MEMORANDUM

Date: July 9, 2021
To: Chehalis Basin Board
From: Larry Karpack, PE and Colin Butler, PE; Watershed Science & Engineering (WSE)
cc: Andrea McNamara Doyle and Nat Kale, Office of Chehalis Basin
Re: Delineation of Late-Century 100-Year Floodplains for the Chehalis Basin

Executive Summary

Background and Purpose

In February 2020, a State Environmental Policy Act (SEPA) Draft Environmental Impact Statement (EIS) was published by the Washington Department of Ecology analyzing the potential environmental impacts of the proposed Chehalis River Basin Flood Damage Reduction Project (Project). Following publication of the SEPA Draft EIS, the Office of the Chehalis Basin (OCB) commenced an evaluation of potential alternatives to the Project in the form of local structural and nonstructural actions. These local actions are focused on reducing flood damage in the mainstem Chehalis River and its tributaries throughout the basin.

Reducing flood risk throughout the Chehalis basin requires a detailed understanding of locations of greatest risk. Currently the best available information to define potential flood risk in the Chehalis Basin are the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs). Unfortunately the FEMA FIRMs have several shortcomings as follows: 1) in many locations the maps are outdated or obviously incorrect, 2) for much of the basin the maps are only "approximate" and as such do not provide any information about flood water levels or depths, and 3) the FEMA maps depict existing conditions hydrology only whereas future floodplain risk management is better focused on the future conditions floodplain, adjusted to reflect projected climate change.

In an effort to improve upon the FEMA floodplain mapping, OCB undertook hydrologic and hydraulic modeling and analysis to inform the delineation of the late-century 100-year floodplain[1]. The delineated future floodplains will be used for the identification and evaluation of potential future local structural and nonstructural actions under consideration as part of the Chehalis Basin Strategy. The approach used to map the late-century 100-year floodplain, and the results thereof, are summarized in this executive summary and described in detail below.

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[1] The "late-century 100-year floodplain" is a delineation of potential future flood hazard with projected climate change. The 100-year (or 1% chance exceedance) floodplain was delineated based on projected changes in hydrology between present day and the year 2080. Projections were made for mid-range and high-end climate projections. The mid-range projection assumes flows will increase by 26% across the entire Chehalis Basin (WSE, 2019a) while the high-end projection assumes flows will increase by 40% to 65%, with spatial variations as described in UW CIG, 2021.

Approach

Current FEMA mapping covers a total of approximately 1,173 miles of rivers and creeks in the Chehalis Basin plus approximately 65 miles of shoreline around Grays Harbor. The FEMA mapped floodplains can be grouped into four general categories: 1) study areas for which new detailed hydraulic models are available, 2) FEMA detailed study areas for which no new modeling is available, 3) FEMA approximate study areas with no available modeling, and 4) coastal flooding areas around Grays Harbor. Different approaches were used to develop floodplain mapping for each of these areas, as follows:

- For areas with new hydraulic models (332 miles) the models were run with projected future flows to directly map the late century floodplains. These areas, therefore, have the highest accuracy of any of the late century floodplain and detailed data, including water surface elevations, flood depths, and flow velocities are available.
- For FEMA detailed study areas without models (39 miles) the existing FEMA floodplain water surface elevations were simply raised up 1 to 2 feet to account for projected climate change and remapped against current topographic data for the floodplain. The future floodplain mapping for these areas is less accurate than areas with new models but assuming the original FEMA studies are of good quality these should provide reasonably accurate depictions of future flood risk. In addition to the floodplain delineation, water surface elevations and flood depths can be extracted for these areas.
- The final, and largest, riverine area type mapped was FEMA approximate study areas. In these areas the existing FEMA maps provide a highly generalized depiction of the floodplain and the existing maps were found to be obviously in error in some locations (e.g. excluding the river channel from the floodplain in some locations or including areas high above the floodplain on bluffs). To delineate the late-century floodplain in these areas a relative elevation mapping (REM) process was used. In this process the elevations throughout the floodplain are related back to low flow water surface elevations in the channel by a value called the height above water surface (HAWS). Each approximate study zone was broken into sub-reaches, and for each sub-reach a HAWS value was selected to best match the general width and shape of the approximate FEMA floodplain. These HAWS values were then increased by 1 or 2 feet to account for projected climate change and all areas within the REM mapping at the higher HAWS value were included in the floodplain. A total of 802 miles of floodplain were mapped using the REM approach.
- For coastal flooding areas around Grays Harbor the late-century 100-year floodplain was delineated by taking the existing 100-year tidal water surface elevation (13.2 feet NAVD) and adding an increase to account for projected sea level rise (SLR). Mapping was prepared for a median projected SLR increase of 1.1 feet and a high-end projected SLR increase of 1.8 feet. Approximately 65 miles of coastal flood zone was mapped including areas up major tributaries draining directly to Grays Harbor. This mapping is somewhat simplistic, as it ignores potential

effects of wind and waves, but it provides a reasonable depiction of the potential increase in late-century flooding and is an accurate depiction of the future floodplain in areas not significantly affected by waves.

Summary of Results

The late-century 100-year floodplain for the Chehalis River basin was delineated using available data sources, hydraulic models, and existing FEMA floodplain mapping. Floodplains were delineated for four area types: 1) areas with new hydraulic models; 2) FEMA detailed study areas; 3) FEMA approximate study areas; and 4) coastal flood zones. Late-century floodplain mapping was prepared for mid-range and high-end projections of climate conditions for the year 2080. A total of 1,173 miles of riverine floodplain and approximately 65 miles of coastal flood zone were mapped for projected late-century conditions. The results of this analysis are available as PDF maps and as GIS shape files.

Together with previous modeling for the SEPA Draft EIS, detailed hydraulic modeling is now available for the mainstem Chehalis River for four climate conditions: 1) existing hydrologic conditions, 2) mid-century climate increases (+12%[2]), 3) late century mid-range climate increases (+26%), and 4) late century high-end (+40 to 65%) climate increases. Modeling is also available for the late-century mid-range (26%) and late-century high-end (40-65%) climate scenarios for all other tributaries for which hydraulic models were available (from WSE, NSD, and FEMA).

Late century water surface elevations (mid-range and high-end) were also estimated for other FEMA detailed study areas (those without new hydraulic models). These analyses are less accurate/more uncertain than the modeled areas because we have no knowledge of the source or quality of the original FEMA mapping data and our assumed late century increases are highly approximate (simply 1-foot or 2-foot elevation increase relative to the FEMA elevations).

While there is significant uncertainty inherent in projecting floodplain water levels and delineations 60 years into the future, we can generally conclude that the areas with new hydraulic models and coastal areas will be the most accurate of the future floodplain delineations, the FEMA detailed study areas without models will be the next most accurate, and the approximate study areas will be the least accurate. The delineations developed herein provide a reasonable basis for understanding how floodplains in the Chehalis Basin may change over the next 60 years. That opinion notwithstanding, we caution that floodplain delineations and flood depths estimated for FEMA approximate study areas should be considered highly speculative and should not be used for regulatory purposes.

[2] Percentage increases for climate change scenarios refer to the average increase in river flows. All flow inputs to the hydraulic model were scaled by this amount, above the historical condition, to represent projected future inflows with climate change.

Conclusions and Next Steps

Reviewing the results of the floodplain mapping the following conclusions can be made:

1. In most areas where new hydraulic modeling was performed, the 100-year water levels for late century mid-range climate conditions were generally less than 1 foot above existing 100-year water levels and 100-year water levels for late-century high-end climate were generally less than 2 feet above existing 100-year water levels. These differences (1 foot for the mid-range climate condition and 2 feet for the high-end climate condition) were used as the basis for projecting water level increases in areas where no new modeling was available.

2. Exceptions to the water level increases described in Bullet 1 are seen on Elk Creek and Scatter Creek. On Elk Creek, the large increase in projected flows and generally confined nature of the floodplain lead to increases of 3 to 4 feet in some locations. The higher late century floodplain is, however, generally confined to a relatively narrow swath along the channel due to the incised nature of the channel. On Scatter Creek the hydraulic modeling showed some larger increases in late century flood depths, but these were isolated to areas just upstream of bridges where local hydraulic conditions cause larger water level increases at the higher flows. Overall, the increases described in Bullet 1, and as used in the late century mapping, appear reasonable for the vast majority of locations.

3. In general there are only small differences between the areal extent of the FEMA floodplain and the projected late century floodplains. This is because in many locations the FEMA delineation encompasses the entire floodplain from valley wall to valley wall, and thus additional flood depths do not significantly expand the floodplain extent.

4. Notable exceptions to the conclusion in Bullet 3 are shown in Figures B-1 through B-7, and can be summarized as follows:

    a. Figure B-1 – South Fork Chehalis and Lake Creek – the late century mapping indicates that these reaches will see a significantly larger floodplain. These increases are attributed to better modeling and better topographic data used in this study.

    b. Figure B-2 – Chehalis River downstream of Doty – The FEMA floodplain in this reach is generally confined to the river channel but the modeling of projected late-century climate conditions indicates that the higher future flows will escape the channel in many locations, resulting in a much wider floodplain.

    c. Figure B-3 – Newaukum River Forks - the late century mapping shows significant changes from the FEMA floodplain for the Forks of the Newaukum River. These changes are attributed primarily to better hydraulic modeling and better topographic data used in this study.

d. Figure B-4 – Chehalis River near Centralia – the 2-Dimensional hydraulic modeling used in the current study is much better suited to identify areas of shallow flooding as compared to the previous analyses done with a 1-D model. The projected increases in flows by late century are also a factor in the expanded late-century floodplain, particularly in West Centralia.

e. Figure B-5 – Satsop River Tributaries – supporting documentation for the existing FEMA mapping for these areas is not available but given the current topographic data it is our opinion that the future conditions mapping, although still very approximate, is a better representation of actual flood risk than the effective FEMA mapping.

f. Figure B-6 – Berwick Creek – the FEMA mapping for Berwick Creek is clearly wrong since it includes areas high up on the hillsides and excludes the creek channel in some locations. The future conditions mapping confines flooding to the creek channel and its floodplain and as such is believed to be a significant improvement over the FEMA mapping.

g. Figure B-7 - Cloquallum Creek – The future conditions mapping shows much greater refinement than the FEMA mapping due to the availability of better topographic data. As such it is believed to be a significantly better representation of actual flood risk than the FEMA mapping.

As stated previously, the data, modeling, and mapping prepared for this study provides a reasonable basis for understanding the potential areal extent of the late-century 100-year floodplain in the Chehalis River basin. This information can be used to evaluate future flood risk and identify appropriate floodplain management actions to reduce risk. Approximately 332 miles of river were remapped using new hydraulic models. To the extent that these newly remapped floodplains differ from the effective FEMA mapping it is recommended that the new analyses be used to seek changes to the FEMA mapping. This should be a relatively straightforward process between FEMA and the affected communities. In areas where deficiencies in the FEMA mapping have been identified, but new hydraulic modeling is not available, we recommend that communities evaluate the impacts of the current FEMA mapping, including uncertainties in flood risk and potentially unnecessary insurance premiums, and determine if new detailed floodplain mapping studies should be pursued. FEMA estimates that new detailed floodplain mapping studies can cost between $5,000 and $20,000 per river mile.

Study Background

The Chehalis Basin Strategy (Strategy) is considering a wide-range of potential actions to reduce flood damage and protect and restore aquatic species in the Chehalis River basin. Actions to be taken under the Strategy will include short- and long-term actions, both small and large scale, and will be taken in numerous locations throughout the basin.

In February 2020, a State Environmental Policy Act (SEPA) Draft Environmental Impact Statement (EIS) was published by the Washington Department of Ecology. The Draft SEPA EIS analyzed potential environmental impacts of the proposed Chehalis River Basin Flood Damage Reduction Project, which includes a new flood retention facility near Pe Ell, Washington and improvements to the Chehalis-Centralia airport levee. Following the publication of the SEPA Draft EIS, the Office of the Chehalis Basin (OCB) led an evaluation of potential alternatives to the flood retention facility in the form of local structural and nonstructural actions. These local actions are focused on reducing flood damage in the mainstem Chehalis River and its tributaries throughout all parts of the basin.

The purpose of this memorandum is to provide hydrologic and hydraulic modeling and analysis to inform the identification and evaluation of potential future local structural and nonstructural actions under consideration as part of the Strategy. This memorandum describes the approach and results of mapping the late-century 100-year floodplain[3], and is directly linked to achieving the Chehalis Basin Board's Local Actions Program Outcomes[4]. OCB will use the floodplain delineations to guide future planning efforts to reduce flood damage and risks throughout the basin, and will make the information available to basin local governments to aid in implementing their floodplain management responsibilities.

Project Overview

The objective of this project is to delineate the late-century 100-year floodplain in the Chehalis River basin. The work includes the following steps:

1. Obtain available Federal Emergency Management Agency (FEMA) floodplain mapping and Base Flood Elevations (BFEs[5]) for the Chehalis Basin.
2. Develop a comprehensive topographic dataset covering all FEMA mapped tributaries.
3. Obtain recent hydraulic models for FEMA mapped rivers and creeks.

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[3] The "late-century 100-year floodplain" is a delineation of potential future flood hazard with projected climate change. The 100-year (or 1% chance exceedance) floodplain was delineated based on projected changes in hydrology between present day and the year 2080. Projections were made for mid-range and high-end climate projections. The mid-range projection assumes flows will increase by 26% across the entire Chehalis Basin (WSE, 2019a) while the high-end projection assumes flows will increase by 40% to 65%, with spatial variations as described in UW CIG, 2021.

[4] Chehalis Basin Board Local Actions Program desired outcome No. 2: "The Local Actions Program will plan for the 100-year flood conditions that are predicted for 2080 when considering outcomes and actions to include in the program" (Doyle, 2020).

