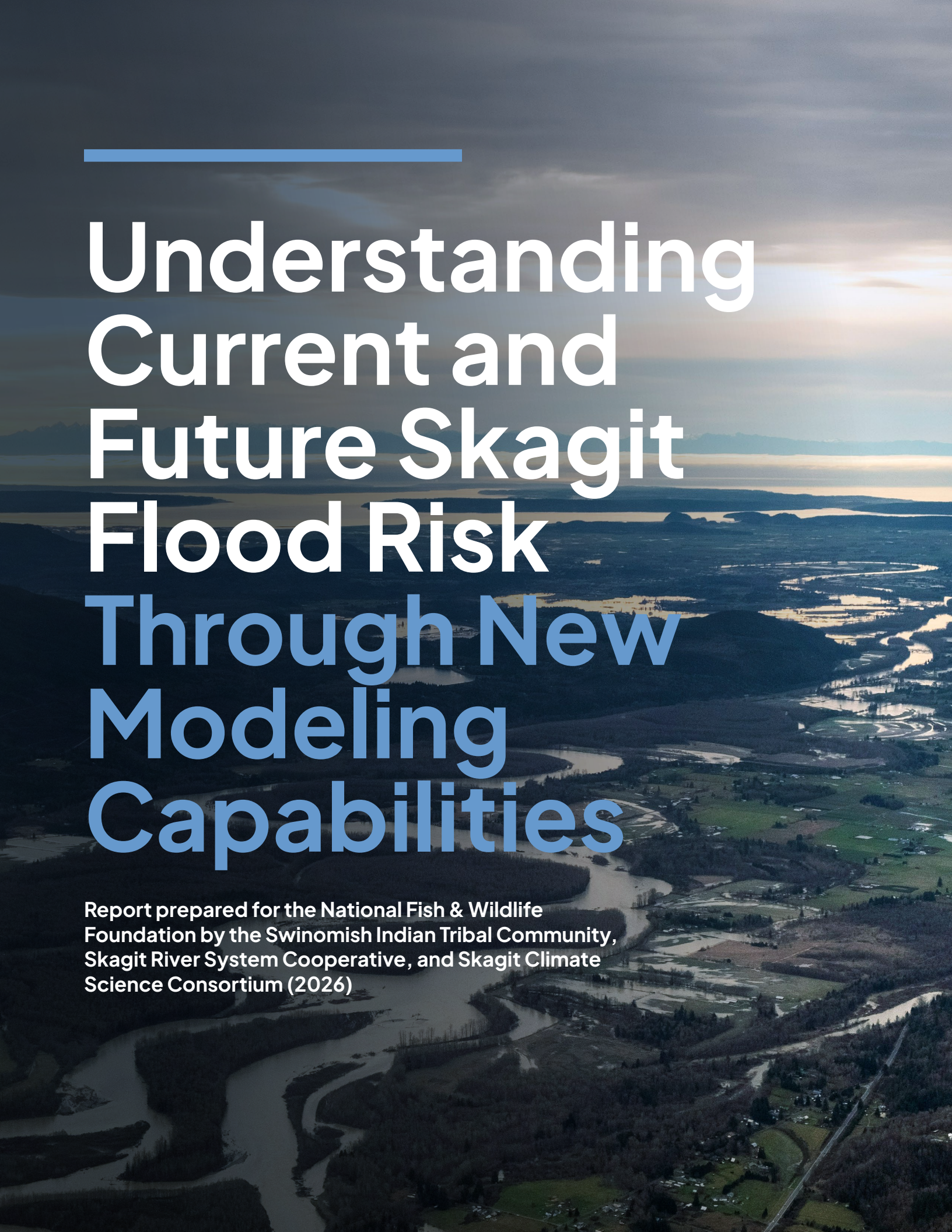


An aerial photograph of a wide river valley at sunset. The sun is low on the horizon to the right, casting a warm glow over the landscape. The river winds through the valley, surrounded by green fields, forests, and some small settlements. The sky is filled with soft, colorful clouds.

Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities

Report prepared for the National Fish & Wildlife
Foundation by the Swinomish Indian Tribal Community,
Skagit River System Cooperative, and Skagit Climate
Science Consortium (2026)

Credits and Acknowledgements

Funding for this work was provided by the **National Fish and Wildlife Foundation**. The project is a collaboration between the **Swinomish Indian Tribal Community**, **Skagit River System Cooperative (SRSC)**, **Skagit Climate Science Consortium (SC2)**, and the **University of Washington**.

Importantly, the work would not have been possible without the technical expertise and contributions of **Northwest Hydraulic Consultants**. The new flood model was built on an existing model developed by the **United States Army Corps of Engineers**, who graciously shared their model for use in this project. We would also like to thank the **boards of directors for both SRSC and SC2** for their support throughout the project.

The project team is immensely grateful for the time, expertise, and input provided by a variety of **staff from Tribal governments, local jurisdictions, state and federal agencies, and local organizations and individuals**, on both the project direction and products. The December 2025 flood event provided a unique opportunity to gather high water marks; a special thanks to **SRSC**, the **Skagit Drainage and Irrigation District Consortium**, and **Northwest Hydraulic Consultants** for coordinating and working collectively to gather high water marks for model validation.

CITATION

Swinomish Indian Tribal Community, Skagit River System Cooperative, and the Skagit Climate Science Consortium (2026). Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities. Report prepared for the National Fish & Wildlife Foundation. (cited as Swinomish et al. 2026)

COVER PAGE PHOTO CREDIT

The Skagit River at the Ross Island reach looking downstream on December 13, 2025: just one day after a record-setting flood in the valley. Bridget Moran, Skagit River System Cooperative

Table of Contents

Introduction	4	Appendix B: Maps	122
The Challenge: Increasing Flood Risk	5	Upriver Flooding Maps	127
Salmon and Ecosystem Impacts	6	Lower River Flooding Maps	155
The Project Team	7	Coastal Flooding Maps	188
Community Engagement	7	Dike Failure Scenarios	203
Report, Map Products, and Visualizations	7	References	219
Conclusion	7		
Project Overview and Objectives	8	Appendix C: June 5th, 2025 Workshop Presentation	221
Project Team	11	Appendix D: The Draft Skagit River Flood Risk Management General Investigation	345
Public Engagement	13		
Identification of Key Contacts	14		
Early Engagement Calls	14		
Focus Groups	15		
Workshop	15		
Direct Community Responsiveness	16		
Open House	16		
Skagit Flooding, Climate Change, and New Flood Modeling	17		
Skagit Hydrology	18		
Skagit Flooding: What Happens Upstream	20		
Affects Flooding Downstream			
Skagit Flooding: Role of the Dams	21		
Impacts of Warming Climate on Flooding	24		
Primer on Skagit Flooding, Climate	35		
Change, New Flood Modeling and			
Insights It Can Provide			
Summary and Conclusion	48		
References	49		
Appendix A: Hydraulic Model	50		

1

Introduction

Introduction

Skagit County faces an urgent and escalating threat from riverine and coastal flooding.

On December 10, 2025, a Level 3 “Go” evacuation order was issued for 75,000 residents. While the forecast predicting record flood levels did not fully materialize, the event still caused significant harm and revealed a critical need for better predictive tools and a unified community response.

Fortunately, the Swinomish Indian Tribal Community (SITC), supported by a National Fish and Wildlife Foundation grant, was already leading a project to modernize flood modeling for the Skagit River. **The project was designed to build upon the best available science to create an updated, climate-informed model of flooding in the Skagit watershed. The new model was intended to foster a shared understanding of flood risks.**

Key goals include:

- **Developing a Modernized Hydraulic Model:** Creating an accessible, high-resolution hydraulic model covering the Skagit and Samish rivers, from their deltas upstream to Marblemount. The flood model incorporates the most up-to-date information on river and coastal flooding, dike failures, and future climate projections.
- **Building Shared Understanding:** Engaging tribal, local, and state governments, as well as the agricultural and environmental sectors, to raise awareness about current and future flood risks, describe the model and modeling results, and gather feedback on the approach and outputs.
- **Visualizing Results:** Providing clear, visual representations of flood depths, extents, velocities and durations to help the public and officials anticipate risks.

The Challenge: Increasing Flood Risk

Climate change is fundamentally altering the Skagit River’s behavior. Projections indicate:

- **More frequent flooding events;**
- **Increased depth of floodwaters; and**
- **Expanded geographic extent of flooding.**

These changes threaten human life and property and are expected to generate millions of dollars in damages, lost revenue, and increased economic stress on farms, families, and businesses. Likewise, higher flows can significantly impact the ecological health of natural systems. How the community chooses to mitigate flood risks impacts the long-term resilience of both human and natural environments.

The Swinomish Tribe has stewarded and been deeply connected to the lands and waters in the Skagit River watershed since time immemorial. Today, as climate change brings new and accelerating challenges—beyond what any one community can control—the Tribe seeks to continue that stewardship and protection in new ways. Like others in the watershed, the Tribe shares concerns about the impacts of flooding on homes, habitat, infrastructure, businesses and communities. The Tribe believes the long-term resilience of both human communities and ecosystems are interconnected and hopes this tool can bring the broader community together as neighbors to constructively discuss shared risk and work together at the scale necessary to reduce future harms.



Salmon and Ecosystem Impacts

This report and products are primarily focused on flood risk and how it impacts people and infrastructure, but floods also affect salmon habitats. These impacts are of significant interest to the Swinomish Tribe. Nontribal discussion of flooding and flood risks often do not include risks to non-human species and ecosystems.

From an ecological perspective, flooding is a natural process and an integral part of salmonid life cycles. Salmon are well adapted to dynamic river environments, and historically, floods helped create the diverse habitats that supported robust salmon populations throughout the watershed. Floodplains, including side channels, sloughs, and wetlands, provide important rearing habitat for juvenile salmon and can also serve as refuge during high flows.

Although flooding can benefit salmon, it can also have negative effects, particularly when it occurs during sensitive life stages or is intensified by human alteration of watersheds. Salmon eggs and recently-hatched alevin remain vulnerable to streambed scour and sedimentation for the duration of the October–March period when most peak-flow events occur. Alevins and fry may be displaced downstream or stranded as floodwaters recede, especially in disconnected floodplains or modified channels. Floods during juvenile rearing

can injure or kill fish through high velocities and channel scour, or prematurely transport juveniles into saltwater before they are physiologically prepared to survive there. Fish that reach estuaries at a smaller size, particularly during winter when food is scarce, may experience higher mortality.

Human modifications to rivers can increase the impacts of flooding on salmon. Dikes, roads, and bank armoring isolate rivers from their floodplains, reducing habitat complexity and concentrating flood flows within the main channel instead of allowing water to spread across the floodplain. This limits access to refuge habitat and can increase bank erosion, cause shifts in spawning habitat and scour redds, amplifying the impacts of flooding on salmon.

Climate change is expected to change both the timing and magnitude of floods. Under historical conditions, occasional large floods could reduce the survival of a single brood year of salmon while also creating and maintaining habitat that benefited future generations. As large floods become more frequent, salmon populations may have less opportunity to recover between events, and the long-term benefits of natural flooding may no longer outweigh the repeated losses. These effects may be compounded by warmer stream temperatures, drought, and other climate-related stressors. How communities choose to manage flood risks will influence the long-term resilience of both human communities and salmon ecosystems.

The Project Team

This project was led by a multidisciplinary team with deep roots in the Skagit basin:

- **Swinomish Indian Tribal Community (SITC):** The project lead and funding recipient.
- **Skagit River System Cooperative (SRSC):** Technical experts in river processes and fisheries.
- **Skagit Climate Science Consortium (SC2):** A non-profit group of scientists, including scientists at University of Washington Climate Impacts Group (UW CIG), providing locally-relevant research to support climate adaptation.
- **Northwest Hydraulic Consultants (NHC):** The lead for the technical development of the hydraulic model.

Community Engagement

Flood management affects a diverse array of people and communities. This project balanced development of a state-of-the-art flood model and associated flood maps with engagement designed to facilitate understanding and use of these new resources. The project team identified and engaged over 185 key contacts across the watershed, including:

- **Tribal, local, and state government elected officials and staff** who make decisions about public safety, environmental health, transportation, land use and other issues while responding to emergencies and planning for the future.
- **Agricultural leaders and business owners** whose livelihoods are threatened by flooding.
- **Environmental and social organizations** focused on ecosystem health and community well-being.

Report, Map Products, and Visualizations

This report provides important information to help interested parties understand Skagit flooding in greater detail and describes how a changing climate is expected to increase river and coastal flood risk. Valuable map products covering the river from upstream of Marblemount down to the coastal areas of Skagit County were created based on input from the community and are in [Appendix B](#). Flood depths, depth-velocity hazards, and duration mapping are included for a variety of locations. Maps also show 10-, 25-, and 100-year flood events for the 2040s and 2080s. Additional maps beyond those in the original project scope were created to be responsive to the level of interest shown

across the County from people wanting access to flood information for specific areas. A limited set of animations, which show flood waters advancing then retreating, can be found on the Skagit Climate Science website (<https://www.skagitclimatescience.org/research/2026-understanding-current-and-future-skagit-flood-risk/>). The model itself is also publicly available for any entity or person with the technical capacity to utilize and run model scenarios. The model is available at: <https://cig.uw.edu/projects/understanding-current-and-future-skagit-flood-risk/>.

Conclusion

The Skagit River Flood Modeling project provides a technical backbone for those affected by Skagit flooding to prepare for current and future flood risks. By making these model results and the model itself available, the project team hopes to empower the community to move from a state of concern to a state of readiness, planning, and action.

While the project team hopes this project can provide useful information, particularly where risks differ from existing maps, **there is no policy or legal requirement to use these over other data sources**. The purpose of the current work is to provide information, not recommendations.

Future work could include further model testing and refinement, problem-solving forums to discuss priorities and flood solutions, and development of tools providing access to key results such as through a web-based map viewer. **The project team hopes that the new hydraulic model, map results, and discussions contribute to the on-going efforts to help Skagit County remain a resilient place for its people, its economy, and its cultural and natural resources heritage.**

2

Project Overview and Objectives

Project Overview and Objectives

The purpose of this project was to develop a state-of-the-art flood model and associated flood maps, combined with engagement to facilitate understanding and use of these new resources.

Now and in the future, flooding:

- Puts tens of thousands of people in harms way;
- Threatens key infrastructure and businesses; and
- Harms and supports already-threatened salmon and ecosystems in the Skagit River.

The good news is that high-quality modeling, survey and computational tools exist and are already being used by communities across Washington State. These tools can help communities understand, plan and prepare for floods, thereby reducing impacts on people, infrastructure, and ecosystems.



Flood risk in Skagit County is high, and climate change is expected to result in bigger and more frequent floods.

The Swinomish Indian Tribal Community (SITC) identified a gap in up-to-date, accessible, and accurate science and information about flood risk. They also saw a gap in broader community discussions about safety and resiliency in the face of increasing flood risk for people and salmon. In 2024, SITC applied for and received a National Fish and Wildlife Foundation grant to develop a hydraulic model for the Skagit and Samish river floodplains as a tool to generate a more detailed and locally-specific understanding of coastal and riverine flood risk and convene the community in dialogue.

The project was initially designed to facilitate conversations through a highly structured value-planning process. This type of process facilitates the development of community-defined solutions to flood risk that simultaneously address multiple values, such as public safety, resilient infrastructure, viable agriculture, and healthy salmon runs and ecosystems. The hydraulic model would then have been used to understand the impact of proposed solutions on flood depths, volumes, extents, velocities and locations. Early feedback from a few critically important participants resulted in re-focusing the project on the first objective presented in the initial proposal: Build a broadly shared technically-based understanding of flood risk that includes community organizations and governments. The project team has worked throughout this project to establish a solid foundation for a now-future effort to potentially advance the last objective from the proposal: host a creative problem-solving forum where extensive local knowledge and expertise can be coupled with state-of-the-art science to explore flood risk reduction and integrated solutions.

Revised objectives for the project, refined by input and engagement from the agricultural sector, environmental organizations, and Tribal, local, and state government staff, include:

- Develop an updated, accessible floodplain model from just upstream of Marblemount to Skagit, Padilla, and Samish bays using up-to-date scientific information and data;
- Include the Samish delta in flood modeling, accounting for the effects of both Skagit and Samish River floods;
- Improve on existing modeling by increasing the resolution, expanding the geographic range, assessing coastal flooding, and incorporating future climate projections;
- Create a forum to engage communities on basic facts about flooding, key features of the new flood model, and the model results;
- Document the project methods and outcomes including engagement, modeling, and results;
- Provide visualizations and animations of model results; and
- Make the model available for use and adaptation by others.

What benefits the model will provide, how it will be implemented, and what conversations should be held in the future will be determined by the governments, organizations, and individuals who are affected by Skagit basin flooding.

”

As a Fire Commissioner and former first responder, accurate flood mapping is critical for response planning and apparatus locating. Planning for these events includes access into and out of critical areas and transportation of people and injured individuals to safe staging areas. Over time these event potentials change and it is essential that planning and preparation be accurate and current.”

— John Doyle, Commissioner Skagit Fire District 13

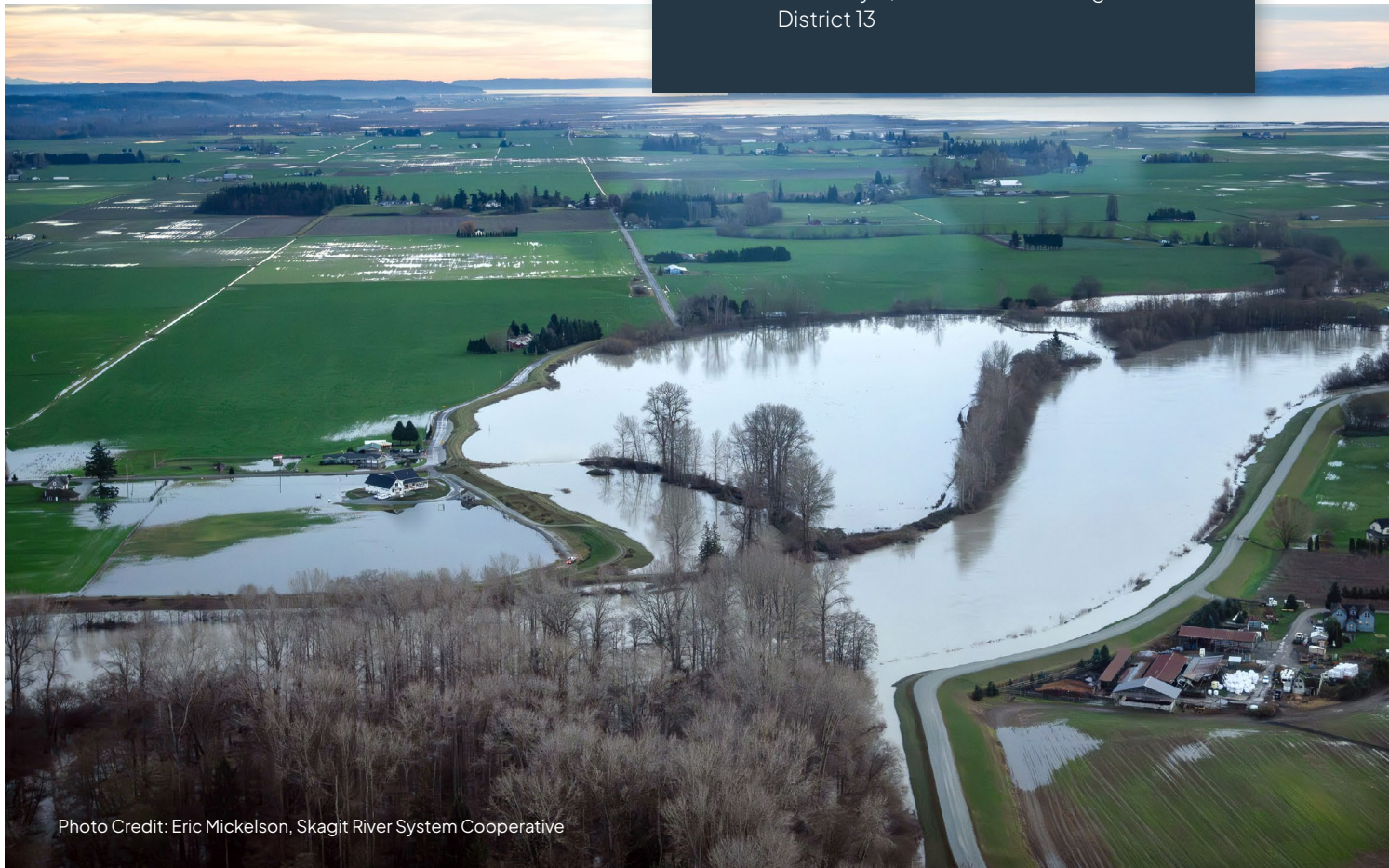


Photo Credit: Eric Mickelson, Skagit River System Cooperative

3

Project Team

Project Team

The project team is comprised of staff and consultants from the Swinomish Indian Tribal Community, Skagit River System Cooperative and the Skagit Climate Science Consortium.

The team brought extensive locally-relevant experience in environmental policy, fish biology, climate change, civil engineering, hydrologic and hydraulic modeling, river processes, climate resilience and adaptation, and engagement processes. Project team members included:

Heather Spore, M.S. *Swinomish Indian Tribal Community (project lead and funding recipient)*

Nora Kammer, M.S. *Skagit River System Cooperative*

Bridget Moran *Skagit River System Cooperative*

Kate Ramsden *Skagit River System Cooperative*

Dr. Guillaume Mauger *University of Washington Climate Impacts Group, consultant to Skagit Climate Science Consortium*

Dr. Alan Hamlet *University of Notre Dame, consultant to Skagit Climate Science Consortium*

Steve Moddemeyer *Consultant to Skagit Climate Science Consortium*

Carol Macilroy, B.S. *Consultant to Skagit Climate Science Consortium*

Kristin Kramer, PE *Northwest Hydraulic Consultants (NHC)*

Vaughn Collins, PE, CFM *Northwest Hydraulic Consultants (NHC)*

THE SWINOMISH INDIAN TRIBAL COMMUNITY

The Swinomish Indian Tribal Community is a federally recognized Indian tribe and political successor in interest to certain tribes and bands that signed the 1855 Treaty of Point Elliott, which among other things reserved fishing, hunting, and gathering rights and established the Swinomish Reservation on Fidalgo Island in Skagit County, Washington. The Swinomish Reservation sits at the mouth of the Skagit River, the largest river system

draining to Puget Sound and the only river in the Lower 48 states that still has all species of wild Pacific salmon and steelhead spawning in its waters. Since time immemorial, the Swinomish Tribe and its predecessors have occupied and utilized vast areas of land and water in northern Puget Sound up to the Canadian border to support the Swinomish way of life.

THE SKAGIT RIVER SYSTEM COOPERATIVE

The Skagit River System Cooperative (SRSC) is a tribal consortium consisting of the Sauk-Suiattle Indian Tribe and the Swinomish Indian Tribal Community. SRSC provides technical and scientific fisheries research, restoration, and environmental services for its member Tribes. On behalf of these two sovereign nations, SRSC works to actively support fisheries recovery and restoration throughout the Skagit River watershed and Whidbey Basin, areas that were ceded to the United States through treaties signed in 1855.

THE SKAGIT CLIMATE SCIENCE CONSORTIUM

The Skagit Climate Science Consortium (SC2) is a nonprofit organization of scientists from various entities working in the Skagit basin to understand how the landscape, plants, animals and people may be affected by changes in the weather and climate of the Skagit watershed. They offer their knowledge in support of the work local people are doing as they understand, assess, plan, and/or adapt to climate related impacts. SC2 provides support in three main ways:

- **Fostering collaborative scientific research** to understand the diverse and interrelated impacts of climate change from the Skagit headwaters to Puget Sound;
- **Producing relevant climate-related products** closely integrated with the Skagit community's needs and concerns; and
- **Serving as a conduit between Skagit communities and SC2 scientists** to assist in the development of adaptation strategies.

4

Public Engagement

Public Engagement

Providing the community with updated flood risk information was a key motivation for this project.

The project team sought feedback from the community throughout the project, iteratively adapting our work to reflect input. To do this, we developed a list of contacts throughout the watershed, conducted early engagement calls, held focus groups, hosted a one-day workshop, and responded to presentation and data requests. Each of these steps is discussed in more detail below.

Identification of Key Contacts

At the beginning of the project, the project team identified an engagement list of approximately 150 people from Tribal, state, federal, local, and special purpose district governments in addition to agricultural, social, and environmental interests. Nontribal government staff (federal, state, local) represented a range of disciplines including emergency management, diking and drainage districts, transportation, regulatory, planning and public works staff, and elected officials. Tribal governmental staff included environmental policy, emergency management, planning, and natural resources staff. Agricultural contacts included representatives from organizations in addition to individual business and land owners. For social and environmental organizations, we engaged with staff and volunteers associated with select organizations.

The project team made a significant effort throughout the project to improve and expand our reach, including being responsive to the input and feedback of participants. Creating a diverse list of people and entities interested in flood risk and potential flood solutions was of such importance that several organizations requested having access to our contact list. During the course of the project it became clear participants did not always feel comfortable being publicly associated with the project, so the list was ultimately kept confidential.

At the end of the project, the list identified approximately 280 individuals and organizations who are potentially interested in Skagit flood issues. We reached more than 185 people directly, and a larger audience through virtual and recorded presentations. Additionally, an Open House is planned in tandem with the release of this report.

Early Engagement Calls

A number of key representatives and leaders within the community were identified for early engagement calls. The team reached out to 38 individuals identified across Tribal, local, state and federal governments; agricultural organizations and producers; and social and environmental organizations. These early engagement calls were conducted from November 2024 through January 2025.

The bulk of early outreach was to local, state, and federal governments including special purpose districts like the dike, irrigation, and drainage districts. Calls allowed the project team to provide a general overview of the project and seek early input on process and structure, potential concerns, and additional outreach needs. Calls resulted in significant additions and updates to the list of contacts. Our initial outreach engaged people in a range of roles: planning, economic development, public works, administrators, elected officials, volunteers, biologists, business owners, and community/environmental staff.

Early feedback from the vast majority of participants ranged from neutral to enthusiastic. Some local government staff expressed skepticism of the project and signaled they might not participate. Some staff from federal agencies expressed interest in participating but were hindered in their ability to do so given agency constraints (i.e., travel restrictions, reductions in staff).

Based on feedback from these calls, the project team improved the clarity and framing of the project. The project team also began making some adjustments

to the modeling, including obtaining specific flood-relevant information such as new channel survey data, observed high-water marks, drainage characteristics, and improvements to the dikes. A full list of improvements to the model can be found in [Appendix A](#).

Terminology: This report intentionally uses the terms *dikes* and *coastal dikes*. The term *dike* is used to describe human infrastructure that keeps water in the river channel and prevents lower levels of flooding from accessing the floodplain. The term *coastal dike* describes human infrastructure that keeps water out of low lying or previously tidally-influenced areas. Nationally, the term *levee* is more commonly used in place of *dike*, for freshwater flood risk reduction infrastructure (i.e., outside of coastal areas). However, the term *dike* is more commonly used in Skagit County. This report adopts the local convention, using *dikes* in riverine areas and *coastal dikes* along the coast.

Focus Groups

In part based on feedback received in the early engagement calls and in part to ensure that the project team was able to facilitate open conversations, separate focus groups were hosted for:

- Tribal governments
- Local governments
- State and federal government agencies
- Agricultural interests
- Environmental and social-service organizations

Approximately 100 people were invited based on their or their organization's interests. In all, 43 people participated in five in-person or virtual focus groups held in February 2025. An additional 15 people signaled an intention or desire to attend but could not or did not ultimately participate. One person asked to be removed from the contact list.

The purpose of the focus groups was to present initial results and gather early feedback from a broad audience interested in flood risk reduction and its intersection with other community interests. Other interests represented in the focus groups included agricultural viability, environmental issues, affordable housing, high risk communities and populations, regulatory risks, growth management, planning, and emergency management

and preparedness. Model results shared at the focus groups were limited to current conditions as modeling of future climate scenarios was not yet completed. Input from participants informed the design of the mapping products, particularly the approach to visualizing the effects of climate change on flooding. The team also made significant edits to the description of the model and its capabilities to increase clarity and provide key information that had not previously been included.

Input gained from the focus groups was also instrumental in further refinement of the project objectives and engagement strategies. In response to feedback, the project focus shifted from a value-planning process to engagement aimed at building awareness and understanding of the model, its capabilities, and results.

Workshop

UNDERSTANDING CURRENT AND FUTURE SKAGIT RIVER FLOOD RISK THROUGH NEW MODELING CAPABILITIES (JUNE 5TH, 2025)

Following the focus group discussions, the project team extended 172 invitations to attend a six-hour workshop hosted by the Project Team at the Mount Vernon Library Commons on June 5, 2025. Approximately 40 people attended. An additional 25 people expressed interest but did not attend. The focus of the day was to:

- Share an overview of flooding in the Skagit and Samish river watersheds;
- Share an overview of the model and preliminary results; and
- Create a forum where the model and model results could be explored, discussed and commented on.

The workshop included over three hours of presentation. Initial map products from the modeling were shared and discussed. Specific map products presented at the workshop included future conditions mapping for river and coastal flooding for the 2040s and 2080s, and an example of a dike failure scenario from the Draft Skagit General Investigation study (USACE 2014; see [Appendix D](#) for more information on this study). Maps showed changes in flood extents and depths at a variety of scales and locations. Feedback received during the workshop informed the final products included in this report.

The presentation slides from the June 5th, 2025 workshop can be found in [Appendix C](#).

After the workshop, over 13 different entities expressed specific interests in the modeling work and noted the relevancy of the project to their immediate needs or concerns. The Swinomish Indian Tribal Community worked

directly with three local and state government entities who requested early access to draft model products prior to public release at the end of the project. This was due to time sensitive planning and infrastructure processes they felt could benefit from updated and more accurate flood modeling. With project completion, final materials are now publicly available. Demand for results also led the project team to release a slightly annotated and improved slide deck for public circulation.

Additional feedback suggested that continued refinement of the project's engagement approach would likely be of best service to the community. Instead of hosting a second community-wide workshop, the project team provided tailored presentations and engagement with specific communities and organizations.

- Swinomish Indian Tribal Community, Tribal Senate
- La Conner Town Council, Mayor and staff
- Padilla Bay Foundation
- Sedro-Woolley, Mayor and executive staff
- Skagit County Board of Commissioners, hosted by the Citizen's Climate Lobby
- Town of Hamilton, staff
- Transition Fidalgo
- US Army Corps of Engineers
- Washington State Department of Ecology
- Washington State Emergency Management Division (October, 2026)

Additional presentations in the scheduling process at the time of report finalization

Direct Community Responsiveness

In response to specific requests, the project team presented the model findings and heard additional input on the project. The project team was able to respond to nearly all requests for presentations. The team presented to:

Open House

On September 2nd, 2026, the project team will host an Open House to present project results to a broader public audience. In order to have this report finalized and available at the time of that event, a summary of the Open House is not included in this report.



Photo Credit: Skagit River System Cooperative

5

Skagit Flooding, Climate Change, and New Flood Modeling

Skagit Flooding, Climate Change, and New Flood Modeling

The following information provides important context for understanding the model, modeling results, and map products.

This section provides an overview of basic Skagit hydrology, examples of how different storms create different flood events based on that hydrology, and the effect of climate change on future flooding. Also covered in this section is information about what a hydraulic model is and how hydraulic modeling tools can be used to understand flood risk and explore how various actions affect flooding and flood risk.

Skagit Hydrology

The Skagit is the largest river draining into Puget Sound, extending into Canada and encompassing much of the high-elevation North Cascades, from Mount Baker to the Cascade Crest. In the lower reaches of the river, the floodplain extends from the South Fork Skagit River near Stanwood to Samish Bay to the north, encompassing the largest delta area in Puget Sound.

The Skagit River system has five major hydroelectric dams. Two of these dams, operated by Puget Sound Energy, are located on the Baker River, a tributary to the Skagit. The other three dams are on the upper Skagit River and are operated by Seattle City Light. The approximate location of each dam can be seen in the map for Figure 1. All five dams produce hydroelectric power while also providing flood control in winter and supplemental flows in summer. When flooding is predicted to occur, the United States Army Corps of Engineers directs operations of the Skagit and Baker dams.

The map in Figure 1 outlines the portion of the Skagit watershed upstream of the dams (blue) along with the remainder of the watershed, some of which is downstream of the flood control provided by the dams (orange). About 47% of the watershed area is above the dams, leaving 53% of the watershed area that is either unaffected or downstream of the dams (USACE 2014, [Appendix D](#)). For reference, about 37% of the basin area is above the Upper Skagit River dams (Gorge, Diablo, and Ross dams), while about 10% is above the Baker River dams (Lower Baker

and Upper Baker dams); together these add up to the 47% of the basin area that is above the five major Skagit watershed dams. The Sauk River, which originates in the upper elevations of the Cascade Mountains, is the largest tributary that is unaffected by the dams.

This report describes an updated flood model covering much of the Skagit River's floodplains (referred to as "Project model", see the [New Flood Modeling and Insights It Can Provide](#) section below and [Appendix A](#) for additional

FIGURE 1: SKAGIT RIVER WATERSHED

Less than half of the Skagit watershed is upstream of the dams.

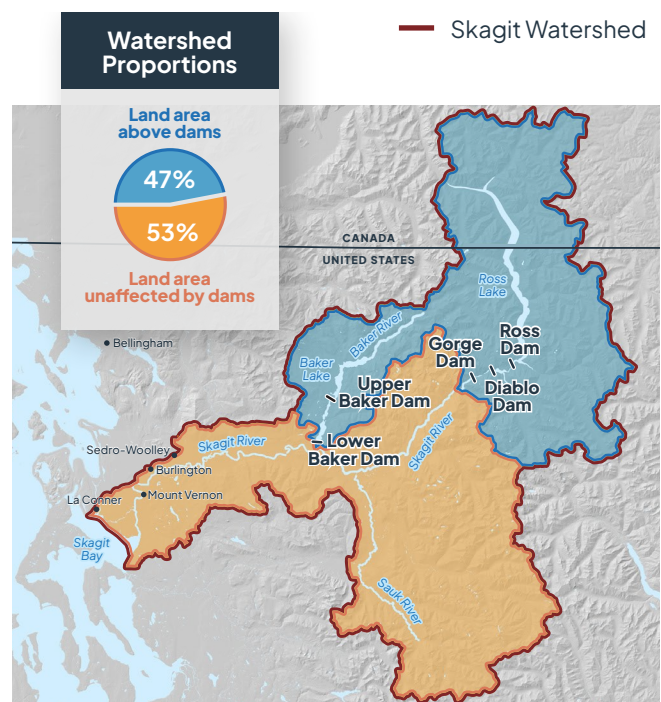


Image credit: Skagit Climate Science Consortium (SC2)

details). The Project model includes the lower reaches of the Samish River and its floodplain. Although a much smaller watershed, the Samish River flows out into Samish Bay near Edison, and its floodplain overlaps with the Skagit River's floodplain. Flooding on the Samish River can be important for the northern part of the Skagit Valley, which is why it is included in the modeling. For the Sauk River, the Project model includes only the lower floodplain, where the Sauk River joins the Skagit.

To understand how water flows, it can be helpful to take a simplified view of the watershed, as shown in Figure 2. The dark blue lines represent the Skagit River and noteworthy tributaries. The triangle symbols in the schematic represent the two Baker River dams and the three upper Skagit River dams. The largest tributaries to the Skagit River are the Sauk, Baker, and Cascade rivers. Nookachamps Creek is much smaller, but it is one of the largest tributaries in the lower watershed. During flood events, water flows out of the river and onto the floodplain, in many places throughout the watershed. This is why the Samish River is included even though it is not a part of the Skagit River watershed: because the lower Skagit and Samish river floodplains overlap.

Key streamflow gages are shown with the orange dots, including at Marblemount, Sauk River, Concrete, Sedro-Woolley, and Mount Vernon (note that Burlington is marked with an orange circle simply for reference, even

though it does not have a gage). This is why flows are often described based on a specific location, such as “flows at Concrete” or “flows at Mount Vernon.” Flows are often discussed in units of cubic feet per second (cfs) of water. The public, governments, and emergency response professionals often rely on river stage—the height of the river at any given location—instead of flow. River stage is often discussed in units of feet.

Using the magnitude of peak flows, measured in cfs, allows for apples-to-apples comparisons of flood events. Although stage (the height of the water surface at the gage location) is what many communities use to predict impacts, it does not allow for apples-to-apples comparisons of the drivers of flood risk. Peak flow and stage are not perfectly correlated. For example, the peak flow (cfs) can increase without affecting the stage if the velocity (or speed) of the river also increases.

Estimating stage is complex because it depends on multiple factors: the speed of the flow, whether the river banks have been overtopped, changes in roughness (vegetation, fill material, revetments, etc.) along the banks and beyond. These factors are why flood modeling is important – flood models capture the physics of fluid flows, accounting for the factors affecting stage. In order to more easily compare across events, we use flow (cfs) when discussing historical floods and the inputs to the flood model.

FIGURE 2: SCHEMATIC DIAGRAM OF THE SKAGIT WATERSHED

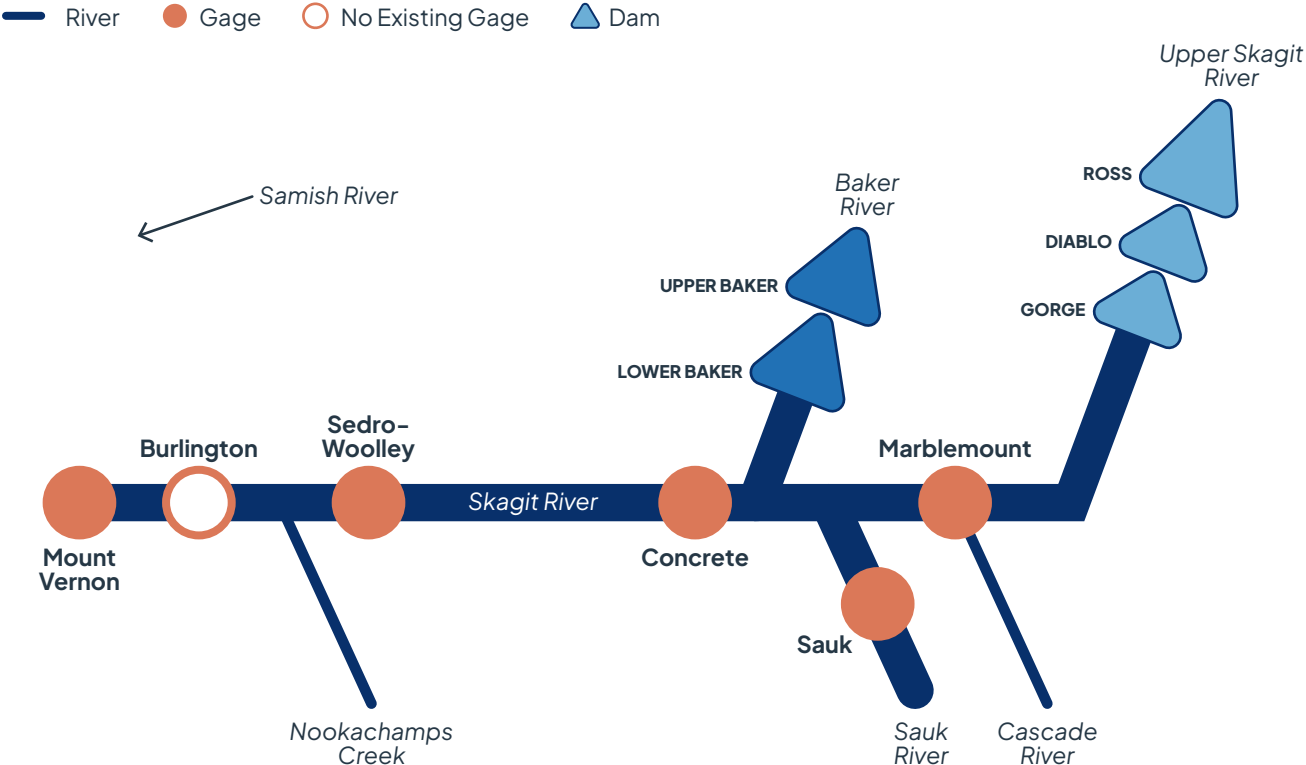


Image adapted from Lee et al. (2016)

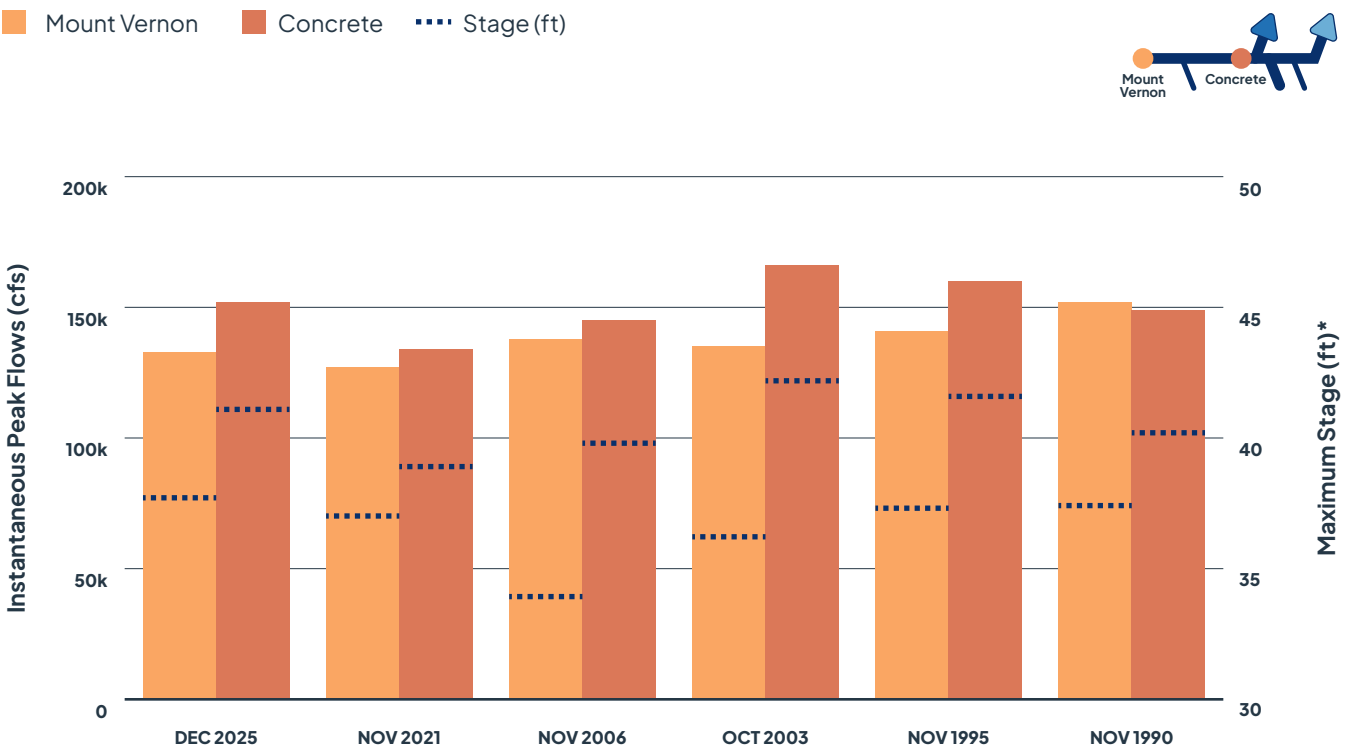
Skagit Flooding: What Happens Upstream Affects Flooding Downstream

It takes time for water to flow downhill. For example, peak flows at the Concrete gage tend to occur about 8 hours before they arrive at the Mount Vernon gage. But comparing flows at these two locations reveals another point: peak flows at Mount Vernon are often smaller than at Concrete. The reason flows sometimes decrease on the way to Mount Vernon is because of flooding or diversion of floodwaters that occurs between the two locations. When water goes overbank it slows the flow, leading to a lower peak flow downstream. In large flood events, flood waters can also divert from the Skagit's main channel and flow directly to Puget Sound, effectively

reducing flows at the Mount Vernon gage. Figure 3 shows that the peak flow is lower at Mount Vernon than at Concrete for five of the six major flood events since 1990. Bars in the figure show the peak instantaneous flows, at Mount Vernon and Concrete, and dotted lines show the maximum stage height for each flood. Note that stage is not measured relative to the same base elevation at each location, meaning that their actual height off the landscape cannot be compared directly. This figure is an illustration of a larger fact about flooding: where flood waters go upstream can have implications downstream, either exacerbating or ameliorating risks for others.

FIGURE 3: MAJOR SKAGIT RIVER FLOOD EVENTS SINCE 1990

Peak flows are almost always higher at Concrete than at Mount Vernon, despite being farther upstream.



(USGS) U.S. Geological Survey, 2026, USGS Water Data for the Nation: U.S. Geological Survey National Water Information System database, accessed April 2026, at <https://doi.org/10.5066/F7P55KJN>.
*Stage is not measured relative to the same base elevation at Concrete and Mount Vernon, so the heights cannot be compared directly.

Skagit Flooding: Role of the Dams

During high flow events, the five dams on the Skagit and Baker rivers (triangle symbols in Figure 2) are operated to reduce flooding downstream. To understand the role of the dams in flooding, it helps to look at both averages and specific historic flood events.

First, let’s look at model results from the average of the top ten Skagit flood events prior to 2022. The bar plots in Figure 4 show results estimating the proportion of the peak flows (for the Skagit River at Concrete) that originated above the upper Skagit dams (light blue), above the Baker dams (dark blue), and from areas below or unaffected by the dams (orange) for two different scenarios. The bar on the left-hand side of the plot shows the hypothetical peak flow at Concrete that would have

occurred if the dams did not exist (based on estimates of “naturalized flows” obtained from Seattle City Light and Puget Sound Energy, labeled “Without Dams” in the plot). The bar on the right-hand side of the plot shows the observed peak flow at Concrete, with the reductions due to dam operations included (labeled “With Dams” in the plot). Note that the orange bar, which shows flows that are unaffected by the dams, is always the same for the “Without Dams” and “With Dams” bar in each plot. This is because the dams have no influence on these flows. On average, across the top 10 Skagit floods, nearly half of the total flow originates from these areas not affected by the dams. Figure 4 does not include the December 2025 flood event, only because the data from that event was not yet available at the time of this analysis.

FIGURE 4: AVERAGE PEAK FLOW AND SOURCES FOR TOP 10 SKAGIT RIVER FLOOD EVENTS

On average, across the top 10 Skagit floods, nearly half of the water comes from areas not affected by dams.

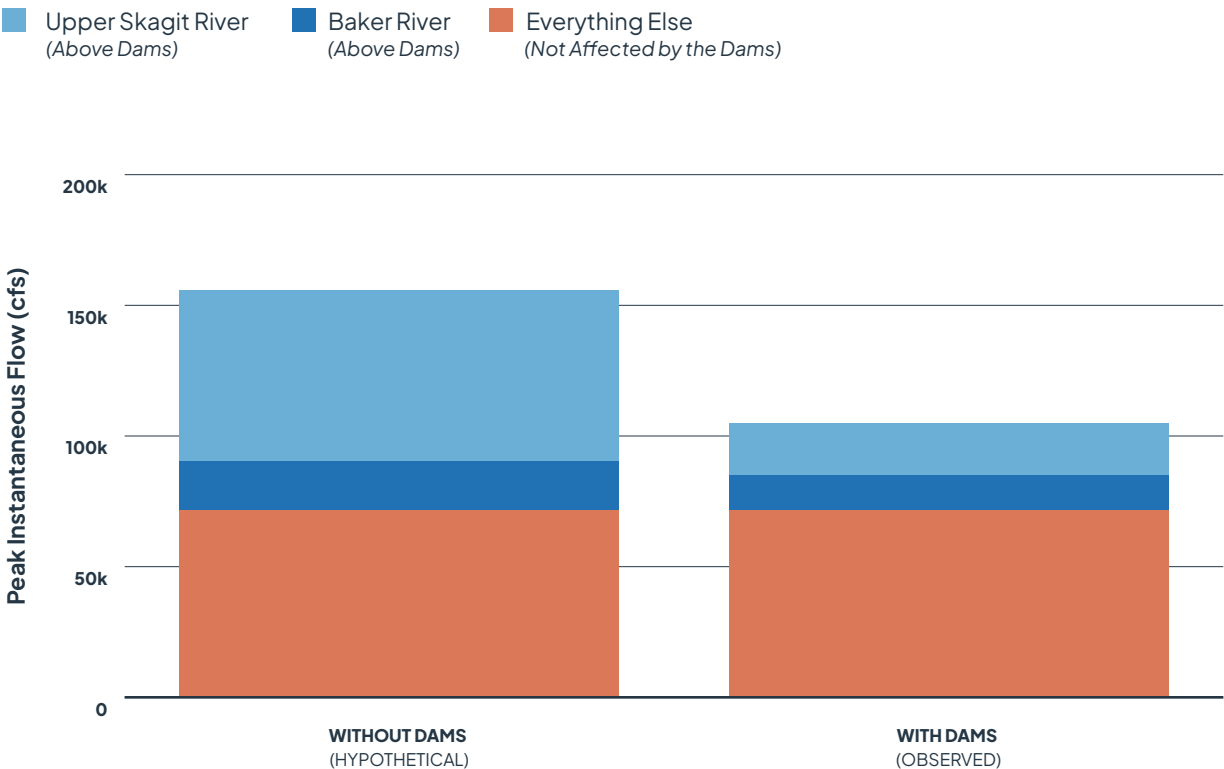
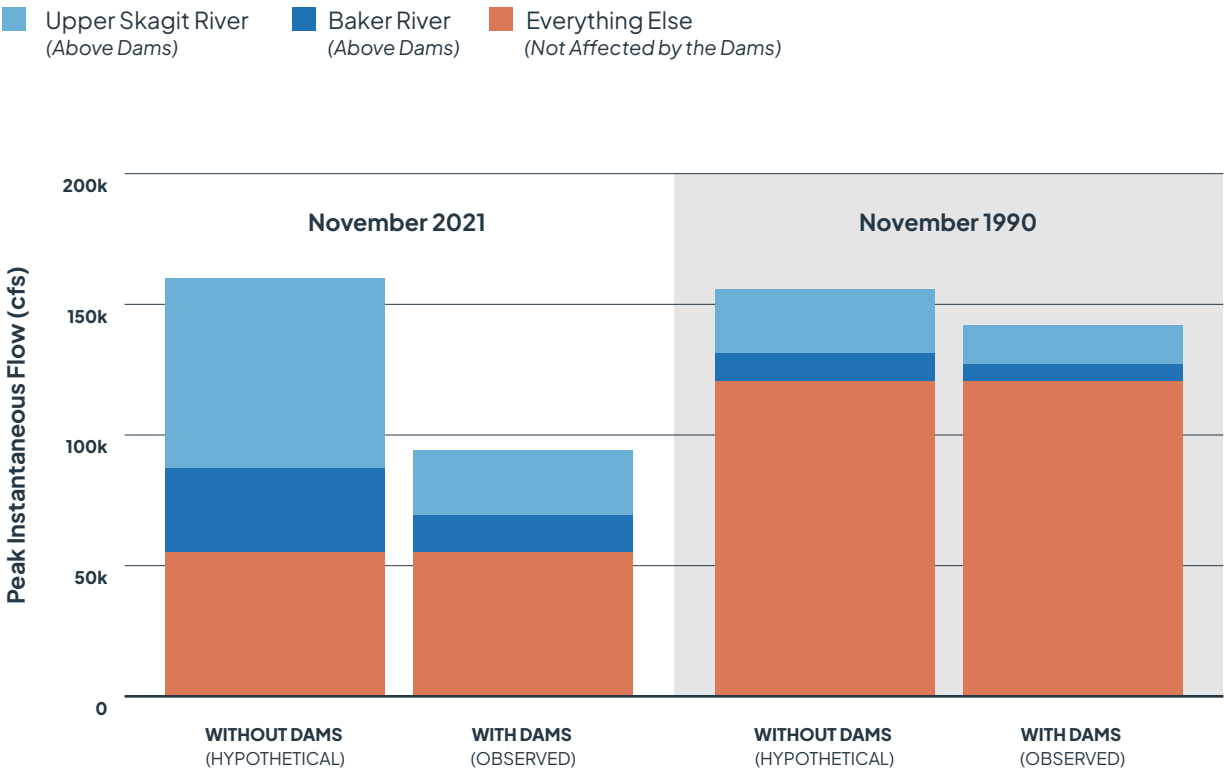


FIGURE 5: SOURCES OF FLOOD WATERS FOR DIFFERENT EVENTS

In 2021, a lot of the precipitation fell above the dams. In 1990, most of the flooding came from areas not affected by the dams.



The plots in Figure 5 show the same type of results, but for two specific flood events. The left-hand pair of bar plots is the November 2021 flood event. This was a major atmospheric river event, the same storm that caused devastating damage in Whatcom County and British Columbia, Canada. The Skagit River dams were able to dramatically reduce the size of the 2021 flood because most of the precipitation fell upstream of the dams. This can be seen by the reduction in total size of the flood when comparing the “Without Dams” and “With Dams” bars in the left-hand pair of plots.

In contrast, the right-hand pair of bar plots (shaded in gray) show that most of the precipitation for the 1990 flood event fell on areas below or not affected by the dams. In this particular event, most of the precipitation fell in the Sauk River basin, which is not influenced by the dams. As a result, the bar graph shows that the dams could not do much to reduce peak flows in the 1990 flood. The bar chart does show that the size of the 1990 flood was lessened by

the presence of the dams, but the effect is small because most of the flows originated from areas not influenced by the dams (orange in each bar).

Understanding the role of the Skagit and Baker river dams is critical to understanding Skagit River flood risk. The flood model and associated map and animation products developed as part of this project incorporate the role of flood storage by the dams. Specifically, the flow inputs provided at the model boundaries – inflows upstream of Marblemount and on the Baker River – account for the effects of the dams on peak flows. For the historic simulation, inflows are based on observed flows at these streamflow gages.¹

¹ The term “historic” is used to refer to any information based on past data. This includes the inflows obtained from the Draft Skagit River General Investigation (USACE 2014) and used as input to the flood model simulations, as well as the historic simulations used as the baseline for developing the 2040s and 2080s change estimates for both peak flows and sea level rise.

As described below, the future flows also account for the dams by using a reservoir model to estimate the effect of the dam on flows. The 2026 Skagit River Seattle City Light dams relicensing settlement includes flood risk management measures that will alter the timing of flood storage and release protocols at the three upriver dams. New operations have not yet gone into effect and are not accounted for in the modeling for this project. The new change to operations could reduce the size of some floods but only those occurring in fall and for which a substantial portion of the precipitation originates above the Upper Skagit dams. Additional technical detail can be found in [Appendix A](#).

”

The Swinomish Indian Tribal Community's and Skagit Climate Science Consortium's 2025 Flood Modeling Presentation was very impactful for Sauk-Suiattle, inspiring a more detailed assessment of how flood risks to the Tribe are changing over time. SITC and SC2's work underscores the importance of proactive resilience planning to prevent and reduce adverse impacts on human and nonhuman communities.”

— Arianna Lapke, Climate Change Specialist, Sauk-Suiattle Indian Tribe



Photo Credit: Eric Mickelson, Skagit River System Cooperative

Impacts of Warming Climate on Flooding

There are many ways a warming climate could affect flooding in the Skagit watershed; Figure 6 lists many of them. However, a few key factors are likely to be most responsible for increasing flooding in the Skagit system. These are:

- Declining snowpack,
- Heavier precipitation,
- Rising sea levels, and
- Increased sediment load.

The following section will provide a quick overview of each factor and how it affects flooding.

“

Flooding of the Skagit River is the highest priority climate change impact that Skagit County must address. This new flood model provides expanded capabilities that will help the County assess the problem and evaluate potential scenarios and actions to improve resilience in the face of increasing risks.”

— Betty Carteret, Skagit County Climate Activist and Educator



Photo Credit: Eric Mickelson, Skagit River System Cooperative

FIGURE 6: CLIMATE CHANGE IMPACTS ON FLOODING

Skagit flood risk is increasing due to the combined forces of multiple changing climate factors.

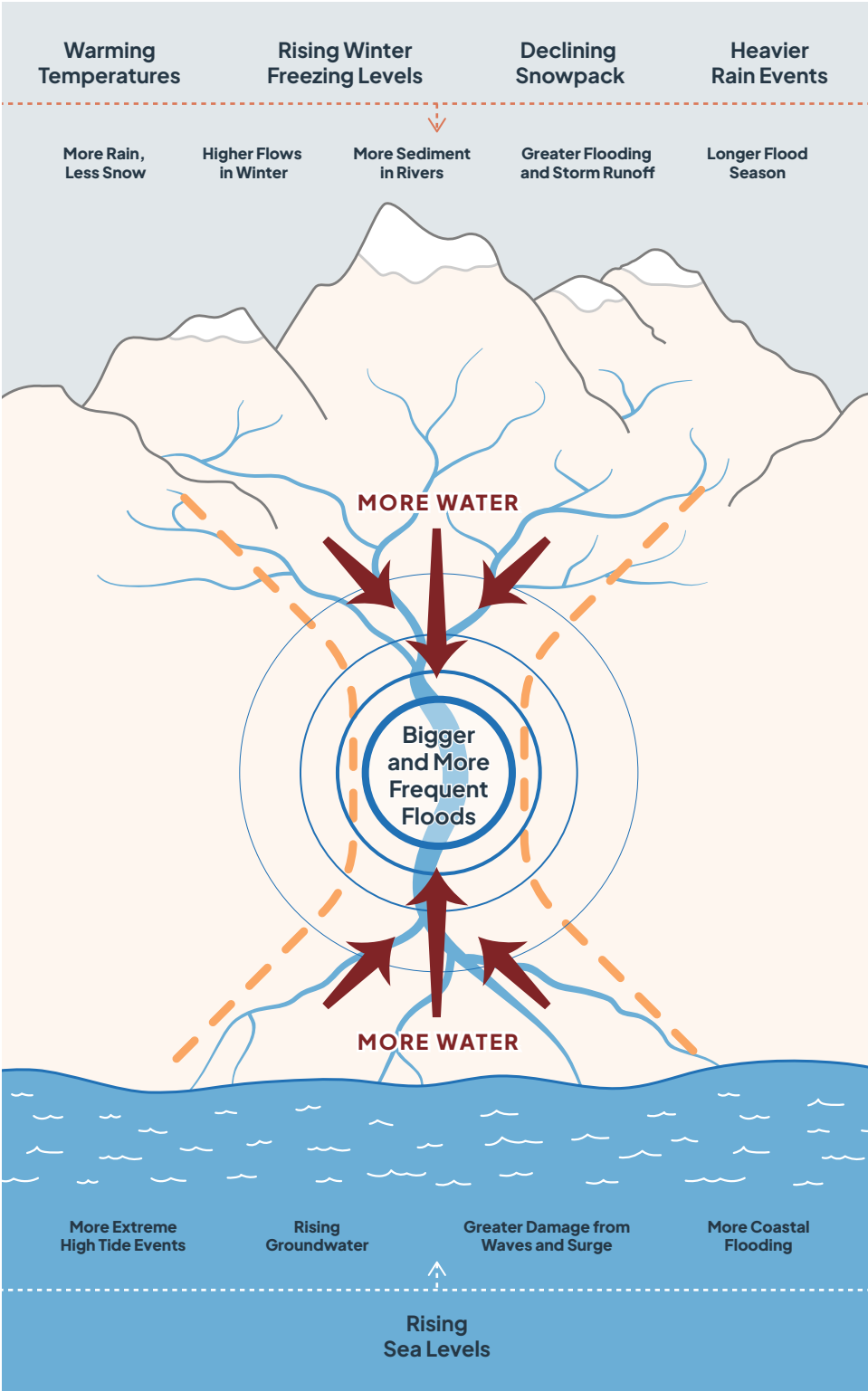


Image credit: Skagit Climate Science Consortium (SC2)

Declining Snowpack: More Rain and Less Snow Means Bigger Floods

As snowpack in the northwest declines, flooding increases. One way to think about the effect of warming on snowpack is in terms of the average elevation of the “snowline” – the elevation where precipitation transitions from snow to rain, as illustrated in the top portion of Figure 7 (Precipitation refers to all forms of water falling from the sky: snow, rain, hail, etc.).

Snow is important because when there is less snow and more rain, the same amount of precipitation can lead to a larger flood. Although the snowline varies from one storm to the next, the average snowline is expected to rise with warming. As the snowline rises, storms bring more rain and less snow to the Skagit watershed. With this increase in rainfall, there is more water available to contribute to flooding.

Research shows that spring snowpack has already declined by about 15–30% across the western United States since the 1950s (Mote et al. 2018). Modeling for the Skagit River watershed estimates the snowpack will be at about 50% of historical levels, on average, by the 2080s (Hamlet et al. 2013). This means that the Skagit watershed has already experienced a shift to more rain and less snow, and that this trend will accelerate over the coming decades. Although Figure 7 does not show the historical change, it shows how the influence of snow is projected to change by the 2040s and 2080s (based on Hamlet et al. 2013). The figure shows the percentage of land area classified as rain-dominated, mixed-rain-and-snow, and snow-dominated in the Skagit watershed. The increase in dark blue, which shows rain-dominated areas, along with the decrease in mixed-rain-and-snow and snow-dominated areas, is a major reason why floods are projected to increase.

FIGURE 7: DECLINING SNOWPACK

Warming brings a shift to more rain and less snow.

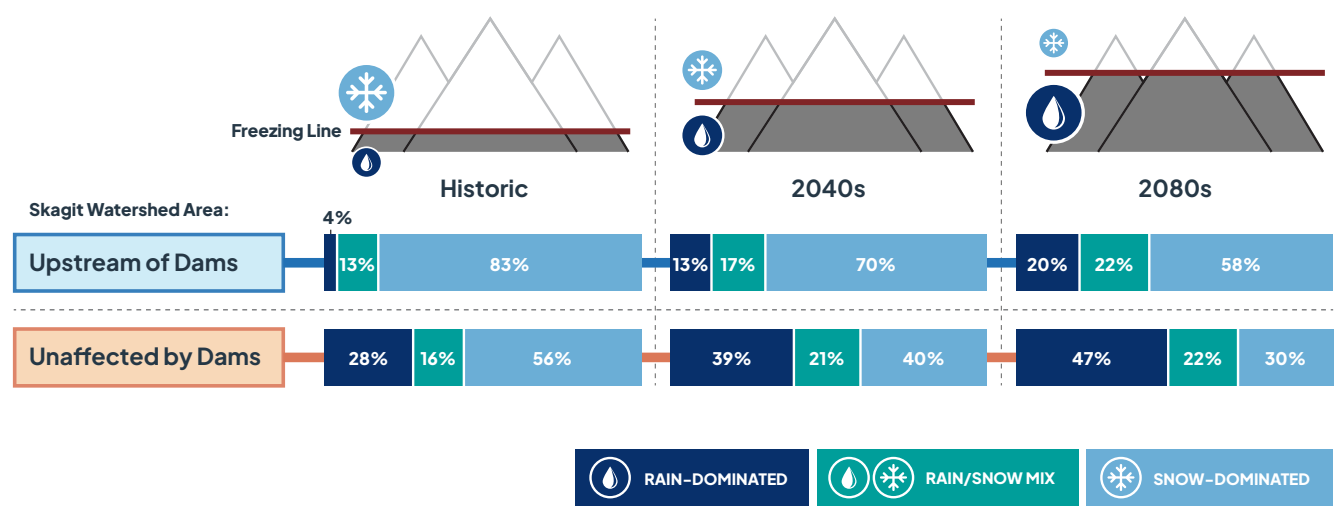
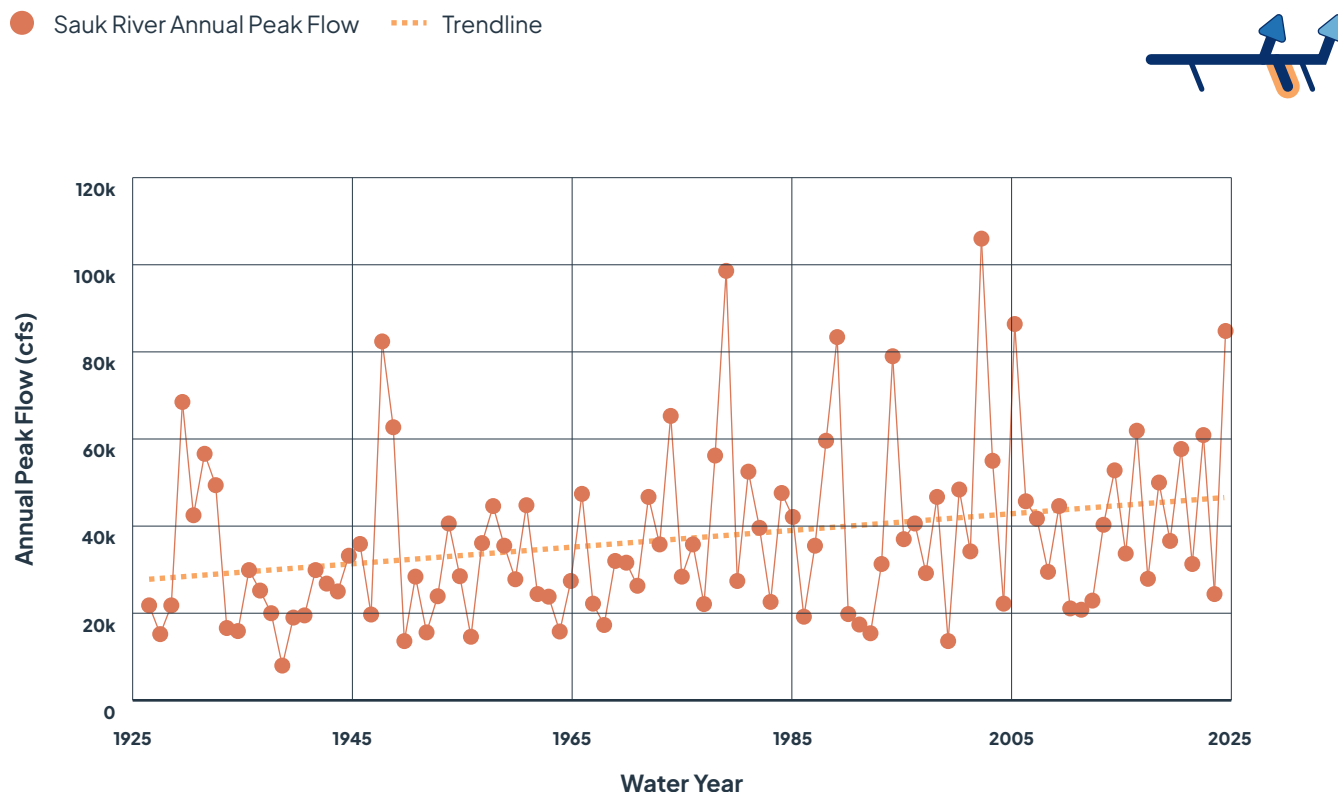


Image credit: Skagit Climate Science Consortium (SC2)

FIGURE 8: INCREASING TREND IN PEAK FLOWS FOR THE SAUK RIVER

The average peak flow post-1975 is higher than the pre-1975 average.



We can see this effect in peak flows on the Sauk River. The graph in Figure 8 shows an upward trend in peak flows since records began in the 1920s. For example, the average peak flow on the Sauk post-1975 was 39% higher than the average peak flow prior to 1975. Scientists cannot say for sure whether this increase in average peak flows is due to increases in precipitation or some other factor. However, precipitation is unlikely to explain the trend because observations do not show a clear upward trend in precipitation in the area. Other non-climate changes (e.g., logging) are also less likely because much of the Sauk River watershed is protected. This suggests declining snowpack

is likely to be playing a role in the trend in peak flows for the Sauk River.

Overall, this shift from snow to rain is probably the biggest driver of changing flood risk on the Skagit River. However, not all of the watershed is at elevations where snow is important. For lower elevation streams (e.g., Nookachamps Creek), changes in precipitation intensity would be more important than decreases in snow – this is the second key factor.

Heavier Precipitation (Rain and Snow)

It is commonly understood that a big storm can bring a flood. This also means changes in the intensity of precipitation (the rate and volume of precipitation delivered during a storm) is likely to affect flooding. Climate models project that the heaviest precipitation events will become +22% more intense by the 2080s on average (Warner et al. 2015). Research is ongoing, but current studies suggest that the primary reason for the increase in precipitation intensity is simply that warmer air holds more water.

An important detail to clarify is that the research *does not* find a large change in other characteristics of these storms (pressure, winds, location, etc.). Instead, the research suggests that – other than precipitation intensity – storm characteristics are similar now and in the future.

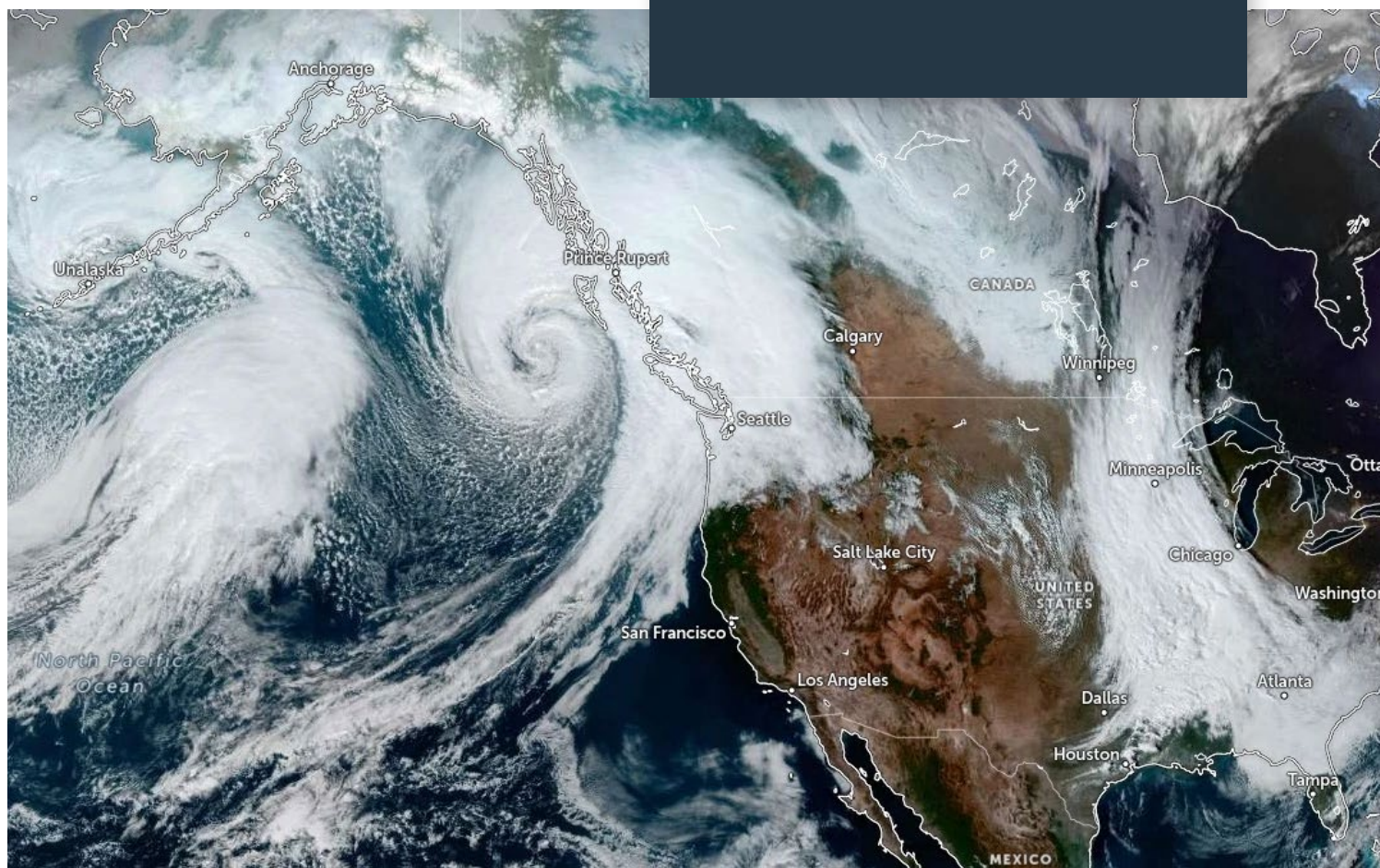
Modeling precipitation is more difficult than modeling temperature, so there is more uncertainty in these results.

However, current science is consistent in showing an increase in the intensity of heavy rain events, meaning that we expect future precipitation events to lead to bigger floods, exacerbating the trend we’re already seeing due to decreases in snowpack.

”

The Town of Hamilton is in strong support of the projected Flood Models. This is a great source of knowledge for the Town to plan more accordingly for future flood awareness!”

— Kym Eldridge, Clerk,
Town of Hamilton



Sea Level Rise

Sea level, tide levels and storm surge all affect the height and extent of coastal flood waters during a flood event as visualized in Figure 9.

In coastal areas and the lower reaches of the Skagit and Samish rivers, sea level rise can contribute to flooding. In addition to elevating routine high tides, sea level rise can affect flooding in two ways: first, by leading to higher flood waters along the coast, and second, by slowing flows coming off the land or in rivers. This is called a “backwater effect”, where higher coastal water levels make it harder for runoff to drain to Puget Sound until the tide comes back down again.

Much of the Skagit delta is already “sub-tidal”, meaning that the land is below the current normal high tide and would be submerged by coastal waters in the absence of dikes. Because of these sub-tidal elevations, there are already times when drainage off the Skagit Delta is delayed due to high tides. With higher sea levels projected, this will happen more often.

In Skagit, Padilla, and Samish bays, models project about 1.5 to 2 feet of sea level rise by 2100 (Miller et al. 2018)². Similar to the findings for precipitation, research does not indicate a change in storm characteristics (pressure, winds, currents) that would lead to changes in storm surge or waves. Instead, future coastal storm events are higher simply because the base sea level is higher. Figure 9 illustrates what this means for coastal flooding.

² Browse the projections in the UW CIG Sea Level Rise tool: <https://cig.uw.edu/projects/interactive-sea-level-rise-data-visualizations/>

FIGURE 9: SEA LEVEL RISE

Sea level rise increases the height of coastal floods.

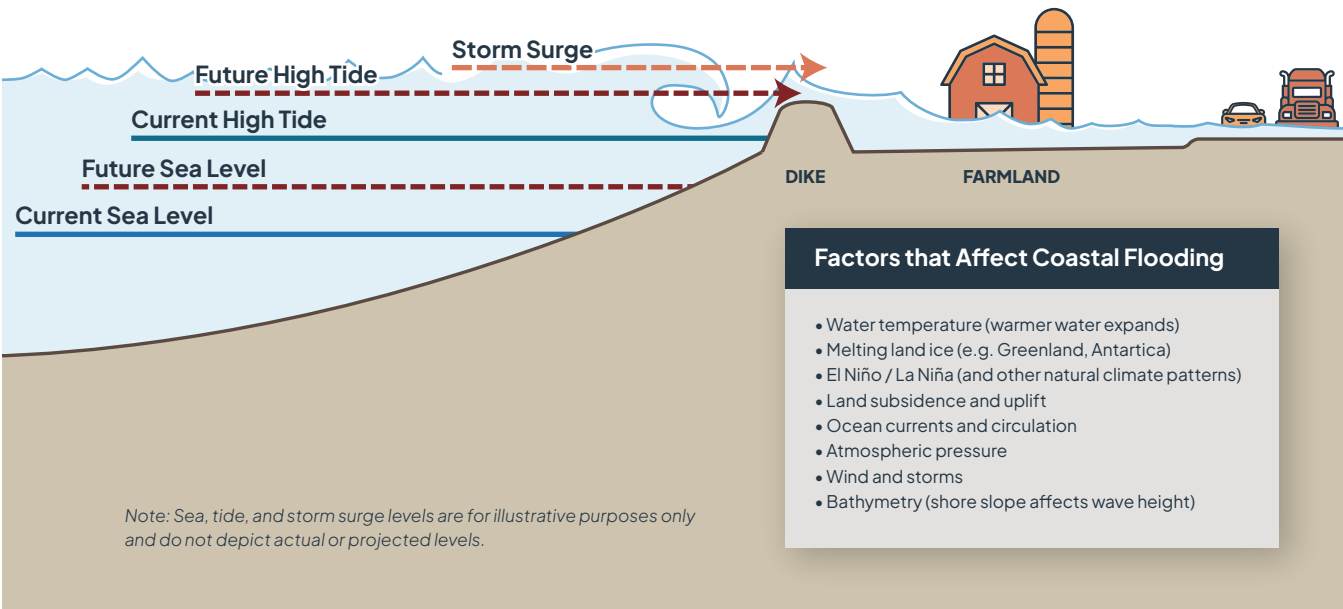


Image credit: Skagit Climate Science Consortium (SC2)

Sediment

Scientists think of rivers as conveyor belts for sediment moving down from our mountains and valleys, as illustrated in Figure 10. Rain, runoff, and landslides mobilize sediment over land, eventually carrying it to creeks and rivers. Rivers also erode and mobilize sediment. In both cases, sediment is transported downstream and deposited in the lower river, Skagit Bay, and Puget Sound. This is why rivers form deltas at their lowest elevations: as sediments deposit over time they create flat areas where river channels can form and meander. With climate change, we expect the volume of sediment transport to increase for a variety of reasons, including:

- receding snowpack and glaciers are exposing new soils to erosion;
- heavier precipitation can increase both erosion and landslide risk; and
- higher river flows can both erode river channels more rapidly and transport more sediment downstream.

At the same time as more sediment is being moved downstream, sea level rise is slowing flows in the lowest river reaches, potentially causing more sediment to

deposit on the river bottom. In natural systems, excess sediment can be deposited on the floodplain during flood events. When dikes are present, sediment is deposited in the channel or transported downstream. This can reduce the river's capacity to convey flood waters without overtopping its banks.

Better understanding of the role of sediment in flooding is critical. For example, one Skagit study used the observed relationship—that higher flows can transport more sediment—to estimate future changes in sediment transport. The researchers found that, due to higher flows, annual average sediment transport in the Skagit River could more than double on average by the 2080s, and that winter sediment transport could more than quadruple (Lee et al. 2016).

The new flood model described in this report used recent surveys of channel depths to make sure it is accounting for recent changes in channel capacity. Future work with the model could further explore the effects of sediment processes, such as the potential for more erosion and the effects of future deposition on flood risk.

FIGURE 10: FLOW OF SEDIMENT

Climate change affects sediment processes throughout the Skagit watershed.

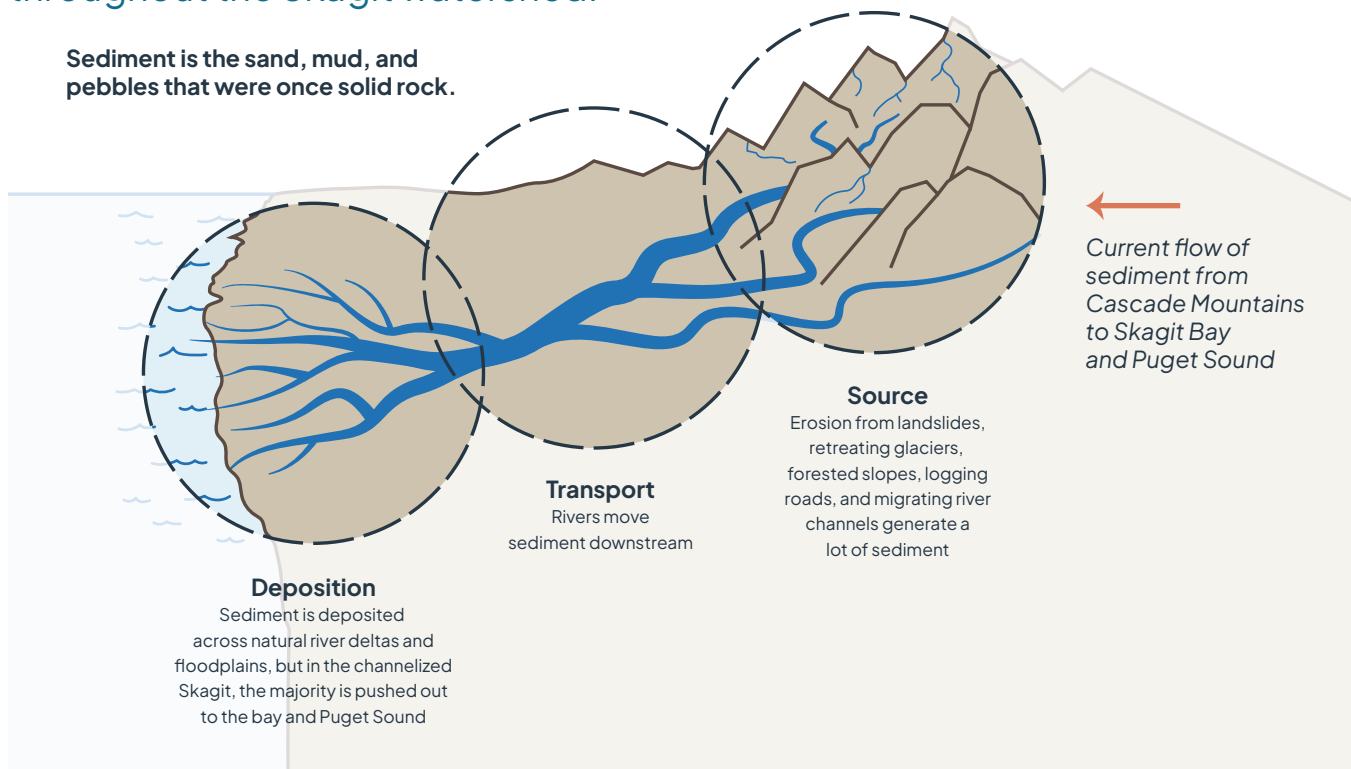


Image credit: Skagit Climate Science Consortium (SC2)

Putting It All Together: Projected Flood Changes in the Skagit

As illustrated in Figure 6, the combination of rising snow elevations, more intense precipitation, increasing sediment transport and deposition, and sea level rise all contribute to an increasing risk of flooding in the Skagit River.

The most comprehensive study on climate change and flooding for the Skagit River estimates that today’s 100–year flood at Mount Vernon would increase by +49%, on average, by the 2080s (Lee et al. 2016). Looking at the results another way, the same study found that today’s 100–year flood (or 1% annual chance event) would happen about four to five times as often by the 2040s (i.e., becoming a 20–year to 25–year event instead of a 100–year event). These projections assume the five dams are operated in the same way they were operated prior to the 2026 Seattle City Light relicensing agreement.

The same study looked at possible changes in dam operations and found that even with adjustments to retain additional flows, the 100–year event is still projected to increase by +42% – only slightly lower than the increase of +49% without any changes. This is in large part due to the volume of flows that originate in parts of the watershed that are not influenced by the dams (see the discussion on Skagit Flooding above).

The projected changes described in the previous paragraph are for the 100–year event only, and just for the Skagit River near Mount Vernon. To develop future flow inputs for the flood model, we analyzed the results from Lee et al. (2016) and two other studies (Hamlet et al. 2013, Bandaragoda et al. 2015, 2019) to obtain estimated changes in the 10–, 25–, and 100–year events for river locations across the Skagit and Samish watersheds.

In all, we obtained projections for seven locations across the watershed. Although we placed a priority on the Hamlet et al. (2013) and Lee et al. (2016) studies, both for the improved calibration and for the regulated flow estimates, the Bandaragoda et al. (2015, 2019) study was used for two tributaries that were not readily available from the previous studies. In order to provide a middle-of-the-road estimate of future conditions we used the median projection for each dataset along with a moderate greenhouse gas scenario (A1B, Nakicenovic et al. 2000). For the Bandaragoda et al. (2015, 2019) study, we averaged results for a low and high greenhouse gas scenario (RCP 4.5 and 8.5, Van Vuuren et al. 2011) to approximate the results for a moderate greenhouse gas scenario. Projections range from near-zero change to an increase of over 50%, depending on the location, time period, and flood frequency considered.

The Hamlet et al. (2013), Lee et al. (2016) and Bandaragoda et al. (2015, 2019) studies provide the percent change in flows, which is applied to the observationally-based peak flow inputs used for the historic simulation. Inputs from the historic flood simulation were obtained from the Draft Skagit General Investigation study (USACE 2014). Additional details, along with the projected changes for each flood frequency and location, are provided in [Appendix A](#).

Table 1 lists the same historical flood events shown in Figure 3, this time only for Concrete. These are provided as a reference alongside Table 2, which shows the flow and stage estimates for the 10–, 25–, and 100–year flood frequencies for the Skagit River at Concrete, comparing the model results for the historic, 2040s, and 2080s time periods. The projections show large projected increases in peak flows.

TABLE 1: MAJOR SKAGIT RIVER FLOOD EVENTS AT CONCRETE SINCE 1990

Event	Peak Instantaneous Flow (cfs)	Maximum Stage (ft)
Dec 2025	152,000	41.1
Nov 2021	134,000	38.9
Nov 2006	145,000	39.8
Oct 2003	166,000	42.2
Nov 1995	160,000	41.6
Nov 1990	149,000	40.2

TABLE 2: HISTORIC AND FUTURE PEAK INSTANTANEOUS FLOWS FOR THE SKAGIT RIVER AT CONCRETE

Event	Historic	2040s	2080s
10–year	129,000 cfs 38.4 ft	179,000 cfs 44.5 ft	221,000 cfs 49.5 ft
25–year	167,000 cfs 43.0 ft	213,000 cfs 48.6 ft	259,000 cfs 53.4 ft
100–year	222,000 cfs 49.5 ft	256,000 cfs 53.2 ft	300,000 cfs 56.8 ft

“Instantaneous peak” refers to the highest 15–minute value. Peak flows and stage were determined from the Project model simulations by extracting results at the Concrete gage (USGS 12194000). Stage is based on the gage datum; to convert to NAVD88 add 133.96 ft.

For example, Table 2 shows that the historic 100-year flow estimate of 222,000 cfs is larger than all of the floods since 1990 (Table 1), and that it is projected to increase to 300,000 cfs by the 2080s. As noted above, projected flow increases for the Skagit River at Mount Vernon will likely be much smaller since a significant amount of water is expected to go overbank and onto the floodplain between Concrete and Mount Vernon.

FLOOD FREQUENCIES: WHAT DO WE MEAN BY THE “100-YEAR FLOOD”?

Scientists typically look across many historical events to estimate the chance, on any given year, that a particular flood event will occur. For example, the so-called “100-year” flood is a common standard used for urban and transportation planning, engineering design, FEMA mapping, flood insurance, and other policy and regulatory applications. The “100-year” description can be confusing for two reasons.

First, the terminology appears to suggest the event could only happen once every hundred years. In fact, “100-year” floods can happen back-to-back or be separated by more than a century. This is because the events are independent. The 100-year event is actually defined as an event that has a 1% chance of occurring in any given year. This is why these are referred to as “flood frequencies”: they are defined by the frequency, or probability, that they will occur in a given year. The same definition applies to any “return period”. For example, the 10-year event is defined as the 10% annual chance event, and the 25-year event is defined as the 4% annual chance event. For a more in-depth explanation of flood frequencies see this USGS page: <https://www.usgs.gov/centers/new-jersey-water-science-center/floods-recurrence-intervals-and-100-year-floods>

The second reason the “100-year” flood term can be confusing is that the statistics around flood volumes and frequencies are changing as the climate warms. As noted earlier, the average peak flow on the Sauk post-1975 was 39% higher than the average peak flow prior to 1975. This means that what statistically was the 100-year flood flow (1% chance of happening in a given year) prior to 1975 is now a much larger event. Part of what makes the current modeling effort significant is that we include results that show how changing flows impact flood risk.

The Lee et al. (2016) study cited the average (+42 to +49%) change in the 100-year peak flow event. However, it is important to remember that every storm, and every resulting flood, is different. This means different storms will be affected by warming in different ways. Figure 11 illustrates this by showing model estimates for how five historic floods would change with warming. For example, if the 2006 Skagit flood were to occur again in the 2040s or 2080s, how much higher would the flows be?

As an example, the modeled 2006 event is shown in the last three bars on the far right of Figure 11. The first bar is the 2006 historic event, the second bar is the 2040s projection, and the last bar shows the same event in the 2080s. As in Figures 4 and 5 above, the light blue bar is the flow originating from above the Skagit dams. The dark blue color is the flow coming from above the Baker dams. The orange color is everything else – all areas where flood storage is not provided by the dams.

Figure 11 contains this same structure for five historic events looking from left to right: 1921, 1983, 1986, 1995 and 2006. In order to simplify interpretation, these results do not include the effects of dam management. The events were chosen because they are the top “unregulated flow” events – in other words, if there were no dams, these would have been the biggest flood events in the record. Because the figure is adapted from Lee et al. (2016), results are not available from the more recent 2021 and 2025 events.

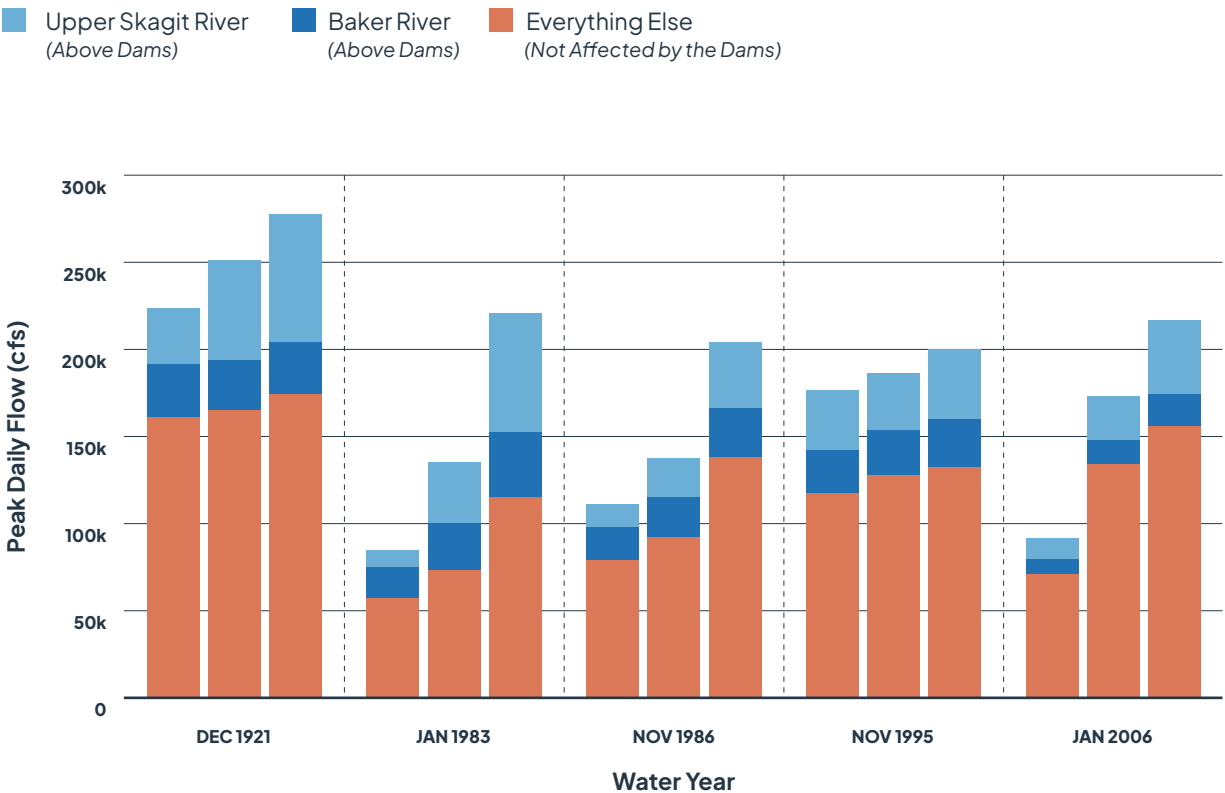
Looking at the results across the entire plot, models project an increase for all five historic events (higher bars for the 2040s and 2080s, in all cases). It also shows that some events change relatively little. For example, the model projects that the 1995 event would lead to flows that are only +14% higher by the 2080s, while the 1983 event is projected to increase by +161%. Overall, the 1921 and 1995 events show smaller increases whereas the increases for 1983, 1986, and 2006 are substantial.

What we are seeing is the contrast between warmer and colder storm events. Warmer events – the flood events of 1921 and 1995 – already have a high proportion of rain compared to snow. For those events, the shift from snow to rain is not as important, so the main effect driving the increases is only the projected increases in precipitation intensity.

In contrast, colder events – the floods of 1983, 1986 and 2006 – have historically had a higher proportion of precipitation falling as snow. With warming, these events increase dramatically because the precipitation will increasingly fall in the future as rain instead of snow, resulting in increased flows during flood events.

FIGURE 11: MORE RAIN, LESS SNOW – A BIG EFFECT ON COLDER FLOOD EVENTS

With declining snowpack, the snowline rises, leading to larger floods as more precipitation falls as rain rather than snow. This change has the biggest effect on colder flood events, because of the higher proportion of snowfall during these floods.



The figure is adapted from Lee et al. (2016), so data are not available for the more recent 2021 and 2025 floods.

These examples illustrate differences among flood events and how climate change will likely affect some flood events more than others.

So far this discussion has only considered the effect of declining snowpack and heavier precipitation events on peak river flows. But earlier we discussed two other important factors: sea level rise and increased sediment mobilization. The flood modeling we describe in this report incorporates the effect of sea level rise (see [Appendix A](#) for these results). The model also incorporates recent changes in the river channel due to ongoing sediment processes. However, we did not evaluate the effect of potential future changes in the river channel on flooding.

Coastal flooding happens when marine waters are elevated due to some combination of tides, low pressure, winds, and coastal ocean currents – sometimes referred to as “storm surge”. Waves are another factor, though remain fairly small in the relatively protected Skagit, Padilla, and Samish bays. Waves are also complex to represent in hydraulic modeling. For both of these reasons, our analysis considers only the surge (or “still water”) component of coastal flooding. Coastal floods are often described using the same flood frequencies approach used for river flooding. We developed estimates for the historic and future 10-, 25-, and 100-year coastal water elevations that were imposed at the coastal boundary of the model.

Research suggests that there is no climate change effect on storm surge. Instead, future coastal floods are higher simply because of sea level rise: the same amount of surge has a higher reach because it is starting from a higher base sea level. As a result we used the same tidal and storm surge values for both the historic and future simulations, simply adding the projected sea level rise to the tides used for the future simulations. We used the Miller et al. (2018) sea level rise projections, because they include the most detailed information on variable rates of rise along Washington's coastline. As with the peak flow projections, we used the median projections and a moderate greenhouse gas scenario to obtain a middle-of-the-road estimate of future conditions. Since a moderate greenhouse gas scenario was not available, we used the average projection across a low and high greenhouse gas scenario (RCP 4.5 and 8.5, Van Vuuren et al. 2011) to approximate the results for a moderate greenhouse gas scenario.

The projections show a median rise of 0.5 feet (6 inches) by the 2040s, and a rise of 1.35 feet (about 16 inches) by the 2080s. This is the amount of sea level rise incorporated into the modeling. Although these differences may seem small, the difference between the height of the 10-yr and 100-year coastal flood is about 4–6 inches for most of Puget Sound. This means that by the 2040s, today's coastal 100-year event is projected to occur about once every 10 years. Additional details, along with the projected changes for each flood frequency and time period, are provided in [Appendix A](#).

The results above show that floods are projected to get bigger with warming. Often infrastructure, regulations, emergency response and other planning efforts are based on observed flows from the past instead of modeled floods in the future. The flood modeling described in this report provides the public and decision-makers with up-to-date information to consider what to use moving forward.



Photo Credit: Eric Mickelson, Skagit River System Cooperative

Primer on Skagit Flooding, Climate Change, New Flood Modeling and Insights It Can Provide

Improvements Relative to Previous Modeling

Flooding was modeled using a hydraulic model. Described in detail in [Appendix A](#), the Project model was developed by Northwest Hydraulic Consultants, building on an existing model that was developed by the U.S. Army Corps of Engineers (USACE 2013). In brief, the model was updated to add coastal flooding (the previous version was developed for river floods only), include new survey and topographic data (river channel and floodplain elevations), better capture drainage infrastructure, add in Samish River flows, and better capture flooding by increasing the resolution and expanded 2D modeling of flows. Figure 12 lists updates to the Project model, ways the model could be updated in the future, and processes that cannot be represented with this model.

These updates mean that the Project model provides a more accurate representation of flood risk than previous modeling efforts (more detail on model calibration and performance is provided in [Appendix A](#)). This is particularly true for Skagit County’s existing FEMA designations, which were adopted in 1985 and are therefore based on much older data and modeling. However, the maps and other results produced as part of this project are not regulatory nor were they designed specifically for emergency response. While the project team hopes that they can provide useful information, particularly where risks differ from the 1985 maps, there is no policy or legal requirement to use these over other data sources. The purpose of the current work is to provide information, not recommendations.

FIGURE 12: PROJECT MODEL UPDATES AND CAPABILITIES



List of features that are included, could be added, or cannot be included in the hydraulic model developed for this project.

Map Products

For this project, the model was used to produce a series of maps ([Appendix B](#)) and a few short animations (found on the Skagit Climate Science Consortium website, see below) that show how flood waters propagate and then recede. A short overview of map types is shown in Figure 13 and further described in this section. Data layers used to create these products (e.g. depth grids) are available on the Skagit Climate Science Consortium website (<https://www.skagitclimatescience.org/research/2026-understanding-current-and-future-skagit-flood-risk/>). The model results can be used to produce additional map and animation products that go beyond what is included here. For technical experts, the flood model itself and associated data layers can be accessed through UW CIG's website (<https://cig.uw.edu/projects/understanding-current-and-future-skagit-flood-risk/>).

WHAT IS THE DIFFERENCE BETWEEN A HYDRAULIC AND A HYDROLOGIC MODEL?

Hydraulic models simulate how water flows. They account for the basic physics of fluid flows – including friction, turbulence, and pressure gradients – to simulate the flow of water in the river channel or over the landscape. They use sophisticated understandings of geographic features as well to create a realistic understanding of water movement. *Hydrologic* models, in contrast, tell us how much water is coming downstream. They are “water budget” models – they determine how water is partitioned between groundwater, evapotranspiration, snowpack, and surface runoff, and the interactions between each.

Hydraulic models almost always require flow inputs at the model boundary (e.g. from tributaries); these inputs are often estimated with a *hydrologic* model.

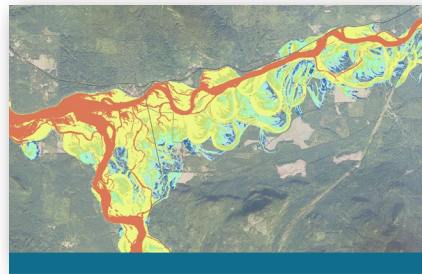
FIGURE 13: MAPS RESULTING FROM THIS PROJECT



Flood Depth Maps

Flood depth maps show the depth and extent of flooding for specific locations and flood frequencies. Maps are included for:

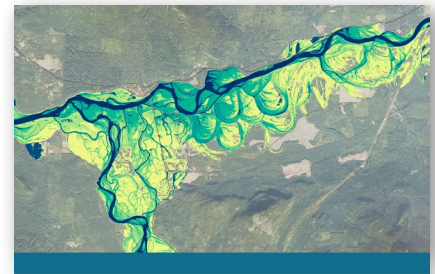
- The 10-year, 25-year, and 100-year events
- 6 dike failure scenarios (historic 100-year event)
- Riverine and coastal flooding
- Historic, 2040s, and 2080s conditions



Depth-Velocity Hazard Maps

Depth-Velocity Hazard maps show the danger posed by flood waters. Maps are included for:

- 100-year events
- 6 dike failure scenarios
- Riverine and coastal flooding
- Historic conditions



Duration Maps

Duration maps show how long flooding lasts for each location. Maps are included for only one scenario:

- Historic 100-year event
- Riverine flooding
- Historic conditions

TABLE 3: MAP PRODUCTS AVAILABLE IN APPENDIX B

				Water Depth	Hazard	Duration
Historic	Coastal	Historic	10-year	✓		
			25-year	✓		
			100-year	✓	✓	
	Riverine	Historic	10-year	✓		
			25-year	✓		
			100-year	✓	✓	✓
	Riverine	Dike Failure Scenario 1	100-year	✓	✓	
		Dike Failure Scenario 2		✓	✓	
		Dike Failure Scenario 3		✓	✓	
		Dike Failure Scenario 4		✓	✓	
		Dike Failure Scenario 5		✓	✓	
		Dike Failure Scenario 6		✓	✓	
Mid-Century (2040s)	Coastal	2040s	10-year	✓		
			25-year	✓		
			100-year	✓	✓	
	Riverine	2040s	10-year	✓		
			25-year	✓		
			100-year	✓	✓	
Late-Century (2080s)	Coastal	2080s	10-year	✓		
			25-year	✓		
			100-year	✓	✓	
	Riverine	2080s	10-year	✓		
			25-year	✓		
			100-year	✓	✓	

The table above and Figure 13 are two different ways of capturing the range of map products available in [Appendix B](#). These products are clustered into map bundles organized by Upriver, Lower River, Coastal and Dike Failure.

The Upriver Map Bundle includes: an overview map of the area and zoomed-in map products for Marblemount, Concrete, Rockport, Hamilton, Lyman, and Sedro-Woolley and the unincorporated communities of Corkindale, Rockport, Van Horn, and CapeHorn. The major tributaries in this reach include the Cascade, Sauk, and Baker rivers.

The Lower River Map Bundle includes: an overview map of the area and zoomed-in map products for the cities of Burlington and Mount Vernon, the town of La Conner, the Swinomish Reservation and the unincorporated communities of Conway, Bow, and Edison. Nookachamps Creek is the only major tributary in this reach, and the maps include the Samish River floodplain, which discharges into Samish Bay at Edison.

The Coastal Map Bundle includes: an overview map of the area and zoomed-in map products for Padilla and Samish Bays, La Conner, and Skagit Bay.

The Dike Failure Map Bundle includes: an overview map of this area and zoomed-in map products for Lafayette Road, above BNSF Bridge, below I-5 Bridge, below Mount Vernon flood wall, above Division Bridge, and North Fork Fir Island (“above” and “below” in these names designate upstream and downstream, respectively). The six dike failure scenarios were initially developed for the Draft Skagit Basin General Investigation Study (USACE, 2014). All dike failure maps are based on river flooding simulations. Although coastal flooding could result in dike failures, none were included in the current study, and the six scenarios presented here are unlikely to be affected by coastal floods.

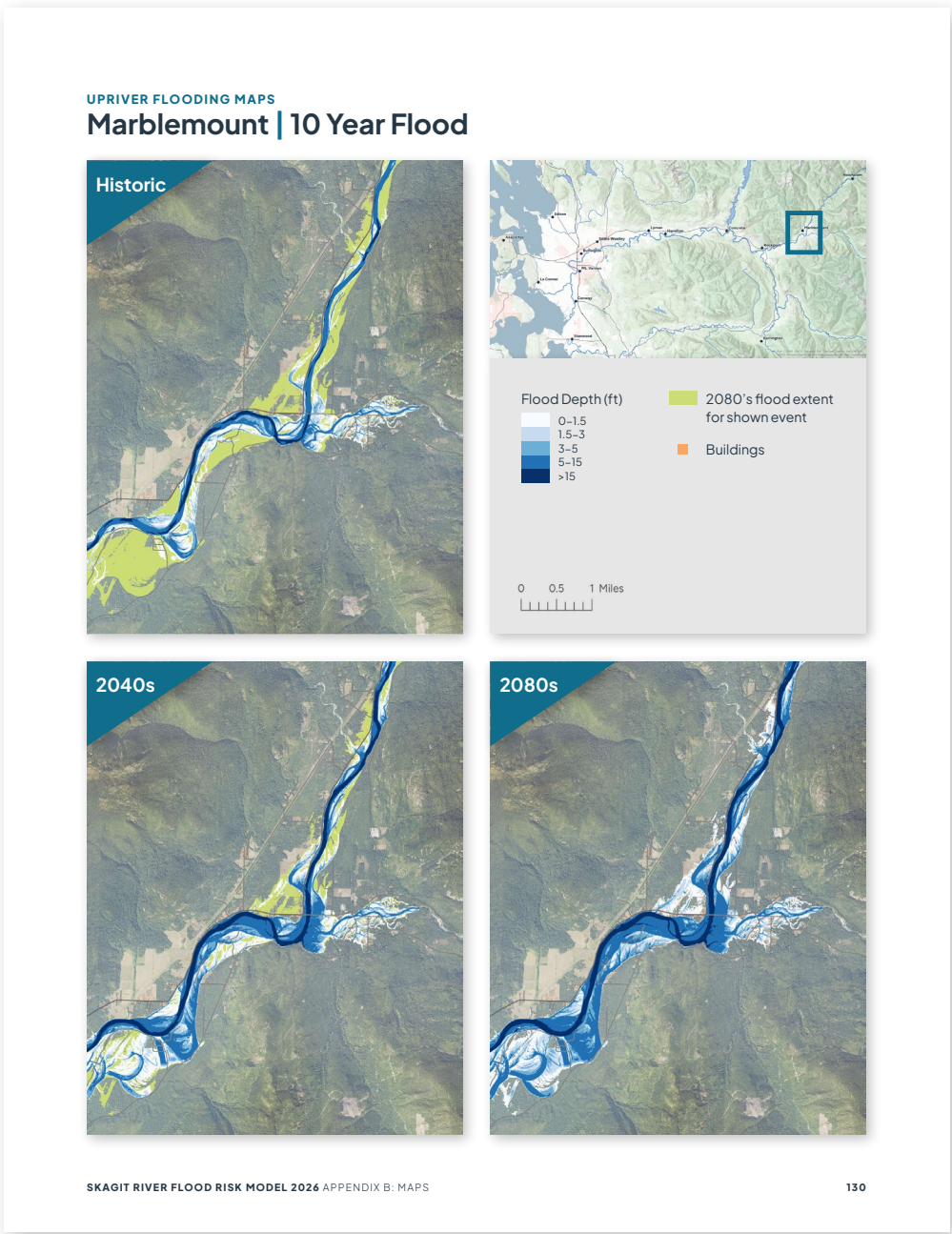
The following sections highlight example results by map type in order to provide a more detailed overview of the content provided in [Appendix B](#).

Disclaimer: The maps below and those provided in [Appendix B](#) are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, channel avulsion, dike failures, larger than modeled events, flood fighting activities or other factors. Maps do not capture flood extents nor depths projected beyond a 100-year (1% annual chance of exceedance) flood event. Maps should be used at your own risk.

Riverine Flood Depths

The flood depth maps illustrate riverine flooding across the floodplain for historic and future conditions. In general, historic 100-year flood extents are similar to the 25-year event in the 2040s and the 10-year event in the 2080s, indicating more frequent flood events in the future and associated increases in flood impacts. This can be seen in the example maps from Marblemount below.

This set of maps show how the flood depths and extents change for a 10-year flood event for historic conditions, the 2040s, and the 2080s. The white to blue shading shows water depths for the timeframe and recurrence interval noted in the upper left corner of each map. The bright green coloring shows the new riverine flood extent expected as a result of climate change in the 2080s. In the example below, the town core of Marblemount can be seen to remain dry for all three scenarios.



