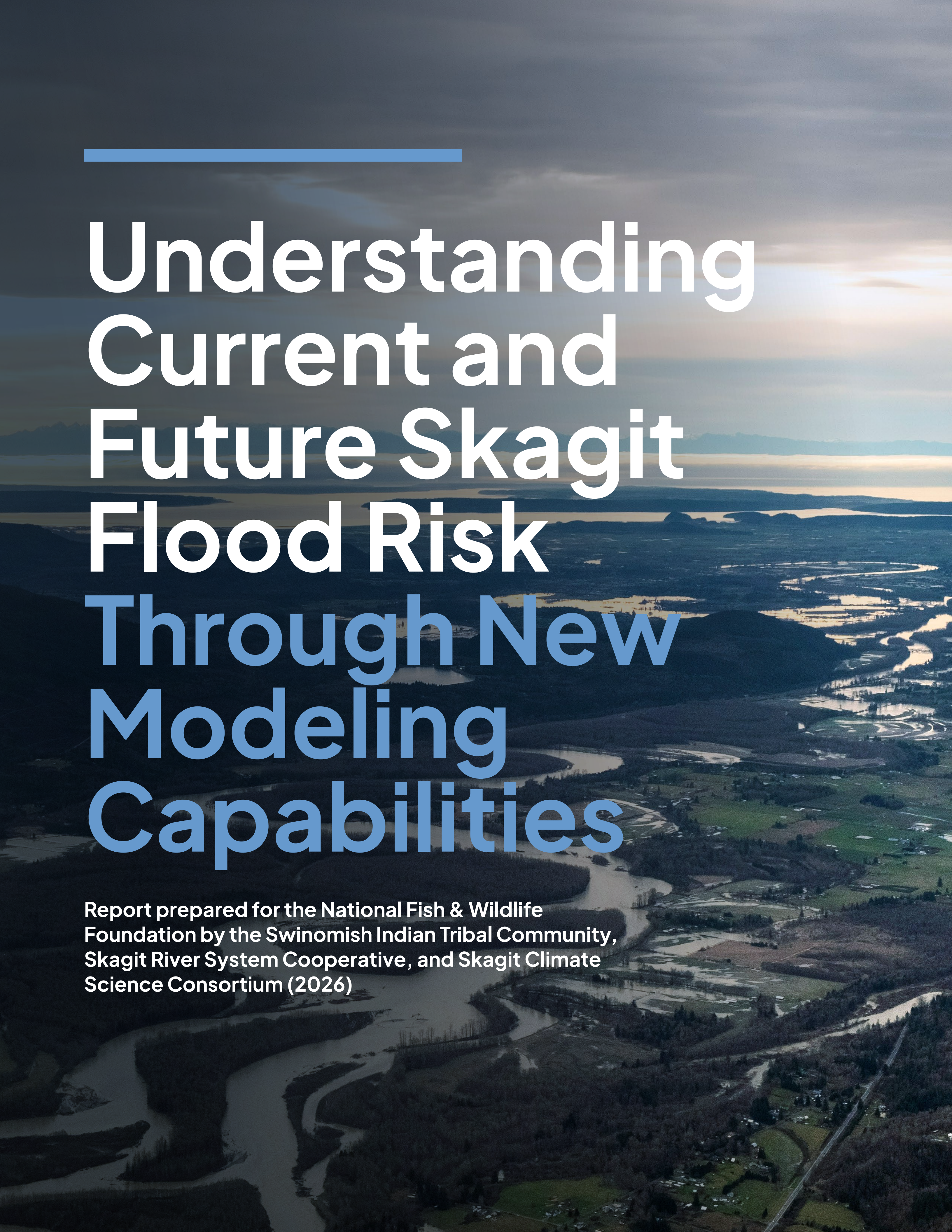

Understanding Current and Future Skagit Flood Risk Through New Modeling Capabilities

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

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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

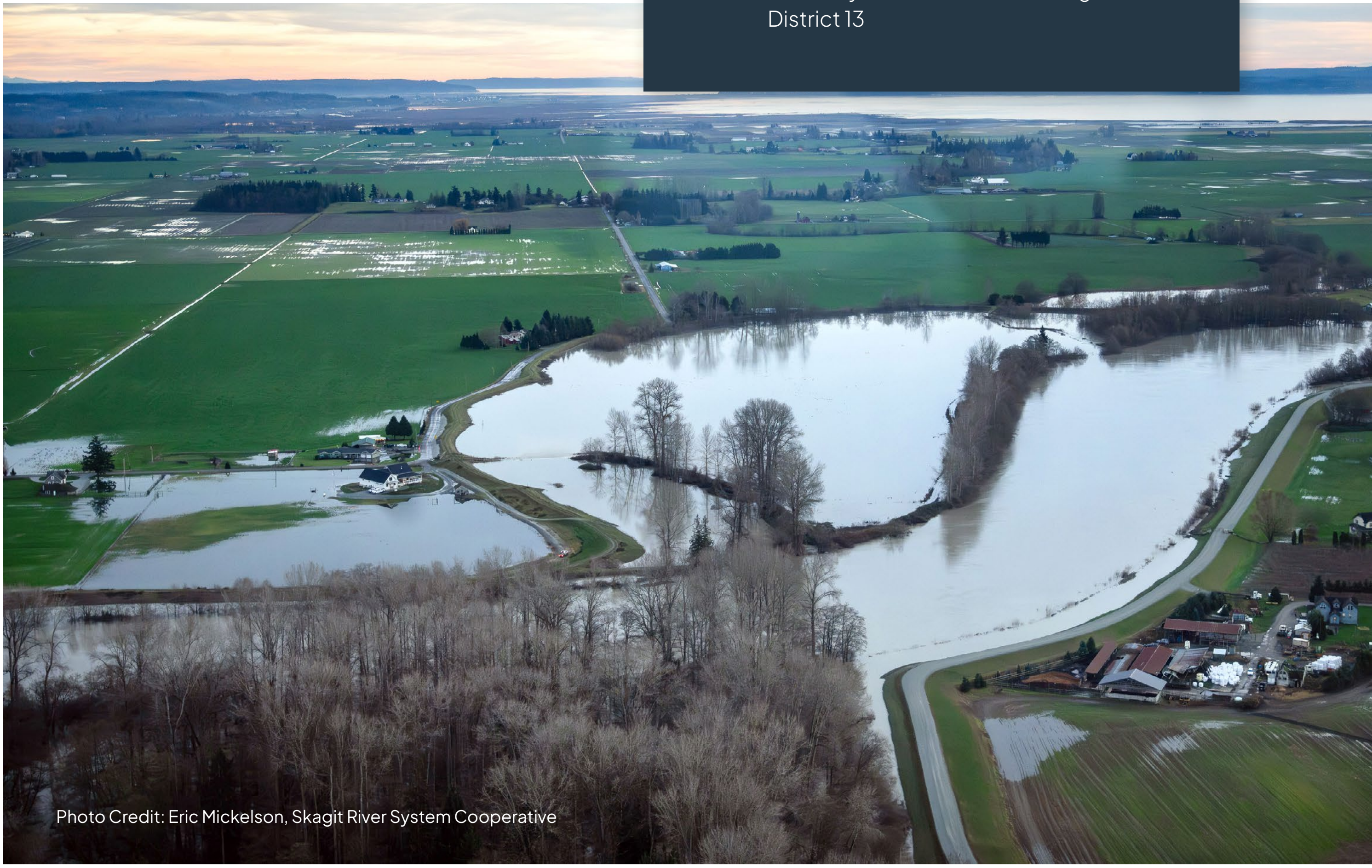


Photo Credit: Eric Mickelson, Skagit River System Cooperative

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.

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:

- 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

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.

