# Creating a Resilient Transportation Network in Skagit County

## Using Flood Studies to Inform Transportation Asset Management

**FHWA Pilot Project Report**

**WSDOT**

**2015**

U.S. Department of Transportation
Federal Highway Administration

Washington State Department of Transportation

## Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the WSDOT Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

## Title VI Notice to Public

It is Washington State Department of Transportation (WSDOT) policy to ensure no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

# Acknowledgements

The Washington State Department of Transportation (WSDOT) would like to thank the following organizations for partnering with us in the development of this adaptation pilot project:

- Skagit County Public Works Department
- U.S. Army Corps of Engineers Seattle District
- Federal Highway Administration's (FHWA's) Offices of Environment, Planning and Realty, and the FHWA's Office of Infrastructure
- WSDOT Sustainable Transportation Leadership Team

WSDOT would also like to extend special thanks and appreciation to our primary contacts at Federal Highway Administration, our Pilot Project Team, and other WSDOT contributors:

- Sharon Love, FHWA Washington Division
- Michael Culp, FHWA Headquarters
- WSDOT Pilot Project Team (in alpha order): Todd Carlson, Brooke Hamilton (WSDOT/Axis Environmental LLC), Casey Kramer, Elizabeth Lanzer, Mark Maurer, Rebecca Nichols, Simon Page, Jim Park, Carol Lee Roalkvam, Sandy Salisbury, John Shambaugh, Elizabeth Sjostrom, and Stu Smith
- Other WSDOT contributors: Kim Glass, John Himmel, Tim Smith, and Gary Ward

Thanks to all of the people we interviewed, who shared their knowledge of existing flood concerns, including representatives of the following organizations:

- Skagit Council of Governments
- Skagit Emergency Medical Services
- City of Anacortes
- City of Burlington
- City of Concrete
- City of Mount Vernon
- City of Sedro-Woolley
- Swinomish Tribe
- Upper Skagit Indian Tribe
- Town of Lyman
- Town of Hamilton
- Dike District 1
- Dike District 12
- Dike Districts 17
- Puget Sound Energy

# Acronyms

| | |
|---|---|
| **ACE** | Annual Chance of Exceedance |
| **ADT** | annual daily traffic |
| **AOC** | areas of concern |
| **CC** | climate change |
| **CIG** | (Washington State) Climate Impacts Group |
| **CIVA** | (WSDOT) Climate Impact Vulnerability Assessment |
| **DEIS** | Draft Environmental Impact Statement |
| **DEM** | digital elevation model |
| **EO** | Executive Order |
| **FTA** | Federal Transit Administration |
| **FEMA** | Federal Emergency Management Agency |
| **FHWA** | Federal Highway Administration |
| **GI** | government investigation |
| **GIS** | geographic information systems |
| **HQ** | WSDOT Headquarters |
| **MP** | milepost |
| **MPO** | Metropolitan Planning Organization |
| **NCHRP** | National Cooperative Highway Research Program |
| **NR** | no regrets |
| **PSE** | Puget Sound Energy |
| **SLR** | sea level rise |
| **SR** | state route |
| **TSP** | tentatively selected plan |
| **USACOE (Corps)** | United States Army Corps of Engineers |
| **USDOT** | United States Department of Transportation |
| **UW** | University of Washington |
| **WSDOT** | Washington State Department of Transportation |

# Contents

# List of Tables



# List of Figures

# Executive Summary

The Washington State Department of Transportation (WSDOT) was fortunate to receive a grant from the Federal Highway Administration (FHWA) to develop options for improving the resiliency of transportation facilities or systems to climate changes and/or extreme weather events. This was WSDOT's second grant. In the first pilot, WSDOT tested FHWA's conceptual risk assessment model and successfully completed a statewide assessment of climate vulnerability of transportation assets. This second pilot project set out to meet FHWA's goal of helping further the state of the practice in applying vulnerability assessment results into decision making.

This study builds on WSDOT's earlier pilot by examining adaptation options in an area of the state we previously identified as highly vulnerable: the Skagit River Basin (Basin). We chose this Basin because it is the focus of a major flood study by the U.S. Army Corps of Engineers (Corps). We knew important decisions about how and where to invest in levees and other flood risk reduction projects were being actively evaluated by the Corps and the local sponsor, Skagit County. We also knew that state transportation assets were likely to be affected but *were not* the focus of their study. WSDOT's pilot presented the opportunity to actively engage with the flood study and search for compatible long-term solutions that create a more resilient transportation system throughout the Basin.

WSDOT's pilot shows transportation planners and asset managers how to leverage a federal flood study, like the Corps' Skagit River Flood Risk Management General Investigation Study (GI study), to improve the resiliency of our highways. The pilot demonstrates how WSDOT's Vulnerability Assessment results, used in combination with federal flood study data, can reaffirm known vulnerabilities and reveal other vulnerable assets. The pilot identifies adaptation strategies for the Basin and highlights future partnership opportunities with the Corps and local governments.

This report includes a series of recommendations and lessons learned that will help other DOTs and regional transportation planning entities reach across jurisdictions and sectors to create integrated asset management strategies.

The pilot team developed eleven site-specific vulnerability assessments and adaptation strategies, which are included in the appendices. Other appendices provide information about our GIS and Hydraulic analyses for those who want to explore the details.

Our work to create a more resilient transportation network in Skagit County is ongoing. This report is really the beginning of a conversation about integrated response to the threats of increased flooding in the Basin. WSDOT will use this pilot study to continue our collaboration with local, tribal, regional, and federal stakeholders.

This page intentionally left blank

# 1 Introduction

The Washington State Department of Transportation (WSDOT) is a leader among state DOTs in the field of transportation asset management and infrastructure resilience. WSDOT is very fortunate to have strong support from Governor Inslee and Secretary Lynn Peterson to better prepare our state transportation systems for the impacts of climate change and extreme weather. We also enjoy federal support. Thanks to a Federal Highway Administration (FHWA) national pilot grant, WSDOT completed a statewide vulnerability assessment in 2011. In 2013, WSDOT received a second FHWA Climate Change and Extreme Weather pilot grant. Figure 1.1 shows our state's continued efforts at adaptation planning.

| 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2015 |
|---|---|---|---|---|---|---|---|
| • Governor forms Climate Action Team | • WSDOT begins considering climate change in environmental reviews | • State Legislation and Executive Order enacted on climate change<br>• WSDOT forms Sustainable Transportation Team<br>• UW releases CIG Assessment | • FHWA awards first pilot grant to WSDOT for CIVA<br>• State CC Response Strategy is developed | • WSDOT conducts CIVA workshops across state<br>• WSDOT publishes FHWA CIVA report | • Ecology publishes state response strategy<br>• FTA awards Sound Transit pilot grant with WSDOT as a supporting partner<br>• WSDOT Integrates CC into asset management | • FHWA awards second pilot grant for Skagit River Basin | • WSDOT publishes Skagit River Basin pilot report |

**Figure 1-1 Washington's Adaptation Planning through the Years**

WSDOT provides and supports safe, reliable, and cost-effective transportation options to improve livable communities and economic vitality for people and businesses. The department is responsible for over 18,500 highway lane miles (including 3,700 bridges) and the Washington State Ferry system, which served 22.8 million passengers in fiscal year 2014. WSDOT also oversees public-use airports, passenger- and freight-rail programs, and numerous public transit programs.

In addition to our climate preparation and emergency management efforts, WSDOT works to build climate-ready infrastructure today by considering climate threats during project-level environmental reviews. WSDOT works with our partners to incorporate long-term resilience strategies into transportation asset management.

This pilot project underscores the fact that state-owned transportation assets are just one piece of the very complex and interdependent fabric that makes up our communities and the transportation network. In western Washington, where so many of the hazards are related to extreme precipitation, flood protection through private, state, tribal, and federal investment is also critically important. We know that "projected regional warming and sea level rise are expected to bring new conditions to Washington State. By mid-century, Washington is likely to regularly experience average annual temperatures that exceed the warmest conditions observed in the 20th century. Washington is also expected to experience more heat waves and more severe heavy rainfall events."[1] The summer of 2014 was the second warmest on record for western Washington; however, it is anticipated that those temperatures will be the norm by mid-century.[2]

With the second FHWA pilot grant in 2013, WSDOT was able to focus on the lower Skagit River Basin (Basin). Major flooding in the Basin is typically a result of winter storms moving eastward across the Basin with heavy rains and warm, snow-melting temperatures. Several storms may occur in rapid succession saturating soils, increasing run-off and landslide risk, raising streams and rivers, and filling reservoirs and natural storage areas. Future extreme weather events will exacerbate this flood risk. The FHWA pilot grant gave us the opportunity to analyze options for adapting and improving the resiliency of our state transportation system. This report summarizes the Skagit River Basin pilot's findings and lessons learned.

## 1.1 Who should read this report?

Our main audience is other state DOTs, FHWA division offices, Metropolitan Planning Organizations, tribes, rural and urban planners, public works staff, and policymakers who want to get a jump-start on integrating adaptation strategies for transportation infrastructure by incorporating studies by other agencies or jurisdictions.

This report gives practical, hands-on tips and lessons learned for how to use existing flood studies to identify "no regrets" strategies. We hope that readers will learn from our experience and work with the wealth of flood hazard reduction information, so that transportation asset managers and flood control managers integrate flood hazard planning into their work.

[1] Snover, A.K., G,S. Mauger, L.C.Whitely Binder, M. Krosby, and I. Tohver, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers.* State of Knowledge Report, prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. Executive Summary, page ES-4.
[2] Cliff Mass Weather Blog, August 20, 2014, and September 1, 2014

## 1.2 What is our pilot all about?

Across the country, site-specific flood studies are available to the public. These studies hold information that can be used by transportation agencies in their adaptation planning. Strategies for a more resilient transportation system need to be compatible with other proposed flood hazard reduction measures if we are to avoid missed opportunities or maladaptation.[3]

WSDOT's pilot shows transportation planners and asset managers how to leverage a federal flood study, like the U.S. Army Corps of Engineers' (Corps') Skagit River Flood Risk Management General Investigation Study (GI study), to improve the resiliency of our highways. The pilot demonstrates how WSDOT's Vulnerability Assessment results, used in combination with federal flood study data, can reaffirm known vulnerabilities and reveal other vulnerable assets. The pilot identifies adaptation strategies for the Basin and highlights future partnership opportunities with the Corps and local governments.

## 1.3 What are the goals and scope of our pilot?

WSDOT's team explored adaptation options for vulnerable state highways and Interstate 5 (I-5) concurrent with a major flood study in the Basin. The Corps and the local sponsor, Skagit County, are actively working on the Corps' GI study to address significant flooding and economic and life-safety threats that impact local communities in the Basin.

### *a. Pilot goals*

The goals of this pilot were to:

- Advance FHWA's Draft Climate Change and Extreme Weather Vulnerability Assessment Framework (Figure 1-2) by developing adaptation strategies for the major transportation infrastructure in the Skagit River Basin.

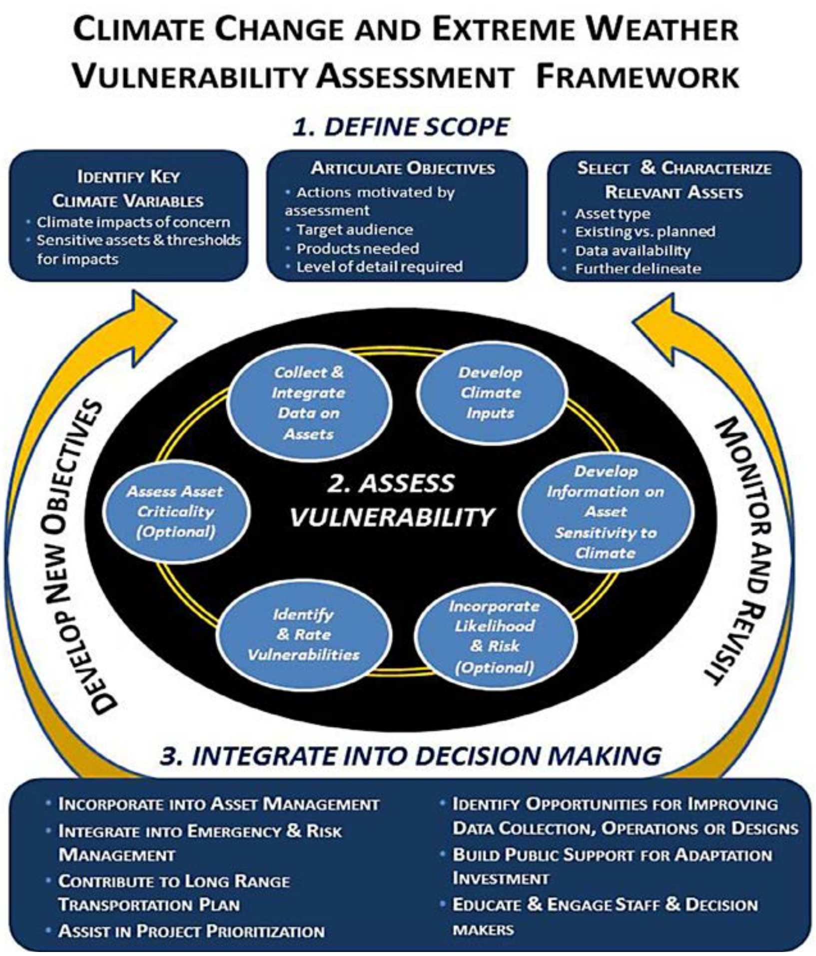



**Figure 1-2 FHWA's Draft Climate Change and Extreme Weather Vulnerability Assessment Framework**

[3] Maladaptation is a change that leads to an increase rather than decrease in vulnerability. It may also occur when an adaptation measure leads to the transfer of the vulnerability of one system to another. For more information, see: http://elibrary.worldbank.org/doi/pdf/10.1596/1813-9450-5568

- Engage with federal and local entities during a major flood study and integrate results into our planning, project design, and asset management processes.

### b. *Pilot outcomes*

WSDOT achieved the following outcomes from the pilot:

- A replicable methodology using federal flood data and available highway data.
- A set of adaptation strategies for the state-owned and state-managed transportation infrastructure within the Basin.

## 1.4 What part of the state's transportation system did we assess?

The pilot area is in the Skagit River Basin, located in the northwest corner of the state, approximately 60 miles north of Seattle. The major cities in the pilot area are Mount Vernon, Burlington, and Sedro-Woolley.

The pilot area boundaries are shown in Figure 1-3 and include sections of I-5, State Route (SR) 9, SR 20, SR 11, SR 536, SR 538; and SR 534.

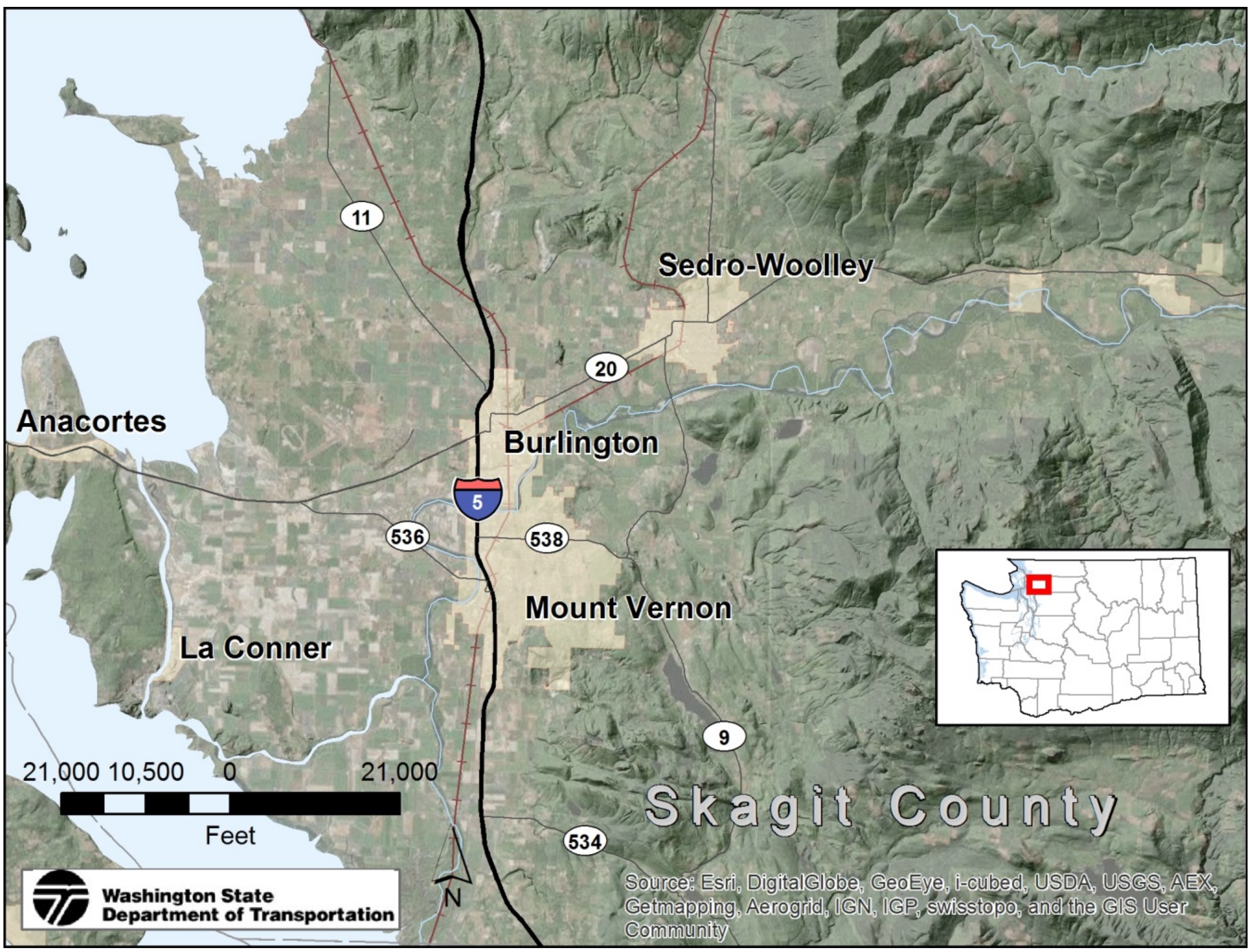



**Figure 1-3 Vicinity Map**

## 1.5 What are the key features of the Skagit River Basin?

*Scenic view overlooking the Skagit River Basin*

According to the Washington State Department of Ecology, the "Skagit River is one of the longest and most flood-dangerous rivers in the Pacific Northwest."[4] It is also the third largest river on the West Coast. The Basin experiences frequent flooding, resulting in damage to both rural and urban areas. It is susceptible to flooding when intense storms occur with heavy precipitation and warm, snow-melting temperatures. These conditions are expected to intensify with our changing climate. In addition, high tides that occur during a flood event or annual extreme high tides further increase the potential for flooding due to their restricting effect on river discharge flows.[5]

The Skagit River drains 3,115 square miles between the crest of the Cascade Range and the Puget Sound. There are five dams and several unregulated tributaries, most notably the Wild and Scenic Sauk and Cascade Rivers, which make up about 50% of the unregulated area before discharging into Skagit Bay. Figure 1-4 shows that 54% of the discharge is unregulated by dams.

There is a complex system of levees along the river, including 50 miles of nonfederal levees and 39 miles of sea diking. The existing levees are based on earthen levees built in the 1890s by the original European settlers. Many of these older levees have been raised and strengthened in recent years, but substandard foundation materials make them vulnerable to failure during major floods due to seepage and internal erosion.[6]

[4] Living with the River: A Guide to Understanding Western Washington Rivers and Protecting Yourself from Floods
[5] Skagit County Natural Hazard Mitigation Draft Plan, 2014. Page 88
[6] *Skagit River Flood Risk Management General Investigation, Skagit County, Washington. Draft Feasibility Report and Environmental Impact Statement*, U.S. Army Corps of Engineers and Skagit County, May 2014.


**Figure 1-4 Map of Regulated and Unregulated Rivers in the Skagit Basin**

The Skagit has a broad floodplain. It is bisected by I-5, which is a critical north/south trade route through Skagit County that carries goods between Mexico and Canada. Since its construction, flood events have not resulted in a closure of I-5 itself, but they have impacted the surrounding state routes and local roads. It should be noted that the largest flood to affect the basin since I-5 was built is a 4% ACE (25-year) storm. If, as anticipated, flood events are exacerbated by climate change to the extent that there is a closure of I-5, domestic and international movement of people and commerce will be severely impacted.

About 28% of the Skagit County population lives within the floodplain of the Skagit River. In order to serve the needs of the ever-growing communities, the majority of our transportation infrastructure is also located in the floodplain. This reach of the river also contains a large, productive agricultural community, which is a basis for tourism. Millions of tourists come for the annual Tulip Festival.

*Tulip fields in Skagit Valley*

The largest documented floods on the Skagit River occurred before the construction of any dams. Ross Dam was completed in 1949 and the Upper Baker Dam was completed in 1959. In 1990, two smaller, yet significant, floods occurred in November. Both floods broke through the Fir Island levee and inundated most of the island's farmland. They both required extensive flood fighting in the vicinity of Mount Vernon. Flood-fighting efforts during floods since 1990 have been successful at preventing levee failures. A flood occurred in November 1995, but this time the flood-fighting efforts were successful at preventing a levee failure at Fir Island and significant damage to downtown Mount Vernon. In 2003, there were two floods in October. Because of reservoir regulation and sandbagging efforts, levees at Mount Vernon and Fir Island were able to withstand the flood without failing. Based on the flood peaks at Concrete, the 1990, 1995, and 2003 floods had ACEs of approximately 10%, 4%, and 4%, respectively. However, future flood-fighting efforts may be overwhelmed in large flood events and are not sustainable for long-term flood risk reduction.

*Flood-fighting efforts in Mount Vernon*

Figure 1-5 shows flood flows over time as well as when the dams were constructed. The dams have reduced peak flows to the extent that recent flows have not exceeded the present dike system capacity. The available flood storage capacity may reduce the 4% ACE flood flow by up to 34,000 cfs and the 1% ACE flood flow by 51,000 cfs.

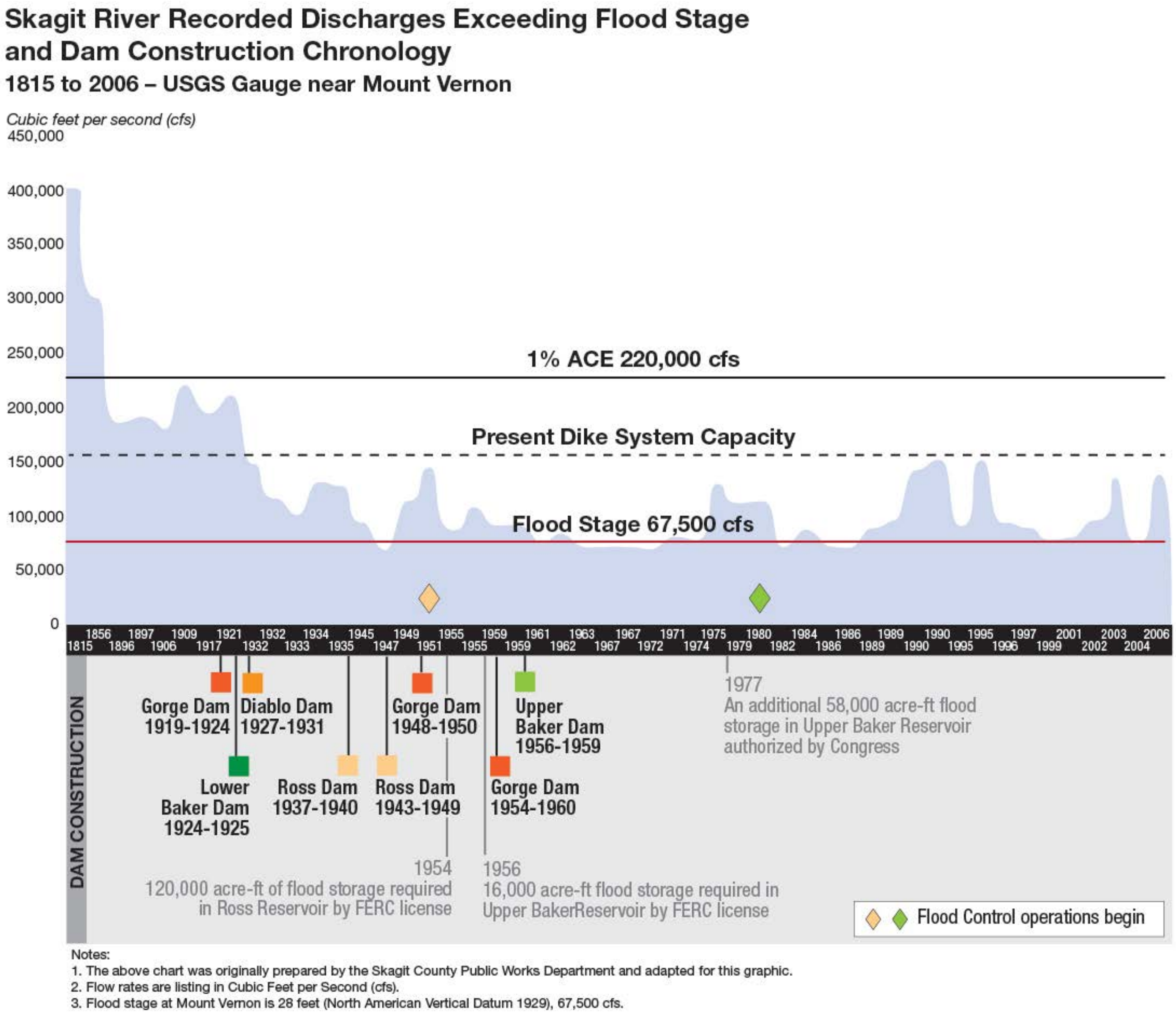



**Figure 1-5 Flood Flows and Dam Building throughout the Years**

Within the Basin, there are three diking districts responsible for construction, repair, and maintenance of the levee and dike systems, and four flood control zone districts. The Corps started its efforts in the Basin many years ago. In June 2014 the Corps issued the Skagit River General Investigation and Draft EIS outlining its proposed tentatively selected plan (TSP). This provided us with an excellent opportunity to address the known flood-related problems in the area and to create stronger partnerships. WSDOT's work with Skagit County and the Corps will continue into the future as we continue our adaptation and preparation efforts.

### ***Who are our partners?***

Our primary partners for this pilot were the sponsor and co-sponsor of the GI study: The U.S. Army Corps of Engineers Seattle District and the Skagit County Public Works Department. Funding was provided by the Federal Highway Administration (FHWA).

FHWA Washington Division staff participated at key milestones. WSDOT Northwest Region and Headquarters staff provided various types of support throughout the 18-month pilot project.

*Tour of the Basin with FHWA, Skagit County, WSDOT*

# 2 Approach

## 2.1 What was our process?

WSDOT had a strong entry point to begin this pilot, using the earlier vulnerability results and the FHWA Framework. For the Skagit River Basin (Basin), these results (Figure 2-1) showed that I-5, state routes, ferries, and rail assets are highly vulnerable to extreme flooding.

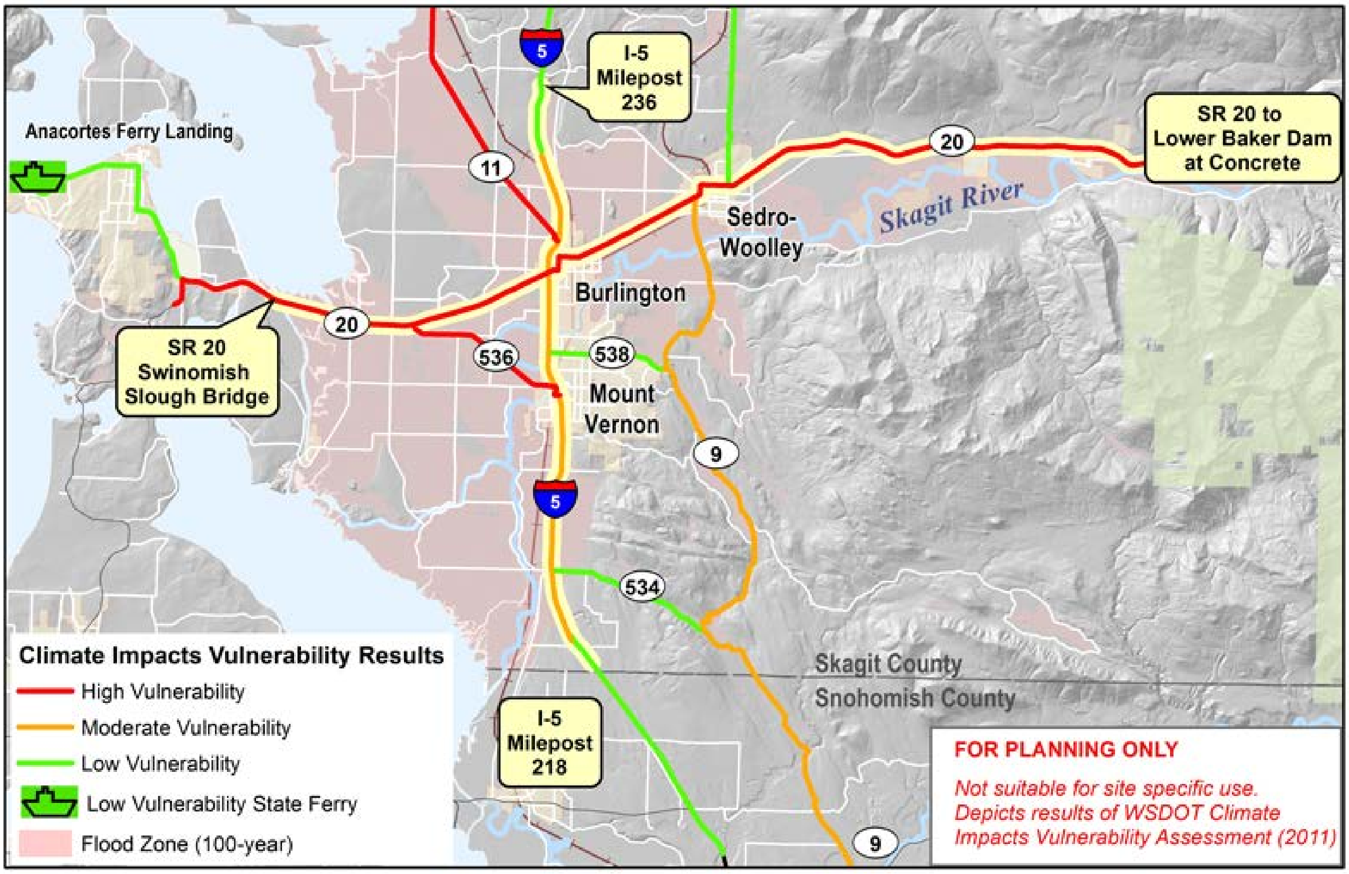



**Figure 2-1 Climate Impacts Vulnerability Assessment Results in the Basin**

As part of the earlier assessment, we compiled the climate data from the Washington State Climate Impacts Group (CIG) and other reports relevant to the Basin.

For the Skagit pilot, our initial step was to establish the team and define the scope of the effort. As envisioned in the grant proposal, we recruited WSDOT staff from both Headquarters and the region, and defined roles by physical location. Our team was a multidisciplinary, decentralized team of WSDOT planners, environmental staff, maintenance/emergency response experts, landscape architects, and engineers. The major phases of our pilot are shown in Table 2-1.

**Table 2-1 WSDOT Pilot Climate Impacts Vulnerability Assessment Skagit River Basin Phases**

| Major Pilot Phases |
|---|
| 1. Conducted 2011 Climate Impacts Vulnerability Assessment. |
| 2. Gathered information and data. |
| a. Updated and localized climate forecasts (CIG)[7]<br>b. Obtained flood data from Skagit County<br>c. Screened and reviewed available geographic information system (GIS) data<br>d. Conducted interviews |
| 3. Reviewed and commented on Corps' GI Study and Draft EIS release. |
| 4. Interpreted, integrated with WSDOT data, and analyzed hydraulic data from Corps. |
| 5. Developed adaptation strategy – Assessed "no regrets" strategies. |

The initial work plan called for us to evaluate the Corps' tentatively selected plan (TSP) once it was available. We had assumed that the Corps would do the hydraulic modeling for the TSP and release it with the Corps' GI study. However, the Corps determined that the TSP might change as a result of public comments, so only modeling of existing conditions was done. Our approach shifted to a detailed study of the Corps' hydraulic data on major flood scenarios under existing conditions (the primary data we received from the GI study). (See Section 2.3 for further explanation.)

## 2.2 How did we gather the data?

We began with WSDOT's qualitative vulnerability assessment results. We then added to that by conducting a series of interviews (Appendix A, Supporting Documents) with local community experts in the pilot area who are actively involved in flood hazard planning, maintenance, and operation of the transportation system, to set the stage for what we know today.

In July 2013, we met with the Corps' GI study's local sponsor, Skagit County Public Works, and toured the GI study area (see photos).

[7] University of Washington Climate Impacts Group

Key takeaways from the tour were:

- Significant infrastructure lies within the floodplain of the Skagit River.
- Local agencies have done considerable work on flood planning and preparation.
- There are potential impacts to state highways from the Future without Corps' Project[8] and three draft action alternatives coming out of the Corps' GI study.
- We have a better understanding of the local geography.

Using the qualitative vulnerability assessment workshop process, in September 2013 we met with County and City staff to (a) gather historic data and learn about their efforts and concerns regarding flooding, and (b) validate the information we already had. We posed the following questions to these partners:

1. What concerns you about hazard mitigation preparation in your community?
2. What locations are you most concerned with?
   - Have you done any work recently that improved this condition?
   - Do you have any improvement plans you are working on?
3. Are there state highway concerns that you have?
4. How do you think these issues should be handled?
5. What concerns do you have when it comes to emergency response?

County staff supplied detailed information on existing conditions and the Future without Corps' Project, including an infrastructure at-risk map, GIS depth files (existing condition) for all floods, a basemap with elevations for the basin, and the Hydrology Technical Document[9] from the Corps' GI study. This data was crucial to our pilot process.

We also reached out to internal and external stakeholders. We conducted interviews with local tribes, diking districts, City planning and public works staff, County emergency response staff, regional planners, and WSDOT maintenance staff. With their help, we identified initial "areas of concern" regarding flood hazards and anticipated extreme weather event impacts. We considered critical local infrastructure such as firehouses, fresh water and wastewater treatment plants, numerous water and gas pipelines, a hospital and medical clinics, and other municipal infrastructure. We asked the same questions we had asked the County in our first workshop.

> We used face-to-face workshops at several key points in data collection and analysis. Several example workshop agendas are found in Appendix A.

> Tip from FHWA's Framework: Successful engagement of internal staff requires listening and incorporating their feedback and perspectives. If these staff members are engaged and feel that they can take ownership of the strategy, they may be more willing to provide valuable insight and leadership. (FHWA Framework, Section 4.1.1)

[8] The Future without Corps' Project is the most likely scenario if no Corps' flood risk management project is implemented for the study time period from 2020 to 2050.

[9] Appendix B, Hydraulics and Hydrology Methodology, is available at: http://www.nws.usace.army.mil/portals/27/docs/civilworks/projects/skagit%20gi/skagitgi-appb-hh-may2014.pdf

Those interviews helped us to understand where problems have occurred in the past on state facilities and local roads, and what emergency response requirements were implemented during floods and other emergency events in the Basin. From this expert knowledge, we identified 23 areas of concern that would supplement the preliminary screening of assets done in the 2011 qualitative vulnerability assessment, and focused on step three of the FHWA model from this point on.

*On May 23, 2013, a portion of the bridge collapsed into the Skagit River near Mount Vernon after being struck by an oversized load. Crews installed temporary spans and reopened the bridge to most traffic on Wednesday, June 19. (Source: WSDOT)*

Note that the Skagit River Bridge emergency (see photo) came up frequently in our interviews. In those discussions, we learned a lot about our detour routes and the impact on local networks and businesses.

## 2.3 What data did we get from the Corps?

When the Corps' GI study and Draft EIS were released in June 2014, our work really shifted into high gear as we began to assess the Corps' data and analysis of impacts. The pilot team reviewed the Draft EIS and submitted comments (Appendix A, Supporting Documents). We met with the Corps and Skagit County and attended public meetings. The Corps Draft EIS provided detailed information on existing conditions, and conceptual (not detailed) information about the action alternatives and the Future without Corps' Project. The GI study and its associated data provided us with a wealth of information on water movement in the Basin. In particular, the County was able to share the following:

- A digital elevation model (DEM) of the land surface of the lower Skagit River floodplain.
- Output from the Corps' FLO-2D floodplain model. This output included water surface elevation and depth grids for 21 existing conditions: flood scenarios that represent various return interval floods (10%, 4%, 2%, 1%, 0.2% ACE flood) and levee failures.

***Data we didn't get from the Corps***

It is important to explain what data we did not get. The Corps' GI Study and Draft EIS did not include model output data for the "No-Action" or TSP alternatives. Nor did we get some of the other desirable FLO-2D output data, such as velocity and duration of inundation. The Corps is continuing to develop and refine the models for these conditions and will supply them to us when they are finished.

For our pilot project, we had to extrapolate how both the Future without Corps' Project and the tentatively selected plan may impact WSDOT's transportation infrastructure (we'll explain that in Section 2.4).

The Corps' GI study describes the climate change data the Corps used in its alternative selection process. The Corps estimated that hydrology changes due to climate change would be an average flood discharge increase of 33% by the end of the project planning period in 2070. The Corps assumed that by the end of its planning period, the existing 1% ACE would increase to about the 4% ACE, and the existing 0.4% ACE would increase to about the 1% ACE. That means larger storms will happen more frequently (i.e., a 0.4% ACE event will become a 1% ACE event and a 1% ACE event will become a 4% ACE event).

Sea level rise was considered in the Corps' analysis, but the extent that the increased sea level will affect floodwater levels is limited to downstream reaches of the river.[10]

The Corps identified the Comprehensive Urban Levee Improvement Alternative as its tentatively selected plan (TSP). This alternative would provide flood risk reduction for the urban areas of Burlington and Mount Vernon by raising existing levees along the Skagit River and constructing a new Burlington Hill Cross Levee along the eastern and northern edges of Burlington.

Generally, the TSP will reduce flood hazards in urban areas by improving and raising existing levees and by adding new levees. This is shown in Figure 2-2.

The Future without Corps' Project assumes that no project would be implemented by the Corps or local interests to achieve flood risk management objectives. The Future without Corps' Project is used throughout the Draft EIS as a baseline against which to compare action alternatives (ACOE, 2014). The Corps also evaluated two bypass alternatives, which they found had higher construction and real estate costs than the TSP.

[10] For this pilot, we did not consider the impact of sea level rise on coastal flooding and its effects on state highway infrastructure, because our focus was the Corps' GI study, which focused on riverine flooding.