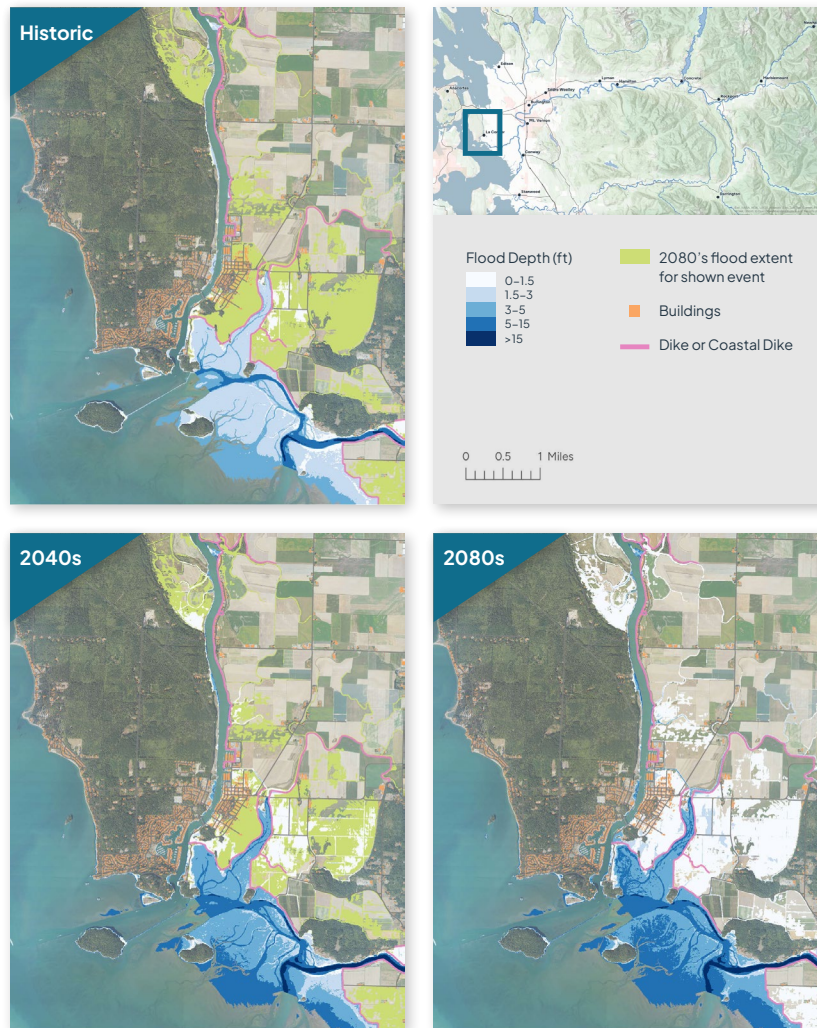
Coastal Flood Depth

The coastal flood depth maps illustrate coastal flooding for historic and future conditions. Coastal flood depth maps are not combined with river flood events. Coastal flooding impacts the Town of La Conner, the Swinomish Reservation, Fir Island, and several unincorporated communities and areas. In general, the 10-year flood extents in the 2080s are similar to or even greater than the historic 100-year extents, indicating more frequent flood events in the future and associated increases in flood impacts. This can be seen in the example maps from La Conner below.

Similar to the river flood depth maps, the example maps show how the flood depths and extents change for a 10-year, or 10% annual chance of occurrence, flood event from historic conditions to the 2080s. The white to blue shading shows water depths for the timeframe and recurrence interval noted in the upper left corner of each map. The bright green coloring shows the new coastal flood extent expected as a result of climate change by the 2080s.

COASTAL FLOODING MAPS

La Conner | 10 Year Flood



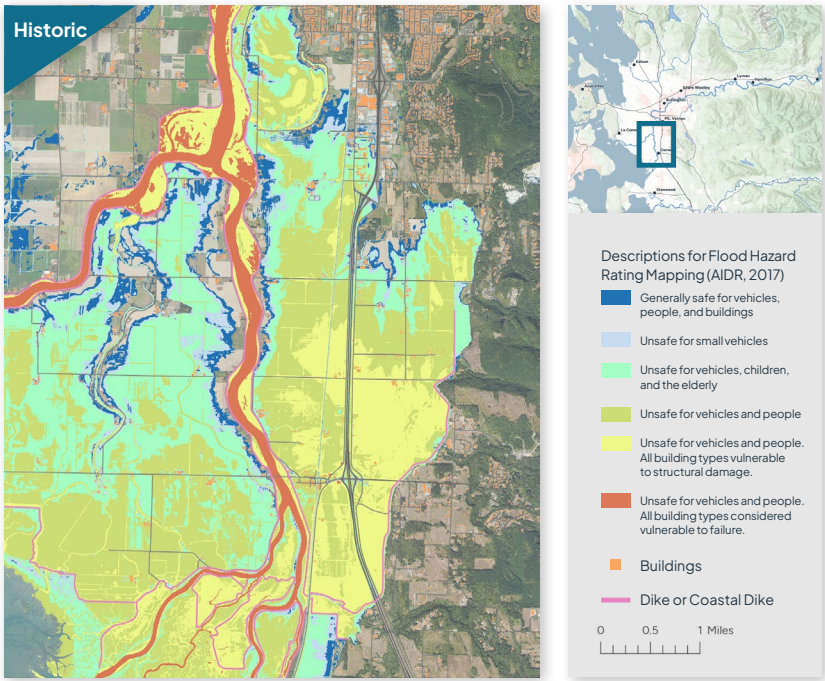
Depth-Velocity Hazard – Riverine Flooding

Water depth is not the only factor that creates flood risk. These maps consider both depth and velocity to define hazard classifications for the risk to people, vehicles, and structures based on guidelines described in [Appendix A](#). These can help people consider the extent to which dangerous isolation or flows may occur, especially if flooding has not happened in those areas previously.

The example hazard map below shows the Conway, south Mount Vernon and Fir Island area for the historic 100–

year event. Dark orange denotes the most unsafe areas with all building types considered vulnerable to failure. Bright green areas are also unsafe with building types vulnerable to structural damage. Darker green progressing to turquoise and blues represent additional hazard classifications noted in the key. Buildings are noted in a lighter orange color. Hazard maps were only developed for the historic 100–year event with no dike failure; additional flooding in the 2040s or 2080s, or due to dike failures, could lead to increased risks.

LOWER RIVER FLOODING MAPS
Conway | Depth-Velocity Hazard

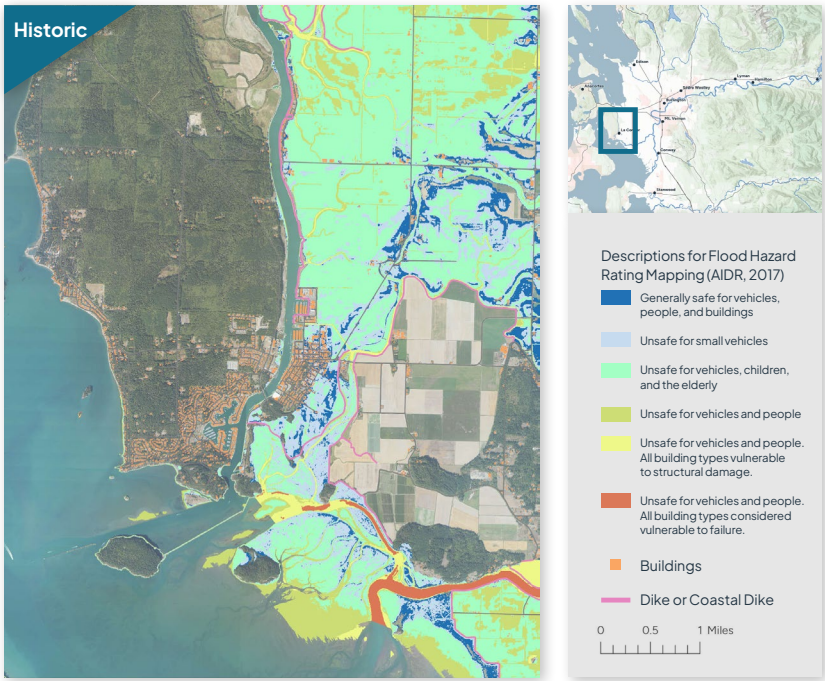


Depth-Velocity Hazard – Coastal Flooding

Depth-velocity hazard maps were also produced for coastal areas. Given the hazard categories were developed for riverine flooding, they may not apply as readily to coastal flood risks (see [Appendix A](#) and B for more information). As with the riverine maps described above, these coastal hazard maps may help people consider the extent to which dangerous isolation or flows may occur, especially if coastal flooding has not happened in those areas previously.

The example hazard map below shows the La Conner area for the historic 100-year event. Dark orange denotes the most unsafe areas with all building types considered vulnerable to failure. Bright green areas are also unsafe with building types vulnerable to structural damage. Darker green progressing to turquoise and blues represent additional hazard classifications noted in the key. Buildings are noted in a lighter orange color. Hazard maps were only developed for the historic 100-year event with no dike or coastal dike failure; additional flooding in the 2040s or 2080s, or due to dike failures, could lead to increased risks.

LOWER RIVER FLOODING MAPS
La Conner | Depth-Velocity Hazard



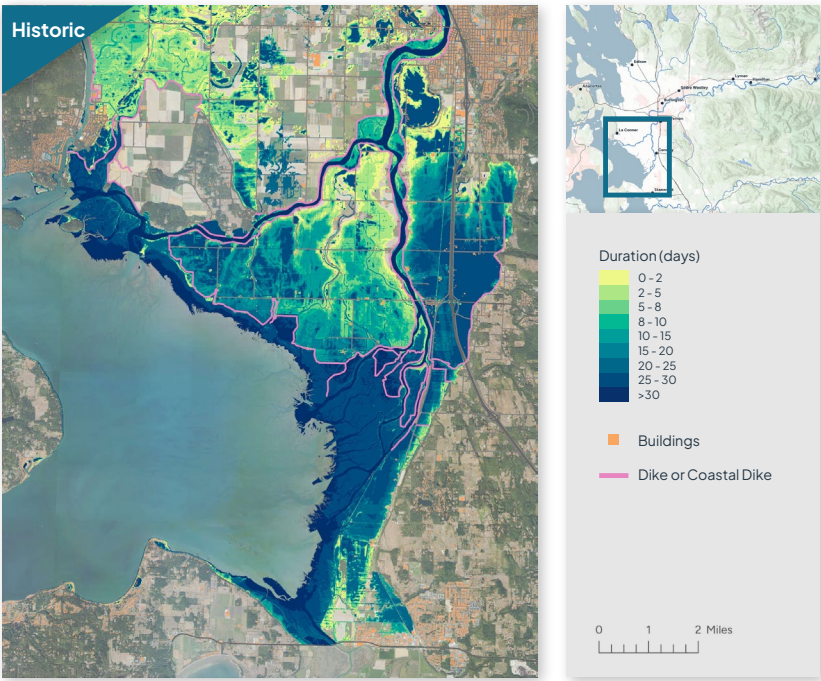
River Flood Duration

Duration maps show the length of time that each location is flooded. These maps do not account for flood fighting actions that could evacuate flood waters more quickly. Duration maps were only created for the historic 100-year river flood (i.e. duration maps were not produced for any dike failure or coastal flood scenarios).

The example duration map shows flood duration for the lower river, extending from Mount Vernon to Skagit Bay. In some areas, shown by the dark blue shades, flooding

persists for over 30 days. Some of the longest flood durations in the lower river occur southeast of La Conner and throughout Fir Island. Although the map also shows some of the longest durations in the area south of Mount Vernon to Conway, these results are likely inaccurate due to limited drainage infrastructure represented in that part of the model domain ([Appendix A](#)). Flood duration maps of the Skagit delta were also produced in a previous study (NHC, 2023); however, this earlier study focused on duration mapping for three select dike failure scenarios.

LOWER RIVER FLOODING MAPS
Skagit Bay | Duration

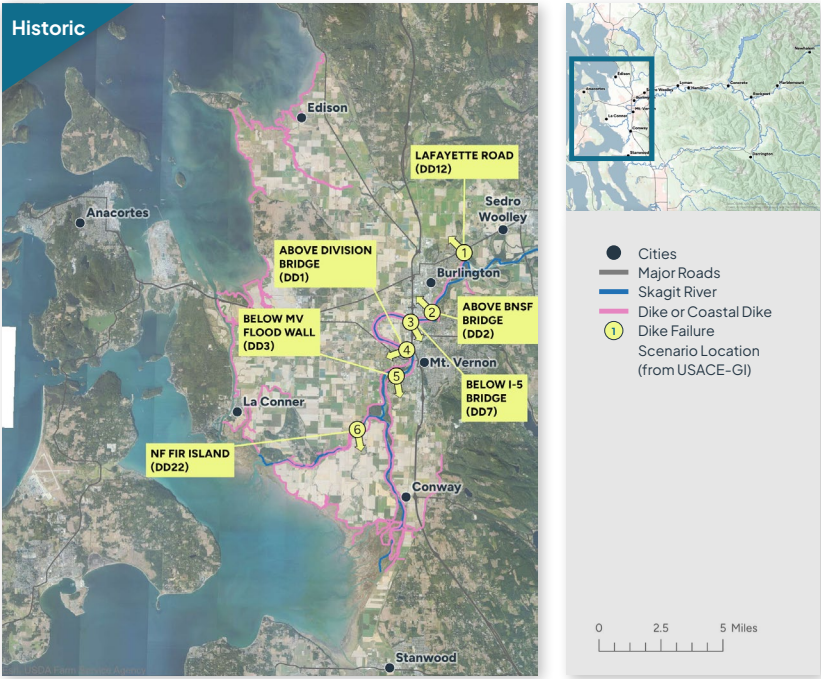


Dike Failure

Three types of maps were produced for the dike failure scenarios: flood depth, depth difference, and depth-velocity hazard maps. Flood maps, including those shown and discussed in the sections above, are often based on simulations in which all infrastructure – including dikes and coastal dikes – remain intact. Flood waters can overtop structures in these simulations, but they do not cause

infrastructure failures. In reality, dikes can fail even when they are not overtopped, and dike failure is a risk during Skagit floods. Understanding how flooding might evolve under different dike failure scenarios is an important part of considering flood risks. [Appendix B](#) provides maps for the six dike failure scenarios evaluated in this study (see [Appendix A](#) for more background on these scenarios).

DIKE FAILURE SCENARIOS Failure Locations (from USACE-GI)



SIX SELECTED DIKE FAILURE SCENARIOS

This map shows the location of the six dike failure scenarios used to develop the depth, depth difference and depth-velocity hazard map products. The arrows show the direction (right bank or left bank) of the failure. The locations of these selected failures are not meant to imply that failures could only occur in these locations nor that they will necessarily occur in these locations. The locations were chosen to be representative of the consequences of failures at different locations along the river and occurring on different sides of the river. The six scenarios were selected for the Draft Skagit Basin General Investigation Study (USACE, 2014).

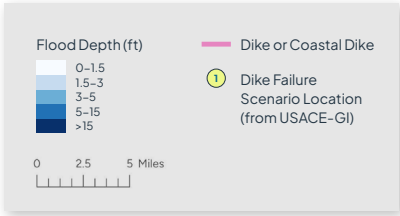
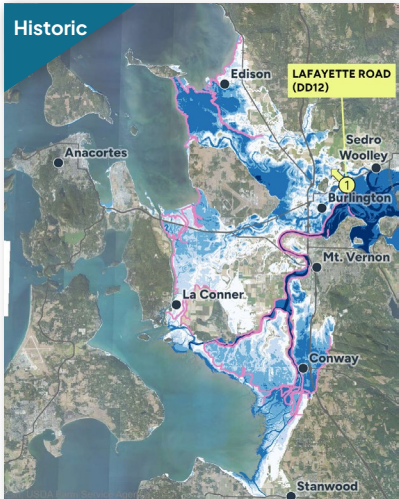
Dike Failure – Depth and Depth Difference

The map examples below explore a potential dike failure at Lafayette Road (DD12) where water moves in the direction of the arrow as a right bank dike failure. The map on the left shows the flood depths that would result from such a failure, using the same color scale as the depth map example shown above. The map on the right shows the difference in flood depth relative to a no dike failure scenario. For example, a dike failure at Lafayette Road results in moderate depth increases (light orange shades) through Burlington to Samish and Padilla bays and some limited

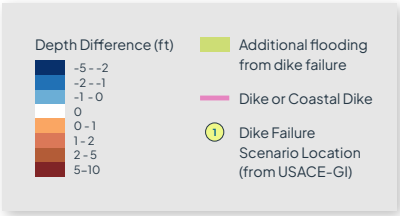
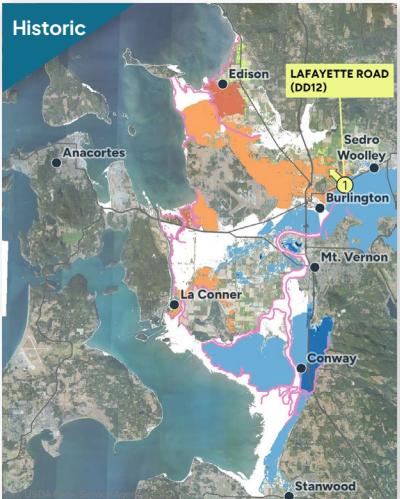
areas with somewhat larger depth increases of 1 to 2 feet (medium red shades) southwest of Edison. The blue areas on the difference map show areas where there is a decrease in flood depths as seen in Fir Island, Conway and Mount Vernon areas. In this example, there are only limited areas exposed to new inundation due to the dike failure: this is the green shading north of Edison, and is barely visible in this example map. These are areas that would not be expected to be flooded in the existing conditions simulation, but do in this dike failure scenario.

DIKE FAILURE SCENARIOS Lafayette Road

FLOOD DEPTH



DEPTH DIFFERENCE



Dike Failure – Depth–Velocity Hazard

Depth-velocity hazard maps were also produced for each of the 6 dike failure scenarios. These maps use the same format as the previous example maps shown for riverine and coastal flooding. The example map below shows the hazard map for the Lafayette Road (DD12) dike failure scenario. Hazard maps for all 6 dike failure scenarios are included in [Appendix B](#).



Animations

Flood animations can be found at the Skagit Climate Science Consortium website (<https://www.skagitclimatescience.org/research/2026-understanding-current-and-future-skagit-flood-risk/>). Animations can be useful to understand flood timing and the progression of flooding over the course of an event. For example, the animation of flood depths for the historic 100-year riverine event shows where flows begin to overtop dike facilities along the lower Skagit. It also shows the timing and routing of the flood wave through Burlington and Gages Slough.

Ways the Model Could Be Used in the Future

The simulations we performed in the current project are often referred to as “existing conditions” simulations because they estimate flooding as it would occur with the river channels, dikes, roads, and other features as they are today. These existing conditions can be updated as new information becomes available. However, now that the model has been developed, it can be used to answer a host of other questions. These fall into two categories:

First, the model could be used to further characterize existing conditions risks. This could include issues such as drainage infrastructure, debris blockage, the effect of buildings, or flooding on some tributaries. For example, the Project model assumes that there is no debris blockage occurring on the major bridges, which likely leads to an underestimate of flood depths at these locations. Future work could test the effect of debris blockage to better understand flooding at these locations (e.g., this was studied extensively for the BNSF bridge in the Draft Skagit General Investigation study, USACE 2014; see [Appendix D](#) for a brief overview of the General Investigation study).

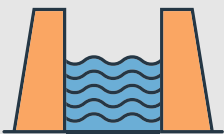
One particular issue, critical to consider regarding current and future risks, is sediment dynamics. The Skagit watershed, especially the Sauk River which drains Glacier Peak, produces large volumes of sediment. As described in the climate section above, this is expected to increase in the future due to receding snowpack, heavier rains, and higher river flows. In a natural system, flooding and channel migration is an important mechanism that distributes,

stores, and transports this sediment across the entire floodplain. In modern times, natural processes have been restricted because the channel is confined between hardened banks or dikes throughout most of the lower basin. Because of that confinement, the sediment in the lower river is typically either transported downstream or deposited within the confined channel, as opposed to adjacent floodplain areas or side channels as in an unconfined system. In parts of the channel where sediment accumulates, flooding could occur more frequently as the channel’s capacity to carry floodwater is reduced over time. The exact effects on flooding are uncertain, since floods often mobilize bottom sediment, effectively deepening the channel during the event itself then filling in as flood flows recede. Similarly, the net effect of climate change is unclear, since higher flows may mobilize more sediment yet increased sediment transport could also result in higher rates of deposition. As a result, we do not always know how channel capacity may change in the future. Nonetheless, observational studies have documented sediment deposition for parts of the lower river (e.g. Figures 8A and 8B in Grossman et al. 2020), and the same could be true at other locations. This is why having current or recently updated bathymetry is important to understanding flood risk in the Skagit. Future modeling work could assess the effect of changes in channel capacity on flood risk. For example, the Project model could be used to test the effect of possible future changes in channel bed elevation on flood risk at key locations of concern.

Second, the model can be used to explore the impact of proposed management approaches, examples of which are shown in Figure 17. The model may inform discussions or planning considerations across these approaches in a variety of ways.

Flood waters have to go somewhere. The model is a powerful tool to help communities consider strategies and trade-offs for reducing harm and increasing benefits of actions. Some modeling has already been done to explore these strategies and trade-offs. For example, several management approaches were evaluated in the Draft Skagit River General Investigation study (USACE 2014, see [Appendix D](#) for a brief overview of this study).

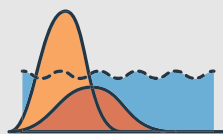
FIGURE 14: EXAMPLES OF BIG PICTURE APPROACHES TO REDUCING FLOOD IMPACTS



Contain the Flow

Dikes and Flood Walls, Channel Modifications

- Dikes and floodwalls are designed to contain the flow so water remains between the river banks.
- Channel modifications such as bridge abutments, levee toe design, and sediment management are often designed to limit obstructions and speed the flow of water



Flatten the Peak

Reservoirs, Dike Setbacks, Floodplain Reconnection, Wetland Reconnection, Forest Management, etc.

- Dams hold back water during floods and release it later (alternative 'rule curves' may increase available flood storage earlier in the fall)
- Floodplain reconnection (e.g. via logjams, setbacks, wetlands) allow the flow to spread and slow.
- Forest management and other upland changes can alter how water (and sediment) is retained and released over land.



Split the Flow

Bypass Channel

- By diverting water, flow in the main river channel is reduced. The effects are comparable to a dike failure, except that the "where and when" are selected in advance, and flow occurs in a prepared diversion channel.



Live with Water

Flood Preparation, Elevate Structures

- Flood preparation includes actions that help communities respond to and recover from flood events, including improved forecasts, emergency management plans, etc.
- Home elevations raise structures above estimated floodwater heights to reduce risk of damages.

Summary and Conclusion

The Swinomish Indian Tribal Community and partners have developed new, accessible flood mapping and visualizations for the Skagit River, including coastal and riverine flooding both under current and future conditions due to climate change. The project aims to provide actionable and accessible information to help tribal, local, and state governments and the broader community recognize and discuss flood risks from Marblemount to the Skagit and Samish deltas. The extensive maps and visualizations allow for easy viewing, and support users in anticipating the potential implications of future flooding for public safety, infrastructure, and other important community values. By providing a strong and discussion-informed technical foundation, the project team hopes to support resilient floodplain management. The core objective of this project is to provide high-quality information; it is strictly intended to inform local decision-makers and the public and does not offer specific policy or project recommendations.

These maps are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, dike failures, larger-than-modeled events, flood fighting activities or other factors. Maps do not capture flood extents nor depths projected beyond a 1% annual chance of exceedance or a 100-year flood event. Maps should be used at your own risk.

Ultimately, the Swinomish Indian Tribal Community and its partners have continued to build upon and broaden the long conversation about flood risk in the Skagit. While this phase focused on building a more detailed, technically-based understanding of risk, the project team hopes the project sets a solid foundation and a set of strengthened or new relationships for future efforts.



For more information, please visit the Swinomish Indian Tribal Community, Skagit Climate Science Consortium, or the Skagit River System Cooperative websites.

References

- Bandaragoda, C., Frans, C., Istanbuluoglu, E., Raymond, C., Wasserman, L. (2015).** Hydrologic Impacts of Climate Change in the Skagit River Basin. Report prepared for the Skagit Climate Science Consortium, Mt Vernon, WA and Seattle City Light, Seattle, WA. https://www.skagitclimatescience.org/wp-content/uploads/2016/04/UW-SC2_SkagitDHSVM-glacierModel_FinalReport_2015.pdf
- Bandaragoda, C., Hamlet, A. F., Istanbuluoglu, E. (2019).** Hybrid methods for producing gridded meteorological forcings in mountain environments. Unpublished manuscript.
- Grossman, E. E., Stevens, A. W., Dartnell, P., George, D., & Finlayson, D. (2020).** Sediment export and impacts associated with river delta channelization compound estuary vulnerability to sea-level rise, Skagit River Delta, Washington, USA. *Marine Geology*, 430, 106336. <https://doi.org/10.1016/j.margeo.2020.106336>
- Hamlet, A. F., Elsner, M. M., Mauger, G. S., Lee, S. Y., Tohver, I., & Norheim, R. A. (2013).** An overview of the Columbia Basin Climate Change Scenarios Project: Approach, methods, and summary of key results. *Atmosphere-ocean*, 51(4), 392–415. <https://doi.org/10.1080/07055900.2013.819555>
- Lee, S. Y., Hamlet, A. F., & Grossman, E. E. (2016).** Impacts of climate change on regulated streamflow, hydrologic extremes, hydropower production, and sediment discharge in the Skagit River Basin. *Northwest Science*, 90(1), 23–43. <https://doi.org/10.3955/046.090.0104>
- Miller, I. M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E. 2018.** Projected Sea Level Rise for Washington State – A 2018 Assessment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project. <https://cig.uw.edu/projects/projected-sea-level-rise-for-washington-state-a-2018-assessment/>
- Mote, P. W., Li, S., Lettenmaier, D. P., Xiao, M., & Engel, R. (2018).** Dramatic declines in snowpack in the western US. *Npj Climate and Atmospheric Science*, 1(1), 2. <https://www.nature.com/articles/s41612-018-0012-1>
- Nakicenovic, N., Alcamo, J., Grubler, A., Riahi, K., Roehrl, R. A., Rogner, H. –H., & Victor, N. (2000).** Special Report on Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. ISBN 0–521–80493–0
- NHC (2023).** Skagit River Delta Flood Drainage Project Flood Modeling, Mapping, and Mitigation Analysis. Prepared by Northwest Hydraulic Consultants Inc. for Skagit County Public Works. May 2023.
- (USACE) U.S. Army Corps of Engineers. (2013).** [Appendix A: Skagit River Basin Static Layers Development for the Rapid Inundation Mapping Tool](#). Prepared for the Seattle District of the U.S. Army Corps of Engineers, by the USACE Modeling Mapping Consequences (MMC) Production Center.
- (USACE) U.S. Army Corps of Engineers. (2014).** Skagit River Flood Risk Management General Investigation: Draft Feasibility Report and Environmental Impact Statement. Prepared for Skagit County, Washington, by the Seattle District of the U.S. Army Corps of Engineers. Available at: <https://www.skagitcounty.net/Departments/PublicWorksSalmonRestoration/main.htm>
- Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., ... & Rose, S. K. (2011).** The representative concentration pathways: an overview. *Climatic change*, 109(1), 5. <https://dx.doi.org/10.1007/S10584-011-0148-z>
- Warner, M. D., Mass, C. F., & Salathe Jr, E. P. (2015).** Changes in winter atmospheric rivers along the North American west coast in CMIP5 climate models. *Journal of Hydrometeorology*, 16(1), 118–128. <https://doi.org/10.1175/JHM-D-14-0080.1>

Appendix A: Hydraulic Model



Photo source: NHC December 2025

Skagit River Flood Risk Modeling

Hydraulic Model Development Report

Prepared by:

Northwest Hydraulic Consultants Inc.

12787 Gateway Drive S.
Seattle, WA 98168
Tel: 206.241.6000
www.nhcwater.com

Prepared for:

Swinomish Indian Tribal Community

11404 Moorage Way
La Conner, WA 98257

August 11, 2026
Final Report

NHC Reference No. 2009212

DOCUMENT TRACKING

Date	Revision No.	Reviewer	Issued For
4/1/2026	0	SITC, SRSC, UW CIG, SC2	Draft
8/11/2026	1	SITC	Final

Report prepared by:



Kristin Kramer, PE
Hydraulic Engineer

Report reviewed by:

A blue ink signature, likely of Vaughn Collins, is written in a cursive style.

Vaughn Collins, PE, CFM
Principal

NHC File Path: Q:\2009212_Full Skagit River 2D Modeling\97 Reporting\0_Final_Report\Skagit River Model Development Report Final.docx

DISCLAIMER

This document has been prepared by **Northwest Hydraulic Consultants Inc.** in accordance with generally accepted engineering practices and is intended for the use and benefit of Swinomish Indian Tribal Community.

Northwest Hydraulic Consultants Inc. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or associated work products by any parties other than Swinomish Indian Tribal Community or for any uses or applications allowed by Swinomish Indian Tribal Community beyond specific application to the Skagit River Flood Risk Modeling project. No other warranty, expressed or implied, is made.

CREDITS AND ACKNOWLEDGEMENTS

The authors would like to thank National Fish and Wildlife Foundation (NFWF) for funding the project through the “Planning for Flood Resilience Capacity and Salmon Habitat Improvement in the Skagit River” grant, and the Swinomish Indian Tribal Community (SITC) for initiating this study and for the support provided during the project. The project is a collaboration with Skagit River System Cooperative (SRSC), Skagit Climate Science Consortium (SC2), University of Washington Climate Impacts Group (UW CIG), and expert consultants. We would like to thank the following members of the project team, in particular:

- Heather Spore Project Manager, SITC
- Nora Kammer SRSC
- Kate Ramsden SRSC
- Guillaume Mauger UW CIG, consultant to SC2
- Carol Macilroy Consultant to SC2
- Steve Moddemeyer Consultant to SC2
- Alan Hamlet Notre Dame, consultant to SC2

The following NHC personnel participated in the study:

- Vaughn Collins Technical Advisor and Reviewer
- Kristin Kramer Hydraulic Modeling
- Peter Hurst Bathymetric Data Collection
- Madalyn Ohrt GIS Specialist

The authors would also like to acknowledge the following organizations for providing data for this project:

- USACE Model data
- Seattle City Light Model data
- WDFW Surface data
- DIDC High water mark data, prior studies

TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Purpose and Background	1
1.2	Study Area	2
2	PREVIOUS STUDIES AND DATA COLLECTION	3
3	MODEL ASSUMPTIONS AND CAPABILITIES	4
3.1	Key Improvements Compared to Previous Models	5
3.2	Key Capabilities, Assumptions and Limitations of the Model	5
3.3	Additional Capabilities with Further Development	6
4	MODEL SCENARIOS	7
5	FLOOD HYDROLOGY AND TIDES	9
5.1	Historic Conditions	9
5.1.1	Inflow Hydrographs	9
5.1.2	Tidal Stage Hydrographs	10
5.2	Future Conditions	11
5.2.1	Inflow Hydrographs	11
5.2.2	Tidal Stage Hydrographs	12
5.3	Inflows and Tides used in the Hydraulic Model	13
6	FLOOD MODEL DEVELOPMENT	17
6.1	Model Geometry	17
6.1.1	Topobathymetric Data	17
6.1.2	Model Domain and Mesh	18
6.1.3	Hydraulic Structures	20
6.1.4	Land Cover and Roughness	22
6.2	Boundary Conditions	24
6.2.1	Riverine	25
6.2.2	Coastal	25
6.3	Run Control Parameters	25

6.4	Calibration and Validation	26
6.4.1	Model Input	27
6.4.2	Calibration: November 2021 Event	28
6.4.3	Calibration: October 2003 Event	32
6.4.4	Validation: December 2025 Event	33
6.4.5	Validation: November 1995 Event	36
6.4.6	Summary	37
6.5	Dike Failure Parameters	38
7	MODEL OUTPUT	40
8	TECHNICAL CONCLUSIONS AND RECOMMENDATIONS	41
9	REFERENCES	43

TABLES, FIGURES, AND PHOTOS IN TEXT

TABLES

Table 2.1	Previously developed hydraulic models and technical studies	4
Table 4.1	Summary of simulation runs	8
Table 5.1	Tidal boundary conditions	10
Table 5.2	Tides plus storm surge (feet)	11
Table 5.3	Future projections scaling factors (1-day duration, median projection) applied to inflow hydrographs in the hydraulic model	12
Table 5.4	Sea level rise	13
Table 5.5	Combined sea level rise and storm surge (feet, relative to NAVD88)	13
Table 5.6	Peak inflows used in the hydraulic model	14
Table 5.7	Peak tidal stage for riverine flood events (feet, relative to NAVD88)	15
Table 5.8	Peak tidal stage for coastal flood events (feet, relative to NAVD88)	15
Table 6.1	Summary of bridges represented in the model domain	22
Table 6.2	Final floodplain land cover areas and roughness values	23
Table 6.3	Final main channel reaches and calibrated roughness values	23
Table 6.4	Reported USGS gage peak stage and discharge for events used in model calibration and validation	26
Table 6.5	Summary of error statistics for the November 2021 calibration event	28
Table 6.6	Summary of error statistics for the October 2003 event	32
Table 6.7	Summary of error statistics for the December 2025 event	34
Table 6.8	Summary of error statistics for the November 1995 event	37
Table 6.9	Dike failure locations from Skagit GI	39
Table 7.1	Flood model outputs	40
Table 7.2	Descriptions for depth-velocity hazard rating mapping (based on (AIDR, 2017))	41

FIGURES

Figure 1.1	Skagit River hydraulic model study area	3
Figure 5.1	Select 100-year inflow hydrographs for historic and future conditions	15
Figure 5.2	Riverine flood event: example of MHHW tidal stage hydrographs for historic and future conditions at the Skagit Bay (North) boundary condition	16
Figure 5.3	Coastal flood event: example of 100-year tidal stage hydrographs for historic and future conditions at the Skagit Bay (North) boundary condition, the vertical line indicates the actual 100-year peak tide	16
Figure 6.1	Data sources used to develop the topobathymetric surface	18
Figure 6.2	Model domain and boundary condition locations	19
Figure 6.3	Example of 2D model mesh showing typical cell sizes	20
Figure 6.4	Overview of hydraulic structures applied in the Project model	21

Figure 6.5	Boundary condition locations	24
Figure 6.6	Difference in simulated minus observed WSEs along the Skagit River mainstem for all events	29
Figure 6.7	November 2021 peak WSE residual distribution for mainstem HWMs and USGS gages (top) and floodplain HWMs (bottom)	30
Figure 6.8	Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 2021 event	31
Figure 6.9	Comparison of simulated and observed stage and discharge at Concrete USGS gage for the 2021 event	31
Figure 6.10	Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 2003 event	33
Figure 6.11	HWM differences along the Skagit River downstream of Burlington	35
Figure 6.12	December 2025 peak WSE residual distribution for HWMs and gages	35
Figure 6.13	Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 2025 event	36
Figure 6.14	Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 1995 event	37
Figure 6.15	Dike failure locations in the 2D model	39

ENCLOSURES

TABLES

Table 1	November 2021 event: simulated and observed water surface elevations along the Skagit River mainstem
Table 2	October 2003 event: simulated and observed water surface elevations
Table 3	December 2025 event: simulated and observed water surface elevations
Table 4	November 1995 event: simulated and observed water surface elevations

SUPPORTING DOCUMENTATION

Topobathymetric Mosaic Development Memorandum

ABBREVIATIONS

Acronym / Abbreviation	Definition
1D	one-dimensional
2D	two-dimensional
AdH	Adaptive Hydraulics
City Light	Seattle City Light
CWMS	Corps Water Management System
DIDC	Skagit Drainage and Irrigation Districts Consortium
FEMA	Federal Emergency Management Agency
HEC-HMS	Hydraulic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydraulic Engineering Center River Analysis System
HWM	high-water mark
LiDAR	light detecting and ranging
MAE	mean average error
MHHW	mean higher high water
NAIP	National Agriculture Imagery Program
NAVD88	North American Vertical Datum of 1988
NF	North Fork
NHC	Northwest Hydraulic Consultants, Inc.
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
PL 84-99	Public Law 84-99, Emergency Response to Natural Disasters
RCP	representative concentration pathway
RM	river mile
SC2	Skagit Climate Science Consortium
SF	South Fork
SITC	Swinomish Indian Tribal Community
Skagit GI	Skagit River Flood Risk Management General Investigation

Acronym / Abbreviation	Definition
SLR	sea level rise
SRSC	Skagit River System Cooperative
SWE-ELM	Shallow Water Equations with a Eulerian-Lagrangian Method
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UW CIG	University of Washington Climate Impact Group
WDFW	Washington Department of Fish and Wildlife
WSE	water surface elevation
ECY	Washington State Department of Ecology
WSDOT	Washington State Department of Transportation

1 INTRODUCTION

The Skagit River Hydraulic Model Development Report has been prepared as part of the Skagit River Flood Resilience Project (Project) on behalf of the Swinomish Indian Tribal Community (SITC), as identified in Resolution No. 2024-09-179. The Project partners include Skagit River System Cooperative (SRSC), Skagit Climate Science Consortium (SC2), and University of Washington Climate Impacts Group (UW CIG). Northwest Hydraulic Consultants (NHC) was contracted by SITC to develop and calibrate a new, reach-wide two-dimensional (2D) hydraulic model of the Skagit River (Project model).

This technical report documents the model development and has been prepared as an appendix to the *Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities report* (SITC et al., 2026, hereafter referred to as the Project Report). The Project Report summarizes the study objectives and watershed context, with mapping products included, while this report documents development of the Project model, including data collection, model assumptions, and limitations.

1.1 Purpose and Background

The goal of the Project is to increase understanding of riverine and coastal flood risk to communities and habitats in the Skagit River watershed using the best available tools and latest data. This has been completed by developing a fully two-dimensional (2D) hydraulic model of the Skagit River from Marblemount to the Puget Sound. Similar efforts to develop updated, reach-wide modeling tools have been undertaken in other western Washington rivers, including along the Nooksack River, the Stillaguamish River, the Puyallup River, and the Skykomish-Snoqualmie-Snohomish river system. These large-scale models help support flood planning and emergency management, and, in the case of the Nooksack model, are actively updated as new data are collected.

A hydraulic model is a computer-based tool that simulates water moving through rivers, floodplains, and coastal areas. Previous reach-wide studies of the Skagit River used partial one-dimensional (1D) models along the main channel as well as floodplain areas upstream of Burlington. A 1D hydraulic model simulates flow in a single, streamwise direction. In contrast, a 2D hydraulic model can simulate flow in both streamwise and lateral directions, allowing the model to better represent complex flow patterns across floodplains, through side channels, and around islands and structures. In addition, a 2D hydraulic model can provide detailed visualization of flow patterns, water surface elevations, flood extents, and various other products which can support flood planning, emergency management, and habitat restoration.

To support the goal of improving floodplain mapping, the Project model was developed with the following objectives:

- Develop a fully 2D hydraulic model of the Skagit River from Marblemount to the Puget Sound, including the entire delta and lower Samish River, to provide detailed flood results mapping within the entire study area;
- Apply the best available topobathymetric and hydraulic structure data from newly available sources and previously developed models and calibrate the model to the November 2021 event; and
- Evaluate riverine and coastal flooding under historic¹ and future climate conditions for three primary areas of interest: flood risk, habitat, and agriculture.

The model builds upon previously developed hydraulic models of the Skagit River and involved extensive data collection to obtain prior hydraulic models, recent calibration data, and the latest available topobathymetry. This study assesses present-day built conditions and does not include evaluation of future flood risk management scenarios. The model has been used to develop mapping products, provided in Appendix B of the Project Report. As part of the Project, the model and results will be available for use and adaptation by others.

1.2 Study Area

The study area covers approximately 85 miles of the Skagit River, primarily within Skagit County, Washington, from seven miles upstream of Marblemount extending downstream into Skagit, Padilla, and Samish bays as shown in Figure 1.1. The hydraulic model includes floodplain mapping for short reaches of major tributaries to the Skagit River, including the Baker, Cascade, and Sauk rivers, as well as the lower ten miles of the Samish River. Flows from these major tributaries are fully incorporated into the model. The study area includes portions of the coastline of the Swinomish Indian Tribal Community reservation, the cities of Burlington, Mount Vernon, Sedro-Woolley, and Stanwood, the towns of Marblemount, La Conner, Concrete, Hamilton, and Lyman, and several other unincorporated communities.

Along the lower Skagit River, a system of approximately 50 miles of dikes and 40 miles of coastal dikes is overseen by diking districts, with some dike facilities co-managed with the U.S. Army Corps of Engineers (USACE) in the PL 84-99 program. Previous studies often refer to facilities along the Skagit River as “levees”; however, “dikes” is the term more commonly used in the local community and will be used throughout this report. The dike systems along the Skagit River generally have the capacity to contain an approximately 20-year return period flood. The coastal dike systems provide protection against coastal events, but can prolong landward flooding

¹ The term “historic” refers to flood model simulations using hydrology from the Skagit River GI (USACE, 2014).

within the Skagit lowlands. More information on historic flooding and watershed characteristics for the Skagit River is included in the Project Report.



Figure 1.1 Skagit River hydraulic model study area

2 PREVIOUS STUDIES AND DATA COLLECTION

Multiple significant studies and planning efforts have been conducted within the Skagit River watershed. To support development of the Project model, NHC reviewed several studies for applicability and collected relevant data and models as needed, as summarized in Table 2.1. This process included coordination with USACE and Seattle City Light to obtain previously developed models. Hydrology used in the Project model is based on the Skagit GI (USACE, 2014). For model development, the USACE's CWMS model (2022) was primarily used as the starting point because it used the same model software, had a similar domain, and had been recently updated and calibrated to the November 2021 event. However, the Delta model (NHC, 2023) was primarily used to obtain culvert and tide gate data, given the project completed an inventory of significant drainage infrastructure in the lowlands, downstream of Burlington.

The additional studies reviewed, along with data incorporated into the Project model, are provided in Table 2.1. Data collected for development of the topobathymetric surface and calibration process are not detailed in this section but are described in sections 6.1.1 and 6.4, respectively.

Table 2.1 Previously developed hydraulic models and technical studies

Title	Source	Model Type	Data Used
Skagit River General Investigation (Skagit GI) ¹	(USACE, 2014)	Separate 1D HEC-RAS and Flo-2D models ²	Hydrology, dike failure locations and parameters
Skagit River Corps Water Management System (CWMS) RAS model	(USACE, 2022)	Combined 1D/2D HEC-RAS model ⁴	Breaklines, initial roughness, bridge geometry, culvert and tide gate data (secondary)
Skagit River Delta Flood Drainage Project (Delta model)	(NHC, 2023)	Three separate 2D HEC-RAS models ³	Culvert and tide gate data (primary), bathymetry, Samish River roughness
Upper Skagit Instream Flow model	(Seattle City Light, 2023)	2D HEC-RAS model ⁵	Breaklines, initial roughness
Maddox Creek Big Ditch Alternatives Evaluation	(NHC, 2020)	2D HEC-RAS model ⁶	Culvert data, breaklines ⁶
Old Highway 99 at Thomas Creek Bridge Replacement	(NHC, 2025)	2D HEC-RAS model ⁷	Bridge and breakline data near Thomas Creek and Samish River ⁷
McGlinn Island Jetty Project	(USACE, 2021)	AdH model ⁸	Report reviewed, bathymetry used ⁸
Skagit Hydrodynamic Model (SHDM) Project	(Whiting et al., 2017)	FV-COM model	Report reviewed, no model data used

Notes:

1. Included review of several reports initiated by USACE and Skagit County dating back to the early 2000s.
2. The 1D HEC-RAS model captures the main channel and floodplain areas upstream of Burlington; the separate Flo-2D model represents floodplain areas within the Skagit delta.
3. Three model domains covered overbank flooding areas downstream of Sedro-Woolley, including Fir Island but not Mount Vernon; the models do not include the mainstem Skagit, North Fork, or South Fork. Samish River was calibrated to the February 2018 flood event.
4. Model recently updated and calibrated to the November 2021 event. Model uses 1D cross sections to represent the main channel as well as floodplain areas upstream of Burlington. The combined 2D areas represent the Skagit delta. Channel bathymetry was applied from the FEMA study, dating back to 1975, and floodplain areas were updated with more recent LiDAR from 2017 and 2019.
5. The model domain extends from Rockport to Newhalem and uses a very fine mesh resolution to support detailed analysis of instream flows and aquatic habitat.
6. The model domain extends from Mount Vernon to Stanwood and does not include the mainstem Skagit or South Fork. Culvert data mainly limited to key infrastructure along I-5.
7. Model developed from the Delta model (NHC, 2023). Used existing conditions geometry and added bridge geometry and breakline resolution added near Samish River and Thomas Creek at Old Highway 99.
8. Bathymetry was obtained using elevations from the AdH model mesh. In 2014, a large channel avulsion occurred on the North Fork. As part of the project, 2019 and 2022 bathymetric data were collected along the recent avulsion, lower North Fork, Swinomish Channel, Skagit Bay, and Padilla Bay.

3 MODEL ASSUMPTIONS AND CAPABILITIES

The Project model has been developed to simulate riverine and coastal flooding along the Skagit River to evaluate flood risk to communities and habitats. The following sections describe

the key improvements relative to previously developed models, the current capabilities of the model, and additional capabilities that could be supported with further development. In addition, this section describes limitations of the model software.

3.1 Key Improvements Compared to Previous Models

The Project model incorporates several key improvements compared to previously developed hydraulic models. For comparison purposes, the following improvements are listed relative to the CWMS model (USACE, 2022), which was primarily used for model development, including:

- Develop a fully 2D model domain of the Skagit River mainstem from Marblemount to the Puget Sound, including floodplain areas upstream of Burlington.
- Expand the model domain into Skagit, Samish, and Padilla bays to allow for modeling of a full tidal range, and the addition of the lower ten miles of the Samish River to simulate floodplain interaction between the Skagit and Samish rivers.
- Model projected flows under climate change conditions. In addition, simulate moderate to major flood events within a fully 2D domain to better understand floodplain activation and routing in addition to facility overtopping.
- Use the latest available bathymetric data sources, from 2012 to 2024, compared to 1975 data.
- Apply a more refined 2D mesh resolution in the mainstem and floodplain areas to provide more accurate routing of flood flows.
- Incorporate additional drainage infrastructure from the Delta model (NHC, 2023) within the Skagit lowlands, downstream of Burlington.

3.2 Key Capabilities, Assumptions and Limitations of the Model

The Project model includes the following capabilities and components:

- The model is capable of accurately simulating flood flows, depths, elevations and velocities in the main channel and floodplain. In addition, the model can simulate flood durations for the historic 100-year riverine flood.
- The model can simulate flows through bridges and culverts and over the crests of dikes and coastal dikes.
- The model can simulate the interaction of riverine flows and tides.
- The model mesh resolution is designed for the accurate routing of flood flows. The resolution is not fine enough to evaluate in-channel habitat or other microscale features, but it is appropriate to identify activation of side channels.

- Representation of the Mount Vernon Flood Wall is included in the model, but other temporary flood fighting techniques are not included, such as construction of temporary sand bag walls and activation of pump stations.
- The model only includes significant culverts and tide gates from the Delta model (NHC, 2023) and CWMS model (USACE, 2022), which are limited to key infrastructure in the delta downstream of Burlington. In addition, limited culvert data is included in the area south of Mount Vernon to Conway as obtained from the Maddox Big Ditch project (NHC, 2020), and no drainage infrastructure was modeled along Gages Slough near Burlington.
- No debris blockage at bridges is simulated.
- Buildings are not discretely represented in the model.
- Hydrologic inputs for the Skagit and Samish rivers are applied from the Skagit GI (USACE, 2014). Inflows to the Skagit River and Baker River are based on reservoir operating policies at Ross Dam and Upper Baker Dam during the time the Skagit GI was developed in 2012. The regulated inflow hydrographs used in this study do not account for recent and/or forthcoming (2026) flood operating policies at Ross and Upper Baker reservoirs.
- The model does not show flood risk related to smaller tributaries.
- The model is a fixed bed model with no sediment transport, bed aggradation or scour simulated.
- The HEC-RAS software used to develop the Project model does not have capability to represent the following processes or conditions:
 - Lateral migration and channel avulsions.
 - Saltwater intrusion or other groundwater dynamics.

3.3 Additional Capabilities with Further Development

With additional development and analysis, the model could also evaluate the following:

- Calibration to the recent December 2025 flood, which best represents current channel characteristics along the North Fork, South Fork, and mainstem through Burlington.
- Proposed flood risk management scenarios.
- Additional hazard mapping products, such as additional flood duration maps (currently only produced for historic 100-year riverine event) and velocity maps with flow vectors.
- Future land use changes that could impact flows such as development related to forest conversion or impervious surface increases.
- Coastal dike failure scenarios.
- Incorporation of soil infiltration rates into the model geometry to simulate losses in the floodplain.

- Model events using spatial precipitation data (rain-on-grid).
- Incorporation of pipe network data into the model geometry.
- Future flood risk with projected channel aggradation and/or widening.

4 MODEL SCENARIOS

A suite of model scenarios was simulated, selected to span the range of meaningful riverine and tidal flood risk now and in the future. The scenarios include the following:

- Riverine and coastal flooding under historic, mid-century (2040s), and late-century (2080s) scenarios for the 10-, 25-, and 100-year flood events. The historic record shows that riverine and coastal floods almost never occur at the same time, therefore riverine floods were paired with normal tides, and coastal floods were paired with mean winter river flows.
- For riverine flooding, the 10-year event was selected to represent a moderate flood event with flows contained within the lower Skagit River dike system. The 25-year event represents conditions where dike overtopping begins to occur, and the historic 100-year event represents a large, damaging event and matches the regulatory flood used by FEMA. These were paired with normal tides with high tides reaching mean higher high water (MHHW).
- For coastal flooding, the same 10-, 25- and 100-year probability events were used, paired with mean winter flows on the Skagit and Samish rivers.
- An “extended” version of the historic conditions 100-year riverine flood was simulated for over a month in order to evaluate the duration of flooding affecting residences, infrastructure, and agriculture. All other simulations were run for shorter periods spanning only the flood event itself.
- Six dike failure scenarios were simulated along the Skagit River under the historic conditions 100-year event, using locations and failure parameters from the Skagit GI (USACE, 2014). These runs were used to evaluate the implications for flood risk downstream of Sedro-Woolley.
- Calibration and validation plans were developed for four significant flood events observed over the past three decades, as further described in Section 6.4.
- Initial conditions plans were developed to establish mean winter flows at the beginning of all simulations, as described in Section 6.3. A separate initial conditions file was created for the December 2025 flood, using observed inflow data, to better establish initial conditions at the Nookachamps area.

A summary of all the simulations is presented below in Table 4.1. Details on the river flow and tidal boundary conditions used for each run are described in the next section.

Table 4.1 Summary of simulation runs

Flood Type	Climate Scenario	River Inflow	Tidal Boundary Conditions
Riverine	Historic	10-year	MHHW
		25-year	
		100-year	
		100-year (extended) ⁴	
	Mid-Century (2040s)	10-year	MHHW + SLR
		25-year	
		100-year	
	Late-Century (2080s)	10-year	
		25-year	
		100-year	
Coastal	Historic	Mean winter flows	10-year tidal stage
			25-year tidal stage
			100-year tidal stage
	Mid-Century (2040s)		10-year tidal stage + SLR
			25-year tidal stage + SLR
			100-year tidal stage + SLR
	Late-Century (2080s)		10-year tidal stage + SLR
			25-year tidal stage + SLR
			100-year tidal stage + SLR
			Historic
Dike Failure (RM 21.3)			
Dike Failure (RM 18.1)			
Dike Failure (RM 16.8)			
Dike Failure (RM 13.1)			
Dike Failure (RM 11.7)			
Dike Failure (NF RM 8.3)			
November 2021 Flood	Historic	Observed (full domain)	Observed
October 2003 Flood		Observed (domain downstream of Concrete)	
December 2025 Flood			
November 1995 Flood			
Initial Conditions	Historic	Mean winter flows (full domain)	MLLW

Flood Type	Climate Scenario	River Inflow	Tidal Boundary Conditions
Initial Conditions	Historic	Mean winter flows (domain downstream of Concrete)	MLLW
Initial Conditions: December Flood ⁵	Historic	Observed (domain downstream of Concrete) ⁵	MLLW

Notes:

1. Sea level rise (SLR)
2. Mean higher high water (MHHW)
3. Mean lower low water (MLLW)
4. A separate “extended” version of the historic conditions 100-year riverine flood was simulated for over a month to evaluate the duration of flooding.
5. A separate initial conditions plan was set up for the December 2025 flood to improve initial conditions for the event.

5 FLOOD HYDROLOGY AND TIDES

Hydrologic inputs and tidal stages were developed for both historic and future conditions for use in the hydraulic model. The methodology and data sources used to develop these inputs are described in this section. Section 5.3 provides summary tables and figures of the inflow and tidal data used in the hydraulic model.

5.1 Historic Conditions

The historic conditions hydrology is based on the Skagit GI (USACE, 2014) while tidal stage is developed from observed tidal conditions. A new hydrologic analysis was not completed as part of this Project.

5.1.1 Inflow Hydrographs

For riverine flood events, hydrologic inputs for the historic conditions were applied from the Skagit GI (USACE, 2014). Flood hydrographs for the 10-, 25-, and 100-year events were obtained from locations in the Skagit GI, with 100-year peak flows listed in Table 5.6. Figure 5.1 shows the 100-year inflow hydrographs for the Skagit River and major tributaries. The Skagit GI used hypothetical flood hydrographs developed roughly based on the shape of the observed hydrograph from the October 2003 flood, matching the maximum instantaneous, one-day, and three-day flows for the respective quantiles from the frequency analysis. Hydrograph timing was determined by evaluating the relationship to past events as well as travel time through the system, as further detailed in the Skagit GI. The historic hydrographs are based on reservoir operating policies at both Ross Dam and Upper Baker Dam at the time the Skagit GI was developed in 2012. The inflow hydrographs used do not account for recent and/or forthcoming (2026) operating policies at Ross and Upper Baker reservoirs, nor potential changes related to the Skagit dams relicensing agreement.

For coastal flood events, mean winter river flows from December to January were determined at the inflow boundary locations used in the hydraulic model, with resulting flows shown in Table 5.6. Mean winter flows were developed using USGS gage data post 1977 when flood control facilities on both Ross Dam and Upper Baker Dam were in operation.

5.1.2 Tidal Stage Hydrographs

NHC developed tidal stage hydrographs at the boundary condition locations described in Section 6.2 with observed NOAA tide data from stations at Seattle and Port Townsend as the basis. Tidal stage hydrographs were scaled to the closest tide prediction (subordinate) station and converted to NAVD88 datum for use in the hydraulic model (Table 5.1). The conversion for the Crescent Harbor station was applied based on published station datum information. NAVD88 conversion data were not available for the Anacortes and Ala Spit Stations; therefore, NOAA's vertical datum transformation tool (2025) was used to determine the datum conversions.

For riverine flood events, tidal stage hydrographs were developed using a period with high tides near the MHHW stage (November 7-12, 2022). The MHHW elevations at each boundary condition are reported in Table 5.7. An example of the tidal stage hydrographs used in the riverine flood event at the Skagit Bay (North) boundary condition is shown in Figure 5.2.

Extreme flood tides were based on observed data from a recent event on December 27, 2022. This event, like other coastal flood events examined, consisted of a single high tide reaching levels substantially higher than those before and after it. Exceedance probability stages for the 10-, 25-, and 100-year events were calculated using exceedance probabilities at the reference stations developed as part of the Washington State Coastal Resilience Project (Miller et al., 2019) (Table 5.2). These stages were transformed to the model boundaries using the same methods as for normal tides as described above. The observed stage hydrograph for the December 27, 2022 coastal flood event was then shifted so that the peak high tide matched the calculated exceedance probability stage. Table 5.8 reports the peak tidal stage at each boundary condition location. An example of the tidal stage hydrographs in the coastal flood event at the Skagit Bay (North) boundary condition is shown in Figure 5.3.

Table 5.1 Tidal boundary conditions

Boundary Condition Location	NOAA Subordinate Station (Tide Predictions)	NOAA Reference Station (Tide Observations)
Samish Bay and Padilla Bay	Anacortes, Fidalgo Island WA	Port Townsend WA (9444900)
Skagit Bay (north)	Ala Spit, Whidbey Island WA	Seattle WA (9447130)
Skagit Bay (south)	Crescent Harbor, Whidbey Island WA	Seattle WA (9447130)

Table 5.2 Tides plus storm surge (feet)

Recurrence Interval	NOAA Seattle Station (1950-2024)		NOAA Port Townsend Station (1980-2024)	
	Rel. to MHHW	Rel. to NAVD88	Rel. to MHHW	Rel. to NAVD88
10-year	2.9	11.9	2.7	10.4
25-year	3.1	12.1	2.9	10.6
100-year	3.4	12.4	3.0	10.7

5.2 Future Conditions

NHC collaborated with the UW CIG to develop future conditions hydrologic and tidal inputs for mid-century (2040s) and late-century (2080s) scenarios, considering climate projections, sea level rise, and storm surge. The following sections summarize the scalars developed by UW CIG for use in the hydraulic model.

5.2.1 Inflow Hydrographs

For riverine flood events, future inflow hydrographs were developed by applying median projections for the 1-day duration as scaling factors to the entire historic conditions hydrographs, described in Section 5.1.1. Although there is a range among the projections for each dataset, the median projections were selected for use to provide a middle-of-the-road estimate of future conditions. Future work could explore the implications of higher or lower changes on flood risks. The scaling factors used in the hydraulic model are reported in Table 5.3, as developed by UW CIG. The 100-year peak flows for the future conditions are listed in Table 5.6. Figure 5.2 shows the 100-year inflow hydrographs for the Skagit River and major tributaries.

The Hamlet et al. (2013) dataset was used as input to the reservoir model results provided in the Lee et al. (2016) study – both studies are based on the same hydrologic model simulations. Although older, these studies were prioritized for two reasons: (1) the model calibration is superior to the more recent Bandaragoda et al. (2015, 2019) studies, and (2) Lee et al. (2016) is the only available study that provides regulated flow projections. The Bandaragoda et al. (2015, 2019) results were used for locations that are not included in the Hamlet et al. (2013) or Lee et al. (2016) results.

The Hamlet et al. (2013) and Lee et al. (2016) studies are based on a moderate (A1B) greenhouse gas scenario, whereas the Bandaragoda et al. (2015, 2019) projections only include a low (RCP 4.5) and high (RCP 8.5) greenhouse gas scenario. In order to approximate the moderate greenhouse gas scenario used in the Hamlet et al. (2013) and Lee et al. (2016) projections, UW CIG averaged the results for the low and high greenhouse gas scenario projections from Bandaragoda et al. (2015, 2019).

For coastal flood events, inflow hydrographs were held constant at mean winter flows for the historic conditions, per Section 5.1.1. Future projections were not applied to riverine inflows for the coastal flooding events.

Table 5.3 Future projections scaling factors (1-day duration, median projection) applied to inflow hydrographs in the hydraulic model

Location	10-year		25-year		100-year		Source
	2040s	2080s	2040s	2080s	2040s	2080s	
Gorge ¹	+77%	+130%	+54%	+97%	+25%	+53%	(Lee et al., 2016)
Cascade ²	+1%	+27%	+2%	+23%	+7%	+18%	(Bandaragoda et al., 2015, 2019)
Sauk	+31%	+59%	+24%	+48%	+13%	+32%	(Lee et al., 2016)
NF Stillaguamish ³	+18%	+25%	+17%	+24%	+16%	+22%	(Hamlet et al., 2013)
Baker	+9%	+25%	+6%	+24%	+3%	+24%	(Lee et al., 2016)
Nookachamps	-6%	+4%	-6%	+6%	-4%	+13%	(Bandaragoda et al., 2015, 2019)
Samish	+11%	+22%	+11%	+22%	+11%	+23%	(Hamlet et al., 2013)

Notes:

1. Gorge projections were applied to the Regulated Marblemount boundary condition.
2. Cascade projections were applied to the Cascade River and local flows between the Cascade and Sauk rivers.
3. NF Stillaguamish projections were used as a proxy for local inflow between Sedro-Woolley and Rockport due to the similarity with local tributaries in this reach.

5.2.2 Tidal Stage Hydrographs

For riverine flood events, tidal stage hydrographs representing MHHW stage (Section 5.1.2) were shifted to account for sea level rise, using projections developed by UW CIG in Table 5.4. As with riverine changes, the median projections were used for sea level rise, obtained in this case from the Miller et al. (2018) study. Although a newer nationwide study is available (Sweet et al., 2022), it does not provide the same level of detail for Washington's coastline, and the projected changes are similar. To approximate the moderate (A1B) greenhouse gas scenario used in the peak flow projections, UW CIG averaged the results for the low (RCP 4.5) and high (RCP 8.5) scenarios in the sea level rise projections. Future work could explore the implications of higher or lower projections on coastal flood risks. The MHHW elevations at each boundary condition are reported in Table 5.7. An example of the tidal stage hydrographs used in the riverine flood event at the Skagit Bay (North) boundary condition is shown in Figure 5.2.

For coastal flood events, the same tidal stage hydrographs from the historic conditions simulations (Section 5.1.2) were applied, as research suggests that tidal anomalies are not expected to change in the future (Miller et al., 2019). These hydrographs were shifted to account for both sea level rise (Table 5.4) and storm surge (Table 5.2) based on values provided by

UW CIG (Miller et al., 2018, 2019). The combined sea level rise and storm surge values are summarized in Table 5.5. Table 5.8 reports the peak tidal stage at each boundary condition location. An example of the tidal stage hydrographs used in the coastal flood event at the Skagit Bay (North) boundary condition is shown in Figure 5.3.

Table 5.4 Sea level rise

Decade	Rise (feet) ¹
Mid-century (2040s)	0.5
Late-century (2040s)	1.35

Notes:

1. Median projections based on average representative concentration pathway (RCP) 4.5 and 8.5 projections (Miller et al., 2018).

Table 5.5 Combined sea level rise and storm surge (feet, relative to NAVD88)

NOAA Station	MHHW	10-year		25-year		100-year	
		2040	2080	2040	2080	2040	2080
Seattle	9.0	12.4	13.3	12.6	13.5	12.9	13.8
Port Townsend	7.7	10.9	11.7	11.1	11.9	11.2	12.0

5.3 Inflows and Tides used in the Hydraulic Model

The following section summarizes the inflows and tides used in the hydraulic model. Peak inflows for the mean winter and 100-year events are reported in Table 5.6. Select inflow hydrographs for the Skagit River and major tributaries are included in Figure 5.3.

For riverine flood events, peak tidal stage is reported in Table 5.7. An example of tidal stage hydrographs used in the riverine flood event at the Skagit Bay (North) boundary condition is shown in Figure 5.1.

For coastal flood events, peak tidal stage is reported in Table 5.8. An example of tidal stage hydrographs used in the 100-year coastal flood event at the Skagit Bay (North) boundary condition is shown in Figure 5.2.



Table 5.6 Peak inflows used in the hydraulic model

Boundary Condition Location	Mean Winter Flow (cfs)	10-year (cfs)			25-year (cfs)			100-year (cfs)		
		Historic ¹	2040s	2080s	Historic ¹	2040s	2080s	Historic ¹	2040s	2080s
Regulated Marblemount	6,630	40,606	71,873	93,394	53,766	82,800	105,919	70,330	87,913	107,605
Cascade River	900	13,214	13,346	16,782	16,172	16,495	19,892	22,130	23,679	26,113
Local – Cascade to Sauk	0	7,959	8,039	10,108	9,663	9,856	11,885	13,330	14,263	15,729
Sauk River	4,560	70,992	93,000	112,877	95,632	118,584	141,535	121,523	137,321	160,410
Local – Sauk to Baker	0	5,487	6,475	6,859	6,661	7,793	8,260	9,188	10,658	11,209
Regulated Baker	2,970	23,851	25,998	29,814	27,990	29,669	34,708	34,279	35,307	42,506
Local – Baker to Sedro Woolley ²	3,410	21,848	25,781	27,310	24,080	28,174	29,859	27,944	32,415	34,092
Nookachamps Creek	240	2,087	1,962	2,170	2,709	2,546	2,872	3,780	3,629	4,271
Samish River	480	2,782	3,088	3,394	3,612	4,009	4,407	5,040	5,594	6,199

Notes:

1. The term “historic” refers to flood model simulations using hydrology from the Skagit GI (USACE, 2014).
2. The distribution of local flows between Baker River and Sedro-Woolley are further described in Section 6.2.1.

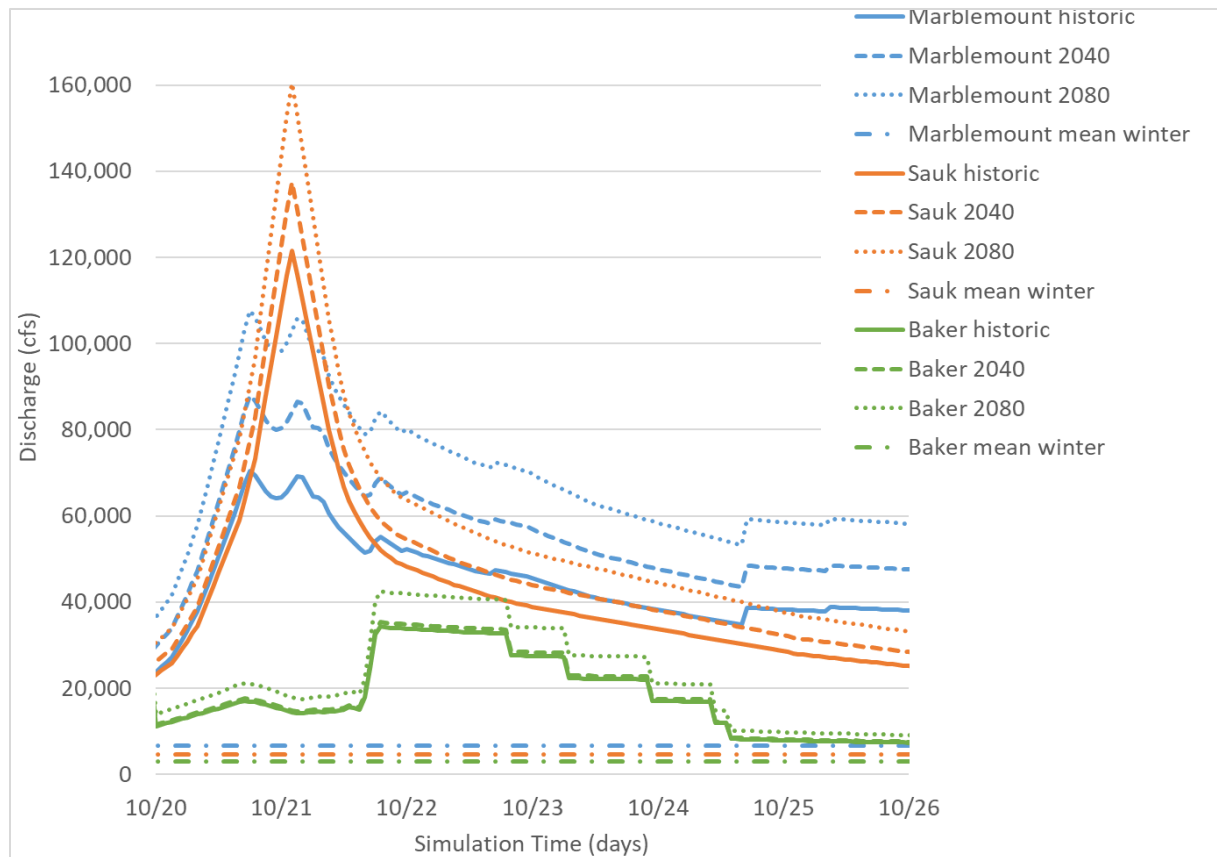


Figure 5.1 Select 100-year inflow hydrographs for historic and future conditions

Table 5.7 Peak tidal stage for riverine flood events (feet, relative to NAVD88)

Boundary Condition	MHHW	MHHW 2040s	MHHW 2080s
Skagit Bay (North)	8.9	9.4	10.2
Skagit Bay (South)	9.5	10.0	10.8
Samish Bay, Padilla Bay	7.7	8.2	9.0

Table 5.8 Peak tidal stage for coastal flood events (feet, relative to NAVD88)

Boundary Condition	10-year			25-year			100-year		
	Historic	2040s	2080s	Historic	2040s	2080s	Historic	2040s	2080s
Skagit Bay (North)	11.6	12.0	12.8	11.7	12.2	13.0	12.0	12.5	13.3
Skagit Bay (South)	12.5	13.0	13.9	12.7	13.2	14.1	13.0	13.5	14.4
Samish Bay, Padilla Bay	10.3	10.8	11.6	10.5	11.0	11.8	10.6	11.1	11.9

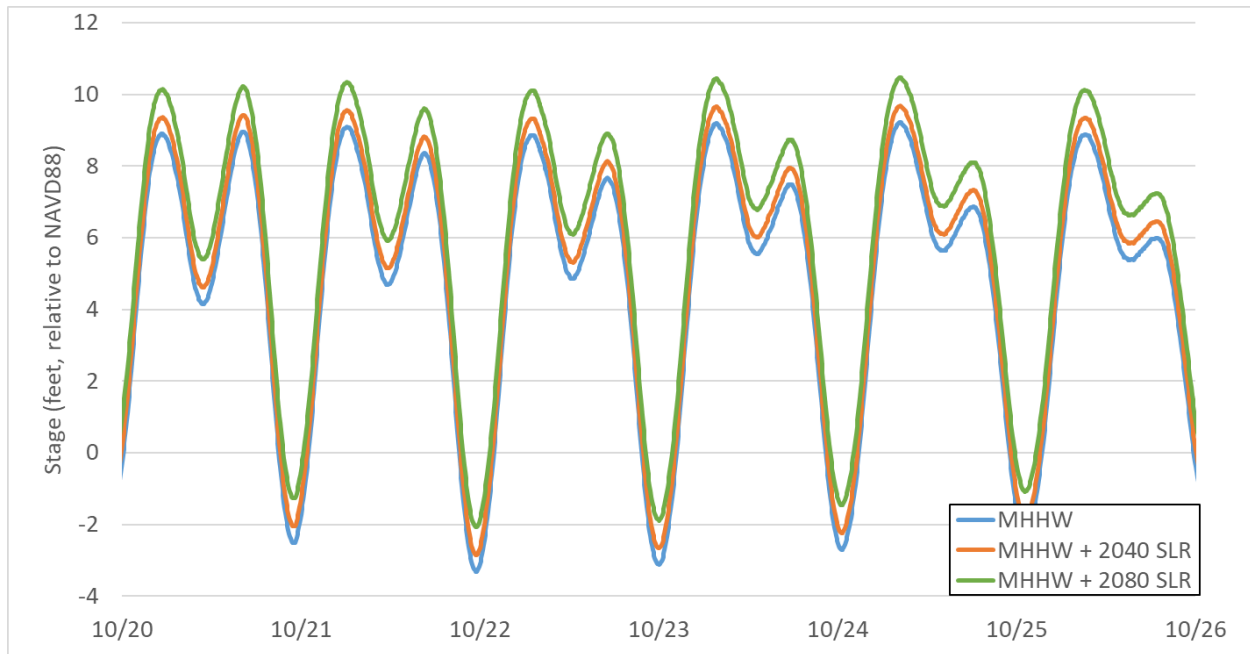


Figure 5.2 Riverine flood event: example of MHHW tidal stage hydrographs for historic and future conditions at the Skagit Bay (North) boundary condition

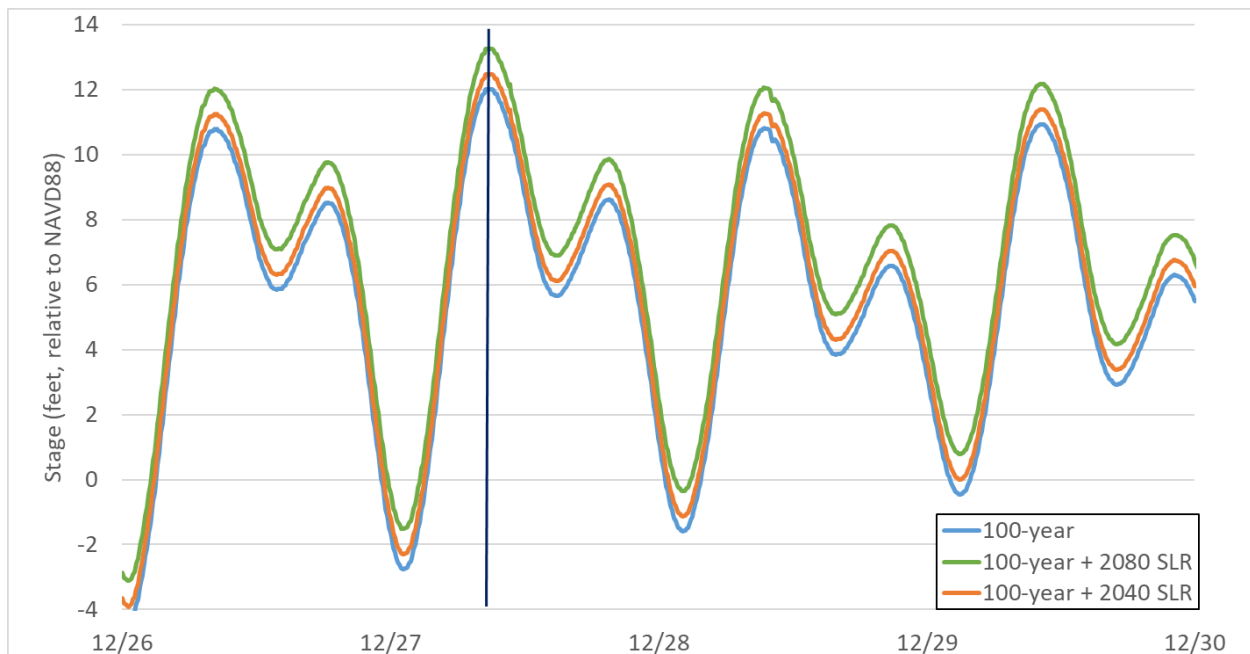


Figure 5.3 Coastal flood event: example of 100-year tidal stage hydrographs for historic and future conditions at the Skagit Bay (North) boundary condition, the vertical line indicates the actual 100-year peak tide

6 FLOOD MODEL DEVELOPMENT

The Project model was developed using 2D capabilities of the USACE's HEC-RAS modeling platform, version 6.6 (USACE, 2024). The 2D HEC-RAS solver computes flow using the full 2D shallow-water equations, allowing for simulation of complex flow patterns in both streamwise and lateral directions. The model is capable of simulating subcritical and supercritical unsteady flows through a full network of open channels and floodplains, including complex terrains with highly non-uniform flows. Development of the hydraulic model components for computer simulations are described in the following sections.

6.1 Model Geometry

The primary components required to develop the 2D model geometry include topobathymetric data, a 2D mesh, infrastructure elements (bridges, culverts, and dikes), and land cover. The following sections describe the collection and preparation of this information.

6.1.1 Topobathymetric Data

NHC compiled the latest available data sources to develop a comprehensive topobathymetric surface for use in the hydraulic model. The data sources used, including limits, are shown in Figure 6.1. In general, bathymetry was developed from boat-based surveys from 2012 to 2024, supplemented with 2022 topobathymetric (green) LiDAR, depicted by the orange areas in Figure 6.1. A more detailed discussion of the data sources and methods used to develop the terrain is in the appended Topobathymetric Mosaic Development Memorandum. In the Project model, some terrain modifications were necessary to correct LiDAR data, including discontinuities along coastal dikes and key drainage segments; these types of corrections are common in LiDAR datasets.

Compared to previously developed models, bathymetry used in the new Project model has been significantly updated. For example, both the current CWMS (USACE, 2022) and Skagit GI (USACE, 2014) models use bathymetry from 1991 downstream of Sedro-Woolley and bathymetry from the 1977 FEMA Flood Insurance Study upstream of Sedro-Woolley. While the CWMS model uses LiDAR sources from 2017 and 2019 in the floodplain areas, the new Project model incorporates more recent LiDAR from 2022 in areas upstream of Sedro-Woolley. Overall, the new Project model will provide a much more accurate representation of current in-channel and floodplain elevations throughout the domain.

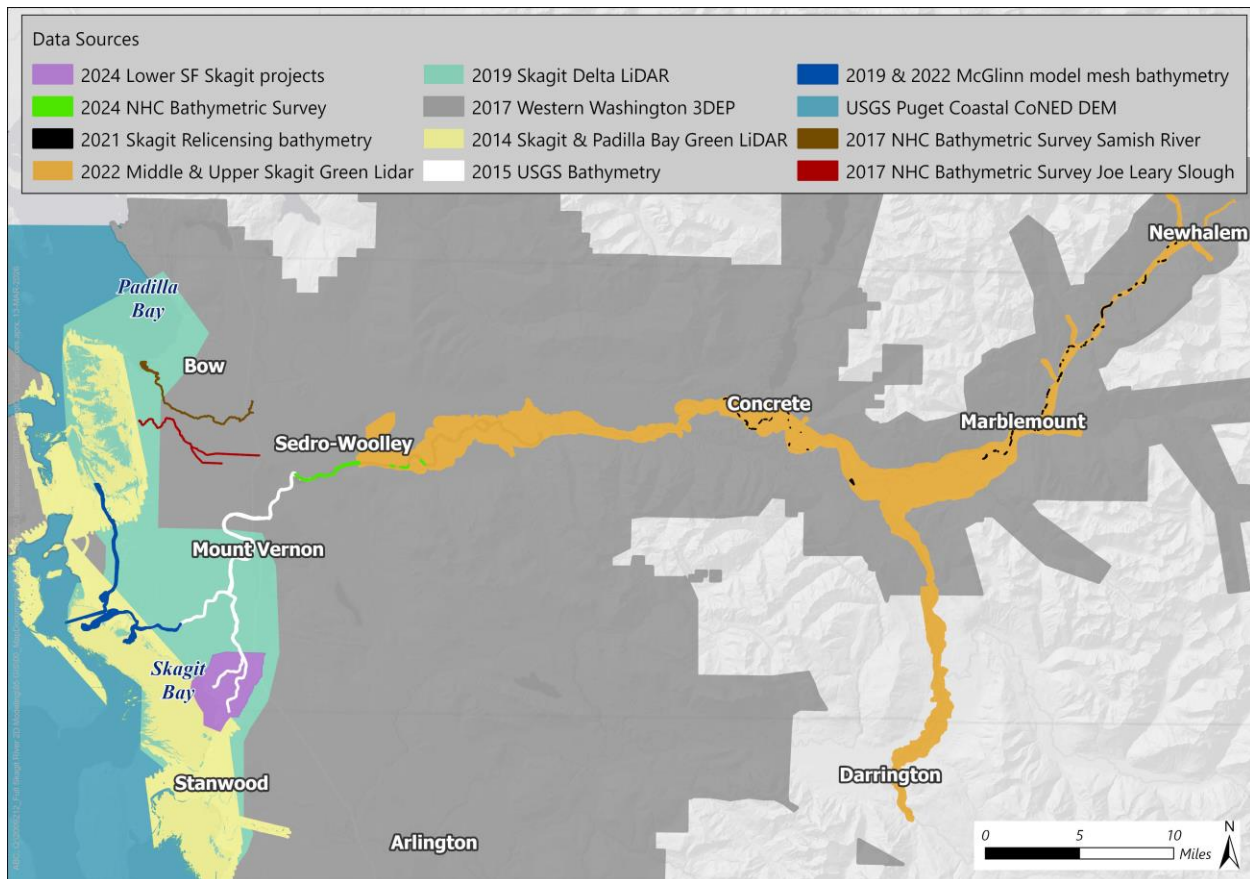


Figure 6.1 Data sources used to develop the topobathymetric surface

6.1.2 Model Domain and Mesh

The 2D model domain includes approximately 85 miles of the Skagit River, from the Puget Sound to the USGS gage above Diobsud Creek near Marblemount, with limits shown in Figure 6.2. The domain includes the Samish River in addition to short reaches of major tributaries to the Skagit, including Baker, Cascade, and Sauk rivers, and Nookachamps Creek. The downstream boundary extends into Skagit, Samish, and Padilla bays to allow for modeling of a full tidal range.

The 2D computational mesh was sized to allow for accurate routing of normal and flood flows while maintaining manageable model run times. The model mesh is comprised of approximately 240,000 cells. Figure 6.3 shows an example of typical cell spacing and breakline definition near the Skagit River mainstem. Within the main channel of the Skagit River and major tributaries, cell size is generally 100 feet. Along the Samish River, the main channel cell size is generally 50 feet. Within the floodplain areas, cell spacing increases to up to 400 feet. Breaklines were added along prominent topographic features to provide refinement and definition to terrain elements such as high points and raised roadways. NHC also applied breaklines to orient main channel

cell faces perpendicular to the direction of flow. Floodplain swales, ponds, ditches and waterbodies were represented as captured by the terrain, described in Section 6.1.1, without manual terrain modifications.

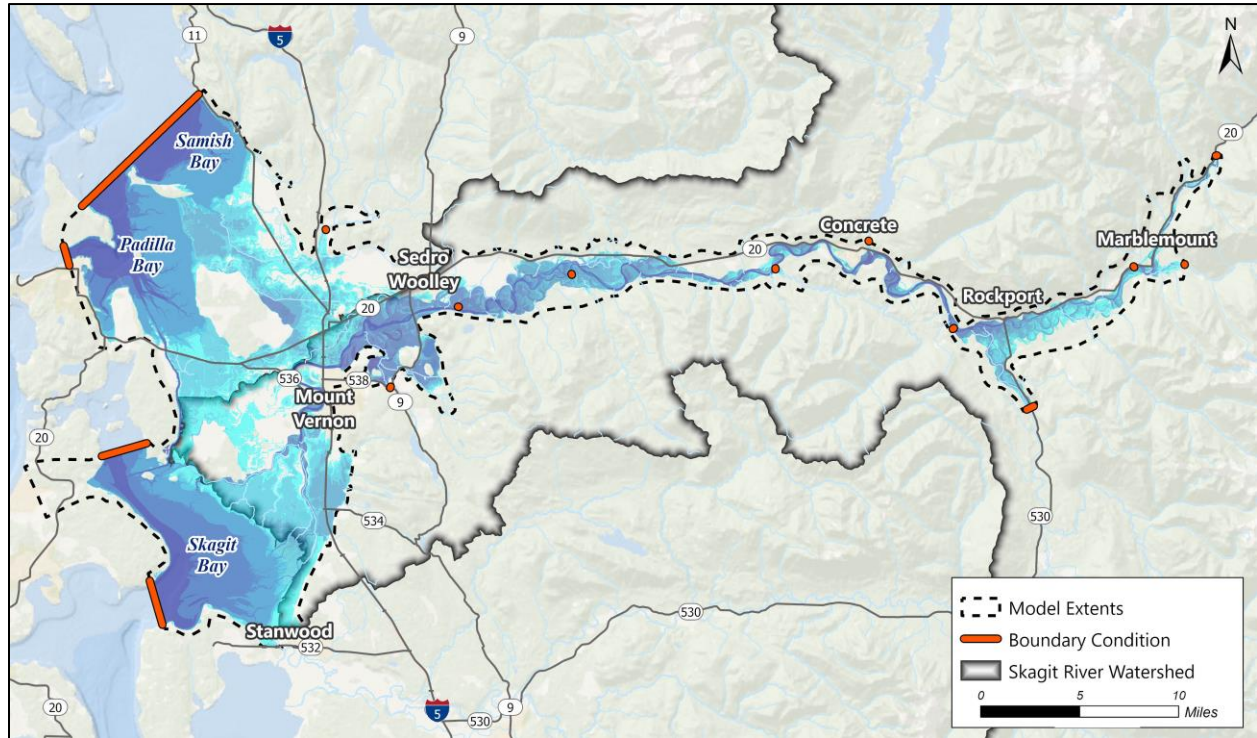


Figure 6.2 Model domain and boundary condition locations

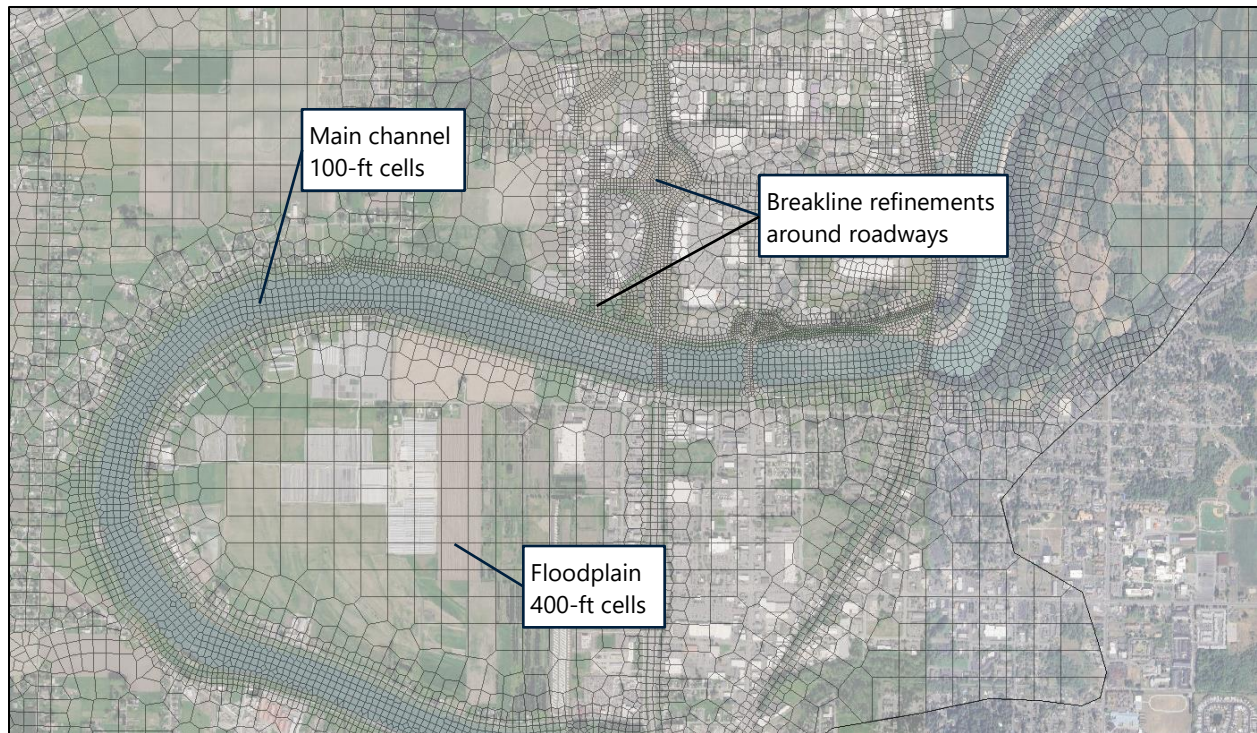


Figure 6.3 Example of 2D model mesh showing typical cell sizes

6.1.3 Hydraulic Structures

Structure representation in the model is limited to main channel bridges, significant relief bridges, dikes, culverts, and tide gates generally downstream of Burlington. The best-available structure data were obtained from prior models, described in Section 2, and used in the new Project model as described in this section. An overview of hydraulic structures applied in the model is shown in Figure 6.4. As part of the Project, NHC did not receive new infrastructure datasets from WSDOT or local governments. In addition, no drainage infrastructure was available or modeled along Gages Slough near Burlington.

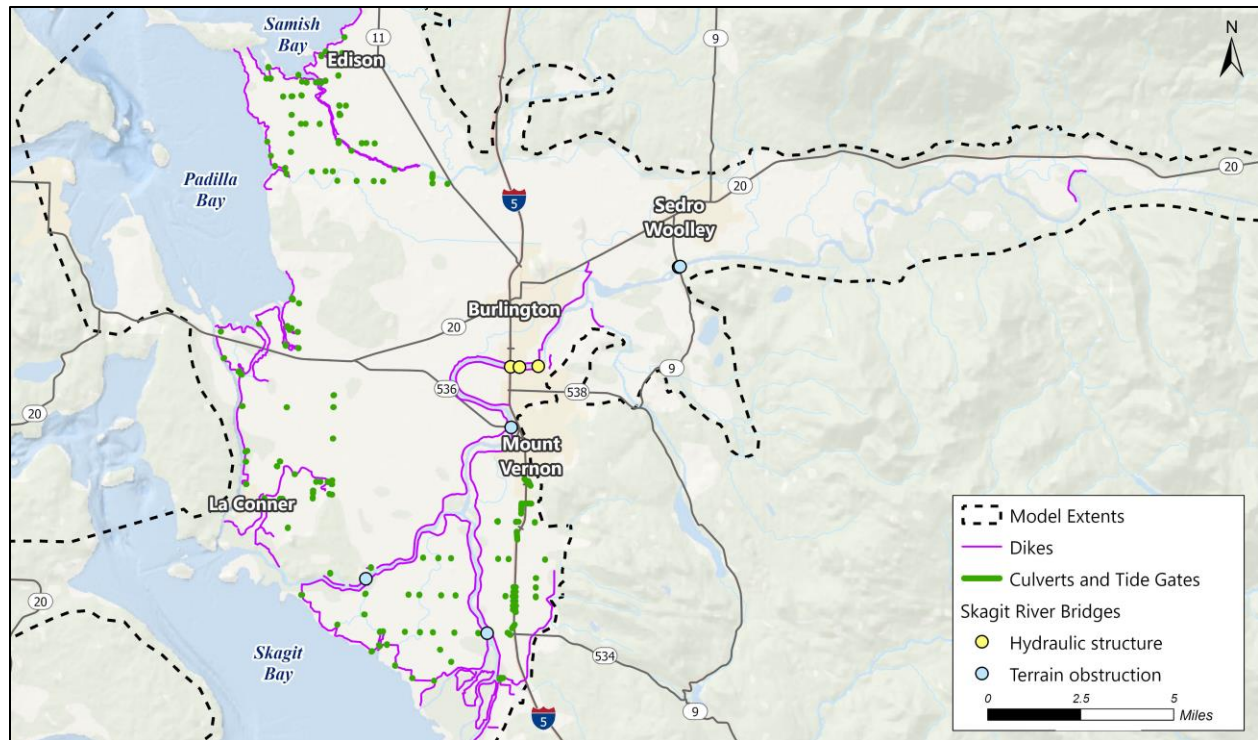


Figure 6.4 Overview of hydraulic structures applied in the Project model

Culverts and tide gates were coded into the Project model based on available data from prior models. Available culvert data were limited to structures greater than 24-inch diameter or span in areas downstream of Burlington, as shown by the green lines in Figure 6.4. Culvert data were primarily obtained from the Skagit Delta model (NHC, 2023) and supplemented with data from the CWMS model (USACE, 2022) and the Maddox Big Ditch project (NHC, 2020), as described in Section 2. The Skagit Delta model was used as the primary source as the study included the most recent inventory of existing drainage features. The structure inventory included a limited field survey; however, in areas where no survey data were available, invert elevations were assumed to match terrain values. The culverts were coded into the model as hydraulic structures, with input data including inlet configuration, pipe length, and invert elevations. Tide gates were modeled as culverts with flap gates (set to no positive flow flaps) preventing saltwater inflow to the interior areas during high tide.

NHC assessed the representation of bridges within the 2D model domain. Data for the bridge geometries were obtained from the CWMS model (USACE, 2022), which simulated bridges in a 1D reach. Two approaches were used to represent bridges within the Project model domain. In the first approach, bridge low chords that are above the maximum simulated discharge (2080 100-year) were modeled using terrain modifications to represent piers and abutments. In the second approach, where bridge decks were anticipated to be in contact with floods (pressurized flow condition), bridges were coded as hydraulic structures with dimensions as defined in the

CWMS model geometry. A summary of the bridges included in the model domain is included in Table 6.1. No debris blockage was modeled at the bridge structures for this project.

Similar to the CWMS model, the bridges at Highway 530 (RM 67.8) and Cascade River Road (RM 78.2) are not included in the model domain, though these features could be added in the future. Based on the calibration results in Section 6.4.2, HWMs near both of these bridge crossings are considered a good match.

Table 6.1 Summary of bridges represented in the model domain

Bridge Name	River	RM	Modeling Method
Best Road	North Fork	4.1	Terrain obstruction
Fir Island Road	South Fork	4.5	Terrain obstruction
Division Street (SR 536)	Skagit	11.5	Terrain obstruction
I-5	Skagit	15.6	Hydraulic structure
S Burlington Blvd	Skagit	15.9	Hydraulic structure
BNSF Railway	Skagit	16.3	Hydraulic structure
Highway 9	Skagit	22.5	Terrain obstruction
Great Northern Railway	Skagit	22.6	Terrain obstruction
Concrete Sauk Valley	Skagit	54.2	Hydraulic structure

Dikes and coastal dikes were coded into the model as hydraulic structures. The types of facilities were divided into segments to allow more discretization in parameters and calculation methods. Discretization of the dike segments within the model will allow for dike failure scenarios to be performed with more flexibility in future applications. Dikes were modeled using the 2D flow equations to maintain model stability. Crest elevations were applied from LiDAR based on the topobathymetric surface described in Section 6.1.1, with exception to the Mount Vernon Flood Wall, which used elevations from the CWMS model (USACE, 2022).

6.1.4 Land Cover and Roughness

Land cover for the floodplain was assigned based on NLCD 2021 data (USGS, 2025) and classified into 13 categories as shown in Table 6.2. Roughness values for each land cover type were determined by literature review and consideration of the calibrated CWMS model (USACE, 2022) and City Light model (2023). Floodplain roughness values were then refined through the model calibration process.

River and major tributaries were delineated separately using NAIP aerial imagery (USDA, 2023) and LiDAR data to define the main channel limits. The Skagit River mainstem values were split into discrete reaches during the calibration process. Main channel roughness values were initially assigned based on review of previously developed models and then refined through the

calibration process. Section 6.4 includes a detailed discussion on the calibration processes. The Samish River values were applied from the Skagit Delta model (NHC, 2023), calibrated to the February 2018 flood event. The final calibrated roughness values for main channel reaches are reported in Table 6.3.

In the future conditions scenarios, no consideration was given for land use changes that could impact flows such as development related to forest conversion or impervious surface increases.

Table 6.2 Final floodplain land cover areas and roughness values

Land Cover	Final Manning's Roughness Coefficients
Open water	0.0275
Developed, open space	0.03
Developed, low intensity	0.05
Developed, medium intensity	0.055
Developed, high intensity	0.06
Barren land	0.03
Forest (deciduous, evergreen, mixed)	0.1 ¹
Shrub-scrub	0.05
Herbaceous	0.055
Pasture-hay	0.05
Cultivated crops	0.055
Woody wetlands	0.08
Emergent herbaceous wetlands	0.07

Notes:

1. Roughness values for the forest zones were refined through the calibration process.

Table 6.3 Final main channel reaches and calibrated roughness values

Reach ¹	RM	Final Manning's Roughness Coefficients
North Fork Skagit River	1-7	0.022
South Fork Skagit River	1-8	0.022
Skagit River from Forks to Burlington	8-17	0.026
Skagit River from Burlington to Hamilton	17-42	0.034-0.036
Skagit River from Hamilton to Rockport	42-66	0.02-0.024
Skagit River from Rockport to Marblemount	66-79	0.032

Reach ¹	RM	Final Manning's Roughness Coefficients
Skagit River upstream of Marblemount	79-86	0.02
Skagit River major tributaries (Nookachamps, Baker, Sauk, and Cascade) ²	N/A	0.03
Samish River ³	N/A	0.025-0.06

Notes:

1. Roughness coefficients for all reaches were calibrated unless noted in this table.
2. Roughness coefficients for the Skagit River major tributaries were not calibrated as part of the project.
3. Calibrated roughness coefficients for the Samish River were applied from the Skagit Delta model (NHC, 2023).

6.2 Boundary Conditions

Boundary conditions used in the Project model consist of the primary Skagit River inflows, major tributary inflows, Samish River inflows, and four downstream stage boundaries. Locations of the boundary conditions are shown in Figure 6.5. Boundary condition inputs were developed for two flood hazard types: riverine and coastal flooding. This section summarizes the hydrologic and tidal inputs applied to the hydraulic model for these two hazard types, while Section 5 details development of the inputs.

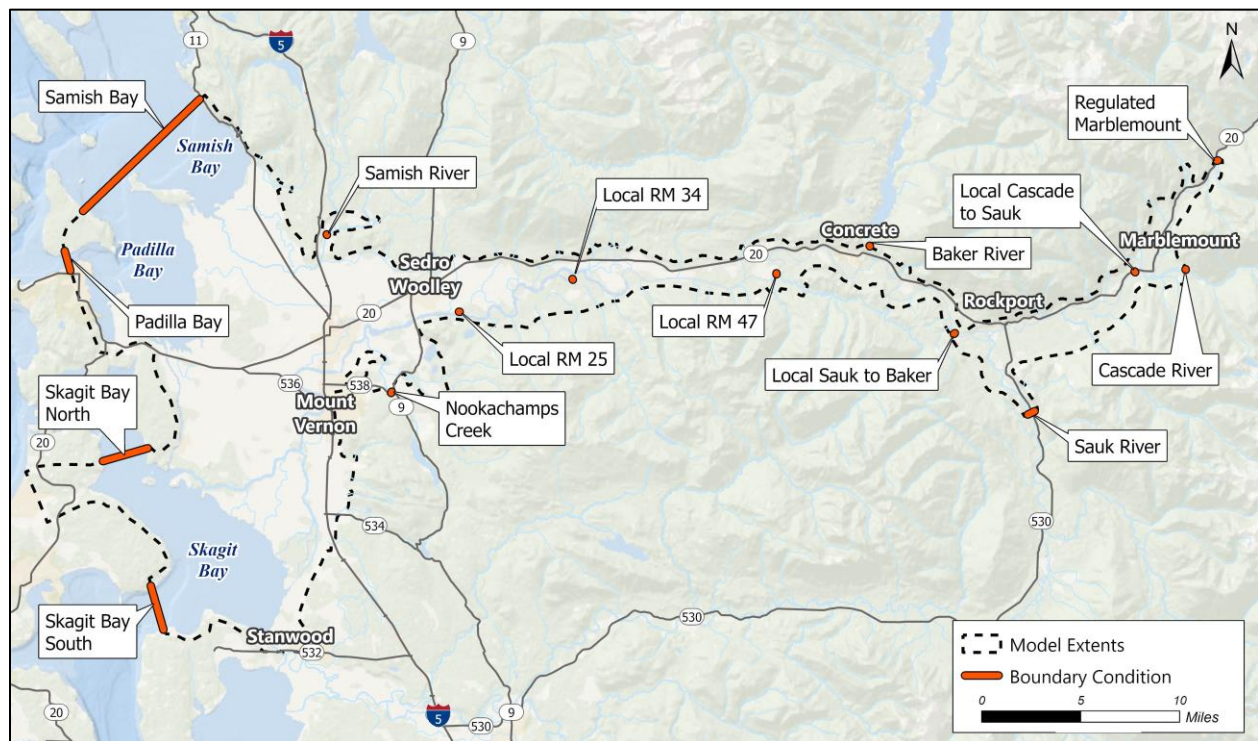


Figure 6.5 Boundary condition locations

6.2.1 Riverine

In historic conditions scenarios, riverine inflows for the 10-year, 25-year, and 100-year flood events were applied using hydrographs from the Skagit GI (USACE, 2014), with peak flows shown in Table 5.6 in Section 5.3. The Skagit GI grouped local inflows from Baker to Sedro-Woolley into a single hydrograph which was distributed evenly along 1D sections in that reach. Because HEC-RAS 2D cannot evenly distribute inflows along a reach the same way as a 1D model, these local inflows were instead applied at three locations in Figure 6.5, labeled "Local RM 25," "Local RM 34," and "Local RM 47." Scaling factors were applied to the Skagit GI hydrographs based on the proportional basin area at each local inflow location. For riverine flood events, tidal boundary conditions are defined as stage hydrographs with high tides near the MHHW stage, as reported in Table 5.7.

In future conditions scenarios, hydrologic inputs were modified by applying climate projection multipliers to the inputs, with peak flows listed in Table 5.6. The downstream tidal boundaries were shifted to account for sea level rise, with peak tidal stage listed in Table 5.8.

6.2.2 Coastal

In historic conditions scenarios, coastal flood boundary conditions were developed for the 10-year, 25-year, and 100-year coastal storm tides, coupled with average winter inflows.

In future conditions scenarios, tidal stage hydrographs representing the MHHW stage were shifted to account for both sea level rise and storm surge. Average winter inflows remained unchanged from the historic conditions scenarios.

6.3 Run Control Parameters

Model computation parameters were selected from a series of preliminary test runs to accurately simulate flood-scale hydraulics in the 2D domain while producing reasonable run times. The full momentum equations set (Shallow Water Equations with a Eulerian-Lagrangian Method, or SWE-ELM) were used with no turbulence model applied. The computational time step was set to a fixed time step of five seconds. Default Theta, tolerances, and solver iteration options were specified for all simulations.

A restart file was used to establish initial conditions at mean winter flows at the beginning of all simulations. The riverine flood events were generally run for an eight-day simulation period to span the inflow hydrographs and routing through the system. To evaluate riverine flood duration for the 100-year event, a separate run was developed with a one-month simulation period to capture interior drainage post peak. The coastal flood events were run for a four-day simulation to span the tidal events.

6.4 Calibration and Validation

The hydraulic model calibration and validation were performed for four significant flood events over the past three decades, as summarized in Table 6.4. Model calibration primarily focused on the November 2021 flood, which best represents the most current channel characteristics. Secondary consideration was given to the October 2003 flood, which was the only dataset that included observed data downstream of I-5, along the North Fork and South Fork. In December 2025, after model development phase was completed for the Project, historic flooding occurred within Skagit County, resulting in the stage of record at Mount Vernon (USGS 12200500) and a stage just below the 1995 event at Concrete (USGS 12194000), as shown in Table 6.4. As a result, the 2025 event was primarily used to validate the model calibration, and the 1995 event was used for secondary validation. While the flood in November 2006 was also a large event, it was not used in this Project because the peaks were slightly lower than 1995 and HWMs collected from this event were mainly limited to the reach between Mount Vernon and Sedro-Woolley.

The goal of model calibration was to replicate the hydrograph shape, peak stage, and peak discharge at the Mount Vernon gage (USGS 12200500), while matching peak stage at other USGS gages within 0.5 feet. In addition, the calibration focused on matching a widespread set of high-water marks (HWMs) within one foot. Matching USGS peak stage within 0.5 feet and HWMs within one foot is considered good for calibration performance, given measurement uncertainty. To achieve this, the Skagit River mainstem was divided into longitudinal reaches and roughness values were assigned to each reach to best match observed data. The 2025 and 1995 events were then used to validate the model's calibration, with focus placed on the more recent 2025 event. Data available for model calibration and validation generally includes USGS gages and HWM datasets collected by various sources. The final calibrated roughness values and longitudinal reaches are shown in Table 6.3 in Section 6.1.4. Model calibration and validation assume no bridge debris.

Table 6.4 Reported USGS gage peak stage and discharge for events used in model calibration and validation

Flood Event	Type	Concrete Gage		Mount Vernon Gage	
		Stage (ft, gage datum)	Peak Flow (cfs)	Stage (ft, gage datum)	Peak Flow (cfs)
November 2021	Calibration	38.93	134,000	36.99	127,000
October 2003 ²	Calibration	42.21	166,000	36.19	135,000
December 2025 ^{3,4}	Validation ⁴	41.13 ⁴	152,000 ⁴	37.73 ⁴	133,000 ⁴
November 1995	Validation	41.57	160,000	37.34	141,000

Notes:

1. Highlighted rows indicate the focus of model calibration and validation.
2. The 2025 and 2003 floods were the only events where HWMs were collected downstream of I-5, along the North Fork and South Fork.

3. The December 2025 flood occurred after the model development phase was completed for the Project. As a result, the model was not calibrated to this event but was used for model validation to evaluate the model performance to a more recent event.
4. Provisional data subject to revision by USGS.

6.4.1 Model Input

The calibration and validation runs required the development of event-specific boundary conditions. For all modeled events, the downstream boundary conditions were applied as tidal stage hydrographs using observed NOAA tidal statistics at stations described in Section 5.1.2. In three of the four runs described below the model was truncated at the USGS Concrete gage. The purpose in doing this was to significantly reduce uncertainty in lower river flows due to cumulative routing errors building up. Combined with tributary scaling, this allowed accurate routing of flows to the delta, as measured by comparing with observed flow at the USGS Mount Vernon gage (USGS 12200500). With more accurate flows there was greater confidence in calibrating roughness values to match observed HWMs and stage at gages. Inflow boundary conditions and model domain limits for the model calibration and validation runs varied by event and available data, as summarized below:

- For the 2021 event, the full model domain was used and USGS gaged flows were applied as inflows on the Skagit River, Samish River and major tributaries to the Skagit, as available. Local inflows (Cascade to Sauk, Sauk to Baker, and Baker to Sedro-Woolley, and Nookachamps) were applied by combining basins from the CWMS HEC-HMS model (USACE, 2022). Scaling factors were then applied to the local inflow hydrographs to best match the observed discharge and stage hydrographs at Mount Vernon (USGS 12200500).
- For the 2003 and 1995 events, the upstream limit of the model domain was truncated at Concrete (USGS 12194000) to match the extents in the Skagit GI (USACE, 2014). Local inflows along the Skagit River were applied from the Skagit GI. USGS gaged flows were applied as inflows on the Skagit River at Concrete and the Samish River. However, the Samish River USGS gage was not online during the 1995 event and was therefore not included in the 1995 validation run.
- For the 2025 event, the upstream limit of the model domain was truncated at Concrete (USGS 12194000) as the validation effort focused on where HWMs were collected, downstream of Sedro-Woolley. Local inflows from Baker River to Sedro-Woolley were applied using the 2003 hydrograph from the Skagit GI and then adjusted using scaling factors to best match the observed discharge at Mount Vernon (USGS 12200500). Local inflows for Nookachamps Creek were applied using the Washington State Department of Ecology (ECY) gage (03G100) located along East Fork Nookachamps Creek at Beaver Lake Road. The ECY gage was then scaled to the mouth of Nookachamps Creek based on regression estimates.

6.4.2 Calibration: November 2021 Event

Calibration data available from the November 2021 event includes USGS gages, surveyed HWMs, and SRSC gage peak stages, with the number of observations summarized in Table 6.5. The calibration data span Mount Vernon to Marblemount, with no data available downstream of I-5.

The simulated WSEs were evaluated longitudinally along the Skagit River mainstem. Figure 6.6 depicts the difference in simulated minus observed WSEs for HWMs and USGS gages for the 2021 event, as shown by orange and green points. Additionally, summary statistics for the errors are summarized in Table 6.5 and Figure 6.7 presents the distribution. Refer to the appended tables for a comparison of all observed points and simulated WSEs. In addition, Figure 6.8 shows a comparison of time series results at the Mount Vernon gage.

Simulated WSEs at the USGS gages generally indicate a good match with less than a 0.5-foot difference, except at Sedro-Woolley and Rockport gages. The model shows no systematic bias with mean errors near zero and no large outliers, as shown in the mean absolute error (MAE) of 0.4 feet and standard deviation of 0.5 feet. As shown in Figure 6.8, there is a very good match at the Mount Vernon gage, within 0.3 feet of stage and 0.1 percent discharge. At the Mount Vernon gage, the simulated peak discharge occurs about 3 hours before the observed peak, as shown in Figure 6.8. At the Concrete gage, shown in Figure 6.9, there is a good match of about 0.5 feet, but the model does tend to oversimulate stage and discharge slightly. However, the timing of the simulated peak discharge matches.

HWMs along the mainstem show mean error near zero and MAE of 0.6 feet indicating a good match. The distribution in Figure 6.7 shows that the model tends to oversimulate WSEs by about 0.5 feet. HWMs in the floodplain tend to show a broader distribution, with floodplain HWMs and SRSC gages having MAEs of 0.9 feet.

