GAGE MASTER PLAN

CHEHALIS RIVER BASIN FLOOD AUTHORITY

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WEST Consultants, Inc.

Table of Contents

List of Figures

List of Tables

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 ....US 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

NAVD88............North American Vertical Datum of 1988

NESDIS.............National Environmental Satellite Data and Information Service

NEXRAD...........Next Generation Radar

NGVD29............National Geodetic Vertical Datum of 1929

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

BACKGROUND

In response to the 2007 and 2009 flood events on the Chehalis River and tributaries, the Chehalis River Basin Flood Authority (Flood Authority) authorized the development and implementation of a flood warning system. During system development, existing hydro-meteorological gage[1] networks operated by a variety of federal, state, local, and private agencies were reviewed. Data from approximately 120 hydro-meteorological sensors in and near the Chehalis River Basin were identified and incorporated into the Chehalis River Basin Flood Warning System. Based on the location and distribution of the existing network gages, the Flood Authority installed eight additional sites measuring rainfall and temperature plus two sites measuring rainfall, temperature, and river level. The new sites helped fill gaps in data monitoring identified after the 2007 and 2009 flood events.

Since 2009, a several new sensors have been added, bringing the total to 168 sensors today. Periodically, new automated sensors become available in the region that could be incorporated into the Flood Warning System. In addition, various new gage, data, maintenance, and technology upgrade issues emerge over time.

GAGE INVENTORY

In early 2017, the Flood Authority undertook a project to update the inventory of existing hydro-meteorological networks to determine opportunities for accessing new data sources that might improve the value of the Flood Warning System, increase leverage and utilization of existing systems, and maximize the use of limited resources. The project team was also chartered to investigate issues related to the possible conversion of the vertical reference water level gage datum from NGVD 29 to NAVD 88. Finally, stage-discharge rating curves used by the National Weather Service at two river gage sites, the Chehalis River at Centralia and the Skookumchuck River at Centralia, were evaluated for accuracy.

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[1] The terms gage and sensor are sometimes used interchangeably in this report. A gage or gaging station can report data from one or more sensors. A rain gage, for example, may report only rain data. However, one gage or gaging station may report multiple data observations. For, example, each of the Flood Authority-owned rain gages report rain, air temperature, and battery voltage. Weather gaging stations may report several data observations including rain, temperature, pressure, humidity, and wind.

A broad spectrum of hydro-meteorological gages was found in and near the Chehalis River Basin from both public and private sources. The inventoried sensor types are summarized in Table E-1. In total, more than 4,800 hydro-meteorological sensors were identified. On the spectrum of hydro-meteorological gages found, precipitation, stage (i.e. water level), and air temperature are the most critical for flood warning system support. Table E-2 shows that 73 precipitation, stage (including tide), and air temperature gages currently report data to the Flood Authority website, Contrail.

Table E-1: Hydro-meteorological Sensors Inventoried

Precipitation	Pressure	Wind Speed
Discharge	Relative Humidity	Wind Direction
Stage	Solar Radiation	Wind Gust
Air Temperature	Tide	Snow Depth
Dew Point	Ocean Temperature	Other

Table E-2: Key Hydro-meteorological sensors in Contrail:

Gage Type	HADS		USGS	METAR	TransAlta	TIDES	Total
	Flood Authority	WSDOE					
Precipitation	10	0	1	3	0	0	14
Stage	2	2	40	0	2	0	46
Air Temperature	8	0	0	3	0	2	13
Total	**20**	**2**	**41**	**6**	**2**	**2**	**73**

As shown in Table E-3, more than 900 additional hydro-meteorological gages were found in and near the Chehalis River Basin, a significant increase from 2009. However, not all of these gages are suitable for integration into the Flood Warning System. The Citizen Science category of gage data, which includes mostly home weather stations, are often of uncertain quality. They were identified as a potential source of data but the data should be properly vetted before use. Another category of gage data is, Professional Not Real Time, considered professional quality but the data were not available for automated collection in a timely manner. Even without these categories of data, 119 existing sensors including 67 precipitation sensors, 52 stage sensors, and 97 air temperature sensors have been identified in and near the Chehalis River Basin that could be added to Contrail. These sensors could more than double the number of key hydro-meteorological sensors supporting the Chehalis flood warning system.

In addition to gage observations, utilizing radar data can improve the rainfall estimates and, therefore, the flood warning system. Three NWS radars collectively cover the Chehalis River Basin and provide spatial and quantitative information about rain storms moving across the basin. Also, nine water vapor monitoring sites have recently been installed in western

Washington. Water vapor gages provide data needed to more accurately forecast rainfall moving into and through the region.

Table E-3: Available Key Hydro-meteorological Sensors

Gage Type	Professional Near-Real-Time with Systems Available to Contrail	Professional Not-Real-Time	Citizen Scientist	Total
Precipitation	67	265	541	873
Stage	52	10	0	62
Air Temperature	97	40	615	752
Total	**119**	**275**	**541**	**935**

Gage Datum

Stream height measurements are referenced to a datum. A datum is a system used to reference a location on or above the Earth's surface. Horizontal datums specifically locate where a point is located on the earth's surface in units of latitude and longitude or similar coordinate system. Vertical datums reference points relative to their height above a selected level surface (such as mean sea level) and this is often expressed in terms of elevation.

As part of this project, the vertical datum for each of the stream gages in the Chehalis River Basin was identified. Currently, the majority of stream gages in the Chehalis Basin measure water levels in reference to an arbitrary datum. Some, however, are reported in NGVD29 and NAVD88, which are established sea level datums. This mix of vertical reference points can cause confusion when gage values referenced to one datum are reported and compared with mapped elevations from a different datum. Differences of 3-4 feet are possible due to the datum definitions. It can be very problematic when flood maps are used to determine the inundated extent of flood waters.

Ideally, all of the water level gages should be referenced to the NAVD88 vertical datum (NGVD29 was superseded by NAVD88 in 1991). The Chehalis River basin covers a large area and the vertical datum conversion has the potential to affect many organizations and people that work with water level data. Cowlitz, Grays Harbor, Jefferson, Lewis, Mason, Pacific, and Thurston Counties, as well as the Confederated Tribes of Chehalis Reservation and others could be affected by the change. People, homes, agricultural lands, businesses, and transportation infrastructure can all be impacted by the change. They may include long standing users of observations and NWS forecasts tied to different datum. For example, the general public use flood inundation maps, emergency operations plans, FEMA maps, and current LIDAR data users.

A full datum conversion is recommended, as well as a coincident community outreach program to ensure a smooth transition. Each gage would first be surveyed to NAVD88 and tied to a benchmark. Gage documentation and databases would need to be updated to reflect the new datum. Rating curves will also need to be adjusted before the gages would be fully converted.

The benefits of a full datum conversion include:

- Consistency between stream gages across the basin
- Numbers that make sense compared to real elevations
- Flood warning elevations are all referenced to the same vertical datum
- NAVD 88 is the standard vertical datum system used in the United States by federal agencies
- Nationwide, NAVD 88 more closely approximates an orthometric datum than NGVD 29
- Flood mapping is based on elevation data; therefore, ensuring that all elevations used for modeling are based on a single current datum is necessary
- Light Detection and Ranging (LiDAR) datasets, used for elevation data, are preferred to be collected in NAVD 88

Rating Curves

Over time, the shape of a river channel can change which may alter the relationship between river stage and the volume of water flowing (i.e. discharge) in the river at that stage. The stage-discharge relationship is typically developed by periodically measuring stream flow over a range of water elevations.

In the case of two critical NWS forecast points in the Chehalis Basin, the Chehalis River gage near Centralia (CENW1) and the Skookumchuck River gage at Centralia (CTAW1), the current stage-discharge relationships were not derived by measurement. Rather, they were estimated using a hydraulic model (i.e. computer model) and updated within the last five years.

The stage-discharge relationship is an important component in flood forecast and warning. The NWS flood forecast models convert precipitation to forecasted river flows. The stage-discharge is used to convert forecast flows into forecast stages. The forecasted stages are then released to the public.

Concerns were recently raised as to the accuracy of these stage-discharge relationships. To address this question, the published NWS stage-discharge relationships were compared with stage-discharge relationships from the most recent calibrated hydraulic model at the two NWS river forecast locations, CENW1 and CTAW1.

Significant differences were found between the most current modeled stage-discharge relationship and the one used by the NWS for the Chehalis River near Centralia. When the Chehalis River near Centralia is above flood stage (65 ft.), the current modeled stage is up to two feet higher for the same discharge. For a moderate flood flow of 40,000 ft^3/sec, the NWS stage-discharge relationship would indicate a stage of approximately 69.3 ft. while the most recent hydraulic model indicates a stage of about 71.2 ft. In other words, the current NWS forecast stages may be underestimating the flood elevations by up to two feet.

At flows below about 15,000 ft^3/sec, the NWS stage-discharge relationship over estimates stage in the Chehalis River near Centralia by as much as two feet. At these flows, the differences are not a problem for flood warning but may be an issue for other interests such as navigation or water treatment plant operations.

Differences of up to 1.5 ft. were noted the Skookumchuck River at Centralia. The NWS stage-discharge relationship tended to underestimate forecast elevations until flows exceeded 9,000 ft^3/sec which is in the moderate to major flood range.

The results of this comparison will be forwarded to the NWS for their consideration and review.

Upgrade GOES DCS

The GOES Data Collection System (DCS) is used as the primary data transmission method for water level data in the Chehalis River Basin. An upgrade to GOES DCS, Version 2 is now available. Both the USGS and the Wahington State Department of Ecology (Ecology) have almost completely transistioned over to the Version 2.0 GOES transmitters as of March 2017. To keep up with its partners within the Chehalis River Basin and avoid the cut-off date of old technology, it is advisable for the Flood Authority to upgrade to GOES DCS, Version 2.0 transmitters during the next two years.

Recommendations

- **Add Additional HADS, USGS, and METAR Precipitation Gages.** Rather than installing more gages on the ground, it is advisable to include gages that are already operating in the Chehalis Basin, but are not yet part of the Chehalis River Basin Flood Warning System.
- **Add Ecology Stream Gages to Contrail**. Five Ecology stream gages that are not included in the HADS system are located in the basin. These gages are primarily located on small tributaries to the Chehalis River (Figure 2 7) and can be added to HADS and then to Contrail.
- **Upgrade Two National Weather Service Flood River Gages near Centralia**. The stream gages on the Chehalis River gage near Centralia and on the Skookumchuck River at Centralia should be upgraded to current technology. (This is complete.)
- **Convert Gages to NAVD88 Datum**. The USGS and the Flood Authority are jointly funding the conversion of the USGS gages in the Chehalis Basin to the NAVD 88 vertical datum by the summer of 2018. Ecology is currently converting their gages to NAVD 88.

- **Outreach Program to Educate Agencies and Public on Datum Conversion**. Create an outreach and educational awareness datum conversion plan, with the goal of providing support to the identified agencies and public about the vertical datum change.
- **Update GOES DCS**. The Flood Authority should upgrade its gages to GOES Version 2.0. (The Flood Authority Authorized the upgrade and the upgrade is in progress.)
- **Add City of Aberdeen Stream Gage to Contrail.** If arrangements are made with the City of Aberdeen to access the City's stream gage data, the data could then be added to the Contrail.
- **Add NWRFC River Forecasts to Contrail**. NWRFC has eight river forecast locations on the Chehalis River. NWRFC River forecasts at these locations can be added as sensors to Contrail. Alarms can then be designed based on the forecasted data.
- **Consider Adding GARR to Contrail.** Gage Adjusted Radar Rainfall (GARR) data uses rain gage data in combination with real-time NEXRAD radar to create a more accurate spatial distribution of real-time precipitation. Although the added benefit of adding GARR will be reduced as more gages are added, there is still a value associated with GARR. It would in increase the accuracy of real time rain on the ground estimates and longer termed archived quality controlled data.

1 Background

1.1 Purpose and Scope

Prior floods in the Chehalis River Basin and the potential for future flood events have created the impetus for increased 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 in an effort 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 River Basin Flood Authority

The Flood Authority was formed in April of 2008, by an inter-local agreement among Lewis, Gray 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.

1.3 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, Gray 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.

1.3.2 Land Cover

The Chehalis Basin is mountainous with low-lying river valleys. Most of the developed land is located 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 tracks 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.

1.3.3 Climate

Temperature in the basin is 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 grid cells 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. The majority of storms originates 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 induced 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 portion of the basin lacks the same magnitude orographic enhancement of precipitation as seen in the North. It receives less rainfall due to its lower elevations and orientation of watersheds. The southern portion of the 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 to the west outside if the basin

There is a strong seasonal signal in the temporal distribution of rainfall. The rainy season is 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.

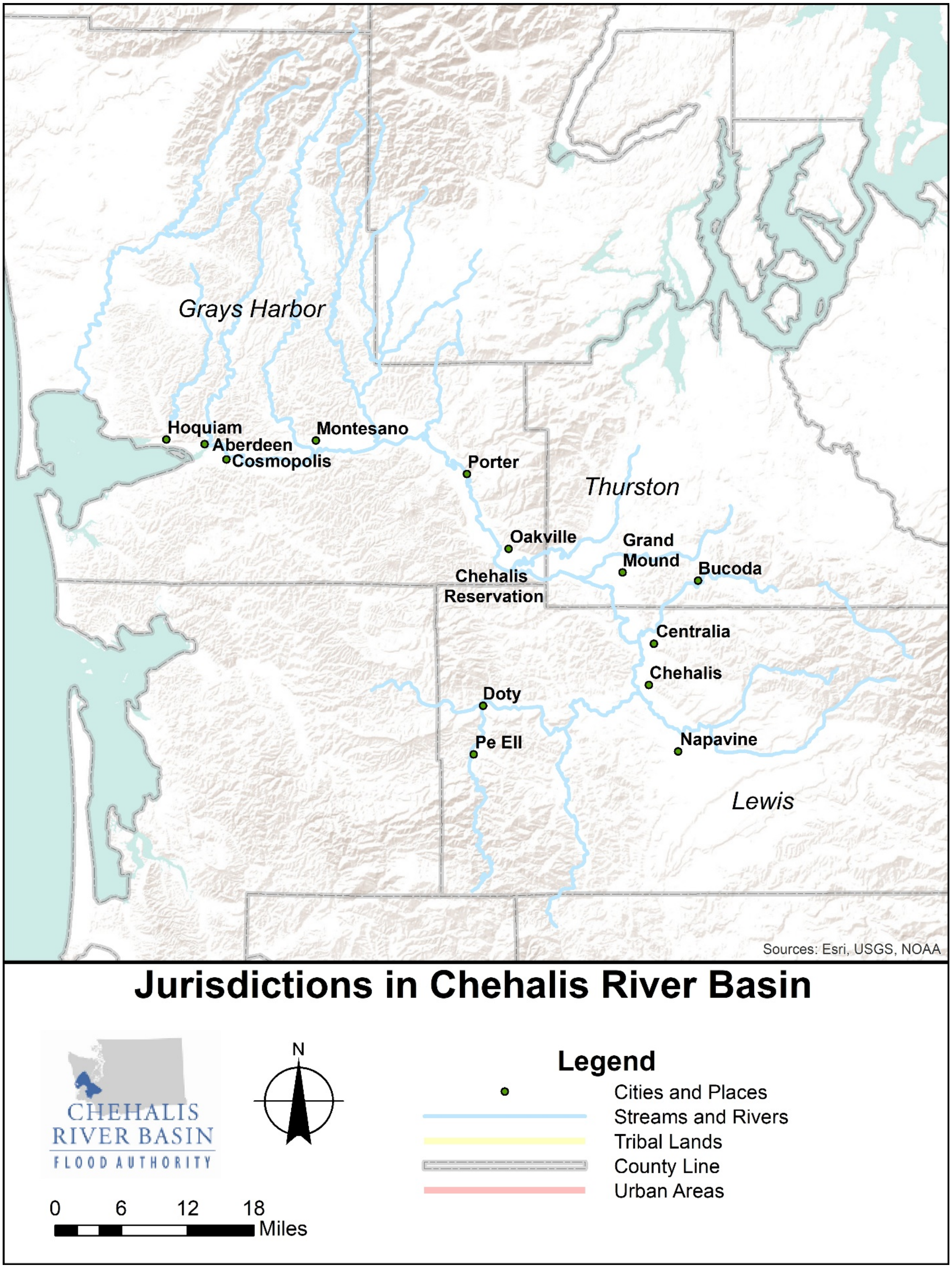

Figure 1-1. Jurisdictions in the Chehalis River Basin

Figure 1-2. Chehalis River Basin Land Cover

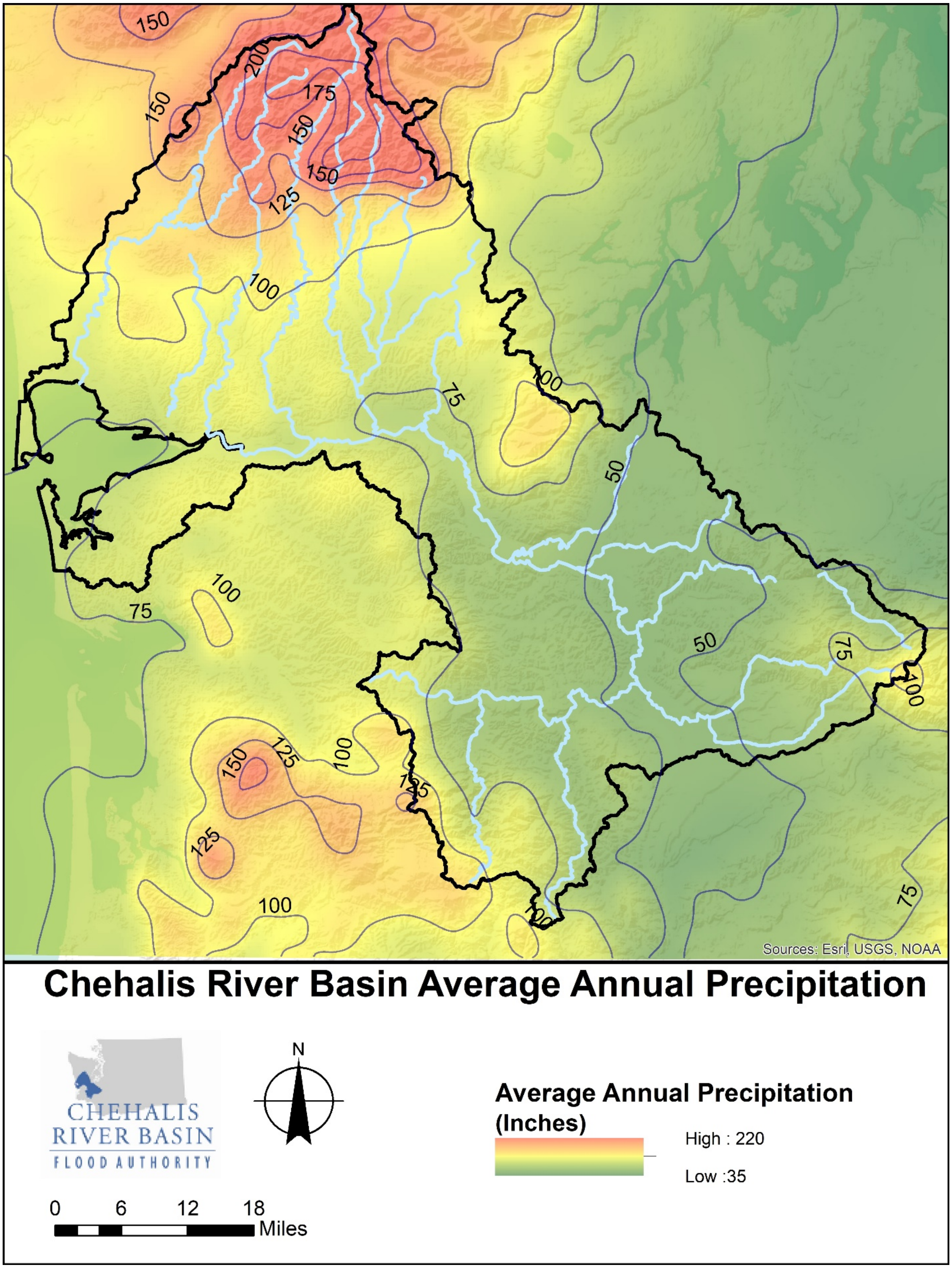

Figure 1-3. Chehalis River Basin Average Annual Precipitation

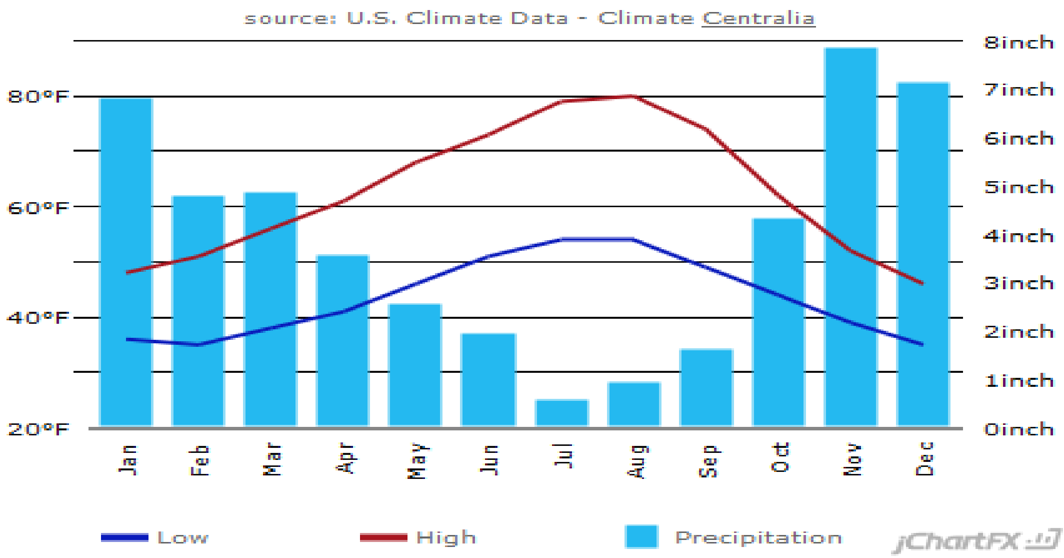

Figure 1-4. Climate Data for Centralia, WA

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.

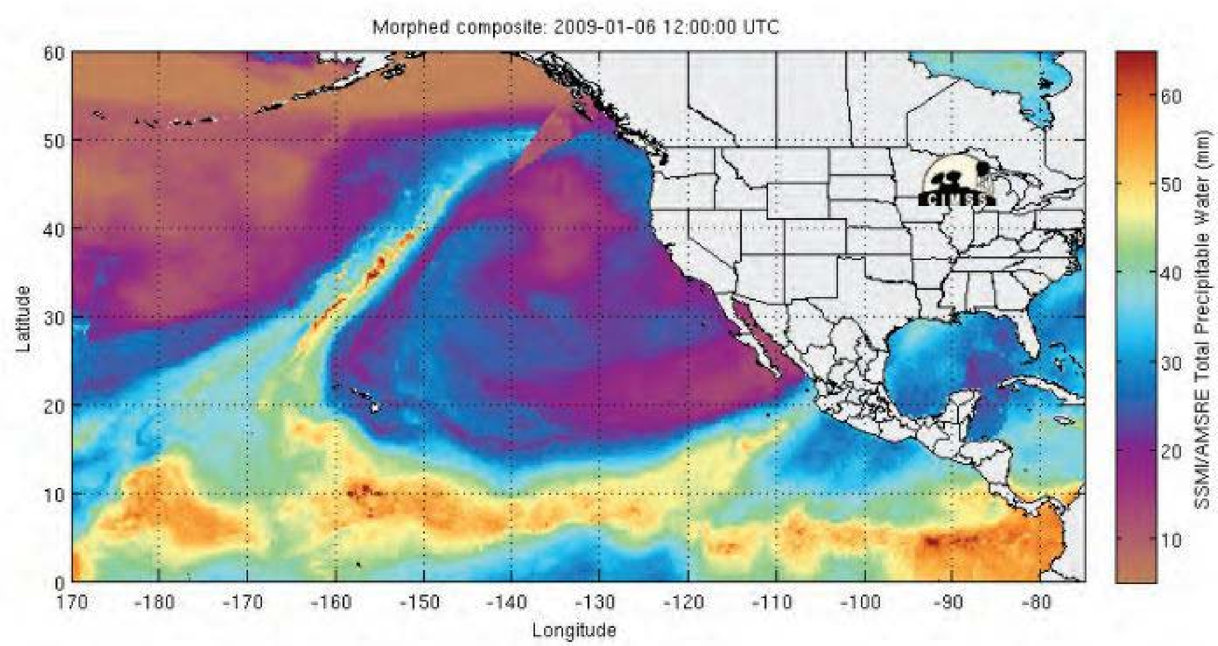

Figure 1-5. Atmospheric River heading for West Coast (USGS$_3$, 2010)

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. Along its route to Grays Harbor, the Chehalis River is joined by a number of tributaries, which are listed in Table 1-1. The additional rivers that discharge into Grays Harbor are listed in Table 1-2. The major rivers and tributaries are shown in Figure 1-6.

Table 1-1. Tributaries to the Chehalis River

Tributary Name
Elk Creek
South Fork Chehalis
Newaukum River
Skookumchuck
Scatter Creek
Black River
Cloquallum Creek
Satsop River
Wynoochee River

Table 1-2 Additional Rivers Discharging into Grays Harbor

River Name
Humptulips River
Hoquiam River
Wishkah River

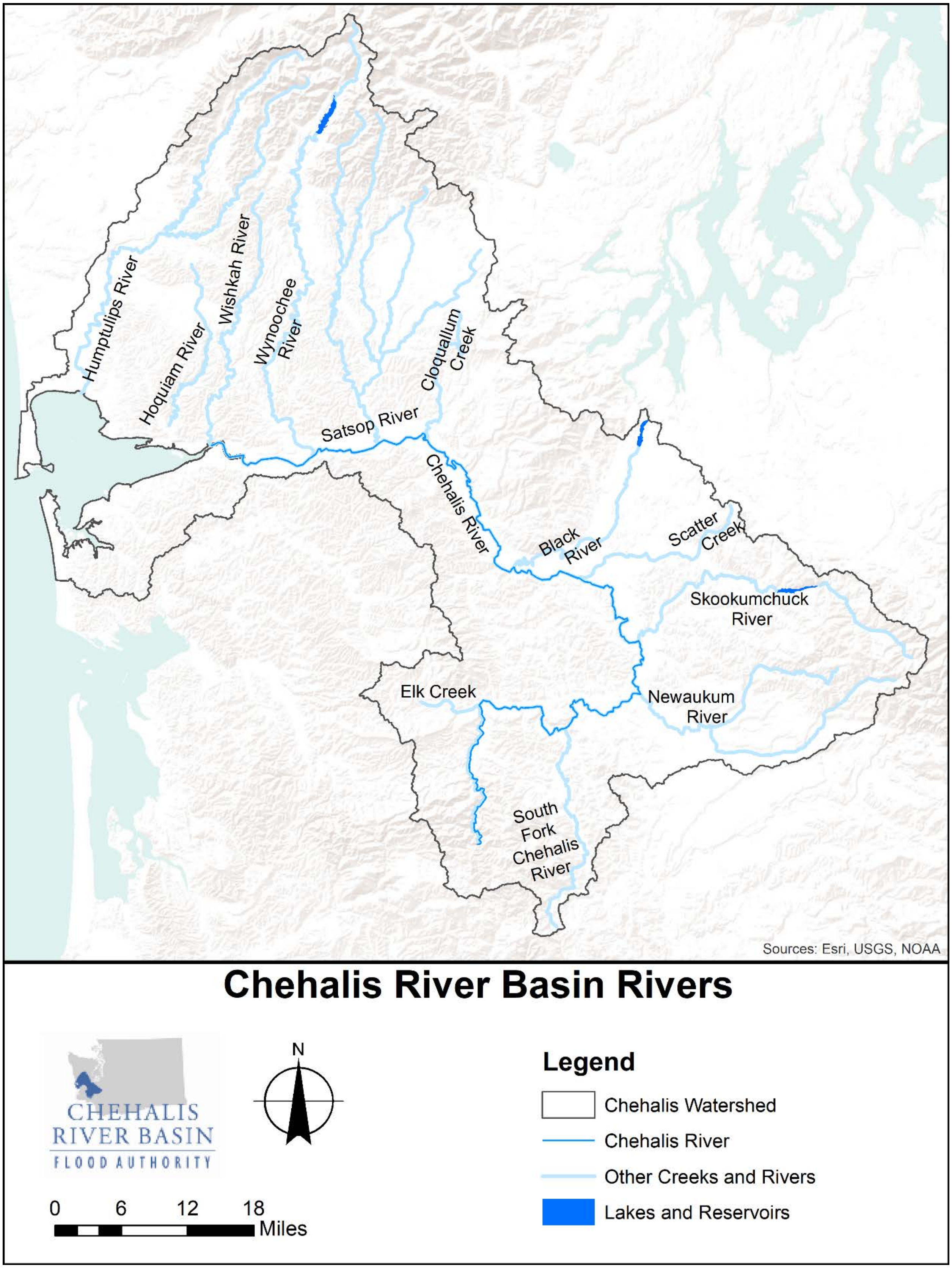

Figure 1-6. Tributaries to the Chehalis River

Long-term average flow in the Chehalis River at USGS stream gaging locations 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 1-3. Median Flow in the Chehalis River ($USGS_1$).

Station Number	Station Name	Long-Term Median Flow (cfs)
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

Table 1-4 Median Flow in Chehalis River Tributaries

Station Number	Station Name	Long-Term Median Flow (cfs)
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 a rain dominated watershed. The exceptions, as indicated by blue shading on (Figure 1-7), are some distant reaches of the basin. These areas are the snow dominated and rain-snow transitional headwaters of the Southern Olympic and Cascade Foothills and the rain-snow transitional headwaters of the Black Hills and Willapa Hills. Therefore, most streamflow in the basin is maintained by groundwater recharge and rainfall.

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_2). 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 (TransAlta, 2017_1).

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, 201

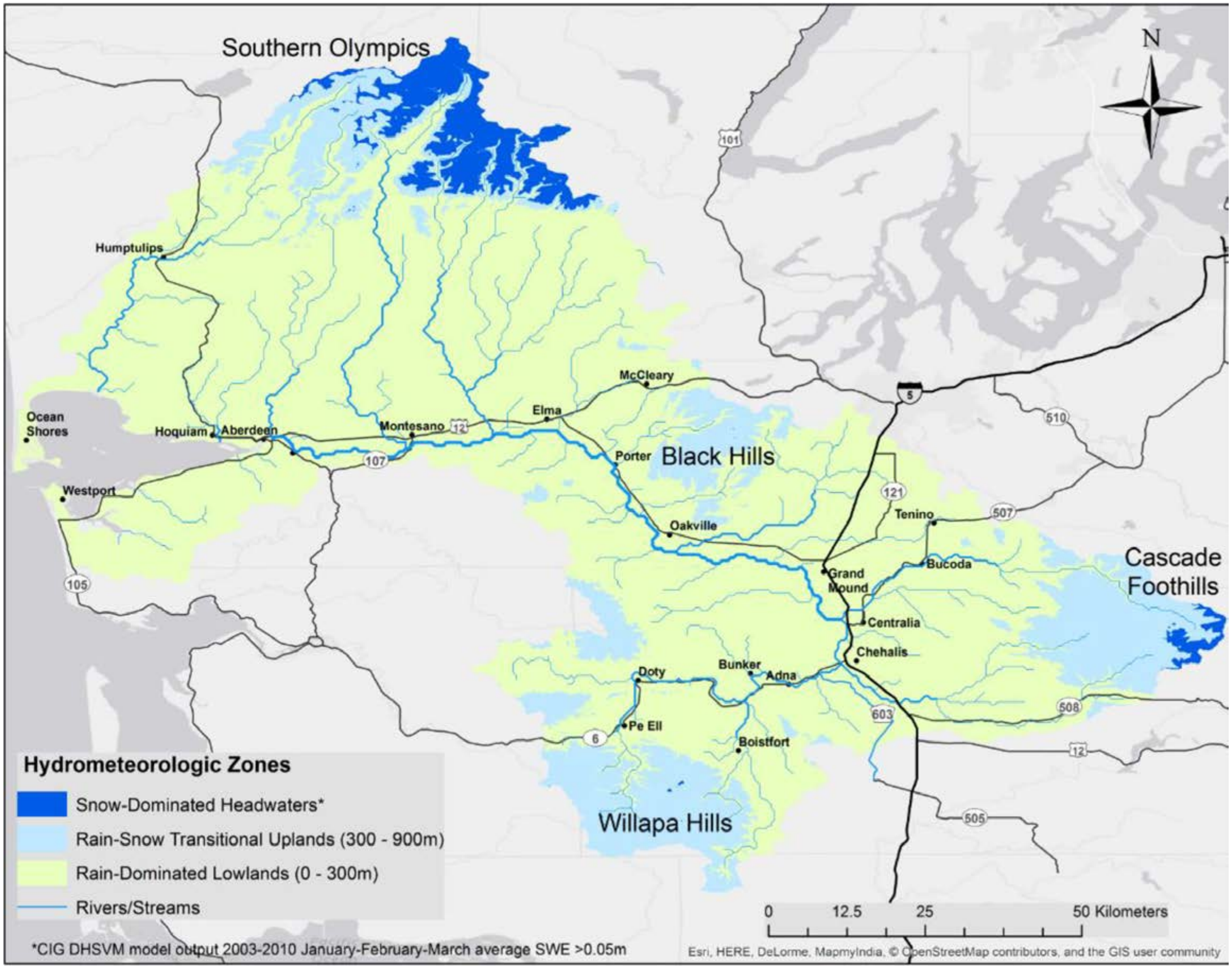

Figure 1-7. Hydro-Meteorological Zones (Perry et al. 2016)

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. The majority of floods are minor, causing minimal damage. Although, occasionally they can be significant resulting in loss of life and property. The last four major floods are presented in detail in Appendix B.

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 1-5. 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.

Table 1-5. NWS Flood Stage Categories

Flood Category
Major Flooding
Moderate Flooding
Minor Flooding

Flood Stage is defined as the water surface level which begins to impact property or commerce and is not necessarily the same as bankfull stage. Flood stages for selected stations in the Chehalis basin are listed in Table 1-6.

Table 1-6. NWS Flood Stages for Rivers in the Chehalis Basin

NWS Station Name	USGS Station Number	USGS Station Name	Flood Stage (Feet)
DOTW1	12020000	Chehalis R near Doty	13.0
NEWW1	12025000	Newaukum R near Chehalis	10.5
CENW1	12025500	Chehalis R near Centralia	65.0
BCDW1	12026400	Skookumchuck R near Bucoda	13.5
CTAW1	12026600	Skookumchuck R at Centralia	85.0
CGMW1	12027500	Chehalis R near Grand Mound	14.0
CRPW1	12031000	Chehalis River at Porter	21.0
SATW1	12035000	Satsop River near Satsop	34.0
MNSW1	12037400	Wynoochee R near Montesano	18.0

In Figure 1-8, the daily average stage during the flood season (November through March) is plotted for the entire historical USGS gage record for the Chehalis River at Ground Mound. The colors match the NWS flood categories to more easily visualize the flood category. Note that most of the flooding occurs from December through February.   Figure 1-8 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 is included to supplement Figure 1-8 and lists the total number of days during each category.

