Sauk River

Comprehensive Flood/Erosion Control Management Plan

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Sauk River Comprehensive Flood/Erosion Control Management Plan

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EXECUTIVE SUMMARY

As with any effort of this magnitude, it is difficult to distill the Sauk River into a few paragraphs. The Sauk lives up to its' designation as a Wild and Scenic River, with emphasis on the Wild. At high flow, the river is powerful, erosive, and can change channels in multiple locations during any given event. To address this dilemma of a quickly changing river and Stakeholders desire to impart order amongst the chaos, Snohomish and Skagit counties embarked on a Comprehensive Flood/Erosion Hazard Management plan. The plan is a quantitative document that provides Stakeholders unprecedented opportunity for informed decision making.

INTRODUCTION

The Sauk River basin encompasses 714 square miles (USGS gage # 12189500 site data) in Northern Snohomish and Southern Skagit counties. This Comprehensive Flood/Erosion Hazard Management plan (The Plan) evaluates erosion and flood hazard in the Sauk River basin, and identifies flood and erosion hazard mitigation opportunities.

Flooding and erosion problems on the Sauk River, particularly in the upper Sauk near the town of Darrington, have worsened in recent years. In the October 2003 flood, estimated at greater than an 80 year event, many homes, property and infrastructure were damaged or destroyed, prompting this study.

Compounding flooding and erosion problems is a complicated array of overlapping state, federal, and local regulations that confuses even the most knowledgeable and patient landowner. The Sauk River, designated Scenic under the Wild and Scenic Rivers Act (WSRA), has an additional overlay of federal regulations including the WSRA and the Endangered Species Act (ESA).

Flooding and erosion are natural disturbances to the riverine ecosystem that forces the dynamic interaction of sediment, water and vegetation to form and reset habitat conditions favorable for salmonid rearing and reproduction (Beechie and Bolton, 1999). Controls at the landscape scale, such as climate, geology, topography, ecoregions (vegetation communities) and disturbance regimes, affect the magnitude and rates of supply and transport of sediment, water and vegetation. Controls on habitat formation at the reach scale, such as channel/valley geomorphic characteristics, riparian conditions and large woody debris (LWD) recruitment, affect routing and delivery (sometimes removal) of sediment, water and vegetation. These habitat forming processes, favorable for fish, can impact infrastructure and human society in ways considered detrimental.

At the same time, landscape and reach-scale controls have been substantially altered by human activities, such as forest road building, riparian clearing and bank armoring. These actions alter the quantity and quality of river habitats for fish. Striking a balance between infrastructure and flood protection and habitat forming processes is critical given the unchanging physical factors inherent in river processes.

Habitat and physical conditions in large rivers are less well documented than in smaller streams because of their size and inaccessibility (e.g., Beechie and Sibley 1997). This has restricted our ability to understand riverine processes and to assess the habitat conditions for functionality relative to performance criteria (i.e., WFPB 1997, NMFS 1996.) It has also affected our ability to identify and prioritize appropriate sites and designs for infrastructure and flood protection, habitat protection and restoration. Analyzing data on the Sauk River and floodplain habitat will improve our understanding of large river processes, and guide flood and erosion damage reduction, project prioritization, and evaluation of feasibility and design.

GOALS

During the course of developing goals and objectives, the Stakeholder Committee decided that establishing a mission statement would be more appropriate for the plan.

The mission statement and corresponding objectives adopted by the Committee are as follows:

MISSION STATEMENT

Produce and implement a Sauk River Comprehensive Management Plan that balances the need for infrastructure and property protection with the protection and restoration of natural resources and outstanding and remarkable values of the Sauk River; (in a manner) that is acceptable to affected landowners, resource agencies, local tribes, interest groups, and local governments; and is consistent with plan elements required by the State of Washington.

OBJECTIVES

1. Collect data and create a database to be used in analysis (both in the current planning effort and in future follow-up activities) that will contribute to a better understanding of natural river processes and the full range of their effects.
2. Describe a range of potential actions to protect property and infrastructure; evaluate their effects on fish and wildlife habitat, as well as their ability to successfully protect property, infrastructure and other land uses.
3. Describe a range of potential actions to protect, restore, or enhance fish and wildlife habitat; evaluate their effects on property, infrastructure and other land uses, as well as their ability to successfully protect, restore or enhance fish and wildlife habitat.
4. Develop appropriate management strategies on a reach-by-reach basis including:

   a. The areas and conditions in the corridor that justify high consideration for flood and bank protection

   b. The areas and conditions in the corridor that justify high consideration for habitat protection and restoration

5. Describe the regulatory environment in the Sauk River corridor, including:

   a. The statutory authority of local, state, tribal, and federal agencies

   b. The required permits, pathways and timelines; particularly during locally declared emergencies

   c. Recommendations for regulatory improvements

6. Provide information on the range of assistance programs available for areas impacted by flood and channel migration, including:

   a. Identifying gaps in these programs

   b. Developing recommendations to fill these gaps

   c. Recommending ways to improve access to existing programs

   d. Develop a process for funding plan implementation

7. Develop an understandable outreach and public education program for the Sauk River Management Plan.

1. INTRODUCTION

1.1 PURPOSE OF THE STUDY

Flooding and erosion problems on the Sauk River, particularly in the upper Sauk near the town of Darrington, have become worse in recent years. In the October 2003 flood, estimated at greater than an 80 year event, many homes, property and infrastructure were damaged or destroyed, prompting this study.

Compounding flooding and erosion problems is a complicated array of overlapping state, federal, and local regulations that confuses even the most knowledgeable and patient landowner. The Sauk River, designated Scenic under the Wild and Scenic Rivers Act (WSRA), has an additional overlay of federal regulations including the WSRA and the Endangered Species Act (ESA).

Flooding and erosion are natural disturbances to the riverine ecosystem that force the dynamic interaction of sediment, water and vegetation to form and reset habitat conditions favorable for salmonid rearing and reproduction (Beechie and Bolton, 1999). Controls at the landscape scale, such as climate, geology, topography, ecoregions (vegetation communities) and disturbance regimes, affect the magnitude and rates of supply and transport of sediment, water and vegetation. Controls on habitat formation at the reach scale, such as channel/valley geomorphic characteristics, riparian conditions and large woody debris (LWD) recruitment, affect routing and delivery (sometimes removal) of sediment, water and vegetation. These habitat forming processes, favorable for fish, can impact infrastructure and human society in ways considered detrimental.

At the same time, landscape and reach-scale controls have been substantially altered by human activities, such as forest road building, riparian clearing and bank armoring. These actions alter the quantity and quality of river habitats for fish. Striking a balance between infrastructure and flood protection and habitat forming processes is critical given the unchanging physical factors inherent in river processes.

Habitat and physical conditions in large rivers are less well documented than in smaller streams because of their size and inaccessibility (e.g., Beechie and Sibley 1997). This has restricted our ability to understand riverine processes and to assess the habitat conditions for functionality relative to performance criteria (i.e., WFPB 1997, NMFS 1996.) It has also affected our ability to identify and prioritize appropriate sites and designs for infrastructure and flood protection, habitat protection and restoration. Analyzing data on the Sauk River and floodplain physical habitat will improve our understanding of large river processes, and guide flood and erosion damage reduction, project prioritization, and evaluation of feasibility and design.

1.2 STUDY AREA

The Sauk River is located in both Skagit and Snohomish counties, in northwest Washington State**,** (Figure 1). Snohomish County is bordered by Skagit County to the north, King County to the south, Chelan County to the east, and Puget Sound to the west. Skagit County is bordered by Whatcom County to the north, Chelan County to the east, Island County to the west, and Snohomish County to the south. The study area of the Sauk River basin, is approximately 714 square miles in area, and is shared by the two counties. Because of this duality, Snohomish and Skagit counties entered into a cooperative agreement in 2005 to partner on creation of this plan.

In the Sauk, reach-scale river and floodplain conditions (hydromodifications, riparian vegetation, and instream habitat) vary from nearly "un-touched" to highly modified. Likewise, the scale and scope of river assessment to date varies among mainstem reaches. In the mid-1990s, Skagit River Systems Cooperative (SRSC) gathered data on bank modifications and in-stream habitat units in the Sauk River (Hayman et al. 1996), and more recently has begun to inventory off-channel habitat (SRSC unpublished data).

Additional inventory and analysis has been completed for this plan, to better understand the sensitivity of this complex and highly dynamic system. Building on existing and new data to update and complete the Sauk River plan has been a critical step that will lead to better, more sustainable flood and erosion control and more habitat protection and creation throughout.

1.3 PLAN DEVELOPMENT

To complete the Sauk Plan, an existing stakeholders group was reorganized to help identify potential causes of flooding and erosion in the basin, flood and erosion hazards, and flood and erosion hazard mitigation opportunities. These will help determine guidelines for future flood and erosion hazard management.

The plan follows the guidelines and requirements regarding the preparation of comprehensive plans, and conforms to the following procedures described in RCW 86.26 and WAC 173-145:

- Establish a citizen and agency participation process
- Set short- and long-term goals and objectives for flood hazard management
- Develop an inventory and analysis of physical conditions
- Determine the need and identify alternatives for flood hazard management measures
- Evaluate alternative measures
- Hold public workshops for evaluation of alternatives
- Complete the draft Sauk Flood/Erosion Plan and associated documentation

- Submit the final Sauk Flood/Erosion Plan to Ecology

1.3.1 Public Involvement

Public involvement is critical to the success of flood/erosion hazard management planning, as proposed measures may affect local landowners and these landowners may be able to provide additional important information. Their understanding of the tools and process, and feedback throughout effort, is needed to develop actions.

The planning process also offers an opportunity to educate the public on the issues, opportunities, and public responsibilities of flood/erosion hazard management. Because the local governments must adopt the plan, it is important that the local community take an active role in developing the plan contents. In the Sauk, a representative sample of the community was present and active for each stakeholders meeting.

1.3.2 Advisory Committee

One of the first steps in developing this plan was to establish a planning advisory committee to engage the public and agencies, and gather their opinions and expertise. Fortunately, an interested and engaged Stakeholder Committee was already focusing on issues on the Sauk, so it was a natural segue to enlist these existing stakeholders in the planning process.

During the initial phases of the project, a smaller subcommittee, known as the Steering Committee, was formed to help guide the process. The Steering Committee met a total of ten times, on the following dates (Table 1-1):

Table 1-1. Steering Committee Meeting Dates

1	November 28, 2005
2	December 19, 2005
3	January 23, 2006
4	February 22, 2006
5	March 1, 2006
6	June 6, 2006
7	July 11, 2006
8	August 8, 2006
9	November 21, 2006
10	December 20, 2006

After the December 2006 meeting, the Steering Committee agreed to combine their efforts with those of the Stakeholder Committee to reduce the time commitments for all.

The Stakeholder Committee consisted of representatives from public and private organizations and agencies.

The committee met ten times (Table 1-2).

Table 1-2. Stakeholder Committee Meeting Dates

1	November 2, 2005
2	November 28, 2005
3	March 1, 2006
4	April 19, 2006
5	June 28, 2006
6	September 13, 2006
7	October 16, 2007
8	December 18, 2007
9	February 19, 2008
10	April 15, 2008

The meetings provided a forum for the committee to provide regular feedback to the counties. The committee also accomplished project review through e-mail or regular mail. Members who were invited, but could not attend meetings, were provided all information for review and comment throughout the process.

The efforts of all committee members were invaluable to the completion of this plan. A cross-section of stakeholders, who represented the key interests on the Sauk River, is shown in Table 1-3 below.

Table 1-3. Sauk River Comprehensive Flood/Erosion Management Plan – Stakeholder Committee

Chuck Steele	WA DOE	David Like	Hampton Lumber
Noel Gilbrough	U.S. Army Corps of Engineers	Paul DeVries	R2
Jack de Young	Fly Fishers Int'l	Diane & Bob Boyd	RRT/Property Owner
Alex Uber	WA Dept. of Fish	Devin Smith	Skagit River System Coop
Greta Movassaghi	US Forest Service	Holley P. Ross	Bryson Rd Sub Flood Control District
Peter Forbes	US Forest Service	Cheryl Ryder	Skagit River System Coop
Lori Kratzer	River Resource Trust	Betsy Stevenson	Skagit County
Brenda White	U.S. Representative Rick Larsen	David Lobo, Sr.	Bryson Rd Sub Flood Control District
Scott Morris	Sauk-Suiattle Indian Tribe	David Lobo, Jr.	Bryson Rd Sub Flood Control District
Bob Aldrich	Snohomish County	Erik Lobo	Bryson Rd Sub Flood Control District
Jim Faucett	RRT, Property Owner	Dana Exum	Bryson Rd Sub Flood Control District
Chuck Beck	Snohomish County Council	Kimberly Snavely	Bryson Rd Sub Flood Control District
Stan Walsh	Skagit Riv. Sys. Coop.	Tom Sibley	National Marine Fisheries Service
Jeff Kamps	WDF&W	John Engel	Snohomish County
		Beth Blattenberger	Seattle City Light
		Ric Boge	Skagit County
		Tom Kearns	Bryson Rd Sub Flood Control District
		Karen Wood-McGuiness	Snohomish County

1.3.3 Goals and Objectives of the Sauk River Comprehensive Erosion/Flood Hazard Management Plan

During the course of developing goals and objectives, the Stakeholder Committee decided that establishing a mission statement would be more appropriate for the plan.

The mission statement and corresponding objectives adopted by the Committee are as follows:

1.3.4 Mission Statement

Produce and implement a Sauk River Comprehensive Management Plan that balances the need for infrastructure and property protection with the protection and restoration of natural resources and outstanding and remarkable values of the Sauk River; (in a manner) that is acceptable to affected landowners, resource agencies, local tribes, interest groups, and local governments; and is consistent with plan elements required by the State of Washington.

1.3.5 Objectives

1. Collect data and create a database to be used in analysis (both in the current planning effort and in future follow-up activities) that will contribute to a better understanding of natural river processes and the full range of their effects.
2. Describe a range of potential actions to protect property and infrastructure; evaluate their effects on fish and wildlife habitat, as well as their ability to successfully protect property, infrastructure and other land uses.
3. Describe a range of potential actions to protect, restore, or enhance fish and wildlife habitat; evaluate their effects on property, infrastructure and other land uses, as well as their ability to successfully protect, restore or enhance fish and wildlife habitat.
4. Develop appropriate management strategies on a reach-by-reach basis including:
    a. The areas and conditions in the corridor that justify high consideration for flood and bank protection
    b. The areas and conditions in the corridor that justify high consideration for habitat protection and restoration
5. Describe the regulatory environment in the Sauk River corridor, including:
    a. The statutory authority of local, state, tribal, and federal agencies
    b. The required permits, pathways and timelines; particularly during locally declared emergencies
    c. Recommendations for regulatory improvements
6. Provide information on the range of assistance programs available for areas impacted by flood and channel migration, including:
    a. Identifying gaps in these programs
    b. Developing recommendations to fill these gaps
    c. Recommending ways to improve access to existing programs
    d. Developing a process for funding plan implementation

7. Develop an understandable outreach and public education program for the Sauk River Management Plan.

1.4 FUNDING THROUGH THE FLOOD CONTROL ASSISTANCE ACCOUNT PROGRAM

The Washington State program to assist local jurisdictions in comprehensive planning and flood control maintenance is described in the state statute *State Participation in Flood Control Maintenance*, Revised Code of Washington (RCW) 86.26, enacted in 1951 and amended in 1984.

Funds for flood management maintenance projects and preparation of comprehensive plans are available through the Flood Control Assistance Account Program (FCAAP).

Procedural information relating to FCAAP and RCW 86.26 can be found in *Administration of the Flood Control Assistance Account Program*, Washington Administrative Code (WAC) 173-145. A copy is available in Appendix D.

The Washington State Department of Ecology (Ecology) distributes FCAAP grant money based on the amount appropriated by the State Legislature each biennium, and the eligibility of the applicant and the proposed project. Proposals are reviewed by several state agencies to ensure that appropriate resource issues and regulations are adequately addressed.

Legislative appropriations for FCAAP grants have varied from no appropriations (during the years 1975 through 1985) to $4.0 million during the 2000 biennium.

The following restrictions apply to the use of the FCAAP grants:

- Grants are limited to 50 percent of the total cost for non-emergency projects.
- The non-emergency FCAAP contribution is limited to $500,000 per county.
- Maximum emergency funds of $150,000 per county per biennium are available on a first come/first serve basis; and the state will fund up to 80 percent of the cost of emergency projects.
- Unused emergency funds ($500,000 total emergency fund) can be disbursed on a discretionary basis by Ecology.
- The state can fund 75 percent of the cost for comprehensive plans.

1.4.1 Requirements for Comprehensive Flood Management Plans

To obtain funds for flood management maintenance projects through FCAAP, jurisdictions must prepare a comprehensive plan that, as discussed in RCW 86.26.105, accomplishes the items outlined in 1-4. The comprehensive plan must also establish and rank appropriate nonstructural and structural measures to reduce flood damages.

The study area may include the entire watershed or, at a minimum, the 100-year frequency floodplain within a reach of the watershed. The Sauk River plan includes measures that describe erosion and flooding problems and solutions throughout the basin.

Table 1-4. Requirements for a Comprehensive Flood Hazard Management Plan.

Washington State law imposes a set of requirements for comprehensive plans adopted in the state. An Ecology-approved plan includes:

1. **For all flood hazard reduction work outlined in the plan:**
   - Establish the need for the work based on historical flooding hazard
   - Identify alternatives, both non-structural and structural
   - Identify potential impacts of the work on resources such as fish and wildlife
2. **Identify and include a map of the entire 100-year floodplain.**
3. **Present conclusions and proposed solutions including priorities of implementation.**
4. **Certify that an acceptable, comprehensive emergency operations plan is in place.**
5. **Include the following in preparation of the plan:**
   - Citizen involvement
   - Coordination between government agencies
   - Establishment of short- and long-term goals and objectives
   - Review of all pertinent regulations
   - Research into past studies and projects
   - Review and approval by Ecology

State law requires that a comprehensive plan describe the area where any proposed projects are located, and the types and locations of existing flood hazards. A complete description of the information that a comprehensive plan must include is contained in WAC 173-145-040. The law allows up to three years for local authorities to complete and adopt a comprehensive plan. Ecology must approve the final comprehensive plan, and the local jurisdiction must adopt the plan subsequent to approval.

1.4.2 Applicant Eligibility

Counties, cities, and other local jurisdictions with flood control responsibilities, such as flood control districts or diking districts, are eligible to receive state funding for flood control maintenance projects. Eligible jurisdictions must file their flood control budget with Ecology by February 15th of each year.

To receive funding for flood control maintenance projects, the county, city, town, or district having planning jurisdiction over the project must have its floodplain management activities approved by Ecology. The requirements include:

- Participation in the National Flood Insurance Program (NFIP)
- Certification of the local emergency response plan by the State Department of Emergency Management
- Restriction of land uses to flood-compatible uses within a river's meander belt or floodway
- Adoption of a Shoreline Master Program (SMP) may also be required

1.4.3 Maintenance Project Eligibility

Evaluation of proposed FCAAP projects identified in the adopted comprehensive plan is based on cost-benefit, local prioritization of projects, intensity of local flood hazard management problems, and consideration of historical information in the comprehensive plan.

Maintenance projects must be based on a comprehensive approach to flood hazard management planning and must meet specific guidelines with respect to project goals. The legislation describes in general terms the maintenance work eligible for funding, which includes "maintaining and restoring the normal and reasonably stable river and stream channel alignment and capacity … and … restoring, maintaining, and repairing natural conditions, works and structures." State participation can also include "restoration and maintenance of natural conditions, works, or structures for the protection of lands and other property from inundation or other damage by the sea or other bodies of water" (RCW 86.26.090).

Funding for enhancement of flood management facilities was authorized by Engrossed Senate Substitute Bill 5411, which was enacted in July 1991. This expanded FCAAP project eligibility to include the purchase of flood-prone properties (provided that the property owners are willing sellers) or land to be used for flood storage; but only if these measures were identified in the applicable comprehensive plan. As described further in the Sauk Flood Plan, significant efforts were made by the Stakeholders Committee to identify public areas that have the potential for flood storage, but a detailed analysis will be required to quantify hydraulic benefits.

The Hydraulic Project Approval (HPA) and the Shoreline Substantial Development and Conditional Use (CU) permits must be obtained before the project is funded by Ecology. In addition, because of the listing of Chinook salmon as threatened under the Endangered Species Act, permitting regulations have become increasingly difficult and complex. All projects must be planned and designed consistent with ESA, applicable Shoreline Master Programs and comprehensive plans; and must benefit public, as opposed to strictly private, interests.

1.4.4 Emergency Projects

A portion of the available FCAAP funding is reserved for emergency use by law. Projects considered emergencies are those that must be done immediately to protect life and property from "unusual, unforeseeable, and emergent flood conditions" (WAC 173-145-000).

Release of emergency funds is contingent on an emergency declaration by the appropriate authority. Depending on the emergency measure, a shoreline permit or HPA may be required.

1.4.5 Consultation with Other Agencies

A variety of state and federal agencies are involved in key river issues, such as fishery resources, wildlife habitat, and public use. The presence of fishery resources, primarily salmon and steelhead, is a key consideration in performing any flood hazard management activities in and around the waters of the State of Washington. The potential loss of fish habitat resulting from construction in and next to rivers has been a major concern for Native American groups, fisheries agencies and sports fishermen, among others.

To ensure that habitat resources are maintained, the Washington State Department of Fish and Wildlife (WDFW) has review authority for most phases of FCAAP. Ecology is required to consult with the WDFW before approving any comprehensive plan. Applicants for flood control assistance project funds must review their proposals with the WDFW, the Washington State Department of Natural Resources (DNR), and the tribes with jurisdiction.

Construction work to be performed in or adjacent to navigable waters of the United States, including wetlands, must be approved by the Army Corps of Engineers (Corps.) The Corps' permit process ensures that all other federal, state, and local regulatory agencies with jurisdiction over the project are properly notified of and approve, the project. The Corps will not approve a project that has been rejected by another permitting agency.

Section 7 of the ESA requires that any project that may impact a listed species is reviewed by either the U.S. Fish and Wildlife Service (USFWS), (which oversees terrestrial animals and freshwater fish species), or the National Marine Fisheries Services (NMFS), which oversees marine anadromous (freshwater and saltwater) species.

The ESA applies to all actions that meet any of the following criteria:

- Projects where a permit from a federal agency, such as the Corps is required
- Projects on federal lands
- Federally funded projects, including projects where federal funding is administered by state agencies
- Projects not possessing a federal connection, but that may cause either direct injury to the listed species, alteration of habitat, or significant disturbance of the habitat

The Sauk River is habitat for a variety of species, including the ESA-listed bull trout, and Chinook salmon. Both the bull trout and the Chinook are listed as threatened species. The goal of our review is to determine the type and extent of impacts and the proper mitigation measures that should be implemented during the course of the project to limit or eliminate these impacts.

1.5 AUTHORITY AND SCOPE

In 2006, Snohomish County worked with consultant R2 Resources Inc., to assist in the development of the risk analysis and technical report for the Sauk River Erosion/Flood Plan. The draft version of the Technical and Regulatory Analysis was completed and submitted to the Stakeholder Committee for review in March 2008. The complete report, including all technical analyses, was submitted to the Stakeholder Committee for review in April of 2009.

Funding for the development of the Sauk River Comprehensive Flood/Erosion Control Plan (the Plan) was provided to the two counties under a 75 percent FCAAP grant from Ecology, with the remaining 25 percent funded by Snohomish and Skagit counties.

The alternatives and recommendations for flood hazard management presented in this plan are in accordance with FCAAP requirements as stated in the RCW 86.26 and the WAC 173-145 (Appendix 3).

The Plan fulfills one of the main requirements for the counties to become eligible for funding from the State of Washington under the FCAAP. State funds from this program can be used for emergency and non-emergency activities that reduce property loss and threats to human health caused by flooding.

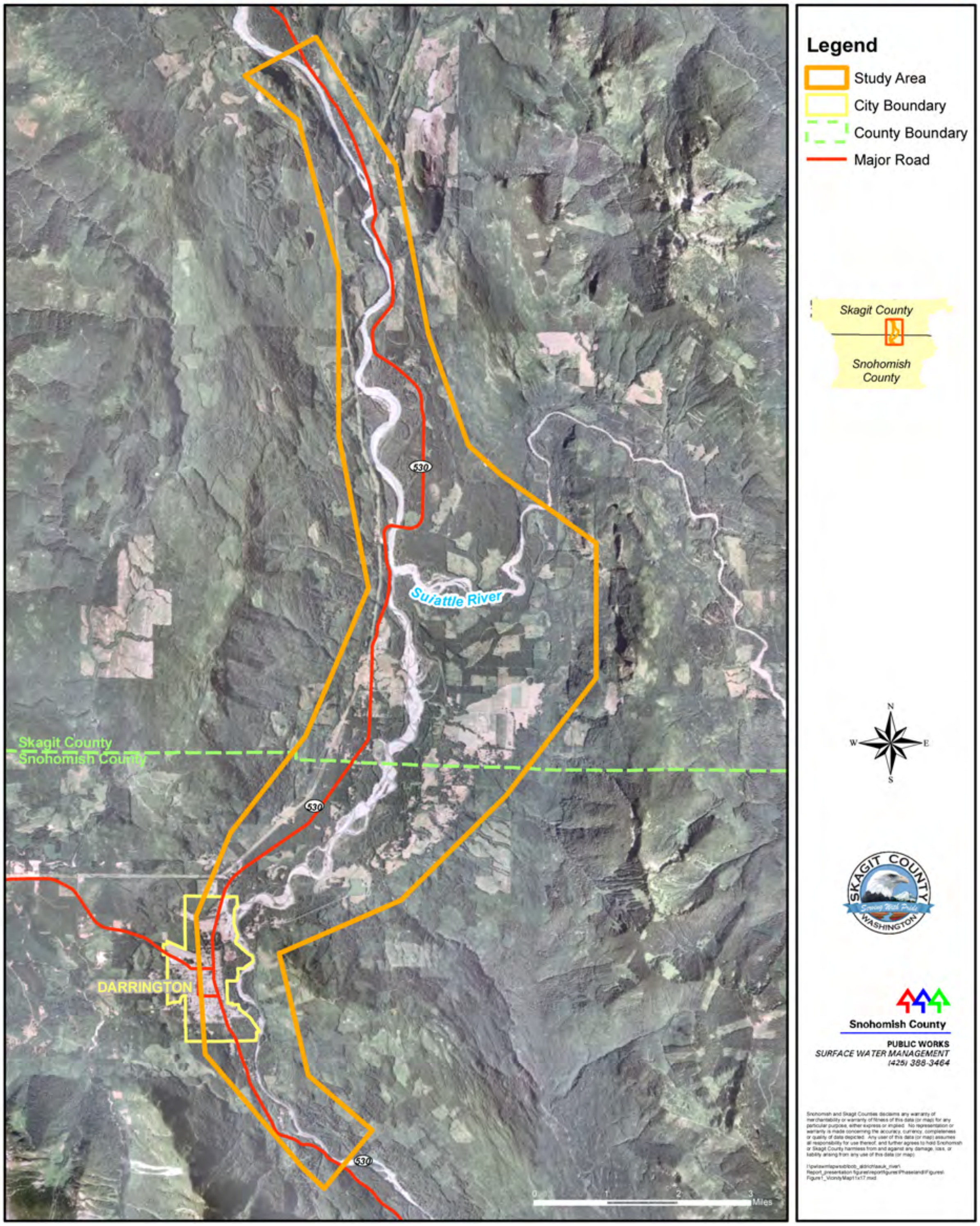
In addition, this plan is also recognized by the FEMA as a mitigation plan to be used to direct post-disaster mitigation measures. In addition to the County's participation in the NFIP, this plan will assist the County in quickly receiving federal funds in the event of a large-scale flood.

1.6 PLAN ORGANIZATION

This document consists of facts regarding the watershed, planning area characteristics, and flood history) and; identified flood/erosion hazard areas; and analysis.

- Chapter 1 – presents the comprehensive plan requirements and the FCAAP requirements the process used to develop this plan; and the organization of the plan.
- Chapter 2 – provides general information on the Sauk River basin and flood patterns in the Sauk River, fundamental information on flooding, hydrology, and sedimentation as well as specific information on Snohomish County’s Flood Warning System.
- Chapter 3 – provides information on applicable federal, state, and local regulations.
- Chapter 4 – provides information on, and an evaluation of Plan Alternatives.
- Chapter 5 – provides information on Recommended Actions.
- Chapter 6 – The Users’ Guide.
- Appendices follow.

Figure 1.1. Sauk River Comprehensive Flood/Erosion Management Plan



2. THE SAUK RIVER BASIN

2.1 OVERVIEW

The watershed of the Sauk is large and complex, formed and altered by the dual action of Continental glaciation, and massive tectonic/volcanic forces. This work encompasses the watershed from a point upstream from the town of Darrington, where a clear demarcation between publicly managed lands and privately owned lands begins. Note: There are various private inholdings in the public lands, but the land is largely managed by the US Forest Service).

This chapter addresses the history, current land uses, ownership, and public infrastructure. Included are discussions on the Mountain Loop Highway, as well as the Wild and Scenic designation of much of the river. Finally, the geographic location, biological and environmental characteristics are discussed. The chapter concludes with a discussion of flooding, current flooding and erosion events, and a short discussion of a flood warning system.

2.2 EARLY SETTLEMENTS

The Sauk River Valley has been home to the Sauk-Suiattle Tribe for centuries. The riches of this glacier-carved, forested area, which included abundant fish, berries, wool (from mountain goats) and edible roots, provided sustenance for their community. Known as the Sah-Ku-Me-Hu, the Sauk-Suiattle were canoe people, who deftly navigated the swift waters of the Sauk, Suiattle, Skagit and Cascade rivers.

The tribe's homelands were the entire drainage area of the Sauk, Suiattle and Cascade rivers. They established an important village at Sauk Prairie, near the confluence of the Sauk and Suiattle rivers. The village consisted of eight traditional cedar longhouses, which were destroyed in 1884 by early settlers.

Today, the Sauk-Suiattle community is located on a 25-acre reservation established in 1983, near the west bank of the Sauk River, south of the confluence of the Sauk and Suiattle rivers. *(Information on the Sauk-Suiattle Tribe was provided by Rebecca Leonard, Tribal Attorney and Scott Morris, Watershed Manager, Sauk-Suiattle representatives)*

The town of Darrington began as a settlement on a gravelly plain set between the Sauk River and the North Fork of the Stillaguamish River, five miles long and a mile-and-a- half wide. Darrington was once referred to as the Burn or Sauk Portage. Until the late 1880s, this area was largely unknown, accessible only by canoe and fish trails that followed the North Fork of the Stillaguamish River from Arlington. In the early 1890s, miners from the East arrived in search of gold in the mountain rivers. The first real wagon road was built around Cicero in 1887. The land was so rough and heavily forested that a portion of the road between Arlington and Oso required a block and tackle to get through. Eventually, a few miners made their way into what is now Darrington and began to settle there.

Around the same time, pioneer James Bedal came to the Darrington area by way of the Skagit River. While exploring the Sauk River Valley, he decided to homestead in Sauk Prairie. There he met Susan Wa-wet-kin, the only daughter of the Sauk-Suiattle chief John Wa-wet-kin. After marrying her, he started a logging business that eventually failed due to the difficulties of moving logs on the river. In the spring of 1891, he moved his wife and baby son to a new homestead claim 18 miles upstream from what is now Darrington. The Bedals and their offspring, Edith Bedal, Jean Bedal Fish, and Harry Bedal, left a lasting legacy in the Darrington area and Snohomish County.

The year 1891 saw the filing of some of the first mining claims in the area. Knute Neste found the Morning Star Lode and the Jumbo Mine on White Horse Mountain, a 7,000-foot white-capped peak three-and-a-half miles outside of Darrington. Other early miners included Loren Robinson, Charles Burns, William Geisler, John Robinson, C. C. Scholman, and George Knudson.

Darrington continued to be an isolated place until the end of the 1890s, with freight coming by canoe or pack horse. In July 1899, the first freight on wheels arrived by way of the North Fork. Less than a year later, miners in the town promised the Seattle & International Railway 75 percent of their ore shipments for the next 15 years, to support the building of a rail line up the Stillaguamish Valley. The railway agreed, and using a new rail-laying machine, completed the 28 mile long extension. Before the work was finished, the Northern Pacific took over the Seattle & International Railway.

The completion of the last bridge into Darrington and the arrival of the first train on May 31, 1901, produced a boom in the town. By now, the town was laid out with 60-foot-wide streets running east and west through the center. Businesses were established. John Montague came up from Oso, and with resident Charles E. Moore, started a general store. The United States Mill began, employing 100 men and cutting 23,000 board feet per day.

Few communities in Snohomish County were as remote as Darrington, which depended entirely on the nearby resources associated with mining and logging. After the 1920s and the arrival of the automobile, the tiny settlement began to grow. In 1922, Standard Oil opened an auxiliary supply station “for gasoline and stove oil” by a stage line *(Cameron, p. 195)*. The following year, silent films came to Darrington at the Rex Movie Theater, though how they were run is speculation. It was not until 1926, when electrical power was brought up river by two local citizens, the Donaldson brothers, that some sort of service was provided. Even that was undependable at first. Some homes had only enough power to run a single light bulb. There was not enough for an electric range.

The formation of the Darrington Improvement Club in 1924 spurred projects such as planting shade trees and putting in street lights. The club cut a road to the elementary school and in 1925 helped form a 29-member volunteer fire department. It raised funds for fire equipment for use on a light truck, bought 20 acres of virgin timber (with the help of the Arlington Commercial Club) for a park, and distributed an illustrated brochure, “Darrington, Where the Trails Begin,” promoting the outstanding recreational opportunities for the average American with their newfound use of the automobile *(Cameron, p. 196).* Fishing, hiking, and camping were the draws to Darrington, activities still cherished today.

The Depression hit hard in Darrington, as it did in many other towns across America. To shore up the economy, the federal government responded with Works Progress Administration (WPA) projects and the opening of the first Civilian Conservation Corps Camp in the area. Camp Darrington opened on May 20, 1933, a half-mile north of the town of the town. It provided work for many local young men. Citizens in the town responded to the economic crisis by creating the Darrington Pioneer’s Cooperative. They “donated their time for credit in order to come together and create jobs, sell firewood for cash, purchase food supplies, build a small sawmill and erect housing” *(Cameron, p. 28)*.

In 1945, Darrington was finally incorporated as a city. Not long after that achievement, it seemed destined to become a ghost town when a couple of the largest logging mills moved out. A lot of the forests had been logged out. Fortunately, another company came in and found work in the winter blow downs. In 1953, logging trucks were busy. Still, the town was on its own, (*Oakley, Janet*, *1/17/09*).

2.3 THE SAUK BASIN TODAY – CURRENT LAND USES AND KEY FEATURES

The Sauk River Basin covers 714 square miles. It has remained relatively undeveloped and sparsely populated, with centers in Darrington and in a few small communities upstream and downstream, particularly along the Bryson Road and Clear Creek area. In 2007, the population of Darrington had only reached 1,613 *(2007 Growth Monitoring Report, Snohomish County Planning and Development Services*) although there are likely that many more people living in the surrounding area.

The chief land use in the Sauk River Basin is forest management, although there is also some agriculture, mining and rural residential housing. Darrington has few businesses and almost no industry that is not timber- related; an industry which has remained economically depressed since the late 1980s.

The Sauk River Basin is well known for its multitude of recreational opportunities. The area is considered a gateway to exceptional hiking, climbing, fishing and camping, as well as the more passive outdoor recreation experiences such as photography and bird-watching.

Darrington's location offers panoramic views of scenic forests and mountains. The main peaks are Three Fingers Mountain (6,854 feet) and Whitehorse Mountain (6,840 feet) to the Southwest, Mount Higgins (5,202 feet) to the northwest, and White Chuck Mountain (6,935 feet) to the east. A large portion of the White Chuck Watershed is designated wilderness and the White Chuck Trailhead is a major portal into the Glacier Peak Wilderness and Glacier Peak climbing routes.

Fishing, either from the bank or from a boat on the Sauk, is a profitable enterprise for several outfitters in Darrington and throughout the valley, as well as a sought-after activity for numerous private fishers. The area is especially known for its excellent fly-fishing. River rafting and boating, both private and commercial is nearly a year-round activity pursued by increasing numbers of boaters.

The US Forest Service has a ranger station in Darrington. They also own and maintain a boat ramp adjacent to the State Highway 530 Bridge on the Sauk, which serves the Suiattle and the upper Sauk rivers. Snohomish County owns and maintains two other boat ramps in the area: an informal ramp at Clear Creek and another at the new Bridge 414 at the Sauk Prairie Road.

Another type of recreation the Darrington area is famous for is the annual bluegrass festival and rodeo. This festival is held in July and draws attendance from all over the Northwest and beyond.

2.3.1 Ownerships / Land Management

Much of the entire Sauk River basin remains in commercially harvestable forestland, owned by federal, state, county and private entities. Different landowners have different management objectives, and the basin is a mix of forests managed for income, habitat/ecological services or recreation and aesthetics. Each of these types of owners has a distinct approach to forest management, and these differences can and do impact the Sauk River.

Within the Sauk River Basin, the majority of forested lands are under federal jurisdiction. Federal forest lands in the basin are part of the Mt. Baker-Snoqualmie National Forest, and the Boulder River and the Glacier Peak Wilderness Areas. The Mt. Baker-Snoqualmie National Forest is managed by the U.S. Forest Service. The wilderness areas are managed by the four federal land management agencies: Bureau of Land Management, Fish and Wildlife Service, Forest Service and National Park Service.

The U.S. Forest Service manages approximately 46% of the land in the basin for multiple uses, including ecological services, recreation, mineral extraction, and other commercial and public uses. This is significant because their regimes do not include clear-cutting for timber harvest purposes.

The Washington State Department of Natural Resources (DNR) manages approximately 24% of the forest lands in the basin, mostly around the Suiattle River and northward. The DNR strives to manage timber lands in a manner that will conserve and enhance the natural systems and resources of their forested state trust lands to produce long-term, sustainable trust income, and environmental and other benefits for the people of Washington. The trust income is distributed annually to counties and state schools, among other entities.

Private forest lands comprise the majority of the forest lands closest to the Sauk River within the study area. Both state and private forest landowners primarily harvest by clear-cutting, which can have an effect on peak floods in the basin.

Within the 100 year floodplain of the Sauk River, land management is also mixture of private and public ownership, with private being more prevalent. Private forestlands comprise the largest percentage of land (43%), followed by State Forest ownership, (26%), private landowners (14%), federal lands (7.5%), government uses (5%), agriculture (1.7%), public forest covers 1.3% of the acreage. Finally, Tribal ownership completes the total at 0.9% of the acreage. Private timber lands on smaller acreages within the floodplain are managed as small woodlots, firewood production, or for logging purposes. Other private timber lands on larger acreages are managed on a large scale for timber production. For example, Hampton Timber, a landowner in this area, manages its holdings for timber production, but tends to rely upon sales for DNR, USFS, and private timber holdings. Bank stabilization projects appear to be the most desired by private landowners, whether they are trying to protect their farmlands, or save a house or cabin from falling into the river.

Agriculture activities are conducted throughout the basin; centered primarily in the fertile floodplain areas of the mainstem Sauk. These operations are declining, as farmers struggle to keep their businesses economically viable. As farms are sold, other more intensive uses may take their place and influence future flooding patterns.

2.3.2 Public Infrastructure

Infrastructure protection is the chief concern for lands owned by government or utilities. As a sparsely populated area, the Sauk River Basin has limited public infrastructure, though what exists has an important impact on the river. Three jurisdictions own and maintain facilities on or near the Sauk River: Snohomish County, Skagit County and the Washington State Department of Transportation (WSDOT).

Snohomish County owns and maintains several road segments from Clear Creek, (the uppermost boundary of this study), to the town of Darrington. Clear Creek Road, near the west side of the river is in an actively eroding, and will likely see either extensive remediation efforts in the future, or abandonment. Clear Creek Road is connected at both ends to the Mountain Loop Highway; and, if abandoned, would create two dead end roads.

On the opposite bank of the river is the North Sauk River Road, which provided access to Sauk Prairie Road for 22 properties and a private timber company. Record rainfalls in October 2003 caused significant erosion, washing out 1,000 feet of this road just outside Darrington. The river now occupies the footprint of the old road. Although the County has been working on a plan to reconstruct a new road with a different alignment, in 2009 the project was still not fully funded.

Further downstream, the Sauk Valley Road crosses the river adjacent to the Hampton Mill. Snohomish County has recently completed this new bridge, which opened the span and removed scour issues for the bridge abutments.

WSDOT owns and operates State Route (SR) 530, a highway which parallels much of the Sauk River from Darrington to the confluence with the Skagit River. SR 530 crosses the river at a point approximately ½ mile downstream of the confluence of the Suiattle and the Sauk rivers, at the Government Bridge.

Further downstream the river is once again bridged to connect SR 530 with the Concrete/Sauk Valley Road. Skagit County owns and maintains this bridge. It appears to be in good shape, although issues with downstream erosion, on the west side of the river, may eventually require protective action on the part of the County.

In several sections of SR 530, the state has had to construct and maintain immense structures designed to protect the highway, testimonial to the power and nature of the river.

2.3.3 The Mountain Loop Highway, a National Forest Scenic Byway

Near Darrington, SR 530 connects with the Mountain Loop Highway, which was classified as a National Forest Scenic Byway in 1991. This historic highway was first established by miners traveling back and forth between mines in 1891, linking Darrington with Granite Falls. Later, it was developed as a road by loggers and members of the Civilian Conservation Corps.

Considered a scenic attraction today, the roadway covers 55 miles through boom-and-bust town sites, abandoned claims, rushing rivers and glacier-clad peaks. The road is paved from Verlot to Barlow Pass, but is graveled to Bedal, upstream from Darrington.

Driving the entire loop is usually limited to late spring through the fall, since snow often lingers at Barlow Pass through late spring. The Mountain Loop Highway attracts many visitors maintained in part by the Forest Service, and in part by Snohomish County.

2.3.4 The Sauk River – Part of the Skagit Wild and Scenic River System

The Skagit Wild and Scenic River System, located in both Skagit and Snohomish counties, was established by Congress in 1978 (Sec 703 of PL 95-625, 11/10/1978.) It includes the following river segments:

- The Skagit River, from the pipeline crossing at Sedro-Woolley, upstream to and including the mouth of Bacon Creek
- The Cascade River, from its mouth to the junction of its North and South Forks
- The South Fork of the Cascade River, to the boundary of the Glacier Peak Wilderness Area
- The Suiattle River, from its mouth to the boundary of the Glacier Peak Wilderness Area at Milk Creek
- The Sauk River, from its mouth to its junction with Elliott Creek
- The North Fork of the Sauk River, from its junction with the South Fork of the Sauk to the boundary of the Glacier Peak Wilderness Area

The National Wild and Scenic Rivers System was created by Congress in 1968 (Public Law 90-542; 16 U.S.C. 1271 et seq.) to preserve certain rivers with outstanding natural, cultural, and recreational values in their natural and free-flowing condition for present and future generations. The Act is focused on safeguarding the special character of these rivers, while also recognizing the potential for their appropriate use and development.

The Skagit Wild and Scenic River System feeds into Puget Sound and features one of the largest bald eagle concentrations in the lower 48 states. Covering over 158 miles, the river system is known for its fisheries resources, rugged canyons, glacier-covered mountains, and densely forested slopes.

The Skagit Wild and Scenic River is located in a unique and beautiful place, largely untouched, yet within a reasonable drive from a number of major metropolitan areas. Development in the Skagit River basin has been increasing since the river was designated in 1978. Management of the Skagit Wild and Scenic River must be consistent with the Wild and Scenic Rivers Act, Section 10(a), which requires the protection and enhancement of the values that caused the Skagit Wild and Scenic River to be included in the National Wild and Scenic Rivers System.

This climate and the Skagit Wild and Scenic River designation have provided abundant opportunities for working in partnership at the watershed scale to fulfill river stewardship responsibilities. The convergence of such abundant natural resources and the growing popularity of the area creates a challenge in balancing use and enjoyment with the long-term sustaining this unique ecosystem. Forest Service river management strategies must push beyond geographical, legal, administrative, political, and personal boundaries to find effective solutions that will sustain the unique features of this river system.

2.4 THE SAUK RIVER - GEOGRAPHIC LOCATION

The Sauk River is located in Snohomish and Skagit counties in northwestern Washington State. At 45 miles in length, the Sauk is the largest free-flowing tributary of the Skagit River, draining an area of the Cascade Range into Puget Sound.

The Sauk River is located in a variety of geographic settings, from steep river-cut valleys flanked by snow-topped ridges to wider valleys carved by large glaciers. The two forks of the Sauk rise in the Cascades in eastern Snohomish County in the Glacier Peak Wilderness and join to form the mainstem of the Sauk at Bedal. From that point, the Sauk flows northwest through a remote section of the Mount Baker-Snoqualmie National Forest to Darrington; meeting several tributaries (the White Chuck River on the east, and Clear Creek on the west) on the way. Continuing north from Darrington, the Sauk meets two other key tributaries, Dan Creek and the Suiattle River, before reaching Rockport.

The Suiattle is a river in its own right, originating from the Suiattle Glacier on the slopes of Glacier Peak in the Cascade Range. The Suiattle joins the Sauk River, north of Darrington, and the Sauk joins the Skagit River at Rockport. The Skagit continues to the west, draining into Skagit Bay, a part of Puget Sound.

Most of the tributaries of the Sauk originate in Wilderness areas, mainly the Glacier Peak and the Henry Jackson Wilderness areas. The fact that the river system emanated from such dramatic and unspoiled settings provided an impetus for its declaration as a Wild and Scenic River. Yet, while the Sauk meanders across the floodplain in and around Darrington, which is surrounded on all sides by private, federal and state timberlands, it is considered only scenic. (Note: There is no difference from an administrative standpoint between a Wild and Scenic Designation, for additional discussion, please refer to Chapter 3.)

2.5 BIOLOGICAL AND ENVIRONMENTAL CHARACTERISTICS

As with the physical resources of the basin, the biological and environmental characteristics of the river are important. Driving many of the processes in the river, sediment is never in short supply, and must be considered both in a physical as well as an environmental sense. The sediment is not a new phenomenon, emanating to a large degree from the slopes of Glacier Peak in the form of lahars. Thus it should be understood that most successful fish species have adapted and flourished under conditions that have waxed and waned for thousands of years.

2.5.1 Fisheries Resources

The Skagit River Basin represents the largest and one of the most unspoiled strongholds of fish and wildlife habitat in the Puget Sound area. Encompassing over 3,100 square miles (8,030 kilometers) of watershed area, the Skagit system is composed of the mainstem Skagit and its tributaries, as well as four secondary river basins: the Baker, the Cascade, the Sauk, and the Suiattle. It includes 80,728 acres (32,670 hectares) of delta, connecting the river to Skagit Bay and Whidbey Basin. The Skagit drainage area includes 2,989 identified streams, covering approximately 4,540 linear miles.

As the largest free-flowing tributary of the Skagit, the Sauk River is important habitat for the Skagit River Basin's anadromous fish populations. The Sauk supports the spawning runs of all five Pacific salmon species (Chinook, Coho, chum, pink and sockeye), summer and winter run steelhead, sea run cutthroat trout, Dolly Varden, bull trout. These include six Chinook stocks (spring, summer, and fall); pink salmon; chum salmon; sockeye salmon; summer and winter run steelhead; sea run cutthroat trout; Dolly Varden, bull trout and char.

Six different stocks of Chinook are present in the Skagit system: Upper Cascade Spring, Suiattle Spring, Upper Sauk Spring, Lower Skagit Mainstem / Tributaries Fall, Upper Skagit Mainstem / Tributaries Summer, and Lower Sauk Summer. *(Skagit River Chinook Recovery Plan, 1995)* The Sauk River Basin includes two independent Chinook salmon populations: the Lower Sauk Summer Chinook and the Upper Sauk Spring Chinook. The Lower Sauk Summer Chinook are those that spawn in the Sauk mainstem and its tributaries (excluding the Suiattle River) downstream of the Darrington bridge. Most of these fish spawn between Darrington and the mouth of the Suiattle River, from September through early October. Lower Sauk Spring Chinook have statistically significant genetic differences from all other Skagit Basin Chinook populations, but they are more similar to other Skagit populations than to Puget Sound Chinook populations.

The Upper Sauk Spring Chinook are those that spawn in the Sauk mainstem and its tributaries, upstream of the Darrington bridge. Most of these fish spawn between the mouth of the White Chuck River and the confluence of the North and South Forks of the Sauk, from late July through early September.

The Suiattle River, tributary of the Sauk and sub-basin, is habitat for an independent spring Chinook population, known as the Suiattle Spring Chinook. Most of these fish spawn from late July through early September. Statistical analysis of all ozyme allele frequency data indicate that

Suiattle Spring Chinook are genetically distinct from all other Skagit Basin Chinook populations, as well as from Spring Chinook produced at Marblemount Hatchery, which were first derived from Suiattle-origin Spring Chinook broodstock (Marshall et al. 1995; Marshall 2001). The Suiattle River Sub-basin is also used extensively for spawning and rearing habitat for bull trout and steelhead.

The White Chuck River, another tributary of the Sauk, originates in the Glacier Wilderness and has a relatively intact drainage basin of older forests of little or no access. This river is known for its high-quality water. It supports Chinook and Coho, a limited amount of pink, sockeye, and sea-run cutthroat and no chum.

As the Sauk flows into the Skagit, the high-quality habitat continues and the Skagit River supports the largest runs of chum and pink salmon in the continental United States. The average annual escapement of chum salmon is 69,000 spawners, and the average annual escapement of pink salmon is 400,000 spawners. The basin also supports sizeable runs of coho salmon, sockeye salmon, and steelhead trout.

The Skagit River also supports the largest population of native char (bull trout and Dolly Varden) in the Puget Sound, and may contain the largest population of bull trout in the state. The native char stock in the lower Skagit River is considered to be “healthy” by the Washington State Department of Fish and Wildlife. The number of bull trout out-migrating from the upper drainage into the Skagit River delta and estuary range is estimated to range from 15,000 to 49,000 juveniles per year.

2.5.2 Riparian Areas

Riparian areas are the narrow strips of land bordering rivers, streams or other bodies of water. Due to their proximity to the water, the plant species and topography in riparian zones differ considerably from those of the adjacent uplands. Although riparian areas may only occupy a corridor throughout a river basin or watershed, these areas have a lot of influence on the overall health of the water body.

Riparian areas provide a number of key ecosystem services, including bank stabilization, fish and wildlife habitat, water storage and release, erosion control, and sediment filtering.

As a relatively unpopulated natural area, riparian areas throughout the Sauk River Basin are relatively intact. The forested areas along the Sauk River, south of Darrington (upstream) are characterized by a coniferous/deciduous overstory dominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and big-leaf maple (*Acer macrophyllum*).

Large coniferous tree species tend to dominate the forest overstory, except in those areas where recent land movement (e.g., landslides, slumping, historic washouts, logging, etc.) has allowed recruitment of deciduous and early-successional tree species.

Downstream from Darrington, this mix continues, although red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and big-leaf maple (*Acer macrophyllum*), tend to dominate the riverbanks in the highly disturbed and braided reaches of the river, most notably from Darrington downstream to the Skagit County Bridge, and from a point approximately three miles upstream from the confluence with the Skagit River.

Decisions regarding the management of these riparian areas should identify and address any potential impacts to the long-standing ecosystem services provided by the native vegetation, including their magnification during flood events.

2.6 PHYSICAL CHARACTERISTICS

In a river basin, the physical characteristics define the nature of the river, a simple fact, yet often underrated. Such physical factors include Topography, Geology, Hydrology, and Climate.

2.6.1 Topography

The Sauk River flows through some dramatic topography. Rugged mountains and wilderness surround the upper Sauk River, leavening into less abrupt ridges and valleys as it meets the Skagit. The glacially-formed valleys have been subjected to numerous eruptions of nearby Glacier Peak, which have given rise to the distinct lahar formations throughout the length of the river.

Glacier Peak is drained on the north and east by tributaries of the Suiattle River, while flows from the southwest and west flow into the White Chuck River. The White Chuck River and the North Fork of the Sauk River meet upstream from Darrington, and form the mainstem Sauk. In this area, the Sauk is relatively steep, with valley walls that sometimes rise directly from the river's edge, leaving little room for meandering. (Figure 1-1) With the steep valley slope, sediments have little opportunity to accumulate, much less form expansive gravel bars.

Immediately adjacent to Darrington, above Darrington Bridge, the slope of the river is at 0.0050; while from the Darrington Bridge to Dan Creek, the slope is 0.0041; and finally, from Dan Creek to the Suiattle, the slope is 0.0027. These slopes, far from gentle, coupled with the immense sediment load from the laharic disposition of the exposed slopes on Glacier Peak, give the river a wild and unpredictable nature borne out by the relatively few dwellings or other infrastructure immediately adjacent to the river.

Downstream, below the bridge, the Sauk gradually flattens, allowing the sediment load to influence the landscape and forcing the river to carve new channels during nearly every flood event. This happens particularly when the Sauk is approaching bankfull, or the two-year flood event. While hardly unexpected, these abrupt and extensive channel changes are not uncommon on the river, particularly downstream from Darrington, and the upstream sediment supply is steady.

With this in mind, any attempts to control this powerful river or stabilize the eroding banks will need to be quite extensive. These actions will also be very expensive and time-consuming in the design, permitting, and construction phases.

2.6.2 Geology

Characteristics of the local and regional geology have a significant impact on watersheds; influencing runoff patterns, sediment sources, channel gradient, hydraulic irregularity, valley form, watershed size and how a stream or river responds to changes in land use and vegetative cover. The modern landscape of most Puget Sound Lowlands, which includes the Sauk River Basin, is underlain primarily by glacial sediments deriving from a period of glacial advance and retreat 18,000-15,000 years ago. These glacial deposits have a wide range of physical properties. Of those properties, permeability and consolidation are the most significant. Permeable sediments permit rapid infiltration and groundwater movement. They also lack cohesion, generating susceptibility to river erosion, migration and accumulation, as well as landslides.

In contrast, other sediments can also be relatively high-density, resulting in cohesive, consolidated deposits that achieve vertical faces forming hard channelization above ground; yet buried beneath the ground, they have a stronger role by allowing for groundwater flow and accumulation.

The interplay between glacial and volcanic activity is strongly represented in the morphology of the Skagit and Sauk river systems, which are representative of those in the broader Puget Lowland. Tectonic forces, (mountain building, uplift, valley creation), have set the scale for this location as well as length of many of west slope Puget Sound rivers, including the Sauk. Because of this relatively uniform Tectonic relationship, these rivers tend to follow a progression of alpine headwaters to confined mountain valleys, to lower gradient lowland valleys, spilling out onto plains. Advance and recession of the major ice sheets also created the north-south trending disposition of the major valleys, including the Sauk.

The geologic setting of watersheds, and of individual stream reaches, will determine what type of channel morphology and habitat features occur under natural conditions, and correspondingly, what restoration or rehabilitation objectives are appropriate and achievable. Yet the influence of geology on rivers and streams is not always straightforward. As a river system evolves, it becomes an agent of geologic change itself, modifying the same landscape that once determined its behavior. Escarpments are incised by gullies and streams; lowlands are filled with alluvium; and the topographic form of the landscape imposed by tectonic, volcanic, and glacial activity becomes modified by patterns of fluvial erosion and deposition along the drainage network. As such, the geomorphology of the Sauk River is strongly influenced by tectonic forces, primarily by the *lahar* flows from Glacier Peak that created the current river planform.

2.6.3 Hydrology

Hydrology in the Sauk River is driven by snowmelt and rainfall. Emanating from high in the Cascades, the main tributaries of the Sauk have varied and distinct headwaters. For example, (71%) of the White Chuck River watershed is designated wilderness, creating a situation where runoff can be expected to remain relatively constant (save for the unknown of long-term climate alterations). In addition, most of the headwaters of the Whitechuck River are the Whitechuck glacier on the flanks of Glacier Peak. Conversely, the headwaters of the South Fork of the Sauk lie in the Henry M. Jackson Wilderness; the Monte Cristo area, (Glacier Basin), a heavily mined area, and the Mt. Baker Snoqualmie National Forest, and though Wilderness designation precludes logging in the Henry M. Jackson Wilderness, this is not true for the rest of the forest land managed by the Forest Service. Thus, we can expect altered hydrologic conditions into the near future, at least until clear-cut units mature. White Chuck mountain, noted for extensive clear-cuts, mining, and roads, provides the flows for Dan Creek, and a host of smaller tributaries. On the north flanks of Glacier Peak, the Suiattle, Ptarmigan, and President glaciers (to name a few), provide flows to the Suiattle, as do others, on the north side of the basin, the most important tributary to the Sauk River. Flows in the Sauk are dominated in the early season by the South Fork melt, and in the latter part of the season, from the Suiattle River flows. The glacial nature of the countless tributaries flowing from Glacier Peak and beyond gives rise to the characteristic milky color of the waters of the mainstem.

2.6.4 Climate

The Sauk River watershed is graced with a relatively mild climate. Typically, climate is mild during the summer, where temperatures tend to run into the 70s, and colder in the winter, where temperatures tend to be in the 30s, with snow not an uncommon site in the surrounding mountains. Winter generally brings 10-15 days of snow, along with significant amounts of rain, fog, foggy rain, and snowy fog. The warmest month of the year is August, with an average temperature maximum of approximately 80 degrees. The coldest month of the year is usually January, with temperatures hovering at 30 degrees.

The average annual rainfall/precipitation is approximately 81 inches, as expected, the winter months tend to be wetter than summer months.

2.6.5 Sauk River Processes

Discussion of many of the physical processes, geomorphic, hydrologic, and to some degree, hydraulic, can be found in Appendix 2 of this document, where the technical analyses are combined to create the risk analysis which forms the basis of this document. The Sauk is a very complex river, with reaches that vary from steep and powerful to flat and meandering. Overshadowing everything is the ultimate process-forming events that emanated from Glacier Peak, vast, pyroclastic forces that created great lahar flows and tephra falls, blanketing the landscape with windborne materials, and creating vast plains of sediment which the river then cut through. Events such as these are relatively recent, some occurring as little as 1800 years in the past, making most of the Sauk a "young" river by most standards.

These characteristics give rise to the unique nature of the Sauk, and explain, to a large degree, the rivers tendency to migrate freely over its floodplain in any given event. This, coupled with extensive floodplain forests, creates a situation where the river not only transports sediments and creates new channels, but also creates large wood jams throughout the floodplain; both in response to, and as a result of, the flood and channel migration regimes.

2.6.6 Sauk River Channel Migration Zone

Because of the highly volatile nature of the Sauk River, much of the floodplain is considered the Channel Migration Zone, (CMZ); although from a regulatory standpoint, the CMZ has not yet been officially delineated. From the information contained in Appendix 2 and 3, it can be seen that the floodplain is relatively confined upstream from the Town of Darrington, but wanders extensively from the Town to the confluence with the Suiattle River, where it becomes somewhat more confined, to where it expands and braids once again approximately two miles upstream from the confluence with the Skagit River.

2.6.7 Historical Record of Flood/Erosion Events

The Federal Emergency Management Agency (FEMA) defines a flood as the inundation of normally dry land resulting from the rising and overflowing of a body of water, and floodplains as land areas along the sides of rivers that become inundated with water during a flood.