[5] Base Flood Elevations, or BFEs, show the water surface elevations corresponding to the FEMA 100-year flood

4. Run the hydraulic models with scaled flood flows to define the late-century 100-year floodplain.
5. Map the late-century 100-year floodplain for all modeled areas using model outputs.
6. Estimate the difference in BFE elevation between the late-century modeled floodplain and existing FEMA mapped floodplains.
7. For FEMA mapped areas with BFEs but no hydraulic modeling, define the late-century 100-year floodplain by adjusting FEMA BFEs upward by the elevation difference determined in step 6.
8. For FEMA Mapped areas with no BFEs and no modeling, estimate the elevation of the approximate FEMA floodplain and then adjust that by an amount as determined in Step 6.
9. For coastal areas, map the late-century 100-year floodplain assuming the current 100-year tidal water surface elevation is increased to account for projected sea level rise.
10. Combine the maps developed in items 5, 7, 8, and 9 into composite late-century 100-year floodplain delineations under mid-range and high-end climate projections.

Existing FEMA Mapping

FEMA floodplain mapping is available for 36 flooding sources (rivers, creeks, and coastal areas) in the Chehalis River basin. All available FEMA mapping was obtained from the FEMA Map Service Center[6]. This includes delineations of Special Flood Hazard Areas (SFHAs) and Base Flood Elevation (BFE) data. The SFHAs include areas of detailed studies (e.g., studies for which hydraulic modeling and analysis was used to delineate the floodplain) as well as approximate studies (without modeling). Within Lewis County, the floodplain mapping available from FEMA only covered the City of Centralia. FEMA mapping data for the remainder of the County was provided by the Lewis County Department of Public Works. FEMA mapping for the 36 flood sources was combined into a single, comprehensive 100-year floodplain for the entire basin. Table 1 lists the tributaries included in current FEMA mapping.

Table 1: FEMA Mapped Floodplains in the Chehalis River Basin

FLOOD SOURCE	FLOOD SOURCE	FLOOD SOURCE	FLOOD SOURCE
Berwick Creek	Delezene Creek	Mill Creek	Scammon Creek
Black River	Dillenbaugh Creek	Mox Chehalis Creek	Scatter Creek
Bunker Creek	Elk Creek	Newaukum River	SF Chehalis River
Charley & Newskah Creeks	Garrard Creek	Newman Creek	SF Newaukum River
Chehalis River	Hoquiam River	NF Newaukum River	Skookumchuck River
Cloquallum Creek	Humptulips River	Porter Creek	Stearns Creek
Coal Creek	Independence Creek	Rock Creek	Wishkah River
Coastal	Johns River	Salzer Creek	Wynoochee River
Davis Creek	Lincoln Creek	Satsop River	Coastal

[6] https://msc.fema.gov/portal/home

Topographic Data

A comprehensive topographic dataset covering all tributaries mapped by FEMA was developed from topographic data sources available through the Washington Department of Natural Resources LiDAR Portal[7]. Table 2 lists the specific data sets obtained and used for this study. No new topographic data collection was conducted for this planning-level study. The data sets listed in Table 2 were mosaiced into a comprehensive basin wide topographic dataset. The mosaic process was configured so that newer LiDAR data took precedence over older data wherever multiple data sets were available. The individual data sets and final mosaic are all referenced to the NAVD 88 vertical datum.

Table 2: Topographic Data Sources for Chehalis River Basin

LIDAR DATASET NAME	SOURCE	DATE COLLECTED
Western Washington 3DEP – North AOI	WA DNR	March 17, 2016 – September 30, 2016
Willapa AOI	WA DNR	January 27-28, 2017
Olympic Peninsula 3DEP – Area 1	USGS	Multiple deployments between September 14, 2017 and April 15, 2019
Thurston County LiDAR	Thurston County	June and July, 2011
Olympic Peninsula 3DEP – Area 2	USGS	Multiple deployments between February 19, 2018 and April 25, 2019
USDA-FS Region-6, Olympic National Forest	USDA Forest Service	Multiple deployments between October 29 and December 14, 2017
Quinault River Basin	Watershed Sciences	Multiple deployments between March 24 and April 9, 2012
LiDAR Remote Sensing Data Collection: Lewis County Study Area, Washington	Puget Sound LiDAR Consortium	Multiple deployments between April 4, 2008 and January 22, 2010
Chehalis River Watershed	FEMA, WA DNR, Lewis County	Multiple deployments between January 28 and April 7, 2012.

Hydraulic Models

Available, recent hydraulic models for FEMA mapped creeks were obtained. These models are listed in Table 3. The models were reviewed for completeness and a general check of model inputs, such as flows, but were otherwise not validated by WSE. Flows used in the models were checked against the FEMA published 100-year flows. Table 4 shows a comparison of flows at key locations. In general, the 100-year flows in the available hydraulic models match pretty well with the FEMA flows. Significant differences in flow for certain reaches (e.g., Elk Creek, Lake Creek, Stearns Creek) were typically because flow inputs in the new hydraulic models were based on more recent and better estimates of the 100-year flow than were used in the older FEMA studies. It should also be noted that flows on the mainstem Chehalis River used in the WSE RiverFlow2D model are generally the same as those used in the FEMA

[7] https://lidarportal.dnr.wa.gov/

study because the effective FEMA study uses the hydrology developed by WEST Consultants and WSE for Chehalis River Basin hydraulic modeling (WEST, 2012).

WSE adjusted flow inputs to the hydraulic models to reflect late-century mid-range and high-end climate change projections (WSE, 2019a; Mauger, 2021). The mid-range climate projection assumes a basin wide flow increase of 26% and is the same late-century climate change projection used in the Draft SEPA EIS. The late-century high-end climate projection assumes flow increases of 40 to 65%, spatially distributed across different tributaries as described in Mauger, 2021.

Table 3: Study Reaches covered by recent hydraulic modeling

MODEL NAME	SOURCE	EXTENT
Tributary Models		
Elk Creek	Natural Systems Design (NSD)	RM 0 to 6
S Fork Chehalis	NSD	RM 5 to 22
Stillman Creek	NSD	RM 0 to 3
Lake Creek	NSD	RM 2 to 13
Bunker Creek	NSD	RM 1 to 10
Deep Creek	NSD	RM 0 to 6
Stearns Creek - W Fork	NSD	RM 0 to 2
Stearns Creek - E Fork	NSD	RM 0 to 6
Newaukum River	NSD	RM 9 to 11
N Fork Newaukum River	NSD	RM 0 to 11
S Fork Newaukum River	NSD	RM 0 to 20
Skookumchuck River	NSD	RM 17 to 22
Satsop River	NSD	RM 0 to 6
Satsop River - E Fork	NSD	RM 0 to 5
Satsop River - W Fork	NSD	RM 0 to 3
Wynoochee River	NSD	RM 6 to 17
Scatter Creek	FEMA	RM 0 to 20
Wishkah River	WSE	RM 0 to 12
Chehalis Mainstem RiverFlow2D Model (WSE, 2019b)		
Chehalis Mainstem	WSE	RM 0 to 108
S Fork Chehalis River	WSE	RM 0 to 6
Bunker Creek	WSE	RM 0 to 2
Lake Creek	WSE	RM 0 to 2
Stearns Creek	WSE	RM 0 to 5+ (incl. Forks)
Newaukum River	WSE	RM 0 to 11
Salzer Creek	WSE	RM 0 to 5
Skookumchuck River	WSE	RM 0 to 22
Lincoln Creek	WSE	RM 0 to 5
Black River	WSE	RM 0 to 11
Satsop River	WSE	RM 0 to 4
Wynoochee River	WSE	RM 0 to 9

Table 4: Comparison of FEMA Flows and New Hydraulic Model Flows

MODELED RIVER	RM EXTENTS	FEMA STUDY LOCATION	DA (SQMI)	FEMA 100-YR (CFS)	MODEL 100-YR (CFS)	MODEL VS FEMA % DIFF
Elk Creek	0 to 6	At confluence with Chehalis R	61	5,600	8,010	43%
S Fk Chehalis River	5 to 22	At confluence with Chehalis R	123	14,800	12,170	-18%
Lake Creek	2 to 13	At confluence with S Fk Chehalis R	28	1,600	2,480	55%
Stearns Creek	N/A	At confluence with Chehalis R	23.2	6,855[1]	3,140	-54%
N Fk Newaukum River	0 to 11	At confluence with Newaukum R	69	7,400	7,550	2%
Newaukum River	9 to 11	At gage near Napavine	155	13,200	14,420	9%
Skookumchuck River	17 to 22	At confluence with Chehalis R	181	13,000	15,100	16%
E Fk Satsop River	0 to 5	Confluence with W Fk Satsop R	199	36,900	36,900	0%
Satsop River	0 to 6	RM 2.3 Gage	299	52,300	59,500	14%
Wynoochee River	6 to 17	Above Black Creek	155	23,000	23000	0%
		Above Wedekind Creek	141	21,200	21,200	0%
Wishkah River	0 to 12	Confluence with Chehalis R	102	18,600	17,200	-8%
Coastal areas	Tidal	Grays Harbor, Hoquiam, Aberdeen	NA	varies	13.2 ft	NA

Note: [1] The value for Stearns Creek taken from the published FEMA Flood Insurance Study appears to be erroneous as it is far too high for a basin of this size.

Mapping the Late-Century Floodplain

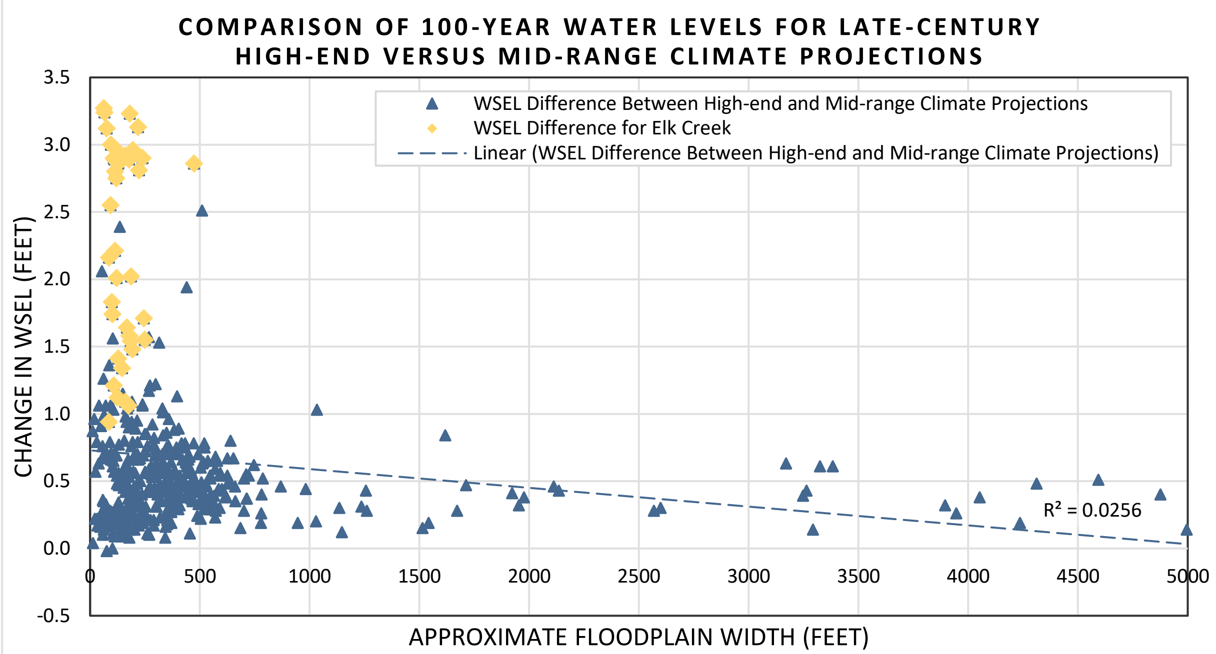
The late-century 100-year floodplain for each FEMA mapped area was delineated using the topographic, hydraulic, and flow data described above. The FEMA mapped areas fall into four general categories: 1) areas with recent hydraulic models; 2) FEMA detailed study areas without available models; 3) FEMA approximate study areas without available models; and 4) coastal flooding areas. The approach taken for developing the late-century 100-year floodplain mapping for each of these area types is described below.

Areas with Recent Hydraulic Models

FEMA floodplains with available new hydraulic models are the simplest areas to map for late-century conditions. For each location (Chehalis River mainstem or tributary), the available models were updated and run using late-century flood flows corresponding to the mid-range and high-end climate change projections. The model outputs were exported and the floodplains were mapped in GIS. The model results from these new simulations were then compared to the FEMA BFEs to estimate projected increases in flood water surface elevations by late-century. Modeled water surface elevations for the late-century mid-range and high-end climate projections at each FEMA BFE location were also compared to determine the impacts of scaling flows up by approximately 50% versus 26%.

The projected increase in water level versus floodplain width at each FEMA BFE is shown in Figure 1. The analysis indicates that a nominal 24% increase in flows (the approximate difference between mid-range and high-end conditions) causes an increase in 100-year water levels of approximately 1 foot or less in all areas except Elk Creek and a few locations on Scatter Creek. The large differences seen in Elk Creek occur near the mouth of the creek and can be attributed to the large projected flow increases and incised nature of the channel in that location. The few large increases on Scatter Creek occur immediately upstream of bridges where the bridge constrictions cause large, localized rises in water levels. Floodplain width was used for the comparison shown in Figure 1 as it was expected that increases in water levels would be inversely related to floodplain width, larger in narrow channels and smaller in wide floodplains.

Figure 1
Increase in Late-Century 100-year Flood Water Levels versus Floodplain Width at FEMA BFE Locations



The dashed line in Figure 1 shows the best fit line through the data. As expected, the best fit line indicates that the projected change in water surface elevations for wider floodplains is smaller than for narrower floodplains. However, as evidenced by the scatter in the data, the correlation between floodplain width and water level increase is not very strong. This is likely because other factors, such as channel shape, level of entrenchment, channel and floodplain roughness, bridge or levee constrictions, and differences in projected precipitation also affect water level increases. Because this correlation is not very strong, a uniform increase of 1 foot above the current FEMA flood water levels was used to adjust future flood levels for the mid-range climate change projection, and an additional 1 foot (i.e., 2 feet total) was assumed for the high-end projection. These increases were applied to the FEMA BFEs in detailed study areas and the estimated flood levels in FEMA approximate study areas, as described below.