Table 6.5 Summary of error statistics for the November 2021 calibration event

Dataset	No. of Points	Mean Error (ft)	Mean Absolute Error (ft)	Standard Deviation (ft)	Max Error (ft)	Min Error (ft)
USGS gages (mainstem)	8	-0.2	0.4	0.5	0.5	-1.0
HWMs (mainstem)	35	0.2	0.6	0.8	2.4	-2.0
HWMs (floodplain)	34	0.3	0.9	1.1	3.0	-1.8
SRSC loggers (floodplain)	9	-0.0	0.9	1.0	1.5	-1.6

Notes:

1. See the appended tables for a detailed comparison of all observed points and simulated WSEs.

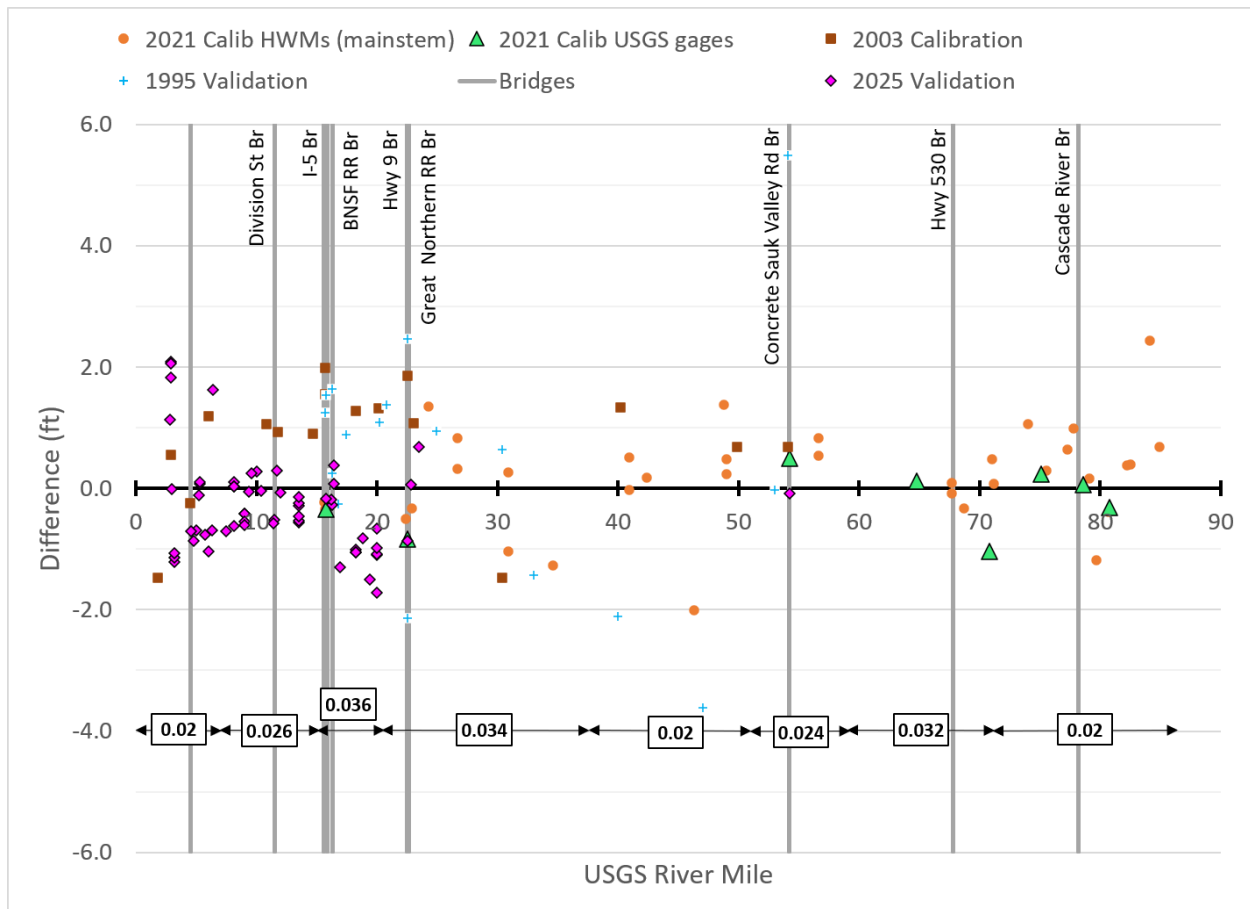


Figure 6.6 Difference in simulated minus observed WSEs along the Skagit River mainstem for all events

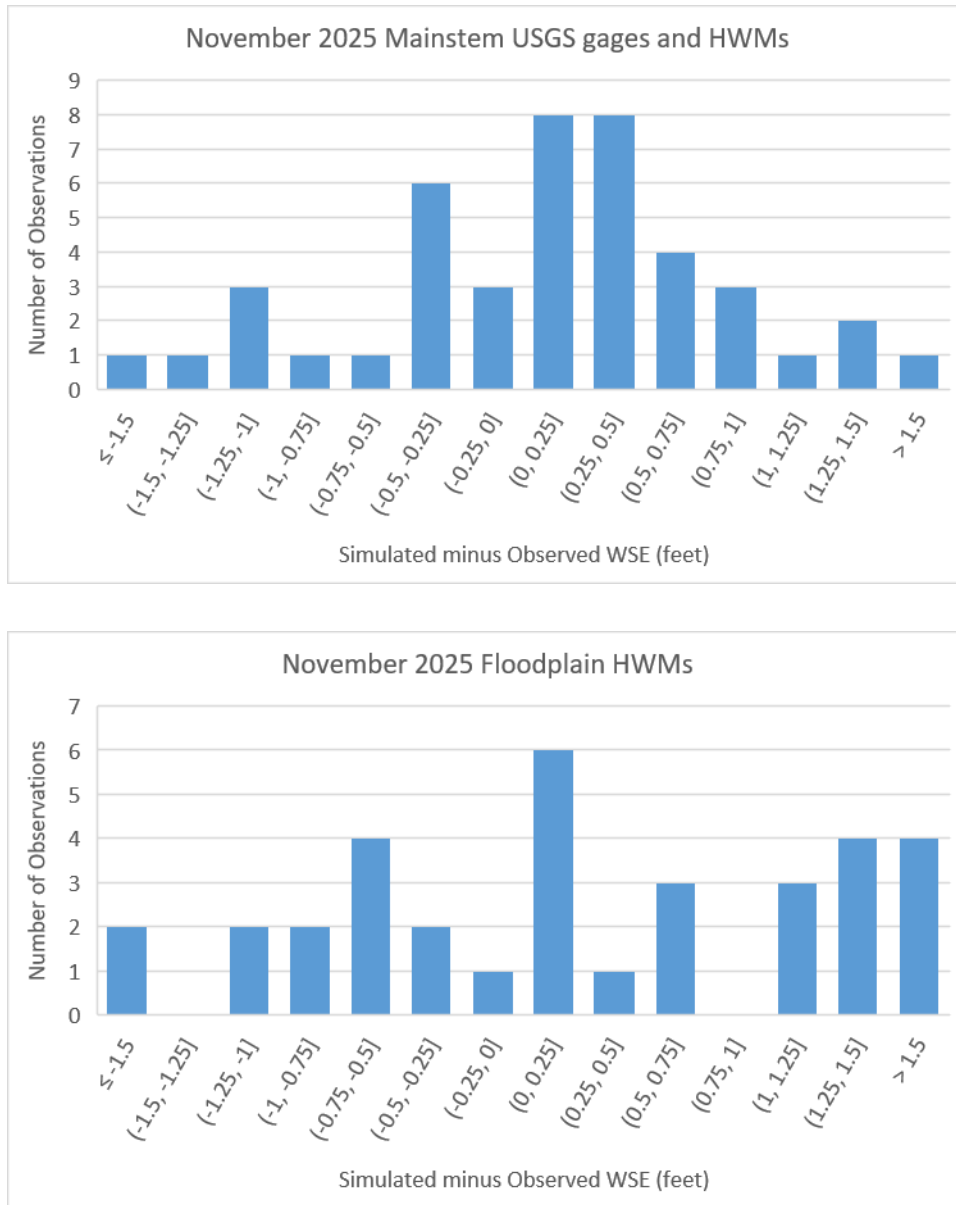


Figure 6.7 November 2021 peak WSE residual distribution for mainstem HWMs and USGS gages (top) and floodplain HWMs (bottom)

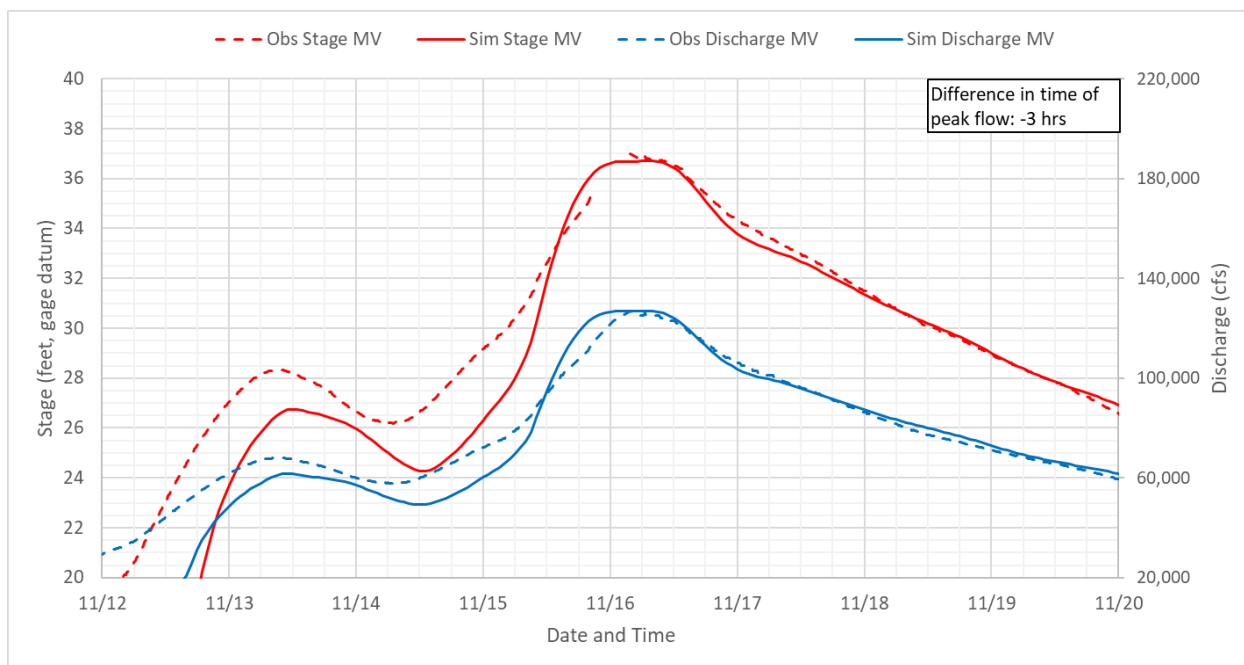


Figure 6.8 Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 2021 event

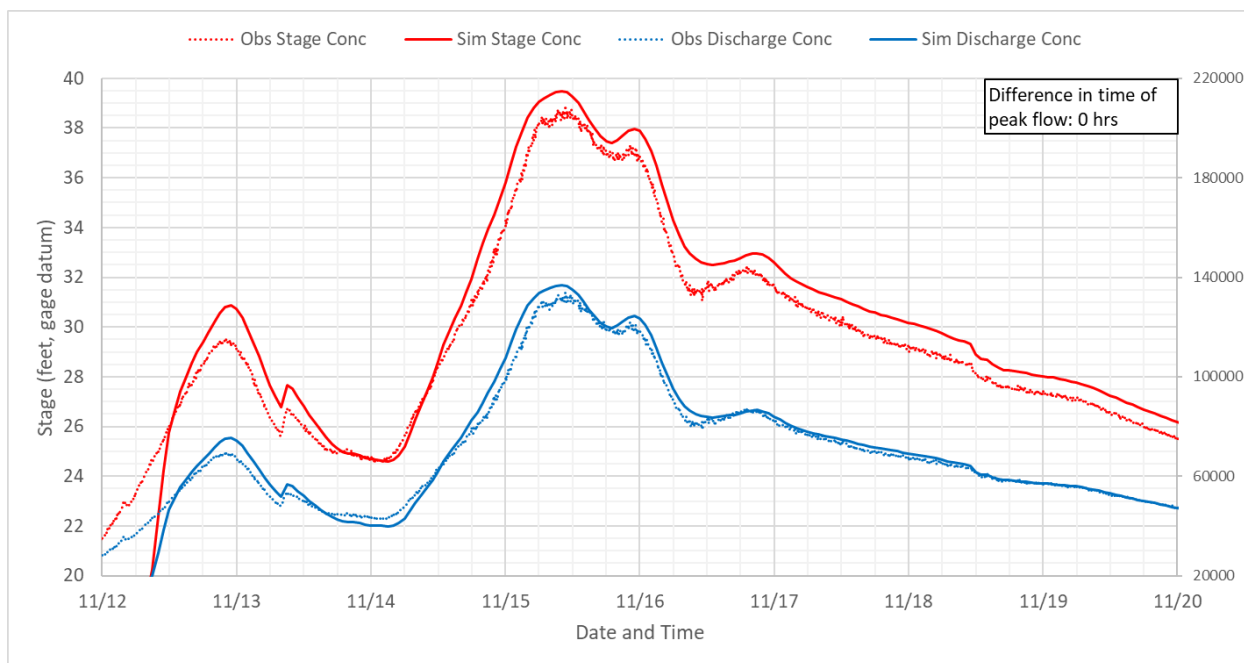


Figure 6.9 Comparison of simulated and observed stage and discharge at Concrete USGS gage for the 2021 event

6.4.3 Calibration: October 2003 Event

Calibration data available from the October 2003 event includes USGS gages and surveyed HWMs from the Skagit GI (USACE, 2014) from Skagit Bay to Concrete. The 2003 event was the only calibration dataset that included HWMs downstream of I-5, along the North Fork and South Fork. However, in 2014, a large avulsion formed on the North Fork which is represented in the Project model. The avulsion has significantly grown since that time, changing bathymetry and hydraulics through the reach, so consideration should be taken when comparing 2003 observed data with simulated results.

Along the profile in Figure 6.6, the 2003 simulated WSEs are consistently higher, by about one foot, as compared with observed data. This is also apparent in the error statistics, with a mean error of 0.8 feet, per Table 6.6. The calibration oversimulation generally implies a loss of channel capacity or conveyance between 2003 and 2015 (the date of the delta main channel bathymetric survey). The calibration process attempted to better match HWMs downstream of I-5, by selecting a lower Manning’s roughness coefficient of 0.02 along both the North Fork and South Fork, per Table 6.3 in Section 6.1.4. However, there wasn’t justification to lower it further based on observed bed conditions and to best match the 2021 observed stage at the Mount Vernon gage. For the 2003 event, the model oversimulates WSE at the Mount Vernon gage by 1.7 feet, as shown in Figure 6.10. Due to a gage failure during the flood, no timing comparisons are possible. Where there was both 2003 and 2021 observed data, the 2021 flood was given more weight in calibration due to recency, closer time to the main channel survey date, and higher number of HWMs.

Table 6.6 Summary of error statistics for the October 2003 event

Dataset	No. of Points	Mean Error (ft)	Mean Absolute Error (ft)	Standard Deviation (ft)	Max Error (ft)	Min Error (ft)
HWMs and USGS gages	17	0.8	1.2	1.0	2.0	-1.5

Notes:

1. See the appended tables for a detailed comparison of all observed points and simulated WSEs.

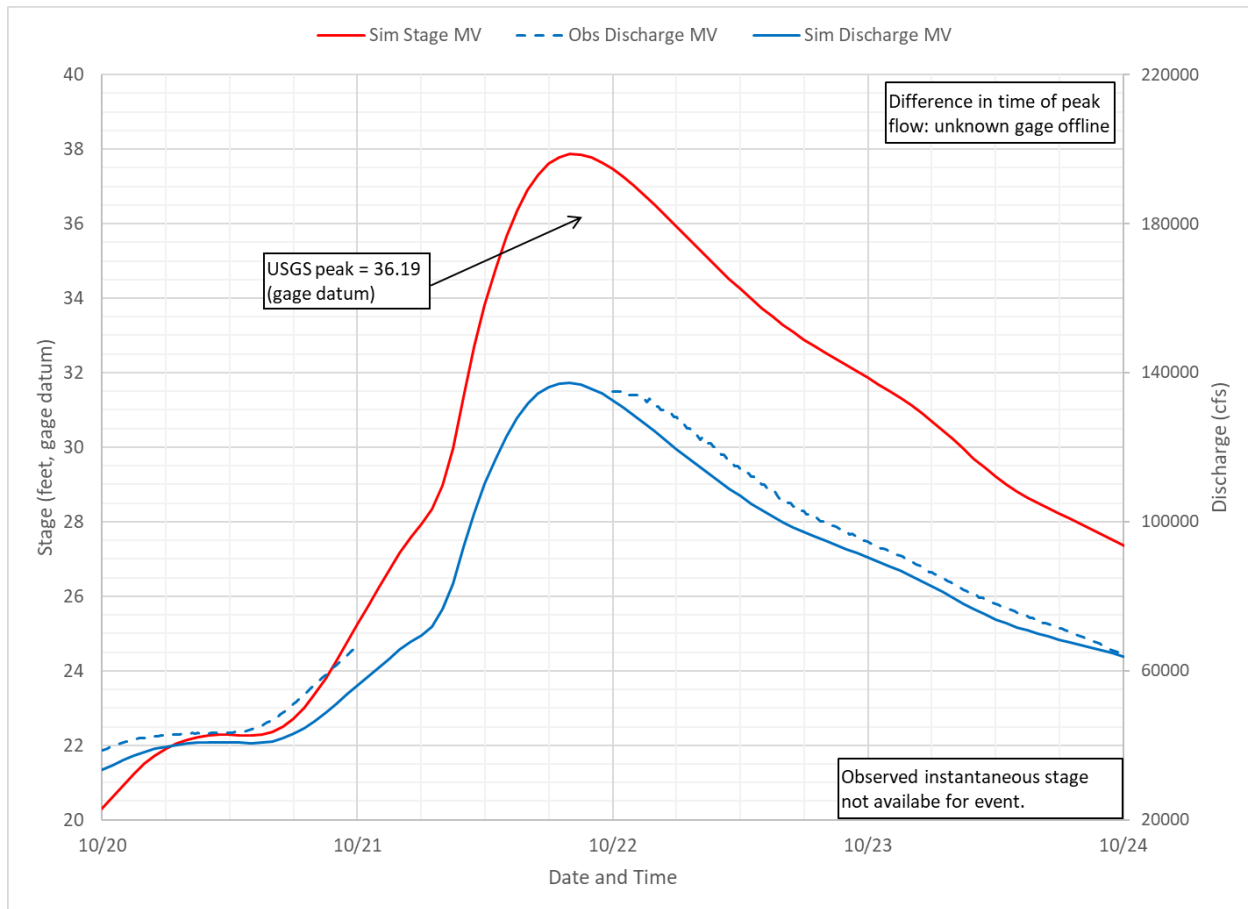


Figure 6.10 Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 2003 event

6.4.4 Validation: December 2025 Event

Observed data available for the December 2025 event includes USGS gages, NHC loggers, and surveyed HWMs, as summarized in Table 6.7. Prior to the event, NHC installed three level-loggers along the North Fork and South Forks to measure stage during the event. During the flood, Skagit Drainage and Irrigation Districts Consortium (DIDC) and NHC staff were deployed to stake and collect HWMs along the Skagit River between Sedro-Woolley and Skagit Bay. NHC met with DIDC staff to gather information and survey HWMs. The HWMs included debris lines, seed lines, and mud lines. Each HWM was evaluated for how precisely it defined the peak stage using the USGS high-water mark uncertainty rating for comparison to the simulated water surface profiles during validation. In addition, NHC reviewed photos and videos from several sources to collect additional HWMs. Refer to the appended tables for all observed data obtained.

As previously mentioned, the 2025 flood occurred after model development phase was completed for the Project. Therefore, the 2025 data were only used to validate the model and to provide insight into future calibration efforts. This Project does not include calibration to the 2025 event.

Along the profile in Figure 6.6, the 2025 simulated WSEs are generally near zero or lower, indicating a trend to generally match or undersimulate WSEs. This is also apparent in the distribution in Figure 6.12 and error statistics in Table 6.7, with a mean error of -0.3 feet and MAE of 0.6 feet. At the Mount Vernon gage, simulated stage and discharge show a very good match with stage within 0.2 feet and discharge within one percent, as shown in Figure 6.13. Similar to the 2021 event, the timing at the gage occurs about 3 hours early. Based on detailed results in the appended table, the undersimulation is most apparent in the Nookachamps area, where WSEs are typically one foot below observations. This could indicate BNSF bridge debris having an impact on simulated WSEs; though further investigation would need to be done to confirm.

Figure 6.11 depicts WSE differences along the North Fork and South Fork, to provide additional detail from the profile plot which superimposes data. Along the South Fork, the model consistently undersimulates WSEs similar to the reach upstream of the split. However, along the lower North Fork, the model oversimulates WSEs by generally one to two feet near Fish Town. The oversimulation in this area could be attributed to poor quality bathymetric survey at Blakes Marina, as described in the appended Topobathymetric Mosaic Development Memorandum. The model also shows very high velocities here, which could indicate that significant scour occurs during floods not captured in the fixed bed model.

Table 6.7 Summary of error statistics for the December 2025 event

Dataset	No. of Points	Mean Error (ft)	Mean Absolute Error (ft)	Standard Deviation (ft)	Max Error (ft)	Min Error (ft)
USGS gages & NHC loggers	6	-0.2	0.6	0.7	1.1	-1.0
HWMs	55	-0.3	0.6	0.8	-1.7	2.1

Notes:

1. See the appended tables for a detailed comparison of all observed points and simulated WSEs.

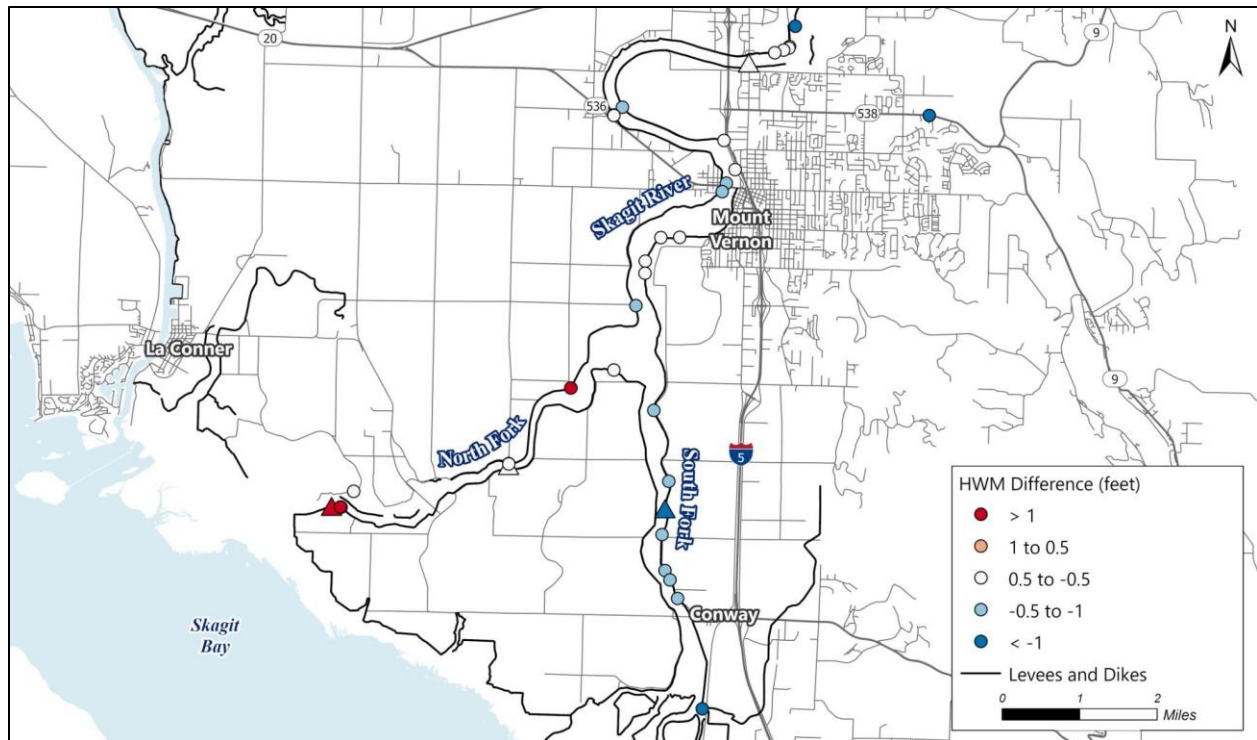


Figure 6.11 HWM differences along the Skagit River downstream of Burlington

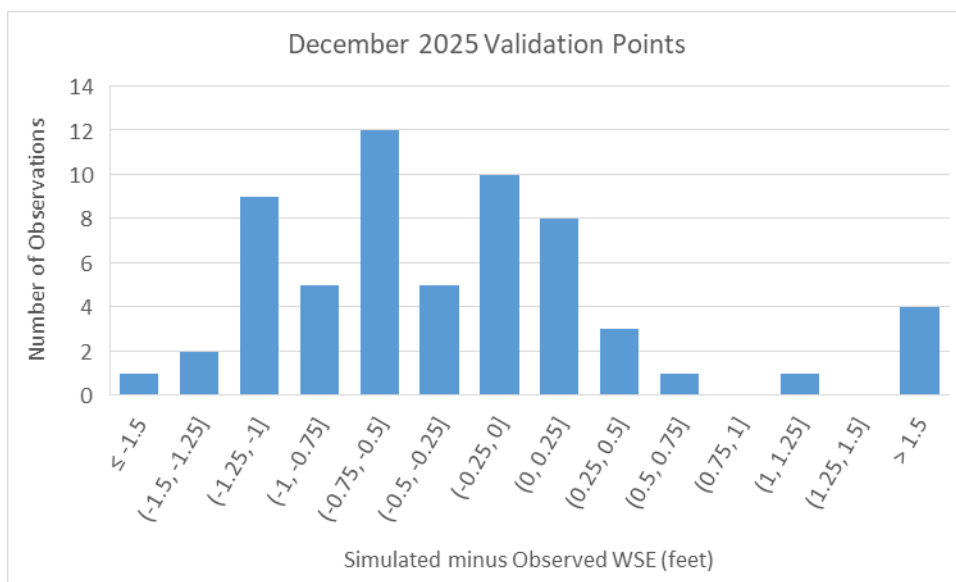


Figure 6.12 December 2025 peak WSE residual distribution for HWMs and gages

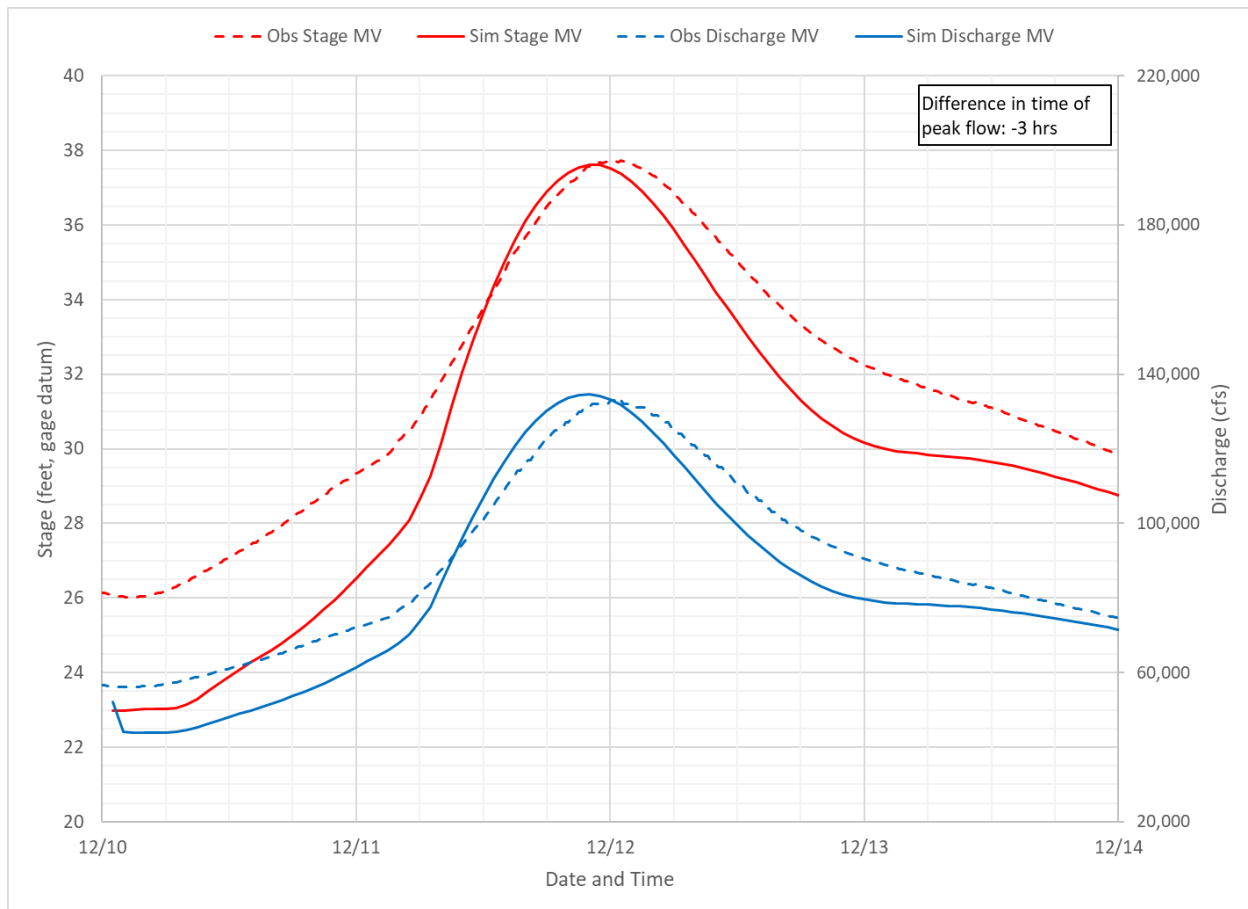


Figure 6.13 Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 2025 event

6.4.5 Validation: November 1995 Event

Observed data available from the November 1995 event includes USGS gages and surveyed HWMs from the Skagit GI (USACE, 2014) from Mount Vernon to Concrete. Similar to the 2003 data, this event occurred prior to the 2014 avulsion, so consideration should be made when comparing 1995 observed data to the Project model.

Along the profile in Figure 6.6, the 1995 simulated WSEs are consistently higher through Mount Vernon and Sedro-Woolley. The 1995 event results in the greatest error, with MAE of 1.6 feet and standard deviation of 2.0 feet, per Table 6.8. The differences are likely attributed to the general aggradational trend of the lower Skagit River between Concrete and Sedro-Woolley. Although, as mentioned in the Skagit GI (USACE, 2014), a few of the USACE HWMs appear to be inconsistent and would require significant variation in roughness to produce a good fit. For the 1995 event, the model oversimulates WSE at the Mount Vernon gage by 1.2 feet, but similar to other events, the simulated peak occurs about three hours early, as shown in Figure 6.14.

Table 6.8 Summary of error statistics for the November 1995 event

Dataset	No. of Points	Mean Error (ft)	Mean Absolute Error (ft)	Standard Deviation (ft)	Max Error (ft)	Min Error (ft)
HWMs and USGS gages	17	0.5	1.6	2.0	5.5	-3.6

Notes:

1. See the appended tables for a detailed comparison of all observed points and simulated WSEs.

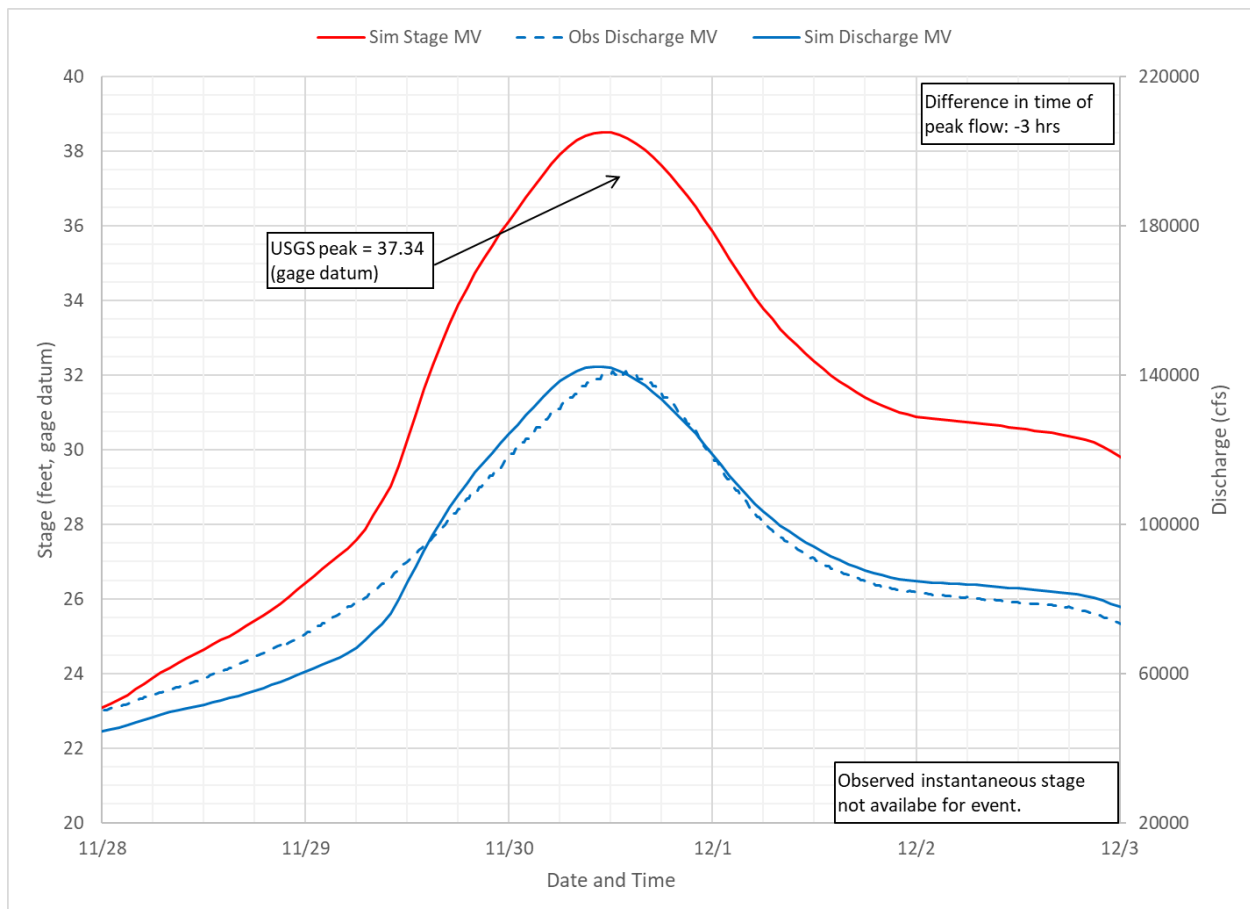


Figure 6.14 Comparison of simulated and observed stage and discharge at Mount Vernon USGS gage for the 1995 event

6.4.6 Summary

The main takeaways from the calibration and validation effort are as follows:

- The 2021 and 2025 events are considered most representative of current channel characteristics represented in the Project model. There are limitations with the calibration

and validation for the 2003 and 1995 events due channel bed changes associated with the 2014 avulsion and general aggradational trend of the lower Skagit River system.

- For the 2021 and 2025 events:
 - Calibration to the 2021 event is considered good from I-5 to Concrete, with HWMs generally within one foot of observed data and USGS gages within 0.5 feet, with exception of Sedro-Woolley and Rockport. However, no calibration data were available downstream of I-5, including the North Fork and South Fork.
 - The 2025 event shows the model generally undersimulates WSEs along the South Fork and oversimulates WSEs along the lower North Fork.
 - The 2025 event shows the largest differences directly upstream of the BNSF railroad bridge, extending upstream to Sedro-Woolley.
- For the 2003 and 1995 events, the model consistently oversimulates WSEs by about one foot which could be attributed to changes in the channel bed.
- Calibration to the 2025 event was not included in this Project; however, the model could benefit from calibration to this event using observed data collected and by potentially collecting newer bathymetric data along the forks extending upstream through Burlington. Additionally, conducting future sensitivity testing with bridge debris could improve model performance in the reach upstream of the BNSF railroad bridge.

6.5 Dike Failure Parameters

Dikes along the lower mainstem Skagit River, North Fork, South Fork, and Samish River provide riverine flood risk reduction in the Skagit delta. The Skagit GI (USACE, 2014) identified the potential for the Skagit River dikes to fail during a 100-year flood, and identified locations of primary risk. As part of the Project model development, six separate runs with dike failures were completed. These runs were computed at the 100-year riverine flood event under historic conditions. Dike failure locations selected matched locations in the Skagit GI (USACE, 2014), and preference was given to failure locations resulting in greatest impacts to urban centers. The six selected failure locations are detailed in Table 6.9 and shown spatially in Figure 6.15. No failure runs were completed on coastal dike facilities.

Dike failure parameters and mechanisms were maintained from the Skagit GI (USACE, 2014). The failures are initiated at a selected water surface elevation based on probability of failure elevation identified in the Skagit GI. The fully developed failure width is 400 feet and the failures were assumed to take three hours to reach the fully developed sizes. Only a single failure was assumed to occur in any one flood event to identify the maximum flood inundation that might occur.

Table 6.9 Dike failure locations from Skagit GI

RM ¹	Physical Location
RM 21.3	Skagit River mainstem right bank near Lafayette Road
RM 18.1	Skagit River mainstem right bank upstream of BNSF bridge
RM 16.8	Skagit River mainstem left bank immediately below I-5 bridge
RM 13.1	Skagit River mainstem right bank upstream of Division Street bridge
RM 11.7	Skagit River mainstem left bank downstream of Mount Vernon Flood Wall
North Fork RM 8.3	North Fork Skagit River left bank

Notes:

1. River miles from the Skagit GI (USACE, 2014).

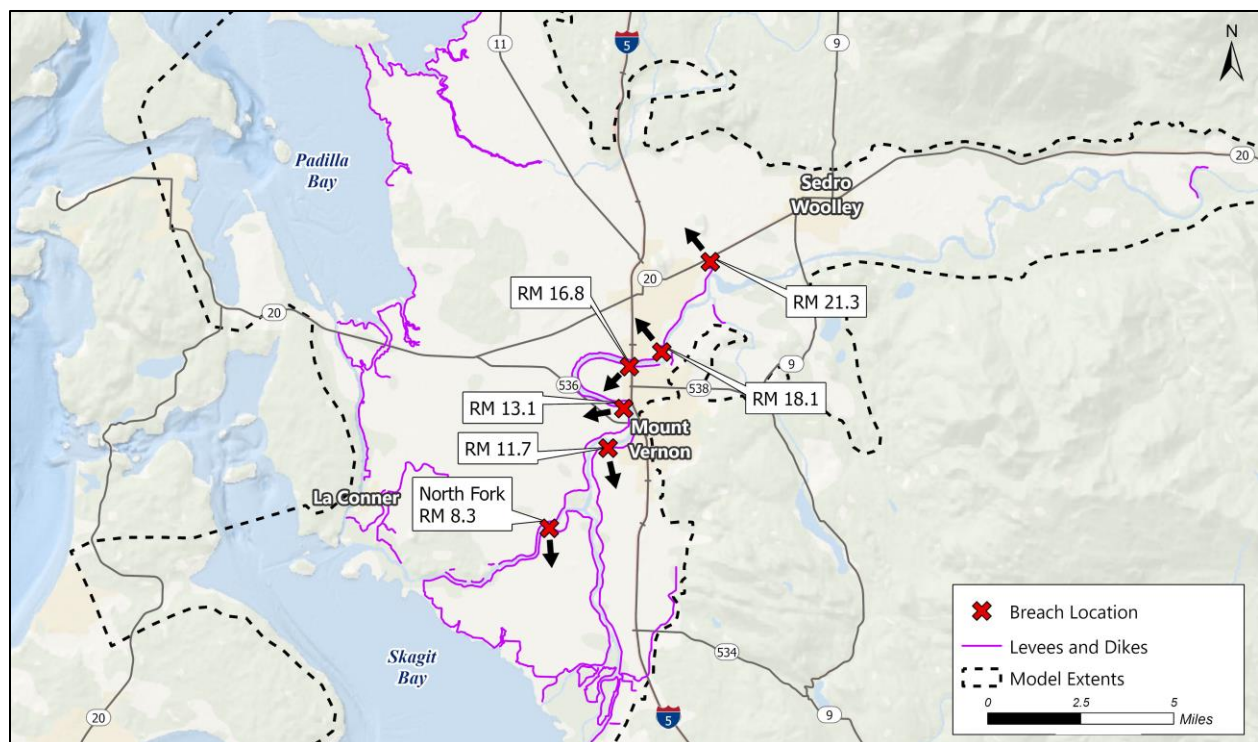


Figure 6.15 Dike failure locations in the 2D model

7 MODEL OUTPUT

This section documents the model output and post-processing methods used to develop the mapping products and animations for the Project. All results are included in Appendix B of the Project Report. Select animation will be available on the Skagit Climate Science Consortium website. Table 7.1 summarizes the output type and the associated post-processing completed. All rasters output from the model have a 3-foot cell resolution.

Table 7.1 Flood model outputs

Output Type	Post-Processing Required
Flood Extent	direct output
Flood Depth	direct output
Flood Velocity ¹	direct output
Water Surface Elevation	direct output
Dike Failure ²	difference maps post-processed in HEC-RAS (with failure minus historic conditions)
Depth-Velocity Hazard	post-processed in HEC-RAS based on classifications (AIDR, 2017)
Flood Duration ³	direct output
Animations	direct output and post-processed in video editing software

Notes:

1. Velocity output shows magnitude only and does not depict flow direction.
2. All other mapping products produced for the project assume no dike failure occurs. Dike failure locations described in Section 6.5.
3. Duration map only developed for the 100-year riverine flood in historic conditions.

The following post-processing was completed on model output:

- Depth difference maps were developed for the dike failure scenarios by calculating the difference between the dike failure minus no-failure scenarios. These layers also highlight newly inundated areas as a result of the dike failure.
- Depth-Velocity hazard maps were developed for this Project based on standard international practice (AIDR, 2017) and classified into six hazard ratings using methodology outlined in Table 7.2, based on limiting depth and velocities. Limitations to the hazard maps include the following:
 - Hazard mapping methodology is based on clearwater riverine hazards.
 - Mapping does not consider secondary hazards such as shoreline and fluvial geomorphic hazards (e.g., erosion, avulsion, debris flows, alluvial fan, etc.).
- Animation videos were created by recording direct output from the hydraulic model that illustrate the timing and progression of flooding during an event. They can help users

visualize the routing of flood waters through the floodplain and as supplemental reference for interpreting model results. Animations are not static maps included in the Project report, but can be generated by technical users familiar with the HEC-RAS modeling software. Animations for select locations can be found at the Skagit Climate Science Consortium website.

Table 7.2 Descriptions for depth-velocity hazard rating mapping (based on (AIDR, 2017))

Rating, color	Description	Classification limit (D*V) (ft ² /s)	Limiting still water depth (D) (ft)	Limiting velocity (V) (ft/s)
H1	Generally safe for vehicles, people, and buildings.	≤3.2	≤1.0	≤6.6
H2	Unsafe for small vehicles.	≤6.5	≤1.6	≤6.6
H3	Unsafe for vehicles, children, and the elderly.	≤6.5	≤3.9	≤6.6
H4	Unsafe for vehicles and people.	≤10.8	≤6.6	≤6.6
H5	Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure.	≤43.1	≤13.1	≤13.1
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.	>43.1	N/A	N/A

8 TECHNICAL CONCLUSIONS AND RECOMMENDATIONS

This report documents the development of the new hydraulic model to improve floodplain and coastal mapping in the Skagit River watershed. This section summarizes the technical findings, with key primary conclusions listed as follows:

- The fully 2D model provides a robust tool to evaluate riverine and coastal flooding under historic and future climate conditions along both the Skagit and Samish systems. While the tool and mapping products can be used for flood planning, infrastructure design, habitat restoration and emergency management, it will not replace the FEMA effective Base Flood Elevations.
- The model provides good calibration to the 2021 event from I-5 to Concrete; however, no calibration data were available downstream of I-5, including the North Fork and South Fork.
- Validation to the 2025 event showed a trend of oversimulating along the North Fork and undersimulating along the South Fork, in addition to oversimulating in the reach immediately upstream of the BNSF bridge.
- For prior events in 1995 and 2003, the model consistently oversimulates WSEs by about one foot which could be attributed to changes in channel bed of the lower Skagit River.

- The Project model will be available for use and adaptation by technical users proficient with the HEC-RAS modeling software.

Based on the technical findings, there are a few recommendations to improve the Project model capability in the future, including:

- Recalibrating the model to the December 2025 event using observed data to improve model performance along the North Fork, South Fork, and near Sedro-Woolley. The recalibration would benefit by applying newer bathymetry along the forks and mainstem Skagit extending upstream to Burlington. The calibration would also benefit by collecting discharge measurements on the North Fork, South Fork, and above the split. Additionally, conducting sensitivity testing with bridge debris to improve model performance in the reach upstream of the BNSF railroad bridge.
- Improving duration mapping by adding pump stations and additional key culvert and bridge infrastructure, such as along Gages Slough and the area south of Mount Vernon to Conway. Setting up long-term model runs to produce duration maps for events other than the historic 100-year riverine flood (e.g., future 100-year flood, dike failure scenarios, coastal flooding).
- Adding bridge geometry at Highway 530 (RM 67.8) and Cascade River Road (RM 78.2).
- Continuing to update the hydraulic model over time to incorporate the latest available data.
- Conducting sensitivity testing to evaluate bed level variability along the Skagit mainstem.
- Exploring the implications of higher or lower projections on coastal flood risks.

9 REFERENCES

- AIDR (2017). Australian Disaster Resilience Handbook Collection. Handbook 7. Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia. Australian Institute for Disaster Resilience (AIDR).
- Bandaragoda, C., Hamlet, A. F., and Istanbuluoglu, E. (2019). Hybrid methods for producing gridded meteorological forcings in mountain environments. Unpublished manuscript. 2019.
- Bandaragoda, C., Istanbuluoglu, E., Raymond, C., and Wasserman, L. (2015). Hydrologic Impacts of Climate Change in the Skagit River Basin. Report prepared for the Skagit Climate Science Consortium, Mount Vernon, WA, and Seattle City Light, Seattle, WA. 2015.
- Hamlet, A. F., Elsner, M. M., Mauger, G. S., Lee, S. Y., Tohver, I., and Norheim, R. A. (2013). An overview of the Columbia Basin Climate Change Scenarios Project: Approach, methods, and summary of key results. *Atmosphere-Ocean*, 51(4), 392–415.
- Lee, S. Y., Hamlet, A. F., and Grossman, E. E. (2016). Impacts of climate change on regulated streamflow, hydrologic extremes, hydropower production, and sediment discharge in the Skagit River Basin. *Northwest Science*, 90(1), 23–43.
- Miller, I. M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., and Grossman, E. (2018). Projected Sea Level Rise for Washington State – A 2018 Assessment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project. 2018.
- Miller, I. M., Yang, Z., VanArendonk, N., Grossman, E., Mauger, G. S., and Morgan, H. (2019). Extreme Coastal Water Level in Washington State: Guidelines to Support Sea Level Rise Planning. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, Pacific Northwest National Laboratory and U.S. Geological Survey. Prepared for the Washington Coastal Resilience Project. 2019.
- NHC (2020). Maddox Creek/Big Ditch Alternatives Evaluation. Final Report. Prepared by Northwest Hydraulic Consultants Inc. for Skagit County Drainage and Irrigation District #17. February 2020.
- NHC (2023). Skagit River Delta Flood Drainage Project Flood Modeling, Mapping, and Mitigation Analysis. Prepared by Northwest Hydraulic Consultants Inc. for Skagit County Public Works. May 2023.

- NHC (2025). Old Highway 99 at Thomas Creek Bridge Replacement Hydraulic Basis of Design Report. Prepared by Northwest Hydraulic Consultants Inc. for Skagit County Public Works Department. June 2025.
- NOAA (2025). Online Vertical Datum Transformation. Vertical Datum Transformations.
- Seattle City Light (City Light) (2023). FA-02 Instream Flow Model Development Study Report for the Skagit River Hydroelectric Project. Report #: Initial Study Report. Prepared by Northwest Hydraulic Consultants, Inc. and HDR Engineering, Inc. March 2023.
- SITC, SRSC, and SC2 (2026). Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities. Report prepared for the National Fish & Wildlife Foundation. 2026.
- Sweet, W., Hamlington, B., Kopp, R. E., Weaver, C., Barnard, P. L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A. S., Krasting, J. P., Larour, E., Marcy, D., Marra, J. J., Obeysekera, J., Osler, M., Pendleton, M., Roman, D., Schmied, L., Veatch, W., White, K. D., and Zuzak, C. (2022). Global and regional sea level rise scenarios for the United States. Report. 2022.
- USACE (2014). Skagit River Flood Risk Management General Investigation Draft Feasibility Report and Environmental Impact Statement. U.S. Army Corps of Engineers. May 2014.
- USACE (2021). Project: 21-1190 Plan, IMW McGlinn Feasibility Phase 3. April 2021.
- USACE (2022). Skagit Corps Water Management System HEC-RAS Model. [Dataset].
- USACE (2024). HEC-RAS River Analysis System 6.6 [Software].
- USDA (2023). National Agriculture Imagery Program. [Dataset].
- USGS (2025). Annual National Land Cover Database (NLCD) Collection 1 Land Cover Conterminous United States. [Dataset].
- Whiting, J., Wang, T., and Khangaonkar, T. (2017). Hydrodynamic Model Development and Application for Restoration Alternatives Assessment - Skagit Delta Hydrodynamic Modeling Project (SHDM). September 2017.

TABLES



Table 1 November 2021 event: simulated and observed water surface elevations along the Skagit River mainstem

Source	River	Location (RM ¹)	Observed (ft, NAVD88)	Simulated (ft, NAVD88)	Difference (ft)
NHC	Mainstem Skagit	84.9	374	374.7	0.7
NHC	Mainstem Skagit	84.1	367.8	370.2	2.4
NHC	Mainstem Skagit	82.5	356.7	357.1	0.4
NHC	Mainstem Skagit	82.2	353.2	353.6	0.4
USGS	Mainstem Skagit	80.8	341.5	341.2	-0.3
NHC	Mainstem Skagit	80.7	341.7	341.3	-0.4
NHC	Mainstem Skagit	79.7	332.1	330.9	-1.2
NHC	Mainstem Skagit	79.1	326.6	326.8	0.2
USGS	Mainstem Skagit	78.6	323.3	323.4	0.1
NHC	Mainstem Skagit	77.8	318.4	319.4	1.0
NHC	Mainstem Skagit	77.3	313.4	314.0	0.6
NHC	Mainstem Skagit	75.5	298.6	298.9	0.3
USGS	Mainstem Skagit	75.1	295.4	295.6	0.2
NHC	Mainstem Skagit	74	282.1	283.2	1.1
NHC	Mainstem Skagit	71.2	256.7	256.8	0.1
NHC	Mainstem Skagit	71	252.7	253.2	0.5
USGS	Mainstem Skagit	70.8	250.5	249.5	-1.0
NHC	Mainstem Skagit	68.7	235.7	235.4	-0.3
NHC	Mainstem Skagit	67.7	232.7	232.6	-0.1
NHC	Mainstem Skagit	67.7	233.4	233.5	0.1
USGS	Mainstem Skagit	64.8	219	219.1	0.1
NHC	Mainstem Skagit	56.6	183.5	184.3	0.8
NHC	Mainstem Skagit	56.6	183.8	184.3	0.5
USGS	Mainstem Skagit	54.2	172.9	173.4	0.5
NHC	Mainstem Skagit	49	146.7	146.9	0.2
NHC	Mainstem Skagit	49	145.9	146.4	0.5
NHC	Mainstem Skagit	48.8	145.6	147.0	1.4
NHC	Mainstem Skagit	46.3	132.7	130.7	-2.0
NHC	Mainstem Skagit	42.4	112.6	112.8	0.2

Source	River	Location (RM ¹)	Observed (ft, NAVD88)	Simulated (ft, NAVD88)	Difference (ft)
NHC	Mainstem Skagit	40.9	106.4	106.9	0.5
NHC	Mainstem Skagit	40.9	107	107.0	0.0
NHC	Mainstem Skagit	34.6	80.5	79.2	-1.3
NHC	Mainstem Skagit	30.9	68	67.0	-1.0
NHC	Mainstem Skagit	30.9	66.7	67.0	0.3
NHC	Mainstem Skagit	26.7	57.4	57.7	0.3
NHC	Mainstem Skagit	26.7	56.9	57.7	0.8
NHC	Mainstem Skagit	24.3	51.5	52.8	1.3
NHC	Mainstem Skagit	22.9	48.6	48.3	-0.3
USGS	Mainstem Skagit	22.5	47.3	46.5	-0.8
NHC	Mainstem Skagit	22.4	46.4	45.9	-0.5
USGS	Mainstem Skagit	15.8	40.8	40.5	-0.3
NHC	Mainstem Skagit	15.7	40.8	40.5	-0.3
NHC	Mainstem Skagit	15.6	40.4	40.2	-0.2

Notes:

1. River mile location based on USGS.

Table 2 October 2003 event: simulated and observed water surface elevations

Source	River ¹	Location (RM ²)	Location (RM ³)	HWM (ft, NAVD88)	Skagit GI (USACE, 2014)		2026 Project Model	
					Sim (ft, NAVD88)	Diff (ft)	Sim (ft, NAVD88)	Diff (ft)
USGS Gage	Skagit	54.10	54.1	176.0	172.3	-3.7	176.6	0.7
Skagit County	Skagit	49.75	49.9	153.8	151.6	-2.1	154.5	0.7
Skagit County	Skagit	40.18	40.2	104.4	103.3	-1.1	105.8	1.3
Skagit County	Skagit	29.90	30.4	67.3	65.8	-1.5	65.8	-1.5
Skagit County	Skagit	22.78	23.0	48.9	47.6	-1.3	50.0	1.1
USGS Gage	Skagit	22.30	22.5	45.6	46.0	0.4	47.5	1.9
Skagit County	Skagit	21.60	20.1	44.5	45.0	0.5	45.8	1.3
Skagit County	Skagit	19.48	18.2	43.5	43.5	0.0	44.8	1.3
Skagit County	Skagit	17.07	15.7	40.4	41.3	0.9	42.0	1.6
USGS Gage	Skagit	17.05	15.7	40.0	41.2	1.2	41.9	2.0
Skagit County	Skagit	15.89	14.7	39.0	39.0	0.0	39.9	0.9
Skagit County	Skagit	13.03	11.8	34.0	34.5	0.5	34.9	0.9
Skagit County	Skagit	12.18	10.8	32.0	32.2	0.2	33.0	1.1
Skagit County	NF	8.09	6.0	25.0	24.6	-0.4	26.2	1.2
Skagit County	NF	4.42	2.9	15.5	12.7	-2.8	16.1	0.5
Skagit County	SF	5.80	4.5	19.7	19.7	0.1	19.4	-0.2
Skagit County	SF	3.52	1.8	14.1	11.1	-3.0	12.6	-1.5

Notes:

1. Skagit (Mainstem Skagit), North Fork (NF), South Fork (SF).
2. River mile location based on the Skagit GI (USACE, 2014).
3. River mile location based on current USGS river mile data.

Table 3 December 2025 event: simulated and observed water surface elevations

Source	River	Location (RM ¹)	Observed (ft, NAVD88)	Simulated (ft, NAVD88)	Difference (ft)
USGS	Mainstem Skagit	54.2	175.1	175.0	-0.1
NHC Dec23	Mainstem Skagit	23.5	50.6	51.2	0.7
NHC Dec23	Mainstem Skagit	22.8	49.7	49.7	0.1
USGS	Mainstem Skagit	22.5	47.9	47.1	-0.9
NHC Dec23	Mainstem Skagit	20.0	46.4	45.3	-1.1
NHC Dec23	Mainstem Skagit	20.0	46.4	45.3	-1.1
NHC Dec23	Mainstem Skagit	20.0	47.1	45.4	-1.7
Photo	Floodplain	20.0	45.0	44.3	-0.7
Photo	Floodplain	20.0	46.2	45.2	-1.0
NHC Dec15	Mainstem Skagit	19.4	46.8	45.3	-1.5
Photo	Floodplain	18.8	38.5	37.7	-0.8
NHC Dec15	Mainstem Skagit	18.2	45.2	44.2	-1.0
NHC Dec15	Mainstem Skagit	18.2	45.3	44.2	-1.1
NHC Dec15	Mainstem Skagit	18.2	45.3	44.2	-1.1
NHC Dec23	Mainstem Skagit	16.9	44.5	43.2	-1.3
NHC Dec23	Mainstem Skagit	16.4	42.1	42.1	0.1
NHC Dec23	Mainstem Skagit	16.4	41.6	41.9	0.4
NHC Dec23	Mainstem Skagit	16.3	42.1	41.9	-0.3
NHC Dec23	Mainstem Skagit	16.2	41.8	41.6	-0.2
USGS	Mainstem Skagit	15.8	41.5	41.4	-0.2
NHC Dec15	Mainstem Skagit	13.5	37.9	37.3	-0.6
NHC Dec15	Mainstem Skagit	13.5	37.8	37.3	-0.5
NHC Dec15	Mainstem Skagit	13.5	38.2	37.7	-0.5
NHC Dec15	Mainstem Skagit	13.5	38.0	37.7	-0.3
NHC Dec15	Mainstem Skagit	13.5	37.9	37.7	-0.2
NHC Dec15	Mainstem Skagit	13.5	37.8	37.7	-0.1
NHC Dec23	Mainstem Skagit	12.0	35.0	35.0	-0.1
Photo	Mainstem Skagit	11.7	34.0	34.3	0.3
NHC Dec23	Mainstem Skagit	11.5	33.9	33.4	-0.5
NHC Dec23	Mainstem Skagit	11.4	33.8	33.2	-0.6

Source	River	Location (RM ¹)	Observed (ft, NAVD88)	Simulated (ft, NAVD88)	Difference (ft)
NHC Dec15	Mainstem Skagit	10.4	32.1	32.0	0.0
NHC Dec15	Mainstem Skagit	10.0	30.8	31.1	0.3
NHC Dec15	Mainstem Skagit	9.6	30.0	30.2	0.2
NHC Dec15	Mainstem Skagit	9.4	29.7	29.6	-0.1
NHC Dec15	Mainstem Skagit	9.0	29.0	28.6	-0.4
NHC Dec15	Mainstem Skagit	9.0	29.0	28.6	-0.4
NHC Dec15	Mainstem Skagit	9.0	29.1	28.6	-0.6
NHC Dec15	Mainstem Skagit	9.0	29.2	28.6	-0.6
NHC Dec15	SF	8.1	28.3	27.7	-0.6
NHC Dec15	SF	8.1	27.6	27.7	0.1
NHC Dec15	SF	8.1	27.6	27.7	0.0
NHC Dec15	SF	8.1	27.6	27.7	0.0
NHC Dec15	SF	7.5	26.0	25.3	-0.7
NHC Dec15	SF	6.3	24.8	24.1	-0.7
NHC Logger	SF	6.0	23.8	22.8	-1.0
NHC Dec15	SF	5.7	23.2	22.4	-0.8
NHC Dec15	SF	5.0	21.5	20.8	-0.7
NHC Dec15	SF	4.8	21.4	20.6	-0.9
NHC Dec15	SF	4.6	20.4	19.7	-0.7
NHC Dec15	SF	3.2	16.7	15.5	-1.2
NHC Dec15	SF	3.2	16.6	15.5	-1.1
NHC Dec15	SF	3.2	16.5	15.5	-1.1
NHC Dec15	NF	6.4	24.5	26.2	1.6
NHC Dec15	NF	5.3	22.1	22.2	0.1
NHC Dec15	NF	5.3	22.1	22.2	0.1
NHC Logger	NF	5.2	22.3	22.2	-0.1
NHC Dec15	NF	3.0	17.2	17.1	0.0
NHC Dec15	NF	2.9	14.4	16.5	2.1
NHC Dec15	NF	2.9	14.7	16.5	1.8
NHC Dec15	NF	2.9	14.5	16.5	2.1
NHC Logger	NF	2.8	14.6	15.7	1.1

Table 4 November 1995 event: simulated and observed water surface elevations

Source	River ¹	Location (RM ²)	Location (RM ³)	HWM (ft, NAVD88)	Skagit GI (USACE, 2014)		2026 Project Model	
					Sim (ft, NAVD88)	Diff (ft)	Sim (ft, NAVD88)	Diff (ft)
USGS Gage	Skagit	54.1	54.1	175.3	171.8	-3.5	180.8	5.5
USACE	Skagit	52.95	53.0	166.6	165.8	-0.8	166.6	0.0
USACE	Skagit	47.55	47.0	142.5	136.2	-6.3	138.9	-3.6
USACE	Skagit	41.1	40.0	107.1	102.5	-4.5	105.0	-2.1
USACE	Skagit	33.3	33.0	75.7	74.4	-1.2	74.2	-1.4
USACE	Skagit	31.45	30.4	65.1	65.7	0.6	65.7	0.6
USACE	Skagit	24.7	24.9	54.6	54.1	-0.5	55.5	0.9
USACE	Skagit	22.4	22.5	50.0	46.2	-3.8	47.8	-2.1
L. Halverson	Skagit	22.3	22.5	45.7	46.2	0.5	48.1	2.5
L. Halverson	Skagit	21.93	20.8	45.1	45.3	0.2	46.4	1.4
L. Halverson	Skagit	21.6	20.2	45.2	45.2	0.0	46.3	1.1
L. Halverson	Skagit	18.57	17.4	43.8	43.3	-0.5	44.7	0.9
L. Halverson	Skagit	17.9	16.8	44.6	42.9	-1.7	44.3	-0.3
C. Bennett Photo	Skagit	17.54	16.3	41.7	42.1	0.4	43.3	1.6
L. Halverson	Skagit	17.53	16.3	43.0	42.1	-0.9	43.2	0.3
L. Halverson	Skagit	17.08	15.8	41.0	41.5	0.5	42.5	1.5
USGS Gage	Skagit	17.04	15.7	41.1	41.3	0.2	42.4	1.2

Notes:

1. Skagit (Mainstem Skagit), North Fork (NF), South Fork (SF).
2. River mile location based on the Skagit GI (USACE, 2014).
3. River mile location based on current USGS river mile data.



SUPPORTING DOCUMENTATION

TOPOBATHYMETRIC MOSAIC DEVELOPMENT

MEMORANDUM

MEMO

To:	Heather Spore, Swinomish Indian Tribal Community	Date:	August 11, 2026
From:	Kristin Kramer, PE (NHC) Madalyn Ohrt, GISP (NHC) Vaughn Collins, PE (NHC)	NHC Reference	2009212
Re:	Development of the Skagit River Topobathymetric Data Mosaic		

1 INTRODUCTION

This memorandum documents the development of the topobathymetric surface mosaic to support the new two-dimensional hydraulic model of the Skagit River for the Skagit River Flood Risk Modeling Project (Project). Northwest Hydraulic Consultants (NHC) was contracted by Swinomish Indian Tribal Community (SITC) to develop and calibrate the new hydraulic model. As part of this work, NHC mosaicked various LiDAR, bathymetric survey, and design datasets to create one comprehensive topobathymetric surface to be used in the hydraulic model. This memorandum describes the data sources used and the methods employed to mosaic the surface.

2 DATA SOURCES

The data sources used to create the comprehensive surface are shown in Figure 1. They comprise of data collected in the form of both topographic and topobathymetric LiDAR, bathymetric data, and design sources. Topographic LiDAR were collected via plane with near-infrared (NIR) laser and, in the case of the 2022 topobathymetric LiDAR collected by NV5 Geospatial (NV5), traditional NIR LiDAR was fully integrated with green wavelength return data in the channel to provide a seamless topobathymetric LiDAR dataset (except for void areas at the time of the flight as discussed in Section 2.1). Bathymetry within the river was compiled from several different data sources, including NHC, USGS, and USACE, as further described in Section 2.2.

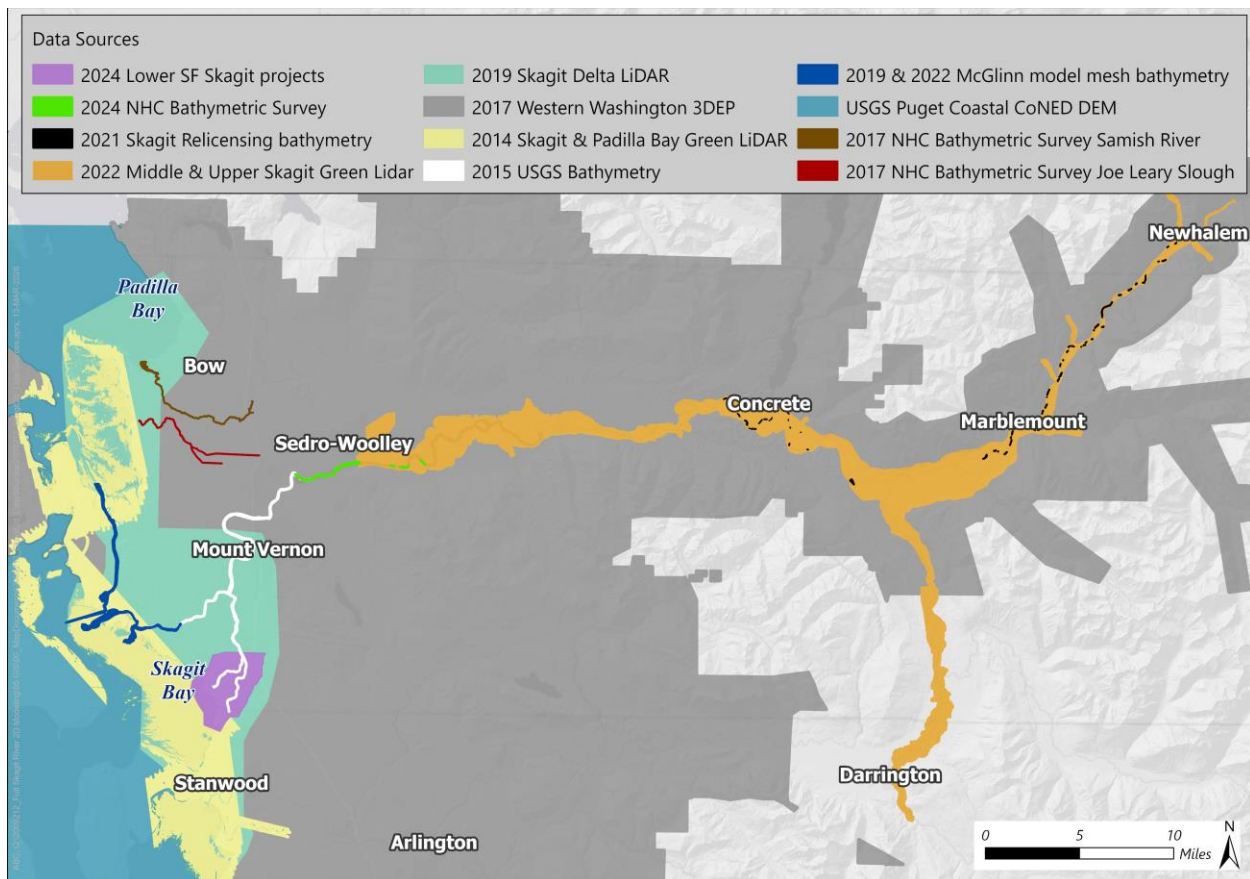


Figure 1 Data sources used to create the mosaicked surface

2.1 Topographic and Topobathymetric LiDAR

Most of the Skagit River floodplain upstream of Sedro-Woolley is covered by topobathymetric LiDAR collected by NV5 in 2022. However, voids exist in the topobathymetric surface because of limitations imposed by water depth, turbulent water, riparian vegetation, and other channel bed conditions. These voids were mapped in a spatial coverage delineating areas void of channel bottom data in the LiDAR sources to better understand the extent of supplemental bathymetric survey to be collected, as discussed in Section 2.1.1.

From Sedro-Woolley to the bay, a majority of topographic LiDAR was applied from 2017 and 2019 sources, with some topobathymetric LiDAR from 2014 providing coverage in Skagit Bay and Padilla Bay. Because a majority of these sources were topographic LiDAR, bathymetric survey was applied to define the riverbed, as discussed in Section 2.2.

2.1.1 Void Filling

Single beam boat surveys conducted by NHC in 2021 and 2024 were used to fill the voids within the NV5 topobathymetric LiDAR. These data were only used to fill void areas within the LiDAR, even if bathymetric data existed beyond the voids. In areas where interpolation occurred between the NHC data and other nearby data points, breaklines were drawn by NHC to produce an adequate merge for use in the hydraulic model. An example of the process is shown in Figure 2. Note that this figure shows two parallel data feeds (black dots in the figure) collected from two different sounders by NHC—one with such tight data spacing that it appears as nearly a solid black line. Not all the void areas in the NV5 topobathymetric data were surveyed by NHC. In these cases, these were smaller void areas which were filled using interpolation between the surrounding LiDAR data.

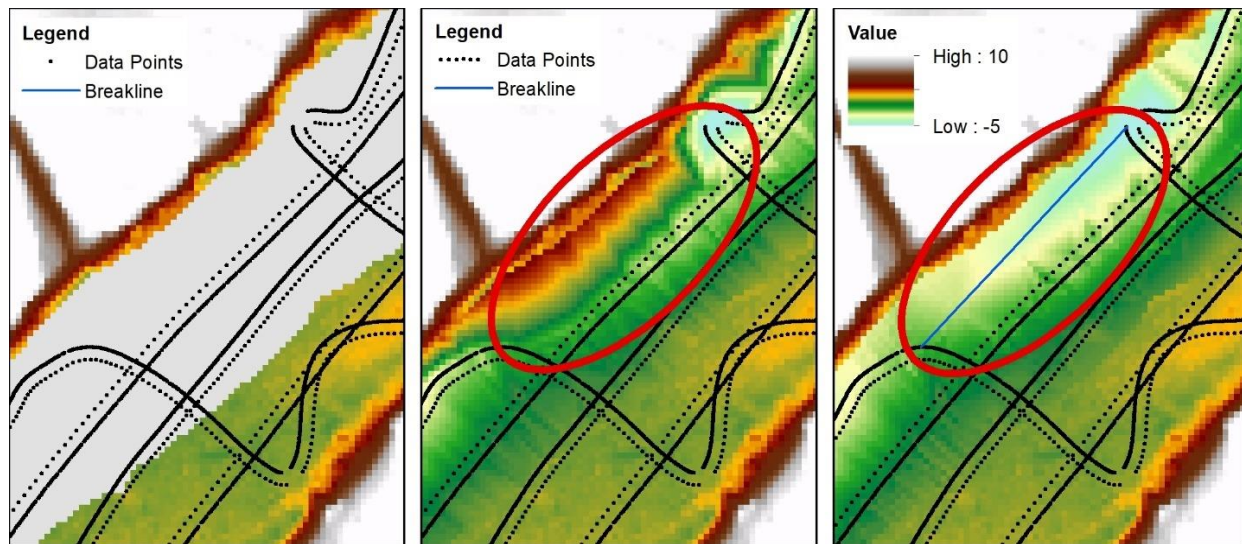


Figure 2 Example void area (left), void area filled with survey data and no breakline (middle), and void area filled with survey data and breakline (right)

2.2 Bathymetric Survey

Bathymetric surveys were initially compiled from available sources from NHC, USGS and USACE from survey dates in 2014, 2015, 2019, and 2022. No recent bathymetry was available near Sedro-Woolley; therefore, during the Project, NHC collected boat-based bathymetric data in 2024 using a single-beam approach to cover this reach, shown in green in Figure 1.

2.3 Design Surfaces

During the Project, NHC obtained data from WDFW covering recently constructed and planned projects along the lower South Fork, including Wiley Slough Dike Raise (constructed), Milltown Island Estuary Restoration (constructed), and Island Unit Estuary Restoration (planned to be constructed in 2027).

3 COMPLETED TOPOBATHYMETRIC MOSAIC PRODUCT AND SOURCE DATA

The completed mosaicked surface has a spatial reference of WA State Plane North HARN feet, a vertical datum of NAVD88 feet and a resolution of three feet. The sources used and described in this memorandum are summarized in Table 2. These data were mosaicked in the order in which they appear in Table 2, with the higher priority dataset overlaying the lower priority datasets in areas where there was overlap.

Table 2 Data sources used to create the topobathymetric surface

Dataset	Year	Contracted by	Source	Type
Lower SF Skagit projects ¹	2024-2027	WDFW	HDR	Design surfaces ¹
NHC Bathymetric survey	2024	SITC	NHC	Bathymetric survey
Middle Skagit Green LiDAR	2022	SRSC	NV5	Green LiDAR
Upper Skagit Green LiDAR	2022	HDR	NV5	Green LiDAR
Skagit Relicensing bathymetry	2021	HDR	NHC	Bathymetric survey
Joe Leary Slough bathymetry	2017	Skagit County	NHC	Bathymetric survey
Samish River bathymetry	2017	Skagit County	NHC	Bathymetric survey
McGlinn model mesh bathymetry	2019, 2022	USACE	USACE	McGlinn Island Jetty Project ADH model mesh, derived from bathymetric survey
Skagit & Padilla Bay Green LiDAR	2014	USACE	USACE	Green LiDAR
Skagit Delta LiDAR	2019	NOAA	Tetra Tech	Standard LiDAR collected during low tide

Dataset	Year	Contracted by	Source	Type
USGS bathymetry	2015	USGS	USGS	Bathymetric survey
Western Washington 3DEP	2017	USGS	Quantum Spatial	Standard LiDAR
Puget Coastal CoNED DEM	2017	USGS	NOAA	Coastal DEM

Notes:

1. The Lower SF Skagit projects include Wiley Slough Dike Raise (constructed), Milltown Island Estuary Restoration (constructed), and Island Unit Estuary Restoration (planned to be constructed in 2027).

4 LIMITATIONS

This mosaicked surface was developed to be used for watershed scale analysis and hydraulic modeling at the concept level, not for detailed design. More detailed topographic and bathymetric data may be necessary for other purposes. This section provides information on some of the limitations of the completed topobathymetric surface.

4.1 Discrepancies Along Merge Line

The mosaicking process used ensures the more recent dataset takes priority over data from previous years. However, this approach does not always create a smooth transition between datasets, as shown in Figure 3 along the Skagit Bay tidal flats. Though the resulting discrepancies along the tidal flats in this area would not have a significant impact in extreme riverine or coastal flooding simulated by the model. Reasons for the differences may include systematic bias in one of the datasets, construction and grading of the land, better determination of bare earth in densely vegetated areas by one of the LiDAR platforms, or the ability of the new LiDAR to penetrate water and maps features such as flooded fields more accurately.

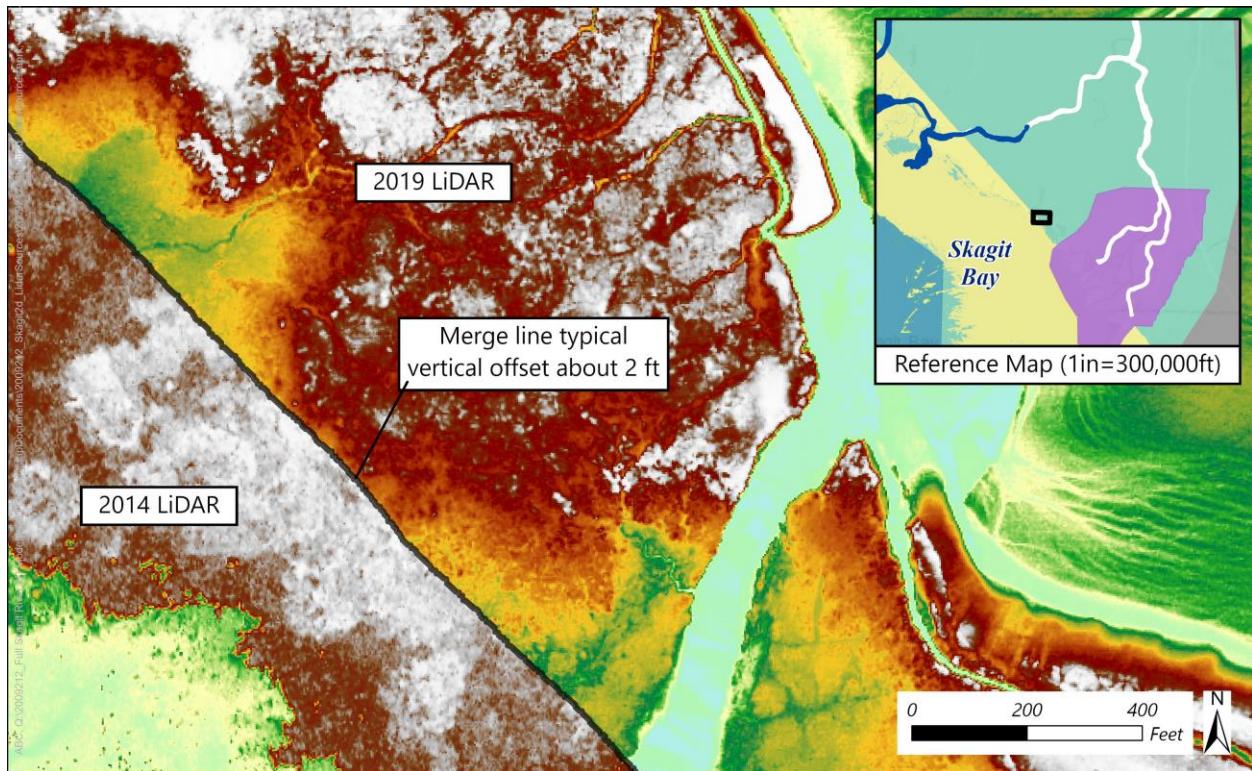


Figure 3 Example of discrepancy between the 2014 Skagit & Padilla Bay Green LiDAR and the 2019 Skagit Delta LiDAR in Skagit Bay

4.2 Discrepancies Within Source Data

Some of the discrepancies are found within the source layers themselves and are not a result of the merging of datasets. As shown in Figure 4, an artifact is found in the 2014 LiDAR south of Skagit Bay in Port Susan. In addition, Figure 5 identifies an area within the ADH Model mesh from the McGlinn Jetty project, derived from 2022 bathymetric survey, where bathymetric data may be missing. However, these issues were determined to not adversely affect hydraulic model results.

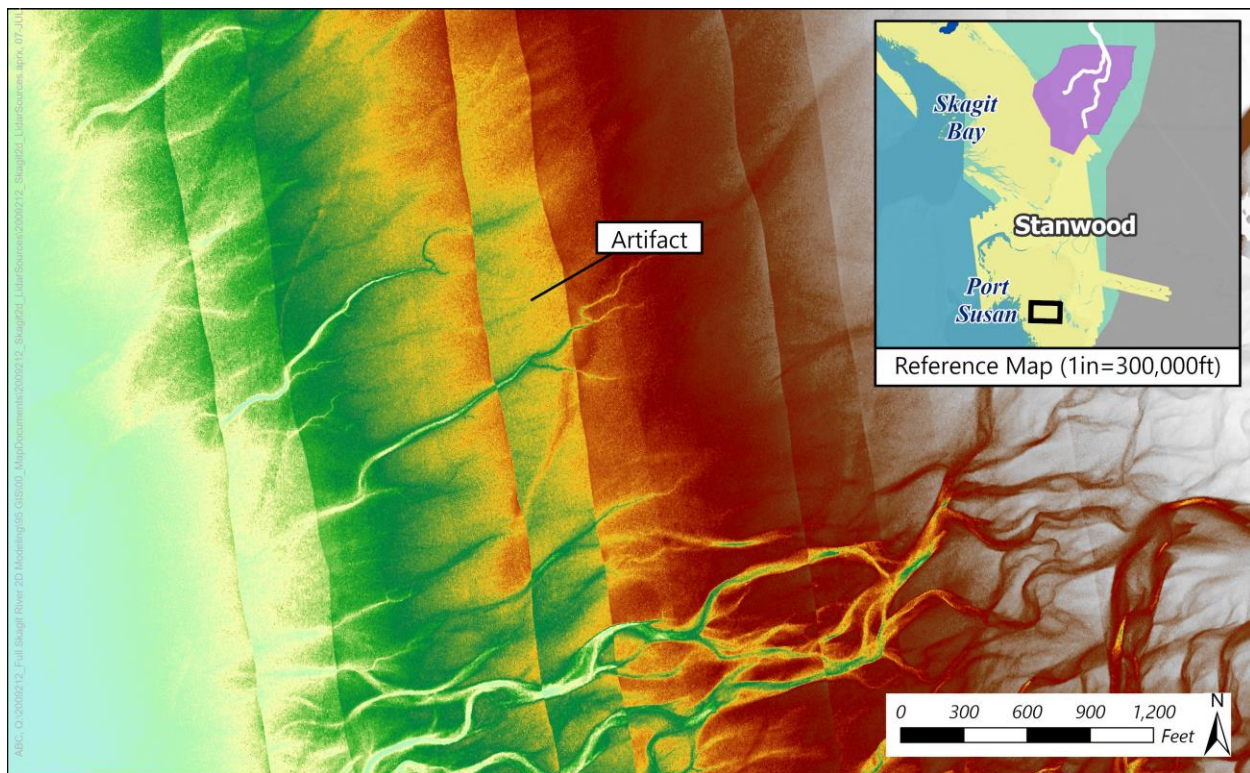


Figure 4 **Artifact found in the 2014 Skagit & Padilla Bay Green LiDAR south of Skagit Bay**

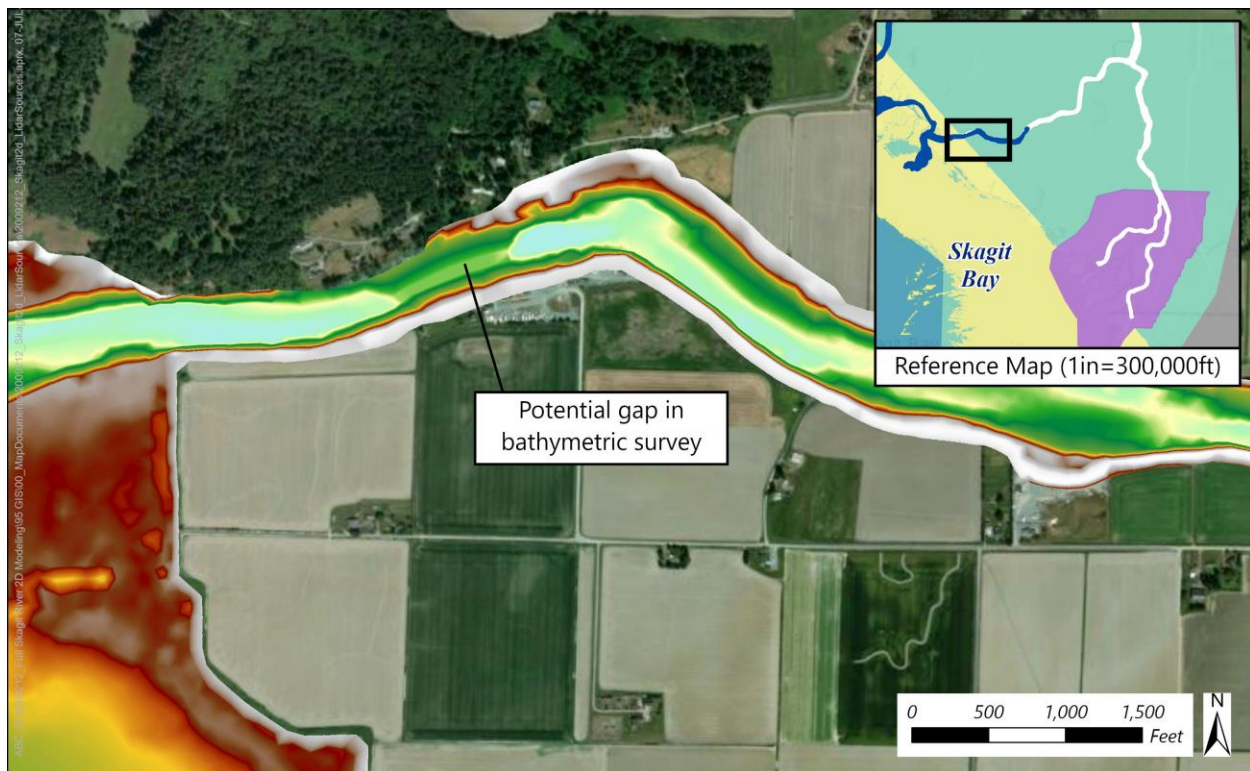


Figure 5 ADH model mesh along the lower North Fork near Blakes's Marina and Fish Town

5 REFERENCES

- NV5 (2022). Middle Skagit River, Washington 2022 Topobathymetric Lidar Technical Data Report.
- NV5 (2022). Skagit River, Washington 2022 Topobathymetric Lidar Technical Data Report.
- OCM Partners. 1887 - 2017 USGS CoNED Topobathy DEM (Compiled 2020): Puget Sound, WA. <https://www.fisheries.noaa.gov/inport/item/59971>.
- Tetra Tech, Inc. (2020). WA Topographic Elevation Data, Skagit and Snohomish Counties, Project Report.
- Quantum Spatial (2017). Western Washington 3DEP LiDAR Technical Data Report.

Appendix B:

Maps

Table of Contents

What Is Included in This Appendix	124	Coastal Flooding Maps	188
Disclaimer	125	How to Read Coastal Flooding Maps	189
Skagit River System Overview	126	Overview Map	190
Upriver Flooding Maps	127	La Conner	191
How to Read Upriver Flooding Maps	128	Padilla and Samish Bays	195
Overview Map	129	Skagit Bay	199
Marblemount	130	Dike Failure Scenarios	203
Rockport	135	How to Read Dike Failure Scenario Maps	204
Concrete	140	Overview Map	205
Lyman and Hamilton	145	Failure Locations (from USACE-GI)	206
Sedro-Woolley	150	Lafayette Road	207
Lower River Flooding Maps	155	Above BNSF Bridge	209
How to Read Lower River Flooding Maps	156	Below I-5 Bridge	211
Overview Map	157	Above Division Bridge	213
Burlington	158	Below Mount Vernon Flood Wall	215
Mount Vernon	163	NF Fir Island	217
Conway	168	References	219
La Conner	173		
Padilla and Samish Bays	178		
Skagit Bay	183		

What Is Included in This Appendix

This appendix contains map bundles for Upriver Flooding (Marblemount to Sedro-Woolley), Lower River Flooding (Sedro-Woolley to Skagit, Padilla and Samish bays), Coastal Flooding, and Dike Failure Scenarios.

Each of these map bundles has a map showing results for the entire map bundle area and then more zoomed in maps for key population centers. Maps include: flood depths, flood hazard (depth and velocity), and duration. For dike failure scenarios, a depth difference map is also included.

FLOOD FREQUENCIES

Floods are described in terms of “flood frequencies”; in this report we provide results for the 10-, 25-, 100- year events. As described in the report, this terminology can be confusing because it makes it sound like a flood event will only happen once in a given timeframe. In fact, the “10-year event” is a shorthand way to describe a flood event that has a 10% probability (or 1 in 10 chance) of occurring in any given year. Similarly, a 25-year event has a 4% chance of occurring in any given year, and a 100-year flood event has a 1% chance of occurring in any given year.

CLIMATE CHANGE

Climate change is projected to result in larger and more frequent floods. For example, models project that today’s 1% annual chance event will become about a 4–5% chance event by midcentury. To help the reader understand how flood risk is changing, this report uses the common terminology of 10-, 25-, and 100-year flood frequencies combined with different timeframes: historic, 2040s and 2080s.

FLOOD DEPTH MAPS

Flood depth maps show the depth and extent of flooding for specific locations and events.

DEPTH-VELOCITY HAZARD MAPS

Depth-velocity hazard maps show the danger posed by flood waters. Based on both water depth and velocity, the maps show the likely risk for children, adults, vehicles, and structures. These maps do not include secondary hazards such as erosion, avulsion, landslides or debris flows.

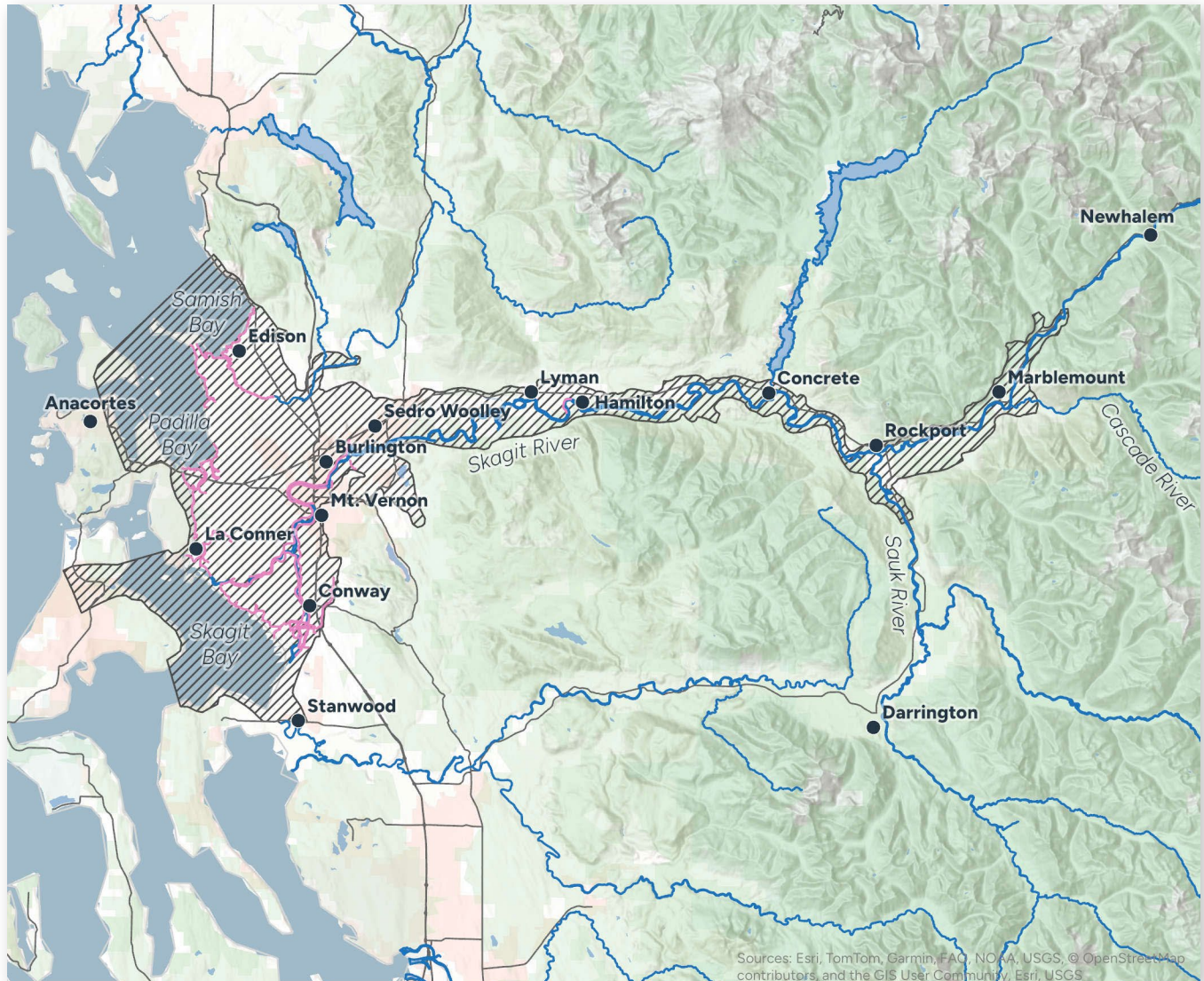
DURATION MAPS

Duration maps show the amount of time a location is flooded. This can be important for understanding the impacts on buildings, roads, dikes, emergency response, livestock, and many other important aspects of flood risk.

Disclaimer

These maps are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, dike failures, events that are larger than those modeled, or other factors. Maps should be used at your own risk. A reference section at the end contains data sources for map products.

Skagit River System Overview

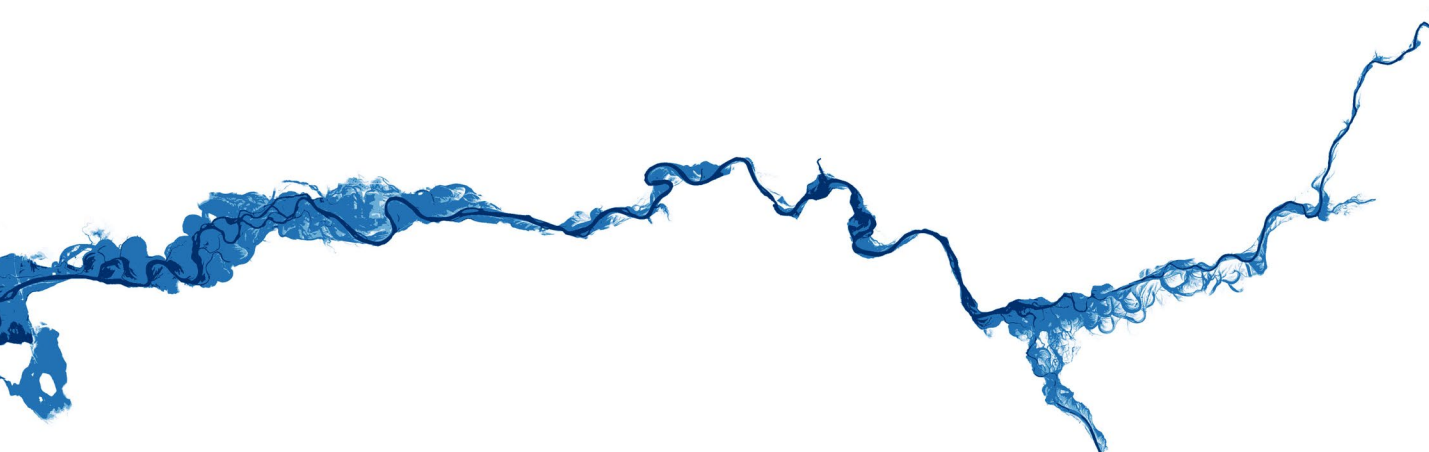


Hydraulic Model Domain

Maps included in [Appendix B](#) are products of the 2-D hydraulic model described in [Appendix A](#). This map shows the model domain. The hatching shows that the model extends into Skagit, Padilla and Samish Bays in order to simulate coastal flooding. Water flowing into the model domain during flood events – from the Baker River, Upper Skagit River, Sauk River, and many smaller tributaries – are all included, even though the hydraulic model simulations are confined to the Skagit River floodplains.

- Cities
- Major Roads
- Rivers
- Dike or Coastal Dike
- ▨ 2D Model Domain

0 2.5 5 10 Miles



Upriver Flooding Maps

This map bundle shows Skagit River flood model results for areas just upstream of Marblemount downstream to Sedro-Woolley.

This set includes an overview map of the area and zoomed-in map areas for Marblemount, Concrete, Rockport, Hamilton, Lyman, and Sedro-Woolley and the unincorporated communities of Corkindale, Rockport, Van Horn, and Cape Horn. Full context for these maps can be found in the full *Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities* report and specific details on the hydraulic model that created these maps can be found in [Appendix A](#). Flood animations for select locations can be found at the Skagit Climate Science Consortium website.

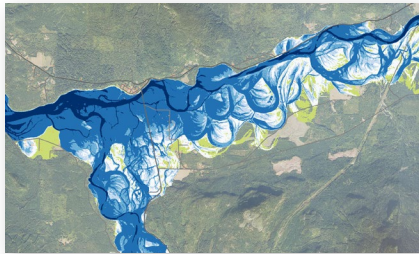
These maps are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, dike failures, larger-than-modeled events, or other factors. Maps should be used at your own risk.

How to Read Upriver Flooding Maps

What These Maps Show

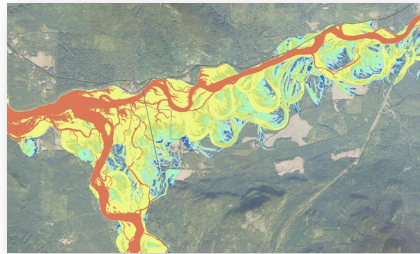
For all maps, the background is based on an aerial image (USDA 2023) and structures are shown as orange rectangles (Microsoft 2022). Pink lines, if present, show dike locations (Skagit County 2022), and dark gray lines show major transportation routes (WSDOT 2008, Skagit County 2019). The river channel itself may change colors depending on the map, but is the darkest shading in all maps.

FLOOD DEPTH MAPS



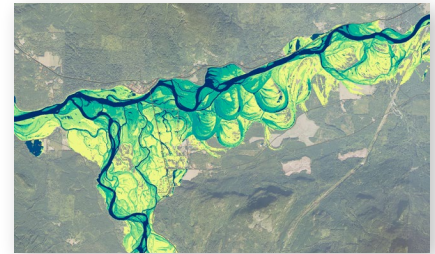
These maps are organized into sets of three, showing results for Historic (top), 2040s (middle), and 2080s (bottom) flood magnitudes. Each set of maps shows the model results for a specific flood frequency: 10-year, 25-year, and 100-year. Maps show the depth of flooding in shades of blue, where darker blue indicates deeper water and lighter blue indicates shallower water. In order to see how flooding is projected to change in the future, the Historic and 2040s maps also show the estimated extent of the 2080s flood in bright green. There is no bright green shading for the 2080s map because the map is already showing the depth and extent of the 2080s flood. All three maps are at the same scale.

DEPTH-VELOCITY HAZARD MAPS



These maps show depth-velocity hazards for a historic 100-year event. Only the historic results are shown; maps for the 2040s or 2080s are not included. The hazard classifications shown in the key were assigned based on a standard international practice (AIDR, 2017) and grouped into six hazard ratings. The hazard mapping is based on clearwater hazards and does not account for secondary hazards such as shoreline and fluvial geomorphic hazards (e.g., erosion, avulsion, debris flows, alluvial fan, etc.). Colors show when water poses a risk to children, adults, vehicles, and structures due to depth, velocity, or a combination of the two.

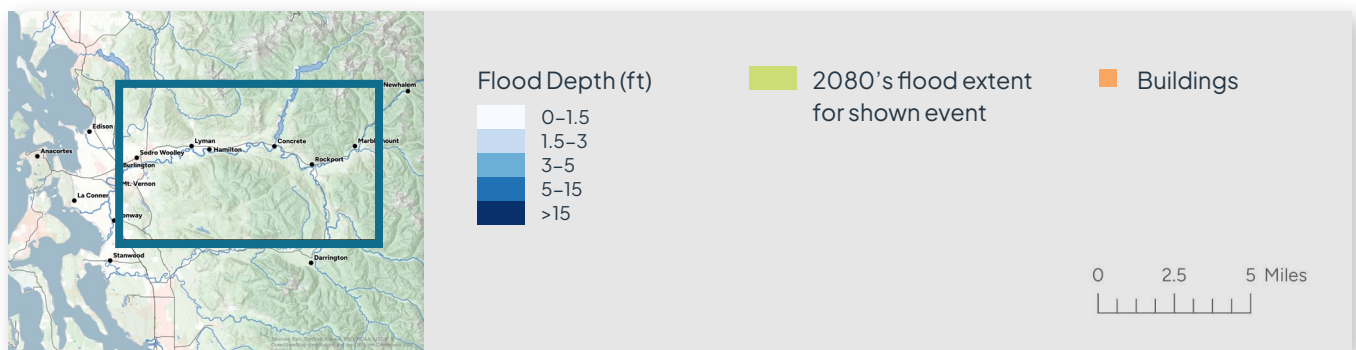
DURATION MAPS



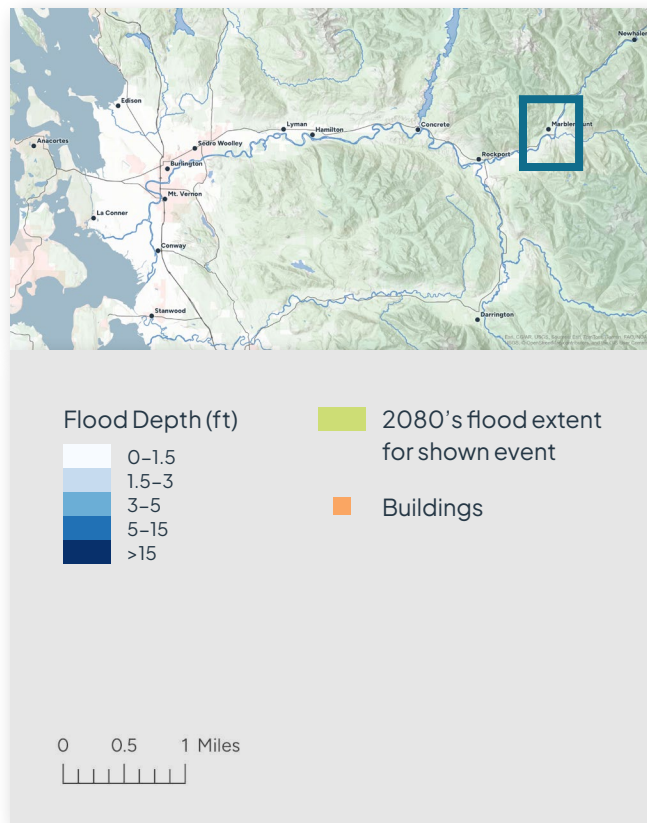
These maps show the amount of time, in days, that each location is inundated during a historic 100-year flood event and do not include flows estimated for the 2040s or 2080s. Duration is shown in shades ranging from dark blue to yellow, with darker shading indicating a longer duration, and lighter shading indicating a shorter duration of flooding.