Flooding is a natural process that shapes the landscape, provides habitat and creates rich agricultural lands. The most common type of flooding, overbank flooding, occurs when downstream channels receive more rain or snowmelt from their watershed than normal, and the excess overloads the channel and flows out into the floodplain.

Damage from overbank flooding varies, depending on the size of the watershed and its terrain. Mountainous areas, like the Sauk River Basin, have faster moving water, which can have a tremendous impact. Generally, the larger the river, the deeper the flood, and the longer it will last. Yet small watersheds with substantial mountain coverage, flooding can pose significant danger.

Settlements are often established along the banks of rivers, where water, fertile soil and a transportation network are available. However, at certain concentrations, human activities will begin to interfere with natural riverine processes. The built environment creates localized flooding problems outside natural floodplains by altering or confining drainage channels. This increases the flood potential by decreasing the stream's capacity to contain flows and increasing the flow rates downstream.

The history of flooding in Snohomish County is an important part of its identity. Historical records of flooding along the rivers and in the glacial-carved floodplains in Snohomish County date back to the nineteenth century when pioneers first settled in the area, but monetary estimates of the damages are scarce.

Each river basin has unique characteristics that contribute to different levels of flooding and damage. Winter floods inundate most of the County's floodplains every three to ten years. Most flooding in Snohomish County results from "rain on snow" events, i.e., heavy, warm rains that also melt a significant accumulated snow pack. In these storm patterns, a first rainfall saturates the soil and then a second storm causes flooding and property damage. The Upper Skagit River Basin drains the northeast quarter of Snohomish County. A portion of this basin, the Sauk/Suiattle River Sub-basin, drains in northeast Snohomish County. The main tributaries of the Sauk River are the White Chuck River and the Suiattle River, the principal rivers that drain Glacier Peak. From the Suiattle, the Sauk then flows 13 miles north to its confluence with the Skagit River, near Rockport. These rivers do not have levee systems and have a history of channel migration and bank erosion during flood events.

Because of the Wild and Scenic River designation, government entities and private property owners are not allowed to place any type of material along these river banks to mitigate these channel changes and bank erosion. In areas where erosion is severe or drastic channel changes occur, homes and property are many times simply "lost" to the river *(Skagit County Website, 2004).*

The Sauk River itself is a Type 1 stream, with flows that are subject to extremes in fluctuation. U.S. Geologic Survey (USGS) flow data over 79 years of record indicate that Sauk River flows upstream of Darrington have fluctuated from a mean daily flow of 443 cfs to a maximum of 44,000 cfs (river mile 32.5). Downstream of Darrington (river mile 5.4), mainstem flows are higher from increased contributing surface waters. In this area, the Sauk River flows range from 1,080 to 106,000 cfs (USGS Flow Data 2006).

Another form of flooding—flash flooding—is typically caused by slow-moving thunderstorms or heavy rains associated with spring or early summer storm systems. There is a possibility for moderate flash flooding within the County, but only along the County's smaller streams and tributaries In general there has been very little flash flooding in the County, though it is increasing as our climate changes.

Table 2-1 shows available damage estimates from past flooding in the Snohomish, Upper Skagit and Stillaguamish River basins.

2.6.8 Recent Flood Events

Additional information on the larger flood events are seen in Table 2-2.

November 27, 1949 Flood Event

The second highest reading of the White Chuck River gauge was 30,200 cfs, although there is no information about any damage during this event.

December 26, 1980 Flood Event

The greatest flood on record occurred December 26, 1980, when the gauge above the White Chuck River recorded 40,100 cfs. This resulted from a flash flood and destroyed buildings and the road in the Clear Creek area south of Darrington.

March 1997 Flood Event

Heavy flooding caused a 50-foot-wide mudslide that closed both lanes of SR 530, 5 miles west of Oso, and created isolation problems for the City of Darrington

October/November 2003 Flood Event

Flooding on the Sauk, Snohomish and Stillaguamish Rivers in October and November of 2003 caused an estimated $1.6 million in damage to private land and $3.3 million in damage to public property, including roads:

- Heavy flooding along the Sauk River caused the river to swell. Darrington was flooded when large logs floated down the river and plugged culverts *(Seattle Times, Oct. 21, 2003)*.
- The North Cascades National Park suffered about $1.7 million in damage to roads and trails. Damage to other structures was estimated to be $1 million.
- An 850-foot section of the North Sauk River Road was washed out above the right bank of the Sauk River, isolating homes southeast of Darrington.

- White Chuck Road, the 10-mile road accessed off the Mountain Loop south of Darrington, suffered several major breaks.
- Over a 24-hour period on the October 17, 2003 weekend, significant damage was done to roads, bridges, trails and other recreation facilities in the Mount Baker-Snoqualmie National Forest. The damage assessment is expected to exceed $8 million.
- Additional significant losses occurred in drainages south and west of Mount Baker and in the upper reaches of the Skagit River system. The loss of more than 15 popular trails, 20 trail bridges, and the breach of more than 30 miles of the Pacific Crest National Scenic Trail occurred. Also damaged and closed were segments of more than 40 roads and many bridge and bridge abutments due to washouts or mud and rockslides *(USDA, December 2003).*

Table 2-1. Flooding Dollar Loss By River Basin

	Estimated Total Damage ($)		
Date of Flood	**Snohomish River Basin**	**Upper Skagit River Basin**	**Stillaguamish River Basin**
December 1921	—	—	400,000[b]
February 1932	8,460,000[a]	—	—
December 1933	9,900,000[a]	—	—
December 1943	1,660,000[a]	—	—
October 1947	144,000[a]	—	—
February 1951	16,600,000[a]	—	339,000[c]
November 1959	9,900,000[a]	—	272,000[c]
December 1964	4,200,000[a]	—	—
December 1975	42,400,000[a]	—	1,474,000[d]
December 1977	—	—	—
December 1979	—	—	—
November 1986	2,000,000[a]	—	—
November 1990	3,611,000[f]	—	64,700
November 1995	—	—	53,000
February 1996	1,200,000	—	>50,000
November 1999	—	—	—
October 2003	Pending	8,000,000[e]	10,000,000

a. 1989 dollars
b. 1930 dollars
c. 1965 dollars
d. 1975 dollars
e. Estimate applies to Mt. Baker-Snoqualmie Forest
f. Public expenditures only

Table 2-2 lists flood-related federally-declared disasters in Snohomish County.

Table 2-2. Snohomish County Flood-related Federal Disasters

Date	No.	President
December 1964	185	Lyndon B. Johnson
December 1975	492	Gerald R. Ford
December 1977	545	James E. Carter
December 1979	612	James E. Carter
November 1986	784	Ronald W. Reagan
November 1990	883	George H.W. Bush
December 1990	896	George H.W. Bush
November 1995	1079	William J. Clinton
February 1996	1100	William J. Clinton
December 1996	1159	William J. Clinton
March 1997	1172	William J. Clinton
November 2003	1499	George W. Bush

2.6.9 Existing and Proposed Flood Warning Systems and Operations

Currently, there are no existing flood warning systems operating in the Sauk River Basin. There are two operational gages, one just upstream from the confluence of the White Chuck River and the North Fork Sauk, (on the North Fork), and one downstream at Sauk, (downstream from the Skagit County Bridge). There has not been a perceived need for flood warning systems on the Sauk River, from an agency perspective. This may change. With increases in flood frequency and population, there has been an increased awareness of the need for a flood warning system in the basin. There are definite logistics challenges, particularly inherent in the difficulty in transmitting a radio or cell phone signal from the gage sites to a repeater, thence to a warning system.

3. CURRENT REGULATORY ENVIRONMENT OF SAUK RIVER CORRIDOR

3.1 INTRODUCTION

The first question to examine when considering a project or activity to restore, stabilize, clear, or build along the Sauk River should be: "Is your project or activity located within a Special Flood Hazard Area (SFHA), Critical Habitat Area, or within 200 feet of Ordinary High Water?"

This report presents the pertinent regulations and permit processes of Federal, State, and local agencies with jurisdiction in the Sauk River project area in both Snohomish and Skagit counties. The regulations and permits affect flood hazard management, construction of flood control facilities, channel and floodplain restoration projects, land clearing, and other construction activities within the study area. Five general types of potential projects/activities were analyzed for their applicable permit processes. They include stabilize shorelines, restoration/habitat enhancement, construction of structures, land clearing/logging, and emergency work during declared emergency conditions.

This report provides clarification of the regulatory jurisdictions, authorities, and information flow pertinent in the Sauk River Corridor Analysis Project Area. Snohomish County, Skagit County, State, and Federal regulations are presented for each type of project/activity. Local Endangered Species Act (ESA) listings and the Wild and Scenic designation of the Sauk River can add complexity to the permit processes.

3.2 STATE, FEDERAL, AND LOCAL PERMITS AND REGULATORY ASSESSMENT

The permit processes are presented in three formats to provide a guide with varying amounts of details depending upon the needs of the user. The first format is a five page matrix that shows generally which permits may be required for a specific activity, and can be found in Appendix 3. These matrices, show the permit names and the project/activity type. The matrices indicate whether a specific permit type is required or not, whether the permit is part of the coordinated Joint Aquatic Review Permit Application (JARPA), and/or if the permit/review is required by a specific county.

The second format is a series of diagrams showing the applicable permits and how they are related to each other. These figures illustrate the permit/review paths to follow, presenting more details of how these permits/reviews work together. (See Figures 3-1 through 3-5).

The third format lists the details for each of the permits/reviews and applicable regulations that apply to each of the potential project/activities. These are presented in Tables 3-1 through 3-3. This format includes details about the project/activity that would require a permit/review, information on where to obtain the permit from, and the approximate review time and cost.

The Appendices include more complete details and information regarding each of the applicable permits and review processes along with permit forms. The appendices also include a glossary.

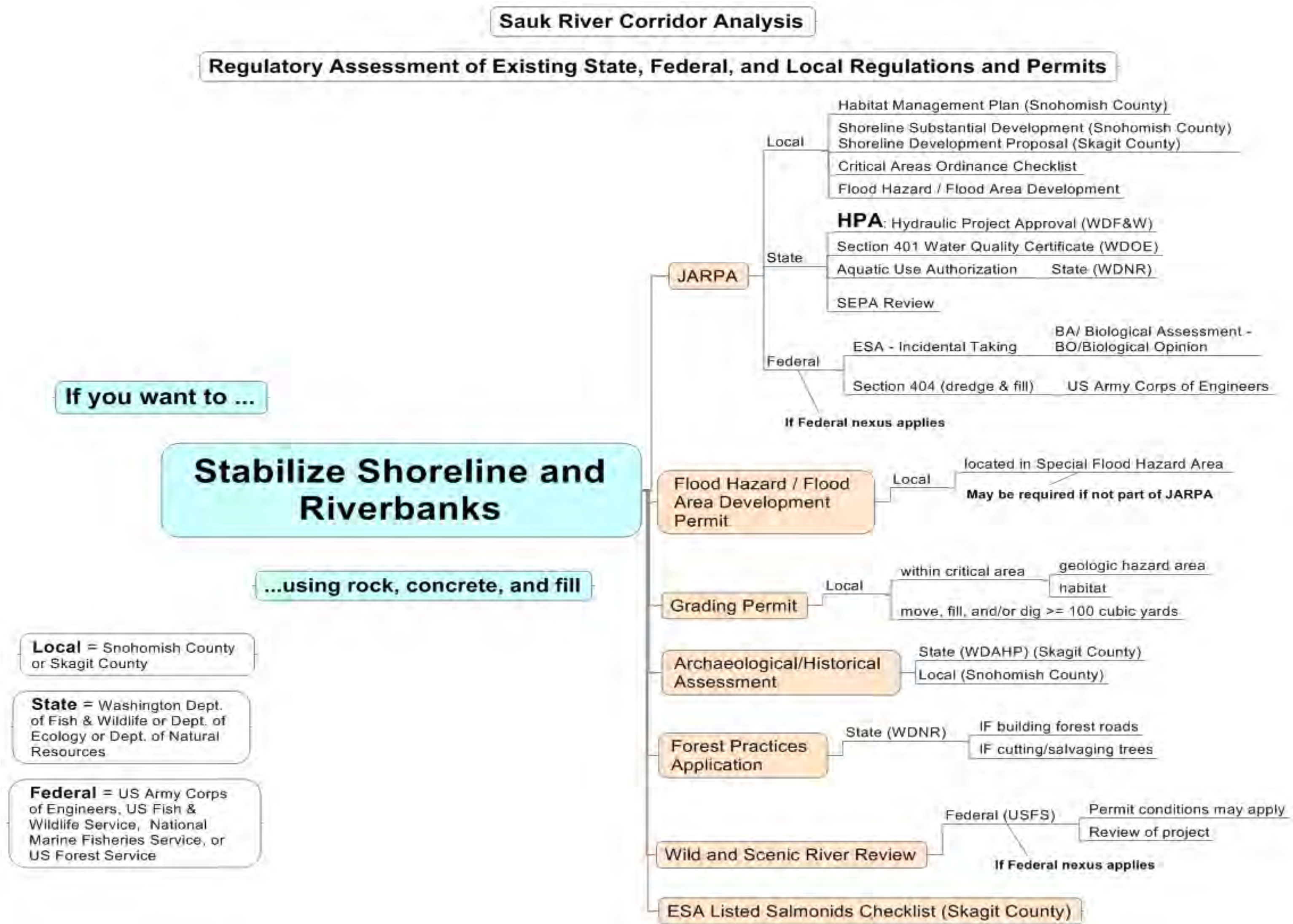


Figure 3-1. Stabilize Shoreline and Riverbanks Potential Permit Flow Chart

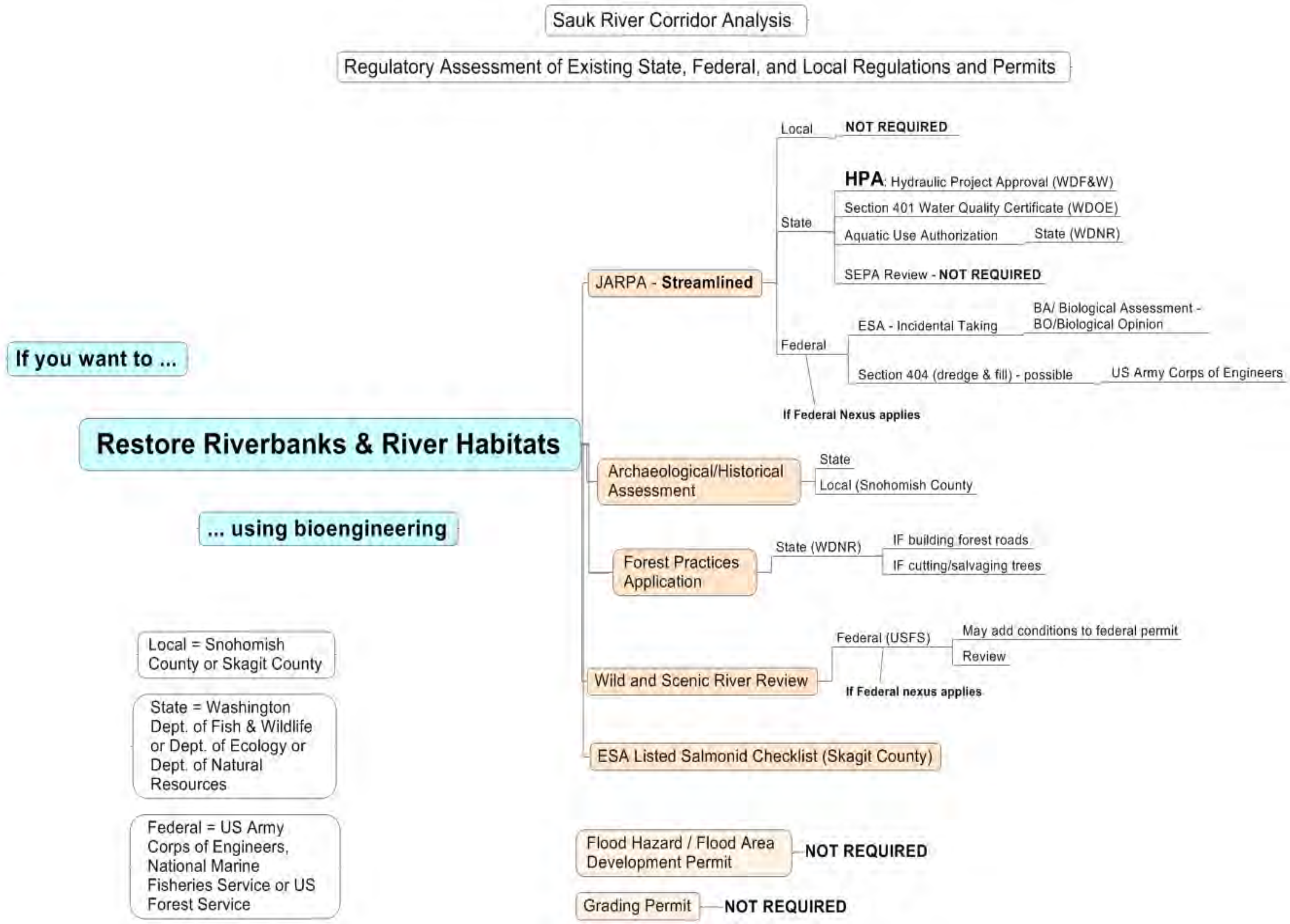


Figure 3-2. Restore Riverbanks and River Habitats Permit Flow Chart

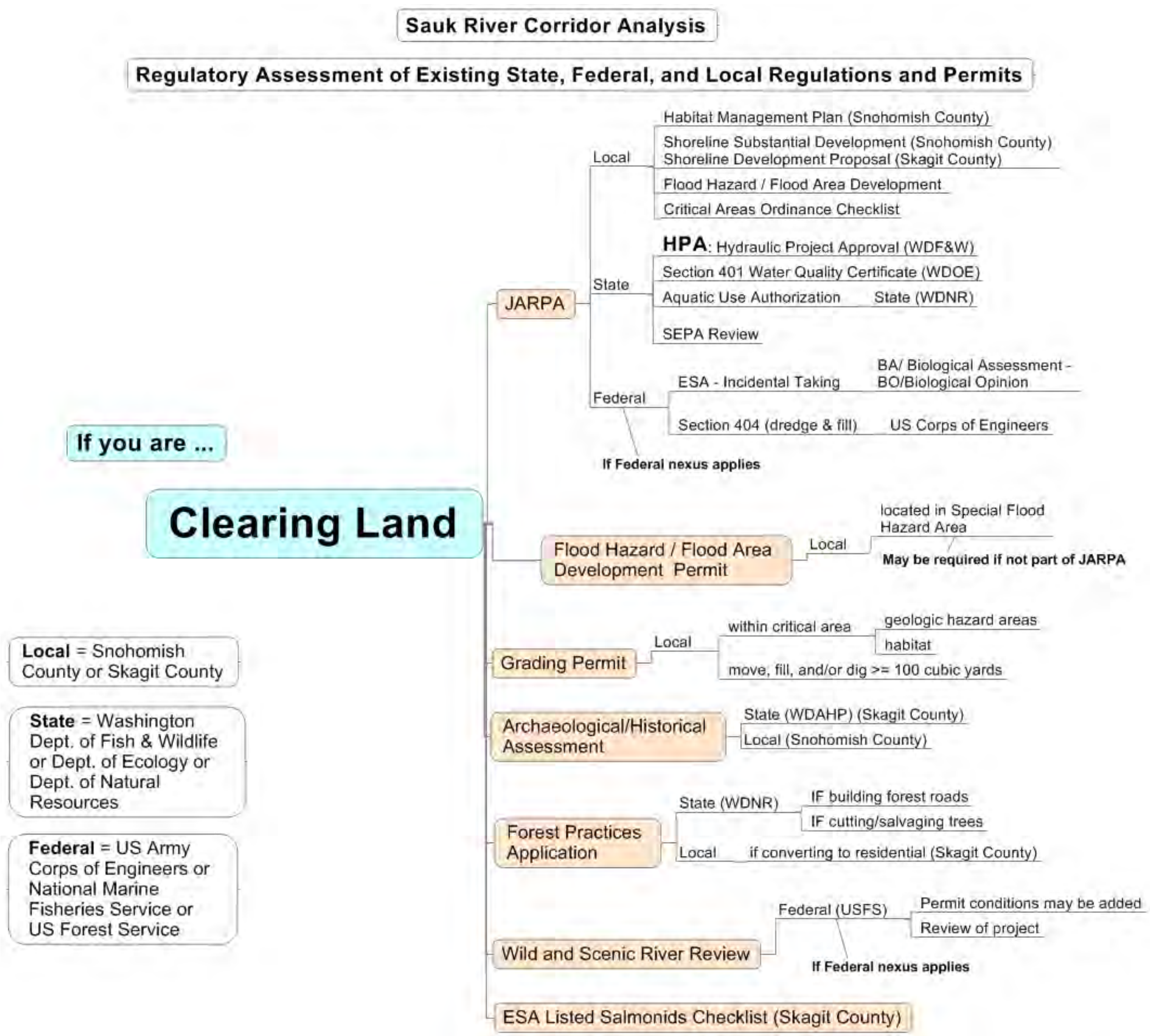


Figure 3-3. Land Clearing Permit Flow Chart

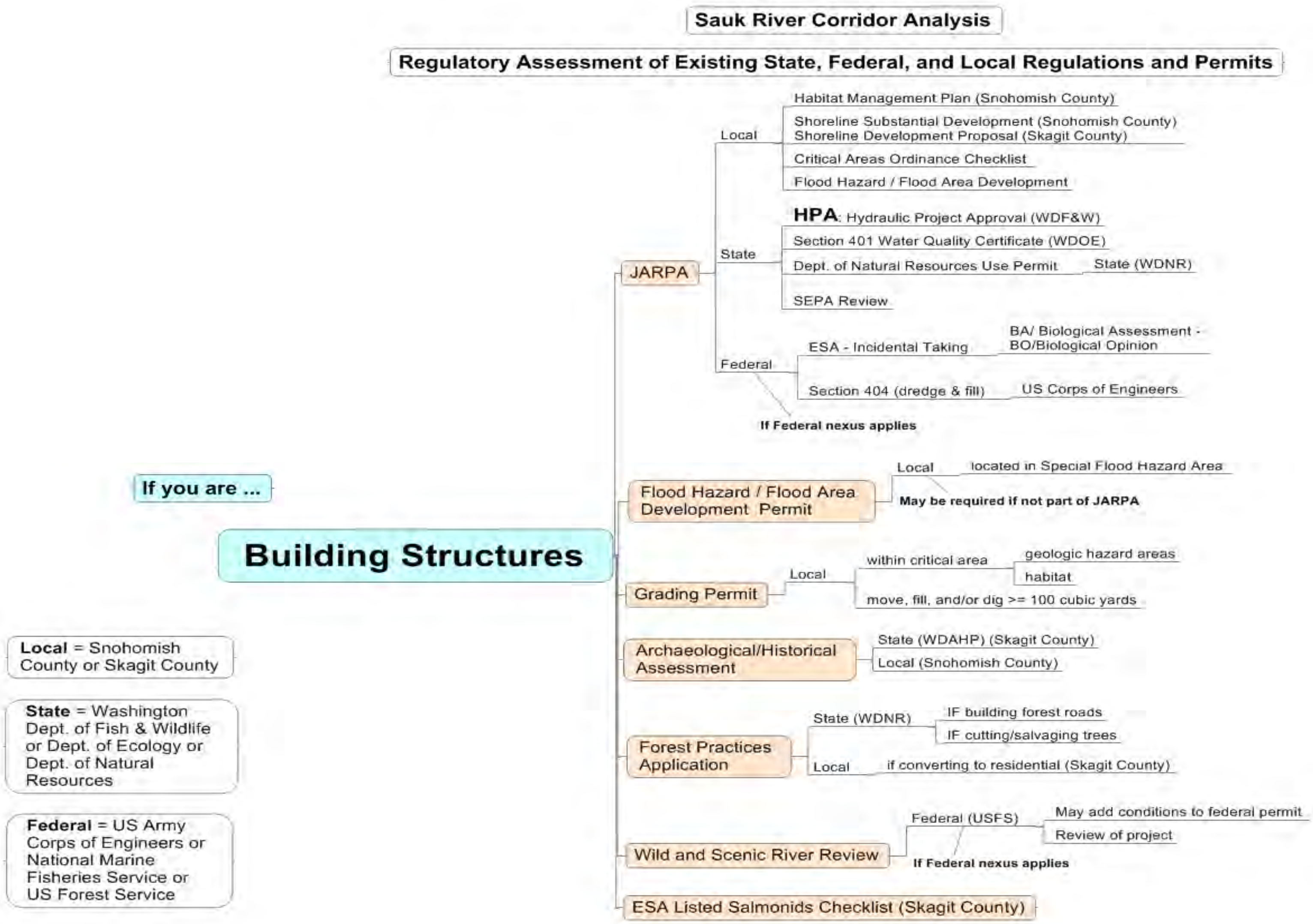


Figure 3-4. Building Structures Permit Flow Chart

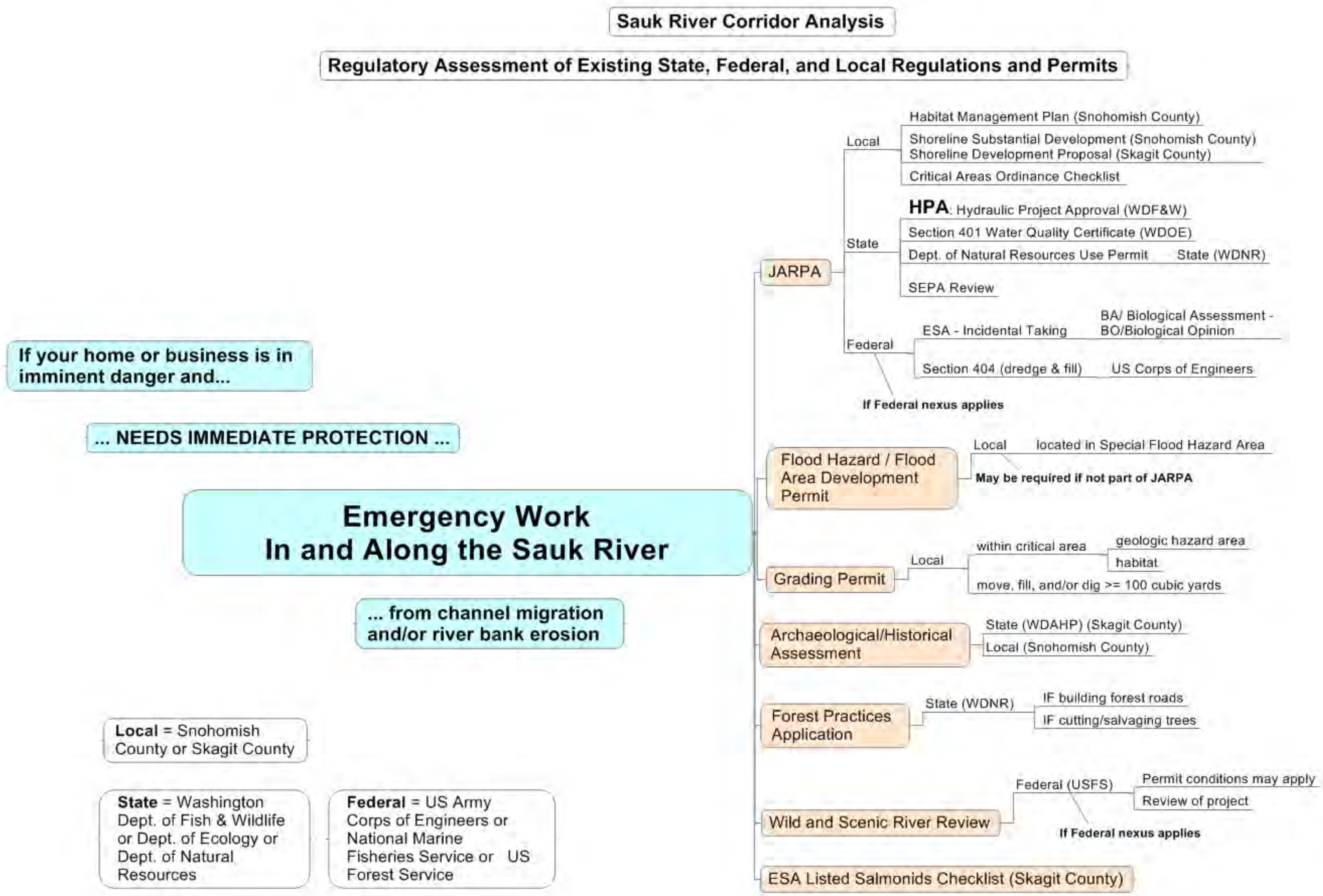


Figure 3-5. Emergency Work Conditions Flow Chart

Detailed Permit Process

Table 3-1

Stabilize Shoreline and Riverbanks
&
Restore Riverbanks and River Habitats

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

If you want to…	If you want to…
STABILIZE SHORELINE AND RIVERBANKS …using rock and fill. Purpose/Effect To protect a structure from channel migration, and/or river bank erosion through the use of rock, concrete, fill, dredging, etc. Permits/Reviews: The following state, local, and federal permits may be required **JARPA – Joint Aquatic Review Permit Application** • Needed if you will be doing any work in or near the water. • Coordinated effort between county, state, and federal agencies that allows you to apply for more than one permit at a time. • Mitigation is usually required for harm done to the environment by the project or activity. • See Appendix 3 for more information. • Permit Cost: Free • Review time: 45 days • Submit to: Washington Dept. of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov	**RESTORE RIVERBANKS AND RIVER HABITATS** …using bioengineering. Purpose/Effect Using bioengineering to restore and/or enhance natural functions of rivers by using natural materials (native plants, tree trunks, dead trees, root wads, degradable fabrics, etc.) in ways that imitate nature to benefit fish and water quality. Permits/Reviews: The following state, local, and federal permits may be required **JARPA – Joint Aquatic Review Permit Application** **STREAMLINED PROCESS FOR FISH HABITAT ENHANCEMENT PROJECT PERMIT** • Needed if you will be restoring an eroded or unstable stream bank using natural materials in ways that benefit fish. • Needed if you will be doing any work in or near the water. • Coordinated effort between county, state, and federal agencies that allows you to apply for more than one permit at a time. • Fish habitat enhancement project waives **some** county and state permits covered in the JARPA, including the SEPA review, speeding up the process. • Mitigation is usually not required because these natural materials are not considered fill. • See Appendix 3 for more information. • Permit Cost: Free • Review time: 45 days

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

The following state, local, and federal permits may be required as part of the **JARPA**: **JARPA** **Local** **Snohomish County** **Habitat Management Plan** • Needed if you will be disturbing plants or earth within 300 feet of a critical area (Sauk River). • See Appendix 3 for more information • Cost: $600 to review plan • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **Shoreline Substantial Development Permit** • May be needed if your project or activity will take place within 200 feet of the shoreline. • See Appendix 3 for more information. • Cost: $450 or more • Review time: Variable	• Submit to: Washington Dept. of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov The following state, local, and federal permits may be required as part of the **JARPA**: **JARPA** **Local** **Snohomish County**: **NOT REQUIRED**

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

• Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **<u>Critical Areas Ordinance Checklist</u>** • Needed if you plan to work within 100 feet of a critical area (Sauk River). • See Appendix3 for more information. • Cost: $250 - $600 for site visit • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **<u>Flood Hazard Development Permit</u>** • Needed if you will be building or grading on land within the 100-year flood zone. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

Skagit County **<u>Shoreline Development Proposal</u>** • Needed if your project or activity is within the 100-year floodplain or within 200 feet of the riverbank. • See Appendix 3 for more information. • Cost: $2,200 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **<u>Critical Areas Ordinance Checklist</u>** • Needed if you plan to work within 200 feet of a critical area (Sauk River). May require a site visit, and a mitigation plan to offset any harm to the critical area or its buffer. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **<u>Flood Area Development Proposal</u>** • Needed if you will be building or grading on land within the 100-year flood zone. Review done by Planning and Development Services when a building or grading permit is submitted. • See Appendix H for more information.	**Skagit County**: **NOT REQUIRED**

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

• Cost: Variable based on type of permit and other factors • Review time: Usually 4-6 weeks • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **<u>State</u>** **<u>HPA – Hydraulic Permit Approval</u>** • Needed if you will be using, diverting, obstructing or changing the natural flow or bed of any fresh water (i.e., Sauk River, tributaries, wetlands, lakes). • See Appendix 3 for more information. • Cost: Free • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov	**<u>State</u>** **<u>HPA – Hydraulic Permit Approval</u>** • Needed if you will be using, diverting, obstructing or changing the natural flow or bed of any fresh water (Sauk River, tributaries, lakes wetlands, etc.). • See Appendix 3 for more information. • <u>Must meet three conditions</u>: o Be part of an approved plan (habitat, comprehensive, flood hazard, etc.) – and – o Be sponsored by an entity in the plan –and – o o Use predominantly bioengineering • Cost: Free • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

Section 401 Water Quality Certification

- Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water.
- See Appendix 3 for more information.
- Cost: Free
- Review time: 1 - 3 months
- Submit to: Washington Department of Ecology (Northwest Region)
  3190 - 160th Ave., SE, Bellevue, WA 98008-5452
  Phone: 425-649-7000
  Website: www.ora.wa.gov

Aquatic Use Authorization

- Needed if your project includes construction, use or activities on submerged land (riverbed) that is owned by the Washington Department of Natural Resources.
- See Appendix 3 for more information.
- Cost: $25, plus a fee to lease the submerged land may apply
- Review time: 6-12 months
- Submit to: Department of Natural Resources, Aquatic Resources Division
  Northwest Region
  919 North Township Street, Sedro Woolley, WA 98284
  Phone: 360-856-3500
  Website: www.dnr.wa.gov/htdocs/aqr

Section 401 Water Quality Certification

- Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water.
- See Appendix 3 for more information.
- Cost: Free
- Review time: 1 - 3 months
- Submit to: Washington Department of Ecology (Northwest Region)
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- Cost: $25, plus a fee to lease the submerged land may apply
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  919 North Township Street, Sedro Woolley, WA 98284
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  Website: www.dnr.wa.gov/htdocs/aqr

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

SEPA – State Environmental Policy Act Review • Needed to determine if your project or activity will cause any environmental harm. • The county that the project is in prepares this review. • Cost: $500 • Review time: variable **Federal** **Endangered Species Act (ESA) Incidental Take Permit** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if your project or activity will harm a threatened or endangered species. A habitat conservation plan must accompany an Incidental Take application. • See Appendix 3 for more information. • Cost: Free to review; habitat conservation plan can cost $10,000 or more • Review time: Variable • Submit to: National Marine Fisheries Service, Northwest Regional Office 7600 Sand Point Way NE, Seattle, WA 98115-0070 Phone: 206-526-6150 Website: www.nwr.noaa.gov	**SEPA – State Environmental Policy Act Review** **NOT REQUIRED** **Federal** **Endangered Species Act (ESA) Incidental Take Permit** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if your project or activity will harm a threatened or endangered species. A habitat conservation plan must accompany an Incidental Take application. • See Appendix 3 for more information. • Cost: Free to review; habitat conservation plan can cost $10,000 or more • Review time: Variable • Submit to: National Marine Fisheries Service, Northwest Regional Office 7600 Sand Point Way NE, Seattle, WA 98115-0070 Phone: 206-526-6150 Website: www.nwr.noaa.gov

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

Section 404 Permit (for dredge/fill work) • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. If your project might affect threatened or endangered species, or their critical habitat, you will be required to submit a Biological Evaluation. • See Appendix 3 for more information. • Cost: $0 - $100 to review; Biological Evaluation can be expensive • Review time: 45 days to 2 years, depending on the type of permit • Submit to: U.S. Army Corps of Engineers, Seattle District Regulatory Branch P.O. Box 3755, Seattle, WA 98124-2255 Phone: 206-764-3495 Website: www.nws.usace.army.mil/PublicMenue/	JARPA **Section 404 Permit (for dredge/fill work)** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. If your project might affect threatened or endangered species, or their critical habitat, you will be required to submit a Biological Evaluation. • See Appendix 3 for more information. • Cost: $0 - $100 to review; Biological Evaluation can be expensive • Review time: 45 days to 2 years, depending on the type of permit • Submit to: U.S. Army Corps of Engineers, Seattle District Regulatory Branch P.O. Box 3755, Seattle, WA 98124-2255 Phone: 206-764-3495 Website: www.nws.usace.army.mil/PublicMenue/
Other Required Permits **Forest Practices Application (State)** • Needed if you will be cutting or removing trees, building a forest road, and/or salvaging standing or fallen (dead) wood for resale or if worth ≥ $5,000. • See Appendix 3 for more information. • Cost: $0 - $1,200 • Review time: 30 days • Submit to: Department of Natural Resources, Forest Practices Division Northwest Region 919 North Township Street, Sedro Woolley, WA 98284 Phone: 360-856-3500 Website: www.dnr.wa.gov/forestpractices/	**Other Required Permits** **Forest Practices Application (State)** • Needed if you will be cutting or removing trees, building a forest road, and/or salvaging standing or fallen (dead) wood for resale or if worth ≥ $5,000. • See Appendix 3 for more information. • Cost: $0 - $1,200 • Review time: 30 days • Submit to: Department of Natural Resources, Forest Practices Division Northwest Region 919 North Township Street, Sedro Woolley, WA 98284 Phone: 360-856-3500 Website: www.dnr.wa.gov/forestpractices/

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

Archaeological/Historical Assessment (State)	Archaeological/Historical Assessment (State)
Skagit County • Obtain assessment from **Washington Department of Archaeology and Historic Preservation (WDAHP).** Needed if you will be disturbing the land you own and thus possibly disturbing or harming archaeological, historic or cultural properties that are protected by the state. Property owners need to send a letter to this department, asking if any cultural resources exist on their property, including a location map, current tax statement and brief summary of the proposed activity. • See Appendix 3 for more information. • Cost: Free to review; archaeological investigation can cost $10,000 or more • Review time: 45-60 days • Submit to: Department of Archaeology and Historic Preservation 1063 South Capitol Way, Suite 106, Olympia, WA 98501 Phone: 360-586-3065 Website: www.daph.wa.gov	**Skagit County** • Obtain assessment from **Washington Department of Archaeology and Historic Preservation (WDAHP).** Needed if you will be disturbing the land you own and thus possibly disturbing or harming archaeological, historic or cultural properties that are protected by the state. Property owners need to send a letter to this department, asking if any cultural resources exist on their property, including a location map, current tax statement and brief summary of the proposed activity. • See Appendix for more information. • Cost: Free to review; archaeological investigation can cost $10,000 or more • Review time: 45-60 days • Submit to: Department of Archaeology and Historic Preservation 1063 South Capitol Way, Suite 106, Olympia, WA 98501 Phone: 360-586-3065 Website: www.daph.wa.gov
Snohomish County • Needed if you will be disturbing the land and thus possibly disturbing or harming known archaeological, historic or cultural properties that are protected by the state. Review is done by the County (Planning and Development Services or Public Works). • See Appendix 3 for more information. • Cost: Free to review; archaeological investigations can cost $10,000 or more • Review time: 45-60 days	**Snohomish County** • Needed if you will be disturbing the land and thus possibly disturbing or harming known archaeological, historic or cultural properties that are protected by the state. Review is done by the County (Planning and Development Services or Public Works). • See Appendix 3 for more information. • Cost: Free to review; archaeological investigations can cost $10,000 or more • Review time: 45-60 days

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

• Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **Wild and Scenic River Review (Federal)** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if you intend to construct a project or work within the riverbed or banks of a Wild and Scenic River (Sauk River as part of Skagit River system), especially channel straightening, diversions, and rock armoring of the shoreline. For any proposed activity that is likely to have adverse impacts on the values of the river system, the Forest Service will work cooperatively the state and local agencies, and landowner(s) to resolve it. The Forest Service may also provide technical assistance to find ways to alleviate or mitigate the potential threat. • Cost: Free • Review time: Variable • Submit to: Skagit WSR Manager:, Mt. Baker Ranger District 810 State Route 20, Sedro-Woolley, WA 98284 Phone: 360-856-5700 Website: www.fs.fed.us/r6/mbs/skagit-wsr/ Darrington Ranger District 1405 Emmens Street, Darrington, WA 98241 Phone: 360-436-1155	• Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **Wild and Scenic River Review (Federal)** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if you intend to construct a project or work within the riverbed or banks of a Wild and Scenic River (Sauk River as part of Skagit River system), especially channel straightening, diversions, and rock armoring of the shoreline. For any proposed activity that is likely to have adverse impacts on the values of the river system, the Forest Service will work cooperatively the state and local agencies, and landowner(s) to resolve it. The Forest Service may also provide technical assistance to find ways to alleviate or mitigate the potential threat. • Cost: Free • Review time: Variable • Submit to: Skagit WSR Manager:, Mt. Baker Ranger District 810 State Route 20, Sedro-Woolley, WA 98284 Phone: 360-856-5700 Website: www.fs.fed.us/r6/mbs/skagit-wsr/ Darrington Ranger District 1405 Emmens Street, Darrington, WA 98241 Phone: 360-436-1155

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

Grading Permit (County)	**Grading Permit (County): NOT REQUIRED**
• Needed if you will be digging, moving, or filling 100 cubic yards or more of rock, soils, or fill in the process of grading, building, or clearing or if your project or activity is within a critical area. **Snohomish County*** • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services* 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS ***Submittal is by appointment only** **Skagit County** • Cost: Based on largest volume of fill or dredge material • Review time: Usually 4-6 weeks • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9491 Website: www.skagitcounty.net	

Table 3-1. Detailed Permit Process: Stabilize Shoreline and Riverbanks & Restore Riverbanks and River

ESA Listed Salmonids Checklist (Skagit County) • Needed to determine if your project or activity will affect any federally-listed endangered or threatened salmonids (salmon or trout). • See Appendix 3 for more information. • Cost: $600 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net	**ESA Listed Salmonids Checklist (Skagit County)** • Needed to determine if your project or activity will affect any federally-listed endangered or threatened salmonids (salmon or trout). • See Appendix 3 for more information. • Cost: $600 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net

Detailed Permit Process

Table 3-2:

Clearing Land
&
Building Structures

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

If you are… **CLEARING LAND**	If you are… **BUILDING STRUCTURES**
Purpose/Effect To harvest timber, grade or clear land, or convert forestland for development purposes. Permits/Reviews: The following state, local, and federal permits may be required **JARPA – Joint Aquatic Review Permit Application** • **Needed if you will be doing any work in or near the water.** • Coordinated effort between county, state, and federal agencies that allows you to apply for more than one permit at a time. • Mitigation is usually required for harm done to the environment by the project or activity. • See Appendix 3 for more information. • Cost: Free to review; site analysis and mitigation design/work can be expensive • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd, Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov	Purpose/Effect Clear land for and construct a new house, garage, shed, bulkhead, etc. Permits/Reviews: The following state, local, and federal permits may be required **JARPA – Joint Aquatic Review Permit Application** • **Needed if you will be doing any work in or near the water.** This is a coordinated effort between county, state and federal agencies that allows you to apply for permits from many government agencies with this single application form. • Mitigation is usually required for harm done to the environment by the project or activity. • See Appendix 3 for more information. • Cost: Free to review; site analysis and mitigation design/work can be expensive • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd, Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

The following county, state and federal permits are covered in the **JARPA**:	The following state, local, and federal permits may be required as part of the **JARPA**:
JARPA **Local** **Snohomish County** **Habitat Management Plan** • Needed if you will be disturbing plants or earth within 100 feet of a critical area (Sauk River). • See Appendix 3 for more information • Cost: $600 to review plan • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **Shoreline Substantial Development Permit** • May be needed if your project or activity will take place within 200 feet of the shoreline. • See Appendix 3 for more information. • Cost: $450 or more • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	**JARPA** **Local** **Snohomish County** **Habitat Management Plan** • Needed if you will be disturbing plants or earth within 100 feet of a critical area (Sauk River). • See Appendix 3 for more information • Cost: $600 to review plan • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **Shoreline Substantial Development Permit** • May be needed if your project or activity will take place within 200 feet of the shoreline. • See Appendix 3 for more information. • Cost: $450 or more • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

<u>Critical Areas Ordinance Checklist</u> • Needed if you plan to work within 100 feet of a critical area (Sauk River). • See Appendix 3 for more information. • Cost: $250 - $600 for site visit • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	**<u>Critical Areas Ordinance Checklist</u>** • Needed if you plan to work within 100 feet of a critical area (Sauk River). • See Appendix 3 for more information. • Cost: $250 - $600 for site visit • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS
<u>Flood Hazard Development Permit</u> • Needed if you will be building or grading on land within the 100-year flood zone. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	**<u>Flood Hazard Development Permit</u>** • Needed if you will be building or grading on land within the 100-year flood zone. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS
Skagit County **<u>Shoreline Development Proposal</u>** • Needed if your project or activity is within the 100-year floodplain or within 200 feet of the riverbank. • See Appendix 3 for more information.	**Skagit County** **<u>Shoreline Substantial Development Permit</u>** • Needed if your project or activity is within the 100-year floodplain or within 200 feet of the riverbank. • See Appendix 3 for more information.

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

• Cost: $2,200 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **Critical Areas Ordinance Checklist** • Needed if you plan to work within 200 feet of a critical area (Sauk River). May require a site visit, and a mitigation plan to offset any harm to the critical area or its buffer. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **Flood Area Development Proposal** • Needed if you will be building or grading on land within the 100-year flood zone. Review done by Planning and Development Services when a building or grading permit is submitted. • See Appendix 3 for more information. • Cost: Variable based on type of permit and other factors • Review time: Usually 4-6 weeks • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net	• Cost: $2,200 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **Critical Areas Ordinance Checklist** • Needed if you plan to work within 200 feet of a critical area (Sauk River). May require a site visit, and a mitigation plan to offset any harm to the critical area or its buffer. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **Flood Area Development Proposal** • Needed if you will be building or grading on land within the 100-year flood zone. Review done by Planning and Development Services when a building or grading permit is submitted. • See Appendix 3 for more information. • Cost: Variable based on type of permit and other factors • Review time: Usually 4-6 weeks • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

State **HPA – Hydraulic Permit Approval** • Needed if you will be using, diverting, obstructing, or changing the natural flow or bed of any fresh water (e.g., Sauk River, tributaries, wetlands). • See Appendix 3 for more information. • Cost: Free • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov **Section 401 Water Quality Certification** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. • See Appendix 3 for more information. • Cost: Free • Review time: 1 - 3 months • Submit to: Washington Department of Ecology (Northwest Region) 3190 - 160th Ave., SE, Bellevue, WA 98008-5452 Phone: 425-649-7000 Website: www.ora.wa.gov **Aquatic Use Authorization** • Needed if your project includes construction, use or activities on submerged land (riverbed) that is owned by the Washington Department of Natural Resources.	**State** **HPA – Hydraulic Permit Approval** • Needed if you will be using, diverting, obstructing, or changing the natural flow or bed of any fresh water (Sauk River, tributaries, lakes wetlands, etc.). • See Appendix 3 for more information. • Cost: Free • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov **Section 401 Water Quality Certification** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. • See Appendix 3 for more information. • Cost: Free • Review time: 1 - 3 months • Submit to: Washington Department of Ecology (Northwest Region) 3190 - 160th Ave., SE, Bellevue, WA 98008-5452 Phone: 425-649-7000 Website: www.ora.wa.gov **Aquatic Use Authorization** • Needed if your project includes construction, use or activities on submerged land (riverbed) that is owned by the Washington Department of Natural Resources. • See Appendix 3 for more information.

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

• See Appendix 3 for more information. • Cost: $25, plus a fee to lease the submerged land may apply • Review time*:* 6-12 months • Submit to: Department of Natural Resources, Aquatic Resources Division Northwest Region 919 North Township Street, Sedro Woolley, WA 98284 Phone: 360-856-3500 Website: www.dnr.wa.gov/htdocs/aqr **<u>SEPA – State Environmental Policy Act Review</u>** • Needed to determine if your project or activity will cause any environmental harm. **The city or county that your project is located in is the 'lead agency' that prepares this review**. • See Appendix 3 for more information. • Cost: $500 • Review time: variable **<u>Federal</u>** **<u>Endangered Species Act (ESA) Incidental Take Permit</u>** • Needed if your project or activity will harm a threatened or endangered species. A habitat conservation plan must accompany an Incidental Take application. • See Appendix 3 for more information. • Cost: Free to review; habitat conservation plan can cost $10,000 or more • Review time: Variable	• Cost: $25, plus a fee to lease the submerged land may apply • Review time*:* 6-12 months • Submit to: Department of Natural Resources, Aquatic Resources Division Northwest Region 919 North Township Street, Sedro Woolley, WA 98284 Phone: 360-856-3500 Website: www.dnr.wa.gov/htdocs/aqr **<u>SEPA – State Environmental Policy Act Review</u>** • Needed to determine if your project or activity will cause any environmental harm. **The city or county that your project is located in is the 'lead agency' that prepares this review.** • See Appendix 3 for more information. • Cost: $500 • Review time: Variable **<u>Federal</u>** **<u>Endangered Species Act (ESA) Incidental Take Permit</u>** • Needed if your project or activity will harm a threatened or endangered species. A habitat conservation plan must accompany an Incidental Take application. • See Appendix 3 for more information. • Cost: Free to review; habitat conservation plan can cost $10,000 or more • Review time: Variable

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

• Submit to: National Marine Fisheries Service, Northwest Regional Office 7600 Sand Point Way NE, Seattle, WA 98115-0070 Phone: 206-526-6150 Website: www.nwr.noaa.gov **<u>Section 404 Permit (for dredge/fill work)</u>** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. If your project might affect threatened or endangered species, or their critical habitat, you will be required to submit a Biological Evaluation. • See Appendix 3 for more information. • Cost: $0 - $100 to review; Biological Evaluation can be expensive • Review time: 45 days to 2 years, depending on the type of permit • Submit to: U.S. Army Corps of Engineers, Seattle District Regulatory Branch P.O. Box 3755, Seattle, WA 98124-2255 Phone: 206-764-3495 Website: www.nws.usace.army.mil/PublicMenue/Menu.cfm?sitename=REG&pagename=mainpage_Permit_Applicant_Info	• Submit to: National Marine Fisheries Service, Northwest Regional Office 7600 Sand Point Way NE, Seattle, WA 98115-0070 Phone: 206-526-6150 Website: www.nwr.noaa.gov **<u>Section 404 Permit (for dredge/fill work)</u>** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. If your project might affect threatened or endangered species, or their critical habitat, you will be required to submit a Biological Evaluation. • See Appendix 3 for more information. • Cost: $0 - $100 to review; Biological Evaluation can be expensive • Review time: 45 days to 2 years, depending on the type of permit • Submit to: U.S. Army Corps of Engineers, Seattle District Regulatory Branch P.O. Box 3755, Seattle, WA 98124-2255 Phone: 206-764-3495 Website: www.nws.usace.army.mil/PublicMenue/Menu.cfm?sitename=REG&pagename=mainpage_Permit_Applicant_Info

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

Other Required Permits	Other Required Permits
	Residential Building Permit (County) **Snohomish County** Needed if you will be constructing a permanent building or an addition to an existing structure. See Appendix 3 for more information. Cost: $16-90 per square foot, or more Review time: 6-8 weeks Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **Skagit County** • Needed if you will be constructing a permanent building or an addition to an existing structure. • See Appendix 3 for more information. • Cost: Based on type of construction and use • Review time: Usually 4-6 weeks • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net/Common/asp/default.asp?d=PlanningAndPermit&c=General&p=main.htm

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

Forest Practices Application (State) • Needed if you will be cutting or removing trees, building a forest road, and/or salvaging standing or fallen (dead) wood for resale or if worth ≥ $5,000. • See Appendix 3 for more information. • Cost: $0 - $1,200 • Review time: 30 days • Submit to: Department of Natural Resources, Forest Practices Division Northwest Region 919 North Township Street, Sedro Woolley, WA 98284 Phone: 360-856-3500 Website: www.dnr.wa.gov/forestpractices/ **Archaeological/Historical Assessment (State)** **Snohomish County** • Needed if you will be disturbing the land and thus possibly disturbing or harming known archaeological, historic or cultural properties that are protected by the state. Review is done by the County (Planning and Development Services or Public Works). • See Appendix 3 for more information. • Cost: Free to review; archaeological investigations can cost $10,000 or more • Review time: 45-60 days • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	**Forest Practices Application (State)** • Needed if you will be cutting or removing trees, building a forest road, and/or salvaging standing or fallen (dead) wood for resale or if worth ≥ $5,000. • See Appendix 3 for more information. • Cost: $0 - $1,200 • Review time: 30 days • Submit to: Department of Natural Resources, Forest Practices Division Northwest Region 919 North Township Street, Sedro Woolley, WA 98284 Phone: 360-856-3500 Website: www.dnr.wa.gov/forestpractices/ **Archaeological/Historical Assessment (State)** **Snohomish County** • Needed if you will be disturbing the land and thus possibly disturbing or harming known archaeological, historic or cultural properties that are protected by the state. Review is done by the County (Planning and Development Services or Public Works). See Appendix 3 for more information. • Cost: Free to review; archaeological investigations can cost $10,000 or more • Review time: 45-60 days • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

Skagit County • Obtain assessment from **Washington Department of Archaeology and Historic Preservation (WDAHP).** • Needed if you will be disturbing the land you own and thus possibly disturbing or harming archaeological, historic or cultural properties that are protected by the state. Property owners need to send a letter to this department, asking if any cultural resources exist on their property, including a location map, current tax statement and brief summary of the proposed activity. • See Appendix 3 for more information. • Cost: Free to review; archaeological investigation can cost $10,000 or more • Review time: 45-60 days • Submit to: Department of Archaeology and Historic Preservation 1063 South Capitol Way, Suite 106, Olympia, WA 98501 Phone: 360-586-3065 Website: www.daph.wa.gov **Wild and Scenic River Review (Federal)** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if you intend to construct a project or work within the riverbed or banks of a Wild and Scenic River (Sauk River as part of Skagit River system), especially channel straightening, diversions, and rock armoring of the shoreline. For any proposed activity that is likely to have adverse impacts on the values of the river system, the Forest Service will work cooperatively the state and local agencies, and landowner(s) to resolve it. The Forest Service may also provide technical assistance to find ways to alleviate or mitigate the potential threat.	**Skagit County** • Obtain assessment from **Washington Department of Archaeology and Historic Preservation (WDAHP).** • Needed if you will be disturbing the land you own and thus possibly disturbing or harming archaeological, historic or cultural properties that are protected by the state. Property owners need to send a letter to this department, asking if any cultural resources exist on their property, including a location map, current tax statement and brief summary of the proposed activity. • See Appendix 3 for more information. • Cost: Free to review; archaeological investigation can cost $10,000 or more • Review time: 45-60 days • Submit to: Department of Archaeology and Historic Preservation 1063 South Capitol Way, Suite 106, Olympia, WA 98501 Phone: 360-586-3065 Website: www.daph.wa.gov **Wild and Scenic River Review (Federal)** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if you intend to construct a project or work within the riverbed or banks of a Wild and Scenic River (Sauk River as part of Skagit River system), especially channel straightening, diversions, and rock armoring of the shoreline. For any proposed activity that is likely to have adverse impacts on the values of the river system, the Forest Service will work cooperatively the state and local agencies, and landowner(s) to resolve it. The Forest Service may also provide technical assistance to find ways to alleviate or mitigate the potential threat.

Table 3-2. Detailed Permit Process: Clearing Land and Building Structures.

• Cost: Free • Review time: Variable • Submit to: Skagit WSR Manager:, Mt. Baker Ranger District 810 State Route 20, Sedro-Woolley, WA 98284 Phone: 360-856-5700 Website: www.fs.fed.us/r6/mbs/skagit-wsr/ Darrington Ranger District 1405 Emmens Street, Darrington, WA 98241 Phone: 360-436-1155 **Grading Permit (County)** **Snohomish County*** • Needed if you will be digging, moving or filling 100 cubic yards (or more) of rock, soil or fill in the process of grading or building, or if your project or activity is within a critical area (Sauk River). • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services* 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS ***Submittal is by appointment only**	• Cost: Free • Review time: Variable • Submit to: Skagit WSR Manager:, Mt. Baker Ranger District 810 State Route 20, Sedro-Woolley, WA 98284 Phone: 360-856-5700 Website: www.fs.fed.us/r6/mbs/skagit-wsr/ Darrington Ranger District 1405 Emmens Street, Darrington, WA 98241 Phone: 360-436-1155 **Grading Permit (County)** **Snohomish County*** • Needed if you will be digging, moving or filling 100 cubic yards (or more) of rock, soil or fill in the process of grading or building, or if your project or activity is within a critical area (the Sauk River). • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services* 3000 Rockefeller Ave, Everett, WA 98201 Phone = 425-388-3311, or 1-800-562-4367, ext. 3311 (*Submittal is by appointment only) Website: www1.co.snohomish.wa.us/Departments/PDS ***Submittal is by appointment only**

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ESA Listed Salmonids Checklist (Skagit County) • Needed to determine if your project or activity will affect any federally-listed endangered or threatened salmonids (salmon or trout). • See Appendix 3 for more information. • Cost: $600 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net	**ESA Listed Salmonids Checklist (Skagit County)** • Needed to determine if your project or activity will affect any federally-listed endangered or threatened salmonids (salmon or trout). • See Appendix 3 for more information. • Cost: $600 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone = 360-336-9401 Website: www.skagitcounty.net

Detailed Permit Process

Table 3-3

Emergency Work In
and
Along the Sauk River

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

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If your home or business is in imminent danger and …
NEEDS IMMEDIATE PROTECTION
…from channel migration and/or river bank erosion

Purpose/Effect:

To protect a <u>structure</u> from immediate danger of channel migration and/or river bank erosion. In general, flooding and other seasonal events that can be anticipated and may occur, but that are not immediately dangerous, are <u>NOT</u> considered emergencies.

Emergency = an <u>unanticipated</u> and <u>imminent</u> threat to public health, safety, or the environment which requires immediate action within a time frame too short to allow full compliance with all regulations and permits.

<u>Permits/Reviews:</u>
Call your county Planning and Development Services Department and WDFW as soon as possible to let them know of your situation and to ask for verbal approval to proceed.

Snohomish County Planning and Development Services
425-388-3311, or 1-800-562-4367, ext. 3311
Washington Department of Fish and Wildlife's local habitat biologist
Mon-Fri 8am-5pm: 425-775-1311; otherwise: 360-902-2537

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<td>
If your home or business is in imminent danger and …
NEEDS IMMEDIATE PROTECTION
…from channel migration and/or river bank erosion

Purpose/Effect:

To protect <u>life</u> or a <u>structure</u> <u>(NOT land)</u> from immediate danger of channel migration and/or river bank erosion. In general, flooding and other seasonal events that can be anticipated and may occur, but that are not immediately dangerous, are NOT considered emergencies.

Emergency = an <u>unanticipated</u> and <u>imminent</u> threat to public health, safety, or the environment which requires immediate action within a time frame too short to allow full compliance with all regulations and permits.