FEMA Detailed Study Areas without Available Hydraulic Models

In FEMA detailed study areas, the late-century 100-year floodplain was developed by:

1. Starting with the existing FEMA BFEs
2. Adding 1 foot of elevation to the BFEs to create 2080 mid-range climate condition flood levels and 2 feet to create high-end climate change condition flood levels
3. Creating water surface planes at the new flood levels
4. Delineating floodplain edges at the intersection of the new water surface planes with the topographic dataset

Clearly, there will be more uncertainty or errors in the future floodplain delineations for detailed study areas with greater hydraulic complexity (e.g., due to bridges, levees, road fills, etc.) and in areas where the slope of the flood water surface is not uniform between BFE locations. There will also be greater uncertainty in areas where late-century water level increases results in breakout flooding that extends unreasonably far from the channel to lower elevations. These areas cannot be properly assessed without additional hydraulic modeling. In some cases the delineated floodplain was truncated based on engineering judgement to better represent assumed late-century flood conditions.

FEMA Approximate Study Areas

In FEMA approximate study areas (which don't have BFEs), an estimate for the existing condition 100-year water surface elevation was needed before flood water level increases could be applied to create the late-century floodplains. The FEMA Zone A (approximate study) flood zone boundaries were first compared to the topographic dataset described above to determine whether the edge of the mapped flood zone could be used to estimate water surface elevations. Unfortunately, the Zone A edges varied significantly in elevation throughout the tributaries, rising up valley walls, crossing road and railroad embankments, and generally including many areas of high ground outside of the actual floodplain. As a result of these inaccuracies, using the existing FEMA Zone A flood boundaries to estimate the 100-year water surface elevation was not possible.

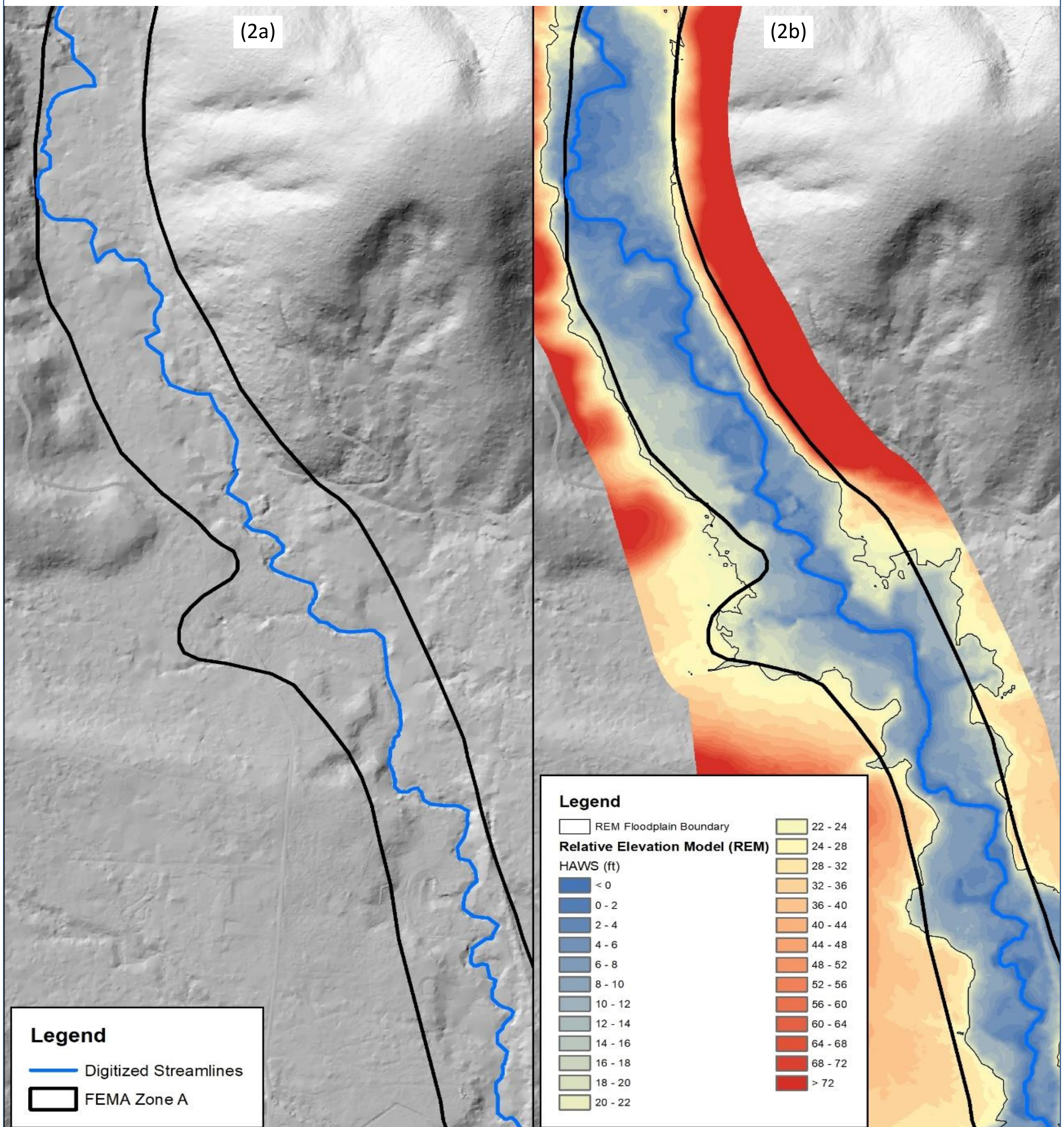
Relative elevation models (REMs) were therefore created for all tributaries for which FEMA flood zones were mapped but recent hydraulic models were not available, including both detailed and approximate FEMA study areas. Tributary channel centerlines for these tributaries were delineated from the topographic dataset and visually reviewed for accuracy. Elevations were then extracted from the tributary centerlines and used to create detrending surfaces representing water surface elevations within each channel at the time of the LiDAR data collections. The detrending water surfaces were then subtracted from the topographic data to produce height above water surface (HAWS) grid data sets. The HAWS grids were visually inspected to determine a relative elevation, or HAWS value, for each stream segment that best corresponded to the mapped FEMA 100-year floodplain. Tributaries were subdivided into smaller reaches as necessary to allow a reasonable match between the width of the REM delineated floodplain and the FEMA Zone A floodplain throughout each reach. Figure 2a shows an example of the mapping including the delineated tributary channel, floodplain topography, and FEMA Zone A floodplain boundary (in black). Figure 2b overlays the topographic data with the REM analysis and delineates the REM floodplain, which was determined to be at a HAWS value of approximately 22 feet in this location, and is shown by the thin black outline in Figure 2b.

The REM mapping relies heavily on visual review and subjective engineering judgement with respect to subdividing reaches and estimating appropriate HAWS values. The process does not consider the hydraulic effects of bridges, road fills, levees, etc. and the REM mapped floodplain sometimes extends unreasonably far from the channel to lower elevations that likely don't actually flood. Although the resulting mapping anomalies cannot be rectified without detailed hydraulic modeling, in some locations the delineated floodplains were truncated based on engineering judgement to represent reasonable late-century conditions. It should also be noted that the sub-reach approach for REM mapping sometimes results in floodplain boundaries that change abruptly from one sub-reach to the next. It is important that users are aware of these issues when using the floodplains for planning purposes.

Comparing the FEMA Zone A floodplain to the REM mapped floodplain in Figure 2, the following observations can be made: 1) the FEMA Zone A floodplain boundary has some obvious errors, locations where the floodplain boundary excludes the river channel and locations where the floodplain encompasses areas that are 70 vertical feet or more above the river channel; 2) the REM floodplain is much better aligned with the valley topography as seen in the upper half of Figure 2b; and 3) the REM floodplain reflects details in the topography (tributary channels, valley walls, inset floodplains, etc.) much better than the Zone A delineation as seen in the middle portion of Figure 2b. In some tributaries it was not possible to replicate the Zone A floodplain as well as is shown in Figure 2, but the REM floodplain was generally thought to be a significant improvement over the Zone A delineation. Furthermore, since the REM mapping has an associated flood depth (i.e., HAWS), it facilitates the process of increasing flood water surface elevations to account for climate change.

Once the REM floodplain boundaries were established, the same approach as was used for the detailed study areas was used to estimate late-century HAWS values for the approximate study areas. The existing condition HAWS values were increased by 1 foot to represent the late-century mid-range climate projection and by 2 feet to represent the late-century high-end projection. The floodplain boundaries delineated at these higher levels were then reviewed for general consistency with the original FEMA Zone A boundaries and refined as necessary to eliminate anomalies. The final late-century 100-year floodplains for approximate study areas were then combined with other mapping areas as described below.

Figure 2
Example Comparison of FEMA Approximate Study Area Floodplain Delineation and Relative Elevation Model



Coastal Flooding Areas

Coastal flooding areas around Grays Harbor were recently delineated by FEMA (STARR, 2017). FEMA generally determined the 100-year coastal flood elevation to be 13.0 feet or lower within Grays Harbor. In recent work for the cities of Aberdeen and Hoquiam, WSE determined that the 100-year tidal water surface elevation of Grays Harbor to be 13.2 feet (WSE, 2016). Given the similarities between these values, it was assumed that using the more conservative value of 13.2 feet was a good approximation for the current 100-year flood level for coastal areas around Grays Harbor. Analyses by the University of Washington Climate Impacts Group estimated that the median (i.e., mid-range) increase in sea level in Grays Harbor by 2080 would be 1.1 feet and the 10% exceedance (i.e., high-end) increase would be 1.8 feet (Miller et.al., 2018). Thus, the late-century 100-year water level for coastal areas surrounding Grays Harbor was determined to be 14.3 feet for mid-range climate projections and 15.0 feet for high-end projections. The coastal 100-year late-century mid-range and high-end floodplain extents were determined by intersecting the mid-range and high-end water surface planes with the topographic data and delineating all wetted areas.

Comprehensive Late-Century Floodplain Mapping

The late-century 100-year floodplains delineated for the four FEMA mapping areas described above were combined into comprehensive 100-year floodplains for the late-century mid-range and late-century high-end climate projections. Floodplain mapping for the entire Chehalis basin is shown in Figures A-1 through A-11. As shown on these maps, there are some areas where the late-century floodplain is not significantly different from the existing FEMA floodplain. This includes much of the mainstem Chehalis River floodplain downstream of Grand Mound where the FEMA floodplain encompasses the entire valley floor and therefore increases in flood depths do not result in significant increases in floodplain area. On the other hand, there are many areas where the projected late-century floodplain is dramatically different from the FEMA floodplain. Some examples of this include the upper Chehalis River between Elk Creek and Meskill (Figure A-1), Chehalis River at Centralia (Figure A-2), the Newaukum River (Figure A-3), the Satsop and Wynoochee rivers (Figure A-8), and the Humptulips River (Figure A-11).

Differences between the projected late-century floodplains and the existing FEMA floodplain result from two primary causes: 1) increases in water levels due to projected climate change, and 2) improvements in the floodplain delineations to better conform to the topographic data. Examples of these are shown in Figures B-1 through B-7. The most significant differences are as follows:

a. Figure B-1 – South Fork Chehalis and Lake Creek – the late century mapping indicates that these reaches will see a significantly larger floodplain. These increases are attributed to better modeling and better topographic data used in this study.

b. Figure B-2 – Chehalis River downstream of Doty – The FEMA floodplain in this reach is generally confined to the river channel but the modeling of projected late-century climate conditions indicates that the higher future flows will escape the channel in many locations, resulting in a much wider floodplain.

c. Figure B-3 – Newaukum River Forks - the late century mapping shows significant changes from the FEMA floodplain for the Forks of the Newaukum River. These changes are attributed primarily to better hydraulic modeling and better topographic data used in this study.

d. Figure B-4 – Chehalis River near Centralia – the 2-Dimensional hydraulic modeling used in the current study is much better suited to identify areas of shallow flooding as compared to the previous analyses done with a 1-D model. The projected increases in flows by late century are also a factor in the expanded late-century floodplain, particularly in West Centralia.

e. Figure B-5 – Satsop River Tributaries – supporting documentation for the existing FEMA mapping for these areas is not available but given the current topographic data it is our opinion that the future conditions mapping, although still very approximate, is a better representation of actual flood risk than the effective FEMA mapping.

f. Figure B-6 – Berwick Creek – the FEMA mapping for Berwick Creek is clearly wrong since it includes areas high up on the hillsides and excludes the creek channel in some locations. The future conditions mapping confines flooding to the creek channel and its floodplain and as such is believed to be a significant improvement over the FEMA mapping.

g. Figure B-7 - Cloquallum Creek – The future conditions mapping shows much greater refinement than the FEMA mapping due to the availability of better topographic data. As such it is believed to be a significantly better representation of actual flood risk than the FEMA mapping.

In addition to the floodplain maps included as attachments to this memorandum, digital versions (GIS shapefiles) of the comprehensive floodplain delineations were provided to the Office of the Chehalis Basin and are available for future studies.

Summary and Conclusion

The late-century 100-year floodplain for the Chehalis River basin was delineated using available data sources, hydraulic models, and existing FEMA floodplain mapping. Floodplains were delineated for four area types: 1) areas with new hydraulic models; 2) FEMA detailed study areas; 3) FEMA approximate study areas; and 4) coastal flood zones. Late-century floodplain mapping was prepared for mid-range and high-end projections of climate conditions for the year 2080. A total of 1,173 miles of riverine floodplain were mapped in this study. This includes 332 river miles with new hydraulic models, 39 miles of FEMA detailed study areas without new models, and 802 miles of FEMA approximate study areas. In addition, more than 65 miles of coastal flood zone around Grays Harbor were mapped for projected late-century tidal flood levels.

Reviewing the results of the floodplain mapping the following conclusions can be drawn:

1. In most areas where new hydraulic modeling was performed, the 100-year water levels for late century mid-range climate conditions were generally less than 1 foot higher than the existing 100-year water levels, and 100-year water levels for late-century high-end climate were generally less than 2 feet above existing 100-year water levels. These differences (1 foot for the mid-range climate condition and 2 feet for the high-end climate condition) were used as the basis for projecting water level increases in areas where no new modeling was available.
2. Exceptions to the water level increases described in Bullet 1 are seen on Elk Creek and Scatter Creek. On Elk Creek, the large increase in projected flows and generally confined nature of the floodplain lead to increases of 3 to 4 feet in some locations. The higher late century floodplain is, however, generally confined to a relatively narrow swath along the channel due to the incised nature of the channel. On Scatter Creek the hydraulic modeling showed some larger increases in late century flood depths, but these were isolated to areas just upstream of bridges where local hydraulic conditions cause larger water level increases at the higher flows. Overall, the increases described in Bullet 1, and as used in the late century mapping, appear reasonable for the vast majority of locations.
3. In general there are only small differences between the areal extent of the FEMA floodplain and the projected late century floodplains. This is because in many locations the FEMA delineation encompasses the entire floodplain, from valley wall to valley wall, and thus additional flood depth does not significantly expand the floodplain extent. Notable exceptions to this are shown in Figures B-1 through B-7.