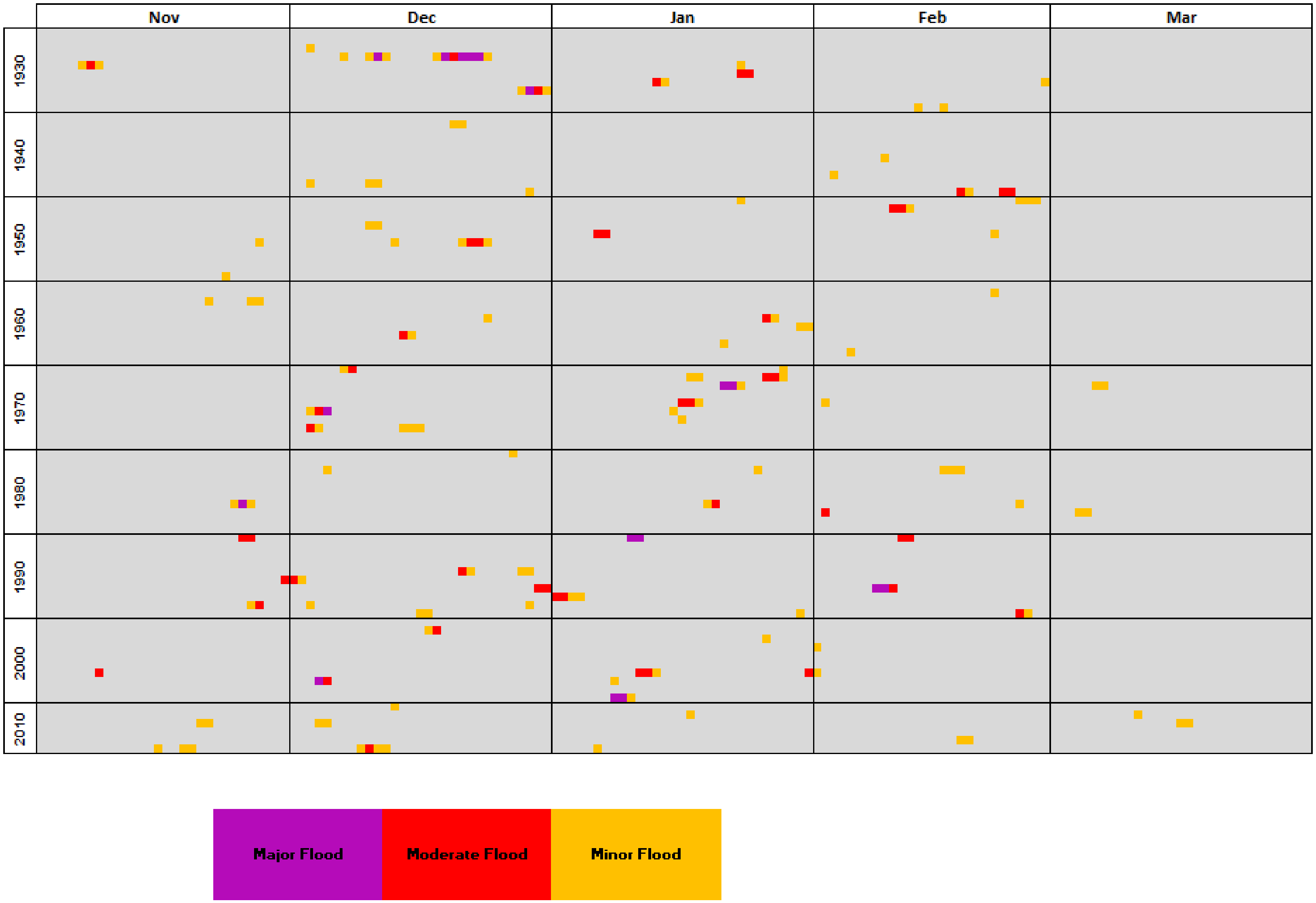

Figure 1-8. Historical Daily Average Stage for the Chehalis River at Ground Mound during the Wet Season

Table 1-7. Number of days above flood stage at Chehalis River at Ground Mound

November- March		Days Above flood stage		
		Minor	Moderate	Major
1931	1932	0	0	0
1932	1933	1	0	0
1933	1934	10	1	5
1934	1935	3	1	0
1935	1936	0	2	0
1936	1937	2	1	0
1937	1938	3	1	1
1938	1939	0	0	0
1939	1940	2	0	0
1940	1941	0	0	0
1941	1942	2	0	0
1942	1943	0	0	0
1943	1944	0	0	0
1944	1945	0	0	0
1945	1946	1	0	0
1946	1947	0	0	0
1947	1948	1	0	0
1948	1949	3	0	0
1949	1950	2	3	0
1950	1951	4	0	0
1951	1952	1	2	0
1952	1953	0	0	0
1953	1954	2	0	0
1954	1955	1	2	0
1955	1956	4	2	0
1956	1957	0	0	0
1957	1958	0	0	0
1958	1959	0	0	0
1959	1960	1	0	0
1960	1961	0	0	0
1961	1962	1	0	0
1962	1963	3	0	0
1963	1964	0	0	0
1964	1965	2	1	0
1965	1966	2	0	0
1966	1967	1	1	0
1967	1968	1	0	0
1968	1969	1	0	0
1969	1970	0	0	0
1970	1971	2	1	0
1971	1972	3	2	0
1972	1973	5	0	2
1973	1974	0	0	0
1974	1975	2	2	0
1975	1976	3	1	1
1976	1977	1	0	0
1977	1978	4	1	0
1978	1979	0	0	0
1979	1980	0	0	0
1980	1981	1	0	0
1981	1982	0	0	0
1982	1983	5	0	0
1983	1984	0	0	0
1984	1985	0	0	0
1985	1986	0	0	0
1986	1987	5	1	1
1987	1988	2	1	0
1988	1989	0	0	0
1989	1990	0	0	0
1990	1991	2	4	2
1991	1992	0	0	0
1992	1993	0	0	0
1993	1994	0	0	0
1994	1995	3	1	0
1995	1996	1	2	0
1996	1997	2	3	2
1997	1998	2	2	0
1998	1999	3	1	0
1999	2000	4	1	0
2000	2001	0	0	0
2001	2002	1	1	0
2002	2003	1	0	0
2003	2004	1	0	0
2004	2005	0	0	0
2005	2006	0	0	0
2006	2007	2	4	0
2007	2008	2	1	1
2008	2009	0	0	0
2009	2010	3	0	2
2010	2011	1	0	0
2011	2012	2	0	0
2012	2013	6	0	0
2013	2014	0	0	0
2014	2015	2	0	0
2015	2016	7	1	0
2016	2017	0	0	0

1.5 Chehalis River Basin Flood Warning System

The Flood Warning System was created by the Flood Authority. The warning system is a tool to inform the public of imminent danger during a flood and to maximize flood awareness. It includes a publicly accessible, Internet-based flood data collection; webpage interface; and automated email alert system. Rain, stream, reservoir, wind, and temperature information are collected, displayed, and used in near real-time. 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 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 G). The following chapter will describe the gage data currently used in the Flood Warning System.

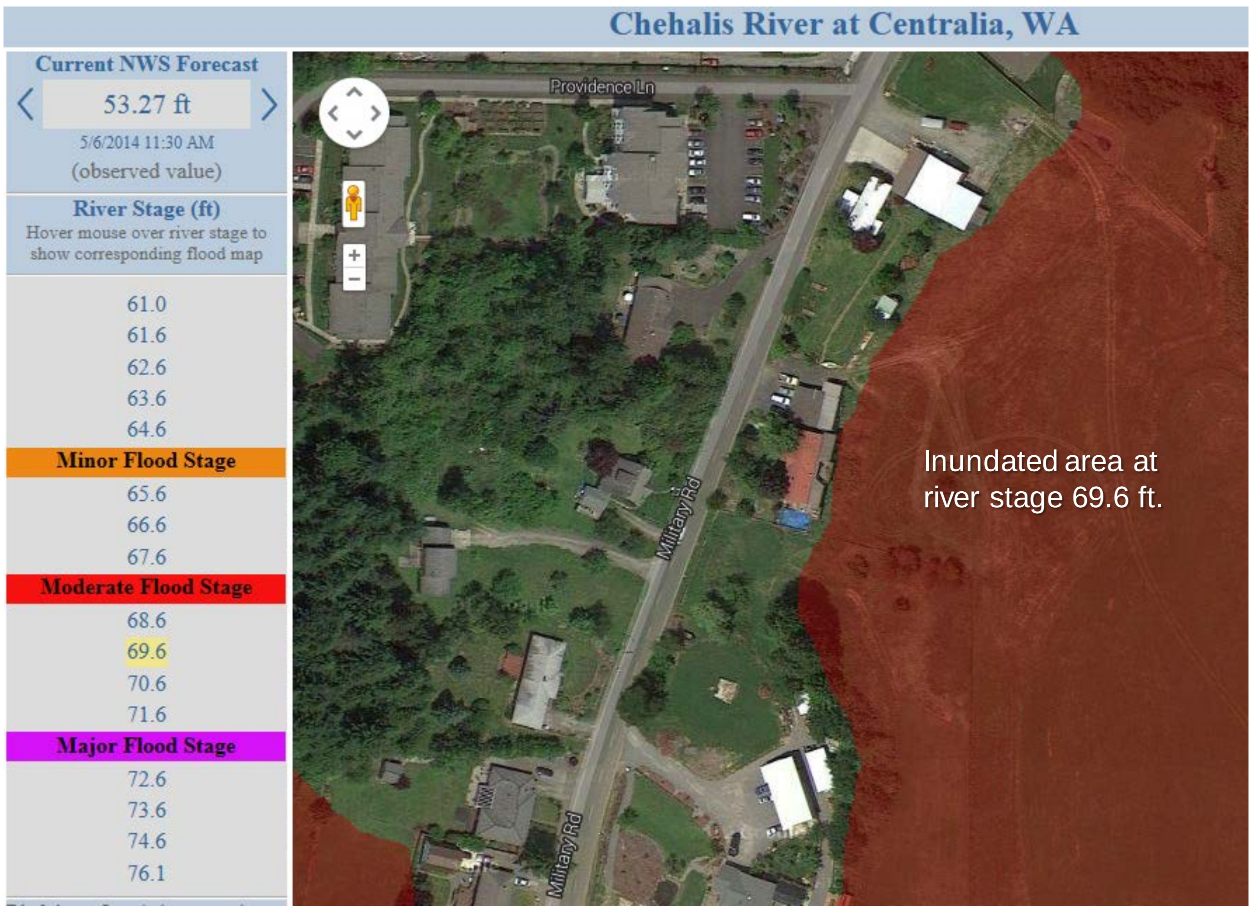

Figure 1-9. Example of Inundation Map Available on Contrail

2 Flood Warning System Gage Inventory

Flood monitoring in the Chehalis River Basin begins with precipitation, temperature, and streamflow measurement. The number, placement, and quality of gages used for monitoring is of particular importance to any Flood Warning System. An inventory of hydro-metrological gages within the Chehalis River Basin was generated as 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 the purpose of 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, 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 chapter 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 Metrological).

2.1 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. 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, and TransAlta. Stations 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.

2.1.1 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. The HADS system acquires raw hydro-meteorological data from gages on the ground and disseminates it through the GOES Data Collection Platforms (DCPs) (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:

- USGS
- NWS
- Flood Authority
- Ecology

2.1.1.1 Flood Authority

The Flood Authority owns 10 precipitation, 10 temperature, and two stream gages. Battery voltage at each site is also reported to support gage maintenance. These gages report through the GOES and are made available to Contrail through HADS. The county also publishes real time flood stages for its monitored rivers through its Emergency Management Department

2.1.1.2 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. Several, but not all, of these gages are connected through HADS.

2.1.2 U.S. Geological Survey's National Water Information System (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, 2017[3])

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 40 USGS stream gages connected through Contrail. Of these, 34 have rating curves which allow for the calculation of discharge from gage height. A full discussion of rating curves is provided in Chapter 4. The USGS cooperates with other entities for funding. The following are some contributors for funding of USGS gages near Chehalis River Basin.

Table 2-1. List of USGS Partners in the Chehalis River Basin

Washington State Department of Ecology
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

*Note NWS does not contribute funding, but contributes time and resources

2.1.3 METAR

The 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.

2.1.4 TIDES

The TIDES system is provided by the Center for Operational Oceanographic Products and is a subsidiary of National Oceanic and Atmospheric Administration (NOAA). It provides Contrail with tide elevations, predictions, and temperatures at two locations near the basin.

2.1.5 TransAlta

TransAlta is a power company operating in the Chehalis Basin. It operates the Skookumchuck Dam in Thurston County, WA. The stage at the outlet from the dam is monitored with pressure transducers that are tied into Contrail. There are two pressure transducers; one is located at the spillway and the other is located just outside the spillway. The pressure transducers at the spillway is referred to as the Narrow Band and give more precise measurements of flows in the spillway. The pressure transducers located just outside the spillway is referred to as the wide band and is accurate for higher range of flows.

2.2 Current Hydro-Metrological Gage Inventory by Type

Three category types of monitoring gages are defined in this section: Stream Measurement Sites, Precipitation Measurement Sites, and other metrological measurement sites.

2.2.1 Stream Measurements

The Flood Warning System is currently connected to 28 stream measurement sites within the basin (Figure 2-1). A gage at each site measures stage height, which it reports through telemetry. Additionally, 17 of the sites have rating curves, which allow for discharges to be reported. The majority of gages report through USGS with four exceptions. The exceptions are two gages owned by Lewis County and one gage owned by the Ecology, all of which report through HADS. The last exception is a gauge at the outlet of the Skookumchuck Reservoir owned by TransAlta.

A USGS gage Chehalis River above Mahaffey Creek Near Pe Ell, WA (Station ID 12019310) was connected to the flood alert system but has recently become inactive due to lack of funding. The Ecology gage Wishkah River near Nisson, WA (site number 22D110) has been inactive in recent years but has recently been reinstalled. A new stream gage has been installed by Ecology at the same location as the decommissioned one.

2.2.2 Precipitation Measurements

The flood alert system is currently connected to 26 precipitation measurement sites that automatically report tipping bucket gages in and around the basin (Figure 2-2). There are ten sites owned by the Flood Authority that report through HADS. Measurements taken at four local airports report through METAR. A single USGS measurement site is present in the basin.

2.2.3 Other Meteorological Measurements

Each of the Lewis County gages, three METAR gages, and two TIDES gages provide other meteorological measurements (Figure 2-3). These measurements include wind speed and direction, temperature, humidity, dew point, wave height, and solar radiation.

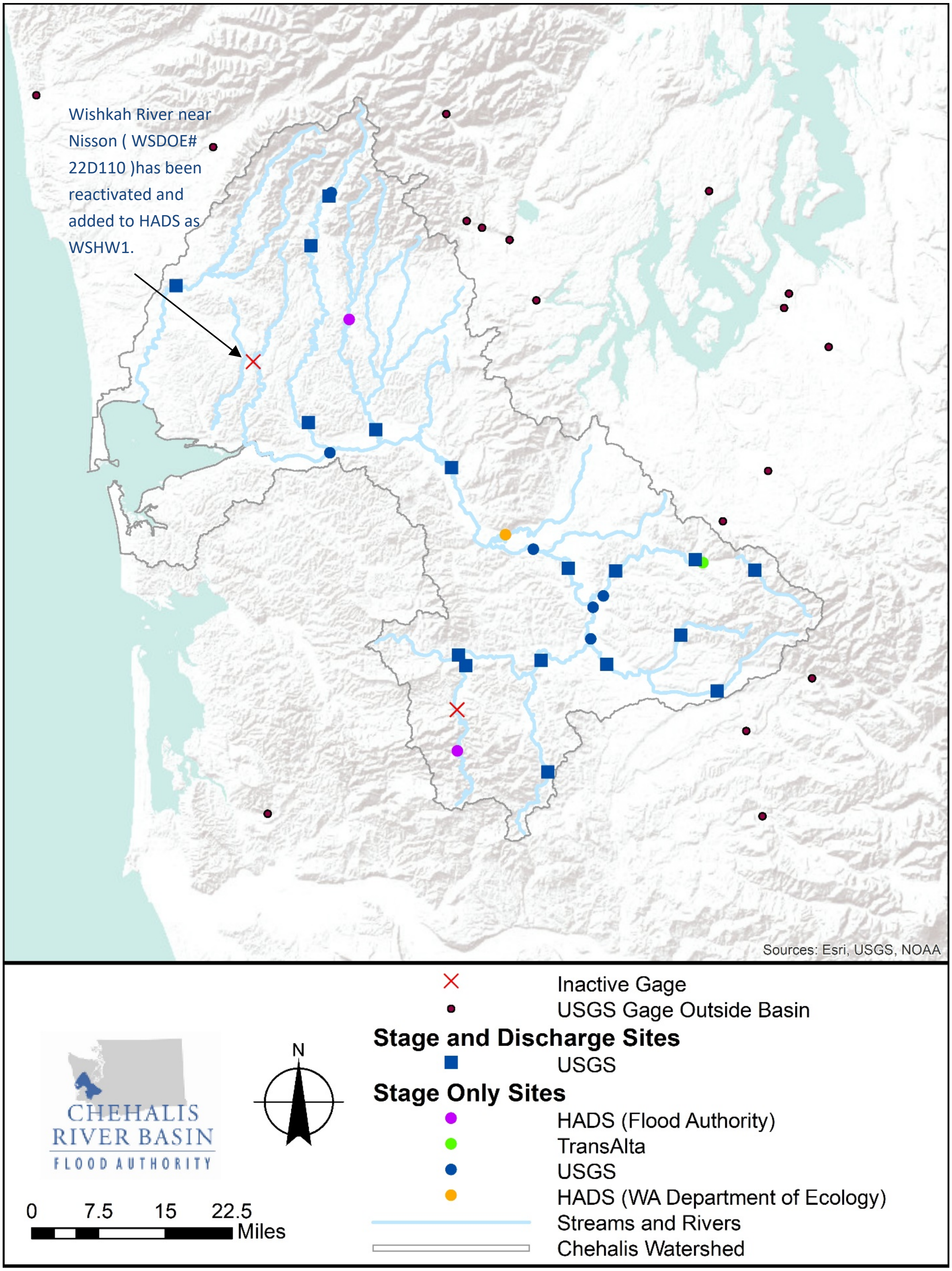

Figure 2-1. Stream Measurement Sites Included in Contrail

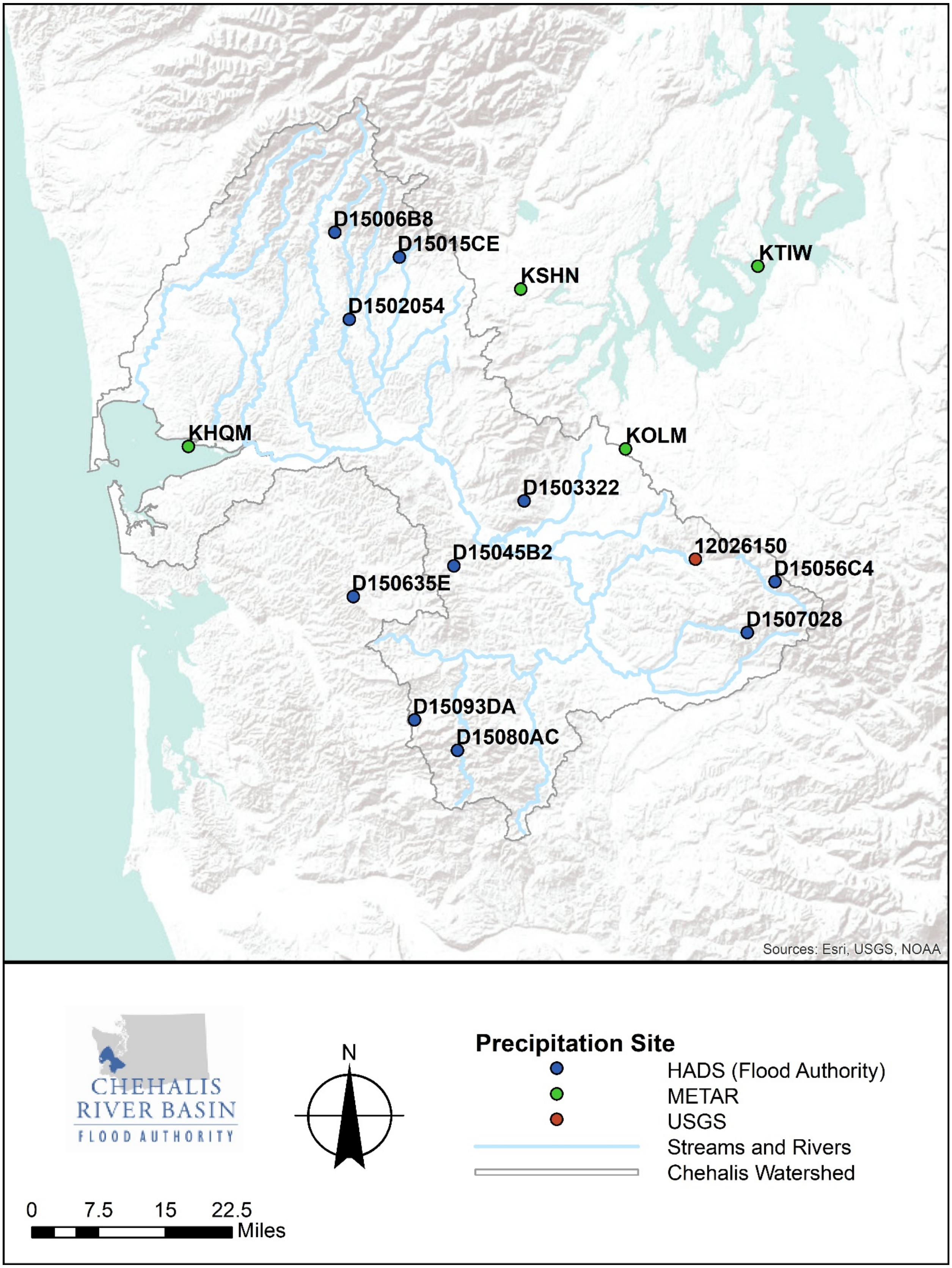

Figure 2-2. Precipitation Measurement Sites Included in Contrail

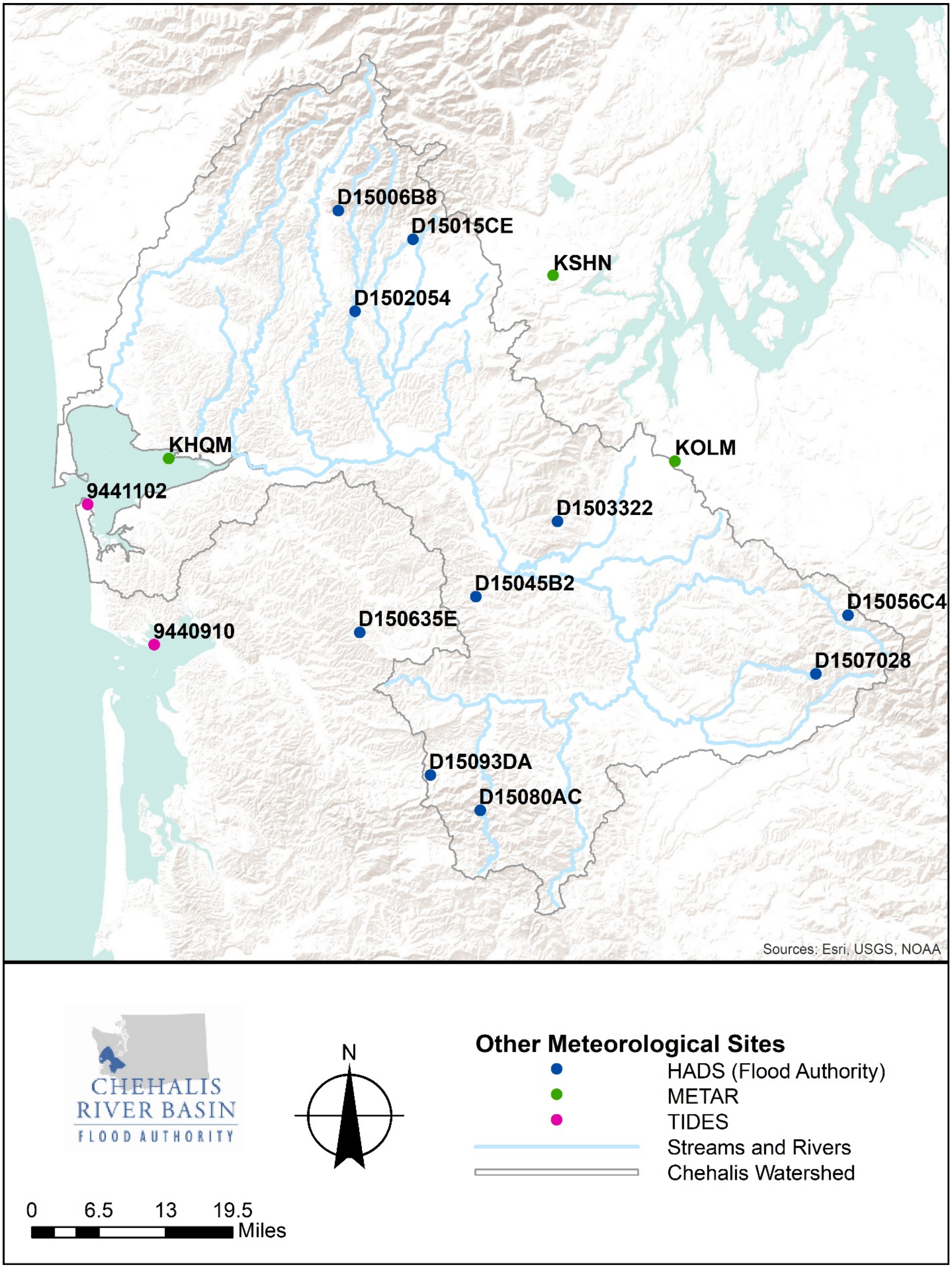

Figure 2-3. Other Hydro-Meteorological Measurements Included in Contrail

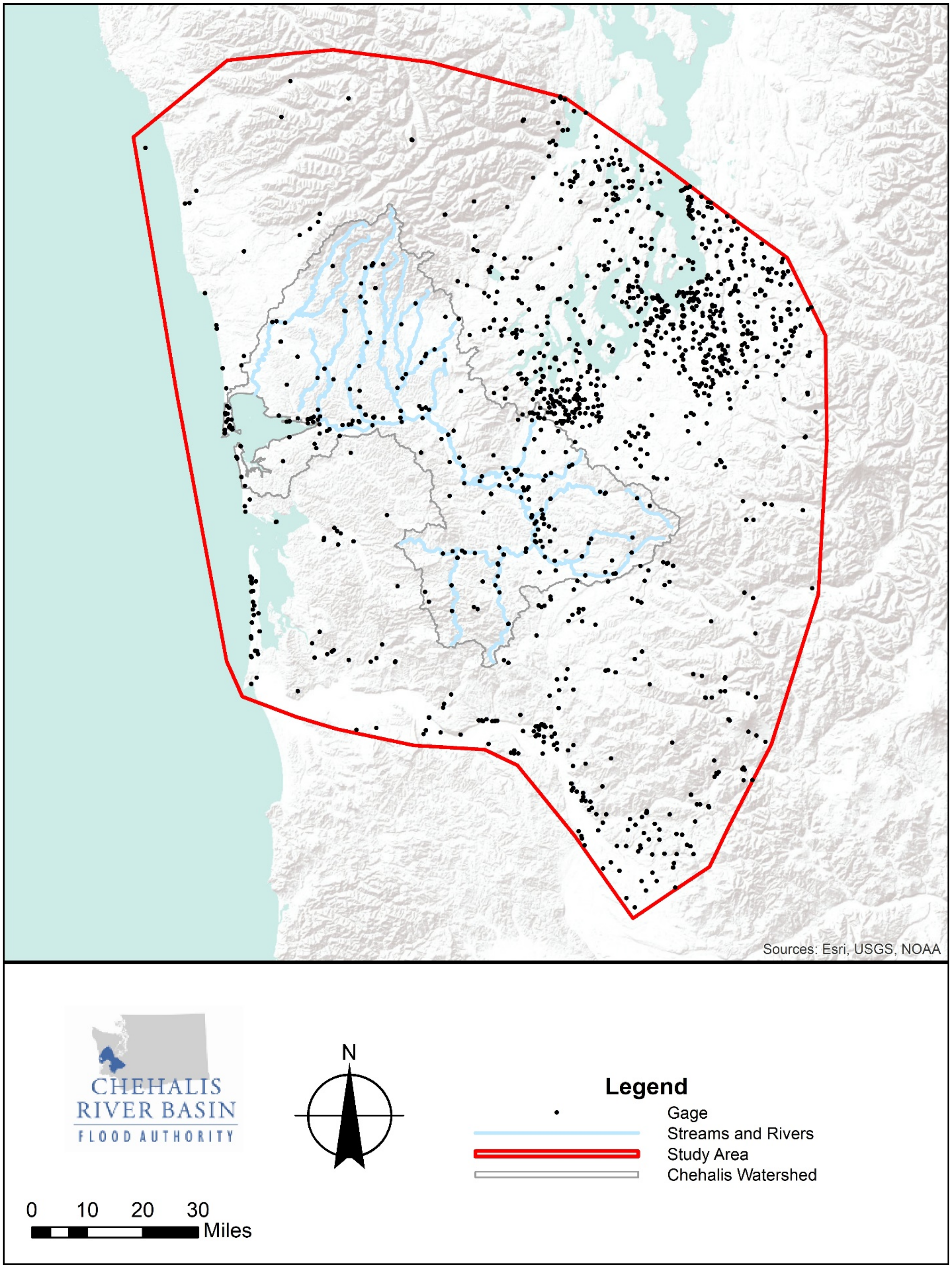

Figure 2-4. Study Area for Gage Inventory

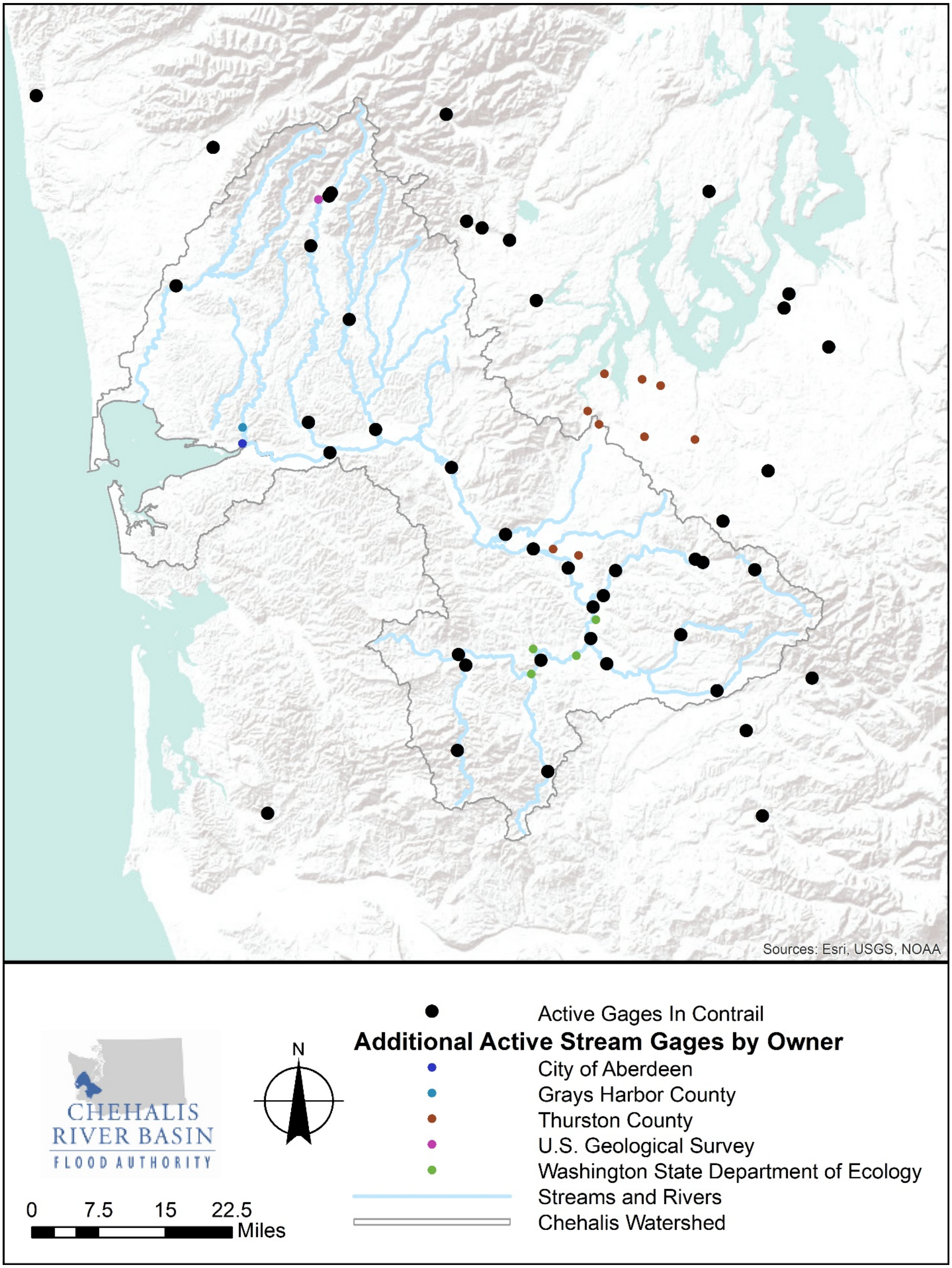

Figure 2-5. Additional Active Stream Gages by Owner

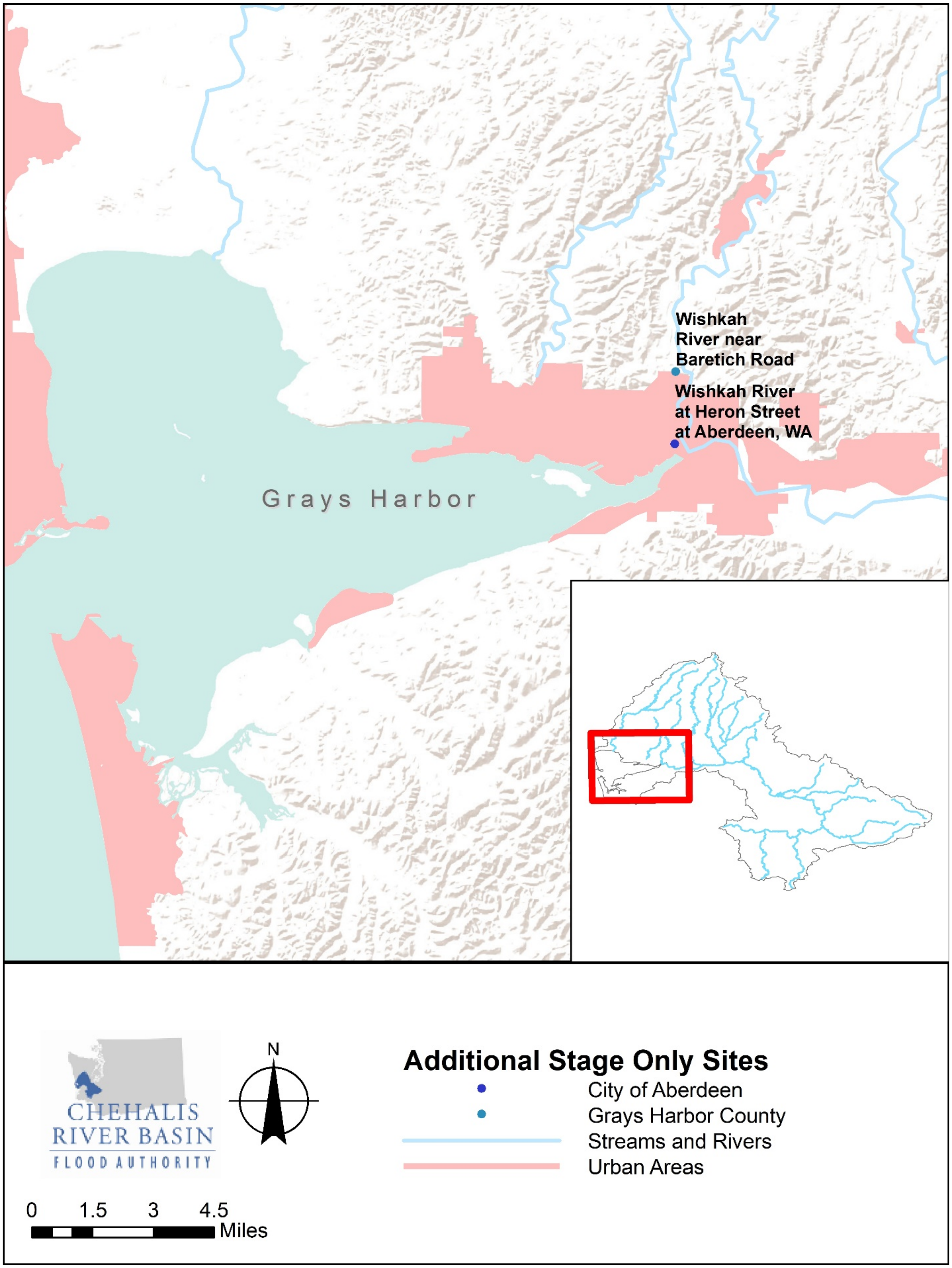

Figure 2-6. Additional Stream Gages near Aberdeen

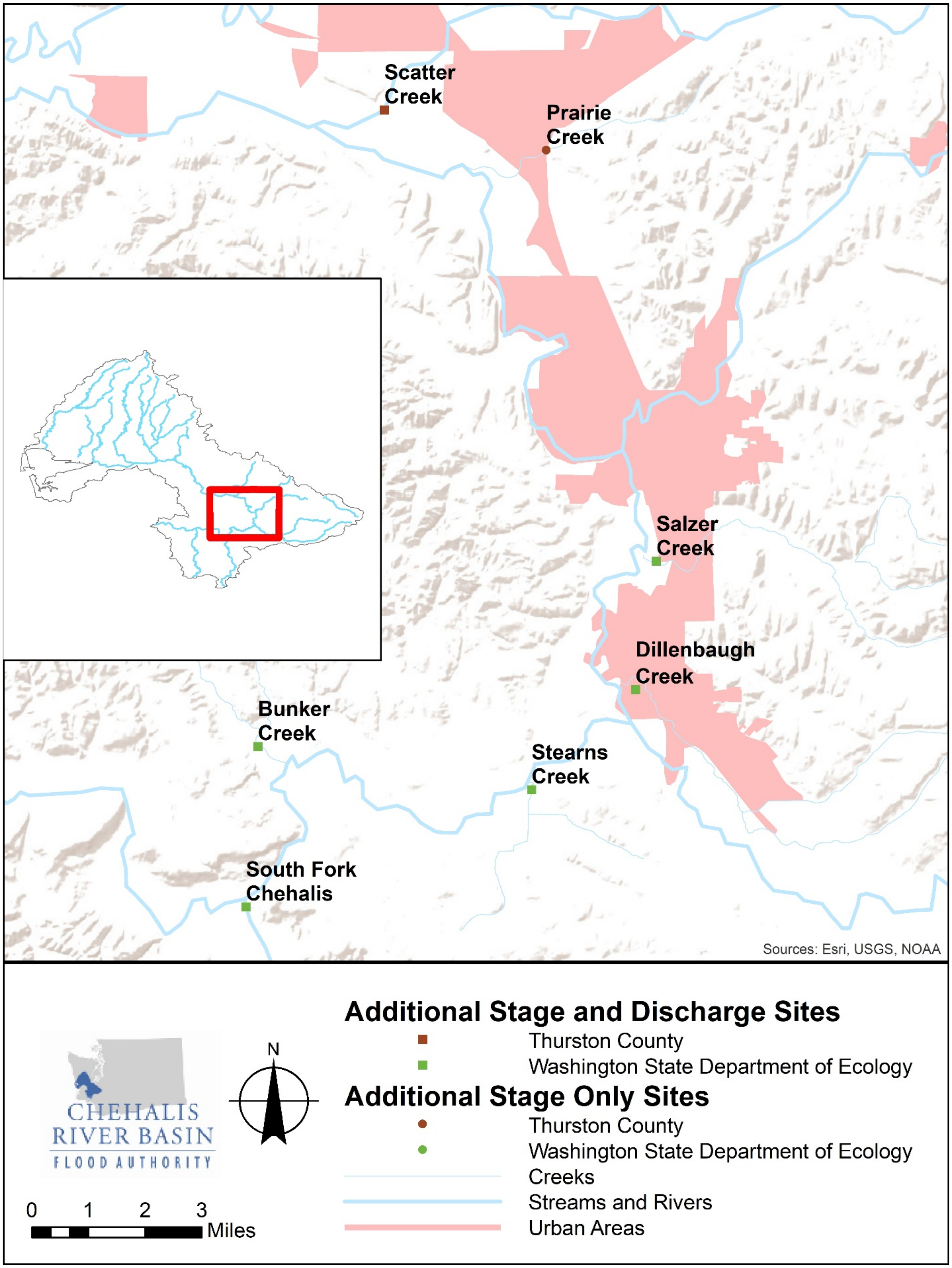

Figure 2-7. Additional Stream Gages near Centralia

Currently, some Ecology (not all) stream gages report into contrail through HADS. Additional Ecology stream gages exist (Figure 2-7). With the appropriate equipment added or an interface to the Ecology database, these stations could be collected by Contrail as well.