<u>Permits/Reviews:</u>
You MUST contact these <u>four</u> government agencies to <u>get verbal approval</u> to proceed <u>BEFORE</u> you can do any work:

Washington Department of Fish and Wildlife's local habitat biologist
Mon-Fri 8am-5pm: 425-775-1311; otherwise: 360-902-2537
County Planning and Development Services Department
Skagit County: 360-336-9306

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Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

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- **When emergency construction or repair of flood protection structures are necessary, permits for the work (including any mitigation for harm done by the work) shall be obtained in a reasonable time frame after the emergency has passed, or the structure or construction shall be removed.**

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- **Washington Department of Ecology's** shoreline management division
  - 425-649-7000; Northwest Regional Office, Bellevue
  - 360-738-6250; Bellingham Field Office
- **US Army Corps of Engineers** permitting division
  - 206-764-3495
- Approval from one government agency does not equal approval from all government agencies. All agencies requiring permits are listed below.
- **When emergency construction or repair of flood protection structures is necessary, permits for the work (including any mitigation for harm done by the work to the environment) shall be obtained in a reasonable time frame after the emergency has passed, or the structure or construction shall be removed.**

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<u>JARPA</u> – <u>Joint Aquatic Review Permit Application</u>

- Needed if you will be doing any work in or near the water.
- Coordinated effort between county, state, and federal agencies that allows you to apply for more than one permit at a time.
- Mitigation is usually required for harm done to the environment by the project or activity.
- See Appendix 3 for more information.
- Permit Cost: Free
- Review time: 45 days
- Submit to: Washington Dept. of Fish and Wildlife
16018 Mill Creek Blvd., Mill Creek, WA 98012
Phone: 425-775-1311
Website: www.wdfw.wa.gov

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Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

The following state, local, and federal permits may be required as part of the **JARPA**:

JARPA

Local

Snohomish County

Shoreline Substantial Development Permit

- May be needed if your project or activity is within 200 feet of the shoreline.
- Needed if you plan to do more than build a bulkhead to protect a single family home from damage or erosion.
- See Appendix 3 for more information.
- Cost: $450 or more
- Review time: Variable
- Submit to: Snohomish County Planning and Development Services
  3000 Rockefeller Ave., Everett, WA 98201
  Phone: 425-388-3311, or 1-800-562-4367, ext. 3311
  Website: www1.co.snohomish.wa.us/Departments/PDS

Critical Areas Ordinance Checklist

- Needed if you will be working within 300 feet of a critical area (Sauk River).
- See Appendix 3 for more information.
- Cost: $250 - $600 for site visit
- Review time: Variable

The following state, local, and federal permits may be required as part of the **JARPA**:

JARPA

Local

Skagit County

Shoreline Development Permit Proposal

- Needed if your project or activity is within the 100-year floodplain or within 200 feet of the riverbank.
- See Appendix 3 for more information.
- Cost: $2,200
- Review time: Variable
- Submit to: Skagit County Planning and Development Services
  1800 Continental Place, Mt. Vernon, WA 98273
  Phone: 360-336-9401
  Website: www.skagitcounty.net

Critical Areas Ordinance Checklist

- Needed if you will be working within 200 feet of a critical area (Sauk River). May require a site visit, and a mitigation plan to offset any harm to the critical area or its buffer.
- See Appendix 3 for more information.
- Cost: $300
- Review time: Variable

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

• Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **<u>Flood Hazard Development Permit</u>** • Needed if you will be building or grading on land within the 100-year flood zone. • See Appendix 3 for more information. • Cost: $300 • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS **<u>Habitat Management Plan</u>** • May be needed if you will be disturbing plants or earth within 300 feet of a critical area (Sauk River). • See Appendix 3 for more information • Cost: $600 to review plan • Review time: Variable • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave., Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	• Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net **<u>Flood Area Development Proposal</u>** • Needed if you be building or grading on land within the 100-year flood zone. Review done by Planning and Development Services when a building or grading permit is submitted. • See Appendix 3 for more information. • Cost: Variable based on type of permit and other factors • Review time: Usually 4-6 weeks • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

State **HPA – Hydraulic Permit Approval** • Needed if you will be using, diverting, obstructing or changing the natural flow or bed of any fresh water (i.e., Sauk River, tributaries, wetlands, lakes). • See Appendix 3 for more information. • Cost: Free • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov **Section 401 Water Quality Certification** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. • See Appendix 3 for more information. • Cost: Free • Review time: 1 - 3 months • Submit to: Washington Department of Ecology (Northwest Region) 3190 - 160th Ave., SE, Bellevue, WA 98008-5452 Phone: 425-649-7000 Website: www.ora.wa.gov	**State** **HPA – Hydraulic Permit Approval** • Needed if you will be using, diverting, obstructing or changing the natural flow or bed of any fresh water (i.e., Sauk River, tributaries, wetlands, lakes). • See Appendix 3 for more information. • Cost: Free • Review time: 45 days • Submit to: Washington Department of Fish and Wildlife 16018 Mill Creek Blvd., Mill Creek, WA 98012 Phone: 425-775-1311 Website: www.wdfw.wa.gov **Section 401 Water Quality Certification** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. • See Appendix 3 for more information. • Cost: Free • Review time: 1 - 3 months • Submit to: Washington Department of Ecology (Northwest Region) 3190 - 160th Ave., SE, Bellevue, WA 98008-5452 Phone: 425-649-7000 Website: www.ora.wa.gov

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

Aquatic Use Authorization

- Needed if your project includes construction, use or activities on submerged land (riverbed) that is owned by the Washington Department of Natural Resources.
- See Appendix 3 for more information.
- Cost: $25, plus a fee to lease the submerged land may apply
- Review time: 6-12 months
- Submit to: Department of Natural Resources, Aquatic Resources Division
  Northwest Region
  919 North Township Street, Sedro Woolley, WA 98284
  Phone: 360-856-3500
  Website: www.dnr.wa.gov/htdocs/aqr

SEPA – State Environmental Policy Act Review

- Needed to determine if your project or activity will cause any environmental harm.
- The City or County that your project is located in is the 'lead agency' that prepares this review
- Cost: $500
- Review time: variable

Federal

Endangered Species Act (ESA) Incidental Take Permit

- Needed if your project or activity requires a federal permit <u>and/or</u> a Federal nexus has been determined (i.e., federal funds, etc.)
- Needed if your project or activity will harm a threatened or endangered species.

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- Needed to determine if your project or activity will cause any environmental harm.
- The City or County that your project is located in is the 'lead agency' that prepares this review
- Cost: $500
- Review time: variable

Federal

Endangered Species Act (ESA) Incidental Take Permit

- Needed if your project or activity requires a federal permit <u>and/or</u> a Federal nexus has been determined (i.e., federal funds, etc.)
- Needed if your project or activity will harm a threatened or endangered species.

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

• A habitat conservation plan must accompany an Incidental Take application. • See Appendix 3 for more information. • Cost: Free to review; habitat conservation plan can cost $10,000 or more • Review time: Variable • Submit to: National Marine Fisheries Service, Northwest Regional Office 7600 Sand Point Way NE, Seattle, WA 98115-0070 Phone: 206-526-6150 Website: www.nwr.noaa.gov **<u>Section 404 Permit (for dredge/fill work)</u>** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. If your project might affect threatened or endangered species, or their critical habitat, you will be required to submit a Biological Evaluation. • See Appendix 3 for more information. • Cost: $0 - $100 to review; Biological Evaluation can be expensive • Review time: 45 days to 2 years, depending on the type of permit • Submit to: U.S. Army Corps of Engineers, Seattle District Regulatory Branch P.O. Box 3755, Seattle, WA 98124-2255 Phone: 206-764-3495 Website: www.nws.usace.army.mil/PublicMenue/Menu.cfm?sitename=REG&pagename=mainpage_Permit_Applicant_Info	• A habitat conservation plan must accompany an Incidental Take application. • See Appendix 3 for more information. • Cost: Free to review; habitat conservation plan can cost $10,000 or more • Review time: Variable • Submit to: National Marine Fisheries Service, Northwest Regional Office 7600 Sand Point Way NE, Seattle, WA 98115-0070 Phone: 206-526-6150 Website: www.nwr.noaa.gov **<u>Section 404 Permit (for dredge/fill work)</u>** • Needed if you will be conducting any activity, including excavation, that might result in a discharge of dredge or fill material into water. If your project might affect threatened or endangered species, or their critical habitat, you will be required to submit a Biological Evaluation. • See Appendix 3 for more information. • Cost: $0 - $100 to review; Biological Evaluation can be expensive • Review time: 45 days to 2 years, depending on the type of permit • Submit to: U.S. Army Corps of Engineers, Seattle District Regulatory Branch P.O. Box 3755, Seattle, WA 98124-2255 Phone: 206-764-3495 Website: www.nws.usace.army.mil/PublicMenue/Menu.cfm?sitename=REG&pagename=mainpage_Permit_Applicant_Info

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

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Other Required Permits

Grading Permit (County) *

- Needed if you will be digging, moving, or filling 100 cubic yards or more of rock, soils, or fill in the process of grading, building, or clearing or if your project or activity is within a critical area.
- See Appendix B3for more information
- Cost: $300
- Review time: Variable
- Submit to: Snohomish County Planning and Development Services*
3000 Rockefeller Ave, Everett, WA 98201
Phone: 425-388-3311, or 1-800-562-4367, ext. 3311
Website: www1.co.snohomish.wa.us/Departments/PDS

***Submittal is by appointment only**

Forest Practices Application (State)

- Needed if you will be cutting or removing trees, building a forest road, and/or salvaging standing or fallen (dead) wood for resale or if worth ≥ $5,000.
- See Appendix 3 for more information.
- Cost: $0 - $1,200
- Review time: 30 days
- Submit to: Department of Natural Resources, Forest Practices Division Northwest Region
919 North Township Street, Sedro Woolley, WA 98284
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Other Required Permits

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1800 Continental Place, Mt. Vernon, WA 98273
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Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

Archaeological/Historical Assessment (State)	Archaeological/Historical Assessment (State)
Snohomish County • Needed if you will be disturbing the land and thus possibly disturbing or harming known archaeological, historic or cultural properties that are protected by the state. • Review is done by the County (Planning and Development Services or Public Works). • See Appendix 3 for more information. • Cost: Free to review; archaeological investigations can cost $10,000 or more • Review time: 45-60 days • Submit to: Snohomish County Planning and Development Services 3000 Rockefeller Ave, Everett, WA 98201 Phone: 425-388-3311, or 1-800-562-4367, ext. 3311 Website: www1.co.snohomish.wa.us/Departments/PDS	**Skagit County** • Obtain assessment from **Washington Department of Archaeology and Historic Preservation (WDAHP).** • Needed if you will be disturbing the land you own and thus possibly disturbing or harming archaeological, historic or cultural properties that are protected by the state. • Property owners need to send a letter to this department, asking if any cultural resources exist on their property, including a location map, current tax statement and brief summary of the proposed activity. • See Appendix 3 for more information. • Cost: Free to review; archaeological investigation can cost $10,000 or more • Review time: 45-60 days • Submit to: Department of Archaeology and Historic Preservation 1063 South Capitol Way, Suite 106, Olympia, WA 98501 Phone: 360-586-3065 Website: www.daph.wa.gov
Wild and Scenic River Review (Federal) • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if you intend to construct a project or work within the riverbed or banks of a Wild and Scenic River (Sauk River as part of Skagit River system), especially channel straightening, diversions, and rock armoring of the shoreline. For any proposed activity that is likely to have adverse impacts on the values of the river system, the Forest Service will work cooperatively the state and local	**Wild and Scenic River Review (Federal)** • Needed if your project or activity requires a federal permit and/or a Federal nexus has been determined (i.e., federal funds, etc.) • Needed if you intend to construct a project or work within the riverbed or banks of a Wild and Scenic River (Sauk River as part of Skagit River system), especially channel straightening, diversions, and rock armoring of the shoreline. For any proposed activity that is likely to have adverse impacts on the values of the river system, the Forest Service will work cooperatively the state

Table 3-3. Detailed Permit Process: Emergency Work in and along the Sauk River

agencies, and landowner(s) to resolve it. The Forest Service may also provide technical assistance to find ways to alleviate or mitigate the potential threat. • Cost: Free • Review time: Variable • Submit to: Skagit WSR Manager:, Mt. Baker Ranger District 810 State Route 20, Sedro-Woolley, WA 98284 Phone: 360-856-5700 Website: www.fs.fed.us/r6/mbs/skagit-wsr/ Darrington Ranger District 1405 Emmens Street, Darrington, WA 98241 Phone: 360-436-1155	and local agencies, and landowner(s) to resolve it. The Forest Service may also provide technical assistance to find ways to alleviate or mitigate the potential threat. • Cost: Free • Review time: Variable • Submit to: Skagit WSR Manager:, Mt. Baker Ranger District 810 State Route 20, Sedro-Woolley, WA 98284 Phone: 360-856-5700 Website: www.fs.fed.us/r6/mbs/skagit-wsr/ Darrington Ranger District 1405 Emmens Street, Darrington, WA 98241 Phone: 360-436-1155 **ESA Listed Salmonids Checklist (Skagit County)** • Needed to determine if your project or activity will affect any federally-listed endangered or threatened salmonids (salmon or trout). • See Appendix 3 for more information. • Cost: $600 • Review time: Variable • Submit to: Skagit County Planning and Development Services 1800 Continental Place, Mt. Vernon, WA 98273 Phone: 360-336-9401 Website: www.skagitcounty.net

4. EVALUATION OF ALTERNATIVES

4.1 INTRODUCTION

Generally speaking, during the preparation of a Comprehensive Flood/Erosion Management Plan (CFHMP), there are required methodologies for discussing alternatives and criteria and prioritization of alternatives. Because of the nature of the Sauk River, (a *lahar,* capable of drastic channel changes with each bankfull event), and the quantitative nature of the analysis discussed in Chapter Two, the project team approached the discussion of alternatives in a slightly different manner.

Instead of listing scores of alternatives and discussing the merits of each, we met with the Stakeholders group for several four hour sessions which resulted in set series of matrices, (Tables 4-1 through 4-6). On the left hand side of the matrix are the techniques, or treatments, thought to be the most effective at mitigating, or creating a desired outcome. For example, a "Structural Projects Mitigation Toolbox" would include actions that involve the construction of structures to reduce the impact of a hazard. Across the top of the Matrix, each "tool" is compared to a criteria, providing a decision making framework rather than a prioritization

In this way, the various techniques, or alternatives, are tailored to river process, and most importantly, matched to the risk factors quantified in the analyses and presented as the "User's Guide" in Chapter 6. As a result, techniques employed in protection efforts, run through the "filter" of the risk analysis, have an improved chance of succeeding and furthermore, improper or inadequate protection measures might not be selected for further design.

4.2 DISCUSSION OF ALTERNATIVE MATRICES

To set the stage for discussion of the in-depth Users' Guide, (Chapter 6), it is important to understand that the individual segment matrices were developed from the overall "action" matrices, (Tables 4-1 through 4-6) and reflect the risk analysis in each individual segment matrix (Appendix 2). The Alternatives Workshops, a series of Stakeholder workshops, facilitated by Kurt Warber, of Parametrix, Inc., notes were an in-depth discussion of the alternatives, and produced the Action matrices.

An excellent question to begin the discussion with is: Why are alternatives necessary? It is rare, although not unheard of, that there is only one good solution to an issue. Most importantly, alternatives provide stakeholders with structured choices to make trade-offs between benefits and impacts of a particular action. A good set of alternatives meets four key goals:

A. Are linked to goals and objectives

B. Allow Stakeholders to make real choices about key issues.

C. Allow real-life comparisons, (e.g., apples to apples)

D. Helps clarify the decision that needs to be made, rather than confuse.

Some typical strategies for developing alternatives include:

1. An emphasis between different goals and objectives.

For example, if goals and objectives included:

   a. Provide all residents with ice cream
   b. Provide all residents with cheese

But there wasn't enough milk to make both, the Stakeholders would develop one alternative that favored ice cream, and another that favored cheese.

2. Range of costs or resource needs
   a. Provide all stakeholders with a shiny new car.

The alternative might range from "the Camry alternative" to "the Lexus alternative"

3. Distribution of costs and benefits.
   a. Prepare one alternative that emphasized benefits, on that emphasized costs

4. Implementation approaches
   a. Prepare alternatives based on how and where implementation might occur

To be effective, alternatives need to be tied to the plan's objectives. Listed below are the objectives developed by the Stakeholder Committee, and tied directly to the Mission Statement:

4.3 MISSION STATEMENT

Produce and implement a Sauk River Comprehensive Management Plan that balances the need for infrastructure and property protection with the protection and restoration of natural resources and outstanding and remarkable values of the Sauk River; that is acceptable to affected landowners, resource agencies, local tribes, interest groups, and local governments; and is consistent with plan elements required by the State of Washington.

Supporting the mission are the objectives used to prepare the Action Alternatives (Tables 4-1 through 4-6):

A. Collect data and create a database to be used in analysis, both in the current planning effort and in future follow-up activity, that will contribute to a better understanding of natural river processes and the full range of their effects.

B. Describe a range of potential actions to protect property and infrastructure; evaluate their effects on fish and wildlife habitat, as well as their ability to successfully protect property, infrastructure and their land uses.

C. Describe a range of potential actions to protect, restore or enhance fish and wildlife habitat; evaluate their effects on property, infrastructure and other land uses, as well as their ability to successfully protect, restore or enhance fish and wildlife habitat.

D. Develop appropriate management strategies on a reach by reach basis including:

    - The areas and conditions in the corridor that justify high consideration for flood and bank protection.

    - The areas and conditions in the corridor that justify high consideration for habitat protection and restoration.

E. Describe the regulatory environment in the Sauk River Corridor, including:

    1. The statutory authority of state, local, tribal, and federal agencies; and the required permits, pathways and timelines, particularly during locally declared emergencies.

    2. Include recommendations for regulatory improvements.

F. Provide information on the range of assistance programs available for areas impacted by flood and channel migration,

    1. Identify program, access and funding gaps in these programs; and

    2. Develop recommendations to fill these gaps.

G. Develop an understandable outreach and public education program for the Sauk River Management Plan.

4.4 CRITERIA FOR EVALUATION

In order to prepare a "mitigation toolbox," criteria were developed to evaluate the appropriateness of typical tools used in river hazard mitigation plans. The criteria developed by the Stakeholder Committee were:

- Appropriate for Sauk system
- Reduces risk of injury or death for residents
- Reduces risk of residential property damage
- Reduces risk of commercial property damage
- Reduces risk of public infrastructure damage
- Maintains or restores natural river processes that create/maintain habitat features
- Makes property owners "whole" (meaning to meet the varied needs of Sauk property owners)*
- Maintains or enhances aesthetic and recreational values of river
- Clarifies, simplifies and streamlines permitting process
- Reduces risk of habitat damage
- Likelihood of success of a particular tool or technique
- Cost efficiency
- Is it a long-term solution?
- Does it prevent activity that will lead to more future problems?

* Note that this has different implications for residential, agricultural, and timber landowners.

Using these criteria, working groups evaluated the available tools, and also added additional tools that they thought might be more appropriate for the conditions on the Sauk. The starting set of tools included:

4.4.1 Prevention

Government administrative or regulatory actions or processes that influence the way land and buildings are developed and built.

- Comprehensive planning and zoning
- Open space preservation

- Building code development and enforcement
- Transfer of development rights

4.4.2 Property Protection

Actions that involve the modification of existing buildings or structures to protect them from a hazard.

- Maintaining Flood Insurance Policy
- Relocation
- Acquisition
- Retrofitting

4.4.3 Public Education and Awareness

Actions to inform and educate citizens, property owners and elected officials, about the flood and erosion hazards inherent in the Sauk River system and potential ways to mitigate them.

- County and State Departments of Emergency Management
- Public education and outreach programs
- Real estate disclosure
- Flood maps and data
- Library resources
- Outreach projects
- Technical assistance
- Real estate disclosure information
- Environmental education programs

4.4.4 Natural Resource Protection

Actions that, in addition to minimizing hazard losses, also preserve or restore the functions of natural systems.

- Wetlands protection
- Maintenance of riparian corridors
- Best management practices

- Erosion and sediment control

4.4.5 Emergency Services

Actions that protect people and property during or immediately after a disaster or hazard event. Services include warning systems, emergency response services and protection of critical facilities.

- Critical facilities protection
- Emergency response services
- Hazard threat recognition
- Hazard warning systems (community sirens, NOAA weather radio, websites)
- Health and Safety Maintenance
- Post disaster mitigation, cleanup assistance

4.4.6 Structural Projects

Actions that involve the construction of structures to reduce the impact of a hazard.

- Bank stabilization

4.5 THE MATRIX

The Stakeholder's evaluation was documented in a matrix, with the tools being evaluated for their effectiveness in meeting the criteria developed earlier. The evaluation of the tool was qualitative, and included a range of:

"– –" Has a strong negative outcome for the criteria
"–" Has a negative outcome for the criteria
"0" Has no impact for the criteria
"+" Has a positive outcome for the criteria
"++" Has a strong positive outcome for the criteria

Tables 4-1 through 4-6 were developed to rate the tools, and are included below:

Table 4-1. Structural Projects Mitigation Toolbox: Actions that involve the construction of structures to reduce the impact of a hazard.

	Appropriate for Sauk System	Reduces risk of injury or death for residents	Reduces risk of residential property damage	Reduces risk of commercial property damage	Reduces risk of public infrastructure damage	Maintains or restores river processes that create/maintain habitat features	Makes owners whole	Maintains or enhances aesthetic & recreational values of river	Clarifies /simplifies/ streamlines permitting process	Reduces risk of habitat damage	Likelihood of success	Cost efficiency	Long – term solution	Prevents similar problems in the future
Rock	-	+	+	+	+	--	**O**	--	--	-	**O**	**O**	-	-
Bypass	+	+	+	+	+	**O**	+	**O**	-	**O**	-	**O**	**O**	**O**
Bio Engineering	++	+	+	+	+	**O**	+	**O**	++	**O**	++	+	+	+

	VOLATILE	SIGNIFICANT	HIGH
Rock	--	--	-
Bypass	**O**	**O**	**O**
Bio Engineering	**O**	+	++

Key:

-- Has a strong negative outcome for the criteria

- Has a negative outcome for the criteria

O Has no impact for the criteria

+ Has a positive outcome for the criteria

++ Has a strong positive outcome for the criteria

Table 4-2. Natural Resources Protection and Enhancement: Actions that, in addition to minimizing hazard losses also preserve or restore the functions of natural systems.

	Appropriate for Sauk System	Reduces risk of injury or death for residents	Reduces risk of residential property damage	Reduces risk of commercial property damage	Reduces risk of public infrastructure damage	Maintains or restores river processes that create/maintain habitat features	Makes owners whole	Maintains or enhances aesthetic & recreational values of river	Clarifies /simplifies/ streamlines permitting process	Reduces risk of habitat damage	Likelihood of success	Cost efficiency	Long – term solution	Prevents similar problems in the future
Off channel habitat protection	++	++	++	++	++	++	**O**	**O**	**O**	++	**N/A**	**N/A**	**N/A**	**N/A**
Hardened bank stabilization	**O**	--	--	--	--	--	+	**O**	--	--	**N/A**	**N/A**	**N/A**	**N/A**
Bioengineered banks stabilization	+	+	+	+	+	+	+	+	+	+	**N/A**	**N/A**	**N/A**	**N/A**
Large woody debris	+	+	+	+	+	+	+	**O**	+	**O**	**N/A**	**N/A**	**N/A**	**N/A**
Floodplain roughing	+	+	+	+	+	+	+	+	+	**O**	**N/A**	**N/A**	**N/A**	**N/A**

	VOLATILE	SIGNIFICANT	HIGH
Off channel habitat protection	++	+	+
Hardened bank stabilization	--	-	-
Bioengineered banks stabilization	O O	O	O
Large woody debris	O	O	+
Floodplain roughening	O	O	+

Key:

--	Has a strong negative outcome for the criteria
-	Has a negative outcome for the criteria
O	Has no impact for the criteria
+	Has a positive outcome for the criteria
++	Has a strong positive outcome for the criteria

Table 4-3. Emergency Services: Actions that protect people and property during and immediately after a disaster or hazard event. Services include warning systems, emergency response services, and protection of critical facilities.

	Appropriate for Sauk System	Reduces risk of injury or death for residents	Reduces risk of residential property damage	Reduces risk of commercial property damage	Reduces risk of public infrastructure damage	Maintains or restores river processes that create/maintain habitat features	Makes owners whole	Maintains or enhances aesthetic & recreational values of river	Clarifies /simplifies/ streamlines permitting process	Reduces risk of habitat damage	Likelihood of success	Cost efficiency	Long – term solution	Prevents similar problems in the future
Critical facility protection	**Y**	+	**?**	++	++	++	**O**	**O**	**O**	++	**N/A**	**N/A**	**N/A**	**N/A**
Emergency response services	**Y**	+	**?**	--	--	--	+	**O**	--	--	**N/A**	**N/A**	**N/A**	**N/A**
Hazard threat recognition	**Y**	+	**O-+**	+	+	+	+	+	+	+	**N/A**	**N/A**	**N/A**	**N/A**
Hazard warning system	**Y**	+	+	+	+	+	+	**O**	+	**O**	**N/A**	**N/A**	**N/A**	**N/A**
Health & safety maintenance	**Y**	+												
Post disaster mitigation	**Y**	+	+	+	+	+	+	+	**O**	+	+	+	+	+

Note: Emergency services were clearly an appropriate part of the mitigation package, but the group working on this section felt that the tools needed more specificity to really evaluate whether they would work for the Sauk and adjacent landowners.

	VOLATILE	SIGNIFICANT	HIGH
Critical facility protection	++	+	+
Emergency response services	++	+	+
Hazard threat recognition	O	O	O
Hazard warning system	++	++	++
Health & safety maintenance	O	O	O
Post disaster mitigation	+	+	+

Key:

--	Has a strong negative outcome for the criteria
-	Has a negative outcome for the criteria
O	Has no impact for the criteria
+	Has a positive outcome for the criteria
++	Has a strong positive outcome for the criteria

Table 4-4. Prevention: Government administrative or regulatory actions or processes that influence the way land and buildings are developed and built.

	Appropriate for Sauk System	Reduces risk of injury or death for residents	Reduces risk of residential property damage	Reduces risk of commercial property damage	Reduces risk of public infrastructure damage	Maintains or restores river processes that create/maintain habitat features	Makes owners whole	Maintains or enhances aesthetic & recreational values of river	Clarifies /simplifies/ streamlines permitting process	Reduces risk of habitat damage	Likelihood of success	Cost efficiency	Long – term solution	Prevents similar problems in the future
Planning & Zoning	+	+	+	+	+	+	+	+	+		+	**O**	+	++
Open space preservation	++	+	+	+	+	++	+	++	+		**O**	+	+	+
Building code development & enforcement	+													
*Transfer of development rights	++	++	++	++	++	++	++	++	++		++	++	++	++
Shoreline/ Environmental Review	++	**O**	**O**	**O**	**O**	++	**O**	++	+		**O**	**O**	**O**	+
*Easement purchase	++	++	++	++	++	++	++	++	++		++	++	++	++

	VOLATILE	SIGNIFICANT	HIGH
Planning and zoning	++	+	+
Open space preservation	++	++	++
Building code development & enforcement	++	++	++
Transfer of development rights	++	+	+
Shoreline/Environmental Review	++	++	+
Easement Purchase	++	++	++

Key:

--	Has a strong negative outcome for the criteria
-	Has a negative outcome for the criteria
O	Has no impact for the criteria
+	Has a positive outcome for the criteria
++	Has a strong positive outcome for the criteria

Table 4-5. Public Education and Awareness: Actions to inform and educate citizens, elected officials, and property owners about the hazards and potential ways to mitigate them.

	Appropriate for Sauk System	Reduces risk of injury or death for residents	Reduces risk of residential property damage	Reduces risk of commercial property damage	Reduces risk of public infrastructure damage	Maintains or restores river processes that create/maintain habitat features	Makes owners whole	Maintains or enhances aesthetic & recreational values of river	Clarifies /simplifies/ streamlines permitting process	Reduces risk of habitat damage	Likelihood of success	Cost efficiency	Long – term solution	Prevents similar problems in the future
Flood maps & data	++	+	+	+	O	+	O	+	O	+	+	+	+	++
Environmental education (students)	++	+	+	+	O	+	O	+	O	+	+	+	+	+
Real estate disclosure	++	O	++	O	O	O	O	O	O	O	+	O	+	+
Hazard information centers (website, library, Forest Service	++	+	+	+	O	+	O	+	O	+	+	+	+	+
Tech. assistance/ Permitting & Design	++	+	++	O	O	++	O	+	++	+	++	+	+	++
Public education & outreach program	++	+	+	+	O	+	O	+	O	+	+	+	+	+

	VOLATILE	SIGNIFICANT	HIGH
Flood maps & data	++	++	++
Environmental education (students)	O	O	O
Real estate disclosure	++	++	+
Hazard information centers	+	+	+
Tech. assistance/ Permitting & Design	++	++	++
Public education & outreach program	+	+	+

Key:

--	Has a strong negative outcome for the criteria
-	Has a negative outcome for the criteria
O	Has no impact for the criteria
+	Has a positive outcome for the criteria
++	Has a strong positive outcome for the criteria

Table 4-6. Property Protection: Actions that involve the modification of existing buildings or structures to protect them from a hazard or removal from the hazard area.

	Appropriate for Sauk System	Reduces risk of injury or death for residents	Reduces risk of residential property damage	Reduces risk of commercial property damage	Reduces risk of public infrastructure damage	Maintains or restores river processes that create/maintain habitat features	Makes owners whole	Maintains or enhances aesthetic & recreational values of river	Clarifies /simplifies/ streamlines permitting process	Reduces risk of habitat damage	Likelihood of success	Cost efficiency	Long – term solution	Prevents similar problems in the future
Relocation	+	**O**	+	+	++	+	+	**O**	**N/A**	+	+	**?**	**O-+**	**N/A**
Acquisition	**Agree to disagree**													
Retrofitting	--													
Flood Insurance	--													
Land swap	+	**O**	++	++	+	++	+	+	**N/A**	++	++	**?**	++	**N/A**
Depends on specific proposals It depends on risk rating														

	VOLATILE	SIGNIFICANT	HIGH
Relocation	O	++	++
Acquisition	++	++	++
Retrofitting	O	O	O
Flood Insurance	++	+	+
Land swap	++	++	++

Key:

--	Has a strong negative outcome for the criteria
-	Has a negative outcome for the criteria
O	Has no impact for the criteria
+	Has a positive outcome for the criteria

4.6 FINAL ALTERNATIVES DEVELOPMENT WORKSHOP

Following the initial "tool box" workshop, March, 2008, the final two alternatives development workshops for the Sauk river Erosion/Flood Hazard Stakeholder committee were held in June and July, 2008. Originally scheduled as a single workshop, the alternatives development section of the committee's work was broken into two workshops to better accommodate participants' schedules and allow some work to be completed between workshops.

During Workshop 1, the committee had developed an Erosion/Flood Hazard Mitigation Toolbox, (Tables 4-1 through 4-6), as a framework to evaluate the expected effectiveness of typical mitigations strategies.

During the final two workshops committee participants applied the toolbox of potential hazard reduction activities developed in Workshop 1 to real segments of the river. Some of the questions explored were:

1. How does the relative risk rating of the river segment affect the potential tools for hazard mitigation?
2. Does adjacent land use interact with the relative dynamism of a river segment to affect the potential success of the tools for hazard mitigation?
3. Would modification of river functions—for example bank stabilization or bar management—be considered as a tool for maintaining or enhancing river habitat function in anything other than a mitigation situation?

Workshop 2 began with an overview of the alternative development process, and then introduced an exercise to begin applying the toolbox of tools that the group worked on earlier.

Based on the outcomes of Workshop 1, the tools that the group believed made sense for the Sauk included a smaller group of options than the original list. Each working group generally agreed that the majority of tools in the original list were focused on reducing flood hazards, rather than erosion hazards. While flooding is an issue for many parts of the Sauk, it is less difficult to manage than the erosion hazard.

The following revised lists include the top scoring tools, and a summary of the discussion that supported the selection of tools that remained on the list:

4.6.1 Prevention

Government administrative or regulatory actions or processes that influence the way land and buildings are developed and built.

- Comprehensive planning and zoning
- Open space preservation
- Building code development and enforcement
- Transfer of development rights

The group working on this set of tools had the general sense that the existing regulatory framework was adequate, but that enforcement was not always consistent or effective. Permit streamlining was also suggested as a way to assist property owners through the overlapping and complex regulatory environment surrounding building structures adjacent to the river or making modifications to the riverbank.

4.6.2 Property Protection

Actions that involve the modification of existing buildings or structures to protect them from a hazard or removal from the hazard area to eliminate future damage.

- Maintenance of Flood Insurance
- Relocation
- Acquisition
- Retrofitting

The group working on this section did not feel that the range of tools available for property protection provided many good options to manage the specific concerns for properties adjacent to the Sauk. Relocation has been used in some locations with success, however it is expensive and depending on the available property may not be a long-term solution. Acquisition is a tool that has also been used in the Sauk, but there was a concern about how much acquisition would be required to be an effective solution to issues along the Sauk, given how many properties could be influenced by erosion and river movement. Retrofitting and flood insurance are important components of a program to manage flood damage, but are not as effective for managing erosion risk.

4.6.3 Public Education and Awareness

Actions to inform and educate citizens, elected officials, and property owners about the hazards and potential ways to mitigate them.

- Hazard information centers
- Public education and outreach programs
- Flood maps and data
- Library resources
- Outreach projects
- Technical assistance
- Real estate disclosure information
- Environmental education programs (focused on schools)

The group working on this section generally felt that public awareness programs were important. To be effective there needs to be a way to get the attention of newcomers and effectively keep up communication with long-term residents. The group suggested adding a disclosure to title documents to ensure that prospective purchasers and lenders understood the implications of purchasing property near the Sauk. While there are existing disclosure requirements for real estate agents, the group had the sense that they are often not followed. A question related to title disclosures wondered what would be used as the boundary to delineate a risk zone related to the disclosure requirements? The conversation also recognized that a line separating properties at risk from those that aren't may also need to be established for other hazard management activities –for example TDR program eligibility areas or buyout eligibility areas.

4.6.4 Natural Resource Protection

Actions that minimizes flood hazard losses, and preserve or restore the functions of natural systems.

- Off-channel habitat protection
- Bioengineered bank stabilization
- Large woody debris placement
- Floodplain roughening

The group working on this section believed that most of the natural resource options included in the original toolkit were focused on flood control, and would not have much value for erosion hazard management in the Sauk system. Tools that might be appropriate for the Sauk included; the protection of off-channel rearing habitat; minimal-impact bank stabilization projects where necessary, to protect adjacent properties; selective use of large woody debris—possibly including management of jams that form from the wood currently in the system—and floodplain roughening to reduce velocity in erosion-prone areas.

Broader discussion on this topic with the whole group addressed the question of whether it would be appropriate to modify the river—for example to harden a bank—to protect existing high quality off-channel habitat. Generally the group consensus was that this strategy would not be a recommended approach.

4.6.5 Emergency Services

Actions that protect people and property during the immediately after a disaster or flood hazard event. Services include warning systems, emergency response services, and protection of critical facilities.

- Critical facilities protection
- Emergency response services
- Flood Hazard threat recognition
- Flood Hazard warning systems (community sirens, NOAA weather radio)
- Health and safety maintenance
- Post disaster mitigation

The group working on this section generally felt that emergency services were important, but that the specifics of an emergency services component (for example what tools were appropriate for the Sauk, where things should be located, etc.) needed to be developed by emergency services providers and documented in a separate emergency services plan. Recommended that the hazard risk management plan call for the development of an emergency services plan, but that it not go into too much detail about the content.

4.6.6 Structural Projects

Actions that involve the construction of structures to reduce the impact of a hazard.

- Bioengineering
- Channel bypass

The group working on this section focused on channel modifications that could be appropriate for mitigating erosion hazards, primarily bank stabilization. Bioengineered solutions were considered the most appropriate technology for bank hardening because of their relative effectiveness, durability, improved habitat performance when compared with other bank hardening approaches, and the likelihood to be preferred in the permitting process. Channel bypasses were also considered possible solutions, although they are a very expensive and technically challenging approach.

The major workshop activity for the evening was an exercise to apply the toolbox developed in Workshop 1 to each segment of the river, taking into consideration the hazard risk rating and any unique characteristics of the river in that segment. As preparation for the exercise, the group was asked to discuss four questions intended to clarify some of the major issues that could help with structuring alternatives.

These questions included:

- What would an alternative that focused on maintaining natural river processes look like?
- What would an alternative that focused on meeting the needs of a varied group of property owners look like? (making property owners whole?)
- What would a regulatory streamlining approach to meeting the plan's mission and objectives look like?
- What would a non-regulatory approach to meeting the plan's mission and objectives look like?

The group generally felt that the first two questions made sense for discussion at the workshop—primarily because they could be applied to different segments of the river to begin putting alternatives together—and that the last two questions should be deferred as a separate discussion on implementation.

Following this discussion, the large group was divided into four working groups. Two groups were generally focused on actions that maintained natural river processes, and two focused on actions that focused on making property owners whole. Discussions within the various groups took different directions depending on participants, however all groups generally discussed both emphasis areas as they looked at different river segments.

Group discussion on making property owners whole generally included a broad range of tools in their analysis, from relocation and acquisition to active river and bank management. The discussion didn't reveal many differences in which tools would be appropriate to apply in different risk settings.

In general, stakeholders agreed that modifications to the river would not likely be appropriate except in a mitigation context. While off-channel habitat and instream features were important, they were also considered transitory elements in the overall river landscape that would likely be replaced in other locations as long as river processes were allowed to function. The believed that modifications to the system to protect habitat features could potentially do more harm than good. Few locations were identified as especially important for maintaining river function over other areas.

Discussion focusing on making owners whole emphasized maintaining flexibility for individual owners, and that the full range of tools should be available for adjacent properties. There was more emphasis on instream river modification in this exercise than in the previous exercise to build the toolbox. Bank hardening was listed as an appropriate in many locations.

There was also extensive discussion of log jam management as a potential activity for reducing flood and erosion hazard. Log jams were considered impediment to river flow, especially during flood events, it was felt that they can raise the velocity of flow along the banks, redirect fast flows towards the banks, or both, resulting in increased erosion risk. Logjam management was used for many years as one of the strategies for reducing the risk of bank erosion or avulsion. There was some disagreement over the effectiveness of this tool for reducing the risk of negative outcomes for adjacent properties, yet there was also some interest in identifying if logjam management might be an effective tool in some situations. Because logjam management does not require hardening the bank or other major structural modifications to the river system, it was perceived as a less invasive form of manipulation of the river system than adding rock or bioengineering banks. The group agreed that demonstrating the effectiveness of logjam management would likely require testing in a regional modeling facility; which would require both time and funding.

Workshop 3 was intended to build on the exercise from Workshop 2 and provide more detailed guidance for the development of alternatives. In Workshop, 2 the groups had looked at mitigation tools along the different segments of the river from the perspective of the risk classification of the river segment. From the group's general conversation, there was an expectation that different management approaches would be appropriate in different segments of the river. The results of that exercise provided good guidance on the range of appropriate tools that might be applicable to managing risks along the entire river, however, it didn't provide the expected distinctions between the tools that might be used in one location rather than another.

To get more feedback on the possible distinctions that could be made between different river segments, the adjacent land uses, and the tools that might be appropriate for each one, workshops began with a discussion of tools that might be appropriate to limit risks for different land uses, and followed with a discussion of the potential application of those tools in selected river segments.

To begin the second discussion, the facilitator presented a draft set of land use categories as a framework for discussing risk management tools. The intent of the categories was to identify whether different tools would be appropriate for managing risk for the different land uses. Following a discussion based on land uses, the plan for the workshop was to test some of the guidelines developed for each land use by applying them to some of the more complex areas of the river.

The land use categories included:

- Public resource lands (primarily timber and mitigation)
- Public infrastructure (primarily roads, in this case SR 530, county bridge)
- Sauk Suiattle Tribal land
- Private timberlands
- Non-timber agricultural lands
- Private commercial/industrial land
- Residential land
- Secondary residences/vacation properties

Prior to this exercise, there was significant disagreement about whether this approach would be effective. Some members of the group didn't see value in distinguishing between land uses. Others suggested that the interaction of land uses and river dynamics depended enough on local conditions that it would be difficult to generalize for each type of use.

It was also discussed that there is often a difference between zoning or ownership and actual use.

For example:

- The Forest Service maintains offices and shops in parts of its property,
- Some residential development is allowed on land zoned for private timber,
- Agricultural lands often include primary residences.

These were recognized as valid concerns, and the group generally agreed that for the purposes of the plan the actual use, rather than the ownership or land use category, would be more appropriate to address. For example, if there was a difference in the preferred risk management tools for timberland and residential, but there was a residence in the risk area on land zoned for timber, then the residence would be treated as a residential property.

Significant discussion focused on the role of the flood/erosion hazard management plan in relation to regulatory structures currently in place. There was recognition that the plan was not regulatory, and did not have the ability to change any current regulatory programs. The plan is only advisory in nature. However, there was also recognition that many of the current regulatory review agencies, either in their capacity as implementers of specific regulatory programs or through the more general activity of SEPA/NEPA review of permit applications, have significant discretionary authority. There was concern/recognition that this plan would influence the discretionary actions of permit reviewers. Several agency representatives indicated that this was likely true, but also noted that there were many areas where the regulations did not provide flexibility for agency discretion.

The process discussion moved back and forth between several possible workshop activities. Eventually, the group agreed that it would be worthwhile to take a look at some segments of the river in detail as a way to evaluate the validity of using a combination of land use and river volatility to determine which tools would be most appropriate. Rather than breaking up into small groups, the whole group participated in the exercise.

Based on specific segments of the river, the group discussed generalized land use categories and the different tools that should be emphasized to reduce the risk of erosion and flood hazard.

4.7 PUBLIC RESOURCE LANDS

Key Question

- Are any risk reduction tools appropriate for public resource lands?

The group discussed whether public and private timberlands should be considered differently or in the same category. There was also recognition that management direction is likely different for public forestland owned by the state and federal governments. WA Dept. of Natural Resources might feel a stronger mandate for revenue generation than the US Forest Service for timberland in the Sauk corridor. Overall, however, there was consensus that the public benefit of maintaining river dynamics was likely higher than the value of merchantable timber that would be lost to river movement.

4.8 PRIVATE TIMBERLANDS

Key Questions

- Do you think differently about private timberlands than public?
- What tools make sense to reduce risk or make owners whole?
- Are different tools appropriate in relation to different risk area for river segments?
- What is an appropriate range of options?
- For example, is any action appropriate?
- Are different tools appropriate for timberlands as compared to residential properties, or are all private lands appropriate for the same tools?
- Are land swaps for other timberlands a preferred tool?
- Would the group support actions that modify natural river processes to protect private timberlands?

(Note: this category focuses on undeveloped timberlands. Timberlands with developed facilities, e.g., buildings, work yards, or other capital facilities, would be managed like other similar types of development.)

In general, structural river modifications were not recommended to protect timberlands, although a range of other risk reduction strategies were considered appropriate. The group discussed the potential downstream impacts of allowing natural river processes on public timberlands, and noted that in some cases, protection of other more developed properties may require structural modification of the river bank on forestlands.

Some structural solutions may be appropriate to consider in areas where the hazard rating was lower (in yellow, rather than red risk segments.) Structural solutions were more likely to be considered appropriate where river processes made them more likely to be sustainable, and where there were smaller ownerships, so that the loss of timber to the river represented a more significant proportion of the entire value of the property.

One category of preventive action was to recommend against conversion of timberlands at risk of erosion damage into residential properties. No upzoning from resource lands designation was considered appropriate. Some residential development is currently allowed under resource lands designation, and these property rights should be considered eligible for sale if a transfer of development rights (TDR) program were implemented for the region.

Private timberlands should be included in programs require real estate disclosure of hazard risks, and title notices if they are implemented as a risk management strategy.

Acquisition of timber lands, land swaps, or purchase of easements might also be appropriate tools either for reducing future risk, providing an incentive against structural modifications to the river, or making timber owners whole.

Other strategies that might be appropriate for making timber owners whole include current use taxation or other tax programs that recognize limitations on development. A riparian lands taxation program was discussed as a model. Group participants unsure if the program was still active, if it was only a pilot program, or if there were mechanisms to maintain the program/extend to the Sauk.

Education programs should be developed for private timber owners to provide information on any risk management programs that are implemented, as well as tax implications of current or proposed programs and funding options available.

4.9 COMMERCIAL/INDUSTRIAL PROPERTIES

Key Questions

- First, are we really just talking about the mill?
- It's hard to imagine that one alternative for the mill site isn't "do whatever you need to do to the river to maintain the mill property." Is that true?
- Are there other alternatives?

The mill is the only commercial industrial property in the study area, and there was general agreement that relocating out of the hazard area could be impractical. In general, hardening of the river bank to protect the mill and associated facilities from erosion hazard was supported by the group.

4.10 AGRICULTURAL LANDS

Key Questions

- Are other agricultural lands similar to timberlands?
- Would different tools be appropriate to reduce risk?
- Are agricultural lands along the river more closely tied to residential uses (i.e., do agricultural owners also live on the agricultural property?)

- Can we separate agricultural lands issues from residential, or are they too closely tied together?

Agricultural lands were considered similar to timberlands in some ways, but also had enough differences that some unique management strategies and tools were more appropriate. While most of the recommendations were expected to be similar to timberlands, the group noted several differences that should be reflected in the hazard management plan.

Agricultural lands are often treated differently than timberlands in terms of their access to support programs and policies. Public education needs to be developed specifically for agricultural land owners to reflect possible differences in access to funding or other programs.

Characteristics of agricultural lands that made them different from timberlands included a possible higher value as a cultural landscape than timberlands, different emergency response requirements (generally due to the higher likelihood of people being on the agricultural lands during a flood event, and the need to deal with livestock in a flood event), and the likelihood that agricultural lands have had more investment for improvement than timber lands have.
Group members noted that several agricultural properties along the river have been managed to provide habitat benefits for salmon, and that those habitat improvements should be considered when agricultural recommendations are developed.

Because of these differences, some members of the group suggested that agricultural lands may be more appropriate for protection from erosion than timberlands, however there was not consensus on this issue. There was general consensus that agricultural lands should be eligible for all acquisition, swap, TDR, and other programs that might be appropriate for timber.

4.11 PUBLIC INFRASTRUCTURE

Most public infrastructure in the erosion risk hazard area are roads, including state highways. The group generally supported recommending relocation of existing critical roadways as a sustainable strategy for maintaining access and reducing the cost of successive emergency repairs. In the short term, bank protection should be developed proactively rather than in reaction to an emergency. Emergency repairs are developed in a crisis atmosphere and are often not able to be appropriately engineered or implemented.

Pre-disaster mitigation funding may be available and should be pursued. As part of disaster preparedness all evacuation routes and critical infrastructure should be identified, and evacuation routes should be signed.

Future development of infrastructure should avoid erosion hazard areas.

The group specifically recommended relocation of SR 530—the only way out of the region (westbound) in a flood emergency.

4.12 RESIDENTIAL PROPERTIES

Key Questions

- Is there a difference between primary and secondary homes?
- Is there a difference between residential properties in different risk categories along the river?
- Is river modification an appropriate tool for protecting residential properties? In all cases or some cases?
- Should an alternative be included that does not recommend river modification as a preferred tool?
- *Are there appropriate mechanisms to encourage the use of bioengineering over placement of rip-rip? Should a choice between those two approaches be left to the homeowner with no assistance, regulatory preference, or other emphasis between the two approaches?*

The discussion began with a question whether all residential properties should be treated alike, or whether there should be a distinction between primary and secondary residences. It was noted that residential properties are categorized by FEMA, and the flood hazard mitigation plan should probably be consistent with FEMA designations if it makes any distinctions between types of residential properties.

There was a strong emphasis on public education as a tool for risk management with residential properties, especially to provide information to prospective purchasers and new homeowners. Realtors should be targeted for educational campaigns, as well as the insurance industry. Real estate disclosures and title notices should be required for properties within the hazard area.

No upzoning should be allowed within the hazard zone, and downzoning should be considered.

Emergency response is most critical for residential properties, and a detailed emergency response plan should be developed with residential properties as the focus.

- The group generally felt that residential properties were more appropriate than others to recommend structural bank modifications for property protection. In their review of the effectiveness of potential tools, bioengineering was preferred over traditional use of rip rap.

There was some discussion of the interaction of risk zones with residential properties, however there was no general consensus about how they should affect management recommendations. This may be an area where alternatives are developed to reflect and discuss differing approaches. There was some support for the idea that relative risk designations could be used as a criteria for guiding public funding for mitigation, particularly for bank stabilization. In the case of bank stabilization public funding would presumably focus on areas where stabilization seemed most sustainable. However, there was also discussion that the relative risk designation should not be considered for publicly funded projects. On the other hand, there was some emphasis that risk designations should not be considered during regulatory review of private bank protection projects.

4.13 GENERAL DISCUSSION ISSUES

During the discussion several issues were raised to provide guidance for the development of the draft hazard mitigation plan:

- The boundaries of a designated hazard zone will be an issue as the planning process develops.
- Some programs, such as title notification, will need clear boundaries to determine which properties are in and which are out. Other aspects of the hazard management plan may not require such clear lines, and should recognize a broader area. It may be appropriate to recognize a core area, then surround it with a buffer zone. The core area would likely require the formal delineation of a channel migration zone. Public education and other more regional actions should extend beyond boundaries of a hazard zone.
- There are not that many key areas in the project area, and they should be studied more carefully for specific recommendations as part of the alternative development process.
- Permit streamlining was discussed in some detail, with the general sense of the group that the scope of streamlining needed to be clarified and that further work by a subcommittee might be appropriate. Some of the general issues discussed included:
- Streamlining can mean different things. Generally the goal of streamlining would be to simplify and shorten the permitting time line for hazard mitigation activities. This would also likely reduce the cost of permitting.
- The hazard mitigation plan does not have any direct regulatory effect, and doesn't change the underlying regulations and implementation guidance that agencies must follow during permit review.
- Two areas that recommendations from the hazard mitigation plan could assist with might be improved information for permit seekers (clearer "road map" type of information for working through the permit process), and better inter-agency coordination.

- A desired outcome of permitting would be that the hazard mitigation activities supported by the plan would be easier to complete. Hazard mitigation activities that were not consistent with the plan would not necessarily be easier to permit, but the plan would not change regulations in a way that would preclude approval of activities that were not preferred. As mentioned above, while the plan is not regulatory, it was recognized that activities that were not preferred by the plan might be disadvantaged in the permitting process where agencies have regulatory discretion within their respective permitting authority.
- There was a concern that permit streamlining could encourage inappropriate river modifications; for example, modifications that were excessively reliant on rock or that weren't expected to be sustainable because of the river dynamics.

At the close of the workshops, the matrices for each segment of the river, (Tables 4-1 -4-6), were discussed, and several "trial" matrices were developed as guidance. From there, staff completed the remainder of the 32 tables for each segment of the Phase 1 reach of the river. A segment is composed of similar risk categories, thus lumping risk into segments that related directly to the river. From the matrices, the "Users' Guide" was developed (Chapter Six), that details the risk categories, inundation frequency, two year avulsion potential, general river slope, channel migration, and aggradation/scour potential for each segment, in effect, providing the background material for each risk category in the segment. For each individual segment, the number of the segment, reading from upstream to downstream, a short summary of problems and the risk factor, recommended actions and alternatives, and notes are provided, Figure One.

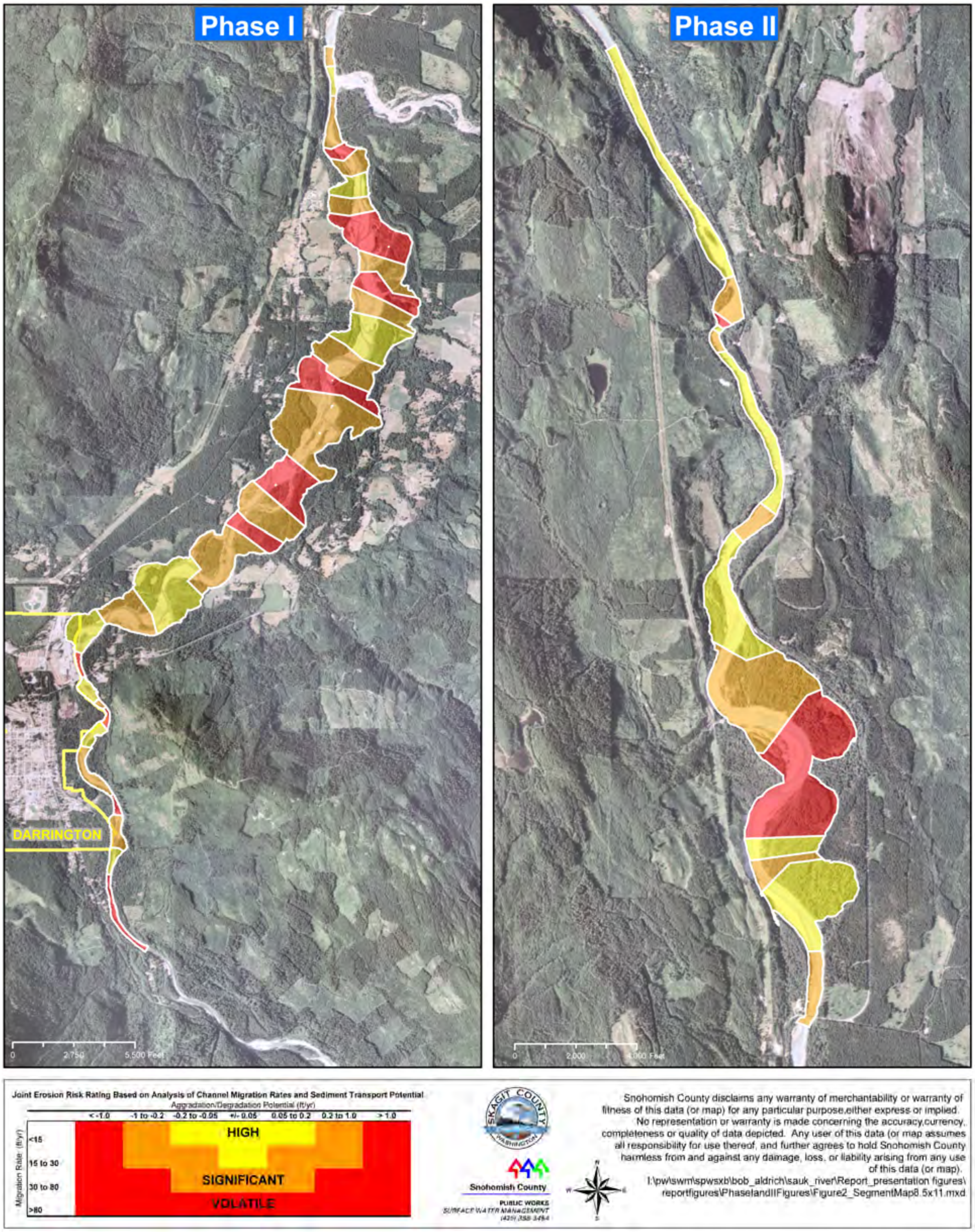
All segments, from 1 (Clear Creek segment) to 46 (approximately 1.5 miles from the Skagit river), are included in Appendix 2. The risk rating, Figure Two, appended, was derived from the Technical Analyses contained in Appendix 4. It is important to understand that the risk rating is based on sound science and engineering. The risk rating segments are compiled from the analysis segments contained in the technical reports, to avoid confusion, the explanations for the delineations in the analysis segments are discussed in the respective analyses. A more thorough discussion of the analysis work, as well as a detailed discussion of the risk segments, and the "Users Guide" for the Sauk river is presented in Chapter 6.

Compiled with special thanks to Mr. Kurt Warber, Workshop Facilitator, Parametrix, Inc.

Table 4-7. Example of Segment Information

REACH: CONFINED SOUTH			
Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
1	• Risk Factor: **Volatile** • Avulsion Potential: **Low** • Aggradation/Degradation: **High** • Inundation: **Low** • Channel movement/erosion: **High**	Structures • buyouts (acquisitions) • relocation Bank stabilization • aggressive engineering (rock) • riparian easement Infrastructure • abandon roads (don't fix) • erosion-proof No action	• High energy system (reach) • Bioengineering not likely to be successful • Existing infrastructure and property damage • Homes and roads lost due to erosion

Figure 4.1. Joint Risk Analysis



5. RECOMMENDED ACTIONS

5.1 BASIN OVERVIEW

The Sauk River is an extremely dynamic, powerful river. Structural control methods are generally not feasible due to the large scale that would be required to moderate the effects of the river, and the associated high costs. This does not rule out some limited structural control methods at certain points along the river, both for flooding and erosion protection. However the "toolkit" available for such approaches becomes limited as a matter of pure economics. The primary reason a quantitative risk based-approach, was used for this report was to provide stakeholders and citizens the tools necessary to make decisions, on a reach by reach basis, regarding flooding and erosion protection, and to provide some of the options available to address those issues.

Within this chapter you'll find recommendations for regulatory improvements, a discussion of public outreach and education, a summary of the recommended actions from Chapter 4, and a discussion of how to use the alternatives matrix. Several additional recommendations are presented, with a brief discussion of implementation.

5.1.1 Recommendations for Regulatory Improvements

An extensive discussion of regulatory programs and pathways was presented in Chapter 3 and Appendix 3. Although we find that the regulatory pathways are complex and overlapping, it pays to spend time with the various matrices, familiarizing oneself with the requirements of each regulatory level. It soon becomes apparent that there is a pathway through the maze, albeit complicated, and dependent on the type of action contemplated.

We do not offer nor recommend any specific changes in the current regulatory regime. Each agency has a unique role and must be dealt with on an individual basis, and within varying temporal time frames. There is no overarching law to change; nor is there one responsible agency, there are several that share responsibility for each and every action on the river.

Common to each agency with permitting authority in the Sauk River is the requirement for applicants to present factual evidence and data in support of proposed actions. This report provides the quantitative basis for most planned activities, thus represents a giant step toward solving flooding and erosion problems from a stakeholder perspective.

5.1.2 Public Education and Outreach Improvements

Given that the only public education and outreach regarding flooding and erosion problems has been the stakeholders meetings and preparation of this plan, improvements should be relatively straightforward.

Any impetus for continued public education and outreach will have to emanate from the Community, although the County will provide appropriate educational materials on flooding and erosion control in the basin.

5.2 EMERGENCY MANAGEMENT IMPROVEMENT RECOMMENDATIONS

Although floods can happen at any time, they are most common from November to February. In other basins, Snohomish County has developed a flood warning system to prepare and respond to flood events. The program is designed to warn residents and agencies of an impending flood so that they can make preparations before flooding occurs. The flood warning system involves river forecasting conducted by the National Weather Service (NWS) and local river monitoring conducted by Snohomish County Department of Public Works Surface Water Management Division (SWM).

When a flood occurs, a coordinated response effort involving multiple jurisdictions and agencies is carried out by the Snohomish County Department of Emergency Management (DEM) Emergency Operations Center (EOC). This is not the case with for Sauk River. At this time the two operable gages on the Sauk are not yet on the County's web page, nor are they linked to a flood warning system. The County has been strongly encouraged by the stakeholders group to make it a recommendation in the Plan that this linkage occur, and that the two gages be placed on the County website.

5.2.1 The Mechanics of Flood Warning

The NWS is the agency responsible for issuing warnings about potential floods. The information used to develop flood warnings is gathered from the United States Geological Survey (USGS) telemetric gage network and from regional weather conditions and patterns. The data is integrated into a hydrologic computer model at the NWS's River Forecast Center in Portland, Oregon. Rainfall reports, soil saturation information, snow depth information, and temperature readings may also be included as variables in the computer model. Depending on the results of the model and the severity of weather conditions, the NWS issues a *flood watch, flood warning, or flood statement.* The NWS also issues river forecasts, which may resemble warning statements or contain detailed stage information, such as the predicted time a river will crest.