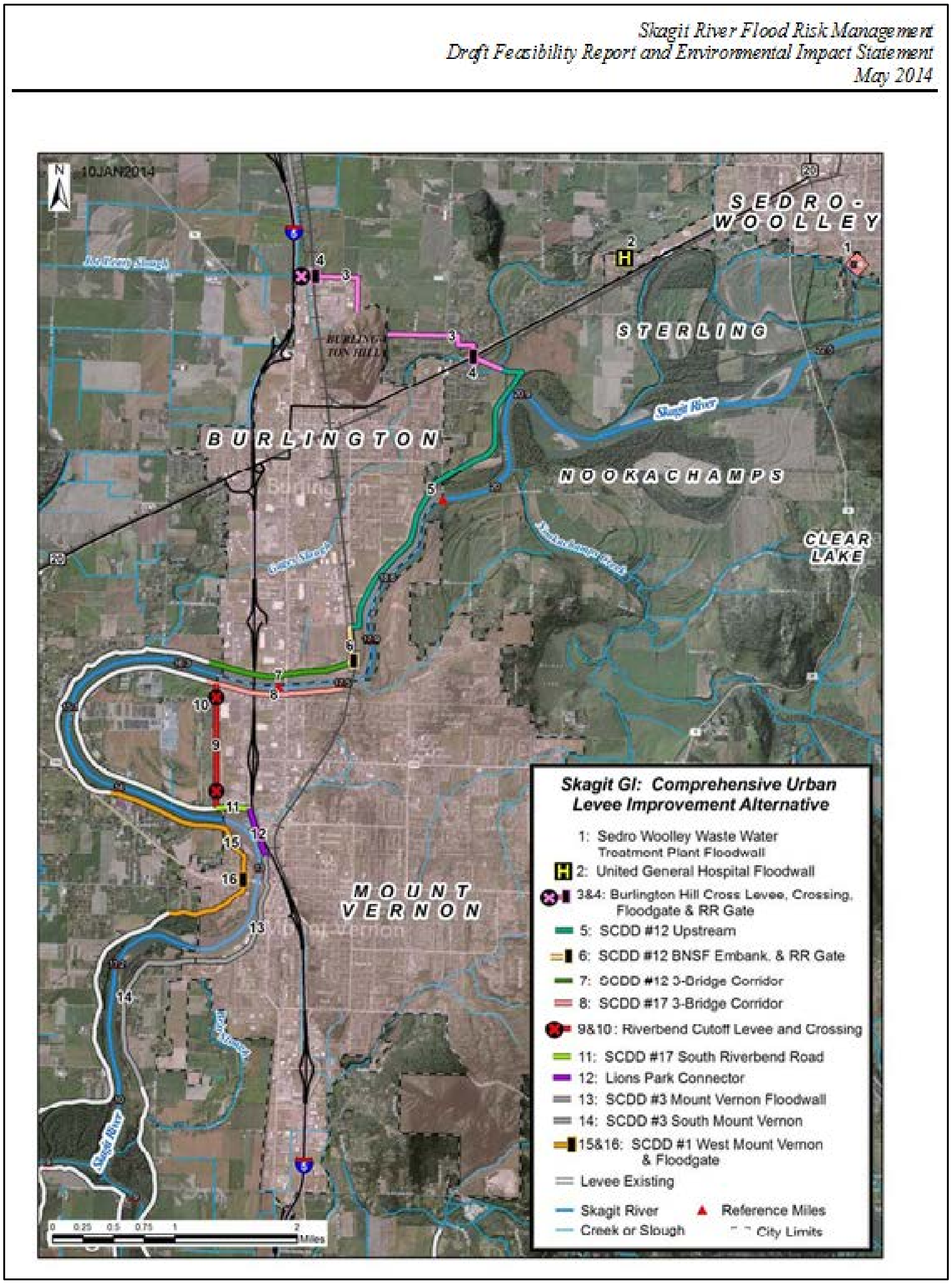


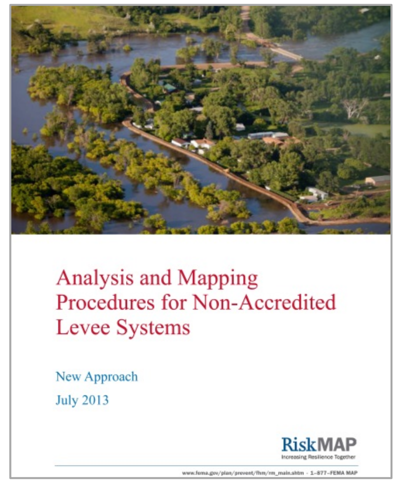

**Figure 2-2 Skagit GI: Comprehensive Urban Levee Improvement Alternative**

### 2.3.1 Why are the flood scenarios in the Corps study different from what we have experienced historically?

As the pilot team reviewed the data, we realized that it didn’t line up with what our local expert interviews had found. It was essential that we rely on the same information the Corps used, while at the same time we needed to understand why there were some differences. The answer is in the methods used for the Corps study.

Many times the Special Flood Hazard Areas (SFHAs) shown on the Federal Emergency Management Agency's (FEMA's) Flood Insurance Rate Maps do not match the extent of historical floods; this is especially true in areas with complex levee systems. Recently, FEMA has adopted new guidelines to better address the flood hazards with non-accredited levees, like those found in Skagit County.

In July 2013, FEMA issued new guidelines for "Analysis and Mapping Procedures for Non-Accredited Levee Systems." The Corps modeling and mapping procedures used in the Skagit River GI study followed those new guidelines and the Corps implemented the "Structural-Based Inundation Procedure."


Analysis and Mapping Procedures for Non-Accredited Levee Systems

New Approach

July 2013

RiskMAP

Increasing Resilience Together

The revised method of SFHA mapping as applied in the Corps' GI study represents a worst-case analysis that is different from what has been observed or may be encountered during future flood events. ***It is important to remember that the SFHAs mapped in areas with complex non-accredited levee systems are areas at risk of flooding, not the areas that will flood during a particular event.***

A very simple example would be the case where levee freeboard does not meet standards. Freeboard requirements compensate for the uncertainty associated with the magnitude of future flood events and the possibility that floodwater levels may exceed the levee system design. If the flood level exceedes the freeboard requirement for a segment of levee, the special flood hazard area must be mapped as if that segment has failed. However, during an actual flood event, the floodwater level may encroach into the levee's freeboard without a failure. In recent years, significant flood-fighting efforts have prevented levee overtoppings and failures during floods estimated to have a 4% ACE.

## 2.4 What did we do with this data and information?

After engaging our partners and gathering data, we used a series of pilot team workshops over the next several months to answer the following key questions:

- What climate threats or extreme weather impacts most affect this Basin?
- What do we know about the "Future without Corps' Project" and "existing conditions"?
- What would the impacts be of the TSP, if it were built?
- What WSDOT-managed assets are of primary concern (and why)?
- How should we define focus areas or highway segments of concern?

At the same time, team members were analyzing and interpreting the data (see photo) so that it was usable for developing adaptation strategies.

*Team workshop with Skagit County*

### 2.4.1 What methods did we use to interpret and use the data?

With all the data gathered and analysis under way, we were able to move forward with finalizing our asset selection and defining the appropriate strategies. WSDOT GIS and hydraulics experts worked together to process the data into information that would be useful in determining impacts to our transportation infrastructure.

In our analysis, we looked at the return flood intervals for the 10%, 4%, 2%, and 1% ACE flood under existing conditions. This was the basis for our detailed look at current vulnerabilities and for brainstorming potential adaptation strategies. In the future, as we get more hydraulic data on the Future without Corps' Project and the TSP, we will carefully examine the Corps' new information about future conditions.

### 2.4.2 How did we refine the data sets and define our areas of concern?

We developed the areas of concern as described in Section 2.2. We then identified data sets, within the GIS, that would impact our evaluation of adaptation options.

The available data was screened for its relevance to WSDOT's adaption decision-making. We identified 35 data sets in our GIS database and overlaid them on the 23 areas of concern/sites from the interviews. Refer to Appendix A and Appendix B for the interview results and GIS methods, respectively.

This analysis showed us that there were many individual areas of concern that were impacted by similar events. In addition, the areas of concern were connected by a highway segment, and when one area of concern was affected on that segment, the same event affected other areas of concern as well.

We refined the list to 11 highway segments for further consideration.[11] Table 2-2 shows the segment names, numbers, corresponding milepost ranges. (See Appendix C, Segment Profiles, for the full GIS results and detailed segment descriptions.)

**Table 2-2 Segment Names with Numbers, Mileposts, and GI Damage Reach #**

| Area Name | Segment Number | Mileposts | GI Damage Reach No. |
|---|---|---|---|
| **Central I-5/SR 538** | 1 | I-5 MP227.25 - 228.17<br>SR 538 MP 0 - 1 | 5A |
| **East SR 20 Burlington** | 2 | SR 20 MP 59.31 - 64.90 | 1A; 6; 1: 8 |
| **East SR 538 Nookachamps Basin** | 3 | SR 538 MP2.35 - 3.22 | 6 |
| **I-5 Gages Slough** | 4 | I-5 MP 228.61 - 229.86 | 1A |
| **North I-5** | 5 | I-5 MP 230.37 - 234.12 | 1 |
| **North SR 9 Skagit River Overflow** | 6 | SR 9 MP 53.49 - 55.37 | 6; 8 |
| **South I-5/SR 534** | 7 | I-5 MP 219.89 - 225.04<br>SR 534 0 - 0.5 | 4 |
| **South SR 9 Nookachamps Basin** | 8 | SR 9 MP 50.92 - 53.57 | 6; 8 |
| **SR 11** | 9 | SR 11 MP 0.14 - 9.06 | 1 |
| **SR 536 Mount Vernon** | 10 | SR 536 MP3.3 - 5.36 | 2: 2A; 4A |
| **West SR 20/SR 536** | 11 | SR 20 MP51.51 - 58.98<br>SR 536 MP 0 -1.89 | 1 |

### 2.4.3 How did we use flood information from the Corps' GI study?

As noted above, the data from the Corps gave us a more in-depth understanding of the existing conditions. The County supplied us with depths to add to the existing floodwater surface elevations. For our pilot, we used a flood scenario that produced the maximum water depth for a highway segment rather than individually analyzing all 21 scenarios from the Corps.

- We determined the maximum depth of flooding per highway segment by subtracting the elevation of the highway from the water surface elevation using GIS.
- We used this to identify conditions of the highway system for the existing 10%, 4%, 2%, and 1% ACE flood.
- We identified the length of state highway flooded under the worst-case condition for each return interval flood.

By calculating the inundation of our assets, we found that most of the areas of concern identified during the interview process were consistent with the flood analysis results. Refer to Appendix D (Hydrology and Hydraulics Methodology) and Appendix B (GIS Methodology) for the details on this step-by-step process, identification of glitches in the data, and troubleshooting efforts related to our flood analysis.

[11] WSDOT is responsible for passenger operations that run on Burlington Northern Santa Fe railroad tracks in the Basin. However, for this pilot, we focused on infrastructure owned by WSDOT.

**Table 2-3 Example of How We Looked at Flood Depths for Existing Conditions**

| Segment ID | Highway Segment | SR* | 10 % ACE Ex.** | 4% ACE Ex.** | 2% ACE Ex.** | 1% ACE Ex.** |
|---|---|---|---|---|---|---|
| **1** | Central I5/SR538 | I-5 | N/A | N/A | 10.80 | 11.19 |
| **1** | Central I5/SR538 | 538 | N/A | N/A | 14.93 | 15.33 |
| **2** | East SR20 Burlington | | 1.69 | 7.85 | 6.33 | 9.54 |
| **3** | East SR538 Nookachamps Basin | | N/A | 1.59 | 3.49 | 4.87 |
| **4** | I5 Gages Slough | | N/A | 4.87 | 6.09 | 7.00 |
| **5** | North I5 | | N/A | 5.21 | 4.65 | 7.98 |
| **6** | North SR9 Skagit River Overflow | | 7.62 | 10.52 | 12.26 | 13.02 |
| **7** | South I5/SR534 | I-5 | N/A | 10.62 | N/A | 15.23 |
| **7** | South I5/SR534 | 534 | N/A | 12.13 | N/A | 14.83 |
| **8** | South SR9 Nookachamps Basin | | 3.57 | 6.94 | 8.60 | 10.05 |
| **9** | SR11 | | N/A | 6.00 | 3.92 | 6.80 |
| **10** | SR536 Mount Vernon | | N/A | N/A | N/A | 8.39 |
| **11** | West SR20/SR536 | 20 | N/A | 10.25 | 10.50 | 12.00 |
| **11** | West SR20/SR536 | 536 | N/A | 4.00 | 5.00 | 4.60 |

*If more than one SR in a given segment.
**Flood recurrence interval.

Note: This table shows our estimates of the flood impacts in maximum depth in feet for each highway segment.

For each segment, the project team created a site-specific vulnerability assessment (which we called a profile). Each profile describes the key features of the segment in terms of highway location and functions; drainage issues; updated vulnerability assessment given Corps' hydraulic data; and discussion of the team's brainstorm of adaptation strategies (see Figure 2.3).

## Segment 1, Central I-5/SR 538

| Segment ID | Highway Segment | CIVA* Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 1 | Central I5/SR538 | L, H | L, M, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 69000 | 11.5% | 11640 | 51, 54 | T1, T3 |

**Segment Description**

**Segment 1, Central I-5/SR 538:** I-5 (MP 227.25–228.17), SR 538 (MP 0–1.00)

This segment is in Mount Vernon. The Skagit River bends around Mount Vernon and frames the southern and northern segment boundary. I-5 is the main north-south corridor for the West Coast, and this segment has an AADT of 69,000. 11.5% of the traffic is truck traffic and it carries more than 10 million tons of freight per year. SR 538 carries between 300,000 to 4 million tons of freight per year. The DHV for this segment is 11,640. I-5 is classified as an Urban Interstate and SR 538 is classified as an Urban Minor Arterial. There is one bridge in this segment as well as six culverts. Five bus routes traverse the segment. The CIVA impacts to this segment are low to moderate for the 2-FT SLR condition and high for the 6-FT SLR condition. This segment is within the Mount Vernon Urban Growth Area. The land use classification categories that surround this segment include commercial, industrial, some residential, Skagit County Public Works, Mount Vernon Police Station, Skagit County Emergency Management, Skagit Valley College. This segment experiences flooding in the existing 10%, 4%, 2%, and 1% ACE events. Maximum flood depths in the existing condition are:

| | 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|---|
| I-5 | N/A | N/A | 10.80′ | 11.19′ |
| SR 538 | N/A | N/A | 14.93′ | 15.33′ |

This segment is not flooded during the 1% TSP event. The segment is listed in Flood Zone A and X500.

**Adaptation Strategies**

The flooding in this segment would be caused by a levee failure due to scour. This would be addressed by the TSP, and that is why no flooding occurs under the Corps' preferred plan. If this plan is built, then other alternatives are not needed to keep this segment functioning. However, if the TSP is not built, there are other options (in no particular order) that could make this segment more resilient:

- Work with local agencies and the Corps to purchase additional storage capacity behind the dams run by Puget Sound Energy.
- Work with the City of Mount Vernon to extend the floodwall to protect I-5, and SR 536.
- Raise I-5 on a causeway above the flood elevation.

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, X500 | – | 34 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 1 | 1 | 6 | Unknown |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | L-M, M-H, H | B, C, D | 9391895 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 204, 205, 207, 513, 8 | | UGA-CL/IND/RES/Public | Skagit Valley College | |

| WSDOT Site (Type) | | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|---|
| | 2 | | Y | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | general investigation |
| CIVA | Climate Impact Vulnerability Assessment | I-5 | Interstate 5 |
| Corps | US Army Corps of Engineers | SLR | sea level rise |
| CULI | Comprehensive Urban Levee Improvement | SR | State Route |

**Figure 2-3 Segment 1 Example**

### 2.4.4 How did our mapping inform our adaptation strategies?

Figures 2-5 through 2-10 show the results of our flood analysis. These images were created by the pilot team to see how the Corps' flood data for existing conditions would impact highways throughout the Basin. They show the maximum flood depth for each highway segment for the 4% and 1% ACE flood event for existing conditions. The figures also show the general direction of flow over the floodplain.

Figure 2-4 shows our pilot study area with the flood hazard locations for the 1%, 2%, 4%, and 10% ACE floods. The yellow boxes outline locations found in Figures 2-5 through 2-10 where we zoom in to take a closer look.

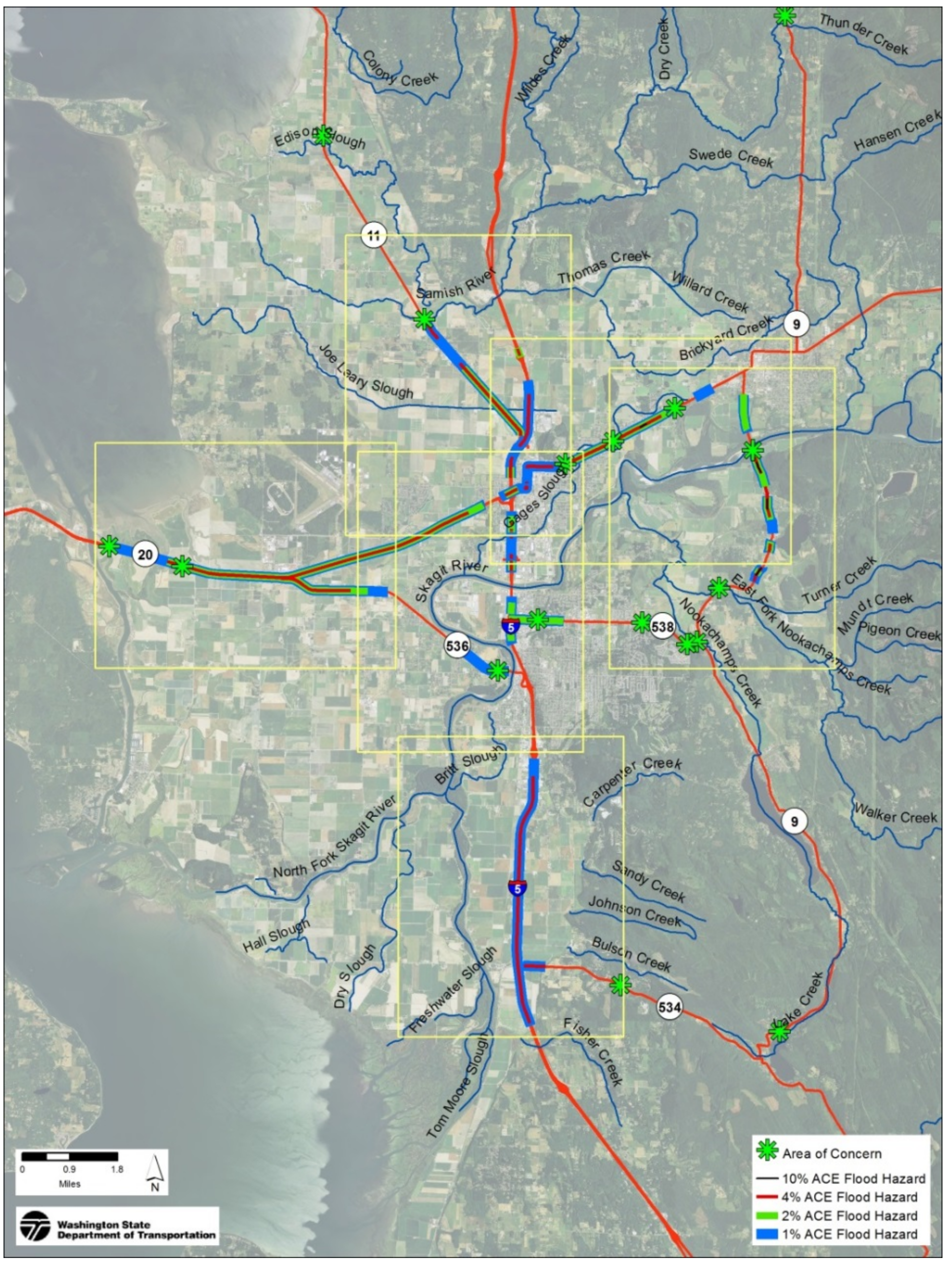



**Figure 2-4 Map Key**

Figure 2-5 shows the northern section of our pilot area. I-5 is shown from left to right and SR 20 and SR 11 are also shown. Arrows indicate the flow of water. We do not have information on volume at this point, so the arrow thickness does not indicate the volume of water, merely the presence and direction with the depth noted.

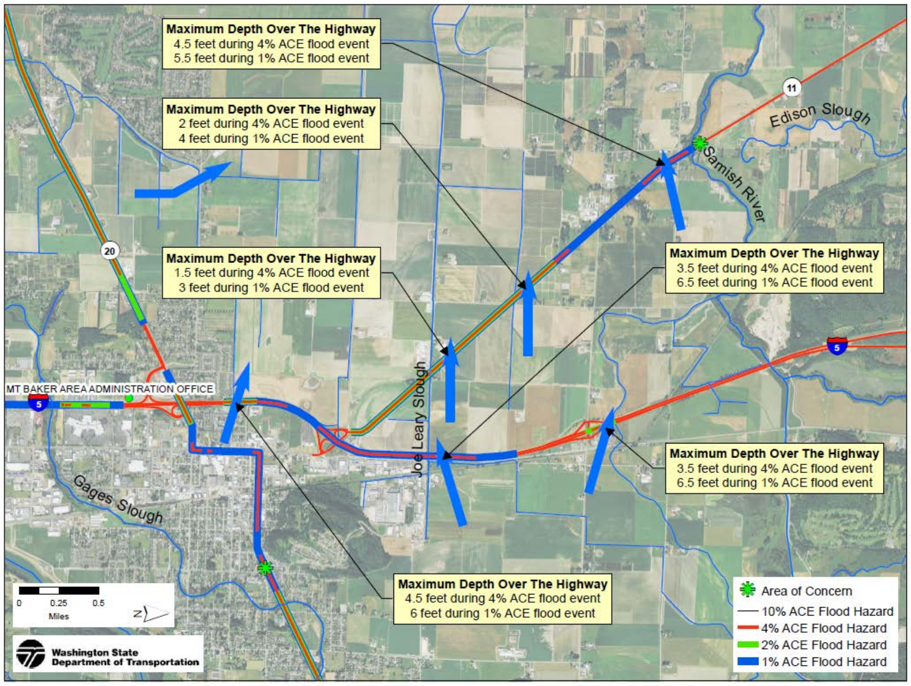



**Figure 2-5 Northern Section of the Pilot Area**

Figure 2-6 shows I-5 just south of the previous view. It shows the direction and depth of flows over I-5, SR 20, and SR 538.

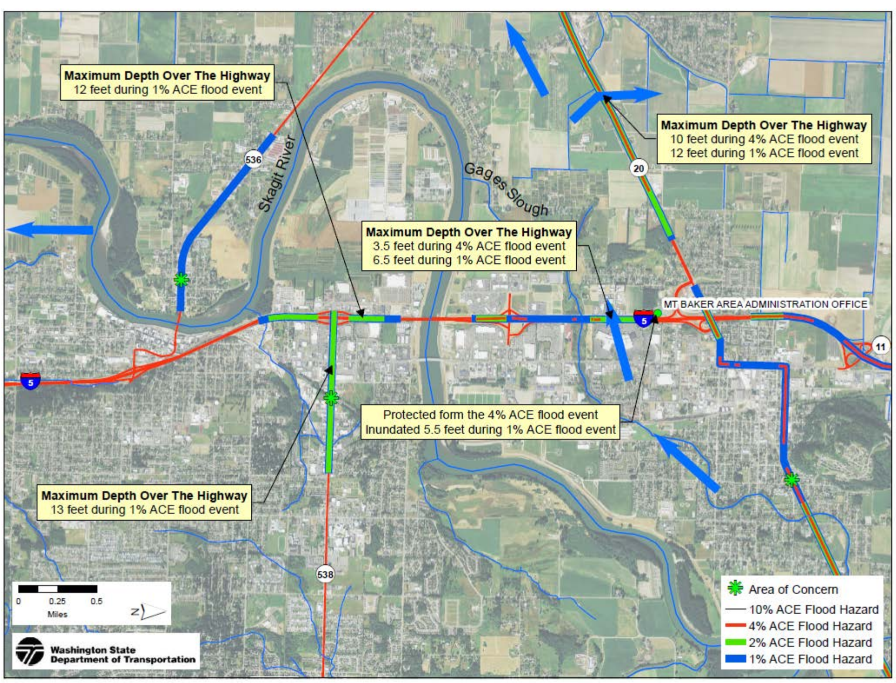



**Figure 2-6 Central and West Sections of the Pilot Area**

Figure 2-7 shows the flow of floodwater around I-5 and SR 534 south of Mount Vernon.

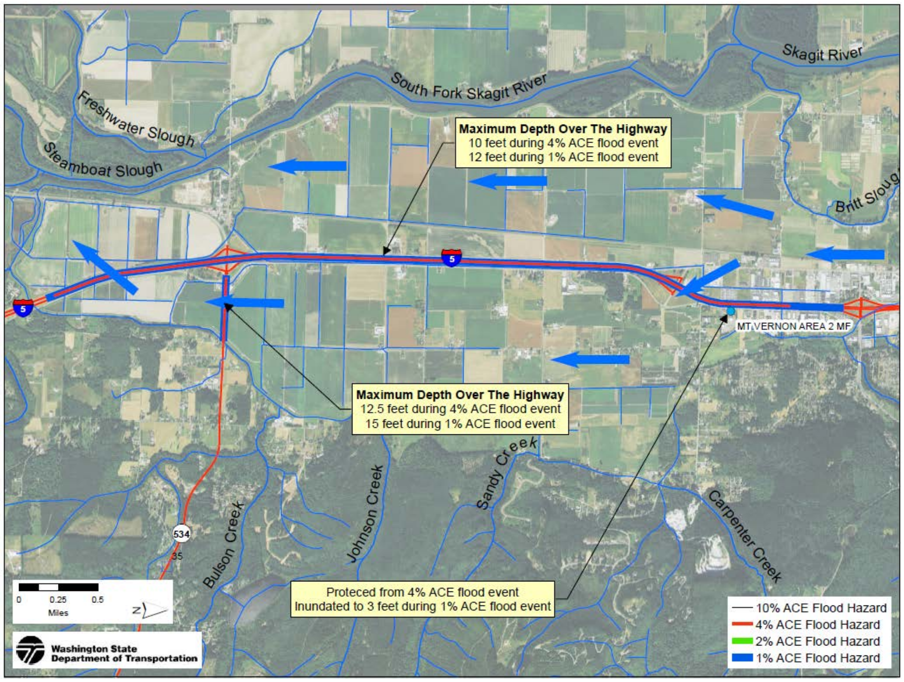



**Figure 2-7 South Section of the Pilot Area**

Figure 2-8 shows the flow of water to the west of I-5 and the City of Burlington, along SR 20 and SR 536.

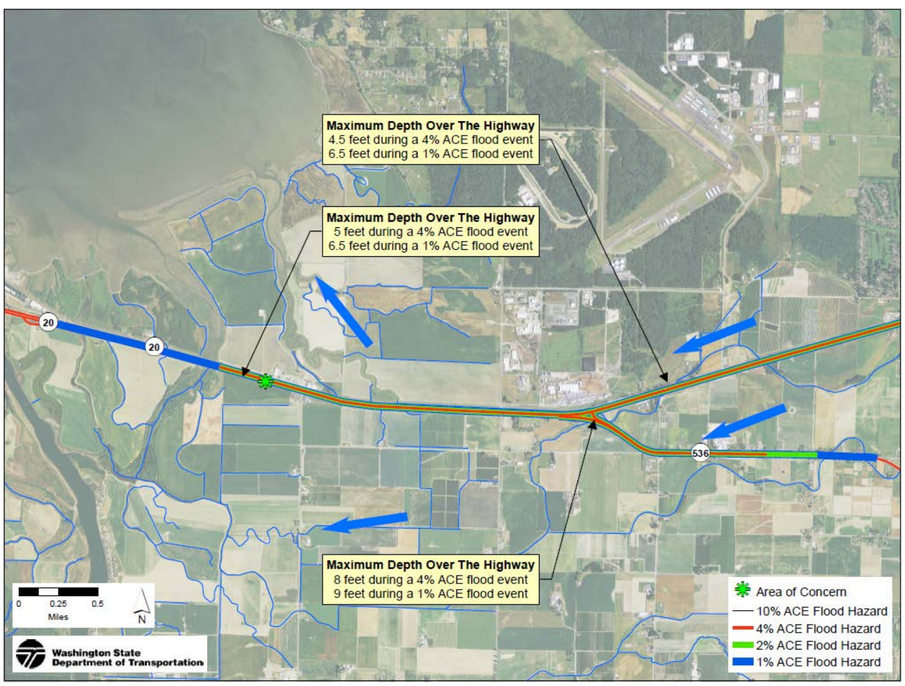



**Figure 2-8 West Section of the Pilot Area**

Figure 2-9 focuses on SR 20, including the cities of Burlington and Sedro-Woolley.

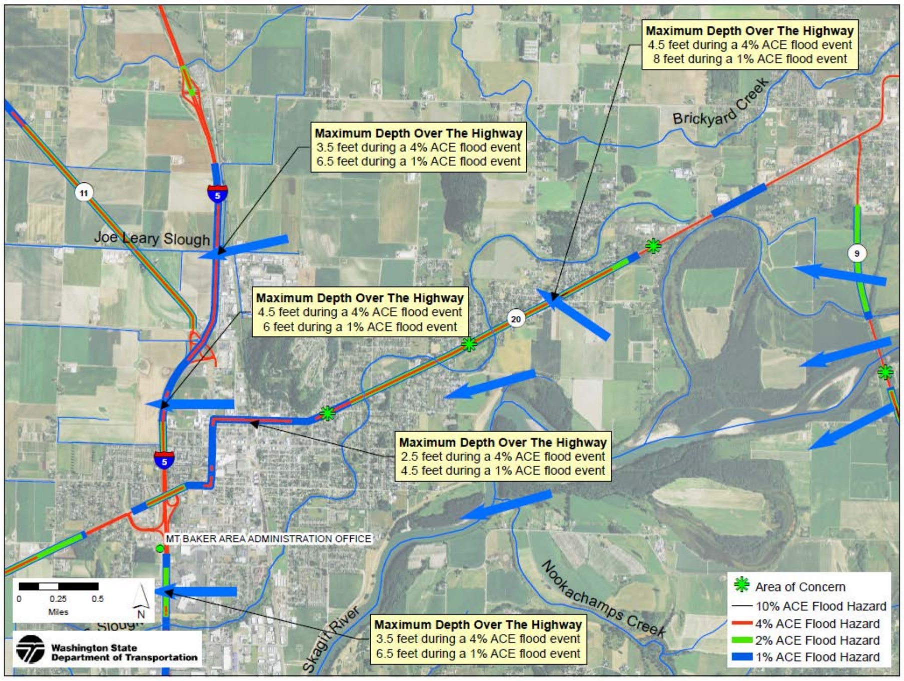



**Figure 2-9 East Section of the Pilot Area**

Figure 2-10 shows the area east of Burlington, including SR 538, SR 9, and SR 20.

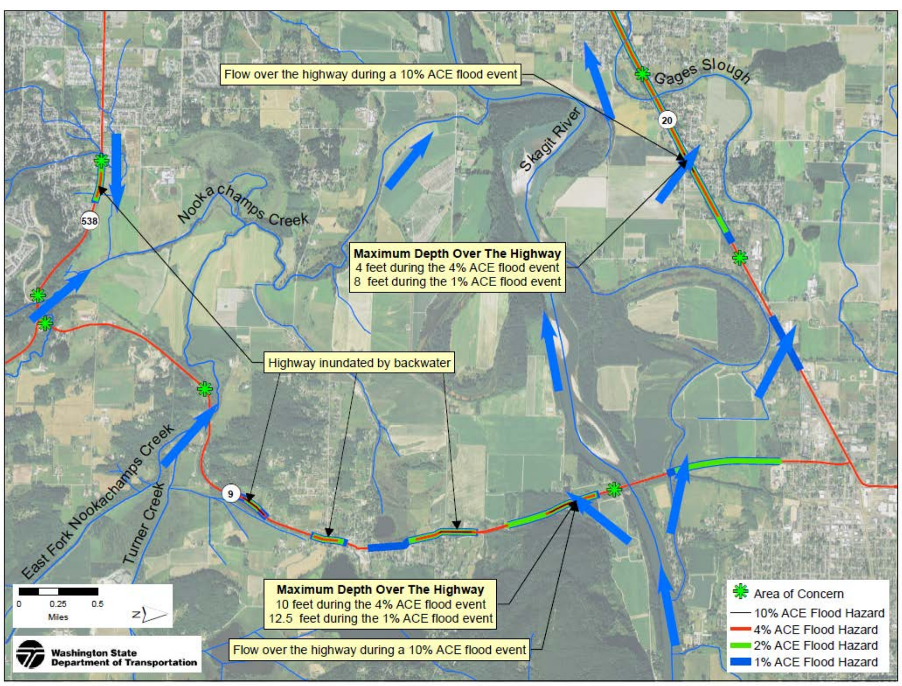



**Figure 2-10 East Section of the Pilot Area**

This series of maps allowed us to consider what we might do if and when a flood of this magnitude would occur.

## 2.5 How did we select our adaptation strategies?

After we analyzed and interpreted the data, we moved toward developing adaptation strategies. Our last series of pilot team workshops focused on developing adaptation options—particularly the "no regrets" strategies.

Ultimately, we developed structural and nonstructural adaptation strategies within a broad diagnostic framework. This was guided by three high-level principles, which were informed from many other pilots and the FHWA Framework:

1. Take a comprehensive decision-making approach that describes the steps engineers, planners, operations and maintenance personnel, and other highway officials can take to assess the range of climate change impacts on the transportation system as a whole and avoid piecemeal decision-making.
2. Take action incrementally within this broader comprehensive approach so that momentum is not lost seeking the total "fix."
3. Be sufficiently flexible to allow for the consideration of updated climate change forecasts and recently completed or proposed flood-related projects (new levees, flood walls, etc.), as well as an examination of a range of potential cost-effective practical solutions.[12]

We read other adaptation studies, such as those from San Francisco (BART), New York City, Baltimore, and Toronto, for examples of adaptation strategies. We used those examples to think about and formulate adaptation strategies for our infrastructure. During team workshops, we evaluated the 11 highway segments in the Basin. Some of those segments had subsegments that were impacted by different flood scenarios. We analyzed those smaller segments and developed adaptation strategies that responded to the specific threat (see Appendix C, Segment Profiles, and Table 3-1).

We walked through each segment and identified potential adaptation strategies that we could use with and without the Corps (TSP and Future without Corps' Project). The strategies included general broad structural (design and construction) actions and nonstructural (planning, detour routes, and partnerships) solutions.

Once the list of strategies was compiled, our hydrologist and stormwater engineer analyzed them using the available data to determine the feasibility of the structural strategies. We then refined (omitted or modified) the strategies based on their feedback.

FHWA defines "no regrets" actions as actions that improve resilience of assets to existing stressors, have co-benefits, or cost little relative to the overall value of the asset. They can build flexibility into designs to allow for changes in the future.

http://www.fhwa.dot.gov/environment/climate_change/adaptation

[12] *Strategic Issues Facing Transportation: Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report*. National Cooperative Highway Research Program. Report 750. 2014

We developed a list of strategies for both the existing condition and the TSP, but we really looked for "no regrets" strategies that would improve transportation infrastructure resiliency regardless of future work by the Corps or local governments. As more data becomes available and the TSP is further refined, we can improve our strategies as needed. Table 3-1 is an example of the iterative list of strategies by highway segment (see Appendix C, Segment Profiles, for details).

A summary of our process is shown in Figure 2-11.

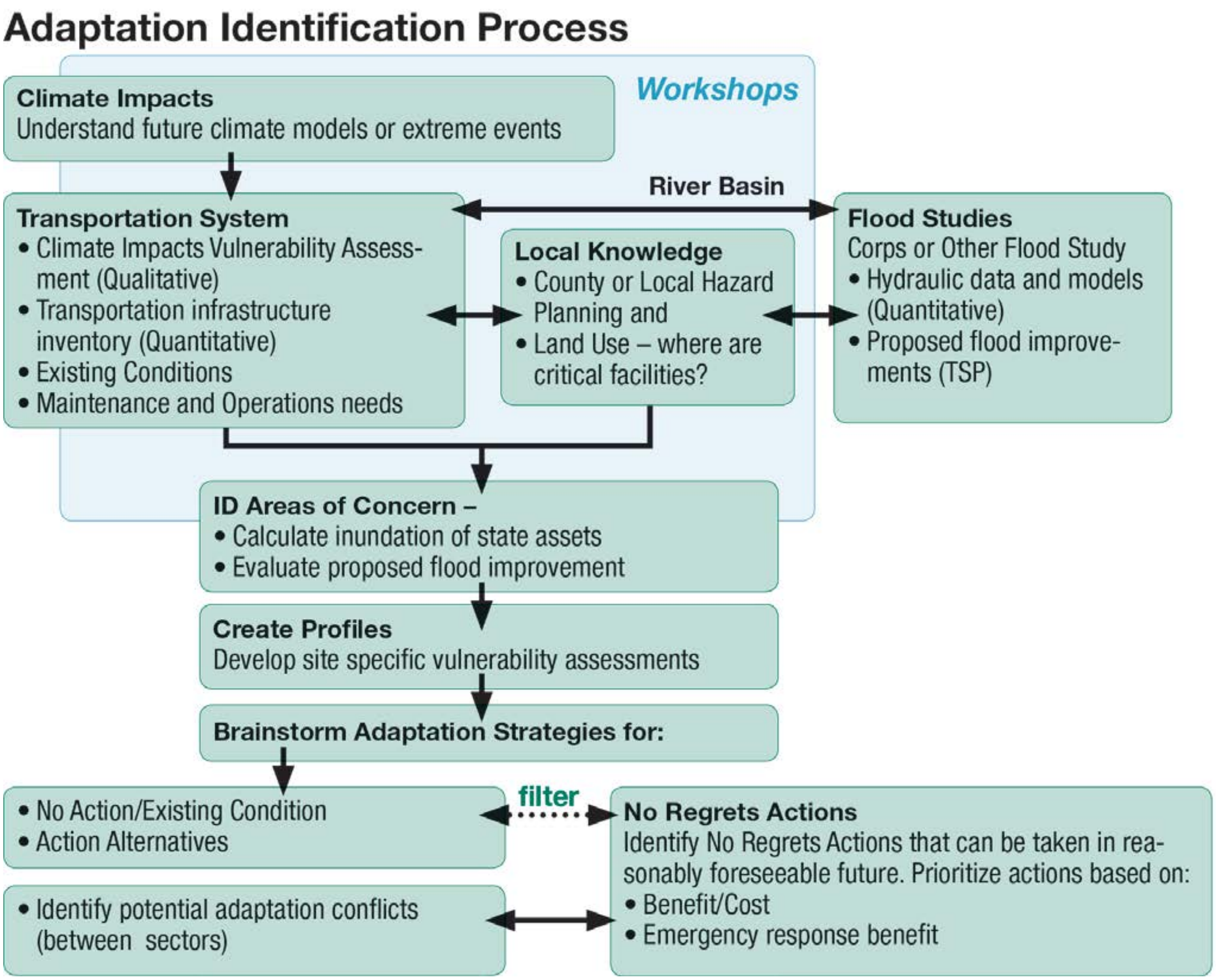



**Figure 2-11 Summary Approach Diagram**

# 3 Findings

## 3.1 What are the key findings from our analysis?

Our key finding is that transportation agencies must collaborate with flood risk managers during adaptation strategy development. We uncovered specific examples where WSDOT—if we had been unaware of the Corps' tentatively selected plan or local flood improvements—could have invested in the wrong place (aka: maladaptation).

This finding underscores the major recommendations of the recently released report from the President's "State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience." It is also consistent with the FHWA Framework (Section 4.1.1): "State DOTs and MPOs have a strong interest in integrating climate change adaptation, hazard mitigation, and transportation planning into a holistic planning process."

Our analysis of the Corps' GI study gives us the foundation for the necessary coordination, as federal, state, and local investments in flood hazard reduction are decided. We found that transportation infrastructure needs to be analyzed in the GI study both for impacts to the transportation system and as a partner in the solution. What one agency does affects the others. All levels of government need to create lasting partnerships in order to achieve community resilience.

Our analysis validated our workshop and interview process. We found through using our GIS and hydraulic analysis, most of the areas of concern identified during our 2011 qualitative vulnerability assessment and the interview process for this pilot were consistent with the flood analysis results. But the analysis found additional locations that the interviews didn't give us. Both processes complement each other and should be used together for watershed-level adaptation strategy development.

After conducting the analysis and reviewing the existing conditions, we discovered two locations, one on SR 20 and one on SR 9, where floodwater would flow over the highway during a 10% ACE flood. These were areas not revealed during our interviews, and were added as areas of concern. We recognized that, just because something has not happened in the past, doesn't mean it can't happen in the future.

Interestingly, large segments on I-5 and SR 534 are flooded under the 4% ACE and the 1% ACE floods, but not the 2% ACE flood. This occurs because the Corps identified the most likely locations for levee breaks, and they occurred in different places for different flood condition scenarios.

As shown in Figure ρζυ (timeline for dam building), there have been no flows in the river over 150,000 cfs, or approximately the 4% ACE. Because of this, no one that we interviewed has seen a 1% ACE event like the one modeled in the GI study.

Generally, the TSP will reduce flood hazards in urban areas by improving and raising existing levees and by adding new levees. Consequently, the transportation assets in these areas also benefit from the improvements. However, in more rural areas, transportation assets, including portions of I-5, SR 20, SR 11, and SR 9, will remain at risk with implementation of the TSP.[13] Our analysis revealed:

- Without the TSP, we estimate that about 90% of I-5 in Skagit County, as well as the rest of the highway system, is at risk of flooding.
- The TSP will eliminate issues on the southern and central portions of I-5 seen during the existing 1% ACE flood.[14]
- The TSP directs floodwaters to the northern section of I-5 near the Joe Leary Slough. This northern section of I-5, and SR 20 east of Burlington, were not identified in the qualitative vulnerability assessment as areas of high vulnerability.
- The TSP maintains or worsens conditions east of I-5 on SR 538 and SR 9, and west of I-5 on SR 11, SR 20, and SR 536.

## 3.2 What strategies did we develop?

For the 11 segments of highway that we identified as vulnerable, we developed a list of strategies for the Future without Corps' project, the TSP, and no regrets. Table 3-1 captures the strategies identified for each segment (See Figure 3-1 for map of segments). When we didn't have enough information about whether or not a strategy would work or solve a problem, we put a question mark (?). You can find all the specific details we considered for each segment in the profiles in Appendix C, Segment Profiles.

Generally, the project team brainstormed the following:

- Nonstructural solutions to help reduce impacts during flood events, like active traffic management, detour routes, etc.
- Solutions recommended in the Corps' GI Study and the TSP
- Other basin-wide ideas such as buying more water storage or flood easements
- Highway related solutions such as fixing culverts where potential blockage exists, hardening the road prism to allow the water to flow over it with minimal damage, realignment and/or raising the road out of the floodplain

[13] Corps, 2014

[14] The Corps used CIG data that assumes the current 1% ACE event will become the approximate 4% ACE event by 2085.