UPRIVER FLOODING MAPS

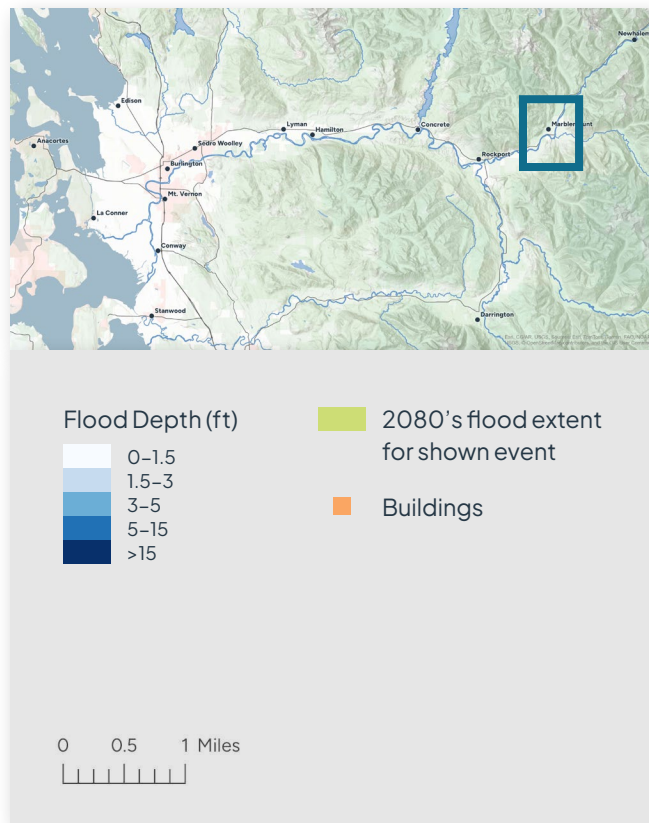
Overview Map



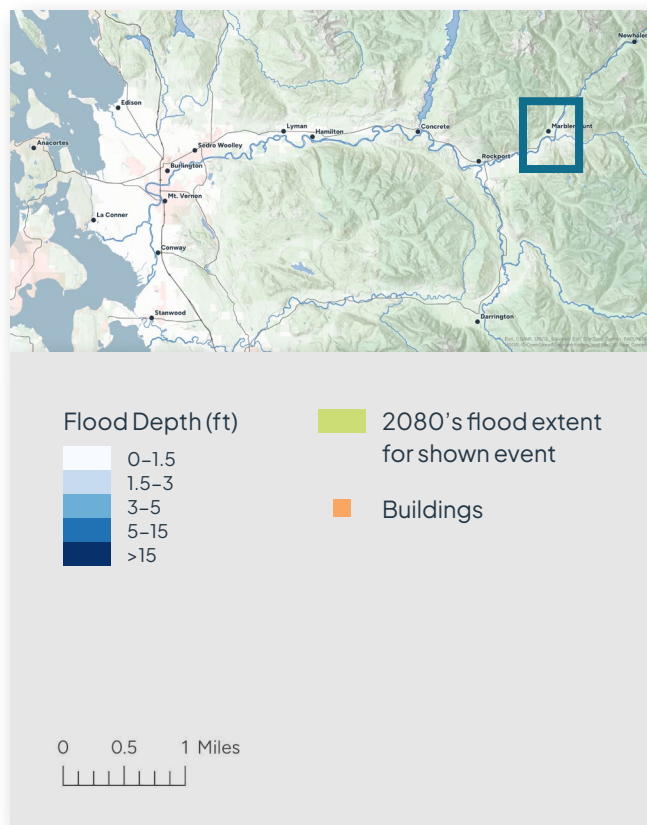
Marblemount | 10 Year Flood



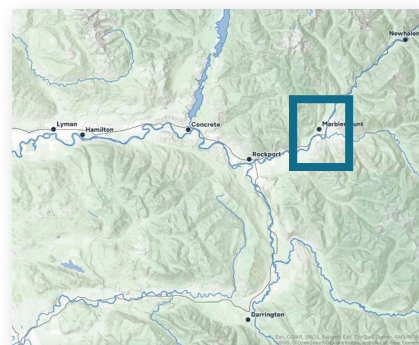
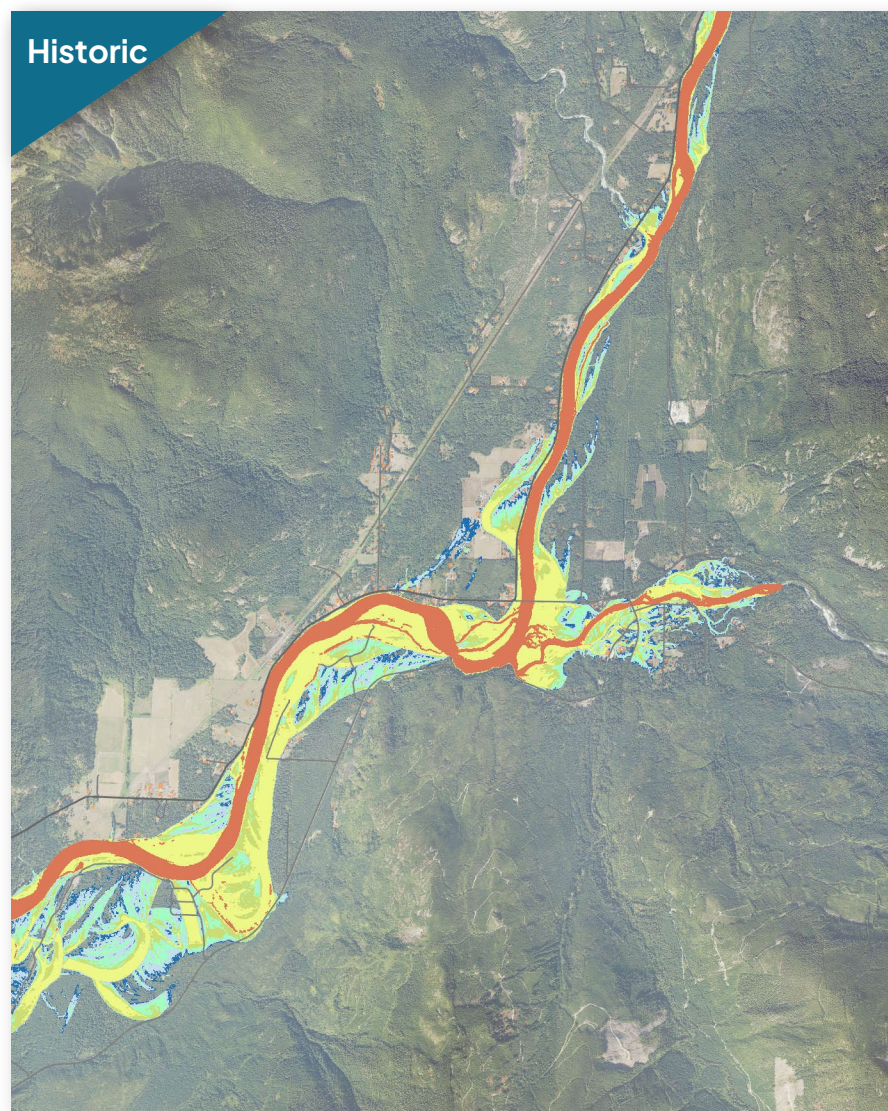
Marblemount | 25 Year Flood



Marblemount | 100 Year Flood



Marblemount | Depth-Velocity Hazard

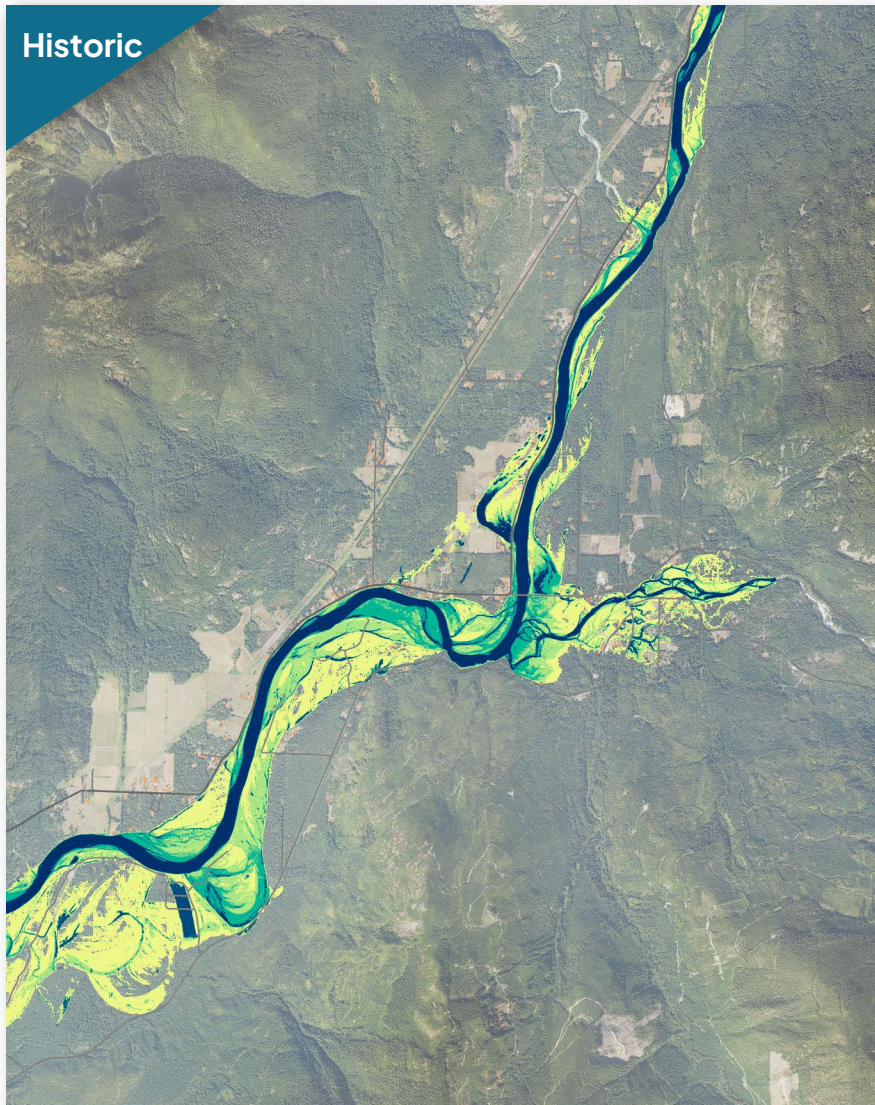


Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

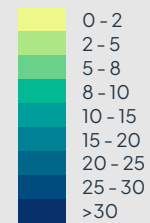
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings

0 0.5 1 Miles

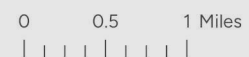
Marblemount | Duration



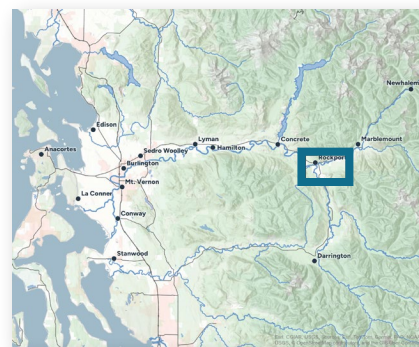
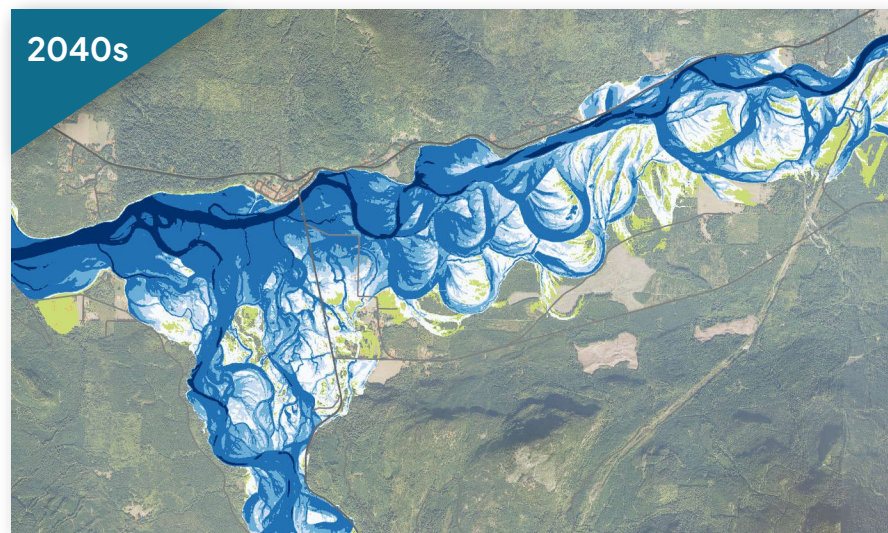
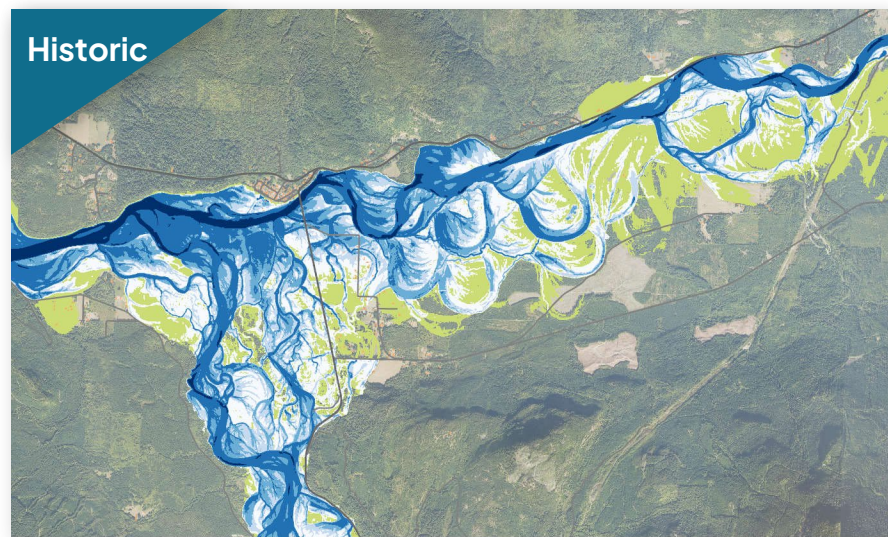
Duration (days)



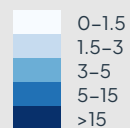
■ Buildings



Rockport | 10 Year Flood



Flood Depth (ft)

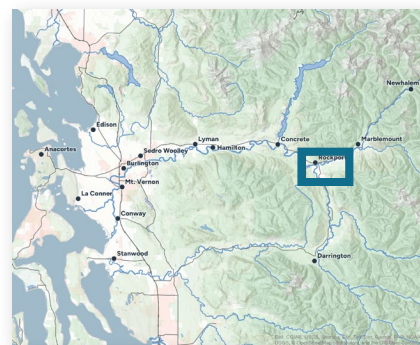
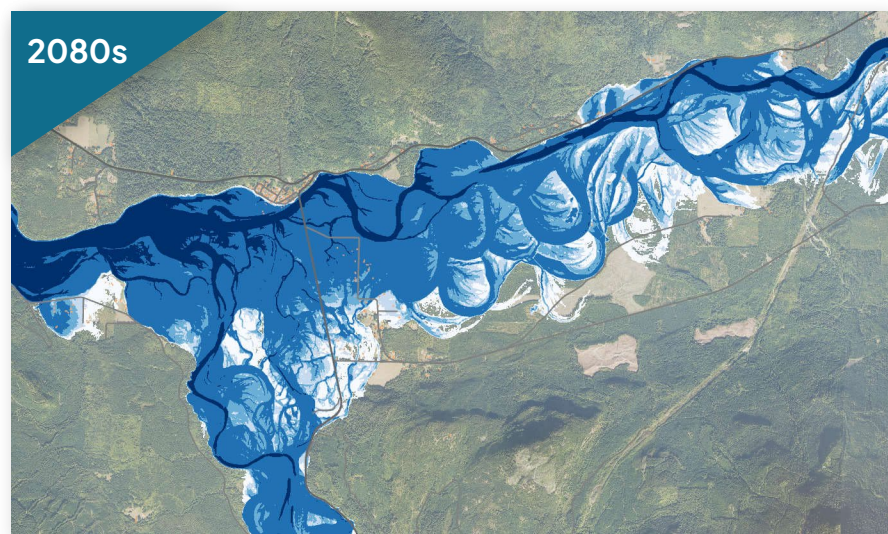
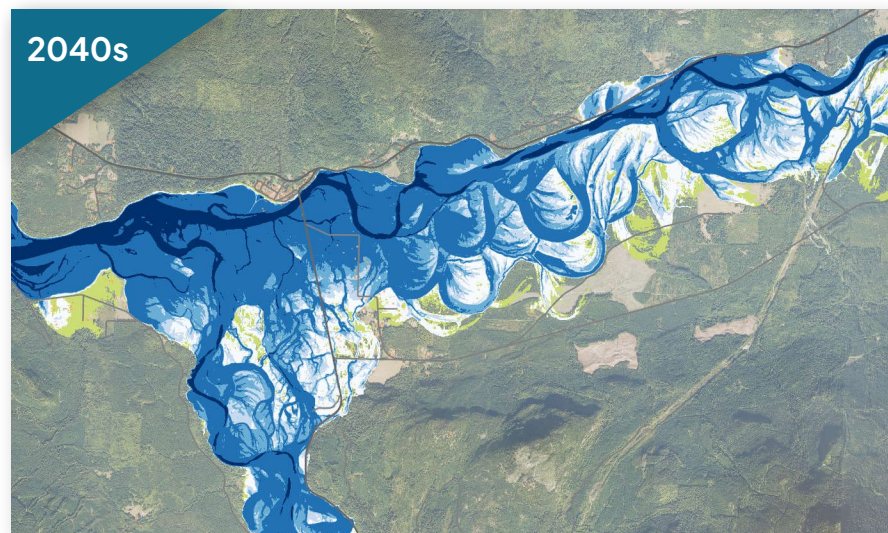


■ 2080's flood extent for shown event

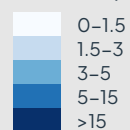
■ Buildings



Rockport | 25 Year Flood



Flood Depth (ft)

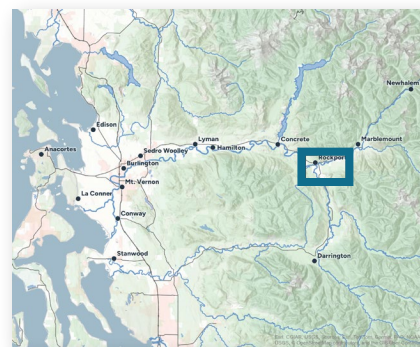
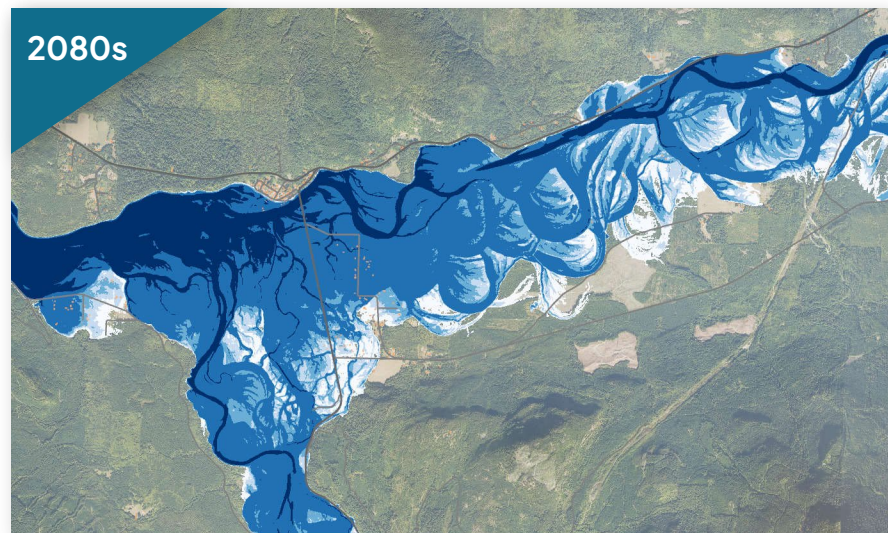
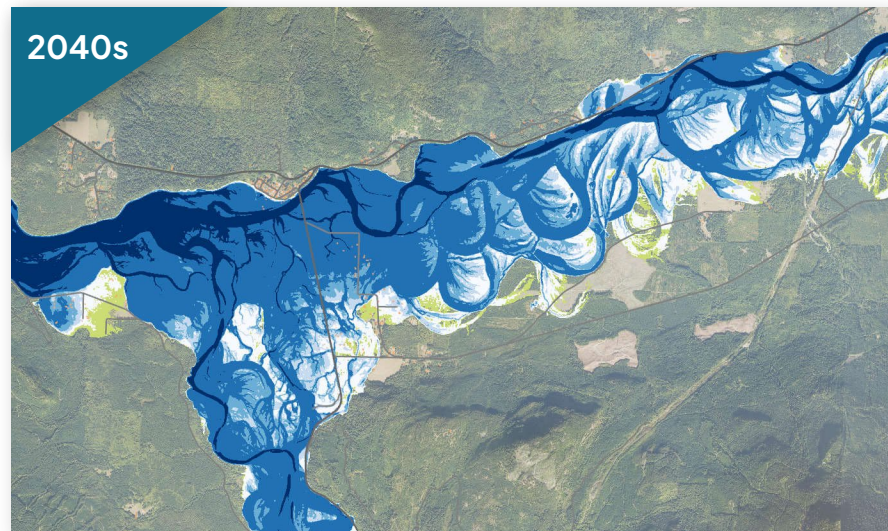


■ 2080's flood extent for shown event

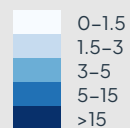
■ Buildings



Rockport | 100 Year Flood



Flood Depth (ft)

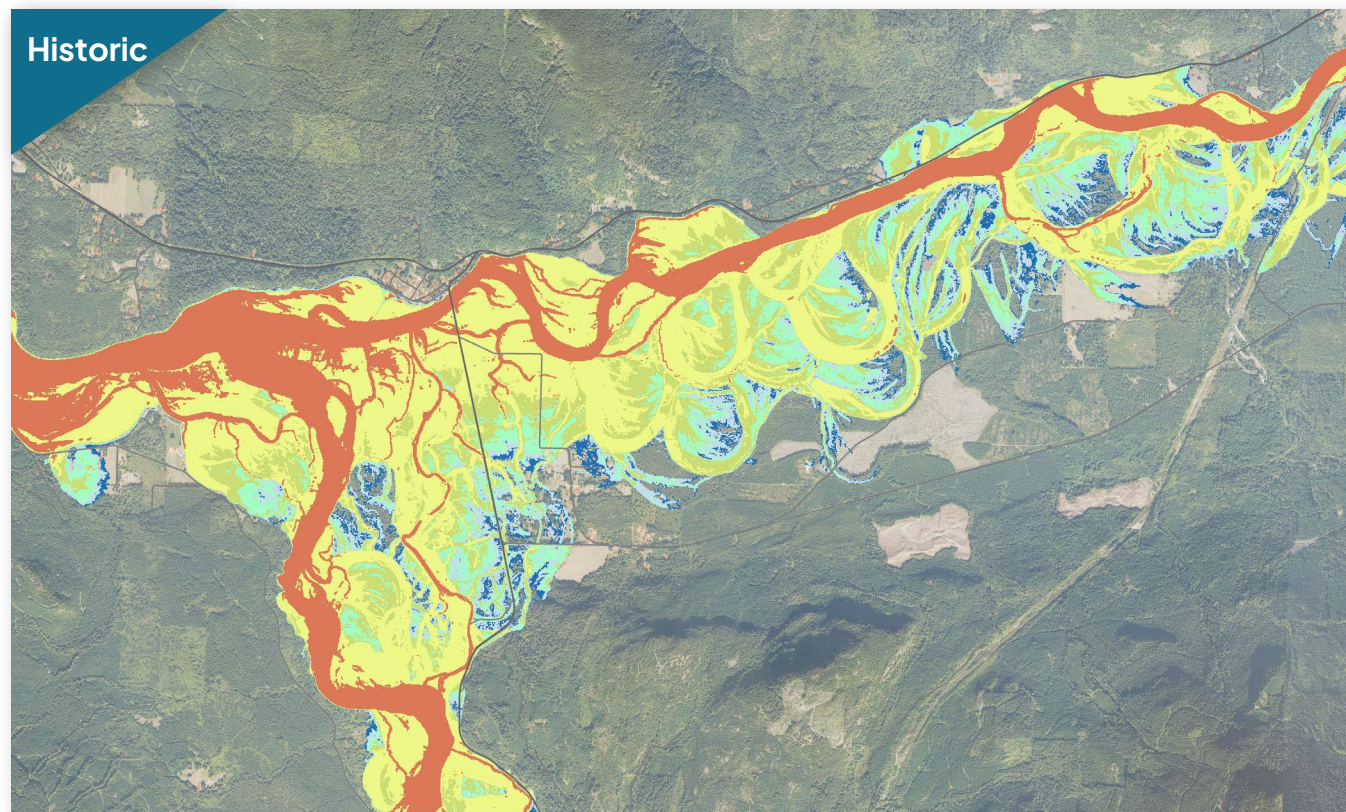


■ 2080's flood extent for shown event

■ Buildings



Rockport | Depth-Velocity Hazard



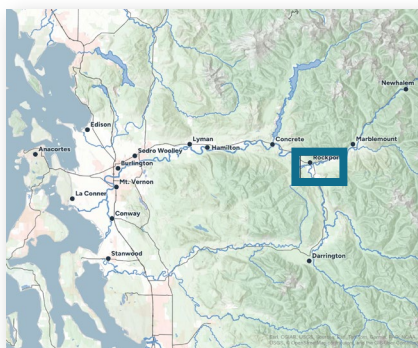
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.

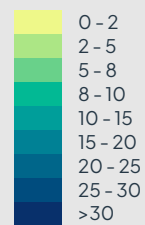
■ Buildings

0 0.5 1 Miles

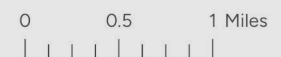
Rockport | Duration



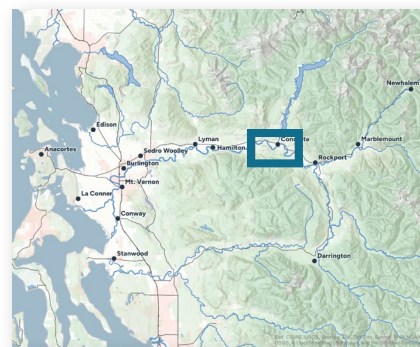
Duration (days)



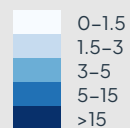
Buildings



Concrete | 10 Year Flood



Flood Depth (ft)

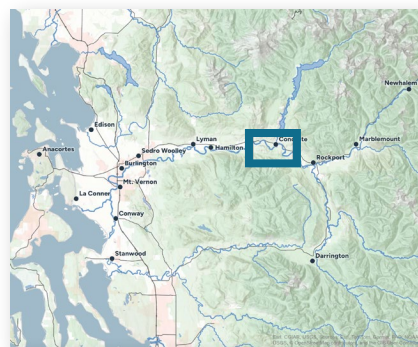
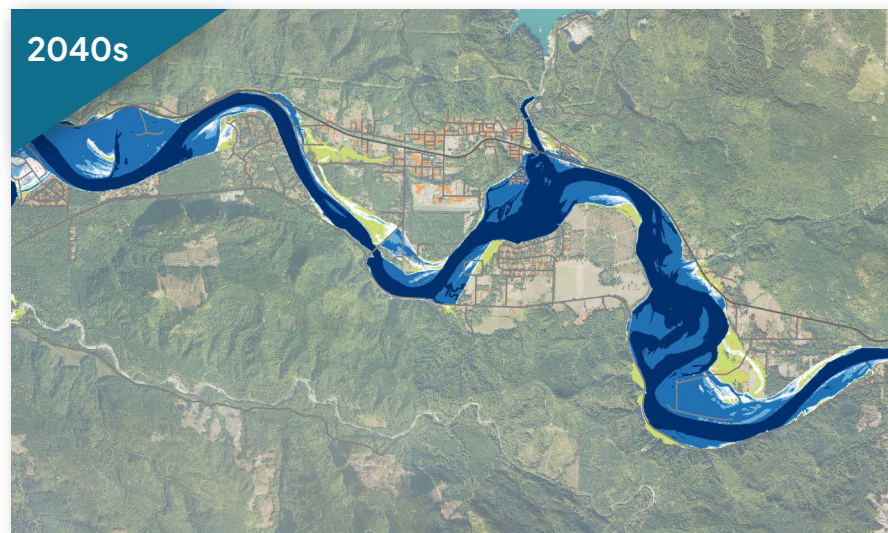


■ 2080's flood extent for shown event

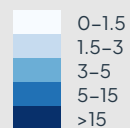
■ Buildings



Concrete | 25 Year Flood



Flood Depth (ft)

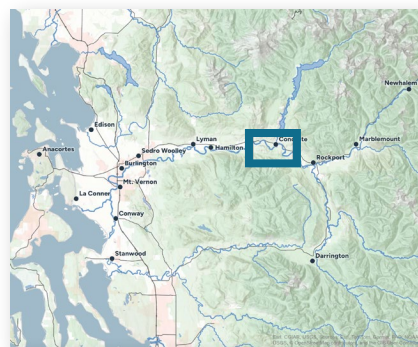


■ 2080's flood extent for shown event

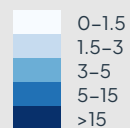
■ Buildings



Concrete | 100 Year Flood

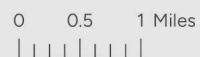


Flood Depth (ft)

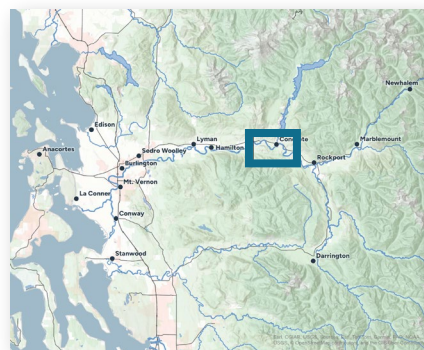
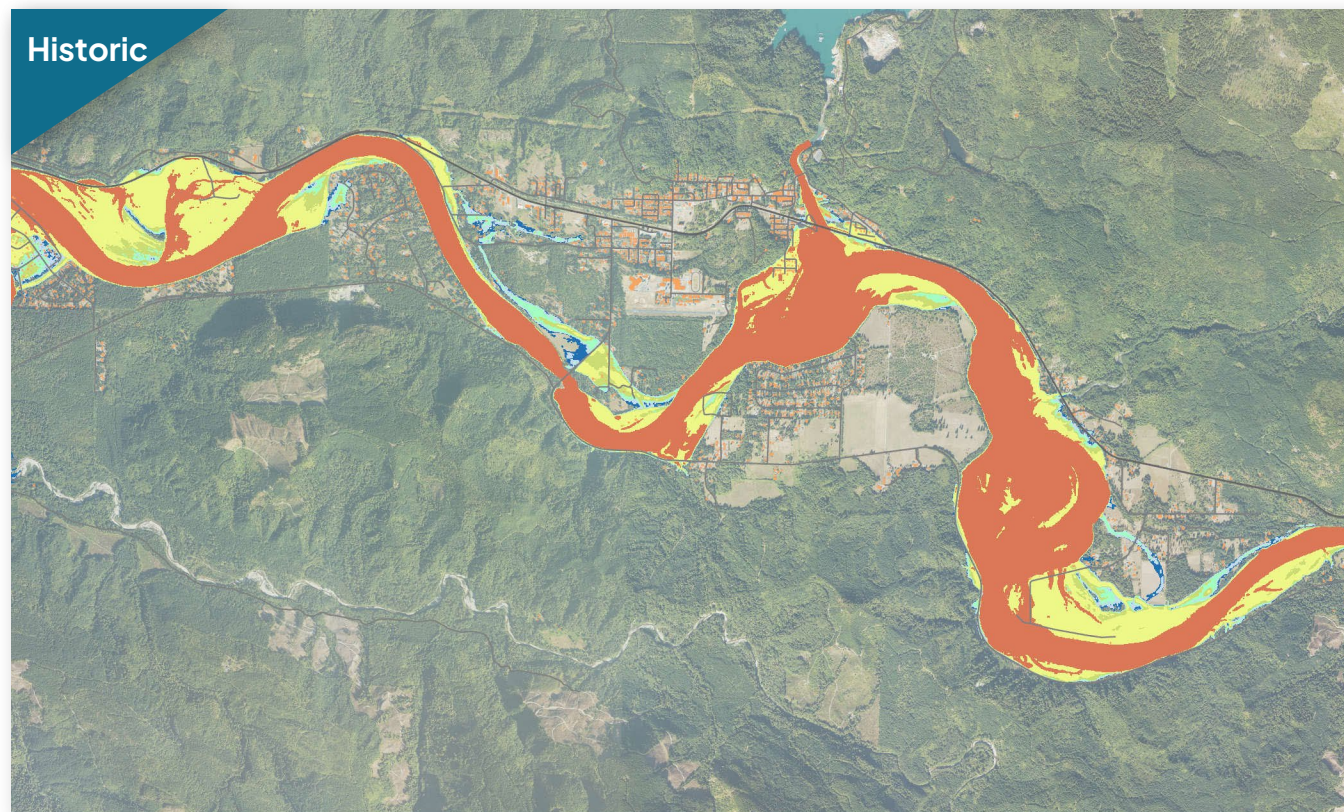


■ 2080's flood extent for shown event

■ Buildings



Concrete | Depth-Velocity Hazard



Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

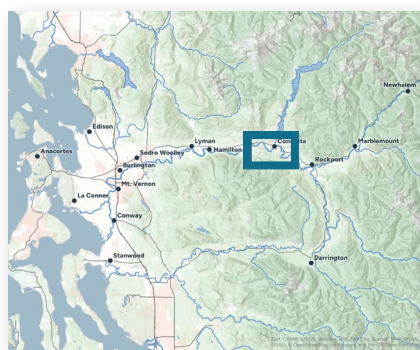
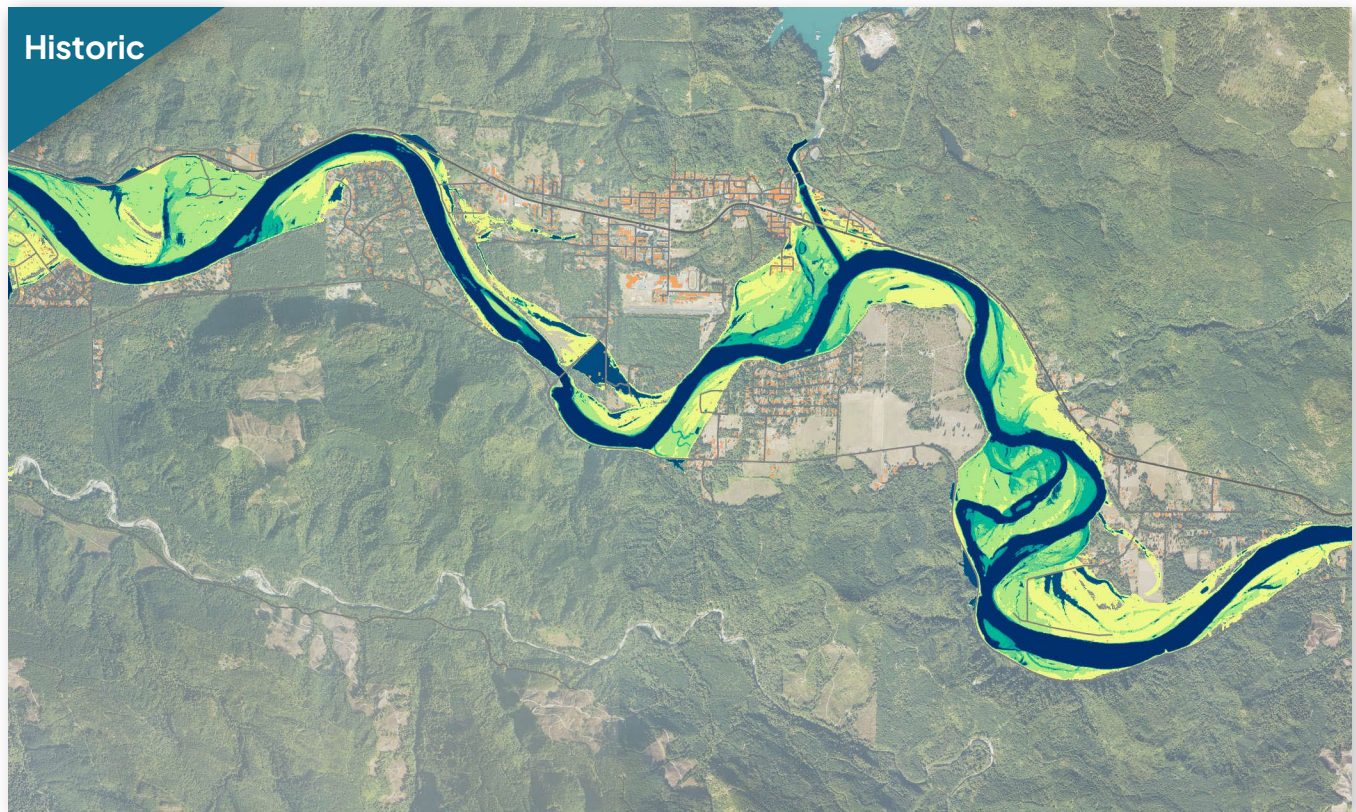
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.

■ Buildings

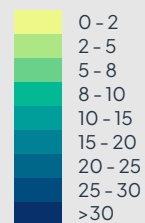
0 0.5 1 Miles

UPRIVER FLOODING MAPS

Concrete | Duration



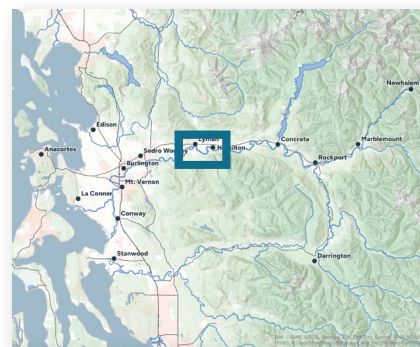
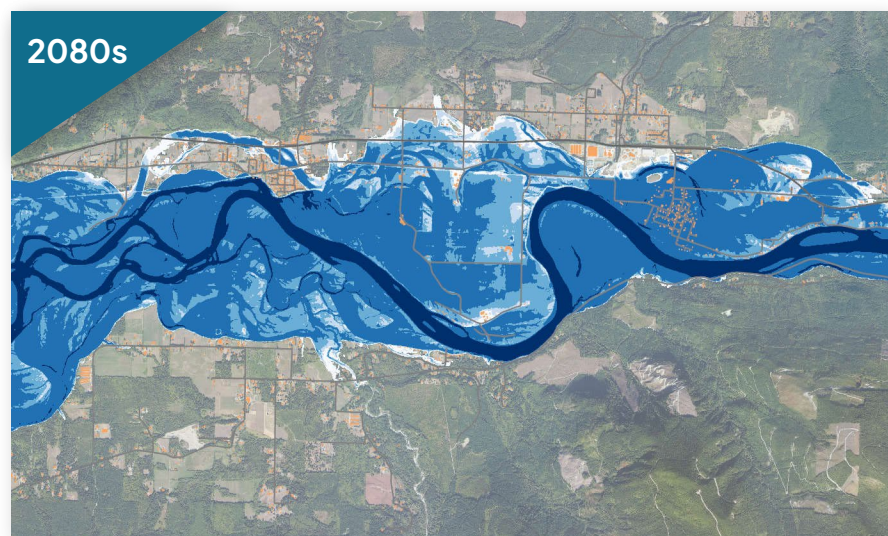
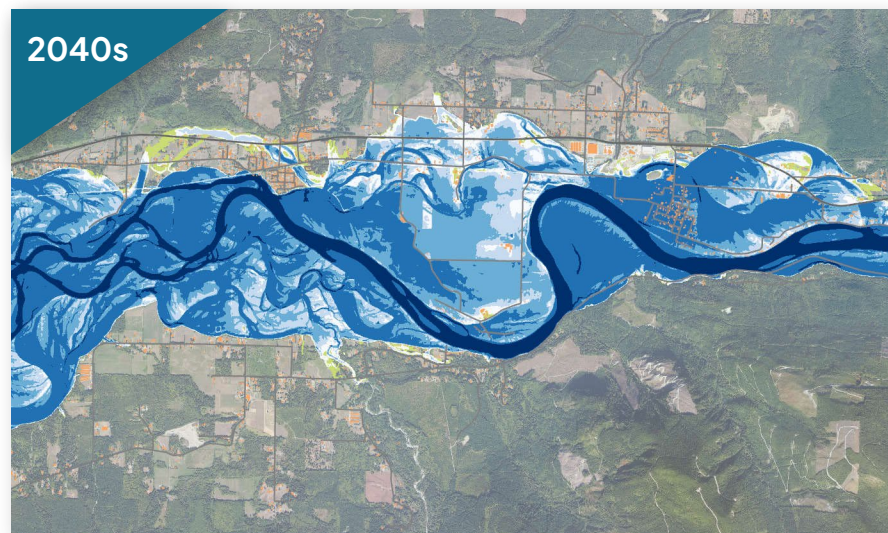
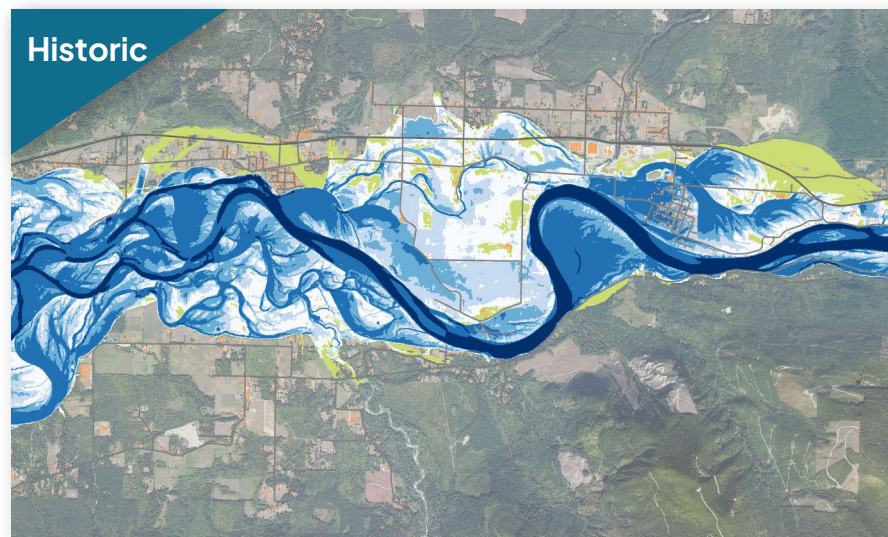
Duration (days)



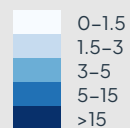
■ Buildings



Lyman and Hamilton | 10 Year Flood



Flood Depth (ft)

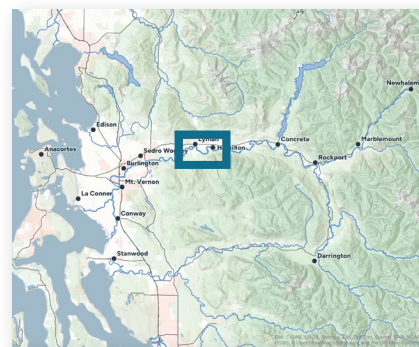
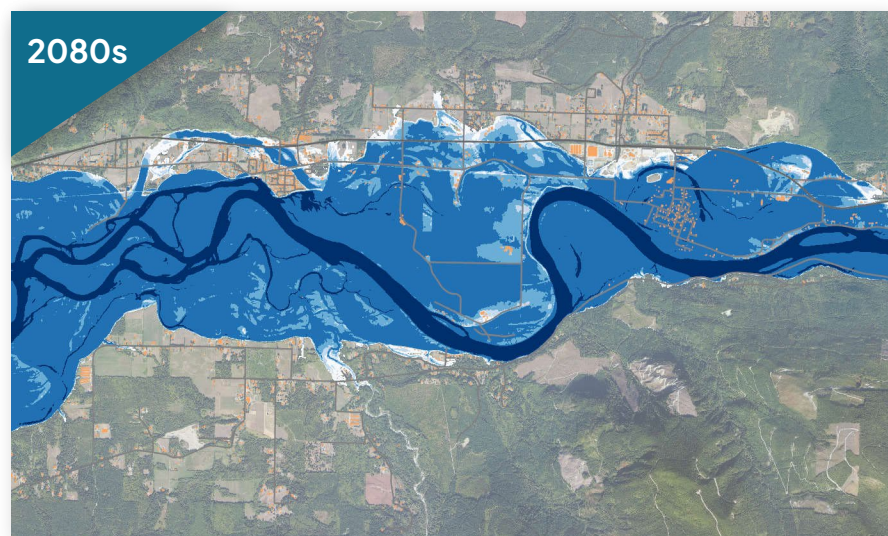
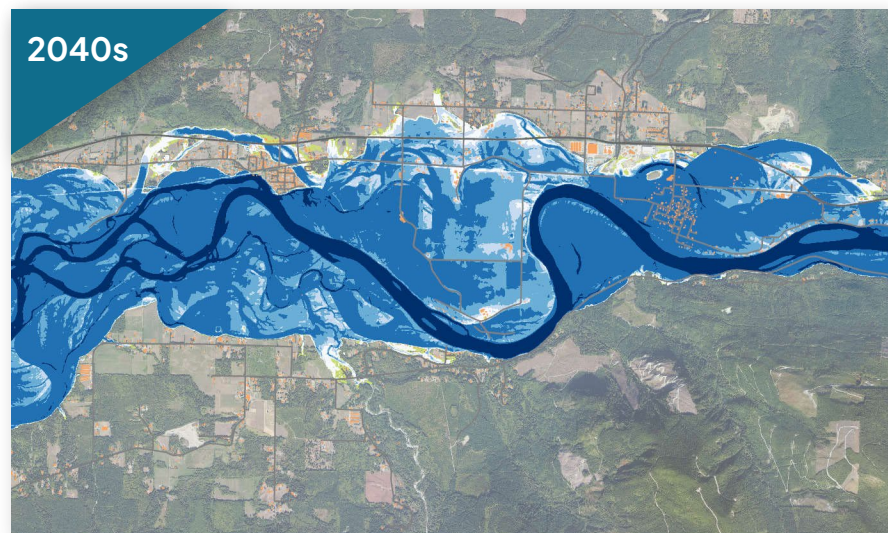
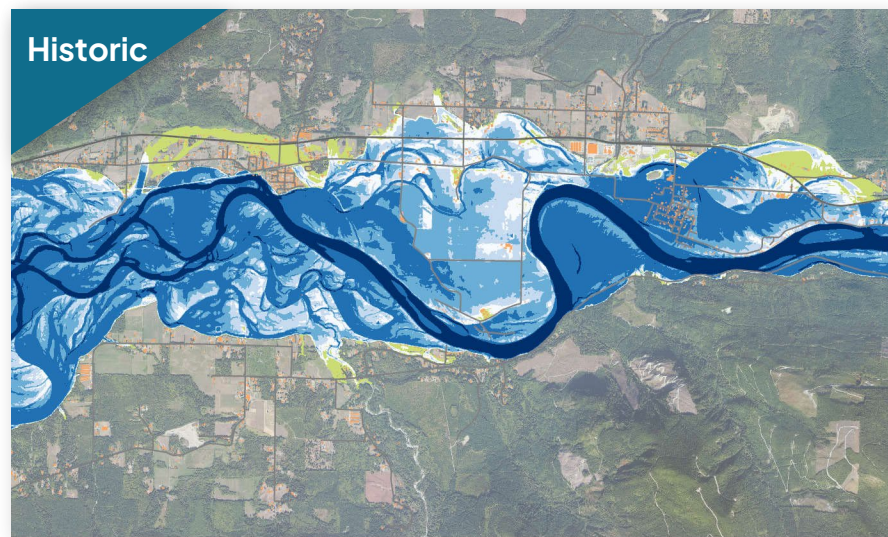


■ 2080's flood extent for shown event

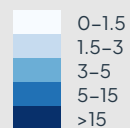
■ Buildings



Lyman and Hamilton | 25 Year Flood



Flood Depth (ft)

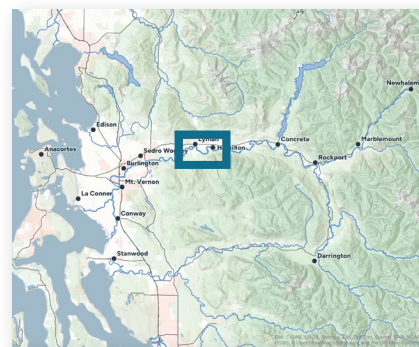
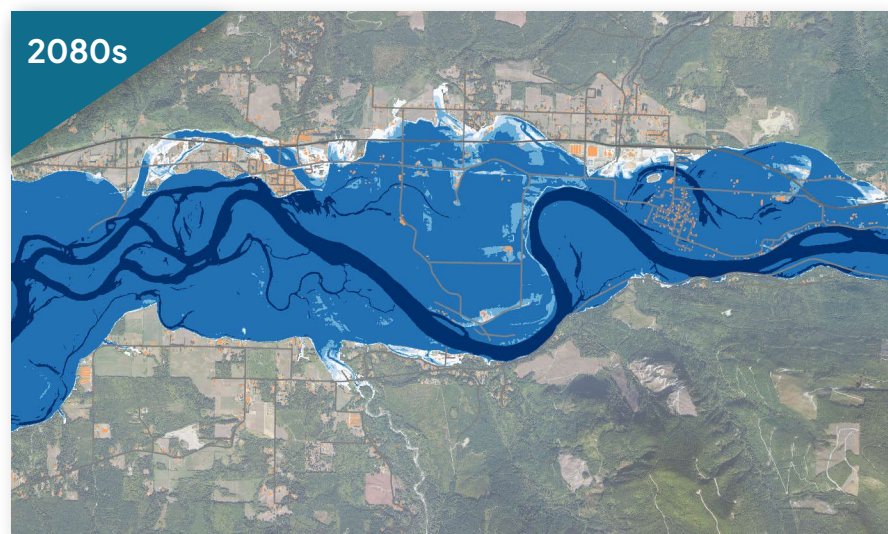
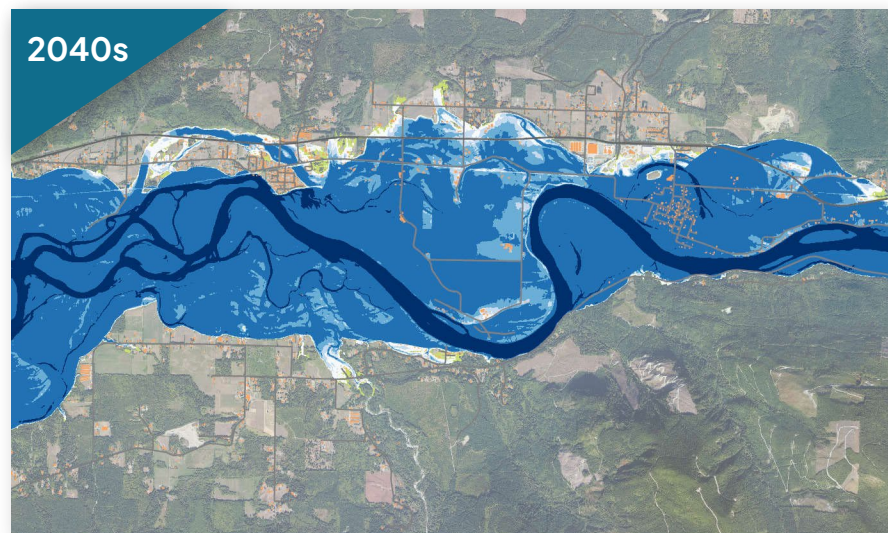
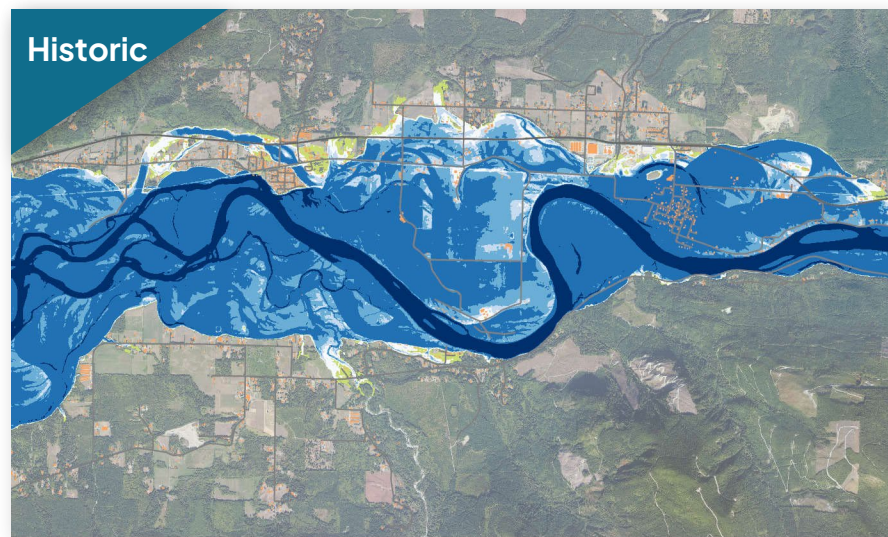


■ 2080's flood extent for shown event

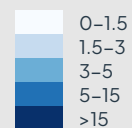
■ Buildings



Lyman and Hamilton | 100 Year Flood

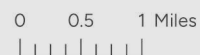


Flood Depth (ft)

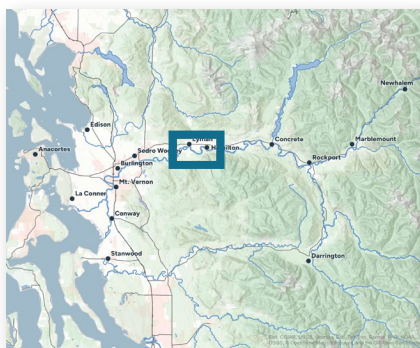
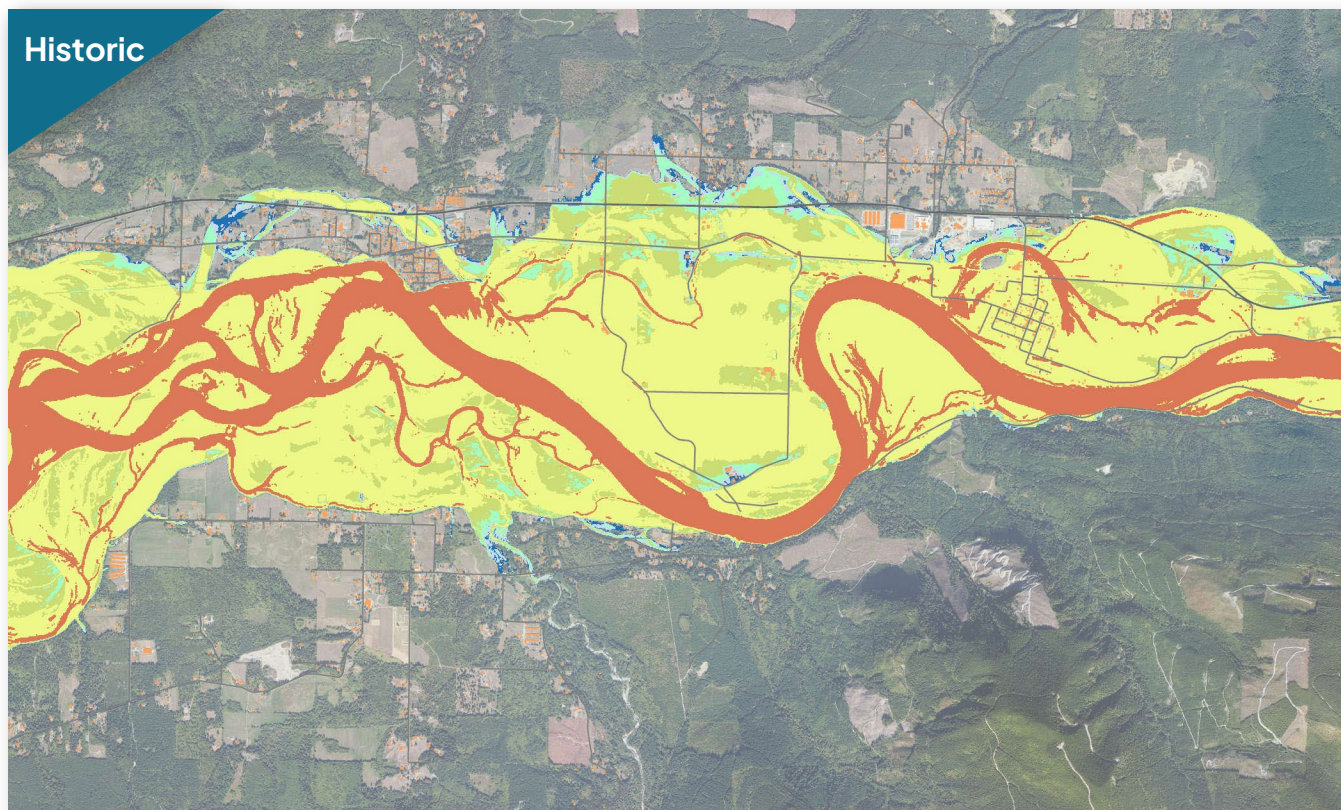


■ 2080's flood extent for shown event

■ Buildings



Lyman and Hamilton | Depth-Velocity Hazard



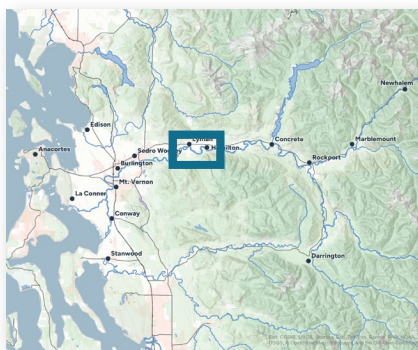
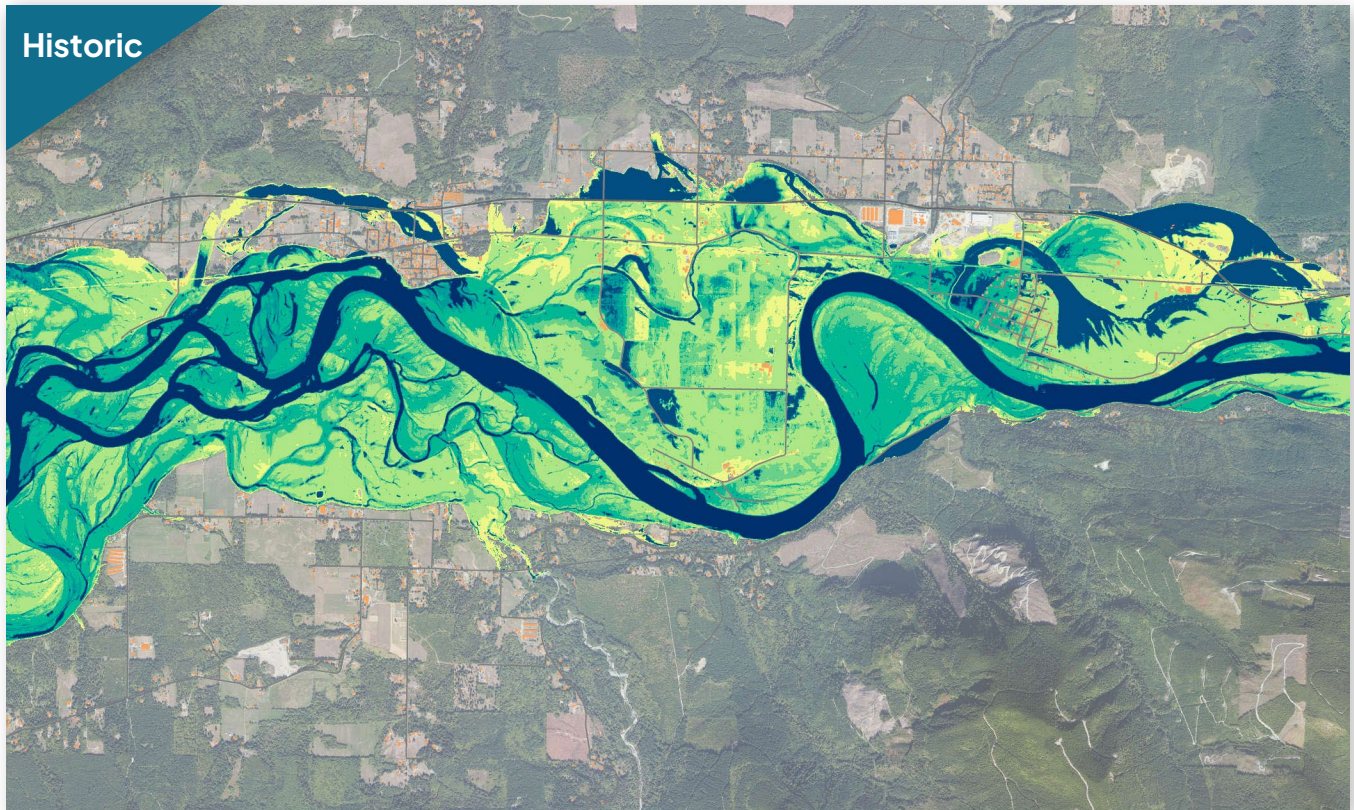
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.

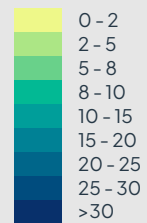
■ Buildings

0 0.5 1 Miles

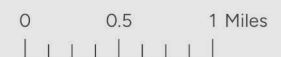
Lyman and Hamilton | Duration



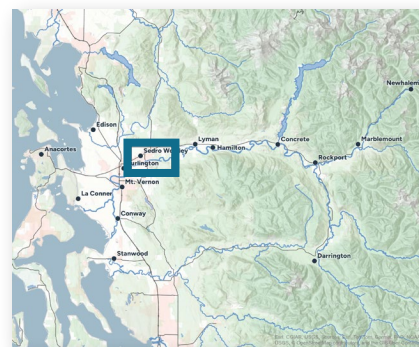
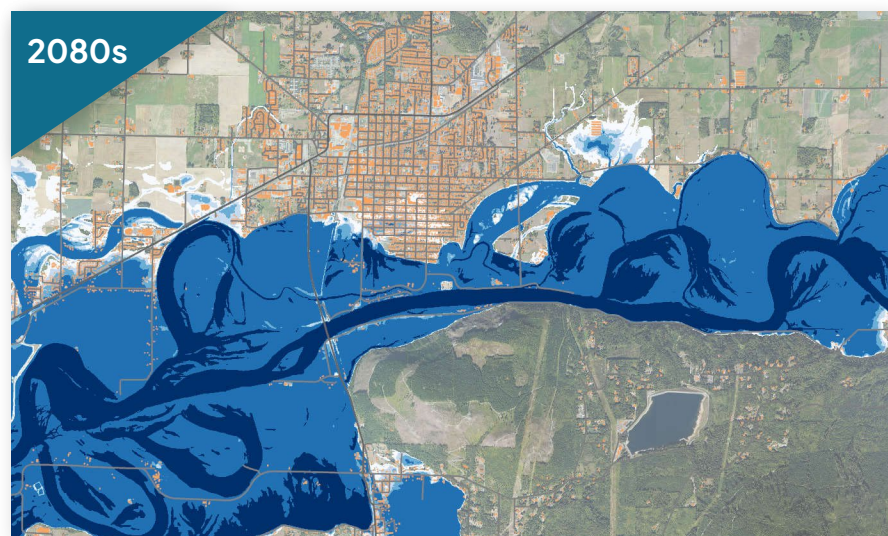
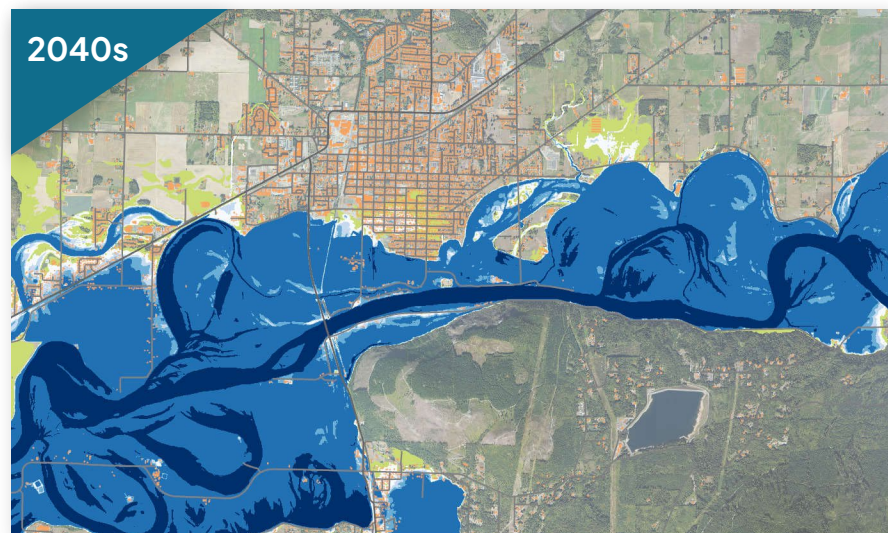
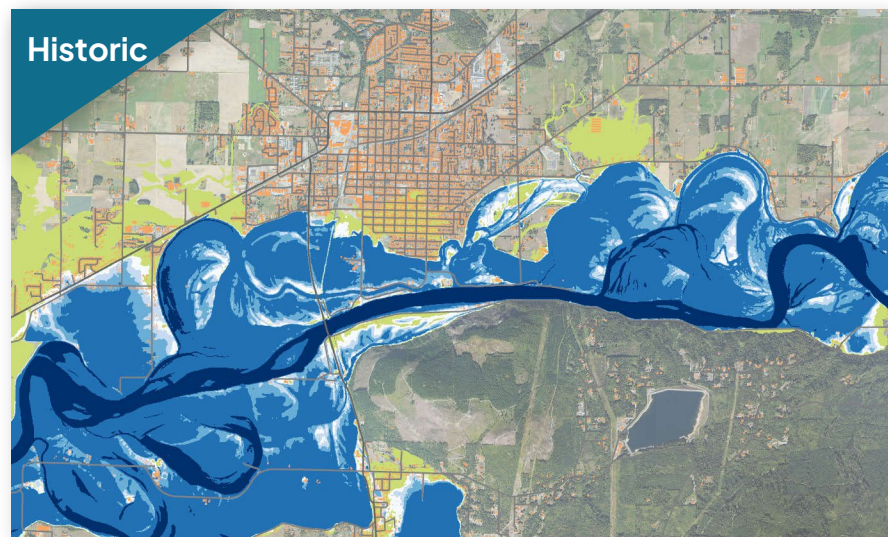
Duration (days)



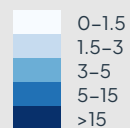
■ Buildings



Sedro-Woolley | 10 Year Flood



Flood Depth (ft)

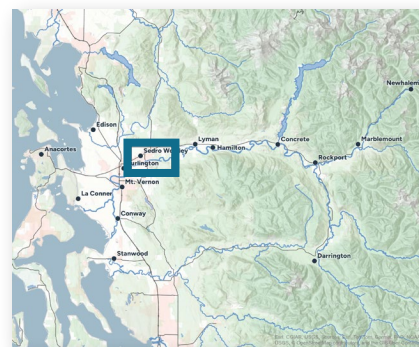
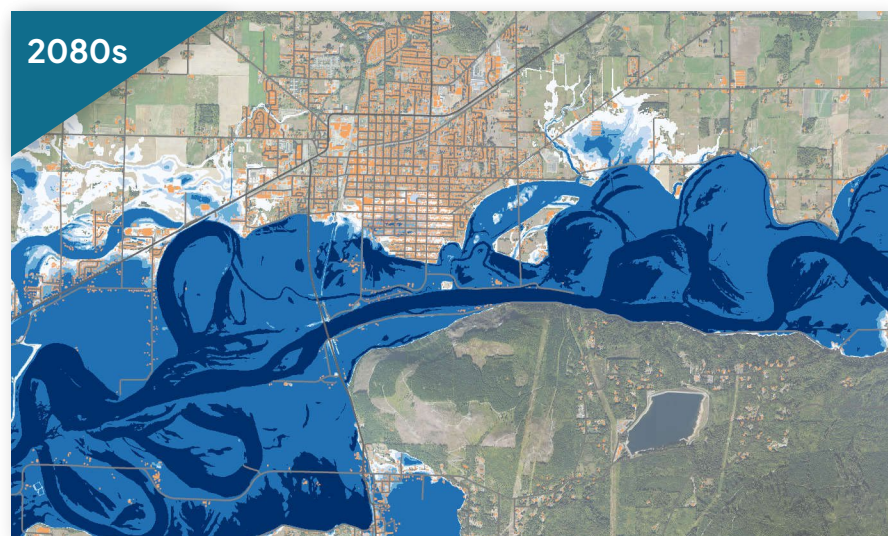
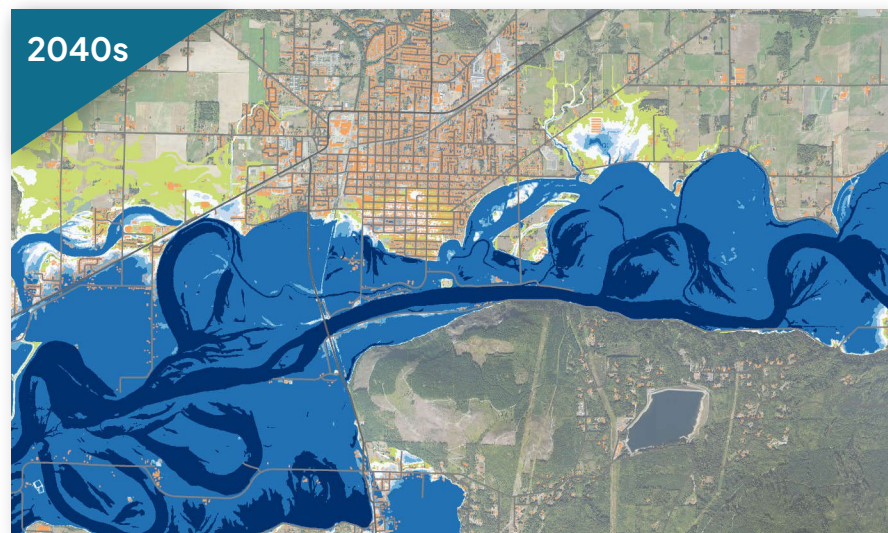
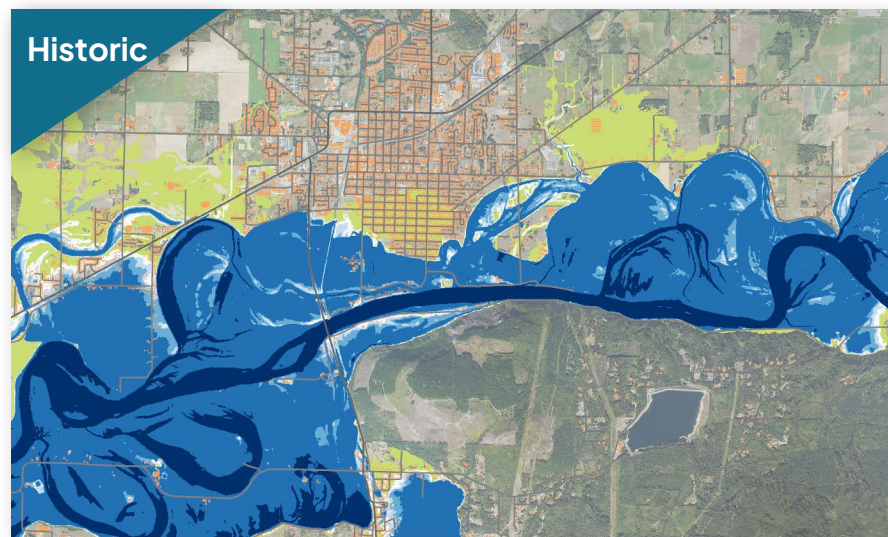


■ 2080's flood extent for shown event

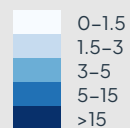
■ Buildings



Sedro-Woolley | 25 Year Flood



Flood Depth (ft)

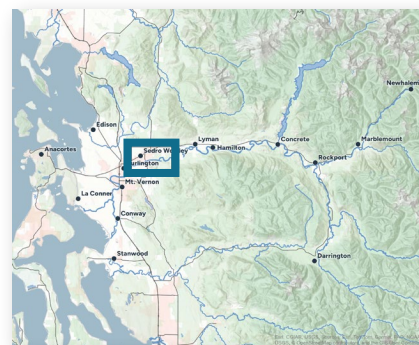
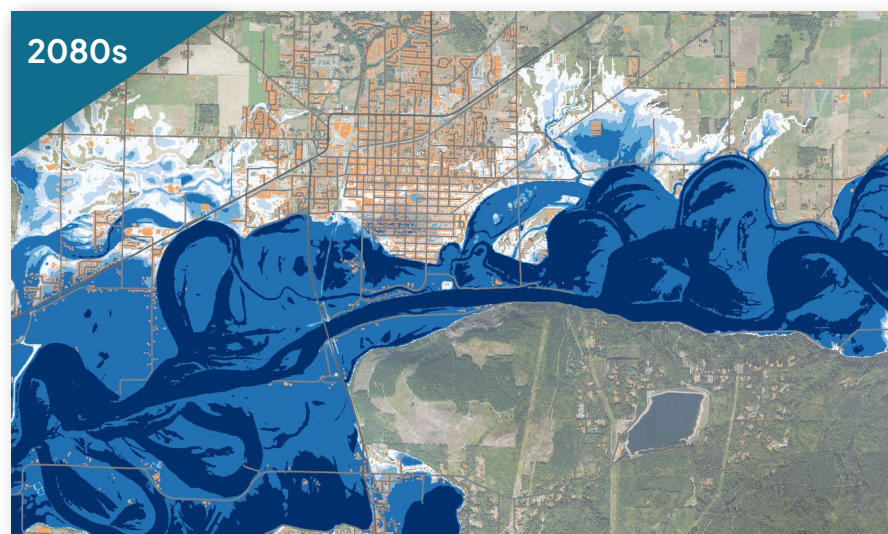
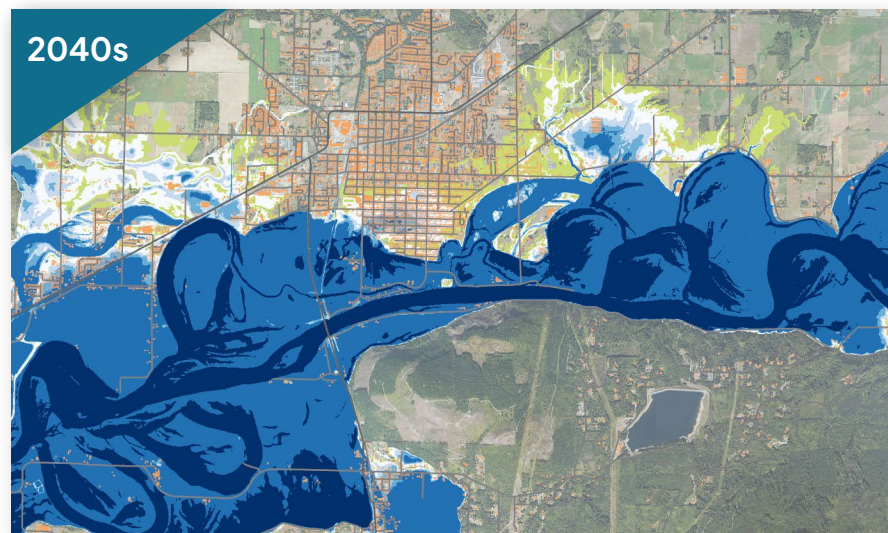
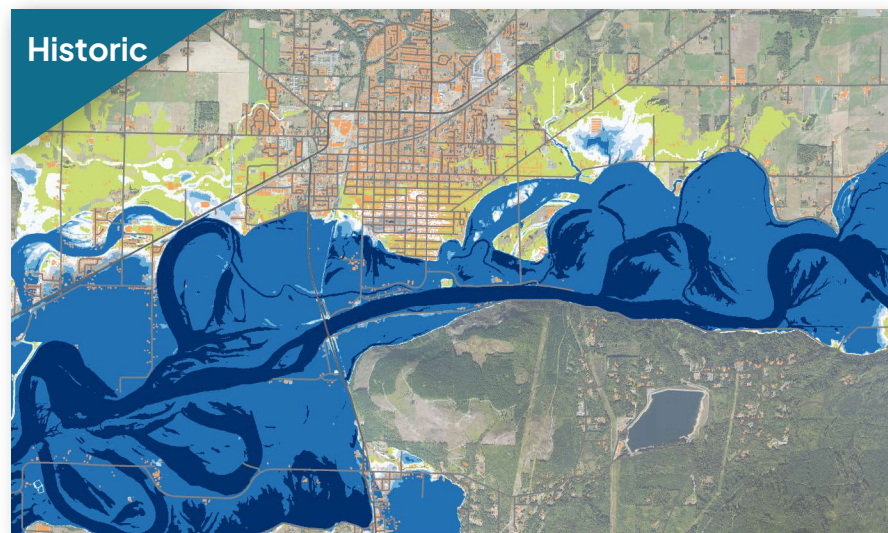


■ 2080's flood extent for shown event

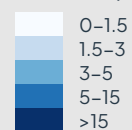
■ Buildings



Sedro-Woolley | 100 Year Flood

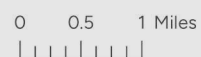


Flood Depth (ft)

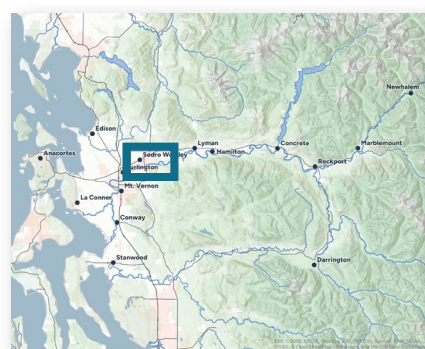
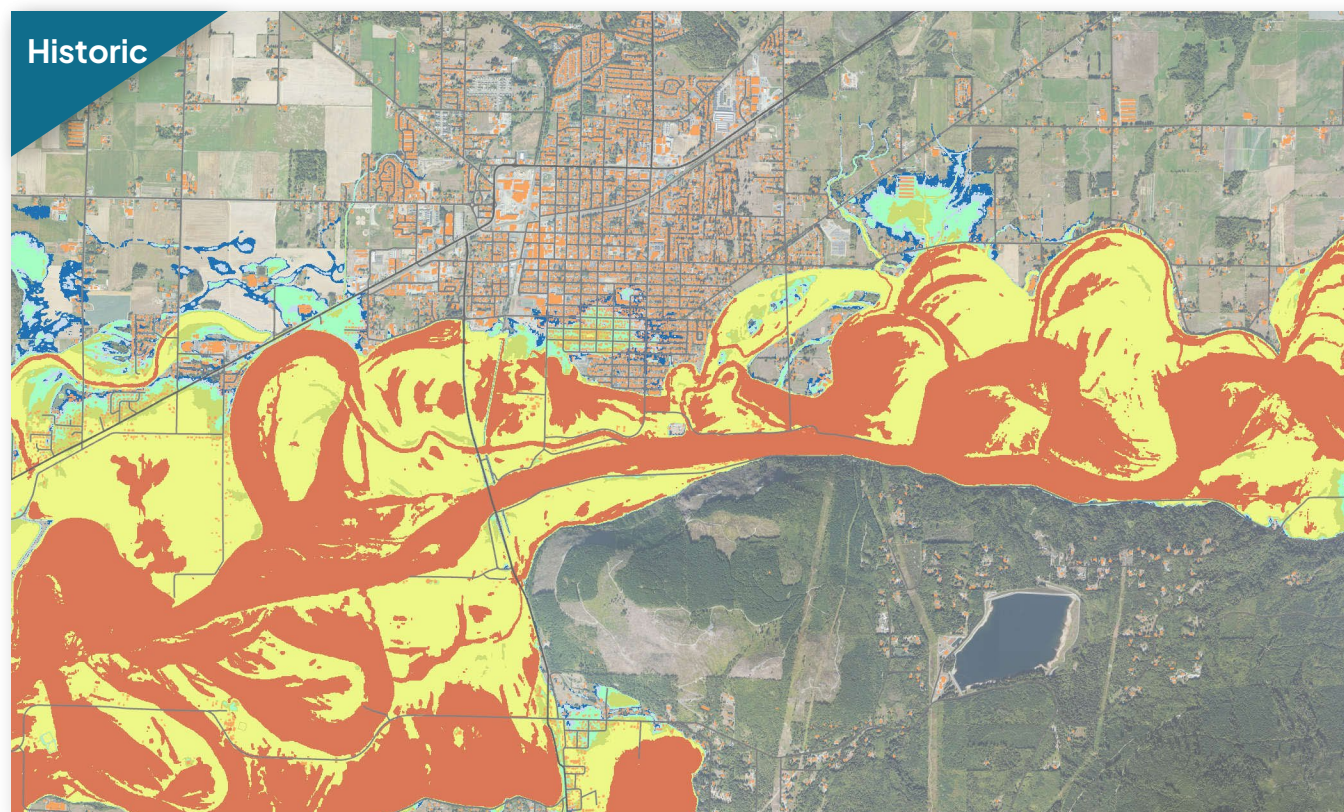


■ 2080's flood extent for shown event

■ Buildings



Sedro-Woolley | Depth-Velocity Hazard



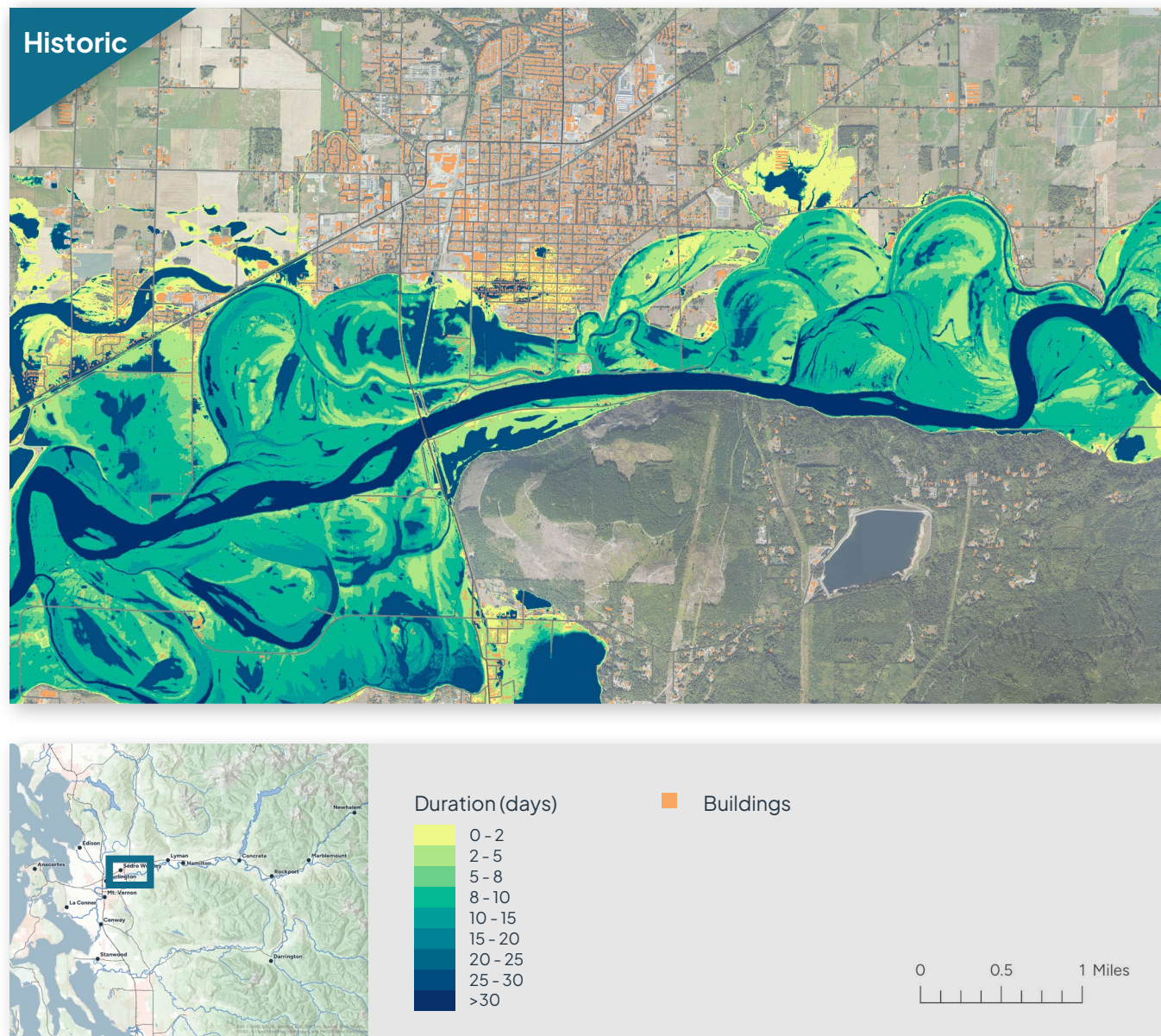
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

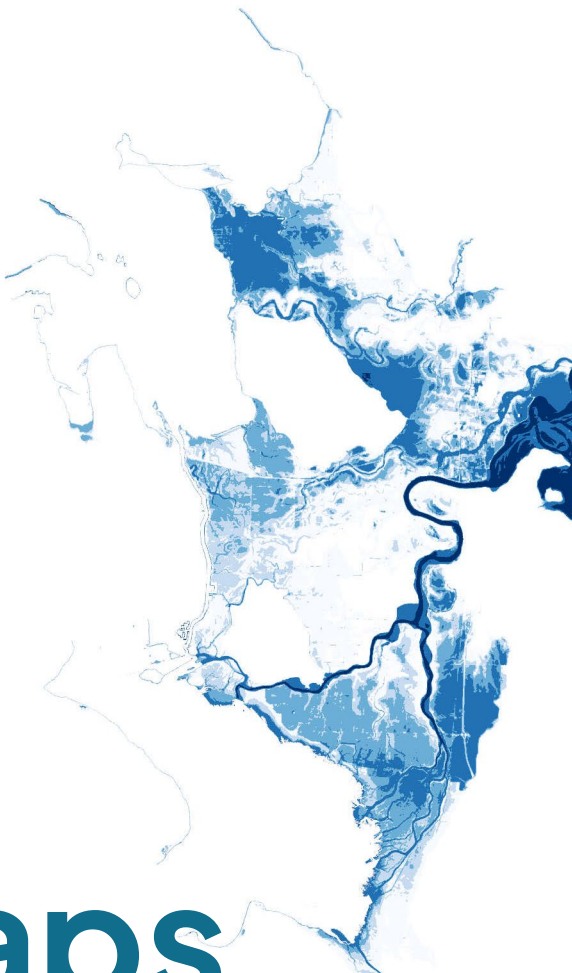
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.

■ Buildings

0 0.5 1 Miles

Sedro-Woolley | Duration





Lower River Flooding Maps

This map bundle shows Skagit River flood model results for areas downstream of Sedro-Woolley.

This set includes an overview map of the area and zoomed-in map areas for the cities of Burlington and Mount Vernon, the town of La Conner, the Swinomish Reservation and the unincorporated communities of Conway, Bow, and Edison. Full context for these maps can be found in the full *Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities* report and specific details on the hydraulic model that created these maps can be found in [Appendix A](#). Flood animations for select locations can be found at the Skagit Climate Science Consortium website.

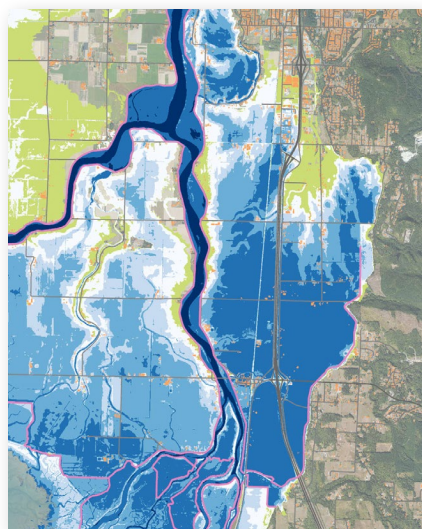
These maps are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, dike failures, larger than modeled events, or other factors. Maps should be used at your own risk.

How to Read Lower River Flooding Maps

What These Maps Show

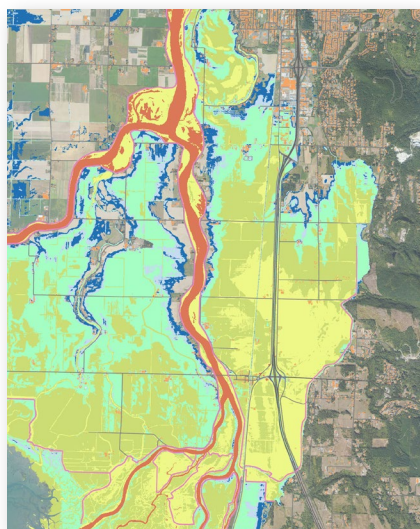
For all maps, the background is based on an aerial image (USDA 2023) and structures are shown as orange rectangles (Microsoft 2022). Pink lines, if present, show dike locations (Skagit County 2022), and dark gray lines show major transportation routes (WSDOT 2008, Skagit County 2019). The river channel itself may change colors depending on the map, but is the darkest shading in all maps.

FLOOD DEPTH MAPS



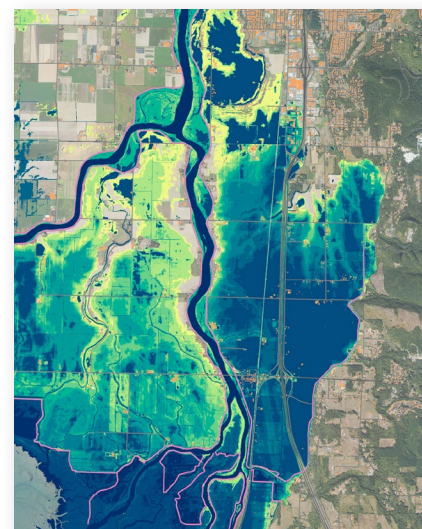
These maps are organized into sets of three, showing results for Historic (top), 2040s (middle), and 2080s (bottom) flood magnitudes. Each set of maps shows the model results for a specific flood frequency: 10-year, 25-year, and 100-year. Maps show the depth of flooding in shades of blue, where darker blue indicates deeper water and lighter blue indicates shallower water. In order to see how flooding is projected to change in the future, the Historic and 2040s maps also show the estimated extent of the 2080s flood in bright green. There is no bright green shading for the 2080s map because the map is already showing the depth and extent of the 2080s flood. All three maps are at the same scale.

DEPTH-VELOCITY HAZARD MAPS



These maps show depth-velocity hazards for a historic 100-year event. Only the historic results are shown; maps for the 2040s or 2080s are not included. The hazard classifications shown in the key were assigned based on a standard international practice (AIDR, 2017) and grouped into six hazard ratings. The hazard mapping is based on clearwater hazards and does not account for secondary hazards such as shoreline and fluvial geomorphic hazards (e.g., erosion, avulsion, debris flows, alluvial fan, etc.). Colors show when water poses a risk to children, adults, vehicles, and structures due to depth, velocity, or a combination of the two.

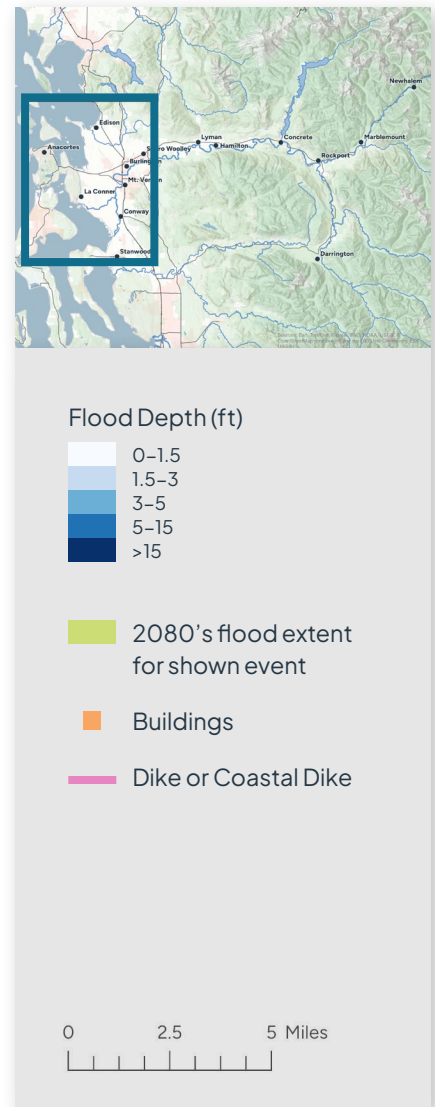
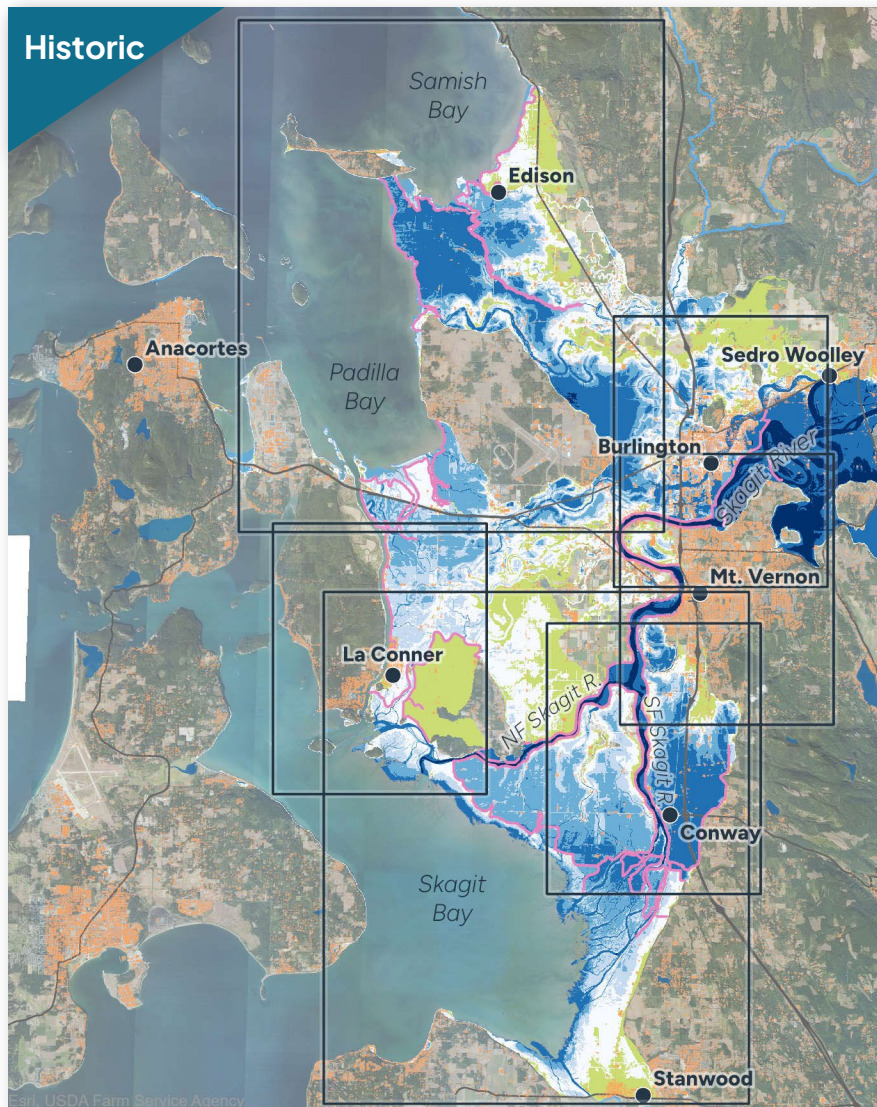
DURATION MAPS



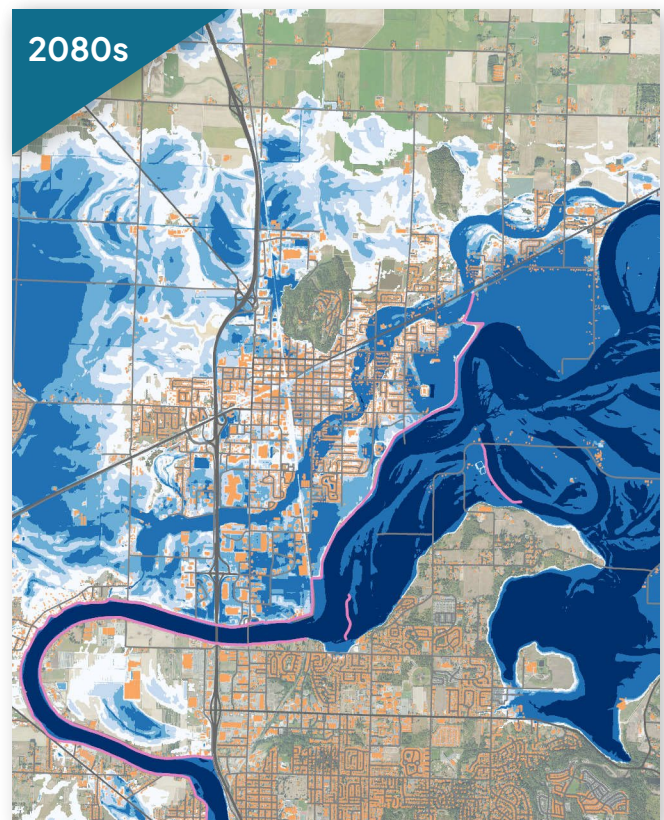
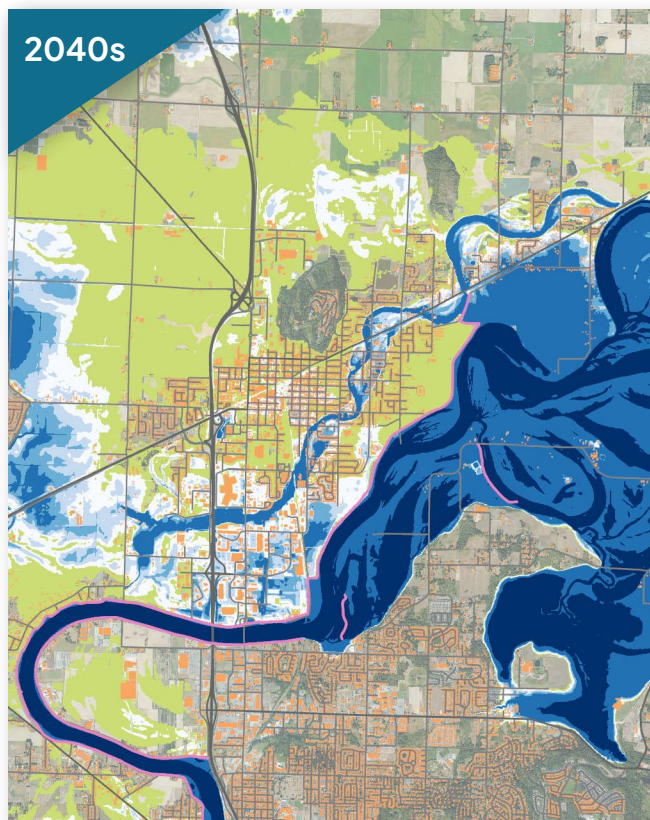
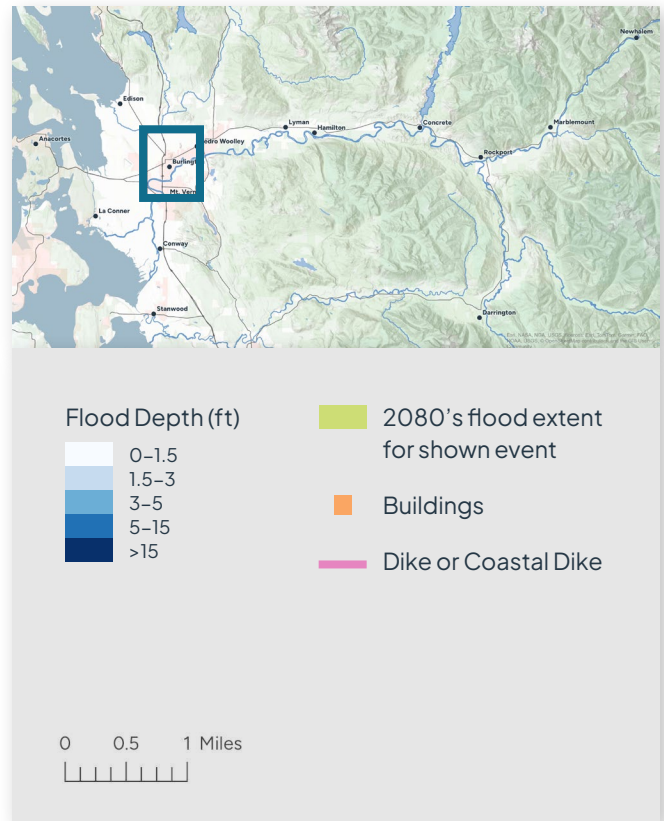
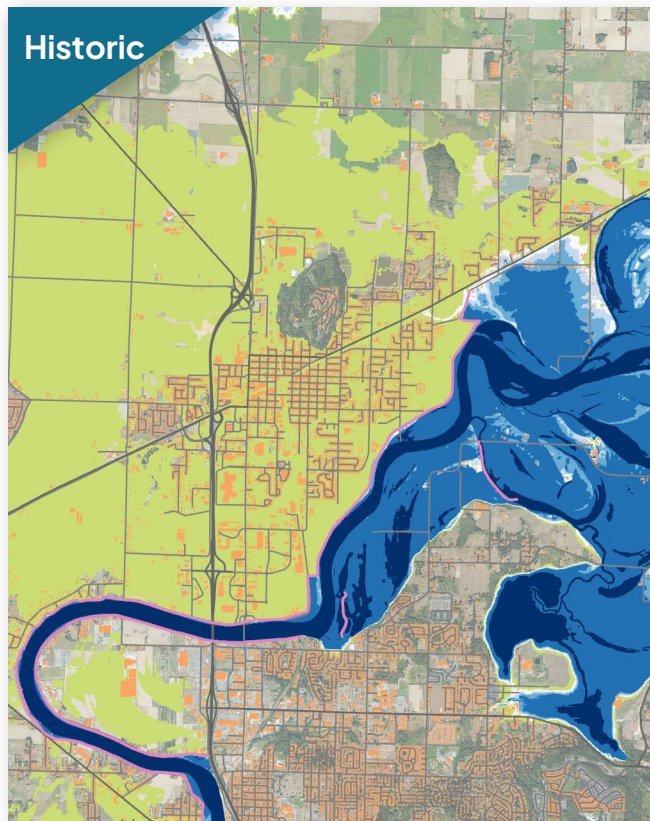
These maps show the amount of time, in days, that each location is inundated during a historic 100-year flood event and do not include flows estimated for the 2040s or 2080s. Duration is shown in shades ranging from dark blue to yellow, with darker shading indicating a longer duration, and lighter shading indicating a shorter duration of flooding.