As knowledge about weather patterns and conditions has improved, the probability of accurately predicting a flood has increased. Recent studies of El Nino and global atmospheric circulation patterns have given weather researchers the ability to identify large-scale weather features that typically lead to flooding (e.g., rain-on-snow events as discussed earlier). Thus, early recognition of threatening weather patterns on a regional scale, combined with statistical data collected from river gages, provides a relatively long lead-time to prepare for a flood event.

Local conditions, however, vary greatly and may not always be included in the NWS's hydrologic models. As a result, Snohomish County conducts its own river monitoring before and during a flood event to supplement NWS's flood statements with information about local conditions that may affect flooding. This information is provided for background, as the County monitors the Stillaguamish, the Snohomish, and the Skykomish, and does not currently monitor the Sauk River, relying on the two USGS instead.

5.2.2 Data Collection

Two types of river gages are used to monitor rivers: automated and manual gages. Automated gages employ telemetric or radio transmissions to measure specific conditions in the river. Manual gages, or staff gages, are large wooden rulers, graduated in feet and tenths, which are observed manually for water level. Although staff gages are useful when multiple readings are reported from one site, automated gages are more efficient because they provide real time data that may be needed on a regular basis during a flood event.

The USGS gages include 12186000 on the North Fork of the Sauk and 12189500 on the mainstem at Sauk, are automated gages.

Automated gages are normally placed far enough upriver so that the time of the expected crest reaching downstream areas can be predicted. Unfortunately, this is somewhat problematic in the Sauk, as the North Fork gage does not record the Whitechuck River, and most of the inhabited portions of the Sauk lie between Darrington and the Suiattle River, making flood crest prediction difficult.

5.2.3 Who's Who in Flood Planning

Many activities are ongoing during a flood event. Public Works staff and Emergency Operations Center (EOC) volunteers are monitoring rivers, (save for the Sauk), checking NWS forecasts, and maintaining contact with the NWS meteorologist who is providing. River analysis charts and tides are plotted, while the DEM flood warning network is updated. Snohomish County's SWM and Road Maintenance Divisions are dispatching field crews to respond to requests for assistance received through phone banks. Field Command Posts (CPs) may be mobilized to allow agencies to handle situations in the field that require immediate attention. The representatives from the interagency team at the EOC are in contact with the CPs to further coordinate the flood fight.

The agencies participating in the interagency team have a specific role at the EOC. The following is a brief explanation of each agency's role, as described in DEM's Flood Operations Manual.

5.2.4 DEM/EOC

The DEM is responsible for establishing a centralized system for coordinating flood operations in Snohomish County. The director organizes and leads the EOC volunteers, and coordinates all inter-agency activities. The EOC volunteers are responsible for operations, analysis and planning of incoming river data, public information, communications, logistics and administration.

The DEM has a flood warning network that is continually updated. The flood warning network is part of a public information system that provides information to the public through news releases, local radio frequencies, or direct telephone contact.

5.2.5 Snohomish County Executive Office

The County Executive is the final decision making authority in a flood fight, and authorizes the Declaration of Emergency.

5.2.6 Snohomish County Department of Public Works

The County Engineer has been designated the Flood Coordinator for the unincorporated areas of the County, and is responsible for the overall direction and control of the flood fight operations for the County. The Flood Coordinator also is the contact with the County Executive and coordinates efforts with the director of the DEM.

The County Engineer prepares the Declaration of Emergency, which is reviewed and approved by the County Executive. The County Engineer has the authority to request and to direct assistance from the Corps, National Guard, other armed forces organizations, and/or public agencies. Phone banks to receive and respond to public requests for assistance for the duration of the flood are provided by the Road Maintenance and SWM Divisions of Public Works.

5.2.7 Snohomish County Sheriff's Department

The Sheriff's Department provides traffic management, assists with dissemination of warning and evacuation, coordinates search and rescue, provides security for evacuated areas, and assists with the collection of field intelligence.

5.2.8 Fire Districts/Emergency Medical Services

The fire districts provide emergency medical aid, assist with dissemination of warnings, evacuation, and suppression of fire. They also assist with the direction and control of any sandbagging operations in incorporated areas and other areas not under supervision of the County Flood Engineer.

5.2.9 Snohomish County Chapter-Red Cross

The Red Cross provides human services assistance to flood victims (food, clothing, temporary shelter, recovery funds, etc.), meals for volunteers and other personnel involved in the flood fight, assesses the human services needs of the community, and coordinates local application of human services program.

5.2.10 U.S. Army Corps of Engineers

The Corps provides field intelligence, carries out federal flood fight operations, provides technical advice and support, and contracts for private sector equipment and resources. Once a river reaches flood stage, the Corps can authorize emergency funds to be used in the event of a dike breach or other unanticipated emergency.

5.3 WHO CAN I CONTACT FOR MORE INFORMATION?

Snohomish County's flood warning system involves cooperation and communication between many agencies. Because floods affect multiple jurisdictions, interagency coordination is essential for an efficient and effective flood fight. The EOC provides the location and framework for a coordinated response needed in unincorporated Snohomish County.

Table 5-1 provides a list of resources for residents who are impacted by flooding in Snohomish County. Please check the DEM for the most current information.

The USGS and the Northwest River Forecast Center (NWRFC) maintain two online sites. Stream flows and other flood information can be obtained from USGS site at www.usgs.com. Flood watches, warnings, and statements in addition to forecast information can be obtained from NWRFC at www.nwrfc.noaa.gov.

5.4 RECOMMENDED MITIGATION STRATEGY ALTERNATIVES BY SEGMENT

Reflecting the dynamic, unique and ever-changing nature of the Sauk River, we proposed recommendations for action by analysis segment, or those small parts of the reach consistent with the analyses detailed in Appendix 4**.** The information and analyses included in this report, will be helpful to stakeholders as they continue to coexist with the river. The matrices, combined with the Users' Guide and risk analysis, (Chapter 6), are a powerful decision-making tool, developed by the stakeholders for stakeholders and decision makers on all levels. Regulatory agencies will find the information useful as well.

Table 5-1. Flood Information Sources.

Flood Information Sources	***Phone Number or Radio Frequency***
Emergencies	Call 911
Flood Information	425-388-3653
NOAA Weather Radio	162.550 MHz
Broadcast Media	KIRO Radio 710 AM or 100.7 FM
Snohomish County Amateur Radio Service	Listen to 146.32/92 for instructions on the correct flood information channel
Citizens Band Radio	Listen to Channel 9 for instructions on the correct flood information channel
DEM non-emergencies; Road conditions and closures	425-423-7635
Surface Water Management Phone Bank-Requests for Assistance	425-388-6467
Road Maintenance Phone Bank	360-862-7500

5.4.1 How to use the Mitigation Strategy Alternatives

The Alternative Matrices are reproduced entirely in Appendix 2, and will only be referenced in this section. To aid in discussion, an excerpt from the Matrix is provided below for discussion, (Table 5-2).

With reference to Table 5-2 Mitigation Strategy Alternatives (Example), below, there is a wealth of information in the Table. The river is divided into Reaches and then subdivided into segments, starting at Clear Creek and moving downstream to just above the confluence with the Skagit River, **(**Figure 1**)**. The segments are further subdivided into analysis segments, (Appendix 4), but for purposes of clarity, the segments are used to group similar characteristics. Overriding all the subdivisions is the actual cross-section work that was completed for the Hydraulic Model built for the effort, (HEC-RAS), and detailed in Appendix 4. Because of the detail involved, it is included in Appendix 4, and used to group cross sections for clarity. In the matrix, the reach is called out in the upper left hand corner. Entering the matrix, the segment #, (which is also used in the Users' Guide, (Chapter 6), is called out. Next is a summary of problems, essentially a characterization of the segment and potential issues. More detail can be found in Appendix 4 and the Users' Guide. The avulsion potential, aggradation/degradation, inundation, and channel movement are combined to form the Risk Factor. In the next column are the recommended actions, solutions, or alternatives that could be used in the segment. Actions are not confined just to private property protection, but include public infrastructure and habitat enhancements. Finally, general notes are included.

Table 5-2. Mitigation Strategy Alternatives (Example)

REACH: CONFINED SOUTH			
Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
1	• Risk Factor: **Volatile** • Avulsion Potential: **Low** • Aggradation/Degradation: **High** • Inundation: **Low** • Channel movement/erosion: **High**	Structures • buyouts (acquisitions) • relocation Bank stabilization • aggressive engineering (rock) • riparian easement Infrastructure • abandon roads (don't fix) • erosion-proof No action	• High energy system (reach) • Bioengineering not likely to be successful • Existing infrastructure and property damage • Homes and roads lost due to erosion

5.5 CAVEATS

There are several important caveats that must be observed when using the matrices, and most importantly, any of the information contained in Appendix 2 and the User's Guide. Because the Sauk is a powerful, active river, the analyses contained in this report should be used in the context that they represent general conditions in a segment. To fully detail problems or prepare design recommendation at a finer resolution, the HEC-RAS model is available, as are all the GIS layers, cross-section, and calibration data. Because of the size of the files, it will be necessary to contact Snohomish or Skagit County Public Works, Surface Water Management, to obtain the information.

Due to the highly variable nature of the river, conditions generally change with each storm event, so it is imperative that users determine current field conditions in comparison to those observed, and modeled, at the time this report was prepared.

All infrastructure locations, property lines, etc, are approximate, due to scale and conversion differences in the various historical photographs used in the analyses. Cross-sections were measured using survey grade GPS equipment, so have been tied to survey monuments on State Highway 530.

5.6 OTHER RECOMMENDED ACTIONS

In addition to the recommendations contained in the Mitigation Strategy Alternatives matrix, several very important tasks should be discussed separately, in order to highlight their importance. These include channel migration zone delineation and technical assistance to landowners

5.6.1 Channel Migration Zone Delineation

A channel migration zone delineation, required for Shoreline Permits in Snohomish County, is a process detailed by WADNR, and adopted by statute by Snohomish County. The study is conducted in accordance with Section 2 of the Forest Practices Board Manual (Title 222 WAC), Standard Methods for Identifying Bankfull Channel Features and Channel Migration Zones, November, 2004, except that areas behind natural or manmade features which limit channel migration that allow fish passage are not included in the channel migration zone.

It was beyond the scope of this analysis to create full regulatory channel migration zone delineation, although many of the elements are inherent in this document. It has been recommended by the Stakeholders committee that the next step be taken; that funding be allocated to complete the necessary tasks for a complete regulatory Channel migration zone delineation for the study area.

5.6.2 Technical Assistance to Landowners

Without a doubt, technical assistance to landowners in the Sauk River should continue. This could be accomplished by continued cooperative efforts between Skagit and Snohomish counties, as well as outreach efforts by both counties. The technical memoranda, Alternatives Matrices and most importantly, Users' Guide, provides Stakeholders with a decision making tool. Once decisions have been made, they provide a "reality check" for designers, engineers and consultants involved in specific projects. In addition, Snohomish County currently operates a Cooperative Bank Stabilization program where landowners, where appropriate, are provided limited funding and designs for bank stabilization work, (emphasis and priority are accorded those projects using bioengineering).

The authors of this report are also available to provide assistance in the interpretation of the report, as well as assisting with technical expertise and obtaining specific datasets.

5.6.3 Purchase of Timber Rights

One recurring theme after floods in the Sauk River is the amount of large woody debris deposited throughout the channel migration zone. Generally speaking, most of the wood in the system was once owned by a river side property owner. This creates a great deal of friction in the community, and serves to hasten riverside harvests on private land. Many landowners see these riverside forests as “retirement planning.” One could argue that harvest in the Riparian Management Zone, (RMZ) is strictly controlled by the Department of Natural Resources. This is true to a point. Harvest regulations include a buffer consistent with the RMZ and the Channel Migration Zone, (CMZ). Unfortunately, the Sauk has the capability to move well beyond a regulatory buffer in a single event, plucking acres of trees from the land. While log jams and woody debris in the landscape are without question the best thing for habitat, the entire geomorphic process is seen as a hardship by landowners, who then seek to protect remaining forests, indulging in expensive and often futile attempts to control the river.

Rather than engage in protracted expensive, and often futile riverbank protection efforts, we propose creation of a voluntary program where landowners are paid a one-time fee for the value of their riparian forest tracts. When they become “public property,” (as they do by falling in the river), it can be considered an even exchange. At this time, this is only a proposal, which agency would fund, administer, and engage in such a program is open to debate.

5.7 IMPLEMENTATION

Traditionally, a Comprehensive Flood Hazard Management Plan contains extensive lists of alternatives and recommendations. In the case of the Sauk Comprehensive Flood/Erosion Hazard Management Plan, alternatives are found in the Alternatives Matrix in Appendix 2, or as part of each segment in the Users’ Guide in Chapter 6**.**

The approach we have used provides a quantitative decision making tool, rather than a static list. This allows each landowner the opportunity to independently decide the direction they might choose in managing their river side property. Although many of the recommendations and alternatives contained in the matrix are similar, each segment should be approached as an analysis unit.

6. THE USERS' GUIDE

6.1 INTRODUCTION

Note: Please refer to the 11 X 17 companion document entitled "Sauk River Comprehensive Flood/Erosion Control Management Plan Users' Guide"

The User's guide for the plan is intended as a standalone document that combines the analyses detailed in Appendix 4. Essentially, the analyses are presented in pictorial form, allowing Stakeholders to locate their property, area of interest, or problem site, and understand the components that created the risk rating for their particular property.

To make the document more "user-friendly," the grouped segments have been allowed two 11" X 17" facing pages. There are several pages of maps and graphs that precede the actual segment discussion. These are important as they provide context as well as an overall location in the watershed. The maps and graphs are:

Figure 1. Vicinity Map showing city boundaries, highways, and the river
This map details the extent of the Plan area, both upstream and downstream. In this map, and the others that follow, the river flows from South to North,

Figure 2. Segment Map overlaid on an aerial photograph of the entire river
This map details the numbered segments used throughout the Manual. To maintain consistency, the segments, (smaller segments with similar risk characteristics), are numbered starting at number 1 in the most upstream segment and ending at number 46 furthest downstream.

Figure 3. Joint Risk Graphic
The Joint Risk Graphic is the result of the combination of several analyses, and provides a picture of the risk from erosion and flooding inherent in each segment. It is worth noting that the original ratings (Low, Medium, and High) were replaced at the request of the Stakeholders Committee, who felt that ratings that actually reflected the power of the Sauk River would be more appropriate. Thus, the original ratings were replaced with High (=Low); Significant (=Medium); and Volatile (=High). Essentially, the Joint Risk rating reflects a combination of the migration rate of the river matched with the aggradation/erosion rate in the segment. (*Note: aggradation is a term used to describe the process of sediment buildup in the bed of a river*). The Risk Rating, combined with all other analysis factors, provides stakeholders with a clear picture of river processes at work.

Figure 4. 2-Year Inundation
The 2-Year Inundation provides a graphical interpretation of the results of the hydraulic modeling (HEC-RAS) and is detailed in Appendix 4. The graphic shows the area the river would occupy during an event that would be representative of a two year event, that is; an event that has the statistical probability of recurring every two years.

Figure 5. 10-Year Inundation
The 10-Year Inundation provides a graphical interpretation of the results of the hydraulic modeling (HEC-RAS) and is detailed in Appendix 4. The graphic shows the area the river would occupy during an event that would be representative of a ten year event, that is, an event that has the statistical probability of recurring every ten years.

Figure 6. 100-Year Inundation
The 100-Year Inundation provides a graphical interpretation of the results of the hydraulic modeling (HEC-RAS) and is detailed in Appendix 4. The graphic shows the area the river would occupy during an event that would be representative of a hundred year event, that is, an event that has the statistical probability of recurring every hundred years.

Figure 7. "Parker" Figure
This figure is the companion to the Main Channel figure (Figure 9) that makes up the risk analysis for each segment, Studying this figure, one begins to observe the "waves" of sediment that travel in a downstream direction, greatly influencing river behavior and morphology.

Figure 8. Geomorphic Reach Breaks
This figure depicts the geomorphic reach breaks in the Sauk, that is, the different reaches of the river that are determined by the differences in slope, channel migration, valley width, and other characteristics.

Figure 9. Main Channels
One graphic that is extremely valuable to understanding the volatile nature of the Sauk River is the position of the main channel. Earliest records start at 1949 and continue through 2004, (2007 is also available but was not flown in time for the study). The channel is dynamic, and can move across the floodplain rapidly, sometimes in one event.

Figure 10. Agricultural and Forestry Land Use
This figure is not used in the analysis, but is provided to show the extent of forest and agricultural land in the Sauk River basin. While this is by no means a comprehensive analysis of land use in the basin, it does demonstrate the respect that residents have paid to the river, and its' ability to move across the floodplain.

6.2 THE USERS' GUIDE

The Users' Guide, has been named to reflect its' expected role as a source of information to help Stakeholders make informed decisions about proposed river actions; particularly for bank protection, fisheries enhancement, infrastructure protection and construction. At no time is it suggested, in the plan, that Stakeholders are prevented from taking action, securing permits, protecting land from erosion and flooding. Likewise, agencies are not denied the opportunity of taking preventative actions as well. The entire plan is designed to be an iterative document, from the ground up, quantifying the processes at work in each and every segment of the study reaches, information that can lead to informed decisions, and can aid and support any kind of design or permit action.

The Users' Guide is necessarily a pictorial representation of the analyses contained in Appendix 4. Many references have been made to the Hydraulic model produced for this report. The HEC-RAS model is a very valuable, (and available tool), not only for design of projects, but in the understanding of the affects that proposed projects may have on the river.

Each segment of the study area has two pages allotted for presentation. With respect to Figure 1, the following descriptors pertain to each segment:

1. Indicates the geomorphic reach within which the segment is contained. There were seven geomorphic "classes" used in the Sauk:

    a. Confined South
    b. Wandering
    c. Transition
    d. Braided
    e. Confined North
    f. Moderately confined
    g. Confined (below Suiattle)

2. Indicates the segment number, reading in an upstream to downstream direction.

3. Provides the risk rating and is color coded to the Joint Erosion Risk Rating analysis.

4. Provides the summary of problems and alternative from Appendix 2.

5. Locator photo, showing historic channel locations, and the actual location of the segment on the river.

6. Provides the relative slope of the segment. As it is derived from simply comparing the upstream and downstream elevation, it does not take into account variations within the segment.

7. Legend for the next four photos.

8. Represents the Joint Risk for the segment. The joint risk rating ranges from High, (the lowest rating), to Volatile, (the highest rating).

9. Represents the deposition/erosion class for the segment. Deposition/erosion is measured in feet/year, and ranges from greater than 1.0/year to less than 1.0/year.

10. Lidar images depicting the risk of avulsion from a two year storm event. The risk is presented from low to high. (Note: some technical terms: an avulsion is defined by a sudden and perceptible loss or addition to land by the action of water, or a sudden change in the bed or course of a stream. The term lidar is an acronym for light detection and ranging, which is a method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of pulsed laser light reflected from their surfaces).

11. Area of inundation modeled for a 2-year flood frequency. The model (HEC-RAS) was used as a basis for determining flow stage (elevation) in each of the analysis segments, which were then combined to form the reach segment. Thus the 2-year elevation represents an average for the combined analysis segments.

APPENDIX 1:

Glossary

Sauk River Comprehensive Flood/Erosion Hazard Management Plan

Glossary

Acronyms

BA	Biological Assessment
BFE	Base Flood Elevation
BMP	Best Management Practice
CFS	Cubic Feet Per Second
CRS	Community Rating System
CMZ	Channel Migration Zone
DNS	Determination of Non-Significance
EA	Environmental Assessment
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FCAAP	Flood Control Assistance Account Program
FEMA	Federal Emergency Management Agency
FHBM	Flood Hazard Boundary Map
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
HPA	Hydraulic Project Approval
JARPA	Joint Aquatic Resources Permit Application
LWD	Large Woody Debris
NEPA	National Environmental Policy Act
NFIP	National Flood Insurance Program
NPDES	National Pollutant Discharge Elimination System
NWRFC	Northwest River Forecasting System
OHWM	Ordinary High Water Mark
RCW	Revised Code of Washington
RFIS	Flood Insurance Re-Study
RM	River Mile
RMZ	Riparian Management Zone
SEPA	State Environmental Policy Act
SMA	Shoreline Management Act
SMP	Shoreline Master Program
WMZ	Wetland Management Zone

Data and Definitions

Geomorphic Data (list)
Habitat Data (list)
Infrastructure Data (list)

Acronyms

BA	Biological Assessment
BFE	Base Flood Elevation
BMP	Best Management Practice

CFS	Cubic Feet Per Second
CRS	Community Rating System
CMZ	Channel Migration Zone
DNS	Determination of Non-Significance
EA	Environmental Assessment
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FCAAP	Flood Control Assistance Account Program
FEMA	Federal Emergency Management Agency
FHBM	Flood Hazard Boundary Map
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
HPA	Hydraulic Project Approval
JARPA	Joint Aquatic Resources Permit Application
LWD	Large Woody Debris
NEPA	National Environmental Policy Act
NFIP	National Flood Insurance Program
NPDES	National Pollutant Discharge Elimination System
NWRFC	Northwest River Forecasting System
OHWM	Ordinary High Water Mark
RCW	Revised Code of Washington
RFIS	Flood Insurance Re-Study
RM	River Mile
RMZ	Riparian Management Zone
SEPA	State Environmental Policy Act
SMA	Shoreline Management Act
SMP	Shoreline Master Program
WMZ	Wetland Management Zone

APPENDIX 2:

Mitigation Strategy Alternatives

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
1	• Risk Factor: **Volatile** • Avulsion Potential: **Low** • Aggradation/Degradation: **High** • Inundation: **Low** • Channel movement/erosion: **High**	Structures • buyouts (acquisitions) • relocation Bank stabilization: • aggressive engineering (rock) • riparian easement Infrastructure • abandon roads (don't fix) • erosion-proof No action	• High energy system (reach) • Bioengineering not likely to be successful • Existing infrastructure and property damage • Homes and roads lost due to erosion

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
2	• Risk Factor: **High** • Avulsion Potential: Aggradation/Degradation: **Moderate** • Inundation: **High** at 10 year event • Channel movement/erosion: **Low**	Structures • buyouts (acquisitions) • relocation, setbacks Bank stabilization: • bioengineering • riparian easement • engineered solution Infrastructure • abandon roads (don't fix) No action	• Lower energy system (reach) • Lower risk • Less aggradation/deposition, almost neutral

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
3	• Risk Factor: **Significant** • Avulsion potential: **Minimal** • Aggradation/Degradation: **Medium** • Inundation potential: **Moderate** • Channel Movement: **Medium** ◦ Braided with preferential flow paths	Structures • buyouts • relocation, setbacks Bank stabilization: • bioengineering –left bank • riparian easements • engineered solution – left & right bank Infrastructure-do not repair due to channel movement potential No action	• Depositional reach • Channel movement shows the beginning of the braiding process • River energy is increasing, more braiding, more aggradation • Inundation bankfull at 2 and 10 year

REACH: CONFINED SOUTH

Segment# (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

4	• Risk Factor: **Volatile**
	• Avulsion potential: **Moderate**
	    • With severe erosion creating a head cutting condition
	• Aggradation/Degradation: **High**
	• Inundation potential: **High** at 10 year event
	• Channel Movement: **Medium**
	    • Braided with preferential flow paths
		Allow channel migration
		Structures:
		    • buyouts
		    • relocation, setbacks
		Bank stabilization:
		    • bioengineering – left bank
		    • engineered solution – left & right bank
		Infrastructure
		    • move out of floodplain
		No action
			• Volatile reach
			• Maximum aggradation to maximum degradation
			• Head cutting is occurring into the reach including avulsion pathways

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Actions / Solutions - Alternatives	Notes (Impacts & Effects)

5	• Risk Factor: **Significant**
	• Avulsion Potential: **High**
	  • left bank has short stretches with high potential
	  • right bank remains at higher risk
	• Aggradation/Degradation: **Moderate to High**
	  • ranges from depositional (upstream) to erosional (downstream)
	• Inundation potential: **High** for 10 year event, mostly right bank
		Structures
		Left bank
		• buyouts (acquisitions)
		• setbacks & relocation
		Right bank
		• setbacks & relocation
		Bank stabilization – right & left bank
		• bioengineering
		Infrastructure – do not recommend new
		No action
			Comments from Stakeholder workshop:
			• Logs on riprap (bioengineering)

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
6	• Risk Factor: **High** • Avulsion potential: **High** • Aggradation/Degradation: **Moderate** overall with left bank more strongly erosional • Inundation potential: **High** for 10 year event along potential left and right bank avulsion routes	Structures – none present • Not recommended due to erosion and inundation pathways Bank stabilization – right & left bank • Bioengineering • Engineering techniques Infrastructure – • New infrastructure not recommended due to erosion and inundation pathways No action	

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

7	• Risk Factor: **Volatile**
	• Avulsion potential: **Moderate**
	  • Potential avulsion route locations are limited
	• Aggradation/Degradation: **High**
	  • Inundation potential: **High** for 2 and 10 year event
	  • ranges from highly erosional to highly depositional
	  • Channel movement: **Low**
		Structures – none present
		  • do not recommend due to erosion and inundation pathways
		Bank stabilization
		  • Bioengineering
		Infrastructure – none present
		  • do not recommend new
		No action
			• Volatile reach
			• Maximum aggradation to maximum degradation
			• Much of right bank is bedrock or riprap

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
8	• Risk Factor: **Significant** • Avulsion Potential: **Moderate** • Aggradation/Degradation: **High** • ranges from highly erosional to highly depositional • Inundation potential: **Moderate** for 10 year event, mostly left bank	Allow channel migration Structures – none present • do not recommend new structures Bank stabilization: Right bank – do not recommend,bank is mostly bedrock Infrastructure-none present • do not recommend No action	• Most of segment is Snohomish County owned

REACH: CONFINED SOUTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

9	• Risk Factor: **High**
	• Avulsion Potential: **Minimal**
	•
	• Aggradation/Degradation: **High**
	  • depositional
	• Inundation potential: **Low** from upstream portions
	• Channel movement: **Low**
		Allow channel migration
		Structures – none present
		  • Do not recommend new structures
		Bank stabilization
		  Left bank
		  • bioengineering
		  Right bank
		  • bioengineering
		  • aggressive engineering
		Infrastructure – none present
		  • do not recommend new infrastructure
		No action
			• County bridge 414 in Segment 10
			• Channel bifurcates
			Comments from Stakeholder workshop:
			• Protect infrastructure, move logjam, lots of riprap

REACH: WANDERING

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

10	• Risk Factor: **Volatile**
	• Avulsion Potential: **Low**
	• Aggradation/Degradation: **Moderate**
	  • depositional
	• Inundation potential: **Low**
	• Channel movement: **Minimal**
		Allow channel migration – right bank
		Structures
		  Left bank
		  • diked
		Bank stabilization
		  Left bank
		  • maintain infrastructure
		  Right bank
		  • bioengineering
		  • do nothing
		Infrastructure – do not recommend new dikes, bridges, or roads
		No action	

REACH: WANDERING

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
11	• Risk Factor: **High** • Avulsion Potential: **High** • Aggradation/Degradation: **Neutral** • slightly depositional • Inundation potential: **Moderate** • Channel movement: **High,** toward right bank	Structures • relocate • setbacks Bank stabilization Right bank: • aggressive bioengineering Left bank • maintain dike • transition to bioengineering Infrastructure • move out of floodplain No action	• Reach is changing due to improved bridge configuration and the existing hardened left bank Comments from Stakeholder workshop: • Move logjam, keep existing channel open

REACH: WANDERING

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

12	• Risk Factor: **Significant**
	• Avulsion Potential: **High**
	• Aggradation/Degradation: **Active**
	  • Sediment wave through segment
	• Inundation potential: **High** for 2 year event
	• Channel movement: **Moderate**
		Allow channel migration
		Structures
		  • remove from floodplain
		  • relocate
		Bank stabilization
		Left bank
		  • PTR –purchase timber rights
		  • riparian easements for channel migration
		  • bioengineering
		Right bank:
		  • PTR – purchase timber rights
		  • bioengineering
		  • engineering
		Infrastructure – none existing
		No action
			• Part of a series of reaches that exhibit an active wave type of aggradation/deposition, flowing from one to another and back again (creating a head cutting situation) noted in "Summary of Problems(s) –Characterization & Potential " as **"sediment wave through segment"**
			  • Effects segments 12, 13, 14, 17, 18, 19,
			Comments from Stakeholder workshop:
			• Bypass

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives
REACH: WANDERING

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
13	• Risk Factor: **High** • Avulsion Potential: **High** • Aggradation/Degradation: **Active High** • Sediment wave through segment • Inundation potential: **High** for 2 and 10 year event • Channel movement: **High**	Allow channel migration Structures • set backs • buyouts Bank stabilization • riparian easements • purchase timber rights (PTR) • aggressive bioengineering (**massive**) • aggressive engineering **(massive)** Infrastructure • relocate No action	Comments from Stakeholder workshop: • Bypass and keep channel open

REACH: WANDERING

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

14	• Risk Factor: **Significant**
	• Avulsion Potential: **High**
	• Aggradation/Degradation: **Active High**
	  • Sediment wave through segment
	• Inundation potential: **High** for 10 year event
		Allow channel migration
		Structures
		  ▪ do not recommend new structures
		  • setbacks
		  • buyouts
		Bank stabilization
		  • riparian easement
		  • PTR – purchase timber rights
		  • aggressive bioengineering
		  • aggressive engineering
		Infrastructure – none existing
		  • do not recommend new infrastructure
		No action
			• Engineered solutions have an extremely low probability of success due to very high shear stress at 2 and 10 year events
			• Would be extremely expensive
			• Meanders extensive
			Comments from Stakeholder workshop:
			• Bypass

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

15	• Risk Factor: **Volatile**
	• Avulsion Potential: **High**
	  ◦ left bank avulsed in 2003
	  ◦ right bank remains **High**
	• Aggradation/Degradation: **High**
	  ◦ degrading with the cutting of new channel
	• Inundation potential: **High** with 2 and 10 year event
		Allow channel migration
		Structures
		  ▪ do not recommend new structures
		  • setbacks
		  • buyouts
		Bank stabilization
		  Left bank
		  • riparian easements
		  • PTR – purchase timber rights
		  • aggressive bioengineering
		  • aggressive engineering
		  Right bank
		  • flood fencing
		  • tree revetments/log jams
		  • buyouts
		Infrastructure – none existing
		  • Do not recommend new infrastructure
		No action
			• Encourage work on right bank
			  ◦ flood fencing and bioengineering would buy time for buyouts, setbacks, PTR, etc.
			• Low probability of success for hard engineering
			• Sheer stress throughout reach is high
			• Major avulsion occurred in 2007

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
16	• Risk Factor: **Significant** • Avulsion Potential: **High,** • Aggradation/Degradation: **High** • Inundation potential: **High** for 2 and 10 year event	Allow channel migration Structures • do not recommend new structures Left bank – no existing structures Right bank • buyouts • setbacks Bank stabilization Left bank • large aggressive bioengineering Right bank • riparian easements • set backs to allow channel migration • PTR – purchase timber rights Infrastructure – none existing • do not recommend new infrastructure No action	• Left bank exhibits high shear stress, would require large scale bioengineering • Aggradation/degradation forces coupled with avulsion potential drives the processes within this reach Comments from Stakeholder workshop: • Keep channel open

REACH: BRAIDED

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

17	• Risk Factor: **Volatile**
	• Avulsion Potential: **High**
	• Aggradation/Degradation: **Active High**
	  ◦ Sediment wave through segment
	• Inundation potential: **High** for 2 and 10 year events
		Allow channel migration
		Structures – no existing structures
		• do not recommend new structures
		• set backs
		Bank stabilization:
		Left bank
		• set backs
		• PTR – purchase timber rights
		• aggressive bioengineering
		• aggressive engineering
		Right bank
		• riparian easements
		• PTR – purchase timber rights
		Infrastructure – none existing
		Not recommended
		No Action
			• River processes in this reach are mostly depositional forces, driving channel migration and avulsion
			  ◦ Fine sands and silts
			Specific comments from Stakeholder workshop:
			• Preservation

REACH: BRAIDED

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

18	• Risk Factor: **Significant**
	• Avulsion Potential: **Very High**
	  ◦ left bank avulsed in 2003
	  ◦ right bank remains with **High** risk
	• Aggradation/Degradation: Active Moderate
	  ◦ Sediment wave through segment
	• Inundation potential: **High** for 2 and 10 year events, occupying most of the floodplain
		Allow channel migration
		Structures
		  • do not recommend new structures
		  • setbacks for existing structures
		Bank stabilization:
		  • No effective structural solutions
		  • riparian easements
		  • PTR – purchase timber rights
		Infrastructure – none existing –
		  • do not recommend new infrastructure
		No action
			• Reach demonstrates typical lahar system with chute cutoff channels
			• Intense avulsion potential

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

19	• Risk Factor: **Volatile**
	• Avulsion Potential: **High**
	  ◦ left bank avulsed in 2003
	  ◦ right bank remains with **High** risk
	• Aggradation/Degradation: Active Moderate
	  ◦ Sediment wave through segment
	• Inundation potential: **High** for 10 year event, occupying most of the floodplain
		Allow channel migration
		Structures
		• do not recommend new structures
		Bank stabilization:
		• Not effective solution
		• riparian easements
		• PTR – purchase timber rights
		• aggressive bioengineering
		• aggressive engineering
		Infrastructure – none existing
		• do not recommend new infrastructure
			• Left bank avulsed 2003 to potential extent of left bank movement

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

20	• Risk Factor: **Significant**
	• Avulsion Potential: **High**
	• Aggradation/Degradation: Active **Moderate**
	    • Sediment wave through segment
	• Inundation potential: **High**
	• Channel movement/erosion: **Low**
		Allow channel migration
		Structures – none existing
		    • do not recommend new structures
		Bank stabilization:
		    • Purchase riparian easements
		    • PTR – purchase timber rights
		Infrastructure – none existing
		    • do not recommend new infrastructure
		Do nothing
			• Reach is a transition between volatile and high
			• Continues with high avulsion risk, an extension of the avulsion episode with the upstream reach

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives

REACH: BRAIDED

<table>
<tr><th>Segment #
(upstream to downstream)</th><th>Summary of Problem(s) – characterization & potential</th><th>Recommended Action(s) / Solution(s) - Alternatives</th><th>Notes (Impacts & Effects)</th></tr>
<tr><td>21</td><td>• Risk Factor: High
• Avulsion Potential: High
• Aggradation/Degradation: Low
• Inundation potential: High
  ◦ entire floodplain inundated at 10 year event
• Channel movement/erosion: Moderate
  ◦ beginning to migrate (braid)</td><td>Allow channel migration
Structures – none existing
  • do not recommend new structures
Bank stabilization:
  • purchase riparian easements
  • PTR – purchase timber rights
  • abandon roads (don’t fix)
  • bioengineering
  • aggressive engineering
Infrastructure – none existing
  • do not recommend new infrastructure
Do nothing</td><td>• Relatively flat gradient
• Avulsion potential is the major force in this reach
• Do not recommend new structures due to the high avulsion potential</td></tr>
</table>

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

22	• Risk Factor: **Significant**
	• Avulsion Potential: **High**
	    • Left bank has already avulsed
	• Aggradation/Degradation: **Moderate**
	    • Relatively balanced depositional/erosional forces over the extent of reach
	• Inundation potential: **High**
	    • 2 year event creates extensive shear stress across the reach
	    • entire floodplain inundated at 10 year event
	    • Channel Movement: **High**
		Allow channel migration
		Structures:
		    • do not recommend new structures – See "Infrastructure" below
		Bank Stabilization
		    • extreme engineering
		    • not appropriate for bioengineering
		Infrastructure – Dike exists
		  Left Bank
		    • Dike remains and is maintained
		        • Structures remain, do not recommend new structures
		    -OR-
		    • Dike is removed
		        • Purchase lands
		        • Remove structures
		        • Remove infrastructure
		  Right Bank
		    • PTR – purchase timber rights
		    • Conservation easements
		Do nothing
			• River lateral action is truncated by dike on left bank
			• Relatively flat gradient
			• Avulsion may occur behind dike
			• Reach is primarily processing sediment downstream

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives
REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

23	• Risk Factor: **Volatile**
	• Avulsion potential: **High**
	• Aggradation/Degradation: **Moderate**
	• Inundation potential: **High**
	  ◦ 2 year event creates extensive shear stress across the reach
	  ◦ Majority of floodplain is inundated at 10 year event
	• Channel Movement: **High**
		Allow channel migration
		Structures:
		• do not recommend new structures – See “Infrastructure” below
		Bank Stabilization
		• extreme engineering
		• not appropriate for bioengineering
		Infrastructure – Dike exists
		Left Bank
		• Dike remains and is maintained
		  ◦ Structures remain, do not recommend new structures
		-OR-
		• Dike is removed
		  ◦ Purchase lands
		  ◦ Remove structures
		  ◦ Remove infrastructure
		Right Bank
		• PTR – purchase timber rights
		• Conservation easements
		
		Do nothing	

REACH: BRAIDED

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

24	• Risk Factor: **Significant**
	• Avulsion Potential: **High**
	• Aggradation/Degradation: **Moderate**
	  • Relatively balanced
	• Inundation potential: **High**
	  • 2 year event creates extensive shear stress across the reach
	  • entire floodplain inundated at 10 year event
	• Channel movement: **High**
		Allow channel migration
		Structures
		• buyouts (acquisitions)
		• relocation
		Bank stabilization
		Left Bank
		• Riparian easement
		• bioengineering
		• aggressive engineering
		Right bank
		• PTR – purchase timber rights
		• Conservation easements
		Infrastructure –
		• do not recommend new infrastructure
		Do nothing
			• Avulsion potential plus aggradation/degradation conditions contribute to the overall significant risk factor
			• Left bank – presently heavily rocked

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

25	• Risk Factor: **Volatile**
	• Avulsion potential: **High**
	• Aggradation/Degradation: **Moderate**
	• Inundation potential: **High**
	  • majority of floodplain is inundated at 2 year event
	  • floodplain is almost completely inundated at the 2 year event
	Channel Movement: **High**
		Allow channel migration
		Structures – none existing
		• do not recommend new structures
		Bank stabilization
		Left bank
		• very aggressive bioengineering
		• aggressive engineering
		• PTR – purchase timber rights
		• conservation easements
		Right bank
		• No action, allow natural river processes
		• PTR – purchase timber rights
		Infrastructure – none existing
		• do not recommend new infrastructure
		Do nothing	

REACH: BRAIDED

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
26	• Risk Factor: **Significant** • Avulsion potential: **Moderate to High** • Aggradation/Degradation: **Moderate** • Inundation potential: **High** • 2 year event occupies the majority of the reach • Channel Movement: **High**	Allow channel migration Structures Left bank • relocate existing structures • do not recommend new structures due to avulsion risk potential Bank stabilization Left Bank • aggressive bioengineering • conservation easements • PTR – purchase timber rights • aggressive engineering Right bank • conservation easements • PTR – purchase timber rights Infrastructure • Protect existing Mill & bridge& clearcreek • Remove existing infrastructure • Relocate Do nothing	

REACH: BRAIDED

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**

27	• Risk Factor: **High**
	• Avulsion potential: **Moderate** to **High**
	• Aggradation/Degradation: **Moderate**
	• Inundation potential: **High**
	    • 2 year event covers most of floodplain
	• Channel movement: **Moderate**
		• Allow channel migration
		• Structures - none existing
		    • do not recommend new structures
		Bank stabilization
		Left Bank
		• conservation easements
		• PTR – purchase timber rights
		• aggressive bioengineering
		• aggressive engineering
		Right bank
		• conservation easements
		• PTR – purchase timber rights
		Infrastructure – none existing
		Do nothing
			Comments from Stakeholder workshop:
			• No enhancement necessary for natural resources
			• Flood insurance
			• All tools apply, less retrofit since not much property is in floodplian
			• Compensation for lost timber values

REACH: CONFINED NORTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
28	• Risk Factor: **Significant** • Avulsion potential: **Moderate to High** • Aggradation/Degradation: **Moderately** degrading • Inundation potential: **High** ◦ 2 and 10 year events covers most of floodplain • Channel movement: **Moderate**	Allow channel migration Structures – none existing • do not recommend new structures Bank stabilization • allow natural river processes to occur Infrastructure – none existing • do not recommend new infrastructure Do nothing	Comments from Stakeholder workshop: • Leave it alone • Appropriate compensation • Appropriate land use (#3) • Allow landowner control over logjams or other causes of erosion* • Selective culling or manipulation of logjams (relative to risk)* *SEE REGULATORY SECTION

REACH: CONFINED NORTH

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
29	• Risk Factor: **Volatile** • Avulsion potential: **Moderate** • Aggradation/Degradation: **High** depositional • Inundation potential: **Moderate** • 10 year event covers most of floodplain	Allow channel migration Structures – right & left bank • buyouts of existing structures • do not recommend new structures • allow natural river processes to occur Bank stabilization – do not recommend • Aggressive bioengineering • Aggressive engineering • allow natural river process to occur Infrastructure – none existing • do not recommend new infrastructure Do nothing	Comments from Stakeholder workshop: • Leave it alone • Appropriate compensation • Appropriate land use (#3) • Allow landowner control over logjams or other causes of erosion* • Selective culling or manipulation of logjams (relative to risk)* *SEE REGULATORY SECTION

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives

REACH: CONFINED NORTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)

30	• Risk Factor: **Significant**
	• Avulsion potential: **High**
	• Aggradation/Degradation: M**oderate**
	• Inundation potential: **High**
	  • 2 and 10 year events consumes most of floodplain
		Structures – none existing
		  • do not recommend new structures
		Bank stabilization
		  Left Bank
		  • Riparian easement
		  • aggressive engineering
		  • not appropriate for bioengineering
		  Right bank
		  • PTR – purchase timber rights
		  • Conservation easements
		Infrastructure – exists on left bank
		  • Move highway
		  • Aggressive protection
		Do nothing
			Comments from Stakeholder workshop:
			• Has some natural bedrock
			• Issue of protection (or relocation) of SR530 infrastructure
			• Address issue of access

REACH: CONFINED NORTH

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
31	• Risk Factor: **Significant** • Avulsion potential: **High** on right bank • Aggradation/Degradation: M**oderate** aggrading • Inundation potential: ◦ all channel contained in 2 year event, consumes most of floodplain	Structures – no structures • do not recommend new structures • allow natural river processes to occur Bank stabilization Left bank • Aggressive engineering • Possibly aggressive bioengineering Right bank • allow natural river process to occur Infrastructure – left bank • relocate highway/road	• **HIGH** avulsion potential on right bank is from the Suiattle River • Inundation: basically 2 year = 10 year = 100 year • No opportunity for PTR Comments from Stakeholder workshop: • More natural bedrock • Move highway • Issue of protection (or relocation) of SR530 infrastructure • Address issue of access

REACH: CONFINED NORTH

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
32	• Risk Factor: **Low** • Avulsion potential: **High** on right bank • Aggradation/Degradation: M**oderate** erosional • Inundation potential: • all channel contained in 2 year event, consumes most of floodplain	Structures – no structures • do not recommend new structures • allow natural river processes to occur Bank stabilization Left bank • Aggressive engineering • Possibly aggressive bioengineering Right bank • allow natural river process to occur Infrastructure – left bank • relocate highway	• **HIGH** avulsion potential on right bank is from the Suiattle River • Inundation: basically 2 year = 10 year = 100 year Comments from Stakeholder workshop: • Allow continued erosion • Relocate highway. • Sandy gravelly bank • Issue of protection (or relocation) of SR530 infrastructure • Address issue of access

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives

REACH: Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
33	• Risk Factor**: Significant** • Avulsion Potential: **Low** • Aggradation/Degradation: **High** • Inundation: • Channel movement/erosion: **Medium**	Allow Channel migration Structures • buyouts (acquisitions) • relocation Bank stabilization: • engineering (rock) • bioengineering • riparian easement Infrastructure • abandon roads (don't fix) • erosion-proof No action	• Bioengineering likely to be successful

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives

REACH: Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
34	• Risk Factor: **High** • Avulsion Potential: **Low, right bank** • Aggradation/Degradation: **Neutral** • Inundation: • Channel movement/erosion: **Low**	Bank stabilization: • bioengineering • riparian easement Infrastructure • abandon roads (don't fix) No action	• Lower energy system (reach) • Lower risk • Less aggradation/deposition, neutral • No structures or roads

REACH: Confined

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
35	• Risk Factor: **Significant** • Avulsion potential: **High** • Aggradation/Degradation: **High Degradation** • Inundation potential: • Channel Movement: **High**	Structures • buyouts • relocation, setbacks Bank stabilization: • bioengineering –left bank • riparian easements • engineered solution – left & right bank Infrastructure-do not repair due to channel movement potential No action	• Depositional reach • Channel movement shows the beginning of the braiding process • River energy is increasing, more braiding, more aggradation • Inundation bankfull at 2 and 10 year

Sauk River Comprehensive Flood/Erosion Hazard Management Plan
Mitigation Strategy Alternatives

REACH: Confined

Segment# (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
36	• Risk Factor: **High** • Avulsion potential: **Lo to High** • Aggradation/Degradation: **Low Aggratadion** • Inundation potential: • Channel Movement: **High**	Allow channel migration Bank stabilization: • bioengineering – Infrastructure • move out of floodplain No action	

REACH: Confined

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Actions / Solutions - Alternatives	Notes (Impacts & Effects)
37	• Risk Factor: **Volatile** • Avulsion Potential: **Low to High** • Aggradation/Degradation: **Ranges low to high** • Inundation potential: • Channel Movement: **High**	Bank stabilization – right & left bank • bioengineering Infrastructure – do not recommend new No action	

REACH: Confined

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
38	• Risk Factor: **Significant** • Avulsion potential: **Medium to High** • Aggradation/Degradation: **Ranges from High degrade. To high aggrad.** • Inundation potential: • Channel Movement: **High**	Structures – none present • Not recommended due to erosion and inundation pathways Bank stabilization – right bank • Bioengineering No action	

REACH: Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
39	• Risk Factor: **High** • Avulsion potential: **High** • Aggradation/Degradation: **Med degrade. to Med aggr.** • Inundation potential: • Channel movement: **High**	Structures – none present Bank stabilization • Bioengineering • Aggressive Engineering Infrastructure –present • do not recommend new • move if possible No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
40	• Risk Factor: **Significant** • Avulsion Potential: **Low Risk** • Aggradation/Degradation: **Low Degrad.** • Inundation potential: • Channel movement: **High**	Allow channel migration Structures – none present • do not recommend new structures Bank stabilization: • Right bank- Highway 530, aggressive engineering Infrastructure- • Move road if possible. No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	Summary of Problem(s) – characterization & potential	Recommended Action(s) / Solution(s) - Alternatives	Notes (Impacts & Effects)
41	• Risk Factor: **High** • Avulsion Potential: **None** • Aggradation/Degradation: **Low to Mod. Aggrad.** • Inundation potential • Channel movement: **Low**	Structures – none present Bank stabilization • bioengineering • aggressive engineering Infrastructure – • do not recommend new infrastructure No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
42	• Risk Factor: **Significant** • Avulsion Potential: **None** • Aggradation/Degradation: **Low degrade.** • Inundation potential: • Channel movement: **Low**	Bank stabilization • do nothing Infrastructure – Existing Bridge - stable No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
43	• Risk Factor: **High** • Avulsion Potential: **none** • Aggradation/Degradation: **Neutral** • Inundation potential: • Channel movement: **Low**	• Bank stabilization: none needed • Infrastructure: existing bridge, stable • No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
44	• Risk Factor: **volatile** • Avulsion Potential: **none** • Aggradation/Degradation: **high degrade.** • Inundation potential: • Channel movement: **med.**	• Bank stabilization: None needed • Infrastructure –existing bridge stable • No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
45	• Risk Factor: **significant** • Avulsion Potential: **high** • Aggradation/Degradation: **High aggrad.** • Inundation potential: • Channel movement: **Moderate**	• Allow channel migration • Bank stabilization : aggressive bioengineering aggressive engineering • Infrastructure: relocate or repair • No action	

REACH: Moderately Confined

Segment # (upstream to downstream)	**Summary of Problem(s) – characterization & potential**	**Recommended Action(s) / Solution(s) - Alternatives**	**Notes (Impacts & Effects)**
46	• Risk Factor: **High** • Avulsion Potential: **low to medium** • Aggradation/Degradation: **neutral** • Inundation potential: • Channel Movement: **medium**	Structures ▪ do not recommend new structures • setbacks • buyouts Bank stabilization • riparian easement • aggressive bioengineering • aggressive engineering Infrastructure –Existing County Road, do not recommend new infrastructure No action	

APPENDIX 3:

Assessment of Regulatory Measures Matrices

Building Structures

		Snohomish Cnty	Skagit Cnty		
	Local (L)				
	State (S)				
	Federal (F)				
	Building Permit	Time: 45 days Cost: Free	Time: 45 days Cost: Free		
	Grading/Fill Permit	Time: variable Cost: $300	Time: 4-6 wks Cost: $300		
	Flood Hazard Permit Application	Time: variable Cost: $300	Check with Skagit County for cost & time		
	Shoreline Substantial Development Permit	Time: variable Cost: $450+	Check with Skagit County for cost & time		
	Critical Areas Ordinance Checklist	Time: variable Cost: $250-$600	Time: variable Cost: $2200		
	Habitat Management Plan (Snohomish County only)	Time: variable Cost: $600			
	ESA Salmonids Checklist (Skagit County only)		Time: variable Cost: $600		
L/S/F	Joint Aquatic Resources Permit Application	Time: 45 days Cost: free	Time: 45 days Cost: free		
	Fish Habitat Enhancement Project				
	Hydraulic Project Approval (**HPA**)	Time: 45 days Cost: free	Time: 45 days Cost: free		
	Section 401 Water Quality Certification	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free		
	Aquatic Lands Use Authorization	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease		
	State Environmental Policy Act (**SEPA**) Checklist	Time: variable Cost: $500	Time: variable Cost: $500		
	Section 404 Discharge of Dredge/Fill in Water	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100		
	Incidental Take Permit (**Endangered Species Act**)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)		
S/L	Forest Practices Application (**FPA**)	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200		
L/S	Archaeological Assessment	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free		
	Wild and Scenic River Review	Time: variable Cost: free	Time: variable Cost: free		
	NOTES:				
	Cost=reflects the direct cost of obtaining a permit or review and will vary with time				
	Indicates required or likely required permit/review		If located in Special Flood Hazard Area		
	HCP=Habitat Conservation Plan				
	Indicates Possibly Required Permit/Review - depends on project				

Restore Riverbanks & River Habitats

	Local (L)				
	State (S)				
	Federal (F)				
		Restoration using bioengineereing			
		Snohomish Cnty	Skagit Cnty		
	Building Permit				
	Grading/Fill Permit				
	Flood Hazard Permit Application	Time: variable Cost: waived	Time: variable Cost: waived		
	Shoreline Substantial Development Permit	Time: variable Cost: waived	Time: variable Cost: waived		
	Critical Areas Ordinance Checklist	Time: variable Cost: waived	Time: variable Cost: waived		
	Habitat Management Plan (Snohomish County only)	Time: variable Cost: waived			
	ESA Salmonids Checklist (Skagit County only)		Time: variable Cost: waived		
L/S/F	Joint Aquatic Resources Permit Application	Time: 45 days Cost: free	Time: 45 days Cost: free		
	Fish Habitat Enhancement Project				
	Hydraulic Project Approval (**HPA**)	Time: 45 days Cost: free	Time: 45 days Cost: free		
	Section 401 Water Quality Certification	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free		
	Aquatic Lands Use Authorization	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease		
	State Environmental Policy Act (**SEPA**) Checklist	Time: variable Cost: waived	Time: variable Cost: waived		
	Section 404 Discharge of Dredge/Fill in Water	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100		
	Incidental Take Permit (**Endangered Species Act**)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)		
	Forest Practices Application (**FPA**)	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200		
L/S	Archaeological Assessment	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free		
	Wild and Scenic River Review	Time: variable Cost: free	Time: variable Cost: free		
	NOTES:				
	Cost=reflects the direct cost of obtaining a permit or review and will vary with time				
	Indicates required or likely required permit/review				
	HCP=Habitat Conservation Plan				
	Indicates Possibly Required Permit/Review - depends on project				

Stabilize Shoreline and Riverbanks

	Local (L)					
	State (S)					
	Federal (F)					
		Using Rock		**Bioengineered (usually with wood)**		
		Snohomish Cnty	Skagit Cnty	Snohomish Cnty	Skagit Cnty	
	Building Permit	Time: 45 days Cost: Free	Time: 45 days Cost: Free	Check w/ PDS (Roxanne)		
	Grading/Fill Permit	Time: variable Cost: $300	Time: 4-6 wks Cost: $300	Not required	Not required	
	Flood Hazard Permit Application	Time: variable Cost: $300	Check with Skagit County	Check w/ PDS (Roxanne)		
	Shoreline Substantial Development Permit	Time: variable Cost: $450+	Check with Skagit County	Not required		
	Critical Areas Ordinance Checklist	Time: variable Cost: $250-$600	Time: variable Cost: $2200	Check w/ PDS (Roxanne)		
	Habitat Management Plan (Snohomish County only)	Time: variable Cost: $600		Not required		
	ESA Salmonids Checklist (Skagit County only)		Time: variable Cost: $600		Time: variable Cost: $600	
L/S/F	Joint Aquatic Resources Permit Application	Time: 45 days Cost: free	Time: 45 days Cost: free	Time: 45 days Cost: free	Time: 45 days Cost: free	
	Fish Habitat Enhancement Project					
	Hydraulic Project Approval (**HPA**)	Time: 45 days Cost: free	Time: 45 days Cost: free	Time: variable Cost: free	Time: variable Cost: free	
	Section 401 Water Quality Certification	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free	
	Aquatic Lands Use Authorization	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease	
	State Environmental Policy Act (**SEPA**) Checklist	Time: variable Cost: $500	Time: variable Cost: $500	Not required	Not required	
	Section 404 Discharge of Dredge/Fill in Water	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100	
	Incidental Take Permit (**Endangered Species Act**)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)	
	Forest Practices Application (**FPA**)	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200	
L/S	Archaeological Assessment	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free	
	Wild and Scenic River Review	Time: variable Cost: free	Time: variable Cost: free	Time: variable Cost: free	Time: variable Cost: free	
	NOTES:					
	Cost=reflects the direct cost of obtaining a permit or review and will vary with time					
	Indicates required or likely required permit/review					
	HCP=Habitat Conservation Plan					
	Indicates Possibly Required Permit/Review - depends on project					

Emergency Work In and Along the Sauk River

	Local (L)				
	State (S)				
	Federal (F)				
		Emergency Work			
		Snohomish Cnty	Skagit Cnty		
	Building Permit				
	Grading/Fill Permit	Time: variable Cost: $300	Time: 4-6 wks Cost: $300		
	Flood Hazard Permit Application	Time: variable Cost: $300	Check with Skagit County		
	Shoreline Substantial Development Permit	Time: variable Cost: $450+	Check with Skagit County		
	Critical Areas Ordinance Checklist	Time: variable Cost: $250-$600	Time: variable Cost: $2200		
	Habitat Management Plan (Snohomish County only)	Time: variable Cost: $600			
	ESA Salmonids Checklist (Skagit County only)		Time: variable Cost: $600		
L/S/F	Joint Aquatic Resources Permit Application	Time: 45 days Cost: free	Time: 45 days Cost: free		
	Fish Habitat Enhancement Project				
	Hydraulic Project Approval (**HPA**)	Time: 45 days Cost: free	Time: 45 days Cost: free		
	Section 401 Water Quality Certification	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free		
	Aquatic Lands Use Authorization	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease		
	State Environmental Policy Act (**SEPA**) Checklist	Time: variable Cost: $500	Time: variable Cost: $500		
	Section 404 Discharge of Dredge/Fill in Water	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100		
	Incidental Take Permit (**Endangered Species Act**)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)		
	Forest Practices Application (**FPA**)	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200		
L/S	Archaeological Assessment	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free		
	Wild and Scenic River Review	Time: variable Cost: free	Time: variable Cost: free		
	NOTES:				
	Cost=reflects the direct cost of obtaining a permit or review and will vary with time				
	Indicates required or likely required permit/review				
	HCP=Habitat Conservation Plan				
	Indicates Possibly Required Permit/Review - depends on project				

Clearing Land

	Local (L)		
	State (S)		
	Federal (F)		
		Clearing Land	
		Snohomish Cnty	Skagit Cnty
	Building Permit		
	Grading/Fill Permit	Time: variable Cost: $300	Time: 4-6 wks Cost: $300
	Flood Hazard Permit Application	Time: variable Cost: $300	Check with Skagit County
	Shoreline Substantial Development Permit	Time: variable Cost: $450+	Check with Skagit County
	Critical Areas Ordinance Checklist	Time: variable Cost: $250-$600	Time: variable Cost: $2200
	Habitat Management Plan (Snohomish County only)	Time: variable Cost: $600	
	ESA Salmonids Checklist (Skagit County only)		Time: variable Cost: $600
L/S/F	Joint Aquatic Resources Permit Application	Time: 45 days Cost: free	Time: 45 days Cost: free
	Fish Habitat Enhancement Project		
	Hydraulic Project Approval (**HPA**)	Time: 45 days Cost: free	Time: 45 days Cost: free
	Section 401 Water Quality Certification	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free
	Aquatic Lands Use Authorization	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease
	State Environmental Policy Act (**SEPA**) Checklist	Time: variable Cost: $500	Time: variable Cost: $500
	Section 404 Discharge of Dredge/Fill in Water	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100
	Incidental Take Permit (**Endangered Species Act**)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)
	Forest Practices Application (**FPA**)	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200
L/S	Archaeological Assessment	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free
	Wild and Scenic River Review	Time: variable Cost: free	Time: variable Cost: free
	NOTES:		
	Cost=reflects the direct cost of obtaining a permit or review, and will vary with time.		If located in Special Flood Hazard Area
	Indicates required or likely required permit/review		
	HCP=Habitat Conservation Plan		
	Indicates Possibly Required Permit/Review - depends on project		

Stabilize Shore

	Local (L)				
	State (S)				
	Federal (F)				
		Using Rock		**Bioengineered (usually with wood)**	
		Snohomish Cnty	Skagit Cnty	Snohomish Cnty	Skagit Cnty
	Building Permit	Time: 45 days Cost: Free	Time: 45 days Cost: Free	Check w/ PDS	
	Grading/Fill Permit	Time: variable Cost: $300	Time: 4-6 wks Cost: $300	Not required	Not required
	Flood Hazard Permit Application	Time: variable Cost: $300	Check with Skagit County	Check w/ PDS	
	Shoreline Substantial Development Permit	Time: variable Cost: $450+	Check with Skagit County	Not required	
	Critical Areas Ordinance Checklist	Time: variable Cost: $250-$600	Time: variable Cost: $2200	Check w/ PDS	
	Habitat Management Plan (Snohomish County only)	Time: variable Cost: $600		Not required	
	ESA Salmonids Checklist (Skagit County only)		Time: variable Cost: $600		Time: variable Cost: $600
L/S/F	Joint Aquatic Resources Permit Application	Time: 45 days Cost: free	Time: 45 days Cost: free	Time: 45 days Cost: free	Time: 45 days Cost: free
	Fish Habitat Enhancement Project				
	Hydraulic Project Approval (**HPA**)	Time: 45 days Cost: free	Time: 45 days Cost: free	Time: variable Cost: free	Time: variable Cost: free
	Section 401 Water Quality Certification	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free	Time: 1-3 mos. Cost: free
	Aquatic Lands Use Authorization	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease	Time: 6-12 mos. Cost: $25+lease
	State Environmental Policy Act (**SEPA**) Checklist	Time: variable Cost: $500	Time: variable Cost: $500	Not required	Not required
	Section 404 Discharge of Dredge/Fill in Water	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100	Time: 45days-2yrs Cost: $0-$100
	Incidental Take Permit (**Endangered Species Act**)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)	Time: variable Cost: free review (HCP up to $10,000)
	Forest Practices Application (**FPA**)	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200	Time: 30 days Cost: $0 - $1200
L/S	Archaeological Assessment	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free	Time: 45 - 60 days Cost: free
	Wild and Scenic River Review	Time: variable Cost: free	Time: variable Cost: free	Time: variable Cost: free	Time: variable Cost: free
	NOTES:				
	Cost=reflects the direct cost of obtaining a permit or review and will vary with time				
	Indicates required or likely required permit/review				
	HCP=Habitat Conservation Plan				
	Indicates Possibly Required Permit/Review - depends on project				

APPENDIX 4:

Sauk River Corridor Analysis, Phase 1 & 2
Geomorphic Assessment and Avulsion Risk Analysis

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Technical Memorandum

Date: April 14, 2008 Project Number: 1681.01/MM101

To: Bob Aldrich
Karen Wood-McGuiness (Snohomish County)

From: Paul DeVries, Ph.D., P.E.