The majority of USGS stream gages have rating curves which allow for discharge to be calculated from stage (see Chapter 4 for full discussion on rating curves). The majority of the other affiliated gages do not. Rating curves are relevant to the Flood Warning System because NWS forecast are converted from discharge to stage using rating curves. An accurate rating curve results in better estimation of stage.

The NWS maintains two stream gages, one located at Skookumchuck River at Centralia (CTAW1) and the other Chehalis River at Centralia (CENW1). These gages correspond to USGS gage numbers 12026600 and 12025500 respectively. The rating curves at these locations were considered of extra importance due to their proximity to Centralia and their use as NWS river forecast points. A study of the accuracy of the rating curves of the NWS gages is provided in Chapter 4.

2.3 Precipitation and Other Hydro-Metrological Measurements

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 2-8).

2.3.1 *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 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 2-9), in particular the RAWS. 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.

2.3.1.1 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.

2.3.2 Professional Not-Real-Time

Networks that have professionally-maintained gages, which do not transmit data in real-time, are listed in Table 2-2. 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. The network includes gages from Thurston County, which are not currently connected to telemetry and therefore are considered not-real-time. One exception is the Thurston County Courthouse (Percival Creek Basin) 23u, which reports automatically.

Table 2-2. Professional Not-Real-Time

Professional Not-Real-Time Networks
Thurston County
Cooperative Observer Network
Climate Reference Network
Community Collaborative Rain, Hail and Snow Network

2.3.3 Citizen Scientist gages

Gages that are considered Citizen Scientist gages include those from Weather Underground (WU) and Automatic Position Reporting System WX NET/Citizen Weather Observer Program (APRSWXNET/CWOP). The gages are maintained by individual community members and vary in quality. WU gives raw data which is weakly quality controlled. APRSWXNET/CWOP has better quality control measures in place.

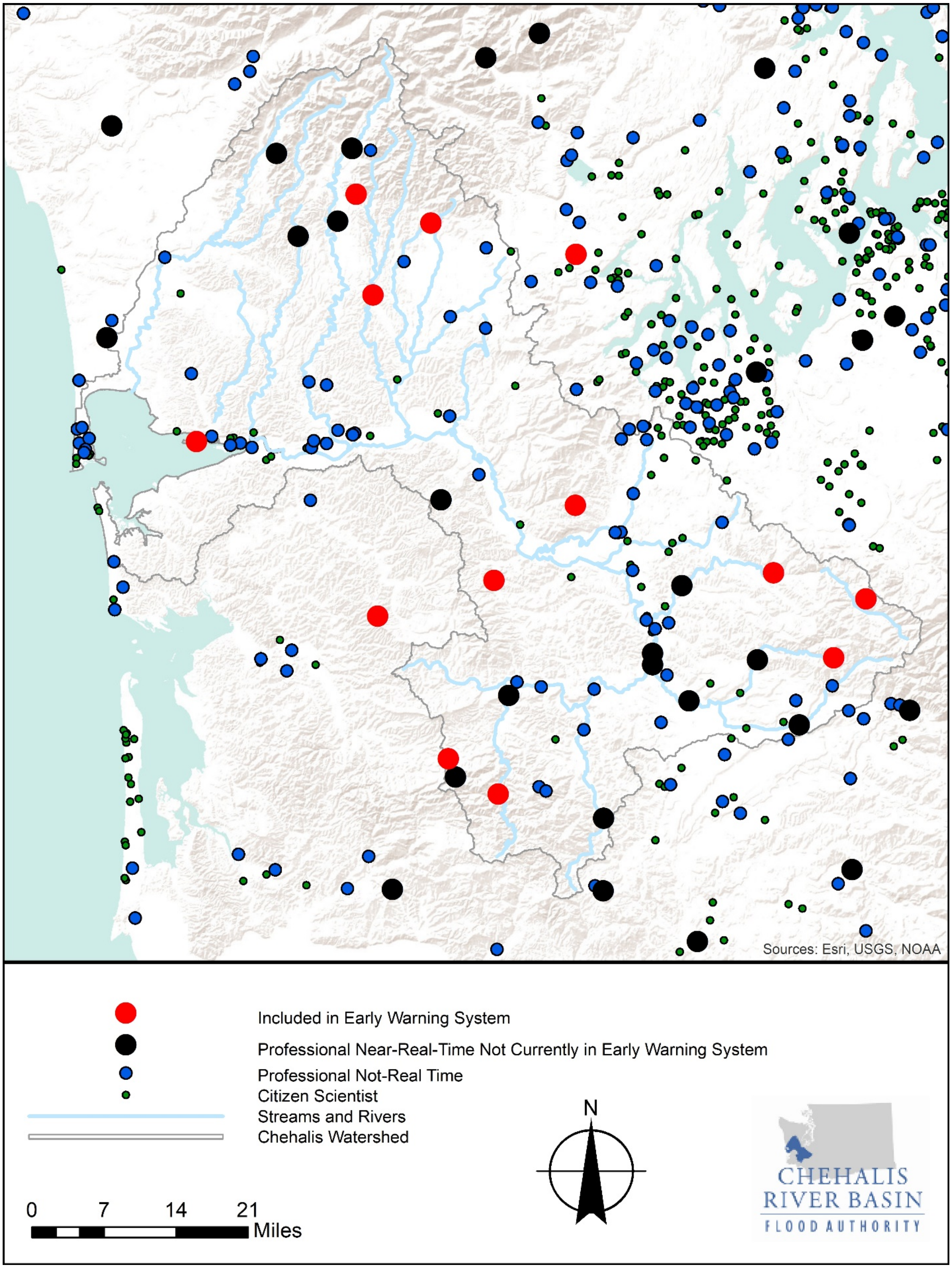

Figure 2-8. All Precipitation Gages in Inventory

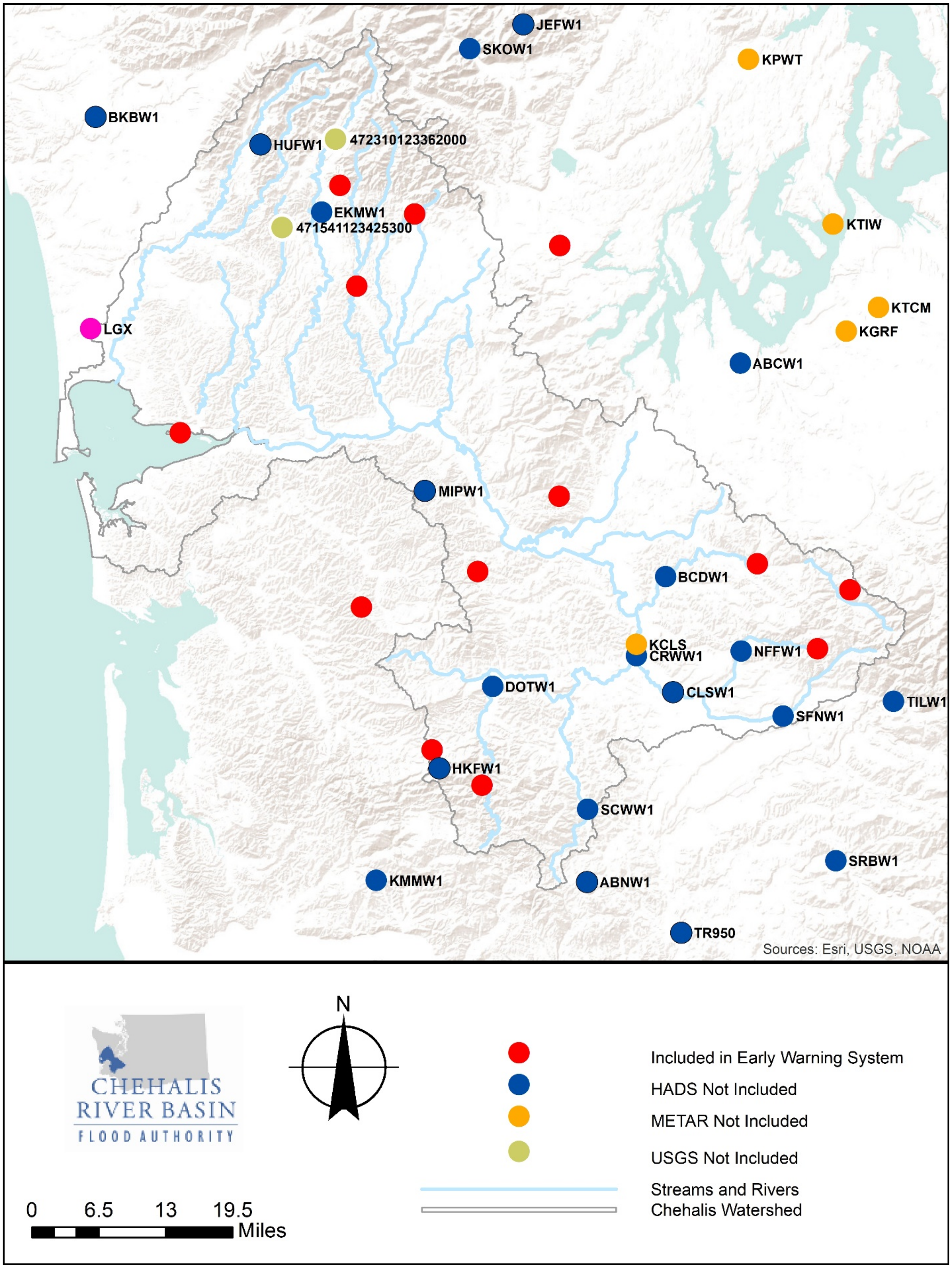

Figure 2-9. Additional Precipitation Gages that can be Added to Contrail

2.4 Summary

A summary of the inventory is provided below. It includes a summary of gages currently in Contrail (**Error! Reference source not found.**) and of all active gages in the vicinity of the Chehalis River Basin (Table 2-4). 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 Work Book. There are an additional 1367 inactive gages included in the database. A description of the database in described in Appendix H.

Table 2-3. Summary of the Inventory

Gage Type	HADS		USGS	METAR	TransAlta	TIDES	Total
	Flood Authority	WSDOE					
Precipitation	10	0	1	4	0	0	15
Discharge	0	0	34	0	0	0	34
Stage	2	2	40	0	2	0	46
Air Temperature	10	0	0	4	0	2	16
Battery	10	0	0	0	0	0	10
Dew Point	0	0	0	1	0	0	1
Pressure	1	0	0	1	0	2	4
Relative Humidity	1	0	0	0	0	0	1
Solar Radiation	1	0	0	0	0	0	1
Tide	0	0	0	0	0	2	2
Ocean Temperature	0	0	0	0	0	2	2
Wind	1	0	0	4	0	2	7
Total	**36**	**2**	**75**	**14**	**2**	**10**	**139**

Table 2-4. Gages in Census

Gage Type	Professional Near-Real-Time with Systems Available In Contrail	Professional Not-Real-Time	Citizen Scientist	Total
Precipitation	67	265	541	873
Discharge	40	1	0	41
Stage	52	10	0	62
Air Temperature	97	40	615	752
Dew Point	1	0	0	1
Pressure	26	7	608	641
Relative Humidity	47	1	616	664
Solar Radiation	17	1	33	51
Tide	2	0	0	2
Ocean Temperature	2	0	0	2
Wind Speed	70	4	616	690
Wind Direction	70	4	616	690
Wind Gust	48	1	111	160
Snow Depth	4	17	0	21
Other	63	107	0	170
Total	**606**	**458**	**3756**	**4820**

2.5 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.

2.5.1 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 2-10 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 2-10 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 2-10 the NEXRAD Langley Hill radar (KLGX) is located in the northwest boundary of the watershed. Due to the 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 gauge 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 describe methods to bias correct radar precipitation estimates using rain gauge 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. Information 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 gauge network would be required to produce rainfall maps with similar resolution to weather radar rainfall products.

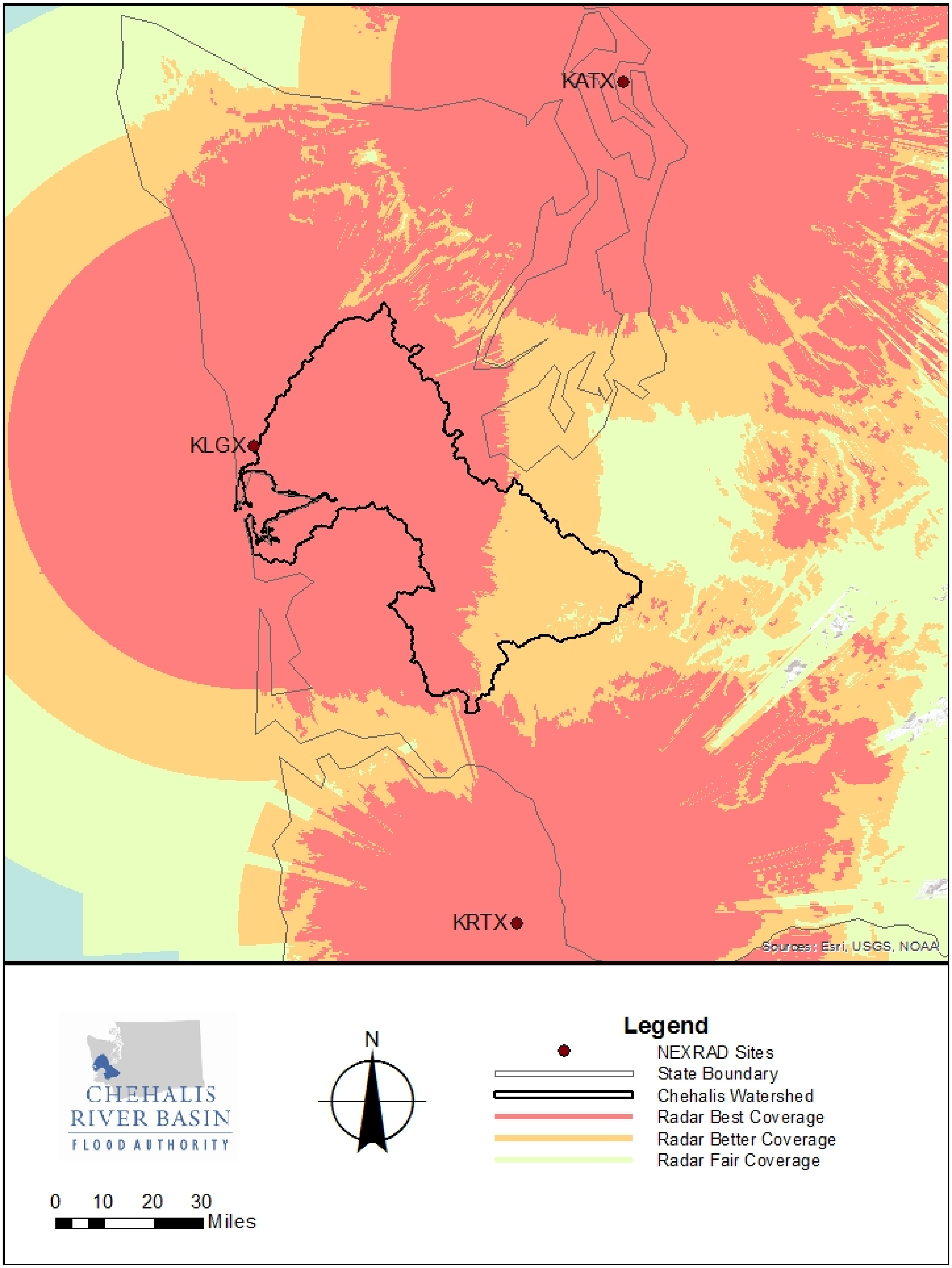

Figure 2-10. NEXRAD Radar Coverage in the Vicinity of Chehalis River Basin

2.5.2 SuomiNet GPS Water Vapor Sites

SuomiNet is a real-time Global Positioning System (GPS) developed for atmospheric research. The network measures delays in GPS signals due to atmospheric water vapor which in turn are used to estimate water vapor in the atmosphere. It can be used to help bias correct the radar data. These sensors are useful because current satellite-based water vapor sensing systems only work over the oceans (Figure 2-11), i.e. when water is the background. Land-based water vapor sensing help 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 2-12). The SuomiNet data can better inform rainfall forecast.

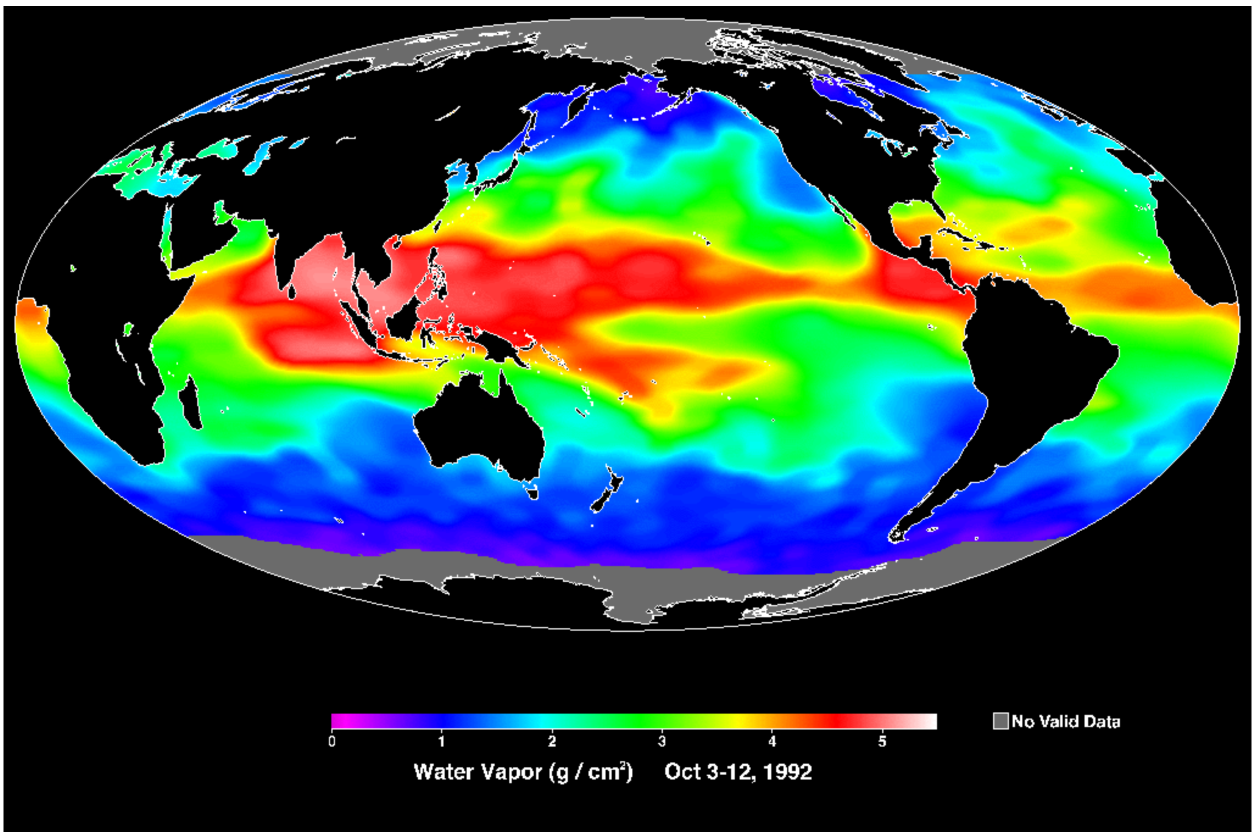

Figure 2-11. Satellite Water Vapor Data (NASA)

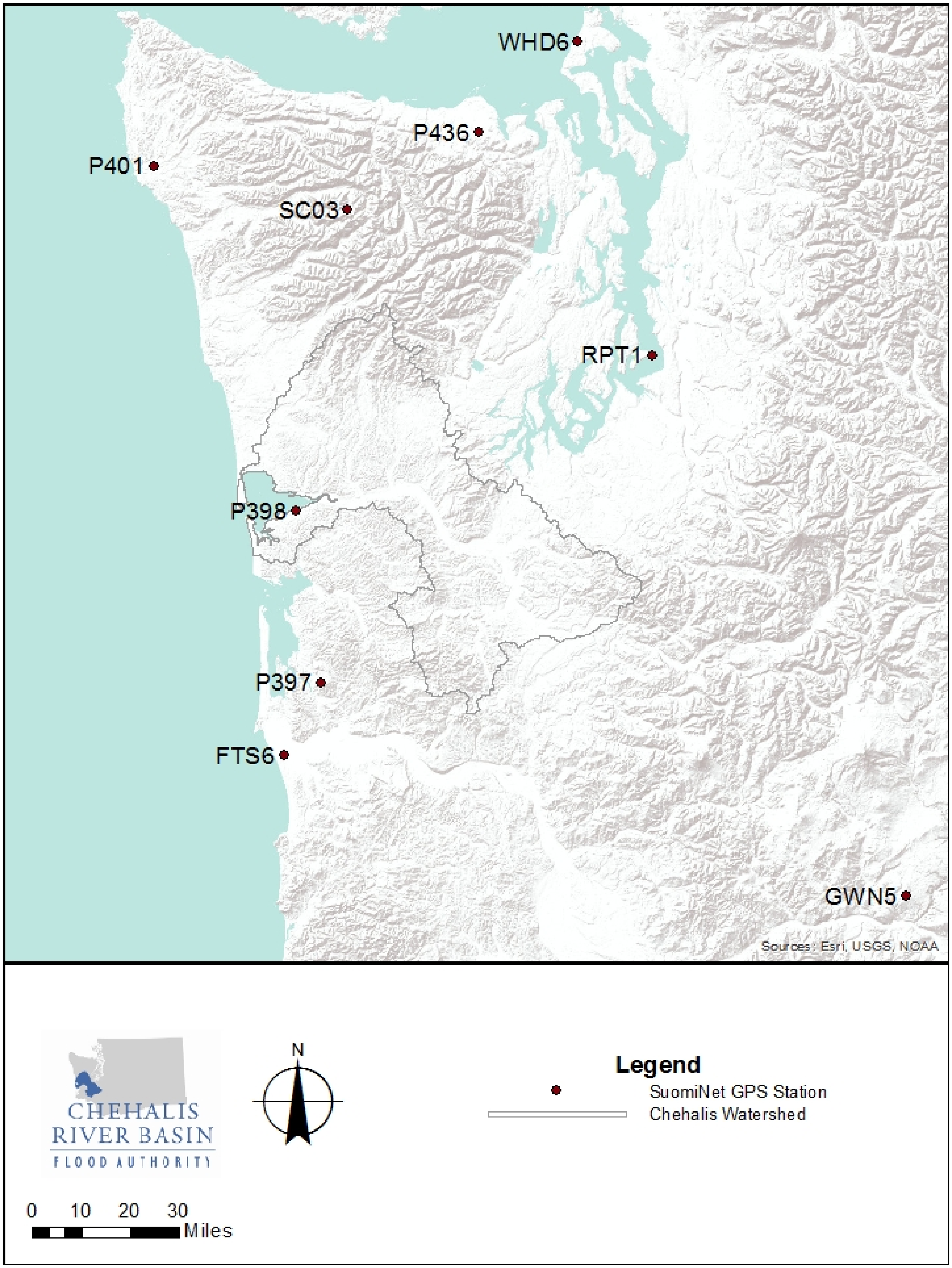

Figure 2-12. SuomiNet Gages

3 DATUM CONVERSION

Stream height is measured in reference to a datum. A datum is a system used to reference a location on or above the Earth's surface. Horizontal datums specifically locate where a point is located on the earth's surface in units of latitude and longitude or similar coordinate system. Vertical datums reference points relative to their height above a selected level surface (such as mean sea level) and often expressed in terms of elevation. There are three types of datums: Arbitrary, NGVD29 and NAVD88. Arbitrary datums are tied to a gage zero and have local reference marks to track the datum over time. NGVD29 is a superseded datum tied to mean sea level and NAVD88 is the more recent replacement for NGVD29. For more detailed background information on these datums, see Appendix E. Also, an electronic database of all gaging stations and their respective datums is included electronically in an Excel workbook with this report. This section will focus more specifically on the vertical datums associated with stream gages in the Chehalis Basin.

Currently, the majority of stream gages in the Chehalis Basin measure water levels in reference to an arbitrary datum, although some are reported in NGVD29 and NAVD88. Using a mix of datums can cause confusion when gage values are compared with mapped elevations as they will be different. A common datum can reduce confusion. It is especially important to be clear on which datum is being referenced when flood inundation maps are utilized to determine the inundated extent of forecast flood waters.

Present day surveying equipment and methods make it reasonable to expect that a common vertical datum such as NAVD 88 can be established at all stream gages. Key benefits for converting all stream gages to NAVD 88 include:

- NAVD 88 is the standard vertical datum system used in the United States by federal agencies
- NAVD 88 is more accurate than NGVD 29
- Flood inundation mapping is based on elevation data; therefore, ensuring that all elevations used for modeling are based on a single current datum is necessary
- Surface water levels tied to NAVD 88 can be compared to structure and ground elevations referenced to the same vertical datum
- Flood warning elevations are all referenced to the same vertical datum
- Stream gage elevations referenced to NAVD 88 can be compared against one another
- Stream gage data could be compared with other data without the need for conversion which can introduce error
- Light Detection and Ranging (LiDAR) datasets, used for elevation data, are preferred to be collected in NAVD 88.
- Referencing gage datums to the current North American Vertical Datum (NAVD) 88 also ensures that the gage datum can be recovered even if the station and reference marks are destroyed during a flood event (Kennedy, 1990).

3.1 Converting Arbitrary Datum or NGVD 29 to NAVD 88

Conversion to NAVD 88 will change the value assigned to water surface levels. Arbitrary, NGVD 29, and NAVD 88 are based on a different vertical reference points and should not be compared without conversion (FEMA, 2015). The actual difference observed between arbitrary, NGVD 29, and NAVD 88 varies spatially.

An example of the difference between arbitrary, NGVD 29, and NAVD 88 is provided in Figure 3-1. In this example, a stream gage reports a stage of 10 ft. with an arbitrary datum. Surveying that same gage to NGVD 29 reveals that a stage of 10 ft. in the arbitrary datum is equal to a NGVD 29 stage of 187 ft. (177 ft. offset). Using various survey techniques or software, it is determined that the conversion from NGVD 29 to NAVD 88 is +3.4 ft. Therefore, the NAVD 88 stage is 190.4 ft., the arbitrary stage is 10 ft., and the NGVD 29 stage of 187 ft. The vertical distance between a given water surface and the structure remains the same, whether the datum is arbitrary, NGVD 29 or NAVD 88. However, if a user has historically seen water levels referenced to NGVD 29 and a change is made to NAVD 88, the same water level will appear to be 3.4 feet higher and might cause confusion.

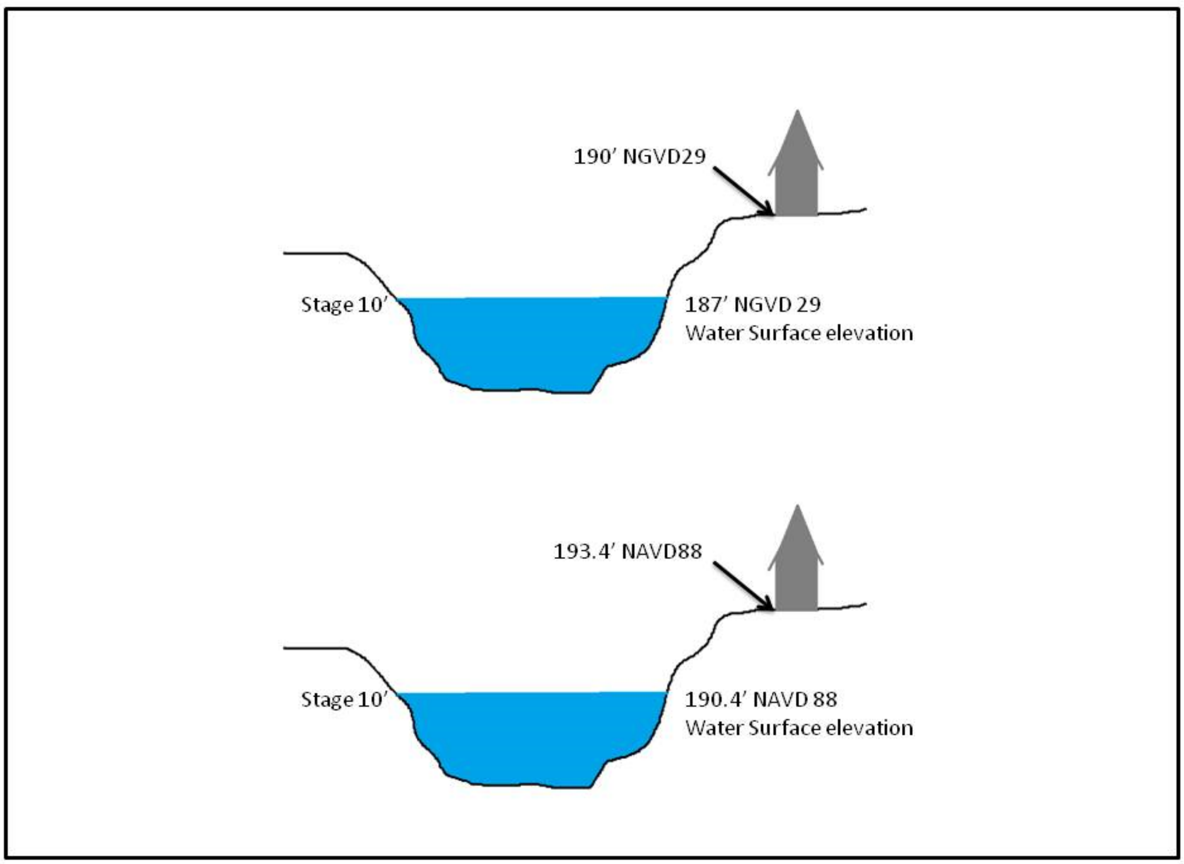

Figure 3-1. Example Datum Differences

3.2 Datum Conversion

3.2.1 Software Solutions

The difference between NGVD 29 and NAVD 88 can be computed by North American Vertical Datum Conversion (VERTCON) and US Army Corps of Engineers Conversion software (CORPSCON). The National Geodetic Survey (NGS) developed VERTCON and has made it publicly available for free download on the NGS website. VERTCON transformations can only be computed between NGVD 29 and NAVD 88 and should only be used for locations within the lower 48 United States. The model was developed using 381,833 datum difference values. VERTCON computes the modeled height difference between NAVD 88 and NGVD 29 for a given location specified by its latitude and longitude. The latitude and longitude inputs can be either from the North American Datum of 1927 (NAD 27) or North American Datum of 1983 (NAD 83) horizontal control datum systems. The accuracy of the model is contingent on the quantity and quality of the input data. Tests of the model show a predictive capability of 2.0 cm RMS error at the 381,833 data points. The model does not maintain full vertical accuracy of geodetic leveling and if higher accuracy is desired users should adjust using published NAVD 88 values. However, VERTCON model accuracy is reliable for a variety of mapping and charting purposes (Mulcare, 2004).

