includes a row for each unique measurement type and place. For stream gages there are separate rows for stage height and discharge, even though discharge is derived from stage height. For each row there are the following columns:

Site Name

The unique gage name.

County

The county that the gage is located in.

Site ID

The unique identification as assigned by the data source.

Sensor

The variable being measured.

Sensor ID

The sensor identification as assigned by the data source, if there is one.

Latitude

The latitudinal coordinate of the site in decimal degrees.

Longitude

The longitudinal coordinate of the site in decimal degrees.

Source

The Network the site data comes from.

Type

The type of measurement. There are three types: Precip (Precipitation), Stream, and Other. Precip includes rain and snow measurements. Stream includes stage, discharge, and water temperature measurements. All other parameters are listed as Other.

Contrail

Binary indicator if the sensor is included in the Contrail site.

MesoWest

Binary indicator showing if the sensor was taken form the MesoWest database.

WebLookup

Binary indicator showing if the sensor data was compiled from manual web lookups.

Shortname

The abbreviation of the sensor network

Status

Indicates whether the sensor is active or inactive

Website

A link to the gage or network website

Sensor Start

The time and date that measurements started

Sensor End

The time and date that measurements ended

Telemetry

Binary indicator showing if the sensor has known telemetry

Manual

Binary indicator showing if the sensor is known to be manually operated

Class

The type of network the sensor is a part of, either Professional Real-Time, Professional Not Real-Time, or Citizen Science.

Appendix G – Flood Warning System Operating Tasks

WEST performs a variety of tasks year-round as a part of the operation of the FWS. The Vancouver, WA office handles the field activities and data management tasks, as described below:

- Quarterly site visits to each gaging station (river/stream, precipitation, webcams) to check sensor operation.
- Pay yearly cellular fees for webcams and data loggers.
- Pay yearly OneRain Camera subscription.
- Emergency trips are made when needed to troubleshoot malfunctioning equipment.
- Arrange for repair or replacement of equipment.
- Raw data from data loggers is saved on WEST Vancouver server and uploaded into Aquarius database after quarterly site visits.
- Once per year, a volumetric calibration is performed on each tipping bucket rain gage.
- Install, remove, and/or relocate gaging stations.
- Reconnaissance for new gaging stations.
- Weekly data checks via the Flood Authority OneRain website to make sure data looks good.
- Secure and renew access agreements with landowners for permission to install and maintain gages.
- Spare gaging equipment (data loggers, sensors, etc) are stored in Vancouver.
- Maintain GOES DCS System Use Agreement.

Other activities, described below, are managed by the Bellevue, WA office:

- Download webcam images at routine intervals to back up on WEST server:
    - Image backups are performed on the first Friday of each month. The process is automated using a Python script, and the images are saved to the WEST Folsom office server.
- Facilitate flood warning contact signups by adding/removing contacts:
    - Requests come in from Scott Boettcher or David Curtis, or through the new online sign-up survey.
    - Contacts are added manually through the Contrail OneRain Alarms - Contacts page.
- Set up new alarms on website when needed.

- Keep code functioning:
    - Code is written in Python. Webcam image download and alert signup count scripts are in Python 3, while the NWS stage forecast script is in Python 2.7.
    - The NWS stage forecast script runs on the WEST Bellevue office shared computer
        - The script pings the NWS Northwest River Forecast Center database every 5 minutes, checking to see if a flood stage is predicted, and passes along predictions to the Contrail site.

Appendix H – Letter to National Weather Service

CHEHALIS RIVER BASIN FLOOD AUTHORITY

February 1, 2023 **SENT Via Email**

Logan Johnson, Meteorologist-in-Charge
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Joe Intermill, Hydrologist-in-Charge
NOAA/National Weather Service, NWRFC
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RE: Meeting To Discuss Chehalis Basin Forecasting Opportunities

Dear Mr. Johnson and Mr. Intermill:

The Chehalis River Basin has a long history of significant flooding. Over the past decade, the Chehalis River Basin Flood Authority (Flood Authority) has invested heavily in flood mitigation projects and a very successful flood warning system. The Flood Authority relies heavily upon National Weather Service (NWS) weather and river forecasts to do its job (i.e., protect people, property, and businesses from flooding). NWS forecasts are essential to protecting life and property, and integral to the Flood Authority's Flood Warning System (www.chehalisriverflood.com). That being said, current NWS forecasts have limitations that, if addressed, would resolve significant coverage gaps in the Basin.