Subject: Results of Geomorphic Analysis of Hydraulic, Hydrologic, Sediment, and Habitat Conditions in the **Upper Sauk River Between Clear Creek and the Suiattle River**

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INTRODUCTION

The Sauk River Comprehensive Floodplain Hazard Management Plan (CFHMP) is to be based on a comprehensive analysis of physical, cultural, societal, regulatory and environmental factors that reflect or govern the influence of flooding conditions on landowners, habitat, fisheries, and infrastructure. From consensus discussions with the existing Sauk River Stakeholders group, the original intent of the Sauk River Management Plan was to produce a plan acceptable to affected landowners, resource agencies, local tribes and local governments that can be used to evaluate:

1) The range of risks to property, infrastructure, and fish and wildlife habitat for areas along the Sauk River floodplain corridor from impacts associated with flooding and channel migration.
2) The areas and conditions in the corridor that justify high consideration for flood and bank protection.
3) The areas and conditions in the corridor that justify high consideration for habitat protection and restoration.
4) The regulatory environment in the corridor, including a) authority of each jurisdiction, b) permit requirements, pathways and timelines, especially during locally declared "emergencies," and c) proactive steps to expedite permitting.
5) The range of public assistance programs available to landowners impacted by flood and channel migration, gaps in those programs, recommendations for filling those gaps, and how access to existing programs can be improved.

Development of the CFHMP is contingent on first gathering and analyzing data on channel morphology, bank conditions and modifications, floodplain conditions and topography, hydrology, hydraulics, riparian conditions and habitat for salmonids. The results of these data collection and analysis efforts will be reviewed by Stakeholder and Technical committees as they develop management alternatives such that infrastructure protection and habitat restoration dollars will be spent where they will have the greatest effect.

This memorandum describes the geomorphic analyses and data evaluated as part of this initial phase of preparing the CFHMP. The analysis concerns the "upper" reach of the Sauk River extending upstream from its confluence with the Suiattle River to just below the confluence with Clear Creek near Darrington, Washington (Figure 1). Similar analyses below the Suiattle River

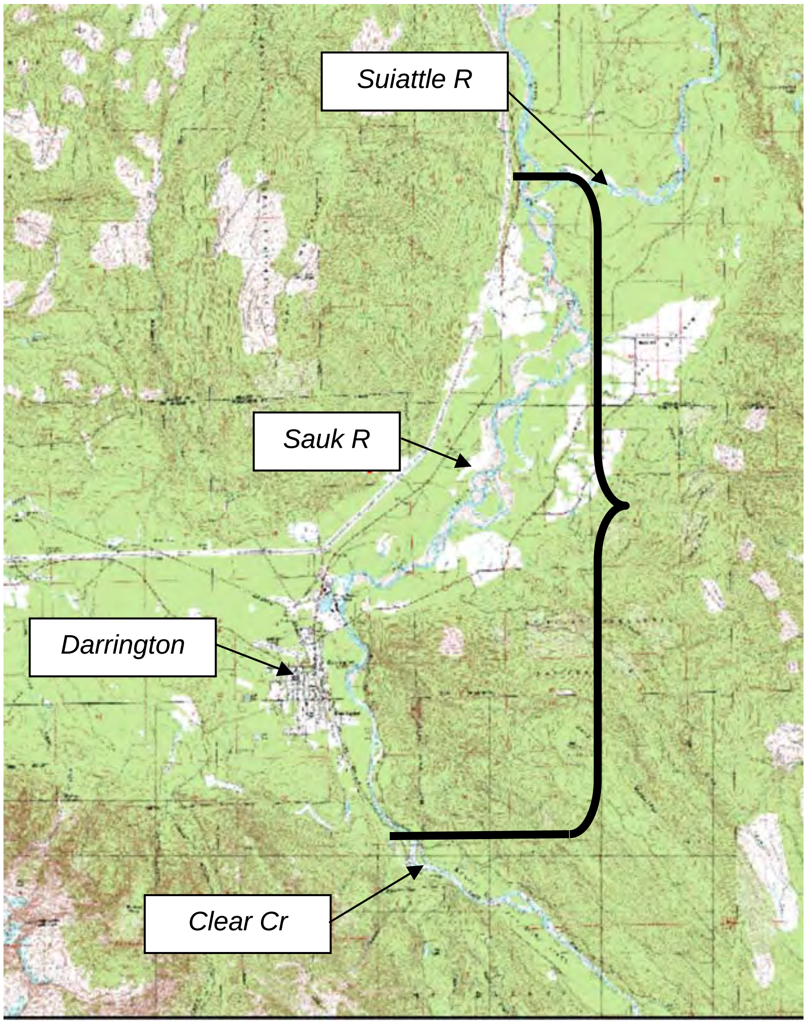


Figure 1. Location of the Sauk River reach analyzed in this memorandum, near Darrington, WA.

would be conducted as funds become available. The present analysis reach is roughly 10½ miles long and has been identified as important for regional salmon recovery. The reach provides particularly important spawning habitat for lower Sauk summer Chinook salmon (*Oncorhynchus tshawytscha*), one of six distinct Chinook stocks identified as being important for recovery in the Skagit basin and for which escapement numbers have declined since the 1970s (SRSC/WDFW 2005). Salmon production in the reach in general is believed to be limited by bedload transport and sedimentation, albeit to a lesser extent than for fish spawning below the Suiattle River. It is generally believed that spawning habitat in the lower Sauk River is among the poorest in the system for incubation survival, and fine sediment levels are generally high throughout the reach.

Declines in escapement in the reach may not necessarily reflect a decline in spawning or rearing habitat quantity, however, where Chinook production is not thought to be limited by side channel area. Flooding-related impacts to incubation success appear to be more important than effects of fine sediment loading (SRSC/WDFW 2005). Severe channel changes and bed disturbance have occurred in the reach in response to particularly the December 1980, October/November 2003, and November 2006 events.

Overall, sediment transport is an important process in the reach. Flooding impacts to salmon and humans alike are strongly influenced geomorphically by the sediment load. The typical heavy fine and coarse sediment load passing through and/or depositing, including material originating from the Whitechuck River after heavy mass wasting in 2003, continues to influence channel migration and erosion processes in the reach, by promoting conditions suitable for channel wandering and avulsion.

The recovery plan advocates floodplain restoration as an action that mitigates the impacts of flood flows on Chinook salmon (SRSC/WDFW 2005). The work and results described in this memorandum can be used to assess opportunities and risks of specific floodplain restoration activities, as well as more general risks to floodplain development and infrastructure. To accomplish this, a strategy was employed of identifying the extent to which shorter, distinct segments within the reach are geomorphically active (or inactive) in terms of sediment transport, deposition, channel migration, and overall erosion tendency. This strategy allowed evaluation of specific locations on the floodplain in the context of local and reach scale constraints. In addition, the results facilitate explanation of the physical cause of specific effects to infrastructure and private land in an intuitive way to stakeholders.

METHODS

A suite of analyses was selected over focusing on a specific method, any one of which on its own would provide some information but would not yield a sufficiently complete picture. Quantitative, process-based analyses (e.g., sediment transport modeling, bank migration rates, gravel bar areas) were favored over channel form (e.g., see Kondolf et al., 2001) or process-based classifications (e.g., channel migration zone mapping; Rapp and Abbe, 2003), so that the results could be used to better answer the question, “What would happen if…” The analysis involved identifying and quantifying (1) physical processes that influence reach channel morphology, (2) hydraulic and sediment transport processes that will affect future condition and channel location in the reach, and (3) the most geomorphically active and inactive segments in reach. To accomplish these tasks, information was analyzed that was critical for assessing processes acting at the reach and site scales (Wissmar and Beschta, 1998; Kondolf, 2000): (1) longitudinal profiles of elevation, gradient, and grain size distributions, (2) hydraulics and hydrology using HEC-RAS, USGS gage data, and surveyed cross-section and flood stage data, (3) bedload transport potential based on a 50-year duration, and (4) aerial photographs for changes in active channel locations and cumulative active gravel bar storage and side channel areas. Important details of the methods are described below.

Longitudinal Profiles

Longitudinal profiles provide an indication of effects of large scale slope changes on sediment transport and deposition patterns. Water surface and thalweg elevation profiles were developed for the reach using the HEC-RAS model data and predictions for the 2-yr flood event. Elevations were also derived from USGS 1:24,000 scale topographic maps for comparison. The HEC-RAS model water surface elevation data were also used to generate stream gradient profiles. Non-vegetated, active channel widths were estimated at each HEC-RAS cross-section from georeferenced aerial photographs taken in 2004, and plotted against river mile (RM).

A total of 24 pebble counts were sampled to characterize upstream-downstream variation in grain size and depositional patterns in the reach. It was generally not feasible to collect data near the thalweg given channel size. Instead, a sample size of 100 stones was selected randomly by moving over the mid-point of active depositional point bars between the water and floodplain and measuring the intermediate axis diameter of each stone. Sampling locations were selected to be geomorphically similar in terms of bar type and relative location on the bar, so that observed longitudinal variation in grain sizes would not reflect locally variable depositional processes, but rather larger scale geomorphic variation. Various percentile particle sizes, including D_{50} (size for which 50 percent of stones were smaller), were computed for each sample and plotted against river mile. Inspection of the longitudinal scatter in D_{50} and D_{90} values indicated that there were three sub-reaches in the plot. Pebble count data were accordingly pooled within each sub-reach to develop grain size distributions. The resulting three grain size distributions were applied across to subsections of the reach modeled in the sediment transport analyses.

Sediment Transport Modeling

HEC-RAS Model Geometric Data

A HEC-RAS steady flow model was constructed to simulate flood flows and predict longitudinal shear stress variation for estimating bedload transport rates and their effect on a coarse sediment budget within the reach. The model was built using bathymetric longitudinal and cross-section profile data collected in the field by County staff, and LIDAR data. All elevations were calculated relative to the NAVD 88 vertical datum. Benchmarks were established and tied-in using real time kinematic (RTK) GPS and a total station. Profile data were collected using a raft that was rowed across channel. Cables were not used to maintain position, and thus the data did not represent a perfectly straight line, which is needed for computing flow rate and stage in HEC-RAS. Elevations were computed by subtracting the water depth from the water surface elevation, which was determined using RTK GPS. The bare earth model LIDAR data were used to complete dry-land portions including exposed bars, side channels, and the floodplain.

The HEC-RAS model extended from the Clear Creek Park put-in to the mouth of the Suiattle River. The reach was modeled assuming flow accretion was minor between Clear Creek and the Suiattle River. The upstream and downstream boundary conditions were approximated using the normal depth assumption in lieu of having measured rating curves. Transect spacing was specified in the HEC-RAS model for the channel centerline, and shoreward of the left and right banks. Transect names were set equal to centerline stationing using a river mile designation. Left and right bank longitudinal stationing was measured on scaled color aerial photographs using GIS. Ineffective flow areas were specified at most transects to help distribute the flow better or to delay engagement of side channels and floodplain areas until higher flows, based on review of aerial photographs and assessing land cover and side-channel size characteristics. The model also integrated cross-section data developed by Northwest Hydraulic Consultants (nhc) for design of the Darrington bridge replacement. The data were provided to R2 and blended into the model.

The model cross-sections, excluding the nhc data, defined “analysis segments” for which other quantities were calculated (e.g., bank migration rate, gravel bar area; Figure 2). Table 1 lists the 2004 main channel river mile for each HEC-RAS model transect defining an analysis segment. Segment 19 includes the bridge analysis cross-sections, and was later divided into two sub-segments extending respectively above and below the Darrington bridge.

HEC-RAS Model Calibration

The HEC-RAS model was partially calibrated using water surface elevations surveyed for four flows, 7,846 cfs, 10,002 cfs, 10,487 cfs, and 48,306 cfs, with discharge magnitude estimated for the former USGS gage located at Darrington (Station No. 12187500; see below for estimation details). Because of various field measurement limitations, most water surface elevations were determined above Dan Creek at the lower flow range. Two of the flows corresponded to real time elevations surveyed during floats (January and November 2006), and the other two to observed high water marks that occurred a short time previous to each float. The November 2006 data corresponded to a flood with an approximately 40-50 year recurrence interval depending on location in the Sauk River basin, and was thus representative of hydraulic conditions and coarse bedload transport during extreme events.

The reach was floated within a week or so of each peak, and flood marks discerned in the field were surveyed using RTK GPS, with vertical errors ranging between less than 0.5 feet to more than 3 feet depending on satellite availability. Additional source of error included channel changes occurring after the November 2006 flood, but while the position of the river may have changed dramatically, the general longitudinal profile would not be expected to change substantially such that high water marks should be generally representative of floodplain inundation levels irrespective of where the channel is located. This assumption seems reasonable for purposes of obtaining an approximately calibrated HEC-RAS model to predict longitudinal variation in sediment transport potential; the model should not be considered accurate for predicting water levels that can be used to delineate the 100-year floodplain, however, without additional field data collection and calibration of floodplain inundation levels.

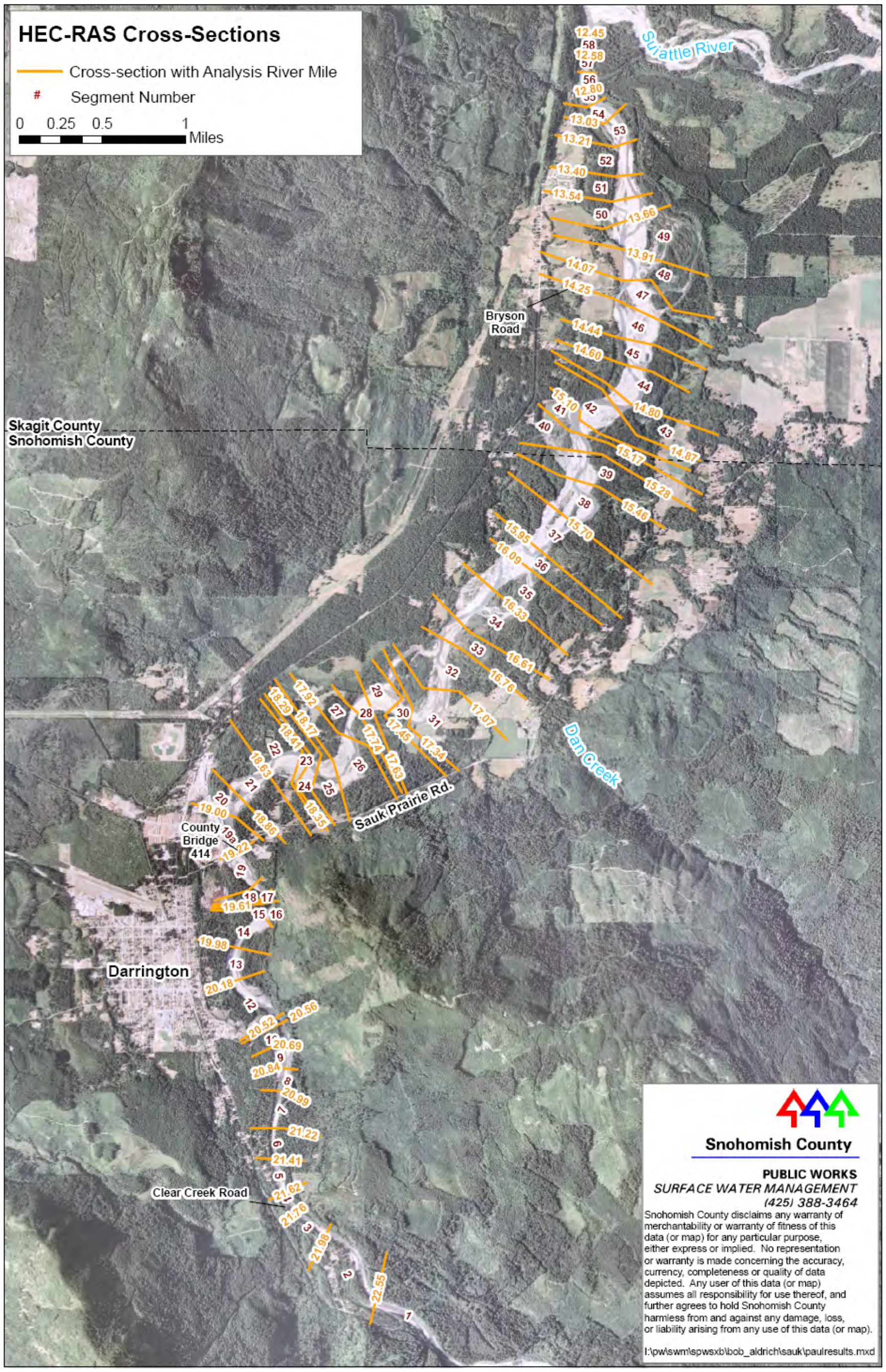


Figure 2. Location of HEC-RAS transects and corresponding analysis segments established to compare sediment transport, channel migration, and other analysis results.

Table 1. River mile system used in the analysis.

Analysis Segment	HEC-RAS 2004 River Mile (Upper Boundary)	Landmarks
1	Na	
2	Na	
3	21.98	
4	21.76	Adjacent to Clear Cr Rd (L Bank)
5	21.62	
6	21.41	
7	21.22	
8	20.99	
9	20.84	N Sauk R Rd Washout (R Bank)
10	20.69	
11	20.56	
12	20.52	
13	20.18	
14	19.98	
15	19.72	
16	19.61	River Choke Point
17	19.58	River Choke Point
18	19.55	
19	19.46	Above Darrington Bridge (414)
19a	19.23	Below Darrington Bridge (414)
20	19.00	
21	18.86	
22	18.64	
23	18.41	
24	18.35	
25	18.29	
26	18.17	
27	17.92	
28	17.74	
29	17.64	
30	17.45	

Table 1. River mile system used in the analysis.

Analysis Segment	HEC-RAS 2004 River Mile (Upper Boundary)	Landmarks
31	17.34	
32	17.07	
33	16.76	
34	16.61	
35	16.33	
36	16.09	
37	15.95	Dan Creek
38	15.70	
39	15.46	County Line
40	15.28	
41	15.17	
42	15.10	
43	14.87	
44	14.80	
45	14.60	
46	14.44	
47	14.25	Bryson Rd
48	14.07	
49	13.91	
50	13.66	
51	13.54	
52	13.40	
53	13.21	
54	13.03	
55	12.90	Hwy 530
56	12.80	
57	12.69	
58	12.58	
59	12.45	Suiattle R Confluence

Peak flood stage marks were indicated as wash and debris lines on exposed soils and sand, debris lines in vegetation, vegetation filaments on trees, logs and moss, differential discoloration of tree trunks, erosion of moss on trees, and other indicators. Multiple signs were identified at each cross-section location, and agreed on by three persons as being suitable estimates of the peak stage.

Calibration focused first on establishing the order of magnitude of Manning's n-values occurring at the November 2006 peak flow level. Predicted water surface elevations were compared with the few surveyed values available to estimate the approximate magnitude of n for high flow in the main channel. The model was then recalibrated to the 7,846 cfs flow level, for which a larger number of survey data were available, via adjustments of Mannings n, expansion, and contraction coefficients of the measured transects until the predicted water surface elevation was similar to the measured. Empirically-based relationships were then derived from geomorphology literature for the sub-reaches above and below the Darrington Bridge that described the expected change in Manning's n with discharge. The relationships were used to estimate an appropriate multiplier for the low flow (7,846 cfs) calibration n-values, resulting in estimated main and side channel n-values for the high flow (48,306 cfs) model as follows:

Upstream of Darrington Bridge: $n|_{High\text{-}Q} = 0.45\ n|_{Low\text{-}Q}$ (1a)

Downstream of Darrington Bridge: $n|_{High\text{-}Q} = 0.63\ n|_{Low\text{-}Q}$ (1b)

The estimated values were compared with the rough values determined initially for the high flow calibration. The estimated values were found to be similar in magnitude to the initial high flow calibration values, and thus were considered suitable for modeling of sediment transport flows.

The model was calibrated and run using the interpolated transect feature of HEC-RAS. The extra transects were needed because there was considered to be too much head loss between measured transects. Adding extra transects stabilized the model better by smoothing between-transect changes in depth and velocity, and distributing energy losses across shorter model segments. Interpolated transects were generally spaced approximately 200-300 ft apart, resulting in drops in water surface elevation between transects generally equal to about 1.0 ft or less at flood stage, a resolution considered sufficient for the river size.

Sediment Transport Simulation Flows

The USGS gage at Darrington has a limited record covering the periods of 1917-22 and 1928-32. The record of the gage at Whitechuck (1218600) extends from 1917-22 and 1928-present. An analysis of available gage data indicated that peak unit runoff (peak cfs/mi^2) at the Darrington gage was closer to that at the Whitechuck gage compared with other gages in the Sauk River basin. To estimate flows in the model reach, flows from the Darrington gage were thus reasonably correlated with flows at the Whitechuck gage. Because high flows were of greatest interest for sediment transport modeling, the instantaneous peak flow records were regressed to generate a conversion relation for flows at the two gages (Figure 3). The resulting relation appeared to fit well through the scatter of mean daily flow data as well, particularly over the high flow range (Figure 4).

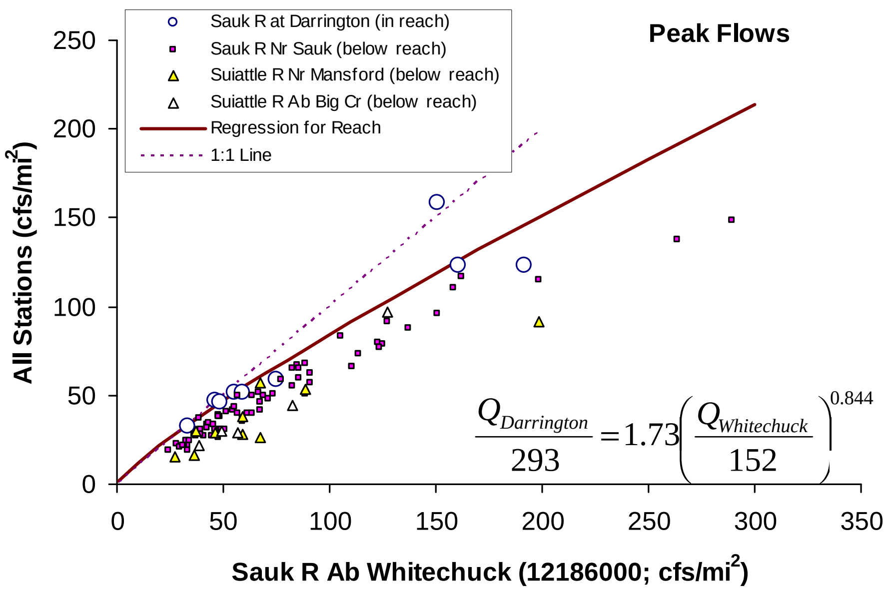


Figure 3. Comparison of peak runoff data and resulting regression curve for instantaneous peak flows at the USGS stream gages on the Sauk River near Darrington and above the Whitechuck River.

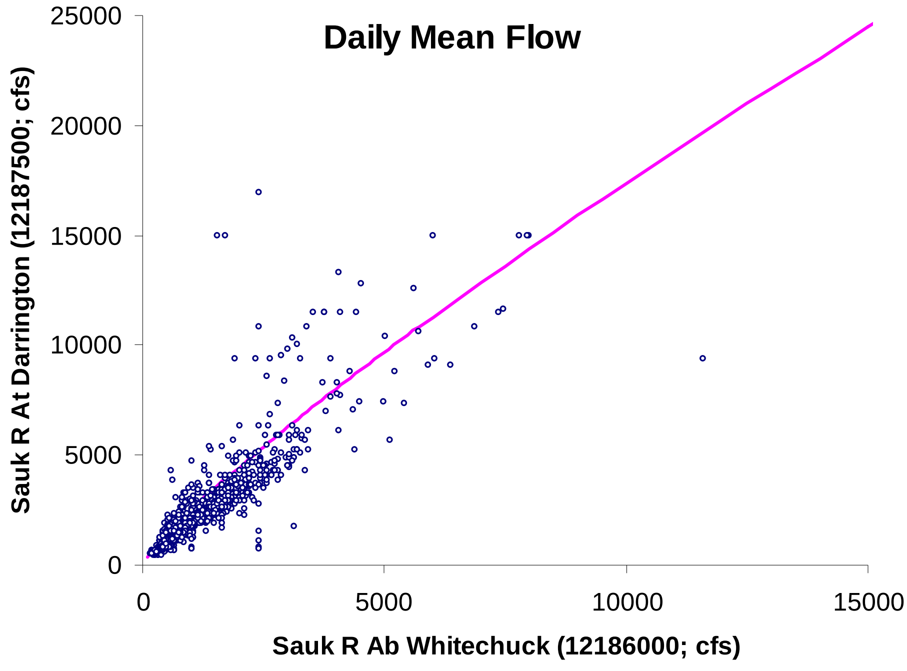


Figure 4. Comparison of regression curve for peak flows with mean daily flows at the USGS stream gages on the Sauk River near Darrington and above the Whitechuck River.

A flow duration curve was generated for the Sauk River Whitechuck gage using available daily mean flow data for the period of record. The curve was converted to a duration curve for the Darrington gage using the regression, and discretized into a histogram approximating the duration of various simulation flow magnitudes as a percent of the length of the record. The distribution of flows was determined based on matching total volume under the curve and total number of days over a 50-year period while also approximating the curve shape.

Sediment Transport Analysis

The simulation flows were modeled in HEC-RAS using the steady flow option, for a series of discharges equal to and greater than the 5 percent exceedance flow, up to the 50 year flood. Relatively little bedload transport occurs in general in alluvial rivers when discharge is below the 5 percent exceedance flow. A 50-year period was simulated to predict the total volume of bedload transported at each HEC-RAS transect and evaluate corresponding long term depositional and erosional trends in the reach over a representative project design life.

The HEC-RAS main channel shear stress predictions were input with grain size distribution data to a Fortran program that predicted sediment transport rate per unit width based on Parker's (1990) bedload transport equation. An approximate sediment budget was developed to characterize analysis segments within the reach regarding their deposition or erosion tendencies, and use that knowledge as a guide to the type of project that may or may not succeed in the segment. For example, fish habitat structures would not be expected to succeed in an analysis segment that was predicted to strongly experience a net gain in sediment over time, because the structures would have a higher risk of burial or abandonment by the river.

The sediment budget was computed for each flow and analysis segment by estimating sediment transport rates at the bounding upstream and downstream HEC-RAS cross-sections, and applying a mass balance equation for bed elevation change between transects as a function of estimated input and output bedload mass transport rates per unit width (q_B), active width (W), distance between transects (L), sediment density (ρ_s), and porosity (P) (DeVries, 2000):

$$Y_T = \int_{t1}^{t2} \frac{\partial Y}{\partial t} dt \cong -\sum_{t1}^{t2} \left[\frac{(q_B W)_{out} - (q_B W)_{in}}{0.5L(W_{in} + W_{out})\rho_s (1-P)} \right] \Delta t \qquad (2)$$

where the incremental change in bed elevation ($\partial Y/\partial t$) was evaluated for each simulation flow and then multiplied by the histogram time increment (Δt) over which the modeled flow occurred during the 50-year period. This was repeated for other flows, and the results summed to estimate a net mean change in bed elevation Y_T between successive HEC-RAS transects. A strongly positive value of the $\partial Y/\partial t$ sum was inferred as an indication of a strong tendency towards aggradation, and a strongly negative value as an indication of a stronger tendency towards degradation (at the same time recognizing that the reach as a whole is aggradational in nature).

The active width used in Equation (2) was specified as the smaller of the wetted main channel width computed by HEC-RAS and an active bottom width in the main channel as judged from a review of cross-section profile morphology and the scaled 2004 aerial photographs. Length was set as the main channel distance between HEC-RAS transects.

The resolution of the HEC-RAS modeling and physical characteristics of the modeled reach were such that predictions of bed elevation change at several pairs of adjacent analysis segments were strongly negative for the upstream segment and strongly positive for the adjacent downstream segment. This phenomenon appeared to reflect locations where the river flow was predicted to experience substantial energy losses due to channel expansion or contraction and directional changes in flow. The HEC-RAS model hydraulic predictions at these locations were characterized in turn by relatively irregular longitudinal trends in velocity and Froude number over short distances. To resolve this, the two analysis segment predictions of bed elevation change were combined using the following weighted formula based on computing total volume between three successive transects consecutively numbered 1, 2, and 3:

$$Y_{T1-3} = \frac{Y_{T1-2} L_{1-2} (W_1 + W_2) + Y_{T2-3} L_{2-3} (W_2 + W_3)}{L_{1-2} (W_1 + W_2) + L_{2-3} (W_2 + W_3)} \qquad (3)$$

Seven classes were developed subsequently and used to characterize deposition trends based on the sign and magnitude of the predicted bed elevation change (Table 2). Each analysis segment was classified accordingly and the results depicted graphically in ARC-GIS.

Table 2. Predicted bed elevation change rate and sign used to classify analysis segments according to sediment transport and deposition characteristics in the Sauk River between the Suiattle River and Clear Creek.

Aggradation Potential Class	Bed Elevation Change Rate (ft/yr)
1	< −1.0 (Extreme Degradation Potential)
2	−1.0 to −0.20 (High Degradation Potential)
3	−0.20 to −0.05 (Moderate Degradation Potential)
4	±0.05 (Minor Change)
5	0.05 to 0.20 (Moderate Aggradation Potential)
6	0.20 to 1.0 (High Aggradation Potential)
7	> 1.0 (Extreme Aggradation Potential)

Aerial Photograph Interpretation

Aerial photographs were available from 1949, 1964, 1974, 1981, 199, 1998, and 2004 (Table 3). The photographs were orthorectified, mosaicked, and georeferenced. The reach was divided into 'analysis segments' using the hydraulic modeling transects as boundaries. This permitted a common framework for synthesizing the results from the various analyses. Spatial and temporal patterns in channel migration rate and gravel bar area were used to infer relative stability of specific analysis segments of the Braided Reach associated with varying geomorphic activity levels.

Historic Channel Planform Mapping

Right and left river bank locations were digitized by the Skagit River System Cooperative's GIS specialist for each year photographs were available. Main and major side channels were mapped. The resulting digitized poly lines were overlaid chronologically and locations compared between consecutive sets of photographs. Migration rates were estimated as the local average offset distance within an analysis segment between successive main channel river bank traces, divided by the number of years between the two sets of photographs. The visual changes and calculated migration rates were used as the basis for classifying an analysis segment according to planform changes, tailored to rates observed in the reach (Table 4).

Table 3. Dates and approximate flow rates of available aerial photography for mapping channel planform and gravel bar area changes in the Sauk River between the Suiattle River and Clear Creek (provided by Kate Ramsden, Skagit River System Cooperative). The width adjustment factor was used to adjust computed gravel bar areas to a common flow level.

Year	Flight (Source)	Date	Scale (Black/White or Color)	Estimated Mean Daily Flow at Darrington (cfs)	Width Adjustment Factor	
					Above Darrington Bridge	Below Darrington Bridge
1949	DIL (Forest Service)	9/20/1949	1:12000 (BW)	2,289	1.36	1.16
1964	EMM (Forest Service)	7/23/1964, 7/24/1964	1:12000 (BW)	4,009	3.47	2.23
1974	S74097 (Army Corps of Engineers)	11/29/1974	~1:10000 (BW)	1,854	1.00	1.00
1981	S81005 (Army Corps of Engineers)	3/2/1981	~1:10000 (BW)	1,752	0.95	0.97
1992	Wild and Scenic River Flight 0032 MB (Forest Service)	8/15/1992	1:8000 (Color)	916	0.60	0.74
1998	98136-MBS (Forest Service)	7/20/1998	1:9600 (Color)	1,644	0.90	0.95
2004	04009-04010-04011 MBS (Forest Service)	6/16/2004	1:8000 (Color)	3,185	3.15	1.83

Table 4. River channel migration rate classification for assessing channel planform changes. Migration may be to either left or right bank directions.

Planform Change Index	Average Migration Rate (ft/yr, one or both banks)
1	< 15 (minor change)
2	15-30 (small change)
3	30-80 (moderate change, wandering tendency)
4	>80 (severe change, braiding tendency)

Gravel/Sand Bar and Side Channel Area Mapping

Exposed main channel gravel/sand bar and clearly visible side channel areas were digitized from the aerial photographs as discrete polygons. Most bars were point bars, although mid-channel bars were also mapped at specific locations where the channel widened substantially so that flow depth was very shallow across the hydraulic control formed by depositing coarse bedload. The reach was divided in each set of aerial photographs into 152 m (500 feet) long segments so that small scale gravel bar features would not be missed. The area of gravel bar mapped in each segment was then computed and summed cumulatively from upstream to downstream in ARC-GIS to reflect the direction of sediment transport and deposition. A running sum was computed for the main channel; separate sums were computed for major side channels, with the river mile determined by the location at which the side channel branched off from the main channel.

Not all of the aerial photographs were taken at similar flows, and differences were expected in gravel bar areas due to differential inundation. The adjustment was done for these and the other flows by calculating wetted width (W_{wet}) as a function of flow in the HEC-RAS model. The following multiplier was computed for each transect:

$$W_{GBref} = W_{GB}\left(\frac{W_{\max} - W_{ref}}{W_{\max} - W_{wet}}\right) \qquad (4)$$

The multiplier effectively converted measured gravel bar widths (W_{GB1}) to the equivalent width for the flow at which the 1974 photographs were taken (W_{GBref}; where corresponding wetted width = W_{ref}). The 1974 photographs were selected as the common basis because the flow that year was in the middle of the spread in Table 3. The maximum channel width (W_{max}) was the greater of the wetted width predicted by HEC-RAS for the 4,009 cfs flow rate and the active width determined for the sediment transport analysis. The average multiplier was calculated for each flow over all transects (Table 3) and used to adjust the gravel bar and side channel area values digitized from a particular set of aerial photographs.

Areas were converted to an equivalent mean width within each analysis segment by dividing the area by segment centerline length. This allowed for making comparisons across different years without the influence of changing thalweg lengths (e.g., associated with channel migration). Locations were identified where mean widths changed by more than 100 ft between photographs, indicting a change in storage and erosion activity. Each analysis segment was classified according to whether or not a substantial change in mean width of active bar or side channel slope occurred, and whether the change represented an overall decrease or increase in area between successive photographs. The resulting classifications were coded for each analysis segment and presented spatially in GIS format.

RESULTS

Longitudinal Profiles

The longitudinal profile of the Sauk River is mildly concave within the analysis reach and exhibits two large scale break points in slope, located in the vicinity of the Darrington Bridge (located at Analysis RM 19.22) and Dan Creek (~RM 15.7; Figure 5). Channel width generally increases in the downstream direction to below Dan Creek, and then quickly narrows at the downstream end of the braided reach (Figure 6).

In general, the grain size distribution became progressively finer in the downstream direction (Figure 7), reflecting the longitudinal profile concavity (Figure 5). At the same time, the grain size distribution profile appeared to reflect breaks at about the same locations depicted for slope in Figure 5, resulting in identifying three sub-reaches (Figure 7). The pooled grain size distributions for each sub-reach are depicted in Figure 8. Figure 8 also depicts the range of Chinook salmon and steelhead trout spawning habitat D_{50} values reported by Kondolf and Wolman (1993) in their review. Substrates appear most suitable for Chinook mainstem spawning in the sub-reaches below the Darrington Bridge.

Sediment Transport Modeling

<u>*HEC-RAS Model Calibration*</u>

The HEC-RAS model was calibrated as closely as possible to the surveyed flood marks, which roughly paralleled water surface elevations surveyed at lower flows (Figure 9). Calibration errors were relatively high, but were within the range of water surface elevation measurement errors recorded for the RTK data (~+/-2-6 ft depending on location): differences between predicted and measured water surface elevations ranged from 3-8 ft, reflecting the uncertainty in the RTK data. However, two lines of evidence suggest that the final n-values selected were generally realistic, and that the difference between measured and predicted more likely reflected error in the measured values:

1) The final calibration values used for Manning’s n were those that minimized the mean water surface elevation prediction error along the reach; and
2) The magnitudes of predicted Froude numbers and mean velocities appeared reasonable for the calibration flows based on modeling experience in other, similar rivers.

The calibrated n-values therefore appeared reasonable for purposes of reach scale sediment transport budgeting.

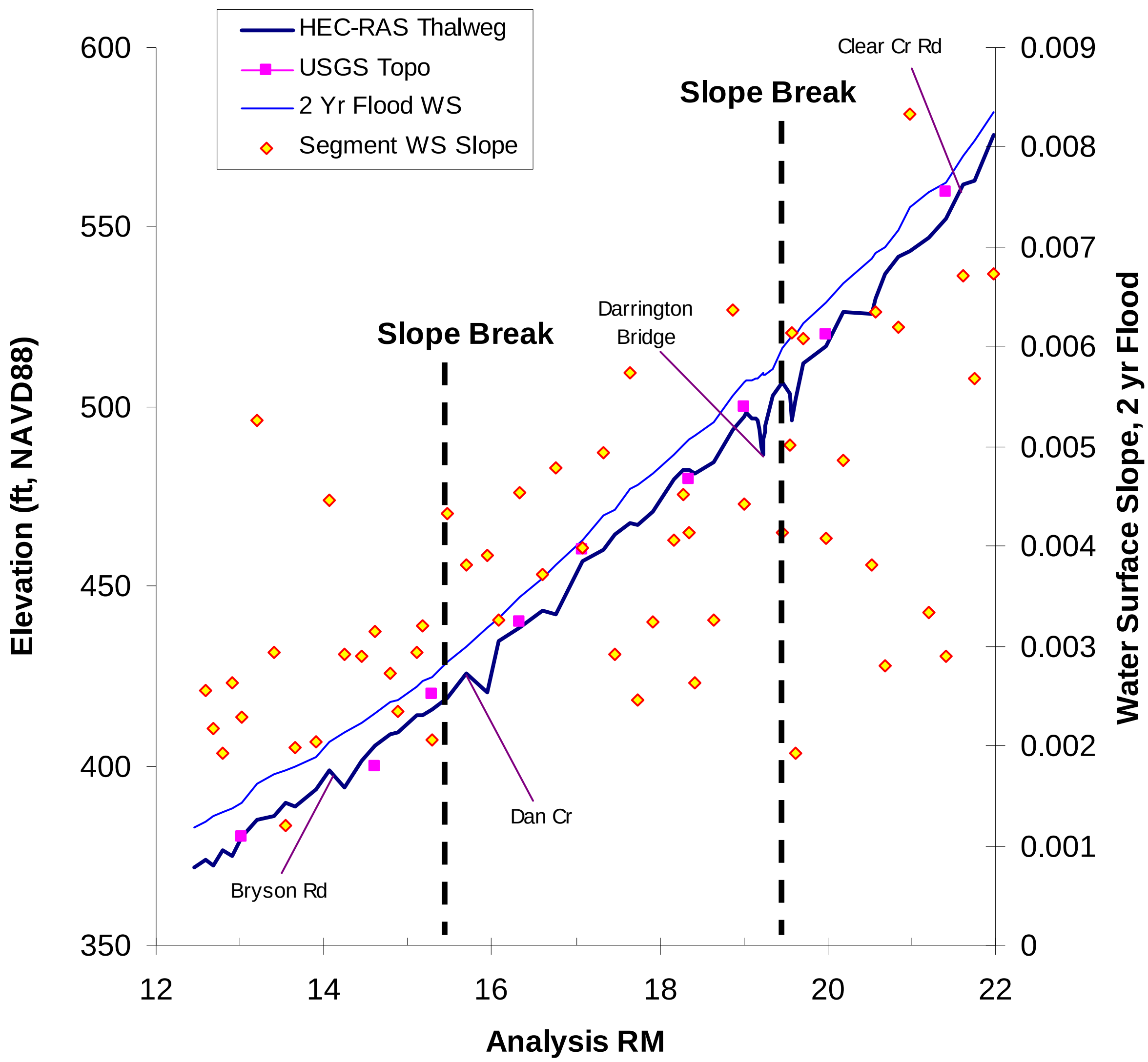


Figure 5. Longitudinal elevation and gradient profiles of the Sauk River from its confluence with the Suiattle River upstream to near the confluence with Clear Creek.

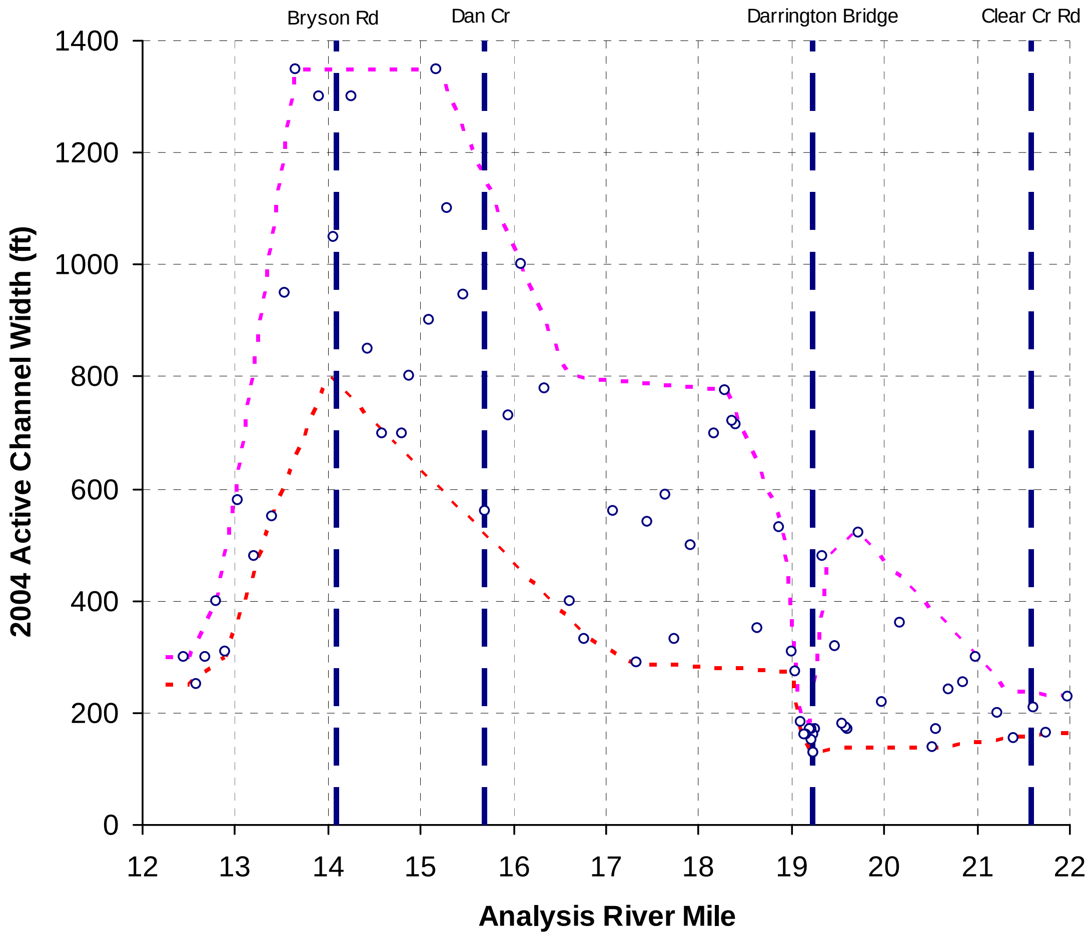
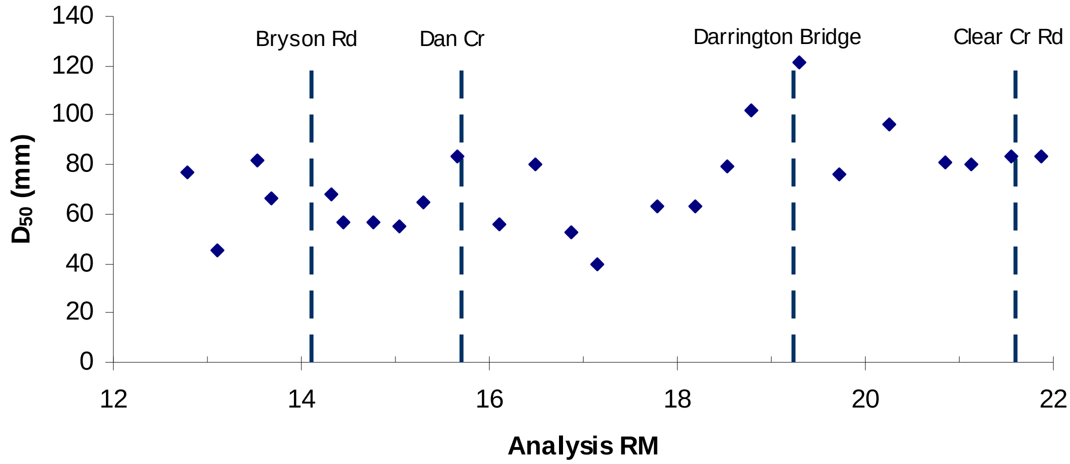


Figure 6. Longitudinal profiles of active channel widths in the Sauk River from its confluence with the Suiattle River upstream to near the confluence with Clear Creek. The lighter dashed lines approximately envelope the range of widths.



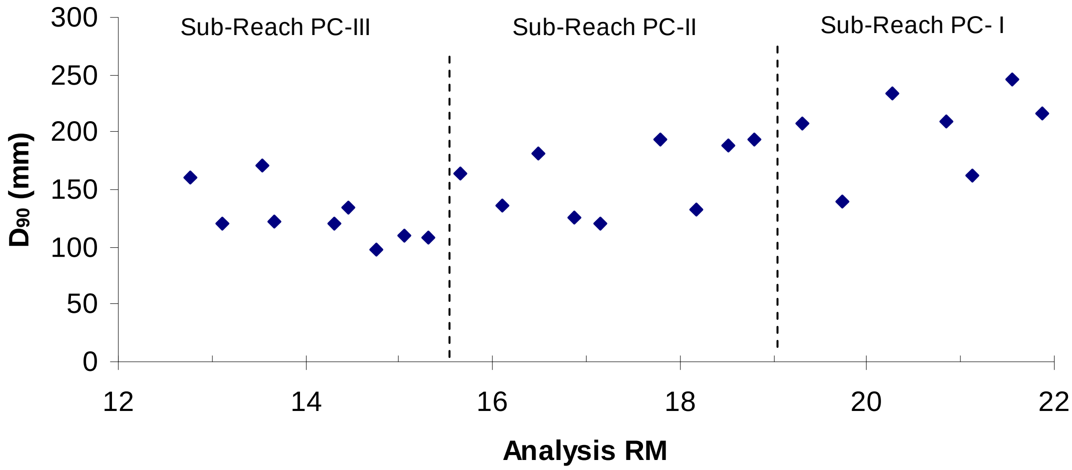


Figure 7. Longitudinal trends in selected grain size distribution percentiles measured on depositional surfaces in the Braided Reach (upper = D_{50}, lower = D_{90}), and corresponding sub-reach breaks in distributions suggested by scatter in the coarser percentile values.

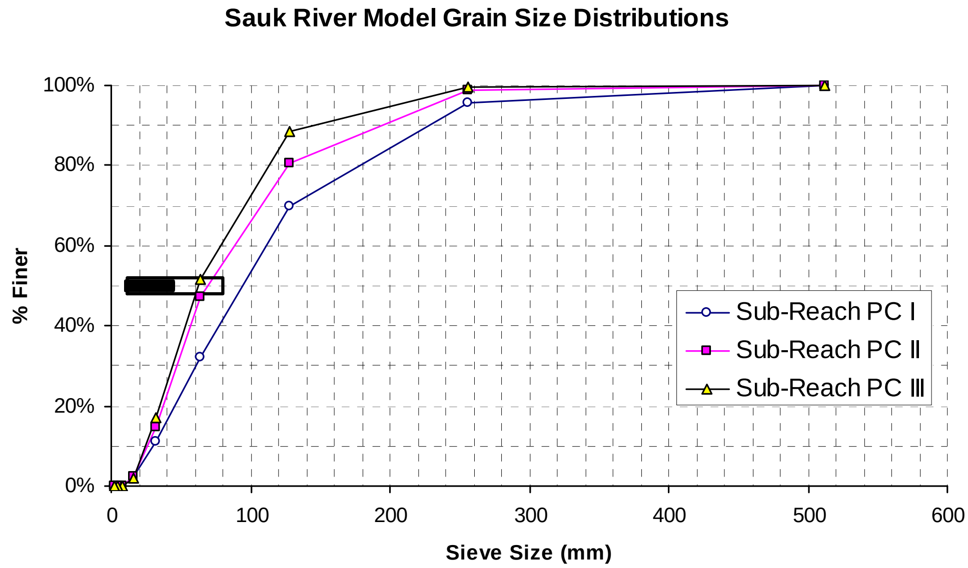


Figure 8. Grain size distributions of pebble counts collected in the Sauk River above its confluence with the Suiattle River. Horizontal bars represent range of D_{50}'s reported by Kondolf and Wolman (1993) as suitable for steelhead trout (filled bar) and Chinook salmon (open bar) spawning.

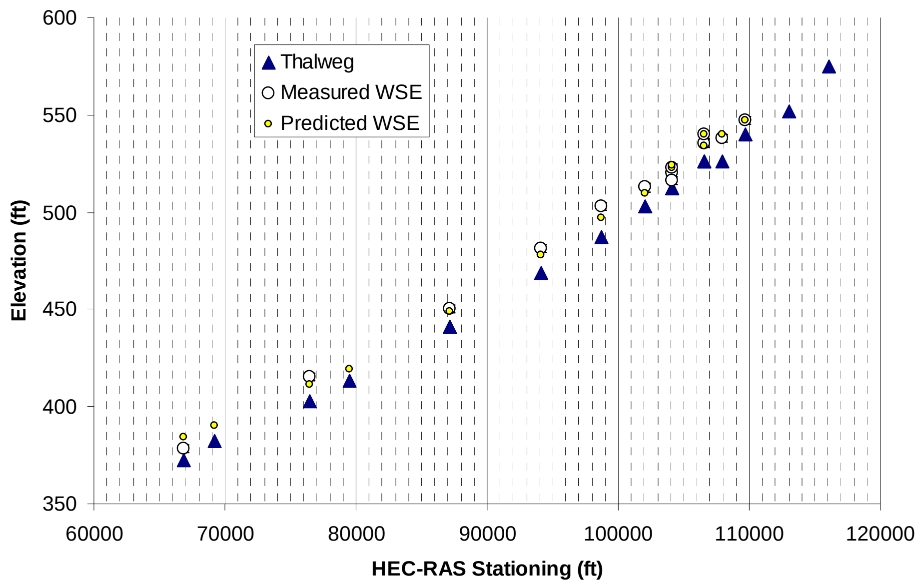


Figure 9. Results of HEC-RAS calibration to surveyed (large, filled circles) water surface elevations, pooled over the 7,846 – 48,306 cfs flow range.

Peak Flow Magnitude, Duration, Frequency

Table 5 summarizes Log Pearson III distribution flood frequency estimates for the Sauk River at Sauk and above the Whitechuck River gages, and regression estimates based on the line depicted in Figure 3 for the Darrington gage. Table 6 summarizes the flows selected for modeling in the HEC-RAS and sediment transport analyses, and their approximate duration.

Table 5. Approximate flood magnitudes estimated for various recurrence intervals at USGS stream gages maintained in the Sauk River.

Gage Name:	**Sauk River at Sauk**	**Sauk River at Darrington**	**Sauk River Above Whitechuck River**
Station No.:	12189500	12187500	12186000
Years Analyzed:	1911, 1928-2005	*na*	1917-2005
Recurrence Interval (years)	**Flow (cfs)**		
100	105,000	56,000	40,000
50	92,000	49,000	34,000
20	75,000	40,000	27,000
10	62,000	33,000	21,000
5	49,000	26,000	16,000
2	30,000	16,000	9,000

Table 6. Sauk River calibration and simulation flows modeled in HEC-RAS for the sediment transport analysis.

HEC-RAS Profile Name	**Percent Exceedance**	**Duration (days)**	**Model Flow (cfs)**
PF1	5	506	6217
PF2	1	268	9151
PF3	0.5	44	11047
PF4	0.4	24	11760
PF5	0.3	20	13040
PF6	0.2	18	14236
PF7	0.14 (~2-yr flood)	15	15891
PF8	0.1	11	17296
PF9	0.03 (~10-yr flood)	6	32996
PF10	0.01 (~25 year flood)	0.5	42326
PF11	0.005 (~50 yr flood)	0.5	49202

Sediment Transport Predictions

The HEC-RAS model resulted in extreme variation in predicted bedload volume gains and losses across adjacent analysis segments at two locations. Smoothing using Equation (3) resulted in a more reasonable appearing plot of predicted bed elevation changes based on Parker's (1990) bedload transport equation (Figure 10). Figure 11 depicts the corresponding spatial variation in aggradation and degradation potentials in the upper Sauk analysis reach. Sub-reaches are evident in which the relative magnitude of aggradation and degradation indicate greater erosion risk, particularly in the vicinity of Clear Creek Road and upstream of Dan Creek. The sub-reach below Dan Creek is characterized by relatively minor aggradation and degradation potential, which reflects a reduced sediment transport capacity associated with flow being more broadly distributed across multiple, wider, shallower, lower gradient channels compared with the river between Darrington and Dan Creek (cf. Figure 12) Such reaches generally process coarse sediment downstream more slowly. Erosion potential is described predominantly by channel migration, as shown in the next section below. There are more distinct sections where flow is deeper and more concentrated in sub-reaches upstream of Dan Creek. Aggradation/ degradation potential correspondingly has a more direct influence on the potential for erosion upstream of Dan Creek.

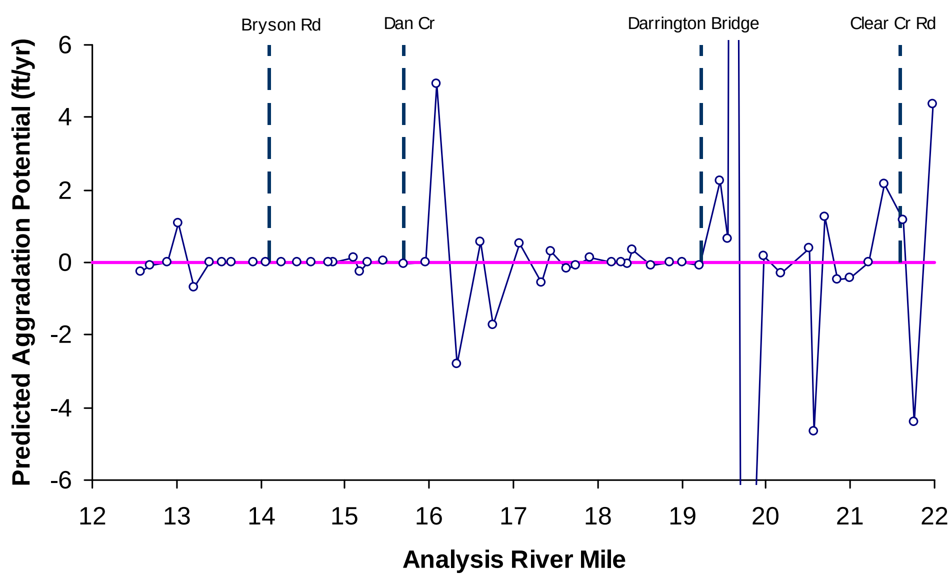


Figure 10. Longitudinal variation in predicted potential bed elevation changes within analysis segments over a 50 year period, as determined by evaluation of HEC-RAS hydraulic modeling output using Parker's (1990) bedload transport equation.

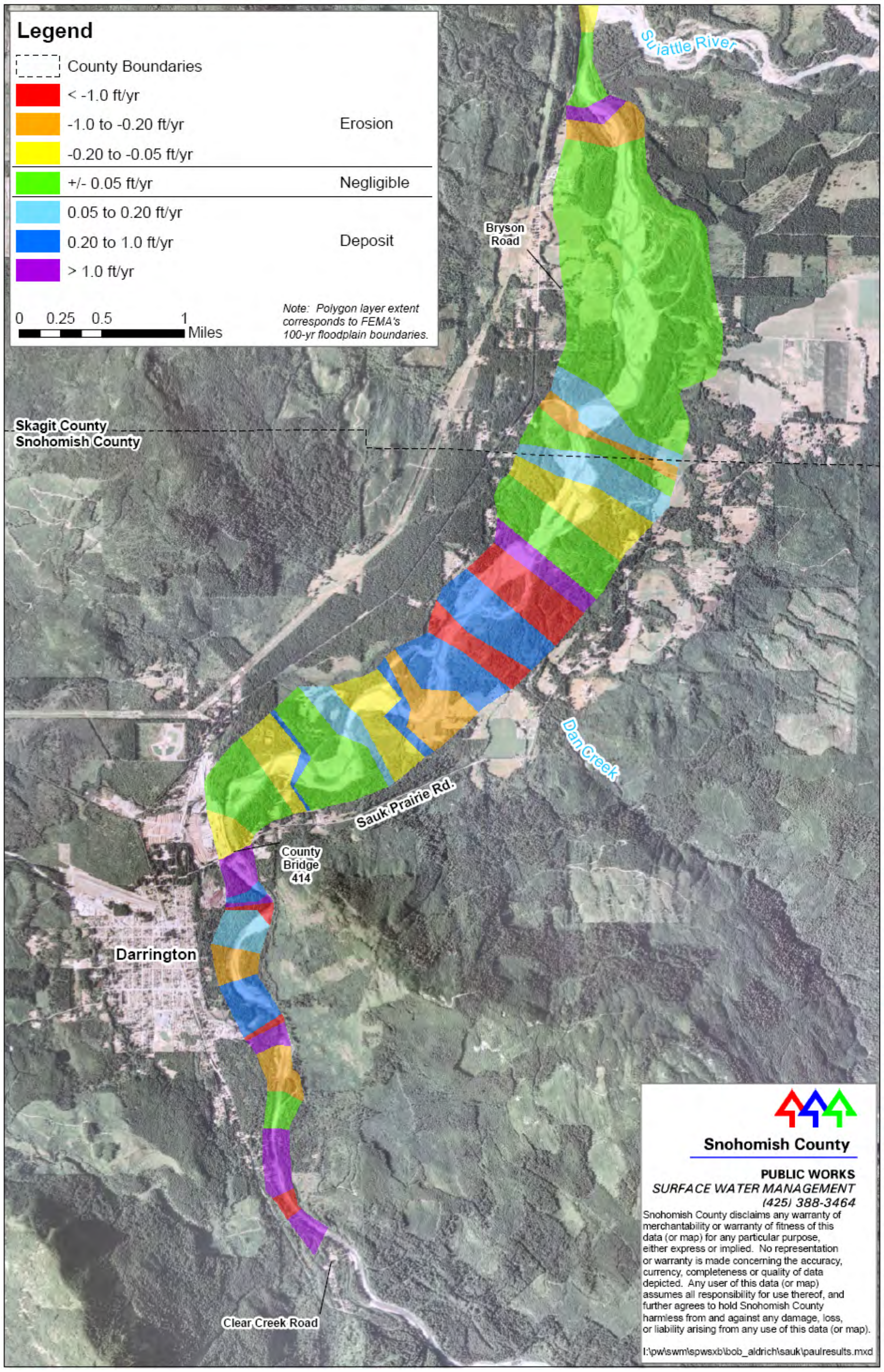


Figure 11. Spatial variation in erosional and depositional trends in the Sauk River above the Suiattle River as suggested by sediment transport modeling using Parker's (1990) bedload transport equation; classifications are as defined in Table 2. Lateral extent depicted is for FEMA 100 year floodplain boundaries.