As stated previously, the data, modeling, and mapping prepared for this study provides a reasonable basis for understanding the potential areal extent of the late-century 100-year floodplain in the Chehalis River basin. This information can be used to evaluate future flood risk and identify appropriate floodplain management actions to reduce risk. Approximately 332 miles of river were remapped using new hydraulic models. To the extent that these newly remapped floodplains differ from the effective FEMA mapping it is recommended that the new analyses be used to seek changes to the FEMA mapping. This should be a relatively straightforward process between FEMA and the affected communities. In areas where deficiencies in the FEMA mapping have been identified, but new hydraulic modeling is not available, we recommend that communities evaluate the impacts of the current FEMA mapping, including uncertainties in flood risk and potentially unnecessary insurance premiums, and determine if new detailed floodplain mapping studies should be pursued. FEMA estimates that new detailed floodplain mapping studies can cost between $5,000 and $20,000 per river mile.

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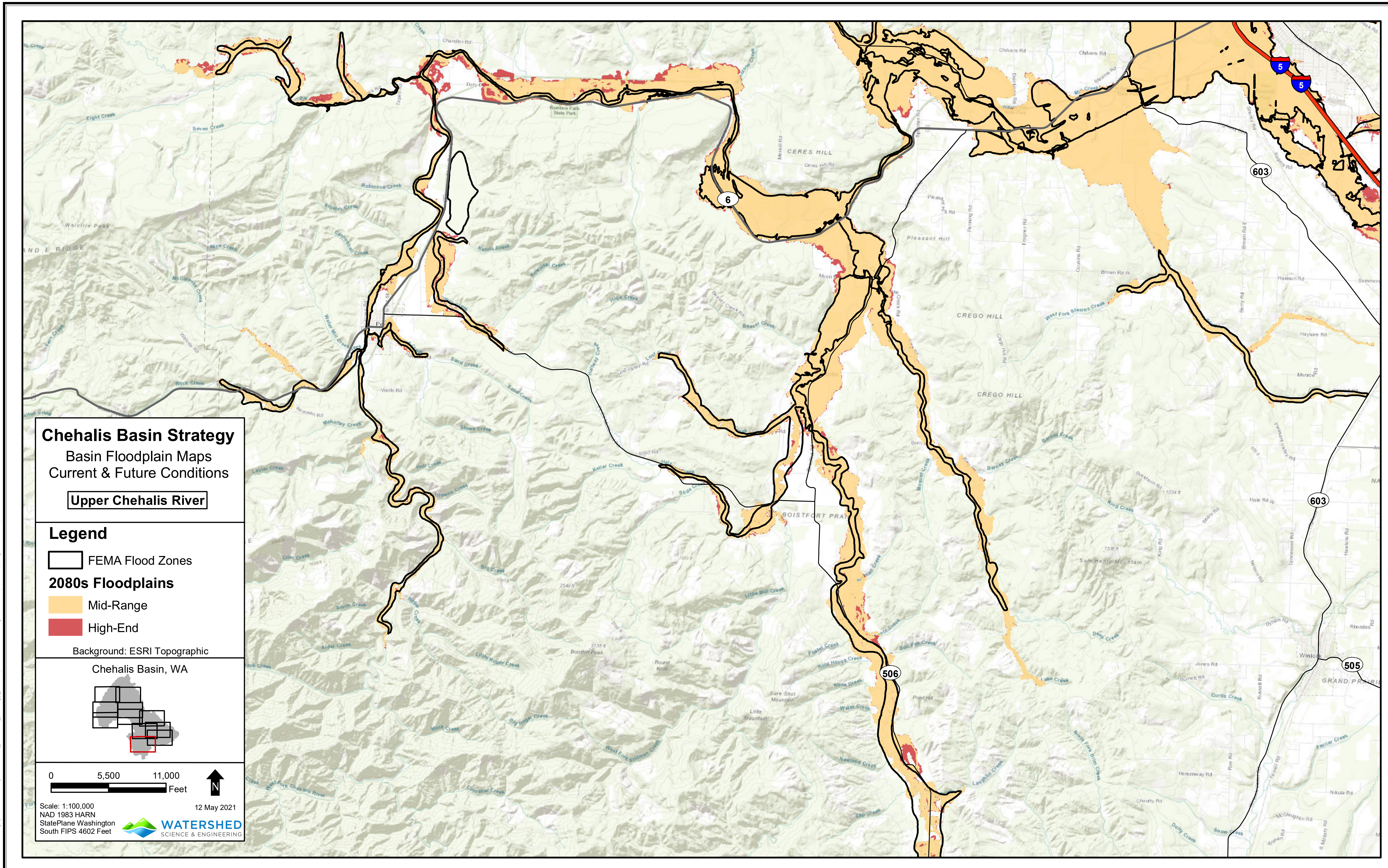

Chehalis Basin Strategy
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Current & Future Conditions
Upper Chehalis River
Legend
FEMA Flood Zones
2080s Floodplains
Mid-Range
High-End
Background: ESRI Topographic
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CREGO HILL
BOISTFORT PRAIRIE
GRAND PRAIRIE
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Figure A-1