LOWER RIVER FLOODING MAPS

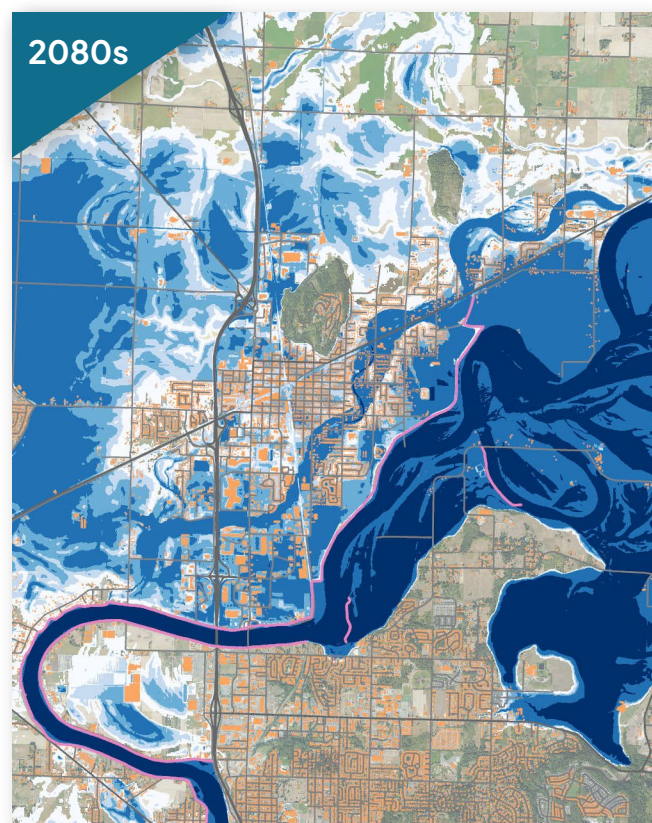
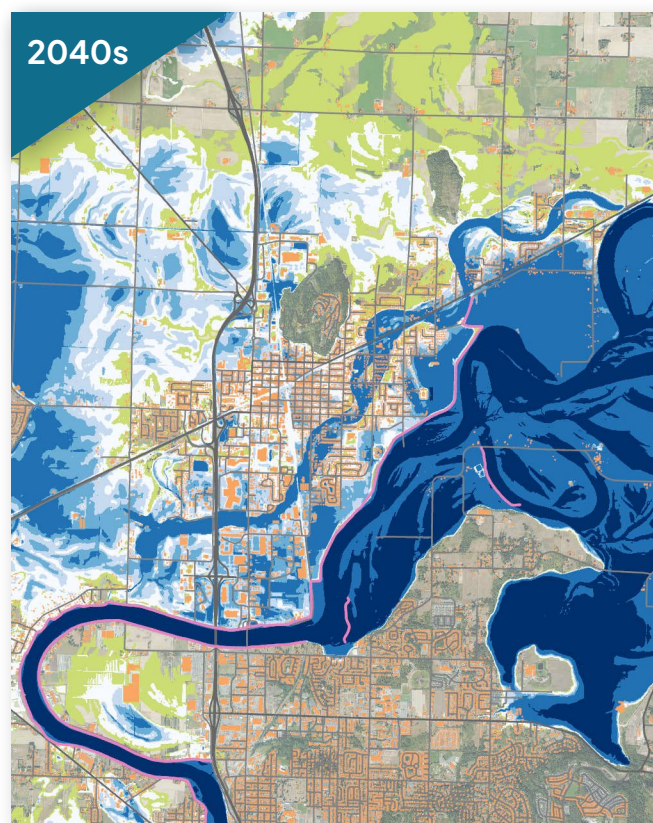
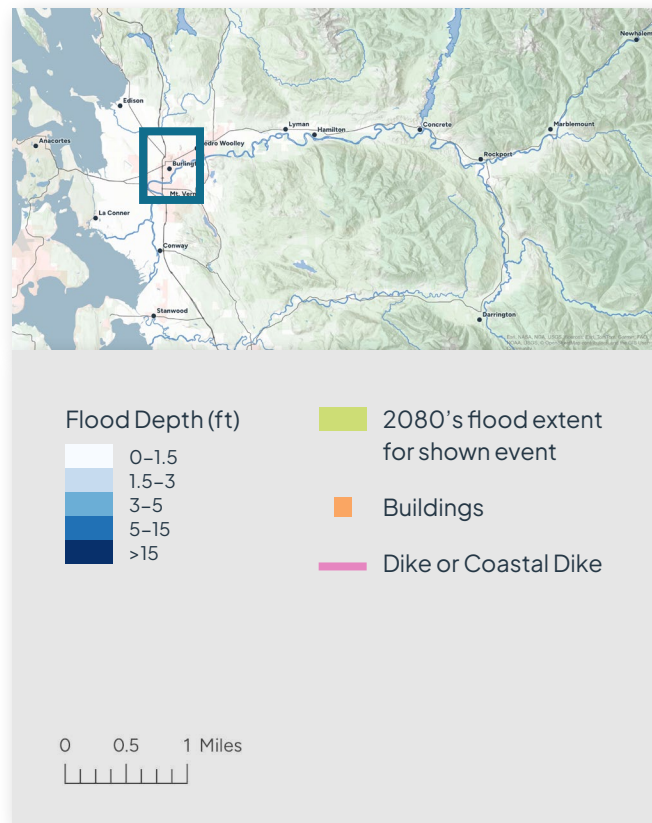
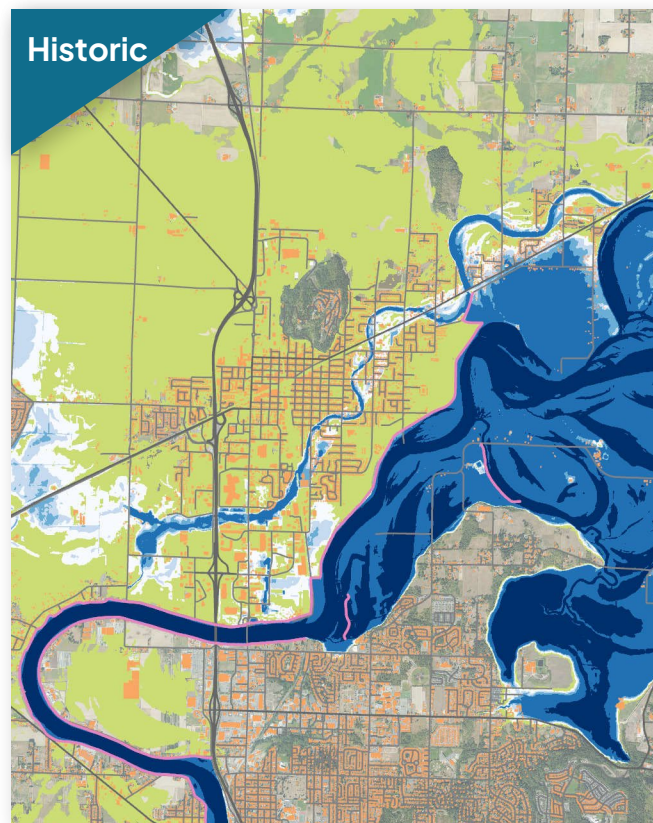
Overview Map



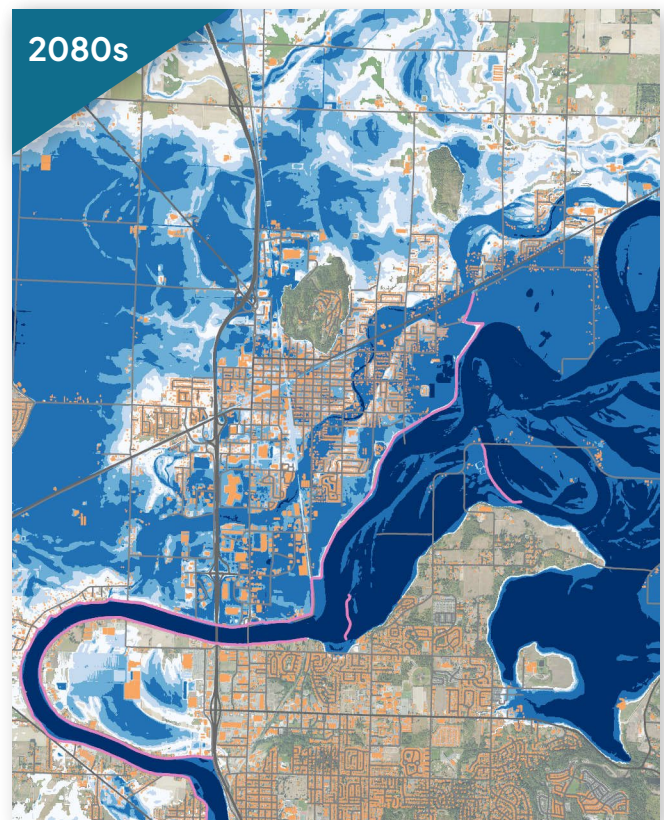
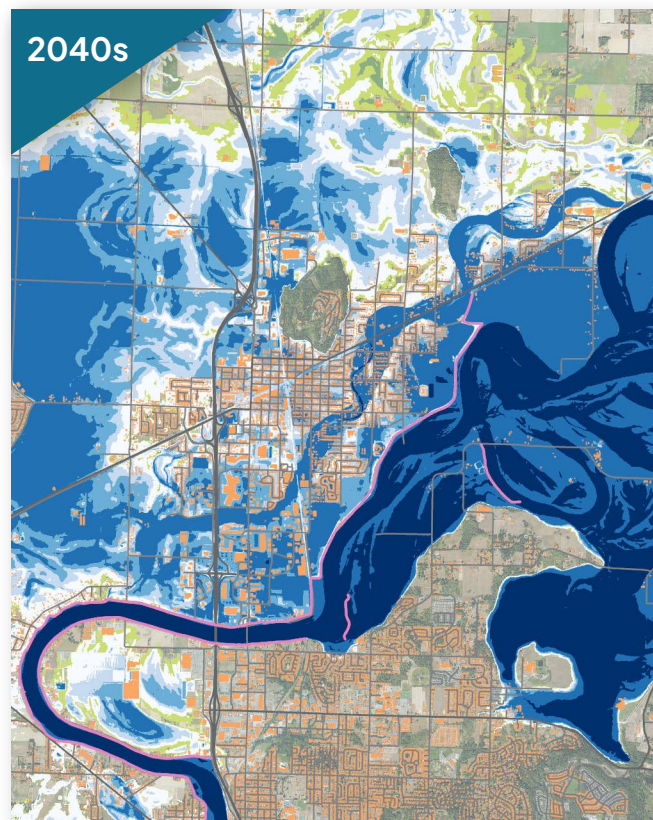
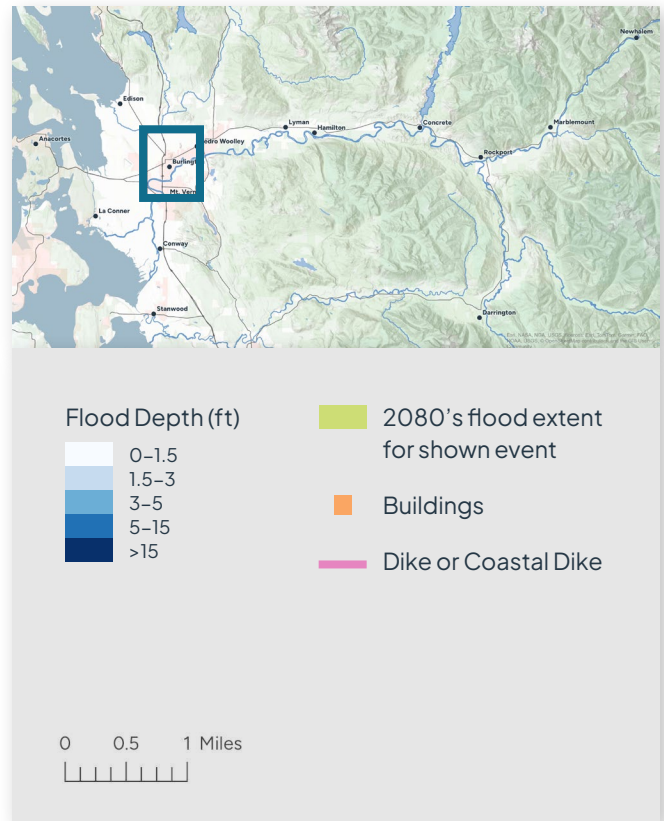
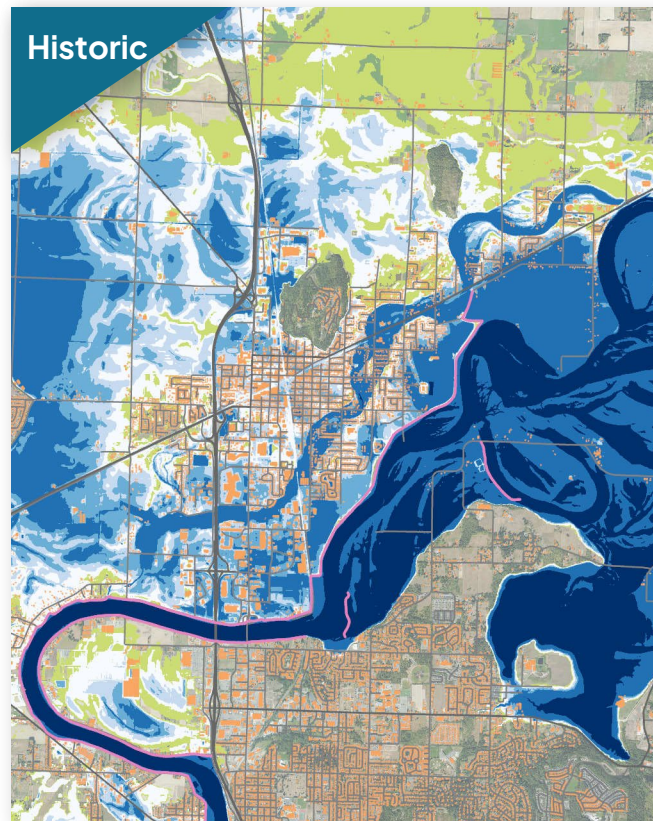
Burlington | 10 Year Flood



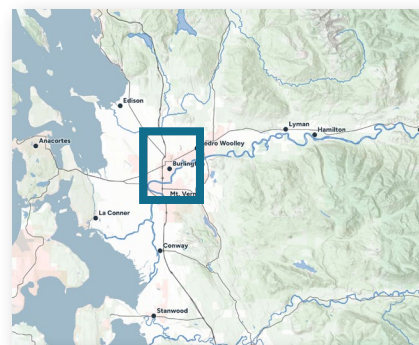
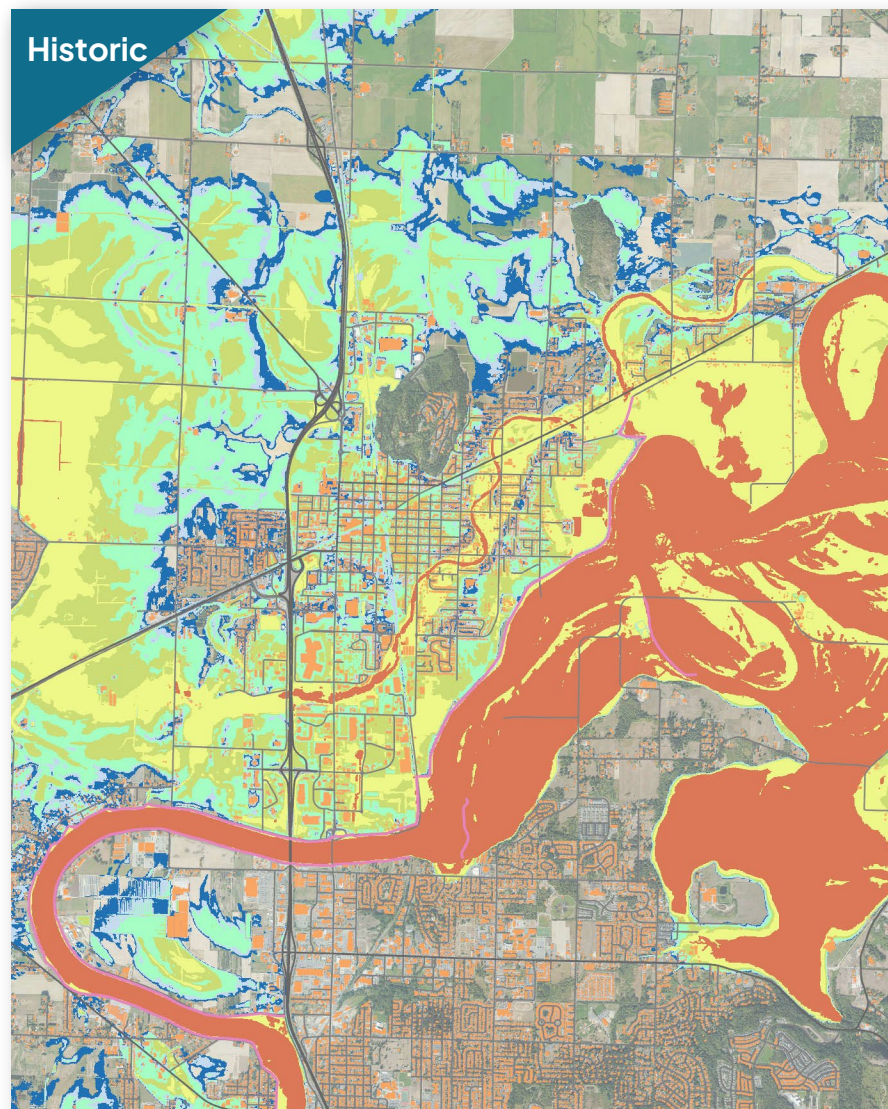
Burlington | 25 Year Flood



Burlington | 100 Year Flood



Burlington | Depth-Velocity Hazard



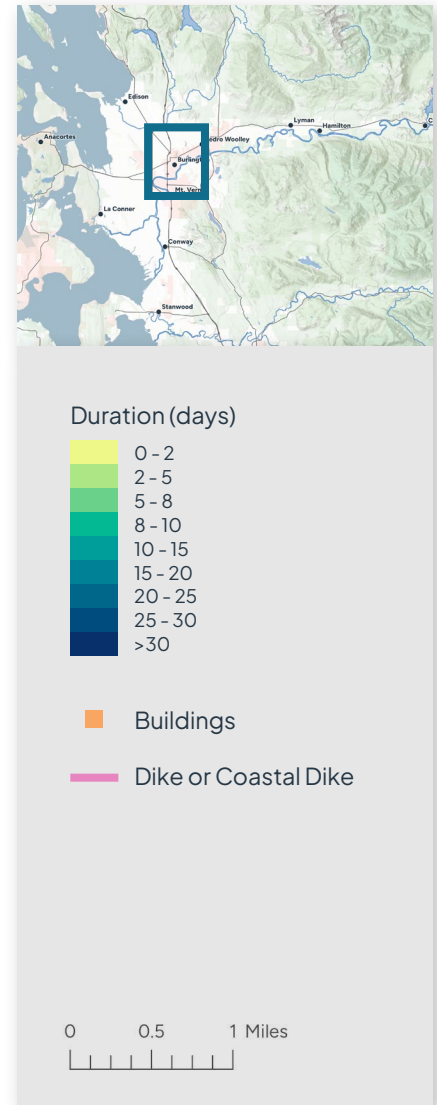
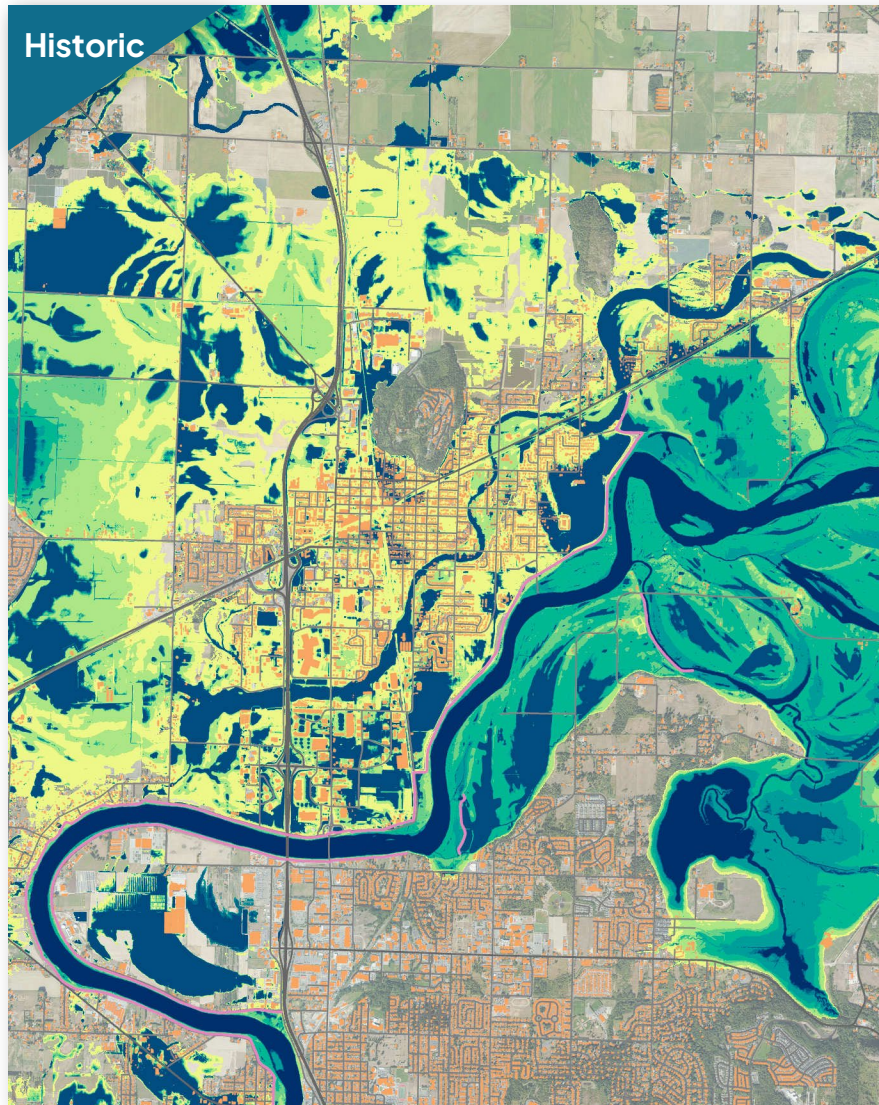
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

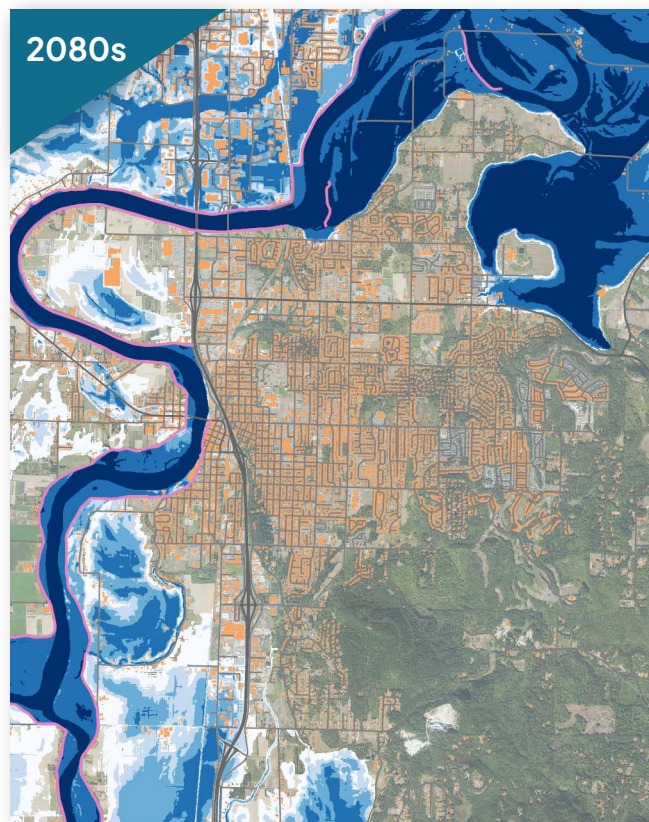
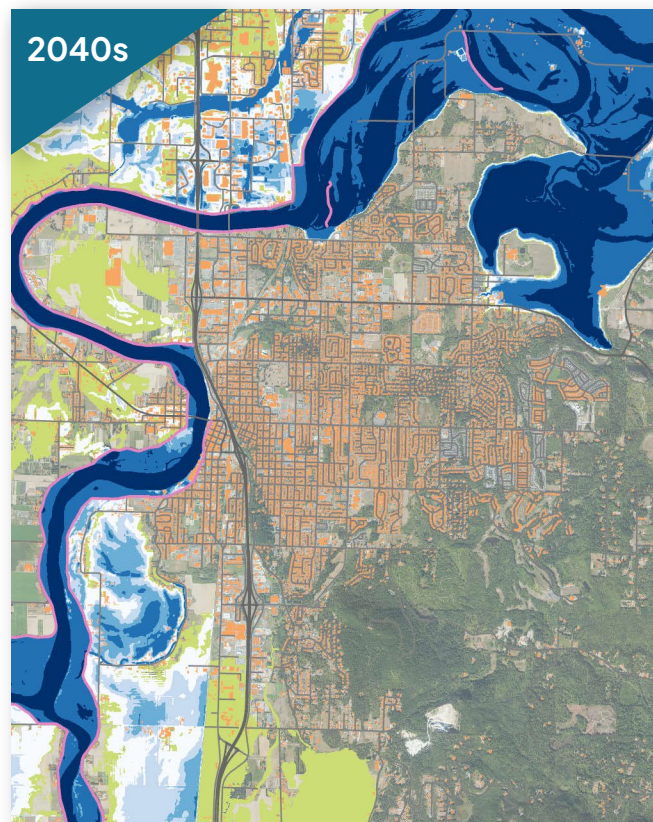
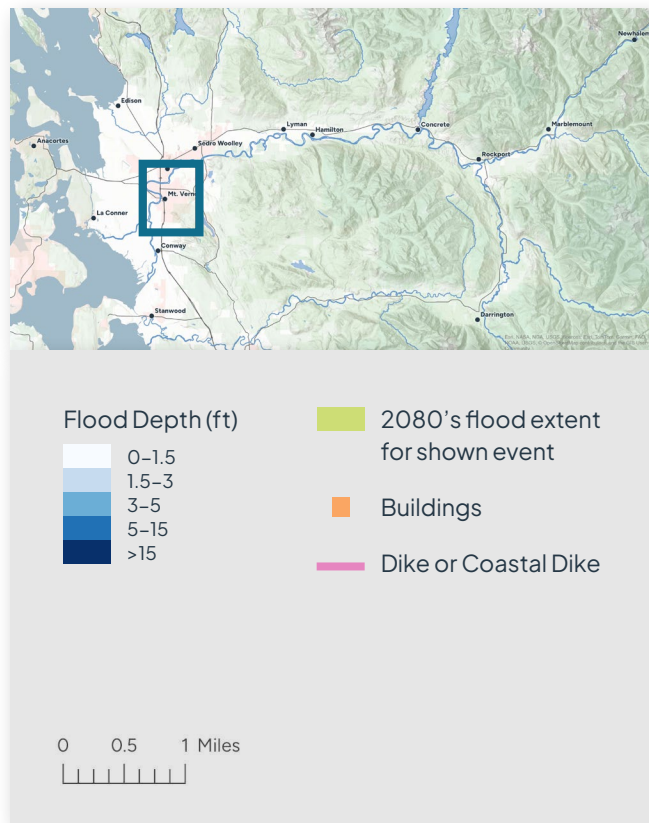
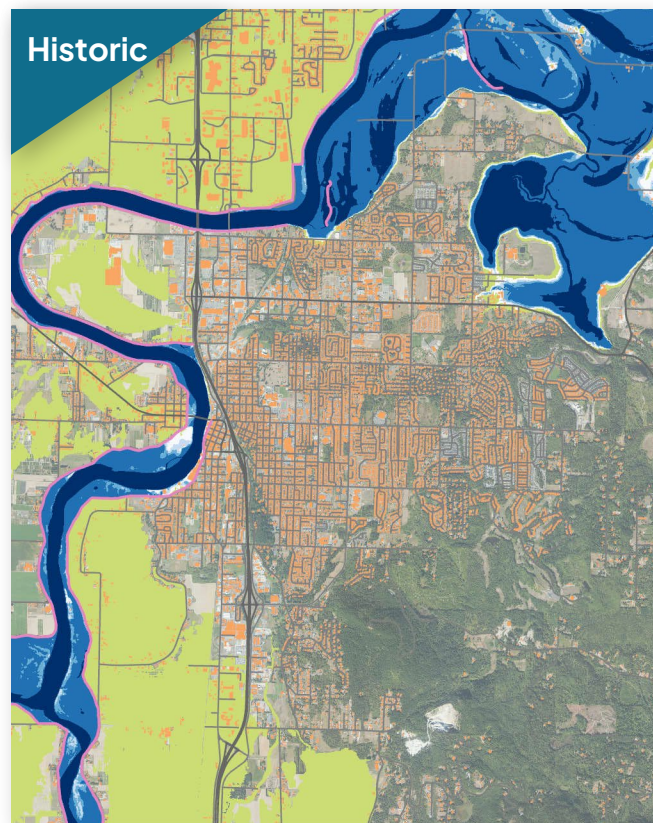
0 0.5 1 Miles

LOWER RIVER FLOODING MAPS

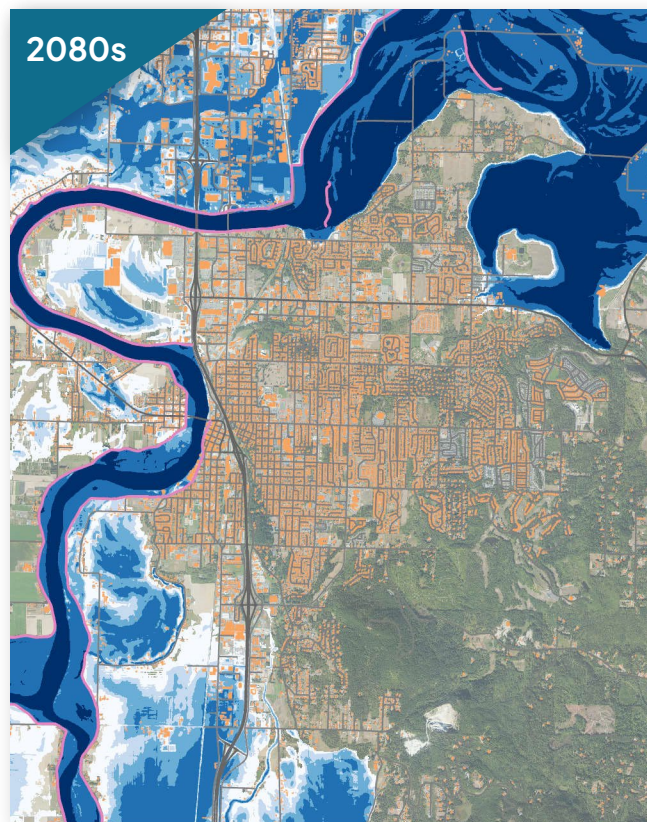
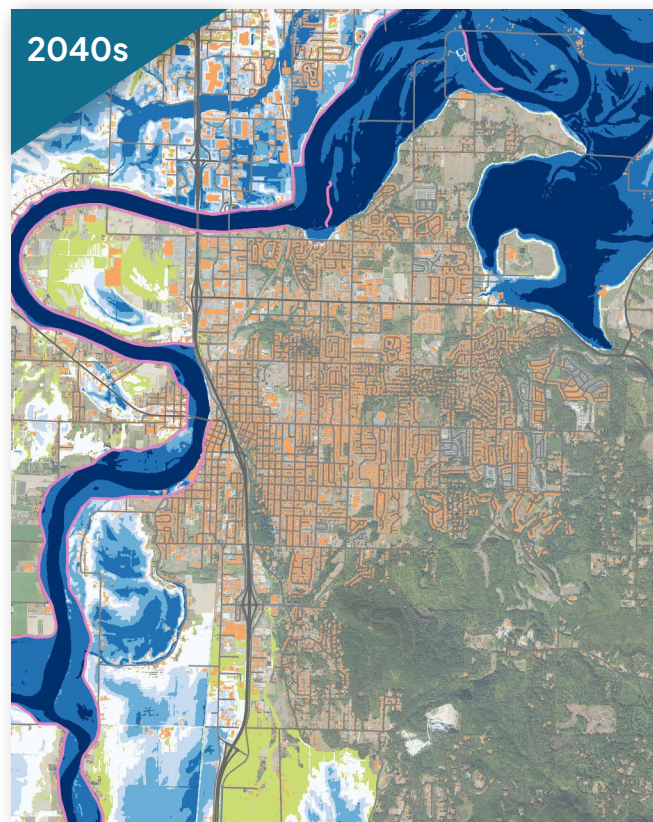
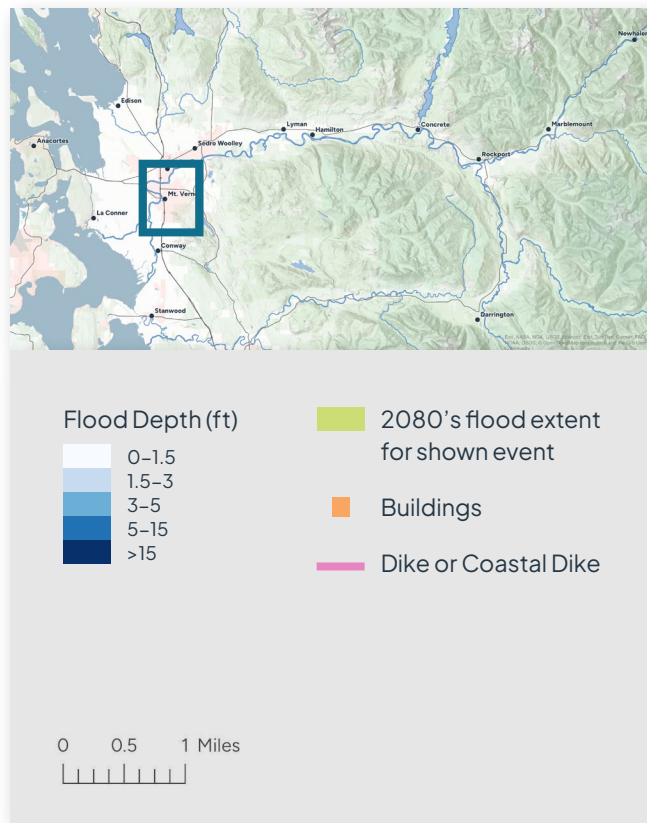
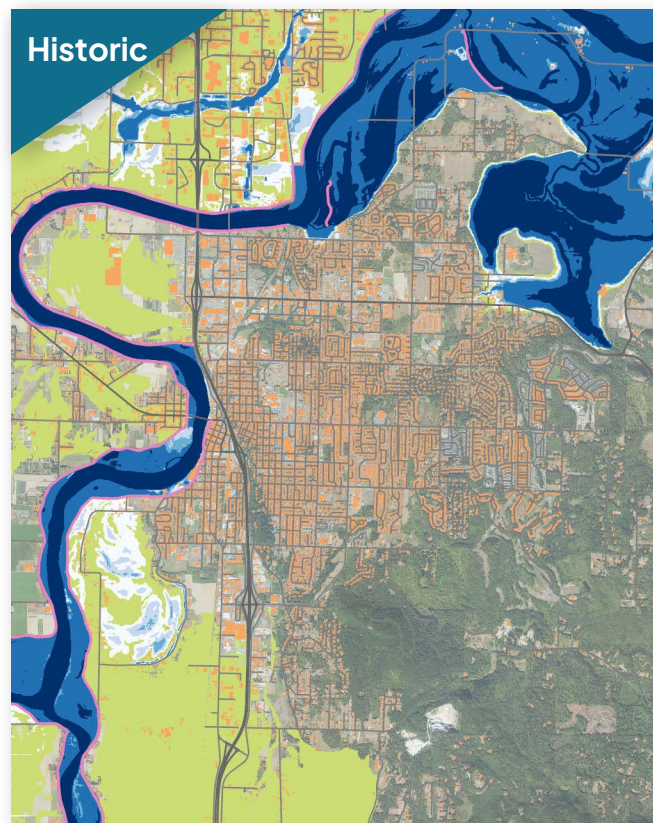
Burlington | Duration



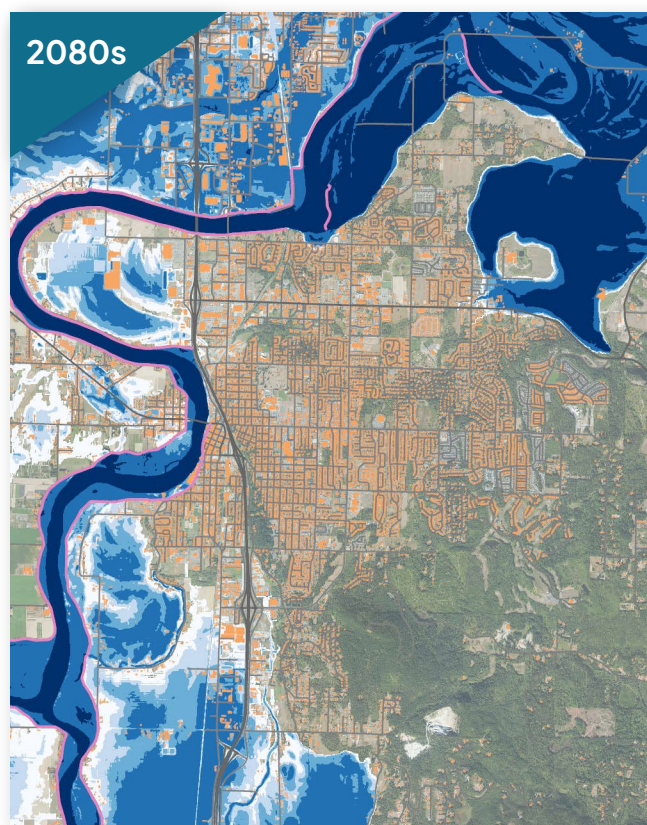
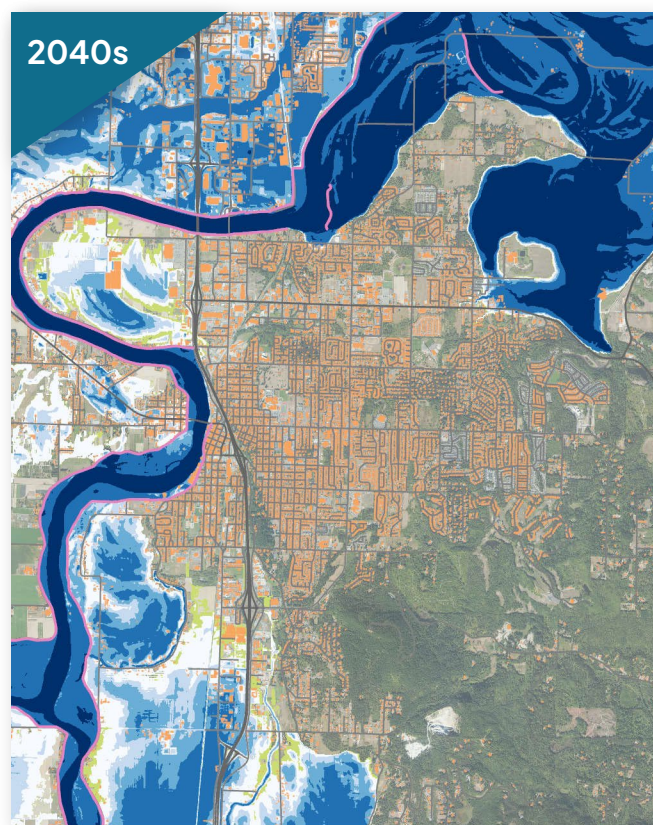
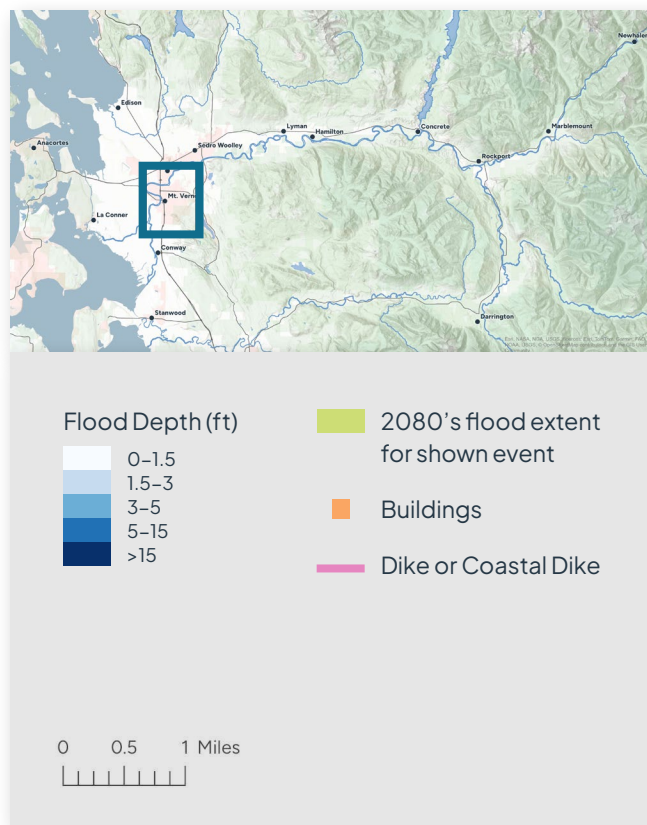
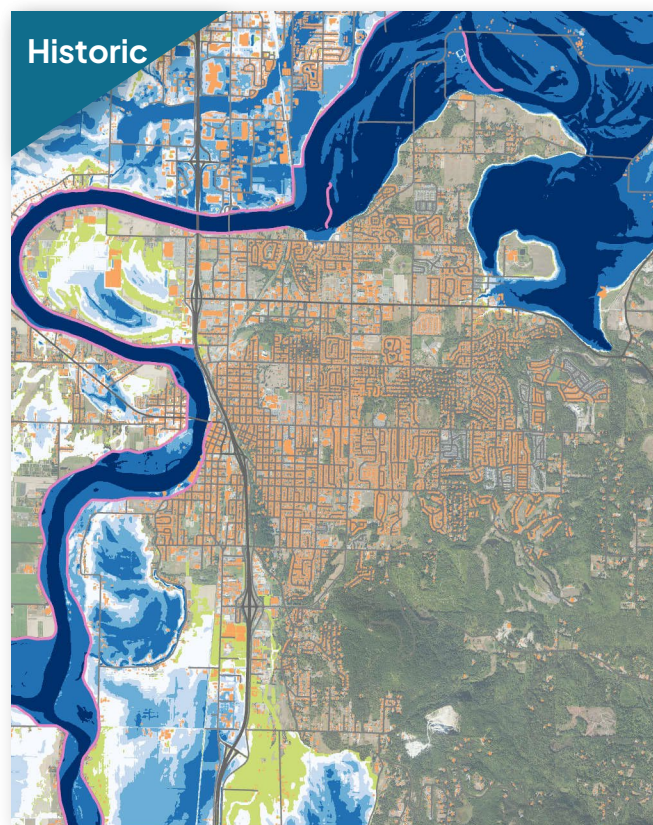
Mount Vernon | 10 Year Flood



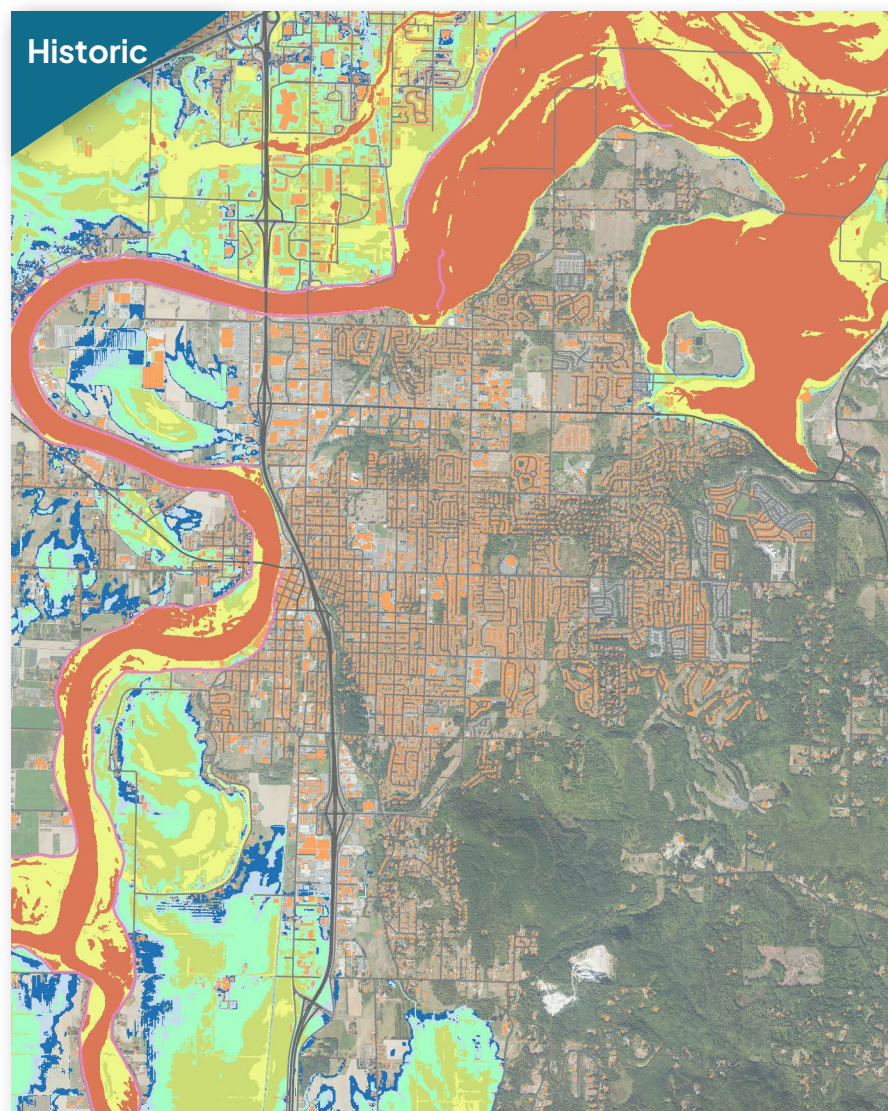
Mount Vernon | 25 Year Flood



Mount Vernon | 100 Year Flood



Mount Vernon | Depth-Velocity Hazard



Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

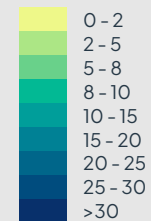
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

0 0.5 1 Miles

Mount Vernon | Duration

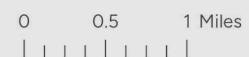


Duration (days)

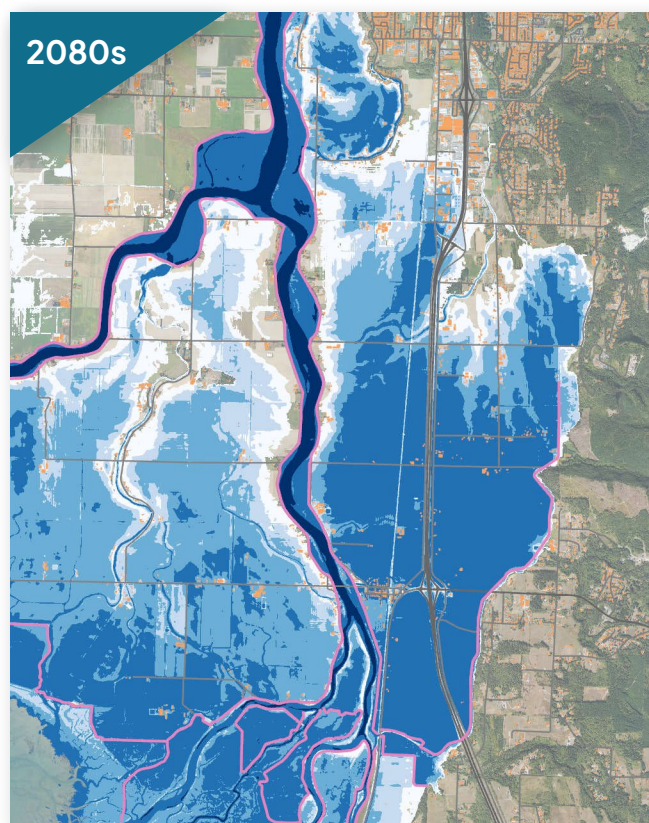
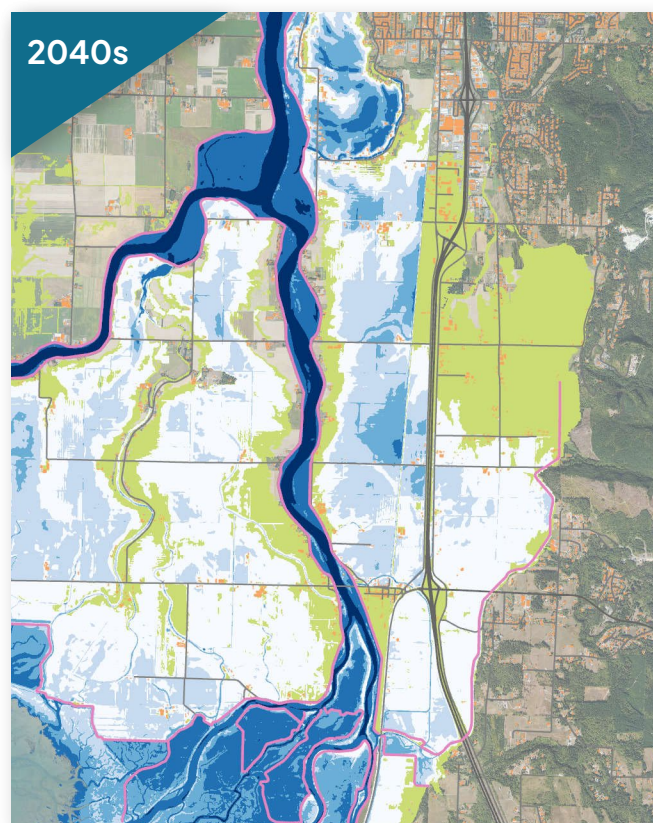
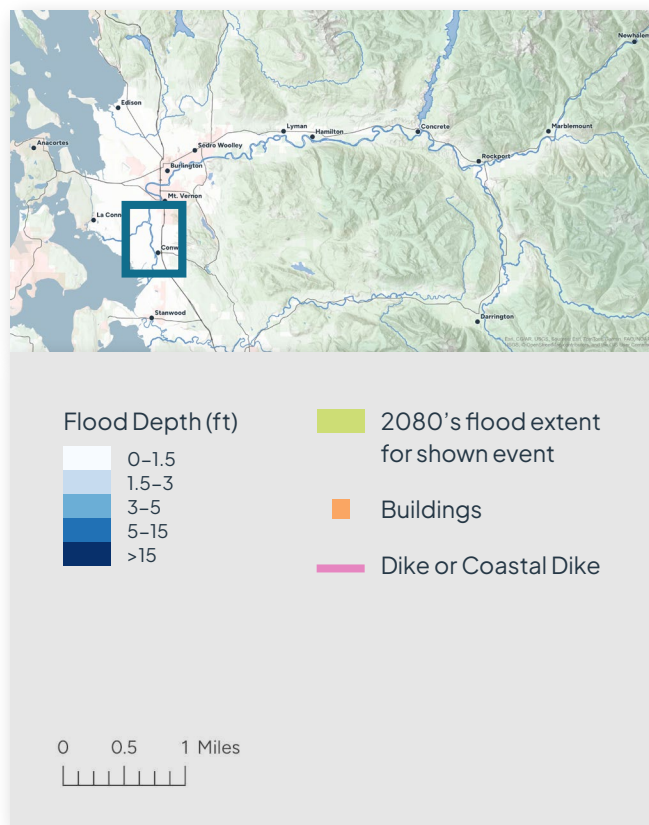
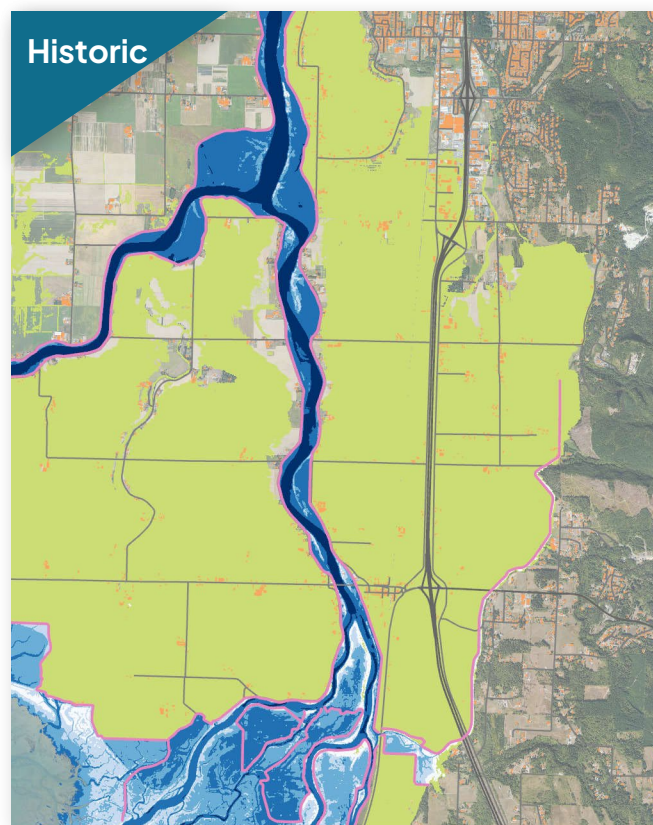


■ Buildings

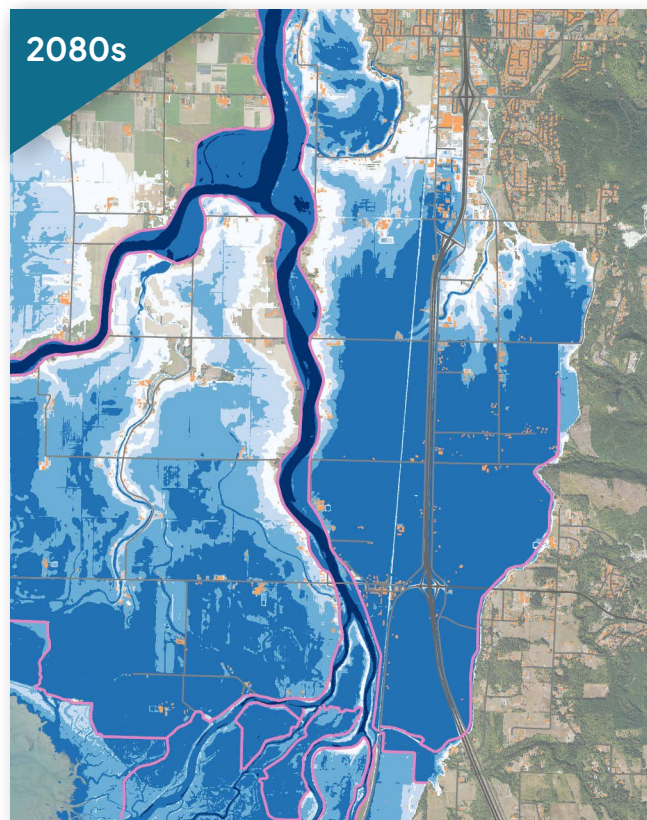
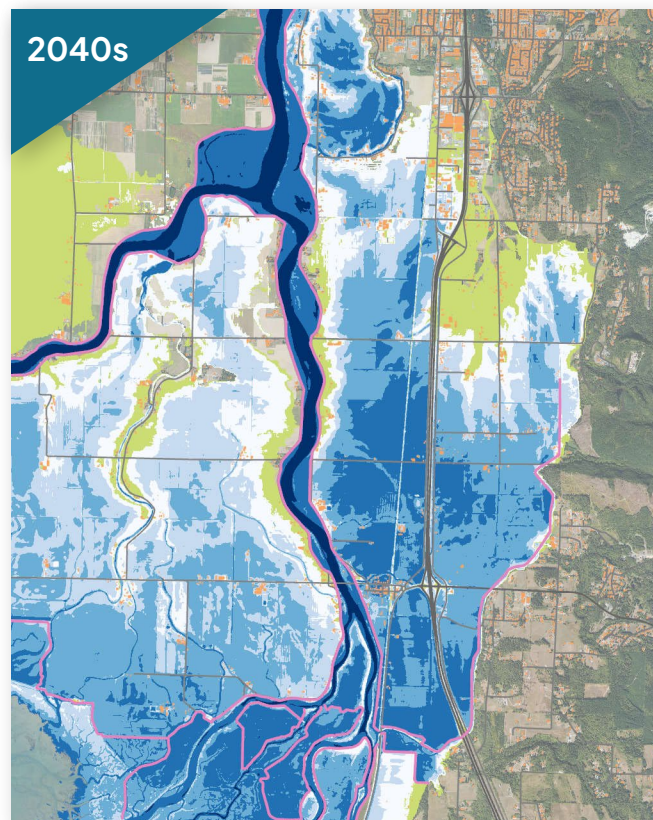
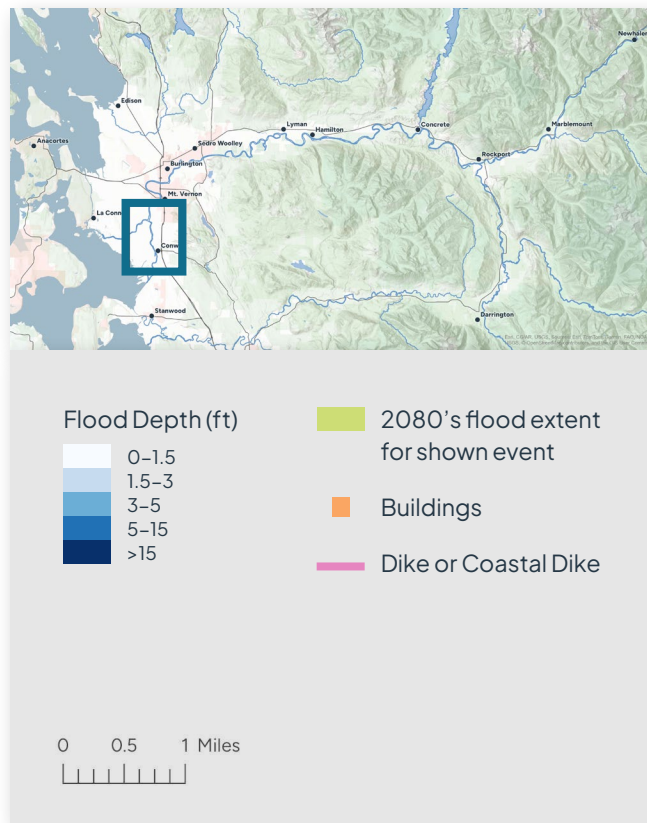
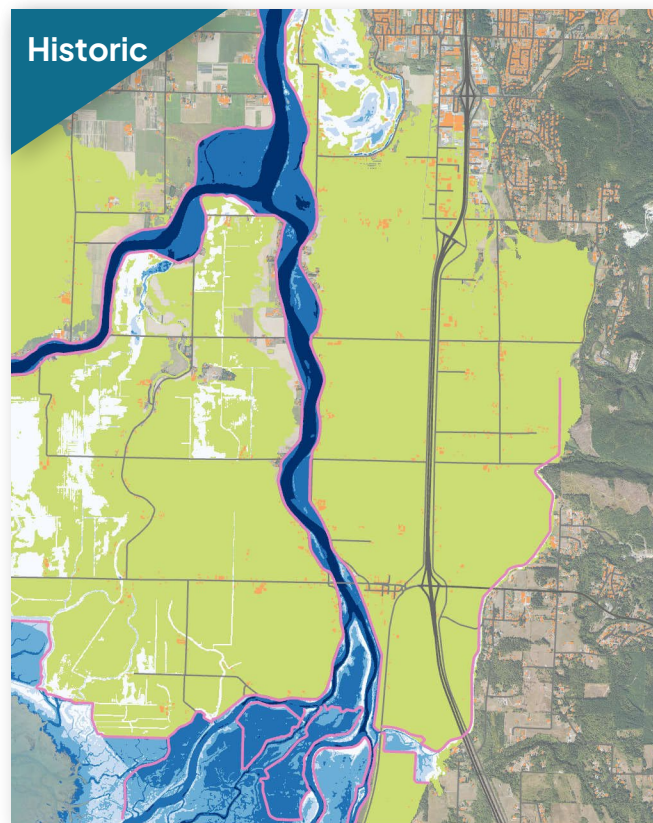
— Dike or Coastal Dike



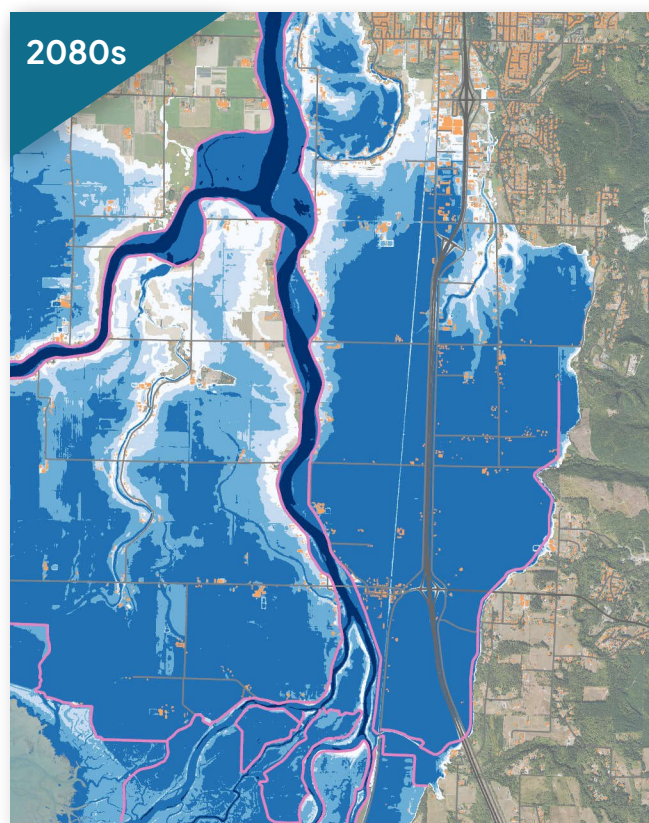
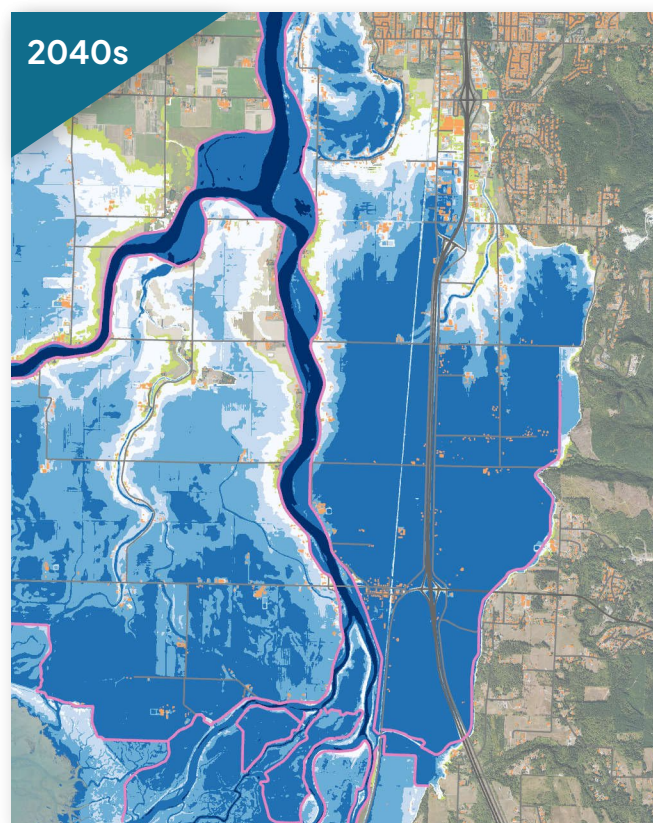
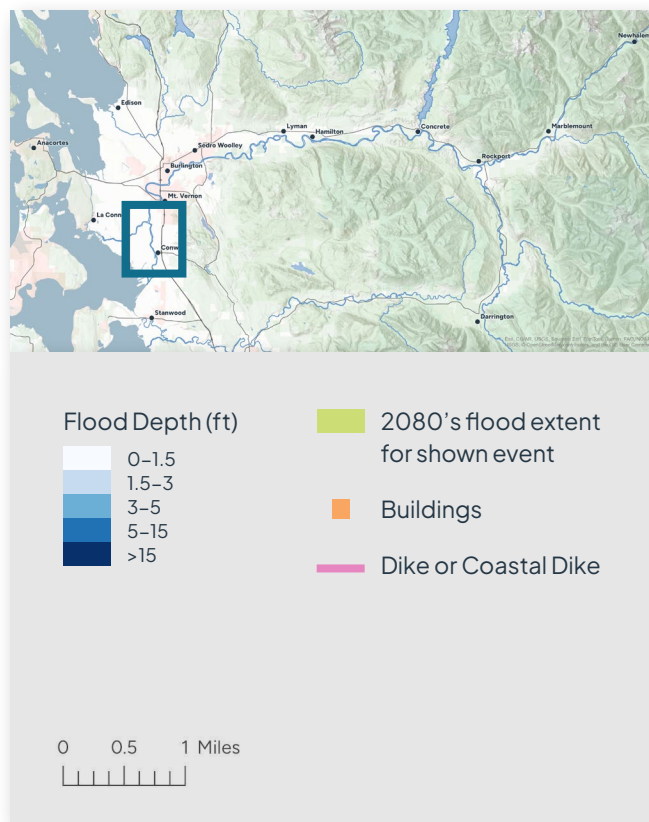
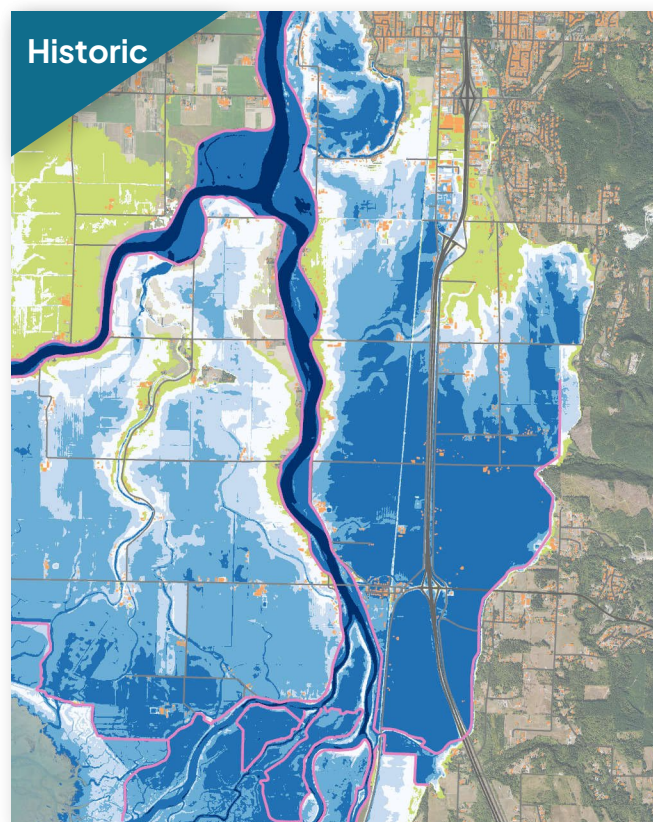
Conway | 10 Year Flood



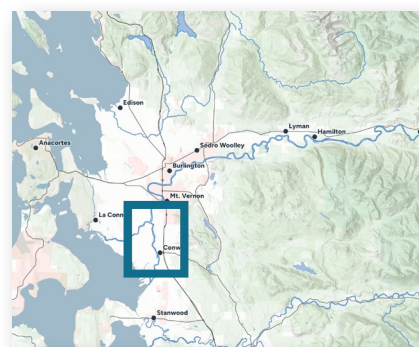
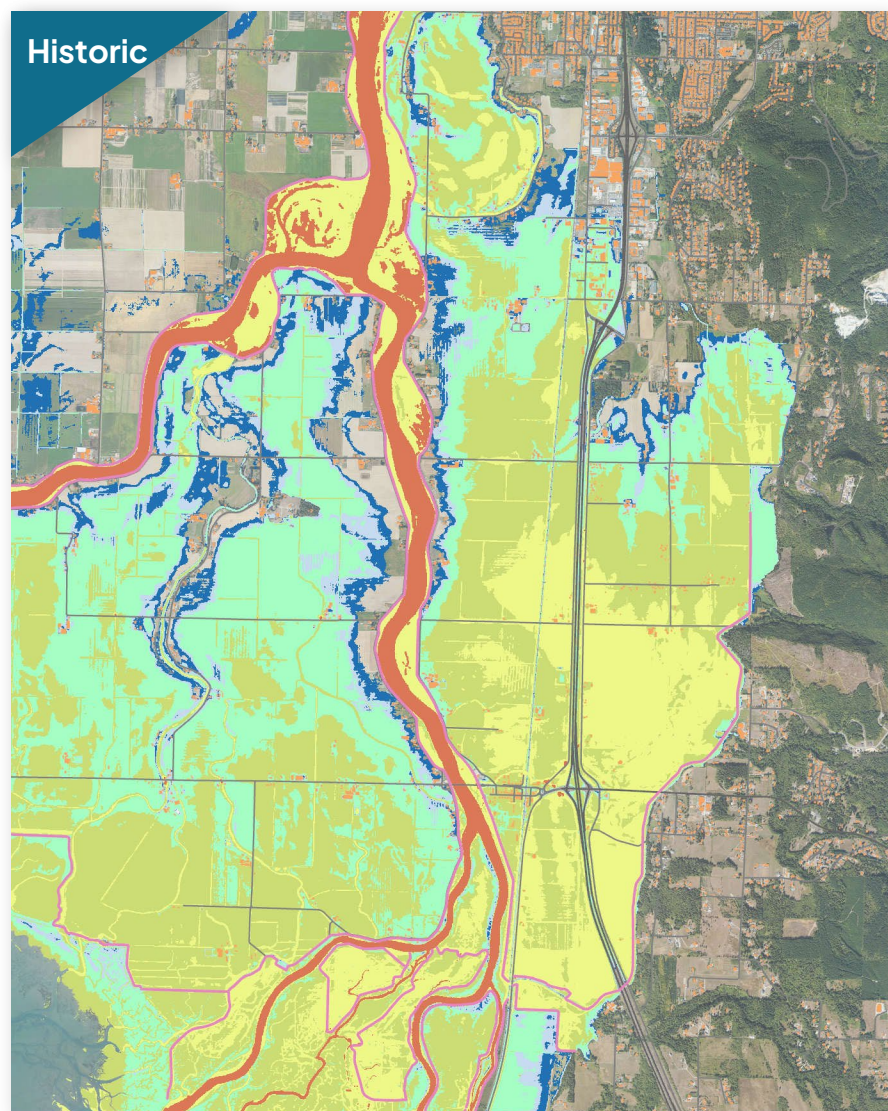
Conway | 25 Year Flood



Conway | 100 Year Flood



Conway | Depth-Velocity Hazard



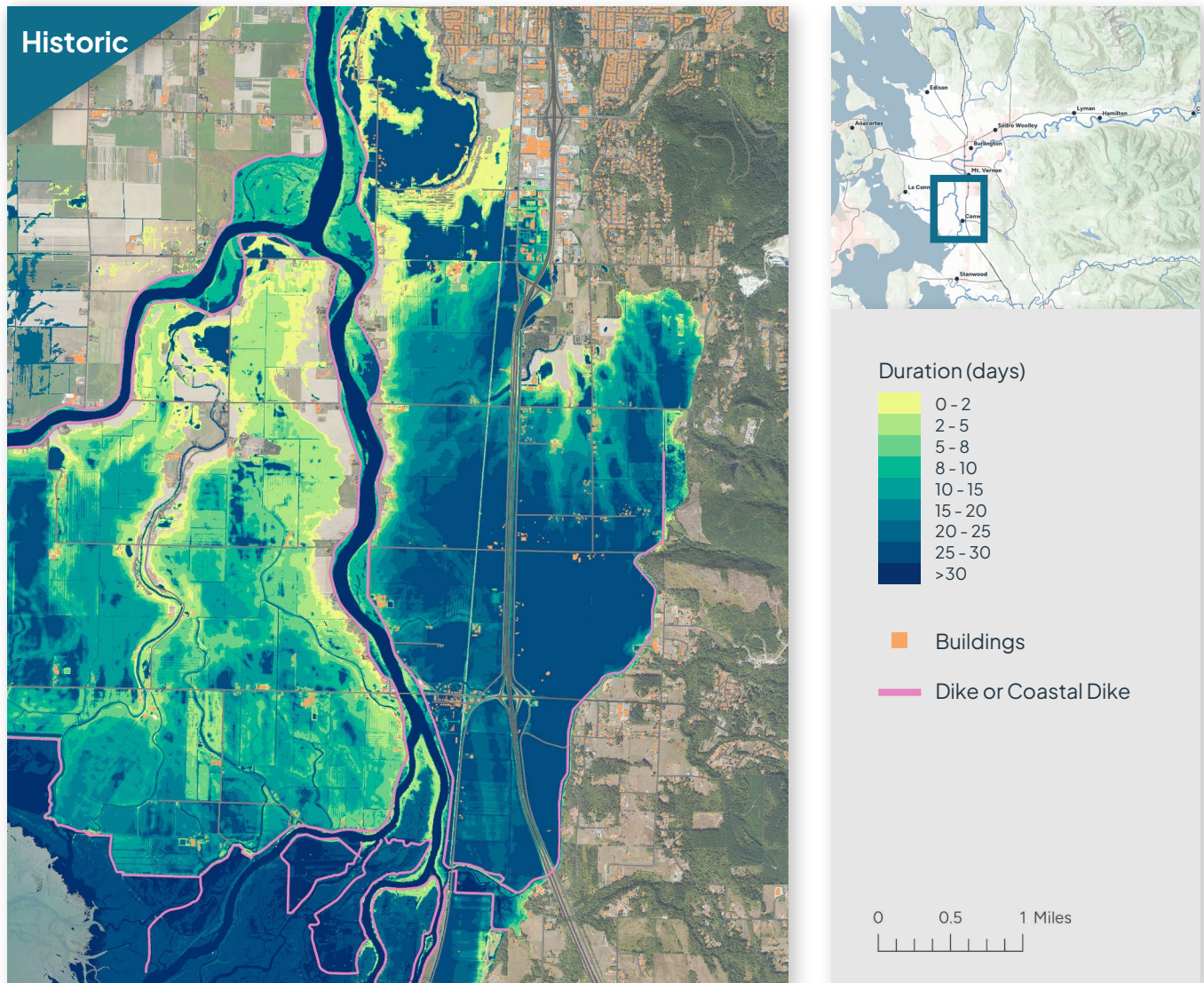
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

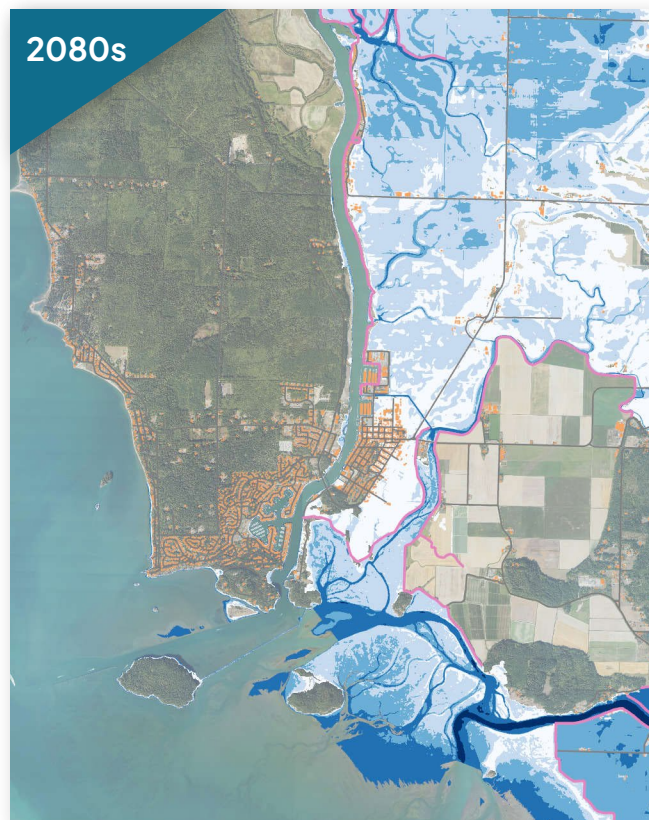
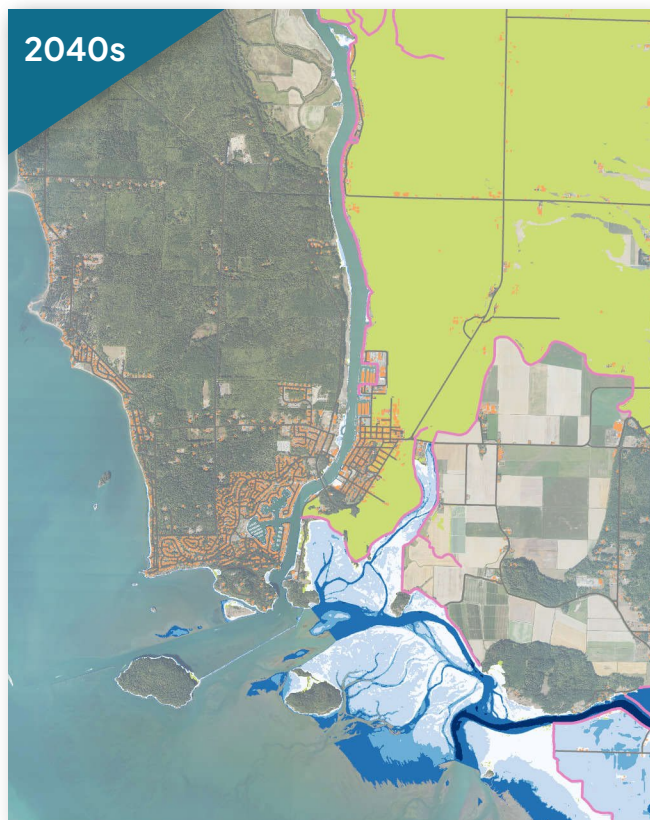
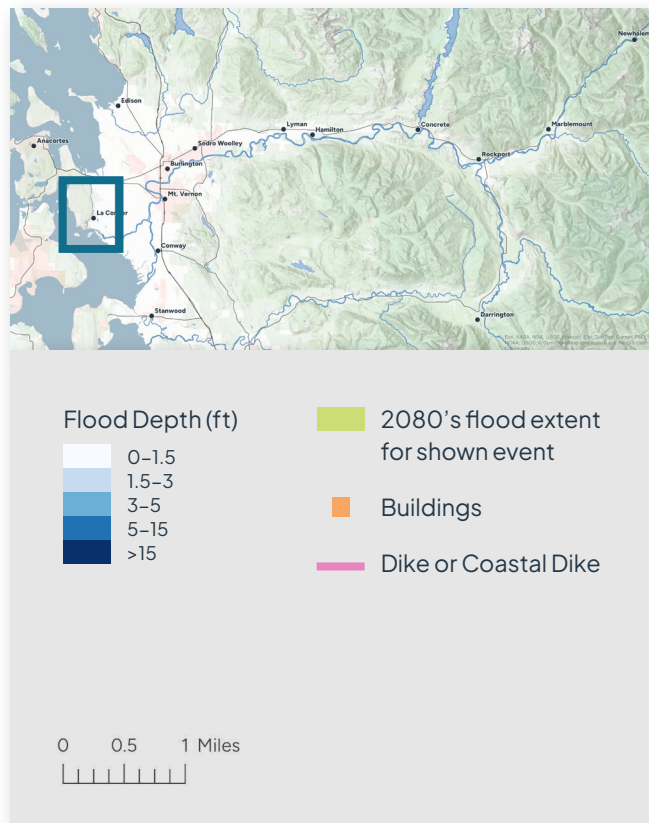
0 0.5 1 Miles

LOWER RIVER FLOODING MAPS

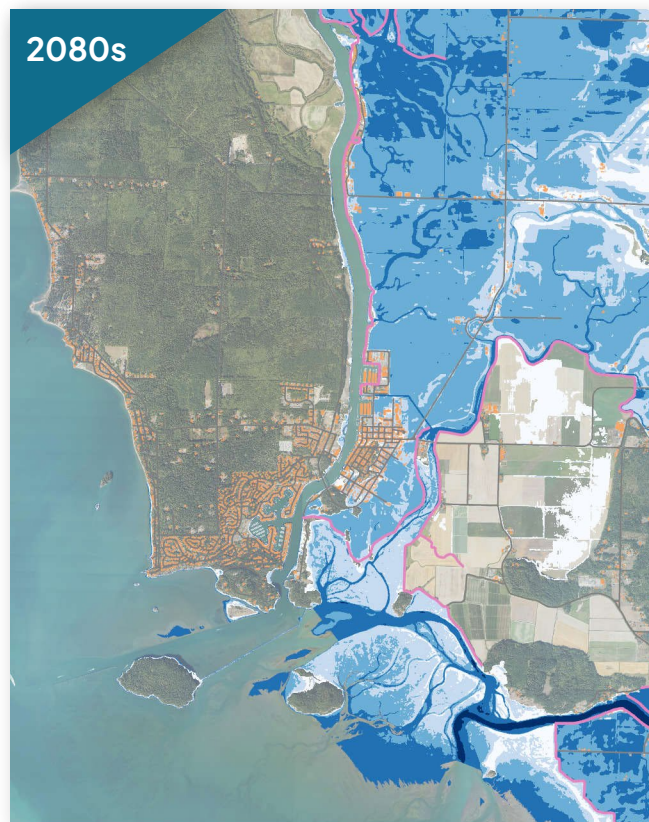
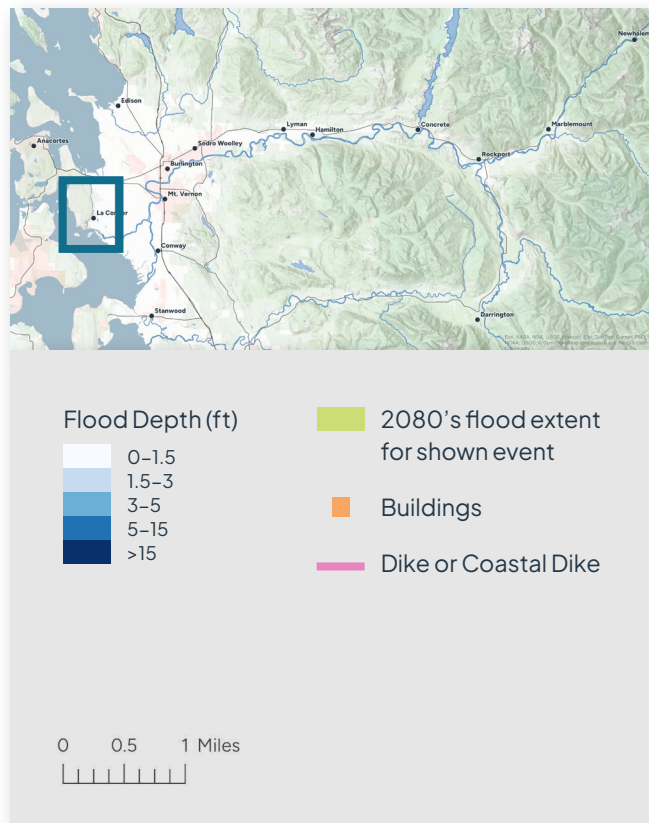
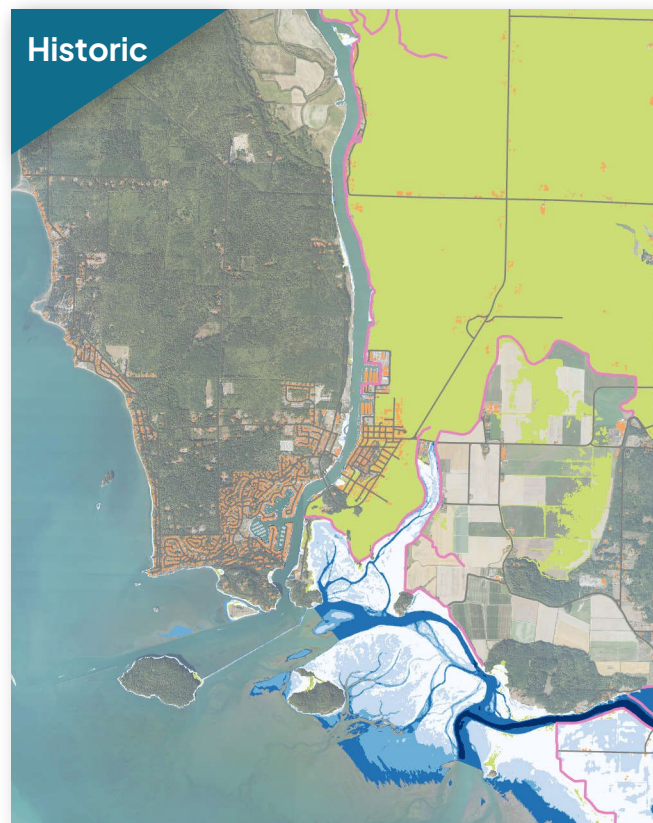
Conway | Duration



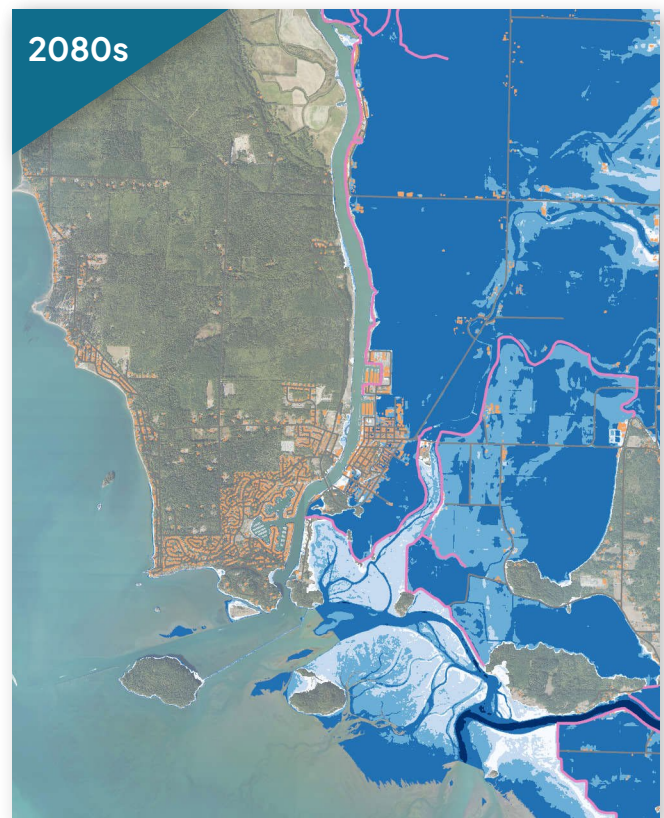
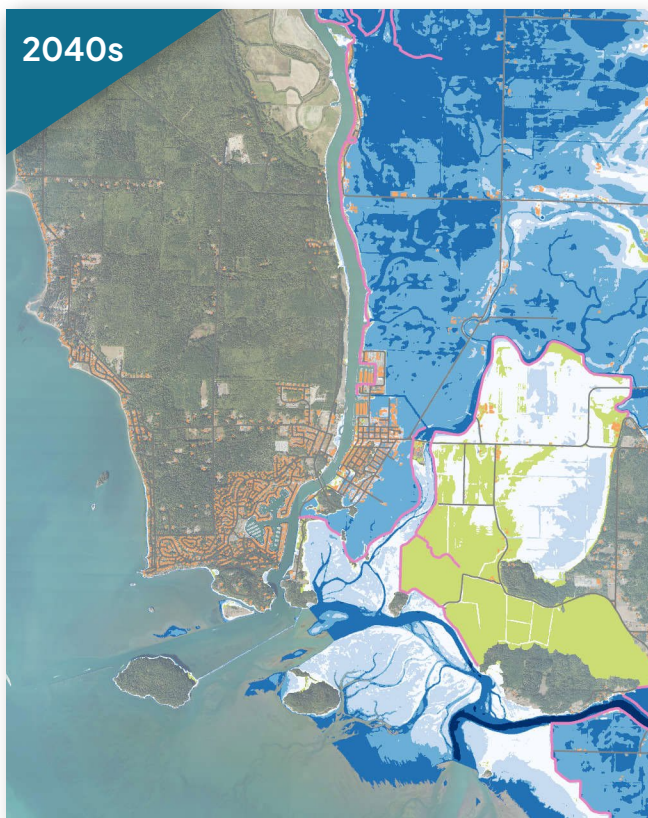
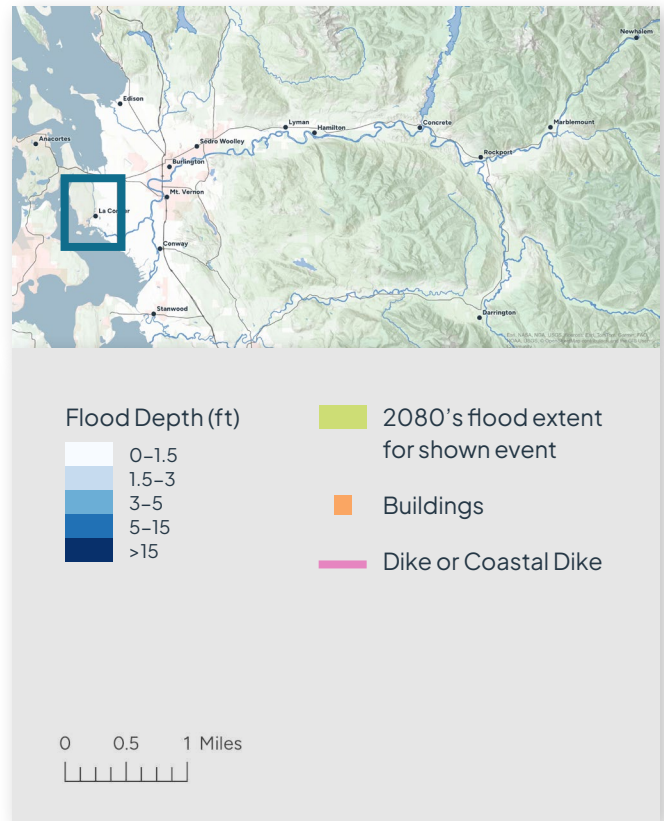
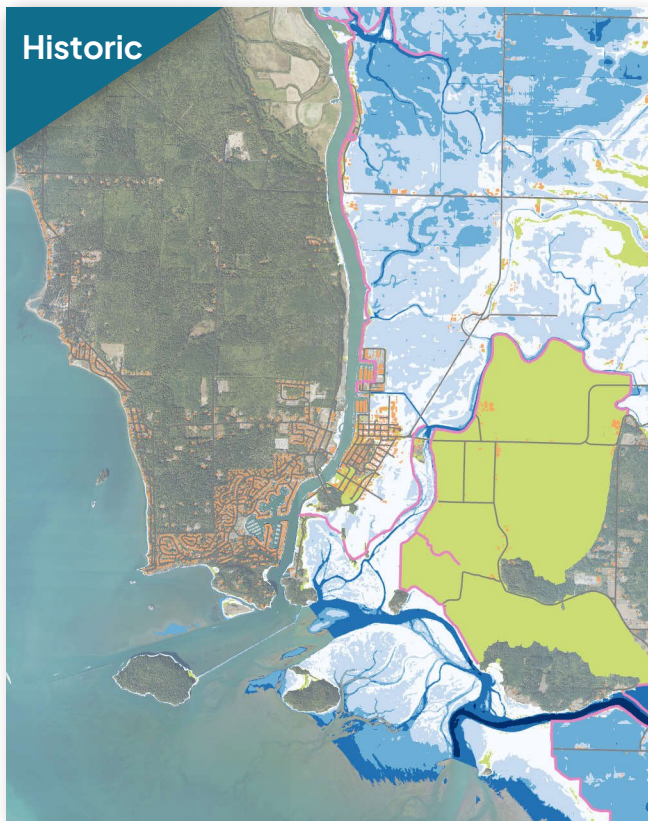
La Conner | 10 Year Flood



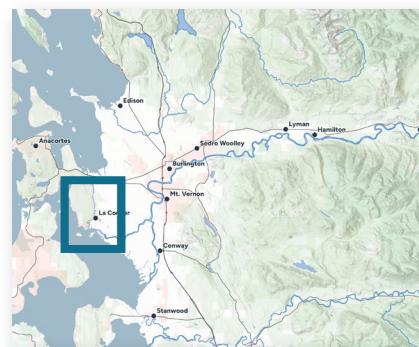
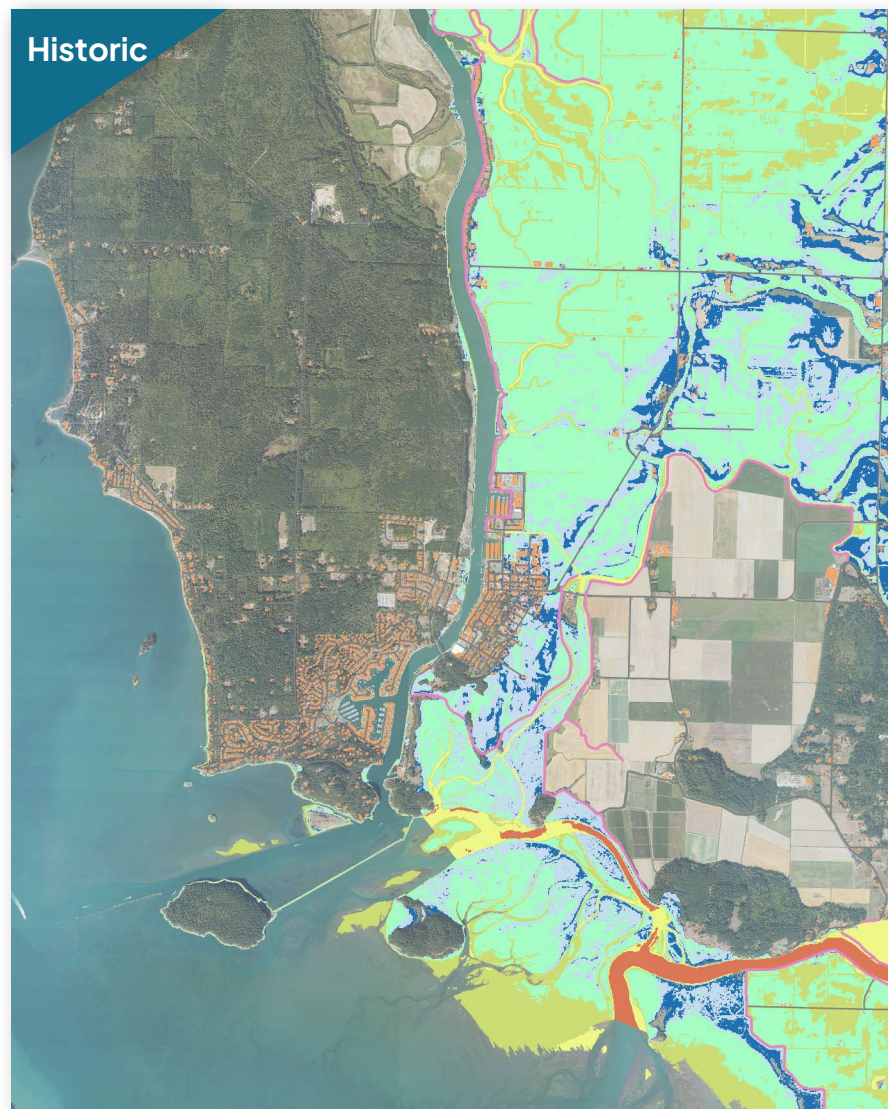
La Conner | 25 Year Flood



La Conner | 100 Year Flood



La Conner | Depth-Velocity Hazard



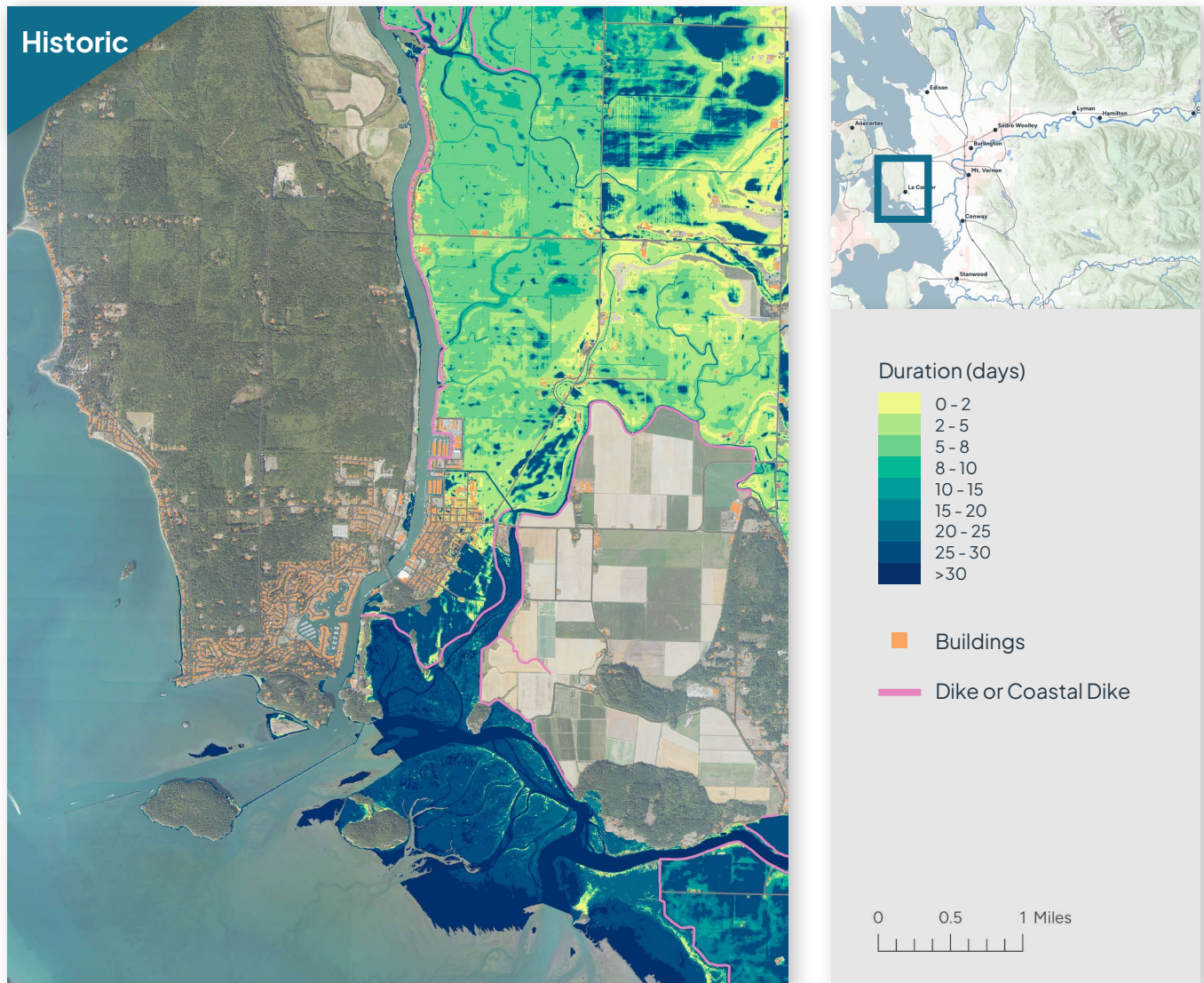
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

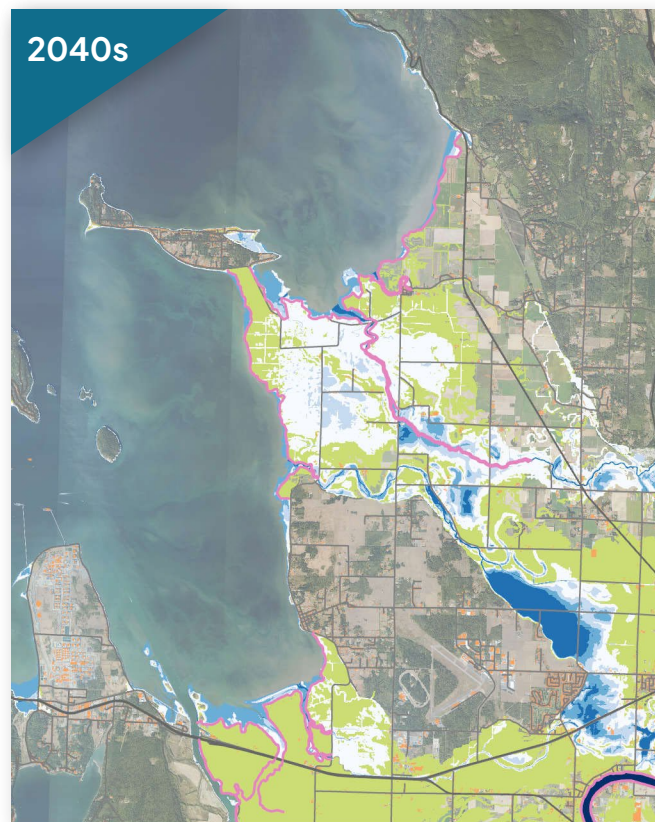
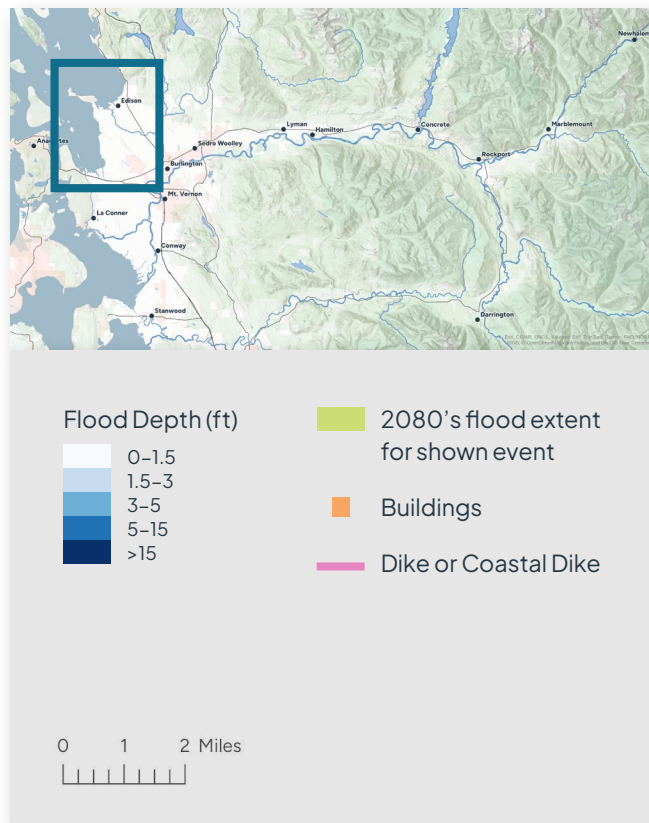
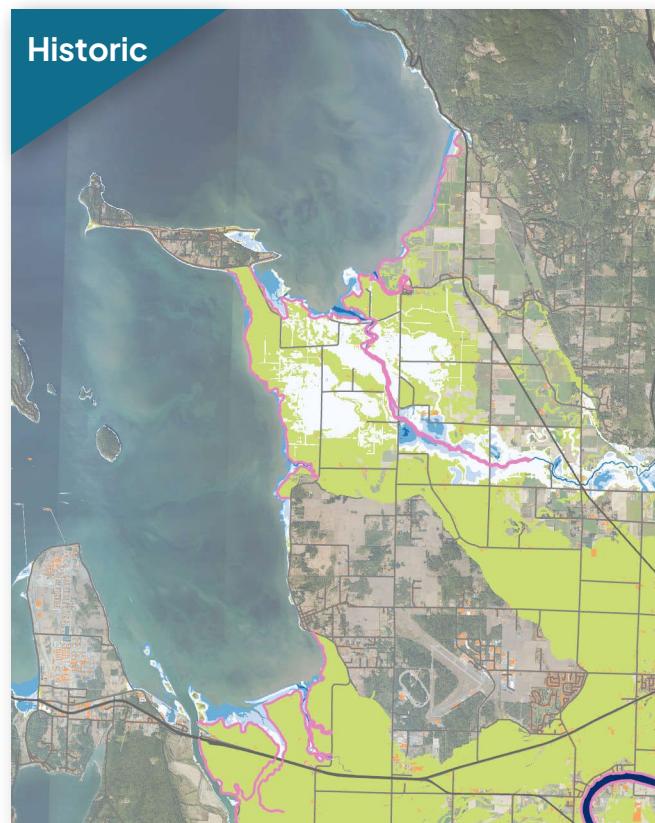
0 0.5 1 Miles

LOWER RIVER FLOODING MAPS

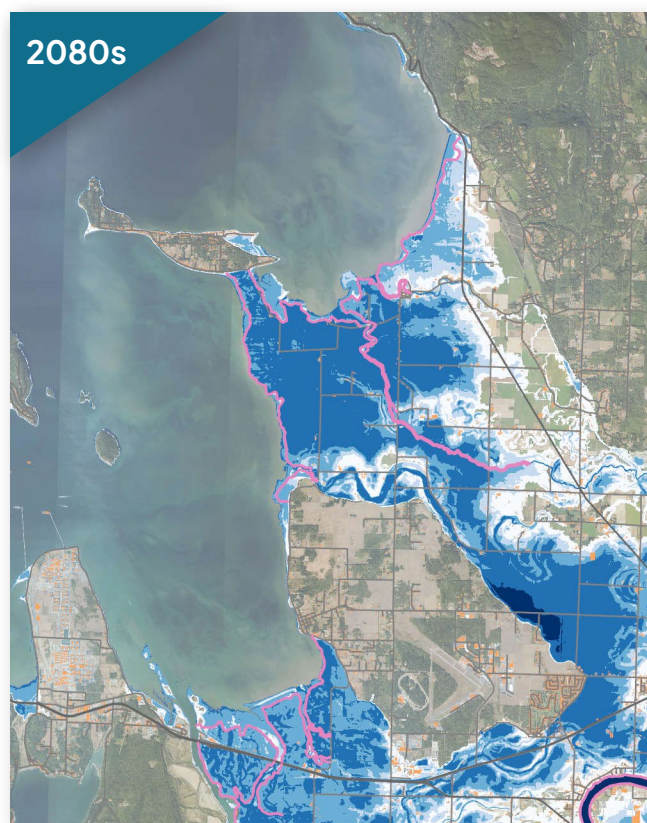
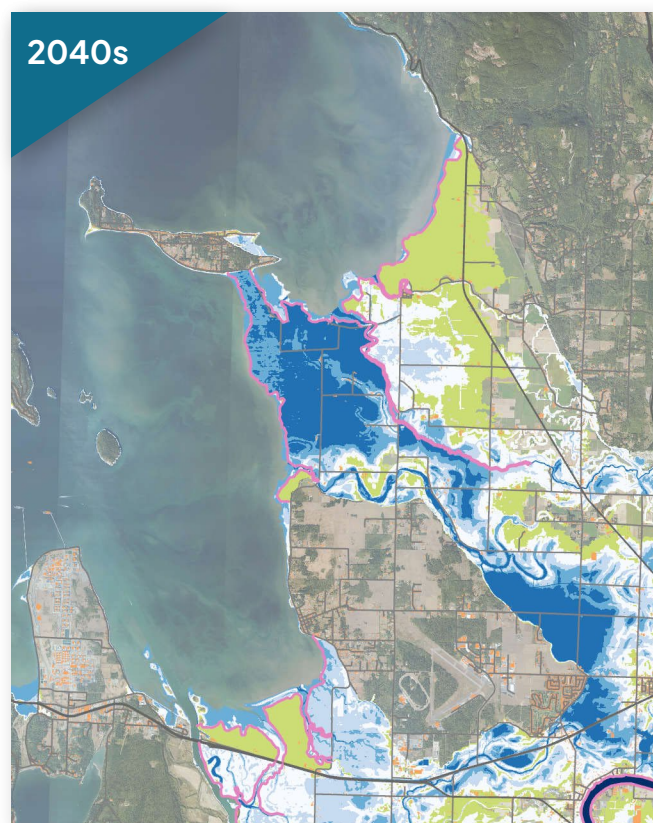
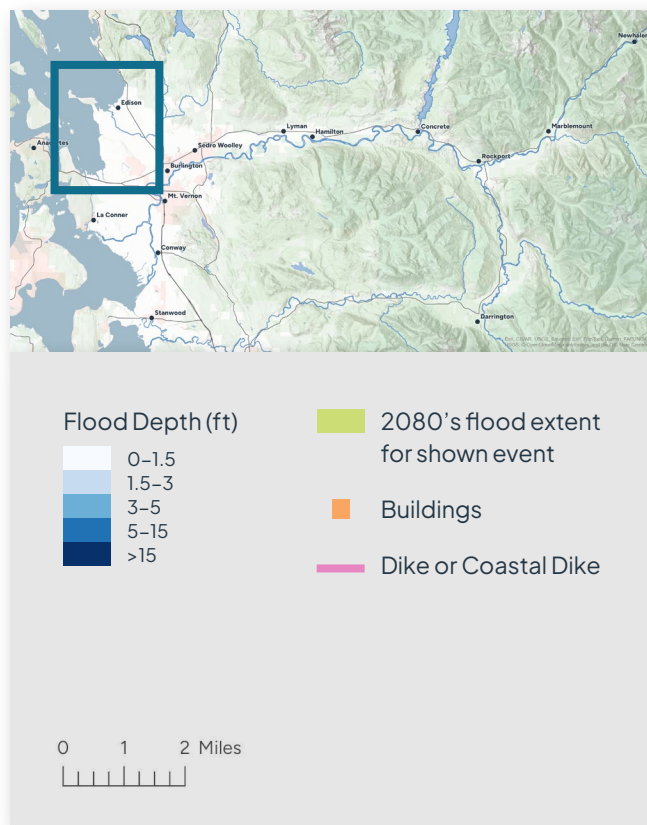
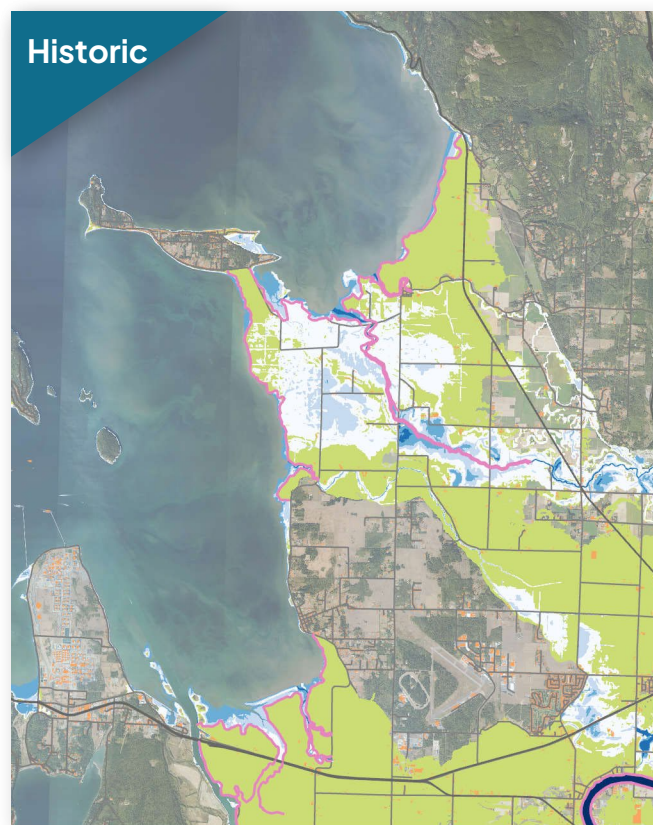
La Conner | Duration



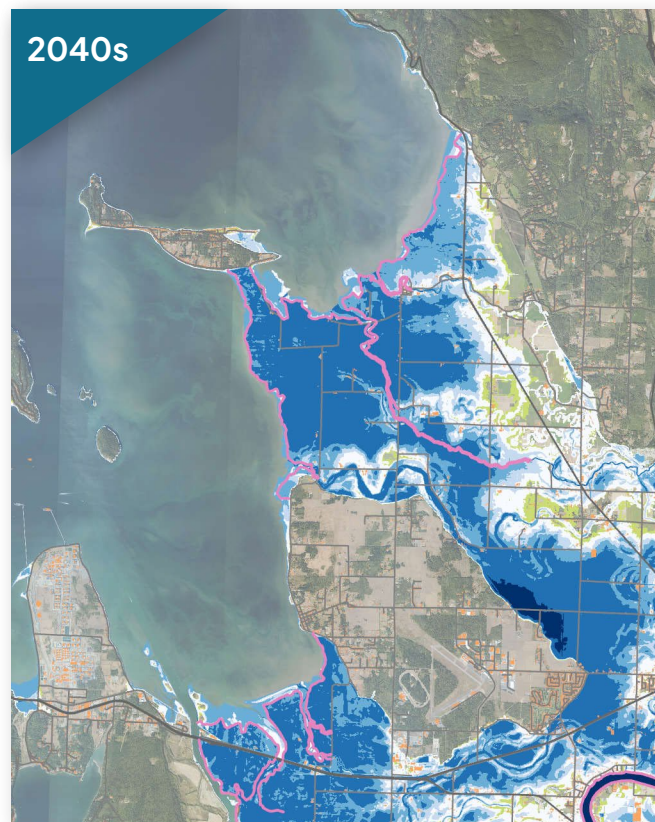
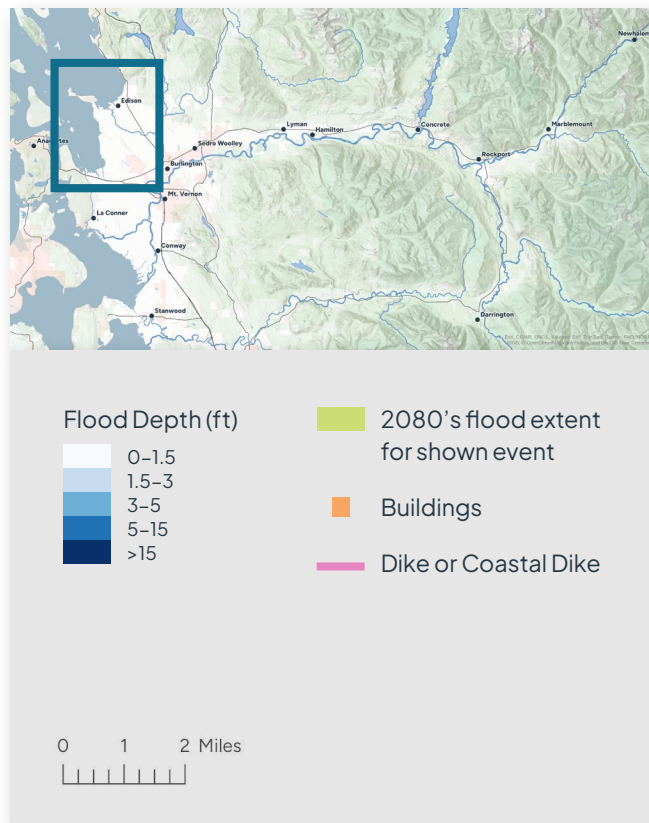
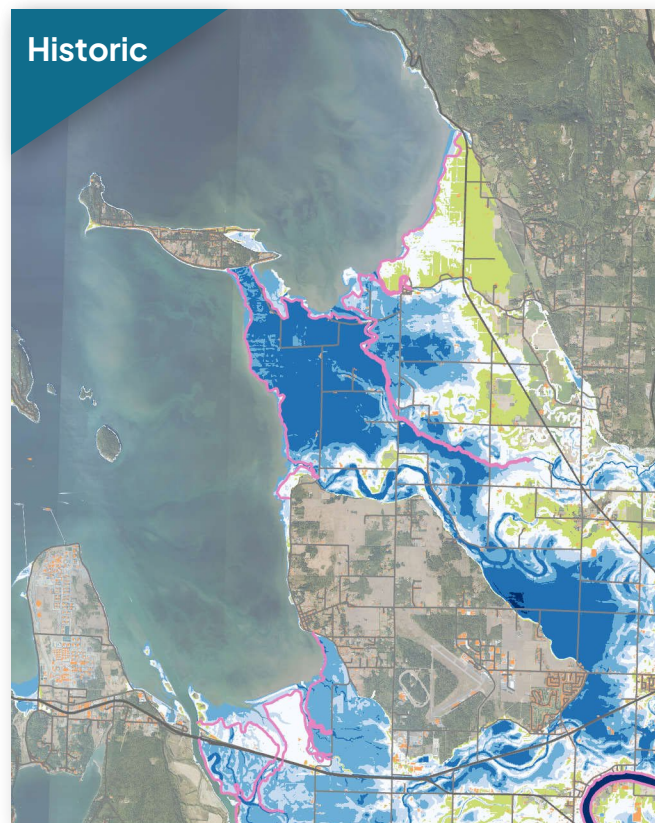
Padilla and Samish Bays | 10 Year