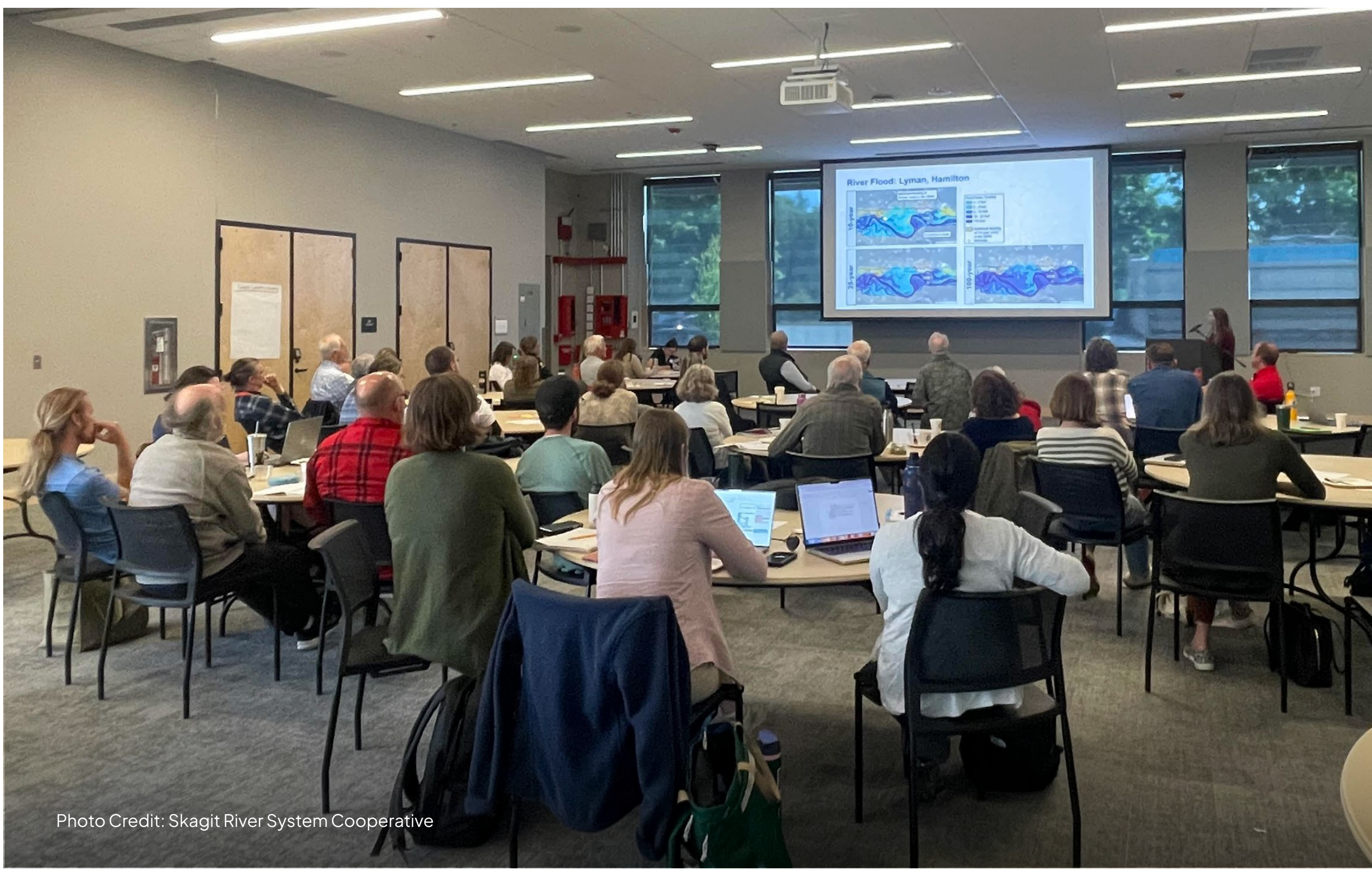


Photo Credit: Skagit River System Cooperative

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.

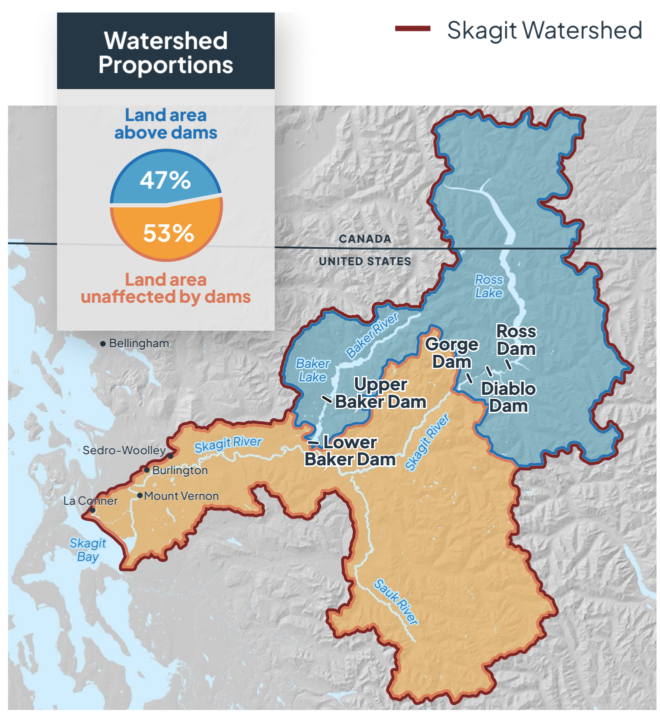


Image credit: Skagit Climate Science Consortium (SC2)

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

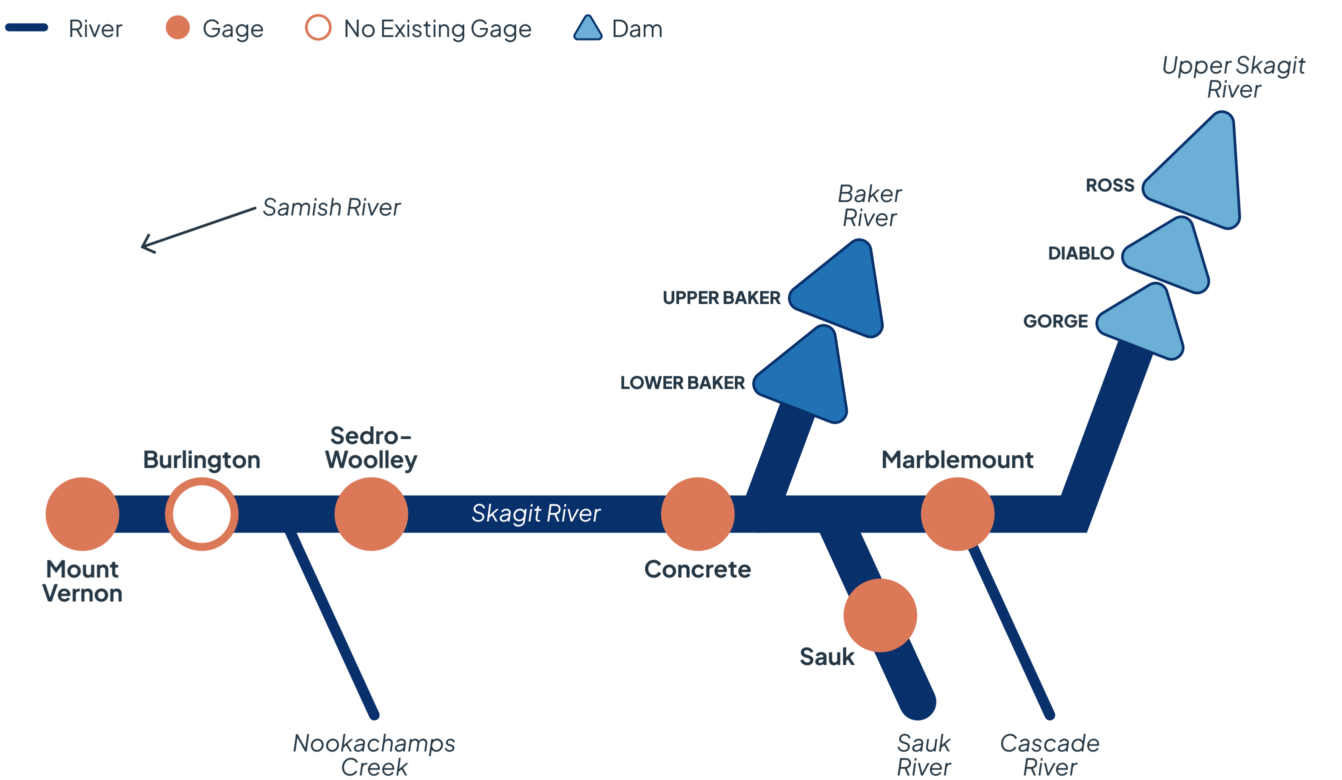


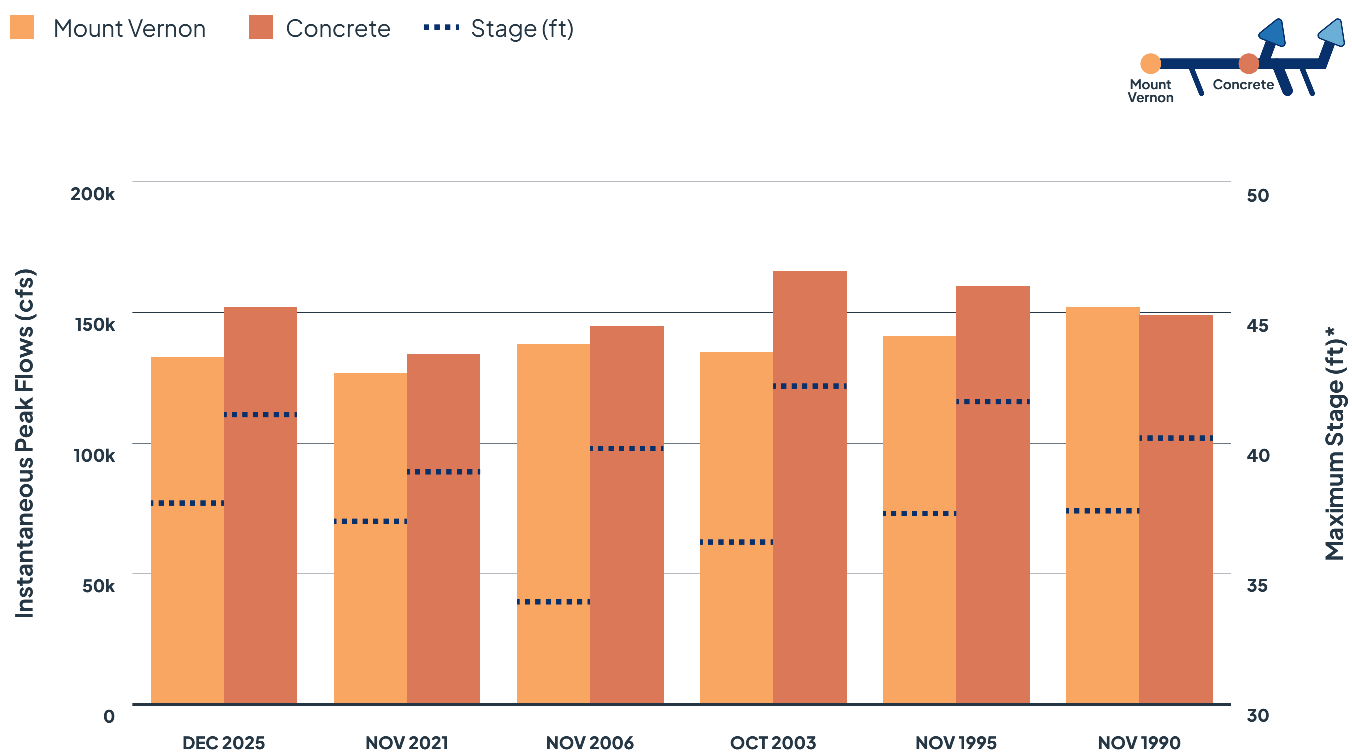
Image adapted from Lee et al. (2016)

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.