We'd welcome the opportunity to meet with you to discuss several ideas we have for filling these gaps and improving Basin-wide forecasting, including:

1. Developing new forecast points below Chehalis River at Porter, and including Grays Harbor estuary, that consider riverine flooding, storm surge, extreme tide events, compound flooding, and inflows from key tributaries.

2. Improving inflow forecasts to and outflow forecasts from the Skookumchuck Reservoir to produce river forecasts on the Skookumchuck River near the Town of Bucoda.

In support of this request (to meet with you), the following is provided for greater context and to underscore the opportunity presented for greater Basin-wide flood warning coverage.

A. Flood and Flood Risk Mitigation History

The Washington Department of Ecology notes that "Over the past few decades, peak seasonal flood levels have been rising -- with five of the Basin's largest historical floods occurring during the last 30 years. Besides the 125-mile-long Chehalis River which flows into the Grays Harbor estuary on the Pacific Coast, the Chehalis Basin also includes the Black, Elk, Hoquiam, Humptulips, Johns, Newaukum, Satsop, Skookumchuck, Wishkah, and Wynoochee rivers, and their tributary streams (https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Chehalis-Basin)." The trend continued in January 2022 with record and near record flooding at many locations in the middle and lower Basin.

In the aftermath of the 2007 and 2009 Chehalis Basin floods, Washington Governor Christine Gregoire created the Chehalis River Basin Flood Authority (2010) to develop flood hazard mitigation measures throughout the Basin. Later, in 2016, the Washington State Legislature created the Washington State Office of Chehalis Basin (OCB) to aggressively pursue a Basin-wide integrated strategy to:

- Reduce long-term flood damage.
- Restore aquatic species.

The intense interest in mitigating flood risk and improving aquatic ecosystems in the Chehalis Basin has fostered millions of dollars of investment over the course of the past 15 years to meet these objectives. Resulting projects include levees, pump stations, improved channel conveyance, bank stabilization, critter pads, residential flood proofing, and improved flood forecast/warning systems, among others. In 2019, because of these and other significant floodplain management activities, the Flood Authority received the prestigious James Lee Witt Local Award for Excellence in Floodplain Management (here).

B. Chehalis River Basin Flood Warning System

In 2010 the Flood Authority authorized development of a flood warning system specific to the Chehalis Basin (www.chehalisriverflood.com). The system was developed and designed to:

- Be a web portal for flood information serving flood preparedness decisions by the Chehalis Basin communities.
- Provide improved data to support and leverage NWS river forecasts in the Basin.

In early-January 2022, record and near record flooding returned to the Chehalis Basin. By all measures the Flood Authority's Flood Warning System was a resounding success. Among the most valuable features of the system were the high-water alerts and flood inundation maps. Currently, there are over 2,400 individuals signed-up to receive email high water alerts from 13 key river gages in the Basin. The email alerts provide subscribers with additional warning time to respond to rising water levels. [See Flood Authority's Data Dashboard #1 here showing ever-increasing growth in usage of the Flood Warning System's email alert program.]

During the January 2022 event, in the largely rural Basin with just 175,000 residents, more than 25,000 unique logins to the Flood Warning System website were recorded. The flood inundation map pages received approximately 73,000 hits in two days, January 6-7. Social media posts about the website and inundation maps by a local newspaper (The Chronicle) and the Washington Emergency Management Department helped drive traffic to the website and inundation maps based on NWS forecasts. (See Figure 1.)