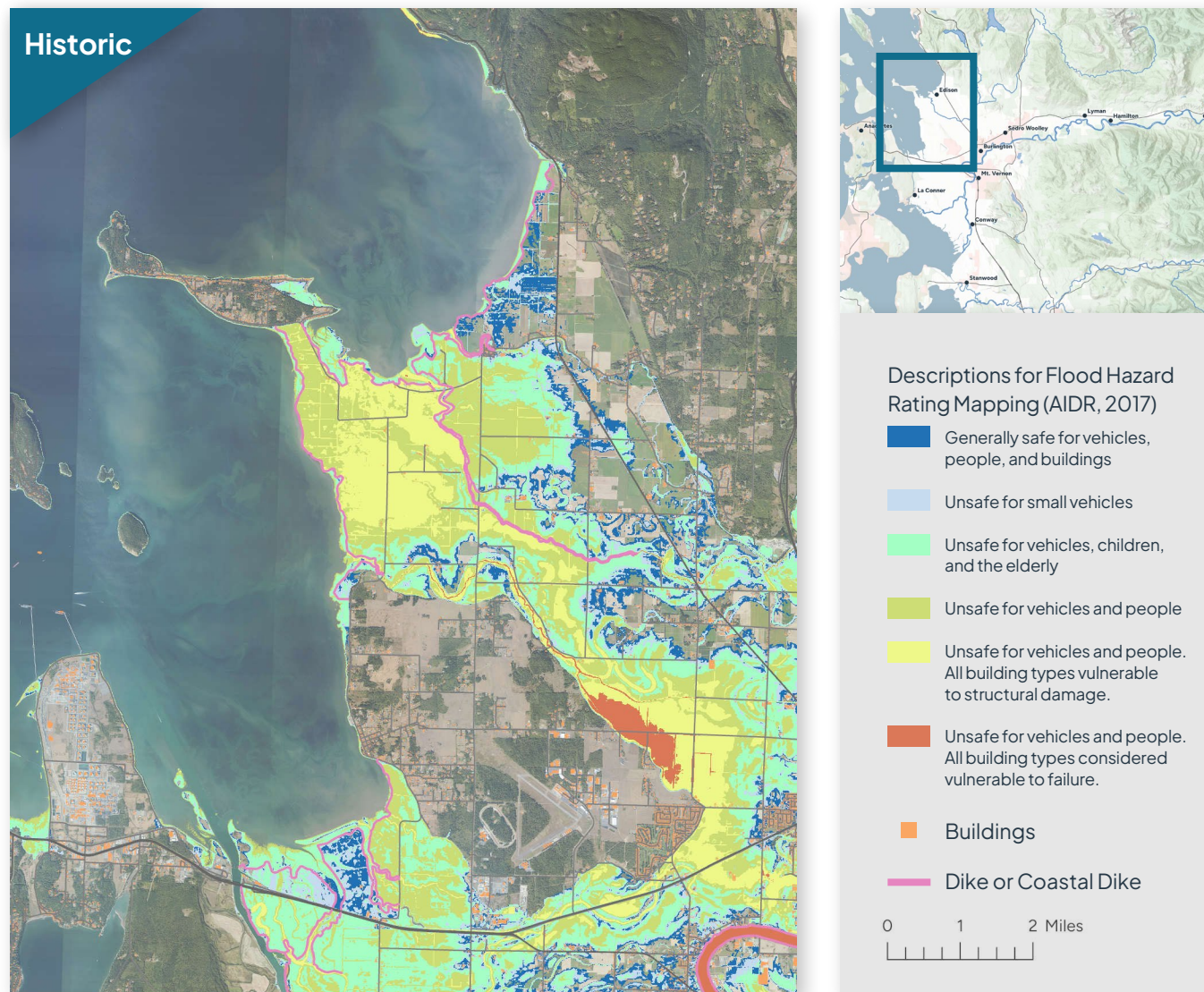
Padilla and Samish Bays | 25 Year



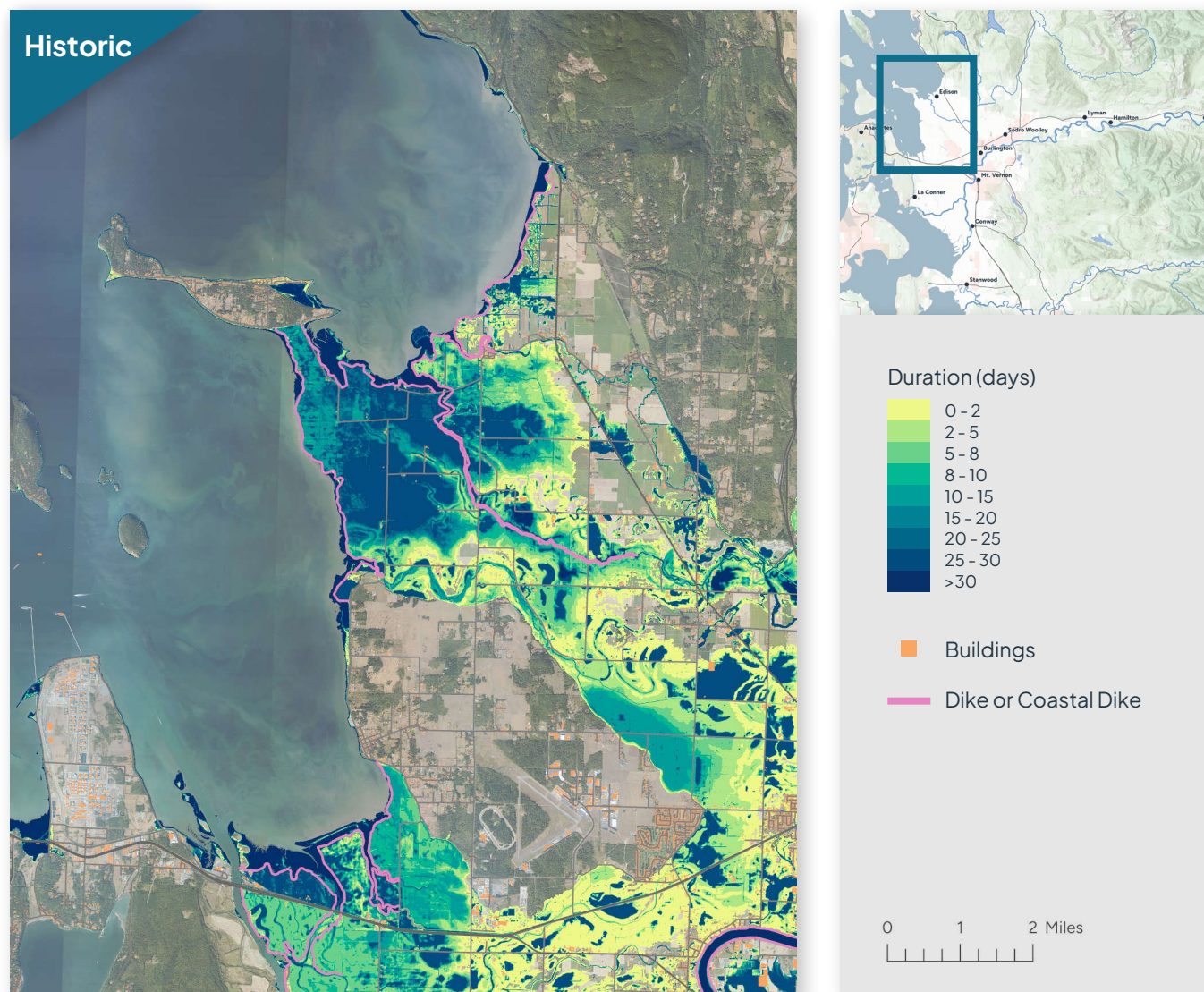
Padilla and Samish Bays | 100 Year



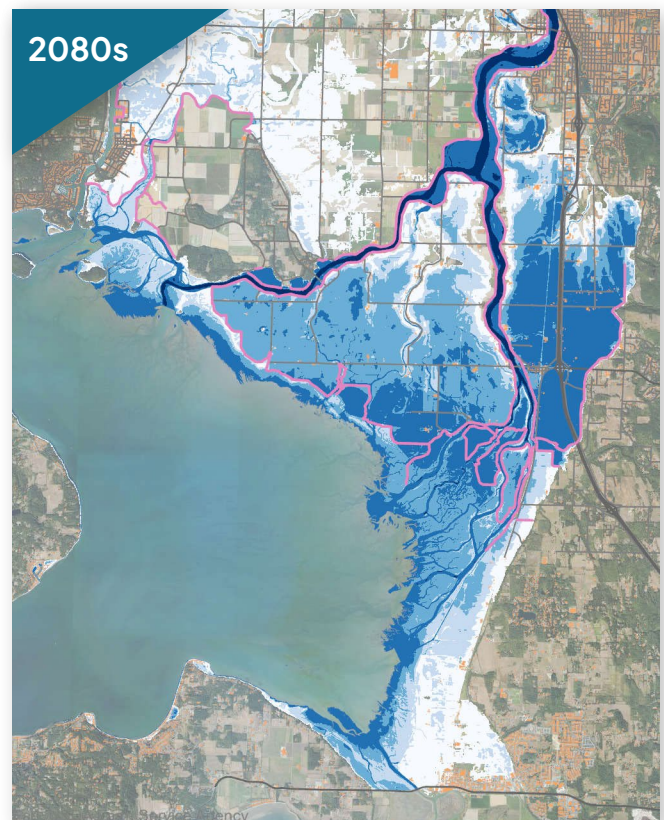
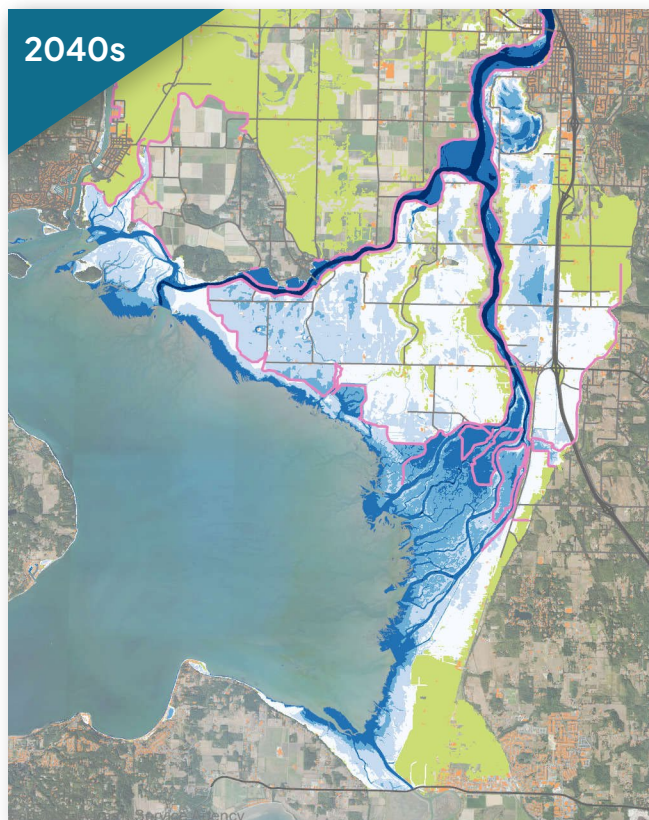
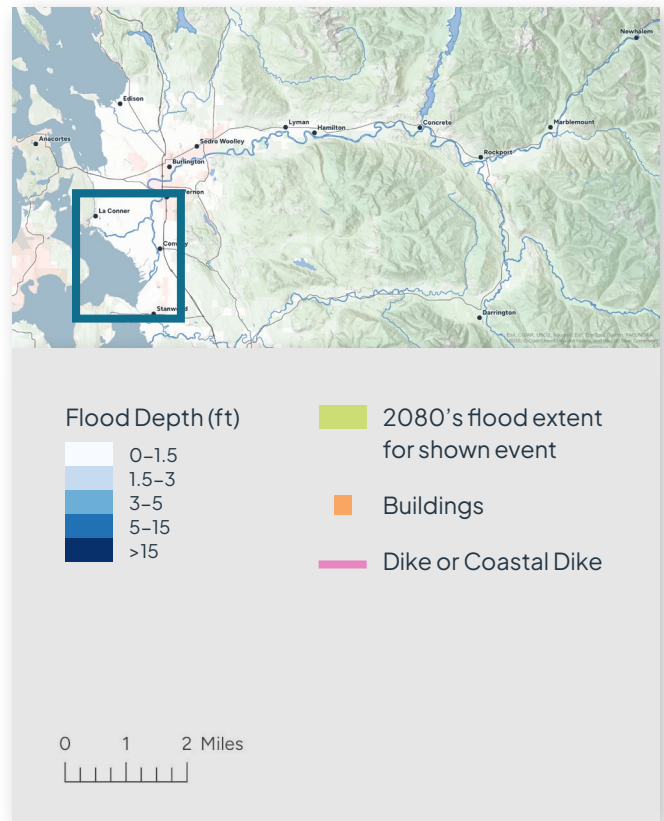
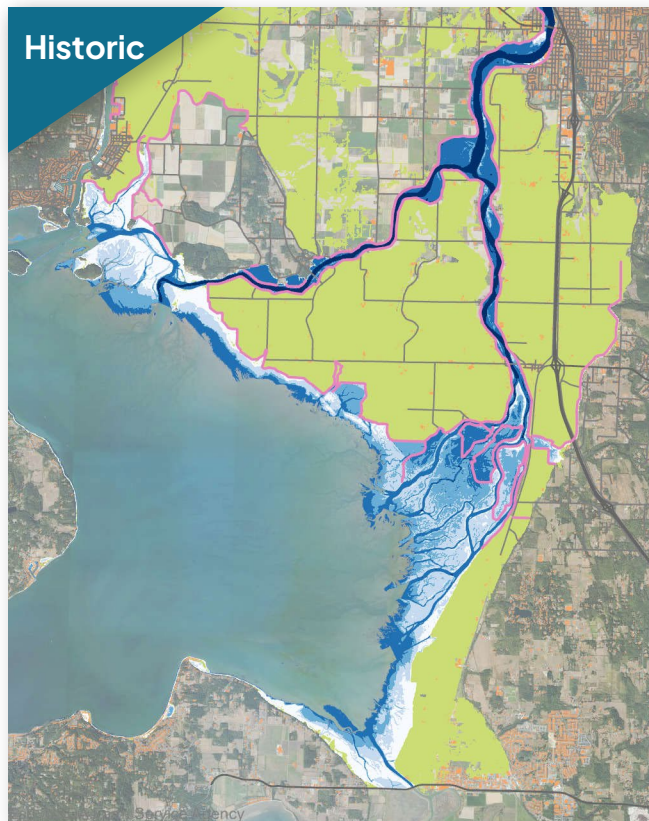
Padilla and Samish Bays | Depth-Velocity Hazard



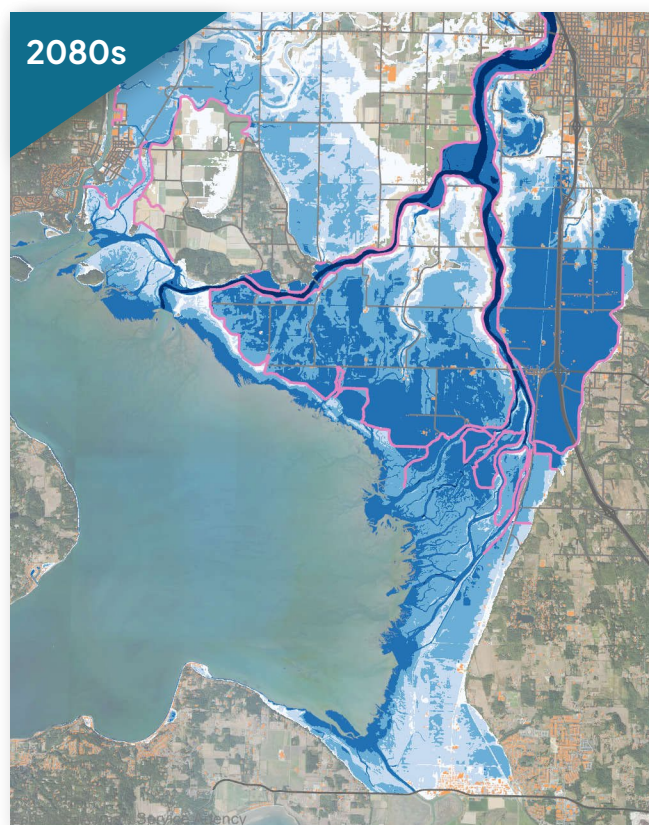
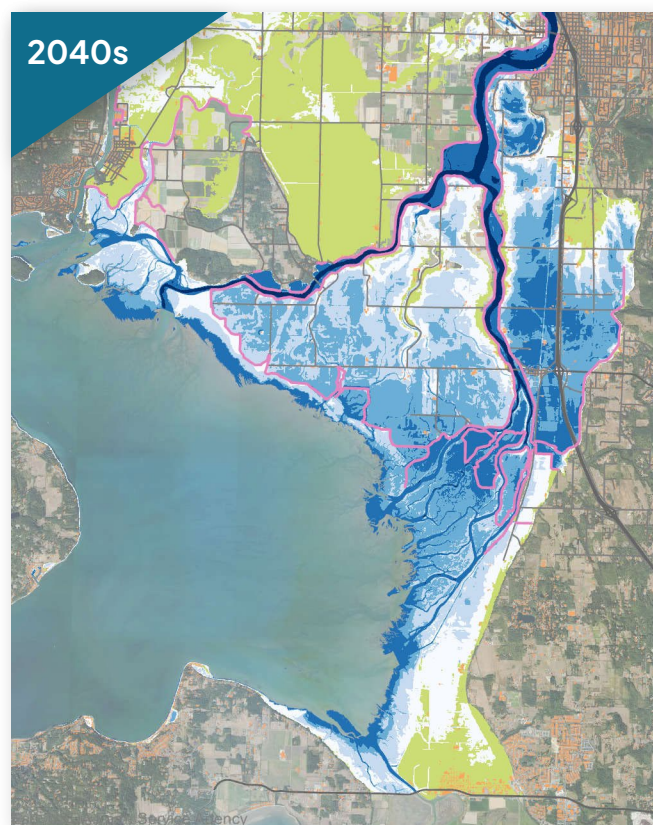
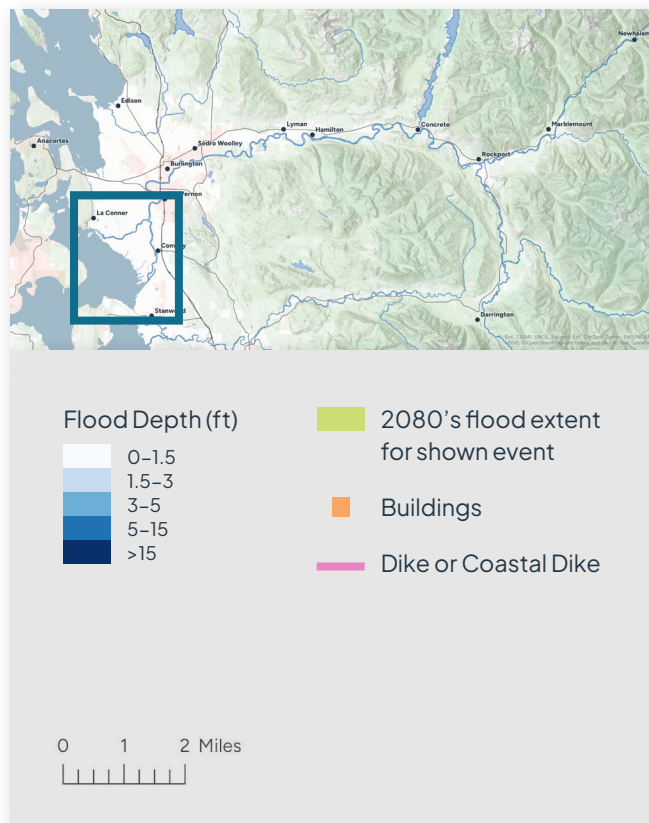
Padilla and Samish Bays | Duration



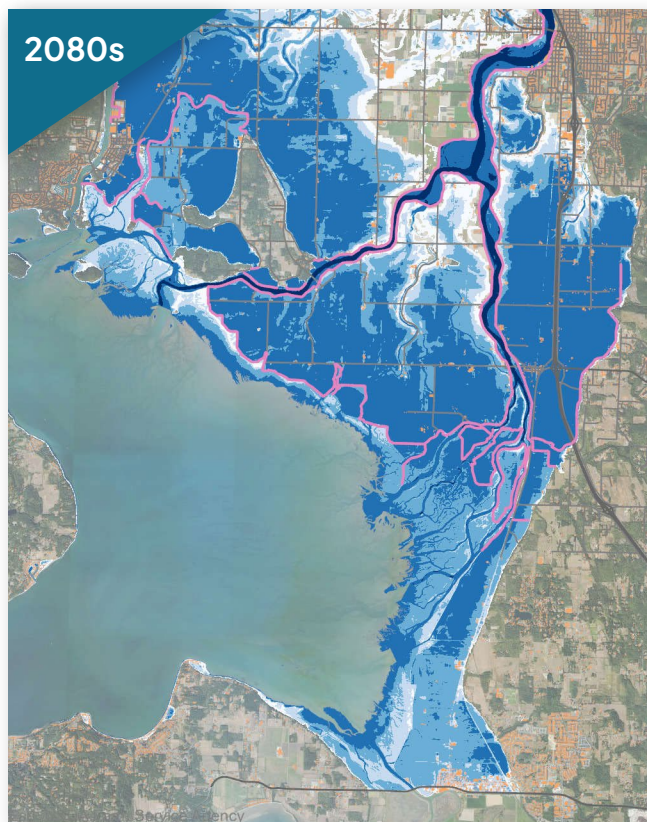
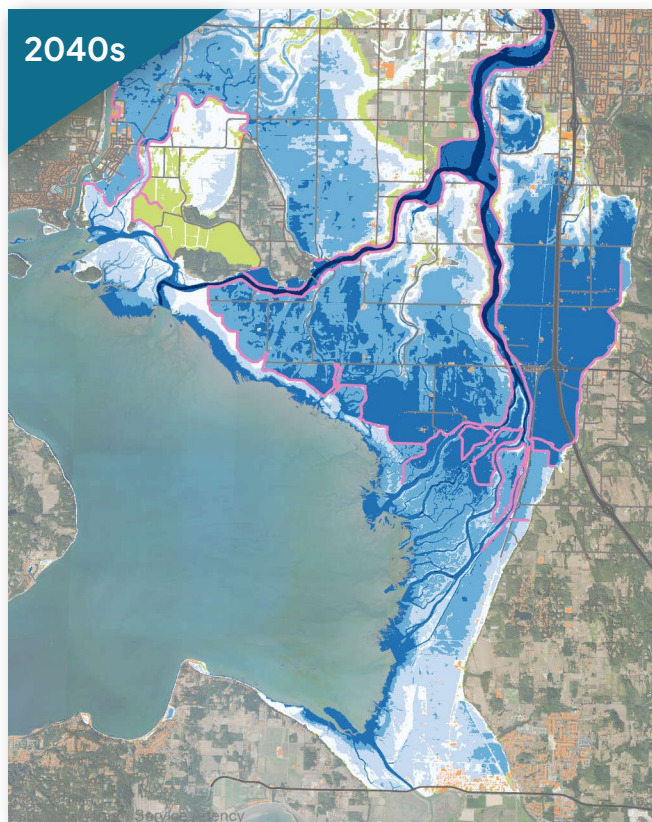
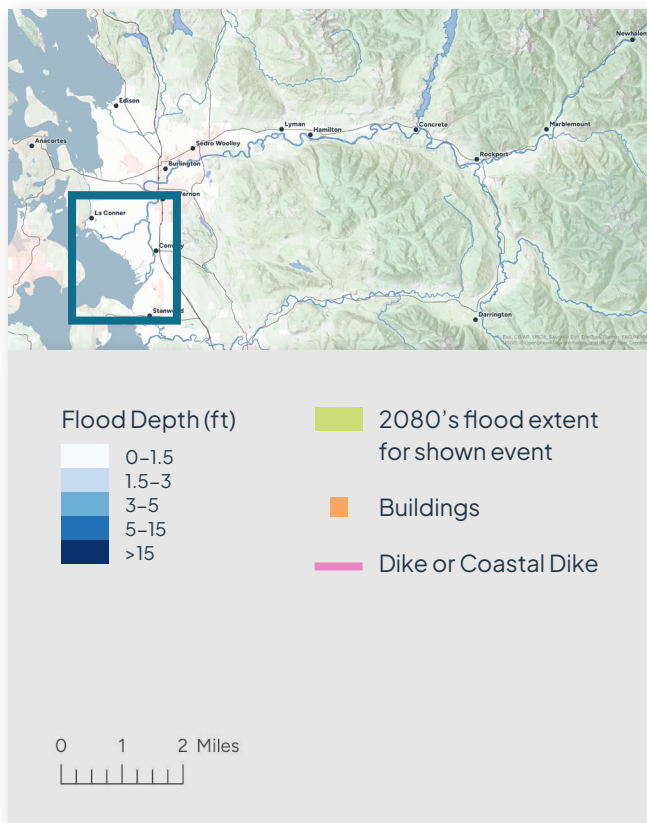
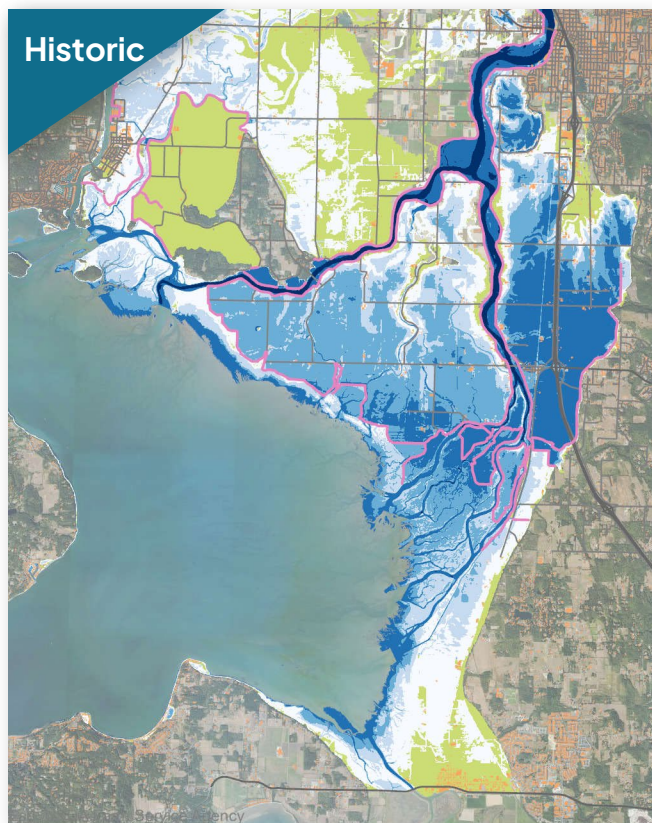
Skagit Bay | 10 Year Flood



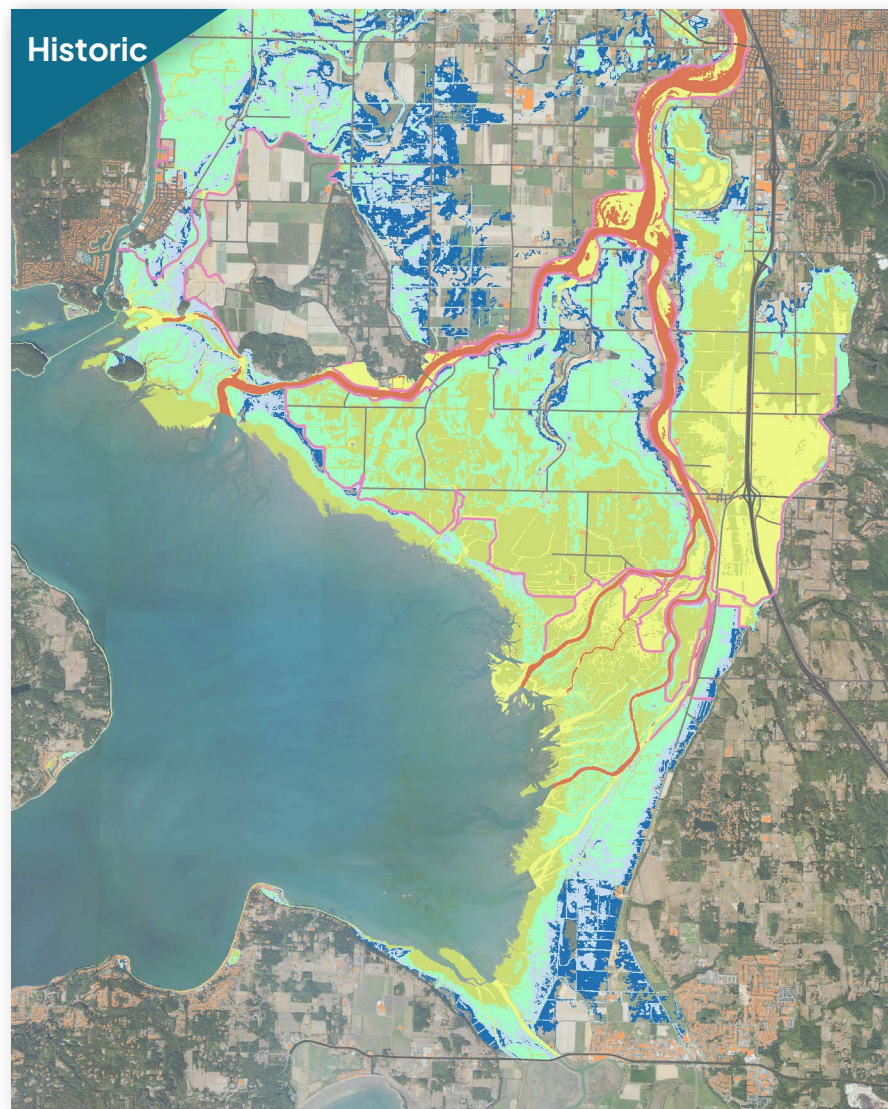
Skagit Bay | 25 Year Flood



Skagit Bay | 100 Year Flood



Skagit Bay | Depth-Velocity Hazard

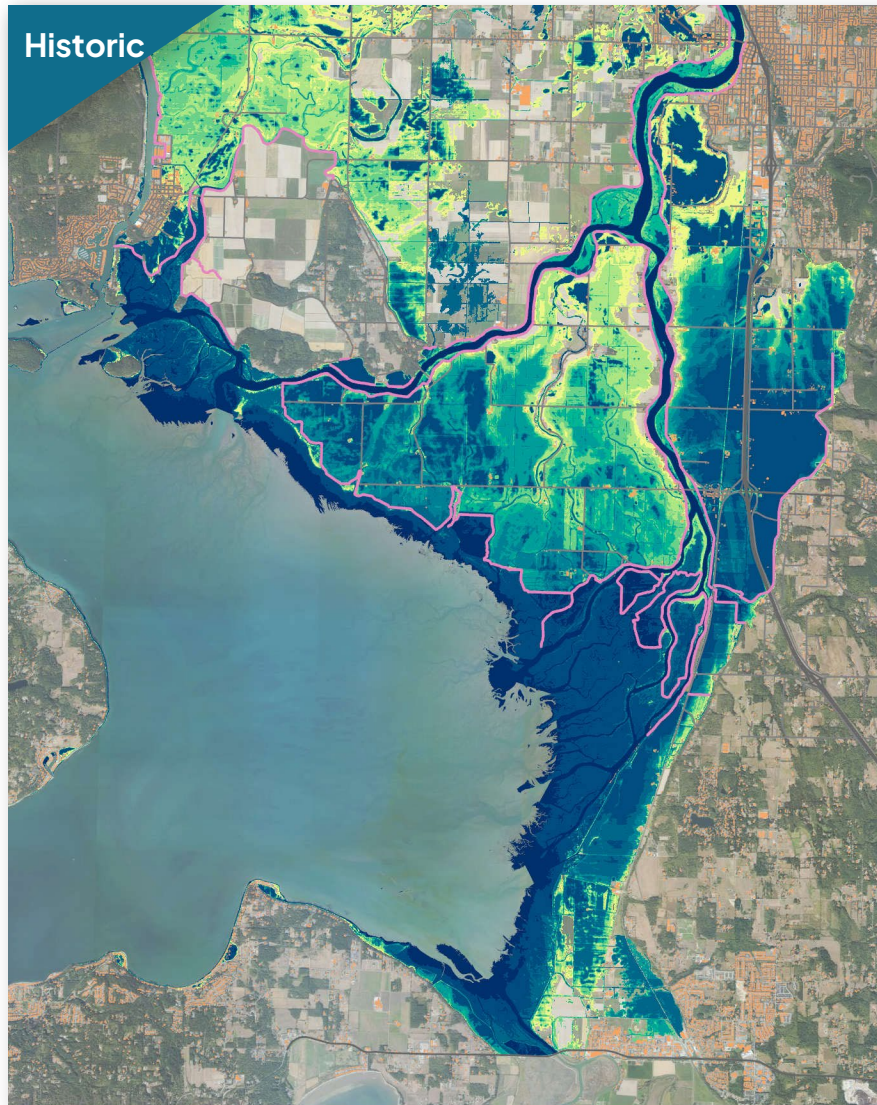


Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

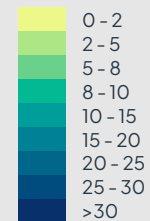
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

0 1 2 Miles

Skagit Bay | Duration



Duration (days)



Buildings

Dike or Coastal Dike





Coastal Flooding Maps

This map bundle shows coastal flooding results for Skagit River areas along Skagit Bay, Swinomish Channel, Padilla Bay, and Samish Bay.

This set includes an overview map of the area and zoomed-in map areas for Padilla and Samish Bays, La Conner, and Skagit Bay. Background information on coastal flooding and climate change can be found in the full *Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities* report and specific details on the hydraulic model that created these maps can be found in [Appendix A](#). Animations for select locations can be found at the Skagit Climate Science Consortium website.

These maps are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, dike failures, larger than modeled events, or other factors. Maps should be used at your own risk.

How to Read Coastal Flooding Maps

What These Maps Show

For all maps, the background is based on aerial imagery (USDA 2023). Structures are shown as orange rectangles (Microsoft 2022). Pink lines, if present, show dike or coastal dike locations (Skagit County 2022), and dark gray lines show major transportation routes (WSDOT 2008, Skagit County 2019). Dark blue lines show rivers on the overview maps. Coastal model results are shown for areas above the mean tide line.

FLOOD DEPTH MAPS



These maps are organized into sets of three, showing results for Historic (top), 2040s (middle), and 2080s (bottom) flood magnitudes. Each set of maps shows the model results for a specific flood frequency: 10-year, 25-year, and 100-year. Maps show the depth of coastal flooding in shades of blue, where darker blue indicates deeper water and lighter blue indicates shallower water. In order to see how coastal flooding is projected to change in the future, the Historic and 2040s maps also show the estimated extent of the 2080s flood in bright green. There is no bright green shading for the 2080s map because the map is already showing the depth and extent of the 2080s flood. All three maps are at the same scale.

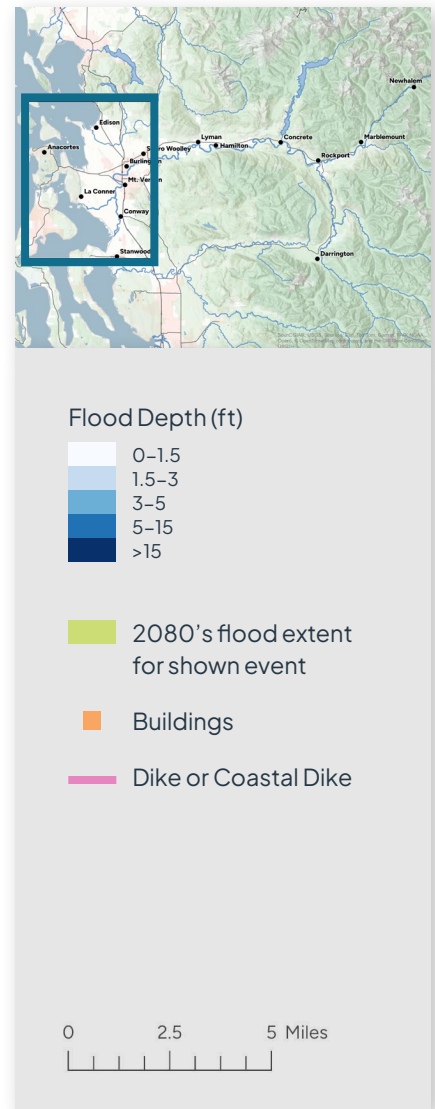
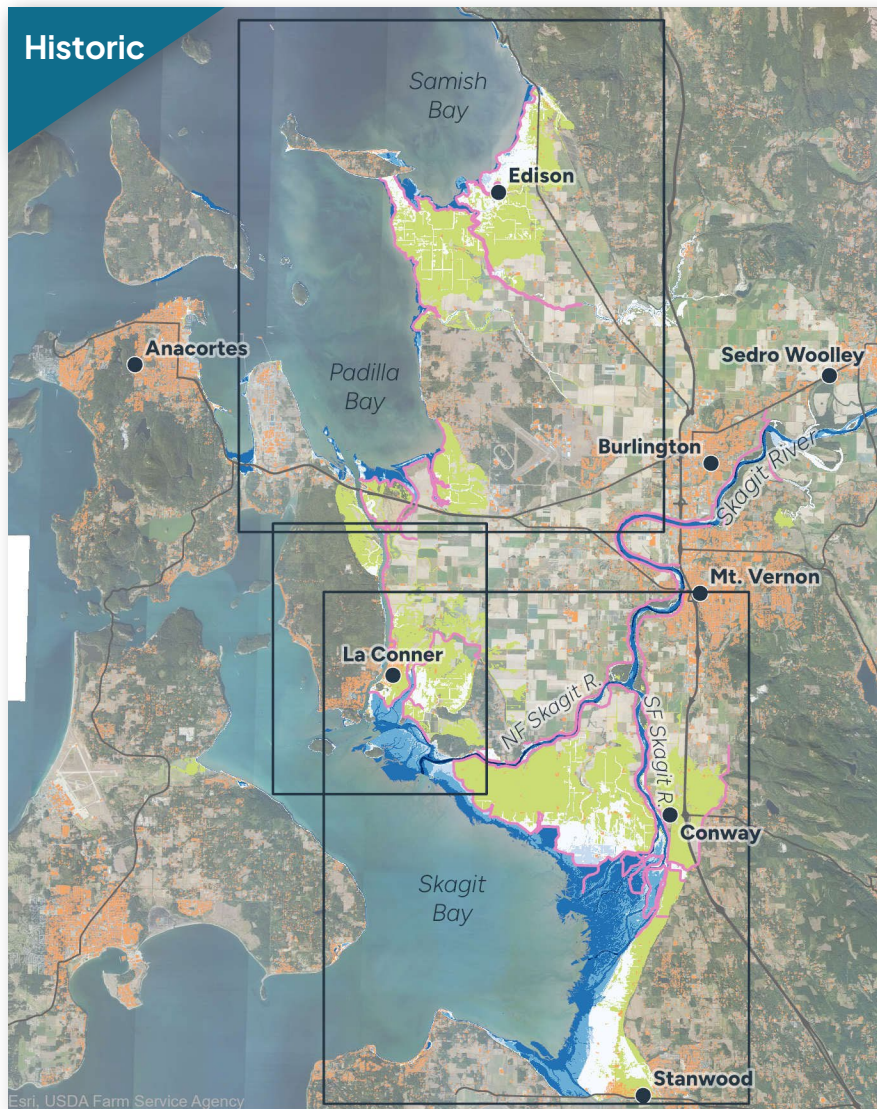
DEPTH-VELOCITY HAZARD MAPS



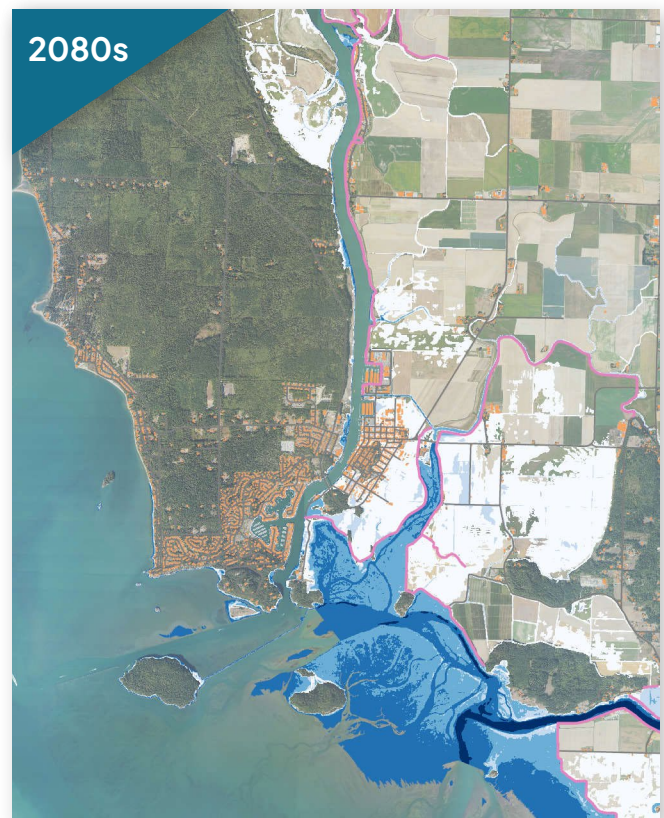
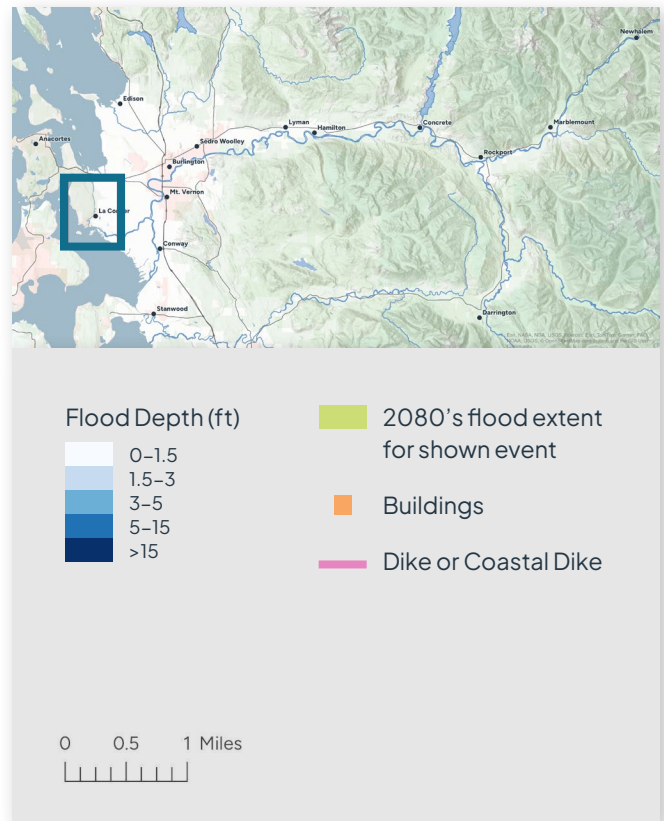
These maps show depth-velocity hazards for a historic 100-year event. Only the historic results are shown; maps for the 2040s or 2080s are not included. The hazard classifications shown in the key were assigned based on a standard international practice (AIDR, 2017) and grouped into six hazard ratings. The hazard mapping is based on clearwater hazards and does not account for secondary hazards such as geomorphic hazards (e.g., erosion, debris flows, etc.). In addition, the hazard categories were developed for riverine flooding, and may not apply as readily to coastal flood risks. Colors show when water poses a risk to children, adults, vehicles, and structures due to depth, water velocity or a combination of the two.

COASTAL FLOODING MAPS

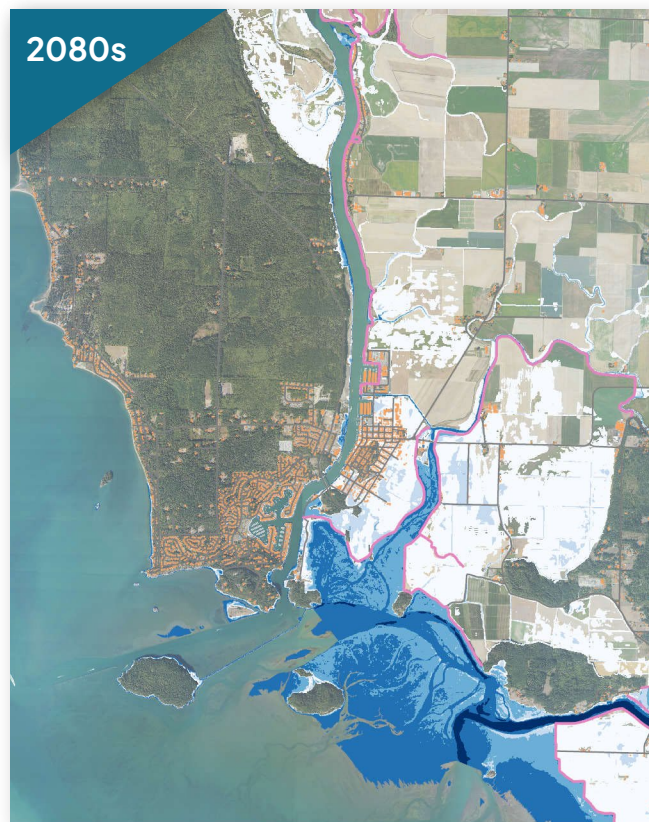
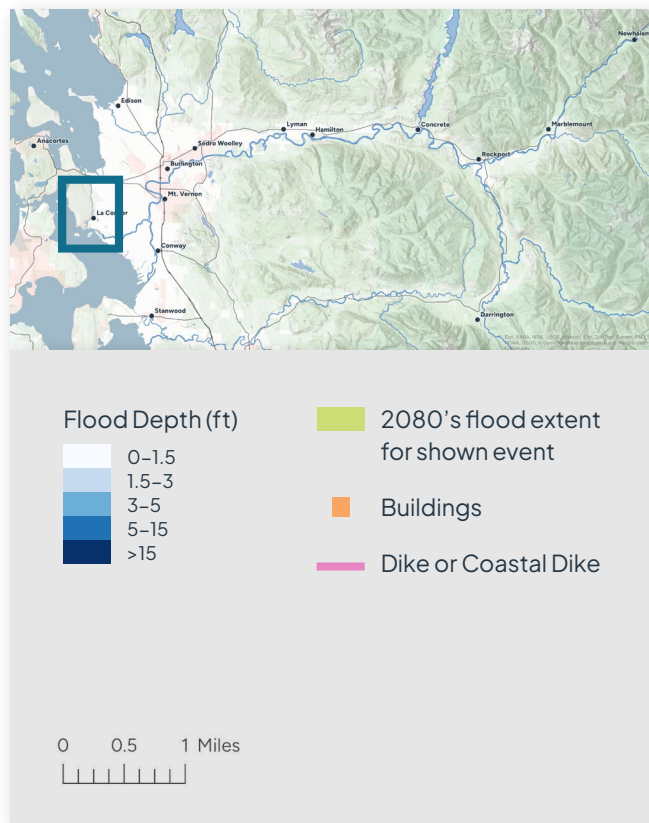
Overview Map



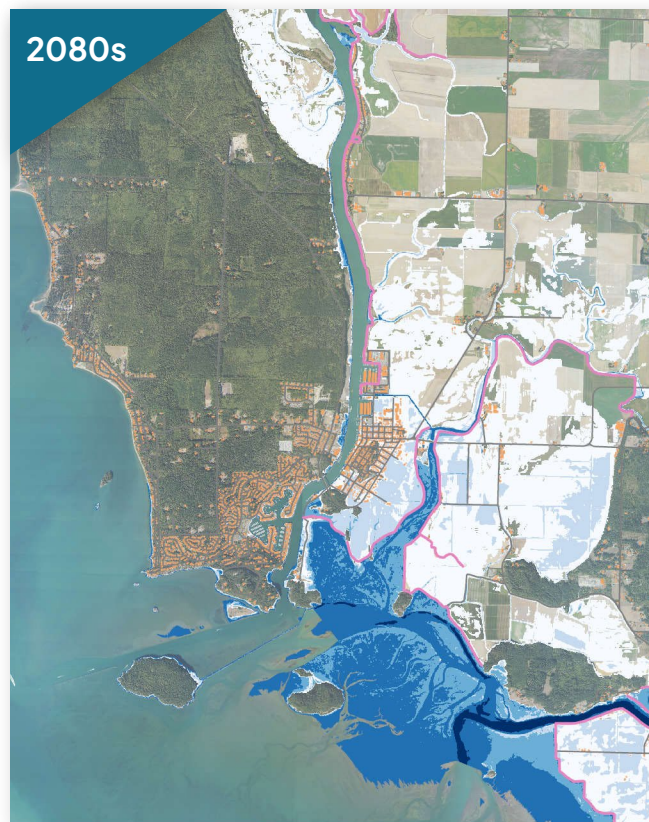
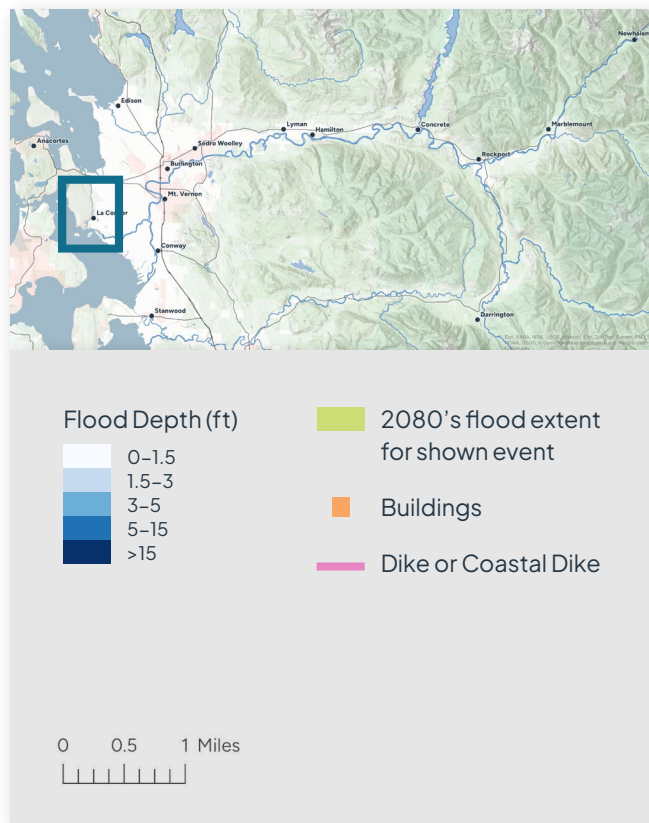
La Conner | 10 Year Flood



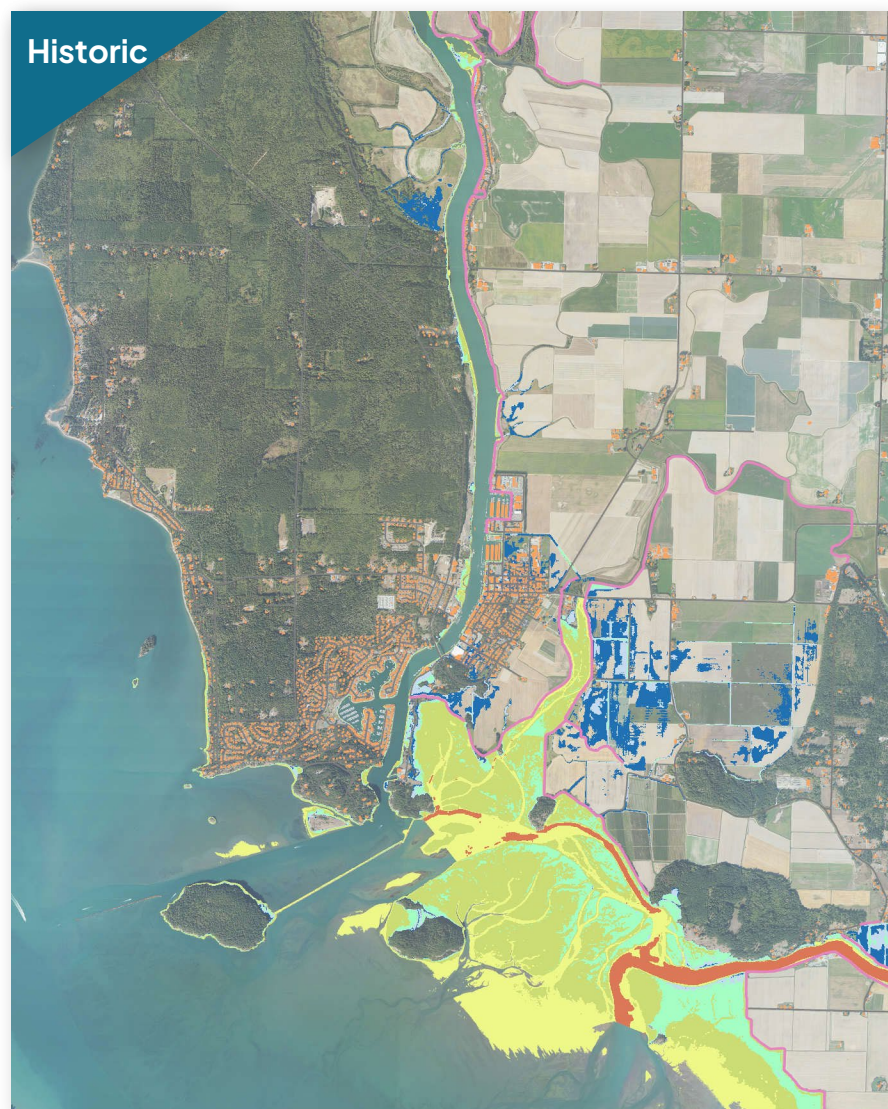
La Conner | 25 Year Flood



La Conner | 100 Year Flood



La Conner | Depth-Velocity Hazard

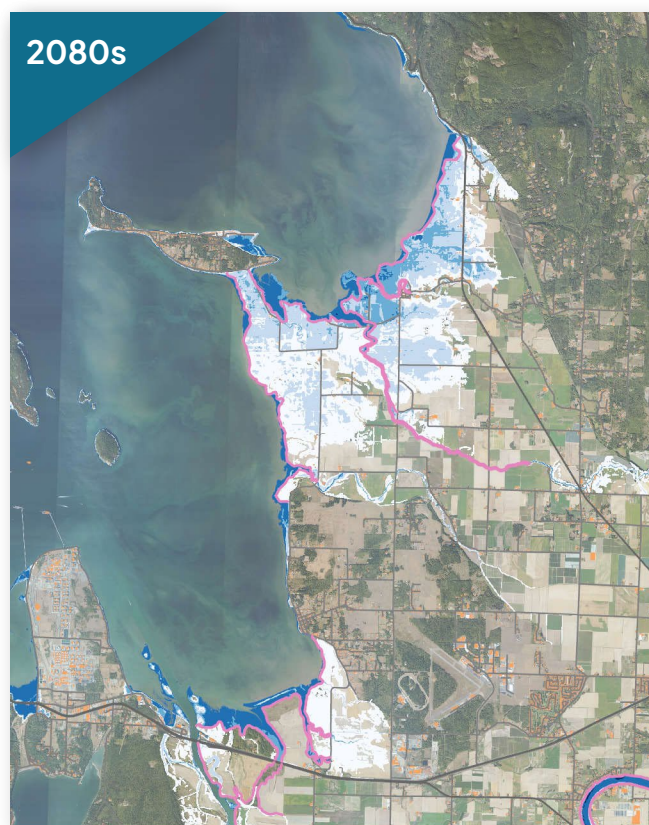
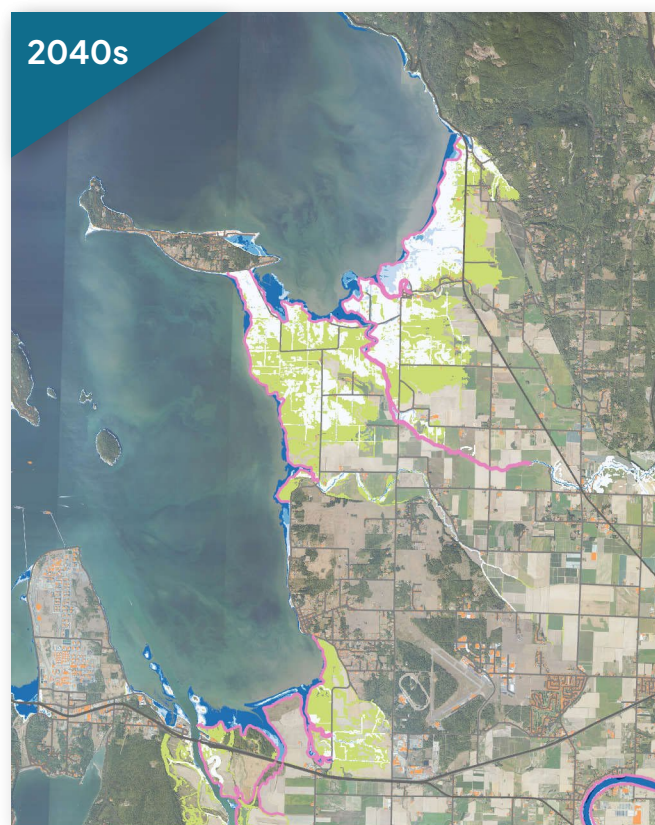
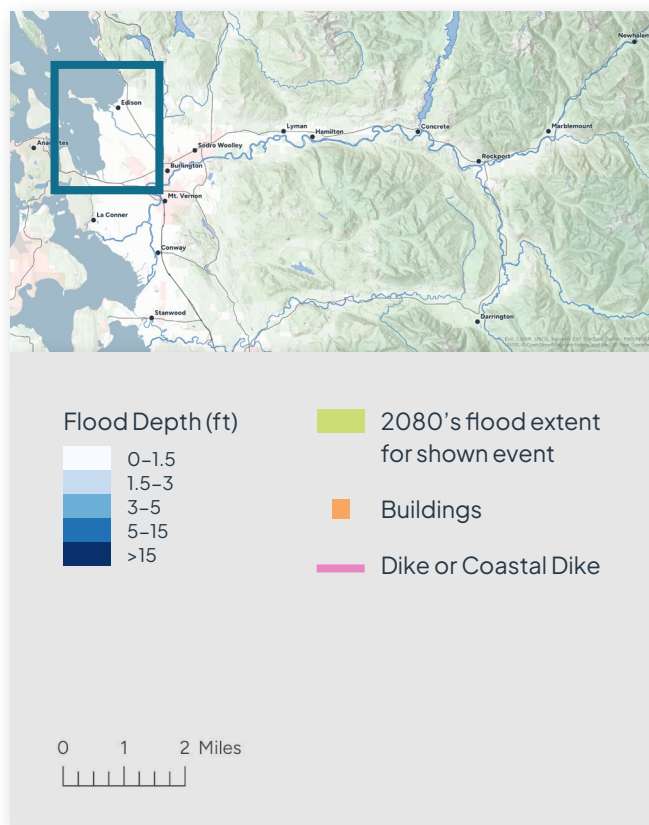
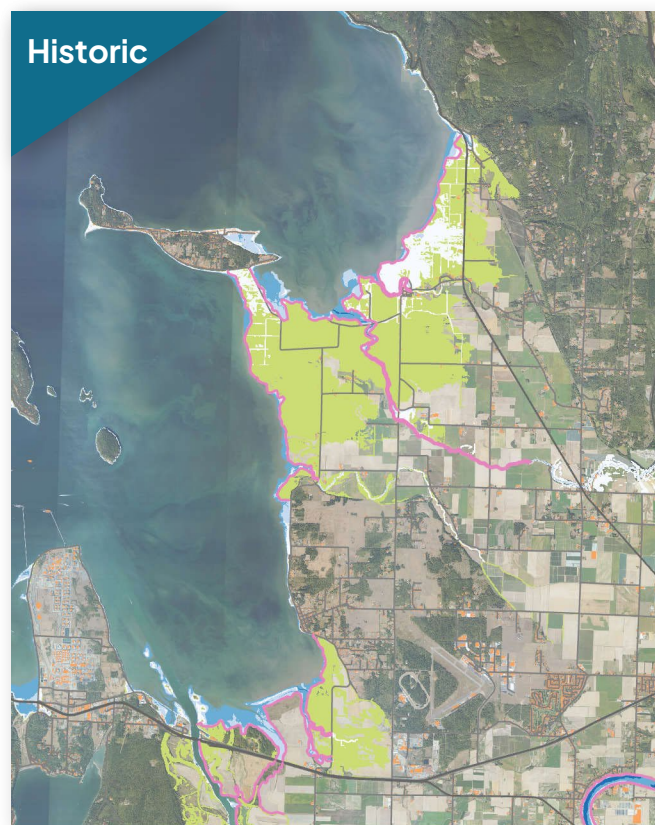


Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

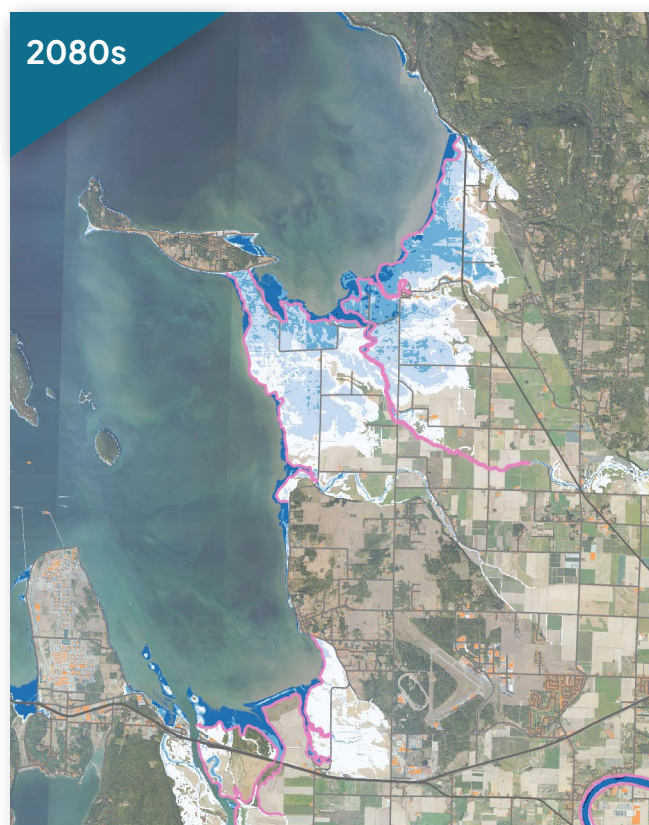
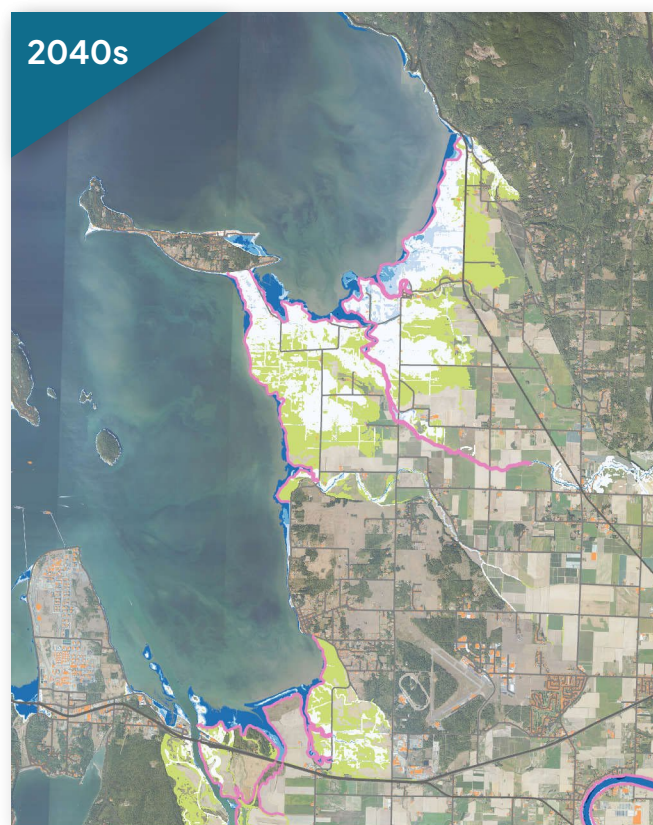
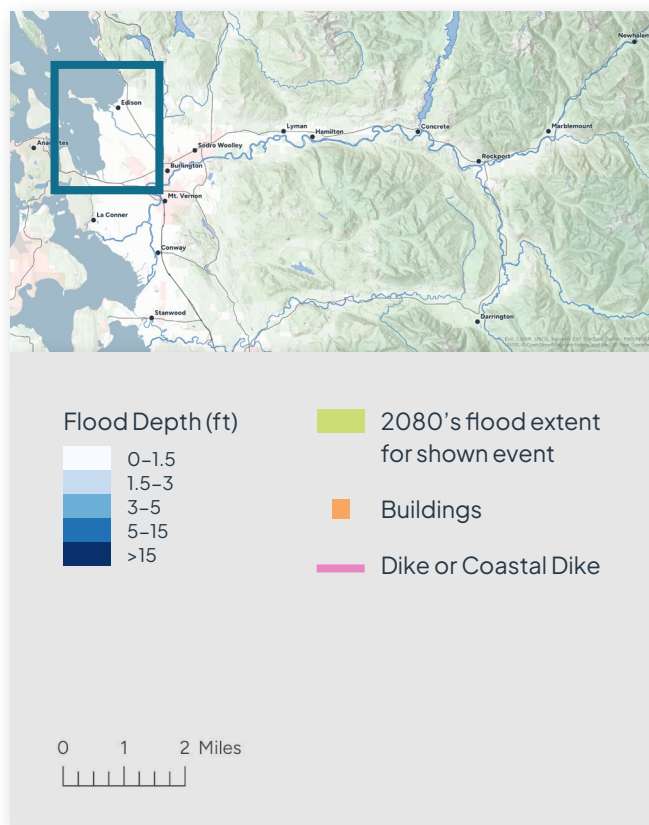
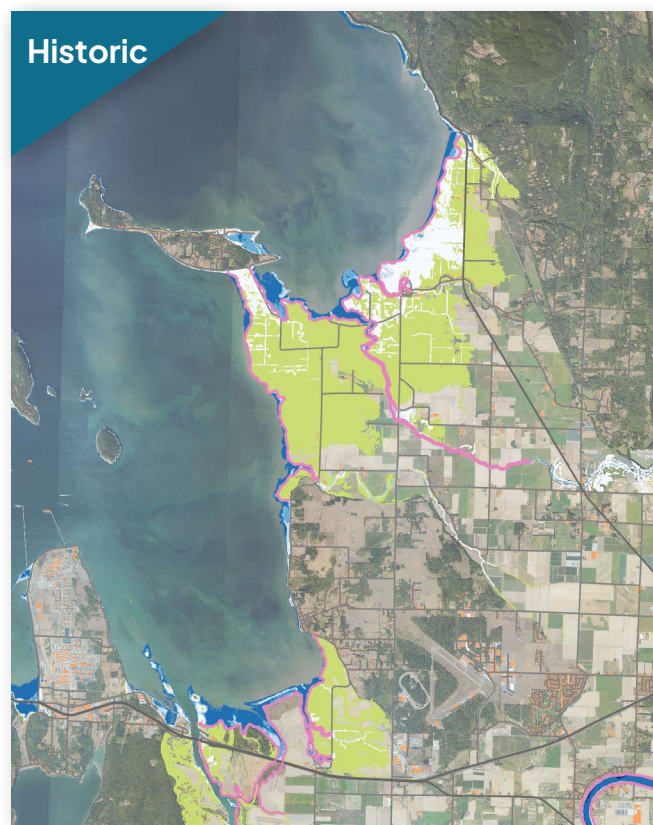
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

0 0.5 1 Miles

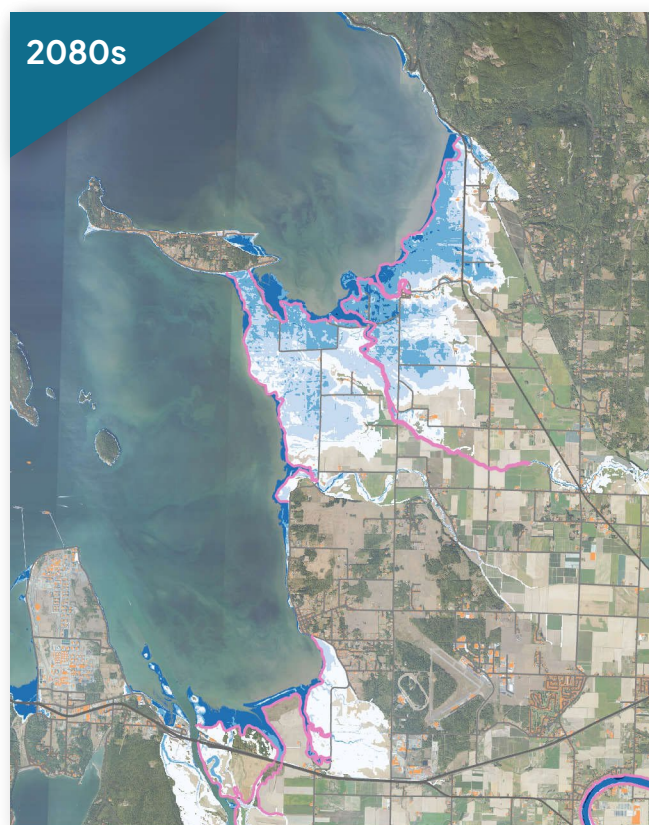
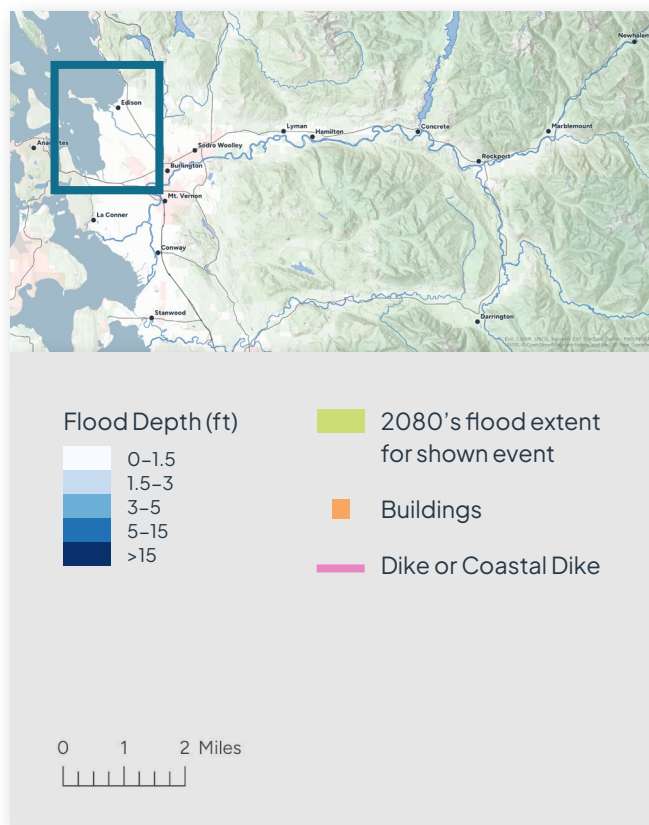
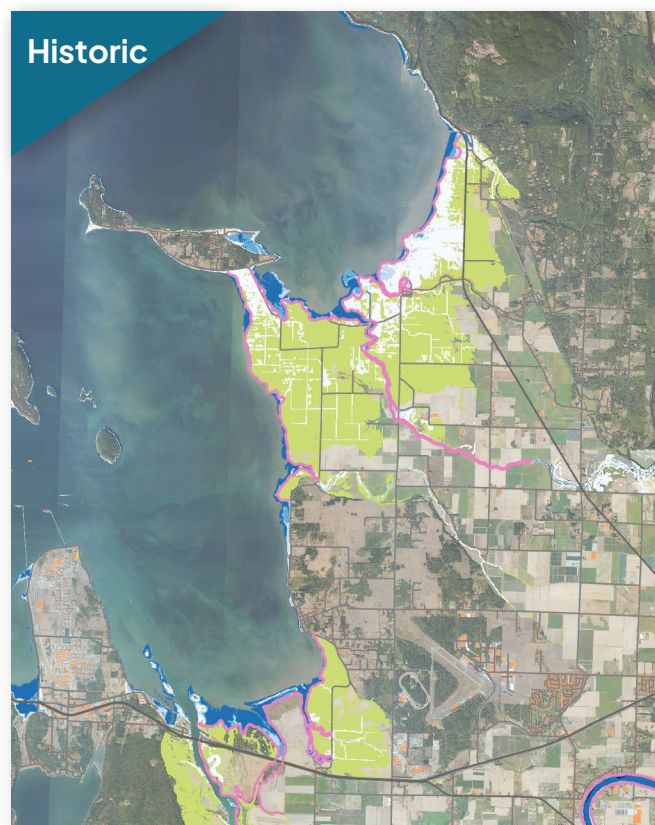
Padilla and Samish Bays | 10 Year



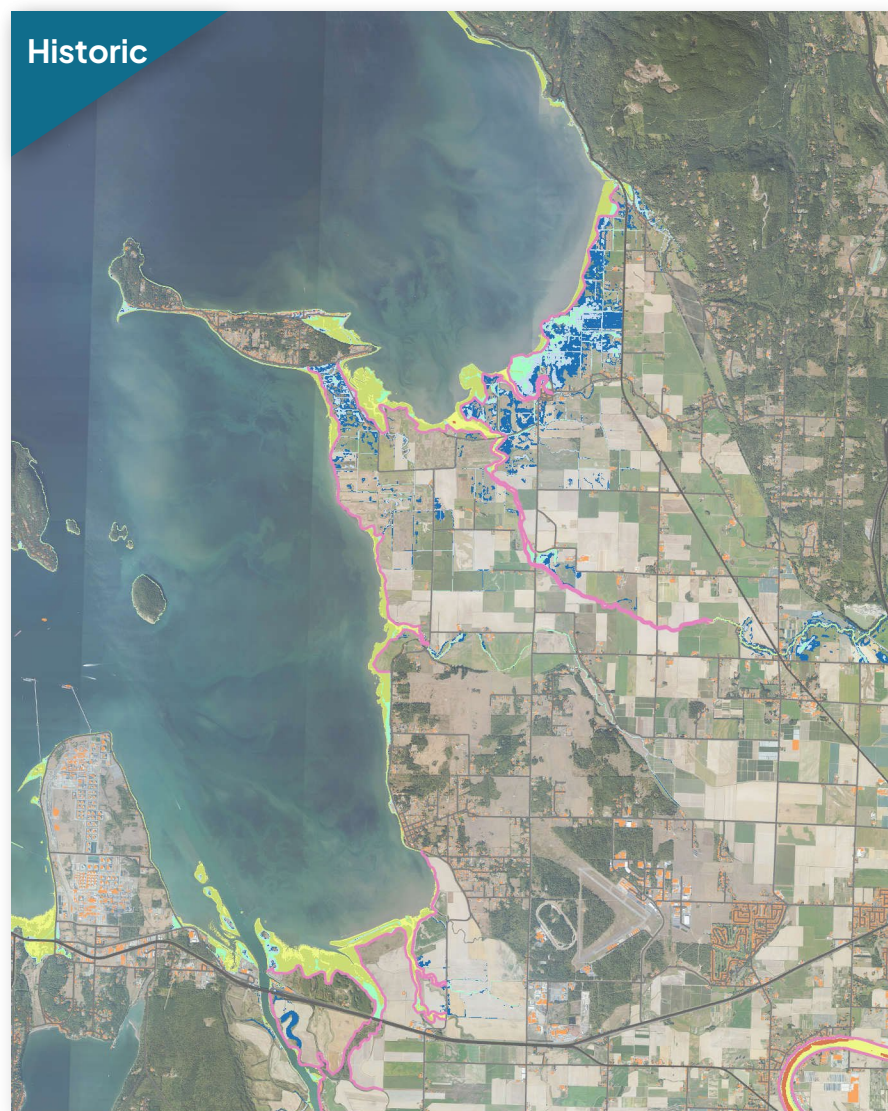
Padilla and Samish Bays | 25 Year



Padilla and Samish Bays | 100 Year



Padilla and Samish Bays | Depth-Velocity Hazard

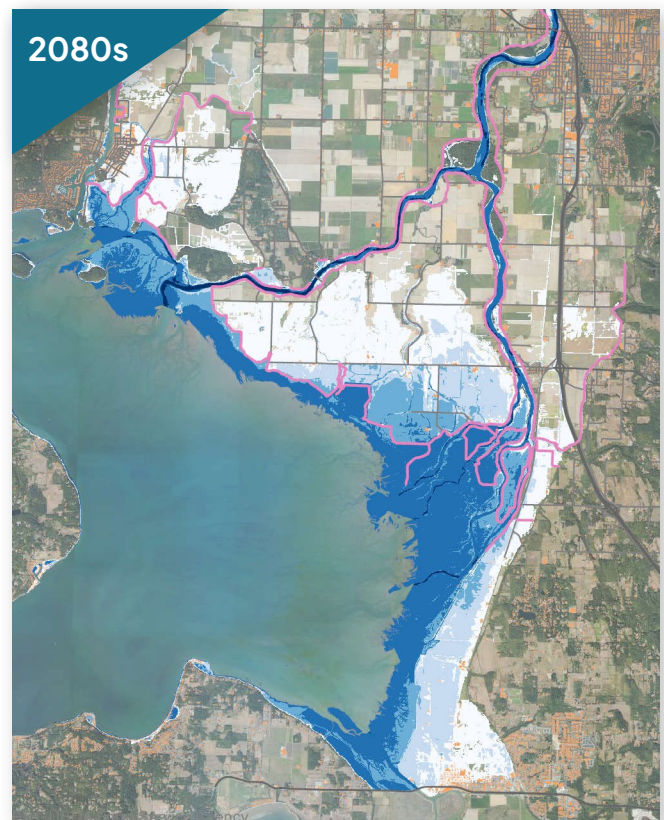
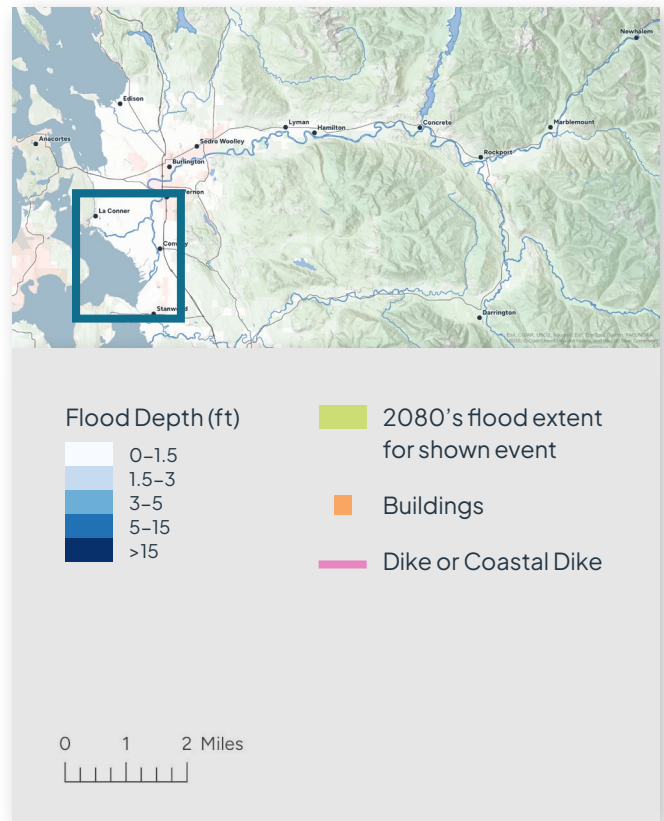


Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

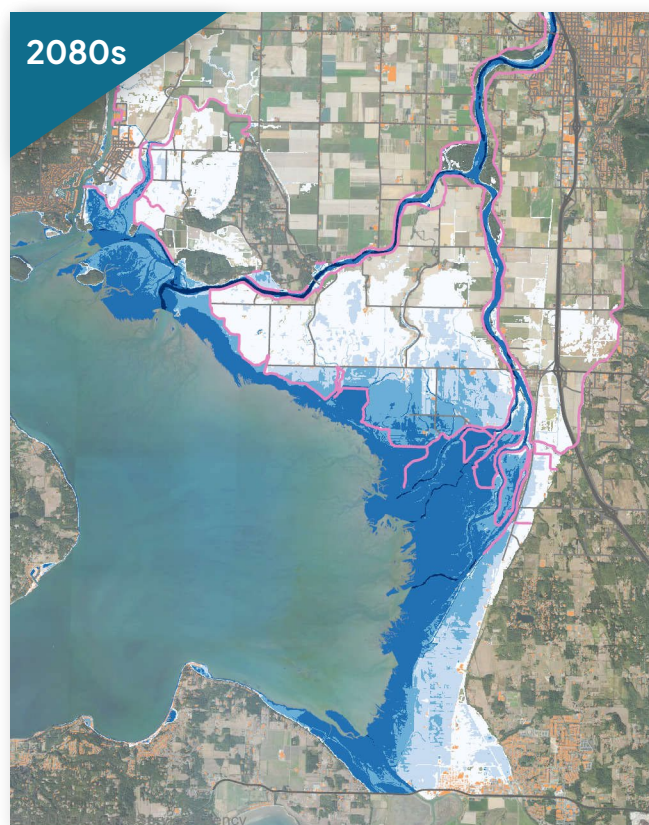
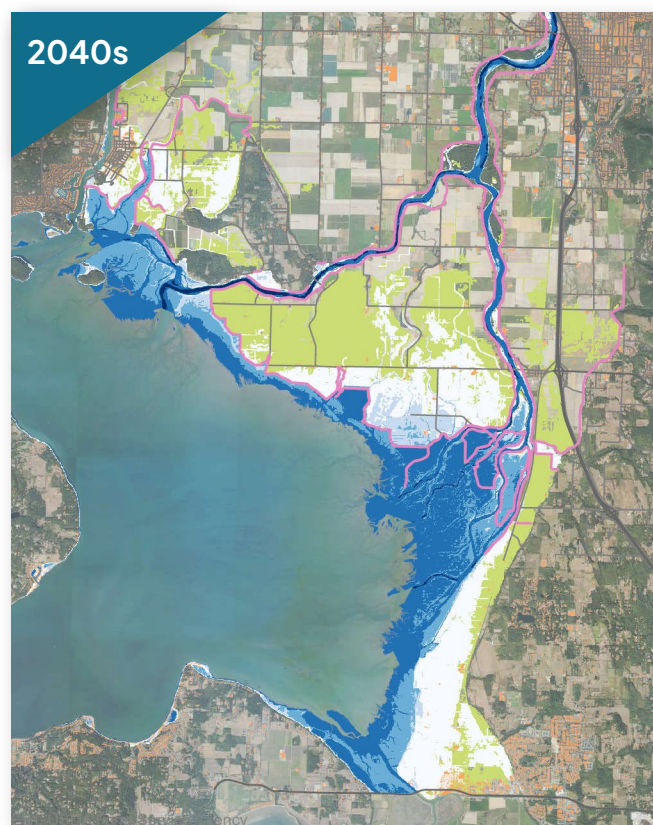
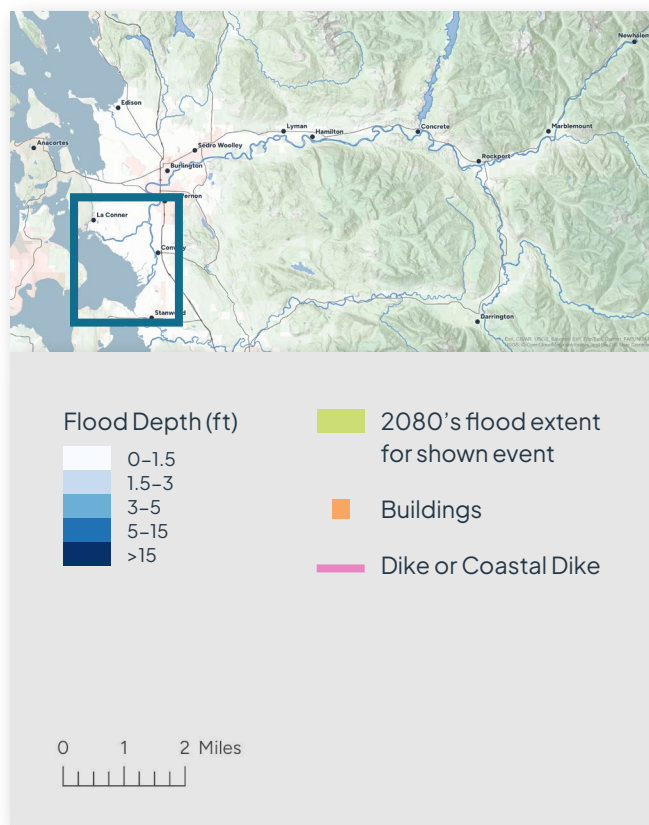
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

0 1 2 Miles

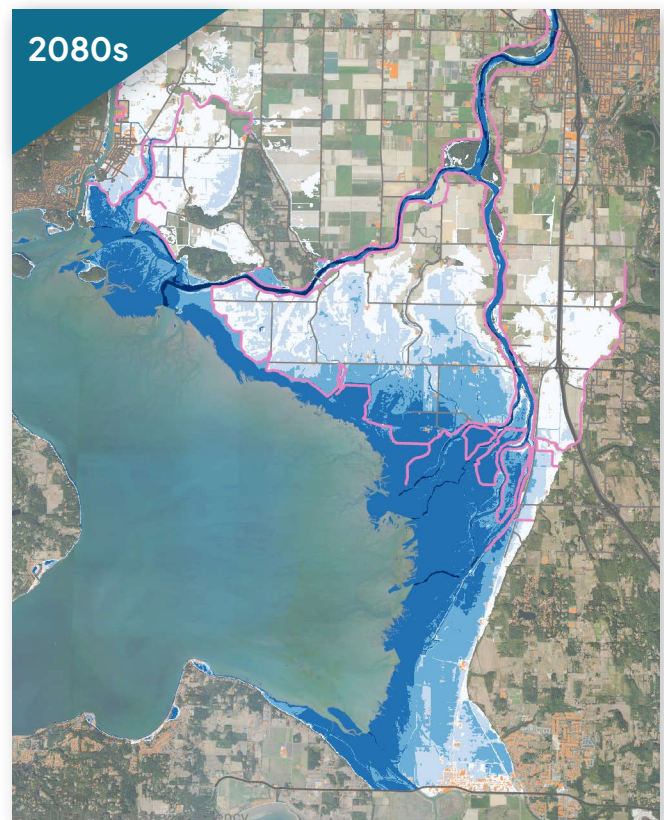
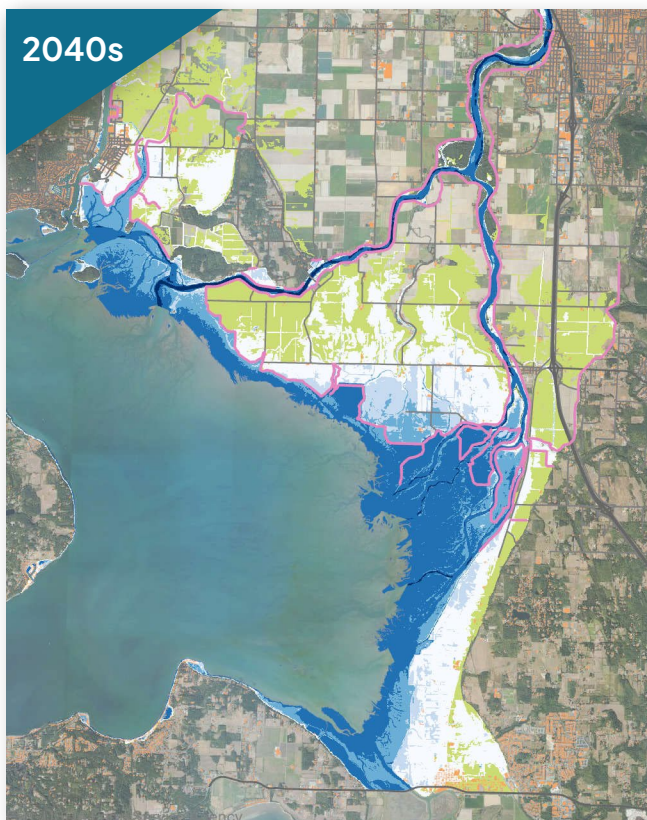
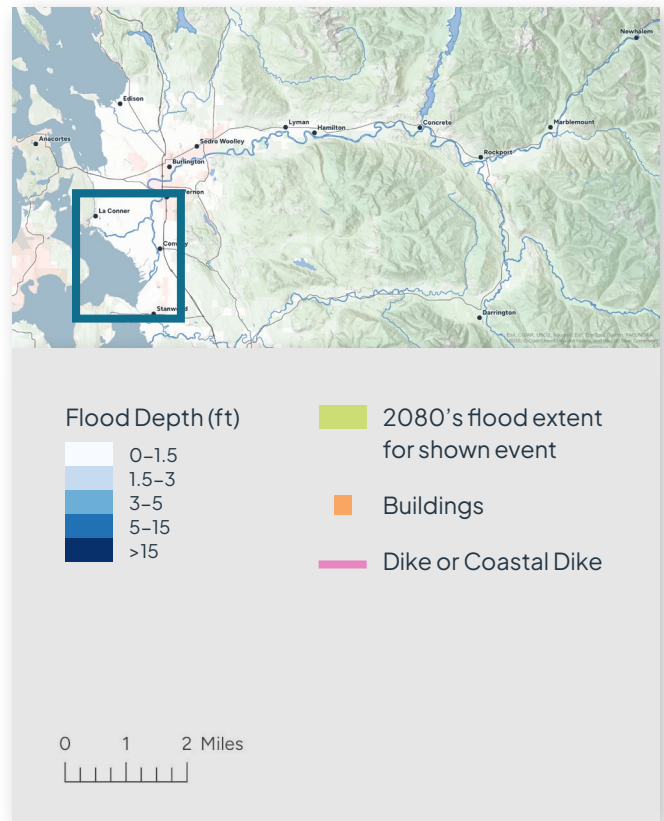
Skagit Bay | 10 Year Flood



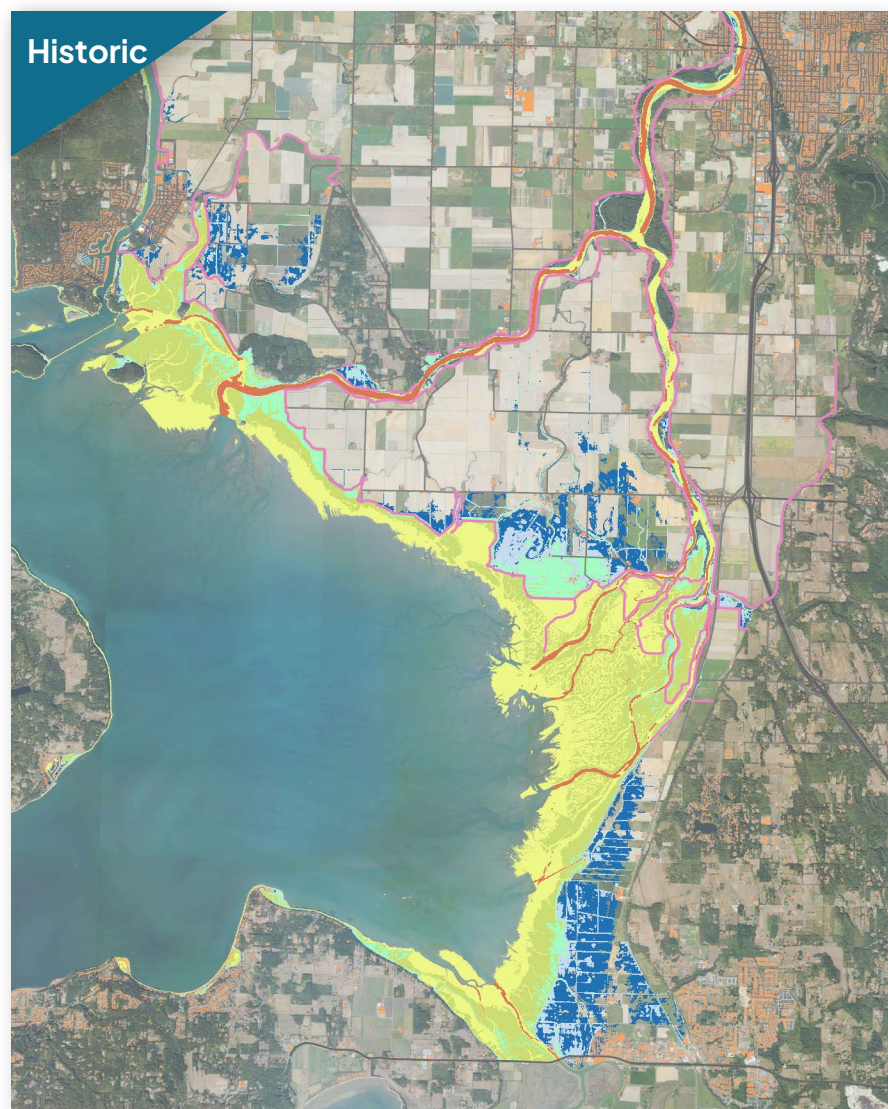
Skagit Bay | 25 Year Flood



Skagit Bay | 100 Year Flood



Skagit Bay | Depth-Velocity Hazard



Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Buildings
- Dike or Coastal Dike

0 1 2 Miles

Dike Failure Scenarios

This map bundle shows the results of dike failure scenarios for Sedro-Woolley downstream to Puget Sound.

There are six dike failure scenarios, all of which were initially developed for the Draft Skagit Basin General Investigation Study (USACE, 2014). All dike failure maps are based on the river flooding simulations. Although coastal flooding could result in dike failures, the six scenarios that we are examining are unlikely to be affected by coastal floods. This set includes an overview map of this area and zoomed-in map areas for Lafayette Road, Above BNSF Bridge, Below I-5 Bridge, Below Mount Vernon flood wall, Above Division Bridge, and North Fork Fir Island. Full context for these maps can be found in the full *Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities* report and specific details on the hydraulic model that created these maps can be found in [Appendix A](#). Animations for select locations can be found at the Skagit Climate Science Consortium website.

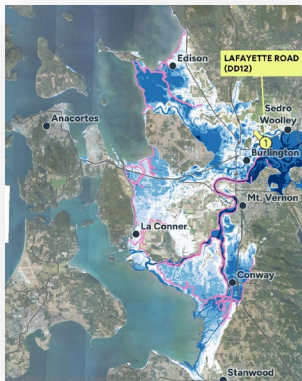
These maps are products of the hydraulic model detailed in [Appendix A](#). They are provided without any warranty of performance or fitness for a particular purpose. They should not be depended upon as a sole source of information as they illustrate potential scales of flooding rather than exact locations and do not account for real-time changes like erosion, dike failures, larger than modeled events, or other factors. Maps should be used at your own risk.

How to Read Dike Failure Scenario Maps

What These Maps Show

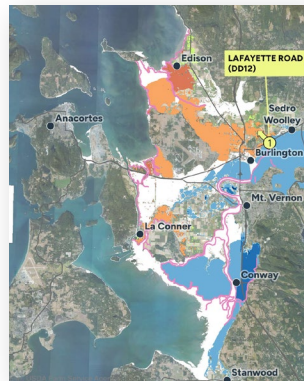
For all maps, the background is based on aerial imagery (USDA 2023). Structures are shown as orange rectangles (Microsoft 2022). Pink lines, if present, show dike or coastal dike locations (Skagit County 2022), and dark gray lines show major transportation routes (WSDOT 2008, Skagit County 2019). Dark blue lines show rivers on the overview maps.

FLOOD DEPTH MAPS



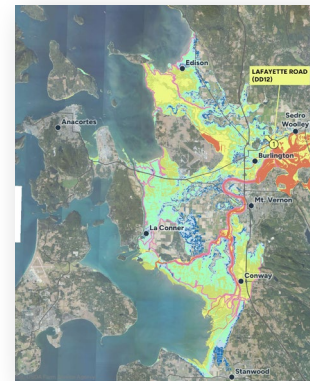
These maps show flood depths for each dike failure scenario. Maps highlight the location of the assumed failure with a green numbered circle. A green arrow shows the direction of the failure (right bank or left bank). Maps show the depth of flooding in shades of blue, where darker blue indicates deeper water and lighter blue indicates shallower water. Dikes or coastal dikes are shown in pink.

DEPTH DIFFERENCE MAPS



These maps show the difference in flood depth for a dike failure during the historic 100-year flood, relative to the “no failure” scenario. Differences are shown in shades of red when the dike failure flood depth is greater than the no failure scenario and shades of blue when the dike failure flood depth is less. White denotes areas with no change in flood depths between the failure and no failure scenarios. Light green shading highlights areas that are flooded in the dike failure scenario but not in the no failure scenario.

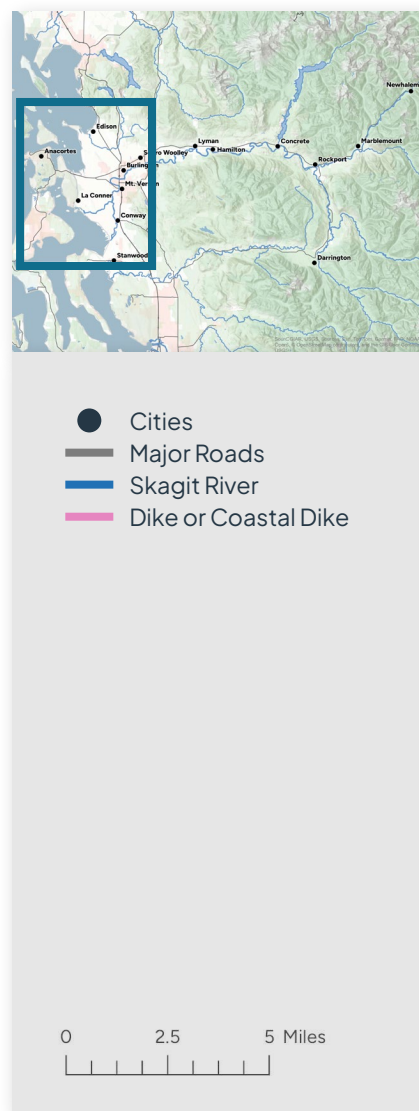
DEPTH-VELOCITY HAZARD MAPS



These maps show depth-velocity hazards for a historic 100-year event associated with a dike failure scenario. The hazard classifications shown in the key were assigned based on a standard international practice (AIDR, 2017) and grouped into six hazard ratings. The hazard mapping is based on clearwater hazards and does not account for secondary hazards such as geomorphic hazards (e.g., erosion, avulsion, debris flows, alluvial fan, etc.). Colors show when water poses a risk to children, adults, vehicles, and structures due to depth, velocity or a combination of the two, where darker blue indicates lower hazard classifications and yellows/oranges indicate the highest hazard classifications.

DIKE FAILURE SCENARIOS

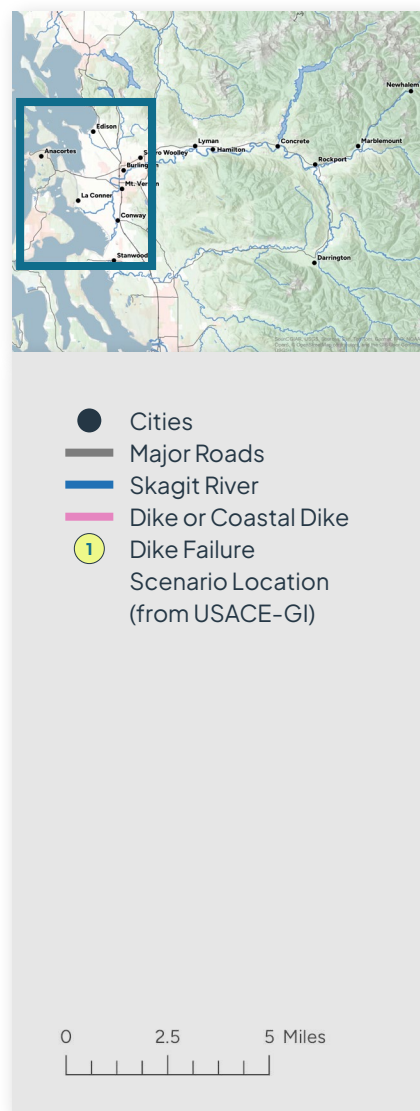
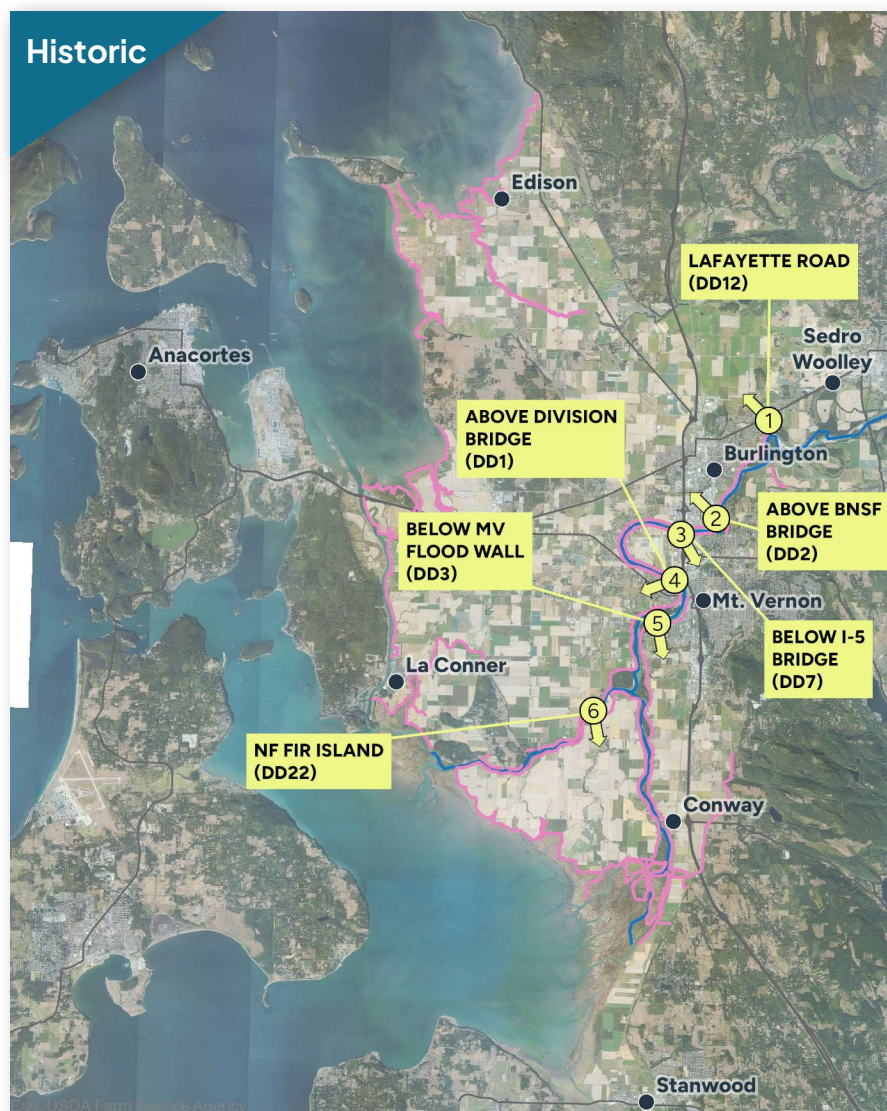
Overview Map



LIKELIHOOD OF A DIKE FAILURE IN A 100-YEAR HISTORIC OR FUTURE FLOOD EVENT

Flood maps, including those shown above, are often based on simulations in which all infrastructure – including dikes and coastal dikes – remains intact. Flood waters can overtop structures in these simulations, but they do not cause failures. In reality, dikes can fail even when they are not overtopped, and dike failure is a risk during Skagit floods. Understanding how flooding might evolve under different dike failure scenarios is an important part of evaluating flood risks. This map bundle provides six examples of failure scenarios in different parts of the lower Skagit system to explore how significantly a failure can affect flood depths and depth-velocity hazards.

Failure Locations (from USACE-GI)



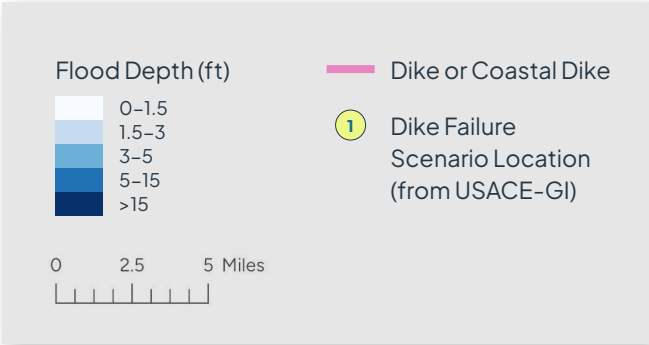
SIX SELECTED DIKE FAILURE SCENARIOS

This map shows the location of the six dike failure scenarios used to develop the depth, depth difference and depth-velocity hazard map products. The arrows show the direction (right bank or left bank) of the failure. The locations of these selected failures are not meant to imply that failures could only occur in these locations nor that they will necessarily occur in these locations. The locations were chosen to be representative of the consequences of failures at different locations along the river and occurring on different sides of the river. The six scenarios were selected for the Draft Skagit Basin General Investigation Study (USACE, 2014).