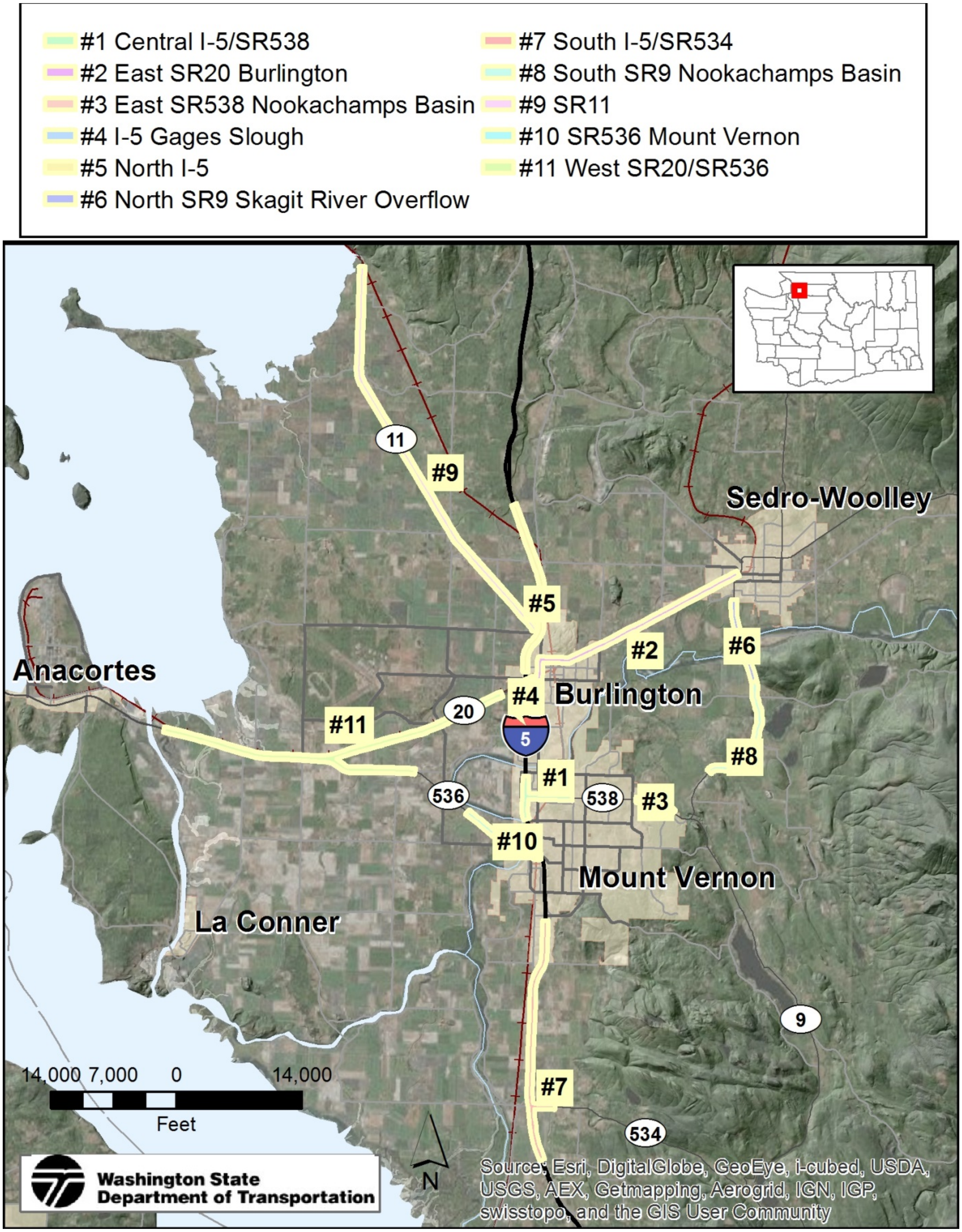



**Figure 3-1 Skagit Segment Index**

**Table 3-1 Conceptual Strategies Identified for the 11 Vulnerable Highway Segments**

| Highway Segments – The Project Team Brainstormed the Following Options (see Figure 3-1) | Strategies | | |
|---|---|---|---|
| | Future without Corps' Project | Tentatively Selected Plan | No Regrets |
| **Segment 1: Central I-5 Anderson Road to George Hopper Road** | | | |
| ▪ Work with local agencies and the Corps to purchase additional storage capacity behind the dams run by Puget Sound Energy (PSE) and Seattle City Light. | x | x | x |
| ▪ Work with the City of Mount Vernon to extend the floodwall to protect state highways. | x | | x |
| ▪ Raise I-5 above the flood elevation. | x | | |
| **Segment 2: SR 20 East of Burlington to Sedro-Woolley** | | | |
| ▪ Reroute traffic onto Cook Road or F&S Grade Road. | ?[15] | x | x |
| ▪ Raise the road (or portions) through this segment and install sufficient culverts or bridges to allow the water to pass from the Skagit River over to Joe Leary Slough. | x | x | ? |
| ▪ A high number of culvert ends are identified in this segment; it is possible that the other end may be buried or obstructed and not operating properly. If those culverts are not functioning properly now, fixing them might relieve flooding issues in smaller floods. | | | x |
| **Segment 3: SR 538 Nookachamps Basin – SR 9 to I-5** | | | |
| ▪ Raise the road (or portions). It appears that this could be done to alleviate flooding for the more frequent flood events but may be difficult for the 2% and 1% ACE flood. | x | x | x |
| **Segment 4: I-5 at – George Hopper to Chuckanut (SR 11)** | | | |
| ▪ Raise I-5 above the flood elevation. | x | | |
| ▪ Make SR 9 less vulnerable to flooding (see Segments 6 & 8) to serve as an alternate route if I-5 is closed for any reason. | x | x | x |
| **Segment 5: North I-5 – Chuckanut (SR 11) to Samish River** | | | |
| ▪ Raise I-5 above the flood elevation. Raise the road (existing). The TSP sends more water to this segment of roadway, so the road would have to be raised to get above the higher flows as compared to existing flood elevations. | x | x | |
| ▪ Work with other agencies to secure additional water storage. (The Corps includes this strategy in the TSP.) | x | x | x |
| **Segment 6: North SR 9 Skagit River Overflow – Sedro-Woolley to Francis Rd./Old Day Creek Rd.** | | | |
| ▪ Explore options for a new alignment out of the floodway. | x | x | x |
| ▪ Raise the road in the existing alignment. | x | x | x |
| Note: Either option would eliminate flooding concerns for this segment and add resilience to north-south travel. SR 9 is an alternate route for I-5. Making this route less likely to flood will improve the resilience of the transportation infrastructure and provide an alternate route that would allow limited north-south traffic flow and access for County residents who would otherwise be stranded or face long detours. | | | |
| **Segment 7: South I-5 Fisher Creek to Anderson Road** | | | |
| ▪ Support the Corps' TSP. Implementing the TSP alleviates flooding in the segment. | | x | |
| ▪ Work with the City of Mount Vernon to extend its floodwall to the south to protect I-5. Further study is needed to determine if this option would protect I-5. | x | | |
| ▪ Raise I-5 above the flood elevation. | x | | |

[15] A "?" indicates that more information or analysis of potential benefits is needed.

**Table 3-1 Conceptual Strategies Identified for the 11 Vulnerable Highway Segments (continued)**

| Highway Segments – The Project Team Brainstormed the Following Options (see Figure 3-1) | Strategies | | |
|---|---|---|---|
| | Future without Corps' Project | Tentatively Selected Plan | No Regrets |
| **Segment 8: South SR 9 Nookachamps Basin – Francis Rd./Old Day Creek Rd. to Turner Creek** | | | |
| ▪ Raise road above the flood elevation. Further evaluation is needed to determine if raising the roadway is feasible in the flood-prone areas near Clear Lake. | x | x | x |
| ▪ Realign the highway. | x | x | x |
| **Segment 9: SR 11 – I-5 to Blanchard Rd.** | | | |
| ▪ Raise road above the flood elevation. | x | x | |
| **Segment 10: SR 536 Mount Vernon – I-5 to Avon Allen Rd.** | | | |
| ▪ Find alternate routes for local traffic and work with the local governments to make those routes more resilient during flood events. | x | x | x |
| **Segment 11: West SR 20 and SR 536 – I-5 to Swinomish Channel** | | | |
| ▪ Find alternate routes for local traffic and work with the local governments to make those routes more resilient during flood events. | x | x | x |
| ▪ Note: Allow the road to be brought back into service after a flood since the flood depths are so deep on SR 20. The following alternatives would allow the road to be destroyed by the flood, but in doing so, save other sections of the road. Both of these strategies might allow the road to be opened sooner after a flood event. | | | |
| □ Harden the road prism to allow the water to flow over it with minimal damage. | x | x | x |
| □ Make portions of the road sacrificial. | x | x | x |
| ▪ Raise road above the flood elevation. | x | x | |

### 3.2.1 What are our "no regrets" strategies?

We concluded that our path may change depending on whether the Corps builds or doesn't build the TSP. With that in mind, we developed "no regrets" strategies that would improve transportation infrastructure resilience regardless of future work by the Corps.

We recommend five primary "no regrets" strategies given what we know l·ű this time:

- SR 20 (east of I-5): Raise the road at the low spot that floods at the 10 % ACE event.
- SR 9: Build a new alignment out of the floodplain or raise the road on a causeway in the existing alignment.
- SR 538 (east end): Raise the road to alleviate flooding for the more frequent flood events.
- Improve the intersection of SR 534/SR 9 to facilitate truck traffic.
- Coordinate with local agencies to identify and improve local routes that provide transportation redundancy.

We will continue to work with the Corps and the County to provide input to the TSP analysis. Once the TSP analysis is complete and the Corps and County make final recommendations, we will be able to create a longer-term plan of action for WSDOT facilities in Skagit County for flooding and weather-related closures that considers future climate impacts.

As a result of this pilot, we conclude that adaptation planning must have an iterative, integrated, multisystem approach. It is essential that WSDOT's plans and actions complement and actively work with federal and local flood protection efforts.

# 4 Lessons Learned:

## 4.1 What lessons did we learn during this process?

We learned several lessons during the pilot in relation to our goals and outcomes.

### 4.1.1 FHWA Framework

We relied on other studies and the FHWA Framework to guide our efforts. FHWA's Framework for adaptation planning and strategy identification was very useful and helped us tie our first vulnerability assessment to the more detailed Skagit River Basin study. In Figure 4-1, we show, via the callout boxes, where our data and other inputs fit into the Framework.

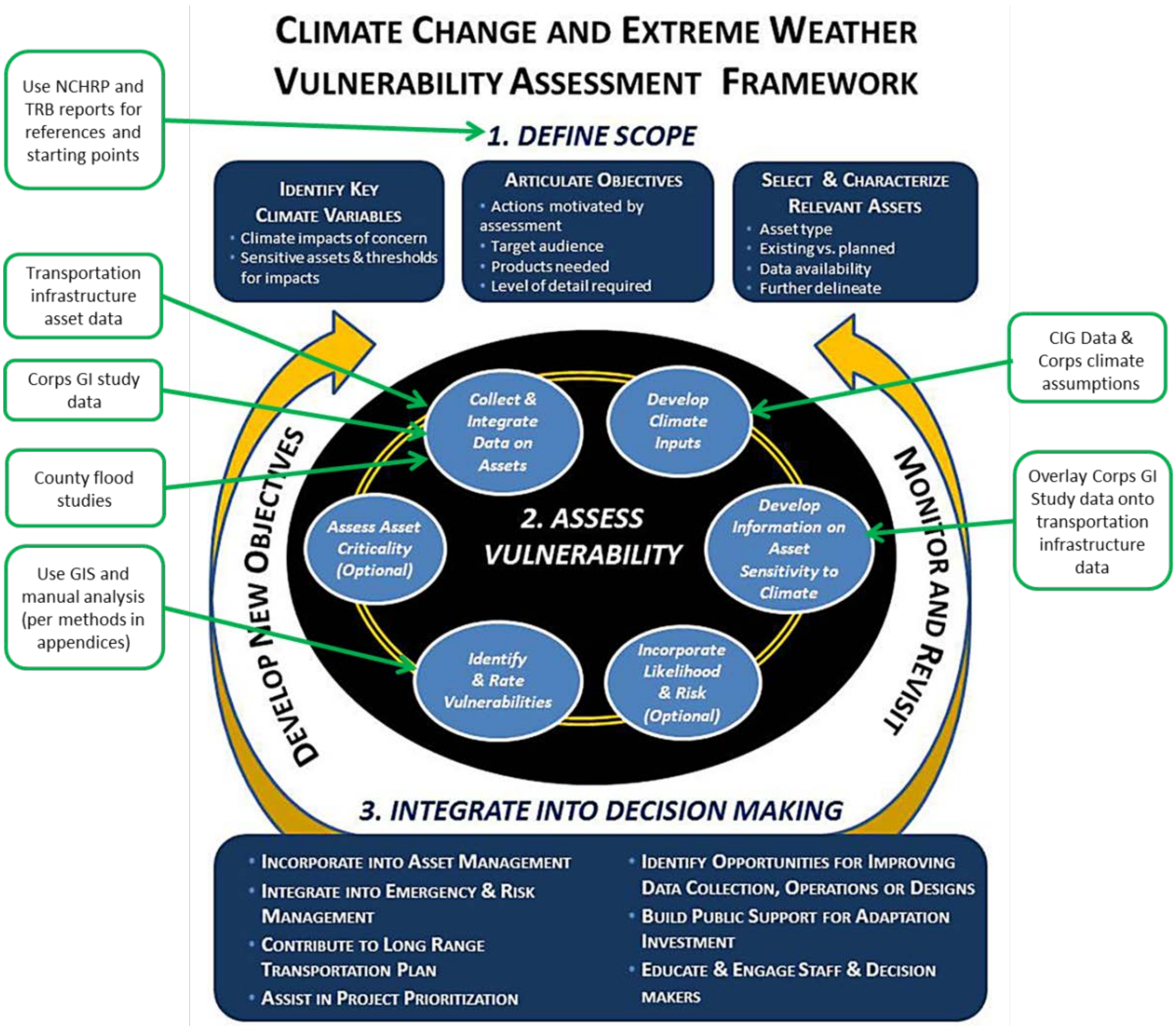



**Figure 4-1 FHWA Vulnerability Assessment Framework: Elements of the Study**

### 4.1.2 Corps flood modeling data

The flood modeling data provides another tool to analyze flood impacts and levee breech scenarios under existing and changing climate conditions. We can use that data to overlay our transportation asset data to determine if there is a risk to our system, and if there is, what adaptation strategies we should explore.

We found that our transportation system relies on flood protection that consists of the levee and dam system. So far, the system has worked. The maps show us the possibilities if the flood protection system fails. They also remind us that just because something hasn't happened in our memory doesn't mean it can't happen in the future or hasn't happened in the distant past (see Figure 1-4).

Predictions from the Climate Impacts Group (CIG) state that, by the end of the century, the current 1% ACE storm event will become the 4% ACE storm event and the 0.4% ACE storm event will become the 1% ACE storm event. The U.S. Army Corps of Engineers (Corps) used this guidance in its GI study and recommended that the tentatively selected Plan (TSP) build the levees to contain the 0.4% ACE storm event.

Corps flood modeling and flood hazard reduction proposals should inform our planning efforts so that our projects do not conflict with Corps or other flood-reduction projects.

### 4.1.3 Engaging with federal and local entities

**Before you begin:** For those of you hoping to work with Corps data, it will simplify the process if the Corps study is completed and all data is available before you begin your analysis. That way you will know what is available and what you need to produce for yourself, and your timeline won't be dependent on another's process.

**Leverage available data sources:** We started with our 2011 vulnerability assessment and added more depth and information to it. As noted above, we now have a greater appreciation of the value contained in completed flood studies. Transportation agencies don't need to wait for a new flood study to be undertaken; they can look at past studies and augment the prior work with climate change data from other sources.

**Don't make assumptions:** We assumed that we would have access to hydraulic modeling data that hadn't been done yet. It's important not to assume that what is needed for a transportation agency can be provided by another agency with a different definition of "infrastructure." The Corps' focus was homes and businesses (the National Flood Insurance Program rate payers), not highways, in their initial report.

### 4.1.4 Building the team

You need staff on your team who know both the local area and the people involved in climate adaptation work so that local responses and statewide policy can be considered in your study.

Make sure you have staff available with the expertise and time to carry the brunt of the workload. We needed staff with flood data analysis and GIS skills as primary team members.

During hydraulics analyses, use staff with resource-specific understanding and local familiarity. Without staff that has at least a basic understanding of how the data were created and the geography of the area, the data gaps may underestimate potential flood hazards, provide false positives, and/or overestimate the depth of flooding.

### 4.1.5 Overcoming challenges

Our greatest challenge was in linking our timeline to the Corps' GI study release. We were very focused on showing how to work with external data. When the Corps' timing was different than we expected, analyzing hydraulic data within the pilot schedule was difficult. This is a lesson in managing expectations. We will continue our analysis of hydraulic data and develop response strategies after this pilot is completed.

When faced with challenges, we stayed focused on our goal to use the FHWA model and the NCHRP 750 Framework[16] to create a replicable process. We also adjusted the scope of our effort to use the valuable information that was available. The conceptual nature of the TSP and our strategies were not sufficient for a detailed cost/benefit analysis.

## 4.2 Recommendations

As we come to the close of this phase of our work, we look back to see what we would do if we had it to do all over again. Some things we did well, other things could have gone more smoothly. Following is a list of considerations for other DOTs that are interested in replicating our approach.

### 4.2.1 What recommendations do we have for other to do this type of work?

1. **Partner with federal and local hazard reduction projects**: Transportation planners and asset managers need to reach out to the Corps in your region and to local flood managers. Find ways to advocate that transportation infrastructure be analyzed in the flood studies.

[16] http://www.camsys.com/pubs/nchrp_rpt_750.pdf

Keep in mind two things: (1) make sure impacts to the transportation system are considered, and (2) promote your DOT as a partner in the solutions (e.g., we should be partners, because what one agency does affects the other).

2. **Use existing studies:** Use completed GI studies or other flood hazard-reduction studies. Work with cities, counties, and the local Corps office or other cooperating agencies to get hydraulic modeling and GIS data.
3. **Use local knowledge to identify where problems areas lie:** Our interview process (Appendix A) worked well for past and existing locations with a history of flooding, sea level rise, river meander changes, and/or landslides. This was especially important since the data collection effort and analysis validated the anecdotal information.
4. **Coordinate:** It would be helpful to coordinate with cooperating agencies early in the process to ensure special data or model outputs are selected to avoid having to backtrack, redo, or rerun models to get that data.
5. **Look at how anticipated extreme weather events may impact problem areas you defined using the interview process:** Future conditions will be different than those you experienced in the past. Stay connected to university climate research centers and your state climatologist.
6. **Model where future changes will impact transportation infrastructure and what those changes might be:** This is where hydraulic data from the Corps is essential. Have specific data on your facilities, such as elevation, for flood impact analysis. For example, be cognizant that the existing 1% ACE might become the 4% ACE when planning future projects, especially those with a long life cycle.

### 4.2.2 What are some tips for using floodplain and hydraulic data from a similar flood study?

We learned a lot about what data the Corps uses. As noted above, the Corps study was still in the early stages, and we anticipate we'll get more information about the plan as it is finalized. Not all Corps studies are conducted the same way, so your experience may differ. Below are some tips associated with using floodplain and hydraulic data from the Corps or local flood managers, and potential issues you should consider:

1. Use the flood study to identify areas subject to inundation (you may have to overlay your own asset inventory). Expect detailed hydraulic analyses of the main channel, especially where there are bridges across the channel.

2. The Corps is likely to focus its cost/benefit analyses on the reduction of inundation of structures related to the National Flood Insurance Program (you may want to highlight costs of replacement or repair of transportation assets).
3. Expect that different hydraulic modeling studies will use different tools. The specific modeling tools will be selected by the hydraulic engineering team to best meet the conditions at the study or project site.
4. Do not expect detailed hydraulic modeling of overbank flows. With the exception of alluvial fans, flood hazards in the overbanks are typically from inundation of slow-moving water. In this case, we were fortunate to have the results of a sophisticated 2D floodplain hydraulics model. This is why we used our data analysis process (see Section 2.4).
5. Do not expect detailed analyses of flood impacts to the structural highway system. Impacts will typically be discussed in general terms of inundation of the highway and the costs of diverting around the inundated segment of highway.

### 4.2.3 What kind of data should you gather?

We learned to pull from our own data sets to augment what we got from interviews and the Corps study. We recommend other state DOTs and MPOs consider pulling data that tells the story about how your assets fit into the community and the region. Show the transportation network in context with other flood or disaster-planning efforts or studies.

Some things we did that helped us create a solid context and broaden our adaptation approach are listed below.

1. We characterized the transportation functions of our current assets, such as ADT, Truck %, and Fed. Functional Classification.
2. We included drainage management infrastructure and topographic conditions that influence drainage.
3. We mapped other hazards like geologic/soils stability issues and tsunami or volcanic hazard zones.
4. We identified community resources (such as hospitals) that need access protection in an emergency event, or natural resources (such as wetlands) that need to be protected or avoided in an adaptation response.

# 5 Conclusions and Next Steps

This study builds on WSDOT's earlier pilot to examine adaptation options in an identified highly vulnerable area: the Skagit River Basin (Basin). Our pilot team collaborated with Skagit County and the U.S. Army Corps of Engineers (Corps). We examined information from local experts and from the Corps' Skagit River Flood Risk Management General Investigation Study (GI study). We achieved our goal of advancing the Federal Highway Administration (FHWA) Framework and integrating the state DOT adaptation strategy with a major flood study.

In our proposal to FHWA, we anticipated that our study would include the following outcomes:

- A set of site-specific adaptation strategies for the state-owned and state-managed transportation infrastructure.
- A replicable evaluation process, including a life cycle cost analysis of multiple engineering and nonstructural adaptation options to reduce risk to infrastructure.
- A plan of action for flooding and weather-related closures to improve public safety and enhance continuity of international freight flow along this corridor that considers future climate impacts.

As we complete this report to FHWA, we recognize that we delivered approximately half of the anticipated outcomes. We focused on processes to analyze flood study data in the context of DOT data availability and to develop "no regrets" adaptation strategies. We took a qualitative look at continuity of operations during weather-related closures based on lessons learned in the Skagit River Bridge collapse and for our "no regrets" strategies.

We have further work to do in the area of life cycle cost analysis. We set forth next steps to more fully scope adaptation options and deliver a plan of action.

## 5.1 What were our key accomplishments?

The key conclusion from our pilot study is that transportation agencies must engage with local and federal flood hazard mitigation project planning efforts.

We created a process for bringing flood studies, such as the Corps' GI study, into state DOT vulnerability assessment and adaptation strategy development. There is a synergy that comes from combining our efforts. When we work together, we can find solutions that might not be possible, and avoid problems that might occur.

We developed a list of "no regrets" strategies that will benefit the area whether or not the Corps' projects are built or there are more extreme weather events.

> "Here's what I would like to tell the partners when I next see them. We listened, we understand, and we want to work with you on the next steps."
>
> Team member comment

## 5.2 How do we summarize our work?

WSDOT's pilot project demonstrates the tremendous value that can be achieved by partnering with the Corps, flood managers, and county public works departments. As a result of this pilot, we started a conversation in the Basin that engaged a variety of partners. We leveraged the good work of Skagit County and the Corps. We can inform each other's work and reduce potential future conflicts by working together.

We developed a replicable process for state DOTs to use federal or other local flood studies in climate adaptation strategy development. Building on the process we used for our qualitative vulnerability assessment, we followed the process in Figure 2-11.

We show what DOTs can to with hydraulic information that is created for another purpose. We explain how we can work to better connect highway-related data to inform federal and local adaptation planning and investment decision-making. We all benefit by working together.

### 5.2.1 Integration (we can't do it alone)

We believe that, in order to be successful, adaptation strategies have to be integrated. The public sector (at all levels) must work with community groups and the private sector. Transportation managers need to coordinate solutions with public works and utilities. Drainage districts and flood protection managers need to work with tribes and cities.

Our pilot demonstrates the value of integration. We found locations where WSDOT—if unaware of the Corps' tentatively selected plan or local flood improvements—could invest in the wrong place and inadvertently block the flow of water that the Corps assumed would occur.

Our team's engagement with the Corps and the County on the Skagit GI study helps us do more than just react to their proposed solution: it makes WSDOT a willing partner in finding long-term solutions.

**Recent Encouragement from All Levels of Government:**

- President Obama's EO 13653 "Preparing the United States for the Impacts of Climate Change" (November 2013)
- Washington Governor Inslee's EO 14-04 "Washington Carbon Pollution Reduction and Clean Energy Action" (April 2014)
- Recommendations of the President's State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience (November 2014)
- FHWA Order 5520, "Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events" (December 2014)

### 5.2.2 What recommendations do we have for the Corps and USDOT?

We recommend that the Corps and USDOT:

- Work together to develop a strategy for integrating agency-sponsored planning efforts, to eliminate the potential for disconnects.
- Strive to reduce regulatory barriers between their two agencies—especially in the way that roads and highways are considered in the Corps' economic analysis (see the Letter to the Corps in Appendix A). We discovered that not all of the Corps' GI studies analyze roads the same way. The Chehalis Basin GI did analyze the impacts to roads, but the Skagit GI has not yet done so.
- Invite FHWA Division offices or the state DOTs to be cooperating agencies in major flood studies.

We recommend that FHWA and the Federal Transit Administration encourage transportation agencies (at all levels) to seek out flood risk-reduction strategies proposed by others— especially when undertaking regional and corridor-level studies. This study points out the advantages to DOTs of using federal flood studies.

### 5.2.3 What ideas do we have for further study?

More research and demonstration pilots are needed to identify and remove administrative, regulatory, and policy barriers that discourage preparedness (FHWA Order 5520[17]). We recommend that USDOT and the Corps conduct a coordinated research project to delve deeper into their current processes and agency missions to see where connections can be improved.

Local agencies are the unifying force bringing federal, state, and tribal policy goals together. There are many recommendations within the report[18] of the President's Task Force that should be mined for further study.

## 5.3 What next steps do we anticipate?

On December 15, 2014, FHWA issued Order 5520, *Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*. This order states that it is FHWA policy to integrate consideration of climate and extreme weather risks into its planning, operations, policies, and programs.

[17] http://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm
[18] http://www.whitehouse.gov/administration/eop/ceq/initiatives/resilience/taskforce

As a state agency, we work with both federal and local agencies. We are working with the state departments of Commerce and Ecology to develop guidance for local vulnerability assessments. We hope to coordinate with local governments on adding climate considerations into their Growth Management Act compliance and long-range planning efforts.

Internal to WSDOT, we will continue our work to integrate climate into decisions, including capital program investments and planning studies. Following are a few specific tasks we plan to work on in the future.

### 5.3.1 Within the Skagit River Basin

WSDOT will continue to work with the community on integrated long-range transportation/land use and emergency planning in Skagit County. WSDOT will monitor progress of the Corps' TSP and local investments, and continue to assess partnering opportunities.

- Members of the pilot team will continue to provide planning and technical support to evaluate and inform the TSP and other local proposals. Team members will conduct additional hydraulic analyses in the Basin using a variety of methods (see Appendix D, Hydrology and Hydraulics Methodology).

WSDOT will refine our plan of action for flooding and weather-related closures to consider future climate impacts and flood hazard-reduction changes in the Basin.

### 5.3.2 Statewide

As a result of this pilot project, WSDOT will integrate what we have learned into corridor planning and transportation studies. We will examine other flood hazard-reduction efforts (especially the Puyallup and Chehalis basins) to identify "no regrets" strategies in those basins.

WSDOT's Climate Change Evaluation guidance and our 2014–2017 agency strategic plan require consideration of climate impacts and discussion of resiliency. wŜŦŜǁ ŭ2 Goal 3 (environmental stewardship) from WSDOT's strategic plan at: http://www.wsdot.wa.gov/secretary/resultswsdot.htm

We will also look for funding to further our adaptation efforts. For example, WSDOT is on the team applying for the 2015 National Disaster Resilience Competition grant. The grant requirements illustrate the strong direction to create and sustain multisector, multijurisdictional, community-based resilience. We are observing that the potential for significant funding and the very detailed grant requirements constitute a strong incentive to work together.

> WSDOT plans and those major capital projects undergoing environmental review (at the NEPA EIS and EA level) in the 2013–15 Biennium will document how climate change and extreme weather vulnerability are considered, and propose ways to improve resilience. –
>
> *Results WSDOT (2014–2017 Strategic Plan)*

The department is committed to preparing WSDOT's Climate-Ready Action Plan for the 2015–2017 Biennium, to focus department efforts, including decision support (asset management and practical guidance), leading by example (best practices), and capacity building for WSDOT staff and our partners.

We look forward to more demonstration pilots and to working with FHWA in interpreting federal direction and new guidance emerging on the consideration of climate change impacts. Most of all, we are excited to work together to leverage federal, state, tribal, and local resiliency opportunities.


*Mount Vernon flood wall*

# Technical Appendix A: Supporting Documents

1. **Interviews with WSDOT Partners**
2. **Letter to the Corps**
3. **Sample Workshop Agendas**

# 1 Interviews with WSDOT Partners

## A-1 Identifying Initial Areas of Concern

As part of the data collection effort for this project, we wanted to understand where problems have occurred in the past on state facilities and infrastructure. The project team identified several sources to consider when defining initial "areas of concern," including the following:

- Partner interviews
- Historical flood data
- GIS to assist in analyzing other factors that intersect with the identified areas.

We used several steps to identify initial areas of concern in the project area.

### a. Project team identified partners in the project area

The table below shows the local jurisdictions, dike districts, utilities, and facility managers identified for interviews.

| Facility | Contact |
|---|---|
| City of Anacortes | City Engineer |
| City of Burlington | Public Works Director<br>Planning Director |
| Town of Concrete | Planner |
| Town of Lyman | Consultant Planner |
| Town of Hamilton | Consultant Planner |
| City of Mount Vernon | City Engineer |
| City of Sedro-Woolley | Public Works Director<br>Planning Director |
| Skagit County | EMS/Homeland Security Program Coordinator<br>Public Works County Engineer<br>Engineering Technician<br>Watershed Planner |
| Swinomish Tribe | Tribal Planning Director |
| Upper Skagit Indian Tribe | Public Works Director |
| Dike District 1 | Commissioners |
| Dike District 12 | Manager |
| Dike District 17 | Manager |
| Puget Sound Energy | Senior Engineering Specialist |
| WSDOT Maintenance<br>WSDOT Ferries | Maintenance Superintendent<br>Director Vessel & Terminal Engineering |

## b. We identified the purpose and objectives for the interviews

We wanted to understand the user needs, facility challenges, potential impacts, and shared vision for how to move forward. We went to our partners and asked them what they had encountered on the state system and within their communities.

## c. We then identified interview questions and support materials

We posed the following questions to each partner:

1. What issues concern you about hazard mitigation preparation in your community?
2. What areas are you most concerned with?
   Have you done any work recently that improved this condition?
   Do you have any improvement plans you are working on?
3. Are there state highway concerns you have?
4. How do you think these issues should be handled?
5. What concerns do you have when it comes to emergency evacuation coordination?
6. Follow-up questions based on dialogue with community.

## d. We developed data table with characteristics

From the information gathered during the interviews, we started to develop areas of concern that each jurisdiction felt warranted further review and mitigation efforts to help safeguard the system. We also utilized information provided in the Skagit County Natural Hazard Mitigation plan.

This was then added to GIS and analysis was run to determine which 31 factors and features would intersect these areas. The 31 data sets included summaries of the concerns; facilities and areas that need protections like hospitals and schools; firehouse and cultural sites; flood and stormwater features like discharge, fish passage, BMPs, FEMA q3 data and tsunami data; climate vulnerability results; existing WSDOT facilities; traffic data sets; landslips; and unstable slopes, to name a few.

Table A-1 is an example of a table we created after the interview results were incorporated into GIS and the additional factors were considered. This information was incorporated and further refined as the process moved into more in-depth GIS analysis of the GI study alternatives.

## Table A-1 GIS Metadata

| Skagit Climate Pilot- vulnerability information mapped by milepost as collected from past experience in this area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SR/Road | Jurisdiction | BMP | EMP | Flood | SLR | Land Movement | Winter storms | Comments |
| 5 | WSDOT | 219 | 226 | X | | | | Low area/ dike failure/High volume |
| 5 | Dike Dist. 12 | 220 | 225 | X | | | | Low area |
| 5 | WSDOT | 226 | 232.85 | X | | | | Low area/dike failure/high volume |
| 5 | WSDOT | 231 | 234 | X | | | | Sterling issue/ pond on I-5 |
| 9 | WSDOT | 41 | 43 | X | | | | 10 feet of water- Nookachamps |
| 9 | WSDOT | 49.82 | 49.88 | X | | | | Bridge |
| 9 | Skagit Co. | 51 | 54 | X | | | | Clear Lake |
| 9 | WSDOT | 54.38 | 54.56 | X | | | | Bridge over Skagit |
| 9 | WSDOT | 63.7 | 66.5 | X | | | | Water over roadway often |
| 9 | WSDOT | 70 | 71 | X | | | | Water over roadway often |
| 11 | WSDOT | 0 | 11 | X | X | X | | Water over road/ landslide |
| 20 | Skagit Co. | 44 | 47 | X | | | | Water over road |
| 20 | WSDOT | 51.56 | 52 | X | | | | Bridge |
| 20 | Dike Dist. 12 | 53 | 54 | X | | | | Culvert issue |
| 20 | WSDOT | 60 | 67 | X | | | | Sterling issue impacts |
| 20 | Hospital Dist. | 63.32 | | X | | | | Hospital |
| 20 | Everyone | 61 | 64 | X | | | | Sterling |
| 20 | WSDOT | 71.57 | 71.84 | | | X | | Very unstable |
| 20 | WSDOT | 75 | 87 | | | X | | Unstable Slope |
| 20 | Skagit Co | 74 | 74.5 | X | | | | Sedimentation /Water over road |
| 20 | Town of Lyman | 72 | 72.7 | | | X | | Landslide |
| 20 | WSDOT | 89 | 92 | | | X | | Landslide |
| 20 | WSDOT | 92.7 | 93.6 | | | X | | Unstable Slope |
| 20 | WSDOT | 98 | 100 | | | X | | Unstable Slope |
| 20 | WSDOT | 101.5 | 101.7 | X | | | | CED/ Channel migration |
| 20 | WSDOT | 109 | 116.5 | | | X | | Landslide |
| 20 | WSDOT | | 48 | | X | | | Sharpes Corner |
| 20 Spur | City of Anacortes | 49 | 51 | | | X | | landslide |
| 20 Spur | City of Anacortes | 49 | | | | | X | Ponds during heavy rain |
| 20 Spur | WSDOT FERRY | 55 | | | X | | | Sea Level Rise |
| 530 | WSDOT | 55 | 56 | X | | | | Channel migration |
| 530 | Skagit Co. | 56 | 56 | X | | | | Bridge |
| 530 | WSDOT | 62 | 63 | X | | X | | Erosion |
| 530 | Skagit Co. | 66 | 68 | X | | | | Water over road |
| 536 | City of Mount Vernon | 4.5 | 5.3 | X | | | | Downtown |
| 538 | City of Mount Vernon | 0 | 3 | X | | | | Dike Overtop |
| 538 | City of Mount Vernon | 2.5 | 2.86 | X | | | | Nookachamps |
| 538 | City of Mount Vernon | 3.47 | 3.53 | X | | | | Stormwater detention |
| 534 | WSDOT | 2 | | | | | X | Stormwater inundation |
| | ***Assumptions- Area - Skagit River basin in Skagit County*** | | | | | | | |
| | ***Anecdotal information from local jurisdictions/ WSDOT Maintenance/ Dike Districts*** | | | | | | | |

## A-2 Partner Interview Results

Following are the summaries of the 16 interviews we conducted during our investigation of initial areas of concerns. For this report, we focused on sharing the anecdotal information provided by each partner that represents existing hazards and concerns in their area of the county and their expertise.

### Partner Interview #1: City of Anacortes

| Interviewed: City Engineer | |
|---|---|
| Population | 16,080 |
| Elevation | 23 feet |
| Geographical Size | 15.53 sq. miles |
| Principal Economic Base | Industrial/Manufacturing |
| Highway | SR 20, SR 20 Spur |


#### *Hazards/concerns in the city:*

- It ponds when it rains hard in the fast lane of SR 20; it often accumulates and becomes pretty deep.
- The city's source of potable water is the Skagit River; the water treatment plant is located adjacent to the Skagit River near the City of Mount Vernon.

## Partner Interview #2: City of Burlington

| Interviewed: Public Works and Planning Directors | |
|---|---|
| Population | 8,500 |
| Elevation | 30 feet |
| Geographical Size | 4.42 sq. miles |
| State Highways | SR 20, I-5 |
| Principal Economic Base | Commercial |


### *Hazards/concerns in the city:*

- All areas in Burlington and the surrounding area are subject to flooding, with the exception of Burlington Hill.
- Levee protection is at approximately the 50-year storm event, with a 25-year profile.
- The 100-year elevation for protecting structures is 27 feet at I-5 and 40 feet at Gardner Road.
- The danger of flooding in Burlington is imminent when the river reaches the stage 38.1 feet. Maximum flood fighting using expedient floodworks is employed and evacuation is necessary, according to Skagit County's Emergency Management Department. Upstream of the Burlington Northern Railroad Bridge, the water is 3 to 4 feet higher because of debris and logjams and the effect of the bridge structure itself. In 2014, Burlington Northern Santa Fe (BNSF) started the discussion about seeking funding to replace the bridge or, at a minimum, remove the central piers of the bridge structure utilizing current construction technology.

- Debris collection under the BNSF Bridge is crucial to transportation connections. Commodities crossing this bridge have exponentially increased, including currently one train a day to Shell/refineries; however, four a day are predicted in the future.
- Whitmarsh Road is blocked at 23.5 feet.
- Hospital is vulnerable to events; contemplated having SR 20 elevated to act as dike to protect the hospital. A ring dike might be a solution.
- Evacuation of nursing home during an event and having a shelter in place is needed. The school district assists in this process.
- Collins Road might need a quick repair to help people get north of SR 20 to Cook road. Dam and rail line keep the road dry now at Sterling area, but has need of sandbags.
- Historical overtopping of the dike has occurred along SR 20 east of District Line Road. Path is across the railroad tracks and down SR 20 into town unless diverted to Gages Slough. If water is diverted to Gages Slough, the area along the slough is subject to inundation. If not diverted, it will go down the road and inundate the Northeast and North/Central Sectors, at a minimum. If extent of flooding has water going north of Burlington Hill, the Burlington Hill Industrial Park will be inundated (North/ Central Sector).
- Overtopping can also be expected at Whitmarsh Road at the cross dike, at the point east of Burlington Boulevard where the underpass takes off, and at points east along the dike (Natagani estate property).
- There is potential levee failure:
    - Near the Wastewater Treatment Plant at the bend in the river. At this location, the Northeast and South Evacuation Sectors will be inundated.
    - Between the railroad bridge and Burlington Boulevard or between Burlington Boulevard/I-5. At this location, inundation will occur in the South Sector, a major commercial and industrial area.
    - West of I-5 near I-5 Auto World. At this location, there are few residences, primary use is auto dealership; the Southwest Sector west of I-5 will be inundated. It is not likely that this will extend north of SR 20.
    - At or near Avon—Not in City Limits. This is west of the Urban Growth Area; however, numerous residences are located adjacent to the levee.