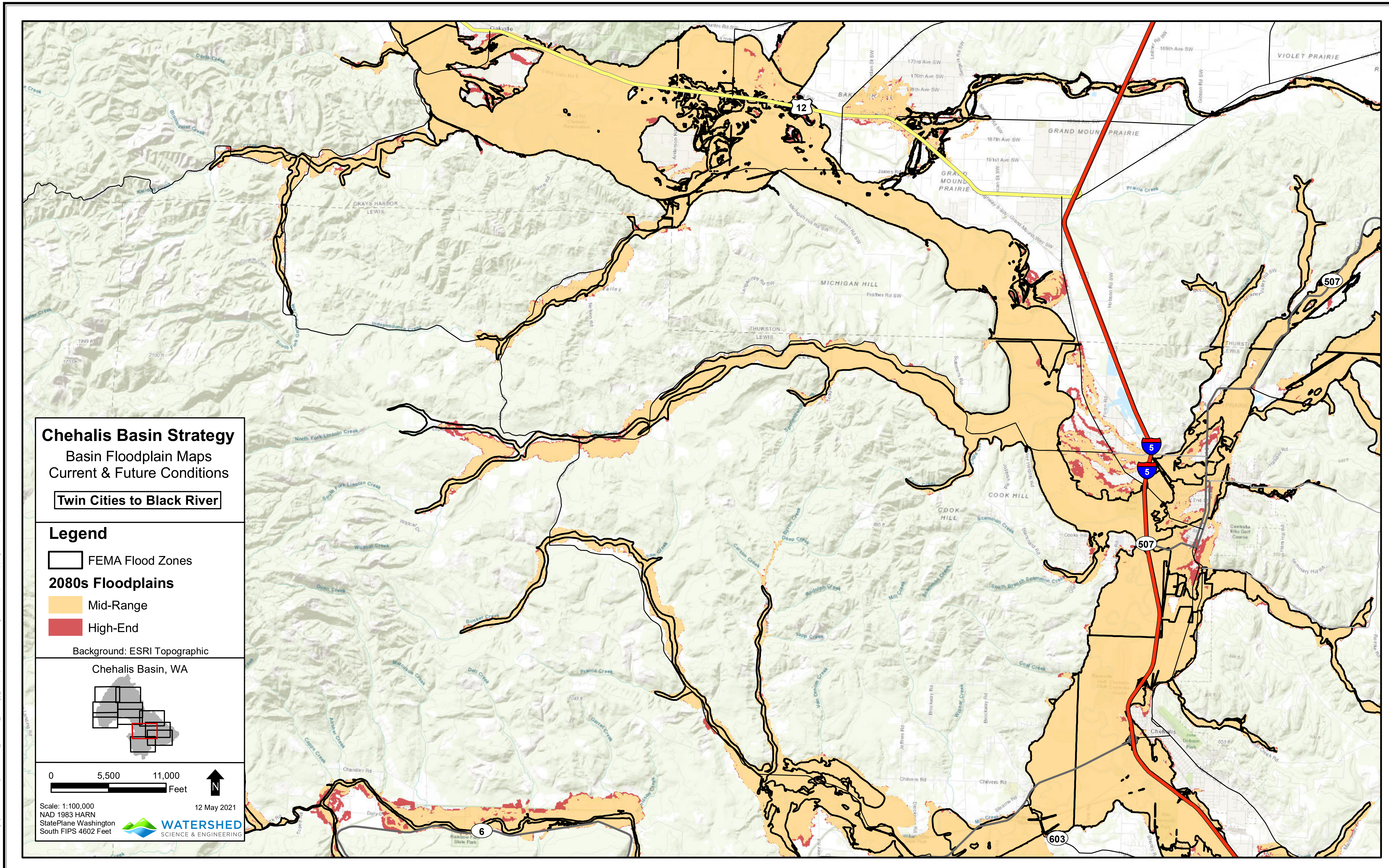

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Figure A-2

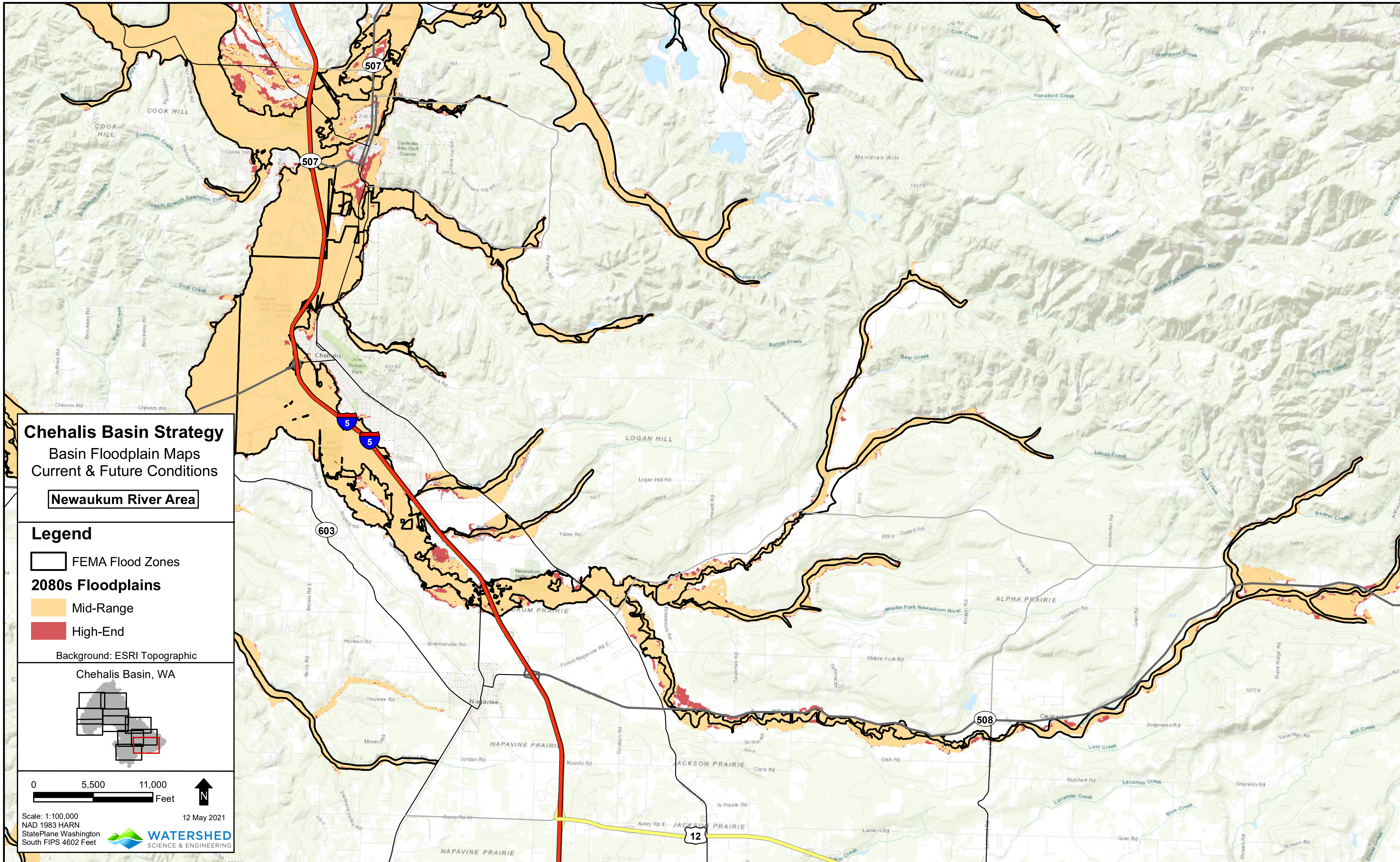

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Figure A-3

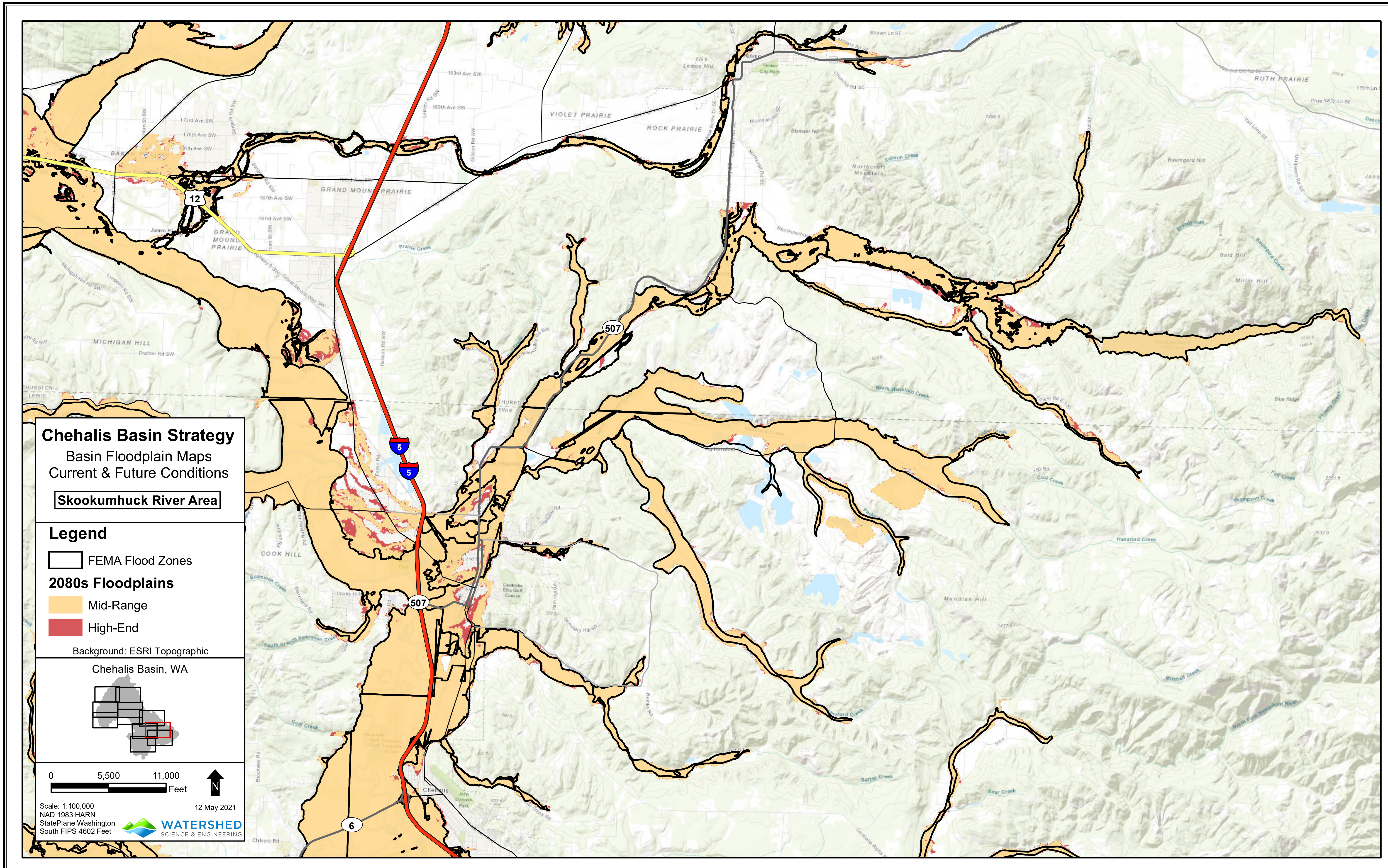

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Figure A-4

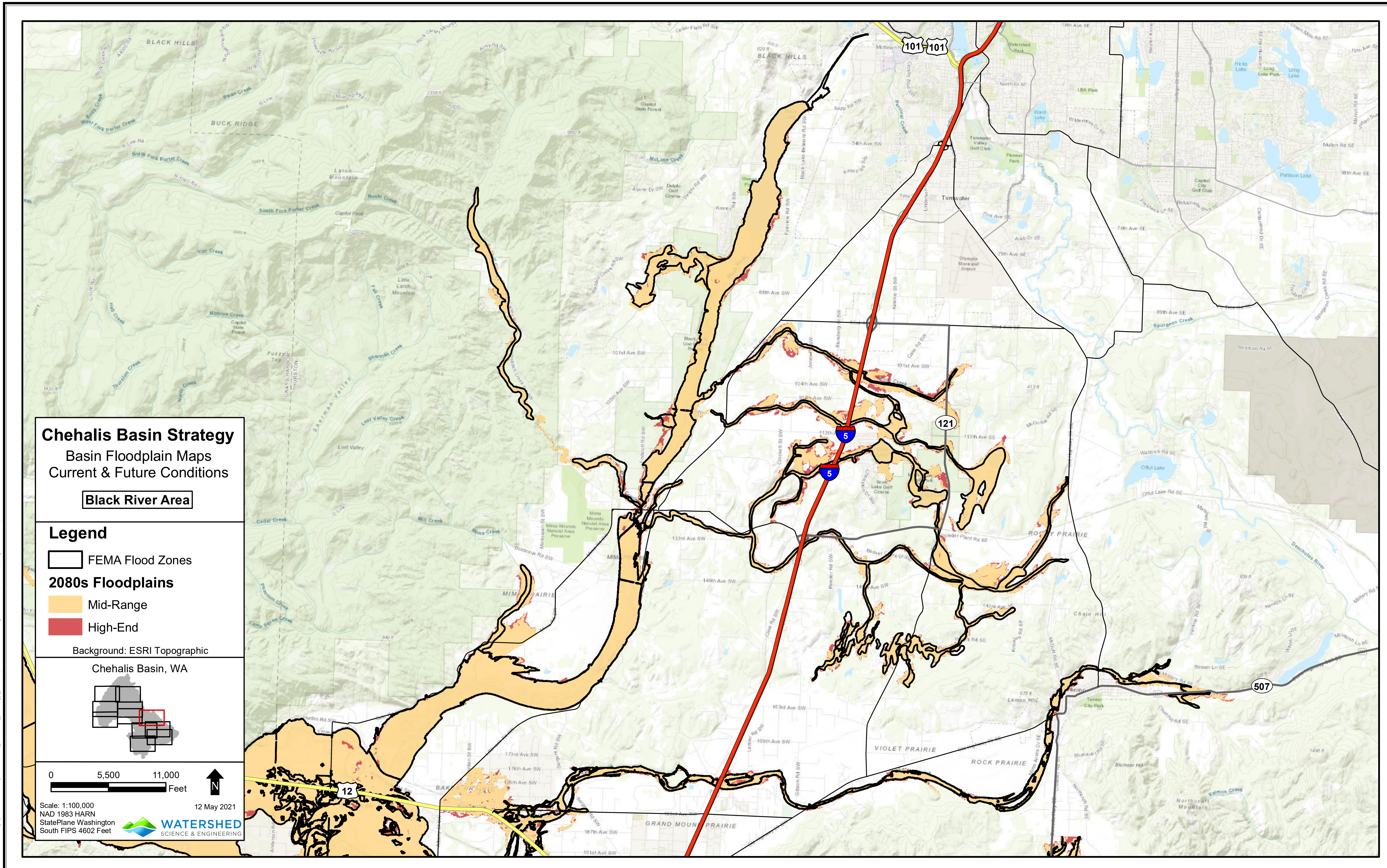
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Figure A-5