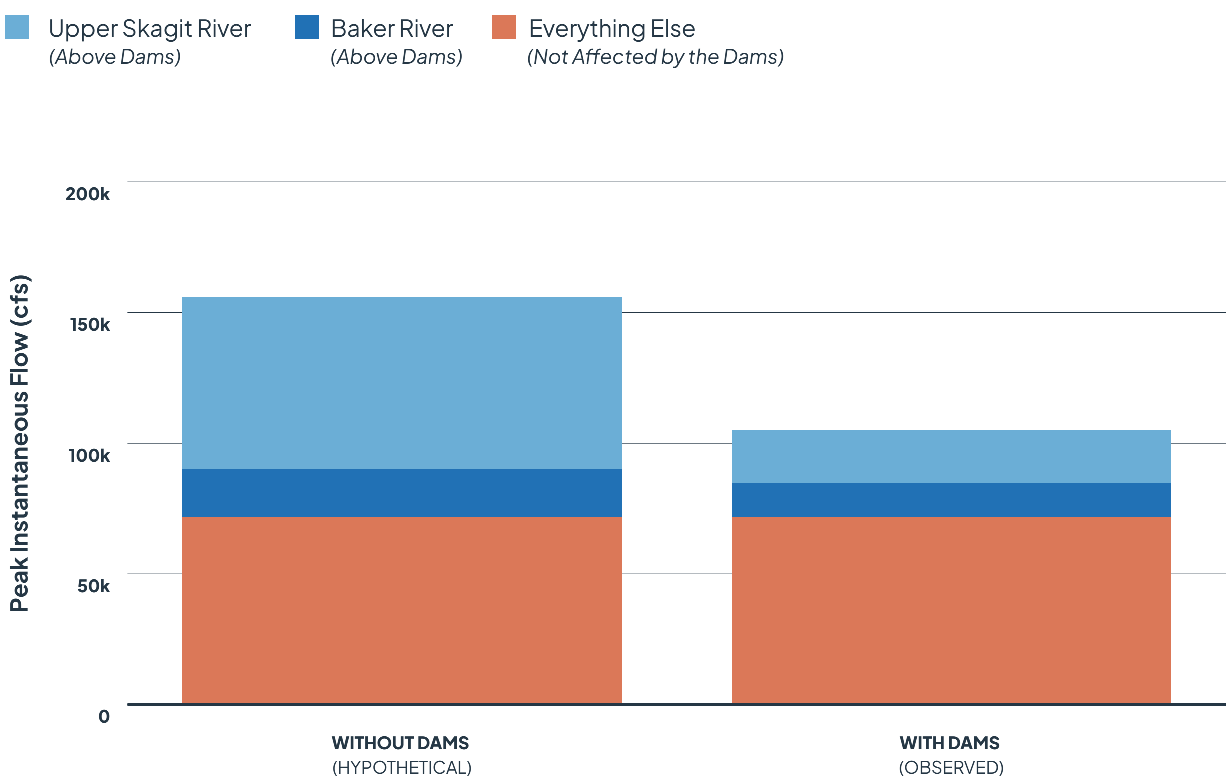
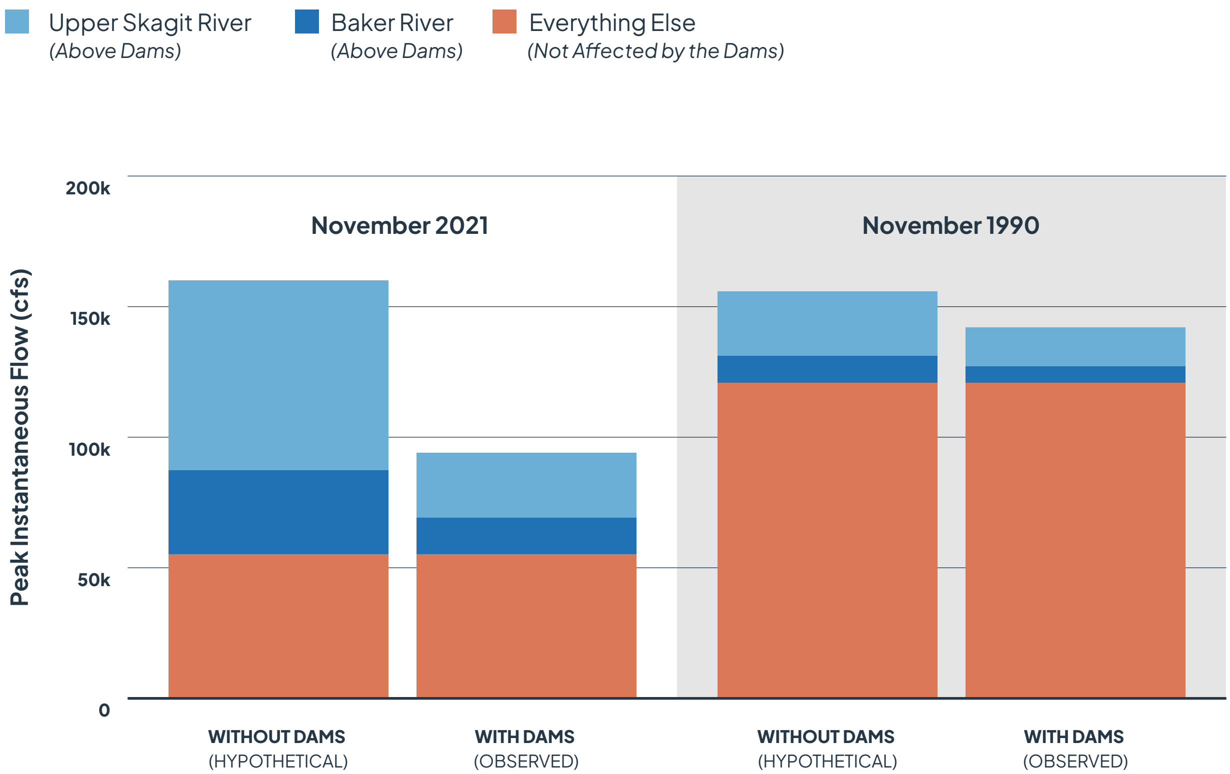


FIGURE 5: SOURCES OF FLOOD WATERS FOR DIFFERENT EVENTS

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.