## Partner Interview #3: Town of Concrete

| **Interviewed: Contract Planner** | |
|---|---|
| Population | 750 |
| Elevation | 276 feet |
| Geographical size | 1.2 sq. miles |
| Neighborhood Characteristics | The Town of Concrete is a modest community consisting of 515 structures with and average value of $85,000 |
| Principal Economic Base | Institutional |
| Economic Characteristic | Economically Disadvantaged |
| State Highway | SR 20 |

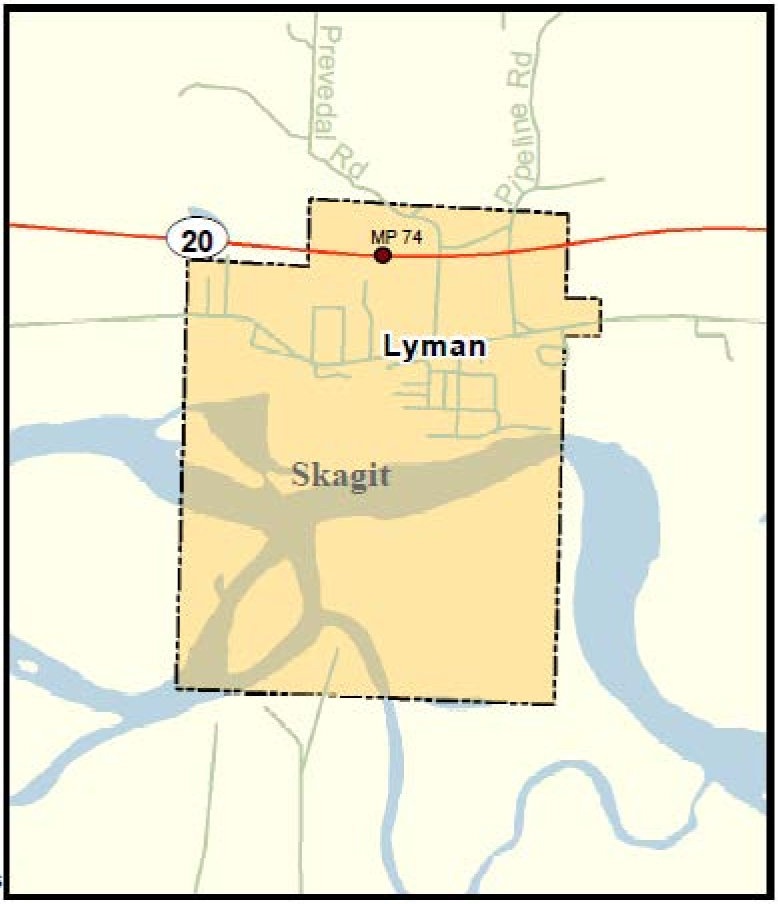

### *Hazards/concerns in the town:*

- There is low elevation of SR 20 through the town—at issue is how it is used to get from the north side of the community to the south and high side—at the high school. The town is working on getting a second off-ramp off SR 20 to provide additional access to this location.
- It is known that if the dam fails, the amount of water that could drain out would reach the community in 7 minutes. They have a warning siren at the high school to alert people to go to high ground.
- There is a municipal airport.

The community is planning to construct a new fire station/public safety building on high ground and out of the 100-year floodplain on Main Street. "Because of its age and its location at the top of an unstable slope that has been designated as a Critical Area (preventing any attempts to stabilize it), the current public safety building is vulnerable to partial or complete collapse because of an earthquake or bank erosion due to a severe flood event or dam failure."

## Partner Interview #4: Town of Lyman

| **Interviewed: Contract Planner** | |
|---|---|
| Population | 442 |
| Elevation | 95 feet |
| Geographical Size | .76 sq. miles (over 60.6% located in Floodway) |
| Principal Economic Base | Some Business and Industrial; Primarily Residential |
| Homes in City Limits | 165 Single Family, 1 Multifamily |
| Highway | SR 20 |




### *Hazards/concerns in the town:*

- SR 20 stays dry through town. Lyman is high and dry—no floods, but landslides farther to the west cause road to be closed.
- Areas within the Town of Lyman and adjacent to the Skagit River are protected by a small rip-rap levee. This levee was damaged during the floods of 1990; repairs were made by the US Army Corps of Engineers.
- During November 2–11, 2006, flooding of the Skagit River caused erosion of the rock revetment (levee) protecting the town.
- In the Town of Lyman, 60.6% of the incorporated land is in the Skagit River floodway, extending south to include the old Lyman Ferry Road across the Skagit River.

## Partner Interview #5: Town of Hamilton

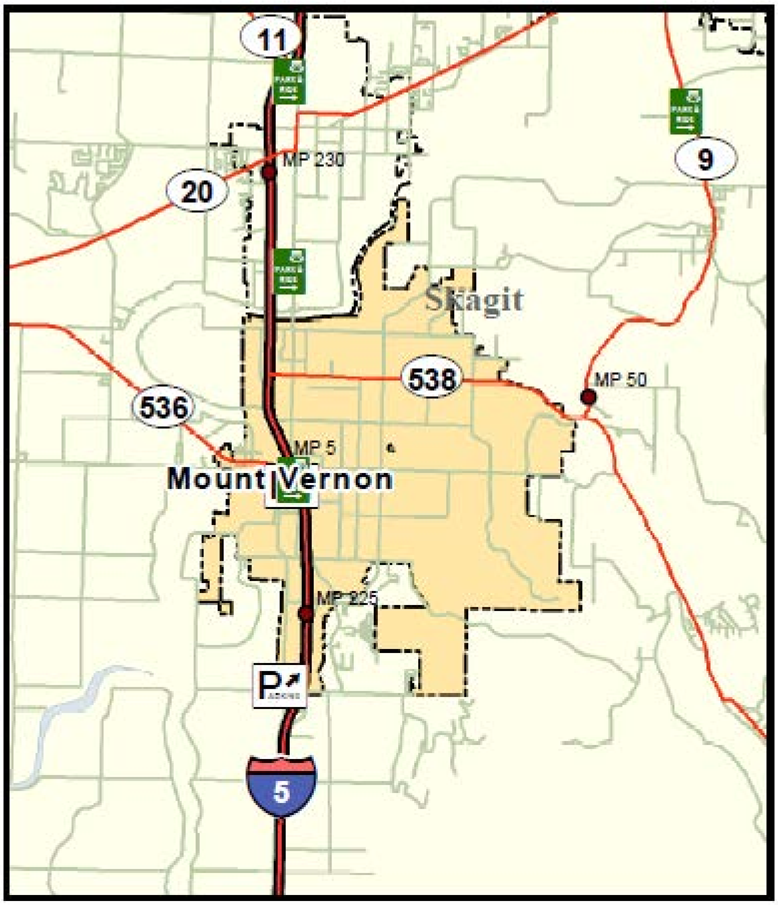
| Interviewed: Contract Planner | |
|---|---|
| Population | 301 (2010 Census) |
| Elevation | 95 feet |
| Geographical Size | .95 sq. miles (over 50% located in Floodway) |
| Principal Economic Base | Business and Industrial; 315 acres in use |
| Homes in City Limits | 103 Single Family, 2 Multifamily |
| Highway | SR 20 |


### *Hazards/concerns in the town:*

- 50% of town is located in the floodway and 100-year floodplain.
- Hamilton faces significant flooding every few years. The flooding is so frequent that many residents have a routine: move the furniture to the second floor of their home and then move to a local church until the flood subsides.
- Support has been building for a plan to move the entire town to a nearby hill. The Hamilton Public Development Authority was established in 2004 to purchase the land necessary for moving the town.

## Partner Interview #6: City of Mount Vernon

| Interviewed: Assistant Public Works Director | |
|---|---|
| Population | 31,743 |
| Elevation | 10 feet to 200 feet above sea level |
| Geographical Size | 12 sq. miles, 8,034 acres |
| Highways | I-5, SR 536, SR 538 |
| Principal Economic Base | Commercial, Government, Residential, Industrial |




### *Hazards/concerns in the town:*

- A significant portion of Mount Vernon is located within the 100-year floodplain.
- Portions of the city are located within a designated floodway.
- Portions of Mount Vernon are prone to landslides due to steep slopes, soil erosion, fractured rock faces, etc. Landslides occur with some frequency during winter storms, resulting in temporary road closures.
- Landslides east of town are an issue.
- If the rail line prevents trains from moving, it causes a blocking of emergency access to the majority of the community.
- A major impact to I-5 can cause havoc for the area in terms of access and congestion.
- If breached, the Skagit Highlands detention pond—earthen dam—will wash out to SR 538.
- On SR 538, water washes over the roadway at field past nursery. This is the route out of town.
- At 18 feet of water, there are rail bridge issues—debris collects and scours pier. Last time it scoured 90 feet of dike and almost took it out.

- If the dike broke between I-5 and the rail bridge, there would be little time to evacuate the area before 6-7 feet of water came over. Critical facilities that could be impacted: city police station, elderly residents, County Public Works, commercial center, and rail line.
- River bend is hard, with large flows that want to take a shorter, more direct path. There are no plans for dike setbacks.
- I-5 floods south of College Way by Blade Chevy dealership adjacent to I-5 by Lions Park at 100-year event.
- SR 536—floodwall underway—need only $5 million to finish up south end/Phase 3. It will protect SR 536 as well as county offices/sheriff, jail, courthouse, and sewer treatment facility.
- SR 538 is an emergency route—the emergency management center is located on the north side after the Community College.
- Currently, if the levee breaches to the south of downtown past the floodwall during 100-year event, the firehouse and city hall will flood from backwater.

## Partner Interview #7: City of Sedro-Woolley

| **Interviewed: Planning and Public Works Directors** | |
|---|---|
| Population | 10,610 |
| Elevation | 56 feet |
| Geographical Size | 4.16 sq. miles |
| Principal Economic Base | Retail and Commercial |
| Repetitive Loss Properties | Southern-most border next to Skagit River—no structures |
| Highways | SR 20, SR 9 |

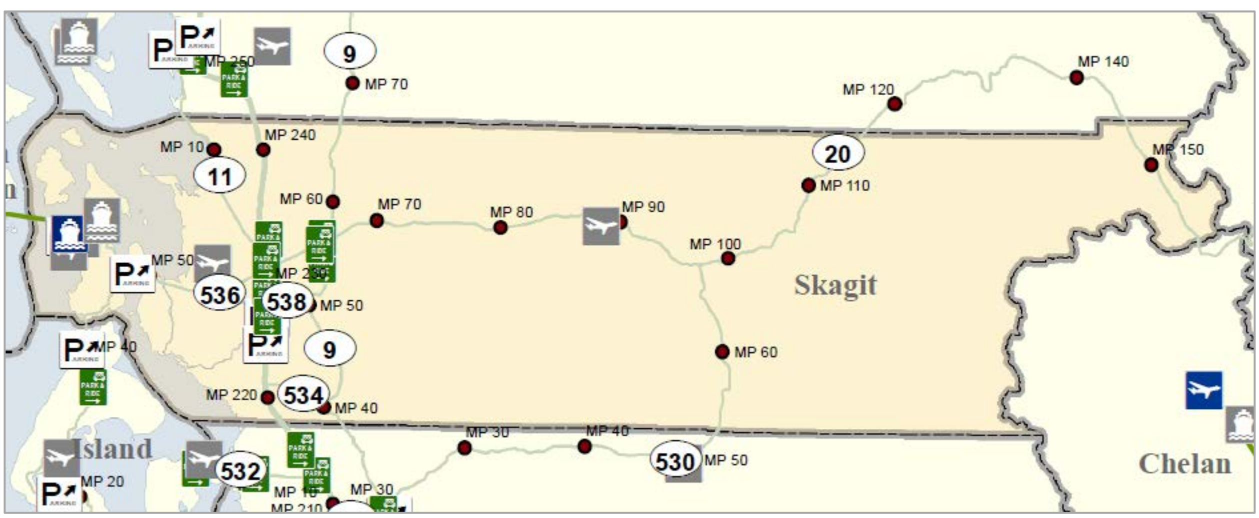

### *Hazards/concerns in the city:*

- A small portion of the City of Sedro-Woolley is located within the 100-year floodplain.

- Fruitdale Road (between Lotto and Portobello) going north needs to be fixed—it was washed out. It is an important alternative route north; it parallels SR 9.
- Access to the hospital is an issue during flood events when SR 20 floods.
- Sewer treatment protection is needed—it was almost lost in a 2006 flood. It is located within the 100-year floodplain.
- SR 9 is covered with water in the low-lying areas during a flood south of town.
- Portions of the City of Sedro-Woolley are prone to landslides due to steep slopes, soil erosion, fractured rock faces, etc.
- The Street Department shop and offices are located in the floodplain. This should be mitigated in place or moved out of the floodplain.
- Riverfront Park landfill, located at the very southern end of the city limits, is an old abandoned landfill. When flooded, this site has been known to have garbage enter the floodwaters.
- Brickyard Creek has had a significant amount of its floodwater storage capacity eliminated due to development. Any discharges into the stream system immediately surge downstream. Increasing this storage capacity would help to attenuate stream discharges. The WA State Fisheries Department has identified a potential site for additional flood storage on property south of Jones Road and west of the railroad, known as the Belles property. Transforming this site would help minimize local flooding.

## Partner Interview #8: Skagit County

| **Interviewed: Public Works County Engineer; Watershed Planner; Engineering Technician; and EMS/Homeland Security Program Coordinator** | |
|---|---|
| Population | 48,117 (2010 Census) Countywide 118,837 |
| Elevation | 56 feet |
| Geographical Size | 1,735 sq. miles, 67 sq/miles |
| Highways | I-5, SR 9, SR 20, SR 20 Spur, SR 536, SR 530, SR 538, SR 534, SR 11 |



### *Hazards/concerns in Skagit County:*

- A significant portion of Skagit County is located within the 100-year floodplain.
- Portions of the county are located within a designated floodway or in a coastal high-hazard V zone.
- Portions of the county are prone to landslides due to steep slopes, soil erosion, fractured rock faces, etc.
- Landslides occur with some frequency during winter storms, resulting in temporary road closures.
- With the exception of the George Hopper Road interchange (Exit 229), the entire I-5 corridor is within the 100-year floodplain.
- **I-5 MP 219-226**
  - County Maintenance facility in south Mount Vernon is at the 7-foot elevation—it would be flooded at a tide of 8 feet. Dikes have failed in the past.
  - Cook Road to South of Hwy 11 is the lowest elevation of I-5 at MP 223 and the most vulnerable location near Allen Elementary and High School in Burlington. Water moves around both sides of Burlington Hill and SR 20 at Gages Slough (south side of the Mall). If there is a levee failure, this is a point of impact, including ramps at SR 536.
- **I-5 MP 231-234**
  - Between the Bridge and Bucannan Hill starts to back up in minor events. By Babcock Road, Drainage, District 21, county would like to see floodgates under east fork of Nookachamps River Bridge. Clearlake area has gone under water on several occasions.
- **SR 9**
  - Some areas south of Sedro-Woolley are landslide prone.
  - Most of SR 9 above Sedro-Woolley is flood prone. Water flows over SR 9 often.
  - F&S Rd is prone to flooding from SW to I-5.
  - South Skagit Hwy has a history of flooding around bridge on SR 9. This is a County Alternative Route.
- **SR 9 MP 49.82-49.88**
  - In 1995, a flood caused the dikes to blow, and an area north of SR 538 was flooded by 10-foot flows.
- **SR 9 in Clear Lake MP 52-54**
  - This area has been made into an island—from water that surrounds it. This worries the EMS department because access would be by air.
- **SR 9 MP 63.7 to 66.5**
  - There is localized flooding over the roadway.
- **SR 11**
  - After a flood event, water can leave the system in low tide.
- **SR 20 MP 48**
  - The flood hazard map shows areas currently impacted by these tidal flows.
  - Pumps at Swinomish golf course worry the county; a 4-foot sea level rise will challenge the system.
  - When there are high tides, and winds blow from the north, a lane of SR 20 will be covered with standing water.
- **SE 20 MP 50.85 Berentson Bridge**
  - There are footing issues on some piers (more seismic issue).
  - There are eastside water issues.
- **SR 20 MP 51.56-59**
  - This road has not flooded in the last 27 years during 25-year events.
  - There is a flood concern at the bridge touchdown at Padilla Bay.
  - This area is vulnerable to levee failure.
- **SR 20 MP 60-67**
  - It gets inundated to the east at Hart Slough oxbow next to SR 20.

- Historically, the railroad south of SR 20 has acted as a dike to prevent water from coming into contact with the roadway. The trail is used to place sandbags to MP 62.5 Hospital Access at MP 63.06 and MP 63.34.
- This is still an active BNSF rail line.
- SR 20 is coincident with SR 9 in town until SR 9 resumes its north/south trajectory.

- **SR 20 MP 67-74**
  - This area has had some high-water events that have threatened the roadway.
  - In the last 27 years—during 25-year events—the road has been passable.
  - There is a risk that this low-elevation area could be blocked due to flood.
  - The pipeline creek is a concern—high-water events could fill cross culverts. Sedimentation is a growing issue in all high-precipitation events.
- **SR 20 MP 74-97**
  - The dam almost overtopped in 1996. In a 100-year event, dams will release water.
  - SR 20 is the evacuation route.
  - Cape Horn is flooded before flood event; slides on either side of Cape Horn; undersized culverts.
  - Rockslides cause erosion and mudslides at MP 90.
  - There are unstable slopes at Mud Hill.
  - Sauk Mountain Road at Rockport State Park is closed due to tree fall, old growth.
- **SR 20 MP 97**
  - When the river is running high, it eats at the riverbank and has threatened to wash out the road.
  - On several occasions in recent years, the riverbank has needed to be lined with large rocks to protect the highway from the barrage of water.
  - At MP 109, 110 goes under water.
  - There are slides on the alternate route.
- **SR 530**
  - Martin Road after the bridge in Rockport goes under.
  - Sauk River could eventually move closer to 530.
- **SR 536**
  - County has not seen any flooding resulting from the river cresting during 25-year events. There's a pump in that area.
  - The area used to flood in the 1900s. A 1951 event shows flooding. The City of Mt Vernon has worked to expand the floodway on the west side of the city, to allow the holding of extra flows—it removed several houses to accommodate this storage area on the north and south side of the SR 536 bridge.

## Partner Interview #9: Swinomish Tribal Community

| **Interviewed: Tribal Planning Director** | |
|---|---|
| Population | 3,300 |
| Geographical Size | 7,450 acres of upland |
| Tidelands | 2,900 acres of tribally owned tidelands |

### *Hazards/concerns in the area:*

- There are no floodplains or frequently flooded areas identified, delineated, or mapped within the Swinomish Indian Reservation.
- There are critical facilities in the area: social services/police station, medical center, dental clinic/ senior center, tribal administration office, planning department, housing department, gymnasium/ daycare/ community center, fisheries office, public works department, sewage treatment system, casino, gas station, fish plant, and water system.

## Partner Interview #10: Upper Skagit Indian Tribe

| Interviewed: Public Works Director | |
|---|---|
| Population | 504/450 on reservation |
| Highway | SR 20, I-5 |

### *Hazards/concerns in the area:*

- There are no floodplains or frequently flooded areas identified, delineated, or mapped within the Helmick Road Reservation or the Bow Hill Complex.
- The critical facilities in the area include sewer, water, roads, community facilities, and residential housing.

## Partner Interview #11: Dike District #1

| Interviewed: Commissioners | |
|---|---|
| Land Area Owned | 20 +/- acres |
| Miles of Dike/Levee | 9 miles |
| Value of Dike/Levee @ $3,500/linear ft | $166,320,000 |
| Number of Pumps | 0 |
| Value of Pumps | 0 |
| Number of Tide Gates | 0 |
| Value of Tide Gates | 0 |
| Value of Equipment Owned | $135,000 |
| Value of Area Served | $214,995,550 |
| Critical Facilities (owned) – Dike District Building | $114,700 |

### *Hazards/concerns affecting Dike District #1:*

- Upstream, the BNSF Bridge is a critical component that has impacts on downstream Dike and Drainage Districts, including Dike District No. 1.

## Partner Interview #12: Dike District #12

| Interviewed: Manager | |
|---|---|
| Land Area Owned | 160 + acres |
| Miles of Dike – Padilla Bay (value @$3,000/ft) | 9.5 ($150,480,000) |
| Miles of Levee – Skagit River (value @$3,000/ft) | 10 ($158,400,000) |
| Number of Pumps (value) | 3 ($170,000) |
| Number of Tide Gates (value) | 11 ($225,000) |
| Value of Equipment Owned | $2,000,000 |
| Value of Area Served | $1,650,637,750 |
| Highways | SR 20, SR 536, SR 11, I-5 |

### *Hazards/concerns affecting Dike District #12:*

- SR 20 has a possible culvert issue on Telegraph Slough west of weigh station.
- Padilla Bay access off dikes is needed for oil response situations.
- United General becomes an island when high flows hit.

- The debris load on RR bridge in Sedro-Woolley area is trash rack that backs up water and helps minimize flow down the channel. Complications occur when it breaks up; it backs up the system. Other back door issues hit Clear Lake before the Skagit River Nookachamps system hits it.

## Partner Interview #13: Dike District #17

| **Interviewed: Manager** | |
|---|---|
| Land Area Owned | 15 acres |
| Miles of Dike/Levee | 5.5 miles |
| Value of Dike/Levee @ $3,500/linear ft | $87,120,000 |
| Number of Tide Gates | 1 |
| Value of Tide Gates | $50,000 |
| Value of Equipment Owned | $150,000 |
| Value of Area Served | $370,238,800 |
| Highways | I-5, SR 538 |

### *Hazards/concerns affecting Dike District #17:*

- There is a concern with the Wal-Mart/Blade Chevy levee.
- Vulnerable areas are: I-5 and College Way/538, the rail line, and the police and county public works building.
- In the Sterling area, the concern is that it will have more flow toward SR 9 Clear Lake once the Comprehensive Urban Levee Improvement project is complete.

## Partner Interview #14: Puget Sound Energy (PSE)

| **Interviewed: Senior Engineering Specialist** |
|---|

### *Hazards/concerns affecting PSE:*

- PSE does not have any issues with the state system hindering its facilities in ways that keep employees from doing their jobs.

## Partner Interview #15: WSDOT Maintenance

| **Interviewed: Maintenance Superintendent** | |
|---|---|
| Highways | I-5, SR 536, SR 538, SR 534, SR 11, SR 9, SR 20 |

### *Hazards/concerns affecting WSDOT Maintenance:*

- **I-5**
  - I-5 has not flooded.
  - South of Skagit County at MP 215 undercrossing had high water but did not crest.
  - In Skagit County, there are high-water challenges at: Fish, Carpenter, Maddox, and Martha Washington creeks.
  - The WSDOT Maintenance office in south Mount Vernon is at 7 feet above sea level, but has never been under water.
  - In 1995, an event blew out the levy at Fir Island area west of I-5.

- **SR 9**
  - This area flooded when a dike blew out in 1995.
  - North of SR 538 was flooded at MP 52-54 by a 10-foot flow.
  - A challenge exists north of SR 534 at MP 41-43 where rocky hillsides blow out.
  - Flooding regularly occurs north of Sedro-Woolley on SR 9 at MP 70.
  - SR 9 has challenges with the Samish River at MP 64.
- **SR 20**
  - East of I-5, multiple flood points have occurred at: Bacon, Coal, Wiseman, and Corkindale creeks. Sometimes these events are the result of the river, and sometimes they occur due to saturation of the hillsides, which are unstable and create severe slides of debris onto the highway.
  - Due to a severe storm with winds, hundreds of heavily-leaved alder trees were snapped, causing debris to hit the highway at about MP 77.
  - In1996, Baker Lake Dam at Concrete almost overtopped at MP 89.
  - At MP 91, Mud Hill has a tendency to cause huge slides of debris about every 6 years. Also, 40 feet from the pavement, water overtops the hill toward the Jersey barrier.
  - Just before MP 63, water gets high often but has not yet crossed the road.
  - At MP 113, water flows over the highway during summer surges in the drainage next to the highway.
  - SR 20, west of I-5, has not flooded.
  - At Sharpes Corner (MP 47), during high tides and a southerly wind, water will cover most of the northern westbound lane.
- **SR 530**
  - The WSDOT facility at MP 39 has unstable slopes and creates severe slides, with large-scale debris on the highway.
  - Moose and Fink creeks have been known to recreate their channels of migration and cover the highway.
  - Government Bridge at MP 56 Suiattle confluence has scour issues, and vertical hillsides continually create slides at MP 60-61.

## Partner Interview #16: WSDOT Ferries Division

**Interviewed: Director, Vessel & Terminal Engineering**

### *Hazards/concerns affecting WSDOT Ferries Division:*

- At the Anacortes Ferry Terminal, sea level rise is a concern. The Ferries Division hopes to develop a new facility to accommodate the expected rise. No funding is available for development at this time.
- Storm surge and tidal change are operational issues that they are planning for.
- They will plan as conditions change, if they do not have a new facility that accommodates their needs.
- Ferry access is on SR 20 Spur/SR 20. Ridership is over 1.9 million a year, providing the only access to the islands. This service is expected to increase by 33% in 2030.

# 2 Letter to the Corps

**Washington State Department of Transportation**

**Lynn Peterson**
Secretary of Transportation

Transportation Building
310 Maple Park Avenue S.E.
P.O. Box 47300
Olympia, WA 98504-7300
360-705-7000
TTY: 1-800-833-6388
www.wsdot.wa.gov

August 4, 2014

Ms. Hannah F. Hadley
U.S. Army Corps of Engineers
CENWS-EN-ER – P.O. Box 3755
Seattle, Washington 98124-3755

*Sent via email to*: skagit.river@usace.army.mil

**Subject:** WSDOT comments on the Draft Feasibility Report and Environmental Impact Statement for the Skagit River Flood Risk Management General Investigation (GI)

Dear Ms. Hadley:

The Washington State Department of Transportation (WSDOT) was pleased to review the Draft Feasibility Report and Environmental Impact Statement for the Skagit River Flood Risk Management General Investigation. We fully support the efforts of the U.S. Army Corps of Engineers (Corps) and Skagit County to create a plan that will reduce flood damage in the basin over the next 50 years.

We, along with many stakeholders in Skagit County, applaud the Corps' efforts to move this very important piece of work forward, particularly since we are engaged in one of 19 Climate Adaptation pilot projects occurring across the nation. Our adaptation work is funded by the U.S. Department of Transportation's Federal Highway Administration (FHWA). Your work and the accompanying data will prove very helpful as we integrate our transportation adaptation planning with the flood risk reduction strategies found in the Tentatively Selected Plan (TSP).

In order to make the Corps product as useful as possible, we offer comments organized into the following three general areas:

1. Inclusion of transportation infrastructure in the structure inventory and as part of the economic impacts due to damage or failure
2. Emergency/evacuation plans
3. Flood risk reduction and highway infrastructure relationships

### 1. Inclusion of transportation infrastructure in the structure inventory and as part of the economic impacts due to damage or failure

**WSDOT:** We appreciate the inclusion of transportation delays as part of the Economics Appendix Section 4.3. We request the Corps EIS or refinement of the TSP also include the cost of structural degradation to transportation infrastructure due to flood impacts including: Interstate 5 (I-5), all other state highways, and other major public infrastructure as part of the structure inventory (or perhaps as another component to "Other Damage Categories").

Our top concern is maintaining the safe and reliable transport of people and goods throughout and through the basin (primarily north/south mobility from British Columbia Canada to central Puget Sound and points beyond).

State highways are infrastructure and should be accounted for in the "cost" side of the damage equation. Infrastructure is identified many times within the Draft Feasibility Report and Environmental Impact Statement:

- **Page 4:** *"Critical infrastructure in and around Mount Vernon and Burlington include I-5, Burlington Northern Santa Fe (BNSF) Railroad, State Routes 9, 20, and 536, numerous water and gas pipelines, light industry, and municipal infrastructure. There is also critical infrastructure in Sedro-Woolley includes State Routes 9 and 20 (critical local access routes)..."*
- **Page 10:** *"The purpose of the Federal action is to reduce flood risks, life safety threats, and damages in the Skagit River Basin as a result of flooding..." We recommend adding "including highway infrastructure."*
- **Page 13:** *"... critical regional infrastructure such as I-5 and State Routes 9 and 20, the BNSF railroad..."*
- **Page 22:** *"Critical Infrastructure in the Floodplain: Interstate 5 (I-5); BNSF Railroad; SR 20, SR 9, and SR 536..."*

We suggest including this list of critical state transportation infrastructure in:

- Table 3-2, page 24: Structures Inventory Under Existing Conditions
- Table 3-3, page 25: Value of Damageable Property
- Table 3-1, page 28, Appendix C: Structure Inventory Under Existing Conditions

We also recommend adding SR 11, county roads, and city streets in the inventory of structures.

It appears that the greatest risk to state highway infrastructure will be on SR 20 at Sterling, SR 9 in the Nookachamps, SR 11 as it crosses the Joe Leary Slough and I-5 between the new Burlington Levee and Bow Hill. We at WSDOT would like to continue assisting the Corps and Skagit County with these refinements. Also, WSDOT owns and operates drainage/stormwater infrastructure, which should be included in the flood flow return—post event drawdown.

Even though *"The CULI Alternative is the alternative that is the most cost effective, has the least real estate impacts, and has the least potential infrastructure impacts (3.9, TSP Recommendation, p-63"),* the cost-effectiveness of this alternative would be enhanced if highway, road, and streets were included in the comparison analysis.

In a recent WSDOT study (http://www.wsdot.wa.gov/projects/i5/sr534cookroadstudy/), the cost of improving I-5 through the Mount Vernon/Burlington urban area was over $1.5 billon. The existing asset value is unknown, but it will likely cost well over $1.0 billion to replace as it currently exists. Any significant flood impact would likely damage I-5 and its structures.

Finally, the GI study's goal is to …*"identify a plan that reduces flood risks and contributes to national economic development."* Transportation infrastructure is a proven vital component of the economy, as was demonstrated on May 23, 2013, when the I-5 Skagit River Bridge collapsed after being hit by an oversized load.

## 2. Emergency/Evacuation Plans

**WSDOT:** We request the Corps EIS or refinements to the TSP include WSDOT and the Washington State Patrol (WSP) in the emergency and evacuation plans.

The discussion of evacuations does not include WSDOT or WSP, both of which would be ver involved (Chapter 3, p-21). And in the Non-Structural Components, there is no reference to creating a coordinated multi-jurisdictional evacuation plan (Chapter 3, p-51).

## 3. Flood risk reduction and highway infrastructure relationships

**WSDOT:** We at WSDOT would value continued partnership with the Corps and Skagit County in an effort to further the relationship among flood risk reduction and highway infrastructure resiliency and severe weather adaptation. The following are important issues to WSDOT that should be refined in the TSP to meet our goals for our adaptation work.

FHWA and WSDOT are exploring how to leverage studies like the Corps GI Study to improve the resiliency of our highways in coordination with local and federal efforts to reduce flood hazards. Our job is to be as prepared as possible. WSDOT's pilot project will:

- Prepare site-specific strategies to improve state transportation infrastructure.
- Evaluate options and (where possible) estimate the life cycle costs of options.
- Develop a plan of action to enhance community emergency response and personal and freight mobility during and post-flood.

(See more info at: http://www.wsdot.wa.gov/sustainabletransportation/adapting.htm)

### Suggestions for TSP refinements:

1. It appears that the CULI does little to reduce the volume and velocity of water and its impact on the SR 9 corridor within the floodway—this may be an area of joint improvement that can help add resiliency to SR 9 and surrounding communities.
2. The Burlington Hill Cross Levee (BHCL) is good for the three-bridge corridor (reduces pressure), but will add to the likelihood of I-5 inundation from the Samish River to Chuckanut (SR 11). If Interstate 5 needs to be modified to increase resiliency, these plans should be coordinated with the Corps TSP.
3. The operations and maintenance of the "floodgates" that intersect SR 20, I-5, and SR 536 should be further defined in the TSP.
4. SR 11 has low-lying areas that could keep it closed for extended periods if it is flooded by water that is diverted through operation of the BHCL. In further refinements to the TPS, interior drainage and how pooled water would be evacuated after a flood event should be analyzed.

5. It appears that the levee expansion for Districts 12 & 17 will eliminate both Whitmarsh and Stewart roads. If there are opportunities to keep these roadways open, WSDOT should be a partner in that planning.
6. *"The increase in Sterling overflow could cause a ½ to ¾ ft. rise in 1% ACE flood elevations (in) the northern floodplain."* As the TSP is refined, the potential impacts to SR 20, SR 11 and I-5 should be determined.
7. Clarification should be included in the TSP with respect to the analysis of climate change (specifically, sea level rise) and how this affects both the Skagit River and tidal flooding beyond the boundary conditions used in the Skagit River hydraulics models.

## Correction:

1. Chapter 3, Page 54, refers to SR 9 as Chuckanut Drive. However, SR 11 is Chuckanut Drive.

Again, thank you for the opportunity to comment on the Skagit River Flood Risk Management General Investigation Draft Feasibility Report. We look forward to continued progress on flood risk management and improved resiliency of our highways in Skagit County.

Sincerely,

Todd Harrison, P.E.

Assistant Regional Administrator
WSDOT – NW Region/Mount Baker Area

Megan White, P.E.

Environmental Services Director
WSDOT – Headquarters

CC: Linea Laird, Assistant Secretary – Engineering and Operations
Amy Scarton, Assistant Secretary – Community and Economic Development
Carol Lee Roalkvam, Environmental Policy Branch Manager
Todd Carlson, Planning and Engineering Services Manager

# 3 Sample Workshop Agendas

**AGENDA**

**FHWA Pilot Project: Climate Adaptation Strategies for the Skagit River Basin**
**Vulnerability Assessment Mini Workshop**
**February 21, 2014 – 9:00 am to 11:30 am**
**WSDOT Mt. Baker Headquarters Office**

**Objective:** Information sharing. Review of initial road segments – update together.

| No. | Task | Time | Facilitator | Approach |
|---|---|---|---|---|
| 1. | **Welcome** | 9:00 – 9:05 | Team Leaders | *Safety briefing & housekeeping* |
| 2. | **Introductions** | 9:05 – 9:10 | Group | *Around the room* |
| 3. | **Workshop Purpose & Overview of Initial Road Segments Locations**<br>• Objective of the workshop<br>• Process Overview<br>*Asking the climate question*<br>*Climate impacts* | 9:10 – 9:20 | Team Members | *Use map as visual* |
| 4. | **Information Sharing from County**<br>• Corps process and timeline<br>• Planned public outreach (GI) | 9:20 – 9:30 | Team Members | *Brief discussion* |
| 5. | **Identify Transportation Assets and Criticality**<br>*Get specific information: Detours, current problems, problems during extreme events from County Staff* | 9:30 – 10:30 | Team Leader<br>All County Staff | *Sandy will record details for the highway segments from the expertise and perspective of the county* |
| 6. | **Discussion of Asset Vulnerability to Climate Impacts** | 10:30 – 10:45 | Team Leader | *Notes to record ratings – agreement from team* |
| 7. | **Meeting Wrap-Up & Next Steps**<br>• Communication Plan | 10:55 – 11:00 | Team Leaders | |

# AGENDA

## FHWA Pilot Project: Climate Adaptation Strategies for the Skagit River Basin
## ”Hands-On-Data” Workshop
## September 17, 2014 – 9:00 am to 12:15 pm
## WSDOT HQ – Rm 2A

**Purpose:** The purpose of this Pilot Team Workshop is to review available data (results of recent GIS and other technical info); brainstorm and document our initial observations; and reaffirm our approach (next steps, methods, tools, products).

**Welcome and Roles – 5 mins** (Team Leader)

**Overview of All Data Products – 30 mins** (Team Members)

- Project Boundary Map
- Flood Maps (10-yr, 25-yr, 50-yr, 100-yr)
- Areas of Concern Map
- Areas of Concern Tables
- Other

**“Hand’s-On-Data” Workshop – 120 mins** (Team Member)

Facilitate and capture key points and observations.

Key Questions:

- *What does the data tell us?*
    - Existing conditions now and into the future (no action)
    - Future conditions (with Corps project)
- *Where does all this information take us?*
    - Does this refine our “approach”?
    - Are there substantive changes needed in our tasks or work plan?
- *What information do we need for the next meeting?*

**Next Meeting Agenda – 5 mins** (Team Leader)

- Proposed Purpose: Review menu of adaptation options from other adaptation planning efforts; develop list of likely options (for No Action Alternative and for Corps’ CULI).
- Review work plan together to see if adjustments are needed.

**Action Items – 5 mins** (Team Member)

## AGENDA

**FHWA Pilot Project: Climate Adaptation Strategies for the Skagit River Basin**
**Strategies Workshop**
**October 13, 2014 – 9:30 am-2:30 pm**
**WSDOT NWR – Goldsmith Building RM 350**

**Purpose:** The purpose of this workshop is to have the team work through a process to define potential adaptation options for the "No Action" Alternative and "CULI" plans. The team will record the process and options for the identified locations.

**Welcome** – **5 mins** (Team Leader)

**Review State Routes with Flood Impacts – 15 mins** (Team Member**)**

- Tools: Table and maps

**Summary of Guiding Principles – 20 mins** (Team Member**)**

- Tools: White paper and TRB report

**Additional Filters to Consider – 15 mins** (Team Member)

**Define Process – 90 mins** (Group Discussion)

- Tools: Guiding principles, filters, FHWA model

**Adaptation Strategies – 5 mins** (Team Member)

- Tools: National Best Practices and local interviews

**Develop Matrix of Likely Options – 120 mins** (Group Discussion)

"No Action" list

"CULI" list

**Next Steps – 10 mins** (Team Leader)

**Action Items – 5 mins** (Team Member)

## AGENDA

**FHWA Pilot Project: Climate Adaptation Strategies for the Skagit River Basin**
**October 31, 2014 – 1:00 pm to 2:00 pm**

**Briefing** (Team Leader)

Provide briefing to technical team on Corps of Engineers Meeting

**Reviews** (Team Members)

- Review schedule and key milestones for the draft report and work plan
- Review Report Outline
  - Agree on format
  - Agree on process
- Review Strategies Matrix
- Review Work Assignments
  - Segment profile characteristics
  - Strategy matrix
  - Methodology & approach
  - Climate
  - Draft briefing presentation
  - List of graphics, charts and figures
  - Other based on report outline

**Next Steps** (Team Member)

- Set expectations for next meeting

# Technical Appendix B: GIS Methodology

# Overlaying the Impact Segments with Available GIS Data Sets

Elizabeth Lanzer, November, 2014

The process described below created tables that were simplified and interpreted by Mark Maurer to create the Segment characterization narratives provided in Appendix X (Profiles) of this report.

The project team identified datasets that would impact their evaluation of adaptation needs and options. They asked for some specific WSDOT datasets, and also asked for other data by general topic. To meet these needs, I used my 15 years of experience supporting WSDOT's environmental assessment work with GIS data and analysis, to pull over 35 data themes from the agency's 700+ dataset GIS library. These 35+ datasets were clipped to western Skagit County and saved to a local file geodatabase to provide for efficient geoprocessing.

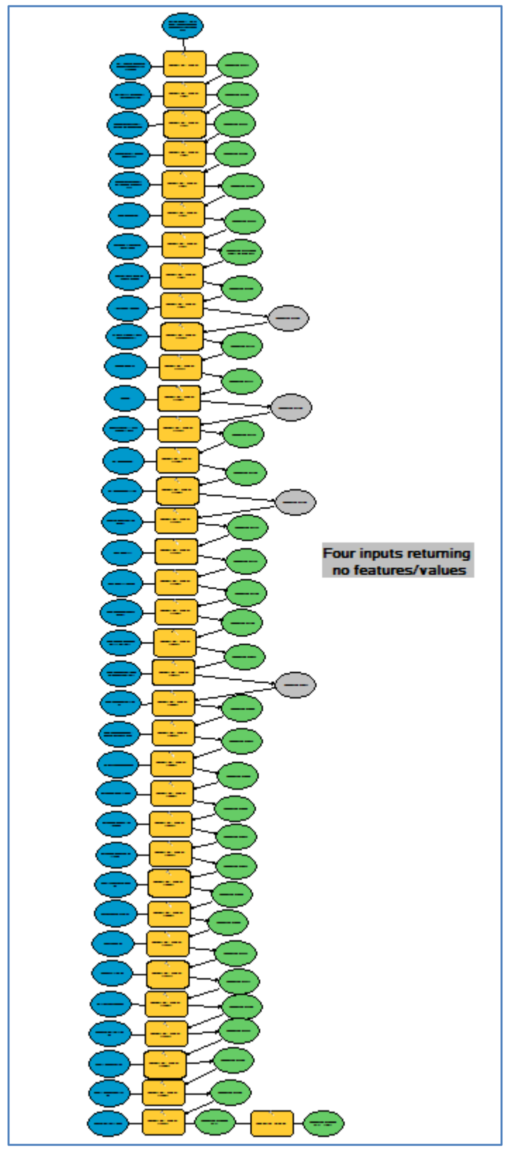



**Figure 1 Primary overlay geoprocessing model (not intended to be legible) showing how characteristics from 30+ layers were compiled onto the impact segments.**

The impact segments were defined using the further extent of impacts across all flooding scenarios as interpreted by Simon Page. These road centerlines were buffered by 200 feet (with flat ends to avoid intersections). 200 feet was used based on accuracies of the datasets being overlaid (1:12,000 – 1:100,000) and the desire to include rather than exclude nearby conditions.

The primary overlay consisted of about 35 cascaded Spatial Join operations (see graphic that is not intended to be legible but presented to illustrate the how the data was compiled into one feature class). Fields were dropped in the Spatial Join to leave only the key characteristic(s) that informed adaptation evaluation in the output. Merge rules were used to summarize multiple value returns. The feature attribute table was exported to Excel. In Excel, two tabs were prepared – one with the Impact segments as columns, and one with the Impact segments as rows.

Overlays for the soils groups and types were overlaid separately to provide a better characterization of soils types in a segment by % of a soils group like Hydrologic D or Hydric. The Soil Survey Geographic Database (SSURGO) soils data for Skagit County was clipped to the impact segment buffers, and then Statistics were run to summarize the area of each soils group within each impact segment.