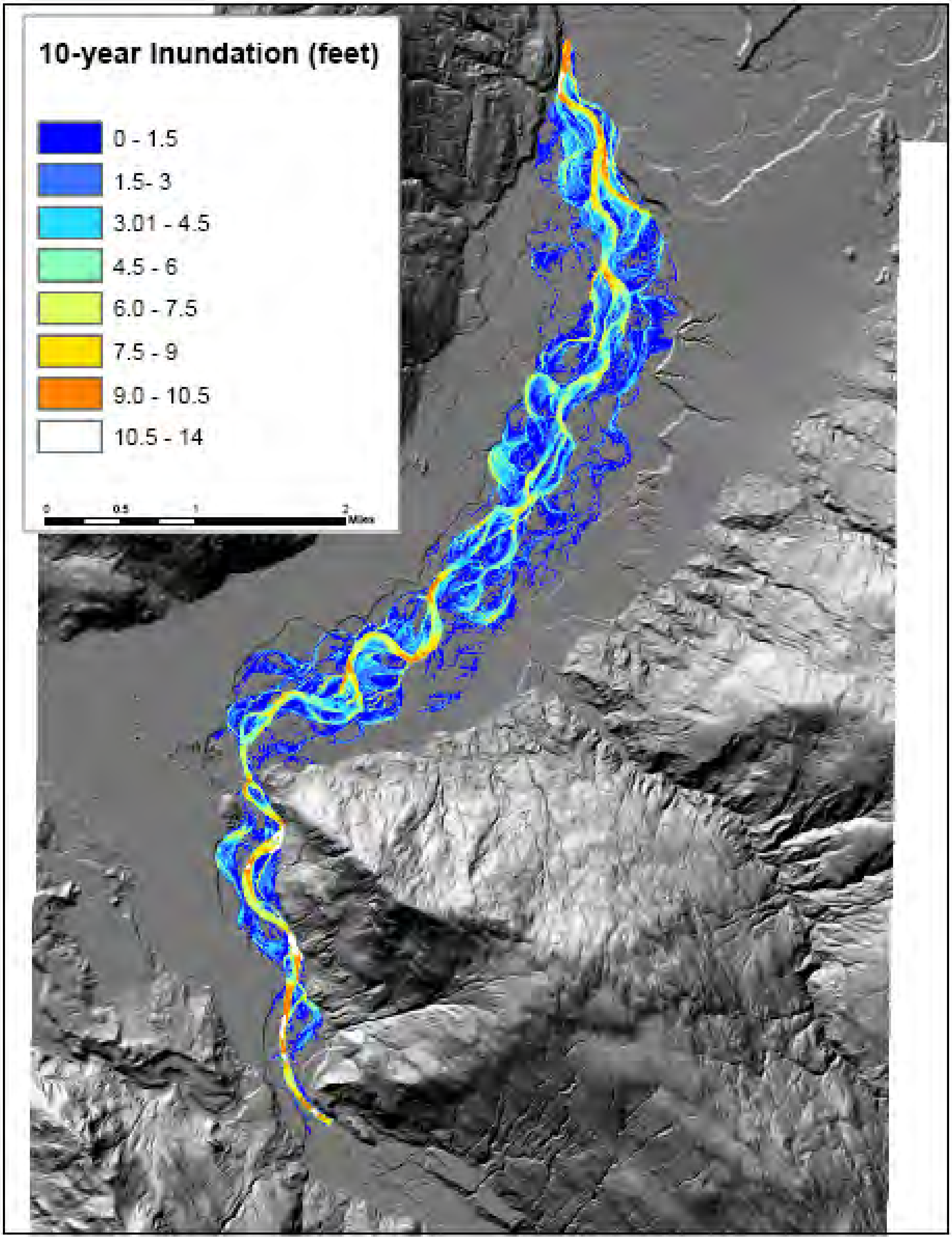


Figure 12. Water depth predicted for the 10-year flood, calculated as the difference between the water surface elevation predicted by the HEC-RAS model and the LIDAR ground elevation.

Channel Migration Patterns

The aerial photograph series provided a relatively periodic determination of channel location, with intervening periods associated with at least one large flood event occurring that exceeded the 2-year event level. The largest events occurred between the 1949-64, 1974-81, and 1998-2004 photographs (Figure 13). The aerial photography mapping and LIDAR data indicate that channel migration has been generally constrained within a narrow floodplain upstream of Darrington. Channel migration has also been relatively limited below about RM 13. Between Darrington and RM 13, the river planform and migration rate patterns are indicative of a transition from a wandering reach above about RM 18 to a braided reach below about RM 17 (Figures 14, 15).

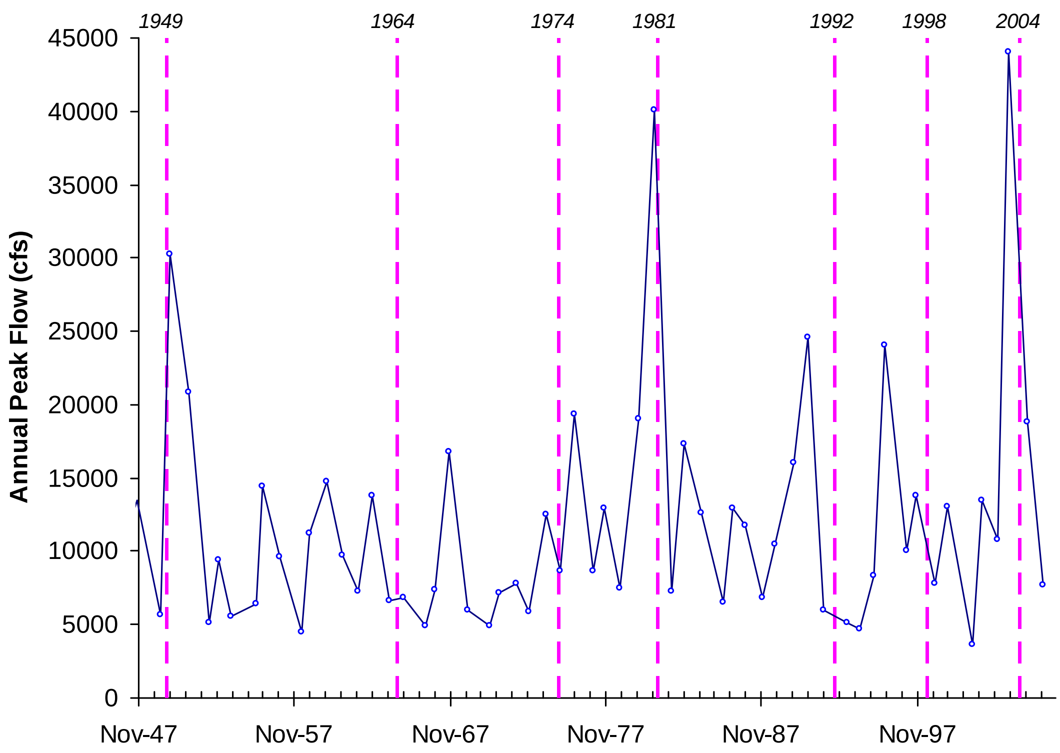


Figure 13. Annual peak flow time series encompassing the aerial photography date range, for the USGS gage Sauk River above Whitechuck (Station #12186000). Dates when each set of aerial photographs were taken are indicated by the dashed vertical lines.

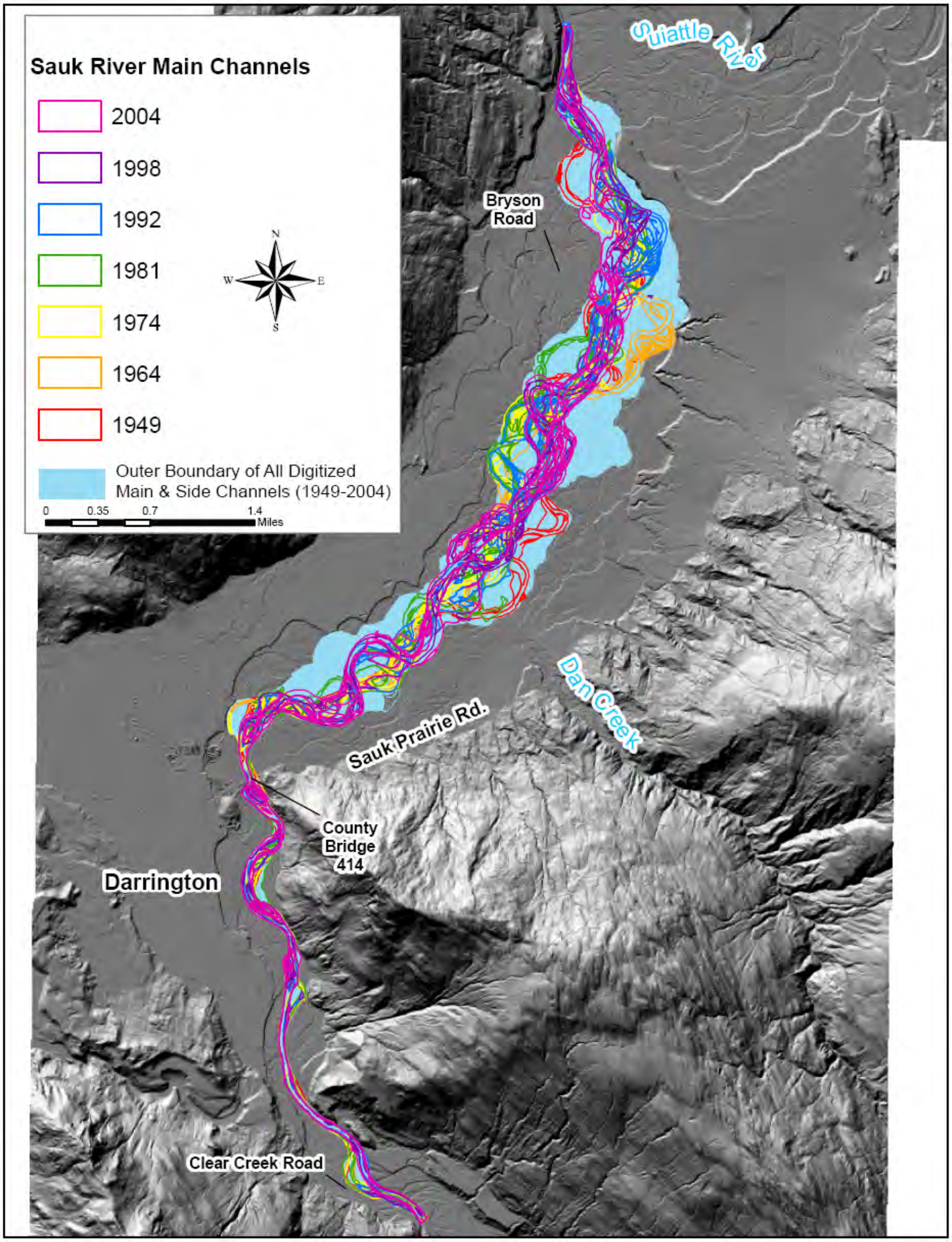


Figure 14. Locations of the main channel of the Sauk River in each set of aerial photographs analyzed for Phase 1. Mapped extent of side channels is indicated by shading.

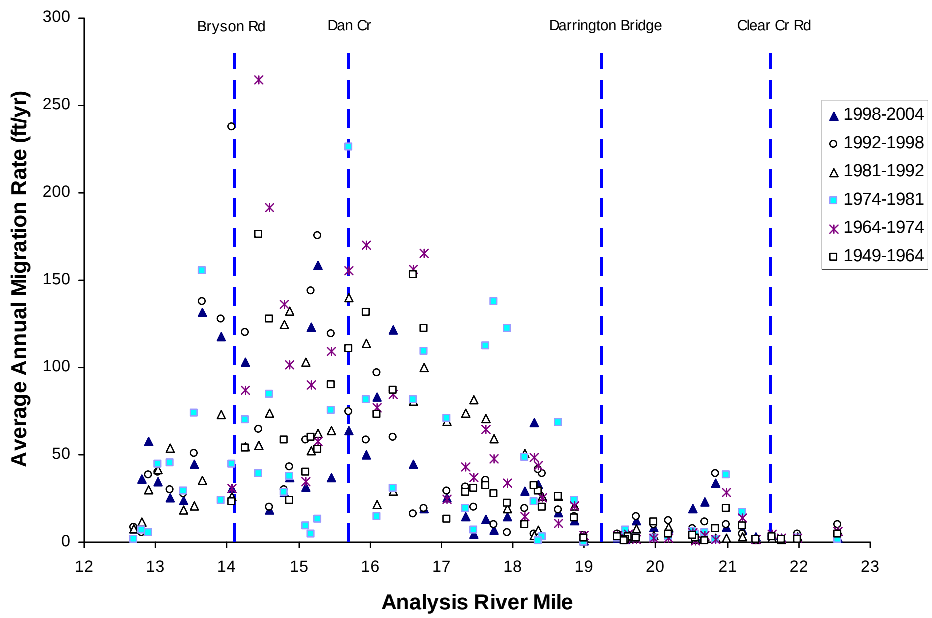


Figure 15. Average annual migration rates of the main channel, computed for each Phase 1 analysis segment of the Sauk River based on the digitized traces from the aerial photographs.

The migration rate patterns depicted by the data scatter in Figure 15 indicate sub-reaches consistent with the longitudinal profile and sediment transport analysis results. In particular, the pattern by which the limiting migration rate varies along the river is consistent with the pattern of channel widths in Figure 6 (Figure 16). There is a clear break in the scatter of migration rate data in the vicinity of the Darrington bridge. Migration rates upstream of the bridge are generally low, reflecting the confined, mostly meandering nature of the channel. Migration rates between the bridge and ~RM 18 are generally comparable to or somewhat greater in magnitude than rates calculated for upstream. This sub-reach corresponds to analysis segments where the river appears to be primarily wandering about the floodplain. Migration rates are generally largest between ~RM 17-13.5, corresponding to the sub-reach where braiding is the primary process of river planform change. This is also where the width of active channel, summed over the main and side channels, is also generally the greatest (Figure 16). The planform change index results provide a summary perspective of historic changes over time, and what the future trend may be (Figure 17):

There has been minor channel migration activity in the confined sub-reach upstream of the Darrington bridge (located around Analysis RM 19.22), with most recent and extensive migration occurring around analysis segments 9 and 10 in the vicinity of where the river has eroded the N Sauk River Road along the right bank.

Migration rates between the Darrington Bridge and about RM 18 have been moderate, with a long term shift in the region of greatest migration activity moving in the downstream direction.

Migration rates in the wandering-braided channel transition sub-reach (between ~RM 18 and RM 16) have been reduced in the last 15 years or so compared with previously. However, the lowermost segments of this sub-reach have migrated more actively in the vicinity of Dan Creek in recent years. The patterns in Figure 17 suggest that the region of greatest channel migration activity is moving in the downstream direction with increasing potential for braiding.

The braided sub-reach between about RM 16 and RM 13 has exhibited relatively large shifts in channel location since at least the 1940s (i.e., over the period of photographic record). There appear to be two general locations of extreme channel shifting indicated in Figure 17, and these regions may be shifting in the downstream direction. One of the two regions encompasses the Bryson Road levee location. This region is also where the channel tends to greatest active width (Figure 16).

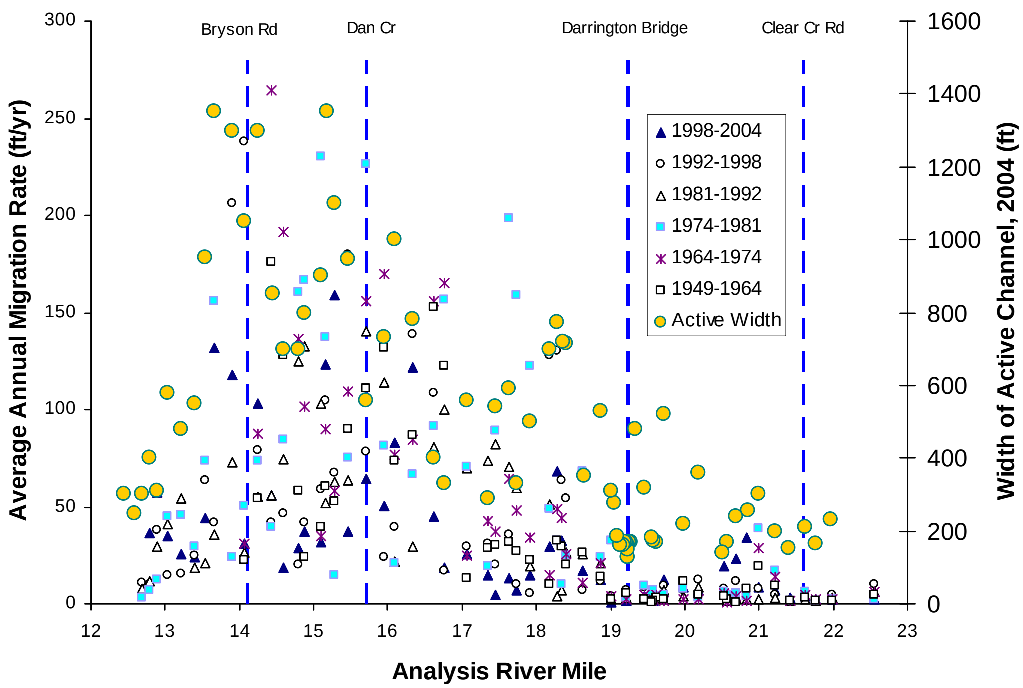


Figure 16. Comparison of upstream-downstream patterns in channel migration rate data with active channel width data estimated from the 2004 aerial photographs, Sauk River above the Suiattle River.

	Analysis Segment	Upstream Boundary RM	Planform Instability Index Calculated From Aerial Photography Series					
			1949-1964	1964-1974	1974-1981	1981-1992	1992-1998	1998-2004
Confined/Meandering	2	22.55	1	1	1	1	1	1
	3	21.98	1	1	1	1	1	1
	4	21.76	1	1	1	1	1	1
	5	21.62	1	1	1	1	1	1
	6	21.41	1	1	1	1	1	1
	7	21.22	1	1	2	1	1	1
	8	20.99	2	2	3	1	1	1
	9	20.84	1	1	1	1	3	3
	10	20.69	1	1	1	1	1	2
	11	20.56	1	1	1	1	1	1
	12	20.52	1	1	1	1	1	2
	13	20.18	1	1	1	1	1	1
	14	19.98	1	1	1	1	1	1
	15	19.72	1	1	1	1	1	1
	16	19.61	1	1	1	1	1	1
	17	19.58	1	1	1	1	1	1
	18	19.55	1	1	1	1	1	1
	19 upper	19.46	1	1	1	1	1	1
	19 lower	19.22	1	1	1	1	1	1
Wandering	20	19.00	1	1	3	1	1	1
	21	18.86	1	2	2	2	1	1
	22	18.63	2	1	3	2	1	2
	23	18.41	2	2	2	2	3	2
	24	18.35	2	3	1	1	3	3
	25	18.29	3	3	3	1	4	3
	26	18.17	1	1	3	3	4	2
Transitional	27	17.92	2	3	4	2	1	1
	28	17.74	2	3	4	3	1	1
	29	17.63	3	3	4	3	3	1
	30	17.45	3	3	4	4	2	1
	31	17.34	2	3	2	3	3	1
	32	17.07	1	2	3	3	2	2
	33	16.76	4	4	4	4	2	2
	34	16.61	4	4	4	4	4	3
	35	16.33	4	4	3	2	4	4
	36	16.09	3	3	2	2	3	4
Braided	37	15.95	4	4	4	4	2	3
	38	15.70	4	4	4	4	3	3
	39	15.46	4	4	3	3	4	3
	40	15.28	3	3	1	3	3	4
	41	15.17	3	4	4	3	4	4
	42	15.10	3	3	4	4	3	3
	43	14.87	2	4	4	4	3	3
	44	14.80	3	4	4	4	2	2
	45	14.60	4	4	4	3	3	2
	46	14.44	4	4	3	3	3	3
	47	14.25	3	4	3	3	3	4
	48	14.07	2	3	3	2	4	3
	49	13.91			2	3	4	4
	50	13.66			4	3	3	4
	51	13.54			3	2	3	3
	52	13.40			2	2	2	2
	53	13.21	*no coverage in 1964*		3	3	2	2
	54	13.03			3	3	1	3
	55	12.90			1	2	3	3
	56	12.80			1	1	1	3
	57	12.69			1	1	1	1

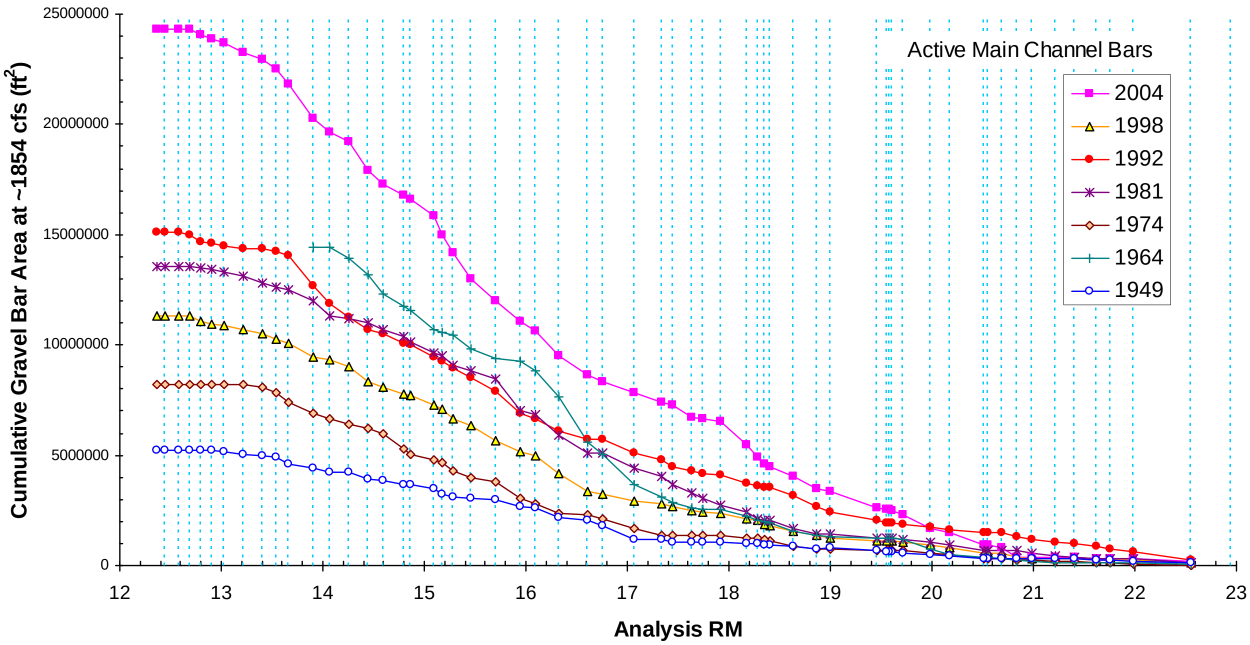
Figure 17. Spatial and temporal variation in channel migration tendencies within analysis segments of the Sauk River above the Suiattle River, as indicated by successive series of ortho-corrected and geo-referenced aerial photographs. Planform change index values are described in Table 4. Arrows indicate apparent upstream/downstream shifts in location of zones of greater and lesser channel change over the aerial photographic record.

Gravel/Sand Bar Storage and Side Channel Area Trends

Figure 18 presents cumulative plots of active gravel/sand bar and side channel areas, adjusted to a common flow level, for all years of aerial photography. The vertical differences between curves to some extent reflects the time between the previous large flood event and the date the photographs were taken (shorter time interval → greater amount of deposit surface area that has not become vegetated yet), error in interpreting older aerial photographs (2004 photographs were in color; older photographs were of lower resolution), and error in adjusting gravel bar areas to a common flow rate (e.g., numbers derived from the 2004 photographs were adjusted upwards by 315%; Table 3).

Nonetheless, useful information may be derived from the data depicted in Figure 18 based on the following observations:

> For analysis segments where successive year's curves are approximately parallel, it may be inferred that there was probably negligible change in gravel bar storage volumes or side channel areas between the two years photographed.
>
> In other locations, the slopes of the plots differ notably, where storage volumes and side channel areas either appear to have decreased or increased between successive photograph years. The rate of change in curves between successive aerial photographs may be calculated as a change in average width of active gravel/sand bar or side channel area. Segments with substantial changes in width, and thus storage of material readily available for bedload transport, are depicted for each pair of successive photographs in Figures 19-21, in a format similar to that presented in Figure 17 for the channel migration results. Results for the main channel are restricted to major bar deposits, whereas results for side channels are for the total area of side channel. Figure 20 represents substantial changes in side channel area, whereas Figure 21 represents gain or loss of any side channel area based on an estimated minimum measurement error of +/- 20ft.
>
> Comparison of large scale differences between Figures 20-21 indicate that side channel gains and losses are generally smaller in magnitude in the wandering and transition sub-reaches located between approximately RM 17-19, than in the downstream braided sub-reach. This result implies that side channels between RM 17-19 are generally smaller in size and flow tends to concentrate more in a main channel, whereas in the downstream braided sub-reach, the flow tends to be more broadly distributed across multiple channels (Figure 12). The main channel location in the braided sub-reach is more likely to shift from one channel to another compared with upstream.



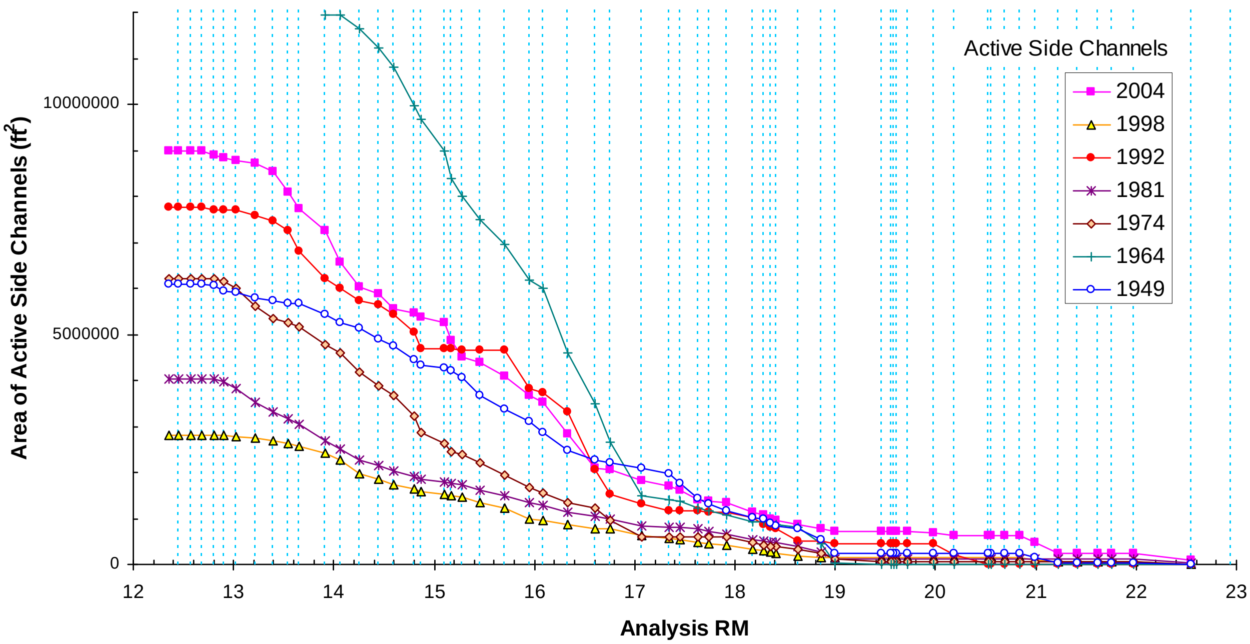


Figure 18. Cumulative active gravel/sand area mapping results for all years that aerial photography was digitized. Results are presented separately for bars occurring in the main channel (top graph) and total area of active side channels (bottom). The locations of the HEC-RAS transects are indicated by the dashed vertical lines.

Main Channel

	Analysis Segment	Upstream Boundary RM	Segments With Significant Changes in Gravel Bar Area Between Successive Aerial Photograph Series (average bar width change > +/- 100 ft) 1949-1964	1964-1974	1974-1981	1981-1992	1992-1998	1998-2004
Confined/Meandering	2	22.550						
	3	21.980				+		
	4	21.760						
	5	21.620						
	6	21.410						
	7	21.220						
	8	20.990			+			
	9	20.840				+		+
	10	20.690						
	11	20.560						
	12	20.520						+
	13	20.180	+	--				
	14	19.980	+	--				+
	15	19.720						+
	16	19.610						+
	17	19.580				+	--	
	18	19.550				+	--	
	19	19.460				+	--	+
Wandering	20	19.000				+		
	21	18.860				+	--	+
	22	18.630	+	--	+		--	+
	23	18.410					+	+
	24	18.350				--	+	+
	25	18.290	+	--	+	--		+
	26	18.170	+	--	+			+
Transitional	27	17.920			+	--		
	28	17.740			+	--		
	29	17.630	+	--	+	--		+
	30	17.450	+	--	+	--	--	
	31	17.340	+	--			--	+
	32	17.070	+	--	+		--	+
	33	16.760	+	--	--		+	+
	34	16.610	+	--	+	--	+	
	35	16.330	+	--	+	--	+	+
	36	16.090	+	--				+
Braided	37	15.950	--	+	+	--	--	+
	38	15.700	+	--	+	+		+
	39	15.460	+	--		+		+
	40	15.280		+		--	+	+
	41	15.170	--					+
	42	15.100	+	--	+			+
	43	14.870	+	+	--	--		+
	44	14.800	+		--		--	+
	45	14.600	+	--			+	+
	46	14.440	+	--		+	+	+
	47	14.250	+	--		+	--	+
	48	14.070	--	+	+	+	--	+
	49	13.910				+	--	+
	50	13.660			--	+		+
	51	13.540				--	+	+
	52	13.400			+	--	+	+
	53	13.210			+			+
	54	13.030			+			+
	55	12.900						+
	56	12.800			+	+	--	
	57	12.690				+	--	

Figure 19. Spatial and temporal variation in active gravel/sand bar storage areas within the main channel for analysis segments of the Sauk River, as indicated by successive series of geo-referenced aerial photographs. Change is represented as a substantial gain (+) or loss (--) in mean width of non-vegetated bar surface in excess of +/- 100 ft.

Significant Side Channel Changes

	Analysis Segment	Upstream Boundary RM	Segments With Significant Losses or Gains in Active Side Channels Between Successive Aerial Photograph Series (average side channel width change > +/- 100 ft)					
			1949-1964	1964-1974	1974-1981	1981-1992	1992-1998	1998-2004
Confined/Meandering	2	22.550						
	3	21.980						
	4	21.760						
	5	21.620						
	6	21.410						
	7	21.220	--					+
	8	20.990	--					+
	9	20.840						
	10	20.690						
	11	20.560						
	12	20.520				+	--	
	13	20.180				+	--	
	14	19.980						
	15	19.720						
	16	19.610						
	17	19.580						
	18	19.550						
	19	19.460						
Wandering	20	19.000	+	--		--		
	21	18.860		--				
	22	18.630				+	--	
	23	18.410	--					
	24	18.350	--			+		+
	25	18.290				+	--	
	26	18.170						
Transitional	27	17.920						
	28	17.740	--					
	29	17.630	--	--				+
	30	17.450	--					+
	31	17.340						
	32	17.070	+	--	--			
	33	16.760	+	--	--	+	--	
	34	16.610	+	--		+	--	+
	35	16.330	+	--		+	--	+
	36	16.090		--				+
Braided	37	15.950	+	--		+	--	+
	38	15.700	+	--	--			+
	39	15.460	+	--		--	+	
	40	15.280	+	--				+
	41	15.170	+	--	--		+	+
	42	15.100	+	--	--			
	43	14.870	+	+	--	+	--	
	44	14.800	+	--	--	+	--	
	45	14.600	+	--	--	+	--	+
	46	14.440	+	--	--			
	47	14.250	+	+	--			+
	48	14.070	--	+				+
	49	13.910	--	+		+	--	+
	50	13.660		+		+	--	+
	51	13.540		+		+	--	+
	52	13.400		+				+
	53	13.210	--	+		--		
	54	13.030		+		--		
	55	12.900	--	+				
	56	12.800						+
	57	12.690						

Figure 20. Spatial and temporal variation in active side channel area for analysis segments of the Sauk River, as indicated by successive series of geo-referenced aerial photographs. Change is represented as a substantial gain (+) or loss (--) in mean width of non-vegetated side channel surface in excess of +/- 100 ft.

Side Channels

	Analysis Segment	Upstream Boundary RM	Segments With Losses or Gains in Active Side Channels Between Successive Aerial Photograph Series (average side channel width change > +/- 20 ft) 1949-1964	1964-1974	1974-1981	1981-1992	1992-1998	1998-2004
Confined/Meandering	2	22.550				--		+
	3	21.980						
	4	21.760						
	5	21.620						
	6	21.410						
	7	21.220	--				+	+
	8	20.990	--				+	+
	9	20.840						
	10	20.690						
	11	20.560						
	12	20.520				+	--	
	13	20.180				+	--	+
	14	19.980						+
	15	19.720						
	16	19.610						
	17	19.580						
	18	19.550						
	19	19.460			--			
Wandering	20	19.000	+	--	+	--	--	+
	21	18.860	+	--		--	+	+
	22	18.630			+	+	--	+
	23	18.410	--	--		+	+	
	24	18.350	--		--	+	--	+
	25	18.290		+		+	--	+
	26	18.170	--				--	+
Transitional	27	17.920	--	--	+	--		+
	28	17.740	--	--	+			
	29	17.630	--	--	+	--	+	+
	30	17.450	--	--			+	+
	31	17.340		--	+	+	--	+
	32	17.070	+	--	--	+	--	+
	33	16.760	+	--	--	+	--	+
	34	16.610	+	--		+	--	+
	35	16.330	+	--	--	+	--	+
	36	16.090	--	--	--	+	--	+
Braided	37	15.950	+	--	--	+	--	+
	38	15.700	+	--	--	--	+	+
	39	15.460	+	--	--	--	+	+
	40	15.280	+	--		--	+	+
	41	15.170	+	--	--	--	+	+
	42	15.100	+	--	--		+	+
	43	14.870	+	+	--	+	--	+
	44	14.800	+	--	--	+	--	
	45	14.600	+	--	--	+	--	+
	46	14.440	+	--	--	--	+	+
	47	14.250	+	+	--		+	+
	48	14.070	--	+	+	+	--	+
	49	13.910	--	+	--	+	--	+
	50	13.660		+	+	+	--	+
	51	13.540	--	+	+	+	--	+
	52	13.400	--	+	--	--	--	+
	53	13.210	--	+	--	--	--	+
	54	13.030	--	+		--	+	+
	55	12.900	--	+	--	--	--	+
	56	12.800	--			+	--	+
	57	12.690						

Figure 21. Spatial and temporal variation in active side channel area for analysis segments of the Sauk River, as indicated by successive series of geo-referenced aerial photographs. Change is represented as a measurable gain (+) or loss (--) in mean width of non-vegetated side channel surface in excess of +/- 20 ft.

COMPARISON WITH HABITAT DATA

Data describing wood loading and hydromodification extent in the study reach were compared with the most recent (1998-2004) channel migration rate and the sediment transport analysis results. The following trends were noted in the data:

The longitudinal densities of large wood pieces and jams in a segment generally follow upstream-downstream trends (Figure 22) that are similar to the results for active channel width and channel migration rates (Figure 16).

The longitudinal densities of large wood pieces and jams were greater in reaches with greater average annual migration rates (Figure 23).

The small number of analysis segments with more than about 40% of both banks visibly armored with riprap preclude general conclusions about the relation between bank protection and channel migration in the analysis reach. However, the data indicate that the few segments with more extensive riprap between Darrington and the Suiattle River still exhibit large channel migration rates (Figure 24). The river has the ability to either erode the opposing bank or avulse around an armored bank.

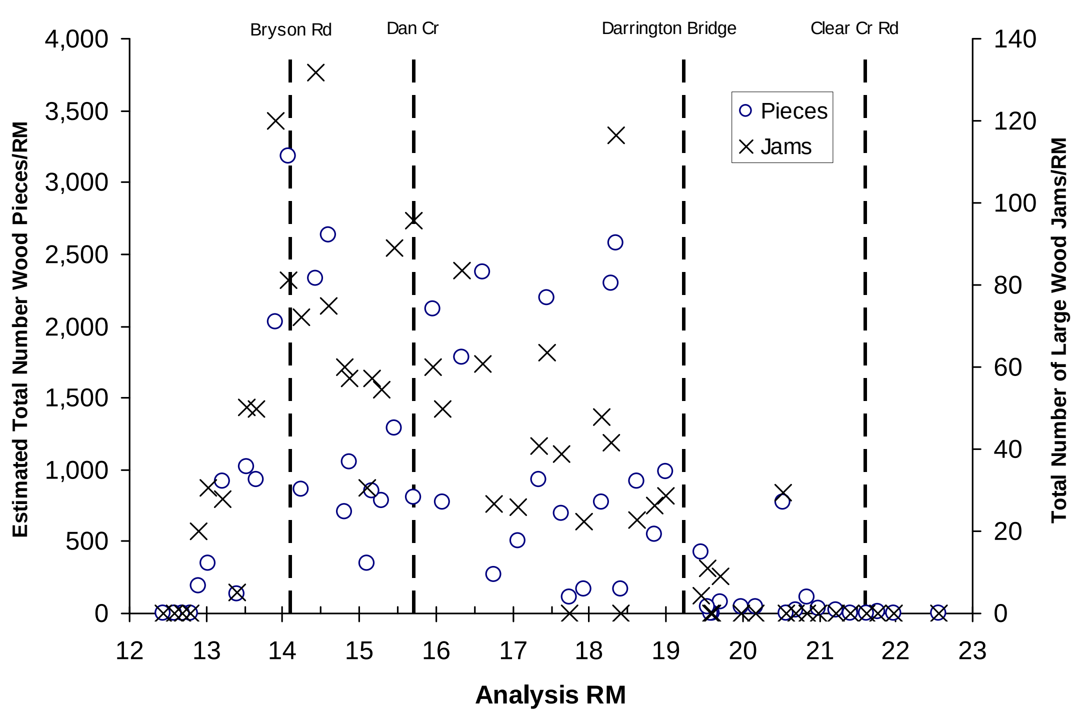


Figure 22. Longitudinal distribution of large wood in the Sauk River upstream of the Suiattle River.

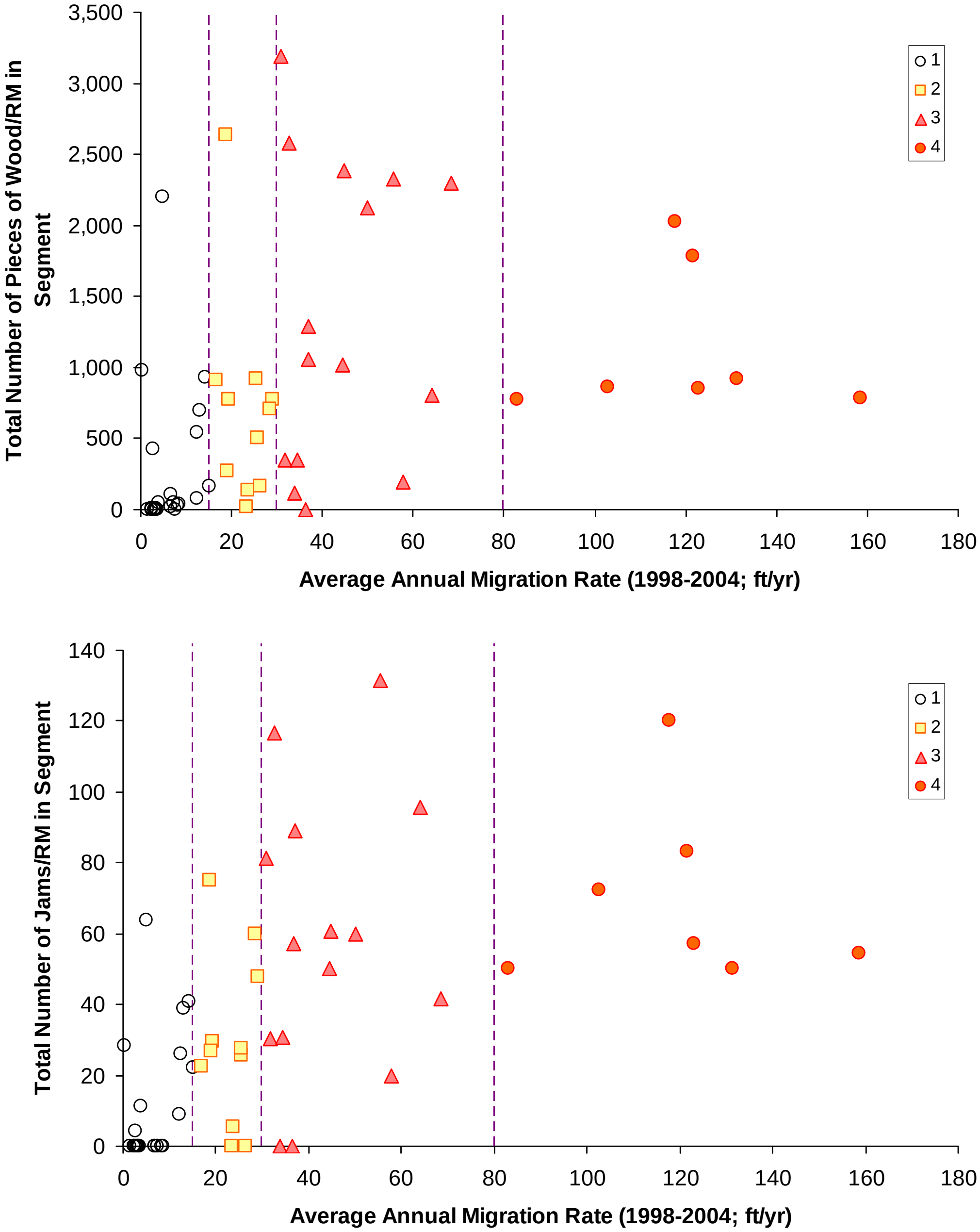


Figure 23. Relation between large wood piece (top) and jam (bottom) densities surveyed in 2005 and average annual migration rate computed between 1998-2004 in the Sauk River, upstream of the Suiattle River. Migration rate classes 1-4 are per Table 4, and divided by the dashed vertical lines.

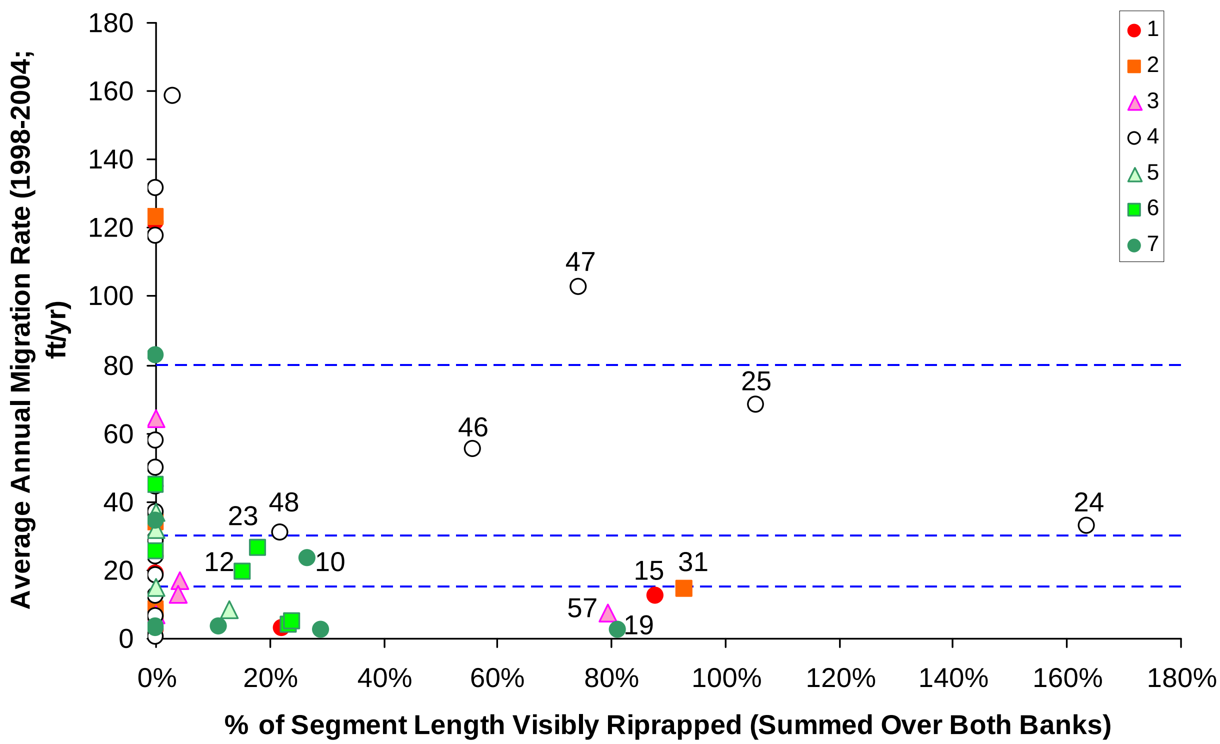


Figure 24. Relation between extent of riprap hydromodification visible from the river, channel migration rate, and aggradation/degradation potential determined from the sediment transport analysis. The horizontal dashed lines depict the migration rate class breaks in Table 4, and the data points are classified according to potential per codes 1-7 in Table 2. Analysis segments with greater extent of riprap and/or migration rates are identified by number.

SYNOPSIS OF ANALYSIS RESULTS

The following general patterns are indicated by the analysis results. The features indicated will likely lead to management prescriptions for fish habitat and land use that vary across the five geomorphic sub-reaches, reflecting characteristic river processes and erosion/deposition risks observed at the sub-reach scale. In particular, the channel migration and potential aggradation/degradation rate results may be combined into a joint erosion risk rating for each analysis segment, and evaluated in conjunction with avulsion risk and flood risk information as part of subsequent sub-reach scale risk assessments.

Large Scale Results: Phase I Reach (Clear Creek Put-in to Suiattle River)

Five geomorphic sub-reaches, roughly delineated in vicinity of, and defined by breaks/longitudinal changes in the following physical attributes:

Darrington Bridge:
- Slope
- Channel widths
- Bar deposit grain size distribution
- Aggradation/degradation potential
- Degree of reworking of active gravel bars in main channel

~RM18:
- Channel widths
- Aggradation/degradation potential

~Dan Creek (N.B., used as geographic reference; Dan Cr likely has negligible geomorphic influence on Sauk R):
- Slope
- Channel widths
- Aggradation/degradation potential

~RM13:
- Channel widths
- Bar deposit grain size distribution
- Aggradation/degradation potential greater upstream
- Degree of reworking of active gravel bars in main channel

In general, slope and grain size distribution percentiles decrease in downstream direction. Sub-reaches below Darrington Bridge and above ~RM13 have greatest channel migration/side channel location changes.

Sub-Reach Results

The five geomorphic sub-reaches are distinguished as follows:

Sub-Reach I (Confined/Meandering): Above Darrington Bridge (Segments 1-19)

a. In Vicinity of eroding bank along Clear Creek Road and downstream properties (segments 3-6):
    - Strong degradation potential along segment 4 where road is adjacent to river
        - Tendency to downcut at bank toe, increasing erosion potential
    - Strong aggradation potential in adjacent upstream/downstream segments
        - Favors upstream avulsion and/or local meandering

b. Upstream of Darrington bridge (segments 16-19):
    - Strong aggradation tendency immediately upstream of bridge
        - Avulsion potential may be reduced/restricted
        - Local meandering may be more likely

Sub-Reach II (Wandering): Darrington Bridge to ~RM18 (Segments 19-26)

- Relatively mild aggradation/degradation potential
- Active channel width and annual main channel bank migration rates increasing downstream
- Side channels generally shorter, more transient than in sub-reach III
- Results suggest reach is primarily processing sediment downstream
- Primarily a wandering channel (single main channel with a few distributary branches; may move through meandering or avulsion)
- Side channel size tends to be smaller than downstream

Sub-Reach III (Transition): ~RM18 to Vicinity of Dan Cr (Segments 27-36)

- Stronger aggradation/degradation potential than upstream and downstream; potential greatest downstream of slope break, which occurs around segment 32
- Channel widths hold steady then continue increasing downstream

Sub-reach = transition from wandering to braided channel

Sub-Reach IV (Braided): Vicinity of Dan Cr to ~RM13 (Segments 37-53)

Low sediment transport capacity overall compared with upstream, favoring local deposition near Dan Creek

No tendency toward either aggradation/degradation potential between analysis segments

Channel widths are widest of entire Phase I reach

Widest tendency in segments 41-50 (Bryson Road levee located within these segments)

Greatest gains and losses in side channel area occur in this sub-reach, and side channel size tends to be large compared with upstream.

Channel widening likely a response to reduced transport capacity in sub-reach, in which coarse sediments are likely deposited and stored for longer term compared with rest of river based on transport capacity, channel migration, and grain size distribution trends.

Sub-reach channel is most closely described as braided (vs. wandering)

Sub-Reach V (Transition/Confined): ~RM13 to Suiattle River (Segments 53-59)

Channel narrows rapidly in downstream direction

Moderate variability in aggradation/degradation potential between analysis segments

Strong aggradation potential in segment 54 is indicative of backwater effect of further channel constriction downstream

Level of Confidence in Analysis and Results

The longitudinal profiles of channel gradient, grain size, sediment transport analysis predictions of aggradation/degradation potential, flow depth channel migration rates, and size and extent of side channel changes over time, all consistently point to the five geomorphic sub-reaches outlined above. More site specific analysis and design will be required to evaluate erosion risk for specific projects and management actions, but the results presented here provide a quantitative estimate of reach scale hydraulic and erosion processes that will affect general suitability of specific measures. The information can be used to infer relative risk associated with different restoration activities (e.g., channel and floodplain connectivity, instream/bank stabilization structures, channel migration training, and bank revetment removal), with respect to whether projects would work against or with natural sedimentation and channel forming processes.

The level of uncertainty about each individual analysis varies depending on the type of data, and can be inferred in many cases from the scatter of data depicted in the graphs above. Specific cases are identified below:

> The flood level and sediment transport predictions should not be used to precisely delineate lateral flood extents and predict actual bed elevation changes. Limited field surveyed flood level data were used to calibrate the HEC-RAS model, with an accuracy of estimated peak flood stage within +/- 2 ft in most cases. Effort to get more accurate survey data would require higher level of funding. Typical sediment transport rate prediction errors range within an order of magnitude. However, the relative differences in sediment transport potential predicted for successive transects should be preserved and not meaningfully affect the results presented in Figure 11, or erosion risk determinations based on those results.
>
> Importantly, the river has changed course at many locations after the November 2006 flood; all channel planform, flood level estimation, and sediment transport predictions are presented here based on pre-flood topography. This is a common problem in active, dynamic, braided channels, where the location of the predicted 100-year flood extent can vary because of change in main channel location. The 1998-2004 aerial photograph sequences and 2003-4 LIDAR and channel elevation data comprise the most recent physical data available. It does not appear feasible to redo the analyses reported here every time the channel moves, but the general trends seen here at the sub-reach scale should be preserved in the foreseeable future, possibly within the next 20-50 years.
>
> The channel migration traces are generally accurate for the main channel and major side channels. Smaller side channels not visible in the aerial photographs will be delineated as part of an avulsion risk analysis using LIDAR data. The collective digitized channel traces for the present and avulsion risk analyses should provide for a reasonable delineation of the channel migration zone.

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APPENDIX
Definition of Channel Migration Classifications

Channel form may be classified according to degree of channel confinement by valley form, planform pattern, presence and extent of islands, types of depositional bars, and extent and character of lateral activity. The following types of channel are observed in the analysis reach, with classifications developed from Richards (1982), Leopold et al. (1995), and Galay et al. (1998):

- Confined/Meandering: Single, sinuous channel at low to bankfull flows with occasional islands and sediment deposits forming point and diagonal bars. Meander pattern sinuosity is generally contained between floodplain terraces and valley side walls. Meander migration in downstream direction is limited.
- Wandering: Channel is unconfined and free to move about floodplain. Slope is generally higher than for a purely meandering channel flowing through unconfined alluvial deposits. Planform represents an intermediate state between meandering and braided condition, with a main channel and frequent islands and small channel splits. Main channel tends to move about the floodplain through a blend of meander bend migration and channel avulsion. Abandoned oxbows or prominent arcuate swales may be present on the floodplain.
- Braided: Irregular channel pattern, with few persistent, clearly defined islands. Flow is shallower than confined/meandering and wandering channels and is distributed more evenly among many channels. Channel tends to move about primarily through avulsion process. Sediment deposits distributed throughout channel net as mid-channel bars.

In both the wandering and braided cases, bedload constitutes a significant fraction of the total sediment transport load.

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Technical Memorandum No. 1

Date: September 22, 2008 Project Number: 1681.01/MM102R

To: Bob Aldrich, Karen Wood-McGuiness, Snohomish County Surface Water Management

From: Paul DeVries Ph.D., P.E.; Sue Madsen, M.S.

Subject: **Avulsion Risk Assessment for Sauk River: Clear Creek to Suiattle River**

1. BACKGROUND

Lateral migration of river channels occurs by two main processes: bank erosion and avulsion. Avulsion involves a sudden shift in channel location that occurs when flood flows spill out of the existing channel banks and cause the erosion of a new channel, with the original channel either retaining flow or becoming abandoned. Avulsions may be initiated by accumulation of sediment or large wood within the channel, which reduces the channel capacity and increases the flow depth upstream. Channel avulsion often occurs where the flow spilling over the floodplain encounters an area with a steep slope and/or topographic features that concentrate flow (Leopold et al. 1964; O'Connor et al. 2003), conditions that frequently occur in abandoned channels or side channels. Channel migration via bank erosion typically occurs every year but progresses relatively slowly, at rates ranging from inches to tens of feet per year. In contrast, avulsions are sudden and may result in rapid channel shifts of hundreds to thousands of feet across the valley floor.

A geomorphic analysis of the Sauk River between Clear Creek and the Suiattle River indicated the existence of distinct reaches along the river in which the characteristic processes of channel migration differ. In the confined reach between Clear Creek and Darrington, the predominant channel migration process is through gradual bank erosion occurring over multiple flood events, with greatest risks to life, infrastructure and property occurring in isolated locations such as along the Clear Creek Road. The risks of gradual bank erosion are generally well appreciated, and the rate of channel change sufficiently slow that landowners generally have time to plan appropriate actions in response. Between Darrington and the Suiattle River, however, channel avulsion presents a much greater risk than bank erosion because the river is able to rapidly carve a new channel at another location on the floodplain. The ability to identify and implement suitable actions in response to avulsion is poorer compared with bank erosion because of the rapidity with which avulsions can occur during a single flood. This is true for both the wandering and transition reaches between Darrington and around Dan Creek, and the braided reach downstream, with the primary difference between reaches reflecting the size of side and major channels created, but not necessarily the overall rate at which channel locations change.

This memorandum summarizes the results of analyses by R2 Resource Consultants (R2) conducted for Snohomish County Surface Water Management (SWM) to aid in the development of a comprehensive flood and erosion hazard plan. The evaluation of relative risk of avulsion reported here pertains to the reach of the upper Sauk River extending between the Clear Creek boat launch downstream to the Suiattle River. This risk analysis is based on a comparison of factors that influence the likelihood of avulsion into existing side channels and overland flow paths, but does not represent a predictive model that can be used to specifically identify where and when such events will occur in the future.

2. METHODS

Avulsion risk was assessed using LiDAR topographic data, HEC-RAS flood modeling results from the geomorphic assessment, and various GIS data. Factors evaluated as contributing to the potential for avulsion included the presence of concentrated flow pathways evident on the topographic surface, the average slope of pathway segments, the general flow level at which the upstream inlet would be inundated, and the inherent erosivity of soils associated with the pathway. Potential factors that could reduce the risk of avulsion were also identified, including vegetation and the presence of infrastructure. The methods used to characterize and identify these various factors are described below.

Flow Paths: Potential avulsion pathway segments were traced on 2 ft contour maps generated from 2005 LiDAR data as linear features with elevations that were generally lower than the surrounding floodplain. Segments began and ended at the main river channel or junctions with other segments. A GIS layer was then constructed by Laura Audette (SWM GIS staff) that depicted each potential pathway segment as a linear feature.

Inundation Flow Level: The elevation of pathway segments branching from the river was used to estimate the return interval event at which each segment and connected segments downstream and upstream would become wetted, using water surface elevations estimated for the 2-year, 10-year, and 100-year event based on the HEC-RAS modeling. Segments below junctions with upstream segments were assumed to be connected at the same level as upstream segments as long as there was no significant break in slope evident on the map downstream. For example, if a downstream segment was connected to two upstream segments with one flowing at the 2-year flood level and the other at the 10-year flood level, the downstream segment was assigned a 2-year flood level risk.

Slope: A longitudinal profile for each pathway was developed by extracting elevation data from a DEM for selected points spaced 100 ft apart along each segment. Average slope was calculated as the average of slopes calculated between points, for each segment. Slope between points was calculated as the difference in elevation between points divided by the length between points (100 ft or shorter, depending on the total length of the segment).

Soil Erodibility: The avulsion pathway layer was overlaid in GIS on a soils map produced by the NRCS. Each soil type is assigned a K_w-factor which represents both susceptibility to erosion and the infiltration rate. Soils with lower K_w-factors are more resistant to erosion due either to high clay content or high infiltration. Soils with higher K_w-factors are more erodible. Soils within the study area were classified as follows based on the NRCS K_w-factor, with greater emphasis placed on the uppermost soil horizon:

1 = K_w-factor > 0.3 (higher erodibility)
2 = K_w-factor 0.2-0.3 (moderate erodibility)
3 = K_w-factor <0.2 (lower erodibility)

Where potential avulsion pathways crossed soils with different K_w-factors, a weighted average class was calculated based on the relative length of channel crossing each soil type.