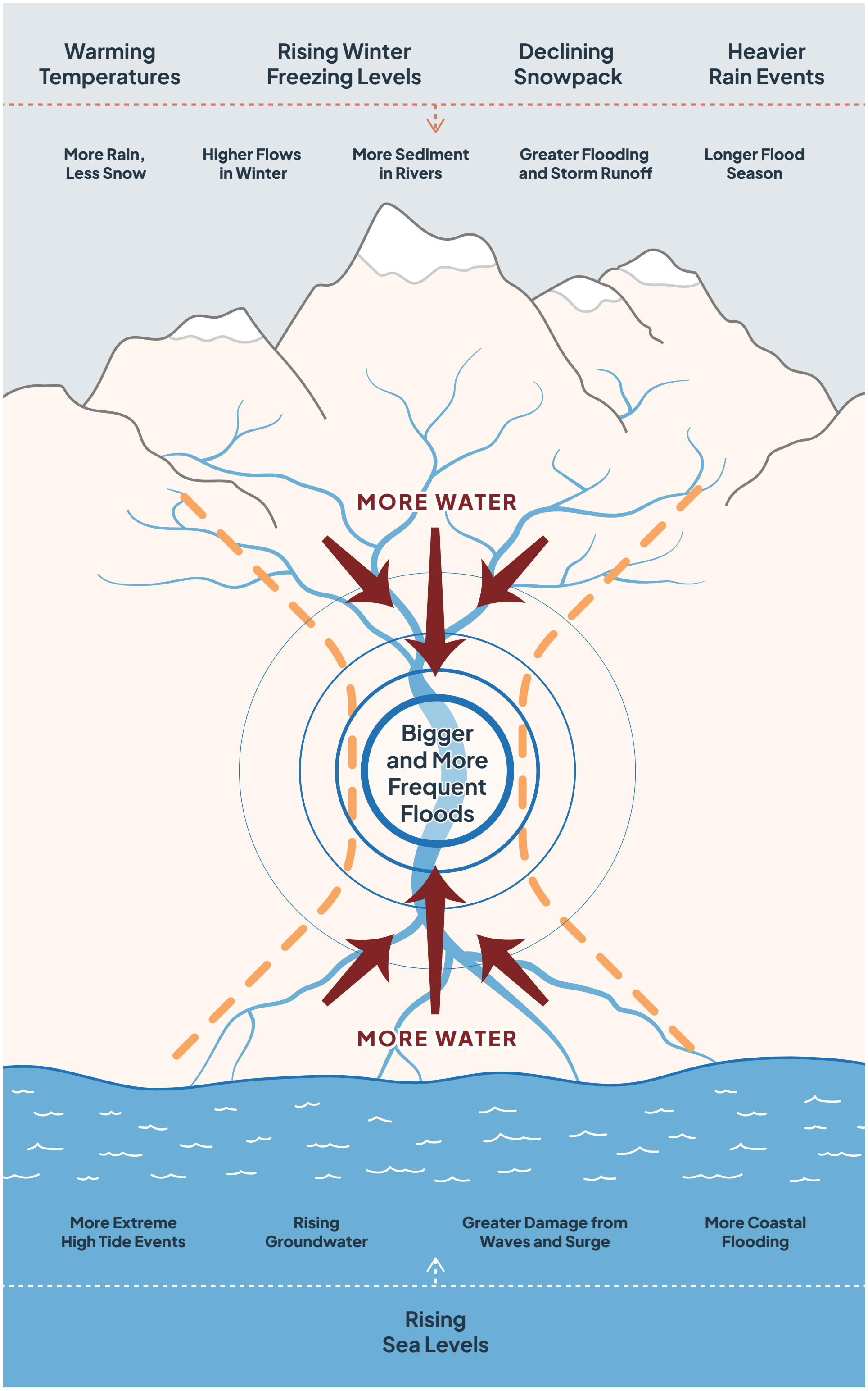


Image credit: Skagit Climate Science Consortium (SC2)

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.

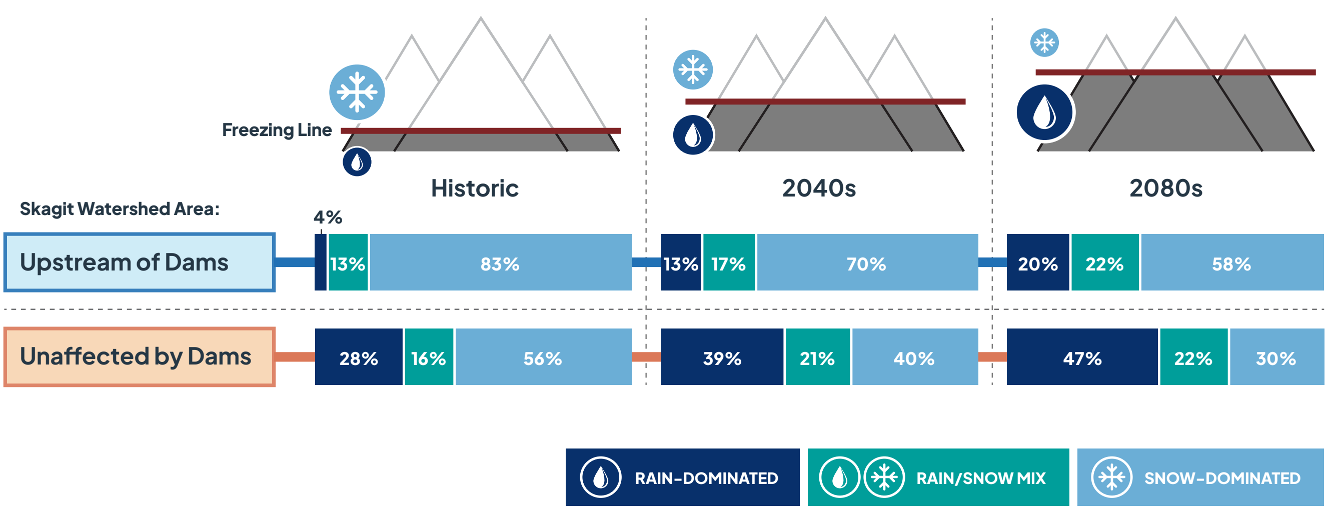
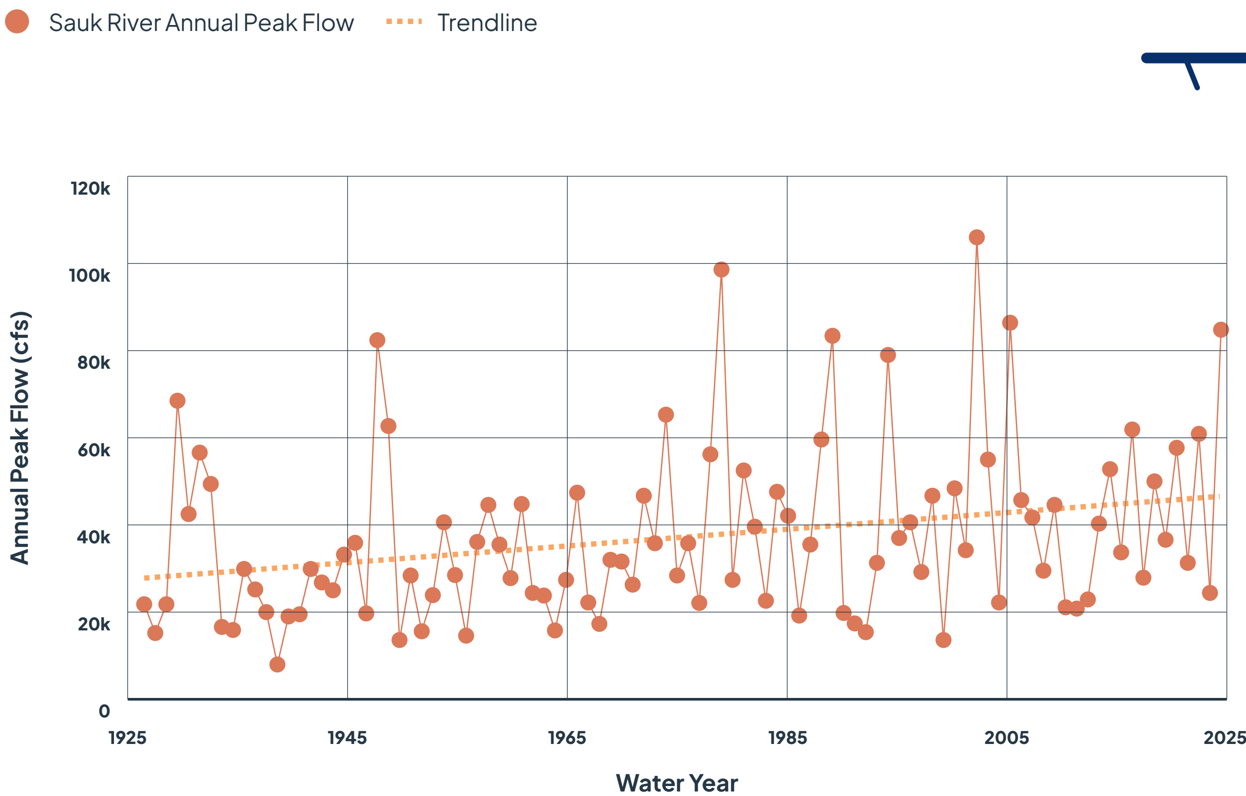


Image credit: Skagit Climate Science Consortium (SC2)

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)

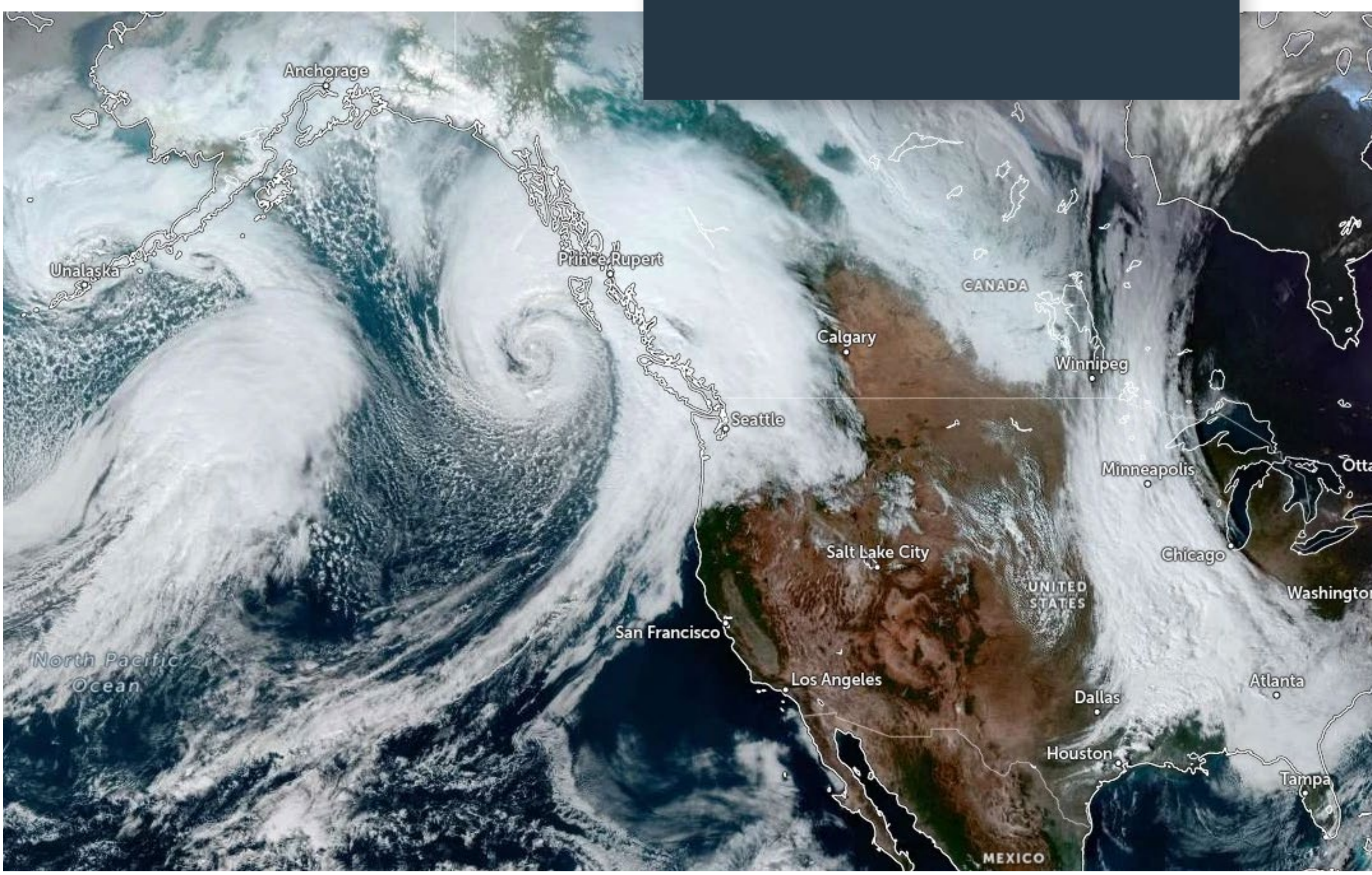
It is commonly understood that a big storm can bring a flood. This also means changes in the intensity of precipitation (the rate and volume of precipitation delivered during a storm) is likely to affect flooding. Climate models project that the heaviest precipitation events will become +22% more intense 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.