To address "outlier" values in the primary overlay result, "Select by Attribute" then "Select by Location" tools were run against the highway characteristics datasets (Traffic, Federal Functional Class & Freight Class). The features on the impact segment highways were selected out by State Route attributes, then, re-selected for the individual segment's spatial extent to create tables showing the range of values falling within the segment buffer, but only on the segment highways. This was needed due to Segments 2 and 10 where the buffer overlay captured values from I-5 when those segments intersected I-5.

### GIS Data Input Screening

To help put the impact segments in context with the USACE Study and other local planning:

- Damage Reaches from the USACE Geotechnical Investigation (GI)
- County Comprehensive Plan Zoning

To characterize the Highway's core transportation functions:

- Average Annual Daily Traffic
- Truck percentage
- Design High Volume
- Federal Functional Classification

- Local Transit Routes
- Park & Rides
- Structures (bridges and under crossings)
- WSDOT Facilities (Sites, Buildings, Fuel Stations)

To characterize the drainage issues and infrastructure currently in place:

- Culverts & Culvert Ends (can't tell which ends go to the same pipes)
- Stormwater Discharge Points
- Approved stormwater treatments including
    - Ponds
    - Ditches
    - Slopes
    - Flow Restrictors
    - Energy Dissipaters
- FEMA Flood Zone / Floodway
- Chronic Environmental Deficiencies (locations requiring repeated maintenance due to recurring location based conditions that are typically drainage related – fixed or yet to be fixed permanently)
- Fish Passage Site Inventory (barriers, fixed structures, and non-barrier river/road crossings)

To characterize soils and geological conditions, other known hazards:

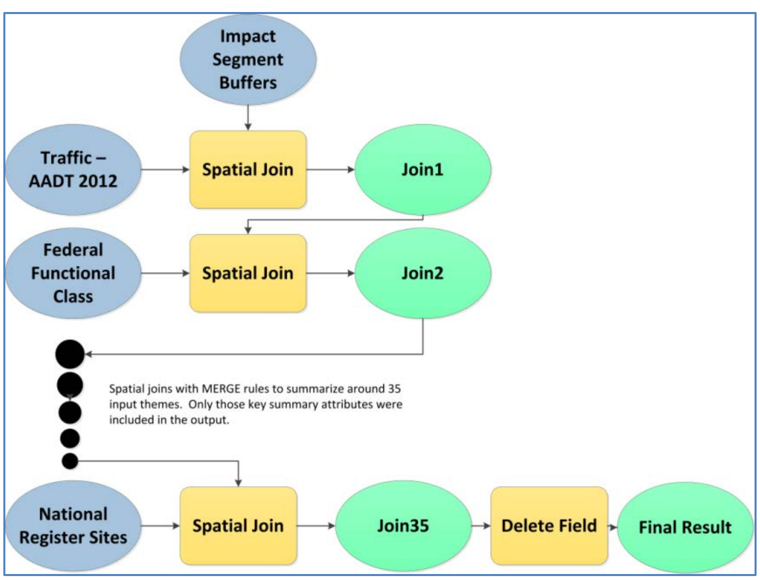
- NRCS Soils (SSURGO)
    - Hydrologic Groups
    - Hydric
- Landslides
- Unstable Slopes Along State Highways
- Liquefaction Susceptibility
- Tsunami Inundation / Evacuation Zones
- WSDOT Climate Impact Vulnerability Assessment ratings

To identify resources or conditions that should be protected or avoided:*

- Hospitals
- Firehouses
- Cemeteries
- Known National Register Sites (including barns)
- Confirmed or Suspected Contaminated Sites

*We wanted to get life-line routes, but weren't able to get to the right source in time for this analysis.

Alternative graphic for primary overlay:



# Calculating Flood Depth in the Skagit Basin

Stu Smith, October, 2014

This process describes how the maximum flood water depth, by flood year, for each raster cell was calculated.

Input data consisted of two sources:

1. Arc Grids from the Corps of Engineers that depict the flood water surface elevation (WSE) on a 400' X 400' cell size, based on a series of flood models based on two factors:
   - 10-, 25-, 50-, 100-, and 500-year floods
   - The location of where levees would breach ("scenario")
   - The grids were named in the form XXwYY, where XX = flood year (e.g., 25), and YY = scenario (e.g., 464, 1239)

2. A lidar-based Grid terrain model of the earth's surface on a 6' X 6' cell size: skagitmosaic

Step 1: Select – by flood year – the maximum water *surface elevation* at each 400' X 400' cell from among the various scenarios:

- The "Cell Statistics" Tool was used. Input grids were the several Corps of Engineers scenarios for that flood year (as described in #1 above), with the Overlay statistic = "maximum" and the "Ignore NoData" option checked on.
- The output was the maximum flood water surface elevation grid for each flood year (10 year was not calculated since there was only one scenario for that year), stored in max_surface_elevation_**XXX**_year_flood, where XXX = that flood year, e.g., 10, 25, 50 100, and 500.

Step 2: Calculate – by flood year – the water *depth* using the 6' X 6' cell size of the terrain model in #2 above.

This was calculated with the Raster Calculator tool. The algebraic expression is:

- (max_surface_elevation_**XXX**_year_flood – skagitmosaic)
- The output raster is: max_depth_**XXX**_year_flood
- Environment settings for the Raster Calculator tool were set:
- Raster Analysis > Cell Size > same as layer skagitmosaic
  - o This insures that the output grid will have the 6' x 6' cell size from skagitmosaic, rather than the 400' x 400' cell size from the max_surface_elevation_**XXX**_year_flood grids.

These results were posted to a file geodatabase depth.gdb containing ten rasters:

Five rasters created by Step 1 depict the maximum water depth, at a 6' X 6' cell size, that occurred among the various scenarios for each flood period. Depth was calculated by subtracting the earth's elevation (contained in the raster skagitmosaic) from the maximum flood surface elevation among the several flooding scenarios (the 10-year flood had only one scenario) for each flood period.

max_depth_10_year_flood
max_depth_25_year_flood
max_depth_50_year_flood
max_depth_100_year_flood
max_depth_500_year_flood

Five 400' X 400' flood surface elevation rasters created by Step 2 are also located in the geodatabase as:

max_surface_elevation_10_year_flood
max_surface_elevation_25_year_flood
max_surface_elevation_50_year_flood
max_surface_elevation_100_year_flood
max_surface_elevation_500_year_flood

Example, using the 50-year flood:

max_depth_50_year_flood = (max_surface_elevation_50_year_flood – skagitmosaic)

## Determining Which Flooding Scenario Contributed to the Greatest Depth for a Given Flood Year

Stu Smith, October, 2014

The process described below is a follow-up to the analysis that calculated the greatest flood depth for each flood year.

DOT scientists were not interested in 500-year floods, so analysis for that flood year was not attempted. Analysis was done for the other flood years: 10, 25, 50 and 100.

Tools used:

- Raster Calculator
- Cell Statistics
- Create Mosaic Dataset
- Add Raster to Mosaic Dataset
- Extract by Attributes
- Build Raster Attribute Table
- Set Null
- Highest Position
- Append

Prior analysis had determined the greatest flood depth that would occur at each cell, by flood year. However, DOT scientists were also interested in which flood scenario contributed to a given cell's greatest depth. Highest Position is the appropriate tool for determining which scenario contributed to the maximum depth. Unfortunately, simply running Highest Position is not sufficient because it will only output a value for those cells where ALL scenarios overlap (think Venn diagram). Where one or more scenarios do not overlap, Highest Position outputs nodata, which is unacceptable. This document describes the process for determining which scenario was responsible for the greatest flood depth for all overlap combinations.

The solution is to run Highest Position multiple times, once for each overlap combination. Here's how to identify each unique overlap combination, using the four scenarios for the 25-year flood:

| Scenario | Value |
|---|---|
| 464 | 1 |
| 1239 | 2 |
| 1379 | 4 |
| 2159 | 8 |

Using the 1, 2, 4, 8… sequence assures that the scenarios will be uniquely represented in subsequent analysis. Adding the "Values" for each scenario combination results in a unique "combination value". Here are the possible combinations for the 25-year flood (for example, 464 by 1379 results in 1 + 4 = 5):

| 2-way | Combination value |
|---|---|
| 464 by 1239 | 3 |
| 464 by 1379 | 5 |
| 464 by 2159 | 9 |
| 1239 by 1379 | 6 |
| 1239 by 2159 | 10 |
| 1379 by 2159 | 12 |

| 3-way | Combination value |
|---|---|
| 464 by 1239 by 1379 | 7 |
| 464 by 1239 by 2159 | 11 |
| 464 by 1379 by 2159 | 13 |
| 1239 by 1379 by 2159 | 14 |

| 4-way | Combination value |
|---|---|
| 464 by 1239 by 1379 by 1259 | 15 |

- (Note that the 4-way overlap creates the same result as using the default Highest Position, described above.)

Thus, every 1-, 2-, 3-, and 4-way overlap combination is uniquely represented by the numbers 1 through 15.

Flood years (such as 50) with just two scenarios, will use only the values 1 and 2, with 3 being the only possible combination value. Flood years with more scenarios will extend the 1, 2, 4, 8 sequence described above. For example, the 100-year flood has seven scenarios, assigned values of 1, 2, 4, 8, 16, 32, 64, with combination values ranging up to 127 (1 + 2 + 4 + 8 + 16 + 32 + 64 = 127). It is important that the values be consistently assigned in ascending scenario number order among all flood years; that is, the scenario with the lowest number, say 464, is assigned value 1, and the second-lowest number is assigned value 2, and so forth.

The analysis process starts by assigning the "values" to each scenario flood depth raster (e.g., depth_XXw_YY_int, where XX = flood year, such as 25, and YY = scenario, such as 464) that had been created in the preceding analysis, outputting the result to a new raster, named depth_XXw_YY_int_ZZ, where ZZ = scenario value:

(depth_25w_464_int * 0) + 1 = depth_25w_464_int_1
(depth_25w_1239_int * 0) + 1 = depth_25w_1239_int_2
(depth_25w_1379_int * 0) + 1 = depth_25w_1379_int_4
(depth_25w_2159_int * 0) + 1 = depth_25w_2159_int_8

- Note that multiplying the input raster "resets" it to zero, and the ensuing addition calculates every cell throughout the raster to that integer value.

Now, by adding the rasters, a sum of combination values can be created for each cell.

Use the Cell Statistic tool to generate a single output raster for each flood year.

- The output rasters from above are the inputs
- Overlay statistic is "sum"
- Ignore nodata is checked on.
- Environments > Processing extent = "union of inputs"
- Output name = depth_XXw_int_cellstats, where XX = flood year (for example, the 25-year flood name would be depth_25w_int_cellstats)

A polygon view of the overlap combinations for each flood year can be generated by 1) creating a Mosaic Dataset and 2) adding all the scenario depth rasters to the mosaic dataset. Then look at the polygon footprints to see which scenario combinations exist, along with the total number of scenario combinations. This two-step process starts with the Create Mosaic Dataset tool, used once per flood year:

- Output location = …\depth_scenario.gdb
- Mosaic Dataset Name = depth_XXw_mosaic_dataset, where XX = flood year
- Coordinate system = NAD83, State Plane North, FIPS 4601, feet

After creation, the Add Rasters to Mosaic Dataset tool is used, with:

- Raster Type = Raster Dataset
- Input Data = Dataset
- Source = the flood depth rasters for that flood year (e.g., depth_XXw_YY_int, where XX = flood year and YY = scenario)
- Update Cell Size Ranges and Update Boundary boxes are checked on

Continuing with the 25-year flood example, there are four polygon footprints with the combination values 1, 3, 12, 15. Note that not every possible combination will necessarily exist within each flood year; in this 25-year flood example only 4 out of a possible 15 combinations exist.

Next, the separate scenario combinations need to be "exploded" into separate rasters, for later use as masks. No "explode" tool exists, so the process must be done individually using the Extract by Attributes tool:

- Input is the Cell Statistics raster from above (e.g. depth_25w_int_cellstats)
- Where clause selects the appropriate combination value, e.g. "Value = 3"

- The output raster name is in the form of depth_XXw_gNN, where XX = the flood year, g stands for “grid”, and NN= combination value. For example, depth_25w_g3 is the raster for the 25-year flood where scenarios 464 and 1239 overlap (hence 1 + 2 = 3).
- This is repeated for each combination value. In the 25-year flood, here are the outputs:
  depth_25w_g1
  depth_25w_g3
  depth_25w_g12
  depth_25w_g15

Each of these output grids, therefore, simply delineates the rectangular grid extent covered by that particular scenario combination. However, within that extent there will likely be cells where all input layers are nodata. Such areas are of no interest since there is no possibility that any of the input layers would be responsible for the highest flood level. The following describes the process for determining what cells are all nodata:

The process ingests the depth rasters appropriate to a given flood year / scenario and sums the depth values. Previously, the nodata values had been converted to -100,000,000, so cells with large negative numbers were nodata. The size of the negative values indicated the number of overlapping depth rasters. For example, -200,000,000 indicated that two rasters were involved (for example, scenarios 464 and 1239). -300,000,000 would indicate three rasters were involved, and so on.

Note that some raster depth values were actually negative (below sea level???); however, none of them ever approached the magnitude of the -100,000,000 value.

The summation was done with the Raster Calculator tool. Here’s an example statement:

depth_25w_464_int + depth_25w_1239_int

The output raster is named sum_XXw_gNN, where XX is the flood year and Y is the scenario combination. Non-overlap cells are then converted to nodata with the Set Null tool with these parameters:
- Input conditional raster = sum_XXw_gNN (the output raster from the sum, directly above)
- Expression = the summed negative value according to the number of overlapping grids (for example, -200,000,000).
- Input false raster or constant value = Input false raster or constant value
- Output raster = maskXXw_gNN, where XX is the flood year and NN is the scenario combination

These above two steps (summation and set null) are contained in models hard-coded for each flood year / scenario combination. These models are named using the form summation_XX_gNN, where XX = flood year and NN = combination value. Each model has the following environment setting:

Model>Model Properties>Environments>Raster Analysis>Mask = depth_XXw_gNN. This mask raster, created above, is unique to each model and therefore is appropriately hard-coded for each.

The Set Null tool should, by default, create an attribute table for the output raster maskXXw_gNN. However, there were times when this did not occur. Therefore, at this point, inspect each of the output rasters and use the Build Raster Attribute Table tool if necessary.

The Highest Position tool is run next, once for each scenario combination. Manually enter the depth layers appropriate to a given scenario combination into the tool in a specific order. The entry order is critical, and must be consistent across all scenario combinations. Depth layers were entered according to their scenario number, in numerical order, with the smallest number first. For example, using the 25-year flood, 464 X 1239 combination, the depth layers were entered into the tool in this order:

depth_25w_464_int
depth_25w_1239_int

Since 464 is a smaller number than 1239, it was entered first.

Here's another example using the 25-year flood, 464 X 1379 X 2159 scenario combination (combination value= 13). The depth rasters were entered in this order:
depth_25w_464_int
depth_25w_1379_int
depth_25w_2159_int

The Highest Position tool's output raster is named:
highest_scenario_XX_year_floods_gNN, where XX is the flood year and NN is the scenario combination

The Highest Position tool's Environment Settings are modified, each time the tool is run, as follows: Environments>Raster Analysis>Mask>mask_XXw_gNN. This is the raster mask from the previous step, and its presence in the Highest Position tool's environment ensures that only non-nodata cells are output.

Then build a .vat with the Build Raster Attribute Table tool.

Note that if all scenarios have the same depth for a given cell, the Highest Position tool selects the first scenario in the input list by default. This was not a problem for the scientists when this work was done in 2014.

The final step is to merge all of the highest_scenario_XX_year_floods_gNN rasters, from the previous step, into one overall raster for that flood year. The output is named in the form:
highest_scenario_XX_year_floods, where XX = a given flood year

Ideally, the Mosaic to New Raster tool should work, but it fails, even with extensive troubleshooting review. Sadly, the Mosaic tool fails as well.

Append is the only tool that worked, but it required some caution:

1. Append combines input rasters into an existing target raster. For consistency, the lowest numbered highest_scenario_XX_year_floods_gNN rasters (from the prior step) were appended into the highest numbered raster. For example, for the 25-year flood combinations, these rasters:
   - highest_scenario_25_year_floods_g1
   - highest_scenario_25_year_floods_g3
   - highest_scenario_25_year_floods_g12

   were appended to:
   - highest_scenario_25_year_floods_g15

2. Since the Append tool overwrites an existing raster (in the above example highest_scenario_25_year_floods_g15 is overwritten) its original version needs to be preserved. This was accomplished by copying it to a remote .gdb prior to the append. After the append has completed, the overwritten raster was renamed and then the original raster was moved back to the working .gdb. Here's an example workflow:
   a. Copy highest_scenario_25_year_floods_g15 to a remote .gdb
   b. Append rasters to highest_scenario_25_year_floods_g15
   c. Rename highest_scenario_25_year_floods_g15 to highest_scenario_25_year_floods
   d. Move highest_scenario_25_year_floods_g15 from the remote .gdb to the working .gdb.

After the append process is complete, the text field "scenario" was added to the highest_scenario_XX_year_floods raster's .vat and populated manually, using the field calculator, with the text values for each scenario. For example, here's the .vat contents for the raster highest_scenario_25_year_floods:

| Objectid | Value | Count | scenario |
|---|---|---|---|
| 1 | 1 | 1497864 | Depth_25w_0464_int |
| 2 | 2 | 9457265 | Depth_25w_1239_int |
| 3 | 3 | 9022531 | Depth_25w_1379_int |
| 4 | 4 | 3092864 | Depth_25w_2159_int |

The scenario values' purpose is to identify and/or label each cell with the scenario that contributed to the highest depth for a given flood year.

The highest_scenario_XX_year_floods rasters are the final output product, and are intended for use by the scientists. They depict which scenario is responsible for the maximum depth at each cell, by flood year

The resulting rasters that identify which scenario within a flood year (10, 25, 50 and 100) contributed to the highest water level, per 6' X 6' raster cell across the Skagit basin:

highest_scenario_10_year_floods
highest_scenario_25_year_floods
highest_scenario_50_year_floods
highest_scenario_100_year_floods

These grids were overlaid on the maximum water level data grids. That enabled determining both the maximum water height and the scenario that contributed to it, by flood year.

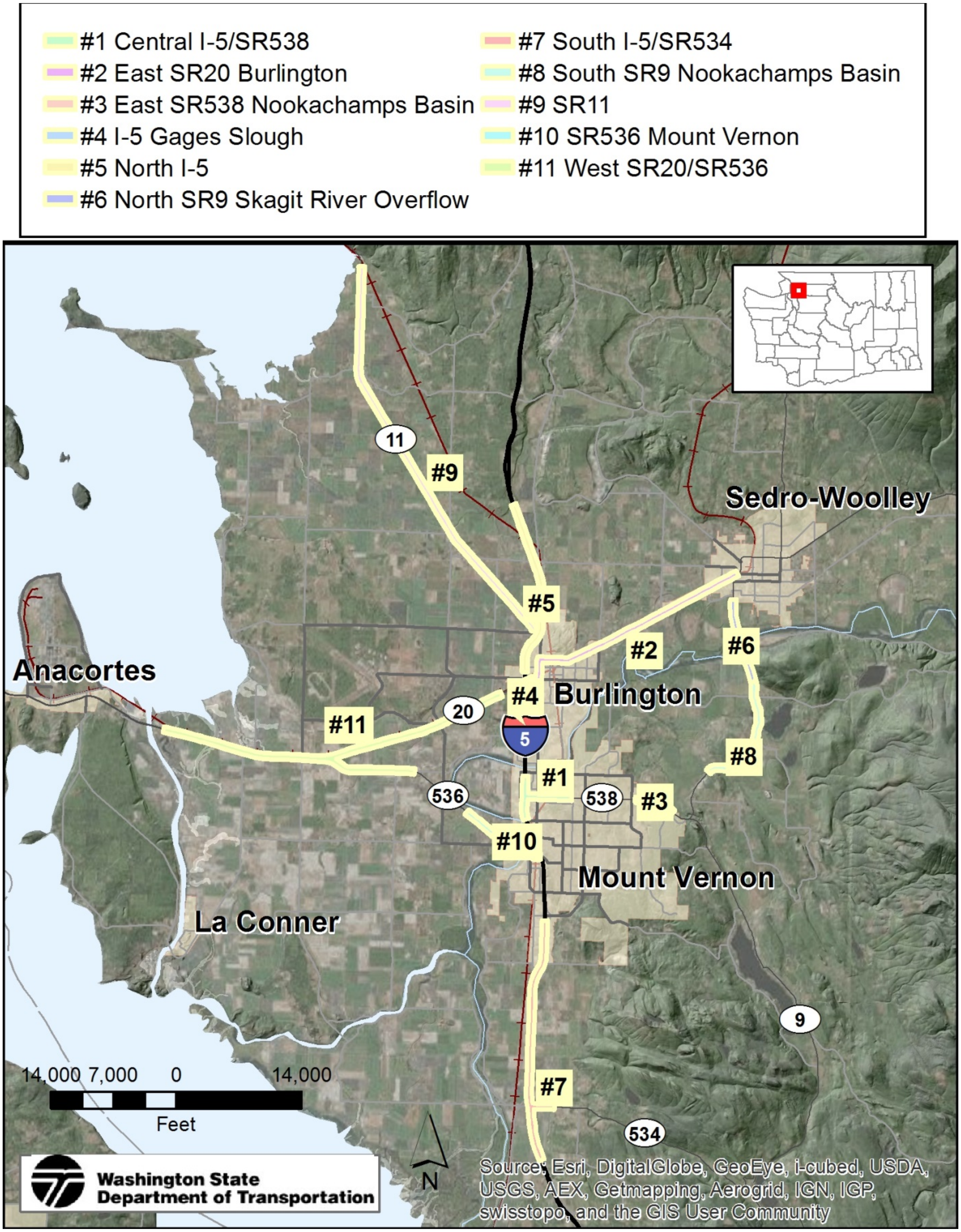
Two considerations with this data:

1. There was only one scenario for the 10-year flood, thus it is the only contributor for that flood year.
2. If two scenarios contributed equally to a cell's maximum water level within a flood year, the scenario with the smallest "scenario number" is recorded as the highest. For example, in the 25-year flood, scenario 464 would be given preference over scenario 1379.

This page intentionally left blank

# Technical Appendix C: Segment Profiles – Skagit Matrices

## Skagit Segment Index



## Segment 1, Central I-5/SR 538

| Segment ID | Highway Segment | CIVA* Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 1 | Central I5/SR538 | L, H | L, M, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 69000 | 11.5% | 11640 | 51, 54 | T1, T3 |

Segment Description

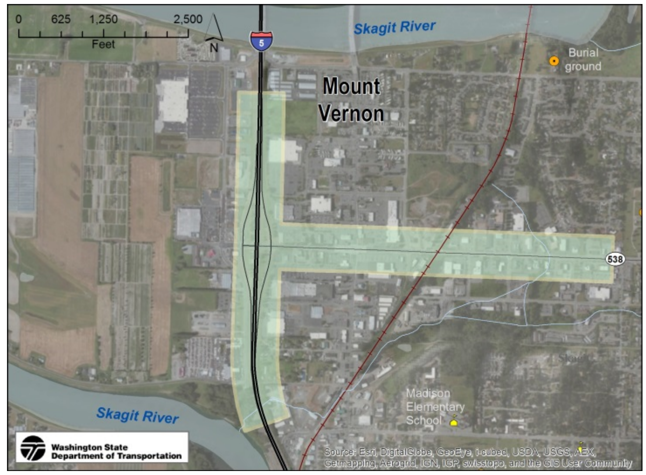
**Segment 1, Central I-5/SR 538:** I-5 (MP 227.25–228.17), SR 538 (MP 0–1.00)

This segment is in Mount Vernon. The Skagit River bends around Mount Vernon and frames the southern and northern segment boundary. I-5 is the main north-south corridor for the West Coast, and this segment has an AADT of 69,000. 11.5% of the traffic is truck traffic and it carries more than 10 million tons of freight per year. SR 538 carries between 300,000 to 4 million tons of freight per year. The DHV for this segment is 11,640. I-5 is classified as an Urban Interstate and SR 538 is classified as an Urban Minor Arterial. There is one bridge in this segment as well as six culverts. Five bus routes traverse the segment. The CIVA impacts to this segment are low to moderate for the 2-FT SLR condition and high for the 6-FT SLR condition. This segment is within the Mount Vernon Urban Growth Area. The land use classification categories that surround this segment include commercial, industrial, some residential, Skagit County Public Works, Mount Vernon Police Station, Skagit County Emergency Management, Skagit Valley College.

This segment experiences flooding in the existing 10%, 4%, 2%, and 1% ACE events. Maximum flood depths in the existing condition are:

| | 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|---|
| I-5 | N/A | N/A | 10.80’ | 11.19’ |
| SR 538 | N/A | N/A | 14.93’ | 15.33’ |

This segment is not flooded during the 1% TSP event. The segment is listed in Flood Zone A and X500.




| Adaptation Strategies |
|---|
| The flooding in this segment would be caused by a levee failure due to scour. This would be addressed by the TSP, and that is why no flooding occurs under the Corps' preferred plan. If this plan is built, then other alternatives are not needed to keep this segment functioning. However, if the TSP is not built, there are other options (in no particular order) that could make this segment more resilient:<br>• Work with local agencies and the Corps to purchase additional storage capacity behind the dams run by Puget Sound Energy.<br>• Work with the City of Mount Vernon to extend the floodwall to protect I-5, and SR 536.<br>• Raise I-5 above the flood elevation. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, X500 | – | 34 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 1 | 1 | 6 | Unknown |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | L-M, M-H, H | B, C, D | 9391895 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 204, 205, 207, 513, 8 | | UGA-CL/IND/RES/Public | Skagit Valley College | |

| WSDOT Site (Type) | | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|---|
| | 2 | | Y | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

## Segment 2, East SR 20 Burlington

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 2 | East SR20 Burlington | M, H | H, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 22900 | 11.5 | 11018 | 53, 54 | T2 |

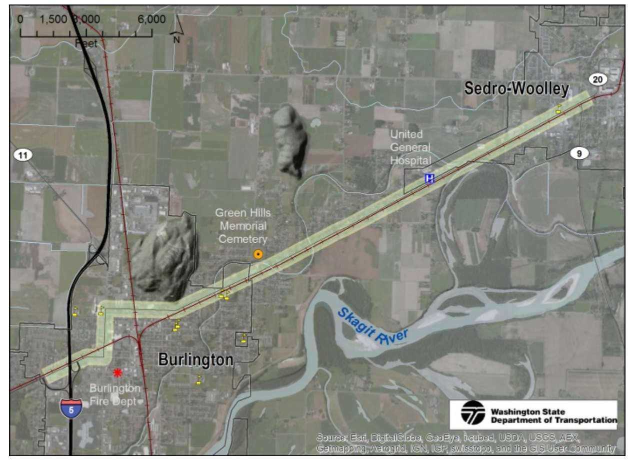
Segment Description

**Segment 2, East SR 20 Burlington:** SR 20 (MP 59.31–64.90) This segment includes SR 20 through the City of Burlington and eastward to Sedro Woolley. This segment is a principal arterial between Burlington and Sedro Woolley and serves two schools and United General Hospital. It has an AADT of 22,900, and truck traffic represents 11.5% of the total traffic. The segment has four freight tonnage classifications that range from more than 10 million to 300,000 million tons per year. The DHV for this segment is 11,018. There is one bridge in this segment and 12 culverts within the segment. At least one of the culverts requires repair to address fish passage issues. There are a high number (14) of culvert ends listed in this segment. That means that one end of the culvert has been located but not the other end. The segment carries four bus routes. The CIVA 2-FT SLR impacts are moderate to high and the 6-FT SLR impacts are also high. The land use categories that surround this segment include agriculture, rural, and commercial/industrial. It lies within the urban growth boundary. This is a Highway of Statewide Significance.

This segment experiences flooding in the existing 10%, 4%, 2%, and 1% ACE events. Maximum flood depths in the existing condition are:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| 1.69’ | 7.85’ | 6.33’ | 9.54’ |

This segment is flooded during the 1% ACE TSP event; however, a shorter length of road will be flooded than in the existing 1% event. The segment is listed in Flood Zone A and X500.




| Adaptation Strategies |
|---|
| This segment runs roughly parallel to the Skagit River and is mainly within the flood plain. The areas that flood during the 1% event are in low-lying areas. The adaptation strategy for this area would be to raise the road. This might be a viable option since the projected flood depths are less than 2 feet. Flooding in the 25% through 1% events is more extensive and much deeper than the 10% event; it is caused by levee failures or overtopping. The flooding in this area is not improved by the TSP. The GI STUDY estimates that the maximum flood depths would be deeper in this segment under the TSP.[1] Raising the road through this segment would be one adaptation strategy, but there would have to be large enough culverts or bridges to allow the water to pass from the Skagit River over to Joe Leary Slough. Other adaptation strategies for this segment include rerouting traffic on to Cook Road or F&S Grade Road. Because of the high number of culvert ends that are identified in this segment, it is possible that the other end may be buried or obstructed and not operating properly. If those culverts are not functioning properly now, fixing them might relieve flooding issues in smaller floods. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, X500 | – | 16 | SWD (3), RS(1) |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 1 | 1 | 12 (14) | Unknown, Repair Req. |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | M-H, H | B, C, D | 25548285 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 8, 513, 300, 717 | | Ag- NRL, RI, RB, UGA | Burlington Edison HS, Sedro Woolley | United General |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| | | | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

[1] Under the CULI, the Corps proposes to put a flood gate across SR 20 as a part of a new levee that would protect Burlington. This floodgate would close SR 20 for the duration of the flood.

## Segment 3, SR 538 Nookachamps Basin

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 3 | East SR538 Nookachamps Basin | L, H | L, M, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 8260 | 7.8% | 1622 | 54 | T3 |

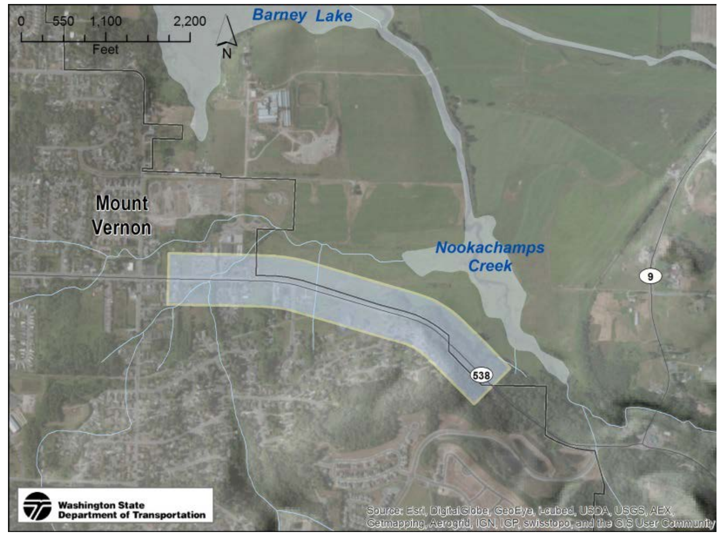
Segment Description

**Segment 3, SR 538 Nookachamps Basin:** SR 538 (MP 2.35–3.22)
This segment is classified as an Urban Minor Arterial and has an AADT of 8,260. 7.8% of the traffic is truck traffic, and it carries between 300,000 and 4 million tons of freight per year. The segment lies in Mount Vernon and connects I-5 with SR 9. It has one bus route but no other public facilities. The CIVA 2-FT SLR impacts range from moderate to high and the 6-FT SLR impacts are also high along this segment. There are no bridges, but there are six culverts, none of which is listed as a fish barrier. The DHV of the segment is listed as 1,622. The land use in this area is agricultural, residential, and commercial.

Flooding occurs through this segment during the 4%, 2%, and 1% ACE events with the following maximum depths:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| NA | 1.59’ | 3.49’ | 4.87’ |

The TSP makes the flooding in this segment worse and floods 0.40 miles more than the existing 1% event. The segment is in Flood Zone A.




| Adaptation Strategies |
| --- |
| The adaptation strategy for this segment would be to raise the road. It appears that this could be done to alleviate flooding for the more frequent flood events, but may be difficult for the 2% and 1% ACE events. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
| --- | --- | --- | --- |
| A | – | 16 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
| --- | --- | --- | --- |
| – | – | 6 (1) | |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
| --- | --- | --- | --- |
| – | VL, L-M | C | 3079740 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
| --- | --- | --- | --- | --- |
| 8 | | Ag-NRL | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
| --- | --- | --- | --- |
| | | | |

LEGEND

| | | | |
| --- | --- | --- | --- |
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

# Segment 4, I-5 Gages Slough

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 4 | I5 Gages Slough | H | M, (H) |

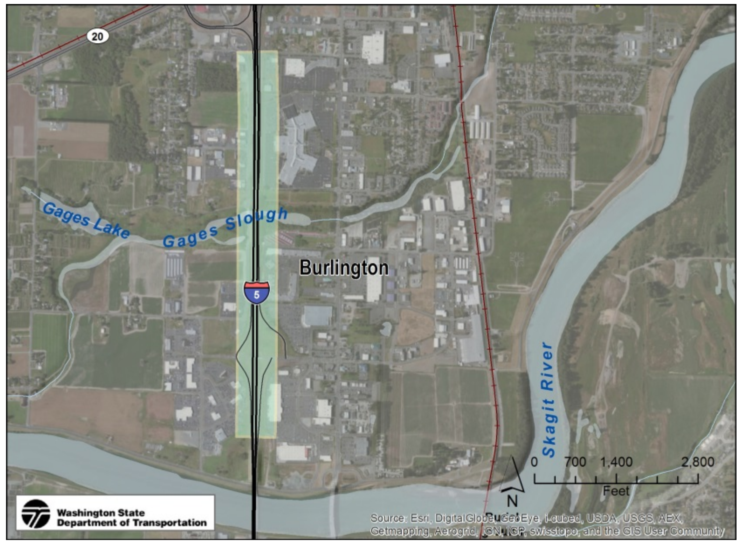
| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 66500 | 11.5% | 11018 | 51 | T1, T3 |

Segment Description

**Segment 4, I-5 Gages Slough:** I-5 (MP 228.61–229.86)
This is a Highway of Statewide Significance.
I-5 is the main north-south corridor for the West Coast, and this segment has an AADT of 66,500. 11.5% of the traffic is truck traffic and it carries more than 10 million tons of freight per year. The DHV for this segment is 11,018. I-5 is classified as an Urban Interstate. This portion of I-5 has three bridges and one culvert, which is not a fish barrier. There is one bus route that uses this segment. The WSDOT Mount Baker Project Engineer's office is located just adjacent to I-5 in this segment. The CIVA 2-FT SLR impacts for this segment are moderate and the 6-FT SLR impacts are high. The land use categories that surround this segment are commerical, public, agricultural, residential.

Flooding occurs through this segment during the 4%, 2%, and 1% ACE events with the following maximum depths:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| NA | 4.87' | 6.09' | 7.00' |




| Adaptation Strategies |
|---|
| The main adaptation strategy for this segment for the existing flood events is to raise the road. A “no regrets” strategy for this segment would be to make SR 9 less vulnerable to flooding. (Segments 6 and 8 could serve as alternate routes if I-5 is closed for any reason.) |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, X500 | – | 8 | RS (3) |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 3 | 1 | 1 (1) | |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | M-H | D | 5917999.7103650812 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 513 | | COM, INDU, RES, Ag | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| Mount Baker Area (Bld) | | | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps’ general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

## Segment 5, North I-5

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 5 | North I5 | L,H | L, M, H, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 66500 | 11.5% | 11018 | 41, 45, 51 | T1, T2, T3 |

Segment Description

**Segment 5, North I-5:** I-5 (MP 230.37–234.12) This is a Highway of Statewide Significance. I-5 is the main north-south corridor for the West Coast, and this segment has an AADT of 66,500. 11.5% of the traffic is truck traffic and it carries more than 10 million tons of freight per year. The DHV for this segment is 11,018. I-5 in this segment is classified as an Urban Interstate, a Rural Interstate, and a Rural Major Collector. There are ten bridges in this segment as well as seven culverts. None of the culverts is listed as a fish barrier. The 80X bus route and the Chuckanut Park and Ride lie within this segment. West View Elementary school is located in this segment. The CIVA impacts to this segment range from low to high, depending on exact location, for the 2-FT SLR condition and high for the 6-FT SLR condition. The land uses surrounding this segment include rural, agricultural, and commercial/industrial.

Flooding occurs through this segment during the 4%, 2%, and 1% ACE events with the following maximum depths:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| NA | 5.21’ | 4.65’ | 7.98’ |

Flooding occurs in this section during the 1% TSP event and covers 0.37 miles more than in the existing 1% event. The main adaptation strategy for this segment is to raise the road. The TSP sends more water to this segment of roadway, so the road would have to be raised to get above the higher flows as compared to the existing flood elevations. Another adaptation strategy would be to work with other agencies to secure additional water storage from Puget Sound Energy; however, this might not be a viable strategy with the TSP since the Corps has included that storage as an assumption for the TSP.


**Bayview 2009 – Land to the west of I-5**

| Adaptation Strategies |
|---|
| Raise road<br>Harden roadway to allow flows and protect road – high velocity location<br>Increase dam storage – work with Corps and local agencies to secure long term funding to purchase storage capacity from Puget Sound Energy |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| | – | 13 | FR (1), SWD (2), RS (1) |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 10 | 2 | 7 | |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | L, M-H | B, C | 15291350 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 80X | Chuckanut | Ag-NRL, RRc-NRL, RRv, RFS, RB | West View Elementary | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| | | | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

# Segment 6, North SR 9 Skagit River Overflow

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 6 | North SR9 Skagit River Overflow | M, H | M |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 9750 | 9.88% | 1836 | 45, 54 | T3 |

**Segment Description**

**Segment 6, North SR 9 Skagit River Overflow:** SR 9 (MP 53.49–55.37)
This segment of SR 9 lies in the floodway of the Skagit River and is one of three sections that have flooding during the 10% event. It has an AADT of 9,750. 9.9% of the traffic is truck traffic and it carries between 300,000 and 4 million tons of freight a year. The DHV on this section is 1,836, and the Federal Function Classes are Rural Major Collector and Urban Minor Arterial. There is one bus route on this segment. There are three bridges and two culverts and no fish passage barriers. Twenty culvert ends have been mapped on this segment. This indicates that there might be culverts that are not functioning properly since one of the ends might be blocked or buried. The CIVA 2-FT SLR impacts for this segment are moderate and this segment is not affected by 6-FT SLR conditions. The Sedro Woolley South Park and Ride lies within this section as well as a WSDOT gravel pit. The land use zoning in this section includes rural and agricultural.

Flooding occurs through this segment during the 10%, 4%, 2%, and 1% ACE events with the following maximum depths:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| 7.62’ | 10.52’ | 12.26’ | 13.02’ |

Flooding occurs in this section during the 1% TSP event; however, the flooding is less extensive and covers slightly less roadway than in the existing 1% event.


| Adaptation Strategies |
|---|
| "No regrets" strategies for this segment would be to build a new alignment out of the floodway or raise the road on a causeway in the existing alignment. Either option would eliminate flooding concerns for this segment and add resilience to north-south travel. SR 9 is an alternate route for I-5. Making this route less likely to flood will improve the resilience of the transportation infrastructure and provide an alternate route that would allow limited north-south traffic flow and access for county residents who would otherwise be stranded or face long detours. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, (FW) | – | 36 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 3 | – | 2 (20) | |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | Bedrock, L, M-H, H | B, C, D | 9703785 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 8 | Sedro Woolley South | Ag-NRL, RRv | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| Gravel Bar (Pit) | | | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

## Segment 7, South I-5/SR 534

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 7 | South I5/SR534 | L,H | L, M, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 63700 | 11.5% | 10633 | 41, 45, 54 | T1, T3, T4 |

Segment Description

**Segment 7, South I-5/ SR 534:** I-5 (MP 219.89–225.04), SR 534 (MP 0–0.5)

I-5 is the main north-south corridor for the West Coast, and this segment has an AADT of 63,700. 11.5% of the traffic is truck traffic and it carries between 10 and 300,000 million tons of freight per year. The DHV for this segment is 10,633. SR 534 has an AADT of 1,934 and truck traffic is less than 1%. I-5 in this segment is classified as a Rural Interstate and a Rural Major Collector. SR 534 is classified as an Urban Minor Arterial. There are four bridges in this segment and 25 culverts. At least one of the culverts is listed as a fish barrier, and others need to be evaluated. The CIVA impacts rating for these segments is low to moderate, depending on location, in the 2-FT SLR condition and high in the 6-FT SLR condition. The Mount Vernon Area 2 Maintenance Office is located along I-5. This is the only segment with a known active unstable slope. The land use zoning in this segment includes agricultural, rural, and commercial/industrial. It also lies within the urban growth boundary.