Chehalis River Basin Flood Authority Flood Warning System Website

Website:
- 25,000 User logins – January 1-10, 2022

Inundation Map Pages:
- 73,000 hits January 6-7, 2022

Third party posts:
- The Chronicle
- WA Emergency Management

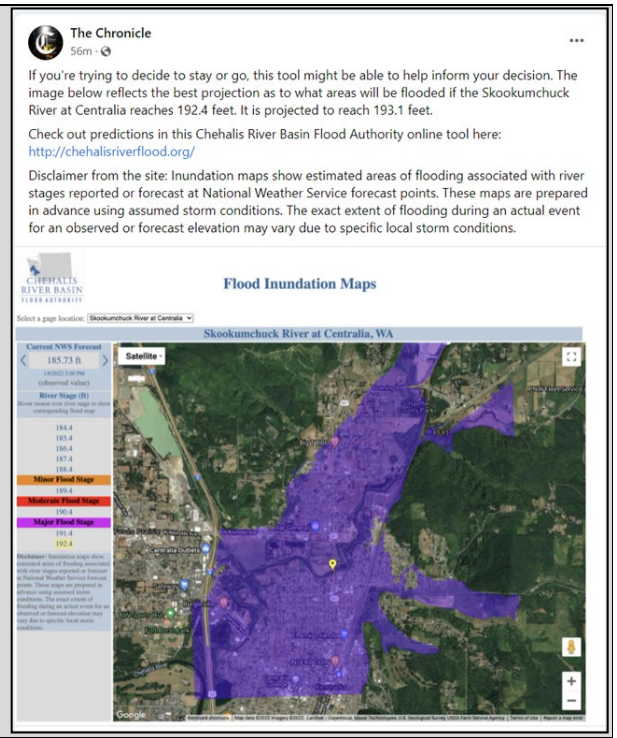

Figure 1: CRBFA Flood Warning System performance during January 2022

Investments in the flood warning system, improved flood plain management policy, and structural improvements made the Chehalis Basin communities better prepared for flooding than ever before. However, further improvements are needed, particularly in the lower Basin.

C. NWS River Forecasting Needs

A post-flood survey of flood warning system users conducted by the Flood Authority identified several areas for improvement. Two are related directly to NWS river forecasts. Survey respondents indicated that:

1. River forecasts are needed on the lower Chehalis River and tributaries between Porter and Grays Harbor.

2. Inflow forecasts to and outflow forecasts from Skookumchuck Reservoir above the town of Bucoda are needed.

D. Lower Basin River Forecasts

Currently, the NWS does not provide specific river forecasts in the lower Basin below Porter. The lower reaches of the Chehalis River are subject to compound flooding which includes riverine flooding from upstream areas combined with routine tidal influences, King Tides, and storm surges. It is our understanding that the current NWS river forecast procedures in the Chehalis River Basin are incapable of accurately accounting for these complex issues. It is also our understanding that the procedures needed to handle these issues exist within the NWS and are operational at other locations.

Improved river forecasts in the lower Basin are needed for several reasons:

1. Improved river forecasts reduce uncertainty and increase time available to complete damage reduction tasks.

2. Many structural investments made in the past decade require or are further enhanced with improved forecasts, including levee closures, pumpstation operations, residential flood proofing, and utilization of critter pads to protect ranch animals, feed stock, and equipment (Figure 2).

3. River stage forecasts in the lower Basin are needed for flood inundation mapping, the hugely popular and valuable tools currently in use in the upper Basin.

4. Climate change adaptation is a key need of the Chehalis Basin where improved forecasting is helpful in enabling residents to react to changes in the magnitude and frequency of flood producing storms coupled with sea level rise.

5. Accurate and timely lower Basin forecasting will substantially enhance management, operation, and ultimately success, of the North Shore Levee project designed to protect significant portions of Aberdeen and Hoquiam. [See recent article about this proposed significant Aberdeen-Hoquiam Flood Protection Project here.]

Figure 2. Example Critter Pads for animals (left panel) and equipment (right panel)

E. Skookumchuck Reservoir

Skookumchuck Dam is a 190 ft high earth fill dam built in 1970 primarily for water supply and includes a small hydroelectric powerhouse. The dam and reservoir were not designed nor managed for flood control, but some flood control benefits are evident. For example, unusually low reservoir levels ahead of the 2007 flood reduced downstream flood damage that would otherwise have occurred.

The dam is located approximately 10 river miles upstream from the town of Bucoda. The timing and magnitude of potential flood producing reservoir outflows impacting Bucoda are highly uncertain and are significantly impacted by available reservoir storage. These uncertainties have a large impact on flood emergency response in the vicinity of Bucoda. Representatives from Bucoda requested forecast inundation maps like those developed for seven other locations within the flood warning system. However, the NWS does not currently provide river stage forecasts at Bucoda. The USGS operates a stream gage on the Skookumchuck River near Bucoda with data starting in 1967 which could be used to develop a river forecast point.

To further protect life and property in the vicinity of Bucoda, the Flood Authority sees a key need for improved inflow/outflow forecasts for Skookumchuck Reservoir and the development of river stage forecasts near the Town of Bucoda.

Thank you for your consideration of this request. We're confident that if we could meet, we could collectively find a way to incrementally improve forecasting and protection for even greater numbers of people and business in the Basin. Please contact Scott Boettcher (Flood Authority staff) at 360/480-6600, scottb@sbgh-partners.com with questions and to schedule a time to meet.

Sincerely,

Vickie R. Raines

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Scott Boettcher, Staff -- Chehalis River Basin Flood Authority
Andrea McNamara Doyle, Director -- WA State Office of Chehalis Basin
Brent Bower, Senior Service Hydrologist -- National Weather Service
Dave Curtis, Senior Vice President -- WEST Consultants