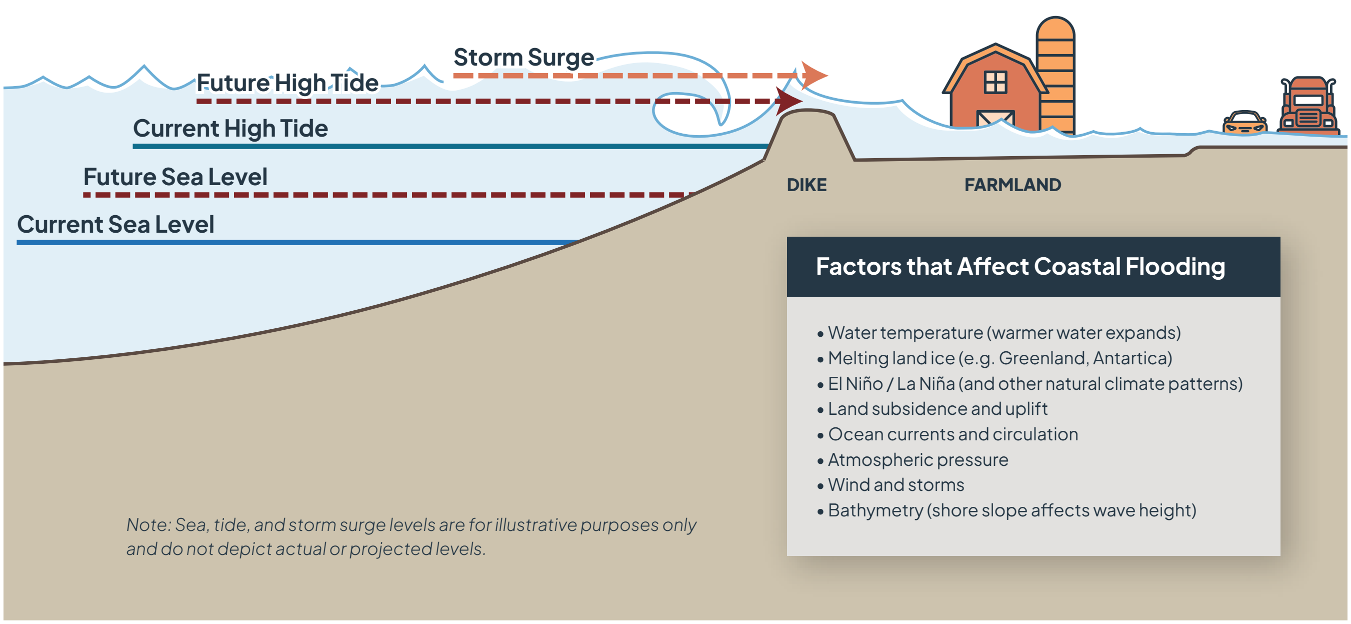


Image credit: Skagit Climate Science Consortium (SC2)

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.

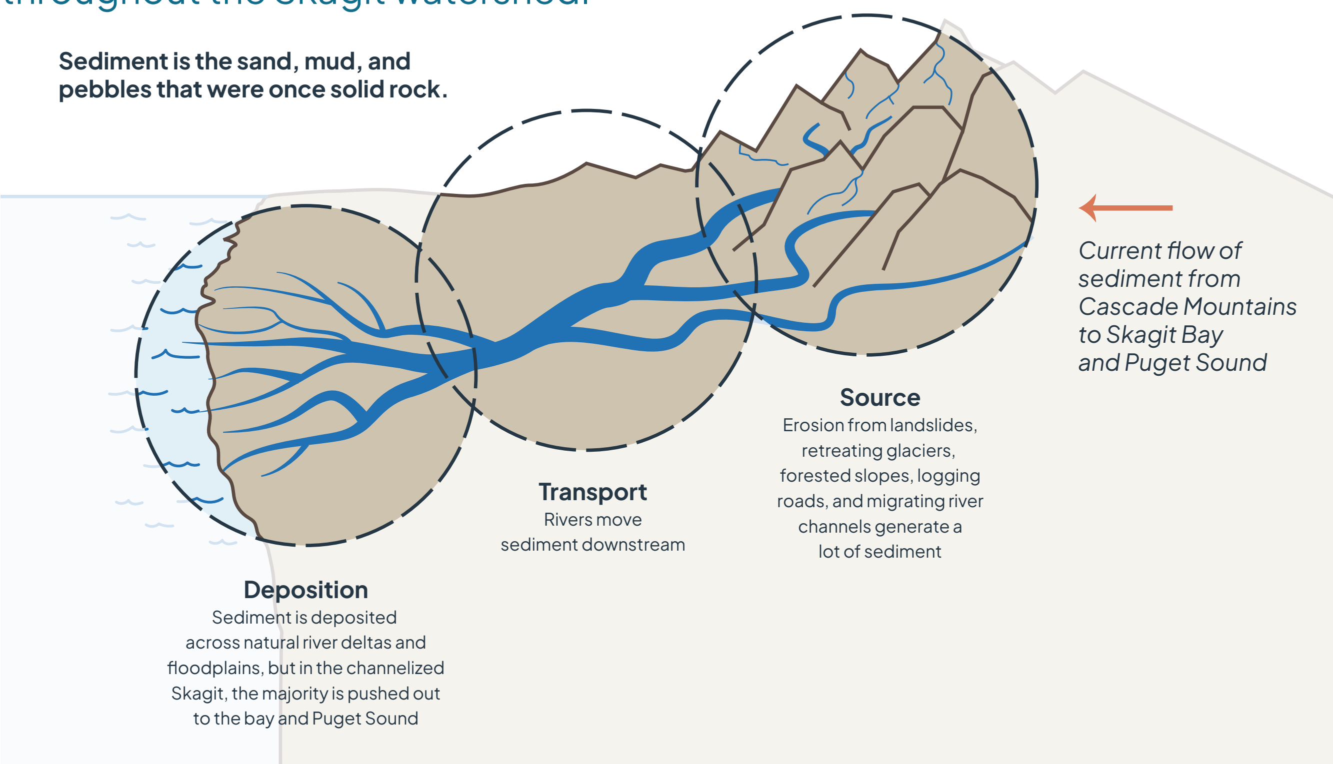


Image credit: Skagit Climate Science Consortium (SC2)

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.