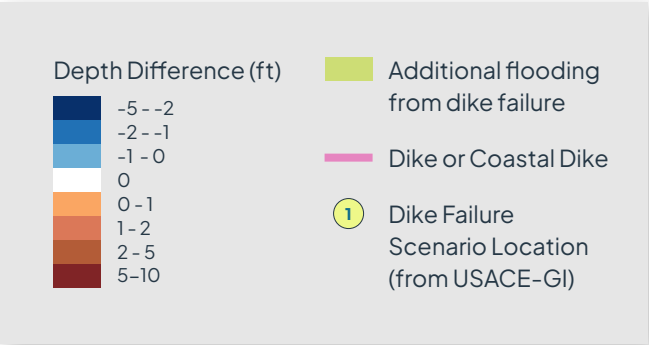
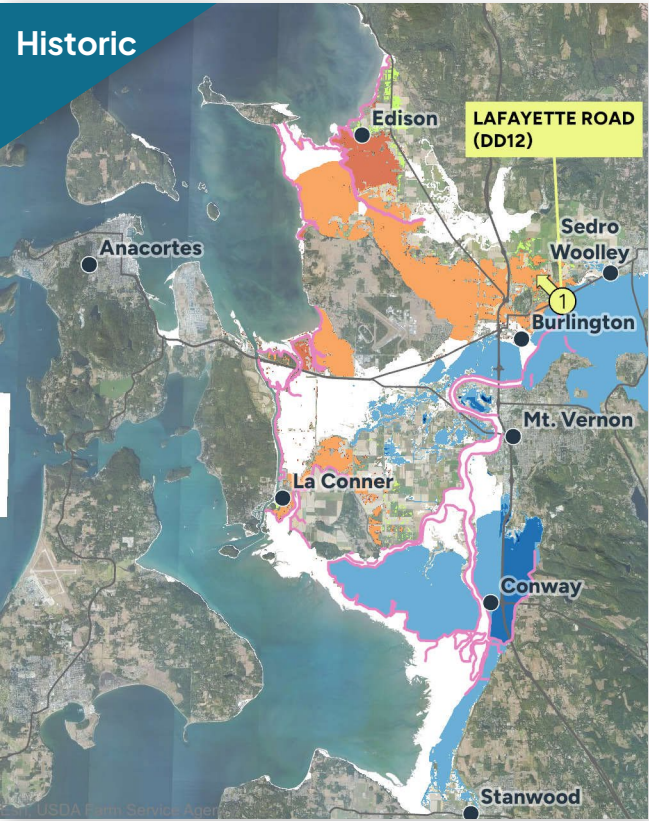
DIKE FAILURE SCENARIOS

Lafayette Road

FLOOD DEPTH

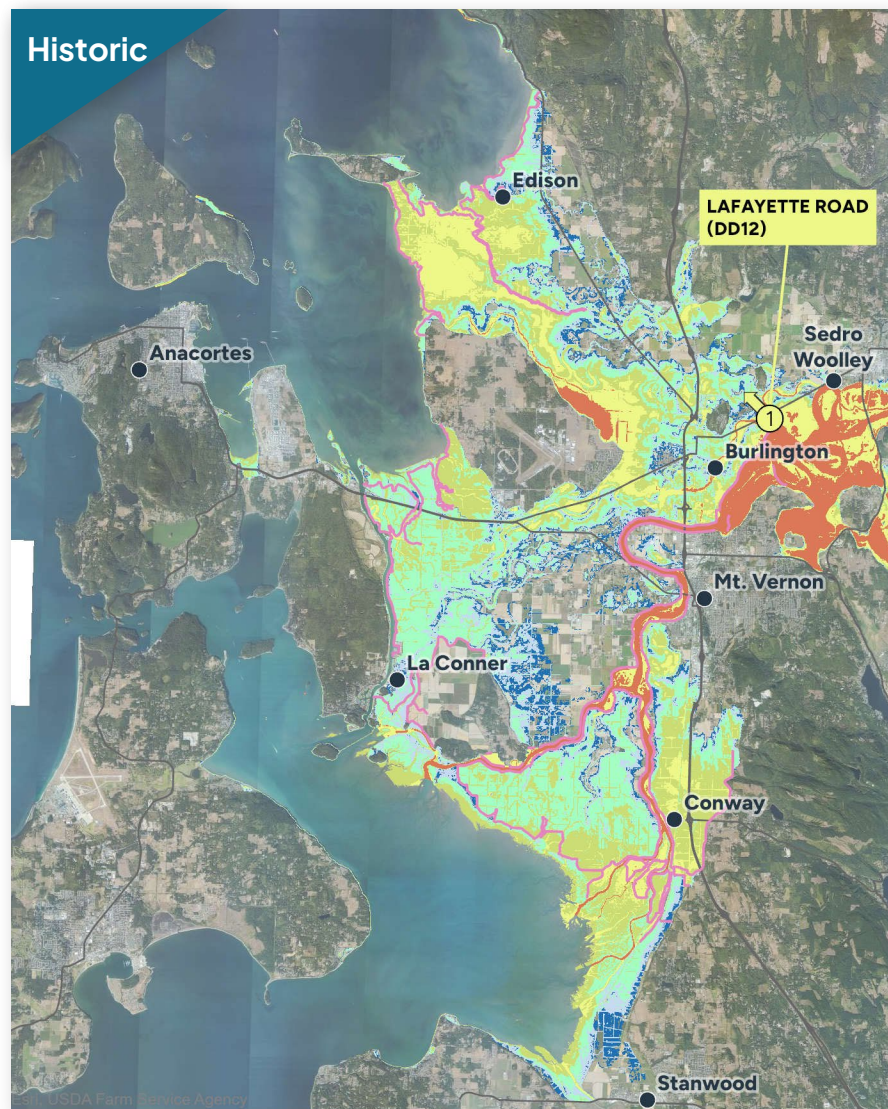


DEPTH DIFFERENCE



Lafayette Road

DEPTH-VELOCITY HAZARD



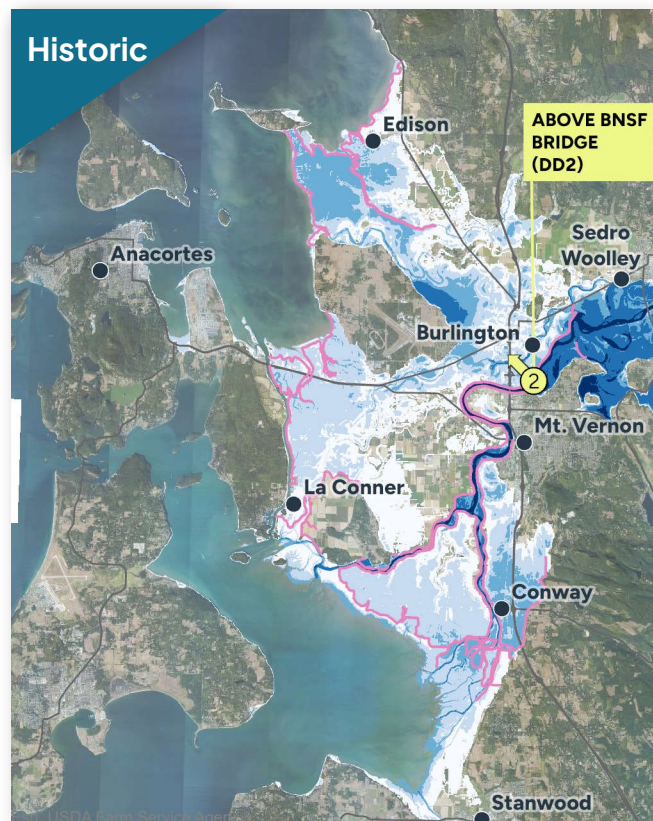
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Dike or Coastal Dike
- 1 Dike Failure Scenario Location (from USACE-GI)

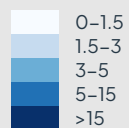
0 2.5 5 Miles

Above BNSF Bridge

FLOOD DEPTH



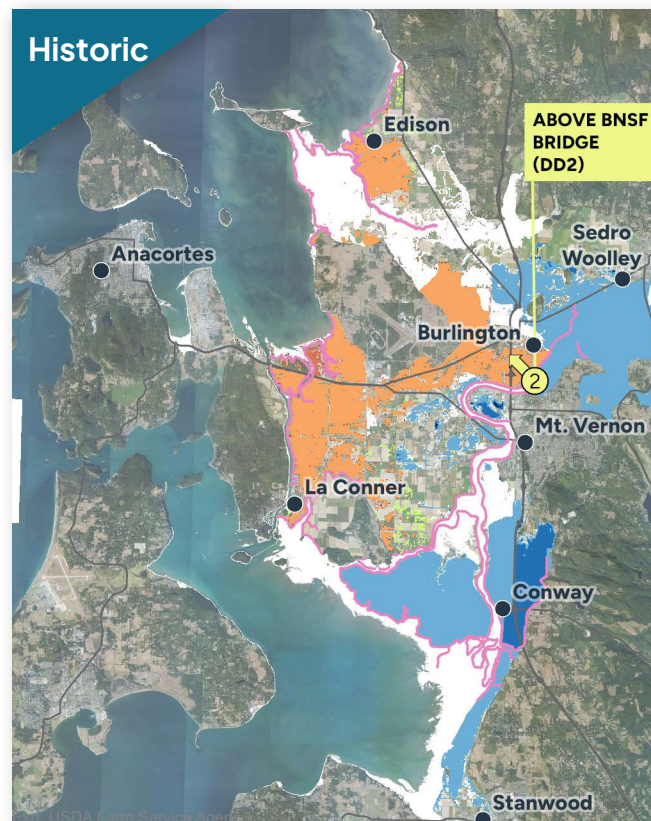
Flood Depth (ft)



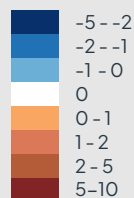
Dike or Coastal Dike

Dike Failure Scenario Location (from USACE-GI)

DEPTH DIFFERENCE



Depth Difference (ft)



Additional flooding from dike failure

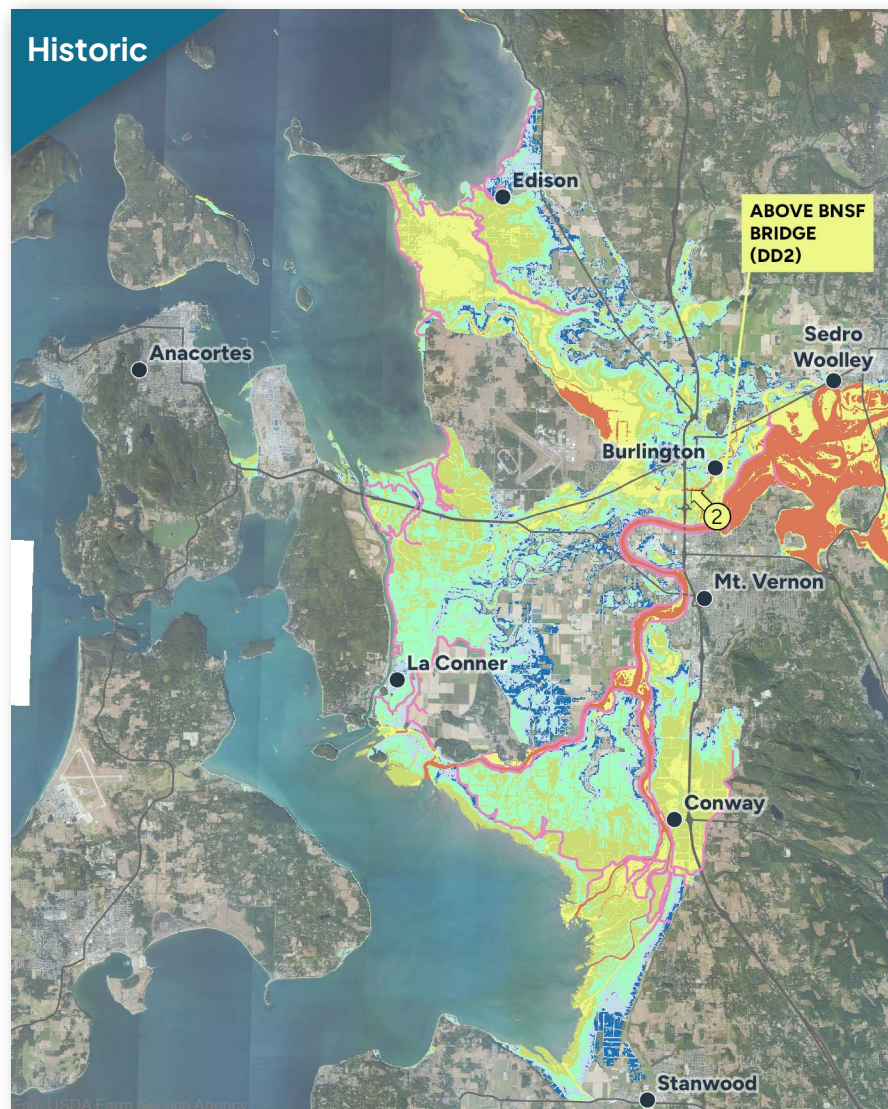
Dike or Coastal Dike

Dike Failure Scenario Location (from USACE-GI)

DIKE FAILURE SCENARIOS

Above BNSF Bridge

DEPTH-VELOCITY HAZARD



Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

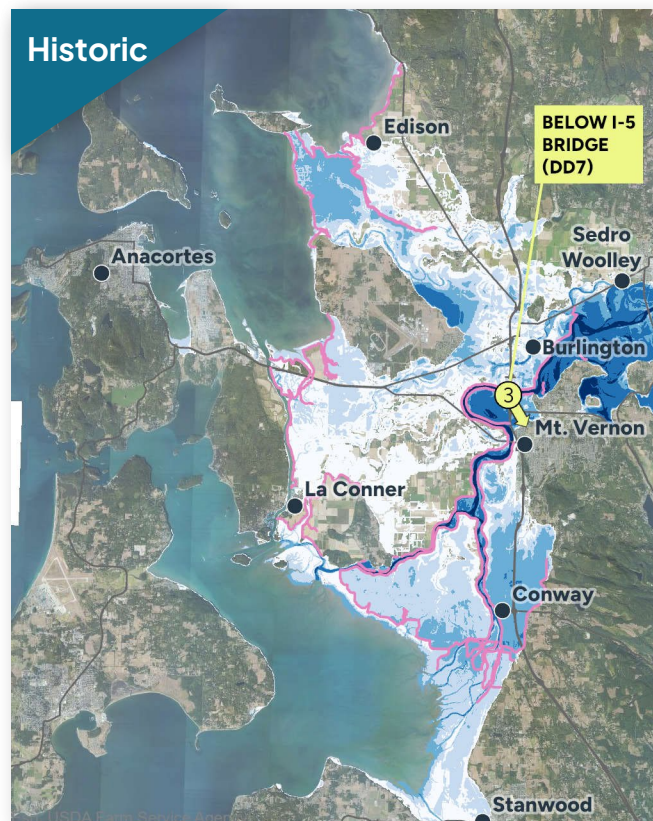
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Dike or Coastal Dike
- 2 Dike Failure Scenario Location (from USACE-GI)

0 2.5 5 Miles

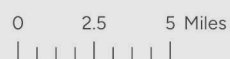
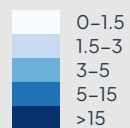
DIKE FAILURE SCENARIOS

Below I-5 Bridge

FLOOD DEPTH



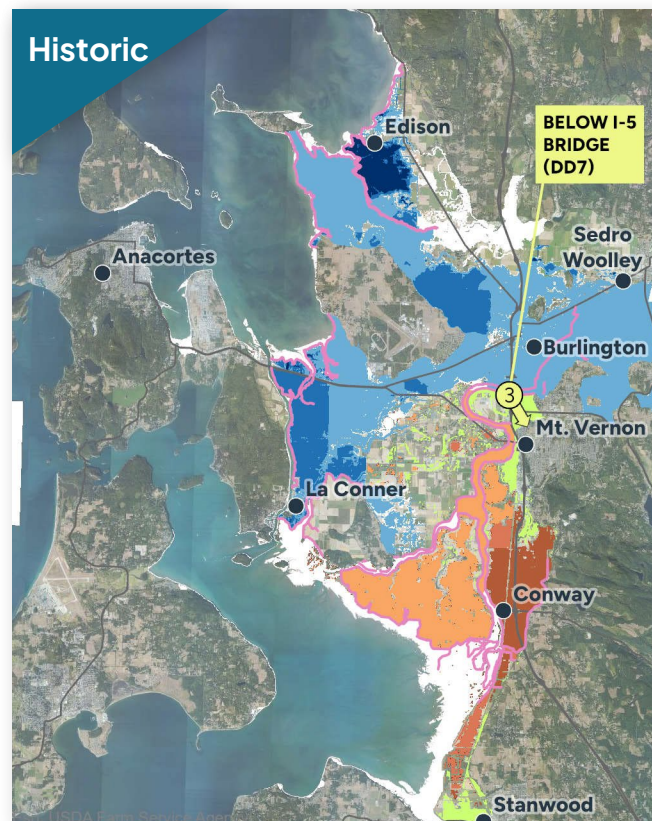
Flood Depth (ft)



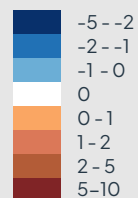
Dike or Coastal Dike

Dike Failure Scenario Location (from USACE-GI)

DEPTH DIFFERENCE



Depth Difference (ft)



Additional flooding from dike failure

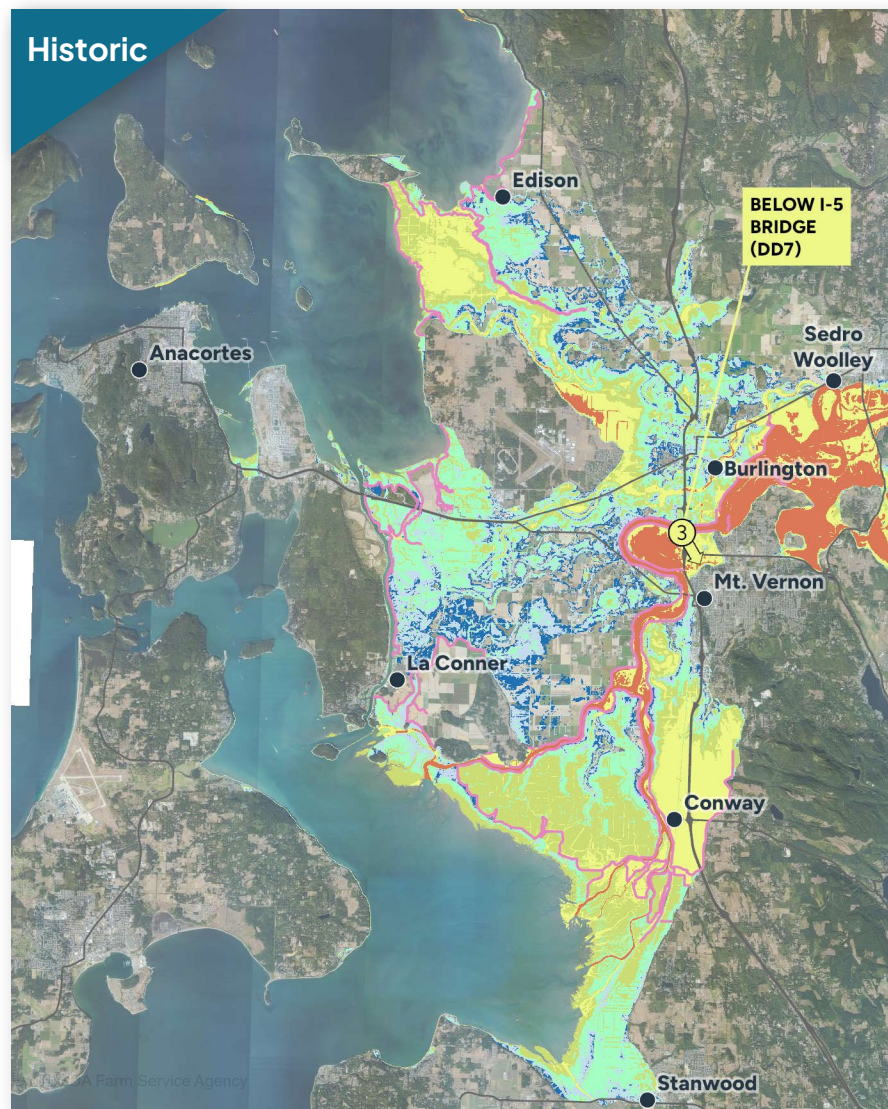
Dike or Coastal Dike

Dike Failure Scenario Location (from USACE-GI)

DIKE FAILURE SCENARIOS

Below I-5 Bridge

DEPTH-VELOCITY HAZARD



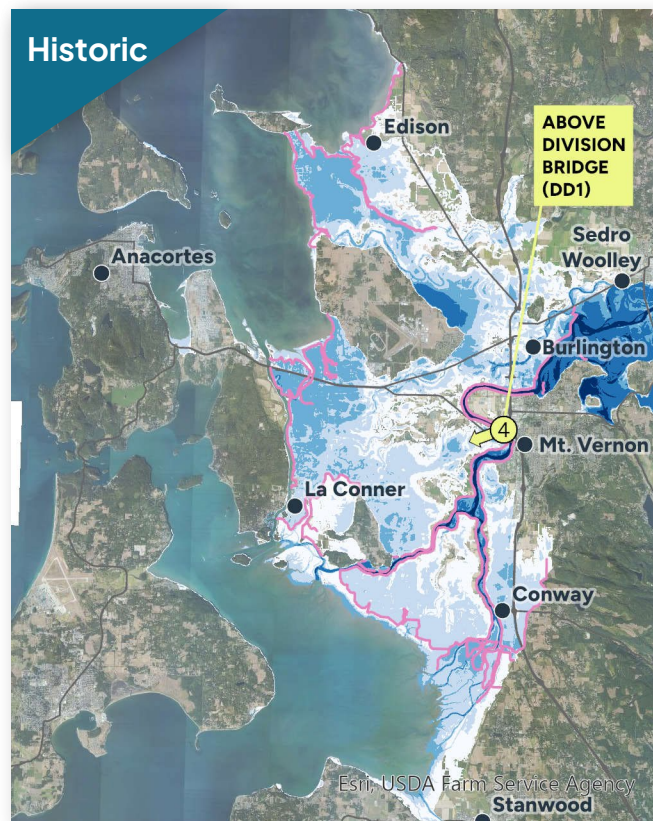
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Dike or Coastal Dike
- 3 Dike Failure Scenario Location (from USACE-GI)

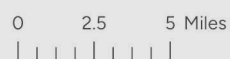
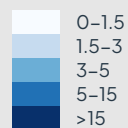
0 2.5 5 Miles

Above Division Bridge

FLOOD DEPTH



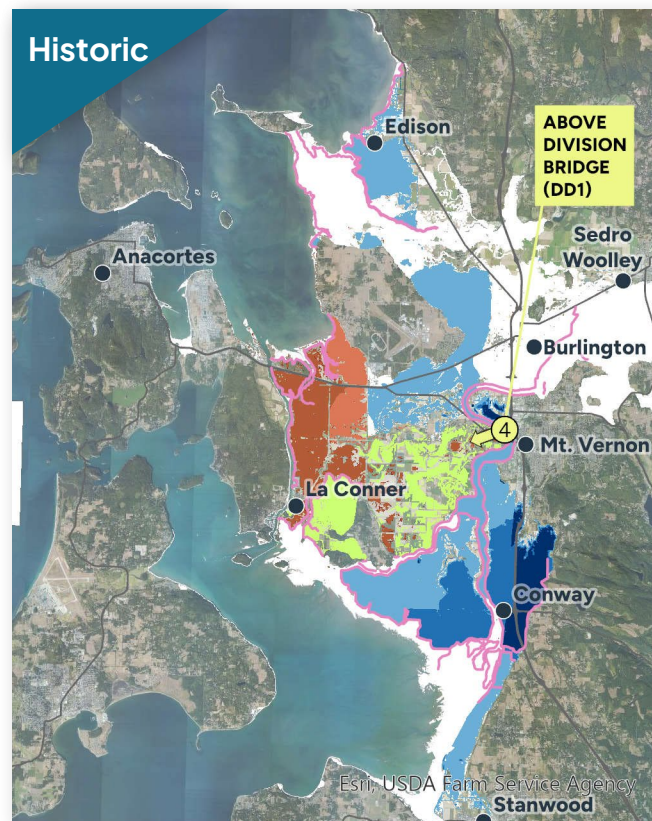
Flood Depth (ft)



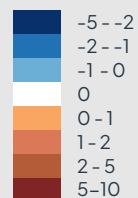
— Dike or Coastal Dike

④ Dike Failure Scenario Location (from USACE-GI)

DEPTH DIFFERENCE



Depth Difference (ft)



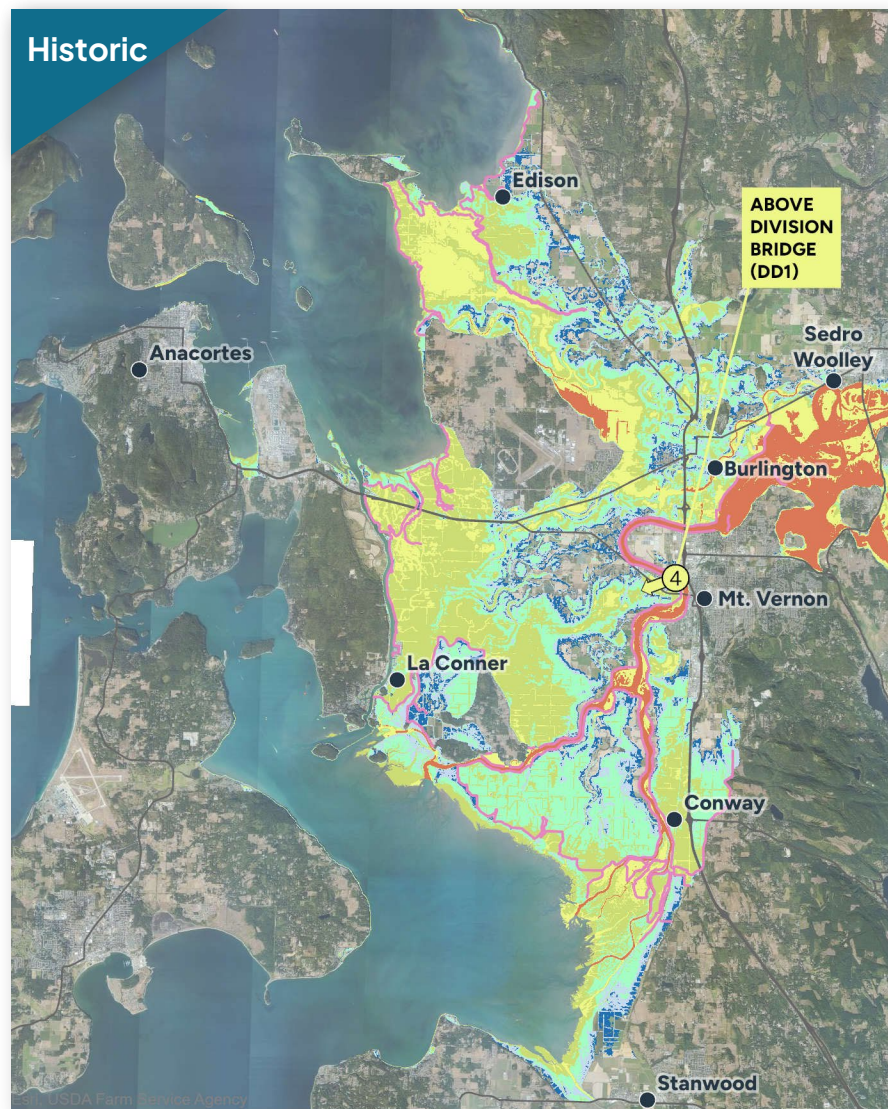
Additional flooding from dike failure

— Dike or Coastal Dike

④ Dike Failure Scenario Location (from USACE-GI)

Above Division Bridge

DEPTH-VELOCITY HAZARD



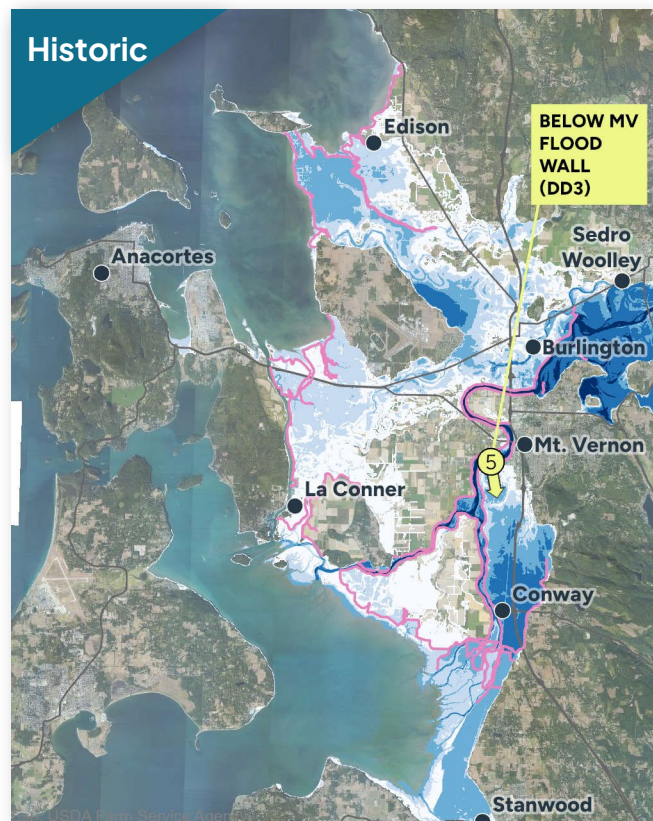
Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Unsafe for vehicles and people. All building types considered vulnerable to failure.
- Dike or Coastal Dike
- Dike Failure Scenario Location (from USACE-GI)

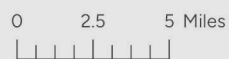
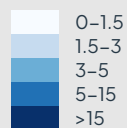
0 2.5 5 Miles

Below Mount Vernon Flood Wall

FLOOD DEPTH



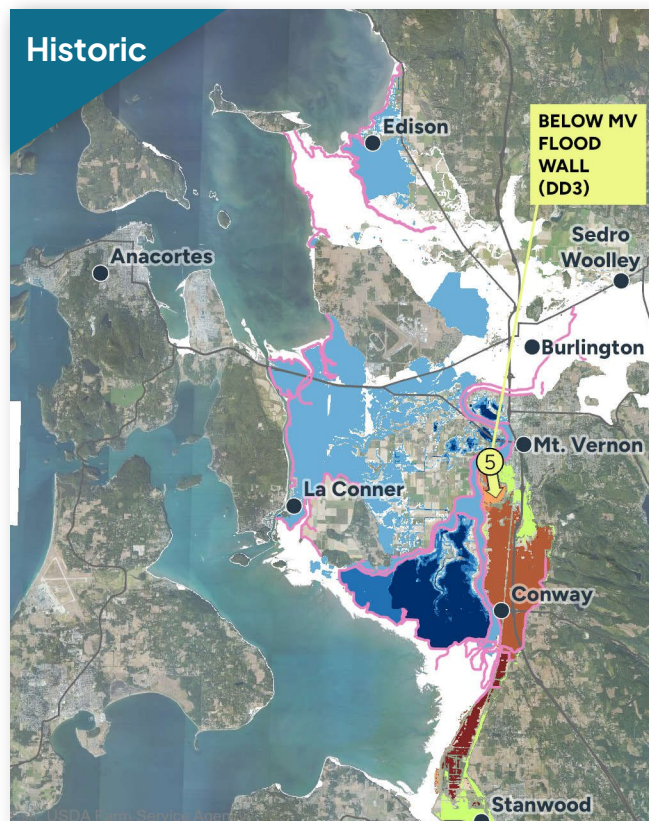
Flood Depth (ft)



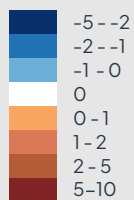
— Dike or Coastal Dike

5 Dike Failure Scenario Location (from USACE-GI)

DEPTH DIFFERENCE



Depth Difference (ft)



 Additional flooding from dike failure

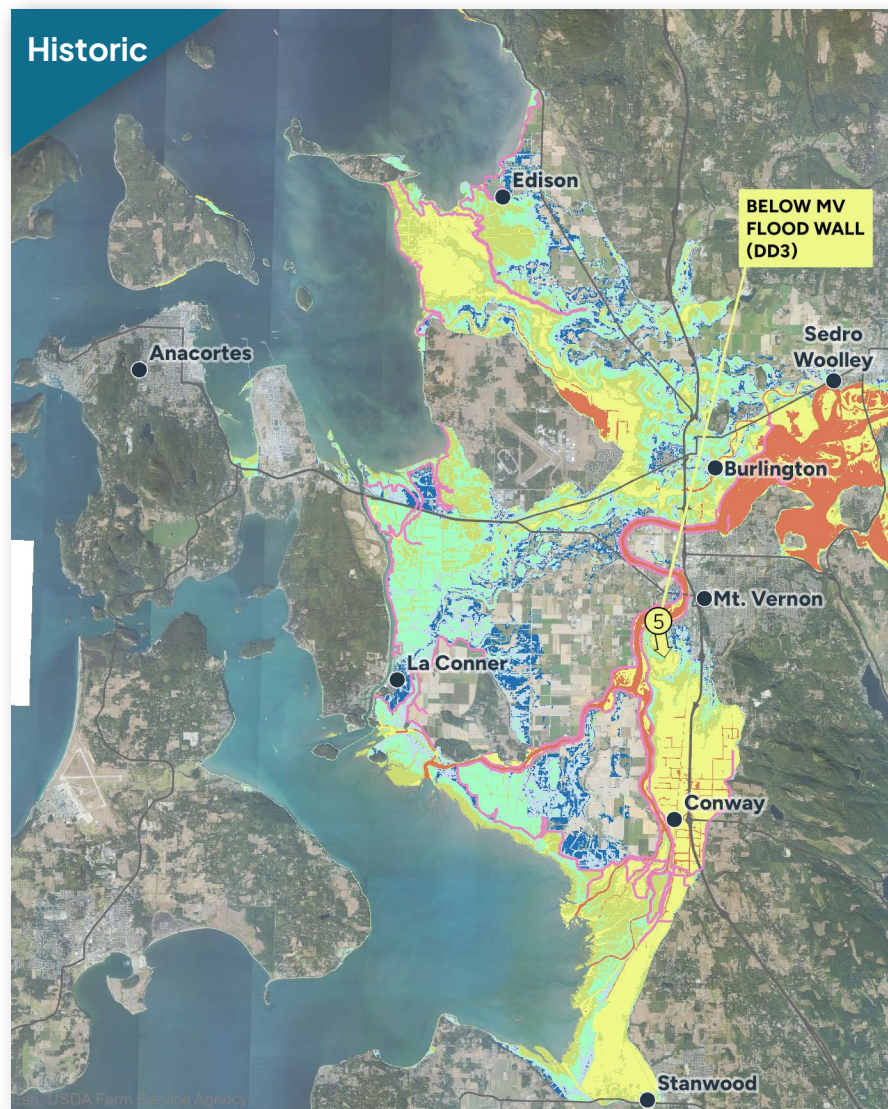
— Dike or Coastal Dike

5 Dike Failure Scenario Location (from USACE-GI)

DIKE FAILURE SCENARIOS

Below Mount Vernon Flood Wall

DEPTH-VELOCITY HAZARD



Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

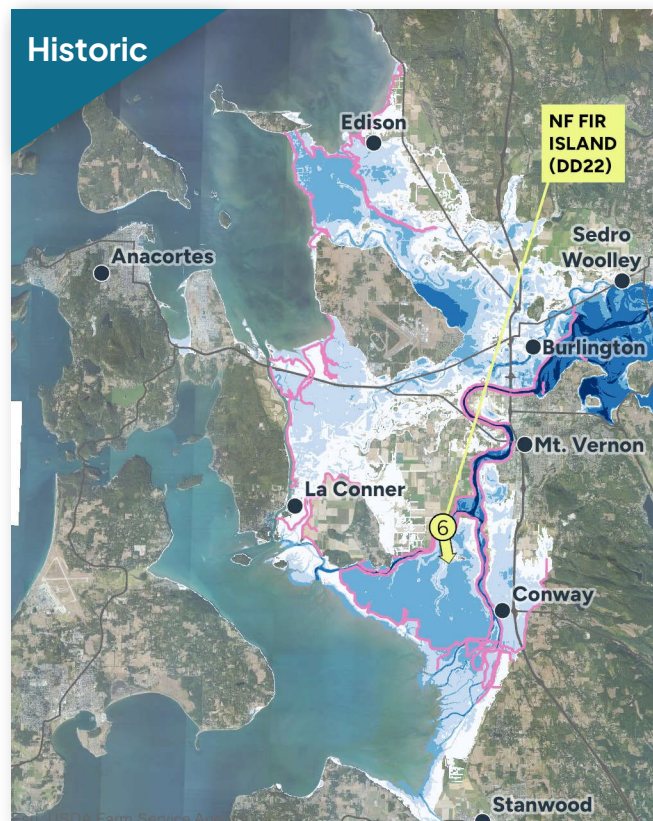
- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Dike or Coastal Dike
- 5 Dike Failure Scenario Location (from USACE-GI)

0 2.5 5 Miles

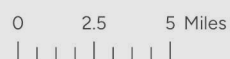
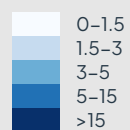
DIKE FAILURE SCENARIOS

NF Fir Island

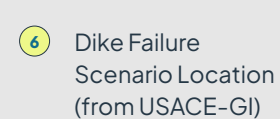
FLOOD DEPTH



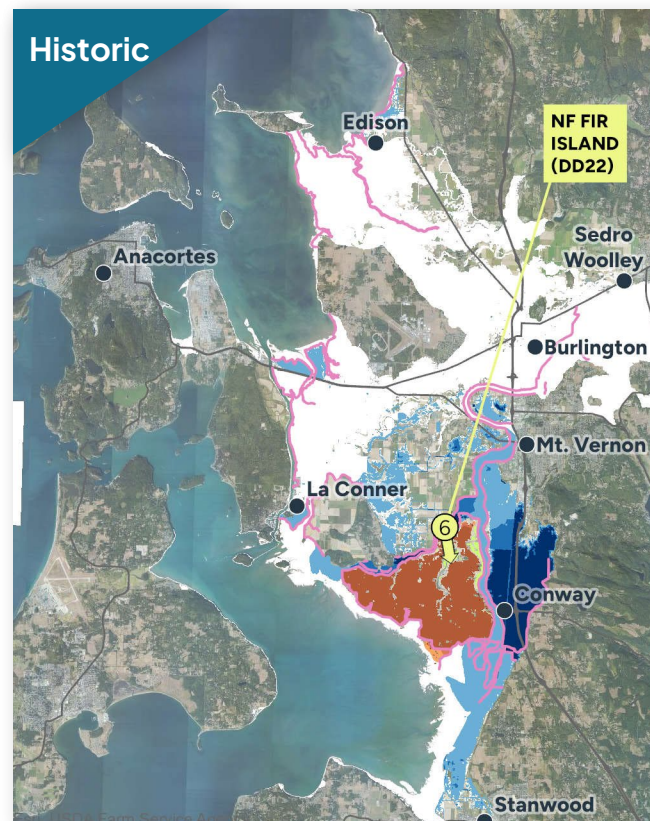
Flood Depth (ft)



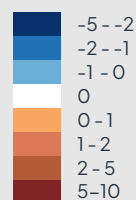
Dike or Coastal Dike



DEPTH DIFFERENCE

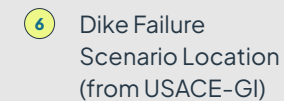


Depth Difference (ft)



Additional flooding from dike failure

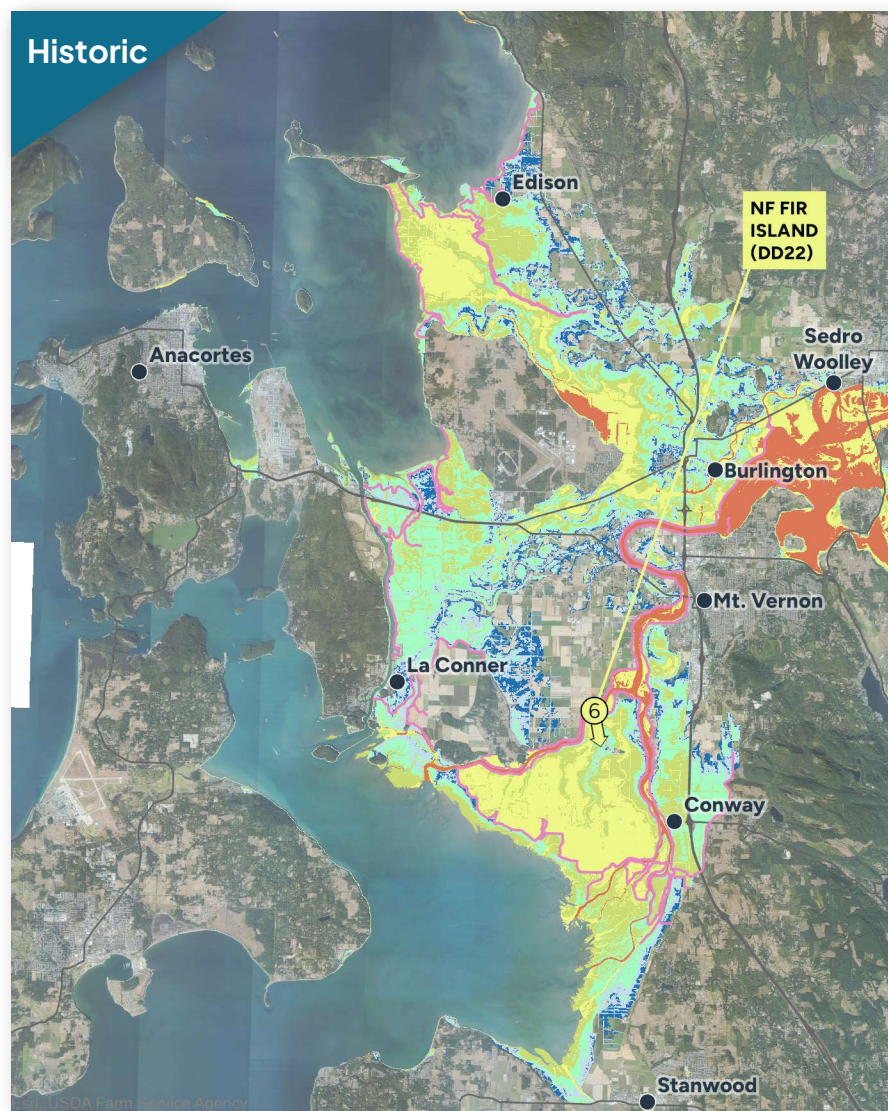
Dike or Coastal Dike



DIKE FAILURE SCENARIOS

NF Fir Island

DEPTH-VELOCITY HAZARD



Descriptions for Flood Hazard Rating Mapping (AIDR, 2017)

- Generally safe for vehicles, people, and buildings
- Unsafe for small vehicles
- Unsafe for vehicles, children, and the elderly
- Unsafe for vehicles and people
- Unsafe for vehicles and people. All building types vulnerable to structural damage.
- Dike or Coastal Dike
- 6 Dike Failure Scenario Location (from USACE-GI)

0 2.5 5 Miles

References

Microsoft (2022). Building Footprints [shapefile]. File last modified 2022. <https://www.arcgis.com/home/item.html?id=bb69f10baf334d4c935a0fb23d758f38>

Skagit County (2022). Dikes and Levees [shapefile]. File last modified 2022.

Skagit County GIS. Road Centerline [shapefile]. File published 2019.

(USACE) U.S. Army Corps of Engineers. (2014). Skagit River Flood Risk Management General Investigation: Draft Feasibility Report and Environmental Impact Statement. Prepared for Skagit County, Washington, by the Seattle District of the U.S. Army Corps of Engineers. Available at: <https://www.skagitcounty.net/Departments/PublicWorksSalmonRestoration/main.htm>

(USDA) United States Department of Agriculture (2023). USDA Farm Service Agency, National Agriculture Imagery Program (NAIP) 2023 Imagery. <https://nracs.app.box.com/v/naip>

Washington State Department of Transportation Cartography/GIS Section. State Routes of Washington at 1:24,000 [shapefile]. File published 2008.

Appendix C: June 5th, 2025 Workshop Presentation

Dear Reader,

Please find below slides presented at a June 5th, 2025 Workshop hosted by the Skagit Climate Science Consortium, Swinomish Indian Tribal Community, and Skagit River System Cooperative to look at preliminary results from flood modeling of the Skagit watershed. Invitations were extended to a broad range of people and entities including local, state, federal governments; quasi-governmental, tribal, non-governmental organizations with responsibilities or interests in understanding, planning for or taking actions in regard to flood risk reduction. The project and workshop objectives can be found in the slide deck.

The slides were not developed as a stand-alone product but to support a presentation. However, based on significant feedback from workshop participants to have access to the information prior to the estimated project report in early 2026, the project team (slide 8) has annotated the slides to improve their utility as an early product.

Please reach out to

Heather Spore; email: hspore@swinomish.nsn.us

Carol Macilroy; email: cmacilroy@gmail.com

If you have any questions, comments or feedback you'd like to share or need additional information.

Understanding Current and Future Flood Risk Through New Modeling Capabilities Skagit River

June 5th, 2025

Presented to Skagit County community members and municipalities by the Swinomish Indian Tribal Community and the Skagit Climate Science Consortium on June 5, 2025.

Welcome and Overview

- Welcome and Introductions
- Project and Project Team overview
- Skagit Climate Science Consortium
- Today's Workshop Agenda

Project: Overview and Objectives

- Develop an updated, accessible floodplain model from the Skagit delta to just upstream of Marblemount using up-to-date scientific information and data
- Build off past work, improve model resolution, expand geographic range, and incorporate coastal flooding and future climate projections

Project: Overview and Objectives

- Create a forum to:
 - Engage around technical products (model and model results)
- Document model assumptions and inputs, provide visuals of model results, and describe process
- Make model available for use/adaptation by others

Project: Overview and Objectives

- Governments, organizations and individuals determine if the model and continued conversations could provide benefit and how/if to move forward upon project completion.

Project Engagement Steps and Timing



Project Team

Heather Spore, MSc	<i>Swinomish Indian Tribal Community (funding recipient)</i>
Nora Kammer	<i>Skagit River System Cooperative</i>
Steve Moddemeyer	<i>Consultant to Skagit Climate Science Consortium</i>
Dr. Guillaume Mauger	<i>University of Washington Climate Impacts Group, consultant to Skagit Climate Science Consortium</i>
Dr. Alan Hamlet	<i>Notre Dame, consultant to Skagit Climate Science Consortium</i>
Carol Macilroy, BSc	<i>Consultant to Skagit Climate Science Consortium</i>
Kristin Kramer, PE	<i>Northwest Hydraulic Consultants (NHC)</i>
Vaughn Collins, PE, CFM	<i>Northwest Hydraulic Consultants (NHC)</i>

Acknowledgements

We would like to thank the following people and organizations for their support and contributions.

- Members of the Skagit community who took part in early conversations
- US Army Corps of Engineers, who provided the original model

SC² Mission

- ***Foster collaborative scientific research*** to understand the diverse and interrelated impacts of climate change from the Skagit headwaters to Puget Sound;
- ***Produce relevant climate-related products*** closely integrated with the Skagit community's needs and concerns;
- ***Serve as a conduit between Skagit communities and SC² scientists*** to assist in the development of adaptation strategies.



SC² Members



- NOAA, National Marine Fisheries Service
- National Park Service (retired)
- Notre Dame University, Civil and Engineering Department
- Padilla Bay Reserve
- Seattle City Light
- Seattle University, Civil and Environmental Engineering
- Swinomish Indian Tribal Community
- Skagit River System Cooperative
- United States Forest Service (retired)
- United States Geological Survey (USGS)

SC² Members



- UW, Climate Impacts Group
- UW, Environmental and Forest Sciences Department
- WSU Center for Sustaining Agriculture and Natural Resources
- WWU, Environmental Science Department
- WWU, Geology Department
- WWU, Marine and Coastal Science program

Broad Expertise

Engineering geologist and hydrogeologist: ground and surface water

Restoration ecologist

Applied marine ecologist

Forestry scientist

Civil engineer: landslides

Climate scientist: adaptation

Soil ecologist

Climate scientist: climate models

Estuarine ecologist

Hydrologist

Fishery and wildlife biologist

Population ecologist

Aquatic ecologist and ecotoxicologist

Civil engineer: flood infrastructure

Geomorphologist

Civil and environmental engineer

Glaciologist

Coastal and marine geologist





- Many significant studies and planning efforts have been done
- Several studies and efforts are ongoing and more are planned
- Hazards from flooding increase the risk for:
 - Loss of home/personal wealth
 - Failure of infrastructure and loss of dollars to repair/replace
 - Lingering losses to local commercial economy
 - Losses and damages to farming income, infrastructure and homes, livestock, crop and field,
 - Losses and damages to habitat and natural resources including salmon impacts like redd scour, siltation, stranding
 - Trauma to adults, children, elderly
 - Long-term impacts to community health for up to 20-years post disaster
- Flood control (dams, levees) can simplify and degrade salmon habitat
- Flood control actions can transfer risk
- There is the potential for a lot of water
- Fractured political landscape makes progress difficult

This project can contribute technically robust information to the complex flood risk reduction puzzle this community is working on.

Purpose of Today

- Share Skagit flooding and model overview and preliminary model results
- Create a forum where the model and model results can be explored, discussed and commented on

Outcomes for Today

- Project team has input from participants on:
 - Framing of flooding and climate change in the Skagit,
 - Model, and
 - Model results that contribute to refinement in products
- Participants meet someone new, hear a new perspective, consider what information would help them as they work to reduce flood risk and if these kinds of results are useful

Today's Agenda

9:00-9:15	Welcome, Introductions and Project Overview
9:15-10:15	Session I: Skagit Watershed Flooding a Brief Overview
10:15-10:40	Session II: Model Overview
10:40-10:55	Break
10:55-12:15	Session III: Sedro-Woolley Upriver
12:15-1:00	Lunch
1:00-3:30	Session IV: Sedro-Woolley Downriver, Breaches, Coastal Flooding
3:30-4:00	Wrap-up and closing

Session I: Flooding in the Skagit Watershed Overview

Outline

- A. Skagit Hydrology
- B. Understanding Skagit Flooding
- C. Climate Change Impacts
- D. What Insights Can Flood Modeling Provide?

Take-aways:

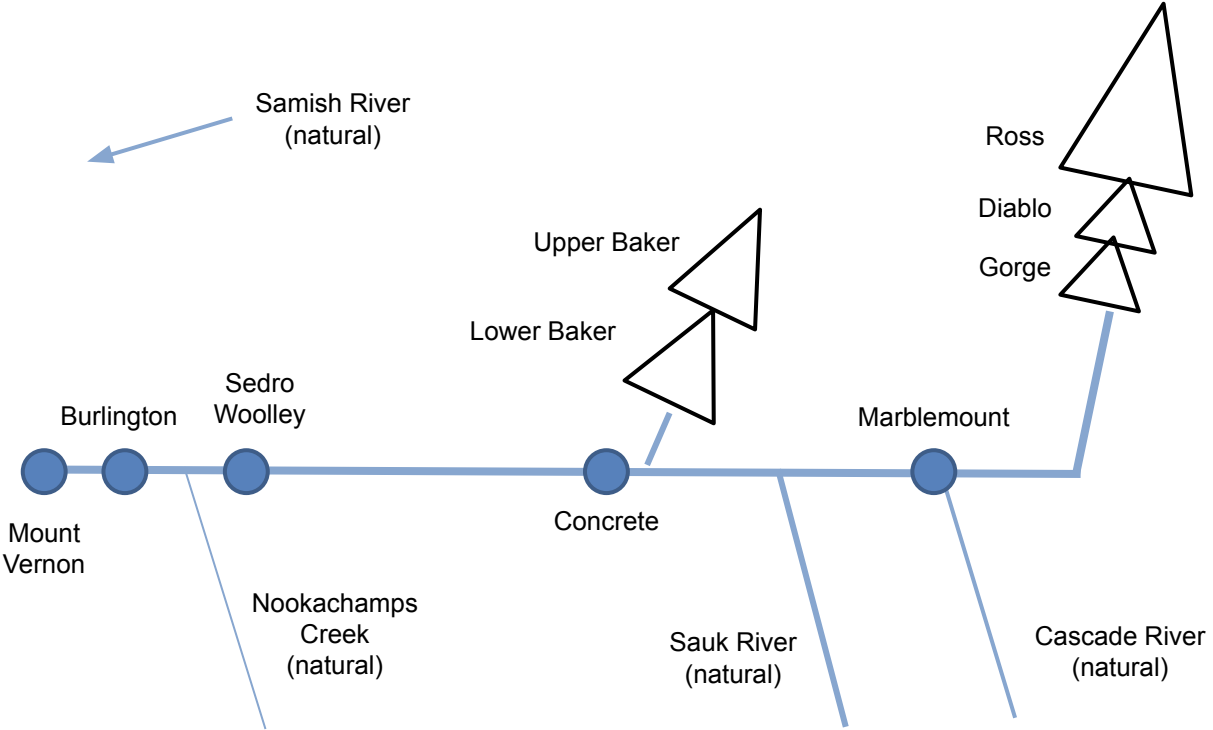
- Reservoirs have a big impact on floods in the Skagit River. Still, 61% of the watershed is downstream of the dams, so they can't address all floods equally well.
- Climate change will increase flood risk, primarily due to declining snowpack, heavier rain events, and sea level rise
- Models like the new Skagit flood model can explore what happens to flow velocity, stage, and inundation under various management approaches.

A) Skagit Hydrology



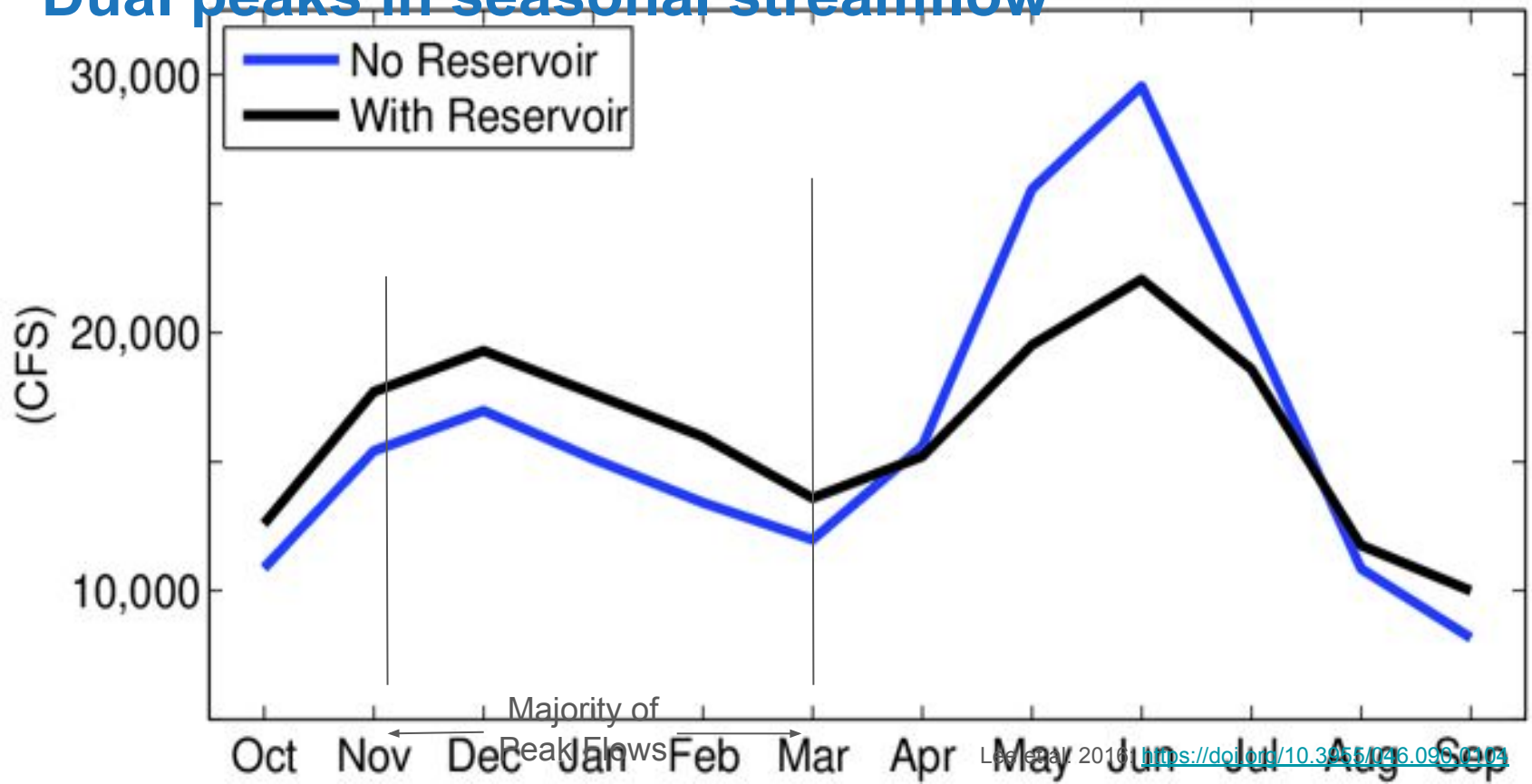
Source: Riedel, J., S. Sarrantonio, G. Seixas, C. Clement, 2020; Skagit River Geomorphology, Report to Seattle City Light, May

Schematic Diagram of the Skagit River Basin



Average Monthly Flow at Mount Vernon

Dual peaks in seasonal streamflow



Hydropower



<https://flic.kr/p/2q1A6FY>

Flood Control



Water Supply



Ecosystems



Agriculture



Source: Brandon Parsons, American Rivers

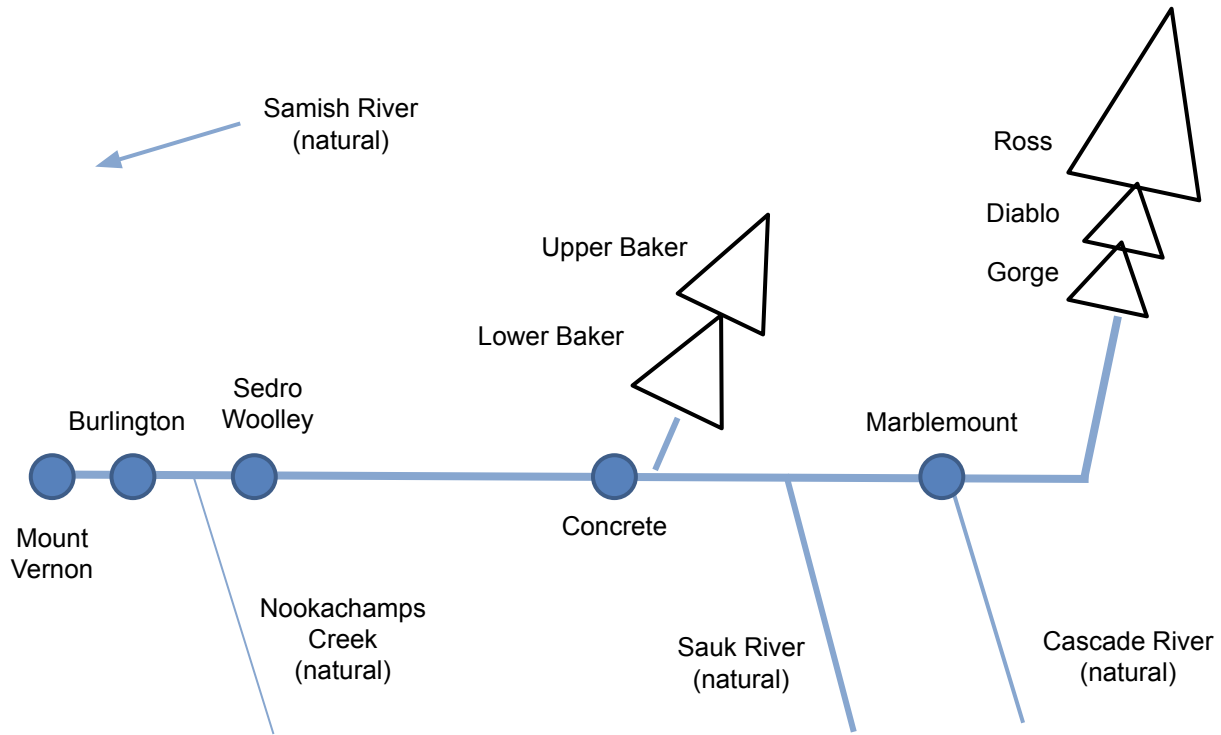
Recreation



Source: Alan Hamlet

B) Understanding Skagit Flooding

Role of Skagit Dams



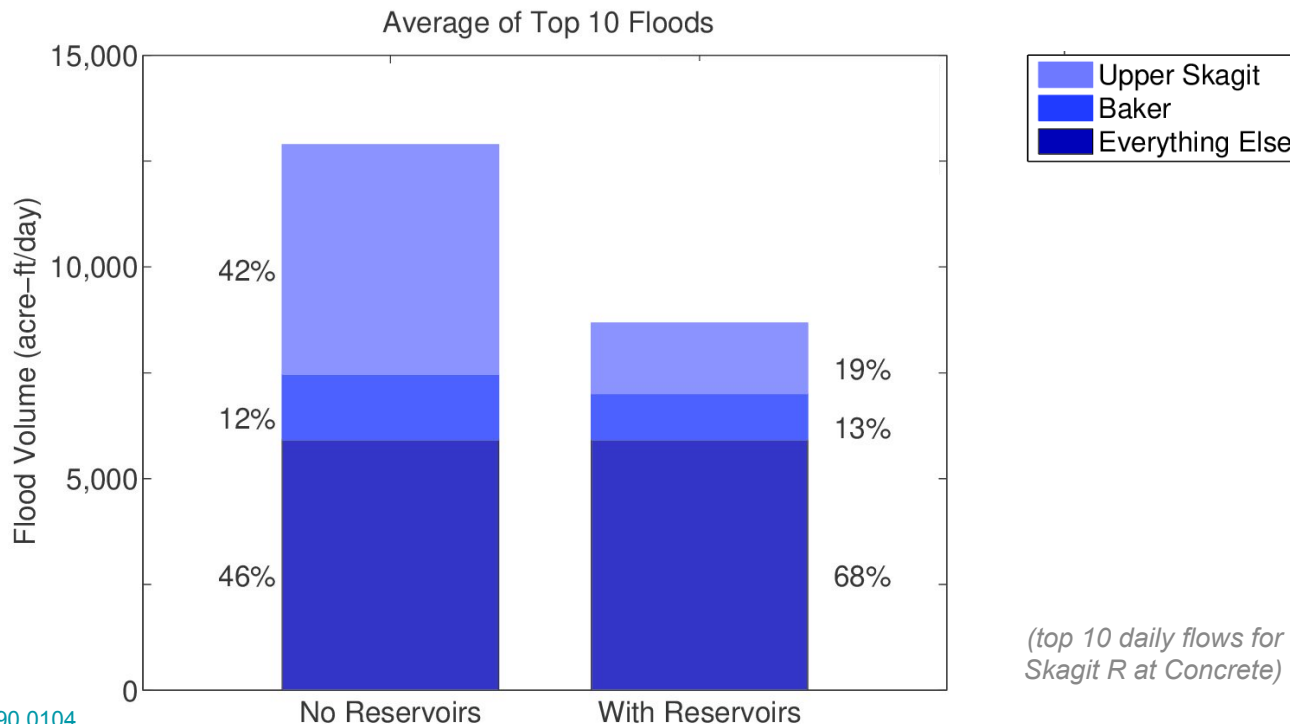
Role of Skagit Dams

**47% of Skagit basin area is
above the dams**

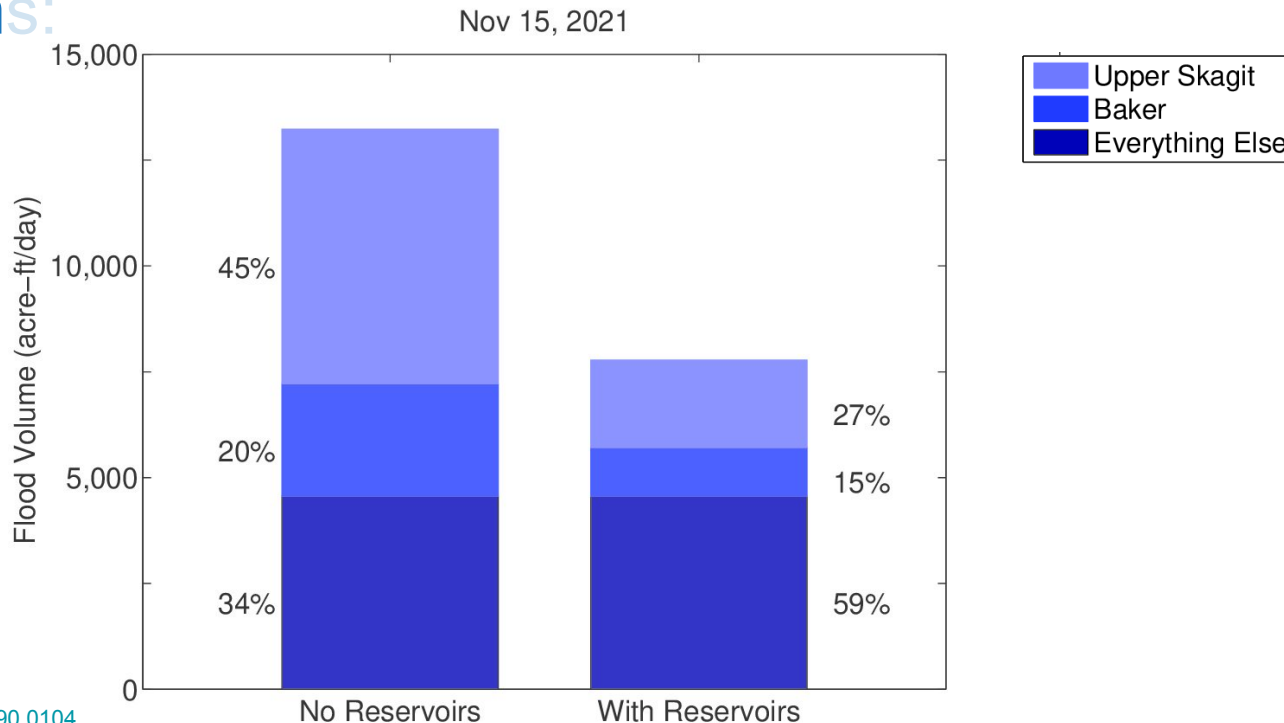
In other words:
**53% of the basin *is unaffected
by the dams***

Note: A previous version of this presentation had the percentages at 69%/31%. This is the area above Ross and Upper Baker dams, but does not include the area above Gorge, Diablo, and Lower Baker dams.

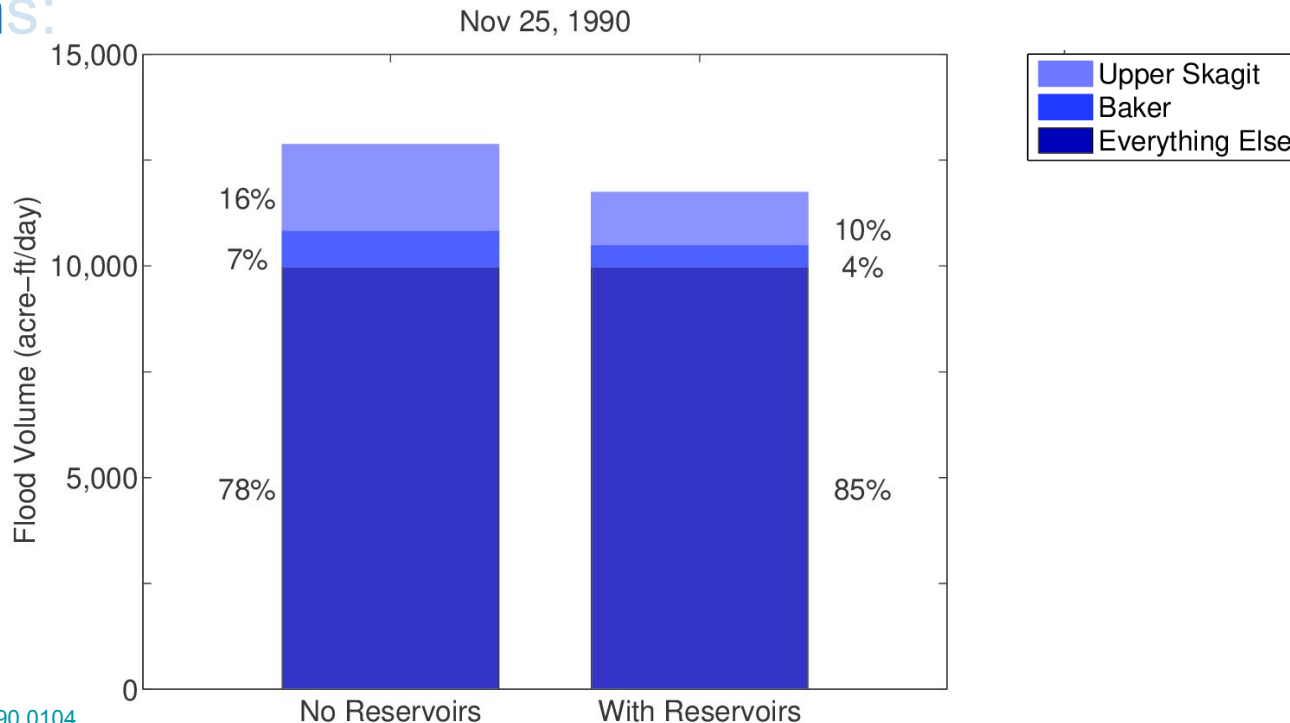
On average, across the top 10 Skagit floods, nearly half of the water comes from below the dams:



In 2021, most of the flooding came from above the dams:



In 1990, 78% of the flooding was not affected by the dams:



What is a “100-year” Flood?

A flood that has a **1 in “100” chance** (or 1%) of occurring in any given year.

100-year flood

= 1% chance per year

= XX% chance in next

25 years

25-year flood

= 4% chance per year

10-year flood

= 10% chance per year

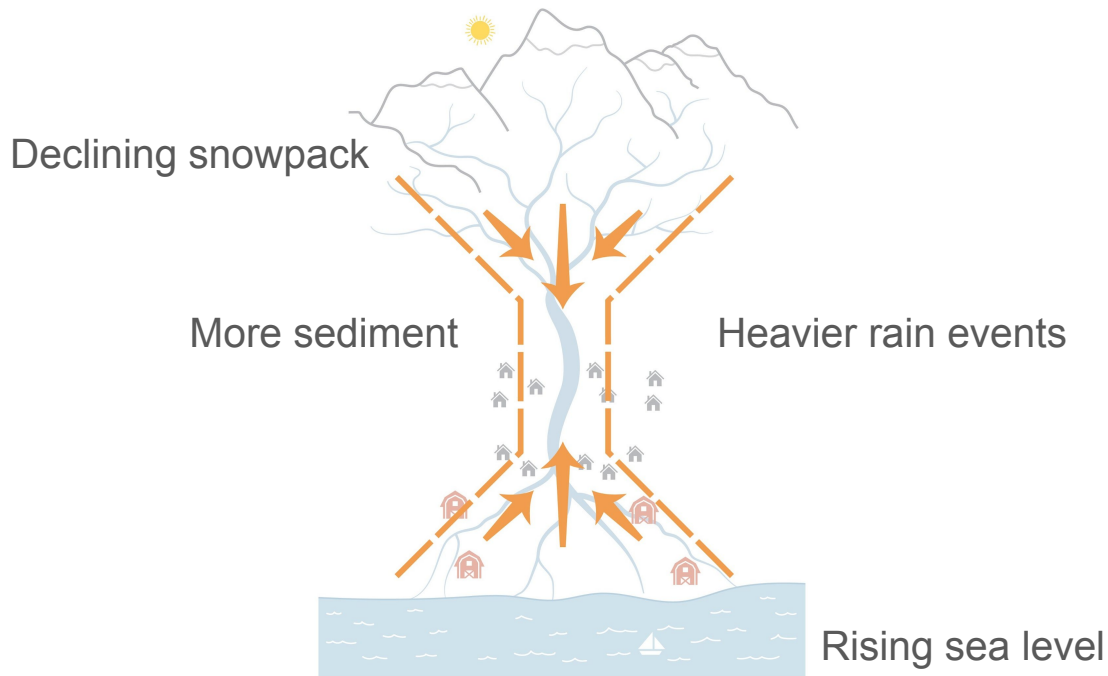
Under “**Existing Conditions**” we determine these floods based on today’s climate conditions.

Under “**Future Conditions**” we use climate projections to understand how these floods could change by the **2040s or 2080s**.

This slide was not presented at the workshop but included based on feedback for clarification.

C) Climate Change Impacts

Changing Climate: Multiple Forces Combine



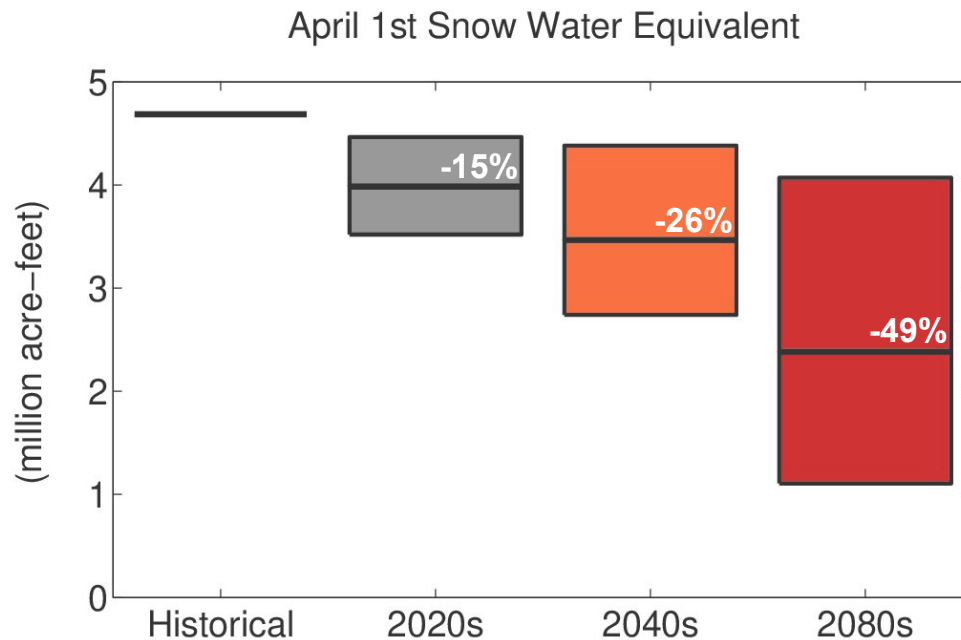


More Intense Heavy Rains

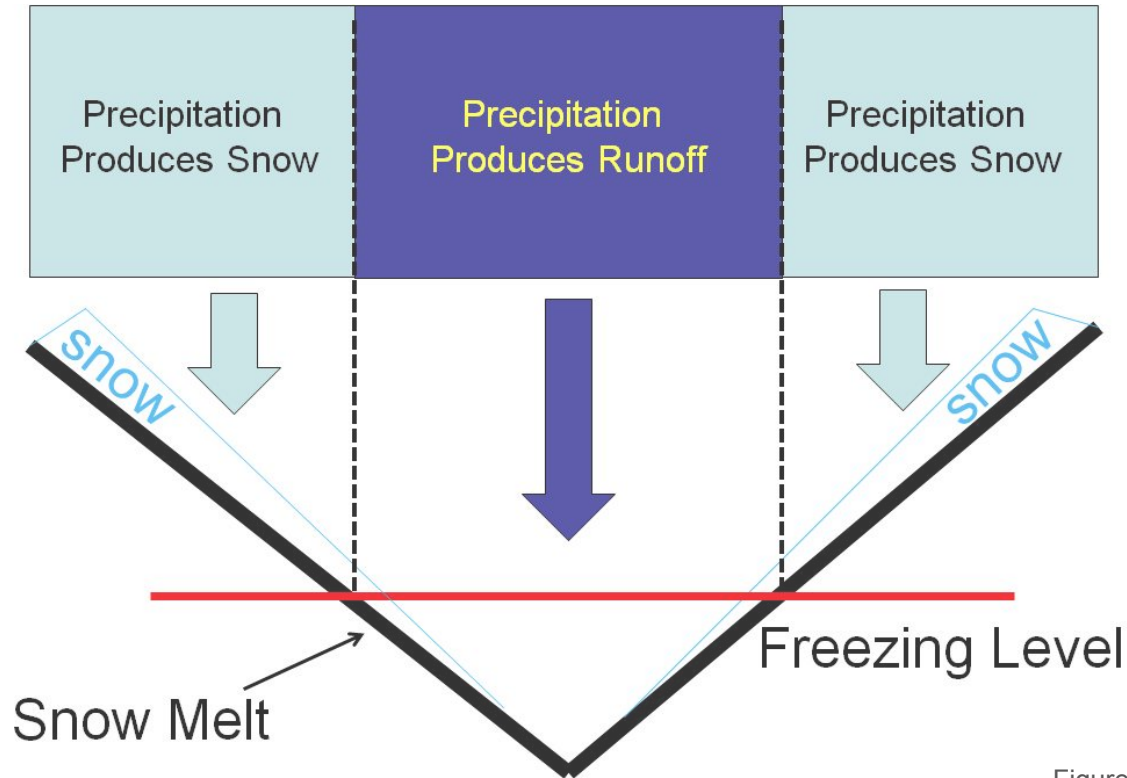
Heaviest rain events (top 1% daily) are projected to become **+22% more intense** by the 2080s (*range: +5 to +34%*).

based on a high-end greenhouse gas scenario (RCP 8.5)
Warner et al. 2015; <https://doi.org/10.1175/JHM-D-14-0080.1>

Accelerating Decreases in Snowpack



Schematic of a Cool Climate Flood



Schematic of a Warm Climate Flood

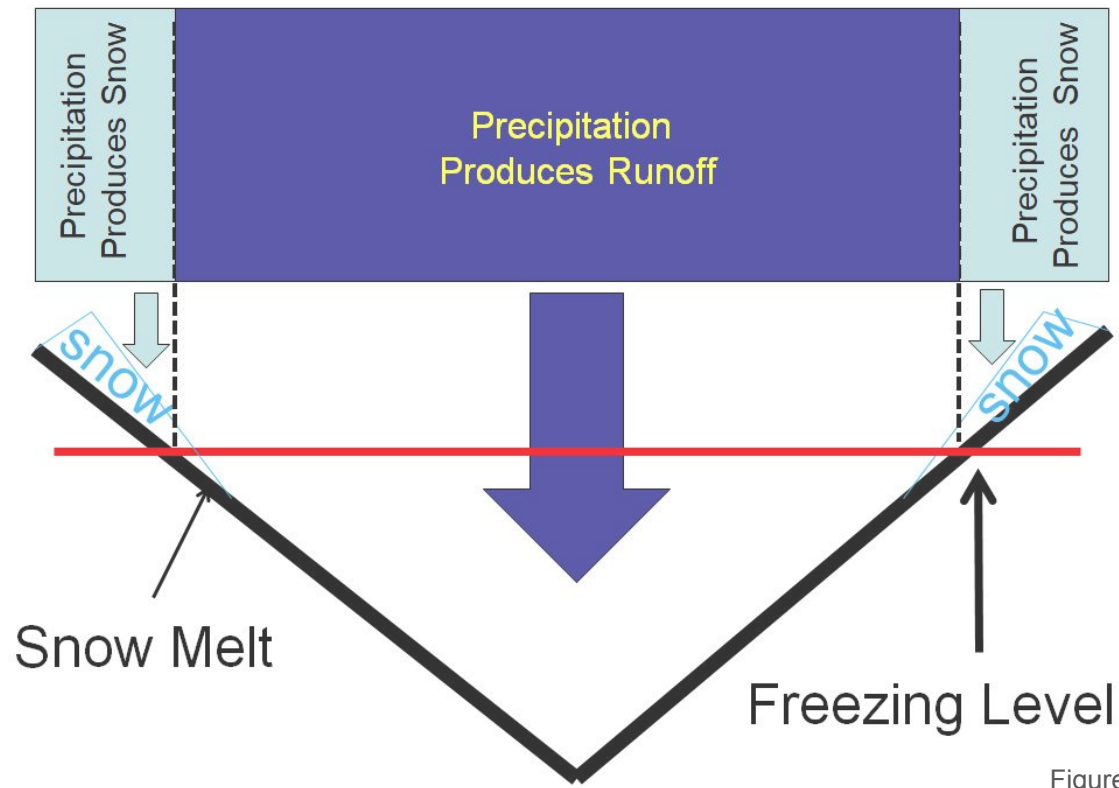
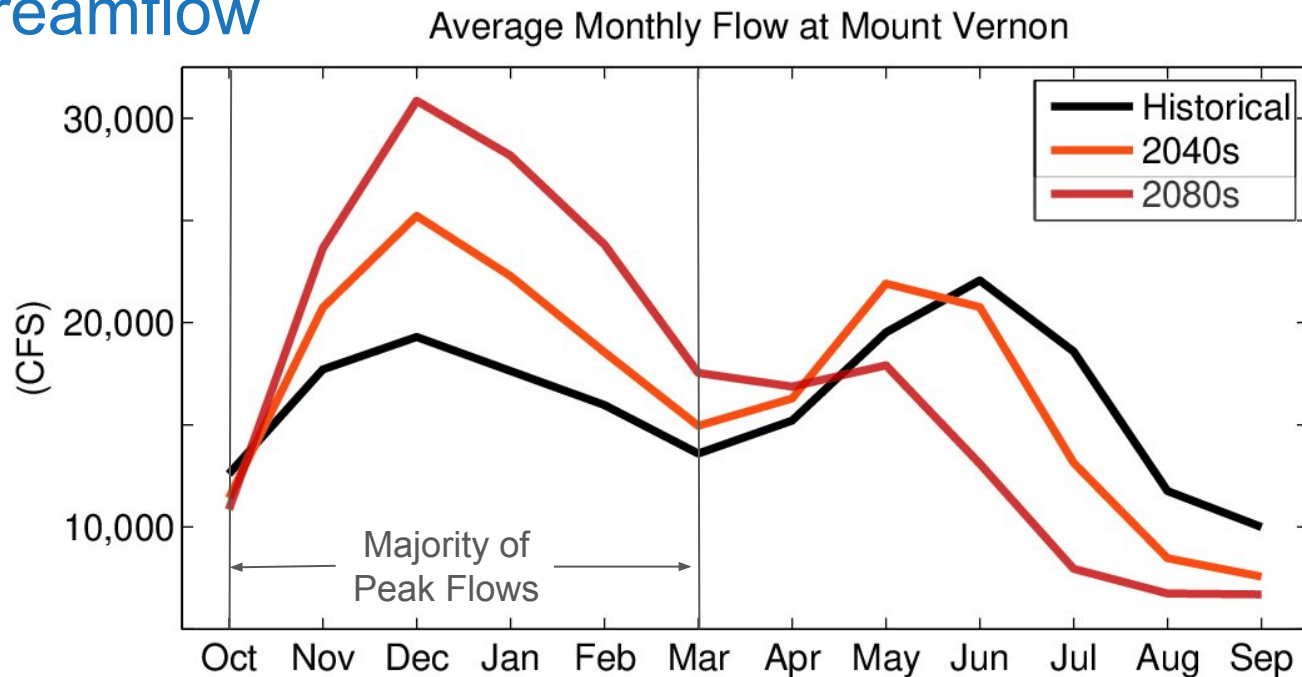


Figure credit: Alan Hamlet

Warmer Climate Shifts to a Winter Peak in Streamflow

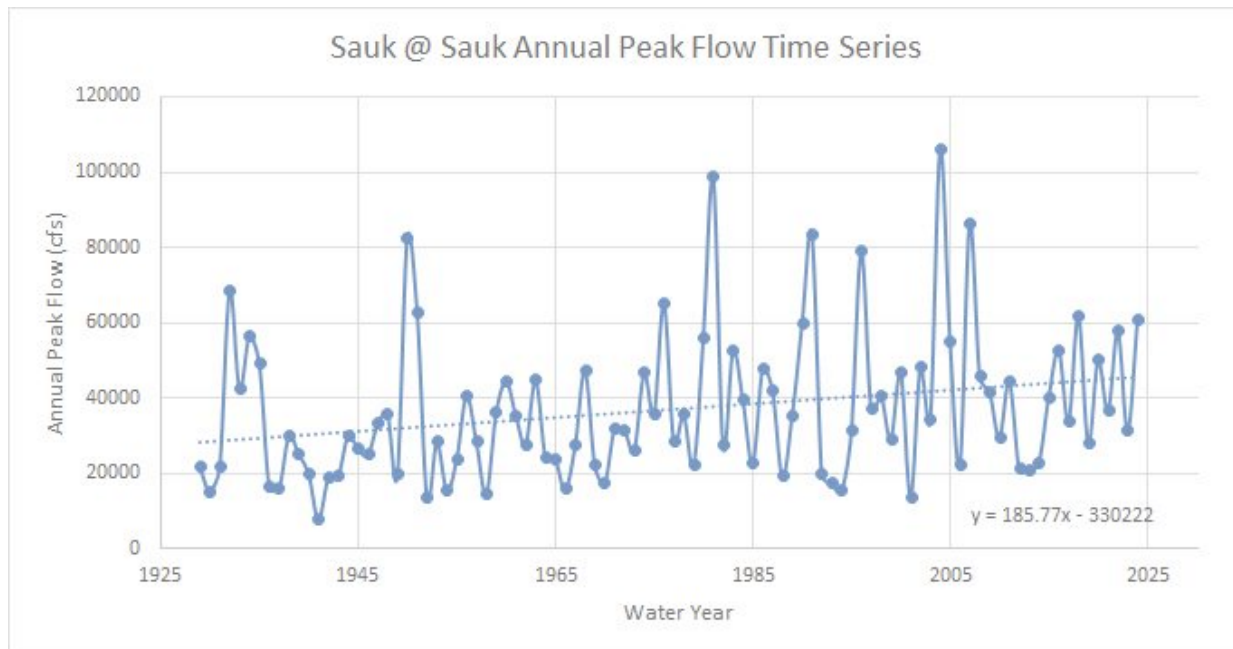


Result: Much Bigger Floods in the Future

At Mount Vernon, the 100-year regulated flood is projected to be 49% bigger, by the 2080s

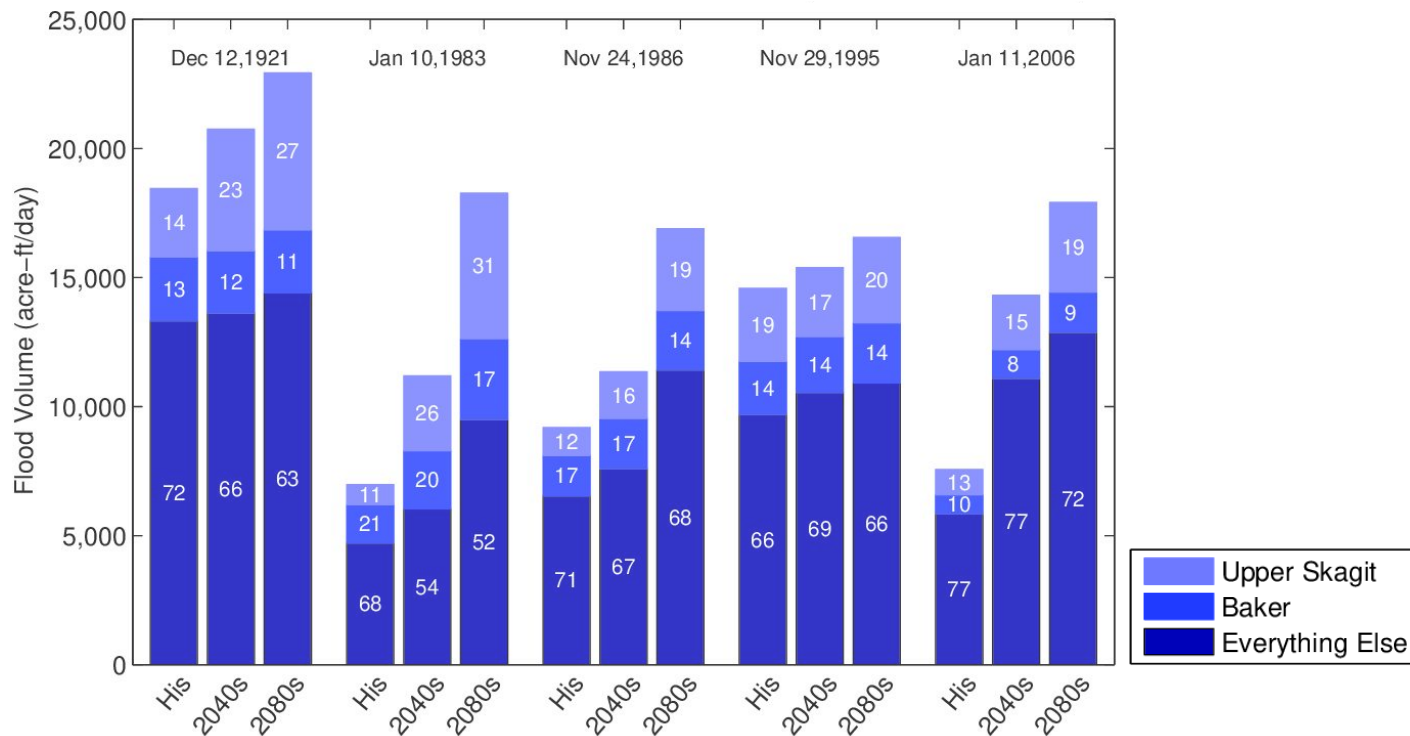
Put another way: By the 2040s, today's "100-year event" will happen about every 20-25 years

Sauk River peak flows (unregulated) have been increasing

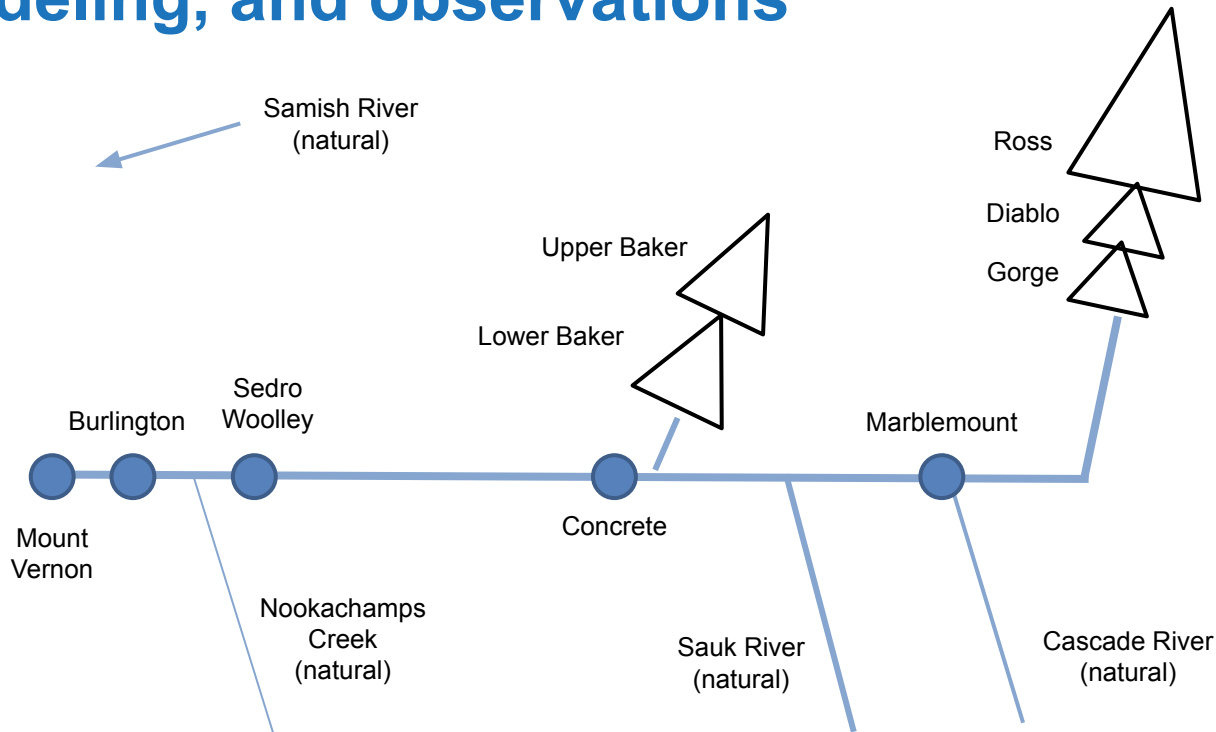


Post-1975 mean is 38.8% higher than pre-1975 mean.
Of the seven highest annual peak flows, five have occurred since 1975.

Every flood is different



Inputs to the flood model came from recent modeling, and observations



(schematic representation of the Skagit and Samish Rivers)

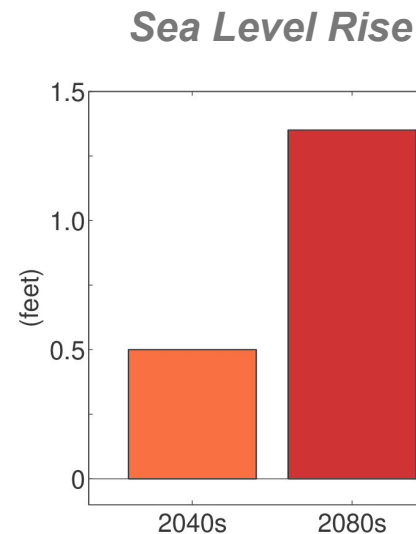
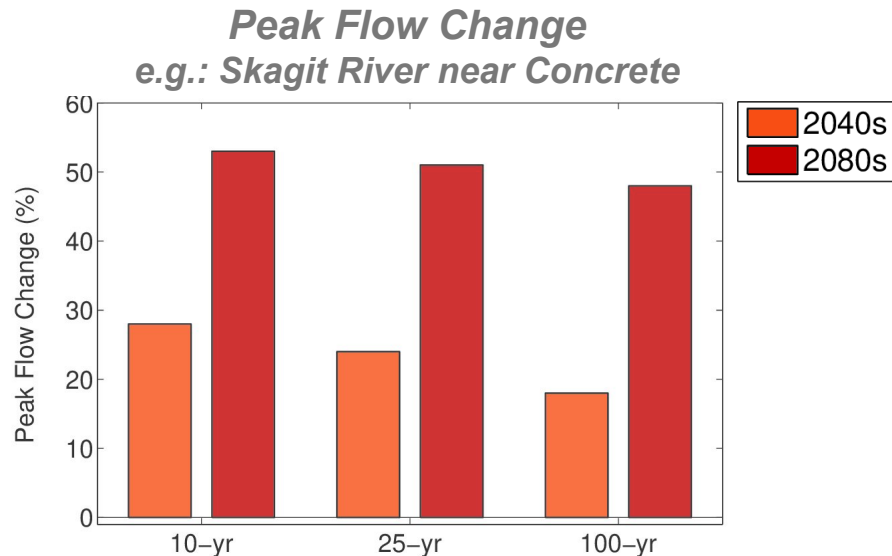
Model Inputs: *Current Conditions*

- **Peak river flows from the Skagit General Investigation**
- **Coastal “surge” estimates from NOAA tide gauges**

Model Inputs: *Future Conditions*

- We used projections for the 2040s and 2080s, in order to have an estimate of near-term and long-term changes.
- Projections are based on a middle-of-the road greenhouse gas scenario (“A1b”), in the range of what current research deems most likely.
- We selected the average projection for each time period, again because it is considered the most likely estimate of future conditions.

Model Inputs: *Future Conditions*



Streamflow: Lee et al. 2016, <https://doi.org/10.3955/046.090.0104>
Sea Level Rise: Miller et al. 2018, <https://cig.uw.edu/projects/projected-sea-level-rise-for-washington-state-a-2018-assessment/>

D) What Insights Can Flood Modeling Provide?

Big-Picture Approaches to Reduce Flood Impacts

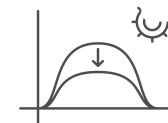
1) **Contain the flow** (*levees, flood walls*)



2) **Flatten the peak** (*reservoirs, natural storage, levee and dike setbacks, forest mgmt, floodplain/wetland reconnection & restoration, etc.*)



3) **Divert water** (*bypass channel*)



4) **Live with flooding** (*flood preparation, elevate structures*)



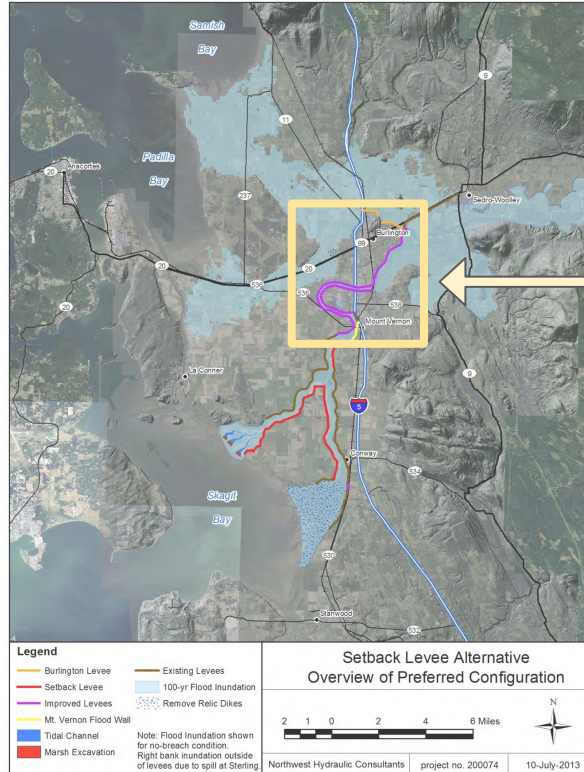


Contain the Flow

1. Strengthen Conventional Infrastructure

US Army Corps of Engineers General Investigation (GI) Draft Environmental Impacts Statement (2013)

Appendix B
pg 171

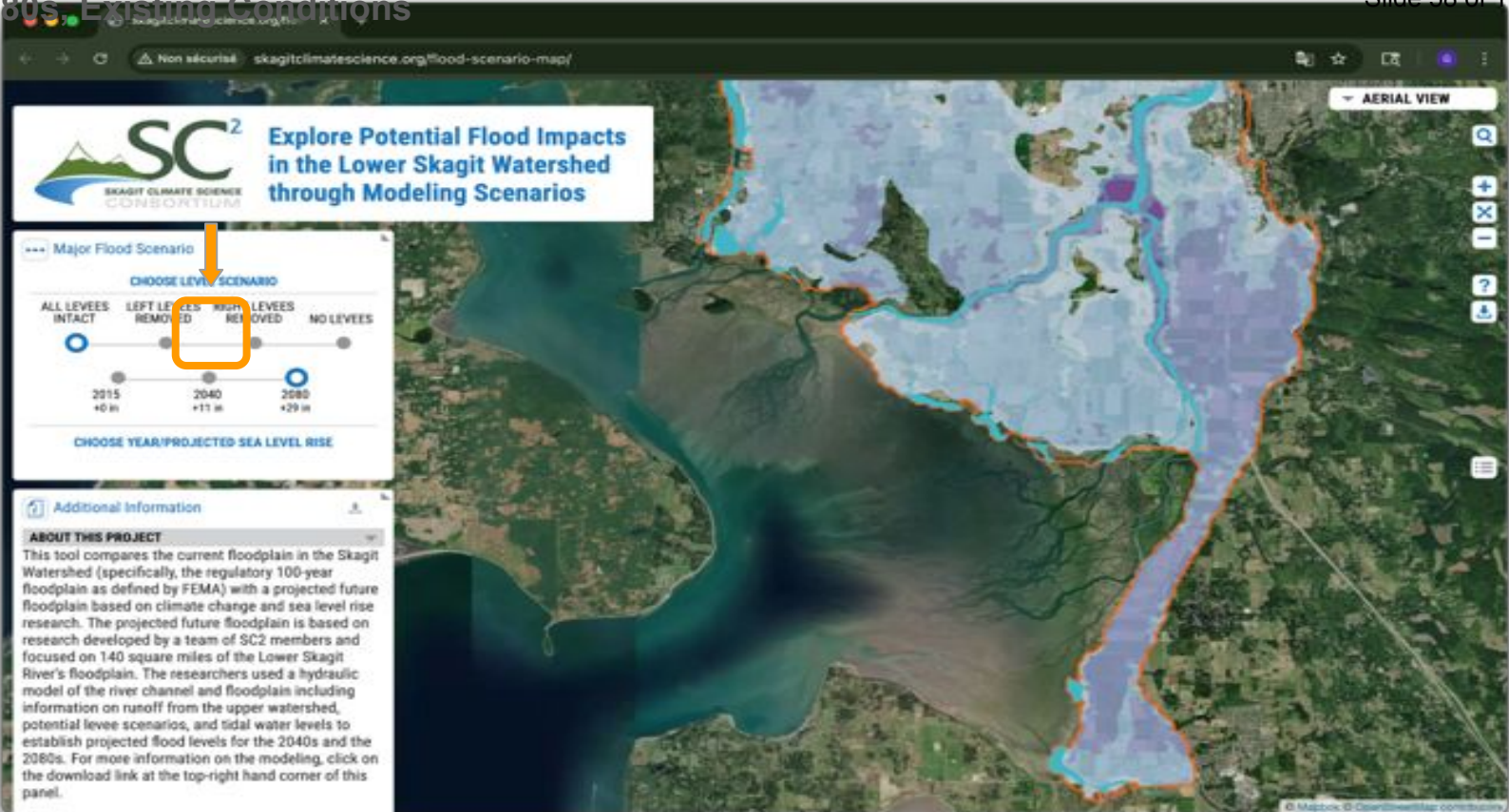


e.g.

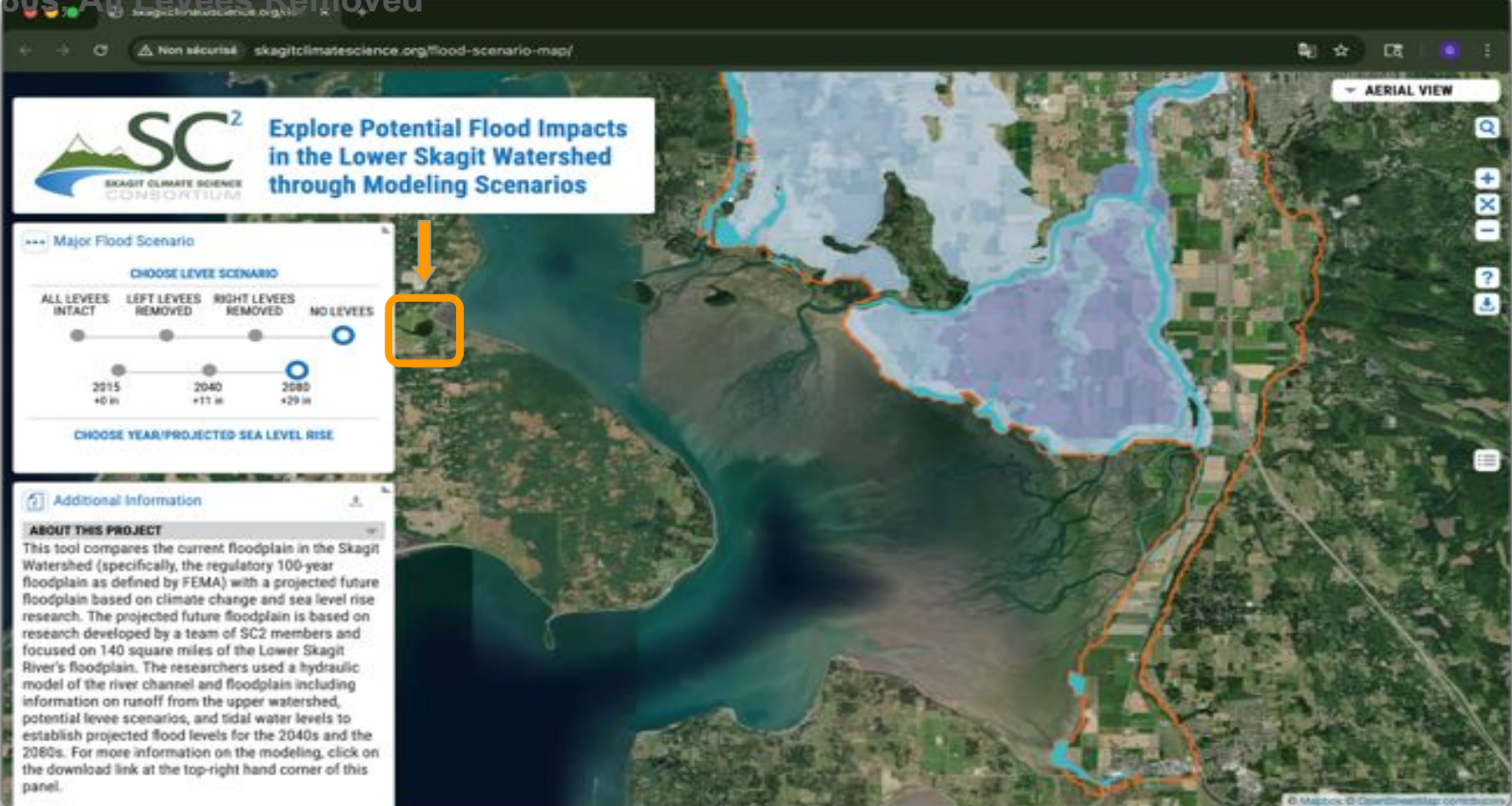
Strengthen existing levees and dikes in known problem areas

Raise height of existing levees

2080s Existing Conditions



2080s: All Levees Removed





2. “Flatten the curve”

Examples:

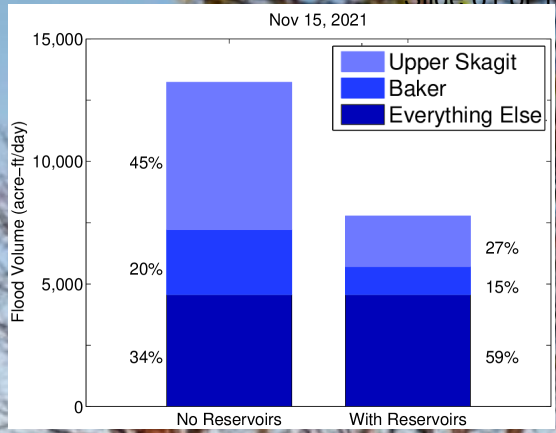
- Dams hold back water during floods and release it later
(alternative ‘rule curves’ may increase available flood storage earlier in the fall)
- Logjams and other changes to tributary channels can increase “roughness” and slow the flow.
- Setback levees give the river more room and provide more natural floodplain function and ecosystem resilience.

Flatten the Curve

Example: Dams



For the November 2021 floods, the water could have reached 8 feet higher in Mount Vernon without the dams.





Example: Setback Levees

Setback levees let the river spread out, more like a natural floodplain, slowing the flow.

Can have ecosystem benefits through restoration of natural floodplain.



Example: King County

<https://kingcounty.gov/en/dept/dnrp/nature-recreation/environment-ecology-conservation/flood-services/capital-projects-studies/jan-road-levee-setback>



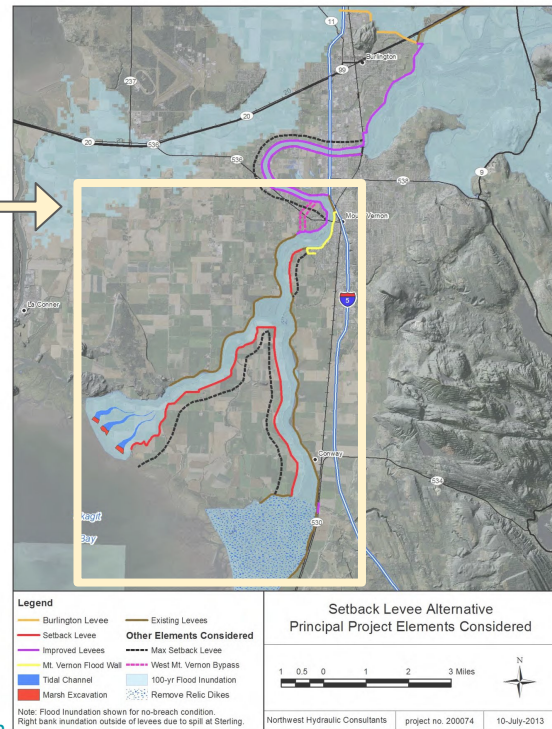
Example: Setback Levees in the Lower Basin

Setbacks were explored in the General Investigation study

Source:

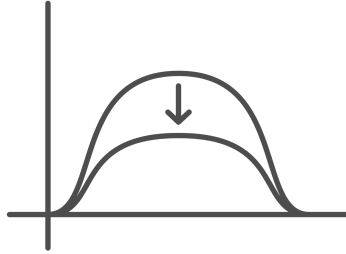
US Army Corps of Engineers
General Investigation (GI) Draft
Environmental Impacts Statement
(2013)

Appendix B, Pg 170



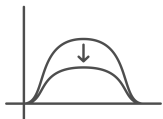
3. Divert Water

(bypass channel)



By diverting water, flow in the main stem is reduced.

The effects are comparable to a levee breach, except that the “where and when” are selected in advance.

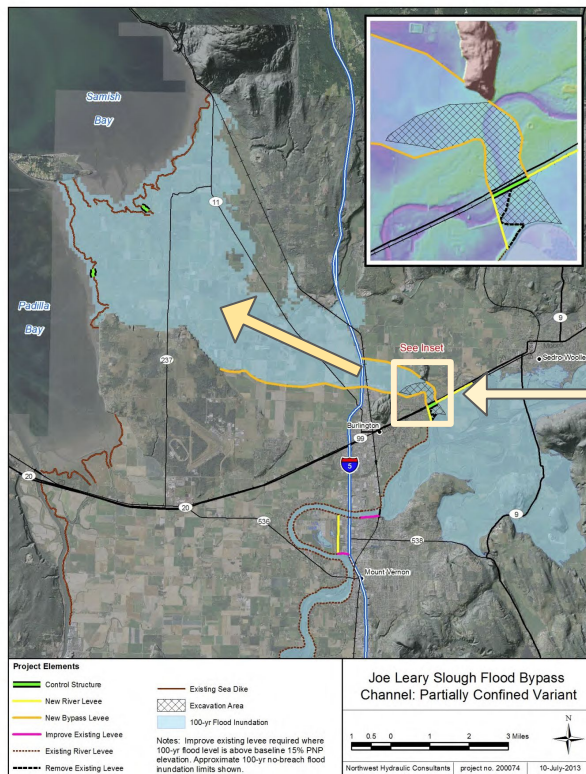


Example Diversion: Joe Leary Slough

Source:
US Army Corps of Engineers General Investigation (GI)
Draft Environmental
Impacts Statement
(2013)

Appendix B, Pg 178

<https://www.skagitcounty.net/Departments/PublicWorksSalmonRestoration/main.htm>



By diverting water, flow in the main stem is reduced.

The effects are comparable to a levee breach, except that the “where and when” are selected in advance.

4. Live with flooding

(flood preparation, elevate structures)



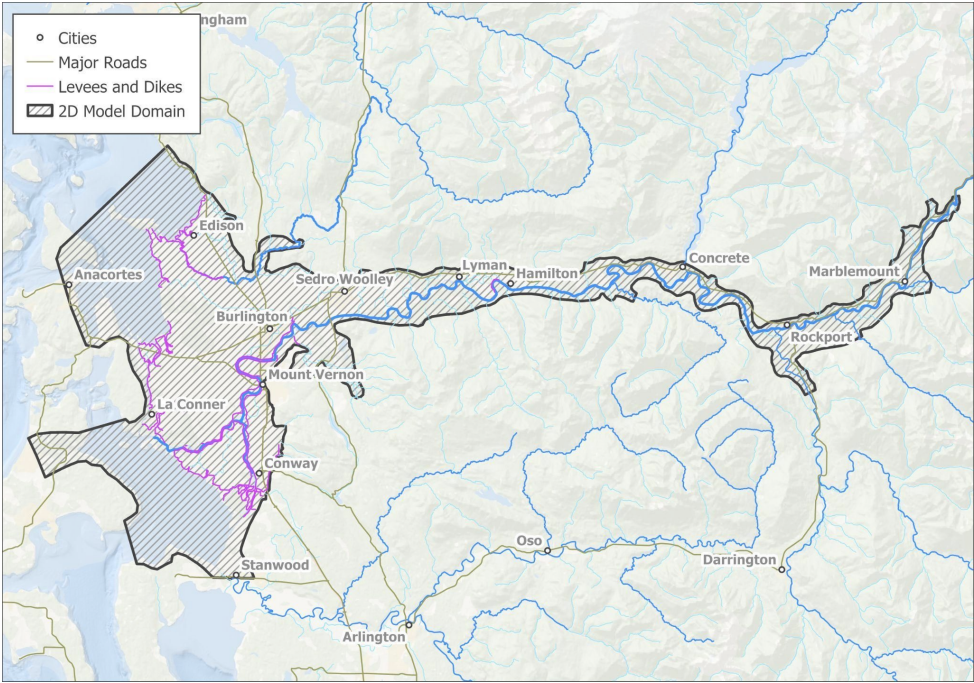
We have not included any examples for “live with flooding”. These are critical flood resilience strategies, but they often cannot be evaluated with the flood model we have developed.

Take-aways:

- Reservoirs have a big impact on floods in the Skagit River
- With 61% of the watershed downstream of dams, they can't address all floods equally well.
- Models project that today's 100-year flood will be happening every 20-25 years by mid-century
- We relied on recent modeling, and observations, to develop riverine and coastal inputs to the flood model
- Models like the new Skagit flood model can explore what happens to flow velocity, stage, and inundation under various management approaches.