The U.S. Army Corps of Engineers (USACE) have developed CORPSCON software for performing conversions between NGVD 29 and NAVD 88. It is based on the NGS programs NADCON, VERTCON, and GEOID XX (Geoid99/Geoid03). Like VERTCON, the model will compute the orthometric height difference between NGVD 29 and NAVD 88 for a given location specified by its latitude and longitude. The vertical conversions are based on the NGS VERTCON program. In lieu of just NAD 27 or NAD 83, CORPSCON allows the user to convert coordinates between Universal Transverse Mercator (UTM), State Plane Coordinates Systems (SPCS), and High accuracy Reference Networks (HARNs). The NGS program NADCON is used to convert between NAD 27, NAD 83, and HARNS. Since NADCON and VERTCON datum transformations are based on a model of 250,000 common stations, accuracy of NADCON and VERTCON transformations can vary depending on location and proximity to common stations (USACE, 2004). There is not a precise mathematical method to convert exactly between datums and the transformation output is an approximate. The Washington State Department of Transportation (WSDOT) generally found accuracies within 0.25 m when using VERTCON or CORPSCON (WSDOT, 2005).

3.2.2 Surveying Solutions

If more accurate elevations are required, the source of the NGVD 29 elevation is suspect, or if a site uses an arbitrary datum, then survey methods can be used to determine a NAVD 88 elevation for a location. Running levels or using high accuracy GPS are two survey methods used to determine what the NAVD 88 elevation is for a specific point. These methods typically use a nearby vertical benchmark as the basis for determining new NAVD 88 elevations. Vertical benchmark information can be found via various sources including state departments of transportation, NGS, counties, cities, etc. Two helpful websites to assist with locating benchmarks are:

- NGS Survey Data Explorer: https://geodesy.noaa.gov/NGSDataExplorer/
- WSDOT Map: http://www.wsdot.wa.gov/Monument/gis/index.html

Recommended data collection methods and guidelines for establishing the vertical datum by differential leveling or Global Navigation Satellite Systems (GNSS) are documented in detail by the USGS (Rylund and Densmore, 2012) and WSDOT (WSDOT, 2005). Differential leveling involves using an engineering level and rod to transfer elevations from a known benchmark to a point with an unknown elevation. Differential leveling is highly accurate, but can be time consuming if the benchmark is a significant distance away from the unknown elevation point (gaging station).

Another guideline is the recent USGS proposal to change the datum to NAVD 88 for gages in the Chehalis Basin. It states that "If no benchmark exists within about ½ mile of the gage, a real-time RTK GPS system will be used to determine the gage elevation. (USGS Proposal to Upgrade the Stream Gaging Monitoring Network of the Chehalis River Basin, Aug 2017)

GPS typically refers to the United States' based system of satellites, while GNSS refers to the network of global satellite constellations. Newer GPS receivers are GNSS capable, meaning that they make use of the additional satellite constellations operated by Russia, Europe, and China. If benchmarks are greater than 0.5 mile from the unknown elevation point then it may be more efficient to use GNSS equipment.

Two accepted methods of GNSS surveying are static and real-time. Static GNSS surveying involves setting up GNSS equipment over an unknown point, collecting a required amount of data and then post-processing that data to determine the elevation of the point. Post processing the data requires specialized office software. Alternately, the data can be uploaded to an NGS website that does the post-processing automatically. When performing static surveying, the receiver is not mobile and the data must be post processed to achieve high accuracy.

During real-time GNSS surveying, a base station or network provides corrections to the mobile GNSS receiver in real-time. Real-time surveying is a widely accepted method that can generate centimeter level accuracy efficiently. With both static and real-time GNSS surveying, redundant measurements are recommended. Detailed information on static and real-time GNSS surveying can be found in the USGS document written by Rydlund and Densmore (2012).

3.3 Inventory for Datum Conversion

Information regarding real-time gaging stations that collect water level data in the Chehalis Basin were inventoried to determine which vertical datum is currently used at each station. Gages researched include those operated by USGS, Ecology, Flood Authority, TransAlta, NOAA, Grays Harbor County, Thurston County, and the City of Aberdeen. Water level data can be found at the following websites:

- USGS real-time gaging stations: https://waterdata.usgs.gov/wa/nwis/current/?type=flow&group%20Key=basin%20cd
- Ecology real-time gaging stations: https://fortress.wa.gov/ecy/eap/flows/regions/state.asp?region=1
- Flood Warning System real-time gaging stations (includes a mix of USGS, Ecology, TransAlta and Flood Authority operated sites): https://chehalis.onerain.com/home.php
- Northwest River Forecast Center (mix of USGS and Flood Authority gage data with forecast information): https://www.nwrfc.noaa.gov/rfc/
- Lewis County Rivers (mix of USGS and Flood Authority gage data): http://rivers.lewiscountywa.gov/#/

The information collected as part of this gage inventory is listed in Appendix H. Detailed information regarding telemetry type, gage datum, offset, and survey type is included in the Excel workbook delivered electronically with this report.

There are three vertical datums used throughout the Chehalis basin: arbitrary, NGVD 29, and NAVD 88. An arbitrary datum has an offset of 0.00 if it is not tied to NGVD 29 or NAVD 88. Arbitrary datums can be related to known datums, such as NGVD 29 and NAVD 88, by adding an offset to the arbitrary datum values. An offset from an arbitrary datum to a known datum must be determined by surveying from a known benchmark or by using less accurate methods such as scaling from topographic maps. Some gages directly report stage values in NGVD 29 or NAVD 88 without requiring an offset.

All 23 of the active USGS stream gages (Table 3-1) in the Chehalis Basin are referenced to NGVD 29 or NAVD 88. Of those, 20 are tied to NGVD 29. Ten of the gages directly report stage values in NGVD 29 or NAVD 88, leaving the remaining 13 to use an offset to convert to a known datum. The ten USGS gages, listed in Table 3-1, that reference NGVD 29 or NAVD 88 directly (with “0” offset) have reference gages and sensors set to read directly in the specified datum. In Table 3-1, USGS “datum” refers to a survey from a known benchmark or GPS, while “elevation” is a less accurate method of determining the datum such as scaling from a topographic map or using a barometer. ($USGS_2$, 2017)

Table 3-1. USGS Water Level Gaging Stations (USGS[1], 2017)

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
12019310	CHEHALIS RIVER ABOVE MAHAFFEY CREEK NR PE ELL	NAVD88	432	USGS "Elevation"
12020000	CHEHALIS RIVER NEAR DOTY	NGVD29	301.1	USGS "Datum"
12020525	ELK CREEK BELOW DEER CREEK NEAR DOTY	NGVD29	0	USGS "Datum"
12020800	SOUTH FORK CHEHALIS RIVER NEAR WILDWOOD	NGVD29	0	USGS "Datum"
12021800	CHEHALIS RIVER NEAR ADNA	NGVD29	0	USGS "Datum"
12024000	SOUTH FORK NEWAUKUM RIVER NEAR ONALASKA	NGVD29	0	USGS "Datum"
12024400	NF NEWAUKUM RIVER ABOVE BEAR CREEK NEAR FOREST	NGVD29	0	USGS "Datum"
12025000	NEWAUKUM RIVER NEAR CHEHALIS	NGVD29	190	USGS "Elevation"
12025100	CHEHALIS RIVER AT WWTP AT CHEHALIS	NGVD29	0	USGS "Datum"
12025700	SKOOKUMCHUCK RIVER NEAR VAIL	NGVD29	710	USGS "Elevation"
12026150	SKOOKUMCHUCK RIVER BL BLDY RUN CR NR CENTRALIA	NGVD29	317.34	USGS "Datum"
12026400	SKOOKUMCHUCK RIVER NEAR BUCODA	NGVD29	198.19	USGS "Datum"
12027500	CHEHALIS RIVER NEAR GRAND MOUND	NGVD29	123.65	USGS "Datum"
12028060	CHEHALIS RIVER NEAR ROCHESTER	NAVD88	0	USGS "Datum"
12031000	CHEHALIS RIVER AT PORTER	NGVD29	23.64	USGS "Datum"
12035000	SATSOP RIVER NEAR SATSOP	NGVD29	0	USGS "Datum"

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
12035100	CHEHALIS RIVER NEAR MONTESANO	NAVD88	0	USGS "Datum"
12035380	WYNOOCHEE LAKE NEAR GRISDALE	NGVD29	0	USGS "Datum"
12035400	WYNOOCHEE RIVER NEAR GRISDALE	NGVD29	630	USGS "Elevation"
12036000	WYNOOCHEE RIVER ABOVE SAVE CREEK NEAR ABERDEEN	NGVD29	401	USGS "Datum"
12037400	WYNOOCHEE RIVER ABOVE BLACK CREEK NR MONTESANO	NGVD29	40	USGS "Datum"
12039005	HUMPTULIPS RIVER BELOW HWY 101 NR HUMPTULIPS	NGVD29	90	USGS "Datum"
12035450	BIG CREEK NEAR GRISDALE	NGVD29	630	USGS "Elevation"

Two examples illustrating the relationship between an arbitrary datum and the NGVD29 datum are included below.

> ***Example 3-1***. *Station 12027500 Chehalis River near Grand Mound displays water levels on the USGS webpage referenced to arbitrary gage datum. The gage is surveyed to NGVD 29 with an offset of 123.65 ft. If the current stage at Grand Mound is 7.94 ft. (arbitrary datum) then the NGVD 29 stage is 131.59 ft. Both values represent the same water surface.*
>
> *NGVD 29 stage = arbitrary (gage) datum stage + offset*
>
> 131.59 ft. = 7.94 ft. + 123.65 ft.
>
> ***Example 3-2.*** *Station 12035000 Satsop River near Satsop displays water levels on the USGS webpage referenced to NGVD 29. The offset is 0 ft.*

Ecology has six, active, real-time gages reporting water level in the basin and one gage, Wishkah River near Nisson, which was decommissioned in 2013 and reinstalled in 2017. The Wishkah River near Nisson gage was fully functional and reporting its measurements online as of September 2017. Table 3-2 lists the Ecology water level gages. All Ecology gages use an arbitrary datum that is not tied to NGVD29 or NAVD88. Arbitrary water level values are displayed on the Ecology website. There has been discussion between Ecology and USGS to survey these stations and tie them to NAVD 88, but that work has not been scheduled. (Clishe, 2017)

Table 3-2. Washington State Department of Ecology Water Level Gages

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
22D110	WISHKAH RIVER NEAR NISSON	Arbitrary	0	None
23H060	SALZER CREEK AT AIRPORT RD	Arbitrary	0	None
23I070	BUNKER CREEK AT CERES HILL RD	Arbitrary	0	None
23J070	STEARNS CREEK AT TWIN OAKS RD	Arbitrary	0	None
23K060	SOUTH FORK CHEHALIS AT HWY 6	Arbitrary	0	None
23L070	DILLENBAUGH CREEK AT RIVERSIDE DR	Arbitrary	0	None
23E060	BLACK RIVER AT HWY 12	Arbitrary	0	None

The Flood Authority currently operates two real-time gages reporting water level in the basin. The Flood Authority is in the process of installing new equipment at or near existing stream gages on the Chehalis River at Centralia and the Skookumchuck River at Centralia. These two gages are currently owned and operated by the NWS to support river forecast operations in the Chehalis River Basin. As demonstrated during 2016-17 season, the decades-old existing equipment is increasingly vulnerable to failure and in need of a significant upgrade to current technology. Once installed, calibrated, and operationally verified, data from the new gages are intended to replace the existing data used in NWS river forecast operations. The two gages currently operated by the Flood Authority use an arbitrary vertical datum that has not been referenced to NGVD 29 or NAVD 88. The two NWS gages have been tied to NGVD 29 by the City of Centralia and both have an offset of 100 ft. All four gages display arbitrary water level values on the NWS and Flood Authority websites.

Table 3-3. Flood Authority gages

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
D1502054	WF SATSOP RIVER AT COUGAR SMITH ROAD NEAR SATSOP	Arbitrary	0	None
D15080AC	CHEHALIS BLW THRASH CRK	Arbitrary	0	None
12025500	CHEHALIS RIVER AT CENTRALIA	NGVD29	100	No Info
12026600	SKOOKUMCHUCK RIVER AT CENTRALIA	NGVD29	100	No Info

TransAlta operates one real-time, water level gage at Skookumchuck Dam. The gage has two separate stage sensors that measure the same water surface location in the reservoir as those that are listed in Table 3-4. The narrow band sensor is used for elevations above 465.0 ft., while the wide band sensor is used for elevations below 465.0 ft. Both sensors are referenced to NGVD 29, but TransAlta has also provided a 3.41 ft. offset to convert the data to NAVD 88, if necessary. A surveyor established the NGVD 29 vertical datum at the dam, based on NGS, WSDOT and Thurston County Control monuments. (Emrich, 2017).

Table 3-4. TransAlta Gages

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
1	SKOOKUMCHUCK (NARROW BAND)	NGVD29	0	"Datum"
1	SKOOKUMCHUCK (WIDE BAND)	NGVD29	0	"Datum"

A division of NOAA, the Center for Operational Oceanographic Products and Services (CO-OPS), operates one tidal gage station in the Chehalis Basin in Westport, WA at the mouth of Grays Harbor (Table 3-5). The gage measures and predicts water levels referenced to mean low low water (MLLW) which is calculated based on the average of lower low water heights observed during the National Tidal Datum Epoch. (NOAA, 2013). The gage is not currently referenced to NAVD 88.

Table 3-5. CO-OPS Gages

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
9441102	WESTPORT- WA	MLLW	0	NOAA MLLW

Grays Harbor County operates one gaging station on the Wishkah River near Baretich Road (Table 3-6) that collects water level information. It is not a real-time gage and it is expected to collect data for at least a few years. It is referenced directly to NAVD 88. (Indrebo, 2017).

Table 3-6. Grays Harbor County Gage

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
20025852	WISHKAH RIVER NR BARETICH RD	NAVD88	0	"Datum"

The City of Aberdeen has installed a water level gage near the mouth of the Wishkah River in Aberdeen, WA (Table 3-7). The gage is integrated with the City's SCADA system, but is not yet surveyed to NAVD 88. (Koski, 2017)

Table 3-7. City of Aberdeen Gage

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
Unknown	WISHKAH RIVER AT HERON ST BRIDGE AT ABERDEEN, WA	Arbitrary	0	None

Thurston County operates two water level gages (Table 3-8) on Scatter Creek and Prairie Creek located in the Chehalis River Basin. Currently, water level data is referenced to an arbitrary datum, but Thurston County's goal is to display it relative to NAVD 88 in the future. (Biever, 2017). Neither of the gages transmits data in real-time.

Table 3-8. Thurston County Gages

Station ID	Station Name	Vertical Datum	Offset (ft.)	Datum Method
65a	PRAIRIE CREEK AT GROUND MOUND	Arbitrary	0	None
55a	SCATTER CREEK	Arbitrary	0	None

A flood warning system only works when information is successfully disseminated to the public. One way that the Flood Authority does this is to allow users from the community to sign up for flood warning alerts for the ALERT Group (geographic area) for which they are concerned. Table 3-9 shows a list of the Alert groups, the gage associated with it, and the number of users signed up for alerts. Note some gages support more users than others. In particular, Chehalis River at Centralia, Skookumchuck River at Centralia, and Newaukum River near Chehalis, support the most users.

Table 3-9. Alert Contacts for the Flood Warning System as of May 2, 2017

Operator	Site Number	Alert Groups	Users Signed Up
USGS	12019310	CHEHALIS RIVER NEAR PE ELL	87
USGS	12037400	WYNOOCHEE RIVER NEAR MONTESANO	54
USGS	12035100	CHEHALIS RIVER NEAR MONTESANO	49
USGS	12020000	CHEHALIS RIVER NEAR DOTY	98
USGS	12025000	NEWAUKUM RIVER NEAR CHEHALIS	120
FLOOD AUTHORITY	12025500	CHEHALIS RIVER AT CENTRALIA	135
USGS	12026400	SKOOKUMCHUCK RIVER NEAR BUCODA	80

Operator	Site Number	Alert Groups	Users Signed Up
FLOOD AUTHORITY	12026600	SKOOKUMCHUCK RIVER AT CENTRALIA	119
USGS	12027500	CHEHALIS RIVER AT GRAND MOUND	90
USGS	12031000	CHEHALIS RIVER AT PORTER	64
USGS	12035000	SATSOP RIVER NEAR SATSOP	55

River forecast data, provided by the NWS is critical to protecting lives and property in the basin during flood events. Based on stream gage water levels and projected rainfall, NWS issues a 1-3 day forecast and a 4-10 day forecast for water level and discharge at each forecast location. This forecast information combined with the flood inundation mapping feature provided by the Flood Authority is invaluable. The NWS river forecast website is: https://www.nwrfc.noaa.gov/rfc/ . The gages used in the NWS river forecast network are listed in Table 3-10.

Table 3-10. River Forecast Points Provided by NWS

Operator	Station ID	Station Name	Vertical Datum
USGS	12020000	CHEHALIS RIVER NEAR DOTY	NGVD29
USGS	12025000	NEWAUKUM RIVER NEAR CHEHALIS	NGVD29
USGS	12026400	SKOOKUMCHUCK RIVER NEAR BUCODA	NGVD29
USGS	12027500	CHEHALIS RIVER NEAR GRAND MOUND	NGVD29
USGS	12031000	CHEHALIS RIVER AT PORTER	NGVD29
USGS	12035000	SATSOP RIVER NEAR SATSOP	NGVD29
USGS	12035380	WYNOOCHEE LAKE NEAR GRISDALE	NGVD29
USGS	12037400	WYNOOCHEE RIVER ABOVE BLACK CREEK NR MONTESANO	NGVD29
FLOOD AUTHORITY	12025500	CHEHALIS RIVER AT CENTRALIA- WA	NGVD29
FLOOD AUTHORITY	12026600	SKOOKUMCHUCK RIVER AT CENTRALIA- WA	NGVD29

3.3.1 Entities Affected by the Vertical Datum Conversion

The Chehalis River basin covers a large area and the vertical datum conversion has the potential to affect many organization and people that work with water level data (Table 3-11). Cowlitz, Grays Harbor, Jefferson, Lewis, Mason, Pacific, and Thurston Counties, and the Confederated Tribes of Chehalis Reservation could be affected by the change in datum. People, homes, agricultural lands, businesses, and transportation infrastructure can all be impacted by the change. They may include long standing users of observations and forecasts tied to different datum. For example, the general public uses flood inundation maps, emergency operations plans, FEMA mappers, and current LIDAR data users. When the reported water level changes, adaptation may take some time.

Table 3-11. Organizations and Counties Affected by Conversion

Identified Organizations and Counties Affected by Change
National Weather Service
United States Geological Survey
Chehalis River Basin Flood Authority
Washington State Department of Ecology
Washington State Department of Transportation
Federal Emergency Management Agency
US Army Corps of Engineers
Confederated Tribes of the Chehalis Reservation
Quinault Indian Nation
Lewis County
Jefferson County
Mason County
Grays Harbor County
Thurston County
Cowlitz County
Pacific County

3.3.2 Partial Vertical Datum Upgrade

The vertical datum conversion does not change the risks associated with flooding. However, it could lead to confusion if river stage data is displayed differently than it has been in the past. Upgrading stream gages from arbitrary or NGVD 29 to the NAVD 88 datum can be done with a partial or full conversion as outlined in Table 3-12.

Under a "partial" conversion plan, gages would be surveyed to NAVD 88 by differential level surveying or by using high accuracy GPS measurements to determine the NAVD 88 elevation at the gage. Each gage has a number of components (staff gages, reference marks, crest stage gages, etc.) that should be surveyed to NAVD 88. Once the gage components have been surveyed, an offset can be calculated that relates the gage datum (arbitrary or NGVD 29) to NAVD 88. A partial conversion would not change the values that the gage is measuring and transmitting. For example, a gage that has always been referenced to an arbitrary datum or NGVD 29 will continue to measure and transmit those values – only gage metadata would be updated to reflect that NAVD 88 has been surveyed to the gage and what the NAVD 88 offset is. Benefits of a partial conversion include:

- All associated alarms and flood stage information remains constant,
- No need to replace staff plates, reset wire weight gages or reset sensors,
- Public outreach is not necessary, and
- NAVD 88 water level data available if needed by applying offset.

A partial conversion allows the gages to be tied into NAVD 88 datum but it also allows other agencies and persons to view the same data they are accustomed to seeing when working with the gage data.

A full conversion would involve surveying and converting all gages to NAVD88. When the gage data is reported, all water levels would be referenced to NAVD 88 and displayed in NAVD 88 elevations. A full conversion is ideal; however, it requires every agency and person using the gage data to adapt to the new water levels. The details of a full conversion are discussed in Section 3.3.3, below.

Both the full conversion and the partial conversion are compared with a Status Quo option and presented in Table 3-12.

3.3.3 Full Vertical Datum Upgrade

A full conversion would pick up where a partial conversion leaves off – displaying NAVD 88 elevations for all users to see. At the gaging location, reference gages and sensors could be reset to read NAVD 88 water levels directly, or a simple offset could be used in the data logger to convert arbitrary or NGVD 29 to NAVD 88. With either choice, NAVD 88 water levels would be displayed in place of the current datum values on the gage website. This would represent a significant change for the end user. An example is illustrated below in Example 3-3.

> ***Example 3-3***. *USGS station 12027500 Chehalis River near Grand Mound displays water levels on the USGS webpage referenced to arbitrary gage datum. If the current stage at Grand Mound is 7.94 ft. (gage datum) then the newly displayed NAVD 88 stage is 135.03 ft. Both numbers represent the same water surface. Changing from NGVD 29 to NAVD 88 is a smaller change but nonetheless, a significant one.*
>
> *Arbitrary datum stage = 7.94 ft.*
> *NGVD 29 stage = 131.59 ft. (arbitrary + NGVD 29 offset)*
> *NAVD 88 stage = 135.03 ft. (using VERTCON offset of 3.44 ft. + NGVD 29 stage)*

Benefits of a full conversion include:

- Consistency between stream gages across the basin
- Numbers that make sense compared to real elevations
- Flood warning elevations are all referenced to the same vertical datum
- NAVD 88 is the standard vertical datum system used in the United States by federal agencies
- NAVD 88 is more accurate than NGVD 29
- Flood mapping is based on elevation data; therefore, ensuring that all elevations used for modeling are based on a single current datum is necessary
- Light Detection and Ranging (LiDAR) datasets, used for elevation data, are preferred to be collected in NAVD 88

Drawbacks to a full conversion include:

- Significant change to water level values
- Significant public outreach and education needed
- Coordination with stakeholders and other data users
- Modification of historical records

Prior to moving forward with a full conversion, a number of steps should be taken to minimize impacts and confusion. Outreach should focus on key audiences that use the gage data to prepare them for the conversion.

If a datum conversion is implemented, organizations that manage stream gages will need to clearly document the datum change. The NWS and USGS provide datum information for each gage that is available to the public. It will be important that emergency management officials using river stage data for flood warning are aware of the changes and potential impacts.

Table 3-12. Summary of Options for Converting to Vertical Datum NAVD 88

Option Number	Name	Description
1	Partial Conversion	Convert vertical datum at gages to NAVD 88. All stream gage datums would be referenced to one datum. Water levels would continue to be displayed in arbitrary or NGVD 29 datum. All associated alarms and flood stage information are not affected.
2	Full Conversion	Convert vertical datum at gages to NAVD 88. All stream gage datums would be referenced to one datum. Water levels would be referenced to NAVD 88 and displayed in NAVD 88 elevations. All associated alarms and flood stage information are affected.
3	Status Quo	No conversion. Gages remain referenced to current datum. Displayed water levels are not affected. All associated alarms and flood stage information are not affected.

4 Rating Curves

Rating curves are used to convert river stage measurements into discharge. Stage measurements change according to the datum used, however, a rating curve is adjusted regularly to continue to record the correct discharge at each stream gage location, even as the riverbed changes. This chapter gives a brief description of rating curves, followed by the results of an investigation regarding the NWS stage-discharge rating curves on the Skookumchuck and Chehalis Rivers near Centralia, WA.

4.1 Rating Curves

To measure streamflow, the height of the water surface, or water stage, is measured and the stage is converted into streamflow, or discharge, using a known relationship of stage to discharge. Stage-discharge relationships can be developed for stream gages by physically measuring the flow of the river with a mechanical current meter acoustic meter at a wide range of stages. If this is not feasible, stage-discharge relationships can also be developed using hydraulic models of the river. For each measurement of discharge there is a corresponding measurement of stage, as shown in the example stage-discharge relationship in Figure 4-1.

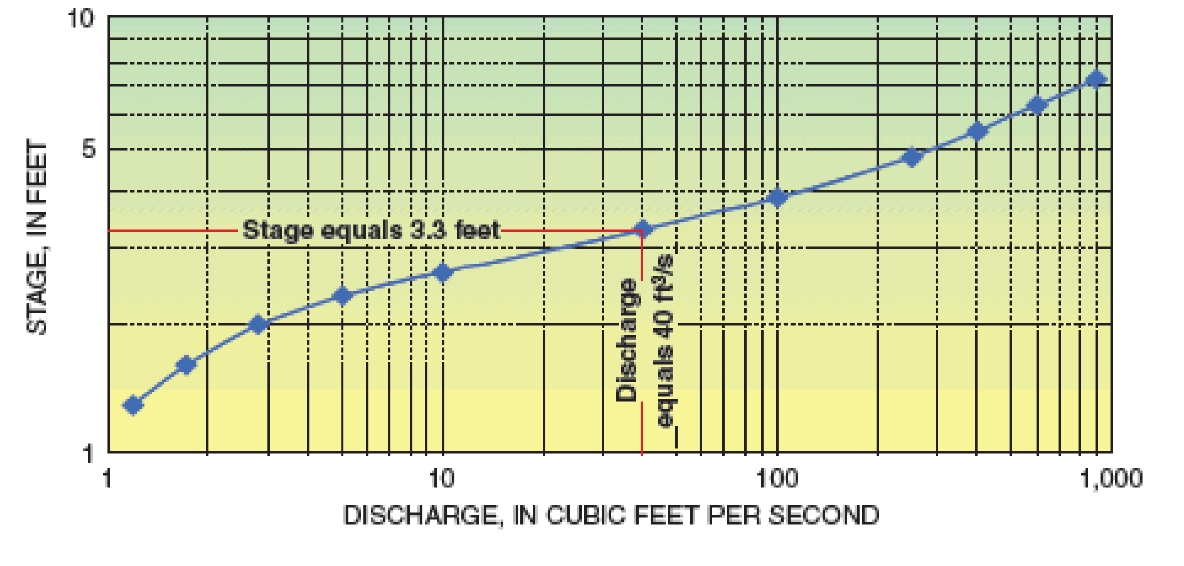

Figure 4-1. Stage-Discharge Rating Curve

In this example of a stage-discharge relationship, when the stage in the river is 3.3 feet, the discharge, or flow, is 40 ft^3/s. The stage discharge relationship depends on many factors of the stream: shape, size, slope and roughness, or coarseness of the sediment. When the size, shape, or slope of the stream channel changes, a new stage-discharge relationship must be developed. The stream channel may change, for example, when a large storm increases the discharge enough to pick up sediment from one part of the stream and deposit it in another.

Faster flows transport more volume and larger pieces of sediment. When the flow lessens and the sediment drops out of the water, a new shape and slope in the streambed are created. It is important to update the stage-discharge relationship for a gage on a regular basis to capture these natural changes to streambeds.

4.2 Rating Curve Investigation for Chehalis and Skookumchuck Rivers

To support the Flood Authority, WEST compared published NWS stage-discharge relationships with stage-discharge relationships from the most recent calibrated hydraulic model at two NWS gage locations, the Chehalis River gage near Centralia (CENW1) and the Skookumchuck River gage at Centralia (CTAW1). CENW1 is located on the Chehalis River approximately 0.75 river miles upstream of the Chehalis-Skookumchuck confluence, while CTAW1 is located on the Skookumchuck River approximately 2.50 river miles upstream of the confluence. Figure 4-2 and Figure 4-3 show both gage locations.

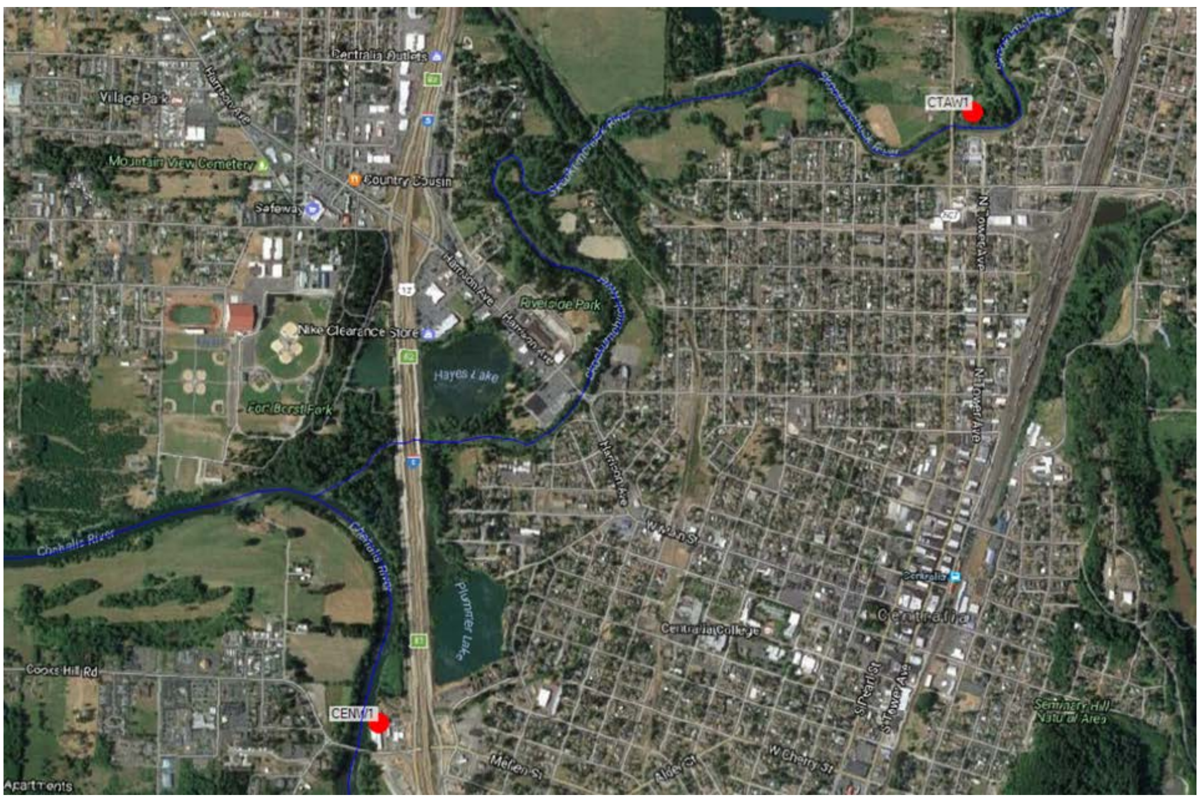

Figure 4-2. Satellite Image of National Weather Service Gage locations Near Centralia

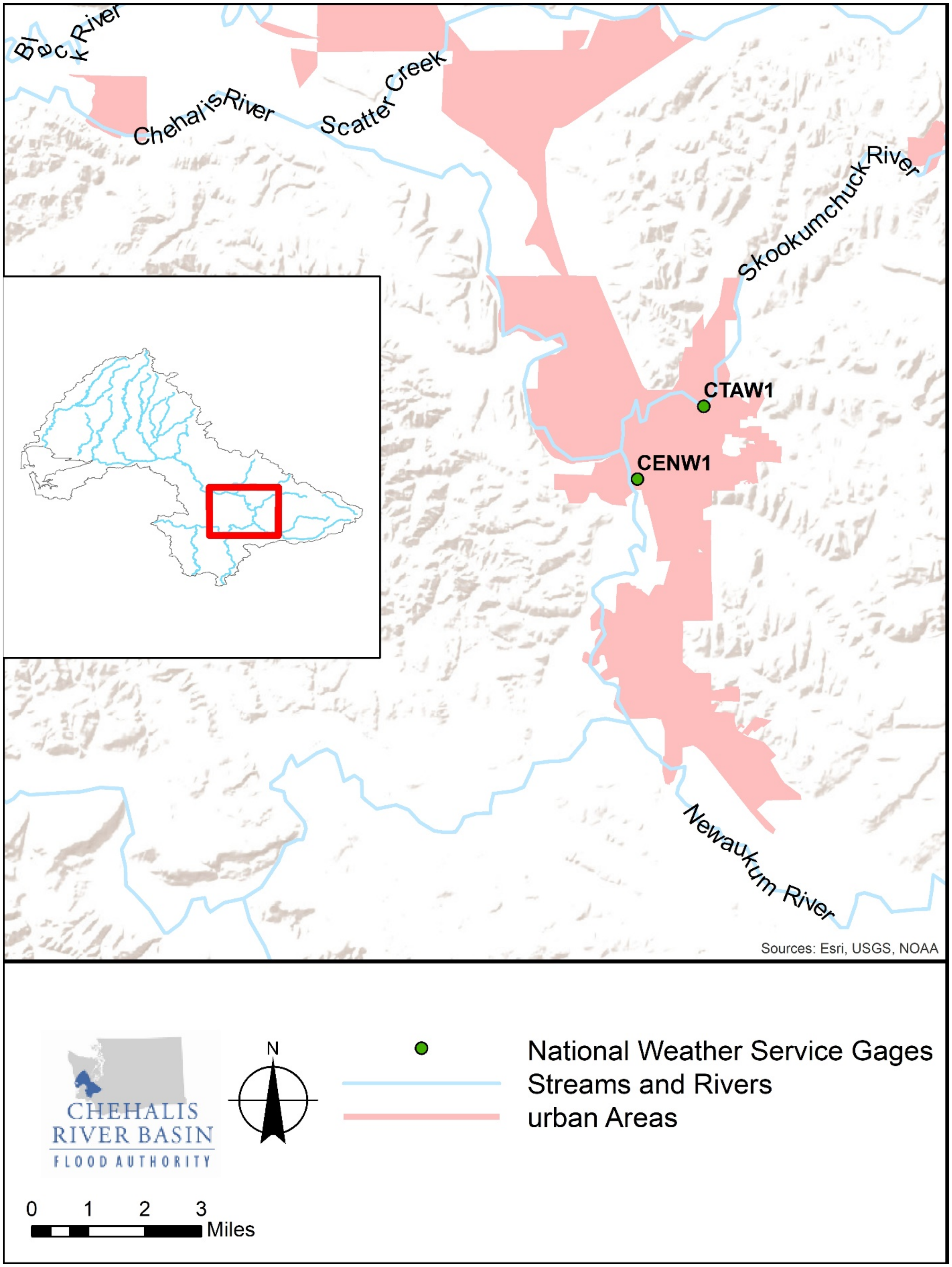

Figure 4-3. Map of National Weather Service Gages near Centralia

For the investigation, WEST obtained the most recent version of the hydraulic model of the Chehalis River system from Watershed Science & Engineering (WSE). WSE provided their 2016 HEC-RAS model, which was developed from previous versions of the Chehalis River model. For more information on model development and calibration, refer to WSE's memo titled *Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species* (WSE, 2014). Using the provided model plans, the model was run in HEC-RAS v5.0.1 and the observed high-water marks from the WSE 2016 model were compared with the results reported in the WSE 2014 model memo to confirm calibration near the area of interest, since the 2014 model is calibrated and well documented. The following events were used to confirm the calibration: February 1996, December 2007, and January 2009. According to the model results, the February 1996 event correlates approximately with a 100-year event at CENW1 and CTAW1, the December 2007 correlates approximately with a 500-year event at CENW1 and a 2-year event at CTAW1, and the January 2009 event correlates approximately with a 20-year event at CENW1 and CTAW1. These events confirm model calibration during larger flood events that cover a wide range of flows.