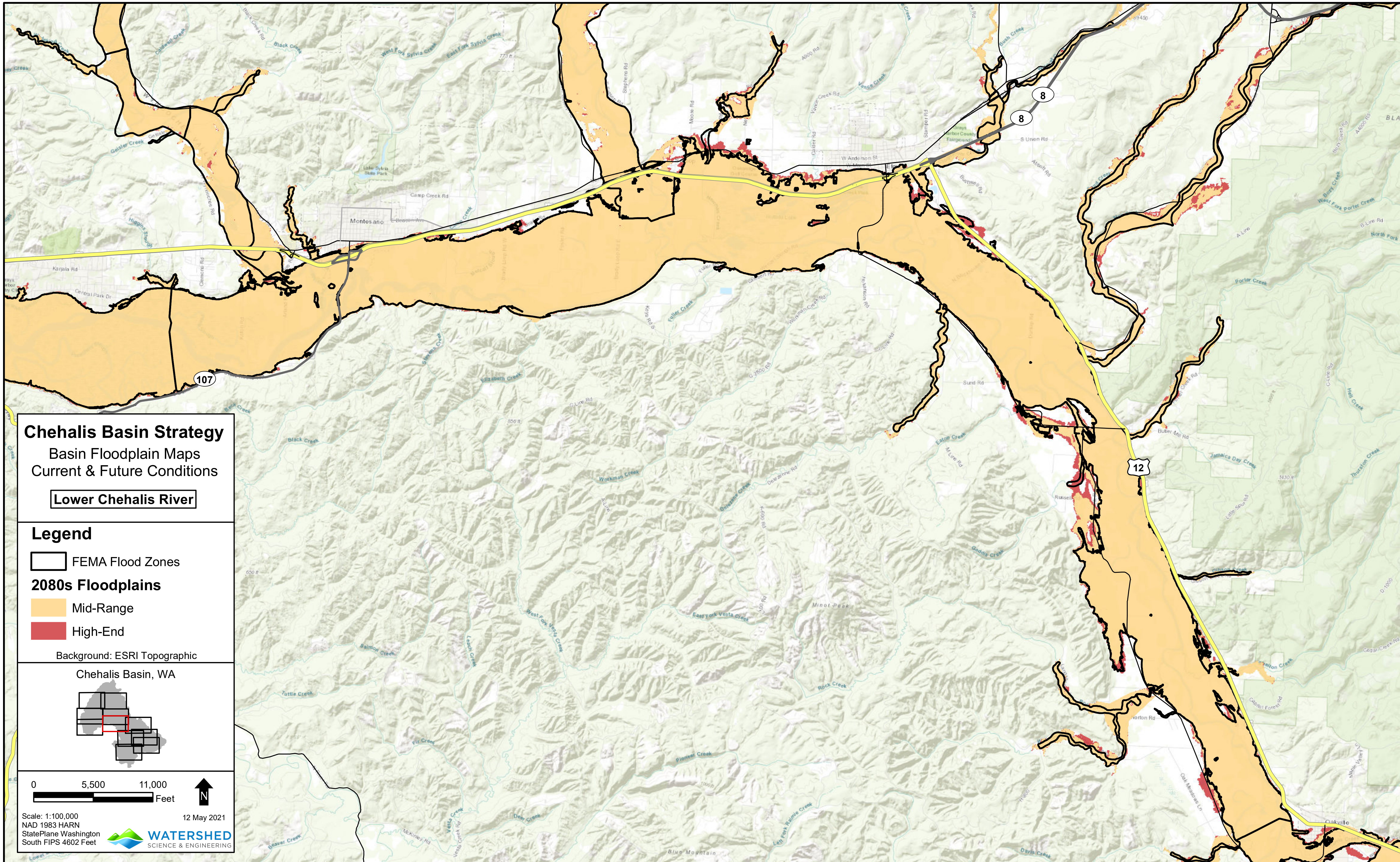

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Figure A-6

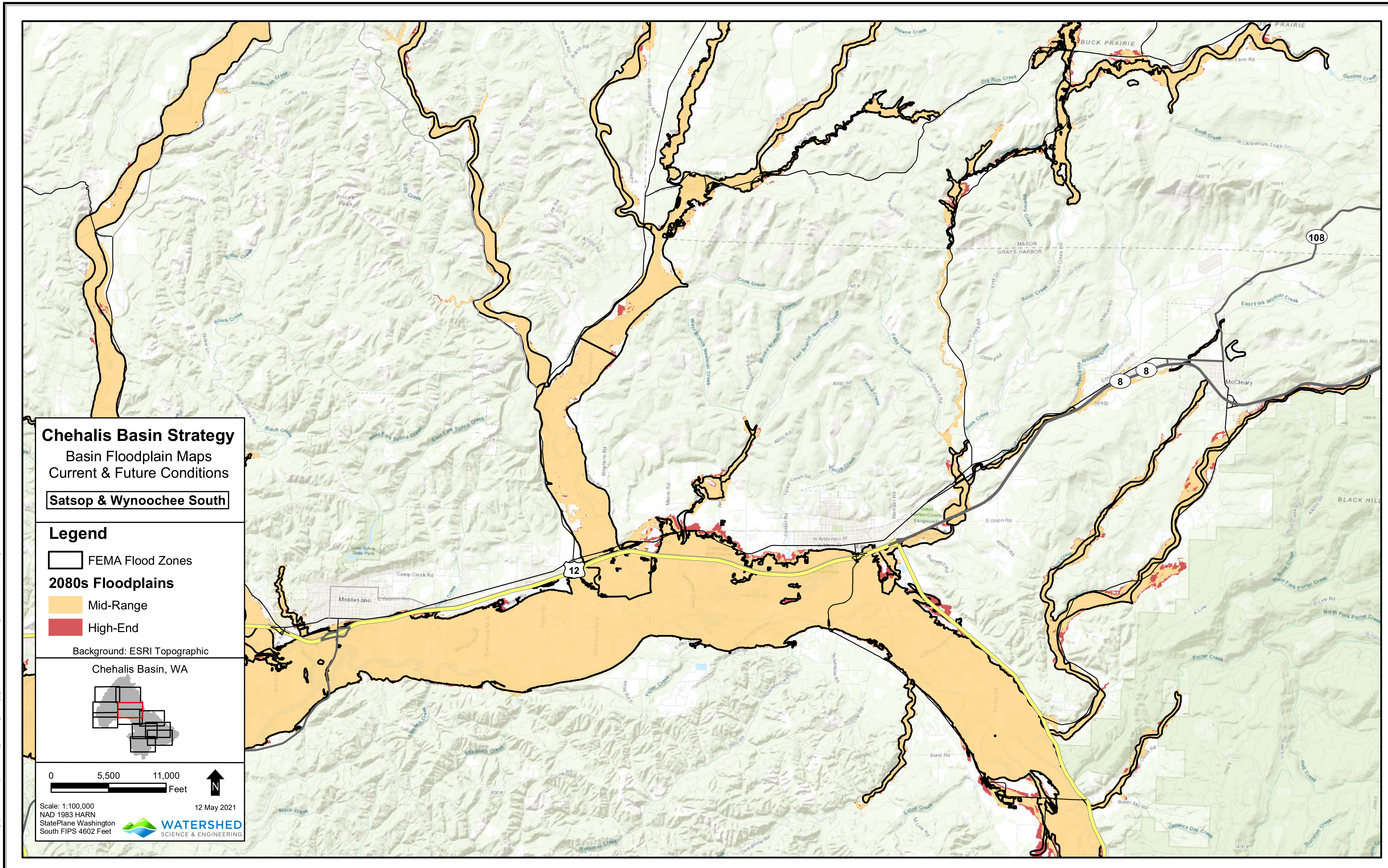

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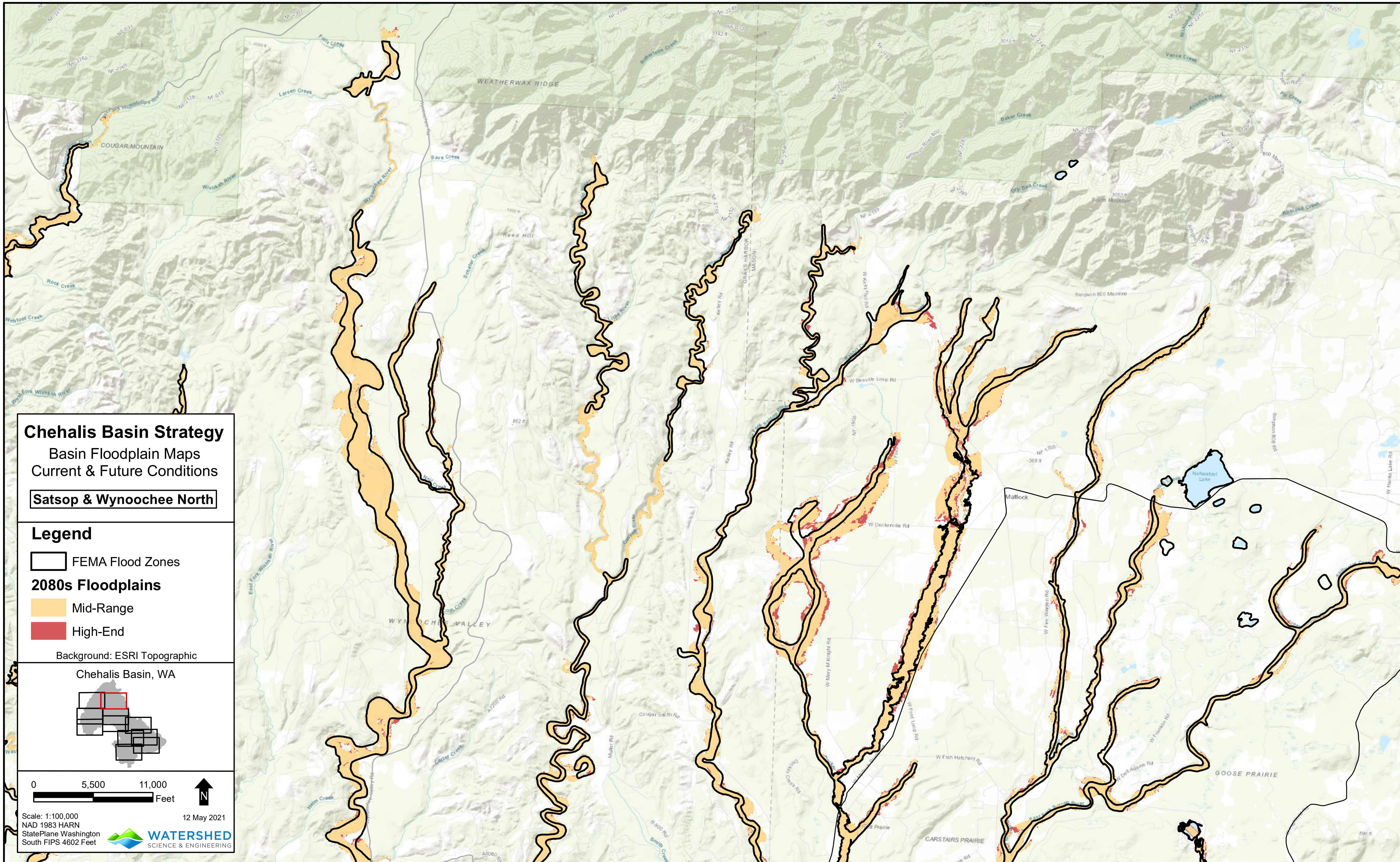
Figure A-7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GOOSE PRAIRIE
CARSTAIRS PRAIRIE
Matlock

Figure A-8

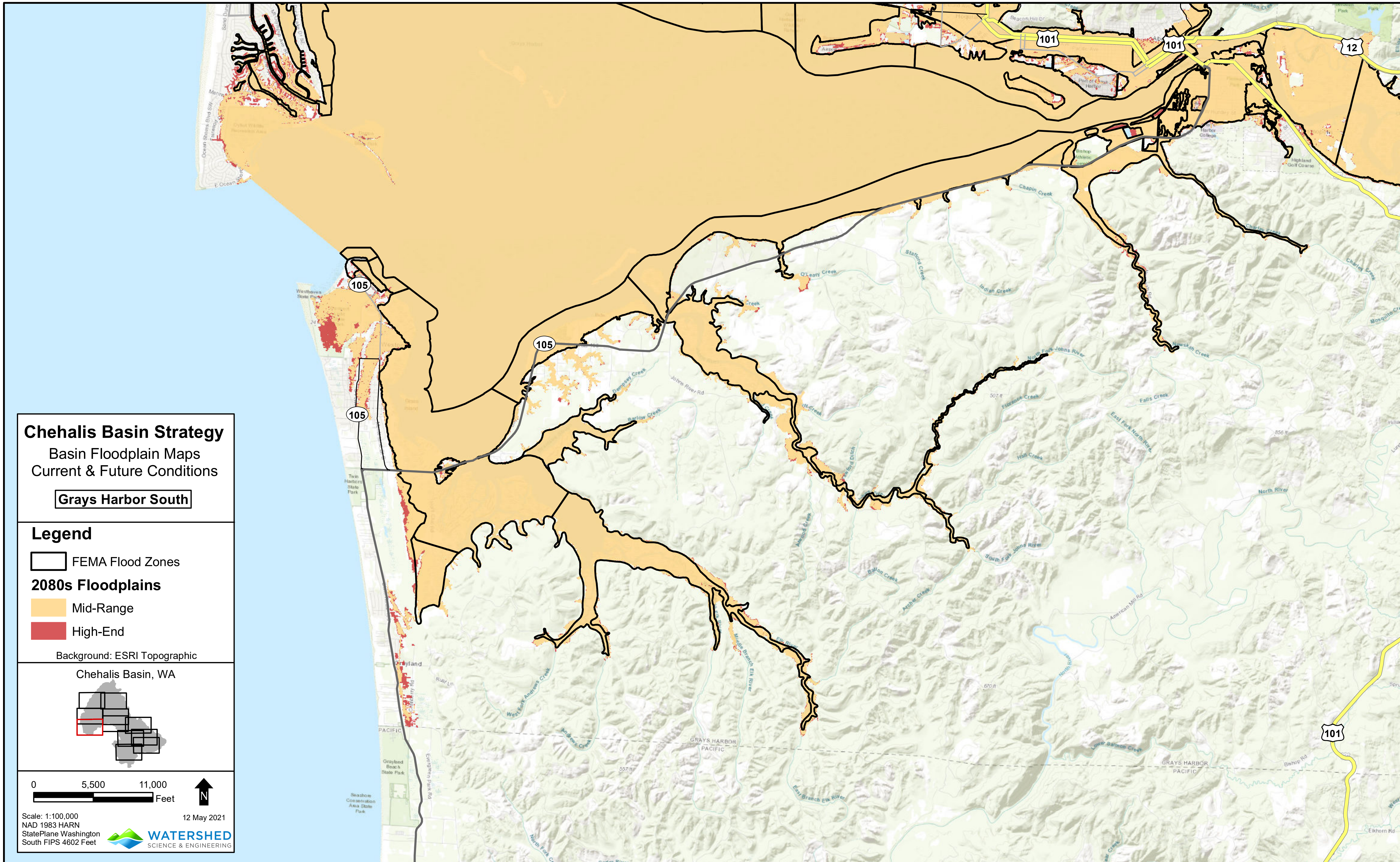

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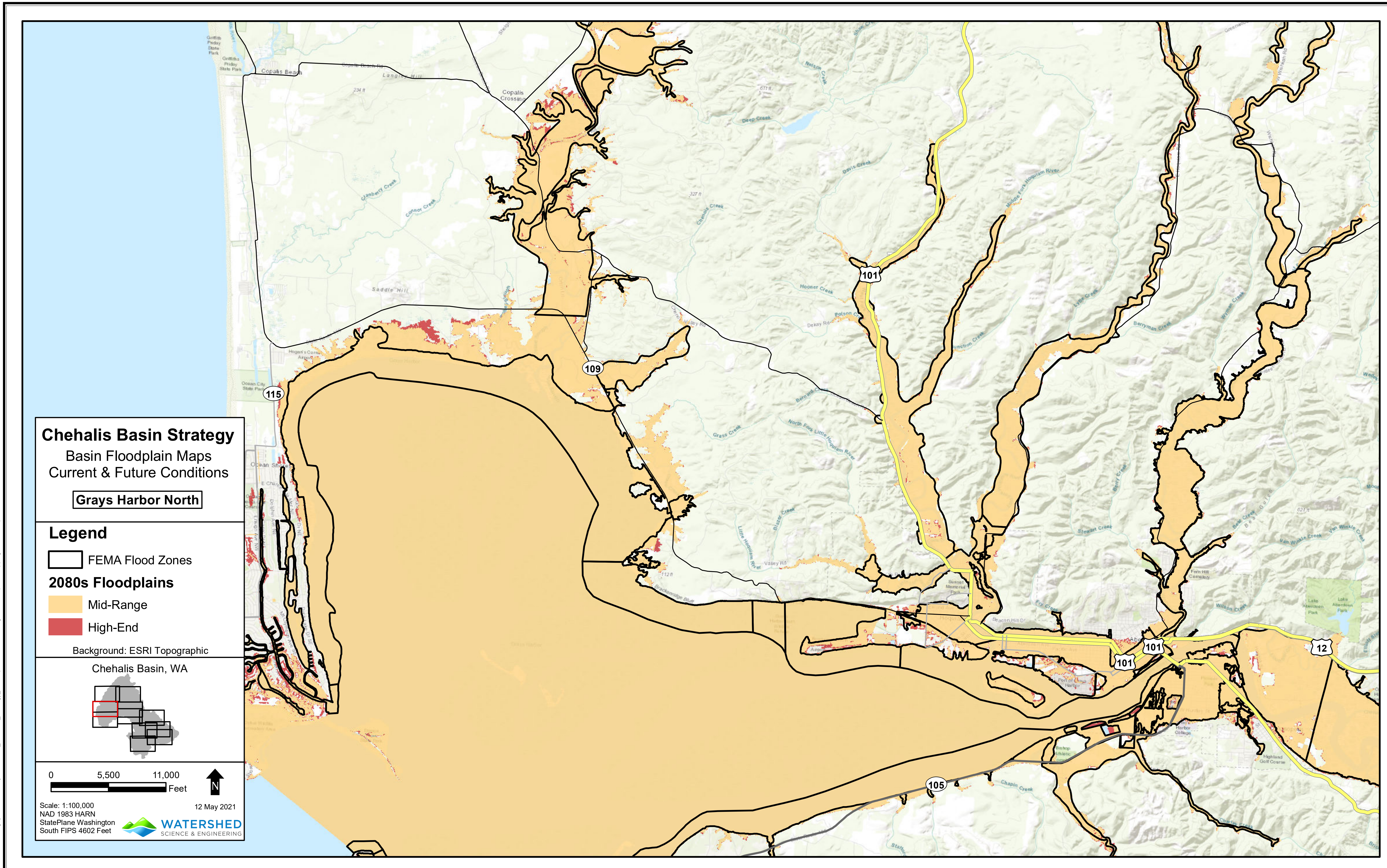
Figure A-9



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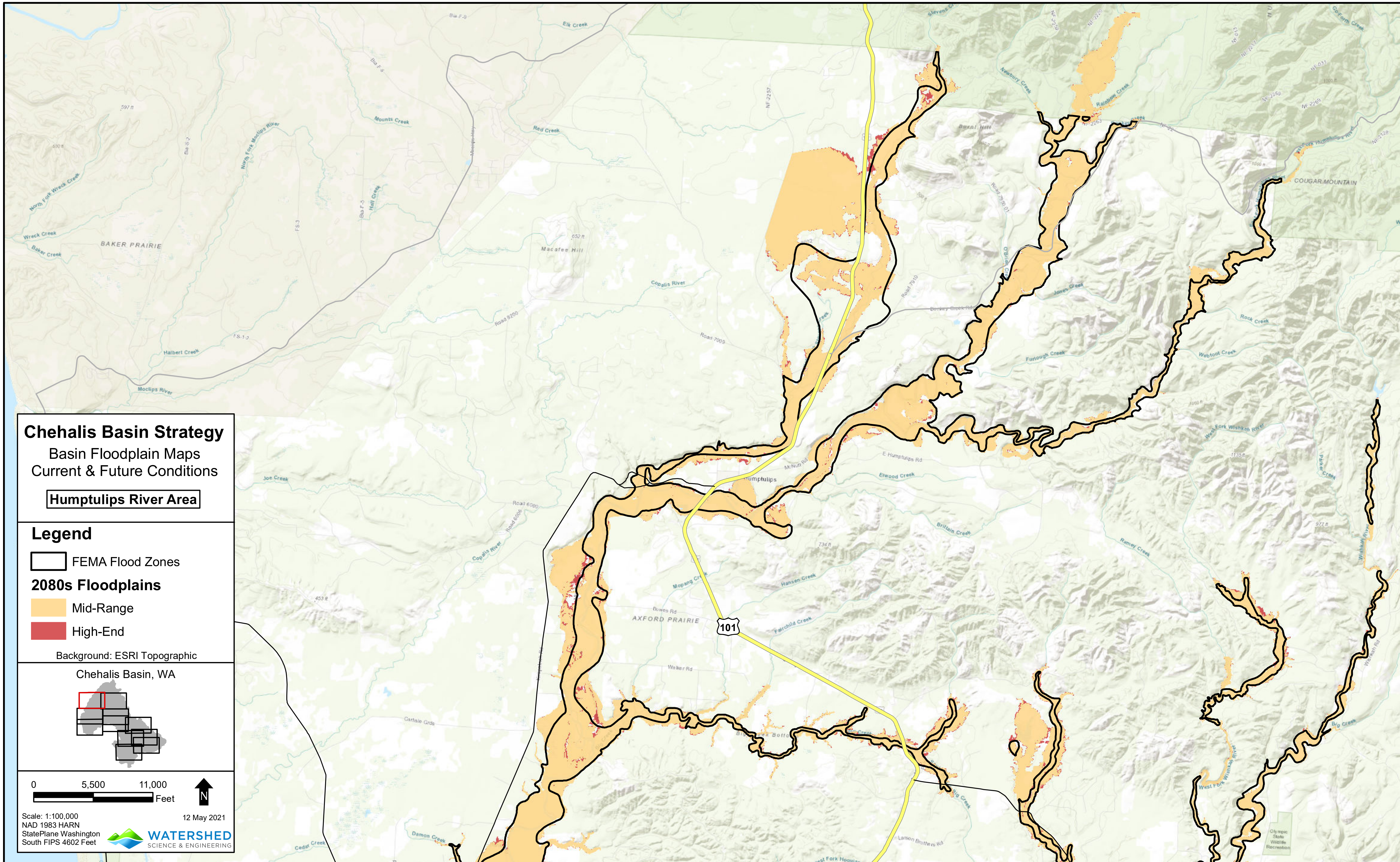