Vegetation Cover: In general, the presence of forest vegetation is anticipated to reduce the risk of avulsion, as trees provide deep, dense root masses that are more resistant to erosion and may inhibit braiding (Miall 1977). In addition, if channels do avulse through forested areas, trees that fall into the new channel provide roughness elements that reduce erosive energy and may temporarily block flow. In the present case, vegetation was assessed visually for each avulsion pathway using aerial imagery closest to the LiDAR data (georeferenced 2003 aerial photographs or 2006 Skagit NAIP). Potential avulsion pathways were classified as forested, non-forested, or open water. Only forest vegetation was considered to potentially reduce the likelihood of avulsion.

Road Grade Controls: The presence of roads can act as both a mitigating factor or exacerbate the risk of avulsion. Paved roads, and to a lesser extent gravel roads represent a “hard point” that is more resistant to erosion over the short-term. However, roads that cross avulsion pathways may also exacerbate the risk if they contain undersized drainage structures or temporarily hold back water and then fail catastrophically. This analysis assumes that roads are monitored and/or protected during floods, and thus moderate the risk of avulsion where they are present. Road crossings were identified from aerial imagery. Paved roads were considered to be more resistant and more likely to be protected during floods, and thus were assigned a greater mitigative factor.

Bank Hardening: The presence of bank hardening can retard avulsion if the river does not erode around the structure and it is designed and built to counter the potential for undermining at the bank toe. Risk needs to be evaluated on a case-by-case basis. This is because the type of structure (i.e., rip rap or LWD), condition of the structure, distance from the upstream and downstream ends of the structure to a floodplain swale, and respective structure end point and swale elevation differences can either be a mitigating factor or not substantially affect avulsion risk depending on the particulars of the site. For that reason, bank hardening was not explicitly included as a factor in this reach-scale avulsion risk analysis.

Joint Avulsion Risk Factors: The factors above were considered for ways to combine them into a joint risk rating system. Weighting factors were conceived and assigned to ranges of each factor. It was decided to combine the flow level, slope, and soil erodibility factors into a weighted joint risk rating system, and apply vegetation and road characteristics as mitigating factors. Each pathway segment identified on the LiDAR topographic surface was rated accordingly, following the gradations and weightings proposed in Table 1. The joint avulsion risk was calculated for each segment as the sum of the weights assigned in Table 1 for return interval event at which the pathway may flow, pathway slope, and soil erodibility. The following joint risk classes were then defined based on professional judgment:

Joint Risk Weight Sum >14 = Class 1 (highest risk)
Joint Risk Weight Sum = 11-14 = Class 2
Joint Risk Weight Sum = 6-10 = Class 3
Joint Risk Weight Sum <6 = Class 4 (lowest risk)

The joint risk rating may be modified by subtracting weights for mitigating factors, with initial recommendations for weights given in Table 1. Alternatively, the mitigating factor ratings can be used on a case-by-case basis in consideration of greater site specific knowledge as to the relative importance each factor could play in mitigating joint avulsion risk.

Table 1. Summary of parameters used to assess theoretical avulsion risk, and the weights assigned to each parameter.

Parameter Criterion		(weight)		
Risk Factors:				
Flood Return Interval Causing Inundation	>100-yr (1)	100-yr (3)	10-yr (6)	2-yr (9)
Slope	<0% (1)	0-1% (3)	1-3% (6)	>3% (9)
Soil Erodibility Class	3 (1)	2 (2)	1 (3)	
Potential Mitigating Factors:				
Vegetation	Forested (-2)	Non-Forested (0)	Open Water (0)	
Road Crossing	Paved (-3)	Gravel (-1)		
Bank Hardening Across Pathway	Rip Rap (-4)	Large Wood (-2)		

3. RESULTS

Figures 1-3 depict the individual avulsion risk factor ratings for each delineated pathway segment. Figure 4 depicts the joint avulsion risk rating based on flow level, slope, and soil erodibility. Figures 5 and 6 depict the ratings for the vegetation and road mitigating factors. GIS coverages for bank hardening are not presented because the available data are incomplete, generally characterizing conditions only along the margins of the main river channel and omitting any extensions into side channels or onto the floodplain.

The individual and joint ratings represent relative risks amongst all potential flow paths based on physical characteristics known to affect the likelihood of avulsion. These risk ratings cannot be used to predict exactly where the channel will move during future storm events, but can be used to prioritize alternatives to reduce the risk of harm to life and property.

4. DISCUSSION

The results depicted in Figures 1-6 are based on topographic and hydraulic data collected prior to the November 2006 flood. Specific ratings may change pending reanalysis of hydraulics reflecting channel changes that occurred during that flood, and may change in the future after other floods. It is probably not feasible to update the ratings each year after flooding because of the expense; however the ratings resulting from this analysis can still be used to assess general risk as described below, and provide an indication of relative differences in avulsion potential for possibly the next 10+ years.

In general, joint risk Class 1 segments would be expected to have the most immediate risk of avulsion in the near future because they are connected frequently at relatively low flood levels, tend to have steeper slopes, and may have more erosive soils. Class 1 pathways with inlets located on the outside edge of meander bends in areas with a tendency toward deposition downstream would be of particular concern as such areas are prone to additional raising of the water surface during large floods. Class 2 segments similarly may be considered to have a relatively high risk of avulsion occurring in the near future under these conditions. As it turned out, the most severe avulsions that occurred during the November 2006 flood (which had between a 10-100 year recurrence interval) occurred for mostly Class 2 segments. The avulsions that occurred appeared to be linked to extensive deposition in the existing channel of coarse bedload, which would be expected to decrease the conveyance capacity of the main channel during flooding, and cause more water to flow over the floodplain and avulse through higher risk segments.

Class 3 segments could become higher risk segments after the river avulses through nearby class 1 or 2 segments. Class 4 segments have lowest relative risk. In general, the farther these two class segments are situated from the main channel, and the longer the total avulsion flow path, the lower the long term risk.

Most of the pathways designated as Class 1 or 2 (i.e., relatively high risk) represent areas that the river has occupied at one time or another during the period spanned by available historic aerial photos (i.e., 1949 through 2004). Notable exceptions include a group of pathways on the west bank near the town of Darrington upstream of the Hampton Mill (Class 2 and 3 channels), and a single pathway on the west bank just downstream of the Hampton Mill.

Forested vegetation is present along many of the potential avulsion pathways and, in some cases, may reduce the relative risk of avulsion. Forest stands consisting of relatively young deciduous species would not provide as much protection against avulsion as older coniferous forests, however. In the Sauk River, the forest age of specific stands on the floodplain generally reflects the last time the channel occupied that location. As noted above, many of the potential pathways identified for this analysis coincide with former channel locations observed on air photos. However, even avulsion pathways that have not been occupied since 1949 appear to support relatively young deciduous vegetation. Continued growth and succession of conifer species should enhance the potential mitigative effect of vegetation, although it will not prevent the risk of avulsion.

Roads and bank hardening such as riprap tend to retard avulsion, often for sufficient time while the flood peak passes. However, these features can also eventually be associated with avulsion. In the case of bank hardening, the river may simply erode around the structure and connect with a potential avulsion pathway segment downstream. In the case of roads, the road may eventually wash out if there is sufficient flow overtopping the road, water on the downstream side of the road is sufficiently lower than upstream, and the flood lasts for a long time. Paved roads are more resistant than compacted gravel roads and may provide additional lead time for emergency erosion countermeasures.

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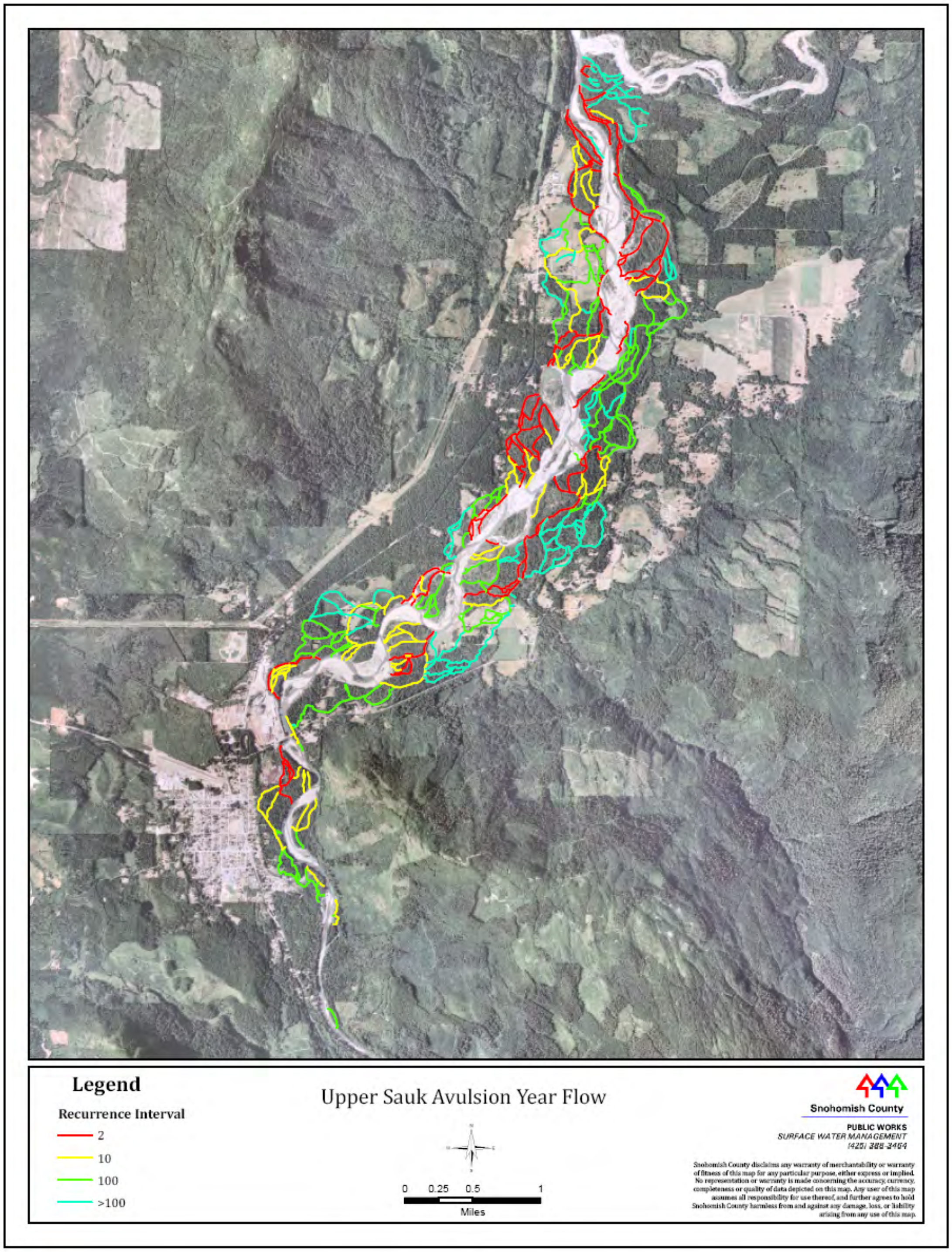

Figure 1. Risk ratings of potential avulsion pathways characterized according to lowest of three flood levels (2-, 10- and 100-year recurrence intervals) at which floodplain or off-channel flow may occur. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

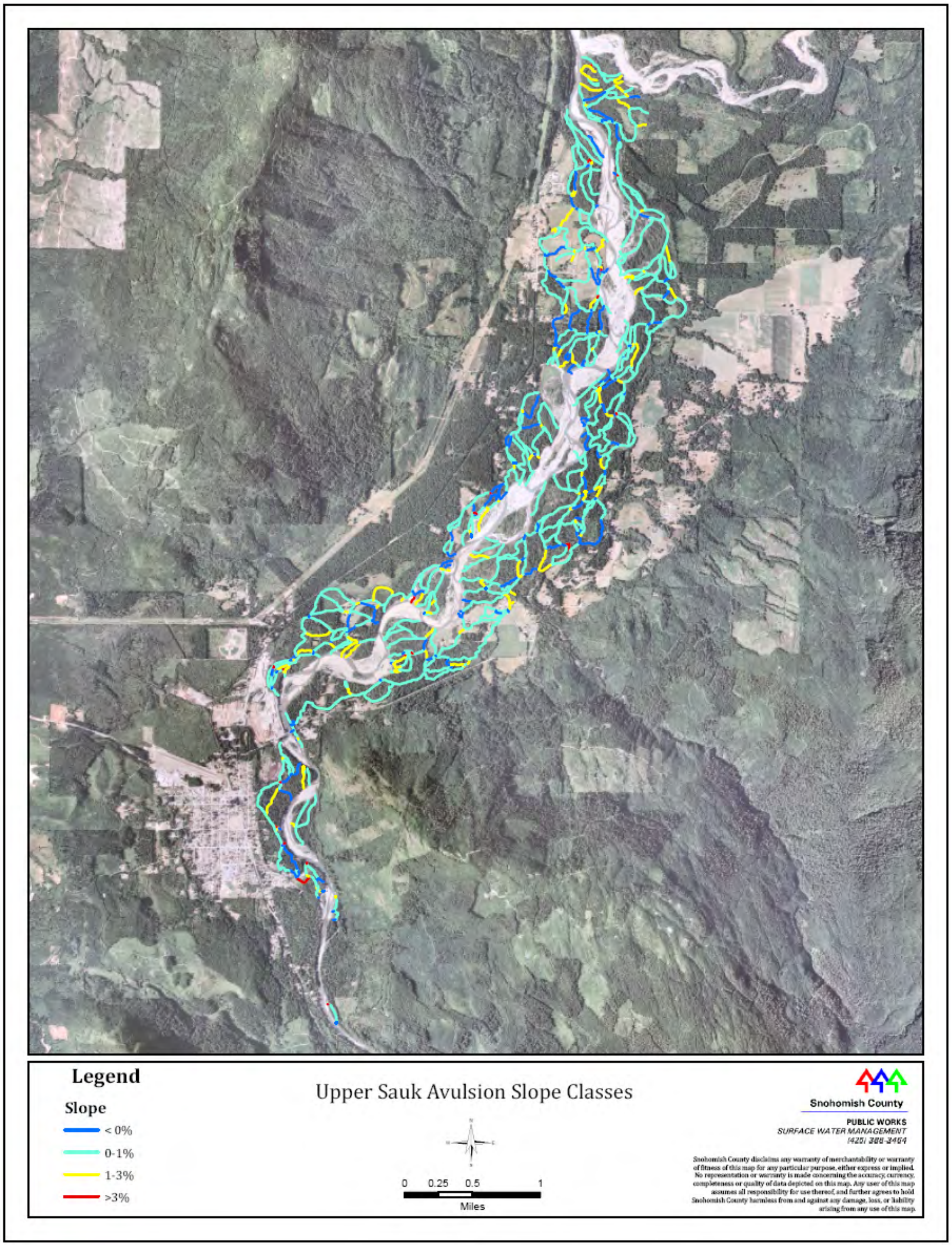

Figure 2. Risk ratings of potential avulsion pathways characterized according to average gradient along each pathway segment. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

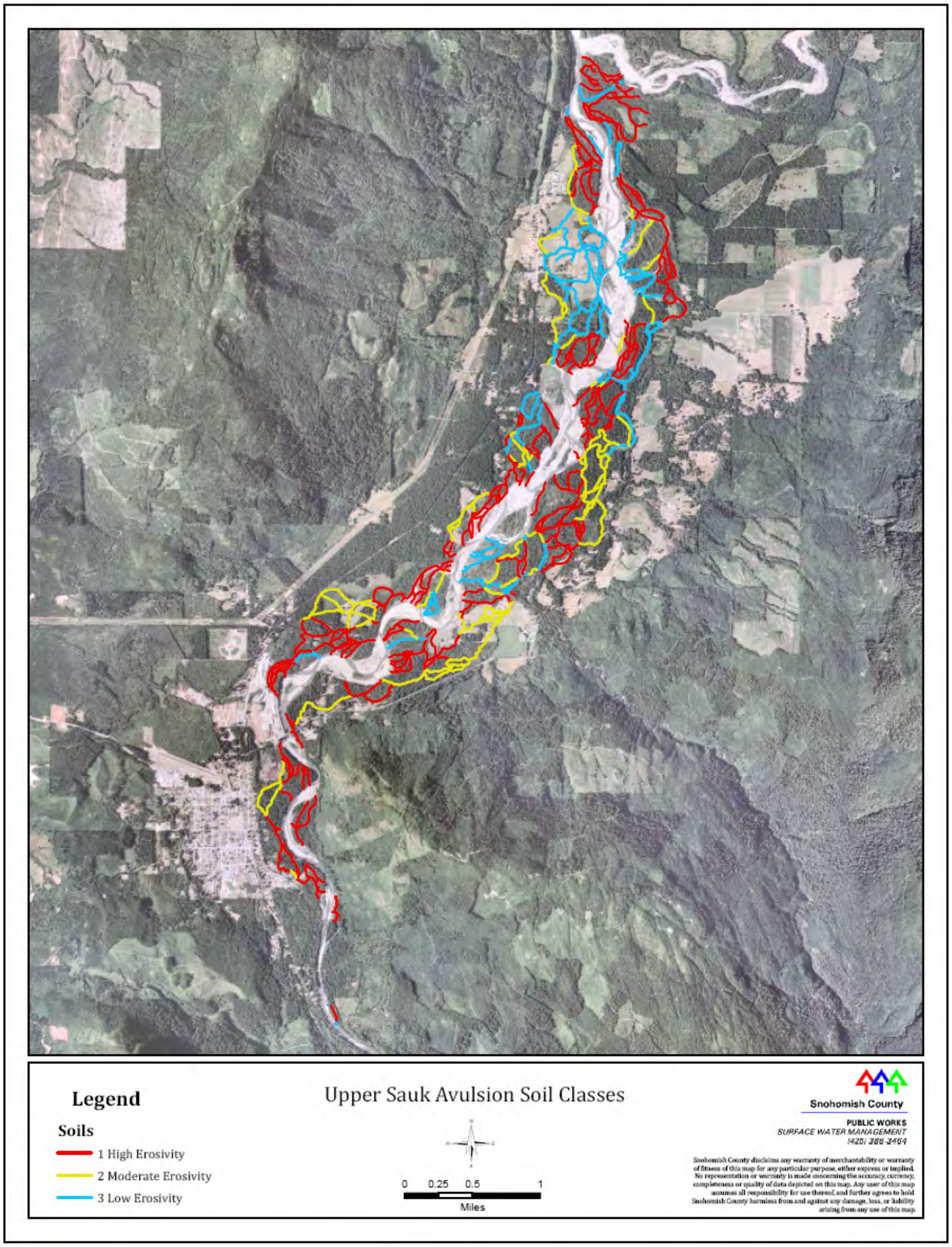

Figure 3. Risk ratings of potential avulsion pathways characterized according to floodplain soil K_w erodibility factors. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

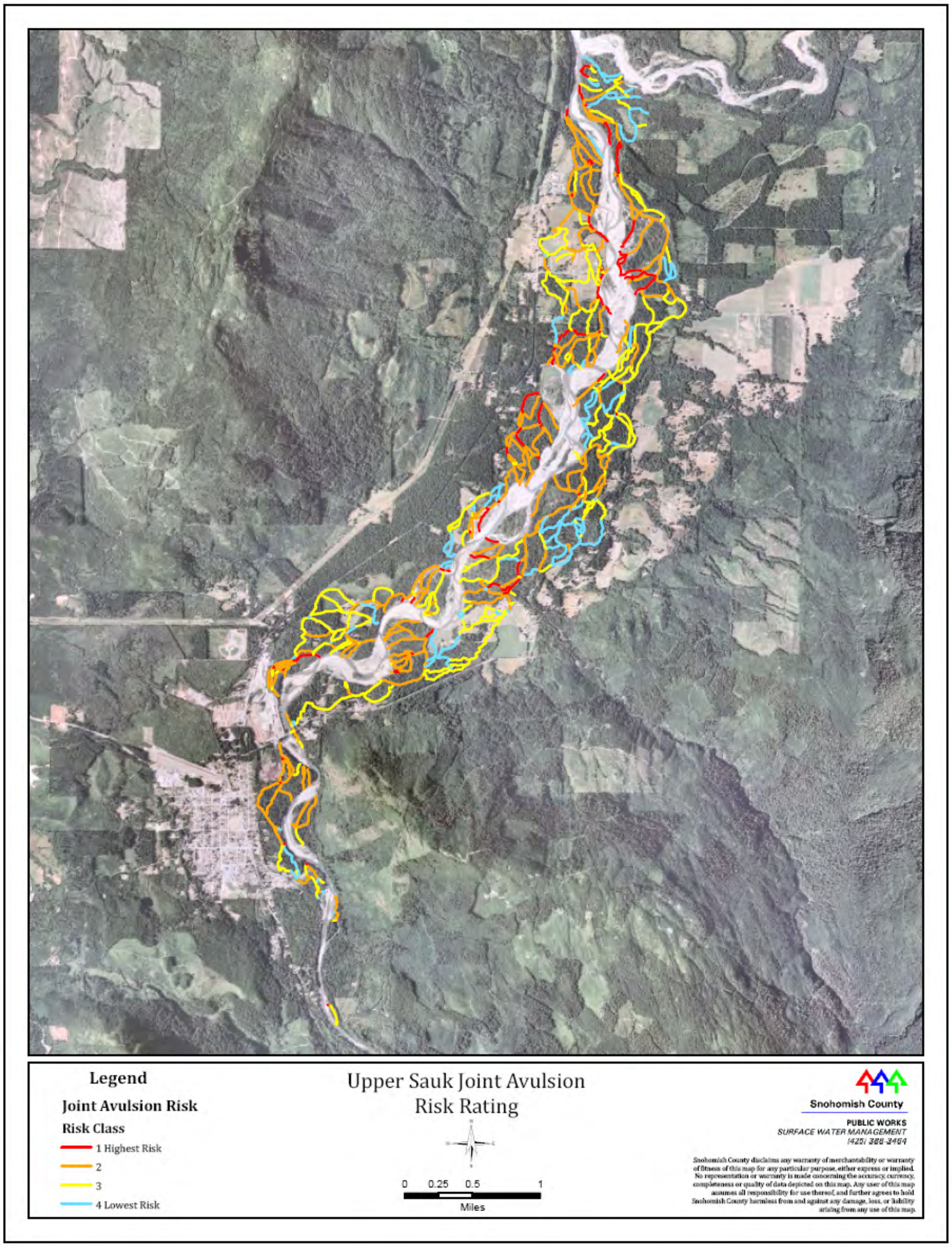

Figure 4. Joint avulsion risk ratings of potential avulsion pathways characterized according to weighted sums of flood flow level, longitudinal gradient, and floodplain soil K_w erodibility factor ratings depicted in Figures 1-3. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

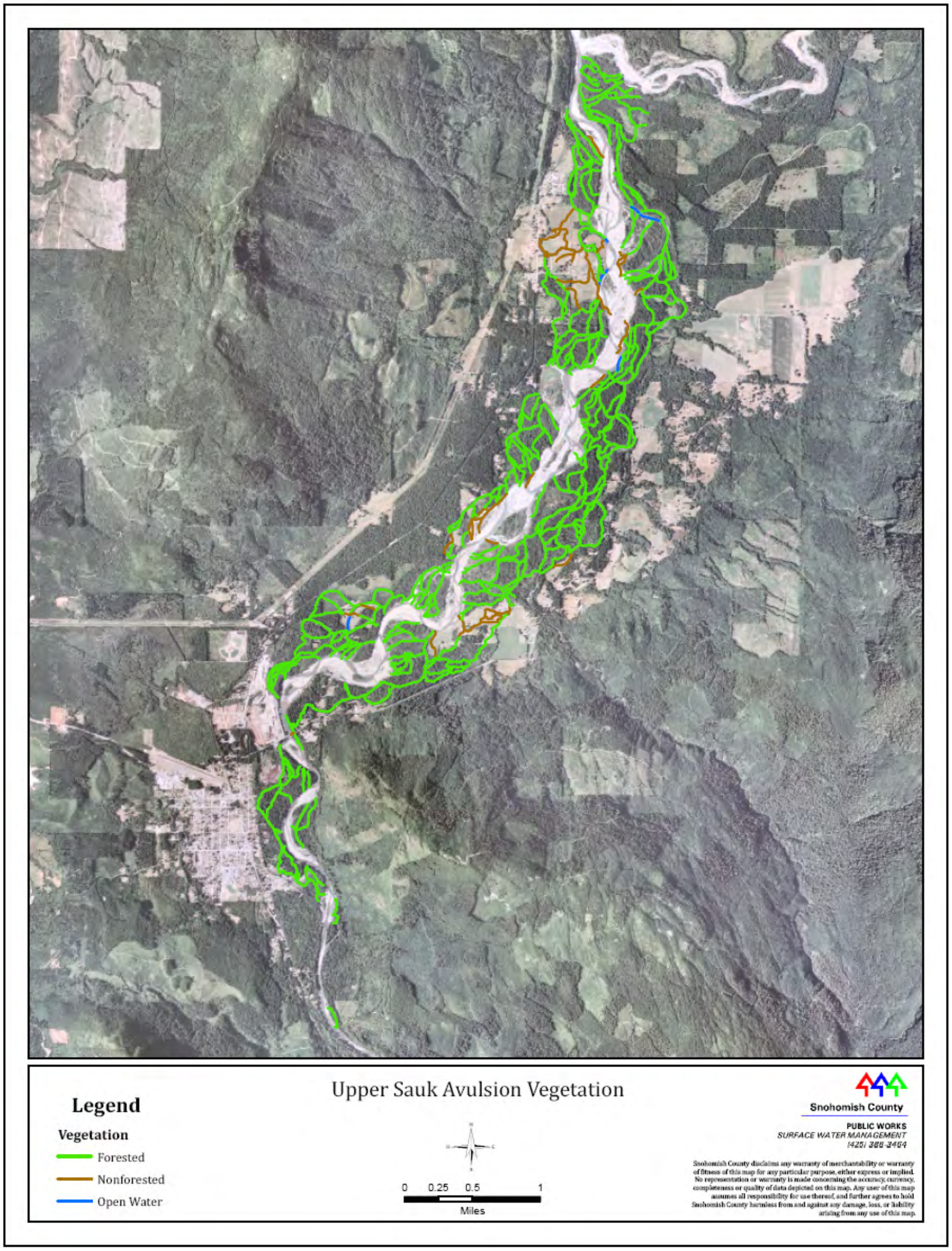

Figure 5. Joint avulsion risk mitigation ratings of potential avulsion pathways characterized according to whether a segment passes through forested land. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

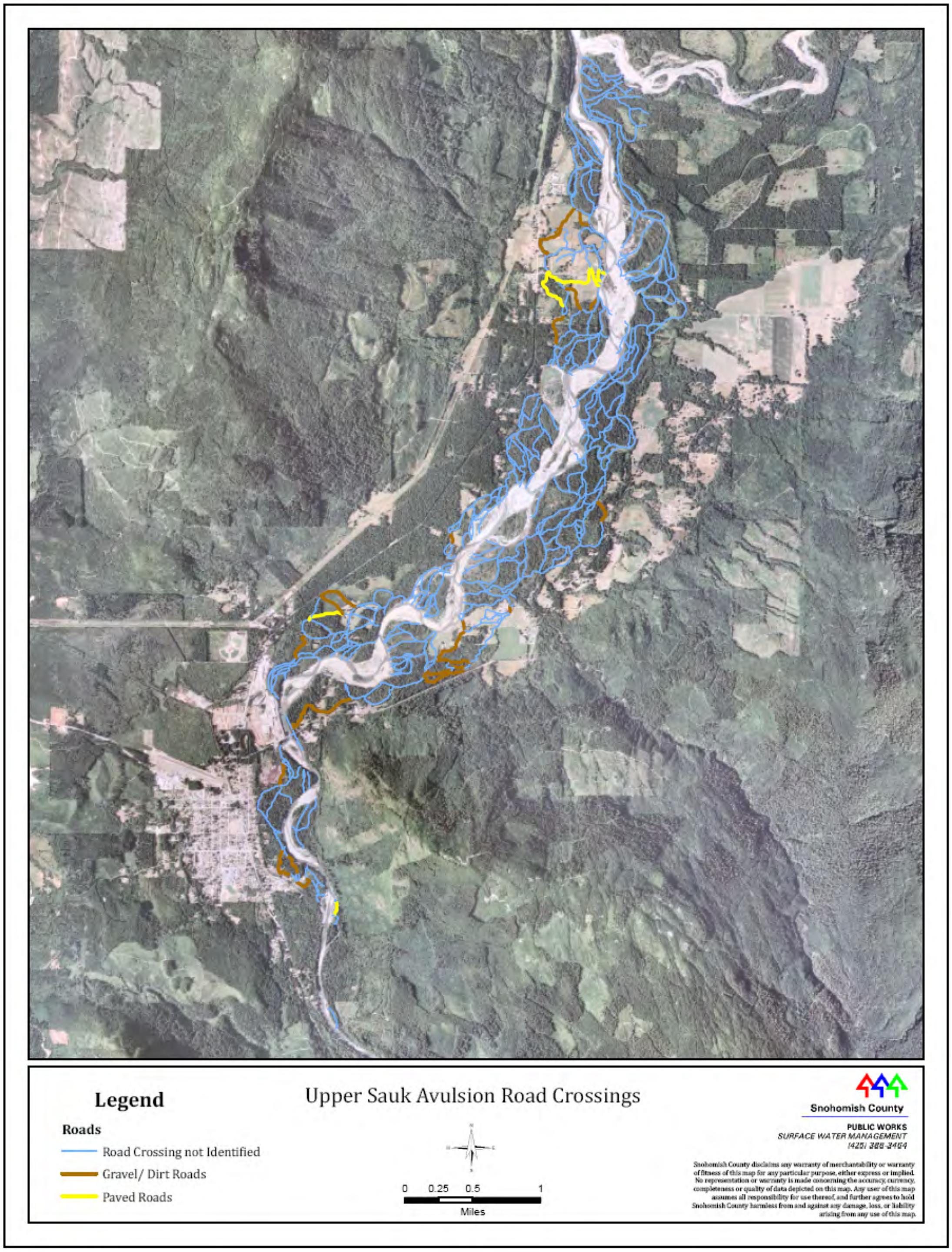

Figure 6. Joint avulsion risk mitigation ratings of potential avulsion pathways characterized according to whether a segment is intersected by a paved or gravel surfaced road. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management. Road coverage may be incomplete and should be evaluated on a site-specific basis.

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Technical Memorandum

Date: June 11, 2009 Project Number: 1709.01/MM101

To: Bob Aldrich (Snohomish County)

From: Paul DeVries, Ph.D., P.E.

Subject: Results of Geomorphic Analysis of Hydraulic, Hydrologic, Sediment, and Habitat Conditions in the **Lower Sauk River Between the Suiattle River and the Lower Delta**

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INTRODUCTION

The Sauk River Comprehensive Floodplain Hazard Management Plan (CFHMP) is to be based on a comprehensive analysis of physical, cultural, societal, regulatory and environmental factors that reflect or govern the influence of flooding conditions on landowners, habitat, fisheries, and infrastructure. From consensus discussions with the existing Sauk River Stakeholders group, the intent of the Sauk River Management Plan was to produce a plan acceptable to affected landowners, resource agencies, local tribes and local governments that can be used to evaluate:

1) The range of risks to property, infrastructure, and fish and wildlife habitat for areas along the Sauk River floodplain corridor from impacts associated with flooding and channel migration.
2) The areas and conditions in the corridor that justify high consideration for flood and bank protection.
3) The areas and conditions in the corridor that justify high consideration for habitat protection and restoration.
4) The regulatory environment in the corridor, including a) authority of each jurisdiction, b) permit requirements, pathways and timelines, especially during locally declared 'emergencies,' and c) proactive steps to expedite permitting.
5) The range of public assistance programs available to landowners impacted by flood and channel migration, gaps in those programs, recommendations for filling those gaps, and how access to existing programs can be improved.

Development of the CFHMP is contingent on first gathering and analyzing data on channel morphology, bank conditions and modifications, floodplain conditions and topography, hydrology, hydraulics, riparian conditions and habitat for salmonids. The results of these data collection and analysis efforts will be reviewed by Stakeholder and Technical committees as they develop management alternatives such that infrastructure protection and habitat restoration dollars will be spent where they will have the greatest effect.

This memorandum describes the geomorphic analyses and data evaluated as part of this initial phase of preparing the CFHMP. The analysis concerns the "lower" 7 mile long reach of the Sauk River extending downstream from its confluence with the Suiattle River to the upstream extent of the depositional confluence zone with the Skagit River, just downstream of USGS Gaging Station No. 12189500 (Sauk River Near Sauk; Figure 1).

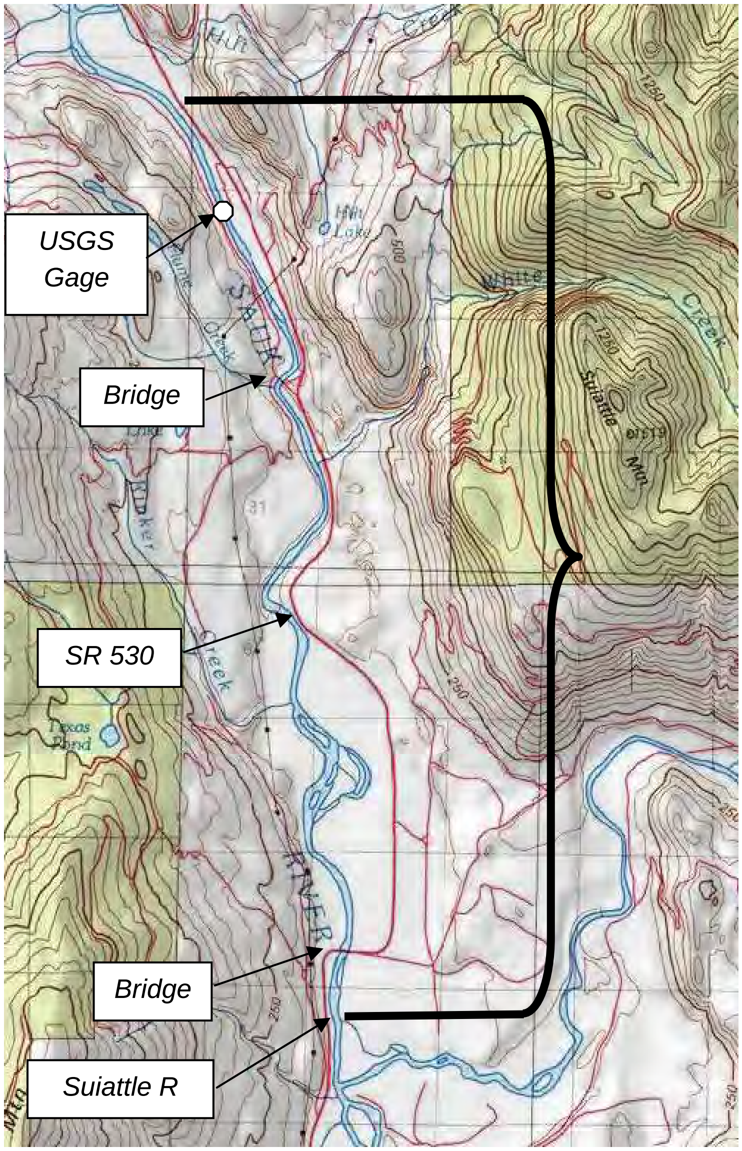


Figure 1. Location of the Lower Sauk River reach analyzed in this memorandum. Note changed location of mouth of Suiattle River.

The reach provides spawning and rearing habitat for lower Sauk summer Chinook salmon (*Oncorhynchus tshawytscha*), one of six distinct Chinook stocks identified as being important for recovery in the Skagit basin and for which escapement numbers have declined since the 1970s. Salmon production in the reach in general is believed to be limited by bedload transport and sedimentation. It is generally believed that spawning habitat in the lower Sauk River is among the poorest in the system for incubation survival, and fine sediment levels are generally high throughout the reach (SRSC/WDFW 2005).

The recovery plan advocates floodplain restoration as an action that mitigates the impacts of flood flows on Chinook salmon (SRSC/WDFW 2005). The work and results described in this memorandum can be used to assess opportunities and risks of specific floodplain restoration activities, as well as more general risks to floodplain development and infrastructure. To accomplish this, a strategy was employed of identifying the extent to which shorter, distinct segments within the reach are geomorphically active (or inactive) in terms of sediment transport, deposition, channel migration, and overall erosion tendency. This strategy allowed evaluation of specific locations on the floodplain in the context of local and reach scale constraints. In addition, the results facilitate explanation of the physical cause of specific effects to infrastructure and private land in an intuitive way to stakeholders.

METHODS

A suite of analyses was selected over focusing on a specific method, any one of which on its own would provide some information but would not yield a sufficiently complete picture. Quantitative, process-based analyses (e.g., sediment transport modeling, bank migration rates, gravel bar areas) were favored over channel form (e.g., see Kondolf et al., 2001) or process-based classifications (e.g., channel migration zone mapping; Rapp and Abbe, 2003), so that the results could be used to better answer the question, "What would happen if…" The analysis involved identifying and quantifying (1) physical processes that influence reach channel morphology, (2) hydraulic and sediment transport processes that will affect future condition and channel location in the reach, and (3) the most geomorphically active and inactive segments in reach. To accomplish these tasks, information was analyzed that was critical for assessing processes acting at the reach and site scales (Wissmar and Beschta, 1998; Kondolf, 2000): (1) longitudinal profiles of elevation, gradient, and grain size distributions, (2) hydraulics and hydrology using HEC-RAS, USGS gage data, and surveyed cross-section and flood stage data, (3) bedload transport potential based on a 50-year duration, (4) aerial photographs for changes in active channel locations and cumulative active gravel bar storage and persistence of side channel areas, and (5) Lidar data, soil maps, land cover and roads layers, and the HEC-RAS model to assess relative risk of avulsion through floodplain channels and swales. Important details of the methods are described below.

Longitudinal Profiles

Longitudinal profiles provide an indication of effects of large scale slope changes on sediment transport and deposition patterns. Water surface and thalweg elevation profiles were developed for the reach using the HEC-RAS model data and predictions for the 2-yr flood event. The HEC-RAS model water surface elevation data were also used to generate stream gradient profiles. Non-vegetated, active channel widths were estimated at each HEC-RAS cross-section from georeferenced aerial photographs taken in 2007, and plotted against river mile (RM).

A total of 9 pebble counts were sampled to characterize upstream-downstream variation in grain size and depositional patterns in the reach. It was generally not feasible to collect data near the thalweg given channel size. Instead, a sample size of 100 stones was selected randomly by moving over the mid-point of active depositional point bars between the water and floodplain and measuring the intermediate axis diameter of each stone. Sampling locations were selected to be geomorphically similar in terms of bar type and relative location on the bar, so that observed longitudinal variation in grain sizes would not reflect locally variable depositional processes, but rather larger scale geomorphic variation. One sample was not used in the analysis because it was determined upon review to represent a different type of geomorphic surface than the rest. Various percentile particle sizes, including D_{50} (size for which 50 percent of stones were smaller), were computed for each sample and plotted against river mile. Inspection of the longitudinal scatter in D_{50} and D_{90} values indicated that there were two sub-reaches in the plot. Pebble count data were accordingly pooled within each sub-reach to develop grain size distributions. The resulting two grain size distributions were applied across to subsections of the reach modeled in the sediment transport analyses.

Sediment Transport Modeling

HEC-RAS Model Geometric Data

A HEC-RAS steady flow model was constructed to simulate flood flows and predict longitudinal shear stress variation for estimating bedload transport rates and their effect on a coarse sediment budget within the reach. The model was built using bathymetric longitudinal and cross-section profile data collected in the field by County staff, and LIDAR data. All elevations were calculated relative to the NAVD 88 vertical datum. Field benchmarks were established and tied-in using real time kinematic (RTK) GPS and a total station. The HEC-RAS model extended from above the SR 530 bridge to downstream of the USGS gage, reflecting influence of access on extent of bathymetric data collection. The reach was modeled assuming flow accretion was minor in the reach.

Transects were established as lines in ARC GIS using aerial photographs. Transects were located to include hydraulic controls and intervening portions of the channel. Dry-land portions of each transect profile were derived from bare earth model LIDAR data, and including exposed bars, side channels, and the floodplain. Wetted channel portions were developed from bathymetry data collected on August 6, 8, and 12, 2008 using a raft that was rowed at a ferry angle across channel. Elevations were computed by subtracting the water depth from the water surface elevation, which was determined using RTK GPS. Cables were not used to maintain position, and thus the data did not represent a perfectly straight line, which is needed for computing flow rate and stage in HEC-RAS. The bathymetry data were therefore projected onto each transect line by using the “Near” command in ARC GIS.

Once the LIDAR and associated Bathymetry cross sections were grouped together in excel, each section was sorted by northings. The station and elevation data was then converted into a .CSV format and imported into the HEC RAS model. Transect spacing was specified in the HEC-RAS model for the channel centerline, and shoreward of the left and right banks. The graphical cross section editor in the HEC RAS model was used to define left and right bank stations. Left and right bank longitudinal stationing was measured on scaled color aerial photographs taken in 2007 using ARCView. Ineffective flow areas were specified at selected transects to help distribute the flow better or to delay engagement of side channels and floodplain areas until higher flows, based on review of aerial photographs and assessing land cover and side-channel size characteristics.

Transects were surveyed but pier and abutment data were not collected to define the two bridges in the model. Thus the hydraulics in the vicinity of the bridges were not evaluated at this time. Errors in flood stage predictions are expected to occur in the vicinity of each bridge, but the errors are not expected to influence the overall results substantially for adjacent segments upstream and downstream.

The model cross-sections defined “analysis segments” for which other quantities were calculated (e.g., bank migration rate, gravel bar area; Figure 2). Table 1 lists the river mile system developed for each HEC-RAS model transect defining an analysis segment, based on the same datum as for the upper reach.

HEC-RAS Model Calibration

The HEC-RAS model was calibrated to water surface elevations at the USGS gage (Station No. 12189500), using the subcritical model run option. The model was calibrated iteratively by adjusting Manning’s n in the channel and outer banks to predict the water surface elevation at the USGS gage for the 2-, 10-, and 100-year flood events. The gage is located at approximately RM 5.0 in the model. The downstream boundary condition was set to normal depth with a slope of 0.002, similar to that predicted for the lower transects during initial model runs. Values of n=0.025 for the channel portion and n=0.095 for the floodplain portion resulted in a reasonable fit to the data, with prediction errors at the gage of +0.55 ft, +0.09 ft, and -0.31 ft for the 2-, 10-, and 100-yr events, respectively. The reach is generally confined, and it was assumed that the channel Mannings n value derived in the calibration applies to the rest of the reach. This assumption seems reasonable for purposes of obtaining an approximately calibrated HEC-RAS model to predict longitudinal variation in sediment transport potential and for differentiating avulsion risk for broadly different flood recurrence intervals, inn this case the 2-, 10-, and 100-year events. The model should not be considered accurate for predicting water levels that can be used to delineate the 100-year floodplain, however, without additional field data collection and calibration of floodplain inundation levels.

The model was calibrated and run using the interpolated transect feature of HEC-RAS. The extra transects were needed because there was considered to be too much head loss between measured transects. Adding extra transects stabilized the model better by smoothing between-transect changes in depth and velocity, and distributing energy losses across shorter model segments. Interpolated transects were generally spaced approximately 200 ft apart, resulting in drops in water surface elevation between transects generally equal to about 1.0 ft or less at flood stage, a resolution considered sufficient for the river size.

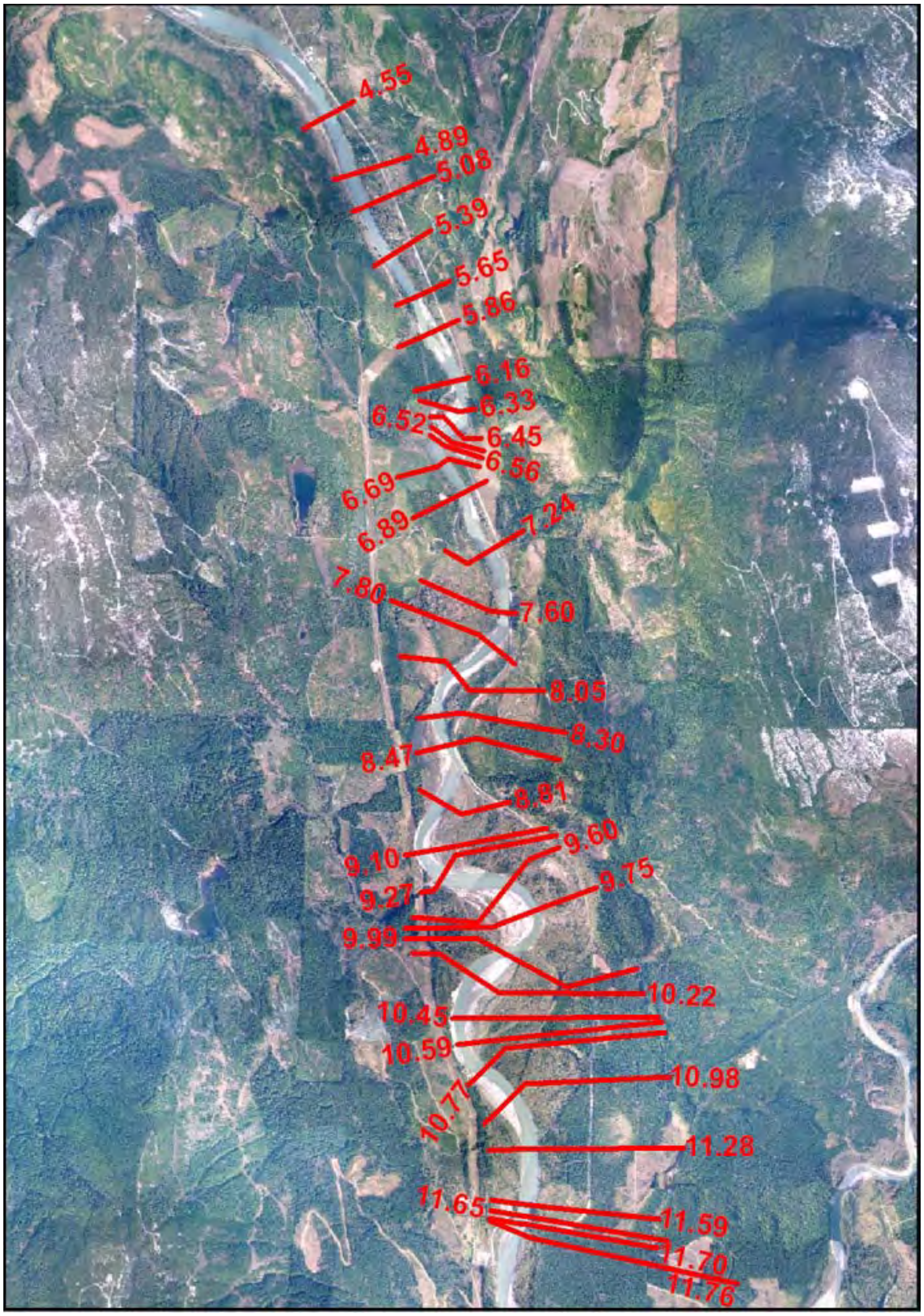


Figure 2. Location of HEC-RAS transects and corresponding analysis segments established to compare sediment transport, channel migration, and other analysis results.

Table 1. River mile system used in the analysis.

Analysis Segment	HEC-RAS 2004 River Mile (Upper Boundary)	Landmarks
60	11.76	
61	11.70	Upstream Side of SR 530 Bridge
62	11.65	Downstream Side of Bridge
63	11.59	
64	11.28	
65	10.98	
66	10.77	
67	10.59	
68	10.45	
69	10.22	
70	9.99	
71	9.75	
72	9.60	
73	9.27	
74	9.10	
75	8.81	
76	8.47	~Top of Confined Sub-Reach; at SR 530
77	8.30	
78	8.05	
79	7.80	
80	7.60	SR 530 Adjacent
81	7.24	
82	6.89	
83	6.69	
84	6.56	Upstream Of Sauk-Concrete Road Bridge
85	6.52	Downstream of Bridge
86	6.45	
87	6.33	
88	6.16	
89	5.86	
90	5.65	
91	5.39	
92	5.08	Near USGS Gaging Station No. 12189500
93	4.89	

Sediment Transport Simulation Flows

The USGS gage has an extensive record extending from 1928 to present. A flow duration curve was generated based on daily mean flow data for the period of record. The curve was discretized into a histogram approximating the duration of various simulation flow magnitudes as a percent of the length of the record. The distribution of flows was determined based on matching total volume under the curve and total number of days over a 50-year period while also approximating the curve shape. Peak flow values used in the analysis were derived in the previous analysis for Phase 1.

Sediment Transport Analysis

The simulation flows were modeled in HEC-RAS using the steady flow option, for a series of discharges equal to and greater than the 5 percent exceedance flow, up to the 50 year flood. Relatively little bedload transport occurs in general in alluvial rivers when discharge is below the 5 percent exceedance flow. A 50-year period was simulated to predict the total volume of bedload transported at each HEC-RAS transect and evaluate corresponding long term depositional and erosional trends in the reach over a representative project design life.

The HEC-RAS main channel shear stress predictions were input with grain size distribution data to a Fortran program that predicted sediment transport rate per unit width based on Parker's (1990) bedload transport equation. An approximate sediment budget was developed to characterize analysis segments within the reach regarding their deposition or erosion tendencies, and use that knowledge as a guide to the type of project that may or may not succeed in the segment. For example, fish habitat structures would not be expected to succeed in an analysis segment that was predicted to strongly experience a net gain in sediment over time, because the structures would have a higher risk of burial or abandonment by the river.

The sediment budget was computed for each flow and analysis segment by estimating sediment transport rates at the bounding upstream and downstream HEC-RAS cross-sections, and applying a mass balance equation for bed elevation change between transects as a function of estimated input and output bedload mass transport rates per unit width (q_B), active width (W), distance between transects (L), sediment density (ρ_s), and porosity (P) (DeVries, 2000):

$$Y_T = \int_{t1}^{t2} \frac{\partial Y}{\partial t} dt \cong -\sum_{t1}^{t2} \left[\frac{(q_B W)_{out} - (q_B W)_{in}}{0.5L(W_{in} + W_{out})\rho_s (1-P)} \right] \Delta t \qquad (2)$$

where the incremental change in bed elevation ($\partial Y/\partial t$) was evaluated for each simulation flow and then multiplied by the histogram time increment (Δt) over which the modeled flow occurred during the 50-year period. This was repeated for other flows, and the results summed to estimate a net mean change in bed elevation Y_T between successive HEC-RAS transects. A strongly positive value of the $\partial Y/\partial t$ sum was inferred as an indication of a strong tendency towards aggradation, and a strongly negative value as an indication of a stronger tendency towards degradation. The active width used in Equation (2) was derived from the aerial photos in GIS. Length was set as the main channel distance between HEC-RAS transects.

The resolution of the HEC-RAS modeling and special hydraulic characteristics in the vicinity of the upstream bridge were such that predictions of bed elevation change were strongly negative for the upstream segment and strongly positive for the adjacent downstream segment. This phenomenon appeared to reflect locations where the river flow was predicted to experience substantial energy losses due to channel expansion or contraction. The HEC-RAS model hydraulic predictions at these locations were characterized in turn by relatively irregular longitudinal trends in velocity and Froude number over short distances. To resolve this, the two transects bounding the bridge were not included in the computations.

The same seven erosion-deposition tendency classes developed for the upstream analysis (Phase 1) were used to characterize deposition trends based on the sign and magnitude of the predicted bed elevation change (Table 2). Each analysis segment was classified accordingly and the results depicted graphically in ARC-GIS.

Table 2. Predicted bed elevation change rate and sign used to classify analysis segments according to sediment transport and deposition characteristics in the lower Sauk River.

Aggradation Potential Class	Bed Elevation Change Rate (ft/yr)
1	< −1.0 (Extreme Degradation Potential)
2	−1.0 to −0.20 (High Degradation Potential)
3	−0.20 to −0.05 (Moderate Degradation Potential)
4	±0.05 (Minor Change)
5	0.05 to 0.20 (Moderate Aggradation Potential)
6	0.20 to 1.0 (High Aggradation Potential)
7	> 1.0 (Extreme Aggradation Potential)

Aerial Photograph Interpretation

Aerial photographs were available from 1944, 1956, 1972, 1981, 1992, and 2006 (Table 3). The photographs were orthorectified, mosaicked, and georeferenced. The reach was divided into ‘analysis segments’ using the hydraulic modeling transects as boundaries. This permitted a common framework for synthesizing the results from the various analyses. Spatial and temporal patterns in channel migration rate and gravel bar area were used to infer relative stability of specific analysis segments of the Braided Reach associated with varying geomorphic activity levels.

Historic Channel Planform Mapping

Right and left river bank locations were digitized by the Skagit River System Cooperative’s GIS specialist for each year photographs were available. Main and major side channels were mapped. The resulting digitized poly lines were overlaid chronologically and locations compared between consecutive sets of photographs. Migration rates were estimated as the local average offset distance within an analysis segment between successive main channel river bank traces, divided by the number of years between the two sets of photographs. The visual changes and calculated migration rates were used as the basis for classifying an analysis segment according to planform changes, tailored to rates observed in the reach (Table 4).

Table 3. Dates and approximate flow rates of available aerial photography for mapping channel planform and gravel bar area changes in the Sauk River below the Suiattle River (provided by Kate Ramsden, Skagit River System Cooperative). The width adjustment factor was used to adjust computed gravel bar areas to a common flow level.

Year	Flight (Source)	Date	Scale (Black/ White or Color)	Coverage of Flight	Estimated Mean Daily Flow at Sauk (cfs)	Width Adjustment Factor
1944	Skagit River/US Army Air Corps	September 1944	1:20,000 (BW)	Complete	1350-5680	0.98
1956	EBK/Forest Service	8/8/1956, 8/14/1956, 8/18/1956, 8/31/1956	1:15840 (BW)	misses a 2500' stretch of mainstem near Suiattle River at upstream end of reach	3160, 3480, 2920, 2279	1.04
1972	EXQ/Forest Service	8/8/1972	1:15840 (Color)	Complete	7580	1.34
1981	S81005 (Army Corps of Engineers)	3/2/1981	~1:10000 (BW)	Misses westernmost section of McCleod Slough	2800	1.03
1992	Wild and Scenic River Flight 0032 MB and 616050C (Forest Service)	(7/17/1992) 8/15/1992	1:12,000 (Color), 1:8000 (Color)	1:8000 flight misses the westernmost section of McCleod Slough. 1:12000 photo used to digitize McCleod Slough	2290	1.00
2006	National Agricultural Inventory Project/USDA NRCS	8/5/2006	1:12000 (Color orthophoto)	Complete	1890	0.97

Gravel/Sand Bar and Side Channel Area Mapping

Exposed main channel gravel/sand bar and clearly visible side channel areas were digitized from the aerial photographs as discrete polygons. Most bars were point bars, although mid-channel bars were also mapped at specific locations where the channel widened substantially so that flow depth was very shallow across the hydraulic control formed by depositing coarse bedload. The area of gravel bar mapped in each segment was then computed and summed cumulatively from upstream to downstream in ARC-GIS to reflect the direction of sediment transport and deposition. A running sum was computed for the main channel; separate sums were computed for major side channels, with the river mile determined by the location at which the side channel branched off from the main channel.

Table 4. River channel migration rate classification for assessing channel planform changes. Migration may be to either left or right bank directions.

Planform Change Index	Average Migration Rate (ft/yr, one or both banks)
1	< 15 (minor change)
2	15-30 (small change)
3	30-80 (moderate change, wandering tendency)
4	>80 (severe change, braiding tendency)

Not all of the aerial photographs were taken at similar flows, and differences were expected in gravel bar areas due to differential inundation. The adjustment was done for these and the other flows by calculating wetted width (W_{wet}) as a function of flow in the HEC-RAS model. The following multiplier was computed for each transect:

$$W_{GBref} = W_{GB}\left(\frac{W_{\max} - W_{ref}}{W_{\max} - W_{wet}}\right) \qquad (4)$$

The multiplier effectively converted measured gravel bar widths (W_{GB1}) to the equivalent width for the flow at which the 1992 photographs were taken (W_{GBref} ; where corresponding wetted width = W_{ref}). The 1992 photographs were selected as the common basis because the flow that year was more recent and near the middle of the spread of flows in Table 3. The maximum channel width (W_{max}) was the greater of the wetted width predicted by HEC-RAS for the 7,580 cfs flow rate and the active width determined for the sediment transport analysis. The average multiplier was calculated for each flow over all transects (Table 3) and used to adjust the gravel bar and side channel area values digitized from a particular set of aerial photographs.

Areas were converted to an equivalent mean width within each analysis segment by dividing the area by segment centerline length. This allowed for making comparisons across different years without the influence of changing thalweg lengths (e.g., associated with channel migration). Locations were identified where mean widths changed by more than 100 ft between photographs, indicting a change in storage and erosion activity. Each analysis segment was classified according to whether or not a substantial change in mean width of active bar or side channel slope occurred, and whether the change represented an overall decrease or increase in area between successive photographs. The resulting classifications were coded for each analysis segment and presented spatially in GIS format.

Avulsion Risk Assessment

Avulsion risk was assessed using LiDAR topographic data, HECRAS flood modeling results, and various GIS data. Factors evaluated as contributing to the potential for avulsion included the presence of concentrated flow pathways evident on the topographic surface, the average slope of pathway segments, the general flow level at which the upstream inlet would be inundated, and the inherent erosivity of soils associated with the pathway. Potential factors that could reduce the risk of avulsion were also identified, including vegetation and the presence of infrastructure. The methods used to characterize and identify these various factors are described below.

Flow Paths: Potential avulsion pathway segments were traced on 2 ft contour maps generated from the 2005 LiDAR data as linear features with elevations that were generally lower than the surrounding floodplain. Segments began and ended at the main river channel or junctions with other segments. A GIS layer was then constructed by Laura Audette (SWM GIS staff) that depicted each potential pathway segment as a linear feature.

Inundation Flow Level: The elevation of pathway segments branching from the river was used to estimate the return interval event at which each segment and connected segments downstream and upstream would become wetted, using water surface elevations estimated for the 2-year, 10-year, and 100-year event based on the HEC-RAS modeling. Segments below junctions with upstream segments were assumed to be connected at the same level as upstream segments as long as there was no significant break in slope evident on the map downstream. For example, if a downstream segment was connected to two upstream segments with one flowing at the 2 year flood level and the other at the 10 year flood level, the downstream segment was assigned a 2-year flood level risk.

Slope: A longitudinal profile for each pathway was developed by extracting elevation data from a DEM for selected points spaced 100 ft apart along each segment. Average slope was calculated as the average of slopes calculated between points, for each segment. Slope between points was calculated as the difference in elevation between points divided by the length between points (100 ft or shorter, depending on the total length of the segment).

Soil Erodibility: The avulsion pathway layer was overlaid in GIS on a soils map produced by the NRCS. Each soil type is assigned a K_w-factor which represents both susceptibility to erosion and the infiltration rate. Soils with lower K_w-factors are more resistant to erosion due either to high clay content or high infiltration. Soils with higher K_w-factors are more erodible. Soils within the study area were classified as follows based on the NRCS K_w-factor, with greater emphasis placed on the uppermost soil horizon:

1 = K_w-factor > 0.3 (higher erodibility)
2 = K_w-factor 0.2-0.3 (moderate erodibility)
3 = K_w-factor <0.2 (lower erodibility)

Where potential avulsion pathways crossed soils with different K_w-factors, a weighted average class was calculated based on the relative length of channel crossing each soil type.