Session II: Model Overview

New Skagit River Model



Parameter	Current Model (USACE)	New Model
Model Type	1D / 2D	Fully 2D
Bathymetry	1975	2022, 2014
Resolution	400 ft	50-200 ft
Skagit Bay, Samish Bay	Not included	Included
Samish River	Not included	Included

New Skagit River Model: Does Include

- ✓ New Bathymetry (2022, 2014)
- ✓ Incorporates recent levee strengthening and habitat projects
- ✓ Riverine flooding (current and future, 10-year, 25-year, 100-year)
- ✓ Levee breaches (6 locations, based on GI)
- ✓ Tides
- ✓ Coastal flooding (current and future)
- ✓ Flood depth, extent, and velocity
- ✓ Flood duration

New Skagit River Model: Does Not Include

- ✓ Sediment transport/deposition
- ✓ Debris build-up on bridges
- ✓ Future land-use/land cover
- ✓ Pump stations
- ✓ Sauk River (flow input included, but terrain is excluded from model)
- ✓ Soils, infiltration

Saltwater intrusion

Channel migration and avulsion

Groundwater

Local stormwater flooding

(✓ = model has capacity to
include in future work)

River Flood: Historical and Simulated Events

Recent Events at Mount Vernon

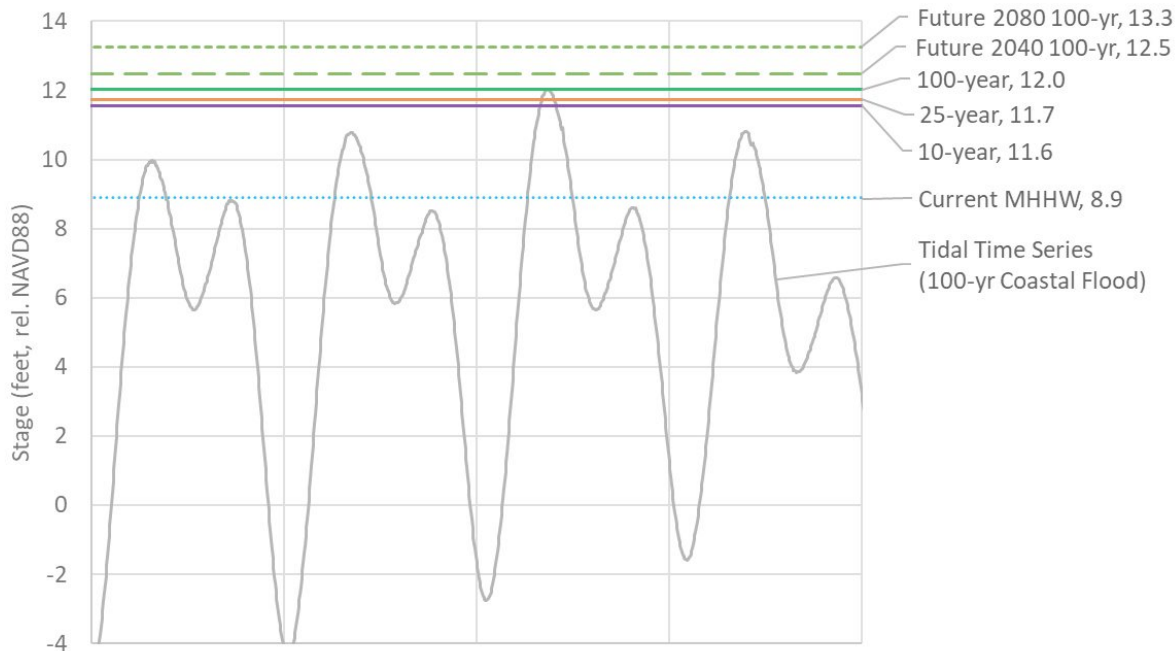
Event	Flow (cfs)	Stage (ft)
Nov 2021*	127,000	37.0
Nov 2006	138,000	33.9
Oct 2003*	135,000	36.2
Nov 1995*	141,000	37.3
Nov 1990	152,000	37.4

Existing (2013 GI) and Future Flows

Event	Flow at Sedro Woolley (cfs)	Flow at Mount Vernon (cfs)
10-year	133,000	119,000
25-year	170,000	150,000
100-year	236,000	171,000
Future 2080 100-year	314,000	176,000

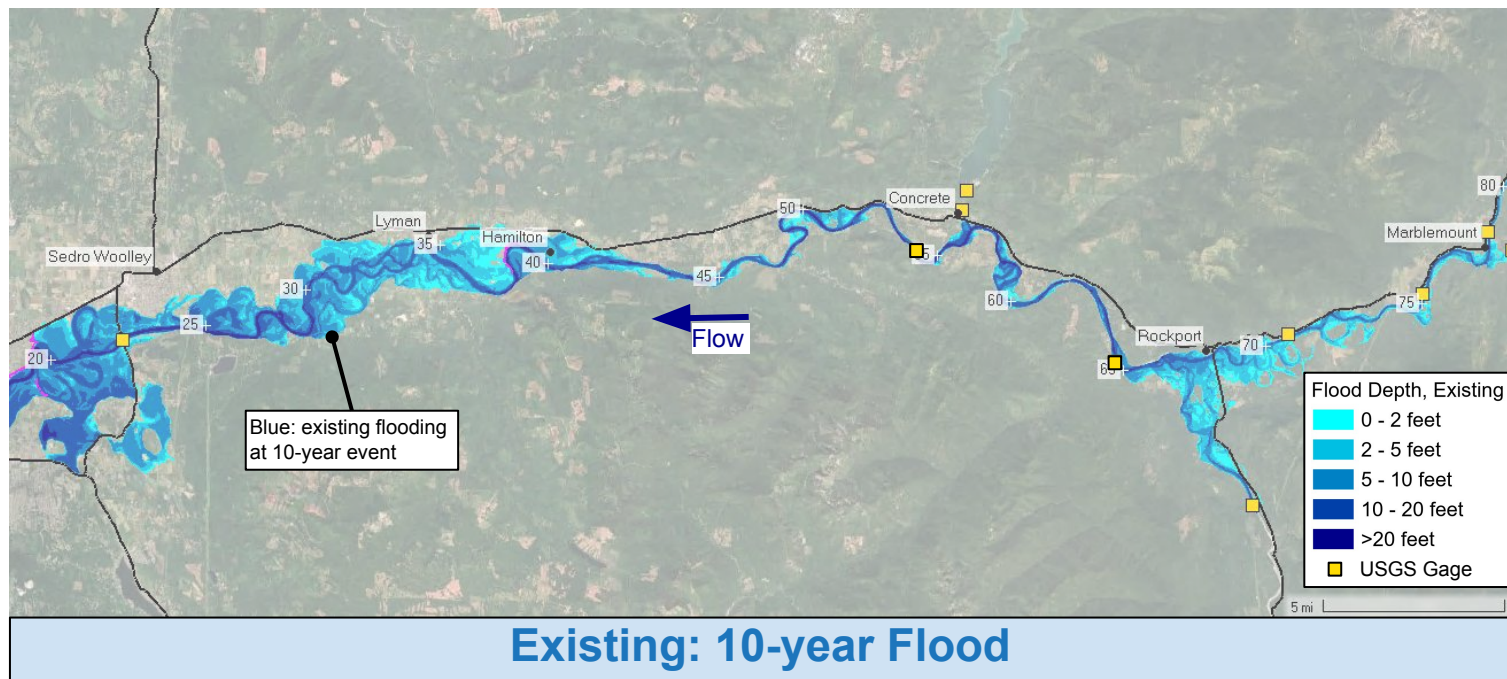
**Model calibrated to USGS gages and High Water Marks*

Coastal Flood: Tidal Elevations

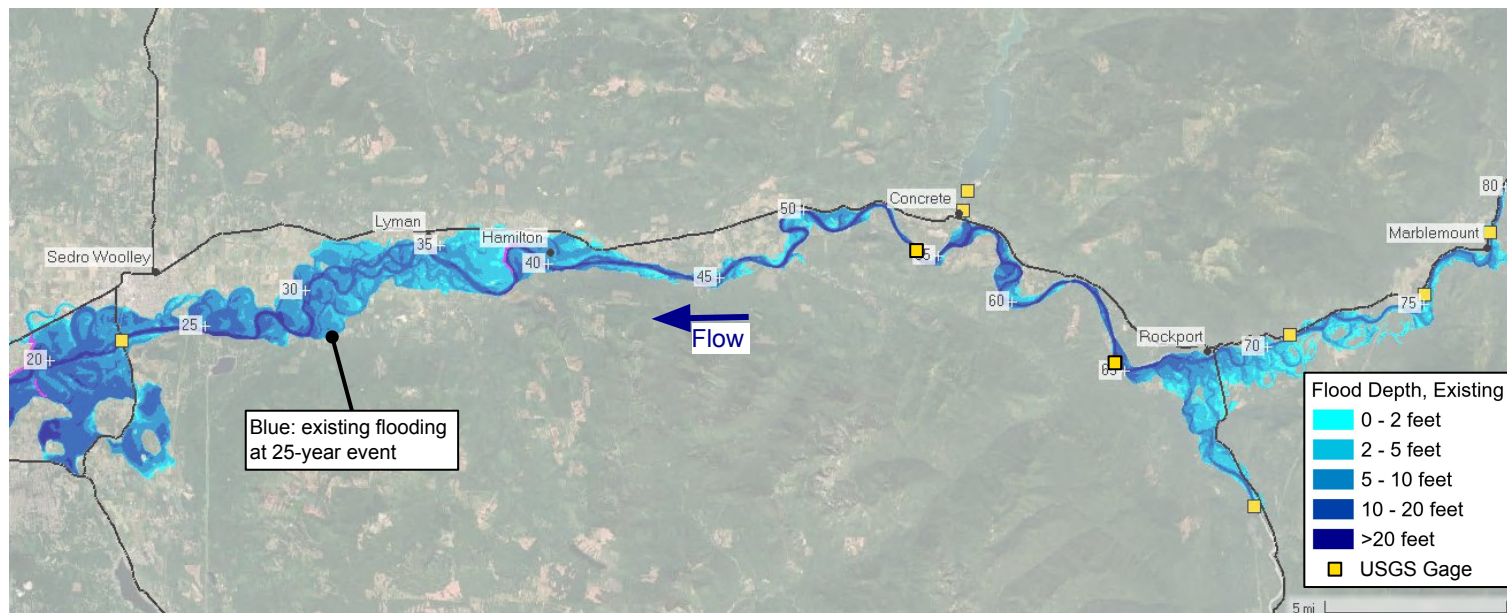


Session III: Current and Future Conditions *Sedro-Woolley Upriver*

Upriver System: River Flood Overview

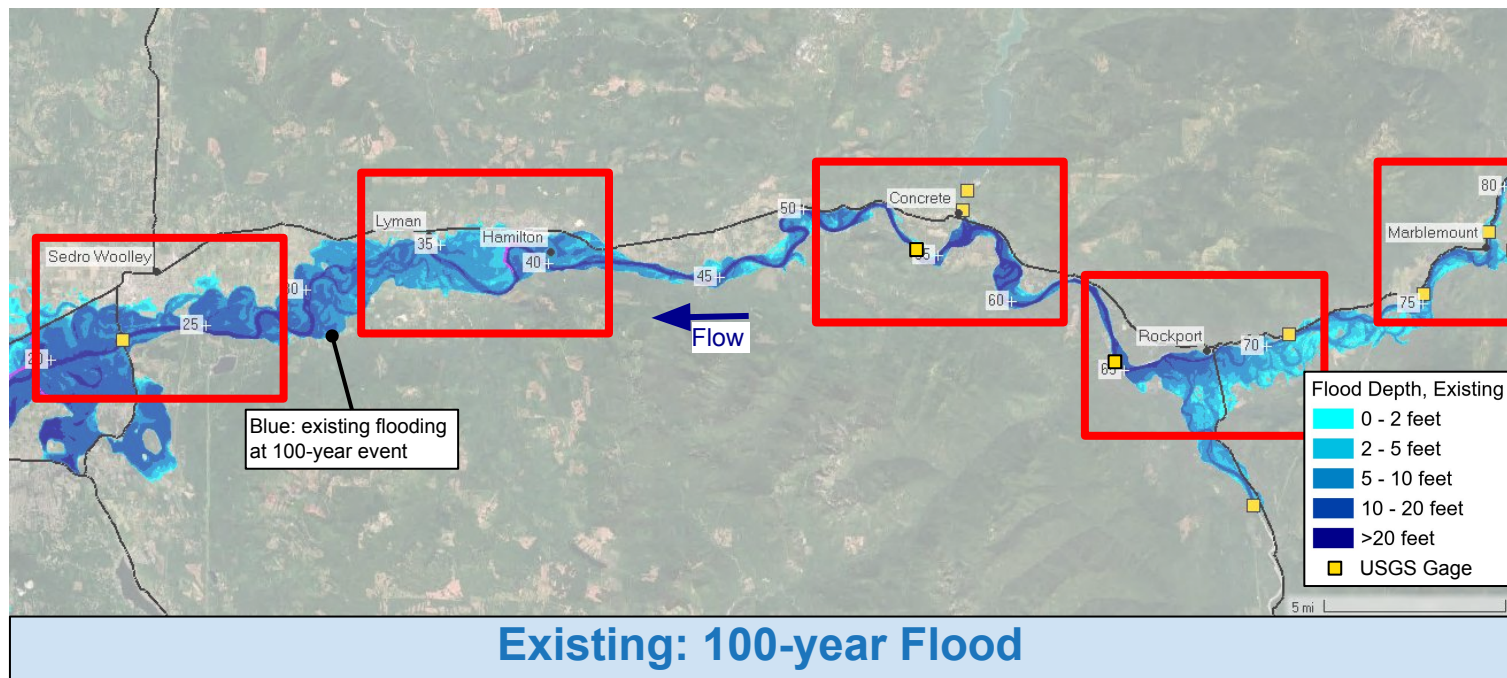


Upriver System: River Flood Overview

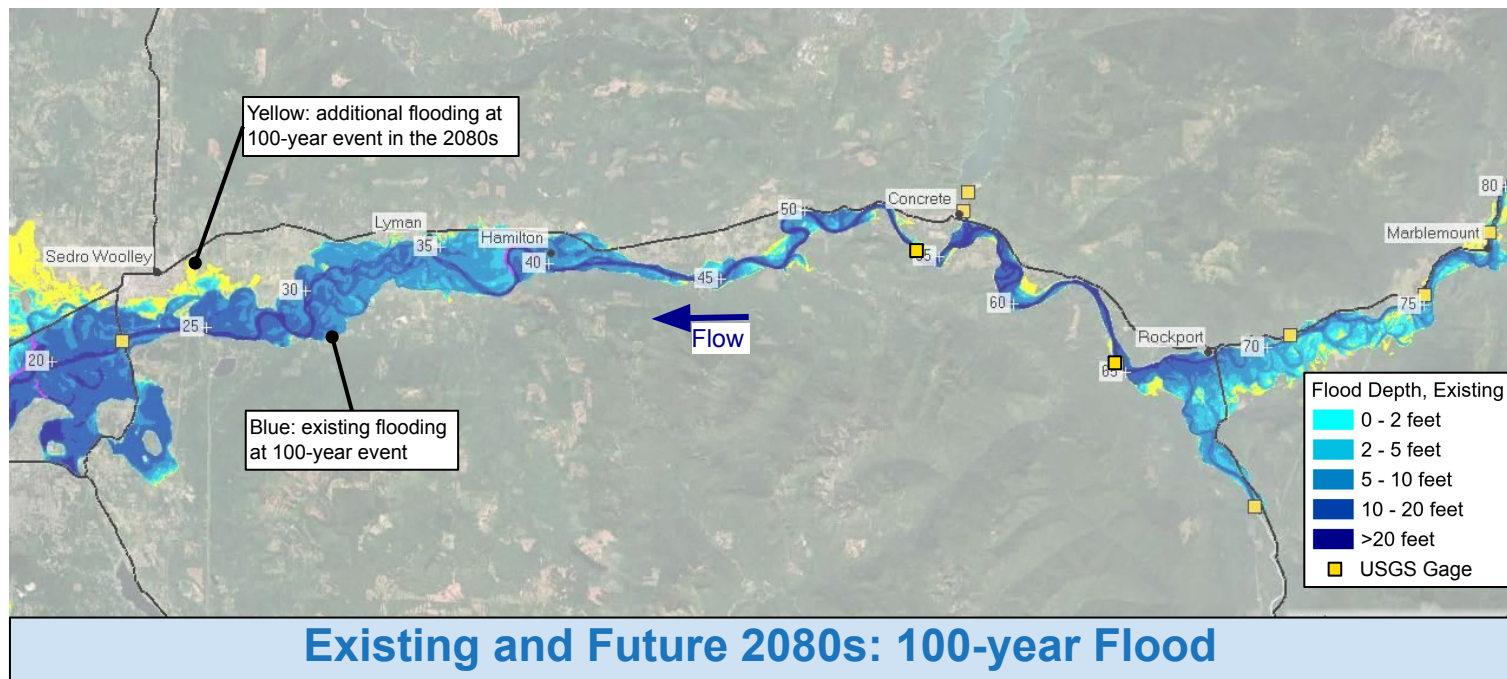


Existing: 25-year Flood

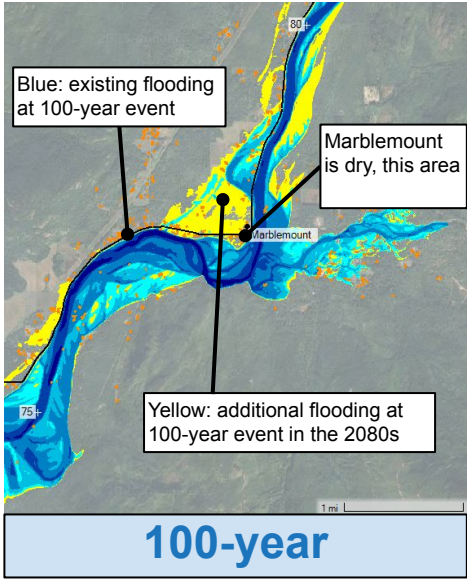
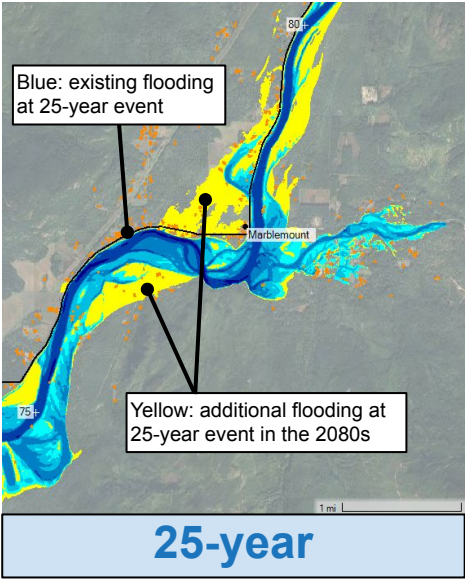
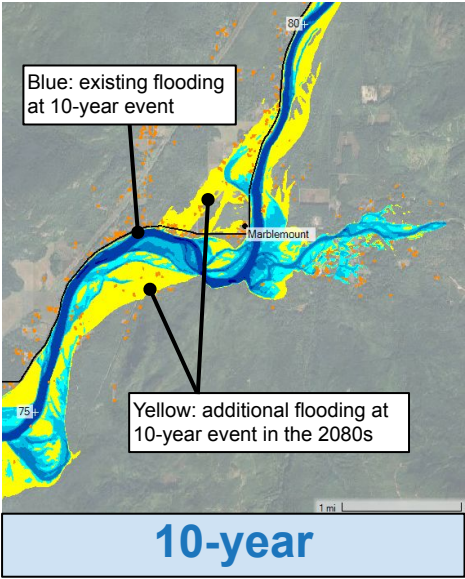
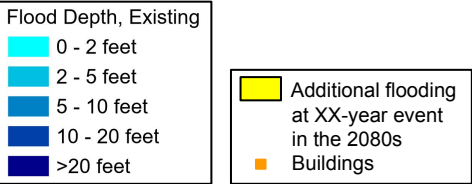
Upriver System: River Flood Overview



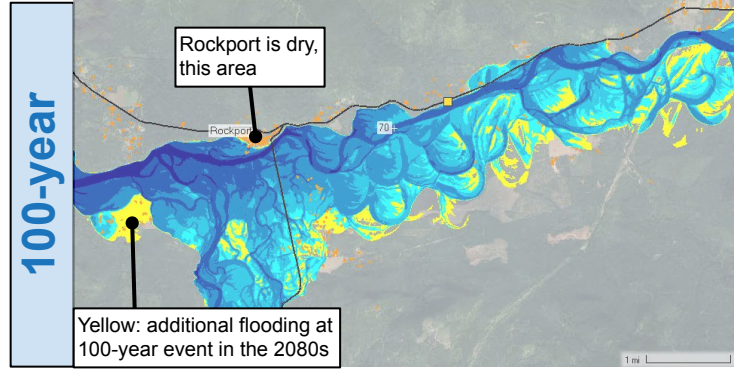
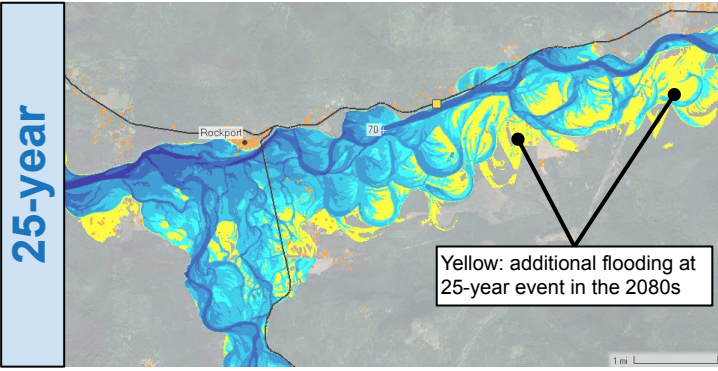
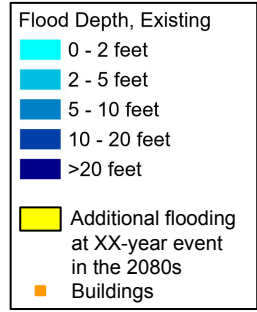
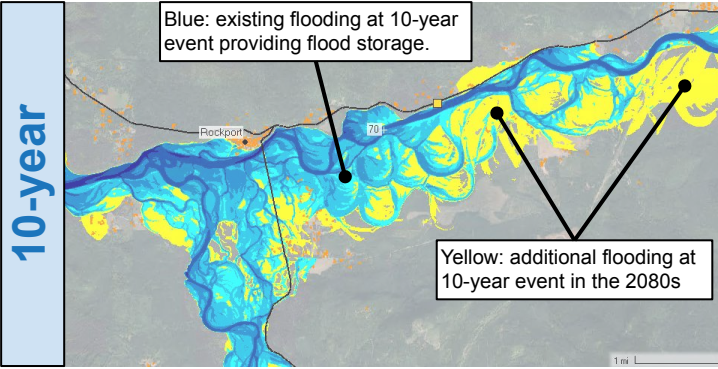
Upriver System: River Flood Overview



River Flood: Marblemount

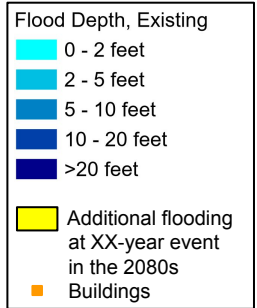
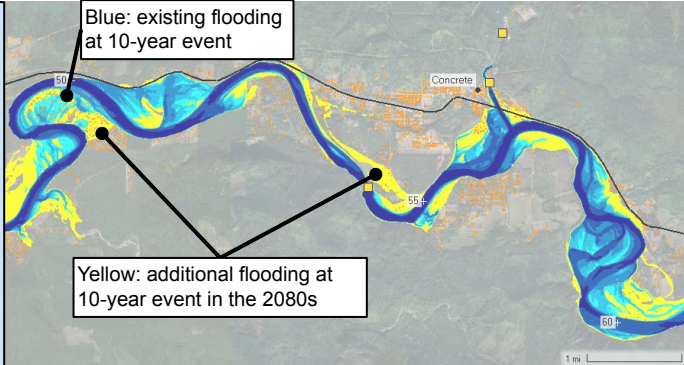


River Flood: Rockport

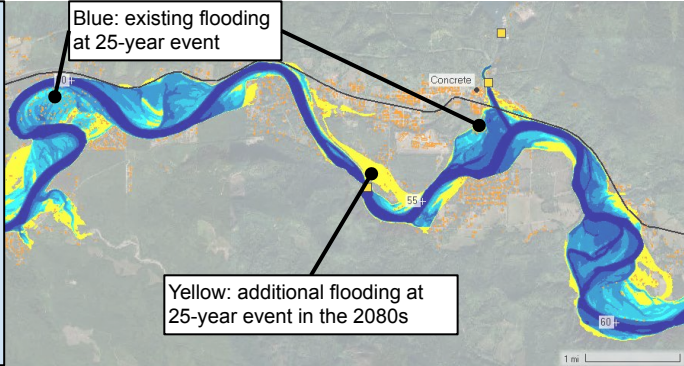


River Flood: Concrete

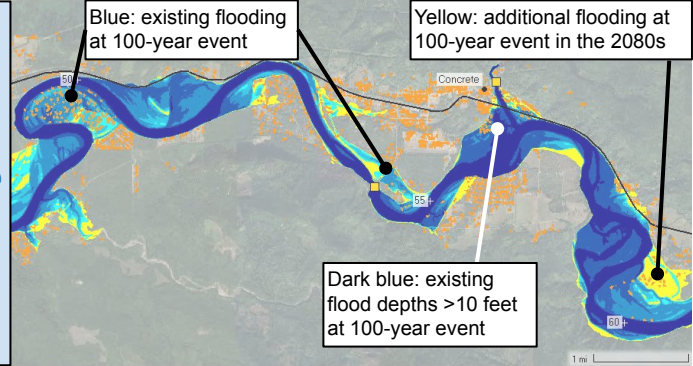
10-year



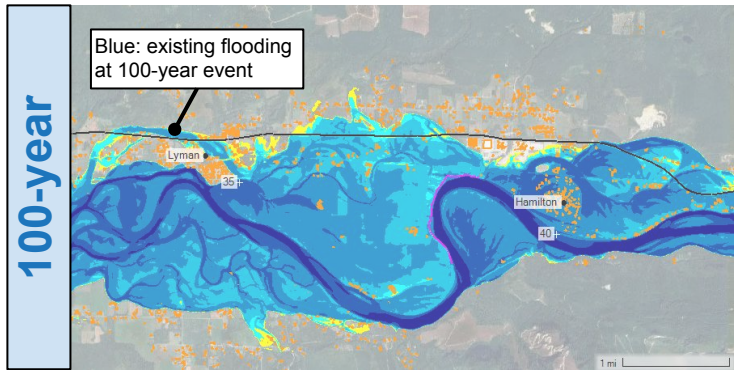
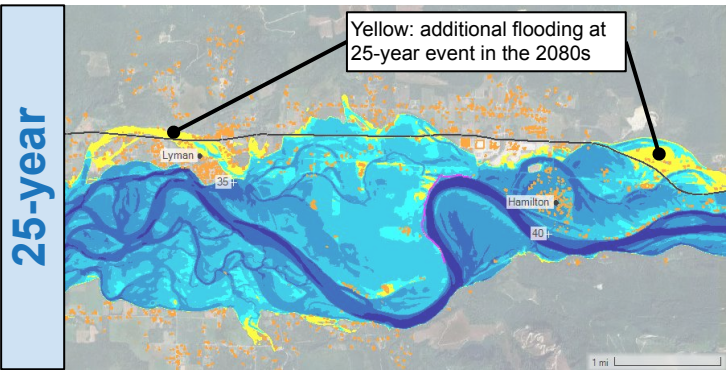
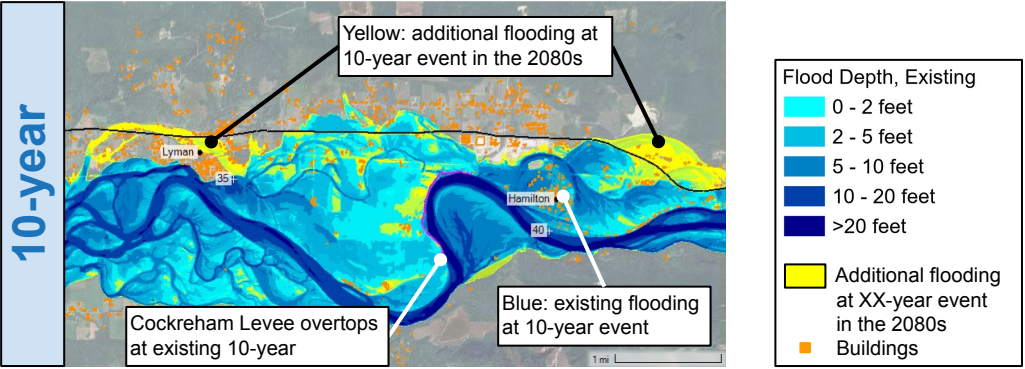
25-year



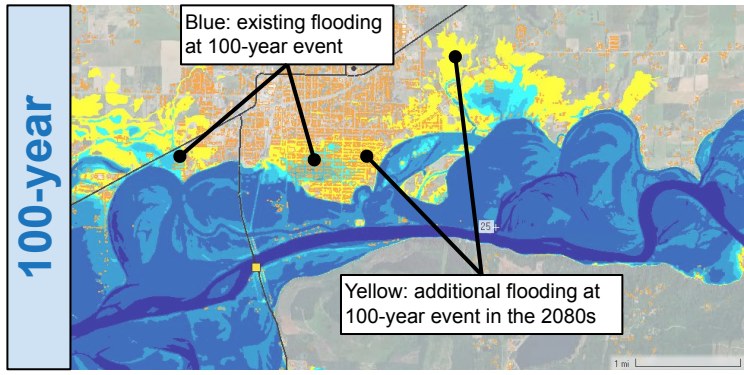
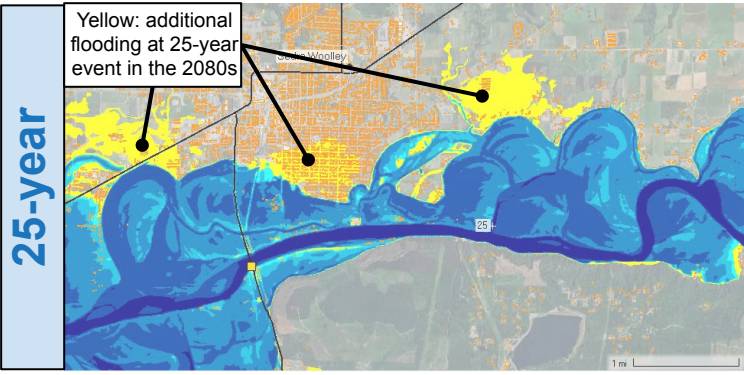
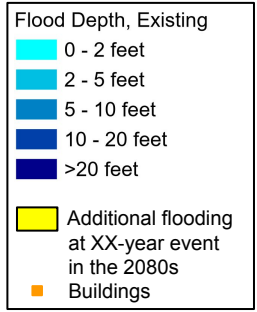
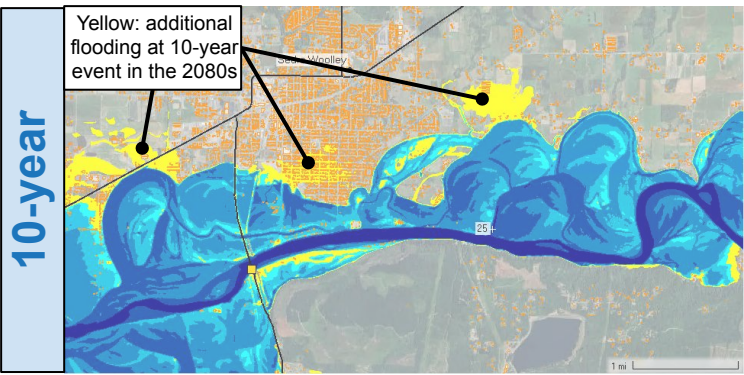
100-year



River Flood: Lyman, Hamilton



River Flood: Sedro-Woolley



Discussion, Input and Reflection Questions

- What do you notice?
- Which specific areas or places do you have concerns about flooding and why?
- Are there potential opportunities or ways to turn challenges into opportunities that you see in these maps?
- Are there management approaches that particularly interest you in understanding their impacts, benefits, and/or implications for others?

LUNCH

Session III: Current and Future Conditions *Sedro-Woolley Downriver*

Outline

A. Riverine Flood

- Overview
- 25-year and 100-year

B. Levee Breaches from GI study

C. Coastal Flood

- Skagit Bay
- Samish Bay and Padilla Bay

A) River Flood

River Flood Depths: Existing Climate Conditions

Assumptions: no breach occurs, tides are normal (no coastal flood)

Flood Depth, Existing

0 - 2 feet

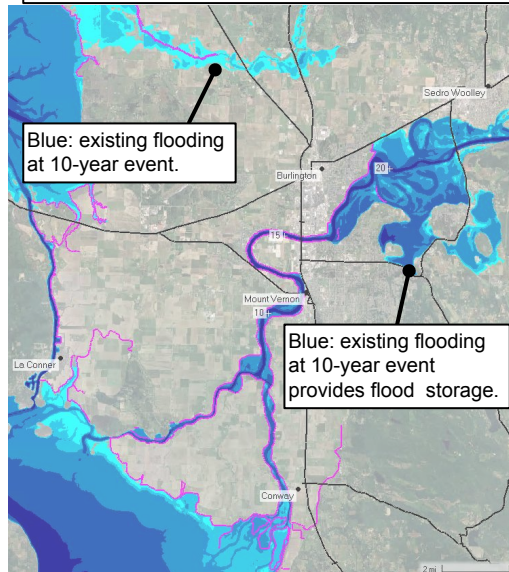
2 - 5 feet

5 - 10 feet

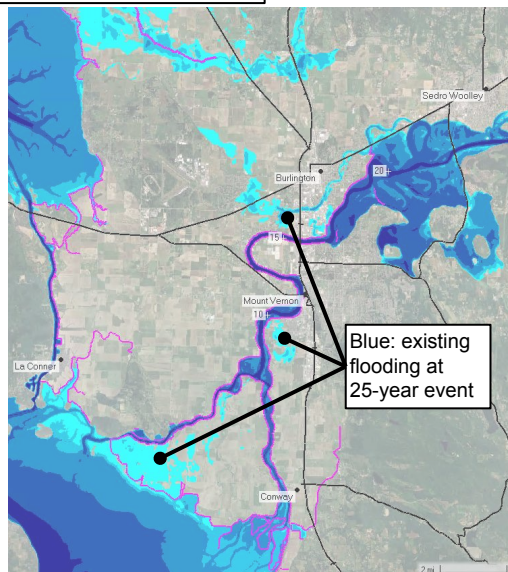
10 - 20 feet

>20 feet

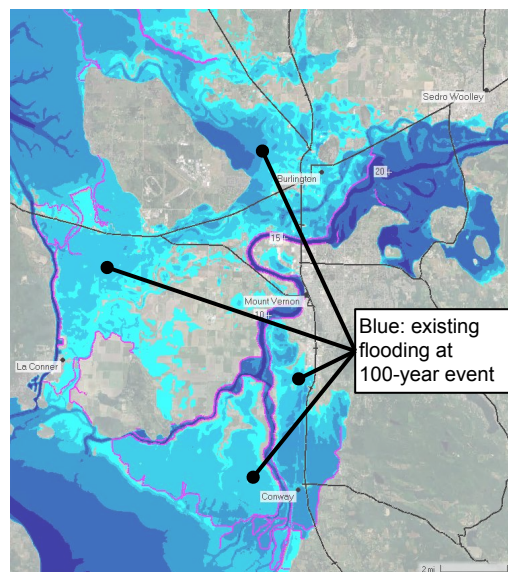
Levee or Dike



10-year

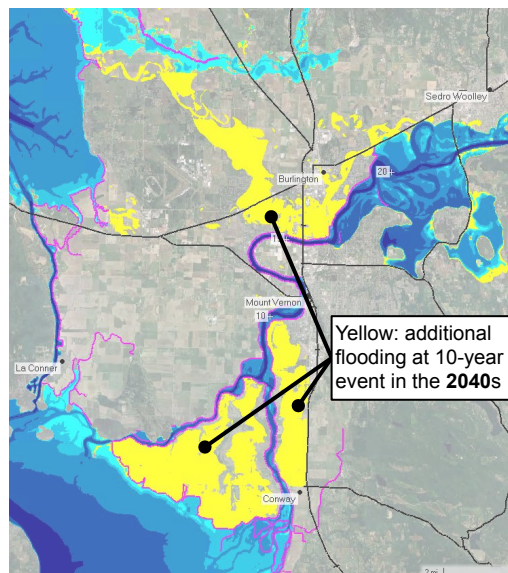
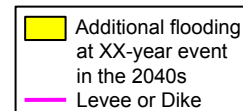
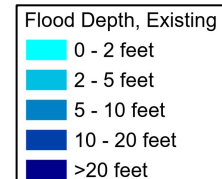


25-year

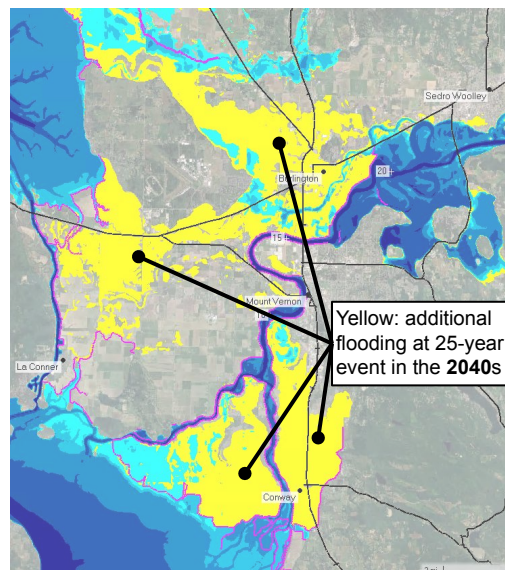


100-year

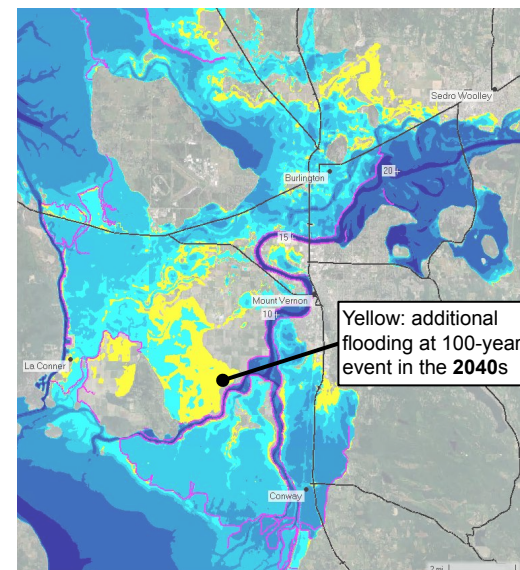
River Flood: 2040s Overview



10-year

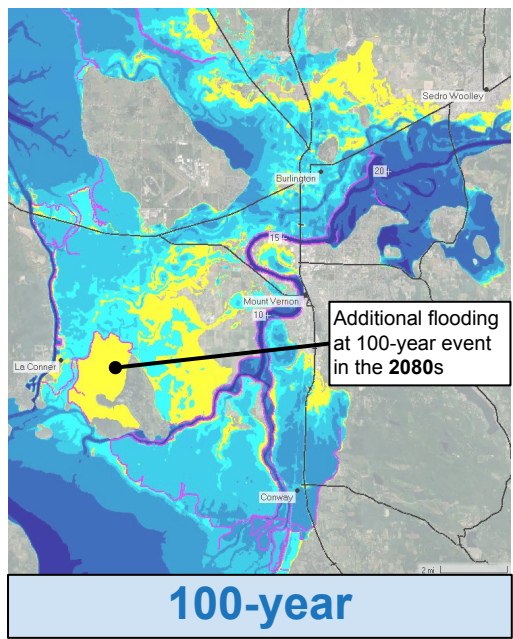
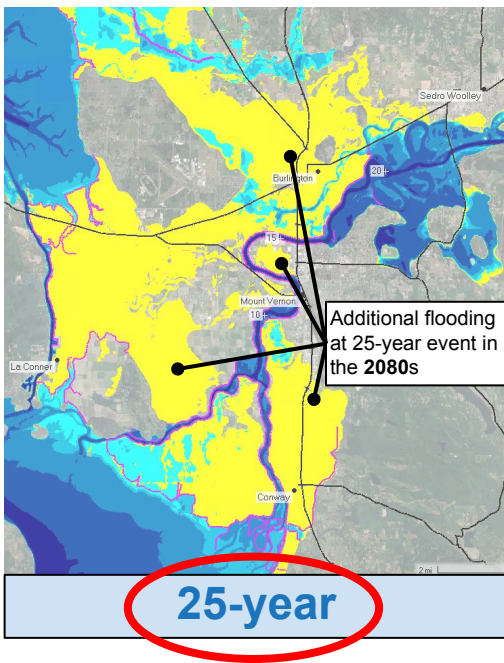
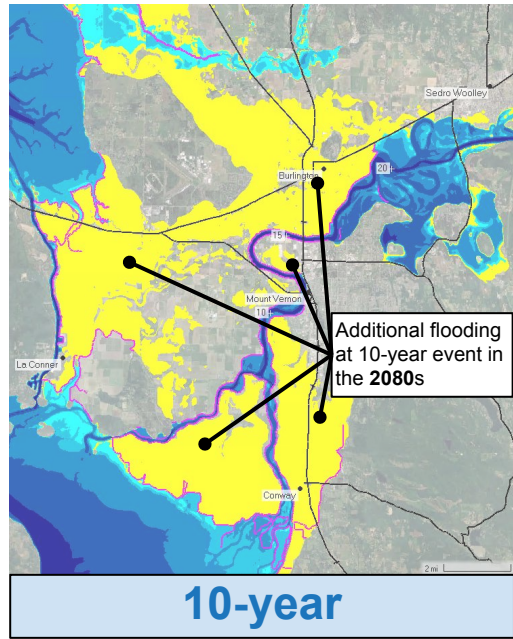
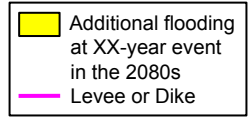
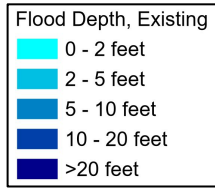


25-year

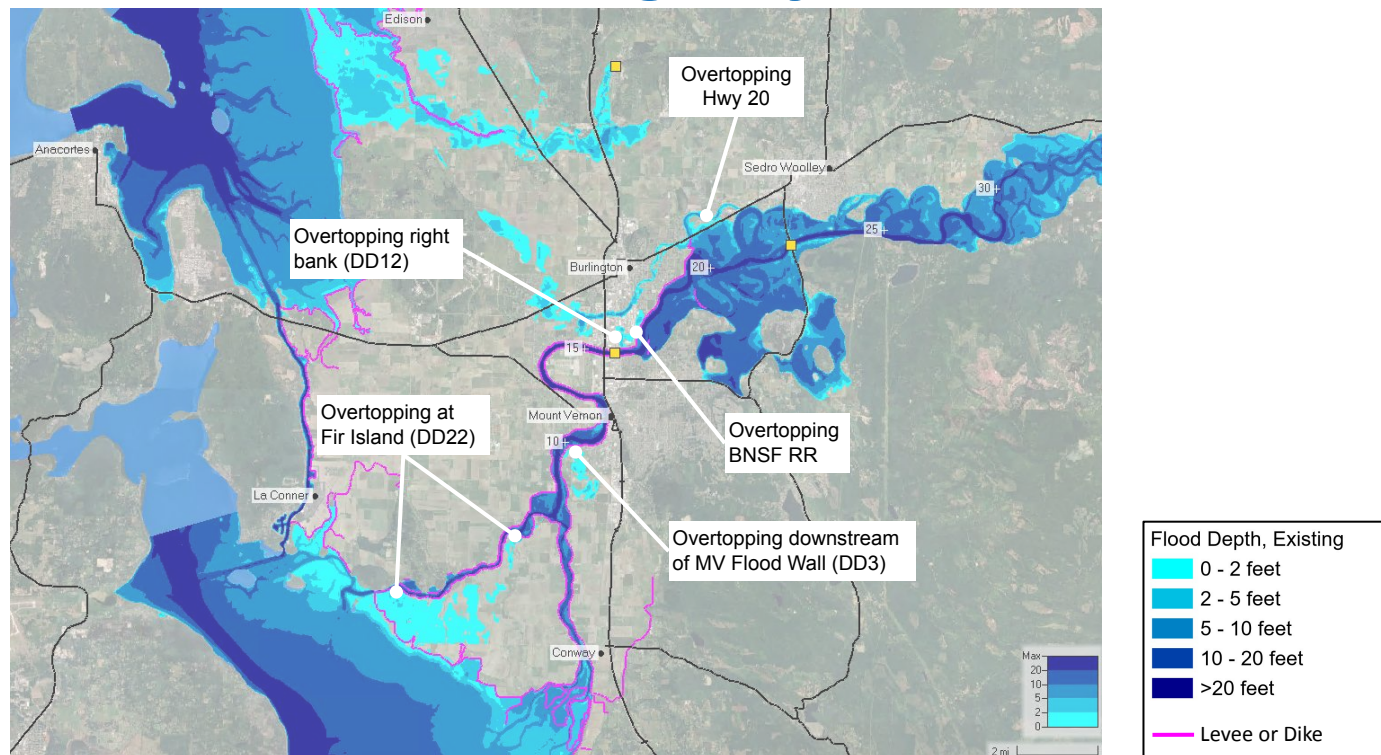


100-year

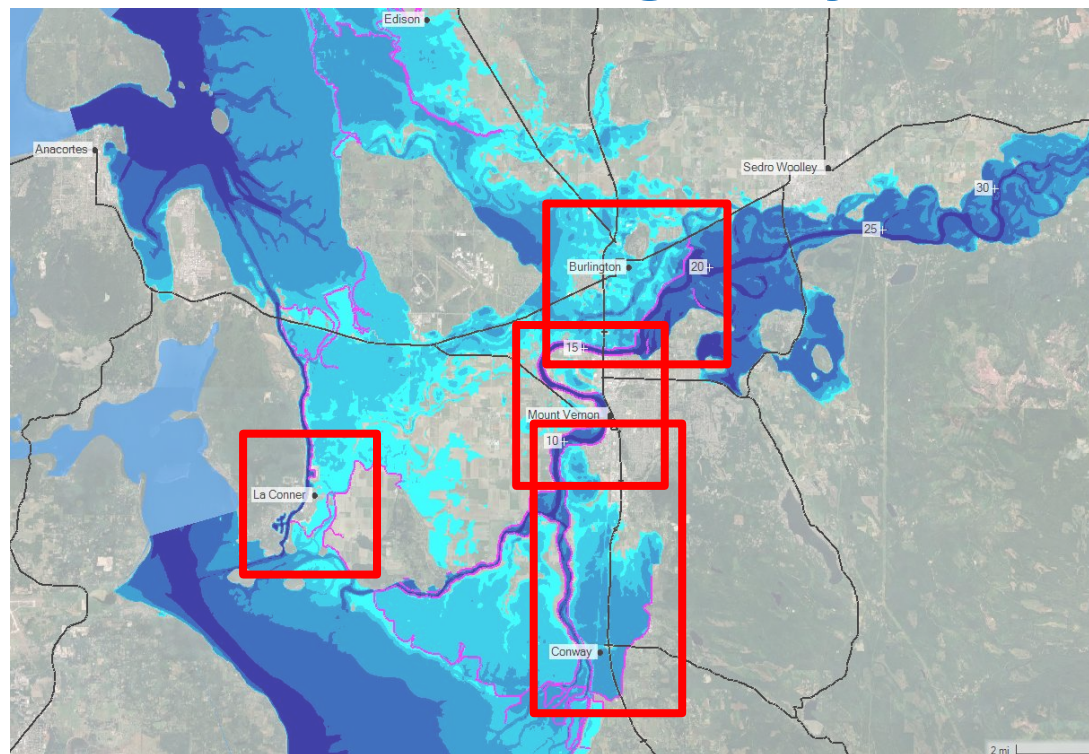
River Flood: 2080s Overview



River Flood: Existing 25-year



River Flood: Existing 100-year



River Flood: Burlington

Flood Depth, Existing

0 - 2 feet

2 - 5 feet

5 - 10 feet

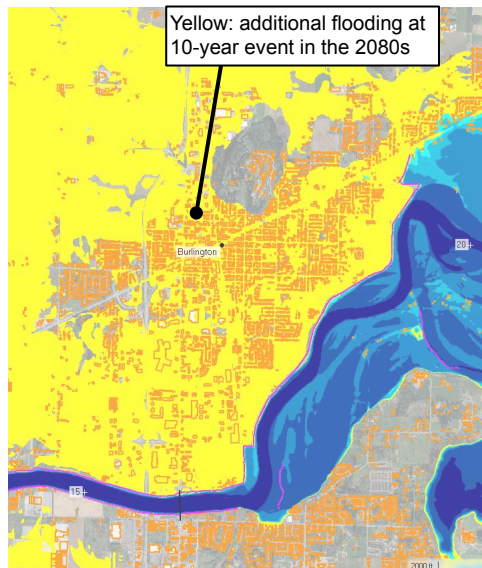
10 - 20 feet

>20 feet

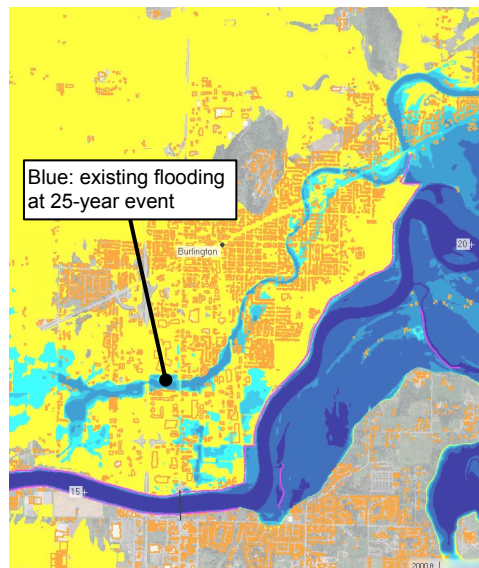
Additional flooding
at XX-year event
in the 2080s

Levee or Dike

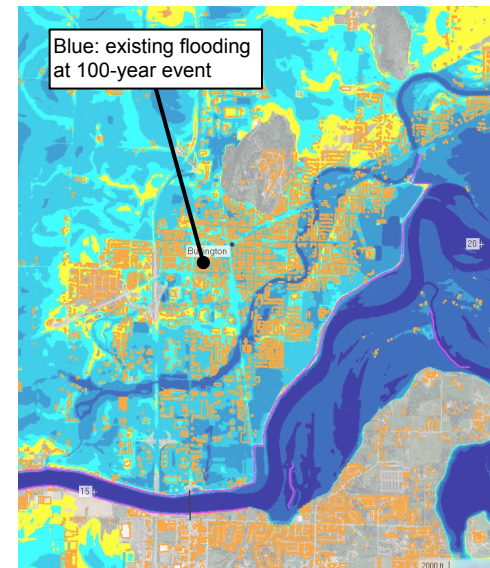
Buildings



10-year



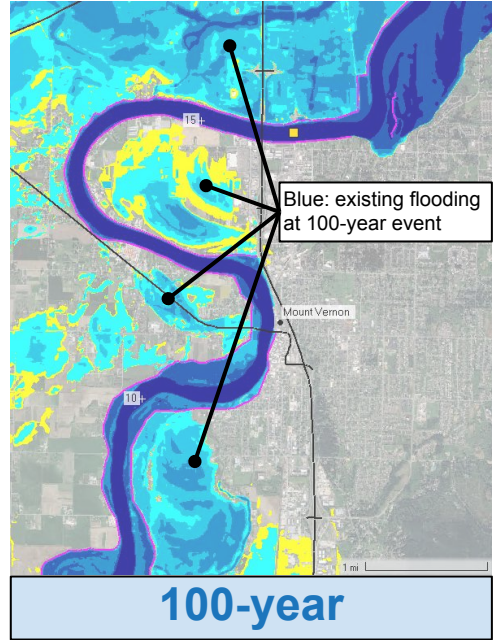
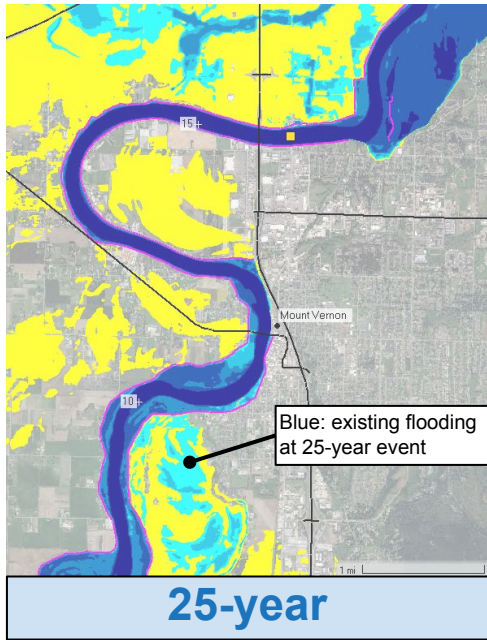
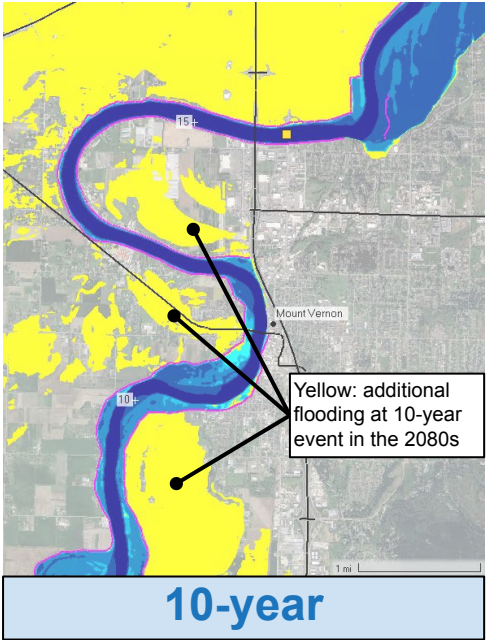
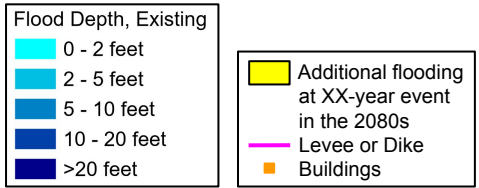
25-year



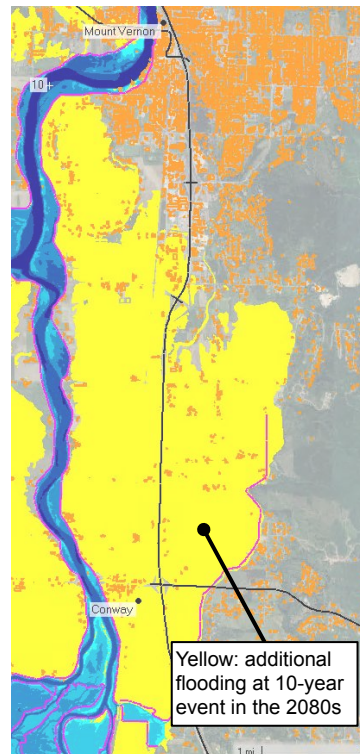
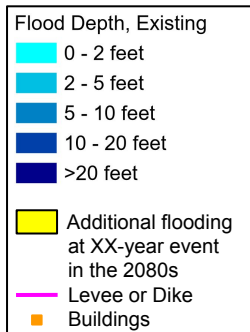
100-year

River Flood: Mount Vernon

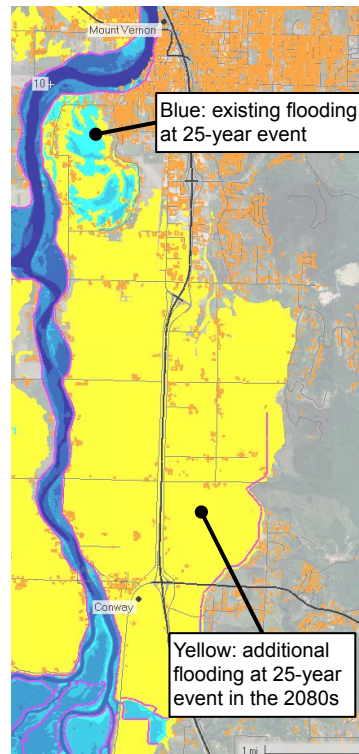
This slide was not presented at the workshop but included based on feedback.



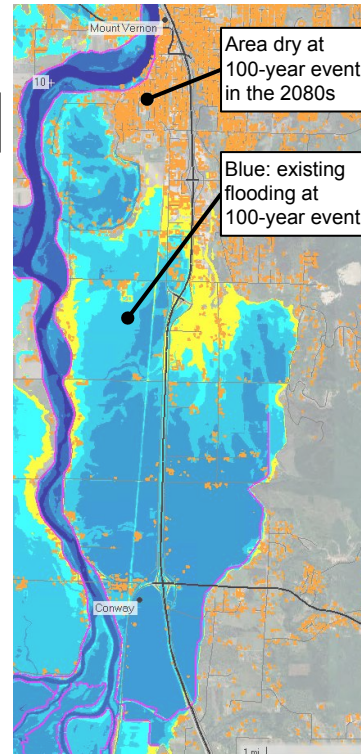
River Flood: South of Mount Vernon



10-year



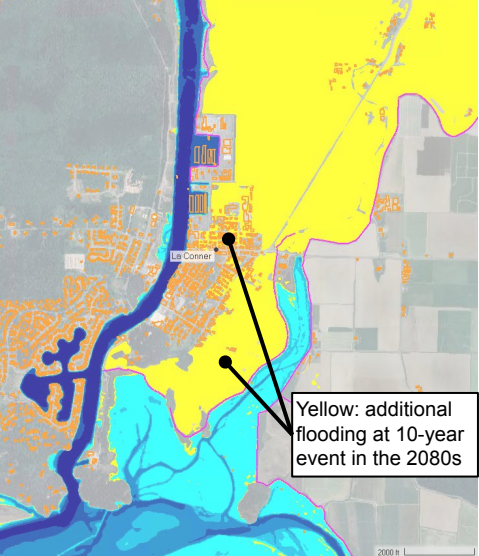
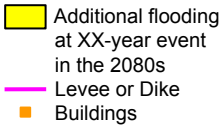
25-year



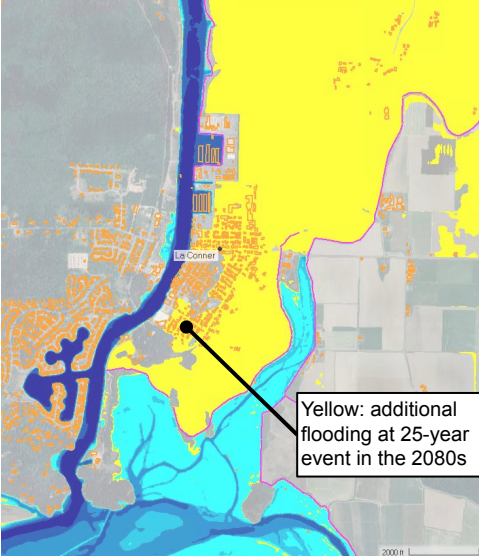
100-year

River Flood: La Conner

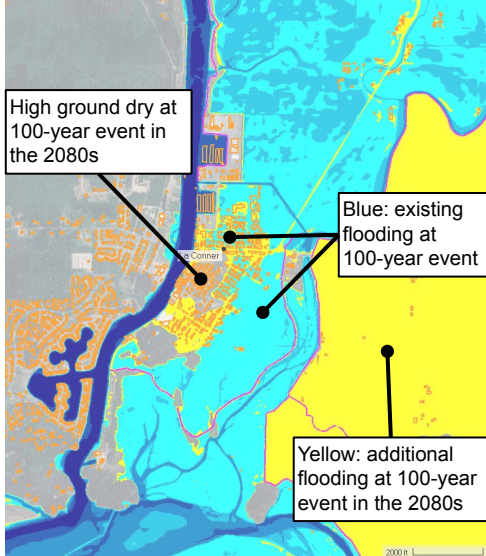
Flood Depth, Existing



10-year



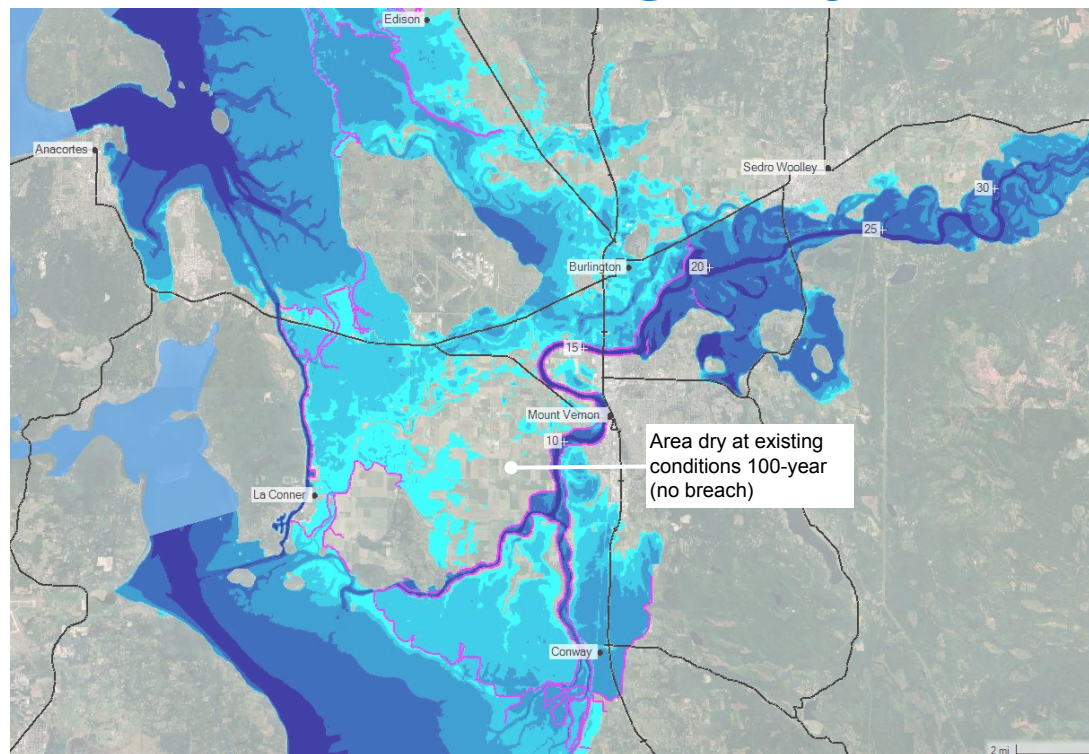
25-year



100-year

B) Levee Breach Scenarios based on Locations from the Skagit GI

River Flood: Existing 100-year

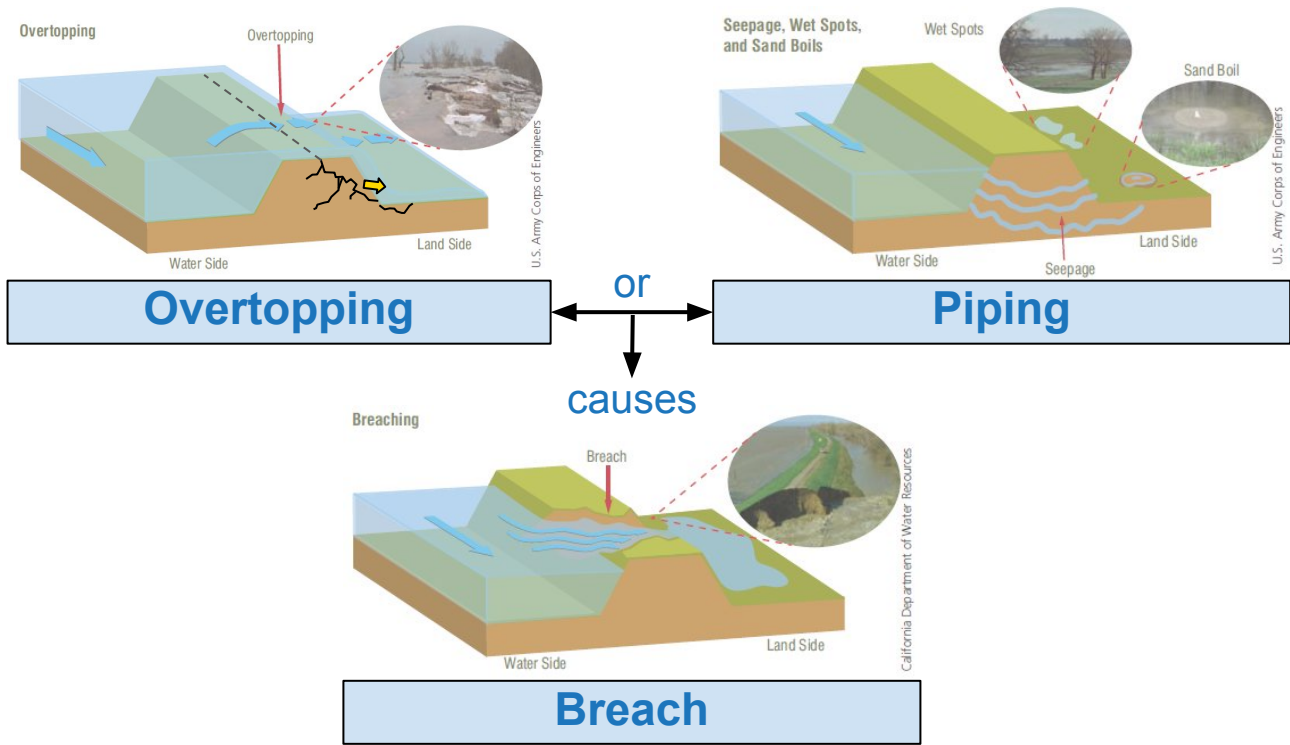


Flood Depth, Existing

- 0 - 2 feet
- 2 - 5 feet
- 5 - 10 feet
- 10 - 20 feet
- >20 feet

Levee or Dike

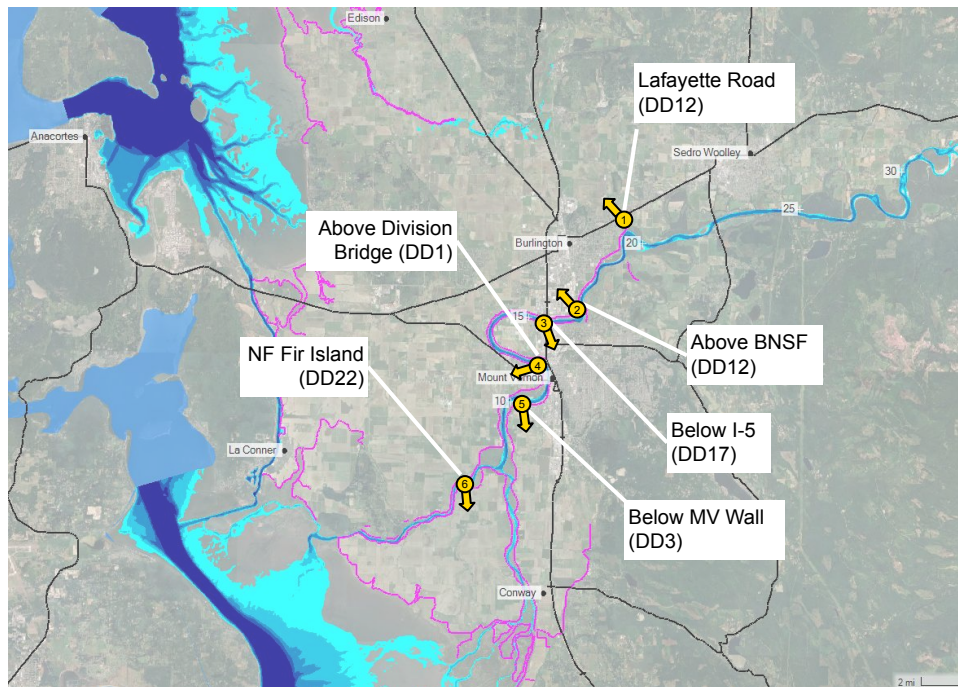
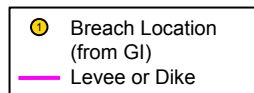
What Causes a Levee Breach?



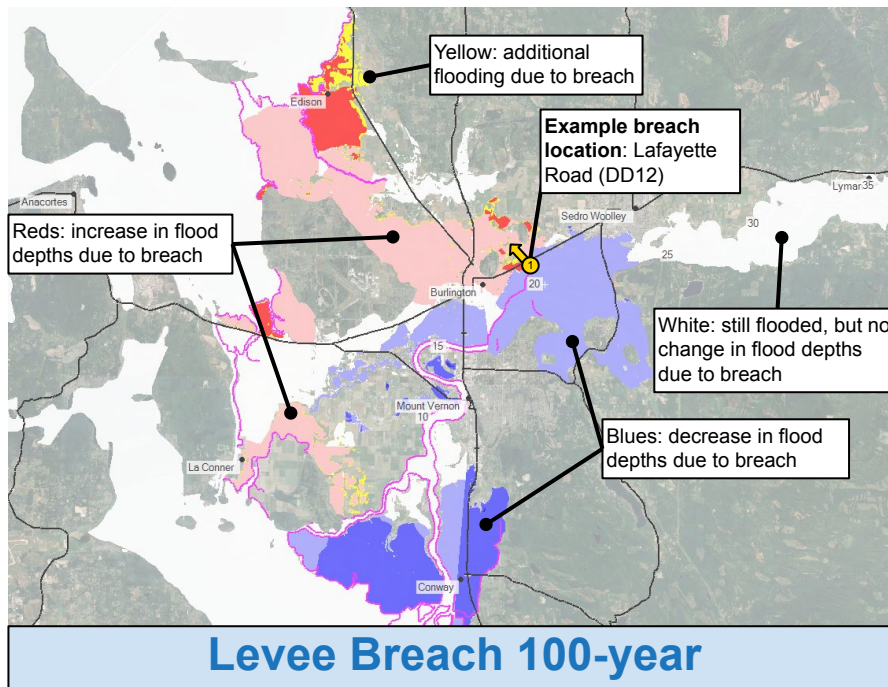
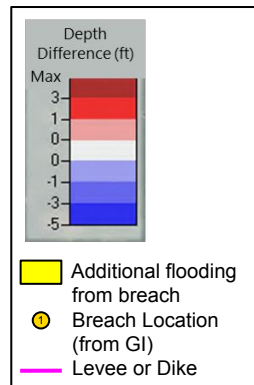
Summary of Skagit Levee System

- Approximately 50 miles of levees
- Capacity to contain approximately a 20-year flood
- Overseen by diking districts; some co-managed with USACE in PL 84-99 program
- Recent levee strengthening projects

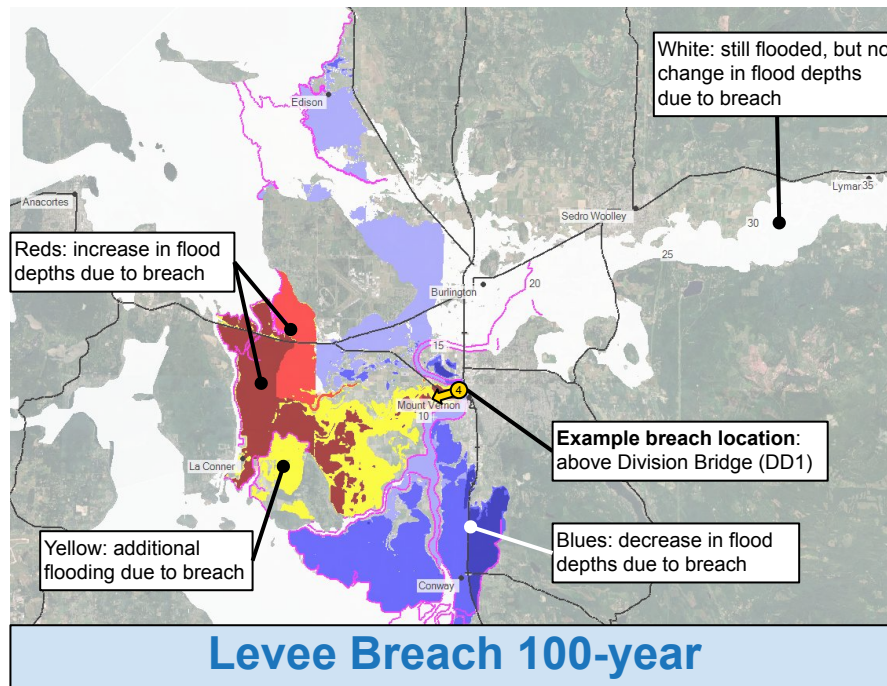
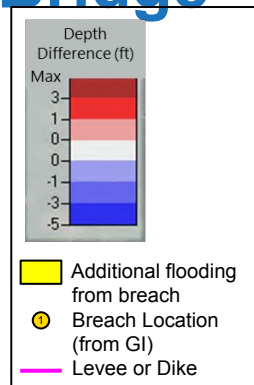
River Flood: 6 Levee Breach Locations from GI



River Flood: Levee Breach at Lafayette Road



River Flood: Levee Breach at Division Street Bridge



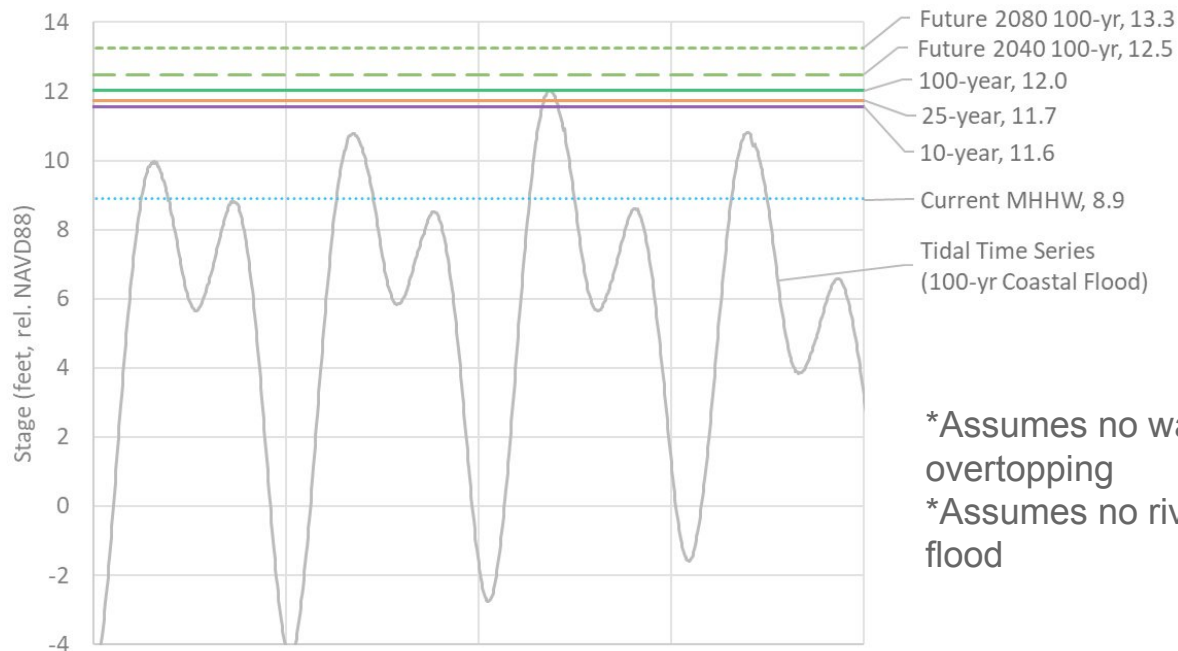
Discussion, Input and Reflection Questions

- What do you notice?
- Which specific areas or places do you have concerns about flooding and why?
- Are there potential opportunities or ways to turn challenges into opportunities that you see in these maps?
- Are there management approaches that particularly interest you in understanding their impacts, benefits, and/or implications for others?

Break

C) Coastal Flood

Coastal Flooding: Tidal Stage

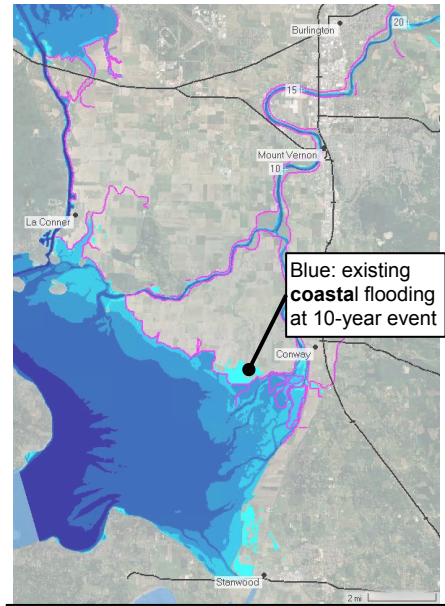
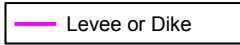
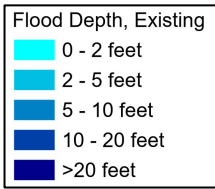


*Assumes no wave overtopping

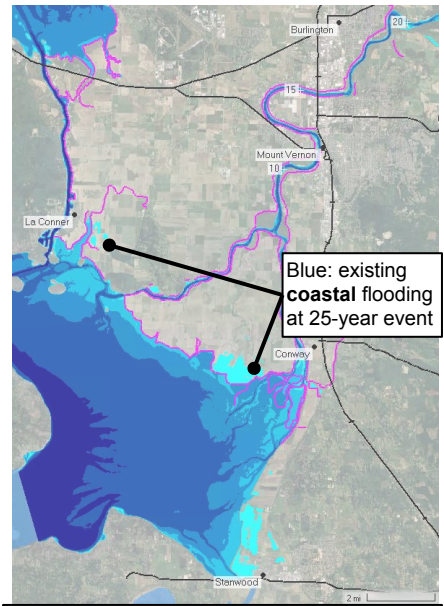
*Assumes no river flood

Coastal Flood: Existing

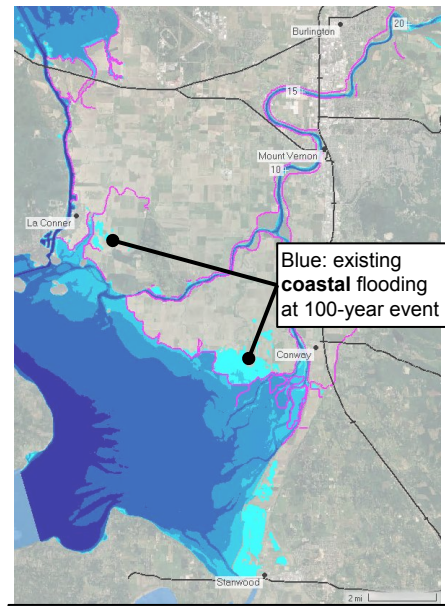
Skagit Bay



10-year



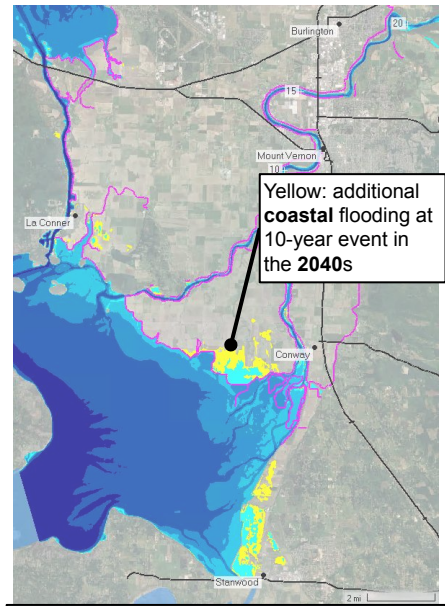
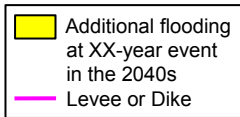
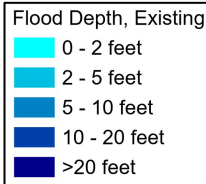
25-year



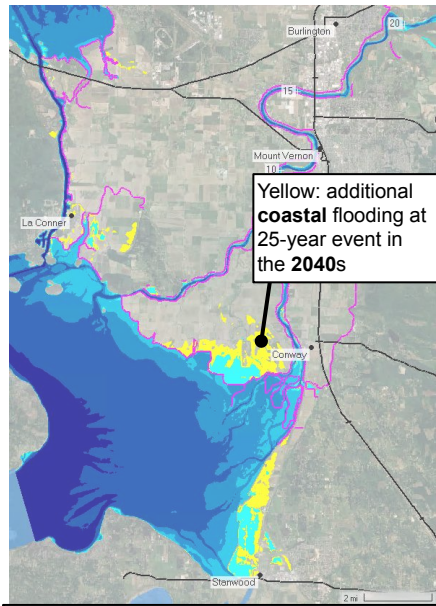
100-year

Coastal Flood: 2040s

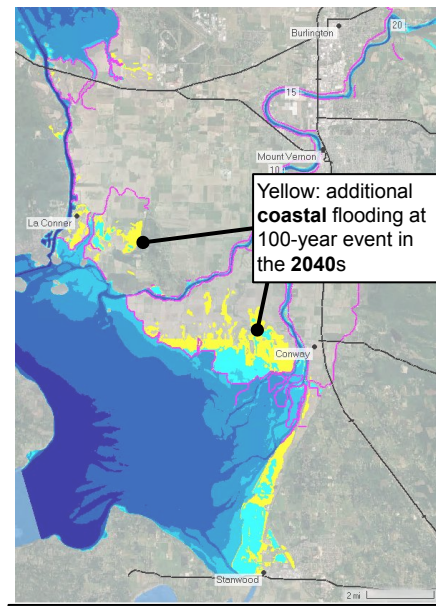
Skagit Bay



10-year



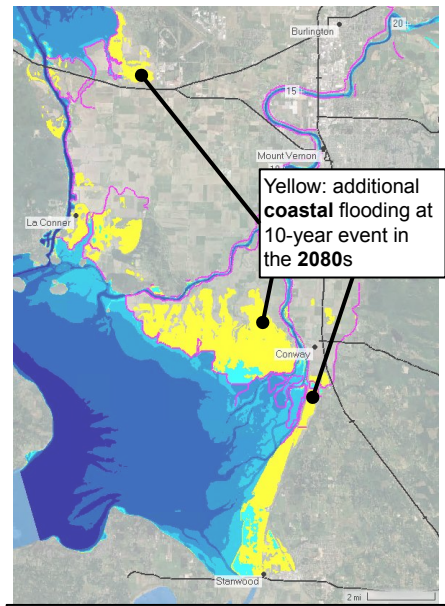
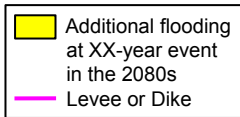
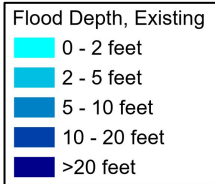
25-year



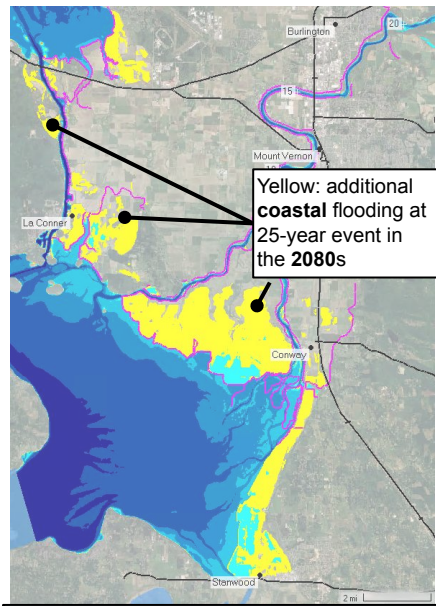
100-year

Coastal Flood: 2080s

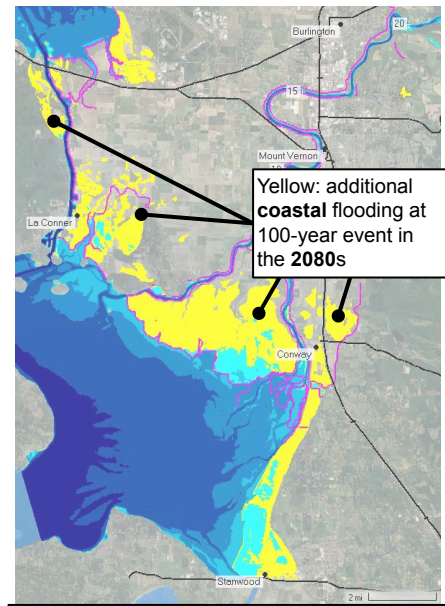
Skagit Bay



10-year



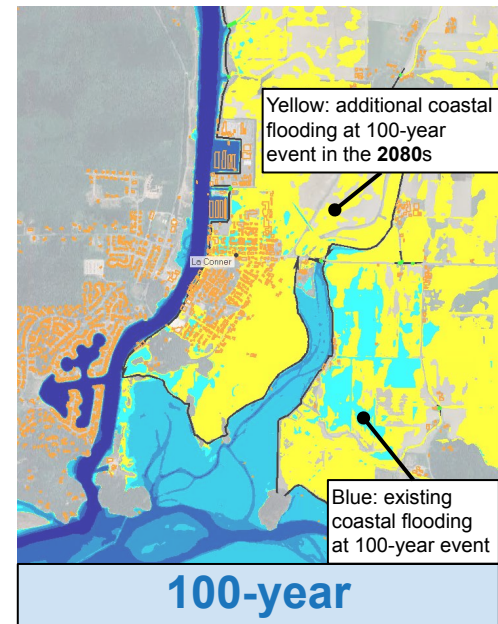
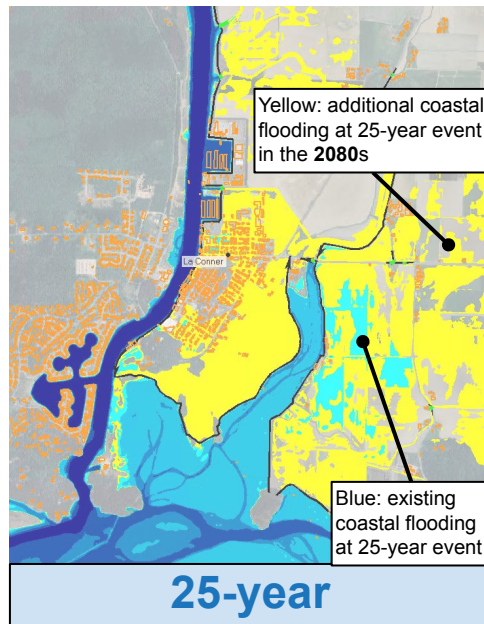
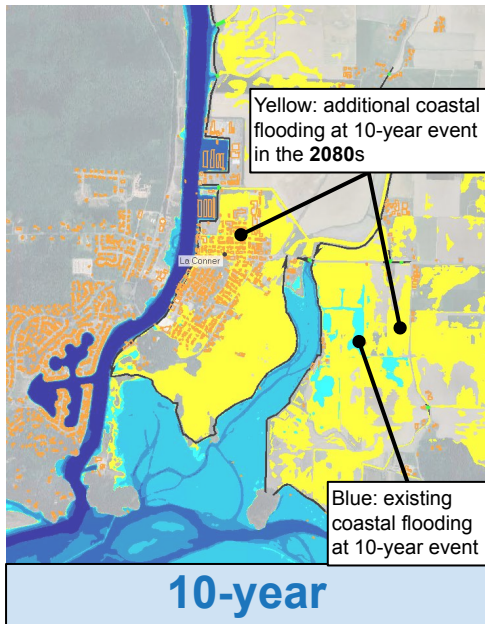
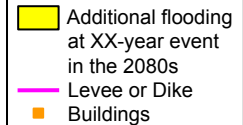
25-year



100-year

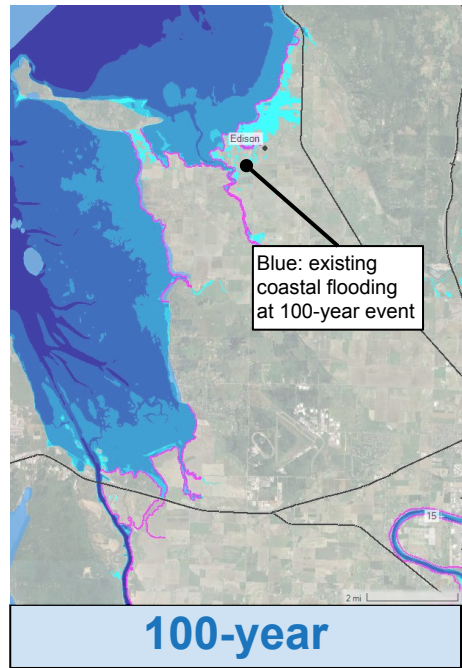
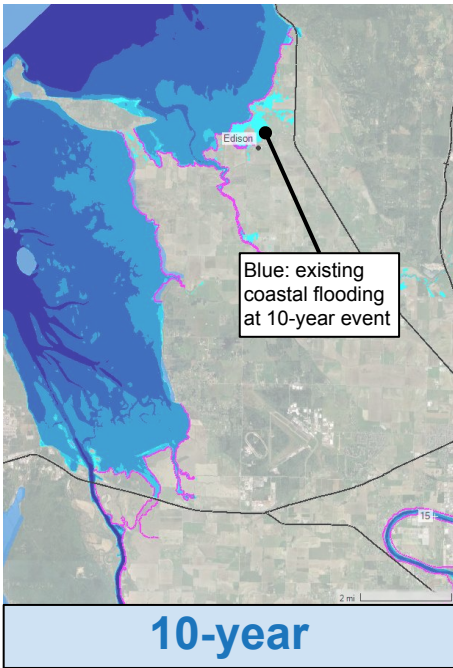
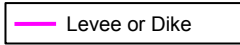
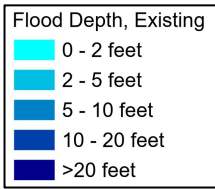
Coastal Flood: La Conner

Flood Depth, Existing



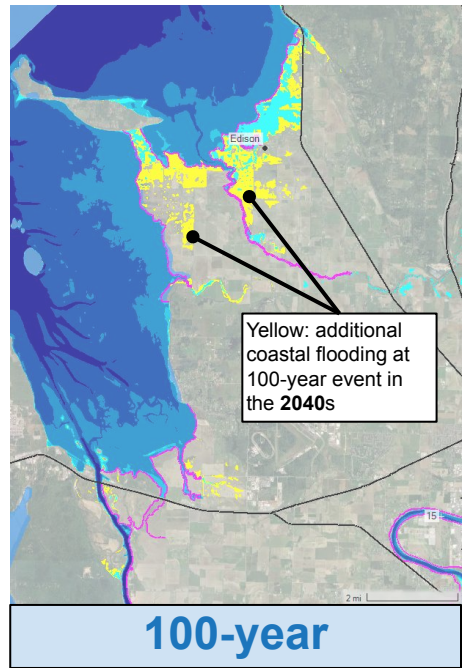
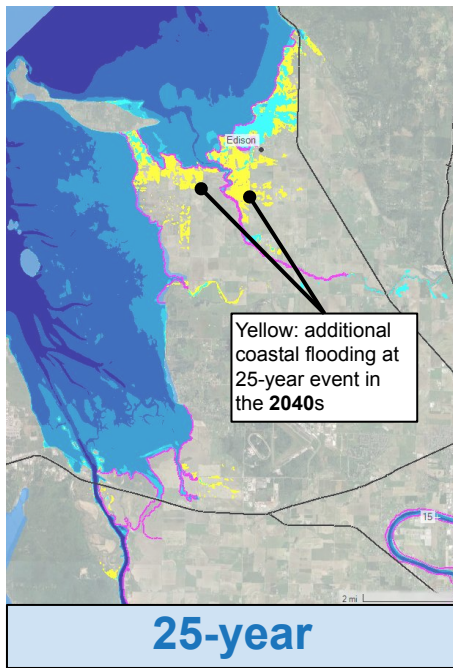
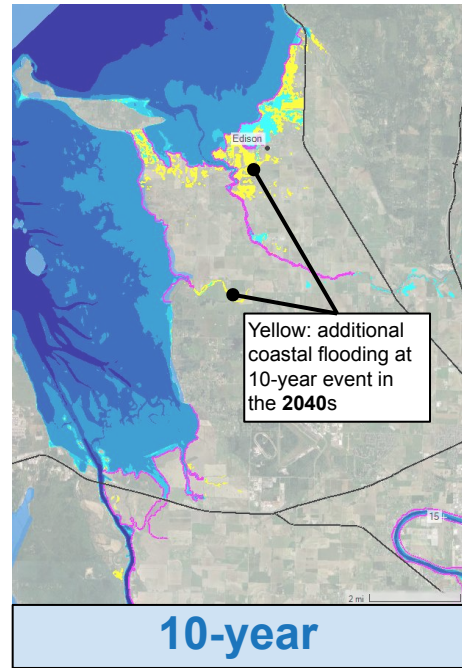
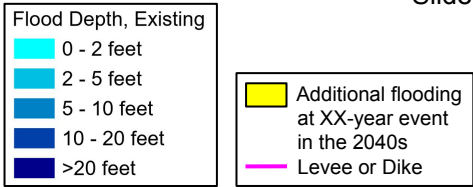
Coastal Flood: Existing

Padilla Bay and Samish Bay



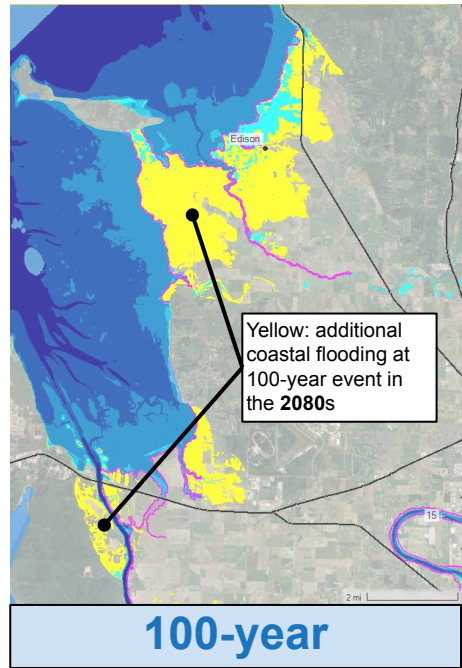
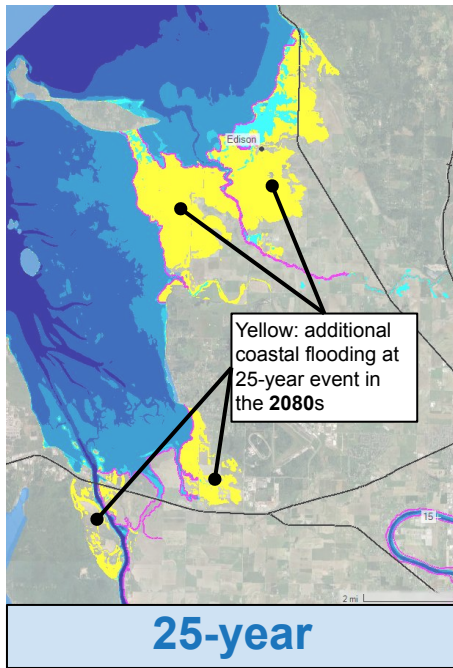
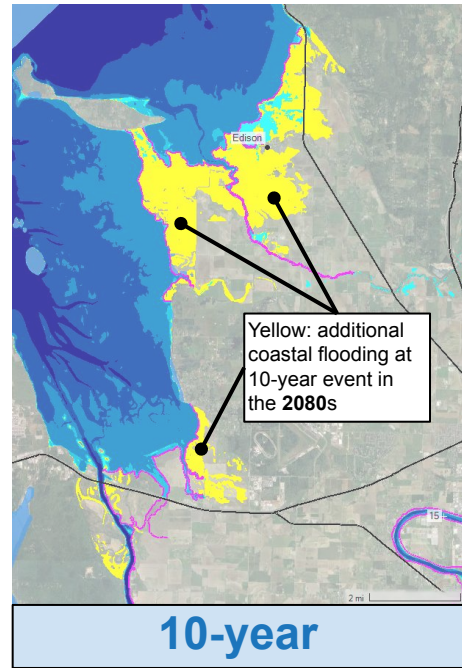
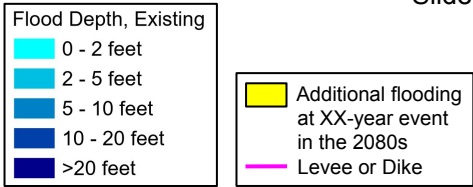
Coastal Flood: 2040s

Padilla Bay and Samish Bay



Coastal Flood: 2080s

Padilla Bay and Samish Bay



Discussion, Input and Reflection Questions

- What do you notice?
- Which specific areas or places do you have concerns about flooding and why?
- Are there potential opportunities or ways to turn challenges into opportunities that you see in these maps?
- Are there management approaches that particularly interest you in understanding their impacts, benefits, and/or implications for others?

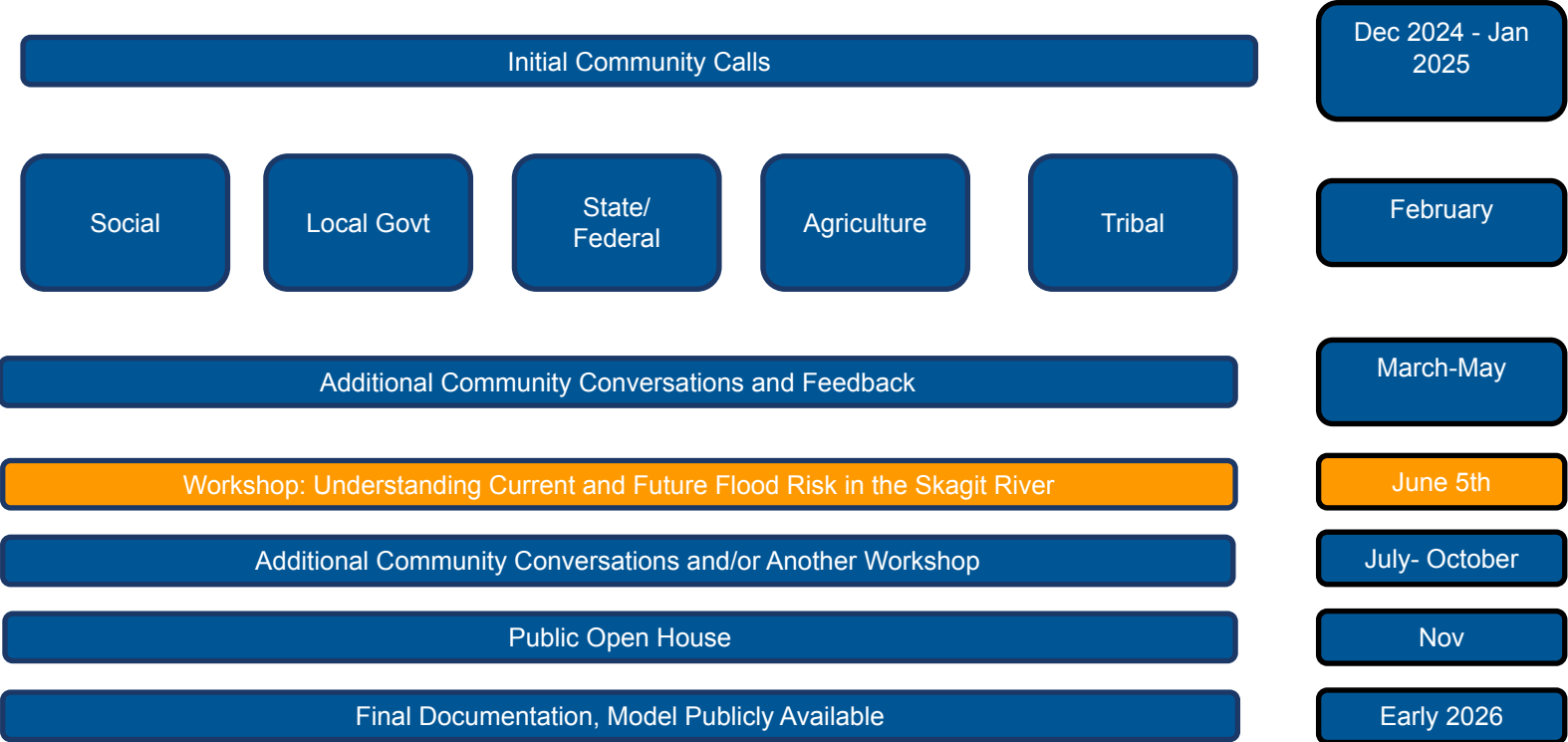
Questions?

Final Question

What meaning are you making of today?

Are there things you'd like to see furthered modeled or discussed in a group like this?

Project Engagement Steps and Timing



THANK YOU!

Mount Vernon Slides
Updated by K. Kramer
January 20, 2026

River Flood: Historical and Simulated Events

Recent Events at Mount Vernon

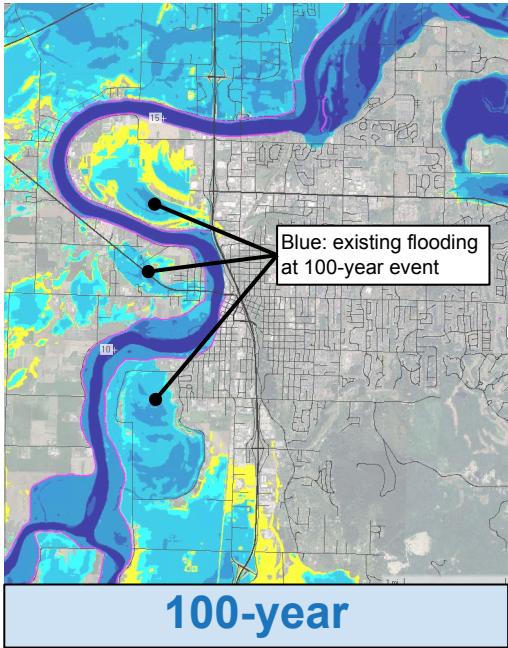
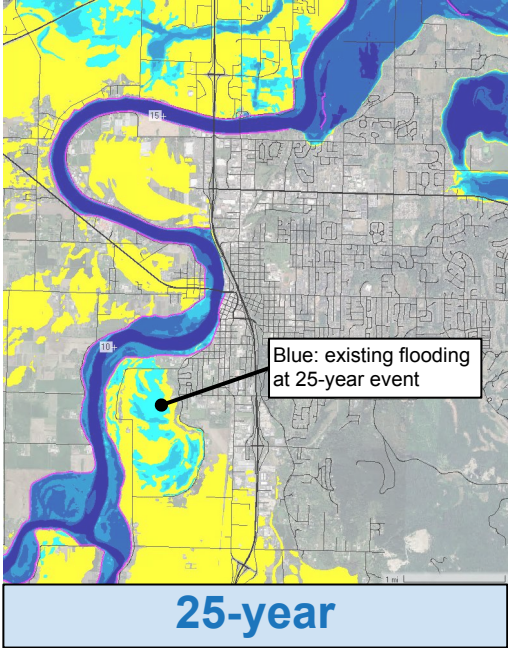
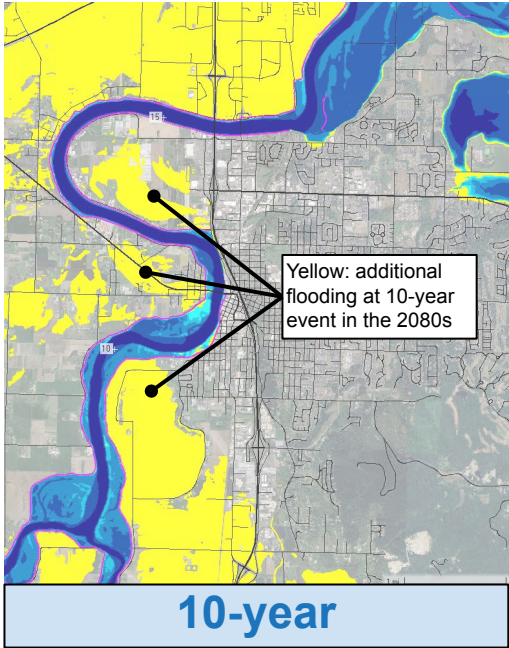
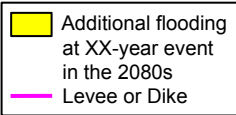
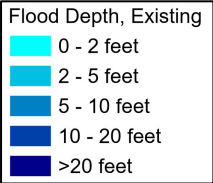
Event	Flow (cfs)	Stage (ft)
Dec 2025	133,000	37.7
Nov 2021*	127,000	37.0
Nov 2006	138,000	33.9
Oct 2003*	135,000	36.2
Nov 1995*	141,000	37.3
Nov 1990	152,000	37.4

**Model calibrated to USGS gages
and High Water Marks*

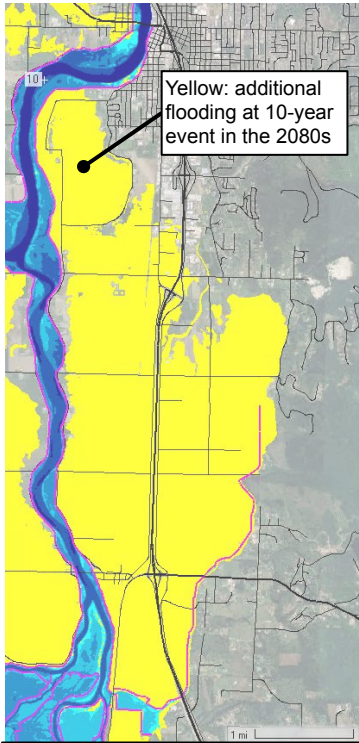
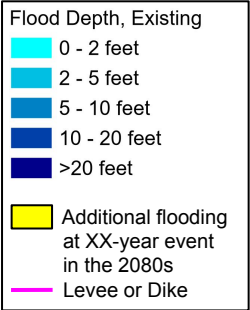
Existing (2013 GI) and Future Flows

Event	Flow at Sedro Woolley (cfs)	Flow at Mount Vernon (cfs)
10-year	133,000	119,000
25-year	170,000	150,000
100-year	236,000	171,000
Future 2080 100-year	314,000	176,000

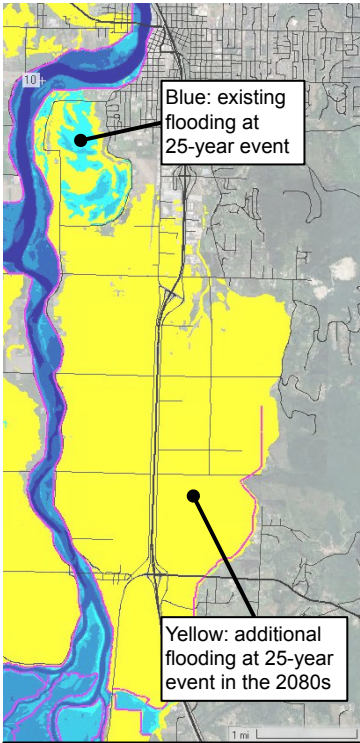
River Flood: Mount Vernon



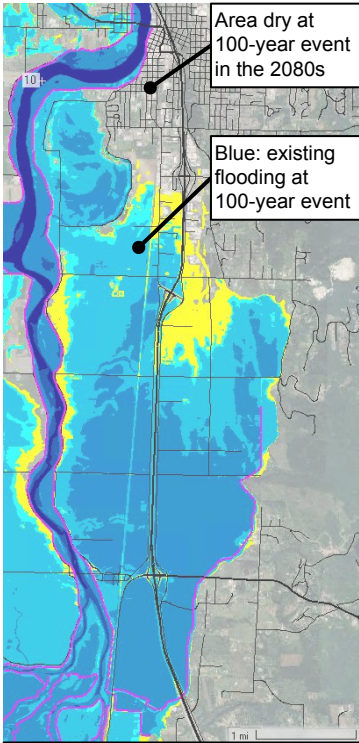
River Flood: South of Mount Vernon



10-year



25-year



100-year

Appendix D: The Draft Skagit River Flood Risk Management General Investigation

The Draft Skagit River Flood Risk Management General Investigation

The Draft Skagit River Flood Risk Management General Investigation study (GI, or “Draft Skagit GI”; USACE 2014) was prepared by the U.S. Army Corps of Engineers (USACE).

The study focused on identifying potential solutions for managing flood risk in the Skagit River basin. To do that, existing flood risk was modeled as well as the potential changes in flooding associated with possible management actions (elevating dikes, diverting flood flows through a bypass channel, etc.). Environmental consequences of the top-ranking management actions were also evaluated. Skagit County was the non-federal sponsor of the study.

The study is labeled ‘Draft’ because the report was never finalized. The GI study lasted from about 1993 through 2015 when Skagit County withdrew, citing concerns about cost overruns and specific aspects of the analysis (Berentson 2015).

The Draft Skagit GI included substantial work to understand past floods, improve modeling of current flooding, and evaluate proposed management actions. It can therefore be a helpful reference for information. Indeed, the current study used the flood frequency estimates as input to the hydraulic model (see [Appendix A](#)). However, the Draft Skagit GI document is long and it can be difficult to locate key information. This section briefly lists some of the key sections of relevance to the current report that may be of interest for further reading.

GI MAIN REPORT

(File name: *SkagitGI-Draft-FR-EIS-MAY2014.pdf*)

This is the main summary of the work, including background and purpose, management “alternatives” that were evaluated, the results of the analysis to assess their strengths and weaknesses, and the draft conclusions of the study. About half of the 242 page report is devoted to the analysis of the strengths and weaknesses of each alternative.

GI APPENDIX B – HYDRAULICS AND HYDROLOGY

(File name: *SkagitGI-AppB-HH-MAY2014.pdf*)

This appendix of the GI contains technical details that were used in our hydraulic modeling, and provides background on their assessment of proposed management alternatives.

[Appendix B](#) combines four separate reports:

- Hydraulic Analysis, Final Report (p.6)
- Hydraulic Technical Documentation (p. 283)
- Hydrology Technical Documentation (p.382)
- Sediment Budget and Fluvial Geomorphology (p.449)

The Hydrology Technical Documentation report was particularly important for our analysis. It describes the analysis of the Skagit Basin hydrology and how the peak flows for each flood frequency were developed. This included accounting for the effect of dams on flows, as well as the relative magnitudes of peak flows on each tributary. These peak flow hydrographs were used as input for the flood simulations in the current study.

LIST OF ALL GI APPENDICES

- A-Planning
- B-Hydraulics and Hydrology
- C-Economics
- D-Environmental
- E-Geotech
- F-Real-Estate
- G-Cost Estimate
- H-Civil Design
- I-Public Involvement

All materials, along with presentations for the public meeting and two commissioner meetings, are available on the Skagit County website: <https://www.skagitcounty.net/Departments/PublicWorksSalmonRestoration/main.htm>