Flooding occurs through this segment during the 4% and 1% ACE events with the following maximum depths:

| | 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|---|
| I-5 | N/A | 10.62’ | N/A | 15.23’ |
| SR 534 | N/A | 12.13’ | N/A | 14.83’ |

Flooding does not occur in this segment during the 2% ACE under the scenarios prepared by the Corps. The different scenarios are based on levee failures at different places and result in the flood waters flowing to different areas of the basin. The levee failure in the 2% ACE causes the water to flow to the north of the river rather than the south so this segment is not flooded. Flooding does not occur in this segment under the TSP.


**Fir Island 2009 – To the west of I-5**

| Adaptation Strategies |
| --- |
| The main adaptation strategies for this segment are to alleviate flooding on SR 9 or to implement the Corps' TSP alternative. Changing SR 9 to alleviate flooding provides a detour route for I-5. Implementing the TSP alleviates flooding in the segment. Another alternative would be to work with the City of Mt. Vernon to extend its floodwall to the south to protect I-5 and SR 534. Further study is needed to determine if this option would protect I-5 and SR 534. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
| --- | --- | --- | --- |
| A | – | 9 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
| --- | --- | --- | --- |
| 4 | 2 | 25 (8) | Unknown, Repair Req. |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
| --- | --- | --- | --- |
| Active, settlement | L-M, M-H, H | C, D | 19523415 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
| --- | --- | --- | --- | --- |
| – | | Ag-NRL, UGA, RRv, RFS | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
| --- | --- | --- | --- |
| Mt. Vernon Area 2 (Bld, FS) | | WH Barn | Y |

LEGEND

| | | | |
| --- | --- | --- | --- |
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

## Segment 8, South SR 9 Nookachamps Basin

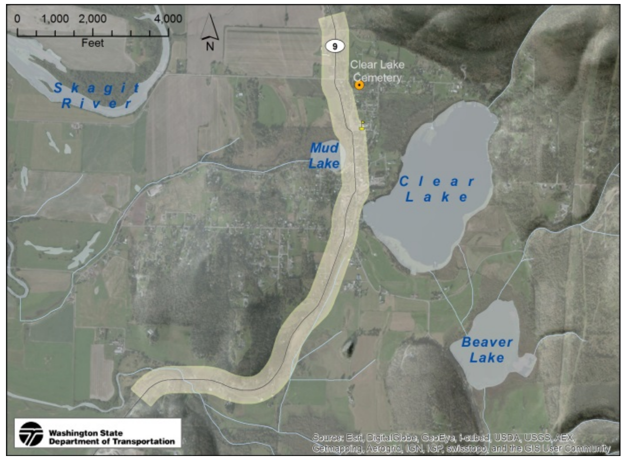
| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 8 | South SR9 Nookachamps Basin | M, H | M |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 9750 | 9.87% | 1836 | 45, 54 | T3, T4 |

| Segment Description |
|---|
| **Segment 8, South SR 9 Nookachamps Basin:** SR 9 (MP 50.92–53.57) This section of SR 9 has an AADT of 9,750. The truck traffic is 9.9% and carries between 300,000 and 4 million tons of freight a year. The DHV for this segment is 1,836. There is only one bridge in this section and two culverts; however, there are 95 culvert ends listed. The high number of culvert ends indicates that there may be many culverts that are not functioning properly. The CIVA 2-FT SLR impacts for this section are moderate. There are no impacts for the CIVA 6-FT SLR condition. The land use zoning within this segment includes agricultural, rural (including a rural residential village), and commercial/industrial. |
| Flooding occurs through this segment during the 10%, 4%, 2%, and 1% ACE events with the following maximum depths: |

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| 3.57’ | 6.94’ | 8.60’ | 10.05’ |

Flooding occurs in this segment in the TSP, and it covers a longer stretch (0.46 mile) of road than in the existing conditions. This segment is in Flood Zone A.




Clear Lake 2003

| Adaptation Strategies |
| --- |
| Realigning the highway or raising the road are the main adaptation strategies for this section of roadway. Further evaluation is needed to determine if raising the roadway is feasible in the flood-prone areas near Clear Lake. Realignment may be the only alternative in those locations. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
| --- | --- | --- | --- |
| A | – | 3 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
| --- | --- | --- | --- |
| 1 | – | 2 (95**) | |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
| --- | --- | --- | --- |
| – | Bedrock, L-M, M-H | C, D | 5540076.3419291675 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
| --- | --- | --- | --- | --- |
| 8 | | Ag-NRL, RRv, RVR, RVC, RB | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
| --- | --- | --- | --- |
| | | | |

LEGEND

| | | | |
| --- | --- | --- | --- |
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

## Segment 9, SR 11

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 9 | SR11 | L | L, H |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 4530 | 10.7% | 990 | 45 | T3, T4 |

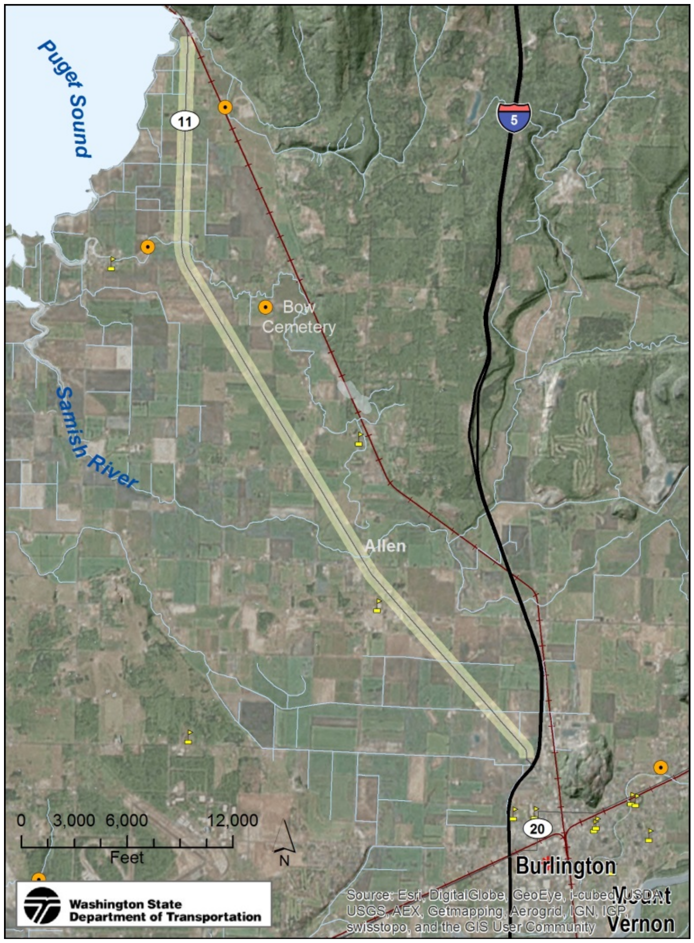
Segment Description

**Segment 9, SR 11:** SR 11 (MP 0.14–9.06) This segment has a low AADT of 4,530 and 10.7% of that is truck traffic. The DHV in this area is 990. It carries between 300,000 and 4 million tons of freight per year and is classified as a Rural Major Collector. There are three bridges and one culvert in this section. The culvert in this section is a barrier to fish passage. There are 95 culvert ends listed. This indicates that there may be a lot of culverts that are not functioning properly because one end is blocked or buried. There are no bus routes in this segment. The CIVA 2-FT SLR impacts for this segment are low and high. The high impact is due to wave action. In the CIVA 6-FT SLR condition, sections of SR 11 would be inundated. The land use zoning in this segment includes agricultural, rural, and commercial/industrial.

Flooding occurs through this segment during the 4%, 2%, and 1% ACE events with the following maximum depths:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| N/A | 6.00’ | 3.92’ | 6.80’ |

Flooding occurs in this segment in the TSP and it floods a longer stretch (2.48 miles longer) than the existing 1% event. This segment is in Flood Zone A and X500.




**SR 11 during the 2009 Flood Event**

| Adaptation Strategies |
|---|
| Raising the road is the only adaptation strategy for this segment. No "no-regrets" strategies were identified for this stretch due to its low AADT. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, X500 | X | 11 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 3 | – | 1 (85) | Repair Req. |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | M-H | C, D | 25733195 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| – | | Ag-NRL, RB, RRv, RC, NRI | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| | | | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

# Segment 10, SR 536 Mount Vernon

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 10 | SR536 Mount Vernon | M,H | H, (H) |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 20100 | 0.05% | 1052 | 53, 54 | T2, T3 |

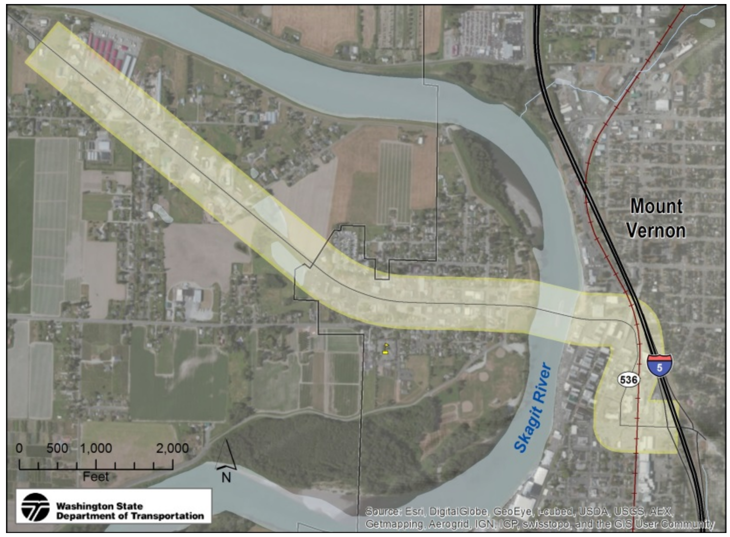
Segment Description

**Segment 10, SR 536 Mount Vernon:** SR 536 (MP 3.3–5.36)
The AADT on this segment is 20,100. The truck percentage is miniscule at 0.05% and it carries 300,000 to 4 million tons of freight per year. The route is classified as an Urban Minor Arterial. There are two bridges and two culverts on this segment. None of the culverts is a fish barrier. There are nine bus routes, and the Skagit STA and Mount Vernon Park and Ride facilities are located on this segment. The CIVA 2-FT SLR impacts are high and the CIVA 6-FT SLR impacts are high on this route. The CIVA looked at the route as a whole and noted flooding and SLR impacts. This segment lies within the urban growth boundary, and the land use zoning includes agricultural and rural.

Flooding occurs through this segment during the 1% ACE events with the following maximum depths:

| 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|
| N/A | N/A | N/A | 8.39' |

Flooding occurs in this segment in the TSP, but a slightly shorter segment of the road is flooded under the TSP than in the existing 1% event. This segment is in Flood Zone A.




**Sandbag Revetment during the 1980 flood event**

| Adaptation Strategies |
|---|
| There were no structural adaptation strategies identified for this segment. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A | – | 12 | |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 2 | 1* | 2 (1) | |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | M-H, H | B, C | 20175915 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 5, 8, 61, 204, 205, 207, 208N, 208S, 513 | Skagit STA, Mount Vernon Park & Ride | Ag-NRL, UGA, RRv | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| | | | |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

## Segment 11, West SR 20/SR 536

| Segment ID | Highway Segment | CIVA Criticality | CIVA Impacts Base (High) |
|---|---|---|---|
| 11 | West SR20/SR536 | M,H | H |

| Estimated AADT Max | Truck Percentage | DHV | Federal Function Class | Freight Class |
|---|---|---|---|---|
| 30580 | 13.2% | 5399 | 42, 43, 44, 53 | T2, T3 |

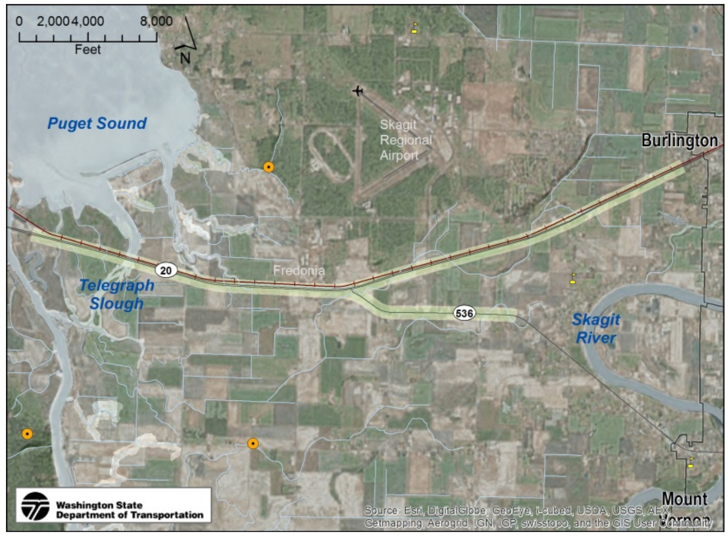
Segment Description

**Segment 11, West SR 20/SR 536:** SR 20 (MP 51.51–58.98), SR 536 (MP 0–1.89)
This segment contains a long portion of SR 20 and a short portion of SR 536 where it intersects SR 20. The AADT on SR 20 is 30,580 and 13.2% of that is truck traffic. This segment of SR 20 carries 4 million to 10 million tons of freight a year. It has a classification of Rural Other Principle Arterial and Urban Other Principle Arterial. The DHV is 2,385. SR 536 has an AADT of 7,418 and 4% truck traffic. It carries 300,000 to 4 million tons of freight a year and is classified as a Rural Minor Arterial. The DHV is 1,435. There is one bus route on this segment. There are nine bridges in the overall segment and 47 culverts; two of the culverts are fish passage barriers. The CIVA 2-FT SLR impacts for this segment are moderate or high due to flooding and sea level rise. The impact varies by exact location. The CIVA 6-FT SLR impact is high. The land use zoning along this segment includes agricultural, commercial/ industrial, and rural. It lies within the urban growth boundary.

Flooding occurs through this segment during the 4%, 2%, and 1% ACE events with the following maximum depths:

| | 10% ACE | 4% ACE | 2% ACE | 1% ACE |
|---|---|---|---|---|
| SR 20 | N/A | 10.25’ | 10.50’ | 12.00’ |
| SR 536 | N/A | 4.00’ | 5.00’ | 4.60’ |

Flooding occurs on both highways in the TSP, but a shorter segment of the road is flooded under the TSP than in the existing 1% ACE event. This segment is in Flood Zone A and X500.




**SR 20**

| Adaptation Strategies |
|---|
| There were many adaptation strategies identified for this section of roadway, but most of them were to allow the road to be brought back into service after a flood since the flood depths are so deep on SR 20. The one adaptation strategy that did alleviate the flooding was to build a causeway and get the road above the water. This would allow the water to move under the road. One adaptation strategy is to harden the road prism to allow the water to flow over it with minimal damage. Another is to make portions of the road sacrificial. Those areas would in essence be destroyed by the flood, but in doing so save other sections of the road. Both of these strategies might allow the road to be opened sooner after a flood event. Another adaptation strategy would be to find alternate routes for local traffic and work with the local governments to make those routes more resilient during flood events. |

| Floodzones (Floodway) | Tsunami Zone | Discharge Points | Stormwater BMP Type (#) |
|---|---|---|---|
| A, X500 | X | 42 | WDP (1), SWD (2), RS (53) |

| Bridges | Under Crossings | Culvert Inventory (End Inv.) | Fish Passage |
|---|---|---|---|
| 9 | – | 47 (6) | Repair Req. (2) |

| Unstable Slope | Liquifaction | Hydrologic Soils Group | Hydric Soils Area (sf) |
|---|---|---|---|
| – | M-H, H | C, D | 13741900 |

| Bus Route | Park and Ride Lots | Land Use Zoning | Schools | Hospital |
|---|---|---|---|---|
| 513 | | Ag-NRL, UGA, RB, RI, NRI, RMI, RRv | | |

| WSDOT Site (Type) | Haz Mat Sites | Historic Barns | Cemetery |
|---|---|---|---|
| | 1 | WH Barn | Y |

LEGEND

| | | | |
|---|---|---|---|
| AADT | annual average daily traffic | DHV | design hourly volume |
| ACE | Annual Chance of Exceedance | GI STUDY | Corps' general investigation |
| CIVA | Climate Impact Vulnerability Assessment | SLR | sea level rise |
| Corps | U.S. Army Corps of Engineers | SR | State Route |
| CULI | Comprehensive Urban Levee Improvement | TSP | tentatively selected plan |

# Technical Appendix D: Hydrology and Hydraulics Methodology

1. **FHWA Pilot Project: Skagit River Basin Severe Weather Adaptation Strategies**
2. **Bridges**
3. **Puget Sound Partnership Report: Near-Term Action WSDOT Floodplain Impacts Methodology for Bridges**

## 1.0 Introduction

The Washington State Department of Transportation (WSDOT) recognizes that floods may significantly impact the operations and maintenance of the state highway system. We anticipate that climate change will lead to not only an increase in the frequency and intensity of extreme weather events, but also in changes to patterns of precipitation, such as snow and the timing of the subsequent melting of that snow in the mountainous regions of Washington (Lee and Hamlet, 2011). The highway system may be damaged by the flow of water over the highway or simply by inundation.

Flow over the highway may cause scouring of the road surface, undermining of the pavement, scouring of embankments, washout of guardrails, accumulation of sediment on the highway surface and adjacent drainage facilities, accumulation of debris in hydraulic structures, and washing out of hydraulic structures (bridges, culverts, and stormwater facilities).

The Federal Highway Administration (FHWA) developed a methodology for estimating embankment damage to flood overtopping as well as evaluating protective measures (Chen and Anderson, 1987). Once floodwater overtops an embankment, erosion will occur when locally high velocities create erosion forces that exceed the strength of the embankment. Embankment failure begins with erosion of the downstream shoulder and slope. Figure 1 shows the typical progression of erosion over time from free flow over the embankment and a submerged flow over the embankment. With a low tailwater condition, the water accelerates over the top of the embankment and passes through critical depth and then forms an undulating hydraulic jump near the toe of the embankment. As the toe erodes, the material above becomes unstable and more erodible. As the tailwater depth increases, a hydraulic jump with standing waves forms just downstream of the grade break between the embankment top and slope.

Inundation may also be very damaging, although not readily apparent. Floodwater may alter the load-bearing characteristics of the roadway fill and underlying soil materials. Consequently, there may need to be a wait time until the road can be inspected and traffic can safely use the road.

Although it is beyond the scope of this analysis to conclusively define all the risks to the state highway system, in the balance of this section, we describe an approach to identifying segments of the state highway system that are vulnerable to flooding and bridges that may impact or be impacted by floodplain functions.

## 1.1 Goals

We have three primary goals in the provision of this analysis:

- Develop processes or procedures to identify segments or features of the state highway system that are susceptible to severe weather events and flooding under existing and future conditions.
- Develop processes or procedures to identify potential constraints that may be encountered when planning future projects, to reduce the risk of damage to the highway system.
- Develop processes or procedures to identify these features that can be applied statewide or even nationwide.

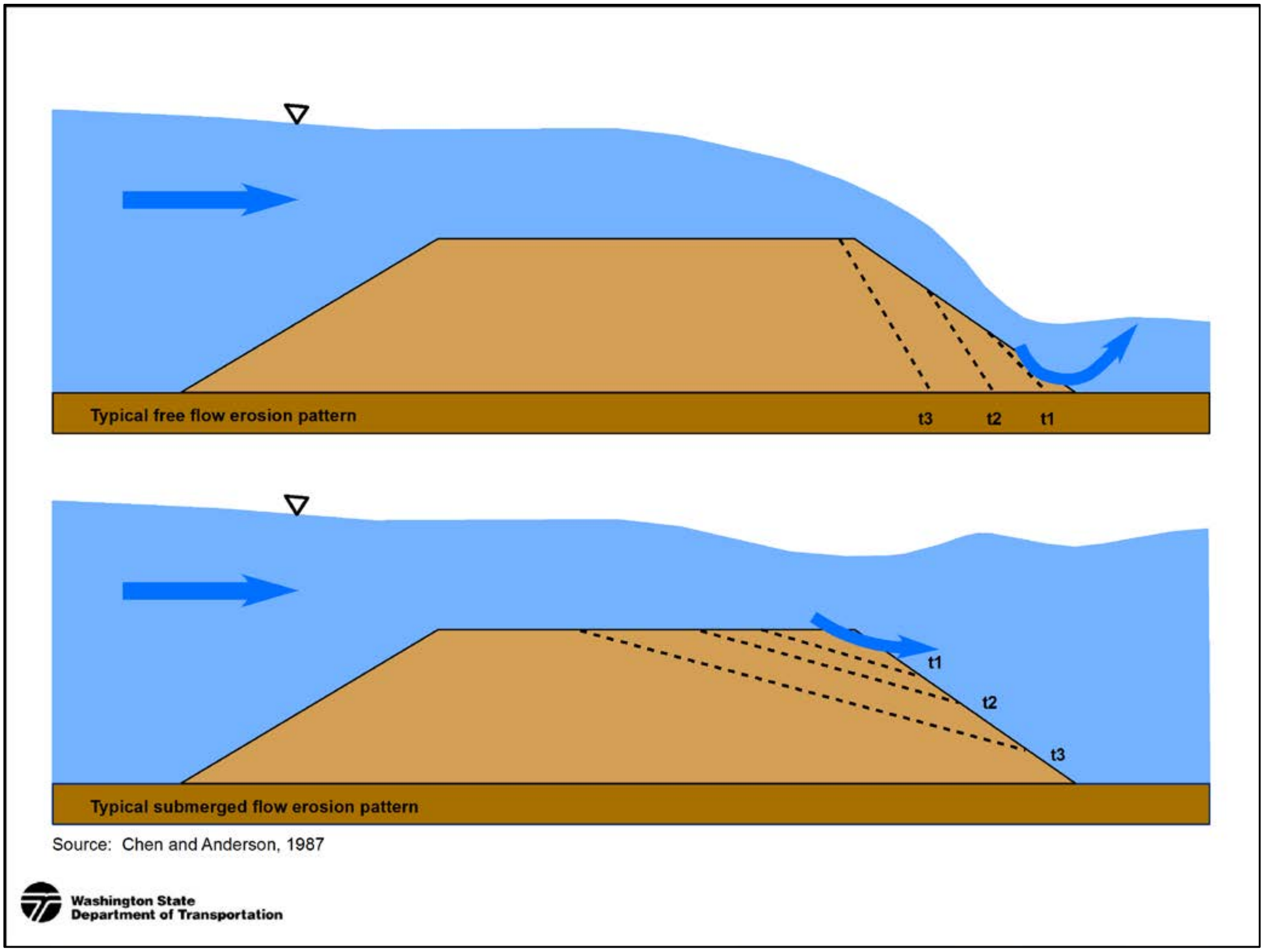



**Figure 1 – Typical embankment overflow erosion progression**

## 1.2 Objectives

Our objectives for the project are to develop processes and procedures to identify segments or features of the state highway system that are susceptible to extreme weather events by leveraging existing WSDOT data, along with data from other state or federal agencies and local governments. Specifically, we intend to:

- Develop processes and procedures using ArcView to process and store data to the maximum extent practicable.
- Collect and use existing data with a minimum amount of manipulation.
- Test processes and procedures.
- Identify weaknesses or problems with the processes and procedures.
- Revise processes and procedures.
- Identify and discuss lessons learned.

## 1.3 Processes and Procedures

We selected the Skagit River basin in Skagit County as the area to develop and test screening processes and procedures. The US Army Corps of Engineers (Corps) recently completed a General Investigation (GI) and draft Environmental Impact Statement (EIS) for flood hazard reduction on the lower Skagit River. This meant we would have access to an abundance of up-to-date topographic and land use data available, as well as a sophisticated two-dimensional hydraulic model that simulated overland flow in the floodplain.

Early in the process, we conducted a preliminary screening to identify WSDOT facilities that were subject to flooding, to define the study area and to identify segments of the highway system that may be susceptible to changes in the precipitation/runoff response due to climate change. In addition, local stakeholders such as diking districts, city and county public works, and WSDOT maintenance staff met to identify their areas of concern regarding flood hazards. These activities are summarized in the body of this report, and the detailed results are included in the Appendix A.

In the balance of this section, we focus on the development of processes and procedures to identify flood hazards that effect state highway facilities using the best available data, representing the conditions on the ground and the output from the hydraulic model developed by the Corps. In Appendix B we discuss the development of processes and procedures to identify constraints to future projects, such as critical facilities (hospitals), wetlands, endangered species, cultural resources, etc.

We further divided the flood hazard analysis into two parts—highways and bridges—as bridges themselves are rarely inundated but may be affected by scour and floodplain processes such as channel migration. Consequently, we developed separate methodologies and tests for highways and bridges. Each of those sections describes our development of preliminary processes and procedures, the data, problems encountered with the data or processes, revisions, results, and lessons learned.

# 2.0 Highways

Flow over the highway may cause scouring of the road surface, undermining of the pavement, scouring of embankments, washout of guardrails, accumulation of sediment on the highway surface and adjacent drainage facilities, and accumulation of debris in hydraulic structures, and washing out of hydraulic structures (bridges, culverts, and stormwater facilities.)

Inundation may also be very damaging, although not readily apparent. To the lay person, the obvious impact is that water on the roadway prevents traffic flow, and once the water drains away, the roads will be ready for travel. However, water alters the load-bearing characteristics of the roadway fill and underlying soil materials. Consequently, there may need to be a wait time (depending on the depth and duration of flooding, as well as the underlying soil materials) as the water drains from the fill materials, until the roadway can be inspected to determine if traffic can safely use the road. State highway engineers may need to evaluate the tradeoff between the user costs of road closure versus the costs of potentially increased road damage.

## 2.1 Preliminary Process and Procedures

As identified previously, the Corps recently completed a GI/EIS to reduce flood hazard in the lower Skagit River basin. As part of that project, the Corps created a high-resolution digital elevation model (DEM) of the land surface of the lower Skagit River floodplain, west of SR 9, using various LiDAR (light detection and ranging) and other topographic sources. The Corps then used this DEM as input to a two-dimensional hydraulic model (FLO-2D) to simulate the overland flow under numerous flood scenarios that represent the existing conditions. FLO-2D output is available as grid data of maximum water surface elevations, maximum depths, maximum velocities, direction of maximum velocities, duration of flooding to specified depth, and tabular data.

WSDOT intended to rapidly identity at-risk sections of the state highway system using ArcView to intersect the highway with the depth grids to identify what sections of road would flood and how deep. We intended to use velocity data to segregate flooded road segments into areas of "flow over the highway" or "inundation" to further refine the vulnerability to damage. The following steps outline this procedure:

- Use ArcView's 3D Analyst tool "Profile Stacker" to intersect WSDOT's road centerline coverage with the output grid data from FLO-2D and get tabular information of where the highway intersects the surface defined by each of the grid cell data sets.

## 2.2 Data

Skagit County, the Corps' cooperating partner for the GI/EIS, provided output data from the FLO-2D model. During the course of this pilot, only water surface elevation and depth grids were available for each model scenario; no other output data was made available by the Corps. They also provided the high-resolution DEM.

- **HIGHWAY DATA –** WSDOT has transportation facilities GIS coverage for the entire state.
- **DEM** – The Corps developed a DEM for the Skagit River GI that was used as the basis of their hydraulic analyses of various flood scenarios. This DEM was made available to WSDOT.
- **FLOOD GRID DATA** – The Corps' models were run for 21 flood scenarios. The scenarios included various return interval floods as well as alternative levee breach failures for most of the return interval floods.

## 2.3 Problems and Revised Procedures

When we examined the Corps' gridded output data, we found that output data was represented with a grid cell size of 400 feet X 400 feet and not the DEM cell size of 6 feet X 6 feet. The grid data for maximum velocities, direction of maximum velocity, and duration of specified depths was not provided during our pilot. We hope this data will be available at a later time. The FLO-2D model has the option to provide these outputs. We do not know if these data are available within the model or if the model would need to be run again with specific commands to get those output grids.

We also do not know how the FLO-2D model was developed. Was the output simplified, or was the 400-foot grid cell used in the computations? If the data had been simplified for presentation, it may have been possible to get the raw data. We reviewed the FLO-2D user's manual, which quickly settled the issue. The manual presented information regarding computational time based on the number of grid cells: a simulation with 50,000 cells would take about an hour to complete, and a simulation with 1,000,000 cells would take about a day to complete. Since the model output provided had approximately 55,000 cells and the DEM had 128 million cells, it became obvious that running the model on the DEM grid was not practical.

After a closer examination of the provided FLO-2D model output and the FLO-2D user's manual, we determined that that the depth grids and the velocity grids, if they had been available, could not be used as planned. Figure 2 shows a diagram of the basic FLO-2D input/output data. Briefly, the DEM was aggregated and represented as the average elevation of the 400-foot x 400-foot model grid cell (green bars on the figure). You can see that at some locations in the floodplain, the average elevation reasonably represents the land surface found in the DEM (brown line on the figure). At other locations such as at highway embankments, the average elevation masks features such as the highway embankment and roadside ditches. The highway embankments and other linear features that may obstruct flow, however, are included in the model as “levee cards” that modify the hydraulic properties of the grid cell boundary (orange box on the figure).

The FLO-2D model is run by applying the flood flow boundary conditions to the model grid. The water surface elevation is then calculated based on the calculated grid cell ground elevation, assumed roughness, and any special grid cell boundary conditions. The maximum water surface elevation for each run is recorded (blue bars on the figure). The maximum depths are calculated by subtracting the calculated ground elevation from the maximum grid water surface elevation from the calculated ground elevation. The maximum velocities are then calculated by dividing the flow through the grid by the product of the grid cell width and the average depth. As described by Chen and Anderson, the maximum velocity occurs just downstream of the grade break on the embankment; the precise location is dependent on the tailwater elevation, which is variable through a flood event. Consequently, as shown on Figure 2, the maximum depth and velocity grids, if available, could not be directly used to evaluate the risk to affected highway segments, as they oversimplify the complex ground elevations and hydraulic conditions found where flood flows overflow the highway embankment (Figure 1).

We revised the screening process to subtract the road surface elevation from the water surface elevation grids to determine depth of flooding. We accomplished this by using the ArcView’s 3-D Analyst tools with WSDOT’s road centerline data, the DEM, and the water surface elevation grids to determine depth of flooding. Following is the process we used:

- Intersect highway centerlines with the DEM and water surface elevation grid data using the ArcMap 3-D Analyst Stack Profile tool to identify the ground surface and water surface elevations along the highway centerlines.
- Use column math to subtract the ground surface elevation from the water surface elevation to determine the depth of flooding within ArcView for each flood or alternatively export the data to Excel for processing.

The results of the process would be a table of approximately 6-foot-long road segments with the ground elevations, water surface elevations, and water depths for each flood scenario that could be manipulated within ArcView or with an outside application like Excel.

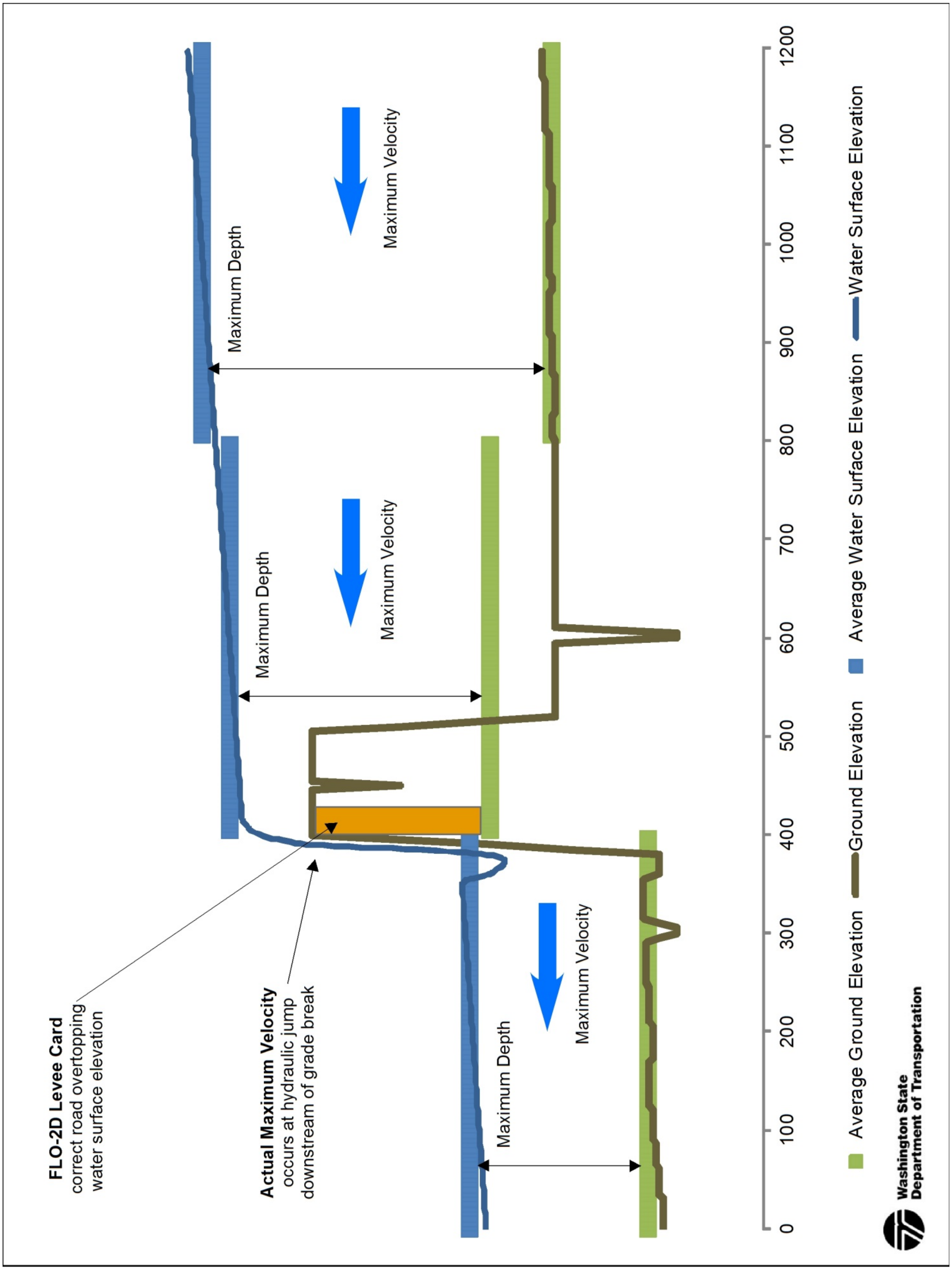



**Figure 2 – FLO-2D Model Output Grids**

After we attempted to use the Stack Profile tool several times unsuccessfully, we needed an alternative process to identify highway segments vulnerable to flooding.

After some consideration, we determined that we would need to manually delineate the flood-susceptible highway segments. To minimize the manual efforts, we created a worst-case floodwater surface for each return interval flood. For planning purposes, rather than individually analyzing all 21 scenarios, we thought that a worst-case analysis would adequately identify highway features susceptible to flooding. Following is the process we used:

- Create new worst-case water surface rasters by using the "Raster Mosaic" tool to overlay and select the highest value for each grid cell.[1]
- Create new high-resolution worst-case depth rasters by using the "Raster Math" tool to subtract the DEM from the worst-cast water surfaces created previously, and set the output raster grid size to the same as the DEM (6 feet X 6 feet).
- Display the worst-case depth rasters on screen and manually delineate the highway segments that would be inundated for each return interval by tracing over the highway centerlines.

To identify the maximum depth of water over each highway segment:

- Convert the delineated highway segments to 3D features using 3D Analyst "Features to 3D" tool using each of the worst-case depth rasters to define the surface to be intersected.
- Use the 3D Analyst "View Profile" tool to examine the profile and use the advanced options tab to identify the maximum depth in the profile.

We found during this manual process, where ArcView still did the heavy lifting, that we had to expend significant effort to carefully ground truth potential inundation areas, especially in areas near levees or berms that would prevent inundation. In many cases, the original water surface elevation grids spanned one or both banks of the Skagit River or other major drainage courses. In those situations, the average water surface is shown on both sides of the levees or berms above the ground surface, although these areas would not actually be flooded. Alternatively, in locations where there is significant dry area (e.g., where the model cells intersect hills) within the grid cell, the cell may have been discarded by the FLO-2D model, leaving a hole in the data set. While delineating the inundation highway segments manually, we found that it was relatively easy to work through these problem areas by switching on and off the DEM and seeing if the highway continued at a similar elevation or if there was a hump in the road.

Although it may have been simpler to generate a table of inundated road sections using the Stack Profile tool as initially intended, a possibly more difficult effort would have been needed to ground truth the results, as they would not necessarily have been easy to display on screen. It would have been hard to visibly discern and resolve problems as well, as some additional preprocessing would have been needed to fill the missing grids with an appropriate water surface elevation.

[1] The Puget Sound Partnership Report: Near-Term Action WSDOT Floodplain Impacts Methodology for Bridges describes how the levee breach scenario that resulted in the highest water surface elevation was added to the grid data. This was not used in identifying the highway segments susceptible to flooding, but provided additional information to support evaluations of potential adaptations to the highway system described in Appendix B.

The maximum depth values also required some close examination. Although now represented on a 6-foot grid, we noticed when examining profiles that sometimes cross ditches were represented in the topographic surface representing the area occupied by the highway. These problems occurred where the highway had been widened after the LiDAR data had been collected or where there was adequate LiDAR scatter around a bridge structure, so that when the data was processed, the channel banks and water surfaces were the lowest elevation returns rather than the bridge deck.

As an added benefit, we used the resulting maximum depth grids to look at other features in the project area for sensitivity to flooding that could not be accessed with the Corps-provided grids. Also, by examining the depth grids, we were able to roughly delineate flow paths and identify, at least coarsely, where the floodwaters would flow over the highway.

We found that in some locations, the DEM was well aged and did not incorporate projects (e.g., SR20/SR536 Indian Slough) that had been implemented since the topographic data was collected. Although there may be some false positives (areas that are indicated to flood but do not) or areas where the depths of flooding is overestimated, the DEM is still adequate as an element of a screening tool, as we would fully investigate individual sites early in the design process of any adaptation.

## 2.4 Results

Table 1 presents the summary length of state highway flooded under the worst-case condition for each return interval flood. Interestingly, a large segment on I-5 and SR 234 is flooded under the 25-year event and the 100-year event, but not the 50-year event; it appears that this occurs because of levee break scenarios. During the 10-year event, there is levee overtopping or failure in the downtown area of Mount Vernon; under the 50-year event, there is an upstream failure that diverts a portion of the flow and relieves the pressure on the downtown area levee system; and under the 100-year event, although the upstream failure still diverts floodwater, it is not enough to relieve the pressure on the downtown area levee and it is overtopped. Table 2 provides a more detailed description of at risk segments of highway.