4.3 NWS Stage-Discharge Rating Curves at CENW1 and CTAW1

A summary of high water mark comparisons is presented in Table 4-1 through Table 4 3. Longitudinal profiles are presented for the Chehalis reach and the Skookumchuck reach in Figure 4 4 and Figure 4 5. The profiles show maximum water surface elevations for each of the three events, as well as the observed high-water marks for each event. Comparisons show that 2016 model results are reasonably close (most within a few hundredths of a foot, several within a few tenths of a foot) to the 2014 model results. Additionally, we examined observed and simulated stage hydrographs at the gage locations that are available in the 2016 model. Figure 4 6 and Figure 4 7 show the CENW1 and CTAW1 comparisons during the December 2007 event, and Figure 4 8 shows CENW1 comparisons during the January 2009 event. The model simulations predict the peak stage within a foot at CENW1 and at CTAW1, and follows the rising and falling limb of the hydrograph reasonably well. Given that the model reasonably predicts the observed high-water marks and the stage hydrographs, the WSE 2016 model was considered to be properly calibrated in the area of interest and no further adjustments were made.

Using the WSE 2016 calibrated model, several synthetic events were run to develop rating curves over a large range of flows at the CENW1 and CTAW1. The events include the 2-, 10-, 100-, and 500-year flood events. Based on results from the calibrated model, the rating curves from all modeled synthetic events were compared to NWS published rating curves (Figure 4 9 and Figure 4 10). Note that the NWS last updated the CTAW1 gage in 2013 and the CENW1 gage in 2016. By comparing all model data simultaneously, a line was fit to best represent the model results at each gage location and create new rating curves based on the fitted lines. The best-fit rating curves are included in Figure 4 9 and Figure 4 10, and summarized in Table 4 4 and Table 4 5.

Table 4-1. Verification of Model Calibration for the February 1996 Event

February 1996 Event	Chehalis River					
	RS	Observed	2014 Model Results	2016 Model Results	Difference Between 2016 Model and Observed	Difference Between 2016 and 2014 Model
	72.8	181.9	181.27	181.25	-0.65	-0.02
	67.86	179.61	178.80	178.81	-0.80	0.01
	67.43	177.70	177.60	177.59	-0.11	-0.01
	66.88	176.54	175.99	175.93	-0.61	-0.06
	66.73	175.61	175.56	175.50	-0.11	-0.06
	66.36	173.12	173.38	173.30	0.18	-0.08
	64.20	164.53	164.30	164.28	-0.25	-0.02
	Skookumchuck River					
	RS	Observed	2014 Model Results	2016 Model Results	Difference Between 2016 Model and Observed	Difference Between 2016 and 2014 Model
	3.84	201.66	200.91	200.92	-0.74	0.01
	2.42	190.69	190.84	190.84	0.15	0.00
	2.21	188.40	188.89	188.90	0.50	0.01
	2.00	187.70	187.49	187.50	-0.20	0.01

Table 4-2. Verification of Model Calibration for the December 2007 Event

December 2007 Event	Chehalis River					
	RS	Observed	2014 Model Results	2016 Model Results	Difference Between 2016 Model and Observed	Difference Between 2016 and 2014 Model
	69.22	181.60	181.69	181.78	0.18	0.09
	68.67	183.20	181.54	181.64	-1.56	0.10
	68.67	181.30	181.49	181.49	0.19	0.00
	67.86	179.80	180.99	180.94	1.14	-0.05
	67.86	179.60	180.90	180.64	1.04	-0.26
	67.51	179.90	179.97	179.84	-0.06	-0.13
	67.43	178.20	179.04	179.00	0.80	-0.04
	66.95	175.50	177.00	176.82	1.32	-0.18
	66.73	175.77	176.31	176.38	0.61	0.07
	66.47	174.42	174.71	174.52	0.10	-0.19
	65.80	171.93	172.33	172.25	0.32	-0.08
	64.90	168.20	169.22	169.00	0.80	-0.22
	Skookumchuck River					
	RS	Observed	2014 Model Results	2016 Model Results	Difference Between 2016 Model and Observed	Difference Between 2016 and 2014 Model
	6.40	210.32	210.50	210.50	0.18	0.00
	2.41	186.55	185.83	185.83	-0.72	0.00
	0.61	176.40	177.36	177.02	0.62	-0.34
	0.49	177.50	177.35	176.99	-0.51	-0.36

Table 4-3. Verification of Model Calibration for the January 2009 Event

January 2009 Event	Chehalis River					
	RS	Observed	2014 Model Results	2016 Model Results	Difference Between 2016 Model and Observed	Difference Between 2016 and 2014 Model
	72.58	179.30	179.63	179.64	0.34	0.01
	64.25	163.11	163.08	163.09	-0.02	0.01
	64.20	163.11	163.03	163.04	-0.07	0.01
	Skookumchuck River					
	RS	Observed	2014 Model Results	2016 Model Results	Difference Between 2016 Model and Observed	Difference Between 2016 and 2014 Model
	6.40	215.66	215.50	215.50	-0.16	0.00
	2.415	189.98	190.31	190.32	0.34	0.01
	2.41	190.83	190.43	190.43	-0.40	0.00

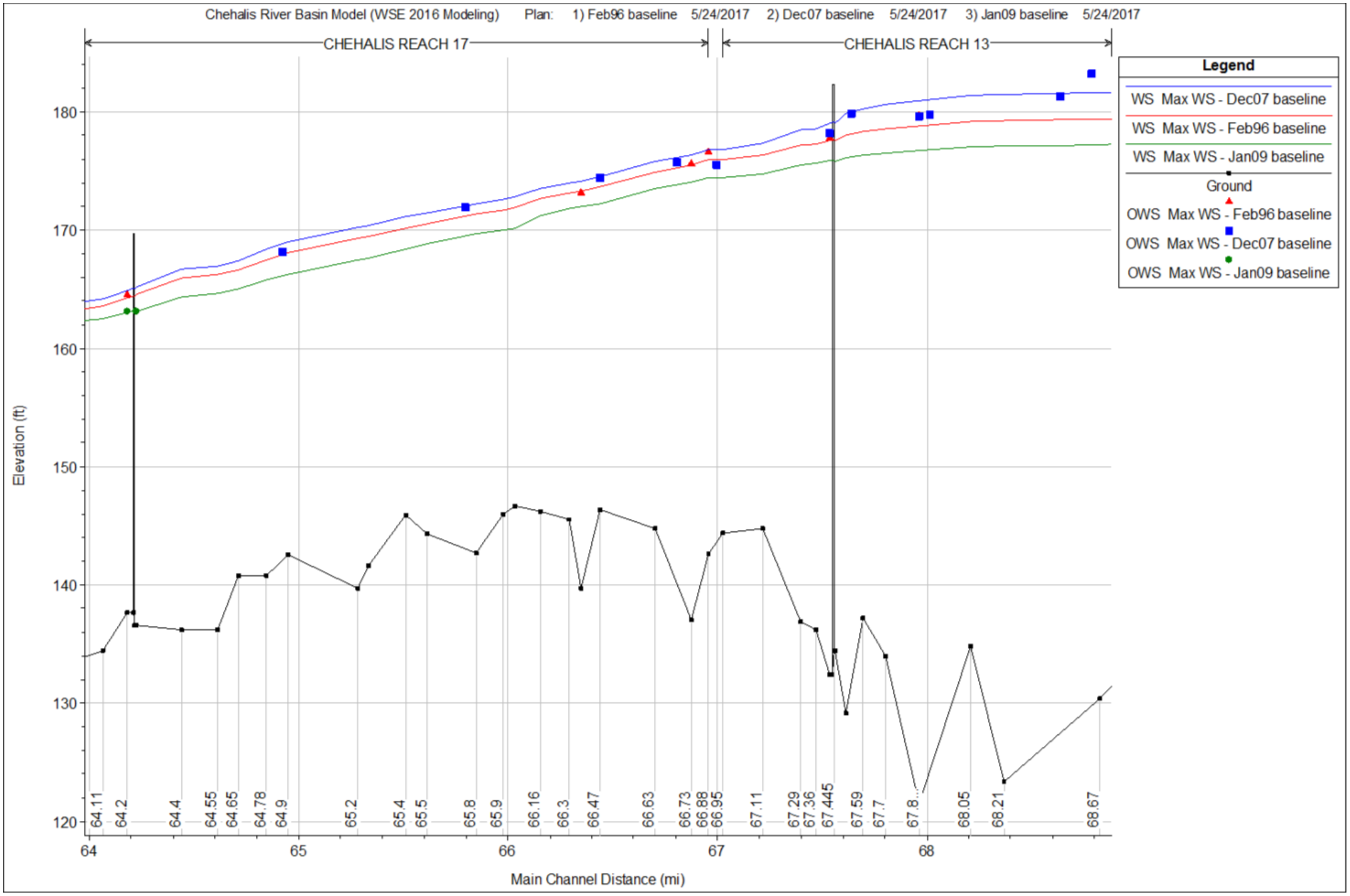

Figure 4-4. Chehalis River Longitudinal Profile

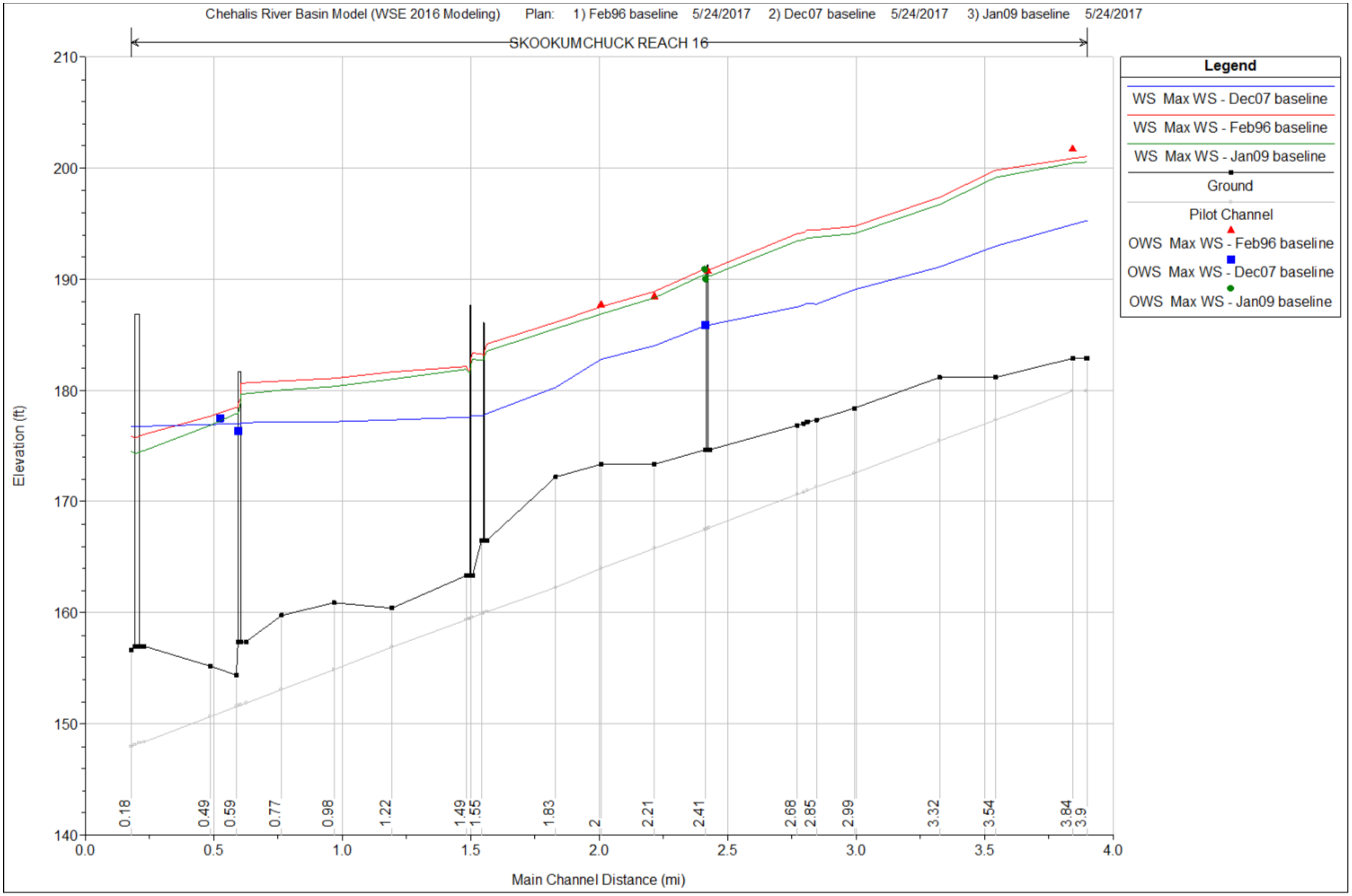

Figure 4-5. Skookumchuck River Longitudinal Profile

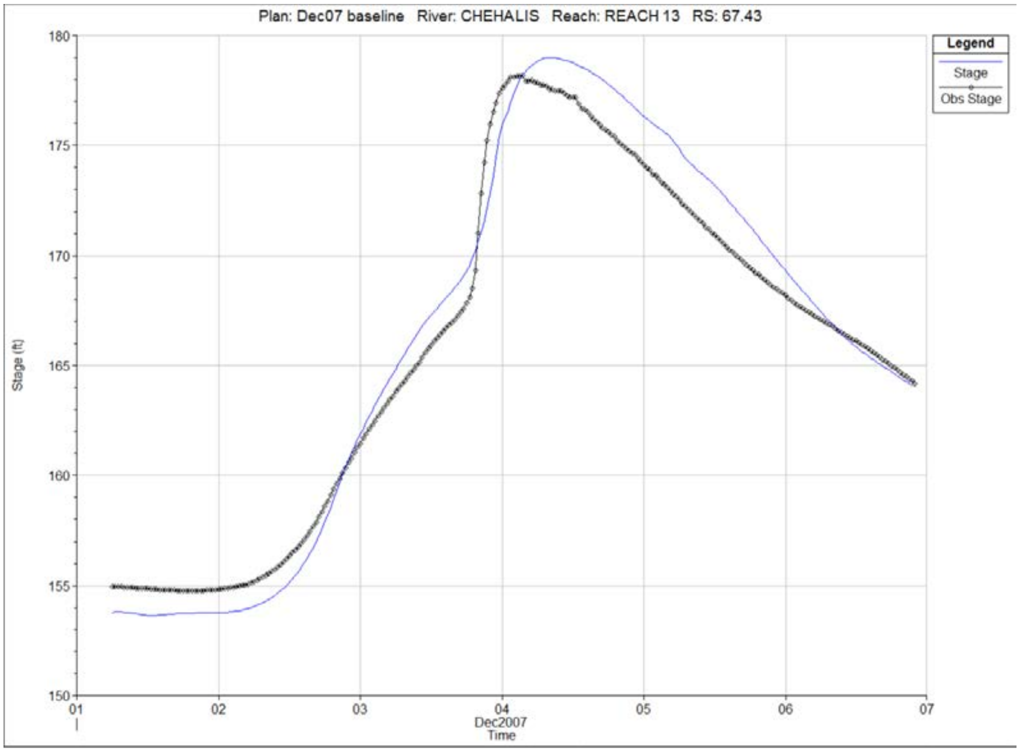

Figure 4-6. Observed vs Simulated Results at CENW1 (December 2007)

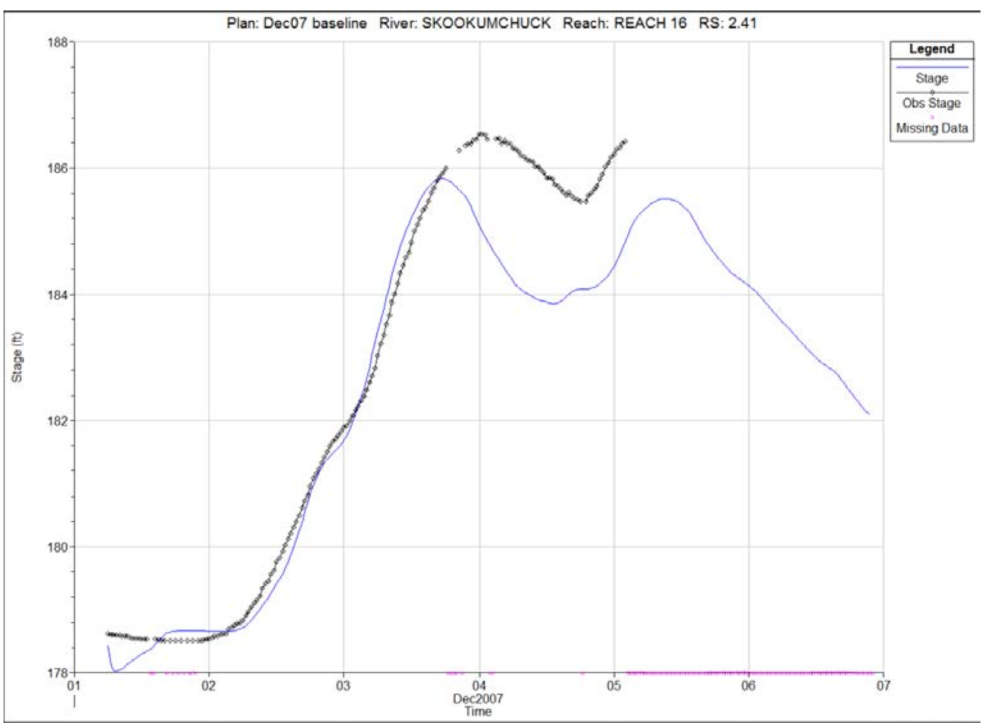

Figure 4-7. Observed vs Simulated Results at CTAW1 (December 2007)

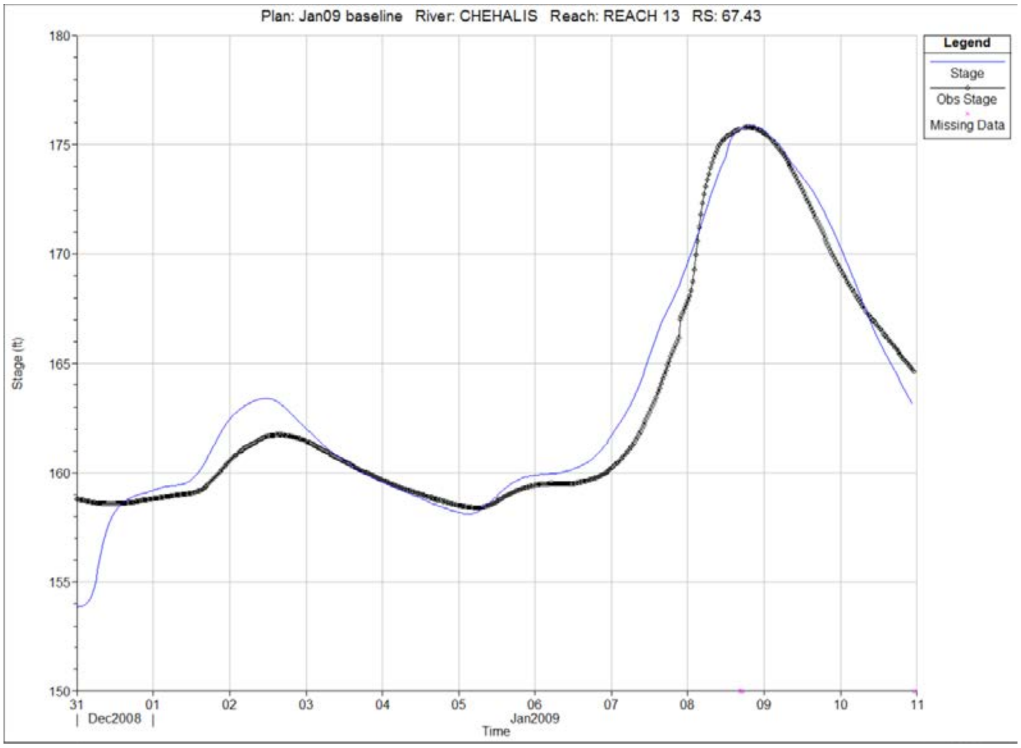

Figure 4-8. Observed vs Simulated Results at CENW1 (January 2009)

For events that have a water surface elevation below approximately 165 feet (NAVD88) at CENW1, model results indicate that the NWS rating curve is over-estimating stage. However, when the elevation of the Chehalis River is above approximately 167 feet, model results indicate that the NWS rating curve is under-estimating stage. For reference, water surface elevations at CENW1 peaked at 167.84 feet during the 2-year event. Conversely, model results indicate that the CTAW1 gage over-estimates flow when the water surface elevations at the gage are below approximately 183 feet, and between 186 feet and 189 feet. CTAW1 is under-estimating discharge compared to the model results when water surface elevations are above 189 feet at the gage. For reference, modeled water surface elevations are at 186.52 feet at CTAW1 during the two-year synthetic event and 189.51 feet during the 10-year event.

Correspondence with NWS indicates that the rating curves at CENW1 and CTAW1 are empirically produced with a hydrologic model and examination of upstream and downstream flows, and not with field discharge measurements. As part of this analysis, rating curves were developed at the site by fitting a regression equation through all the modeled synthetic stage-discharge data at each of the two sites of interest. Because the 2016 Chehalis River model was calibrated for larger flow events that simulate a range of flows and predict observed time series and high-water mark data reasonably well, the best-fit rating curves derived from the hydraulic model are expected to provide a reliable stage-discharge relationship during higher flow events.

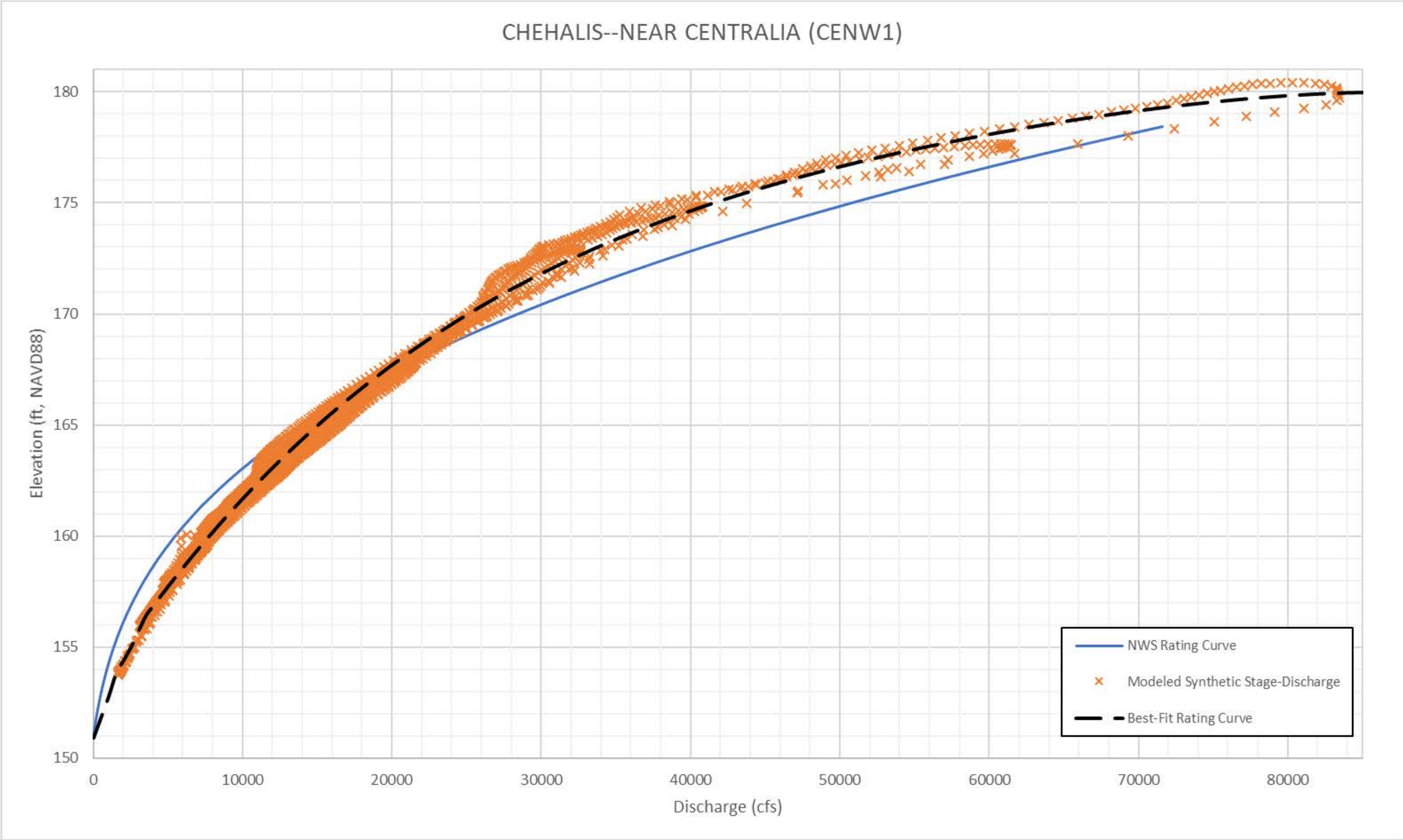

Figure 4-9. Chehalis River near Centralia (CENW1) Rating Curves

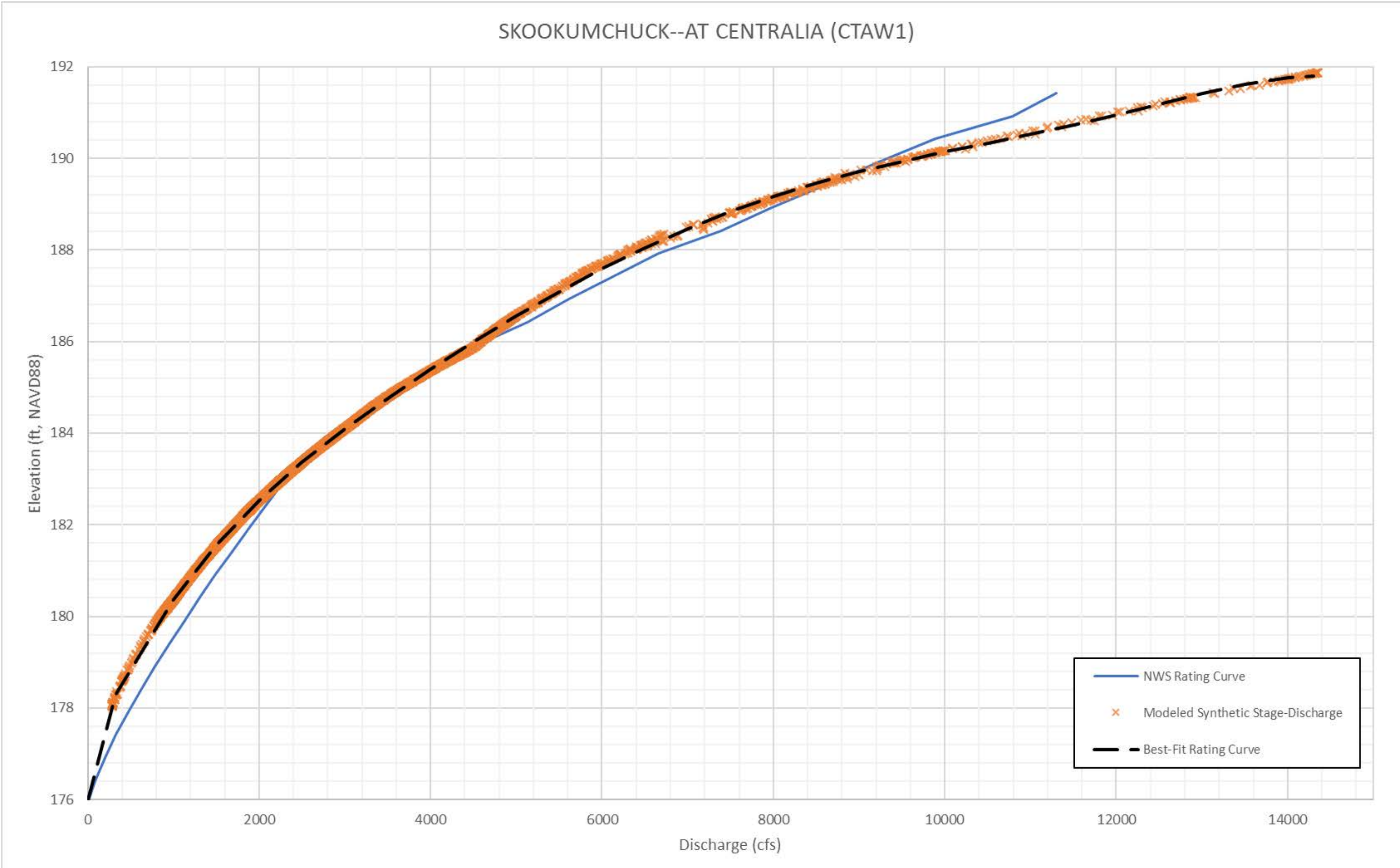

Figure 4-10. Skookumchuck River at Centralia (CTAW1) Rating Curve

Table 4-4. Best-fit Rating Curve at Chehalis River Gage near Centralia (CENW1)

CENW1		
Stage (feet)	Elevation (ft., NAVD88)	Discharge (cfs)
47.50	150.92	0.00
48.42	151.84	500.00
49.35	152.77	1000.00
50.38	153.80	1500.00
50.98	154.40	2000.00
51.58	155.00	2500.00
52.29	155.71	3000.00
53.45	156.87	4000.00
55.18	158.60	6000.00
56.79	160.21	8000.00
58.28	161.70	10000.00
59.67	163.09	12000.00
60.96	164.38	14000.00
62.16	165.58	16000.00
63.27	166.69	18000.00
64.30	167.72	20000.00
65.25	168.67	22000.00
66.13	169.55	24000.00
66.95	170.37	26000.00
67.71	171.13	28000.00
68.41	171.83	30000.00
69.06	172.48	32000.00
69.67	173.09	34000.00
70.23	173.65	36000.00
70.75	174.17	38000.00
71.24	174.65	40000.00
71.69	175.11	42000.00
72.11	175.53	44000.00
72.51	175.93	46000.00
72.88	176.30	48000.00
73.22	176.64	50000.00
73.55	176.97	52000.00
73.86	177.28	54000.00
74.15	177.57	56000.00
74.42	177.84	58000.00
74.68	178.10	60000.00
74.92	178.34	62000.00
75.15	178.57	64000.00
75.36	178.78	66000.00
75.56	178.98	68000.00
75.74	179.16	70000.00
75.91	179.33	72000.00

CENW1		
Stage (feet)	Elevation (ft., NAVD88)	Discharge (cfs)
76.07	179.49	74000.00
76.20	179.62	76000.00
76.32	179.74	78000.00
76.42	179.84	80000.00
76.50	179.91	82000.00
76.55	179.97	84000.00
76.58	179.99	86000.00

Table 4-5. Best-fit Rating Curve at Skookumchuck River Gage at Centralia (CTAW1)

CTAW1		
Stage (feet)	Elevation (ft.,	Discharge
72.58	176.00	0.00
74.87	178.29	322.35
76.95	180.37	1000.00
78.14	181.55	1500.00
79.11	182.53	2000.00
79.94	183.36	2500.00
80.67	184.09	3000.00
81.34	184.76	3500.00
81.97	185.39	4000.00
82.57	185.98	4500.00
83.13	186.55	5000.00
83.67	187.08	5500.00
84.17	187.58	6000.00
84.63	188.05	6500.00
85.05	188.47	7000.00
85.42	188.84	7500.00
85.75	189.17	8000.00
86.04	189.46	8500.00
86.29	189.71	9000.00
86.52	189.93	9500.00
86.72	190.14	10000.00
86.91	190.33	10500.00
87.11	190.53	11000.00
87.31	190.73	11500.00
87.53	190.95	12000.00
87.76	191.18	12500.00
87.99	191.41	13000.00
88.19	191.61	13500.00
88.34	191.76	14000.00
88.38	191.80	14300.00

5 Recommendations

5.1 Add additional HADS, USGS, and METAR Precipitation Gages

5.1.1 Recommendation

Rather than installing more gages on the ground, it is advisable to gain access to the gages that are already located in the Chehalis Basin, but are not yet part of the Flood Warning System. These gages include those that are part of the HADS, USGS, and METAR systems. (Figure 5-4 and Figure 5-5). This also includes the RAWS network, which reports through HADS. There are currently 19 precipitation gages that can be added to Contrail (Table 5-1) within a few days. Each gage may contain multiple sensors (for wind, precipitation, humidity, streamflow, water quality, etc.), however, it is the precipitation sensors that is recommended here. Two gages in Figure 5-4 are USGS stream gaging stations that also contain precipitation sensors, which are not yet in Contrail.

Table 5-1. List of Precipitation Gages that can be added to Contrail

Site Name	Site ID	Contrail Data System
ELK MEADOWS RAIN GAUGE NEAR MONTESANO 20N	EKMW1	HADS
BLACK KNOB	BKBW1	HADS/RAWS
MINOT PEAK	MIPW1	HADS/RAWS
HUMPTULLIPS	HUFW1	HADS/RAWS
TILTON RIVER ABOVE BEAR CANYON CREEK NEAR CINEBAR 4SE	TILW1	HADS
CHEHALIS RIVER NEAR DOTY 1S	DOTW1	HADS
NORTH FORK SKOKOMISH RIVER BELOW STAIRCASE RAPIDS NEAR HOODSPORT 11NW	SKOW1	HADS
CHEHALIS RIVER AT WASTEWATER TREATMENT PLANT AT CHEHALIS 1W	CRWW1	HADS
NORTH FORK NEWAUKUM RIVER ABOVE BEAR CREEK NEAR FOREST NEAR ONALASKA 7NW	NFFW1	HADS
SOUTH FORK CHEHALIS RIVER AT WILDWOOD NEAR RYDERWOOD 6NW	SCWW1	HADS
ABERNATHY MTN.	ABNW1	HADS/RAWS
Chehalis-Centralia Airport	KCLS	METAR
SKOOKUMCHUCK RIVER NEAR BUCODA 3SW	BCDW1	HADS
KM Mountain ALERT	KMMW1	HADS
SOUTH FORK NEWAUKUM RIVER NEAR NEAR ONALASKA 1E	SFNW1	HADS
CHEHALIS	CLSW1	HADS/RAWS
HUCKLEBERRY RIDGE	HKFW1	HADS/RAWS
WYNOOCHEE LAKE NEAR GRISDALE- WA	12035380	USGS
ABERDEEN RESERVOIR NEAR GRISDALE, WA	471541123425300	USGS

5.1.2 Cost

The Contrail web plan currently in place with OneRain allows for additional sensors to be added for a relatively low cost. With 168 sensors currently in Contrail and the public website, the cost is $5,275/year. Additional sensors added to the system would increase the cost according to Table 5-2. An interpolation of Table 5-2 yields an increase in the annual cost of approximately $137 for the addition of 19 sensors.

Table 5-2. Additional Cost of Added Gages

Additional gages	Increased Cost	Annual Cost
12	$ 87	$ 5,362
24	$ 173	$ 5,448
36	$ 259	$ 5,534
48	$ 329	$ 5,604
60	$ 398	$ 5,673

5.1.3 Time Estimate

It is estimated to take a day to add the additional sensors to Contrail.

5.2 Add Ecology Stream Measurements to Contrail

Five Ecology stream gages that are not included in the HADS system are located in the basin. These gages are primarily located on small tributaries to the Chehalis River (Figure 2-7) and can be added to HADS and consequently to Contrail. Although they are small streams, some are located near developed areas and could be an important part of the flood warning system.

The Ecology would need to add the additional data points to the HADS Network. This would require a partnership with the Ecology.

5.2.1 Cost

There would be a marginal cost of approximately $35 (interpolated from Table 5-3) per year to add the five Ecology gages. Table 5-3 shows the additional costs associated with added gages to Contrail.