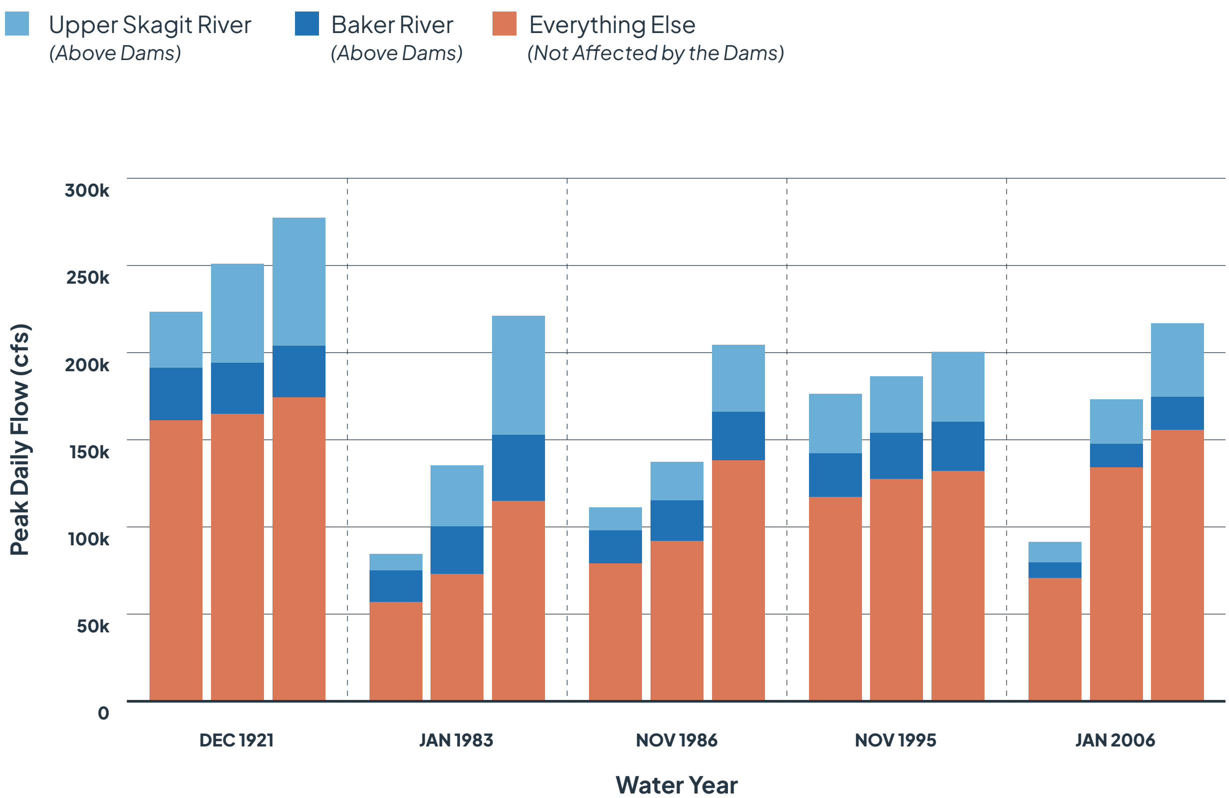
Looking at the results across the entire plot, models project an increase for all five historic events (higher bars for the 2040s and 2080s, in all cases). It also shows that some events change relatively little. For example, the model projects that the 1995 event would lead to flows that are only +14% 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

Updates to the Model

- New channel bathymetry (2022, 2014)
- Incorporates recent levee strengthening and habitat projects
- Riverine flooding (current and future, 10–year, 25–year, 100–year)
- Dike failures (6 locations, based on Draft Skagit General Investigation)
- Tides
- Coastal flooding (current and future, 10–year, 25–year, 100–year)

Could Be Added in the Future

- Future channel bathymetry (sediment processes)
- Debris build-up on bridges
- Future land-use/land cover
- Pump stations
- Extend model up Sauk River
- Soils, infiltration
- Localized flooding

Not Possible With Current Model

- Saltwater intrusion
- Channel migration and avulsion
- Groundwater
- Local stormwater flooding

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.

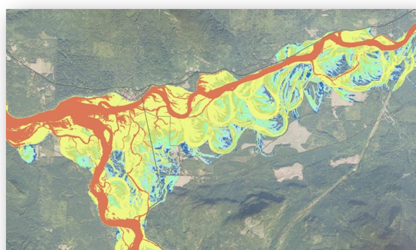
Hydraulic models almost always require flow inputs at the model boundary (e.g. from tributaries); these inputs are often estimated with a *hydrologic* model.

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.

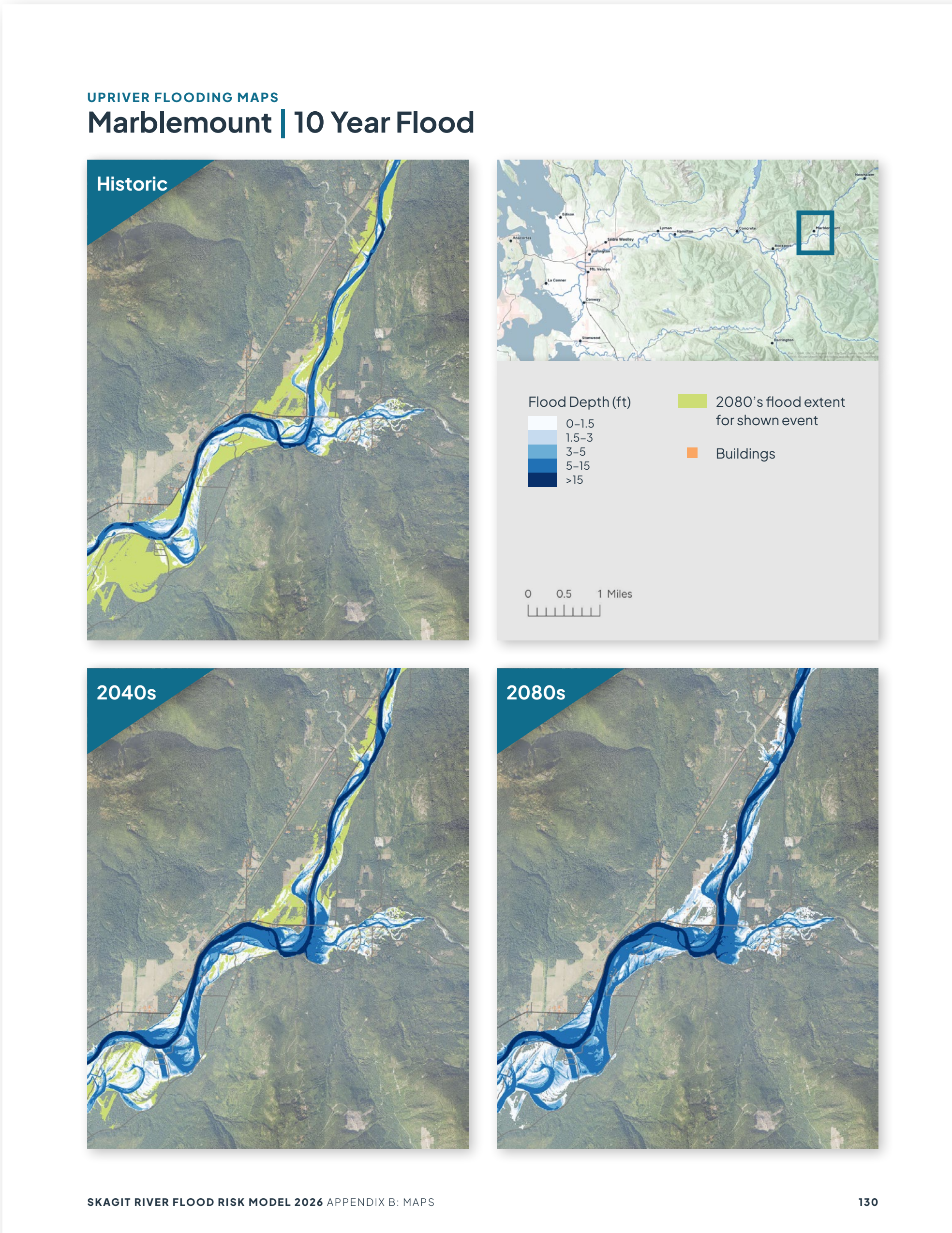
The following sections highlight example results by map type in order to provide a more detailed overview of the content provided in Appendix B.

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

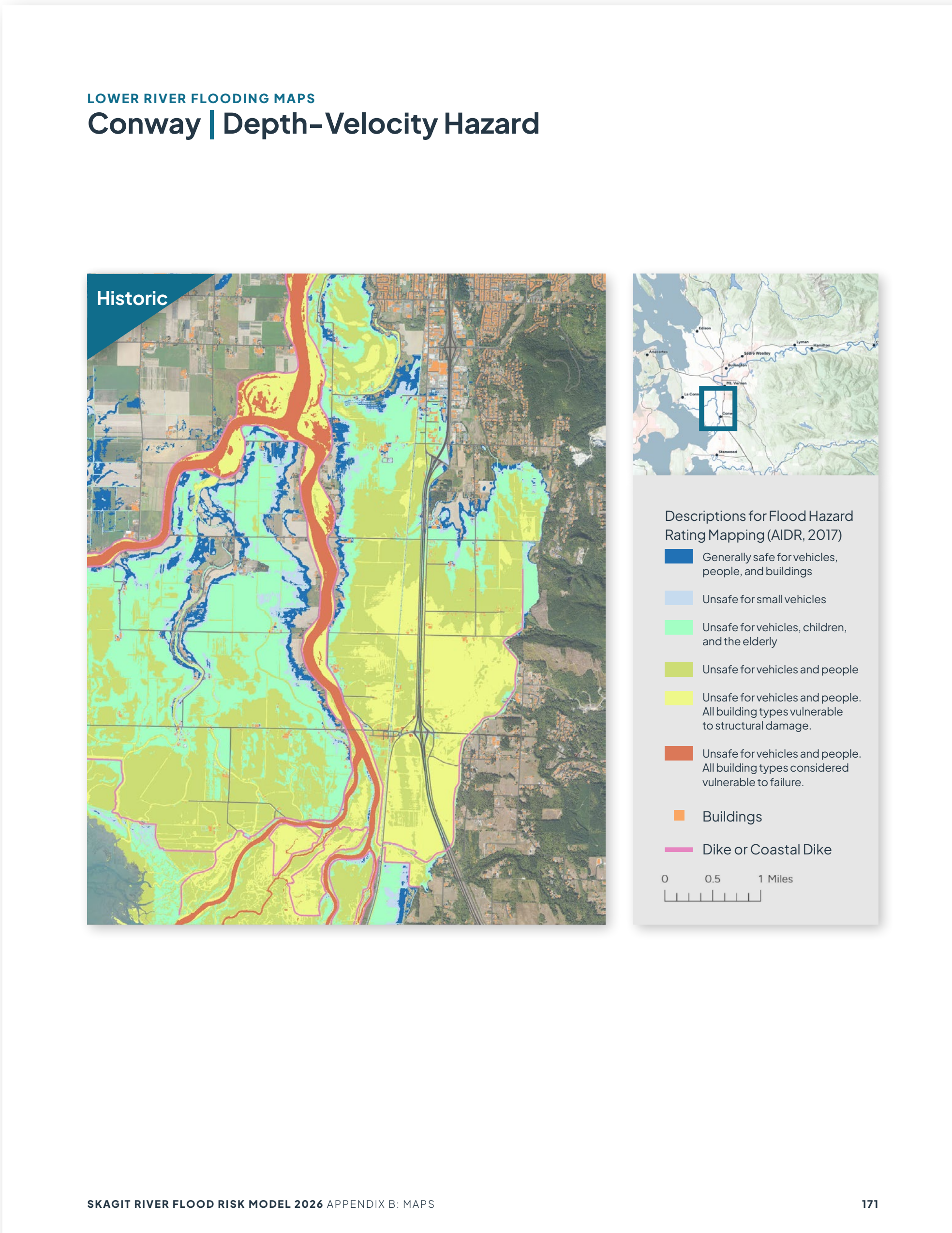
The coastal flood depth maps illustrate coastal flooding for historic and future conditions. Coastal flood depth maps are not combined with river flood events. Coastal flooding impacts the Town of La Conner, the Swinomish Reservation, Fir Island, and several unincorporated communities and areas. In general, 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.