Figure A-11

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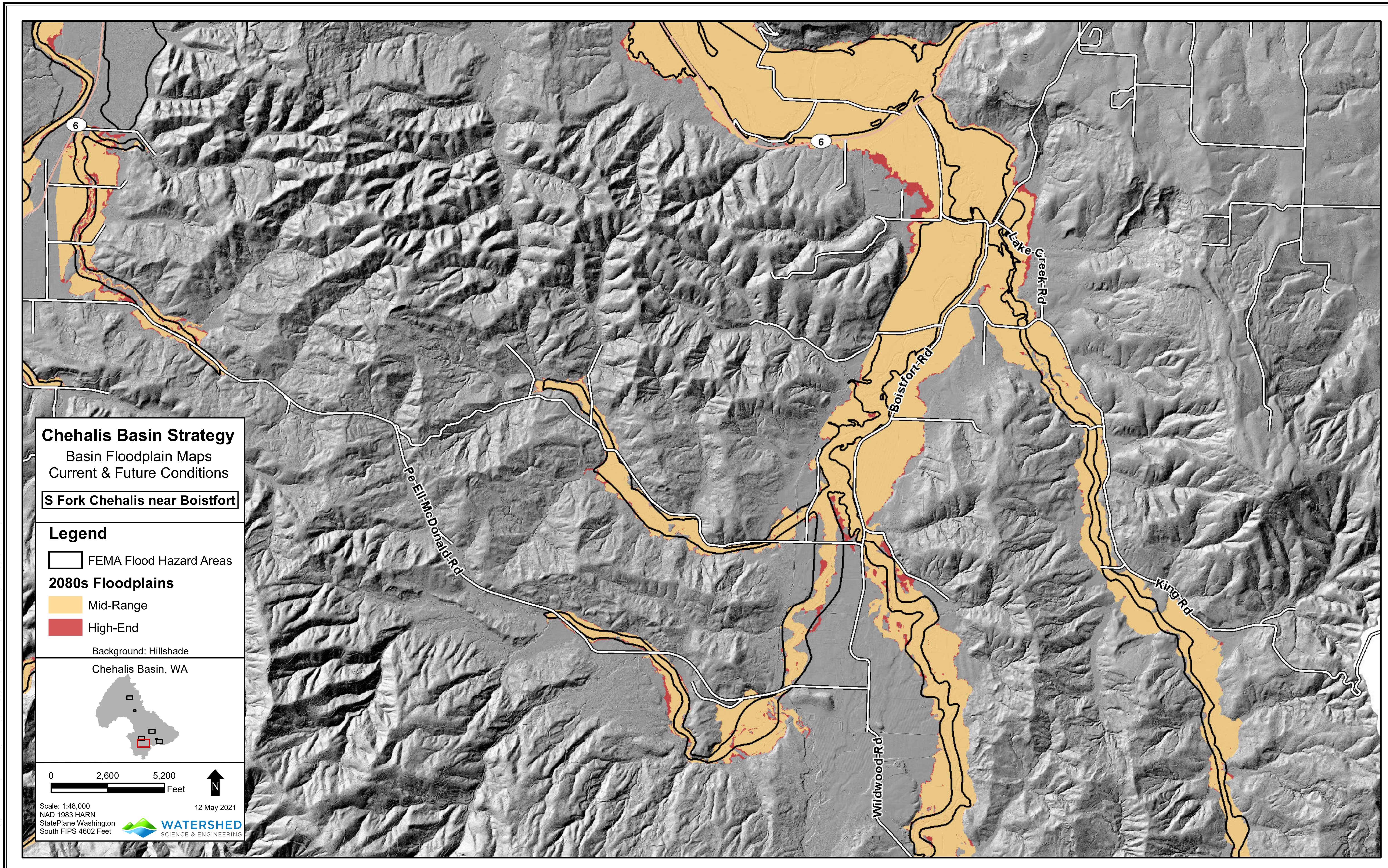

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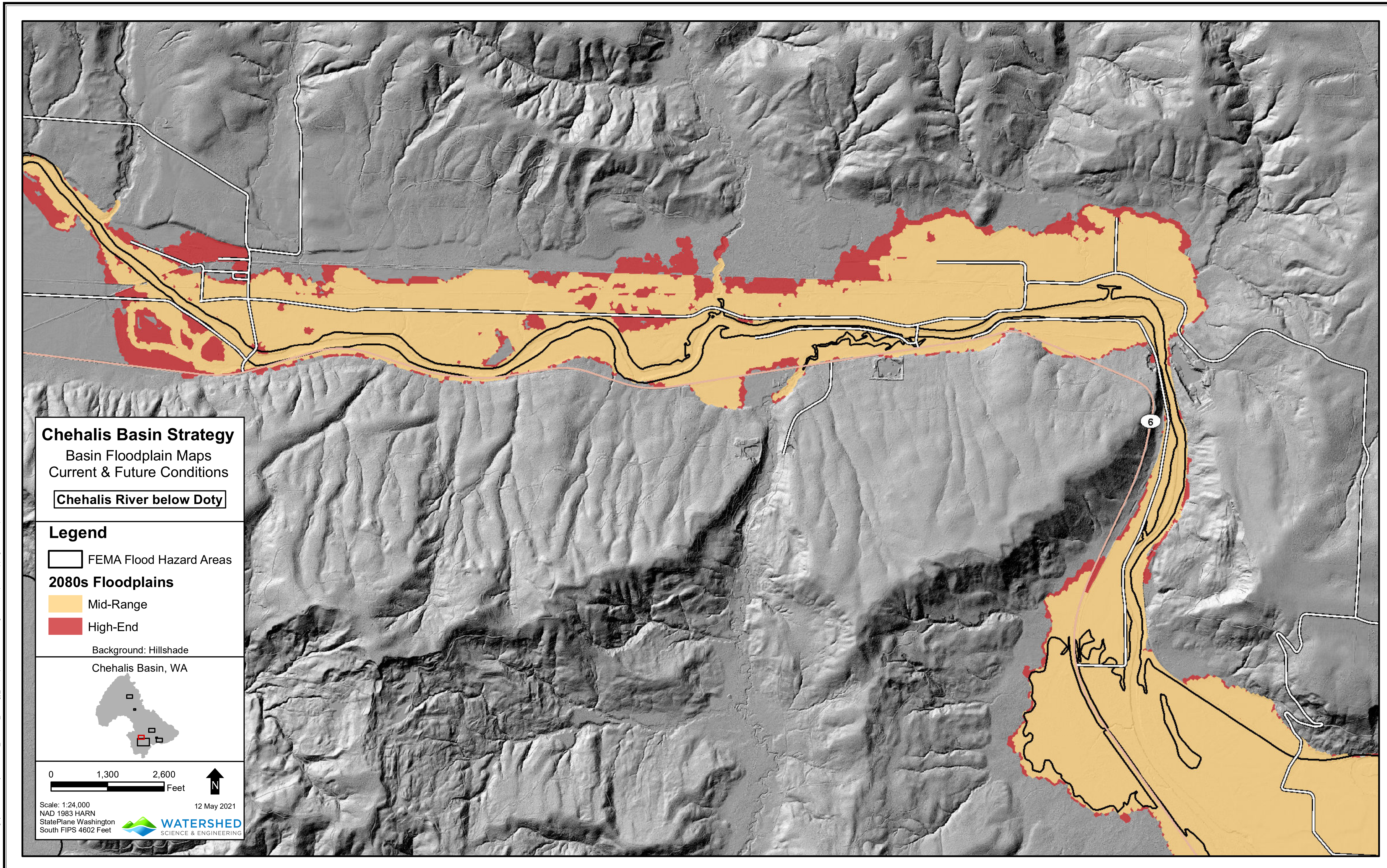
Figure B-1



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High-End
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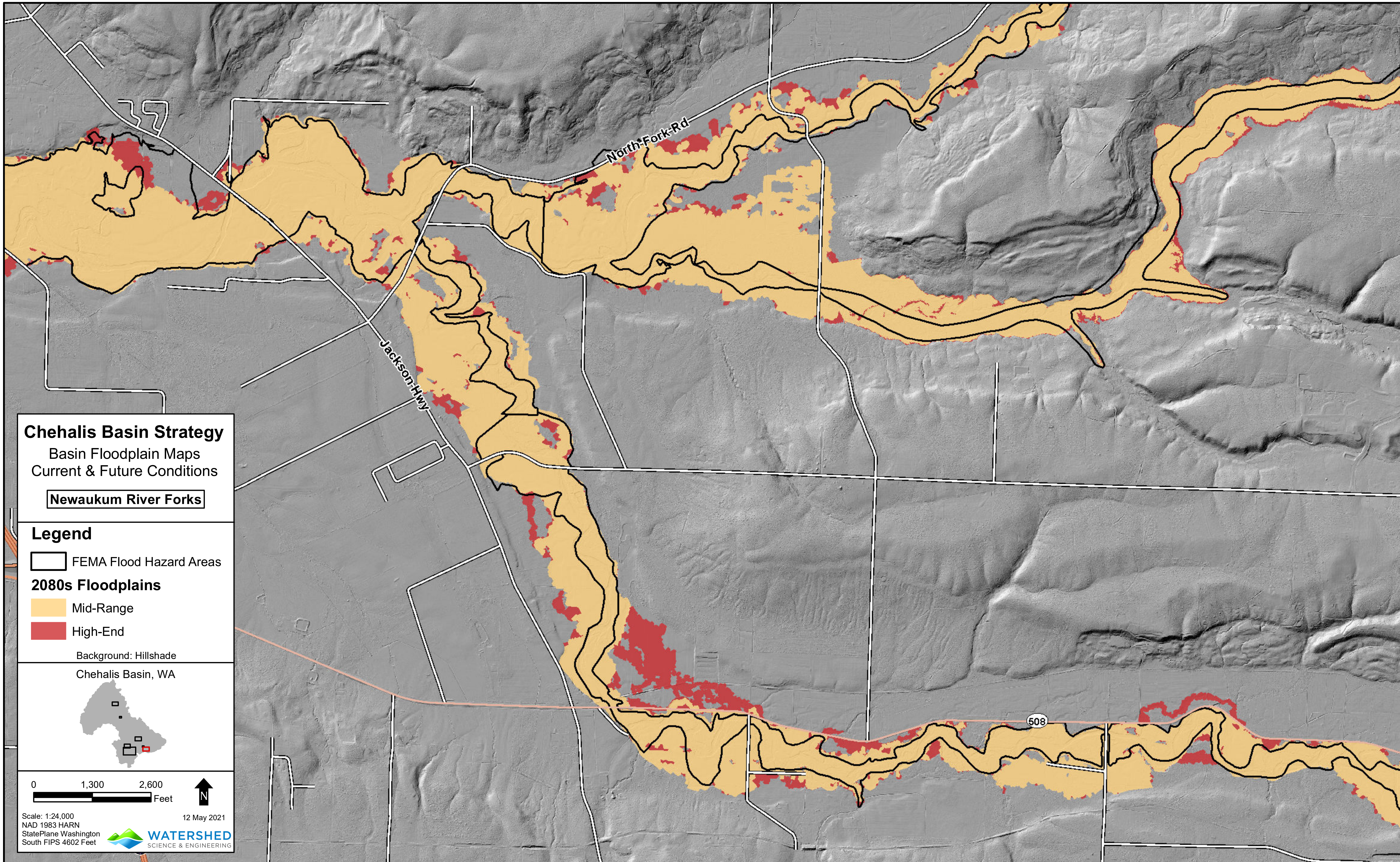
Figure B-2