Table 5-3. Additional Cost of Added Gages

Additional gages	Increased Cost	Annual Cost
12	$ 87	$ 5,362
24	$ 173	$ 5,448
36	$ 259	$ 5,534
48	$ 329	$ 5,604
60	$ 398	$ 5,673

5.2.2 Time Estimate

The Ecology is currently in conversation with NWS regarding the addition of their gages to HADS. It appears this coordination is take place. Once the additional Ecology gages are part of the HADS network, they could be added to Contrail immediately, likely during 2017-18 flood season.

5.3 National Weather Service Flood River Gages Near Centralia

The two weather service stream gages near Centralia, Chehalis River gage near Centralia (CENW1) and Skookumchuck River gage at Centralia (CTAW1), are critical components of the Flood Warning System. These gages are the most requested for flood alerts (Figure 5-1). It is important that these gages remain in operation with their equipment modernized.

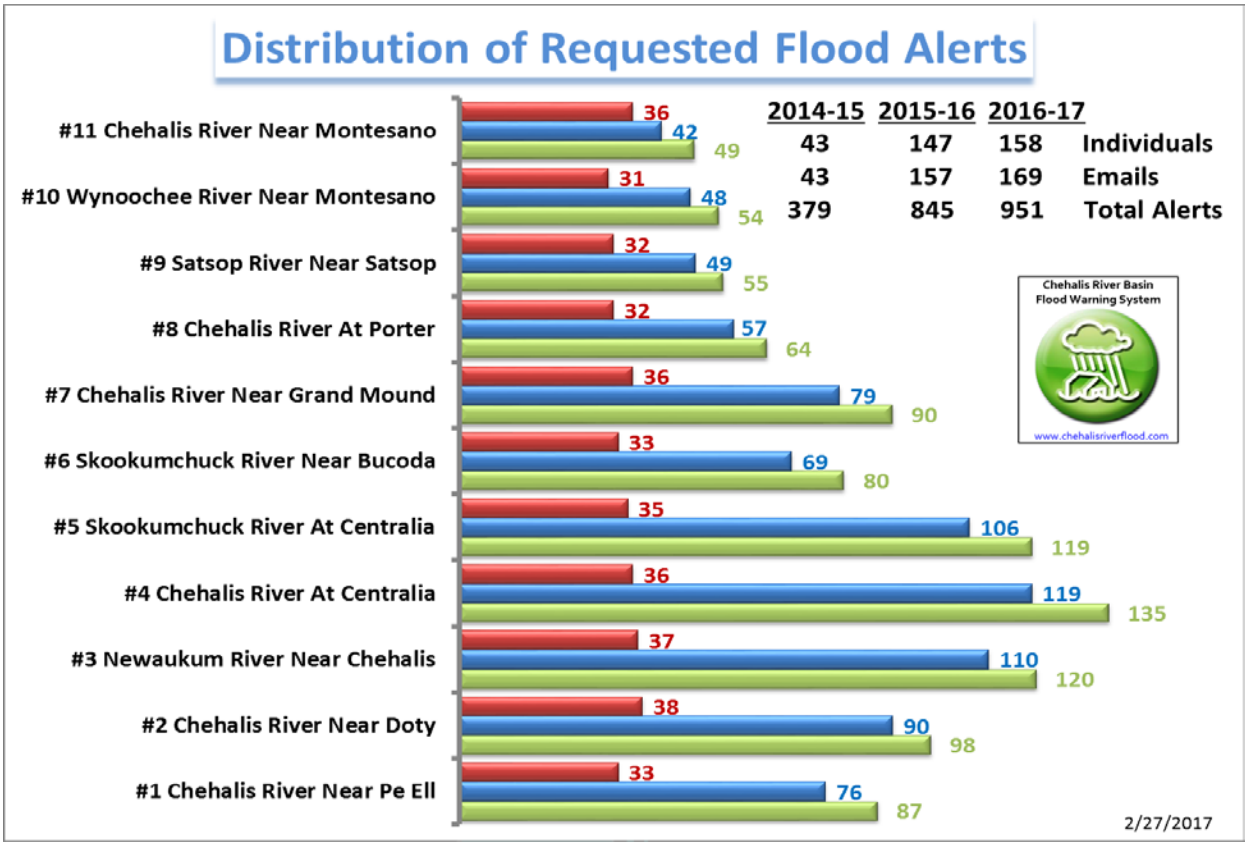

Figure 5-1. Distribution of Requested Flood Alerts

In 2017 the equipment at these sites underwent an upgrade. The outdated equipment was replaced by electronic stage sensors and the data is now recorded onsite by data loggers. Near real-time data will be transmitted from the gages using the National Environmental Satellite Data and Information Service (NESDIS) GOES system.

The stations will now be visited by experienced technicians on a regular basis to prevent equipment malfunctions and proactively assess other problems. Site visits will include documentation that explain what was done; comparing wire-weight gage readings to stage measurements from sensors, checking power supplies, visual inspection of equipment, downloading data from the data logger which can be used to backup GOES data, and resolving any issues that could influence data quality and reliability. If significant differences are found between wire-weight gages readings and stage measurements from the sensor, the sensor will be reset to read the same as the wire-weight gage.

A minimum of three survey reference marks was established at each station. Detailed information documenting the location, elevation, and survey dates of reference marks and wire-weight gages were retained. A detailed description of the gage upgrades are in Appendix J.

5.3.1 Cost

The cost to upgrade the two NWS gages was $61,595.

5.3.2 Timeline

The work has been completed as documented in Figure 5-2 and Figure 5-3.

Figure 5-2. NWS Gage Upgrade Chehalis River at Centralia, WA

Figure 5-3. NWS Gage Upgrade Skookumchuck River at Centralia, WA

5.4 Survey Gages to NAVD 88

5.4.1 Full Datum Upgrade for Stream Gages

Convert the datum at all USGS gages stream gages in Chehalis River Basin, as listed in Table 5-4, to NAVD 88. All stream gages would be referenced to the same datum. Water levels would be referenced to NAVD 88 and displayed in NAVD 88 elevations.

Table 5-4. List of 16 Stream Gages in the Chehalis River Basin for Datum Change

USGS Station No.	Station Name	Current Datum	Probable Conversion Method
12020000	Chehalis River near Doty	Arbitrary	GPS
12020525	Elk Creek below Deer Creek near Doty	NGVD 29	GPS
12020800	South Fork Chehalis River near Wildwood	NGVD 29	Levels
12021800	Chehalis River near Adna	NGVD 29	Levels
12024000	South Fork Newaukum River near Onalaska	NGVD 29	GPS
12024400	North Fork Newaukum River above Bear Creek near Forest	NGVD 29	GPS
12025000	Newaukum River near Chehalis	NGVD 29	GPS
12025100	Chehalis River at Wastewater Treatment Plant at Chehalis	NGVD 29	Levels
12025500	Chehalis River at Centralia	NGVD 29	VERTCON

USGS Station No.	Station Name	Current Datum	Probable Conversion Method
12025700	Skookumchuck River near Vail	NGVD 29	GPS
12026150	Skookumchuck River below Bloody Run Creek near Centralia	NGVD 29	Levels
12026400	Skookumchuck River near Bucoda	NGVD 29	VERTCON
12026600	Skookumchuck River at Centralia	NGVD 29	Levels
12027500	Chehalis River near Grand Mound	NGVD 29	VERTCON
12031000	Chehalis River at Porter	NGVD 29	Levels
12035000	Satsop River near Satsop	NGVD 29	Levels

5.4.2 Cost

The USGS and the Flood Authority are jointly funding the conversion for a cost of $27,100. Of which the Flood Authority will pay $17,100.

5.4.3 Timeline

The USGS is currently in surveying phase of the datum conversion process. The current schedule aims for a full conversion by early summer of 2018.

5.5 Upgrade GOES DCS

The GOES Data Collection System (DCS) is used as the primary data transmission method for water level data in the Chehalis River Basin. GOES is used for the following reasons: large basin size, rugged terrain, remotetness, and the reliability and cost efficiency associated with the GOES system. Gages that measure environmental parameters (such as water level, air temperature, precipitation, etc.) transmit data at routine intervals via the GOES DCS

Both the USGS and Ecology have almost completely transistioned over to the Version 2.0 GOES transmitters as of March 2017. To keep up with its partners within the Chehalis River Basin and avoid the cut-off date of old technologythe Flood Authority upgrading to Version 2.0 transmitters during the next two years.

The Flood Authority operates ten gages in the Chehalis River Basin, and each of the gages has a GOES DCS with transmitter.

5.5.1 Cost

The cost to upgrade the transmitters is $22,244.53

5.5.2 Timeline

The upgrade is in progress.

5.6 Outreach and Educational for Datum Change

Create an outreach and educational awareness datum conversion plan. Achieving a smooth transition will be a collaborative effort. Designated outreach partners will need to be identified to help implement an outreach and education plan. The goal is to provide support to the identified agencies and public about the vertical datum change. All outreach materials should stress the importance of using a common vertical datum and what that change could impact. The outreach plan includes:

- Outreach flyer: The outreach flyer will provide information about what a vertical datum is, why the transition to a new datum is important, expected transition timing, and what affect the datum change will have on organizations and the public. The flyer should be a one- or two-page document that is easily interpreted by the general public.
- Social media postings published on the internet (Lewis Country Rivers, USGS, Ecology, Flood Warning System, local agencies, etc.) and sent out via email.
- Notifications sent to federal, State, and local officials of the datum change and points of contacts for further information
- Public meeting events held to help inform about the switch so organizations and communities can plan accordingly. Presentation materials (such as PowerPoint presentations) would explain the change and highlight potentially affected parties.
- Notices to Chambers of Commerce, press, relevant websites

The outreach events and educational programs will help facilitate the process and promote awareness and dialogue in the community. Based on the outreach response, follow-up workshops may be necessary to provide additional support. Before implementing the datum change, coordination meetings with affected agencies should be held to identify key issues and to coordinate the transition. Annual flood preparedness meetings have a good test-audience for outreach events.

5.6.1 Cost

The cost will vary depending on the scope of the plan.

5.6.2 Timeline

Ideally, the initial outreach effort should be started before the datums are converted. However, this will be on-going effort and should coincide with the datum conversion timeline.

5.7 Add City of Aberdeen Stream Gage

5.7.1 Recommendation

The City of Aberdeen has a stream gage on the Wishkah River (Figure 2-6). It is connected to supervisory control and data acquisition (SCADA) system. Arrangements have not been made to add this streamflow data to Contrail. If arrangements are made with the City of Aberdeen to transmit the data outside of their secure network, it could be added to the Flood Warning System. This arrangement would be similar to the arrangement with TransAlta for the gage on the Skookumchuck River.

5.7.2 Cost

If Aberdeen where able to provide the data on an unsecure server, in one of several standard formats, there would be no cost, other than the incremental additional sensor cost in Contrail. If Aberdeen did not have the technical ability to provide the data on an unsecure server, an Information Technology (IT) Consultant would need to be hired to do this. OneRain generally does not offer this kind of support. A general estimate for the cost to hire an outside IT consultant would be in the range of $1,000 to $3,000.

5.7.3 Time Estimate

The sensor could be added to the Flood Warning System within a 2-3 weeks.

5.8 Gage-Adjusted Radar Rainfall

5.8.1 Recommendation

Gage Adjusted Radar Rainfall (GARR) uses meteorological gage data in combination with real-time NEXRAD radar to create a fully spatial distribution of real-time precipitation. Point data, such as that received from precipitation sensors, is more accurate, but is spatially limited. GARR allows for more accurate, spatially-variable estimates of rainfall. It marries rain gage measurement with the spatially-distributed information from NEXRAD radars to provide ground-truthed, spatially-distributed rainfall information. The GARR method derives rainfall rates from 1-km^2 or 2-km^2 radar pixels and calibrates these rates using rain gage data to produce ground-truthed rainfall estimates.

There is added benefit to the Flood Authority to add GARR to the flood warning system, but this benefit is reduced as more gages are added to the system. Although GARR is not necessary, the Flood Authority should consider GARR because of its ability to give more accurate spatial distribution of rainfall.

5.8.2 Cost

GARR could be added to Contrail for a one-time cost of $3,000 and an annual cost of $13,200. The product can be prorated for the heavy flood season (Mid-December through mid-March) for $3,300. Upgraded subscriptions offered through OneRain would offer some additional features and a reduced long-term cost for GARR, but an increased short-term cost (See Appendix G for details). These upgrades include Contrail Server and Contrail Base Station. The primary benefit of the Contrail Server and Contrail Base station subscriptions as it relates to

Chehalis Flood Authority is a reduced annual cost ($7,200) for GARR and the additional of other features described in (Appendix I).

The Contrail Base Station option would require the Flood Authority to host the server outside of the OneRain servers and therefore it would not have 24/7 support; this option is not advised. If GARR is added to Contrail, it is recommended to keep the Contrail Web Subscription to have access to the 24/7 support from OneRain.

5.8.1 Time Estimate

GARR is not currently implemented in Contrail. It is estimated to take 1-2 months to add GARR with the existing Contrail Web Subscription. If the Contrail Server or Contrail Base Station Subscription were selected, it would take an additional 2-4 months (see appendix G for details into the implementation of Contrail Server and Contrail Base Station).

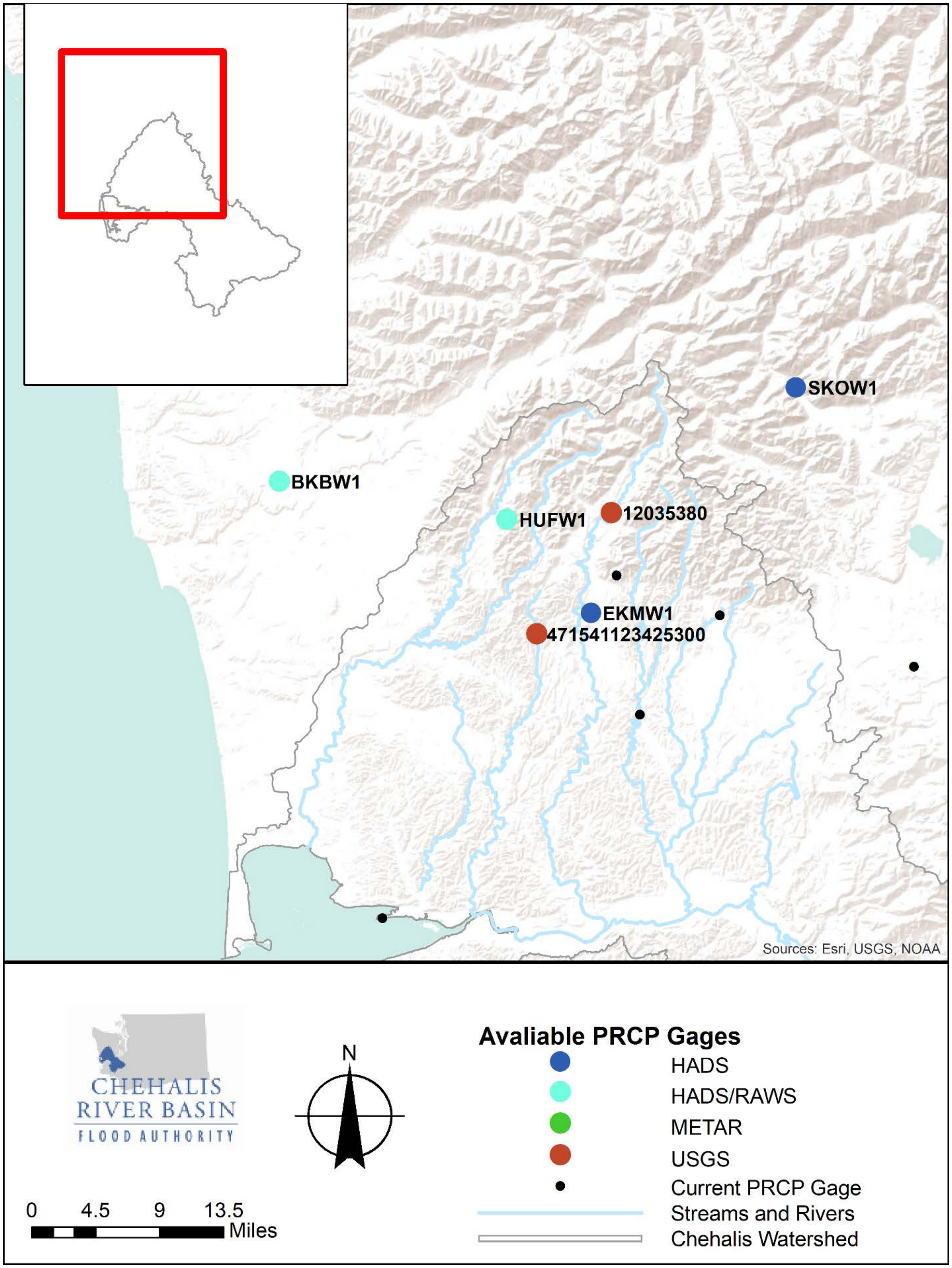

Figure 5-4. Available Precipitation Gages in Northern Chehalis Watershed for Use in Contrail

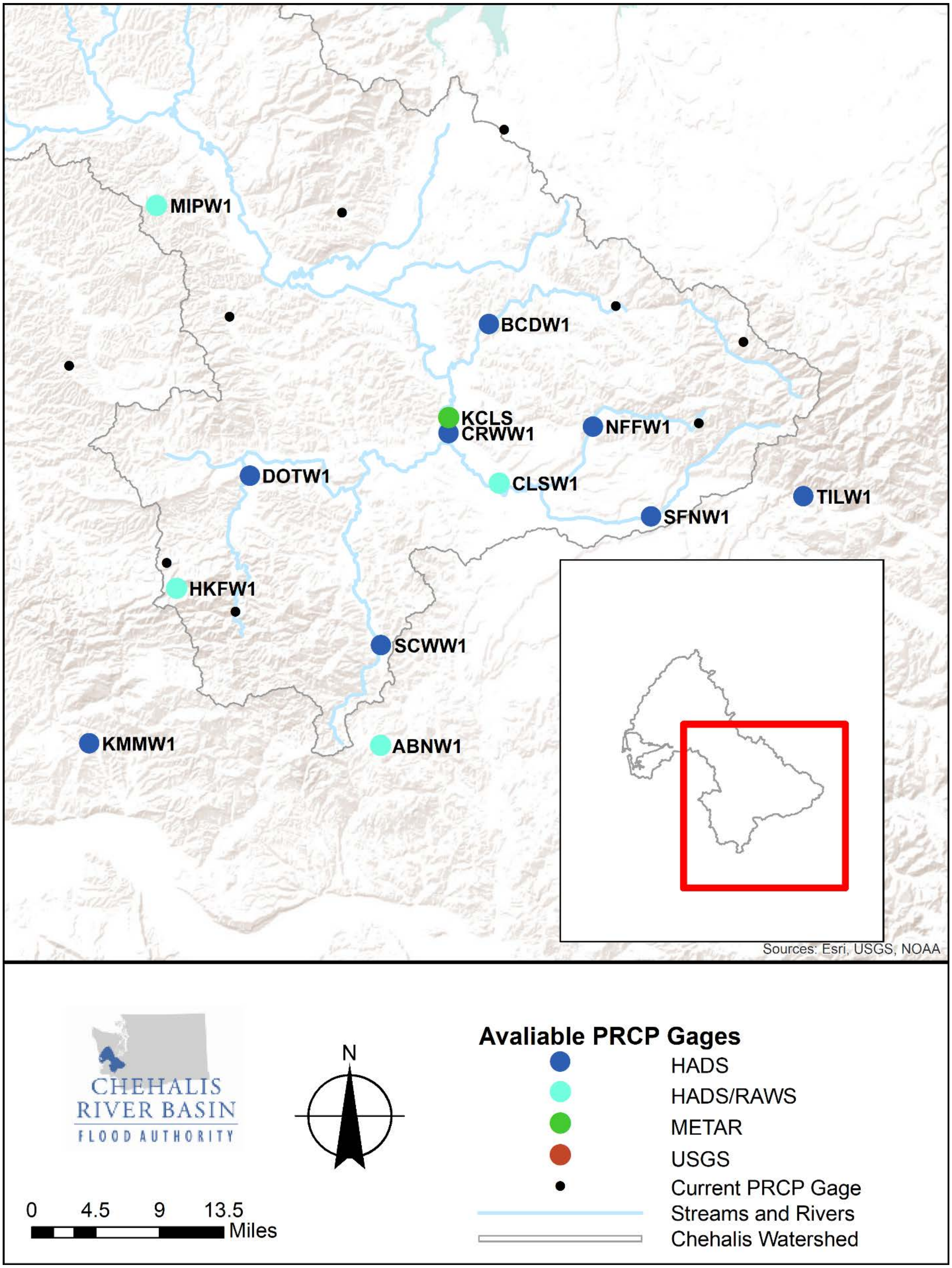

Figure 5-5. Available Precipitation Gages in Southern Chehalis Watershed for Use in Contrail

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Appendix A - High Flows at Major Gages in Chehalis

The ten largest flood crests at each USGS flood-monitoring gage location within the Chehalis Basin are listed in Table A-1 through Table A-6

Table A-1. Ten Largest Flood Crests on the Chehalis River at Centralia (CENW1)

Rank	Date	Flood Stage (ft.)
1	12/4/2007	74.78
2	2/9/1996	74.31
3	1/10/1990	73.5
4	1/8/2009	72.4
5	11/25/1986	71.99
6	1/21/1972	71.65
7	11/25/1990	71.3
8	12/5/1975	71.17
9	1/26/1971	70.2
10	12/30/1996	70.18

Table A-2. Ten largest Flood Crests on the Chehalis River at Porter (CRPW1)

Rank	Date	Flood Stage (ft.)
1	12/5/2007	26.06
2	2/9/2009	25.22
3	1/9/2009	24.65
4	1/11/1990	24.52
5	1/22/1972	23.88
6	1/27/1971	23.50
7	1/2/1997	23.43
8	11/25/1986	23.36
9	12/5/1975	23.36
10	11/26/1990	23.17

Table A-3. Ten Largest Flood Crests on the Skookumchuck River near Bucoda (BCDW1)

Rank	Date	Flood Stage (ft.)
1	02/08/1996	17.87
2	01/08/2009	17.72
3	01/10/1990	17.33
4	11/25/1990	17.23
5	04/05/1991	16.82
6	01/21/1972	16.82
7	12/30/1996	16.76
8	12/09/2015	16.60
9	02/11/1990	16.60
10	03/09/1977	16.51

Table A-4. Ten Largest Flood Crests on the Skookumchuck River at Centralia (CTAW1)

Rank	Date	Flood Stage (ft.)
1	02/08/1996	87.27
2	01/10/1990	87.10
3	04/05/1991	86.68
4	01/21/1972	86.60
5	01/08/2009	86.58
6	11/25/1990	86.50
7	02/11/1990	86.38
8	12/30/1996	86.17
9	12/10/1953	86.00
10	01/26/1971	86.00

Table A-5. Ten Largest Flood Crests on the Newaukum River near Chehalis (NEWW1)

Rank	Date	Flood Stage (ft.)
1	02/08/1996	13.54
2	01/07/2009	13.49
3	12/03/2007	13.45
4	01/05/2015	13.14
5	11/07/2006	13.00
6	11/18/2015	12.79
7	11/24/1986	12.76
8	01/09/1990	12.75
9	11/24/1990	12.73
10	11/26/1998	12.50

Table A-6. Ten Largest Flood Crests on the Chehalis River near Grand Mound (CGMW1)

Rank	Date	Flood Stage (ft.)
1	12/04/2007	20.23
2	02/09/1996	19.98
3	01/10/1990	19.34
4	11/25/1986	18.41
5	12/29/1937	18.39
6	01/21/1972	18.21
7	01/08/2009	18.18
8	11/25/1990	18.12
9	12/05/1975	17.73
10	04/06/1991	17.66

Appendix B - Historic Floods 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_1, 2017)

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 heards 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 damages in the state of Washington were estimated at over $500 million. ($NWS_1$, 2017) (OWSC, 2007)

Figure B-1. Image of Flooding During the 2007 Chehalis 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-2) 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-3) and throughout western Washington. The saturated soils, 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-4). The crest of the Chehalis River measured at Centralia was 72.4 feet on January 8th, seven feet above flood stage. The total damages were estimated at $72 million. ($NWS_1$, 2017)

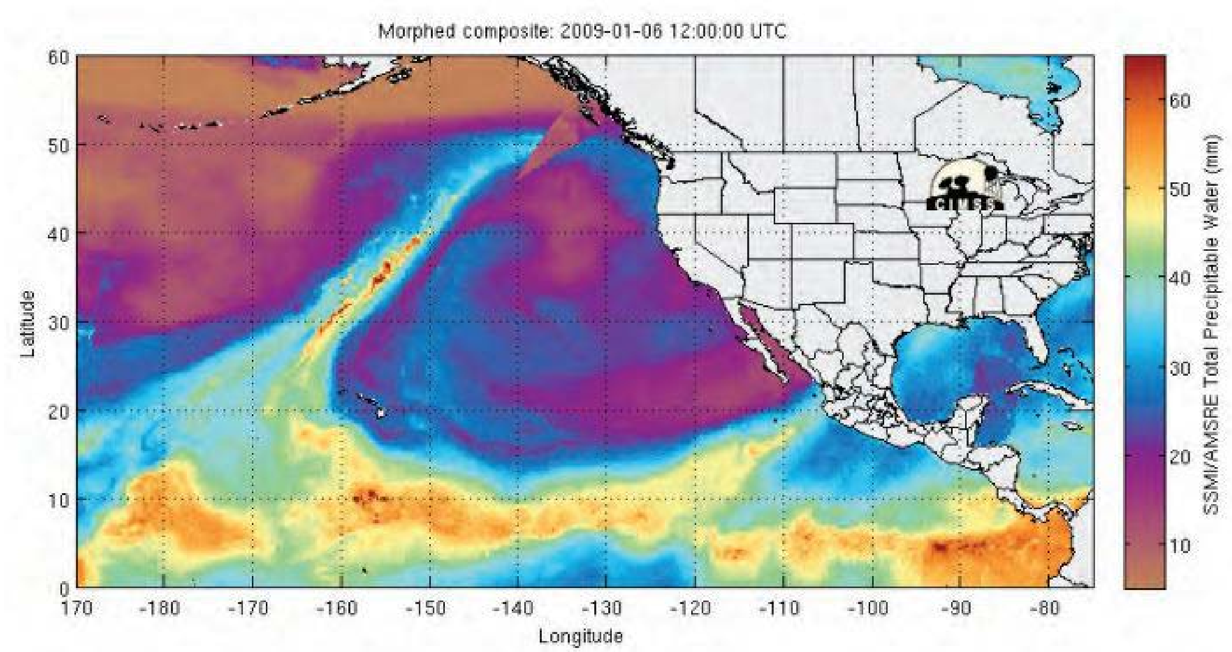

Figure B-2. Satellite Image of Atmospheric River Jan. 6, 2009 ($USGS_3$, 2010)

Figure B-3. Image of Flooding During the 2009 Chehalis Flood

B.3 February 1996

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 damages were estimated at $120 Million throughout Washington. (NWS_1, 2017)

B.4 January 2015

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-5). 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)