**Table 1 – Summary of Length of the State Highway System Inundated Under the Worst-Case Flood Scenarios for Each Annual Chance of Exceedance.**

| State Route | Annual Chance of Exceedance | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **10 Percent** | | **4 Percent** | | **2 Percent** | | **1 Percent** | | **0.2 Percent** | |
| | **feet** | **miles** | **feet** | **miles** | **feet** | **miles** | **feet** | **miles** | **feet** | **miles** |
| 5 | -- | -- | 35,680 | 6.76 | 17,056 | 3.23 | 47,247 | 8.85 | 52,614 | 9.96 |
| 9 | 3,071 | 0.58 | 7,432 | 1.41 | 10,799 | 2.05 | 13,897 | 2.63 | 20,283 | 3.84 |
| 11 | -- | -- | 11,411 | 2.16 | 3,844 | 0.73 | 14,931 | 2.83 | 47,087 | 8.92 |
| 20 | 730 | 0.14 | 47,555 | 9.01 | 44,928 | 8.51 | 62,026 | 11.75 | 70,692 | 13.39 |
| 534 | -- | -- | 2,170 | 0.41 | -- | -- | 2,211 | 0.42 | 3,313 | 0.63 |
| 536 | -- | -- | 8,440 | 1.60 | 10,119 | 1.92 | 19,136 | 3.62 | 2,938 | 5.63 |
| 538 | -- | -- | 882 | 0.17 | 6,761 | 1.28 | 7,135 | 1.35 | 7,847 | 1.49 |
| Total | **3,801** | **0.72** | **113,570** | **21.52** | **16,880** | **3.20** | **166,583** | **31.53** | **204,774** | **43.86** |

## Table 2 – Highway Segments At Risk by Flood Scenario

| State Route | Annual Chance of Exceedance | Highway Segment | | Length | | Maximum Depth | Highway Segment at Risk from Each Breach Scenario: Annual Chance of Exceedance (%) and Breach Location (River Mile) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Milepost Start | Milepost End | | | | 10% ACE | 4% ACE | | | | 2% ACE | | 1% ACE | | | | | | |
| Route | Percent | Miles | Miles | Feet | Miles | Feet | -- | 4.64 | 12.39 | 13.79 | 21.59 | 16.79 | 17.89 | 4.65 | 8.28 | 12.39 | 13.79 | 16.78 | 17.89 | 21.59 |
| 5 | 4 | 224.69 | 219.95 | 25,070 | 4.75 | 10.6 | -- | -- | X | -- | -- | -- | -- | -- | -- | X | -- | X | -- | -- |
| 5 | 4 | 228.85 | 228.66 | 1,023 | 0.19 | 4.6 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 5 | 4 | 228.89 | 228.98 | 499 | 0.09 | 4.9 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 5 | 4 | 229.30 | 229.27 | 148 | 0.03 | 3.3 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 5 | 4 | 229.40 | 229.39 | 73 | 0.01 | 1.7 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 5 | 4 | 229.45 | 229.41 | 209 | 0.04 | 0.9 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 5 | 4 | 229.58 | 229.52 | 296 | 0.06 | 3.6 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 5 | 4 | 230.41 | 230.82 | 2,137 | 0.40 | 5.2 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 5 | 4 | 232.10 | 231.06 | 5,495 | 1.04 | 5.1 | -- | -- | -- | -- | X | -- | -- | X | X | X | X | X | X | X |
| 5 | 4 | 233.00 | 232.86 | 730 | 0.14 | 2.3 | -- | -- | -- | -- | X | X | -- | X | X | X | X | X | X | X |
| 5 | 2 | 227.32 | 227.64 | 1,676 | 0.32 | 9.6 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- |
| 5 | 2 | 227.84 | 228.06 | 1,189 | 0.23 | 10.8 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- |
| 5 | 2 | 228.85 | 228.66 | 979 | 0.19 | 6.1 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 5 | 2 | 229.70 | 229.38 | 1,642 | 0.31 | 5.4 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 5 | 2 | 230.62 | 230.41 | 1,100 | 0.21 | 4.6 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 5 | 2 | 233.02 | 232.82 | 1,051 | 0.20 | 1.5 | -- | -- | -- | -- | X | X | -- | X | X | X | X | X | X | X |
| 5 | 1 | 219.90 | 225.03 | 27,129 | 5.14 | 13.8 | -- | -- | X | -- | -- | -- | -- | -- | -- | X | -- | X | -- | -- |
| 5 | 1 | 227.26 | 227.64 | 2,019 | 0.38 | 9.3 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- |
| 5 | 1 | 227.84 | 228.17 | 1,737 | 0.33 | 11.2 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- |
| 5 | 1 | 228.63 | 229.79 | 6,106 | 1.16 | 7.0 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 5 | 1 | 230.41 | 232.36 | 10,256 | 1.94 | 8.0 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 9 | 10 | 52.03 | 51.86 | 919 | 0.17 | 1.6 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 10 | 53.42 | 53.22 | 1,073 | 0.20 | 3.6 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 10 | 53.92 | 54.12 | 1,079 | 0.20 | 7.6 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 4 | 52.05 | 51.74 | 1,641 | 0.31 | 6.9 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 4 | 52.53 | 52.37 | 841 | 0.16 | 1.3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 4 | 53.06 | 53.65 | 3,167 | 0.60 | 6.5 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 4 | 53.89 | 54.23 | 1,783 | 0.34 | 10.5 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 2 | 51.99 | 51.88 | 581 | 0.11 | 8.5 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 2 | 52.37 | 52.57 | 1,049 | 0.20 | 3.5 | -- | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 2 | 53.01 | 53.45 | 2,302 | 0.44 | 8.6 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 2 | 53.63 | 54.24 | 3,261 | 0.62 | 12.3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 2 | 54.76 | 55.45 | 3,606 | 0.68 | 2.6 | -- | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X |
| 9 | 1 | 51.73 | 52.06 | 1,768 | 0.33 | 10.1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 1 | 52.36 | 52.59 | 1,254 | 0.24 | 5.0 | -- | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 1 | 52.74 | 53.46 | 3,811 | 0.72 | 9.7 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 1 | 53.65 | 54.26 | 3,245 | 0.61 | 13.0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

| State Route | Annual Chance of Exceedance | Highway Segment | | Length | | Maximum Depth | Highway Segment at Risk from Each Breach Scenario | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Annual Chance of Exceedance (%) and Breach Location (River Mile) | | | | | | | | | | | | | |
| | | Milepost Start | Milepost End | | | | 10% ACE | 4% ACE | | | | 2% ACE | | 1% ACE | | | | | | |
| | Percent | Miles | Miles | Feet | Miles | Feet | -- | 4.64 | 12.39 | 13.79 | 21.59 | 16.79 | 17.89 | 4.65 | 8.28 | 12.39 | 13.79 | 16.78 | 17.89 | 21.59 |
| 9 | 1 | 54.71 | 55.44 | 3,819 | 0.72 | 3.4 | -- | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X |
| 11 | 4 | 0.14 | 1.92 | 9,559 | 1.81 | 5.2 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 11 | 4 | 2.55 | 2.90 | 1,852 | 0.35 | 6.0 | -- | -- | -- | -- | X | -- | -- | X | X | X | X | X | X | X |
| 11 | 2 | 0.14 | 1.80 | 8,941 | 1.69 | 3.9 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 11 | 1 | 0.14 | 2.96 | 14,931 | 2.83 | 6.8 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 20 | 10 | 62.70 | 62.57 | 730 | 0.14 | 1.7 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 4 | 58.64 | 52.70 | 31,433 | 5.95 | 10.3 | -- | -- | -- | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 4 | 59.68 | 59.42 | 1,370 | 0.26 | 2.0 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 20 | 4 | 59.91 | 59.80 | 573 | 0.11 | 1.2 | -- | -- | -- | -- | X | -- | -- | X | X | X | X | X | X | X |
| 20 | 4 | 59.97 | 59.94 | 171 | 0.03 | 1.2 | -- | -- | -- | -- | X | -- | -- | X | X | X | X | X | X | X |
| 20 | 4 | 60.75 | 60.22 | 2,853 | 0.54 | 3.5 | -- | -- | -- | -- | X | -- | -- | X | X | X | X | X | X | X |
| 20 | 4 | 63.03 | 60.91 | 11,155 | 2.11 | 7.9 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 2 | 58.95 | 52.70 | 33,081 | 6.27 | 10.5 | -- | -- | -- | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 2 | 59.68 | 59.42 | 1,411 | 0.27 | 2.7 | -- | -- | -- | -- | X | -- | X | X | X | X | X | X | X | X |
| 20 | 2 | 63.14 | 61.16 | 10,436 | 1.98 | 6.3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 1 | 58.98 | 51.54 | 39,325 | 7.45 | 12.0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 1 | 63.21 | 59.31 | 20,665 | 3.91 | 9.5 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 20 | 1 | 64.13 | 63.75 | 2,036 | 0.39 | 1.0 | -- | -- | -- | -- | -- | -- | -- | X | X | X | X | X | X | X |
| 534 | 4 | 0.08 | 0.50 | 2,170 | 0.41 | 12.1 | -- | -- | X | -- | -- | -- | -- | -- | -- | X | -- | X | -- | -- |
| 534 | 1 | 0.07 | 0.49 | 2,211 | 0.42 | 14.2 | -- | -- | X | -- | -- | -- | -- | -- | -- | X | X | X | -- | -- |
| 536 | 4 | 0.21 | 0.00 | 2,101 | 0.40 | 3.0 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 536 | 4 | 1.19 | 0.00 | 6,339 | 1.20 | 4.0 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 536 | 2 | 0.21 | 0.00 | 2,101 | 0.40 | 4.0 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 536 | 2 | 1.51 | 0.00 | 8,018 | 1.52 | 5.0 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 536 | 1 | 0.21 | 0.00 | 2,107 | 0.40 | 4.0 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 536 | 1 | 1.89 | 0.00 | 10,023 | 1.90 | 4.6 | -- | -- | -- | -- | X | X | X | X | X | X | X | X | X | X |
| 536 | 1 | 4.70 | 3.37 | 7,005 | 1.33 | 8.9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- |
| 538 | 4 | 2.57 | 2.73 | 882 | 0.17 | 1.6 | -- | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 538 | 2 | 0.00 | 0.99 | 5,456 | 1.03 | 14.9 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- |
| 538 | 2 | 2.51 | 2.75 | 1,305 | 0.25 | 3.5 | -- | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 538 | 1 | 0.00 | 1.00 | 5,491 | 1.04 | 15.3 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- |
| 538 | 1 | 2.46 | 2.77 | 1,644 | 0.31 | 4.9 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

Based on the screening data, it appears that there are two locations, one on SR 20 and one on SR 9, where floodwater would flow over the highway during a 10 percent Annual Chance of Exceedance (ACE) flood event, and these areas should be highlighted as areas of concern. Several other locations along SR 9 and SR 538 appear to be inundated under the 10 percent ACE flood event by backwater on the Skagit River causing overflow and accumulation of floodwaters in the Nookachamps basin.

Figure 3 shows the previously identified areas of concern, the affected highway segments, and an index of areas covered by Figures 4 through 9. Figures 4 through 9 provide a more detailed interpretation of the flood hazard conditions; depicting the flood flow paths and noting the maximum depths under the 4 percent and 1 percent worst-case flood conditions.

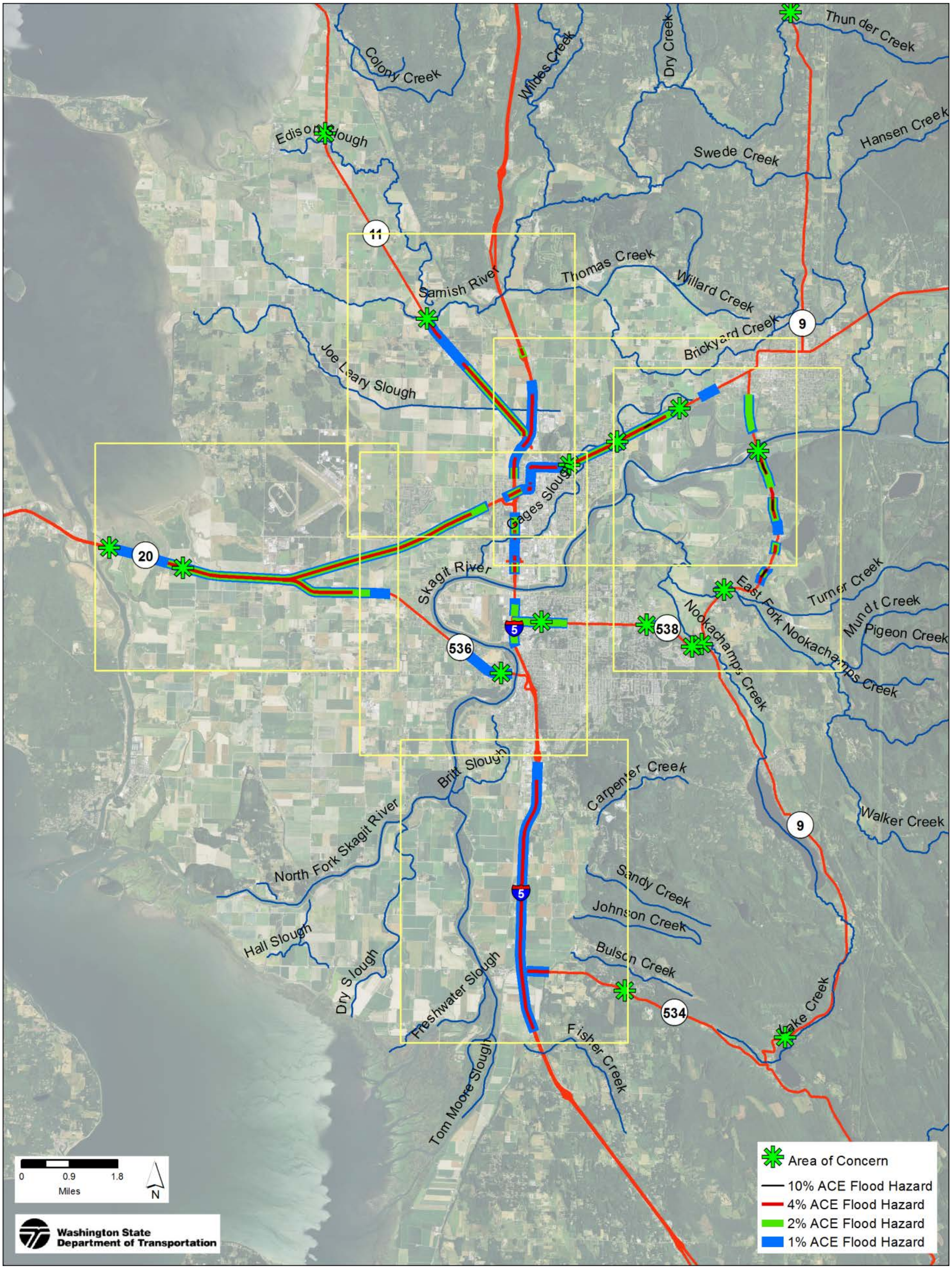
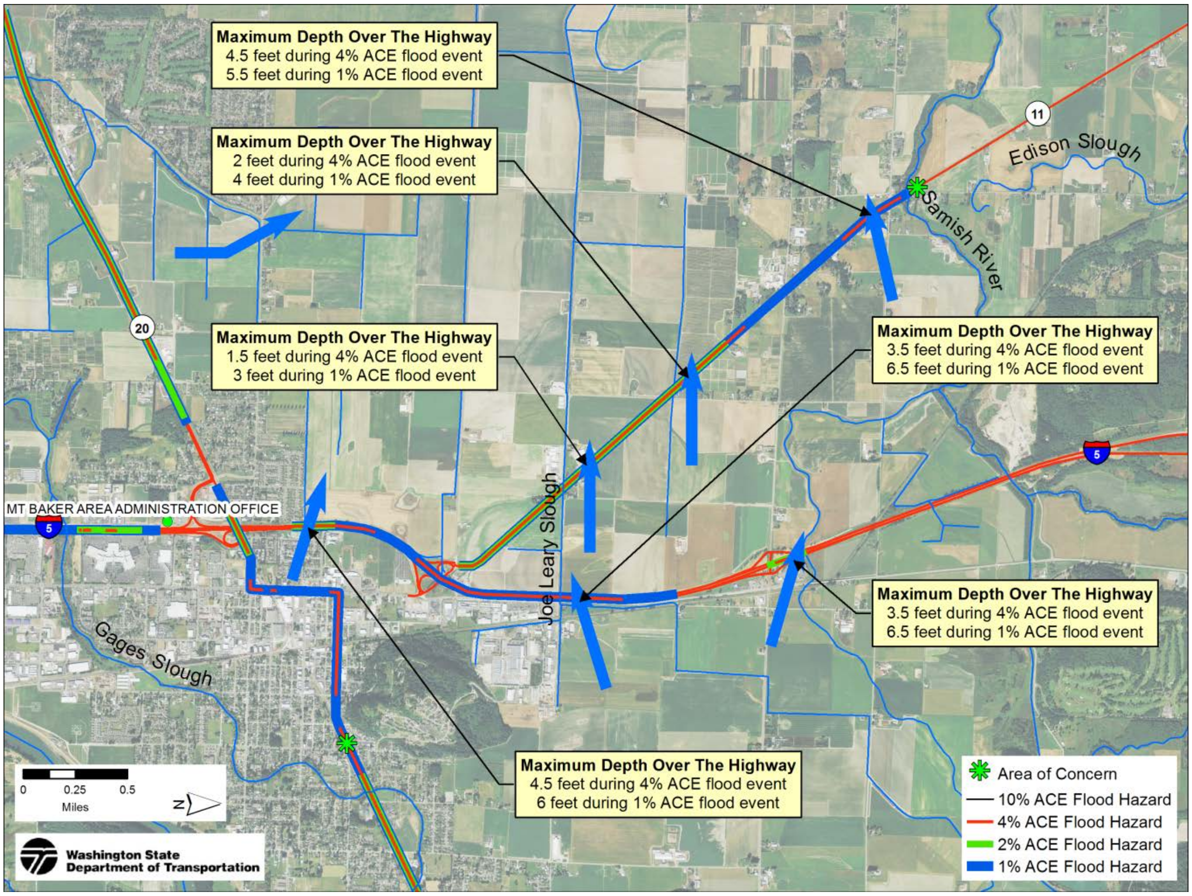



**Figure 3 Highway Segments and Areas of Concern**




### Figure 4 I-5 North

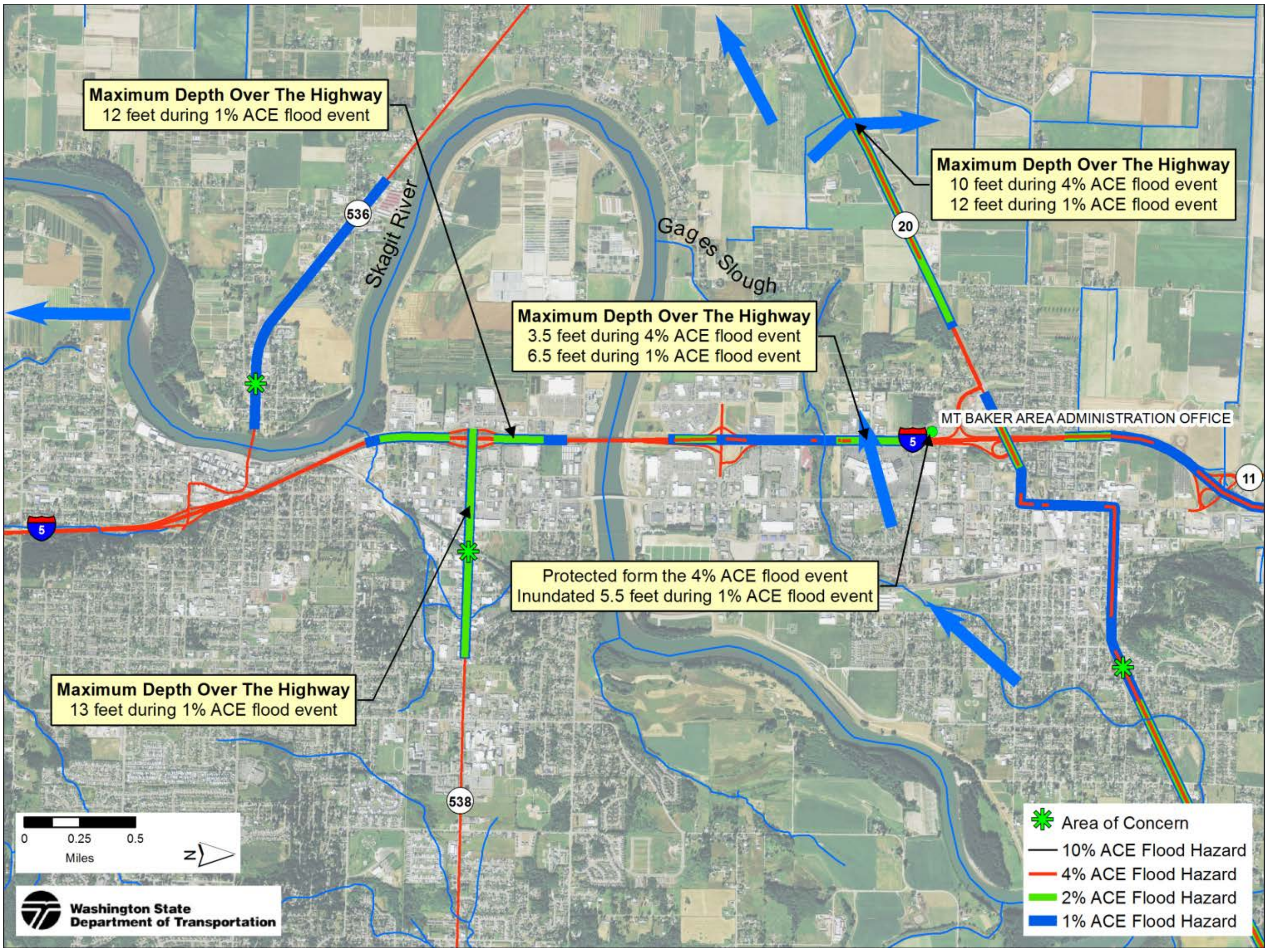



**Figure 5 I-5 Central**

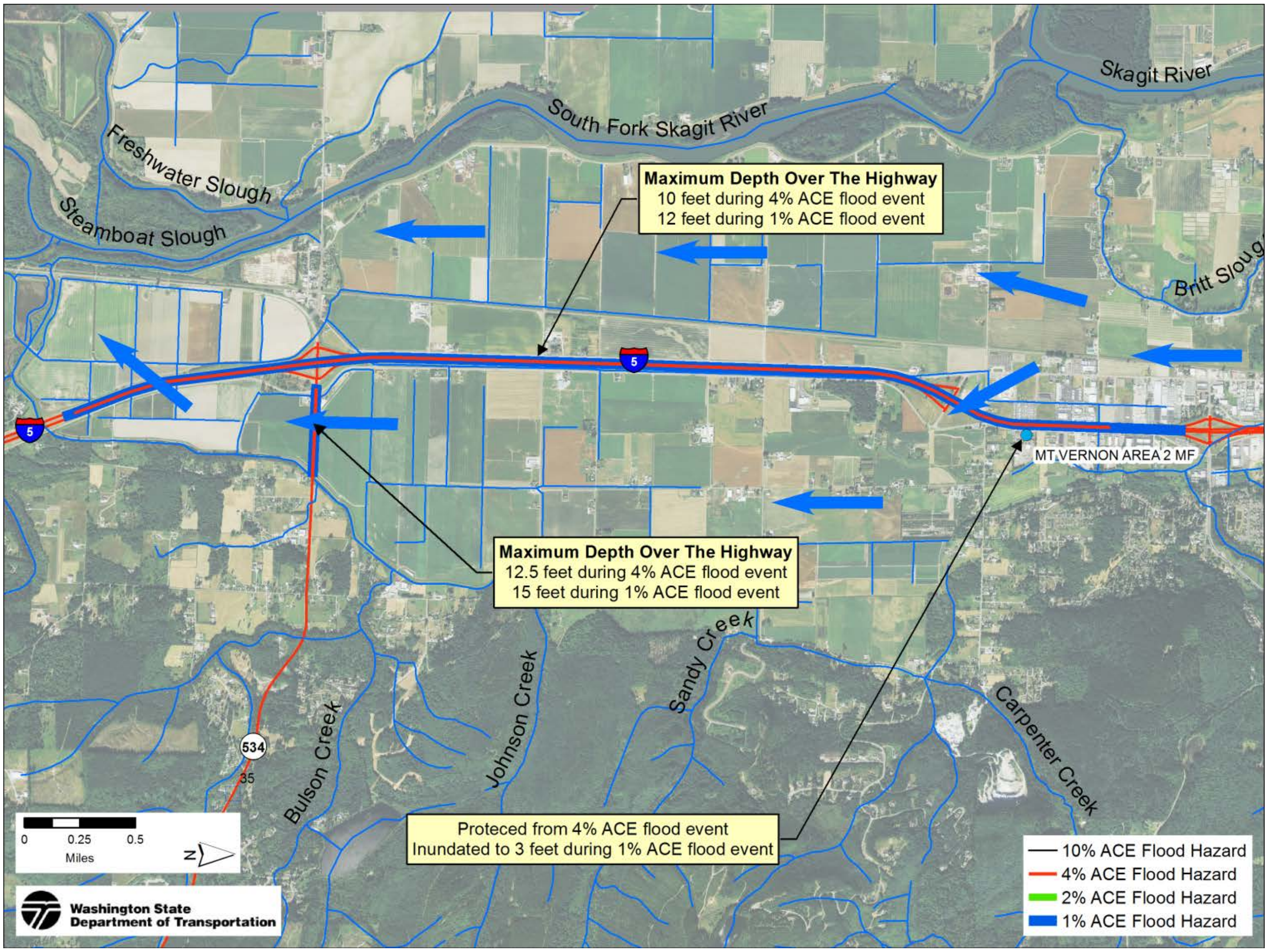



**Figure 6 I-5 South**

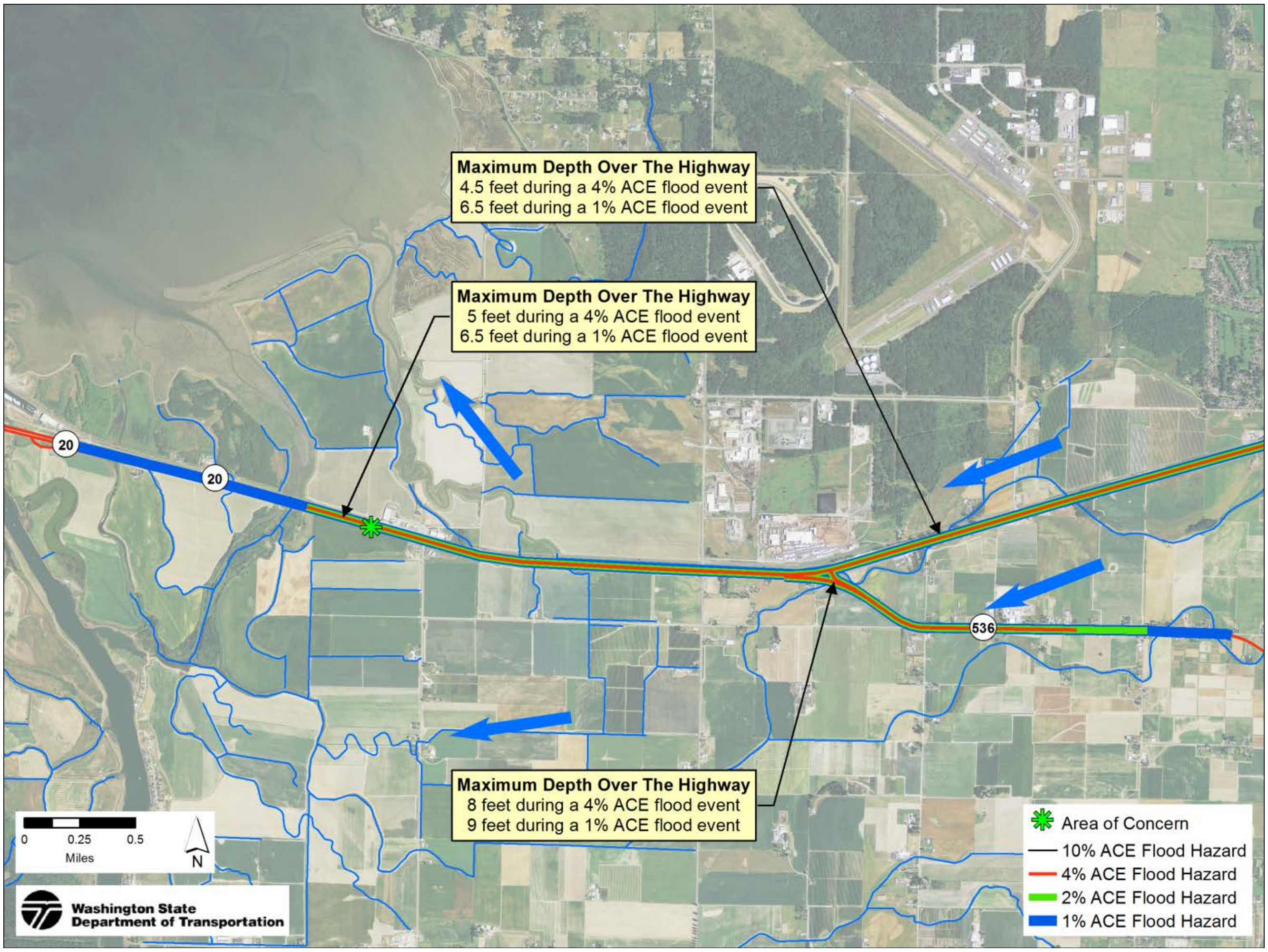



**Figure 7 SR 20 West**

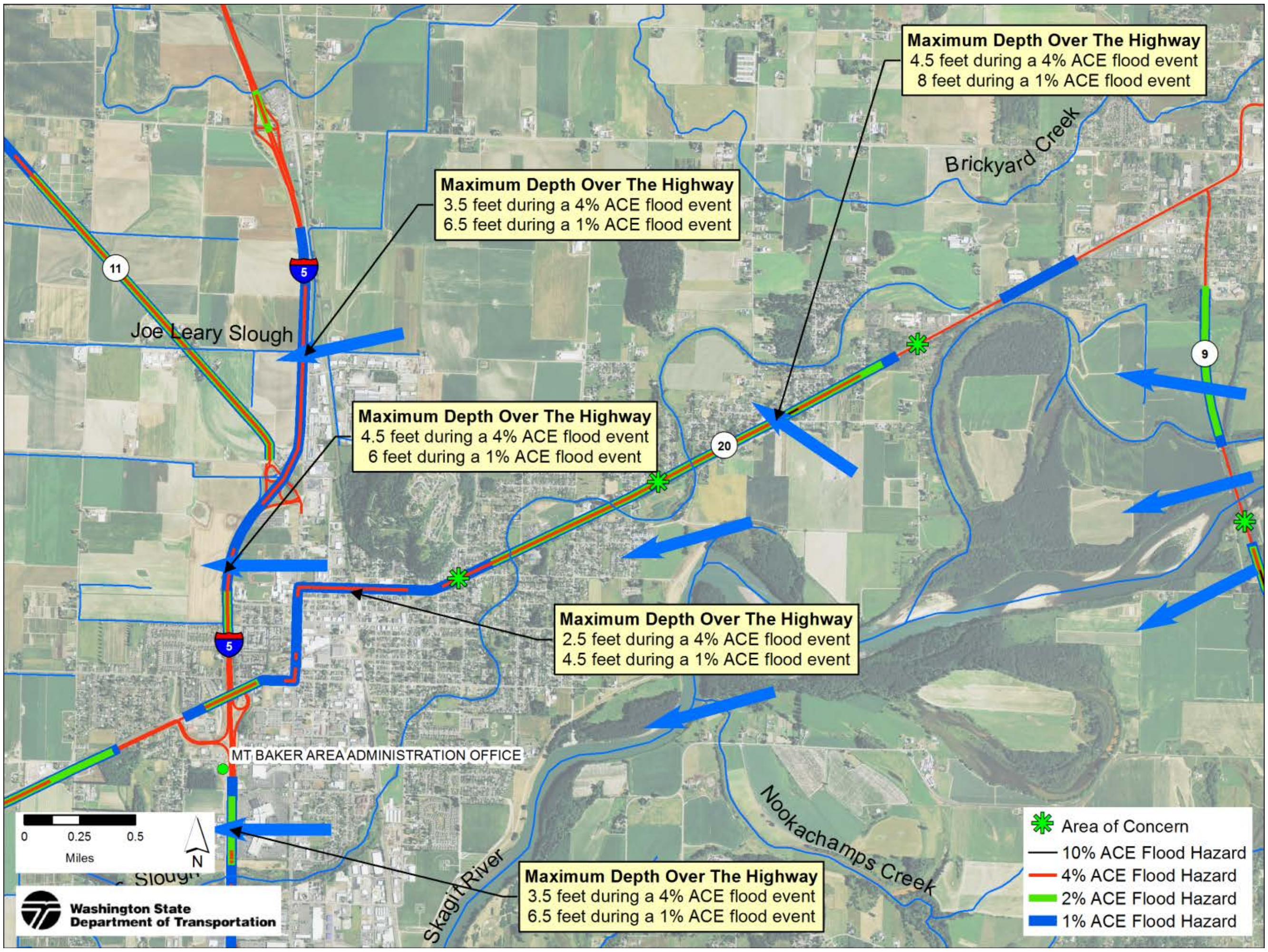



**Figure 8 SR 20 East**

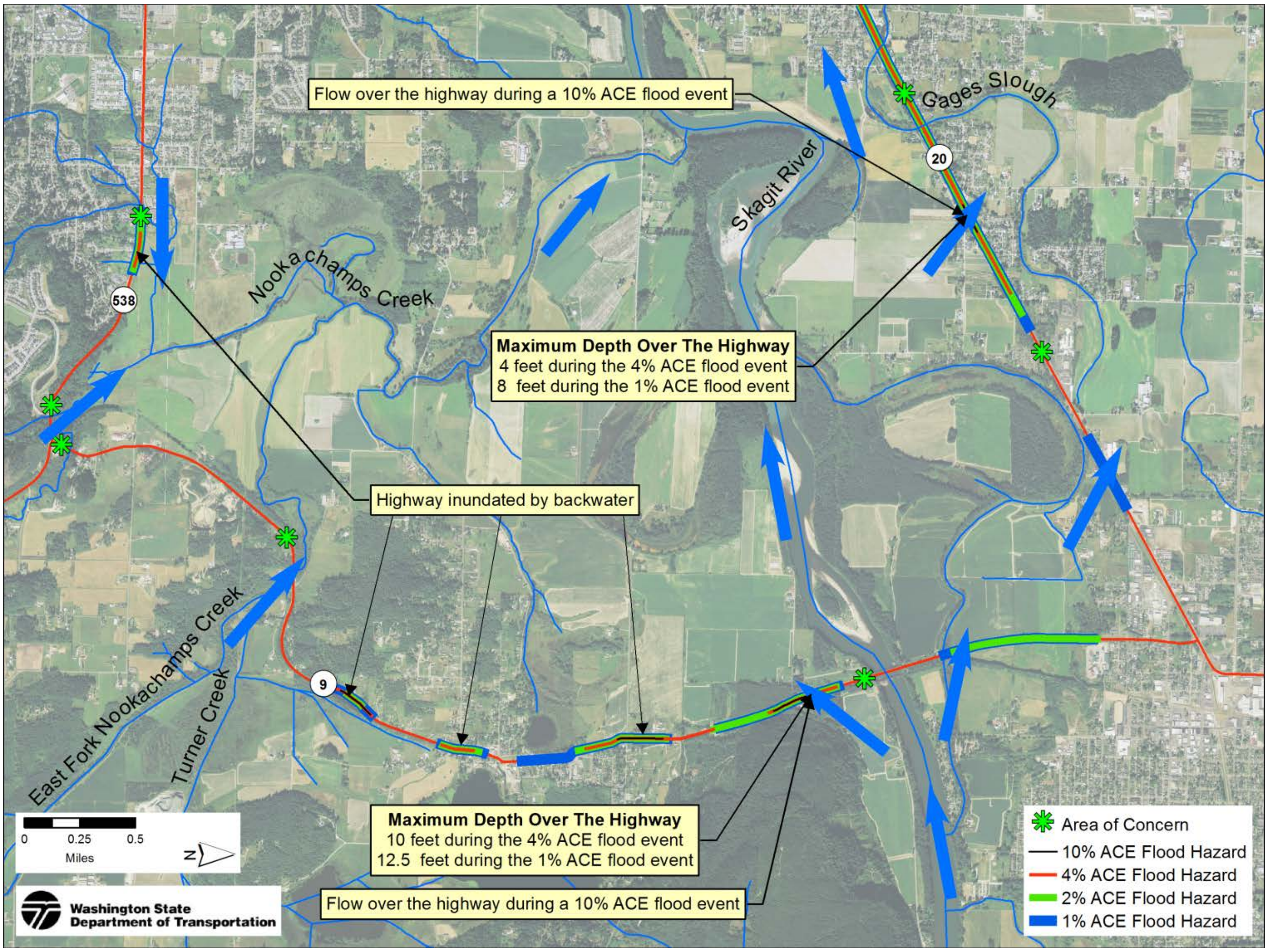



**Figure 9 SR 9**

## 2.5 Lessons Learned

We learned several lessons during the process, some of which were related to problems using the ArcView tools, but also others that were critical to the process.

1. **Coordinate Early** – Coordinate and partner with cooperating agencies early in the process to ensure special data or model outputs are selected without having to backtrack, redo, or rerun models to get appropriate data.

2. **Know Your Data** – Review and understand the data before developing analysis processes and procedures. Developing a process without the data in hand may cause problems, as you may not be able to conduct the analyses and provide the answers that were desired and anticipated by other members or partners of the project team. In this case, what we thought was a very easy ArcView process of intersecting lines with grid data, evolved into a much more labor-intensive manual process. It was not possible for us to identify the severity of hazards related to the velocity of floodwaters over the highway, because, as shown in Figure 2, the FLO-2D model did not provide that output.

3. **Use Staff with Resource-Specific Understanding** – Although the processes we developed appear simple and ripe for fully exploiting the capabilities of ArcView to identify highway segments susceptible to flooding, we found that the data available was not useable in its original form. Understanding the local flood conditions allowed us to confidently use the water surface elevation data to create more detailed floodwater depth maps. While manually delineating susceptible highway segments, it was possible for us to work through gaps in the data, discontinuities caused by edges on the water surface grids, and discontinuities caused by the limitations of the DEM. Without an operator that had at least a basic understanding of how the model data was created, the data gaps or discontinuities may have underestimated potential flood hazards, provided false positives, and overestimated the depth of flooding.

## Bridges

In response to the Puget Sound Partnership Action Agenda, Near Term Actions (NTA), WSDOT previously developed a screening methodology to identify bridges located within floodplains and prioritize them based on floodplain impacts. Figure 10 shows the FEMA Q3 floodplain and state highway transportation features, including the bridges.

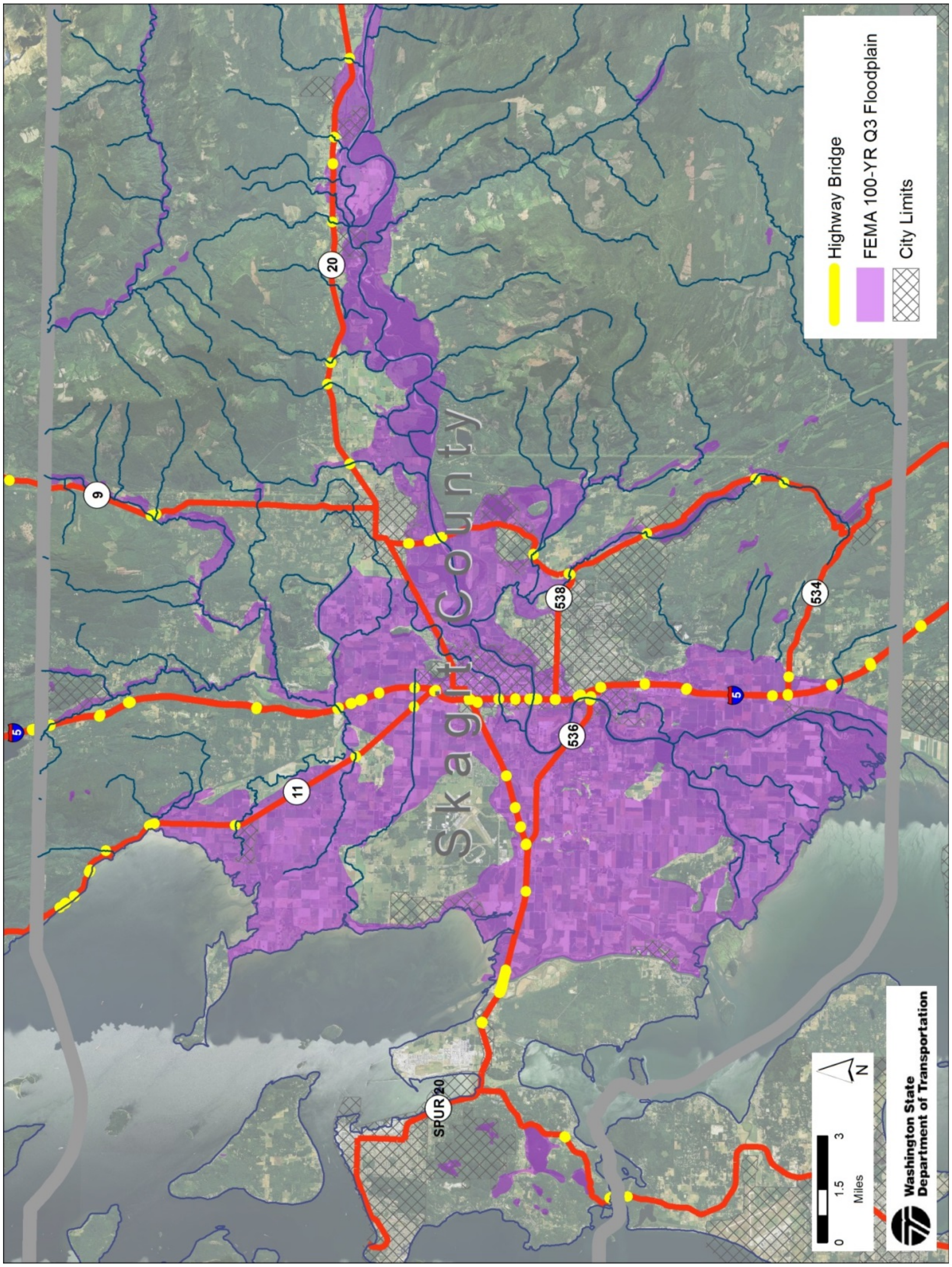



**Figure 11 – FEMA Q3 Floodplain and State Highway Bridges in Skagit County**

This pilot project provided us an opportunity to apply and test those methods with the Skagit Valley. Because this analysis was not dependent of the Corps GI/EIS, we applied it county wide. As described in the PSP Action Agenda memo outlining the methodology, bridges that confine the active river channel have the potential to dramatically impact the floodplain. This is due to the fact that the size of a bridge relative to the floodplain crossing affects every floodplain process and function, including channel migration; formation of side channels and other aquatic, wetland, or riparian habitats; floodplain storage; sediment transport; large woody material (LWM) recruitment and transport; and flood flow conveyance.