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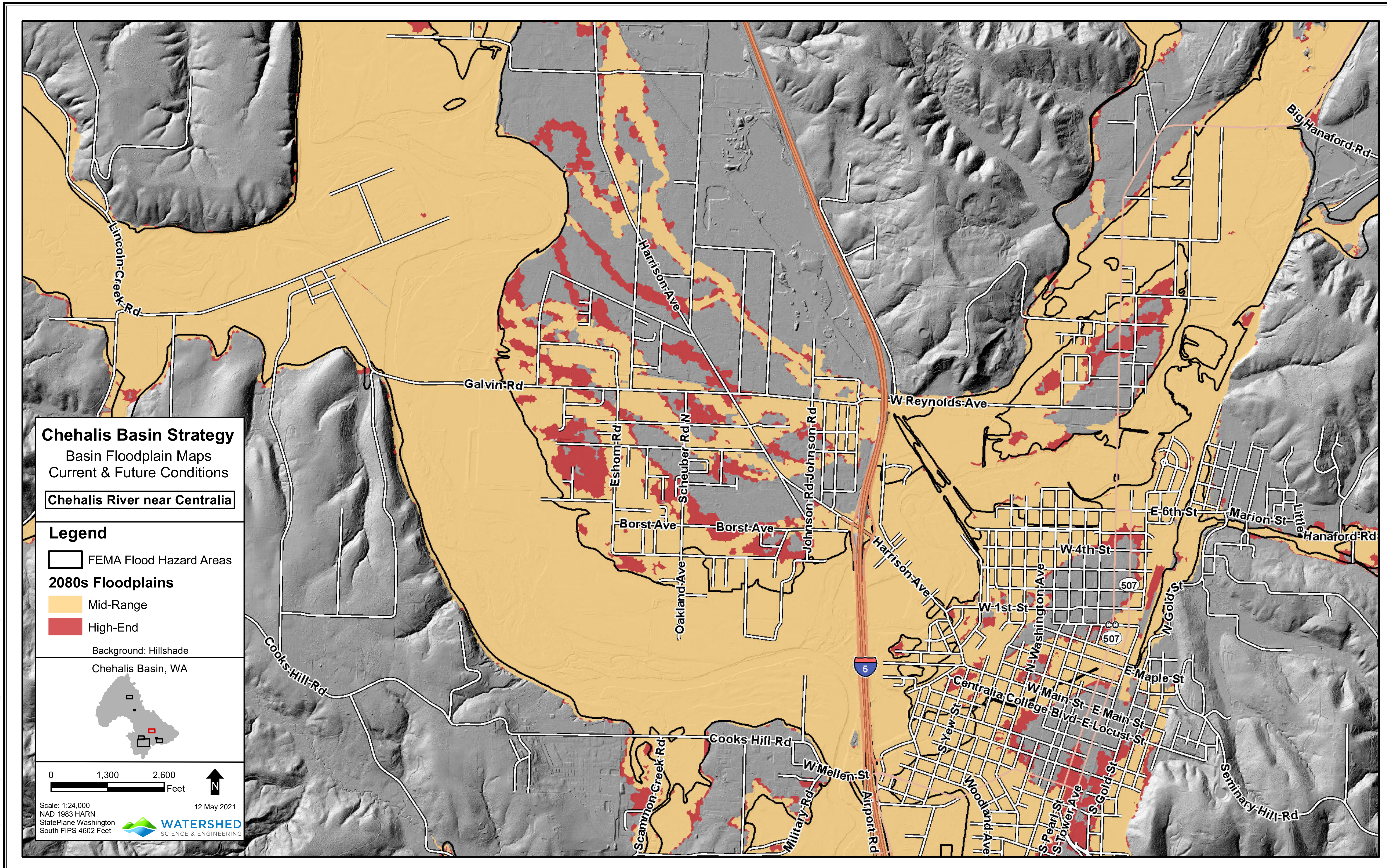

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Little Hanaford Rd
W 4th St
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W 1st St
N Gold St
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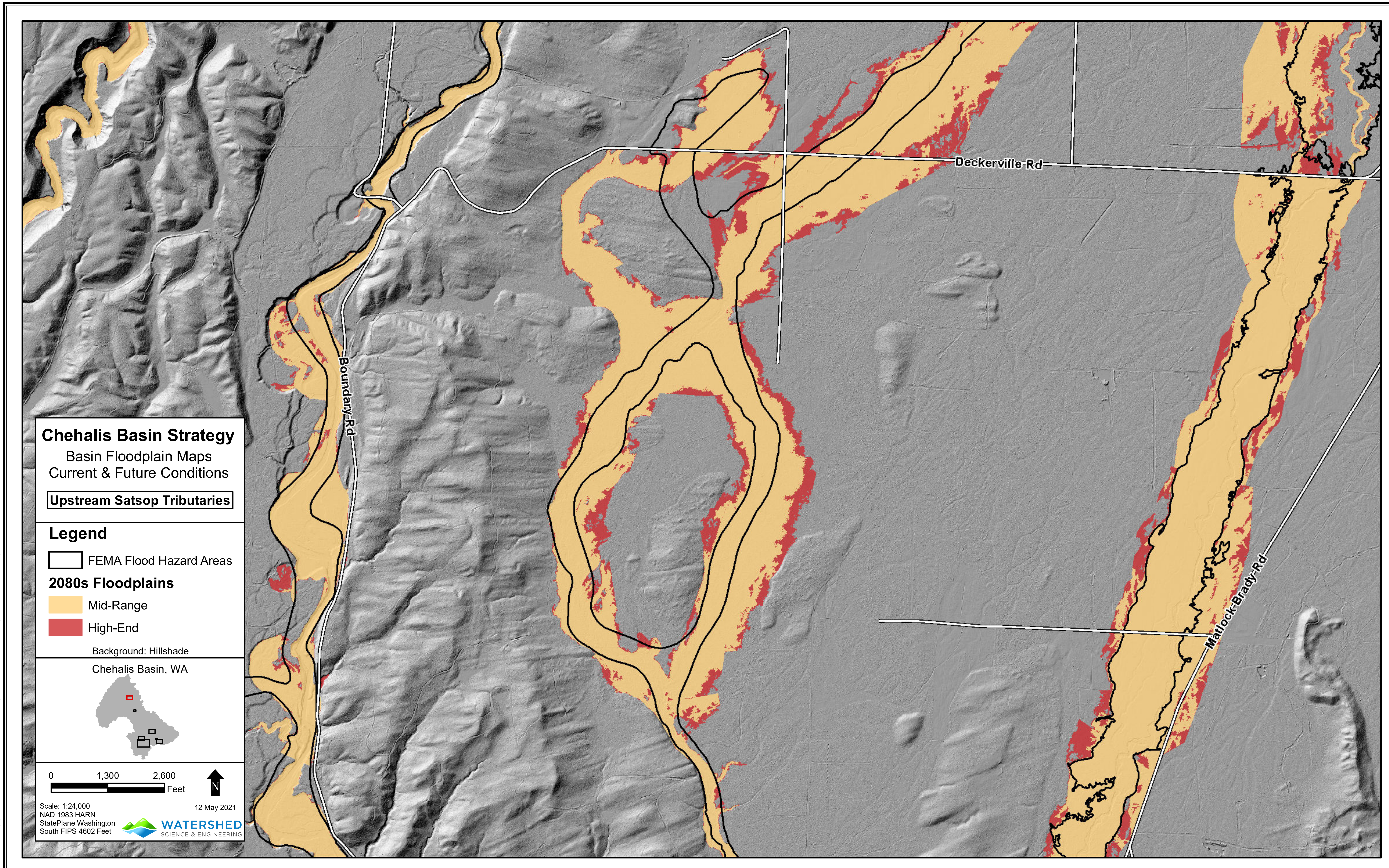

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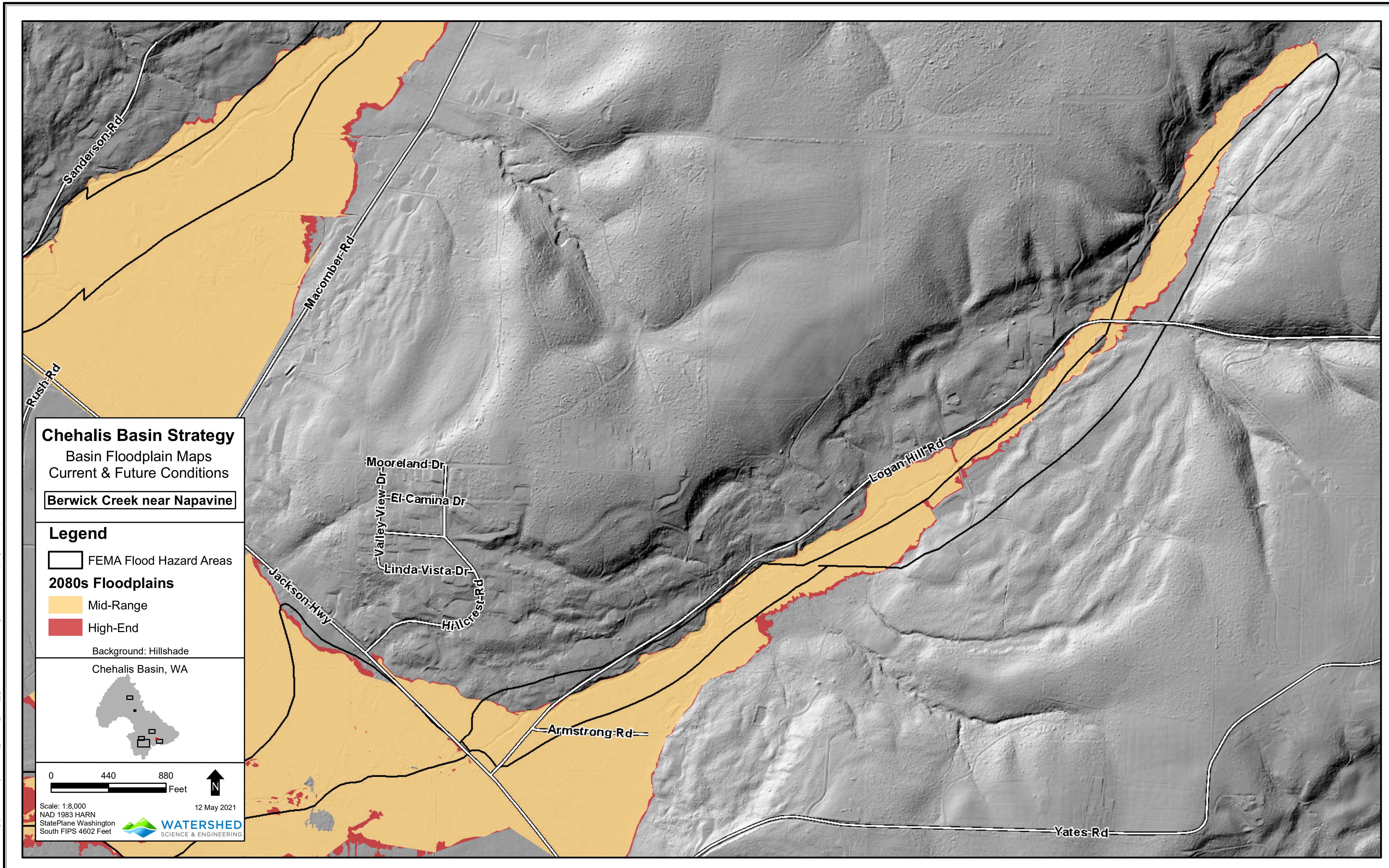
Figure B-5



Chehalis Basin Strategy
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Macomber Rd
Rush Rd
Mooreland Dr
El Camina Dr
Valley View Dr
Linda Vista Dr
Hillcrest Rd
Jackson Hwy
Logan Hill Rd
Armstrong Rd
Yates Rd
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Figure B-6

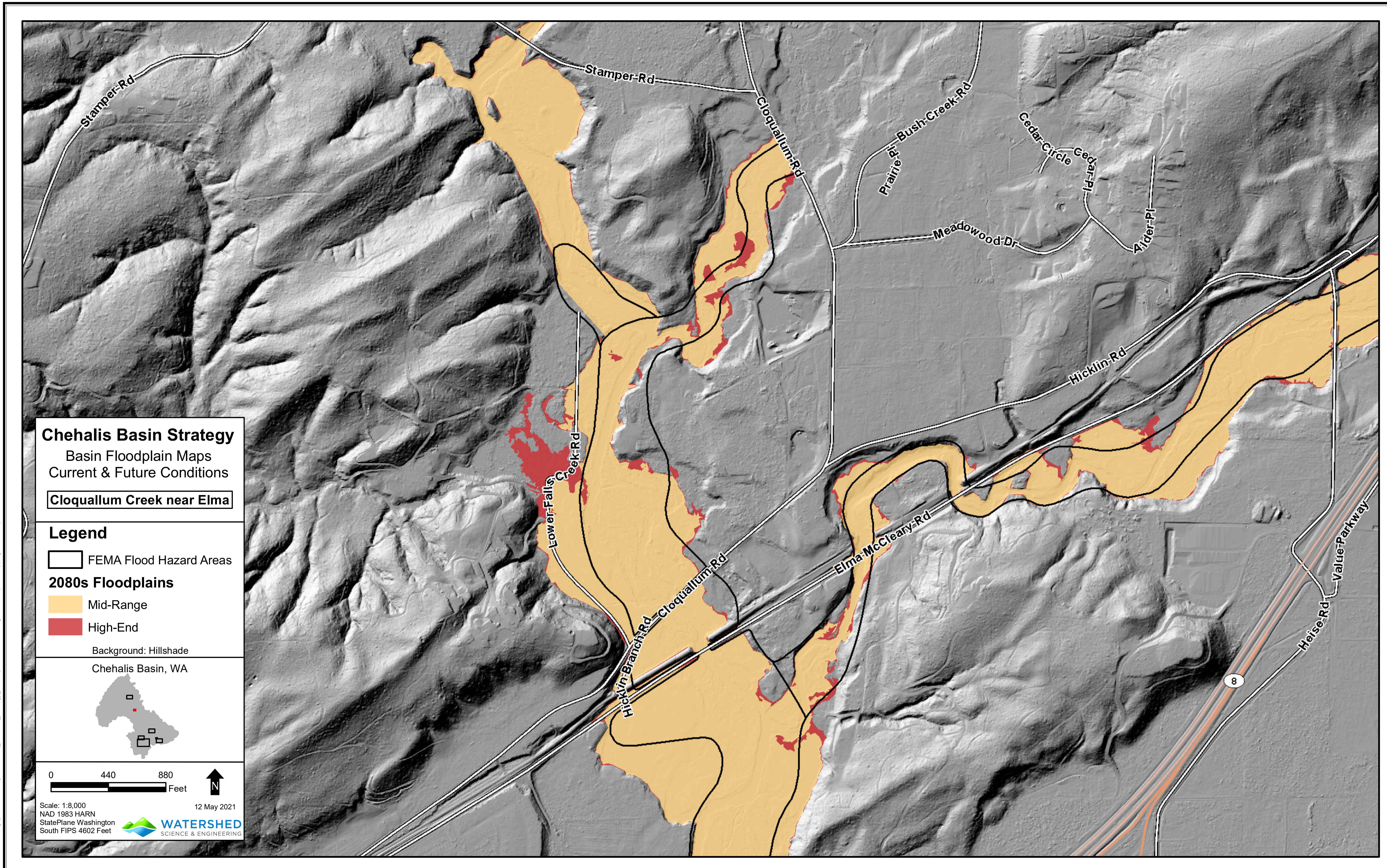

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Figure B-7