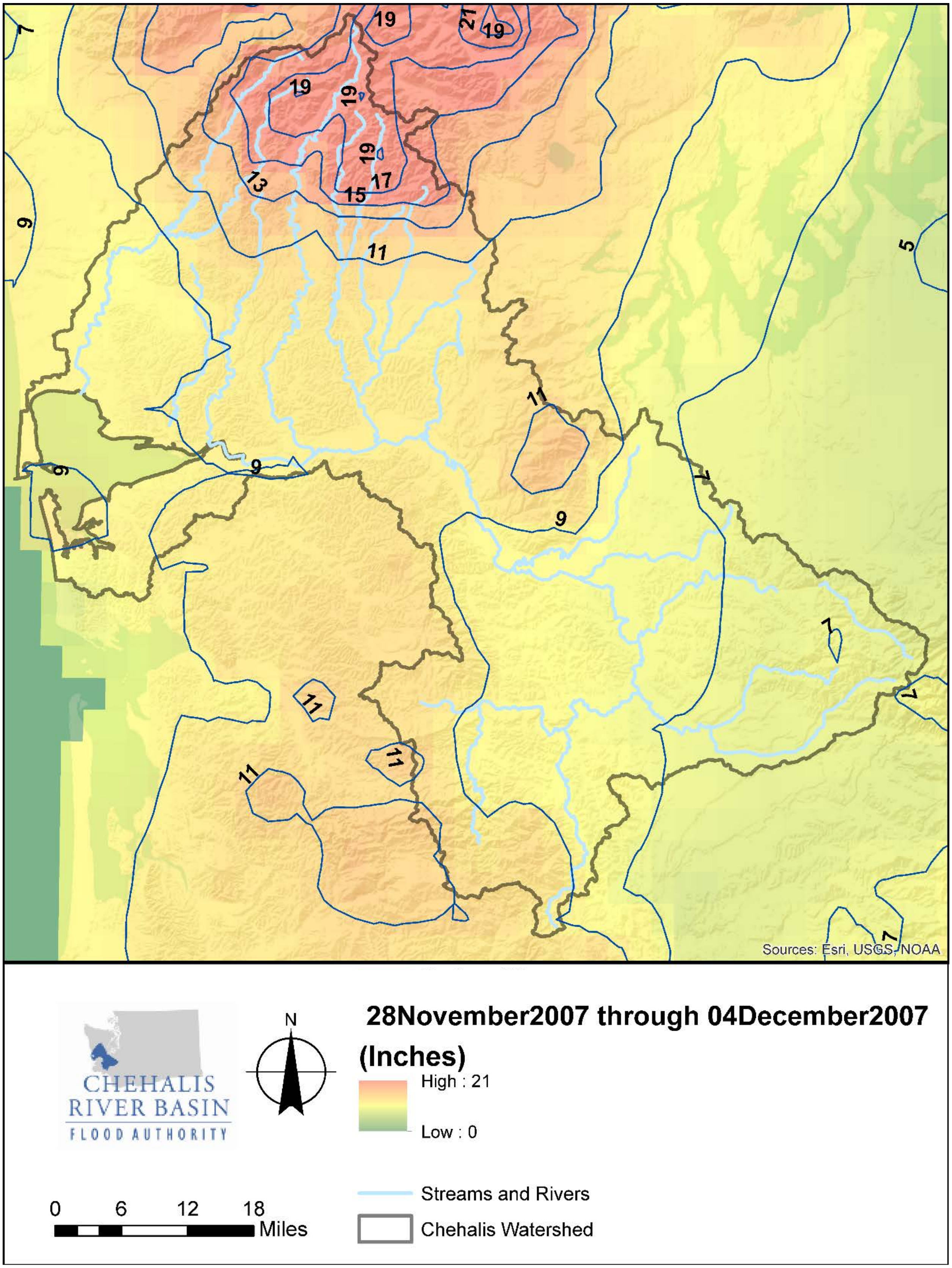

Figure B-4. PRISM Accumulated Precipitation Resulting in the December 2007 Flood

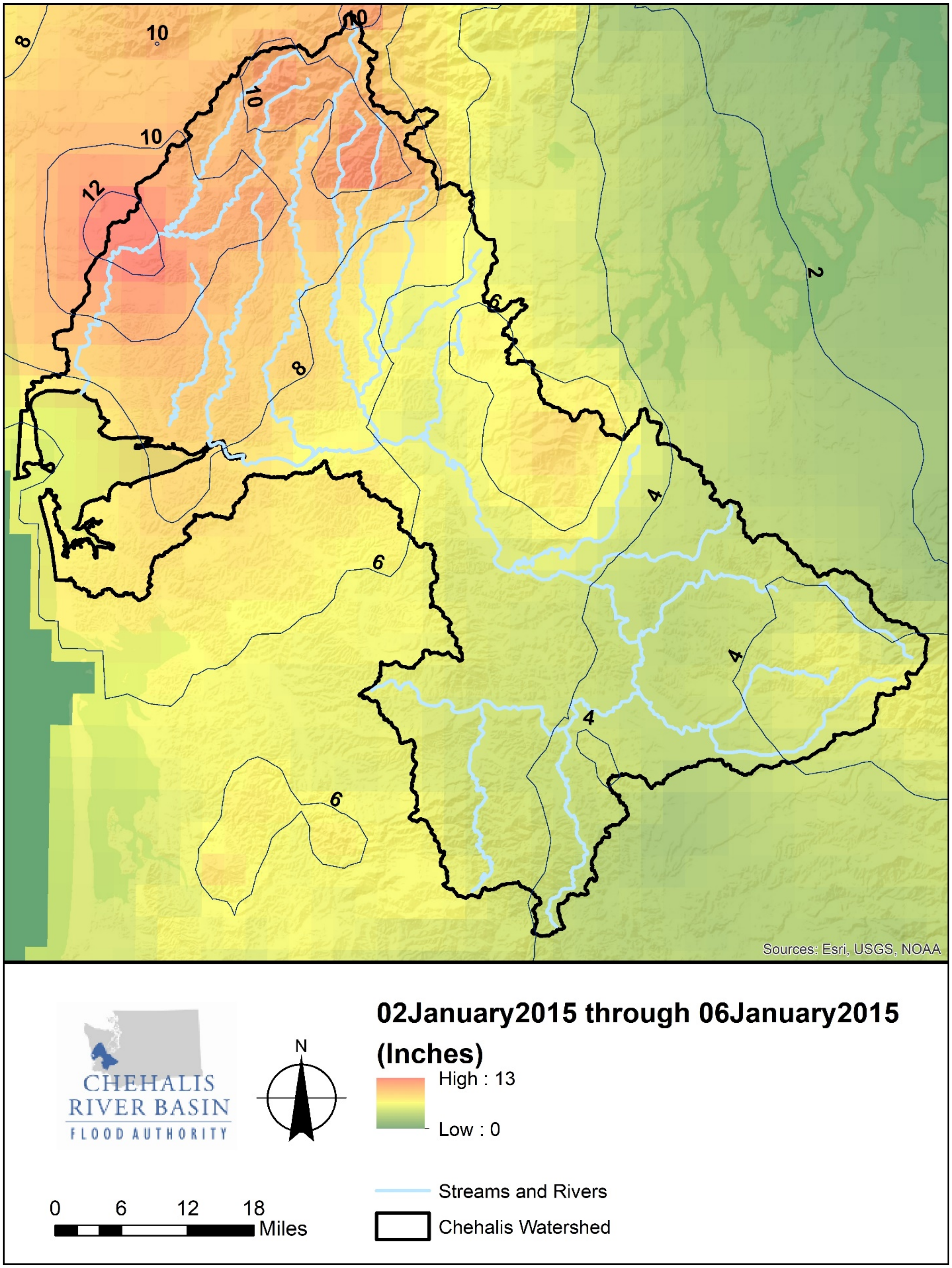

Figure B-5. PRISM Accumulated Precipitation Resulting in the January 2009 Flood

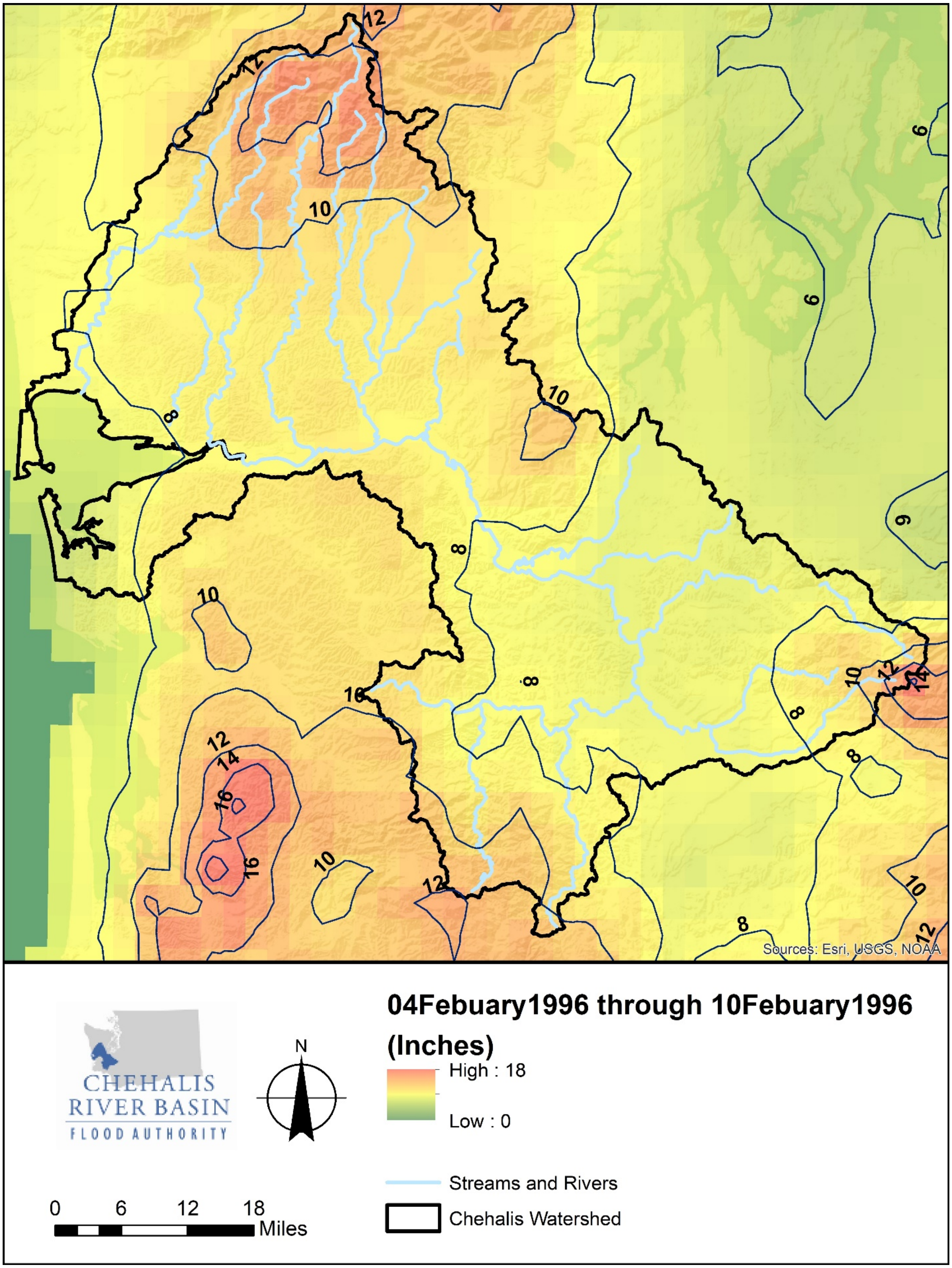

Figure B-6. PRISM Accumulated Precipitation Resulting in the February 1996 Flood

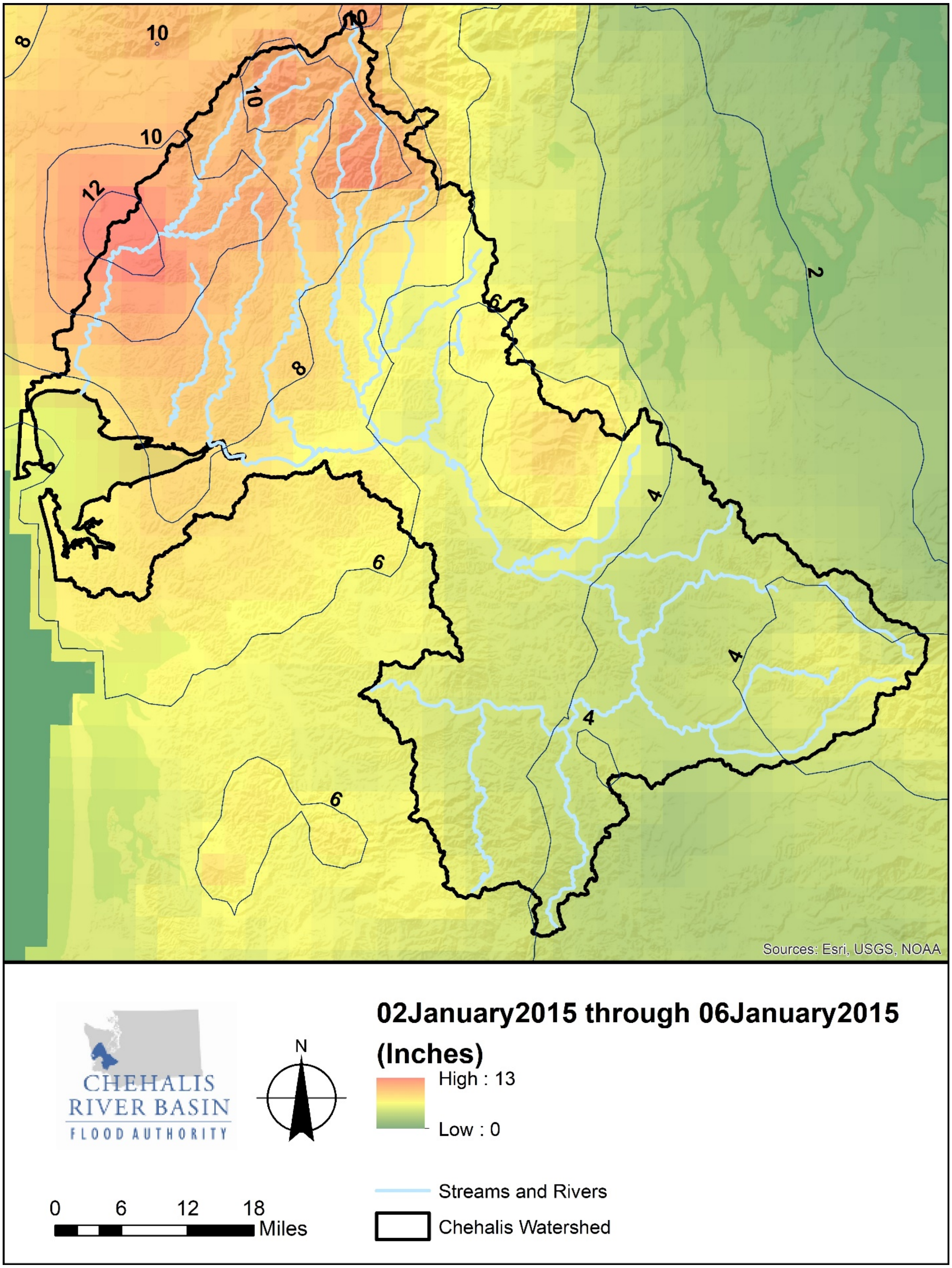

Figure B-7. PRISM Accumulated Precipitation Resulting in the January 2015 Flood

Appendix C - Flood Monitoring Methods

C.1 Precipitation

Precipitation is measured either using a physical instrument, such as a rain gage, or by using 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 buckets moves past it while performing a “tip” and records the time of the bucket tip (The Constructor, 2017). 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.

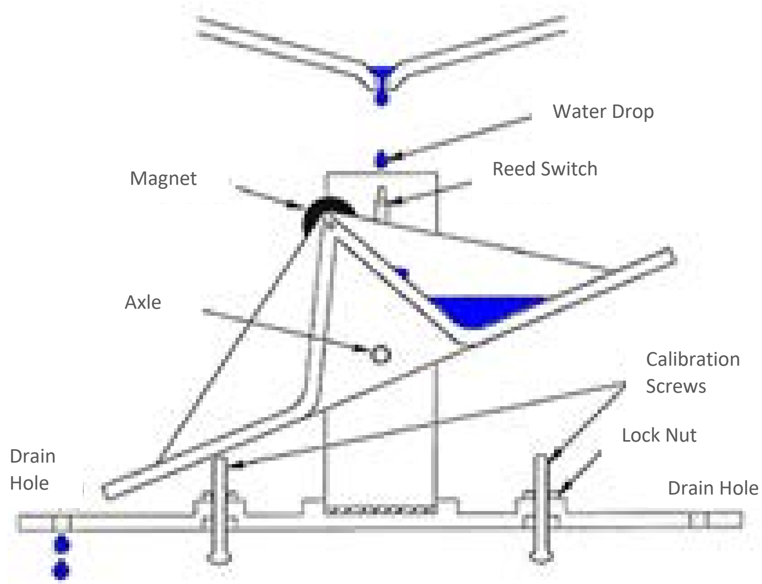

Figure C-1. Tipping bucket diagram (The Constructor, 2017)

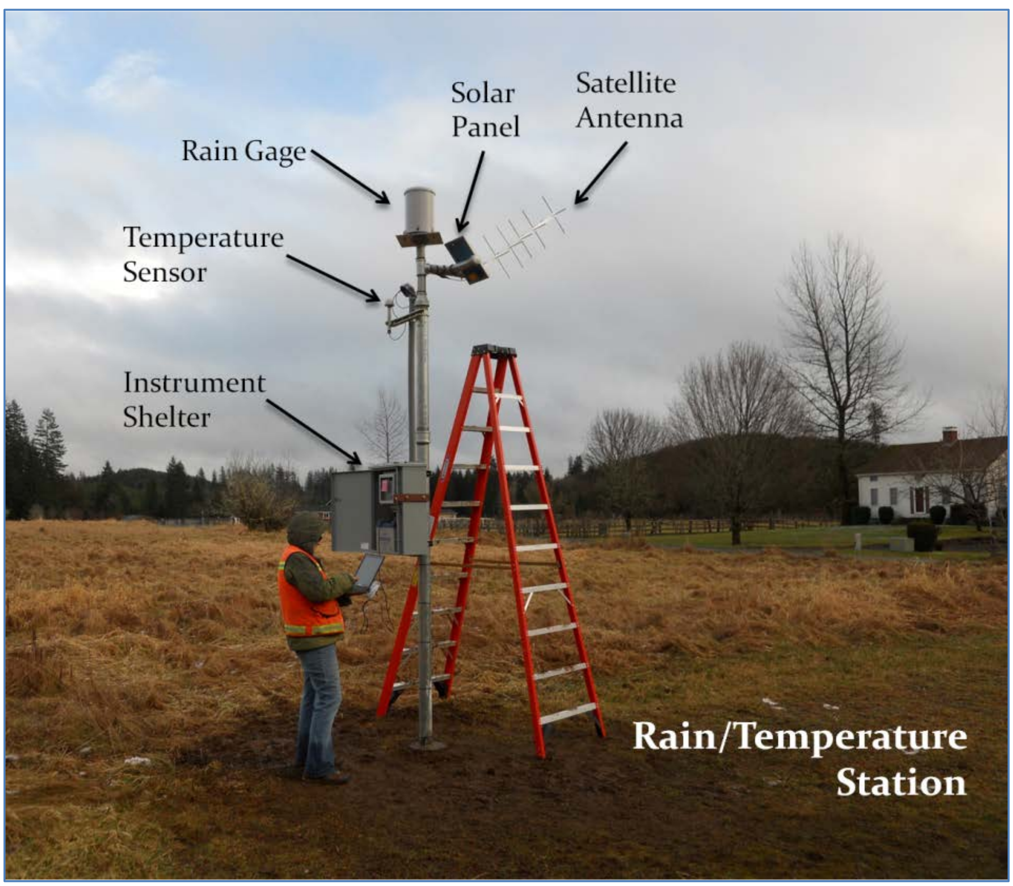

Figure C-2. A tipping Bucket Weather Station in the Chehalis River Basin

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.

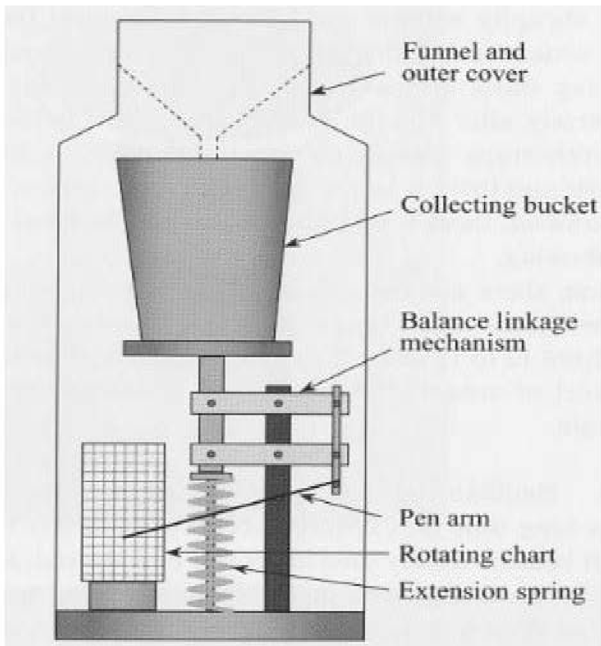

Figure C-3. Weighing Bucket Rain Gage (The Constructor, 2017)

C.1.1.3 Syphon Gage

A syphon 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 syphon will drain out the water from the container. A syphon 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 so 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 a 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 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 manners 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 meteorologist 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.

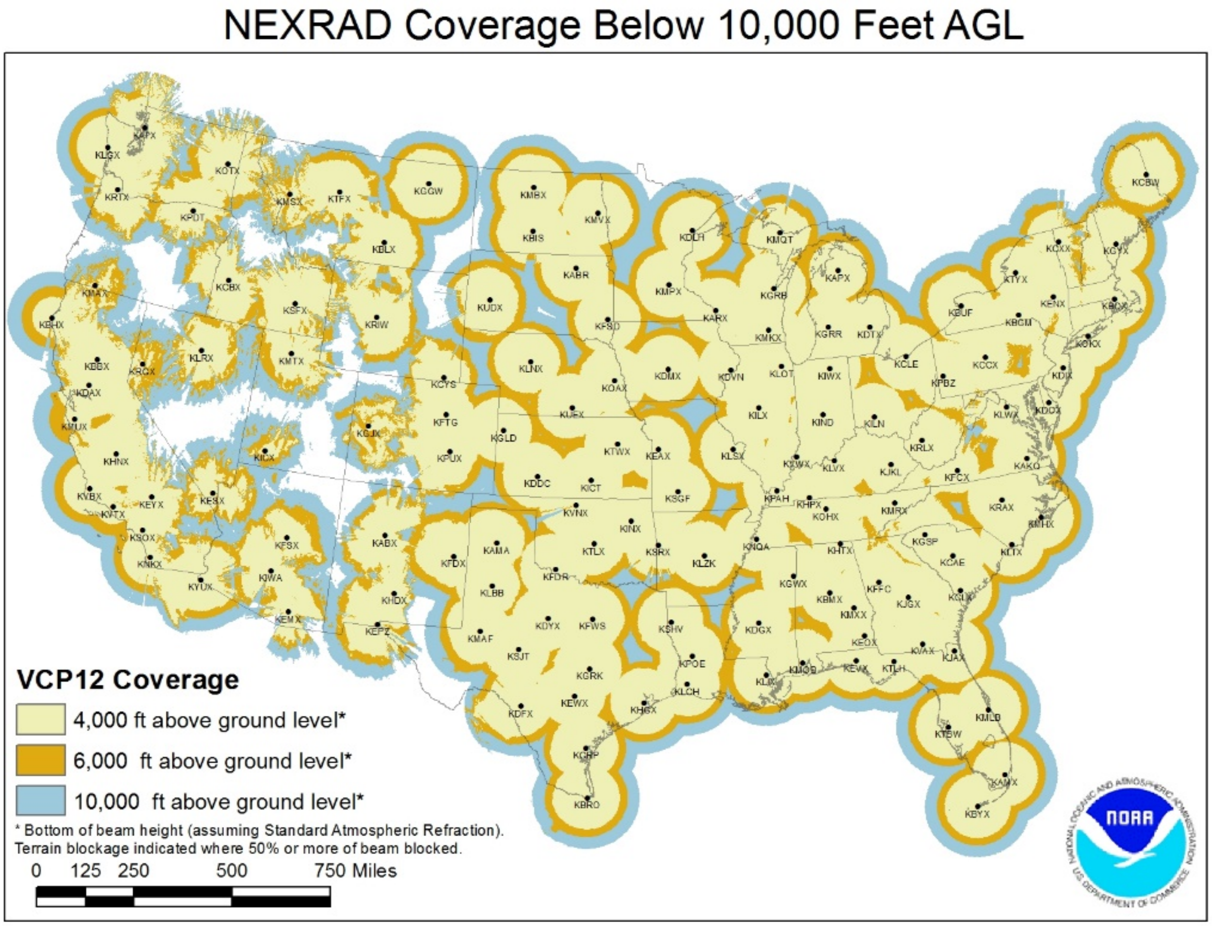

Figure C-4. NEXRAD Coverage of the United States

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_2, 2017)

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_2, 2017). 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-5.

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-4.

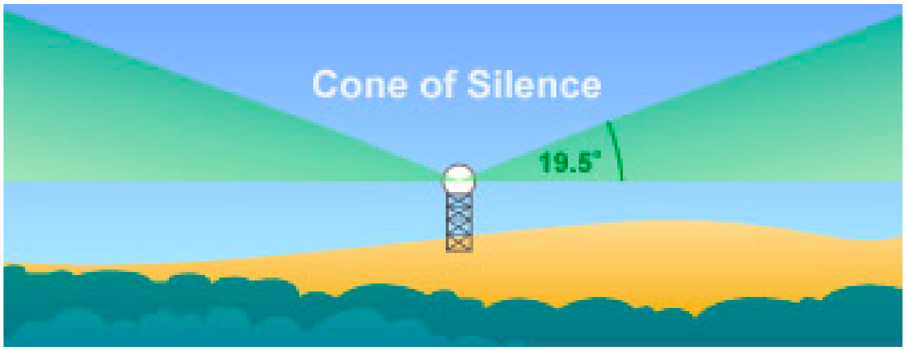

Figure C-5. RADAR Cone of Silence

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 storm, flood conditions, and mudslides.

Figure C-6. Satellite Orbiting Earth. Photo by NASA

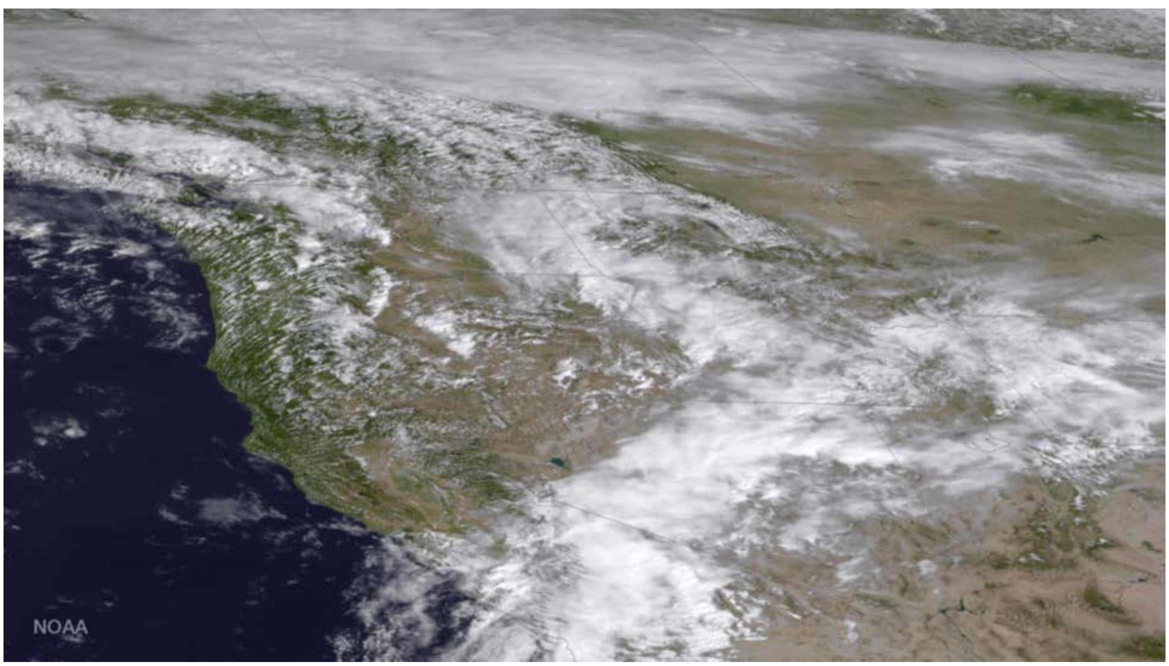

Figure C-7. Satellite Image of a Weather Systems

C.1.3 Other Meteorological Variables

The sensors in a weather station, in addition to a rain gage can include: A thermometer measures the 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 lake 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. Drifting buoys are more common and are one foot to 18 inches in diameter (Lumpkin and Pazos, 2006).

C.2 Streamflow

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, shown in 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 to the electronic measuring devices that may be installed in the stream. Some staff gages are placed in stilling wells so the water level remains constant. 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. 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-11 indicates that it is a real-time station. The box on top of the stilling well in Figure C-11 is also a real-time station as it has a solar panel and antenna located on top of the green box that houses the recording equipment. An outside reference gage, typically a staff gage, is read periodically to verify that the recorded gage heights from the stilling well is the same as the water levels in the stream.

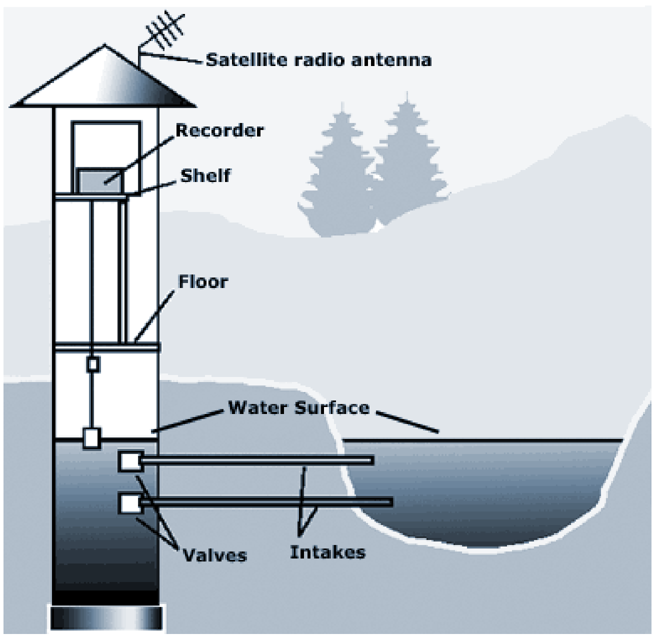

Figure C-9. A Diagram of a Stilling Well at a Stream Gaging Location

Figure C-10. USGS stilling Well Attached to a Bridge in a Stream

C.2.3 Weir/Flume

Weirs and flumes are favorable measuring devices when streamflow is low. Both weirs and flumes converge the stream flow into an area of known volume so that an accurate flow measurement can be made. Weirs and flumes are used in combination with bubbler systems or pressure transducers to determine both the stage and the cross-sectional flow area to make a direct calculation of flow rather than converting flow using a rating curve. They can be used in a recording gage or a real-time gaging station.

C.2.4 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 is the same as the water levels in the stream.

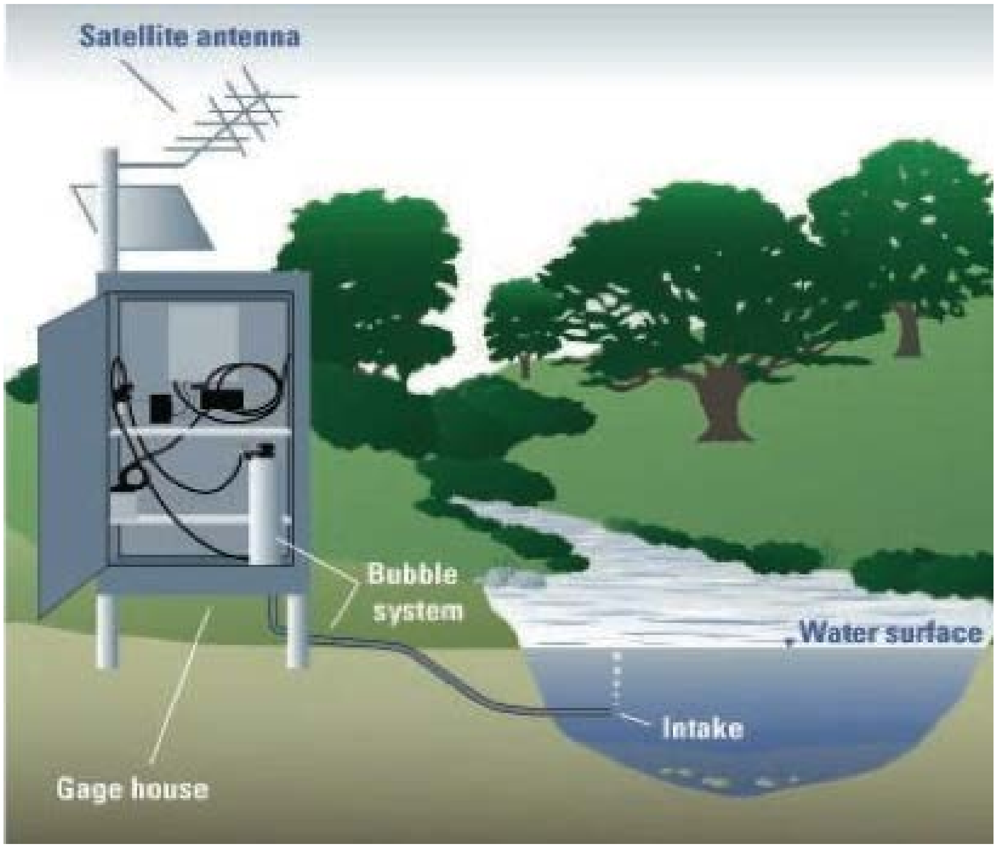

Figure C-11. Stream gage with Bubbler System (Image by USGS)

C.2.5 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-12, with the exception of the bubbles. Rather than using a tube that emits a gas into the stream or stilling well, a pressure transducer (Figure C-12) rests in the stream, usually affixed to something stationary, or it is secured to the inside of a stilling well. 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

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 (via various sources) for distribution and is typically hosted on a website.

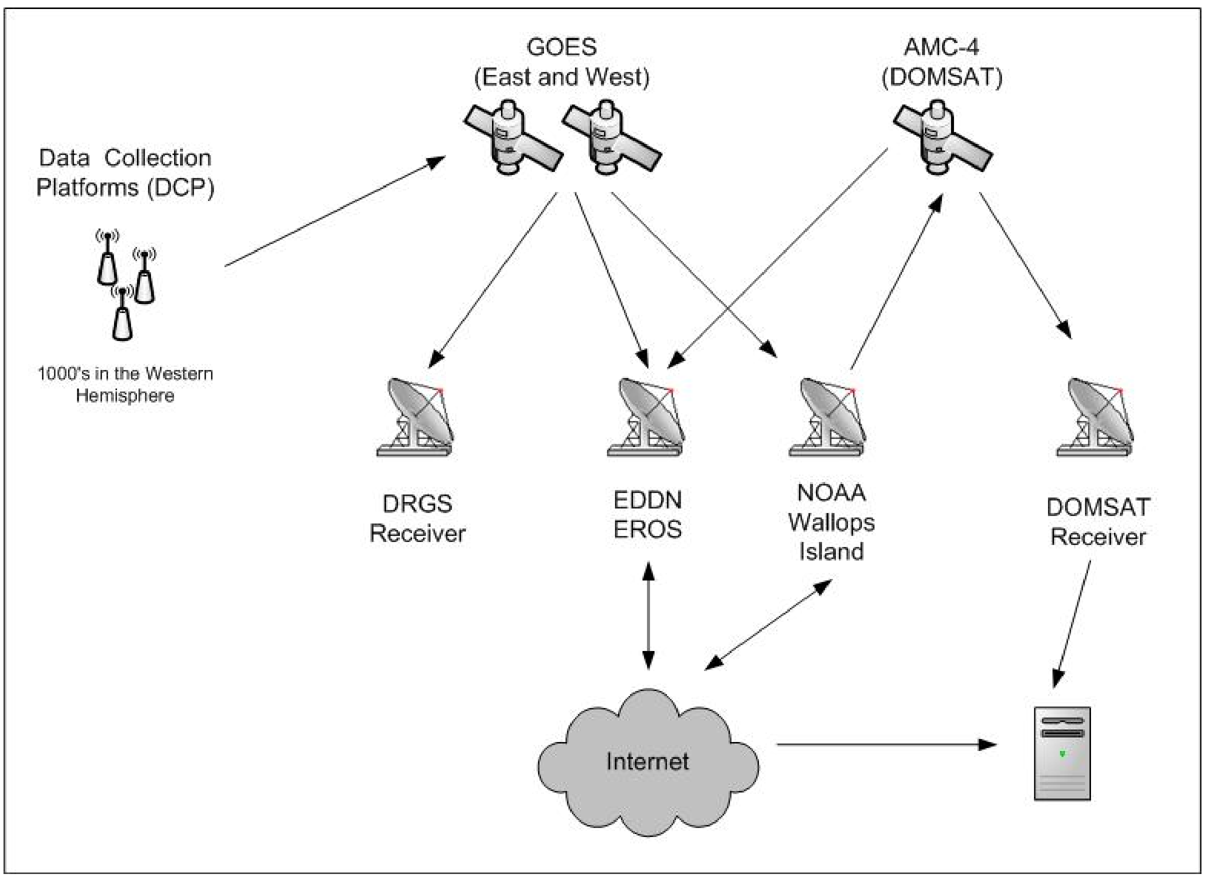

Figure D-1. Depiction of the GOES Data Transmission (USGS, 2014)

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, but NOAA strongly encourages users to transistion to Version 2.0 transmitters prior to this deadline. Switching over to Version 2.0 transmitters double channel capacity of the GOES DCS and allow 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 Athority, 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.

USGS plans to have all of their GOES transmitters upgraded before the cutoff date. After receiving stimulus money in 2009, USGS purchased numerous GOES transmitters (Version 1.0) for the region which means they have a significant number to upgrade. Similarly, Ecology plans to transition by the cutoff date. They have almost completely transistioned over to the Version 2.0 transmitters as of March 2017.

The Flood Authority operates ten gages in the Chehalis River Basin, and each of the gages has a GOES DCP with transmitter. The cost to upgrade each transmitter (WaterLog H-2221 models) is approximately $1,800 (including parts, labor, shipping and tax) as of May 2017. There are five full years left before the upgrade to Version 2.0 transmitters is required. The Flood Authority will upgrade to Version 2.0 transmitters during the 2017 and 2018 calendar years.

The GOES Data Collection Platforms operated and maintained by the cooperators have four basic components.

- Environmental sensors
- A data logger for recording the sensor's information
- A UHF radio transmitter
- A Yagi antenna

The data originates from DCPs owned and/or operated by more than 100 cooperators. The NESDIS, another agency within NOAA, operates and maintains the GOES Data Collection System

(DCS). The GOES East DCS is physically located at the Wallops Island, Virginia Flight Facility. It is at this facility where the DCP data is downlinked from the GOES satellites and relayed to HADS. The data is relayed through an uplink to the Domestic Communications Satellite (DOMSAT) as well as a file transfer through a dedicated circuit to the NWS Telecommunication Gateway (NWSTG).

HADS uses DOMSAT as its primary data feed. The data are received in a nearly continuous flow from Wallops Island though uplinks to DOMSAT. HADS downlinks and buffers this data into two files per minute and processes this data at 3-minute cycles. The HADS processing environment has many redundant features. There are two servers capable of processing the data, one considered the primary system, one the hot backup. There are three ways HADS acquires the raw DCP data. The first is a downlink of data from DOMSAT, which is considered the primary method. HADS can failover to an internet feed and/or to a feed from the dedicated circuit from Wallops Island to the NWSTG.

DCPs are capable of operating into 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 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.

Appendix E - Datums

E.1 Arbitrary Datum

An arbitrary datum (also known as gage datum) is a vertical datum established to determine the water level above a determined level reference. As a general rule, a permanent vertical gage datum is maintained at a stream gaging station and remains unchanged for the life of the station (Kennedy, 1990). The gage datum can be a nationally recognized datum or an arbitrary datum. Often an arbitrary datum is established for convenience when the station is first installed. Arbitrary datums do not require surveying from known benchmarks, use standard staff plates ranges, and the lower number ranges are generally easier to work with compared to real elevation numbers. Each station using an arbitrary datum has its own unique gage datum and gage height observations, which are not necessarily a direct representation of local elevations. It is a routine practice to compute stream discharge at a gaging station using gage height values referenced to an arbitrary datum (Sauer and Turnipseed, 2010). When individual stations are referenced to their own arbitrary datum it is not possible to compare water level elevations between stations.

E.2 National Geodetic Vertical Datum of 1929

The National Geodetic Survey (NGS) is the agency of the Federal government responsible for developing a common and consistent vertical datum which provides the framework for all positioning activities in the nation. One of the most widely used vertical datums in the United States was the Sea Level Datum of 1929. On May 10, 1973, this datum was renamed the National Geodetic Vertical Datum of 1929 (NGVD 29) because it was determined that the datum was not equivalent to mean sea level. The base, zero elevation, for NGVD 29 was developed from information collected at 26 tide gages along the coasts of the United States and Canada in the early 1900s. It later became apparent the system was flawed and different tide gages had different elevations relative to each other.

E.3 North American Vertical Datum of 1988

The North American Vertical Datum of 1988 (NAVD 88) is the current vertical datum system in the United States and was officially confirmed in 1993 as the vertical datum of the National Spatial Reference System (NSRS). NAVD 88 was computed based on new information collected since NGVD 29 was created. Over 600,000 km of survey leveling, thousands of destroyed benchmarks, and effects of crustal movement, land subsidence, and post-glacial rebound all contributed to the decision to replaced NGVD 29 with NAVD 88. In some areas, distortions as great as 9 meters were seen between NGVD 29 and NAVD 88. NAVD 88 is the preferred and recommended datum being used by federal agencies. NAVD 88 is more accurate than NGVD 29 and is now the standard vertical datum in surveying.

Appendix F - Major Gages Near Centralia

F.1 Skookumchuck River (USGS 12026600) at Centralia, WA

The National Weather Service gaging station Skookumchuck River at Centralia, WA is located at the Washington State Route 507 (North Pearl Street) bridge in Lewis County, Latitude 46°43'52", Longitude 122°57'10". This station is in Hydrologic Unit 17100103 and has a drainage area of 172 square miles.

https://waterdata.usgs.gov/wa/nwis/uv/?site_no=12026600&PARAmeter_cd=00060,00065

This station is commonly known as 12026600 to conform to the nationwide USGS downstream order numbering system. The NWS station identification number is CTAW1. The NWS owns this station and provides direction to City of Centralia Public Works employees who perform site maintenance and respond to issues that arise on an as-needed basis. Annual site visits are made to clear sediment from the stilling well with a Vactor vacuum excavator truck. (Kahle Jennings, City of Centralia Public Works Director, Email)

F.1.1Station History

A history of this station was provided by the NWS in Seattle, WA.

Gage Location/Remarks for NWS Station CTAW1:

- Maintenance began 1/14/1905.
- 1/14/1905-10/08/1964: Wire weight gauge at the Harrison Bridge site.
- 01/11/1950 – 08/26/1965 Staff gauge located on Harrison Bridge, 1.8 mi downstream from current site and at the same datum. City of Centralia engineers were the observers.
- 10/08/1964 – 10/04/1973 – Resistance gauge with telemetry to City Hall. Wire weight gauge at the Pearl St. Bridge site, with datum 100.0 feet used as reference gage.
- 10/04/1973 – 07/01/1989 – Telemark gauge at the Pearl St. Bridge site. Wire weight gauge present for backup. Float.
- 04/01/1989 Shaft encoder (Handar 436A) driven by a MM float, with a LARC (Handar 550A). Wire weight gauge remains for backup and reference gauge.