One on the key problems with bridges is that they force all flows through single openings. Although those openings may provide adequate cross-sectional area to convey the flows, the configuration of the openings do not mimic natural channel/floodplain configurations. Consequently, bridges locally cause increased depths and velocities of floodwaters, which in turn may cause scour of the bridge piers and abutments. The local effects of bridges may also cause a disruption of the sediment transport continuity, causing channel degradation or aggradation in the reaches above or below the bridge. This may affect channel migration processes as well as associated aquatic and riparian habitats.

Consequently, the screening methodology uses the ratio of bridge opening to floodplain width (S/FW) as the primary driver of floodplain impact and then modifies that value by considering the number of traffic lanes (PW), a land use development modifier (PD), a presence of estuary modifier (ES), and a climate change vulnerability modifier (CV):

**S/FW-PW+PD-ES-CV**

Where:

| | | |
|---|---|---|
| S/FW | = | primary driver of floodplain impact |
| PW | = | number of traffic lanes |
| PD | = | land use development |
| ES | = | presence of an estuary |
| CV | = | climate change vulnerability |

The following describes our efforts to gather the required data to apply the screening methodology and identify areas where data acquisition or interpretation was more complicated than we anticipated.

## 3.1 Methods

We extracted a list of bridges for Skagit County from WSDOT's transportation facilities GIS database. We then refined the list to eliminate grade separations and other bridges that are not associated with 4$^{th}$ order or higher streams or rivers. We further reduced the resulting list of 60 bridges to 49 water crossings, as 11 bridges were parallel structures created by separate bridges for each direction of traffic on divided highway segments of I-5 and SR 20.

Most of the modifier information can be quickly collected for each bridge, number of lanes, and land use development by using aerial photography, either within the agency's GIS database or simply using Bing or Google Maps available on the Internet. Climate change vulnerability had been previously assessed (cite the CIVA report).

The bridge span opening information was a bit more time-consuming to gather, as we had to query the WSDOT Bridge Engineering Information System for each bridge, and we had to examine the layout plans to determine the width. We took care to review all the layout sheets, because in some cases the bridges had been modified or replaced over time. (Note: Although WSDOT has a GIS layer containing bridges, the lengths in this database do not necessarily match the lengths shown on the layout sheets; presumably, the lengths in this GIS coverage were based on photo interpretation and may have been adequate for this level of screening).

Applying the estuary modifier was not clear cut. The Skagit and Samish Rivers provide freshwater inputs to Skagit, Padilla, and Samish Bays. The methodology specifically called out estuaries such as the Duwamish, Puyallup, and Deschutes to *not* receive an estuary modifier because the Ports of Seattle, Tacoma, and Olympia, respectively, have extensively developed these estuaries. The Skagit and Samish deltas have largely been reclaimed from their associated estuaries with dikes and ditches for mostly agricultural uses. Though these are recognized as agricultural areas of "statewide importance," there is pressure to restore estuary functions as part of the Puget Sound Nearshore Estuary Restoration Project (PSNERP) by removing tide gates and dikes and restoring some tidal channels. Although the Skagit River is tidal above the I-5 crossings, the I-5 corridor is largely developed and constrained by a levee system. This makes it unlikely that there would be significant estuary functions that could be altered by changing the configuration of the WSDOT bridges. As a result, we identified only the SR 11 crossing Colony Creek/McElroy Slough as having had potential for improved estuary functions.

The floodplain width is the most difficult feature to measure and interpret. Assigning the floodway width brought up three significant issues:

1. The Skagit River floodplain extends from wall to wall of the valley and across the entire delta. Along the I-5 corridor, the floodplain is approximately 7 miles wide. Along with state highways, there are numerous county roads, railroads, levees, and urban centers that impact and prevent restoration of floodplain functions. These conditions led us to several questions:

    - Should the floodplain width be segmented and applied to each crossing?
    - How should the floodplain be segmented?
    - What about other bridge structures, such as grade separations, that do not cross active water courses but would act as conveyance features during extreme flood events?

    Along the I-5 corridor, we decided to attribute the floodplain width only to the area that the active channels could move or would be allowed to move (effective floodplain width). The effective floodplain width was assumed to be the distance between the levees for the Skagit and Samish Rivers, between the topographic channel banks for poorly defined ditches, or the top of the banks for maintained drainage facilities.

2. As is common in rural communities, only major rivers like the Skagit, Samish, and Sauk have detailed Special Flood Hazard Area (SFHA) studies and maps. Minor streams are not analyzed, although there may be a flood hazard and a significant investment in road crossings and associated infrastructure. We found that where minor streams were crossed by state highways and a SFHA is mapped, the SFHA is likely a result of a backwater condition or floodplain inundation related to one of the major rivers; it doesn't necessarily reflect the floodplain or any analysis of that minor stream. It was also found that some crossings had no floodplains mapped.

    In these situations, some professional judgment is needed to select a floodplain width. We used the NRCS County Soils map and DNR Geology maps to identify areas of hydric soils and river wash materials, respectively, that were likely subject to frequent flooding. We used aerial photographs, scour reports, and photos of the bridges in the WSDOT Bridge Engineering Information System to refine or estimate the widths of the floodplains at these crossings.

3. The Corps' Skagit River GI is investigating flood hazard reduction measures for the Skagit Valley, including bypass channels that parallel SR 20 and Joe Leary Slough that could result in improved conveyance channels intersected by SR 20 and SR 11 west of I-5. The Corps' GI is also investigating setback and improved levees around the urban centers that could impact WSDOT's bridges along the I-5 corridor. Should we consider actions planned by other entities when determining the effective floodplain width? Although, in the long-term, we may implement projects that may cause WSDOT to reevaluate the function of bridges in the Skagit River floodplain, at this time we determined it was speculative to assign higher priority or sensitivity to bridges in these study areas in evaluating needs for a NTA.

## 3.2 Additional Modifiers

When looking at a SFHA map, it is not possible to identify the depth and velocity of water in the floodplain. Although susceptible to inundation and providing floodplain storage, much of the floodplain may not be contributing to channel migration functions; formation of side channels and other aquatic, wetland, or riparian habitats; sediment transport; or LWM recruitment and transport.

Along major rivers, where we have completed detailed floodplain analyses, there are several other metrics that could be included to better identify facilities that have floodplain impacts. The FEMA flood profiles identify the low and high cords of bridge structures as well as plotting the water surface elevations for several return interval floods. From this data, we can see where a bridge may not have adequate freeboard to pass debris during a flood or could be overtopped, and where the bridge and its approaches are constricting the flood flows, increasing the water surface elevation immediately upstream of the bridge.

We added the following metrics to assist with prioritization:

1. **Detailed Study (DS)** – Yes: no adjustment; No: add 0.5. Without a detailed study of the particular bridge crossing, there is a substantial level of uncertainty about the adequacy of the crossing and its potential to impact floodplain functions. This is especially true where a SFHA is mapped as a result of backwater conditions from another water course. Adding to the score decreases its priority.

2. **Freeboard (FB)** – Yes: no adjustment; No: subtract 0.02 if there is less than 3 feet of freeboard (F) above the 100-year profile; subtract 0.10 if there would be a pressure flow (P) condition for the 100-year profile; or subtract 0.20 if the bridge would be overtopped (O) by the 100-year profile. Bridges without adequate freeboard may be considered deficient, and planning may be already underway for a replacement. Subtracting from the score increases the priority. It is desirable to have floodplain functions fully evaluated if a bridge replacement project is in the planning stages.

3. **Head Loss (HS)** – No: no adjustment; Yes: subtract 0.06 if observable on 10-year (10%) profile (10); 0.04 if observable on 50-year (2%) profile (50); or 0.02 if observable on 100-year profile (100). Subtracting from the score increases the priority. The rationale for increasing correction for increasing return interval is that many ecologically important functions occur in the active channel and on the floodplain at less than the 100-year (1%) return interval flood.

## 3.3 Results

Table 3 provides a summary of the bridge identification and the scoring conducted according to the initial screening methodology and a revised scoring with the additional metrics. Interestingly, the results gave the highest initial ranking to a drainage ditch along I-5 (BN 5/719E) that appears to convey agricultural drainage from a relatively small area and provide flood conveyance when the Skagit and or Samish Rivers overflow during significant flood events. Even with the revised scoring metrics, it still ranks highly, as topographically, the overflow pathway appears to be large compared to the bridge opening. The original methodology did not highly prioritize the SR 9 (BN 9/223) bridge over the Samish River because the floodplain is locally narrow. However, the flood profile (Panel 11P) shows that the bridge would be overtopped in a 100-year flood event. It also shows that, even during more frequent flood events, there is head loss through the bridge. This indicates that flows may be constricted by the bridge, possibly making the bridge and abutments susceptible to scour as well as causing channel formation effects up- and downstream of the bridge. The revised scoring method brings the ranking of BN9/223 up 16 places.

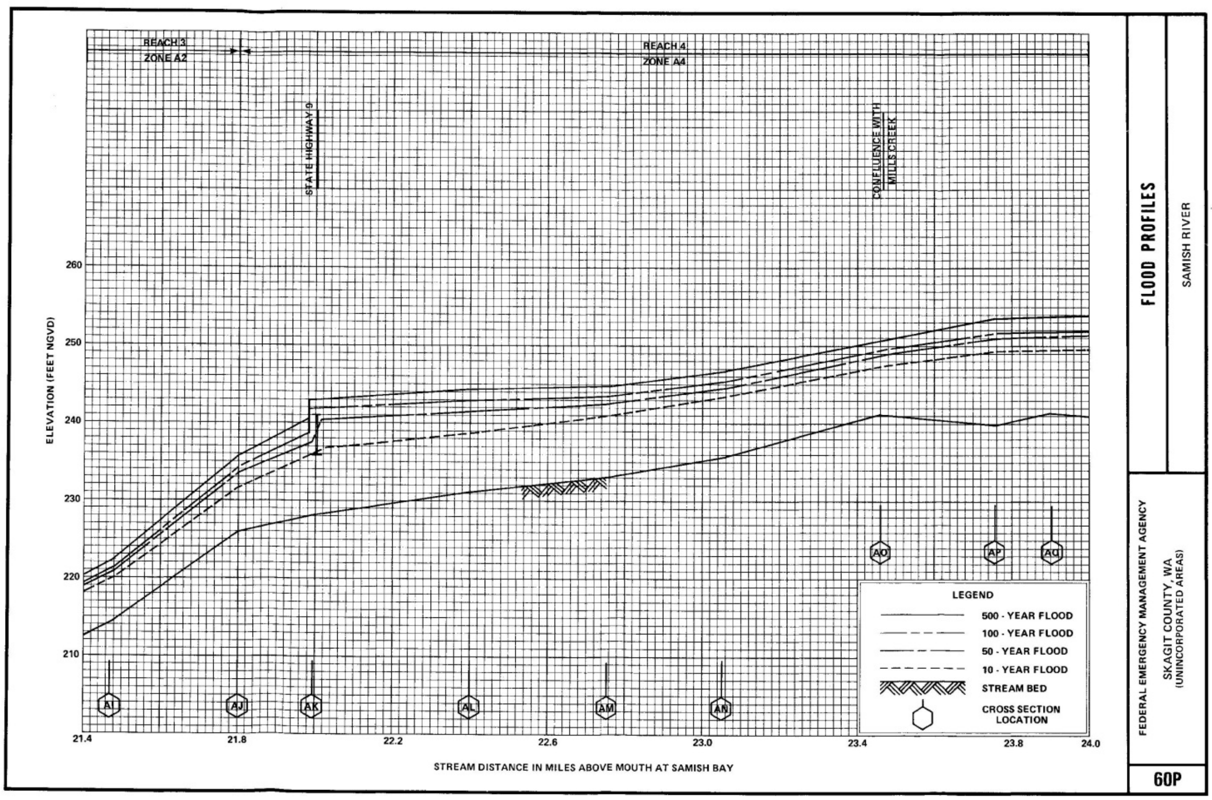



**Figure 12 Profile Panel 60P**

## 3.4 Lessons Learned

We learned several lessons during the process, some of which were related to problems with using the ArcView tools; however, others were critical to the process.

1. **Know Your Data** – Review and understand the data before developing analysis processes and procedures. Developing a process without the data in hand may cause problems, as you may not be able to conduct the analyses and provide the answers that were desired and anticipated by others. In this case, what we

thought was a very easy process of measuring the lengths of lines across the special flood hazard zone shown on the FEMA Q3 data, evolved into a much more labor-intensive process that relied on user interpretation of the data.

2. **Use Staff with Resource-Specific Understanding** – Although the processes developed appear simple to implement, they required some level of interpretation by an operator familiar with the floodplain mapping process. Without some professional judgment, we would rank bridges that appear to span wide developed floodplains higher than bridges that are in danger of being washed out during significant flood events.

---

Lee, Se-Yeun, A.F. Hamlet, 2011. Skagit River Basin Climate Science Report. Prepared for Skagit County and the Envision Skagit Project. Prepared by the University of Washington Department of Civil and Environmental Engineering and The Climate Impacts Group.

Chen, Y. H. and B. A. Anderson. Development of a methodology for estimating embankment damage to flood overtopping. (FHWA/RD-86/126) Prepared for FHWA – Office of Engineering and Highway Operations, McLean, VA. Prepared by Simons, Li & Associates, Fort Collins, CO.

## Table 3 – Summary of Bridge Screening for Skagit County

| BRIDGE IDENTIFICATION | | | | BRIDGE SCREENING METHODOLOGY | | | | | | | REVISED BRIDGE SCREENING METHODOLOGY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| County | Route | Crossing Name | Bridge No. | S/FW | PW | PD | ES | CV | Total Score | Rank | Detailed Study | Freeboard | Head Loss | DS | FB | HL | Revised Total Score | Revised Rank | Change |
| Skagit County | 5 | SAMISH R | 5/720E | 0.22 | 0.02 | 0 | 0 | 0.02 | 0.18 | 3 | Y | Y | N | 0 | 0 | 0 | 0.18 | 1 | 2 |
| Skagit County | 530 | SAUK RIVER BRIDGE | 530/207 | 0.41 | 0.01 | 0 | 0 | 0.03 | 0.37 | 12 | Y | Y | N | 0 | 0 | 0 | 0.37 | 2 | 10 |
| Skagit County | 9 | SAMISH RIVER | 9/223 | 0.42 | 0.01 | 0.25 | 0 | 0.02 | 0.64 | 19 | Y | O | 10 | 0 | -0.2 | -0.06 | 0.38 | 3 | 16 |
| Skagit County | 5 | DRAINAGE DITCH | 5/719E | 0.11 | 0.02 | 0 | 0 | 0.02 | 0.07 | 1 | N | Y | N | 0.5 | 0 | 0 | 0.57 | 4 | -3 |
| Skagit County | 20 | HANSEN CREEK | 20/229 | 0.16 | 0.01 | 0 | 0 | 0.03 | 0.12 | 2 | N | Y | N | 0.5 | 0 | 0 | 0.62 | 5 | -3 |
| Skagit County | 20 | E FK RED CABIN CR | 20/241 | 0.25 | 0.01 | 0 | 0 | 0.03 | 0.21 | 4 | N | Y | N | 0.5 | 0 | 0 | 0.71 | 7 | -3 |
| Skagit County | 20 | BACON CR | 20/280 | 0.26 | 0.01 | 0 | 0 | 0.03 | 0.22 | 5 | N | Y | N | 0.5 | 0 | 0 | 0.72 | 8 | -3 |
| Skagit County | 20 | SR 20 OVER DAMNATION CR | 20/283 | 0.31 | 0.01 | 0 | 0 | 0.03 | 0.27 | 6 | N | Y | N | 0.5 | 0 | 0 | 0.77 | 9 | -3 |
| Skagit County | 20 | HIGGINS SLOUGH | 20/220N | 0.33 | 0.02 | 0 | 0 | 0.03 | 0.28 | 7 | N | Y | N | 0.5 | 0 | 0 | 0.78 | 10 | -3 |
| Skagit County | 9 | BATEY SL | 9/217 | 0.08 | 0.01 | 0.25 | 0 | 0.02 | 0.30 | 8 | N | Y | N | 0.5 | 0 | 0 | 0.80 | 11 | -3 |
| Skagit County | 20 | DRAINAGE DITCH | 20/213.5 A | 0.36 | 0.01 | 0 | 0 | 0.03 | 0.32 | 9 | N | Y | N | 0.5 | 0 | 0 | 0.82 | 12 | -3 |
| Skagit County | 20 | JONES CR | 20/238 | 0.15 | 0.01 | 0.25 | 0 | 0.03 | 0.36 | 10 | N | Y | N | 0.5 | 0 | 0 | 0.86 | 13 | -3 |
| Skagit County | 9 | W FK NOOKACHAMPS CREEK | 9/208 | 0.15 | 0.01 | 0.25 | 0 | 0.02 | 0.37 | 11 | N | Y | N | 0.5 | 0 | 0 | 0.87 | 14 | -3 |

| BRIDGE IDENTIFICATION | | | | BRIDGE SCREENING METHODOLOGY | | | | | | | REVISED BRIDGE SCREENING METHODOLOGY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| County | Route | Crossing Name | Bridge No. | S/FW | PW | PD | ES | CV | Total Score | Rank | Detailed Study | Freeboard | Head Loss | DS | FB | HL | Revised Total Score | Revised Rank | Change |
| Skagit County | 5 | FRIDAY CREEK | 5/726E | 0.40 | 0.02 | 0 | 0 | 0 | 0.38 | 13 | N | Y | N | 0.5 | 0 | 0 | 0.88 | 15 | -2 |
| Skagit County | 530 | WHITE CREEK BR | 530/210 | 0.54 | 0.01 | 0 | 0 | 0.03 | 0.50 | 14 | N | Y | N | 0.5 | 0 | 0 | 1.00 | 16 | -2 |
| Skagit County | 530 | ROCKPORT BRIDGE | 530/290 | 0.05 | 0.01 | 0.5 | 0 | 0.03 | 0.51 | 15 | N | Y | N | 0.5 | 0 | 0 | 1.01 | 17 | -2 |
| Skagit County | 9 | SKAGIT RIVER | 9/215 | 0.33 | 0.01 | 0.75 | 0 | 0.02 | 1.05 | 28 | Y | Y | N | 0 | 0 | 0 | 1.05 | 18 | 10 |
| Skagit County | 20 | ROCKY CR | 20/271 | 0.60 | 0.01 | 0 | 0 | 0.03 | 0.56 | 16 | N | Y | N | 0.5 | 0 | 0 | 1.06 | 19 | -3 |
| Skagit County | 9 | HARTS SL | 9/216 | 0.09 | 0.01 | 0.5 | 0 | 0.02 | 0.56 | 17 | N | Y | N | 0.5 | 0 | 0 | 1.06 | 20 | -3 |
| Skagit County | 20 | DIOBSUD CREEK | 20/277 | 0.12 | 0.01 | 0.5 | 0 | 0.03 | 0.58 | 18 | N | Y | N | 0.5 | 0 | 0 | 1.08 | 21 | -3 |
| Skagit County | 9 | LAKE CR | 9/205 | 0.18 | 0.01 | 0.5 | 0 | 0.02 | 0.65 | 20 | N | Y | N | 0.5 | 0 | 0 | 1.15 | 22 | -2 |
| Skagit County | 5 | HILL DITCH | 5/702W | 0.22 | 0.03 | 0.5 | 0 | 0 | 0.69 | 21 | Y | Y | N | 0.5 | 0 | 0 | 1.19 | 6 | 15 |
| Skagit County | 11 | SAMISH RIVER | 11/4 | 0.53 | 0.01 | 0.75 | 0 | 0.03 | 1.24 | 35 | Y | Y | N | 0 | 0 | 0 | 1.24 | 23 | 12 |
| Skagit County | 20 | RED CABIN CREEK | 20/238.5 | 0.30 | 0.01 | 0.5 | 0 | 0.03 | 0.76 | 22 | N | Y | N | 0.5 | 0 | 0 | 1.26 | 24 | -2 |
| Skagit County | 11 | OYSTER CR | 11/8 | 0.88 | 0.01 | 0 | 0.06 | 0 | 0.81 | 23 | N | Y | N | 0.5 | 0 | 0 | 1.31 | 25 | -2 |
| Skagit County | 20 | SWIFT CREEK | 20/268 | 0.98 | 0.01 | 0 | 0 | 0.03 | 0.94 | 24 | N | Y | N | 0.5 | 0 | 0 | 1.44 | 26 | -2 |

| BRIDGE IDENTIFICATION | | | | BRIDGE SCREENING METHODOLOGY | | | | | | | REVISED BRIDGE SCREENING METHODOLOGY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| County | Route | Crossing Name | Bridge No. | S/FW | PW | PD | ES | CV | Total Score | Rank | Detailed Study | Freeboard | Head Loss | DS | FB | HL | Revised Total Score | Revised Rank | Change |
| Skagit County | 20 | SWINOMISH-D BERENTSON BR | 20/211N | 0.57 | 0.02 | 0.5 | 0.06 | 0.03 | 0.96 | 25 | N | Y | N | 0.5 | 0 | 0 | 1.46 | 27 | -2 |
| Skagit County | 9 | E FK NOOKACHAMPS CR | 9/211 | 0.30 | 0.01 | 0.75 | 0 | 0.02 | 1.02 | 26 | N | Y | N | 0.5 | 0 | 0 | 1.52 | 28 | -2 |
| Skagit County | 20 | MEADOW CREEK | 20/207.3 | 1.09 | 0.01 | 0 | 0 | 0.03 | 1.05 | 27 | N | Y | N | 0.5 | 0 | 0 | 1.55 | 29 | -2 |
| Skagit County | 20 | HIGGINS SLOUGH | 20/214N | 0.87 | 0.02 | 0.25 | 0 | 0.03 | 1.07 | 29 | N | Y | N | 0.5 | 0 | 0 | 1.57 | 30 | -1 |
| Skagit County | 20 | HIGGINS SLOUGH | 20/217N | 0.37 | 0.02 | 0.75 | 0 | 0.03 | 1.07 | 30 | N | Y | N | 0.5 | 0 | 0 | 1.57 | 31 | -1 |
| Skagit County | 20 | WISEMAN CR | 20/235 | 0.64 | 0.01 | 0.5 | 0 | 0.03 | 1.10 | 31 | N | Y | N | 0.5 | 0 | 0 | 1.60 | 32 | -1 |
| Skagit County | 5 | GAGES SLOUGH | 5/713E | 0.17 | 0.02 | 1 | 0 | 0.02 | 1.13 | 32 | N | Y | N | 0.5 | 0 | 0 | 1.63 | 33 | -1 |
| Skagit County | 20 | BAKER R | 20/259 | 0.24 | 0.01 | 1 | 0 | 0.03 | 1.20 | 33 | N | Y | N | 0.5 | 0 | 0 | 1.70 | 34 | -1 |
| Skagit County | 9 | THUNDER CREEK | 9/222 | 0.26 | 0.01 | 1 | 0 | 0.02 | 1.23 | 34 | N | Y | N | 0.5 | 0 | 0 | 1.73 | 35 | -1 |
| Skagit County | 9 | LAKE CR | 9/204 | 1.35 | 0.01 | 0 | 0 | 0.02 | 1.32 | 36 | N | Y | N | 0.5 | 0 | 0 | 1.82 | 36 | 0 |
| Skagit County | 20 | GRANDY CR | 20/256 | 0.62 | 0.01 | 0.75 | 0 | 0.03 | 1.33 | 37 | N | Y | N | 0.5 | 0 | 0 | 1.83 | 37 | 0 |
| Skagit County | 5 | JOE LEARY SLOUGH | 5/716E | 0.97 | 0.02 | 0.5 | 0 | 0.02 | 1.43 | 38 | N | Y | N | 0.5 | 0 | 0 | 1.93 | 38 | 0 |
| Skagit County | 20 | HIGGINS SLOUGH | 20/223N | 0.55 | 0.02 | 1 | 0 | 0.03 | 1.50 | 39 | N | Y | N | 0.5 | 0 | 0 | 2.00 | 39 | 0 |

| BRIDGE IDENTIFICATION | | | | BRIDGE SCREENING METHODOLOGY | | | | | | | REVISED BRIDGE SCREENING METHODOLOGY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| County | Route | Crossing Name | Bridge No. | S/FW | PW | PD | ES | CV | Total Score | Rank | Detailed Study | Freeboard | Head Loss | DS | FB | HL | Revised Total Score | Revised Rank | Change |
| Skagit County | 9 | S FK NOOKACHAMPS CR | 9/210 | 0.84 | 0.01 | 0.75 | 0 | 0.02 | 1.56 | 40 | N | Y | N | 0.5 | 0 | 0 | 2.06 | 40 | 0 |
| Skagit County | 536 | SKAGIT RIVER | 536/15 | 1.15 | 0.01 | 1 | 0 | 0.03 | 2.11 | 43 | Y | Y | N | 0 | 0 | 0 | 2.11 | 41 | 2 |
| Skagit County | 20 | ALDER CR | 20/253 | 1.17 | 0.01 | 0.75 | 0 | 0.03 | 1.88 | 41 | N | Y | N | 0.5 | 0 | 0 | 2.38 | 42 | -1 |
| Skagit County | 11 | SR 11 OVER RR - BLANCHARD | 11/7 | 1.79 | 0.01 | 0.25 | 0.06 | 0.03 | 1.94 | 42 | N | Y | N | 0.5 | 0 | 0 | 2.44 | 43 | -1 |
| Skagit County | 5 | TROOPER SEAN M O'CONNELL | 5/712 | 1.22 | 0.02 | 1 | 0 | 0.02 | 2.18 | 44 | N | Y | N | 0.5 | 0 | 0 | 2.68 | 44 | 0 |
| Skagit County | 20 | JACKMAN CREEK | 20/262 | 2.44 | 0.01 | 0 | 0 | 0.03 | 2.40 | 45 | N | Y | N | 0.5 | 0 | 0 | 2.90 | 45 | 0 |
| Skagit County | 20 | CANOE PASS | 20/207 | 2.45 | 0.01 | 0 | 0 | 0.03 | 2.41 | 46 | N | Y | N | 0.5 | 0 | 0 | 2.91 | 46 | 0 |
| Skagit County | 20 | MUDDY CREEK | 20/247F | 1.78 | 0.01 | 1 | 0 | 0.03 | 2.74 | 47 | N | Y | N | 0.5 | 0 | 0 | 3.24 | 47 | 0 |
| Skagit County | 20 | MUDDY CR | 20/247 | 2.34 | 0.01 | 1 | 0 | 0.03 | 3.30 | 48 | N | Y | N | 0.5 | 0 | 0 | 3.80 | 48 | 0 |
| Skagit County | 530 | BOHS SLOUGH | 530/289 | #DIV/0! | 0.01 | 0 | 0 | 0.03 | #DIV/0! | 49 | N | Y | N | 0.5 | 0 | 0 | #DIV/0! | 49 | 0 |

## Puget Sound Partnership Report: Near-Term Action WSDOT Floodplain Impacts Methodology for Bridges [2]

The request for development of floodplain priorities based on impact has two central aspects

1. Potential impact of approximately 500 bridges on floodplains draining to Puget Sound.
2. Potential impact of approximately 185 miles of roadway that traverse floodplains draining to Puget Sound.

Although roads and bridges are both components of the transportation infrastructure, they are built and managed very differently. They also affect floodplains in different ways. Because of these differences, evaluating floodplain impacts for bridges must take a different methodological path than evaluating floodplain impacts from roads.

Transportation impacts to floodplains are most dramatically expressed in the form of bridges that confine the active river channel as well as the floodplain. This is due to the fact that the size of a bridge relative to the flood plain crossing affects every floodplain process and function including channel migration, formation of side channels and other habitat, flood storage, sediment transport, and large woody material (LWM) recruitment and transport.

Bridges are both physically and temporally discrete structures. That means they have a discrete project life span that is separate from the roads to which they are attached. When a bridge has reached the end of its structural life, it is removed and replaced with a new structure. At the time of replacement new information related to engineering, highway use, and environmental impacts is brought to bear to improve and update the bridge design. This is the logical phase for making improvements, such as those that would lessen floodplain impacts.

Highway roadbeds, on the other hand, are not discrete structures with a given (and finite) project life span. Roads may be repaired, repaved, widened, etc., but it is very seldom that entire roads are removed and replaced. Rather, they go through a periodic process of maintenance, repair and occasional upgrade. This makes correcting deficiencies such as floodplain impacts much more difficult. Another way in which roads are not physically discrete is that they are attached to other WSDOT and non-WSDOT infrastructure (on and off ramps, arterials, local roads, rail crossings, driveways, utility lines and corridors, etc. If one desires to raise or move a road, the attached infrastructure must be modified as well. This creates great difficulty, expense and disruption as it now entails moving the entire local transportation network and utility web.

Because of these differences WSDOT recommends that implementing the NTA focus on looking at our bridges with perpendicular crossings over larger ($4^{th}$ and $5^{th}$ order) streams and rivers. Figures 1 and 2 are schematics depicting and contrasting perpendicular bridge impacts and parallel roadway impacts.

[2] Strategy A5.4 NTA 1, *The 2012/2013 Action Agenda for Puget Sound,* Puget Sound Partnership

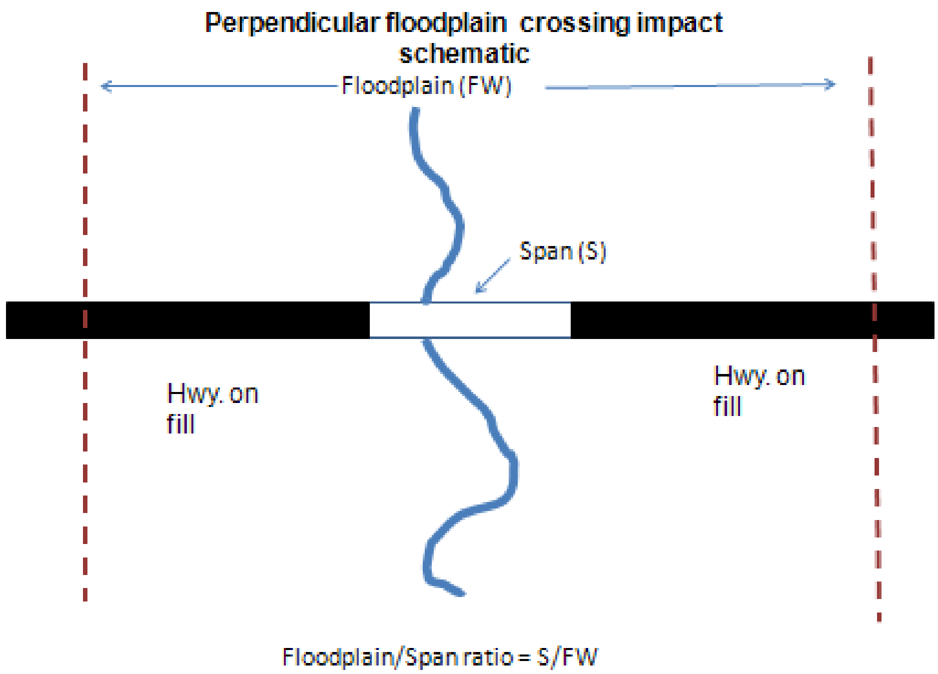



**Figure 1. Perpendicular floodplain crossing impact schematic.**

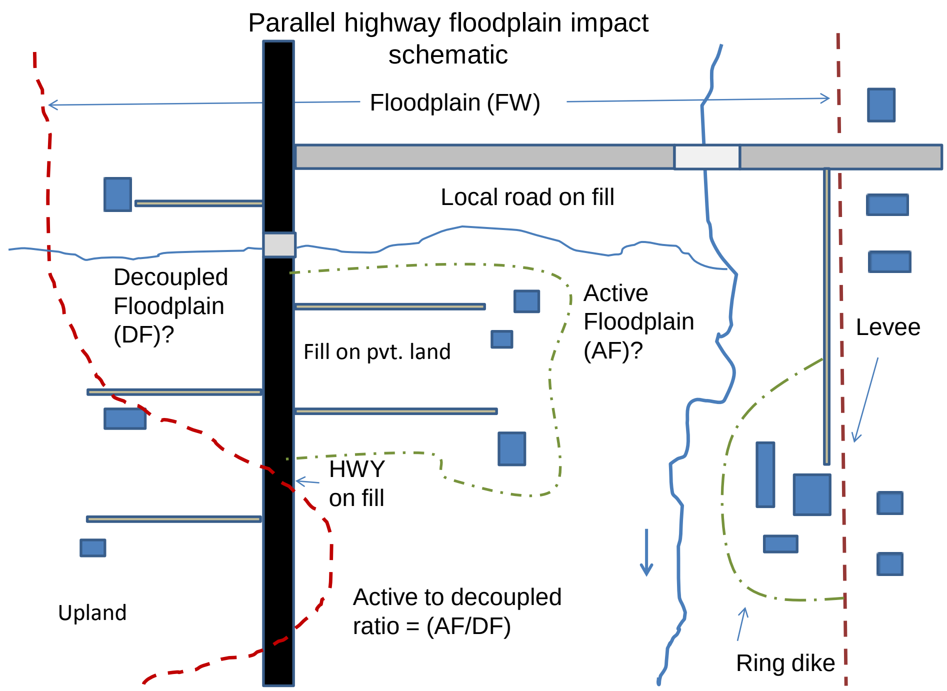



**Figure 2. Parallel highway floodplain impact schematic.**

Bridges tend to cross the floodplain and river in a more or less perpendicular orientation. This is particularly true of bridges over larger rivers with jurisdictional floodplains. Roadways, on the other hand, tend to parallel rivers with jurisdictional floodplains. Smaller bridges cross tributary streams that may or may not have jurisdictional floodplains. To complicate matters further, some portions of these roads may be within jurisdictional floodplain boundaries, while other segments of the same roads may be outside jurisdictional floodplains, depending on local topography and other factors.

Because of the inherent differences between perpendicular floodplain crossings (bridges) and parallel highways with segments in floodplains, two separate methods must be developed in order to evaluate relative floodplain impacts. This document presents a method for evaluating perpendicular span and fill bridge crossings of floodplains. A method for evaluating parallel road segments in floodplains is under development and will be presented as a separate document.

**Prioritizing Perpendicular Floodplain Crossings on Larger Streams and Rivers**

When evaluating impacts of transportation infrastructure to floodplain functions, the ratio between bridge span length and total flood-plain crossing is fundamental. This is due to the fact that the size of a bridge relative to the flood plain crossing affects every floodplain process and function including channel migration, formation of side channels and other habitat, flood storage, sediment transport, and LWM recruitment and transport.

The core metric, for evaluating relative floodplain impacts from bridges using the ratio between the bridge span and the total crossing width that is within the jurisdictional floodplain, is shown below:

**Bridge crossing span to floodplain width ratio**

**S/FW**

Where:

S = span length and

FW= total floodplain crossing width

For example, bridge “A” crosses the river and floodplain using a 100-foot long bridge, and two 500-foot approach fills. If we divide the 100-foot bridge by the total 1100-foot floodplain crossing we derive a span-to-width ratio of 0.09. Bridge “B’ crosses the floodplain using a 200-foot long bridge and two 500-foot approach fills. We derive a span-to-width ratio of 0.16. The smaller the span-to-width ratio, the more impact there is to the floodplain.

The ratios derived correspond to the percentage of the floodplain crossing that is spanned. In this example bridge “A” has more impact to the floodplain.

### Prism Width Modifier

The second metric used in the evaluation gages the relative width of floodplain fills. For this we are going to use the number of roadway lanes as an easily identifiable representation of relative fill prism width. The following modifiers will be applied to the span-to-floodplain width ratio to define the relative impacts of the fill prism width (PW), assuming that removing wider fill prisms provides greater benefit for flood storage and other floodplain functions. The equation is expressed as

**S/FW-PW**

PW is applied as follows:

- 2 Lanes—subtract 0.01
- 4 Lanes—Subtract 0.02
- 6 Lanes—Subtract 0.03
- 8 or more Lanes—Subtract 0.04

### Proportional Development Modifier

Another important factor to consider when evaluating floodplain improvements to WSDOT infrastructure is surrounding development. The environmental lift from a WSDOT improvement project is inherently greater in areas where there is little to no surrounding floodplain development. For example, the environmental benefit of lengthening a bridge over an estuary  where there is no adjacent floodplain development (such as the U.S. 101 crossing over the Duckabush River) will be vastly superior to placing larger bridges across a heavily developed floodplain (such as the Puyallup River in Tacoma). In the latter example, the adjacent development effectively cancels the benefits of the longer bridge because floodplain processes cannot be restored. In the Duckabush example however, the replacement with a longer bridge accomplishes complete floodplain process restoration with one discreet project.

For our test cases we used 2011 aerial photos in the WSDOT GIS Workbench to determine the ratings for proportional development (PD). We considered using land use cover data, however we found that that data set has a rather course level of precision, is not complete or uniform for the entire Puget Sound basin, and is somewhat dated. Using the 2011 aerial photographs proved to be a simpler, more reliable way of obtain a readily scalable, up-to-date metric. First we divide the floodplain in the vicinity of the bridge crossing into four quadrants. We analyze the development in each quadrant and apply PD as follows:

- No development: Add 0
- Development in 1 quadrant: Add 0.25
- Development in 2 quadrants: Add 0.5
- Development in 3 quadrants: Add 0.75
- Development in 4 quadrants: Add 1.0

In order to evaluate proportional adjacent development the following modifiers will be applied to the span to fill ratio.

The equation thus becomes:

| S/FW-PW+PD |
| --- |

### Estuary Modifier

Of all the many habitat types found in Puget Sound basin floodplains, the most rare and valuable are the few remaining estuaries. An **estuary** is geomorphically defined as a partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea.

Estuaries form a transition zone between river and ocean environments and are subject to both marine influences, such as tides, waves, and the influx of saline water; and riverine influences, such as flows of fresh water and sediment. Remaining natural estuaries on Puget Sound typically consist of large alluvial fans bisected with intricate networks of distributary channels. For the purposes of this study, former estuaries that have been heavily developed into port facilities (Olympia (Deschutes River), Tacoma (Puyallup River), Seattle (Duwamish River) will not be defined as estuaries. With regard to the Port of Everett (Snohomish River), there are considerable restoration efforts under way. Because of this, the Snohomish River estuary will be considered to have estuary restoration potential.

Recent studies indicate that as much as 73% of our estuarine habitat has been lost to development. Among their important functions is the critical role they play as habitat for smoltification of salmonids as they prepare to go to sea. In order to prioritize these critical habitat areas an estuary modifier (ES) has been developed[3]. If the floodplain crossing being evaluated is also crossing an estuary, this modifier is applied to the span-to-width ratio. This modifier is calculated as "estuary present**—**Subtract 0.06."

The equation thus becomes:

**S/FW-PW+PD-ES**

### Impact Rating, "The Race to the Bottom"

The Impact Rating is derived from applying the various modifiers to the span-to-width ratio. For this we use GIS (for Q3 floodplain data), aerial photographs, a development modifier, fill prism measurements, presence of an estuary (if applicable) and WSDOT's Bridge Engineering Information System for bridge length and other structural metrics. This method is designed to be simple, quick, and easy to replicate. This is critical as roughly 500 bridges need to be evaluated. It is important to note that because the ratings are based on the span-to-width ratio, the crossings that have the most impacts to floodplains are those crossings that have the **lowest** scores.

[3] The data source for the presence of estuaries is the WSDOT GIS Workbench, which is based on WSDOT aerial photography.

### Comparison to Climate Vulnerability Modifier

The Near Term Action also requires "consideration of WSDOT's 2011 Climate Impacts Vulnerability Assessment Report". The priority list will be modified based on information in this report[4] to adjust for climate change threats. While the Climate Change Study is based on highway segments rather than specific bridge structures, some bridges that are particularly vulnerable to climate change are described in the study. Most of these, however, are associated with potential sea level rise and thus are not necessarily pertinent to floodplain impacts. There are other highway segments, however, in higher elevations of the Puget Sound basin where impacts are anticipated along rivers that are fed by glaciers. Glaciers are already melting and are carrying large sediment loads from exposed soil. Sediment loads fall out on the journey to the sea and raise the beds of rivers. This causes lateral instability of the river channel, which impacts roadways along those rivers. The assumption, then, is that a longer, higher bridge that accommodates streambed aggradation and lateral migration would have environmental benefits as well as increase the resilience of the highway system.

Each Highway segment was rated "High", "Moderate" or "Low" (see maps and narrative in the appendix that follows), based upon its location in the 'sea to mountain' landscape spectrum. Values developed for applying Climate Vulnerability (CV) are as follows:

High-- Subtract 0.03

Moderate-- Subtract 0,02

Low-- Subtract 0

The equation thus becomes:

**S/FW-PW+PD-ES-CV**

[4] *Climate Impacts Vulnerability Assessment* Report, prepared by the Washington State Department of Transportation for submittal to the Federal Highway Administration, November 2011