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.

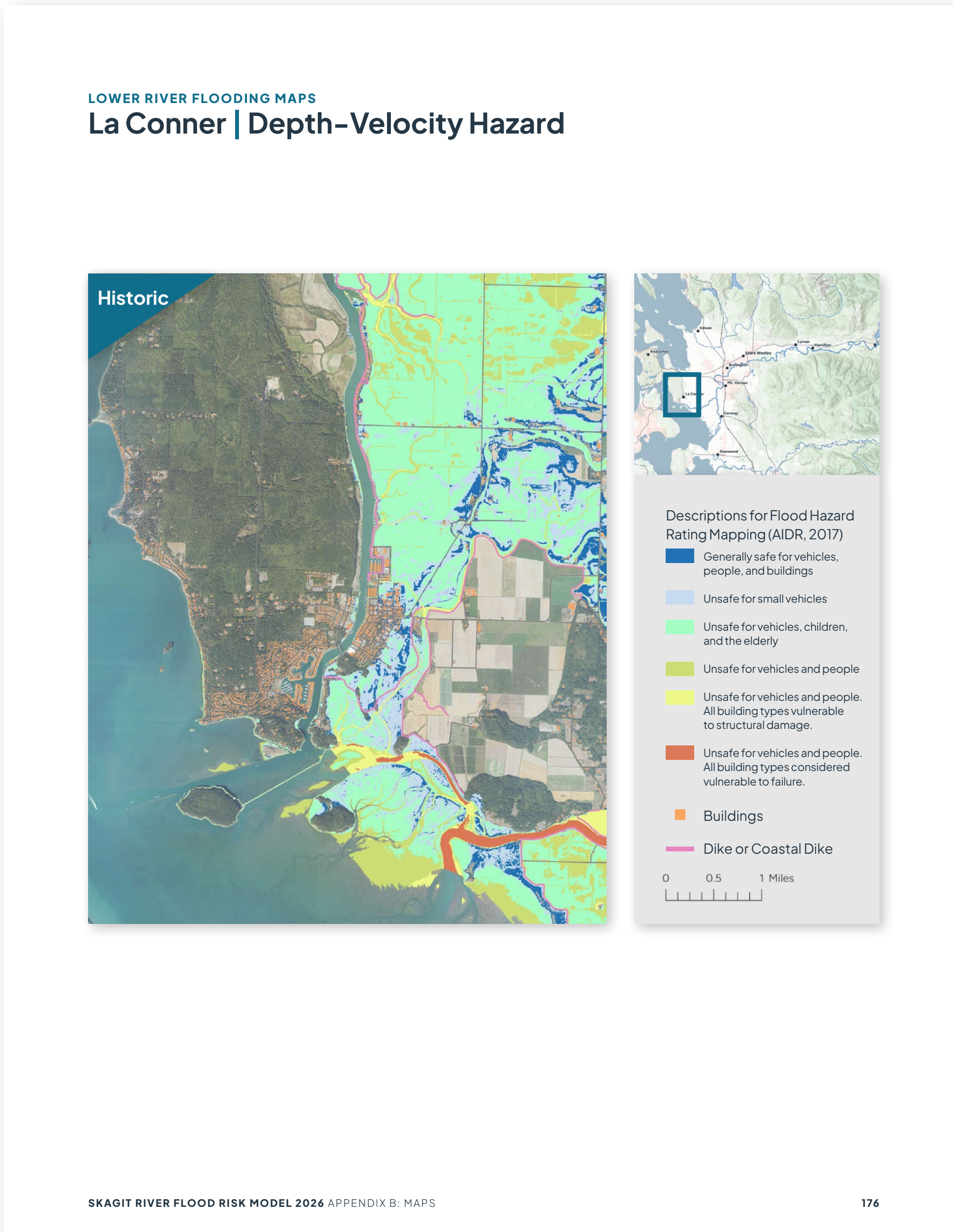
The example hazard map below shows the Conway, south Mount Vernon and Fir Island area for the historic 100-year event. Dark orange denotes the most unsafe areas with all building types considered vulnerable to failure. Bright green areas are also unsafe with building types vulnerable to structural damage. 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.



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.

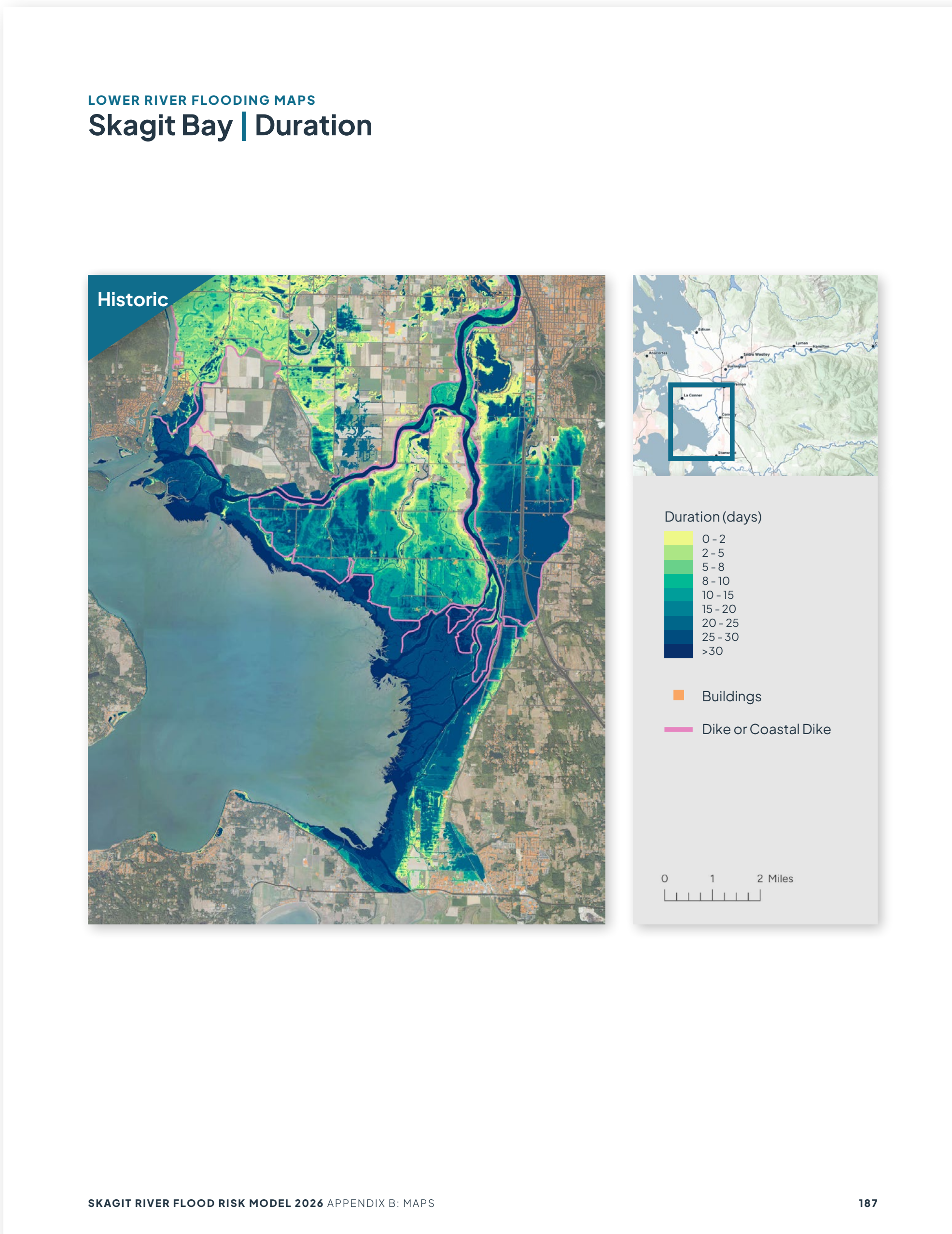
The example hazard map below shows the La Conner area for the historic 100-year event. Dark orange denotes the most unsafe areas with all building types considered vulnerable to failure. Bright green areas are also unsafe with building types vulnerable to structural damage. Darker green progressing to 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.