(Brent Bower, NWS Form E – 19 / NWS Report on River Gage Station)

F.1.2 Current Equipment

Stage measurements are taken inside of a 12-inch diameter corrugated metal pipe (stilling well) attached in a vertical position to the downstream side of the bridge. A buried pipe extending horizontal from the stilling well to the river allows water to enter and leave the stilling well. The movement of a float rising and falling with stage inside of the stilling well is measured by a sensor (shaft encoder). The shaft encoder is connected to a Limited Automatic Report Collector (LARC) data recorder. A stage measurement is taken automatically at 30-minute time intervals and this information is sent through land based telephone lines from the LARC to the NWS every 60 minutes.

The reference gage is a wire-weight gage fastened to the downstream bridge rail. The wire-weight gage is a device that is used to measure the stage by lowering a weight fixed to the end of a cable. A counter displaying the stage in feet is read when the weight is lowered to the point where it appears to touch the top surface of the water. Measurements from the stage sensor in the stilling well are referenced to visual observations taken at the same time from the wire-weight gage. Instantaneous observations of stage from the wire-weight gage values measured by the stage sensor should agree with each other. If significant differences are noted the stage sensor is reset to read the same as the reference gage.

F.1.3 Survey Reference Marks

Reference marks, measured stage data, and data displayed on websites are referenced to an arbitrary datum.   NGVD 29 elevations can be calculated by adding a 100-foot offset to the arbitrary datum, for example if flood stage is designated as 85.00 ft. it is equivalent to an NGVD 29 elevation of 185.00 ft.

Survey reference points were provided by the National Weather Service in Seattle, WA. The Survey Reference Points for NWS Station ID CTAW1 are:

- Benchmark: Chiseled Square on top of concrete end post at NE corner of bridge, at end of walkway next to pavement. Given elevation 94.70 ft. (gage datum). Date of survey unknown.
- Wire-Weight Gage Checkbar: 93.78 ft. (gage datum). Date of survey unknown.

(Provided by Brent Bower, NWS Form E – 19 / NWS Report on River Gage Station)

Site characteristics do not allow for developing a reliable stage-discharge rating, the method most often used to compute river discharge data from stage data. Variable backwater conditions that develop at the gage when Chehalis River water levels are high severely influence the stage at the Skookumchuck gage. Given these conditions the NWS must compute discharge using a computer generated synthetic rating developed from hydraulic analysis and modeling.

USGS records indicate that 19 miscellaneous discharge measurements have been made at this station but as explained above they could not be used to develop stage-discharge ratings. A discharge measurement is a manual measurement of flow typically made with mechanical or acoustic type current-meter equipment.

F.1.4 Historic Peak Data

Historic peak flow stage measurements and the dates upon which they occurred on the Skookumchuck River in Centralia are in Table F-1.

Table F-1. Historic Crests

NWS Historic Crests - Skookumchuck River (USGS 12026600) at Centralia, WA							
Rank	**Stage in ft.**	**Date**		**Rank**	**Stage in ft.**	**Date**	
1	87.27	2/8/96		12	85.59	11/24/86	
2	87.10	1/10/90		13	85.46	12/4/75	
3	86.68	4/5/91		14	85.26	2/2/87	
4	86.60	1/21/72		15	85.20	12/16/99	
5	86.58	1/8/09		16	85.17	12/30/95	
6	86.50	11/25/90		17	85.17	11/30/95	
7	86.38	2/11/90		18	85.10	1/6/54	
8	86.17	12/30/96		19	85.02	1/31/06	
9	86.00	12/10/53		20	84.54	2/1/03	
10	86.00	1/26/71		21	83.81	1/06/15	P
11	85.60	12/12/55		22	83.76	2/18/14	P
(P) Preliminary values subject to further review							

(Source: National Weather Service)

F.2 Chehalis River (USGS 12025500) at Centralia, WA

The NWS gaging station Chehalis River at Centralia, WA is located at the Mellen Street Bridge in Lewis County, Latitude 46°42’45”, Longitude 122°58’39”. This station is in Hydrologic Unit 17100103 and has a drainage area of 647 square miles. This station is commonly known as 12025500 to conform to the nationwide USGS downstream order numbering system. The NWS station identification number is CENW1. The NWS owns this station and provides direction to City of Centralia Public Works employees who perform site maintenance and respond to issues that arise on an as-needed basis. Annual site visits are made with a Vactor vacuum excavator truck to clear sediment from the stilling well. (Kahle Jennings Email)

F.2.1 Station History

A history of this station was provided by the National Weather Service in Seattle, WA.

Gage Location/Remarks for Station CENW1:

- Maintenance began 12-20/1949 Ended: 12/7/1959. Present site of old Mellen St. Bridge, 30 feet downstream from the present site. Same datum.
- 12/7/1959 – present site of Mellen St. Bridge. A light was added in 1/9/64.
- 11/9/1960 – staff gauge was added to a pier of the old bridge. Wire weight was still the main gauge.

- 11/21/1966 – 11-16-1973: Telemark gauge became the main gauge, with wire weight and staff gauges for backup.
- 11/16/1973 – 06/20/1988: an FP ADR on a float tape gauge with a BDT replaced the telemark. Wire weight and staff gauges still in place.
- 06/20/1988: Shaft encoder (Handar 436A) driven by a MM float and F-P rain gauge, with a LARC (Handar 550A). Wire-weight is used as reference gage. A staff gage on the west side of the river provides a secondary reference gage.

(Brent Bower, NWS Form E – 19 / NWS Report on River Gage Station)

F.2.2 Current Equipment

Stage measurements are taken inside of an 18-inch diameter, corrugated, metal pipe stilling well dug into the east river bank, a short distance downstream from the Mellen Street Bridge. A stage measurement is taken automatically at 30-minute time intervals and this information is sent through land-based telephone lines from the LARC to the NWS every 60 minutes.

The reference gage is a wire-weight gage fastened to the upstream bridge rail near the center of the span. Stage observations from the staff gage are not considered to be as reliable as those from the wire-weight gage. Instantaneous observations of stage from the wire-weight gage and values measured by the stage sensor should agree with each other. If significant differences are noted the stage sensor is reset to read the same as the wire-weight gage.

F.2.3 Survey Reference Marks

Reference marks, measured stage data, and data displayed on websites is referenced to an arbitrary datum. NGVD 29 elevations can be computed by adding a 100-foot offset to the arbitrary datum, for example if flood stage is designated as 65.00 ft. it is equivalent to an NGVD 29 elevation of 165.00 ft.

Survey reference points were provided by the NWS in Seattle, WA. The Survey Reference Points for NWS Station ID CTAW1 are:

- Reference Mark designated as RM 4: Top of bridge seat on east approach. Given elevation 77.35 ft. (Gage datum). Date of survey unknown.
- Wire-Weight Gage Checkbar: 83.80 ft. (gage datum). Date of survey unknown.

(Brent Bower, NWS Form E – 19 / NWS Report on River Gage Station)

Site characteristics do not allow for developing a reliable stage-discharge rating. Varying amounts of sediment deposition in the Chehalis River and high water levels at the mouth of the Skookumchuck River influence the stage at the Chehalis gage location. Given these conditions the NWS must compute discharge using a computer generated synthetic rating developed from hydraulic analysis and modeling.

USGS records indicate that 24 miscellaneous discharge measurements have been made at this station but as explained above they could not be used to develop stage-discharge ratings.

F.2.4 Historic Peak Data

Historic peak flow stage measurements and the dates upon which they occurred on the Chehalis River in Centralia are in Table F-2.

Table F-2. Historic Crests

NWS Historic Crests - Chehalis River (USGS 12025500) at Centralia, WA							
Rank	**Stage in ft.**	**Date**		**Rank**	**Stage in ft.**	**Date**	
1	74.78	12/4/07		26	68.12	4/24/96	
2	74.31	2/9/96		27	67.86	12/10/15	P
3	73.50	1/10/90		28	67.63	1/19/86	
4	72.40	1/8/09		29	67.61	1/11/06	P
5	71.99	11/25/86		30	67.58	12/16/99	
6	71.65	1/21/72		31	67.54	3/4/87	
7	71.30	11/25/90		32	67.34	11/8/06	P
8	71.17	12/5/75		33	67.27	12/7/70	
9	70.20	1/26/71		34	66.50	1/24/82	
10	70.18	12/30/96		35	66.17	12/28/94	
11	69.91	2/11/90		36	66.10	2/26/50	
12	69.73	11/27/98		37	66.00	2/17/82	
13	69.60	2/25/99		38	65.80	12/4/82	
14	69.20	2/10/51		39	65.45	12/29/98	
15	69.10	1/16/74		40	65.42	12/3/98	
16	68.80	1/1/97		41	65.38	1/15/98	
17	68.77	12/17/01		42	65.38	1/15/98	
18	68.70	12/3/77		43	65.31	1/30/99	
19	68.62	1/6/54		44	65.30	12/27/80	
20	68.58	12/22/55		45	65.25	1/21/67	
21	68.50	11/30/95		46	65.09	3/20/97	
22	68.43	1/30/06	P	47	65.07	2/10/17	
23	68.29	4/5/91		48	62.46	2/18/14	P
24	68.26	2/2/87		49	62.25	1/6/15	P
25	68.22	12/21/94					
(P) Preliminary values subject to further review							

Source: National Weather Service

Appendix G- Contrail

Contrail is a data collection and management system. It manages the hydro-meteorological data and make it available through a web interface. Real-time weather data is transmitted to GOES where it is intercepted and made available through Contrail (Figure G-1). Users are able to access the data through the Contrail home page (Figure G-1). 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 G-3) and flood inundation maps are included to give the user reference (Figure G-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.

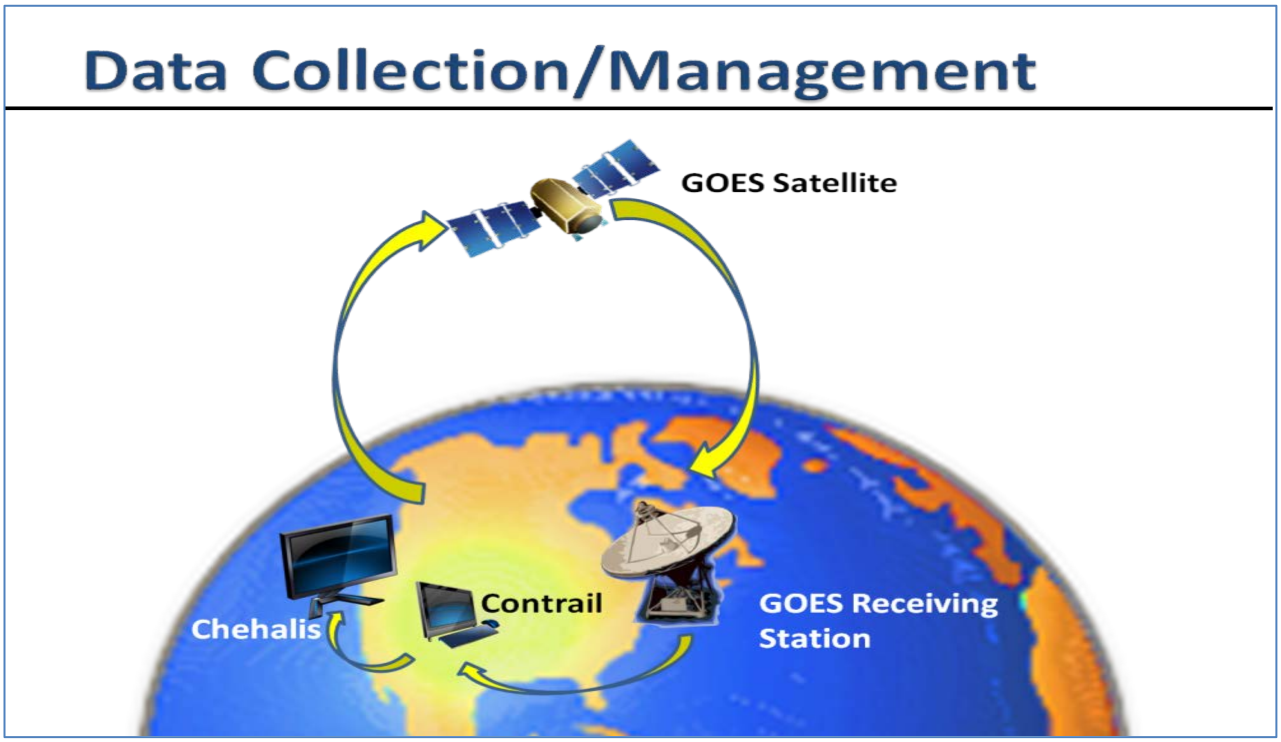

Figure G-1. Schematic of Data Collection and Management through Contrail

Figure G-2. The Contrail Home Page for Chehalis River Basin Flood Authority

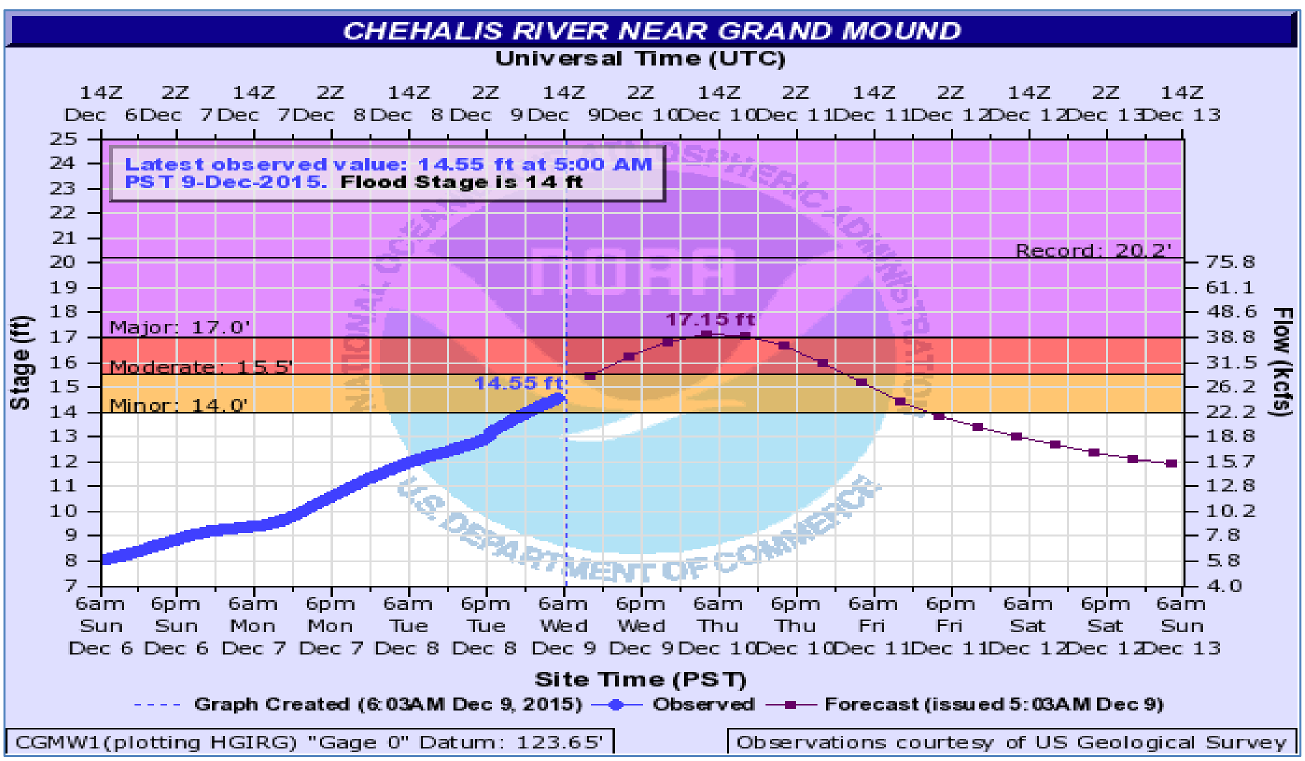

Figure G-3. Example of National Weather Service River Forecast Link

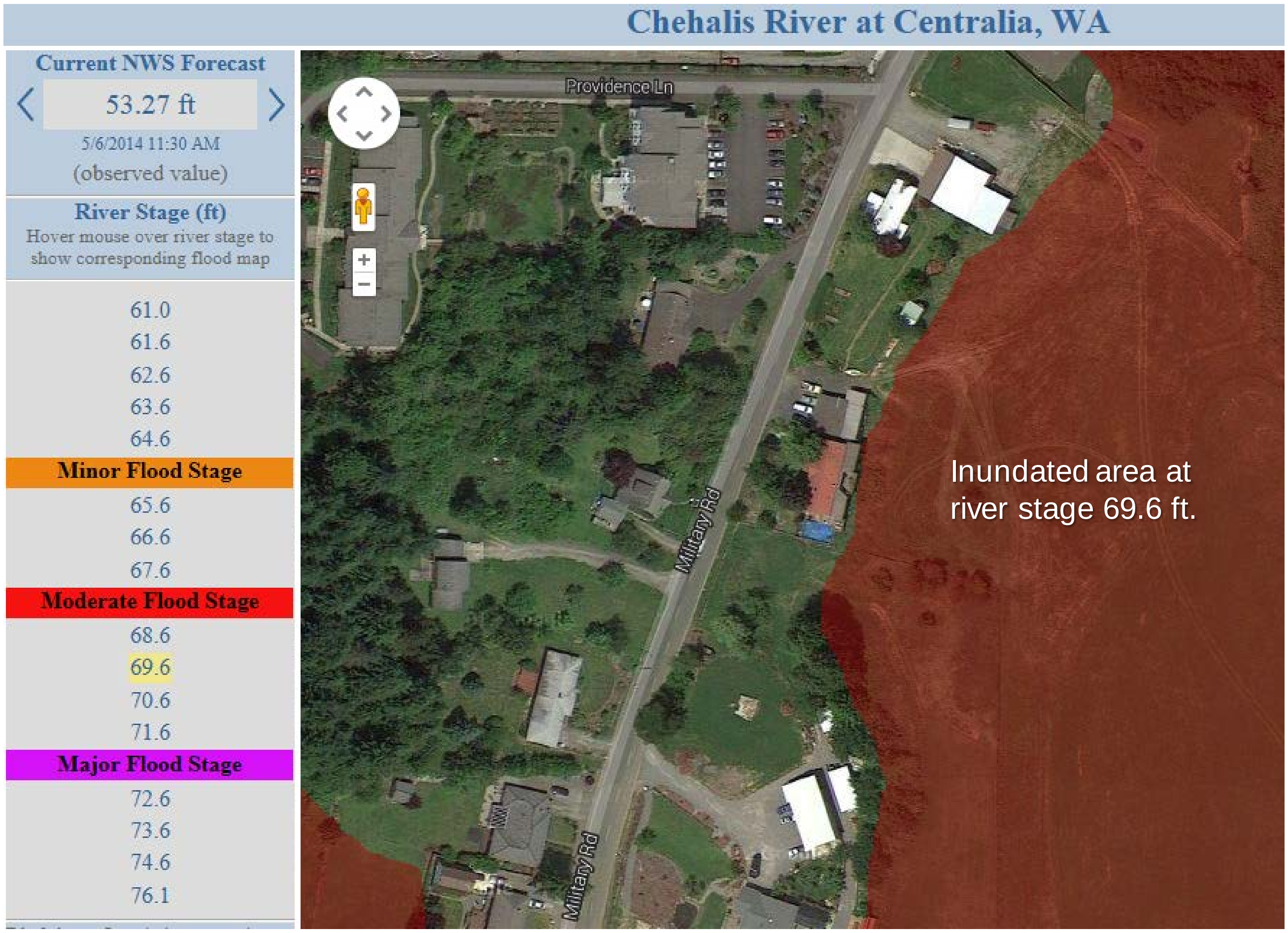

Figure G-4. Example of Inundation Map Available on Contrail

G.1 Current Flood Alert System Alarms

G.1.1 Overview

Alarms are sent via email from the OneRain server to alarm recipients after a trigger is met. The trigger is defined by Contrail Site Administrators and is defined in the form of an equation. For example, when the height of a river at any particular site is greater than a specified value. There are currently 11 alarms in the system (Figure G-5). Each is made to trigger at a predetermined river stage. There are no precipitation alarms.

G.1.2 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 G-6 shows the distribution of requested flood alerts. The requested alerts have been steadily increasing over the last few years. Figure G-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.

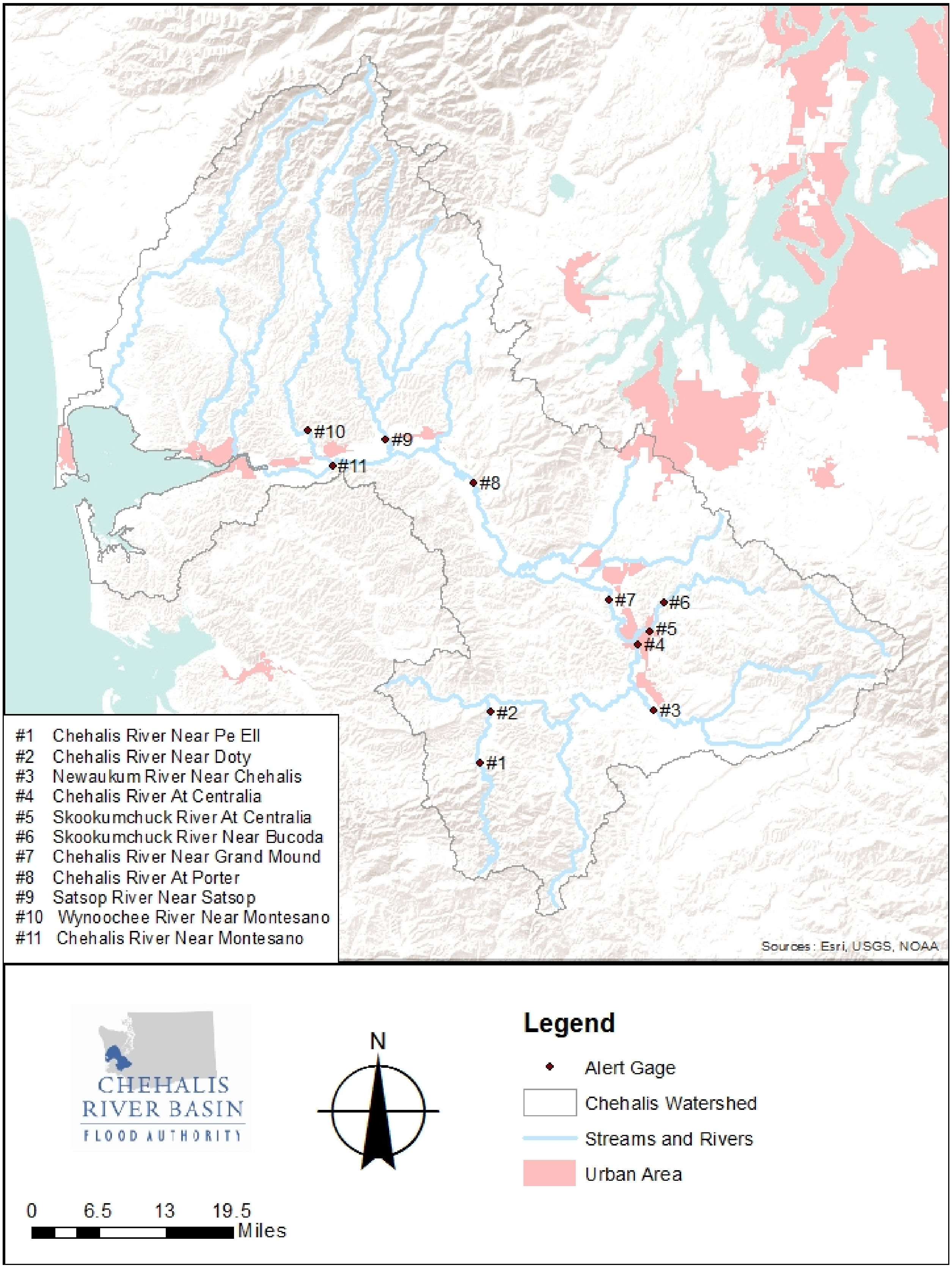

Figure G-5. Alarms in the Chehalis River Basin Flood Warning System

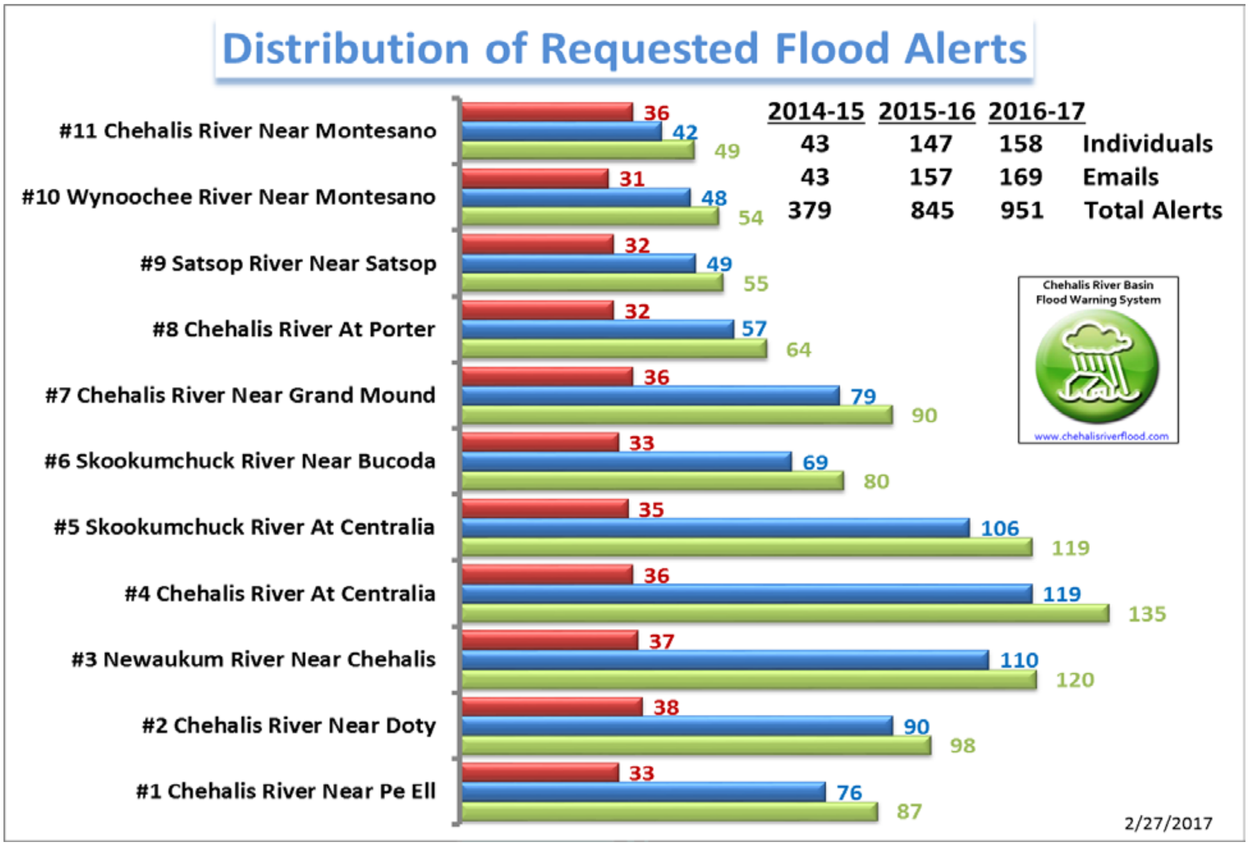

Figure G-6. Distribution of Requested Flood Alerts

Alarm Number	Gage Name	Alarm Stage Height (ft.)	Number of Alarms	
			2015-16 Flood Season	2016-17 Flood Season
1	Chehalis River near Pe Ell	22	6	0
2	Chehalis River near Doty	11	2	2
3	Newaukum River near Chehalis	9.75	3	2
4	Chehalis River at Centralia	64	2	1
5	Skookumchuck River at Centralia	83	1	1
6	Skookumchuck River near Bucoda	12	3	3
7	Chehalis River near Grand Mound	13	2	3
8	Chehalis River at Porter	20	3	3
9	Satsop River near Satsop	33	7	2
10	Wynoochee River near Montesano	17	0	0
11	Chehalis River near Montesano	12	28	13

Figure G-7. Alarm stage height and frequency of alarms

Appendix H - Database Inventory Description

The Flood Warning System Inventory Database takes the form of an Excel Work Book. The information in the inventory was taken from several places. These include an 1) automatically generated report 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:

Column explanations:

Site Name

The unique gage name.

County

The county the gage is located in.

Funding

Where the funding for the gage is known, it is included here. It is applicable to USGS gages, as gages are often maintained by a cooperation between agencies.

Site ID

The unique identification assigned by its data source.

Measurement

The unique variable being measured.

Latitude and Longitude

The coordinates of the site in degrees.

Source

The Network the data comes from.

Category

The type of measurement. There are three types: Prcp (Precipitation), Stream, and Other. Prcp includes rain measurements. Stream includes stage, discharge, and water temperature. Other includes all other measurements listed on Table H-.

Short Name

The abbreviation of the source.

Contrail System

The data system it can be brought into contrail in.

Status

Indicates whether the gage is active or inactive.

Website

Indicate where additional information in the gage can be found.

End Year

Indicates the year where the last measurement was taken if the gage is inactive.

Offset to Datum

The offset in feet of the current datum where applicable.

Gage Datum

The name of the current Datum.

Datum Method

The Datum Method.

Known Telemetry

Binary indications if the gage has telemetry.

Known Manual

Binary indications if the gage is manual.

Contrail

Binary indications if the gage was taken from the Contrail database.

MesoWest

Binary indications if the gage was taken from the MesoWest database.

WebLookup

Binary indications if the gage was manually taken from online information.

GHCND

Binary indications if the gage was from the GHCHN database.

MSHR

Binary indications if the gage was from the MSHR database.

WU

Binary indications if the gage was from the Weather Underground database.

Table H-1. Unique Measurement Types in Database

Precipitation	Wave Height
Discharge	Wave Secondary Swell Period
Stage	Wave Secondary Swell Wave
Air Temperature	Wind Peak Speed
UV Exposure	Wave Primary Swell Dir
Snow Water Equivalent	Wave Primary Swell Height
Snow Fall	Wave Primary Swell Period
Snow Depth	Wave Period
Pressure	Battery
Relative Humidity	Dew Point
Solar Radiation	Evapo-Transpiration
Water Temperature	Residual
Wind Direction	Stage Narrow Band
Wind Speed	Stage Wide Band
Wind Gust	Tide Elevation
Soil Temperature	Tide Prediction
Moisture Soil	

Table H-2. Unique Networks in Database

U.S. Geological Survey
Grays Harbor County
TransAlta
Washington State Department of Ecology
Thurston County
Chehalis River Basin Flood Authority
City of Aberdeen
Cooperative Observer Network
Automatic Position Reporting System WX NET/Citizen Weather Observer Program
Hydro-meteorological Automated Data System
National Ocean Service Physical Oceanographic Real-Time System
National Weather Service/Federal Aviation Administration
Weather For You
Washington State Department of Ecology Air Quality Network
Interagency Remote Automatic Weather Stations
Washington Department of Transportation
Natural Resources Conservation Service
Climate Reference Network
AgWeatherNet
FSL Ground-Based GPS
National Ocean Service Water Level Observation Network
US Coast Guard Puget Sound
Moored Buoys and CMAN
AIRNow
U.S. Transportable Array
Multi-Agency Profiler Surface Observations
Bonneville Power Administration Network
Northwest Avalanche Center
Union Pacific Railroad
TIDES
Weather Underground
NEXRAD
Community Collaborative Rain, Hail & Snow Network

Appendix I- OneRain Subscriptions

OneRain offers three subscription options. These include Contrail Web, Contrail Server, and Contrail Base Station. The flood authority currently subscribes to the Contrail Web for an annual cost of $5,261. This service provides the Contrail web interface, public website, and other feature described in Appendix G and shown in Table I-1.

Table I-1. Subscription Comparison

	Contrail Web	Contrail Server	Contrail Base Station
Public Website	x	x	x
Data Exchange	x	x	x
Unlimited Sensors		x	x
Exclusive Server		x	x
Increased Customization		x	x
Hosted Server	x	x	
Client Hosts Server			x
Contrail Inventory Plus		x	x
Contrail Analytics		x	x
Discounted GARR		x	x
One Time Cost	N/a	$20,860	$33,000
Annual Cost	$5,261	$5,000	$12,000
Additional IT cost	N/a	N/a	~5,000-10,000

I.1 Contrail Base Station

The subscription can be upgraded to Contrail Base Station for a cost of $33,000 and an annual cast of $12,000. The Contrail client will be provided with their exclusive server software and can add an unlimited number of gages. The client will be expected to host the server and will not have 24/7 tech support. They will have tech support during normal business hours. The additional IT cost for Contrail Server would be on the order of $5,000 to 10,000. It will also include a discount for GARR, Contrail Inventory, and Contrail Analytics.

I.2 Contrail Server

The subscription can be upgraded to Contrail Server for cost of $20,800 and an annual cost of $5,000, the Contrail customer will be provided with their exclusive server hosted in a cloud service. There will be no cost to add additional sensors. It will also include a discount for GARR, Contrail Inventory, and Contrail Analytics

Relevant features that come with both Contrail Server and Contrail Base Station, in addition to unlimited sensors is, Contrail Inventory Plus and Contrail Analytics Features. Contrail Inventory

Plus allows for notes and updates to be recorded about individual gages in the system. Contrail Analytics Feature allows for extended exports of data (Contrail Web is limited to data export of one year). Additionally, Contrail Analytics can flag gages that may not be working properly. Another important consideration is the cost of Gage Adjusted Radar Rainfall (GARR) with Contrail Server or Contrail Base Station. With Contrail Web the annual cost of GARR is $13,200. With Contrail Server or Contrail Base Station, the annual cost of GARR is reduced to $7,200.

Appendix J – Upgrade Centralia Streamgages

Skookumchuck River (USGS 12026600) at Centralia, WA and Chehalis River (USGS 12025500) at Centralia, WA were recently upgraded by WEST. These upgrades will meet modern standards data from the gages will be transmitted using the National Environmental Satellite Data and Information Service (NESDIS) GOES system. The old NWS gages will be kept in service until the NWS choses to decommission them. Details about the streamgage modernization are below.

J.1 Details for Skookumchuck River (USGS 12026600) at Centralia, WA

The shaft encoder stage sensor which was installed in 1989 was replaced by a bubbler type stage sensor in the channel near the downstream side of the Pearl Street (SR-507) Bridge. The stilling well is no longer needed. The bubbler has a small self-contained air compressor and air tank. Air bubbles from the tank are released through polyethylene tubing into the river. The tubing is protected by steel pipe which is anchored to the streambed. Pressure measurements are taken every 15 minutes, converted to stage, and recorded on an electronic data logger. A GOES satellite radio transmits the 15-minute data from the site on an hourly basis.

The GOES antenna and a solar panel will be attached to a steel pipe mast. The wire-weight gage will be moved to the downstream bridge railing so that it is closer to the stage sensor. All components are located within the road right-of-way. Permission for the upgrades was obtained from WSDOT. WSDOT has designated the bridge as structurally deficient and prioritized it for bridge replacement.

J.1 Details for Chehalis River (USGS 12025500) at Centralia, WA

The shaft encoder stage sensor which was installed in 1988 was replaced by a non-contact radar type stage sensor attached to the upstream side of the Mellen Street Bridge (SR-507) owned by the City of Centralia. After obtaining permission from the City the radar sensor was clamped to a vertical steel bridge beam on the upstream side of the bridge next to the existing wire-weight gage. The time that it takes for radar pulses emitted downward by the sensor to reflect off the water surface and back to the sensor is used to measure the distance of the sensor above the water surface. Measurements from the radar are taken every 15 minutes, converted to stage, and recorded on an electronic data logger. A GOES satellite radio transmits the 15-minute data from the site on an hourly basis.

The radar sensor, data logger, GOES radio, and 12-volt power supply were installed inside of locked steel electrical enclosures which are clamped to bridge beams and accessible from the bridge walkway. The GOES antenna and a solar panel was attached to the upstream side of the bridge beam out of reach from the walkway. Use of the stilling well was discontinued.