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.

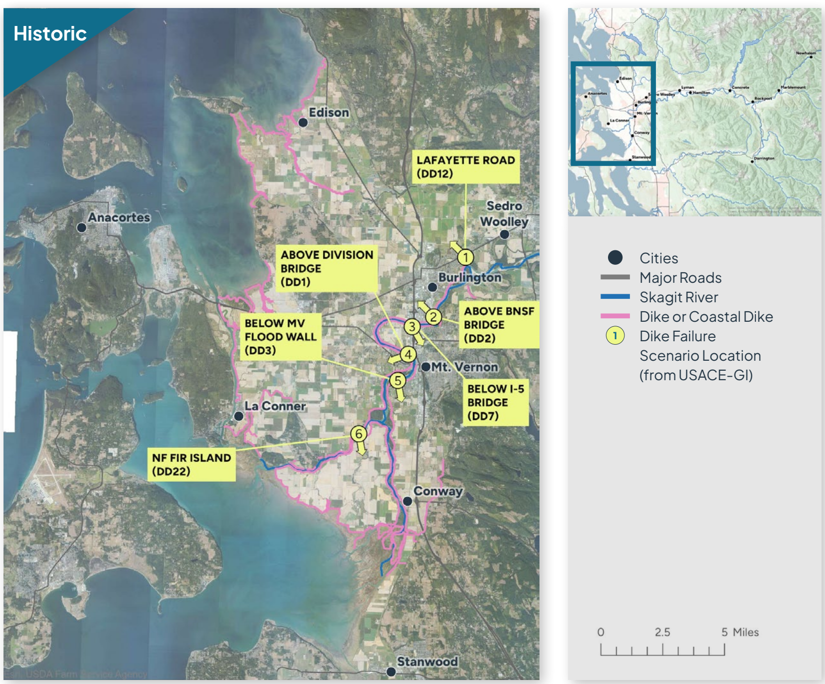


Dike Failure

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).

SKAGIT RIVER FLOOD RISK MODEL 2026 APPENDIX B: MAPS 206

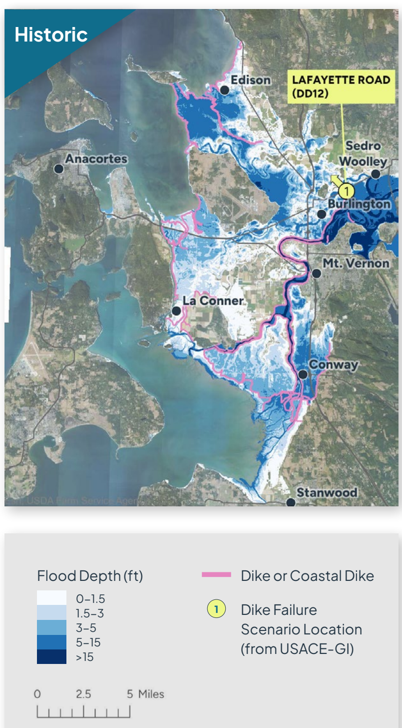
Dike Failure – Depth and Depth Difference

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.

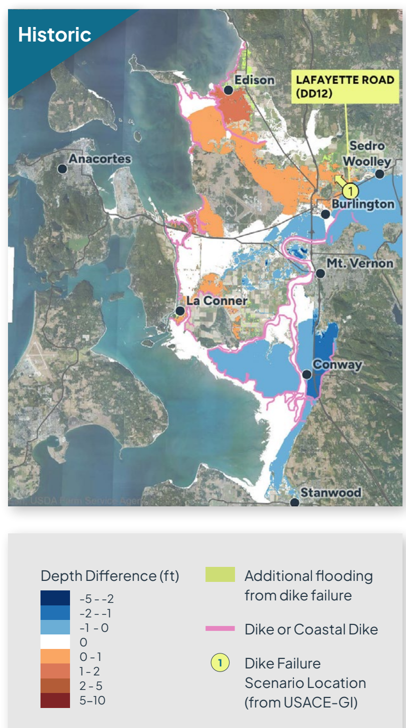
DIKE FAILURE SCENARIOS

Lafayette Road

FLOOD DEPTH



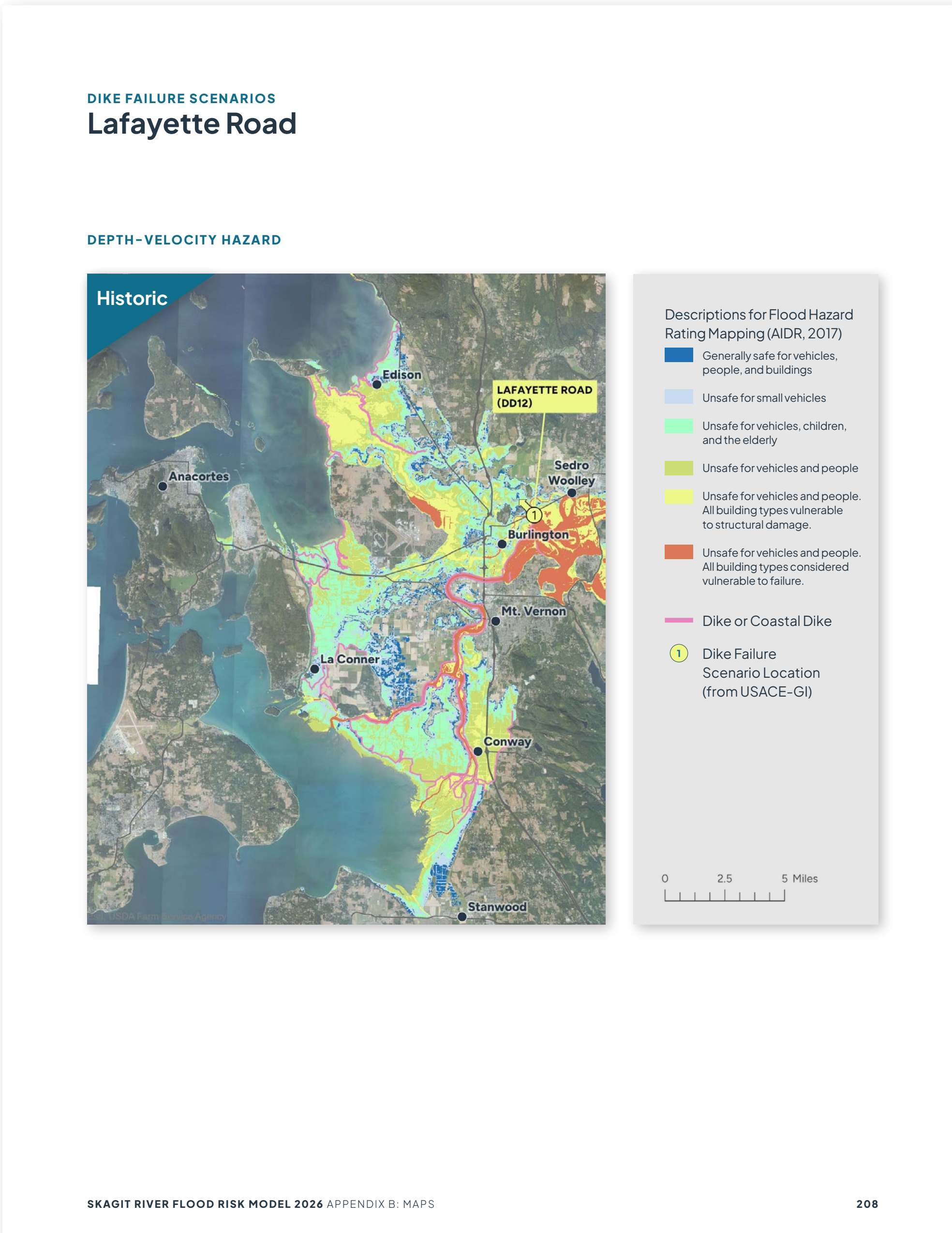
DEPTH DIFFERENCE



SKAGIT RIVER FLOOD RISK MODEL 2026 APPENDIX B: MAPS 207

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).

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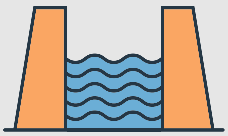
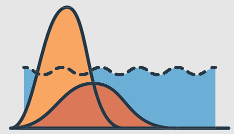
FIGURE 14: EXAMPLES OF BIG PICTURE APPROACHES TO REDUCING FLOOD IMPACTS



Contain the Flow

Dikes and Flood Walls, Channel Modifications

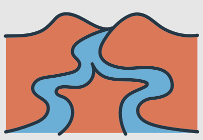
- Dikes and floodwalls are designed to contain the flow so water remains between the river banks.
- Channel modifications such as bridge abutments, levee toe design, and sediment management are often designed to limit obstructions and speed the flow of water



Flatten the Peak

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

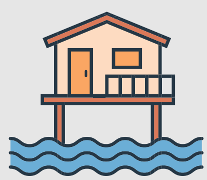
- Dams hold back water during floods and release it later (alternative 'rule curves' may increase available flood storage earlier in the fall)
- Floodplain reconnection (e.g. via logjams, setbacks, wetlands) allow the flow to spread and slow.
- Forest management and other upland changes can alter how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

SWINOMISH INDIAN TRIBAL COMMUNITY

SC2 SKAGIT CLIMATE SCIENCE CONSORTIUM

SKAGIT RIVER SYSTEM COOPERATIVE

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

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