Vegetation Cover: In general, the presence of forest vegetation is anticipated to reduce the risk of avulsion, as trees provide deep, dense root masses that are more resistant to erosion and may inhibit braiding (Miall 1977). In addition, if channels do avulse through forested areas, trees that fall into the new channel provide roughness elements that reduce erosive energy and may temporarily block flow. In the present case, vegetation was assessed visually for each avulsion pathway using aerial imagery closest to the LiDAR data (georeferenced 2003 aerial photographs or 2006 Skagit NAIP). Potential avulsion pathways were classified as forested, non-forested or open water. Only forest vegetation was considered to potentially reduce the likelihood of avulsion.

Road Grade Controls: The presence of roads can act as both a mitigating factor or exacerbate the risk of avulsion. Paved roads, and to a lesser extent gravel roads represent a “hard point” that is more resistant to erosion over the short-term. However, roads that cross avulsion pathways may also exacerbate the risk if they contain undersized drainage structures or temporarily hold back water then fail catastrophically. This analysis assumes that roads are monitored and/or protected during floods and thus moderate the risk of avulsion where they are present. Road crossings were identified from aerial imagery. Paved roads were considered to be more resistant and more likely to be protected during floods, and thus were assigned a greater mitigative factor.

Bank Hardening: The presence of bank hardening can retard avulsion if the river does not erode around the structure and it is designed and built to counter the potential for undermining at the bank toe. Risk needs to be evaluated on a case-by-case basis, however, where type of structure (i.e., rip rap or LWD), condition of the structure, distance from the upstream and downstream ends of the structure to a floodplain swale, and respective structure end point and swale elevation differences can either be a mitigating factor or not substantially affect avulsion risk depending on the particulars of the site. For that reason bank hardening was not explicitly included as a factor in this reach-scale avulsion risk analysis.

Joint Avulsion Risk Factors: The factors above were considered for ways to combine them into a joint risk rating system. Weighting factors were conceived and assigned to ranges of each factor. It was decided to combine the flow level, slope, and soil erodibility factors into a weighted joint risk rating system, and apply vegetation and road characteristics as mitigating factors. Each pathway segment identified on the LiDAR topographic surface was rated accordingly, following the gradations and weightings proposed in Table 1. The joint avulsion risk was calculated for each segment as the sum of the weights assigned in Table 1 for return interval event at which the pathway may flow, pathway slope, and soil erodibility. The following joint risk classes were then defined based on professional judgment:

- Joint Risk Weight Sum >14 = Class 1 (Highest risk)
- Joint Risk Weight Sum = 10-14 = Class 2
- Joint Risk Weight Sum = 6-10 = Class 3
- Joint Risk Weight Sum <6 = Class 4 (lowest risk)

The joint risk rating may be modified by subtracting weights for mitigating factors, with initial recommendations for weights given in Table 5. Alternatively, the mitigating factor ratings can be used on a case-by-case basis in consideration of greater site specific knowledge as to the relative importance each factor could play in mitigating joint avulsion risk.

Table 5. Summary of parameters used to assess theoretical avulsion risk, and the weights assigned to each parameter.

Parameter	**Criterion (weight)**			
Risk Factors:				
Flood Return Interval Causing Inundation	>100 yr (1)	100 yr (3)	10 yr (6)	2 yr (9)
Slope	<0% (1)	0-1% (3)	1-3% (6)	>3% (9)
Soil Erodibility Class	3 (1)	2 (2)	1 (3)	
Potential Mitigating Factors:				
Vegetation	Forested (-2)	Non-Forested (0)	Open Water (0)	
Road Crossing	Paved (-3)	Gravel (-1)		
Bank Hardening Across Pathway	Rip Rap (-4)	Large Wood (-2)		

RESULTS

Longitudinal Profiles

Aerial photograph interpretation indicates the existence of two sub-reaches. Upstream of about RM 8.45 the channel is moderately confined and meandering, whereas downstream with little evidence of substantial meandering. The break location between the two reaches is reflected in most of the data analyzed. There appears to be an inflection point around the sub-reach break where the longitudinal profile is mildly convex in the moderately confined sub-reach and mildly concave in the confined sub-reach (Figure 3). Average sub-reach slopes are comparable (0.0026 and 0.0025, respectively). Active channel widths are generally higher upstream and lower downstream (Figure 4).

In general, the grain size distribution became progressively coarser in the downstream direction in the moderately confined reach (Figure 5), reflecting increasing distance from a large upstream supply from both the Suiattle River and the braided reach. This increasing distance may effectively be associated with a general increase in the downstream direction of the ratio of transport capacity in the reach to the supply of sediment from upstream. There were insufficient samples in the confined reach to draw inferences, largely because there were few point bar surfaces that could be sampled consistently.

The pooled grain size distributions for each sub-reach are depicted in Figure 6. Figure 6 also depicts the range of Chinook salmon and steelhead trout spawning habitat D_{50} values reported by Kondolf and Wolman (1993) in their review. Substrates in the moderately confined reach are comparable to those in the braided reach upstream of the Suiattle River, and could potentially support Chinook spawning. Conversely, substrates in the confined reach are similar to those in the confined reach upstream of the Darrington Bridge and are generally unsuitable for spawning. The lower-most sample depicted in Figure 5 appears suitable for spawning, however, and may be more representative of substrates below the analysis reach.

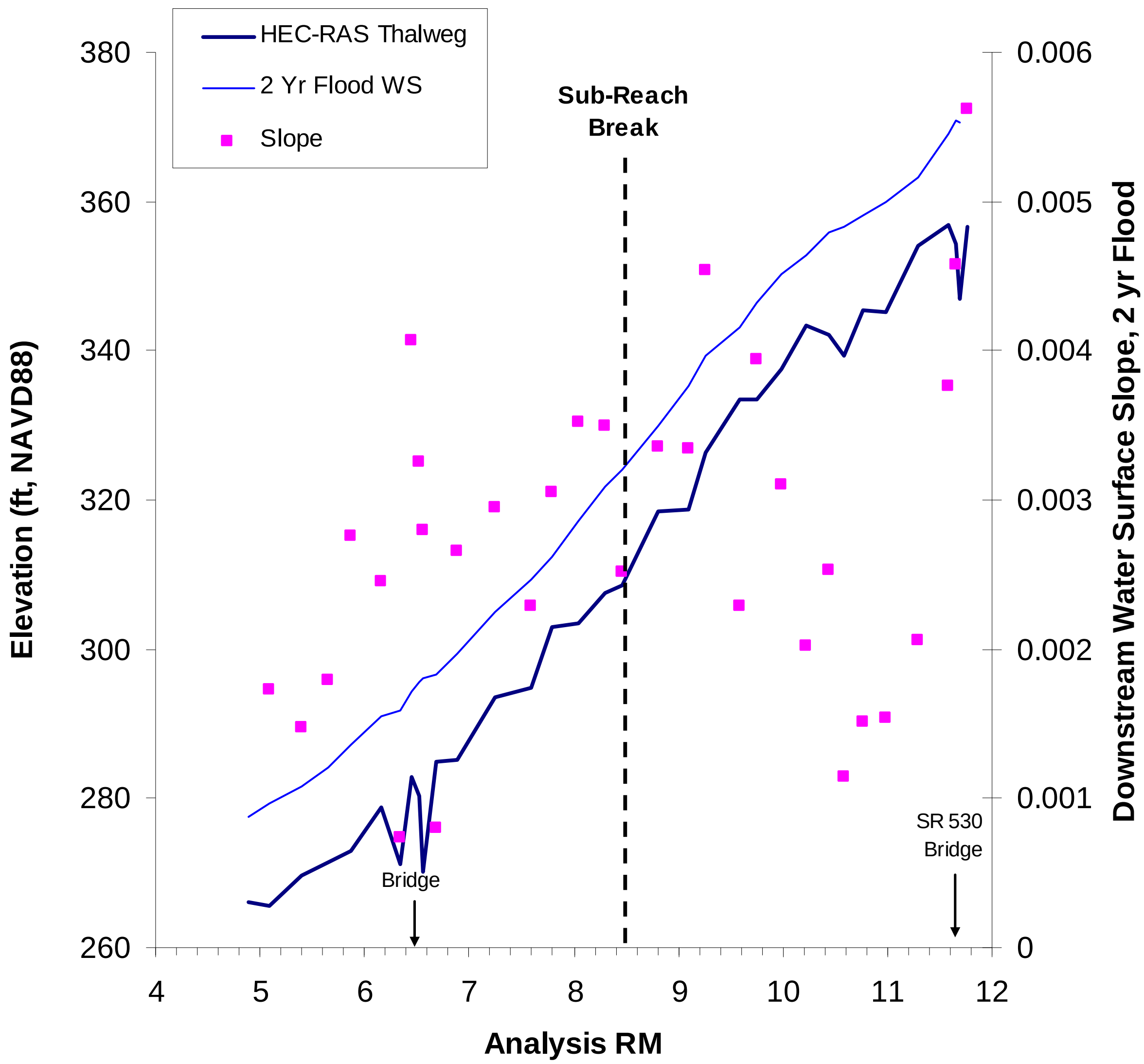


Figure 3. Longitudinal elevation and gradient profiles of the Sauk River from its confluence with the Suiattle River upstream to near the confluence with Clear Creek.

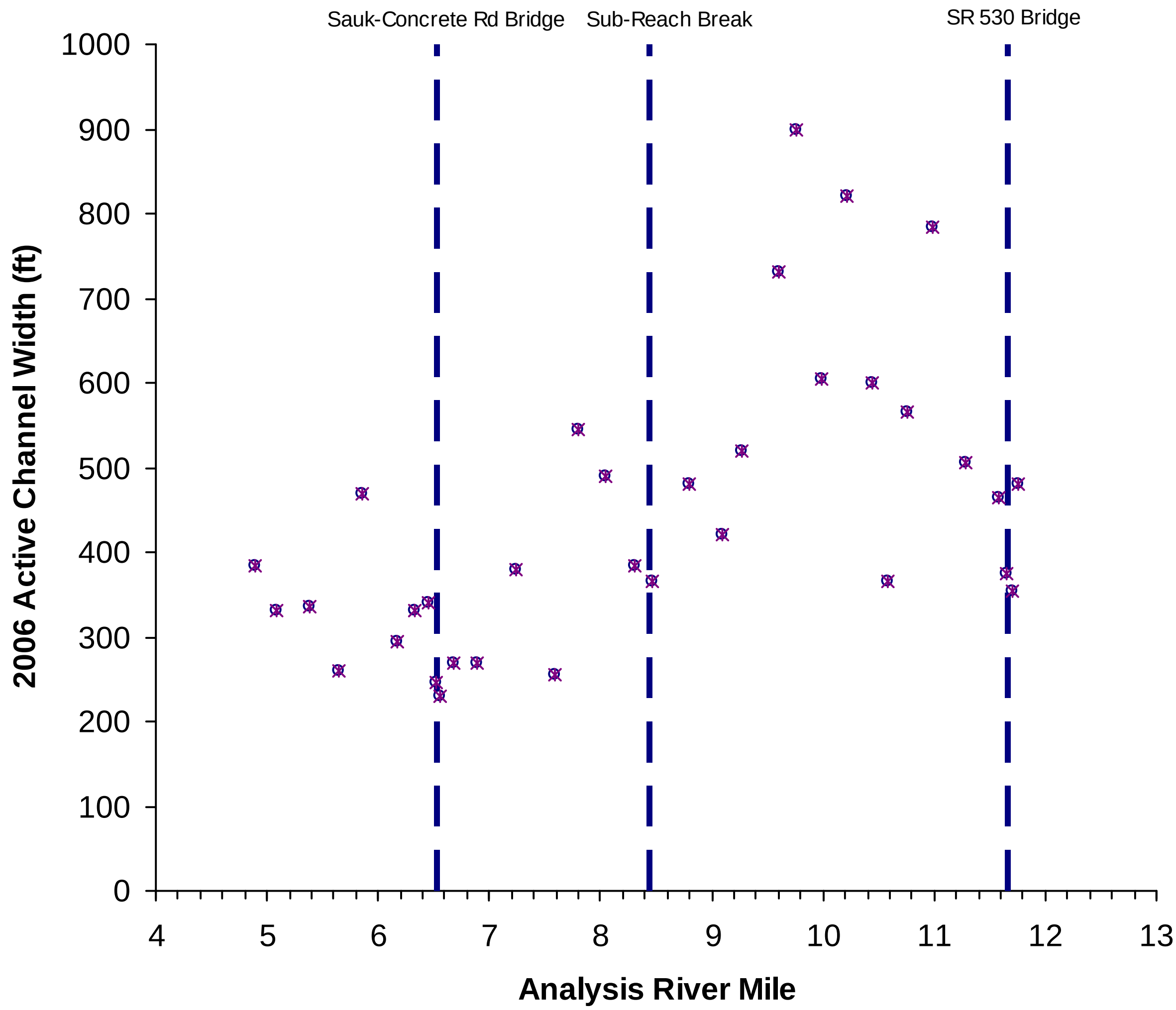
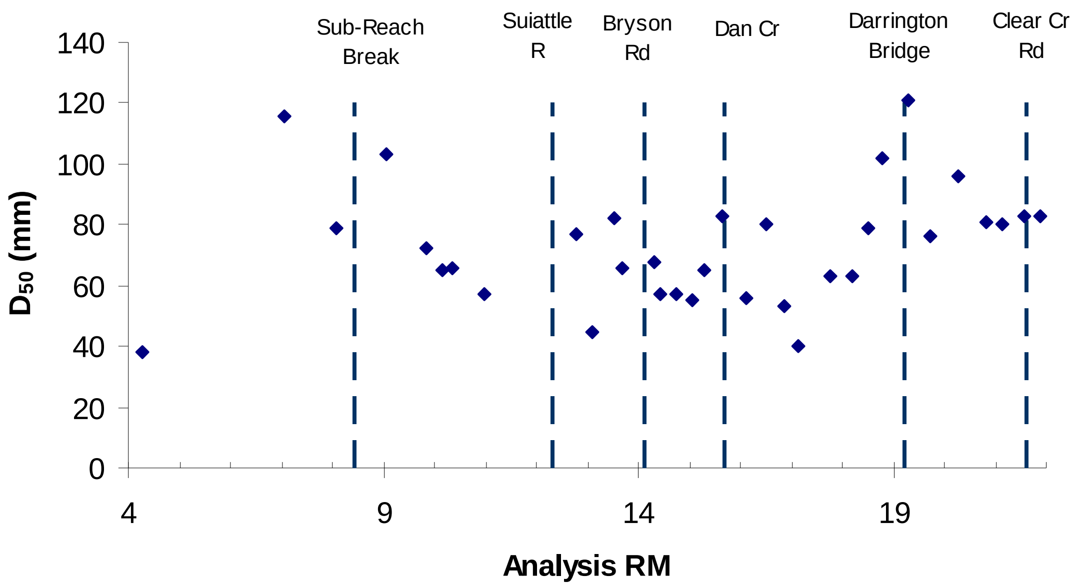


Figure 4. Longitudinal profiles of active channel widths in the Sauk River from its confluence with the Suiattle River downstream to near the USGS Gaging Station No. 12189500.



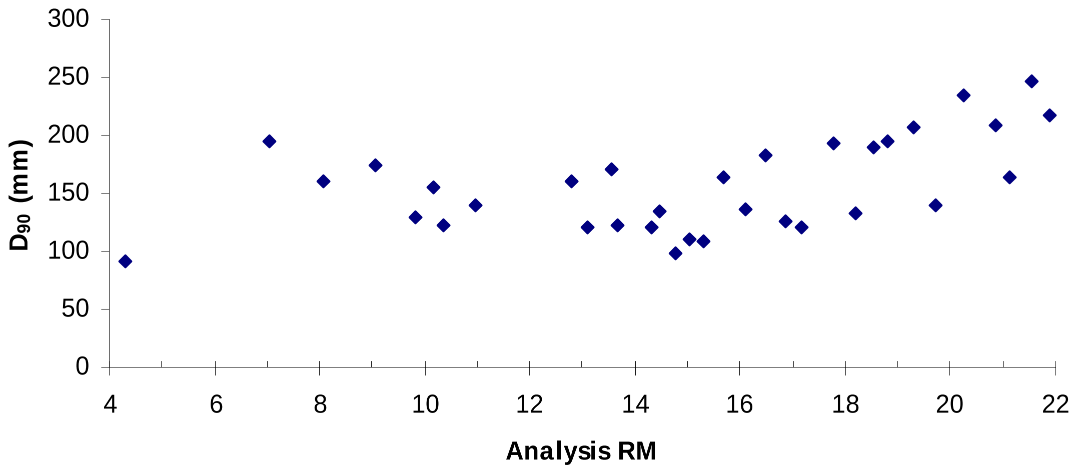


Figure 5. Longitudinal trends in selected grain size distribution percentiles measured on depositional surfaces in the Lower Sauk River (upper = D_{50}, lower = D_{90}), and sub-reach breaks in distributions.

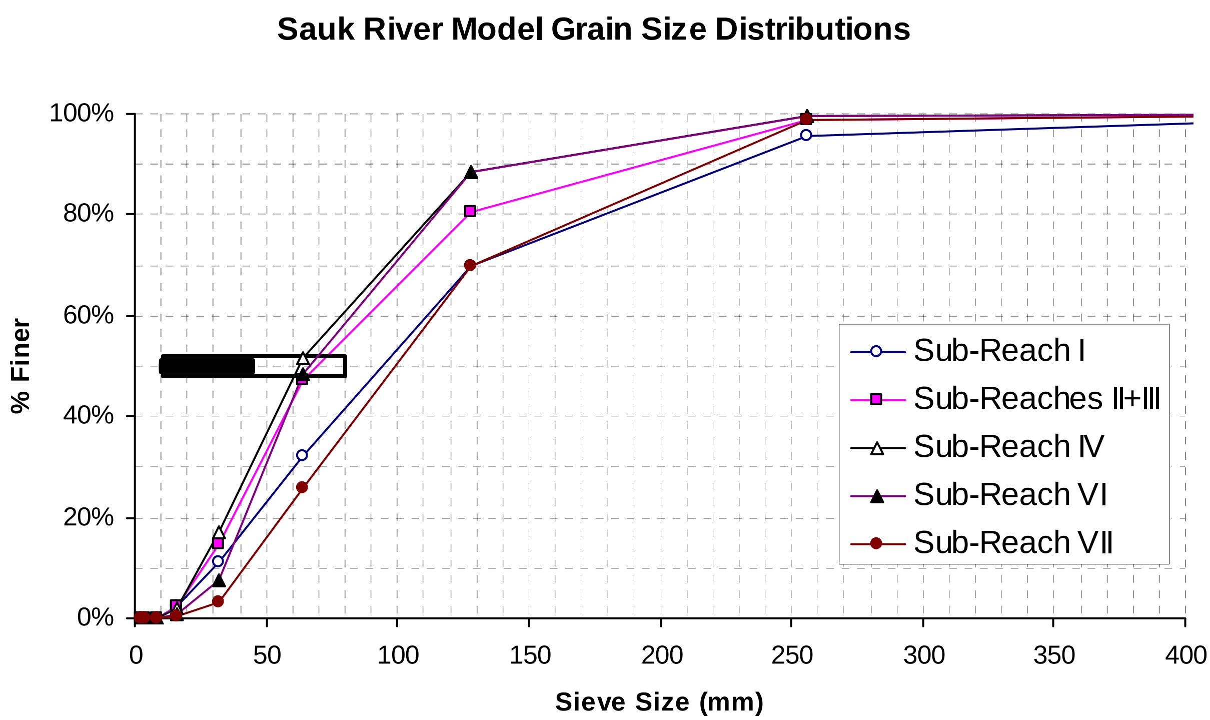


Figure 6. Grain size distributions of pebble counts collected in the Sauk River above and below its confluence with the Suiattle River. Horizontal bars represent range of D_{50}'s reported by Kondolf and Wolman (1993) as suitable for steelhead trout (filled bar) and Chinook salmon (open bar) spawning.

Sediment Transport Modeling

Peak Flow Magnitude, Duration, Frequency

Table 6 summarizes Log Pearson III distribution flood frequency estimates for the Sauk River Near Sauk. Table 7 summarizes the flows selected for modeling in the HEC-RAS and sediment transport analyses, and their approximate duration.

Table 6. Approximate flood magnitudes estimated for various recurrence intervals at the USGS stream gage Sauk River Near Sauk, Station No. 12189500.

Recurrence Interval (years)	Flow (cfs)
100	105,000
50	92,000
20	75,000
10	62,000
5	49,000
2	30,000

Table 7. Sauk River simulation flows modeled in HEC-RAS for the sediment transport analysis.

HEC-RAS Profile Name	Percent Exceedance	Duration (days)	Model Flow (cfs)
PF1	5	506	10,416
PF2	1	267	16,813
PF3	0.5	44	20,680
PF4	0.4	24	22,120
PF5	0.3	20	24,000
PF6	0.2	18	27,050
PF7	0.14 (~2-yr flood)	15	30,000
PF8	0.1	11	35,050
PF9	0.03 (~10-yr flood)	7	62,000
PF10	0.01 (~25 year flood)	0.5	*79,140*
PF11	0.005 (~50 yr flood)	0.5	92,000

Sediment Transport Predictions

The HEC-RAS model resulted in extreme variation in predicted bedload volume gains and losses across adjacent analysis segments at the upstream SR 530 bridge location. Ignoring the small scale variation associated with the Smoothing using Equation (3) resulted in a more reasonable appearing plot of predicted bed elevation changes based on Parker's (1990) bedload transport equation (Figure 7). Figure 8 depicts the corresponding spatial variation in aggradation and degradation potentials in the upper Sauk analysis reach. The break between the two sub-reaches is evident in the figure. The relative magnitudes of predicted aggradation and degradation are greater and more variable in the upstream, moderately confined reach. The downstream confined reach appears to process sediment downstream more uniformly, with relatively little variation except in the vicinity of the lower bridge. These differences are generally consistent with the channel migration results, as shown in the next section below.

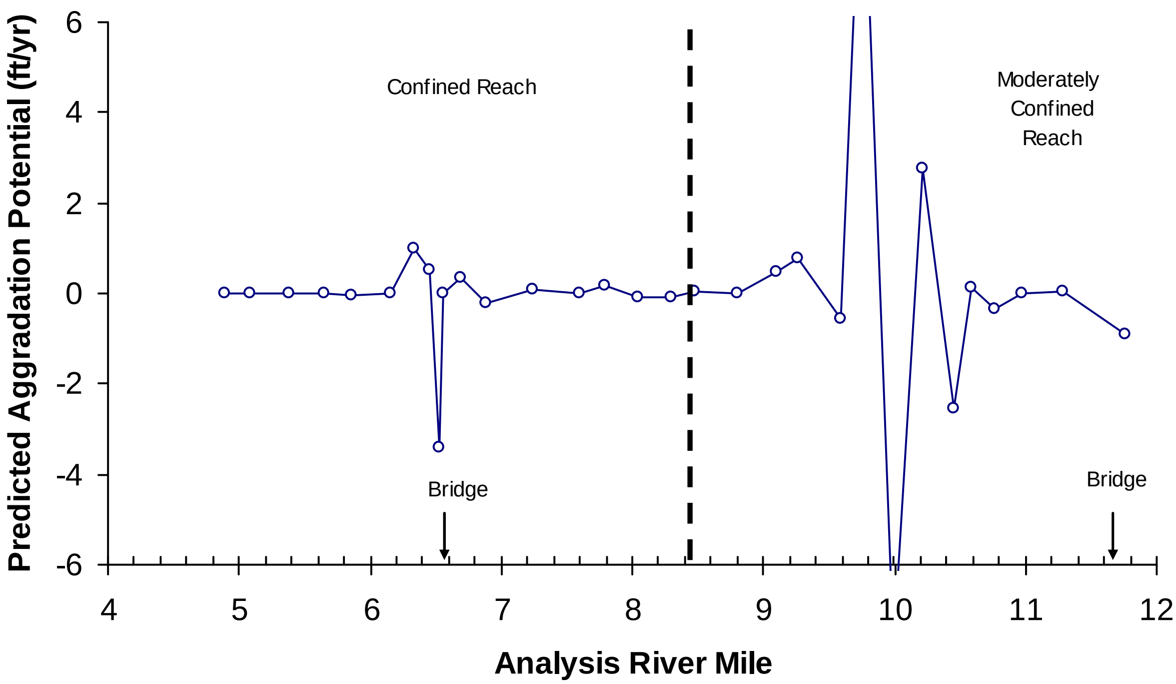


Figure 7. Longitudinal variation in predicted potential bed elevation changes within Lower Sauk River analysis segments over a 50 year period, as determined by evaluation of HEC-RAS hydraulic modeling output using Parker's (1990) bedload transport equation.

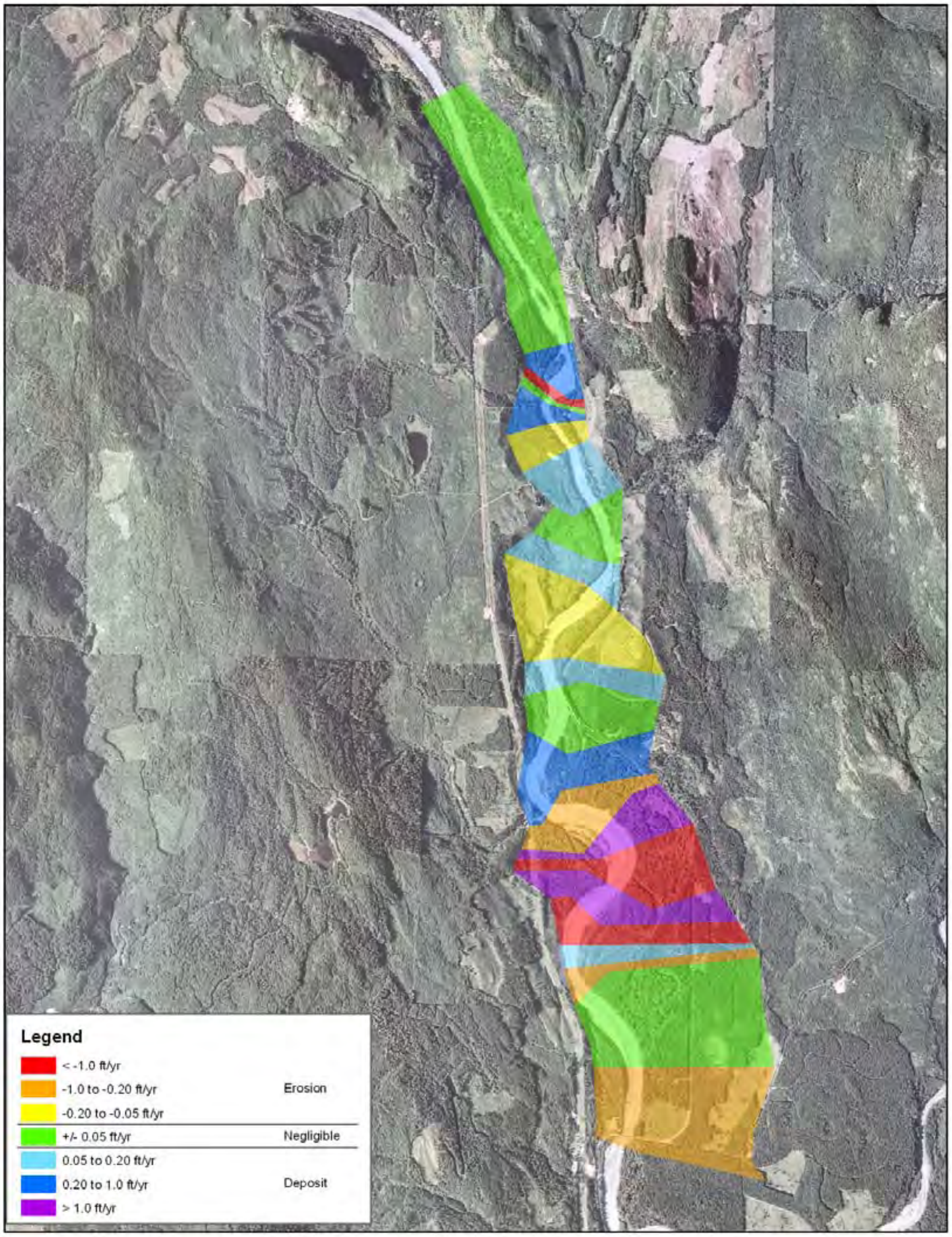


Figure 8. Spatial variation in erosional and depositional trends in the Sauk River above the Suiattle River as suggested by sediment transport modeling using Parker's (1990) bedload transport equation; classifications are as defined in Table 2. Lateral extent depicted is for FEMA 100 year floodplain.

Channel Migration Patterns

The aerial photograph series provided a relatively periodic determination of channel location, with intervening periods associated with at least one large flood event occurring that exceeded the 2-year event level. There was at least one large event that occurred between the times each set of photographs was taken, with the possible exception of the 1956-72 period although it should be noted the record is incomplete (Figure 9). The aerial photography mapping and LIDAR data indicate that channel migration has been generally constrained within the confined reach, and active in the moderately confined reach (Figures 10, 11). At some bends, there has been a clear downstream movement of a sinusoidal waveform was noted over time evident at some bends (Figures 11, 12).

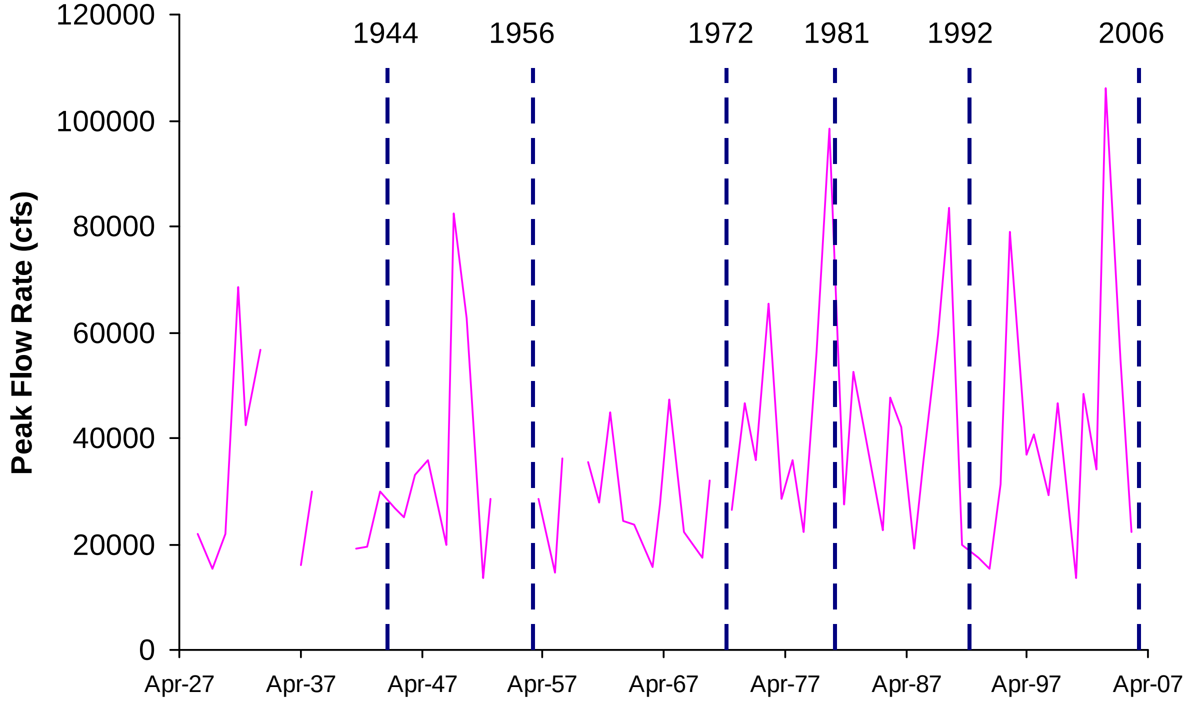


Figure 9. Annual peak flow time series encompassing the aerial photography date range, for the USGS gage Sauk River above Whitechuck (Station #12186000). Dates when each set of aerial photographs were taken are indicated by the dashed vertical lines.

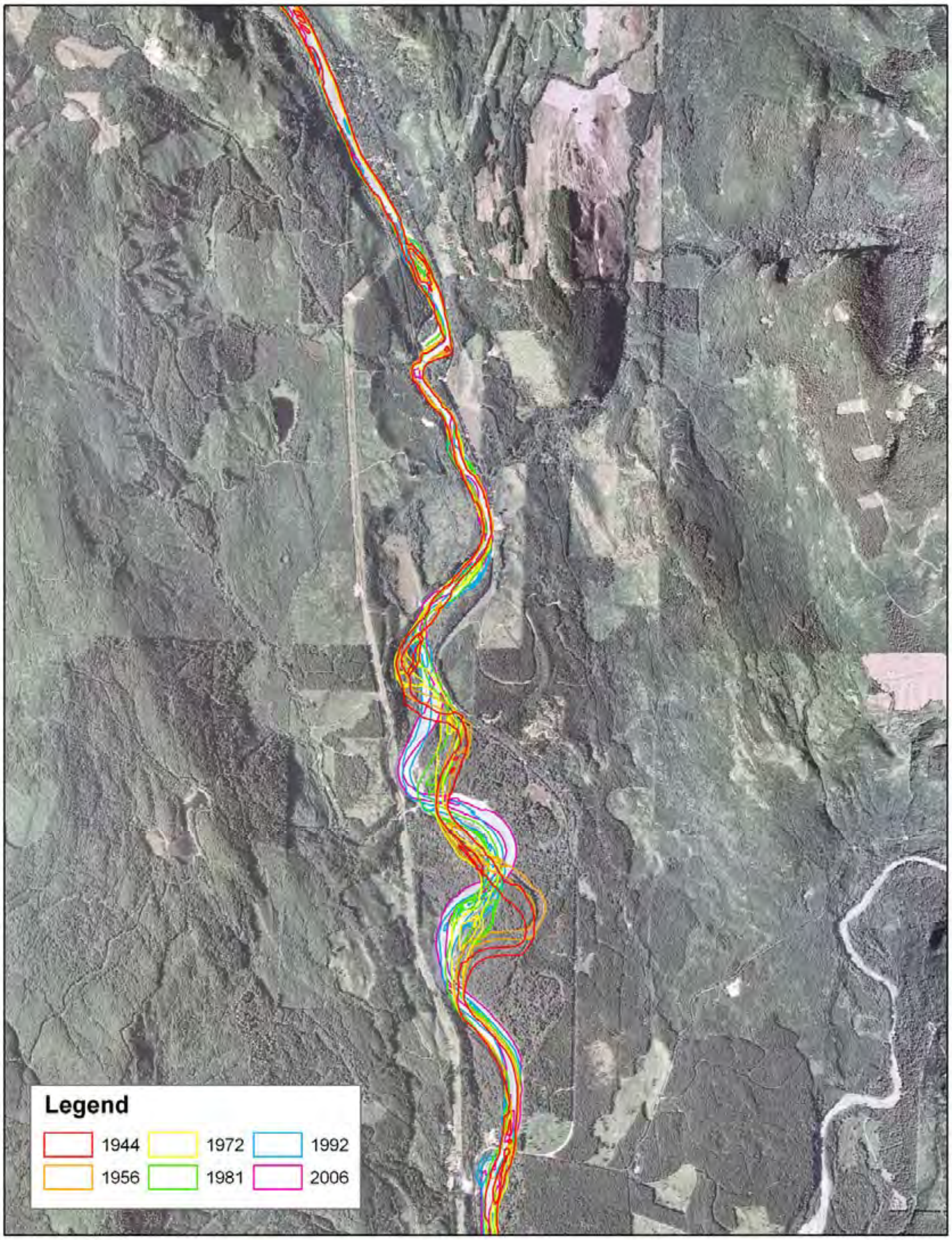


Figure 10. Locations of the main channel of the Sauk River in each set of aerial photographs analyzed for Phase 1. Mapped extent of side channels is indicated by shading.

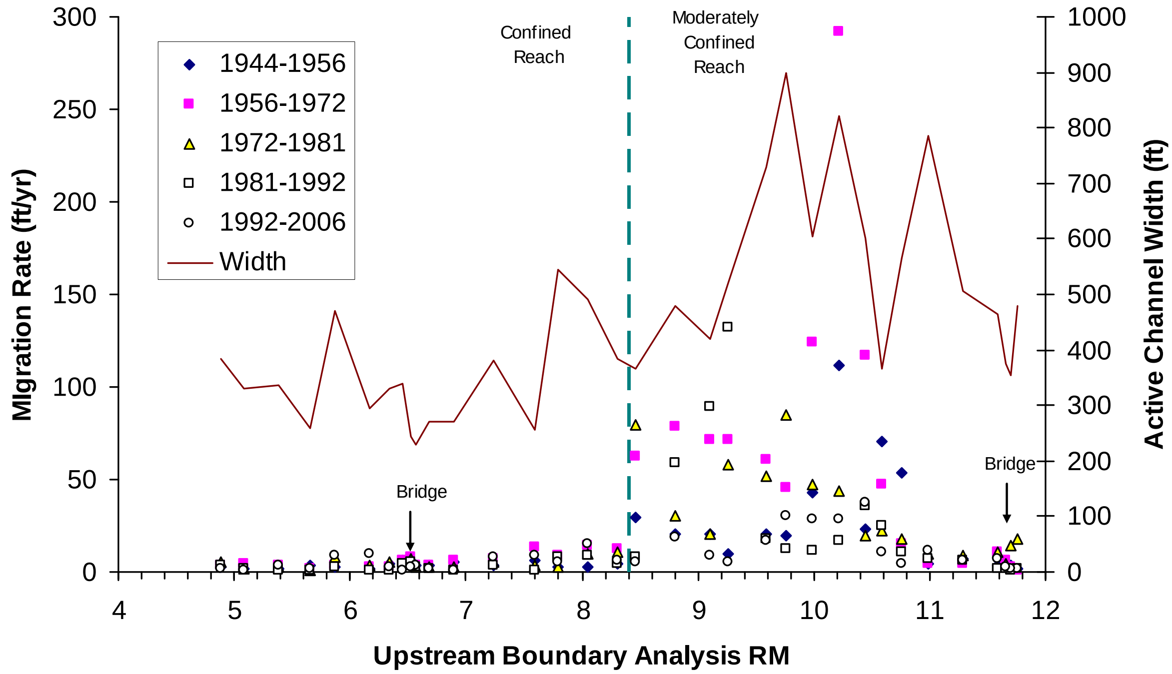


Figure 11. Annual maximum migration rates of the main channel, computed for each Phase 2 analysis segment of the lower Sauk River based on the digitized traces from aerial photographs.

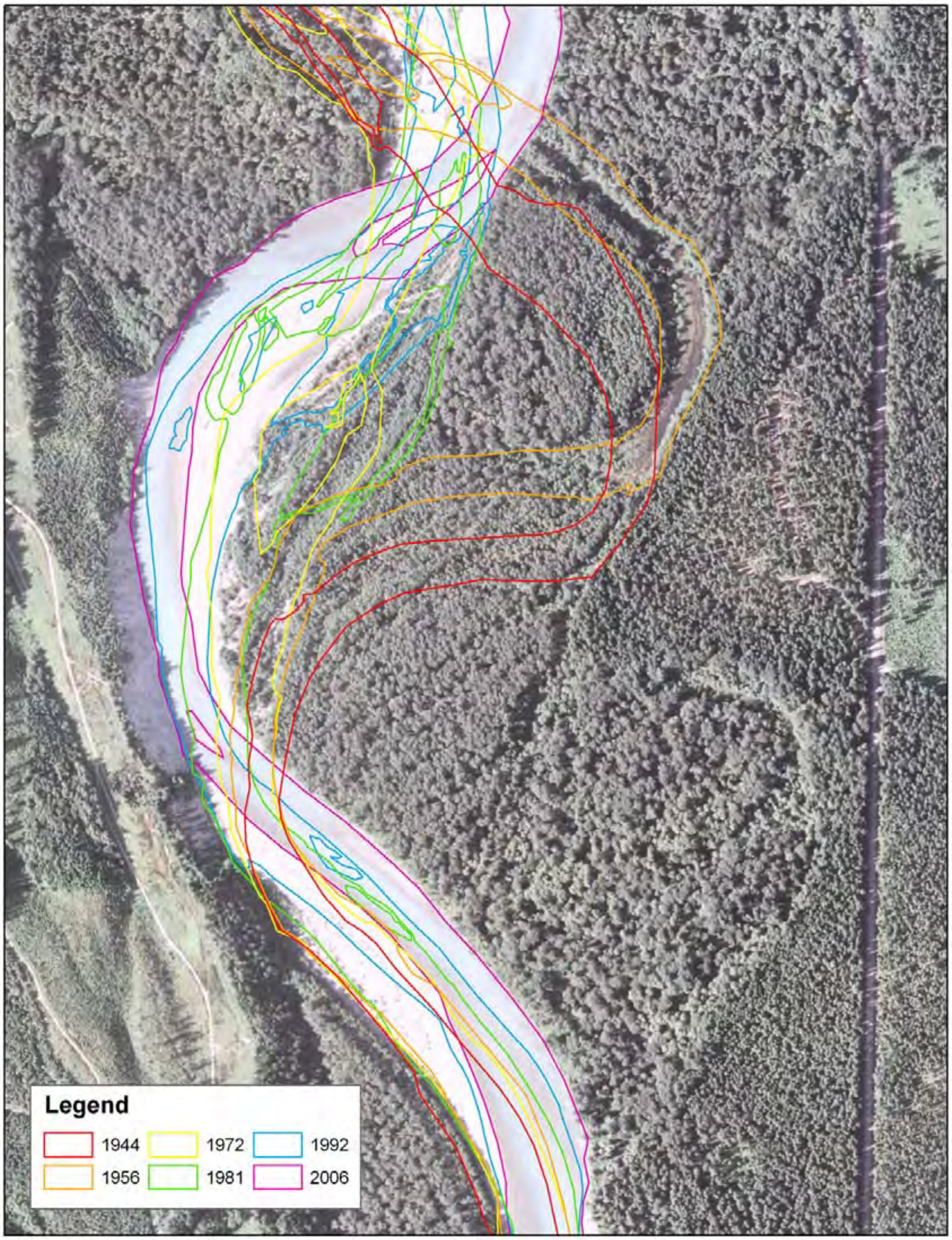


Figure 12. Example of meander translation evident in the aerial photography time series for the lower Sauk River. The area depicted extends from RM 9.75 to RM 11.28.

The migration rate patterns depicted by the data scatter in Figure 11 indicate sub-reaches consistent with the longitudinal profile and sediment transport analysis results. There is a clear break in the scatter of migration rate data near RM 8.45. Migration rates in the moderately confined sub-reach are generally comparable in magnitude to rates calculated for much of the braided and wandering reaches located upstream of the Suiattle River. Thus maximum lateral bank erosion rates are comparable for meandering and wandering processes in the Sauk River, and only exceeded by braiding processes where the valley floor is wide enough to accommodate avulsions.

The planform change index results provide a summary perspective of historic changes over time, and what the future trend may be (Figure 13). Notably, the greatest amount of change appears to have occurred during the 1956-72 period, which implies that there must have been at least one large flood during that period that was not part of the USGS peak flow time series. The pattern in the data suggests that the bank locations with greatest instability are gradually moving downstream (Figure 13), consistent with the general downstream movement of the planform wave (Figure 12). Notably, the greatest meander migration after the November 2006 flood appears to have occurred in segments 69-72 suggesting that the trend indicated by the upper arrow is continuing, and migration rate could potentially increase over the next 10+ years. Conversely, meander migration in segments 73-76 appears to be slowing down, with relatively little migration observed in the 2007 photos used in the HEC-RAS analysis.

Sub-Reach	Analysis Segment	Upstream Boundary RM	Planform Instability Index Calculated From Aerial Photography Series				
			1944-1956	1956-1972	1972-1981	1981-1992	1992-2006
Moderately Confined Sub-Reach	60	11.76	1	1	2	1	1
	61	11.70	1	1	1	1	1
	62	11.65	1	1	1	1	1
	63	11.59	1	1	1	1	1
	64	11.28	1	1	1	1	1
	65	10.98	1	1	1	1	1
	66	10.77	3	1	2	1	1
	67	10.59	3	3	2	2	1
	68	10.45	2	4	2	3	3
	69	10.22	4	4	3	2	2
	70	9.99	3	4	3	1	2
	71	9.75	2	3	4	1	3
	72	9.60	2	3	3	2	2
	73	9.27	1	3	3	4	1
	74	9.10	2	3	2	4	1
	75	8.81	2	3	3	3	2
	76	8.47	2	3	3	1	1
Confined Sub-Reach	77	8.30	1	1	1	1	1
	78	8.05	1	1	1	1	2
	79	7.80	1	1	1	1	1
	80	7.60	1	1	1	1	1
	81	7.24	1	1	1	1	1
	82	6.89	1	1	1	1	1
	83	6.69	1	1	1	1	1
	84	6.56	1	1	1	1	1
	85	6.52	1	1	1	1	1
	86	6.45	1	1	1	1	1
	87	6.33	1	1	1	1	1
	88	6.16	1	1	1	1	1
	89	5.86	1	1	1	1	1
	90	5.65	1	1	1	1	1
	91	5.39	1	1	1	1	1
	92	5.08	1	1	1	1	1
	93	4.89	1	1	1	1	1

Figure 13. Spatial and temporal variation in channel migration tendencies within analysis segments of the Sauk River below the Suiattle River, as indicated by successive series of ortho-corrected and geo-referenced aerial photographs. Planform change index values are described in Table 4. The arrows indicate apparent upstream/downstream shifts in location of zones of greater and lesser channel change over the aerial photographic record.

Gravel/Sand Bar Storage and Side Channel Area Trends

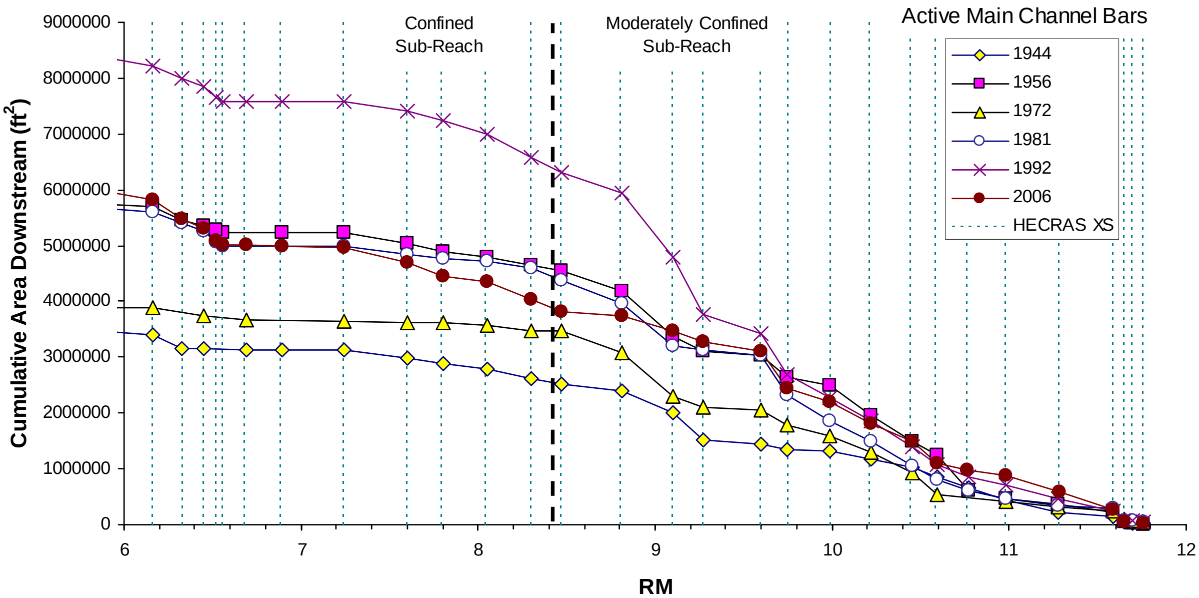
Figure 14 presents cumulative plots of active gravel/sand bar and side channel areas, adjusted to a common flow level, for all years of aerial photography. The vertical differences between curves to some extent reflects the time between the previous large flood event and the date the photographs were taken (shorter time interval → greater amount of deposit surface area that has not become vegetated yet), error in interpreting older aerial photographs (color generally better than black & white; older photographs were of lower resolution), and error in adjusting gravel bar areas to a common flow rate.

Nonetheless, useful information may be derived from the data depicted in Figure 14 based on the following observations:

The most prominent result is the general channel stability and small area of active gravel bars and side channels in the confined sub-reach.

For analysis segments where successive year's curves are approximately parallel, it may be inferred that there was probably negligible change in gravel bar storage volumes or side channel areas between the two years photographed.

In other locations, the slopes of the plots differ notably, where storage volumes and side channel areas either appear to have decreased or increased between successive photograph years. The rate of change in curves between successive aerial photographs may be calculated as a change in average width of active gravel/sand bar or side channel area. Segments with substantial changes in width, and thus storage of material readily available for bedload transport, are depicted for each pair of successive photographs in Figures 15-16, in a format similar to that presented in Figure 13 for the channel migration results. Results for the main channel are restricted to major bar deposits, whereas results for side channels are for the total area of side channel.



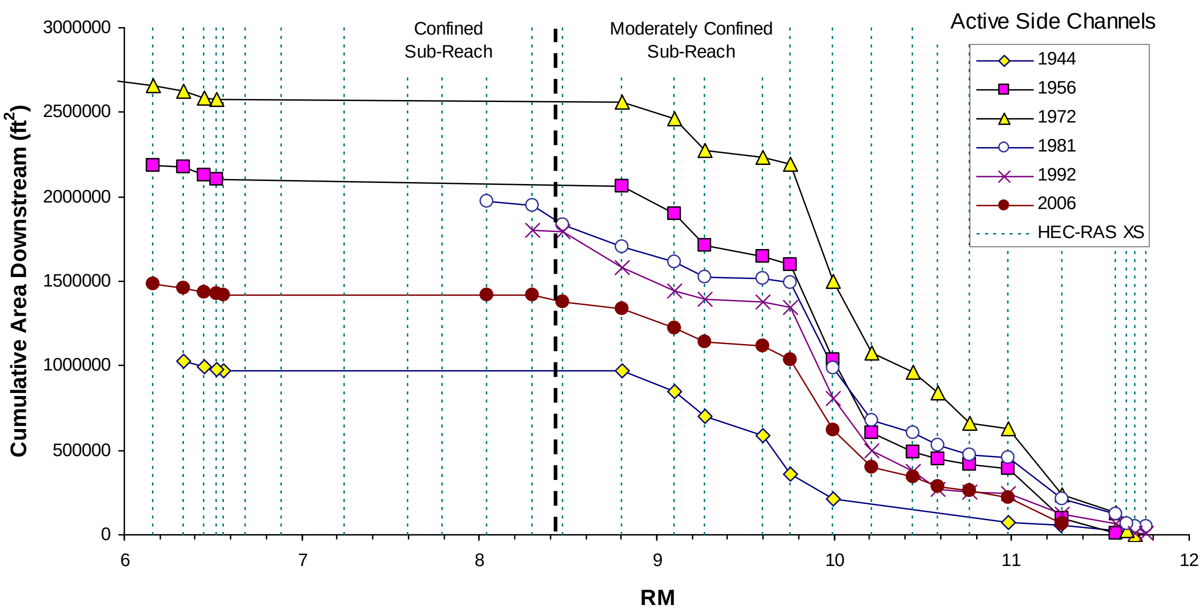


Figure 14. Cumulative active gravel/sand area mapping results for all years that aerial photography was digitized. Results are presented separately for bars occurring in the main channel (top graph) and total area of active side channels (bottom). The locations of the HEC-RAS transects are indicated by the dashed vertical lines.

Upstream Boundary (RM)	Segments With Changes in Gravel Bar Area Between Successive Aerial Photograph Series				
	1944-56	1956-72	1972-81	1981-92	1992-2006
11.76		+			--
11.70					--
11.65					+
11.59					
11.28				+	
10.98				+	
10.77		--	+		
10.59	+	--	--		--
10.45		+	--		
10.22	+				--
9.99	+	--			
9.75	+		+		--
9.60	+		+		
9.27				+	--
9.10	--			+	--
8.81	+			+	--
8.47	+				--
8.30			+		
8.05				+	
7.80				+	--
7.60					
7.24					
6.89		--	+		
6.69	--	+	--	+	
6.56	+	--	+	--	
6.52	+	--	+		
6.45	--	+	--		
6.33		--	+		
6.16		+	--		
5.86				+	
5.65	--	+	--	+	
5.39	+				
5.08					--
4.89	--				+

Figure 15. Spatial and temporal variation in active gravel/sand bar storage areas within the main channel for analysis segments of the lower Sauk River, as indicated by successive series of geo-referenced aerial photographs. Change is represented as a substantial gain (+) or loss (--) in mean width of non-vegetated bar surface in excess of +/- 100 ft.

Upstream Boundary (RM)	Segments With Changes in Side Channel Area Between Successive Aerial Photograph Series				
	1944-56	1956-72	1972-81	1981-92	1992-2006
11.76			+	--	
11.70					
11.65					
11.59					
11.28					
10.98	+		--	--	
10.77	+				
10.59		+	--		
10.45					
10.22					
9.99	+				
9.75	+	+	--		--
9.60	--				
9.27					
9.10					
8.81					
8.47	--	--	+		--
8.30					
8.05				--	+
7.80			--	+	--
7.60					
7.24					
6.89					
6.69					
6.56	--				+
6.52	+	+	--		
6.45					
6.33					
6.16	+				
5.86	--	+			--
5.65		--	+		
5.39					
5.08					
4.89					

Figure 16. Spatial and temporal variation in active side channel area for analysis segments of the lower Sauk River, as indicated by successive series of geo-referenced aerial photographs. Change is represented as a substantial gain (+) or loss (--) in mean width of non-vegetated side channel surface in excess of +/- 100 ft.

Avulsion Risk

Figures 17-19 depict the individual avulsion risk factor ratings for each delineated pathway segment. Figure 20 depicts the joint avulsion risk rating based on flow level, slope, and soil erodibility. Figures 21 and 22 depict the ratings for the vegetation and road mitigating factors. GIS coverages for bank hardening are not presented because the available data are incomplete, generally characterizing conditions only along the margins of the main river channel and omitting any extensions into side channels or onto the floodplain.

The individual and joint ratings represent relative risks amongst all potential flow paths based on physical characteristics known to affect the likelihood of avulsion. These risk ratings cannot be used to predict exactly where the channel will move during future storm events, but can be used to prioritize alternatives to reduce the risk of harm to life and property.

The results depicted in Figures 17-22 are based on topographic data collected in 2005 and hydraulic data collected after the November 2006 flood. The channel migration tracings in Figure 10 are all from the summer of 2006 and earlier. Thus, the risk ratings may have changed for some channels since the inception of this analysis. Specific ratings may change pending reanalysis of hydraulics reflecting channel changes that occurred during that flood, and may change in the future after other floods. It is not feasible to update the ratings each year after flooding because of the expense, however the ratings resulting from this analysis can still be used to assess general risk as described below, and provide an indication of relative differences in avulsion potential for possibly the next 10+ years.

In general, joint risk Class 1 segments would be expected to have the most immediate risk of avulsion in the near future because they are connected frequently at relatively low flood levels, tend to have steeper slopes, and may have more erosive soils. Class 1 pathways with inlets located on the outside edge of meander bends in areas with a tendency toward deposition downstream would be of particular concern as such areas are prone to additional raising of the water surface during large floods. Class 2 segments similarly may be considered to having a relatively high risk of avulsion occurring in the near future under these conditions.

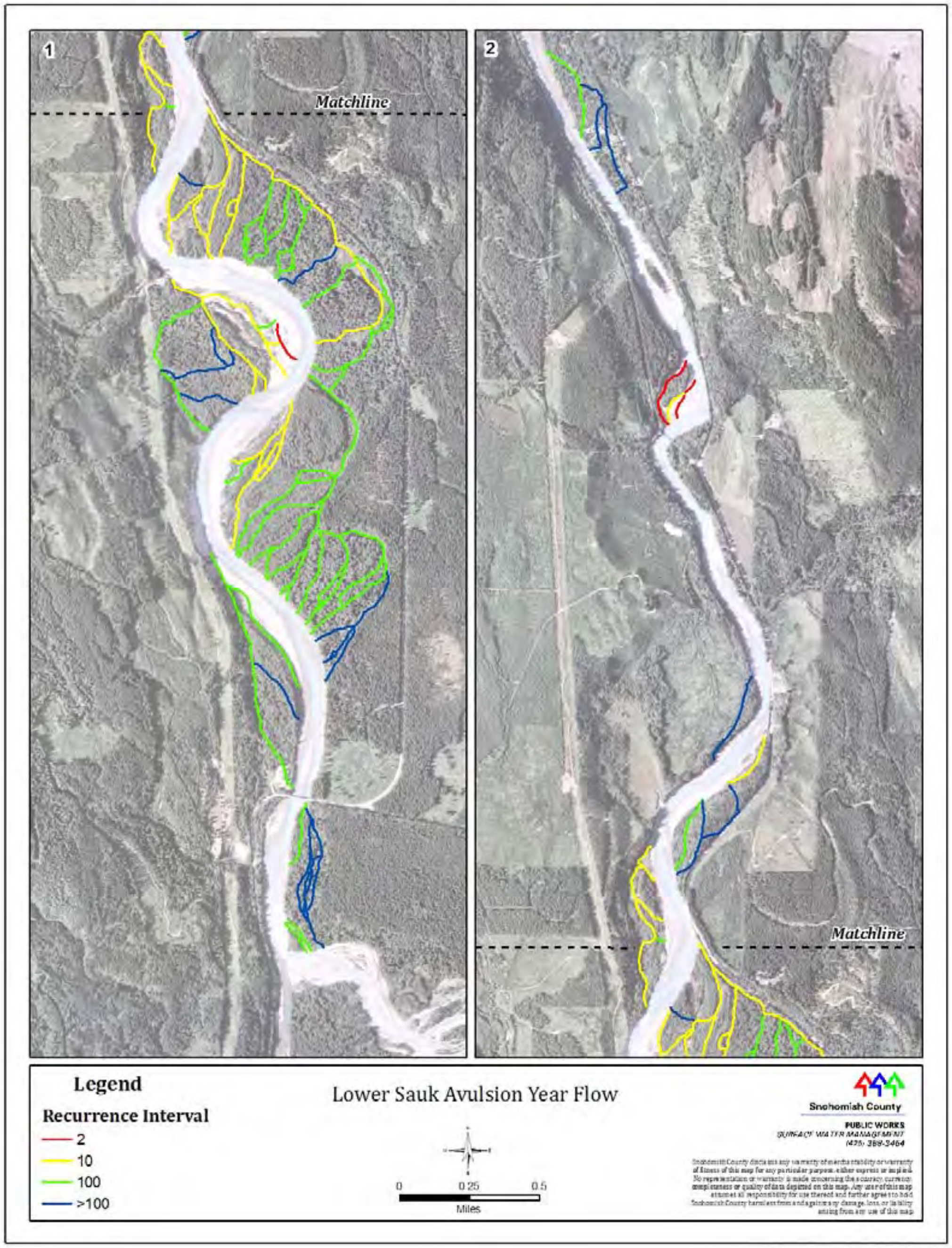


Figure 17. Risk ratings of potential avulsion pathways characterized according to lowest of three flood levels (2-, 10- and 100-year recurrence intervals) at which floodplain or off-channel flow may occur. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

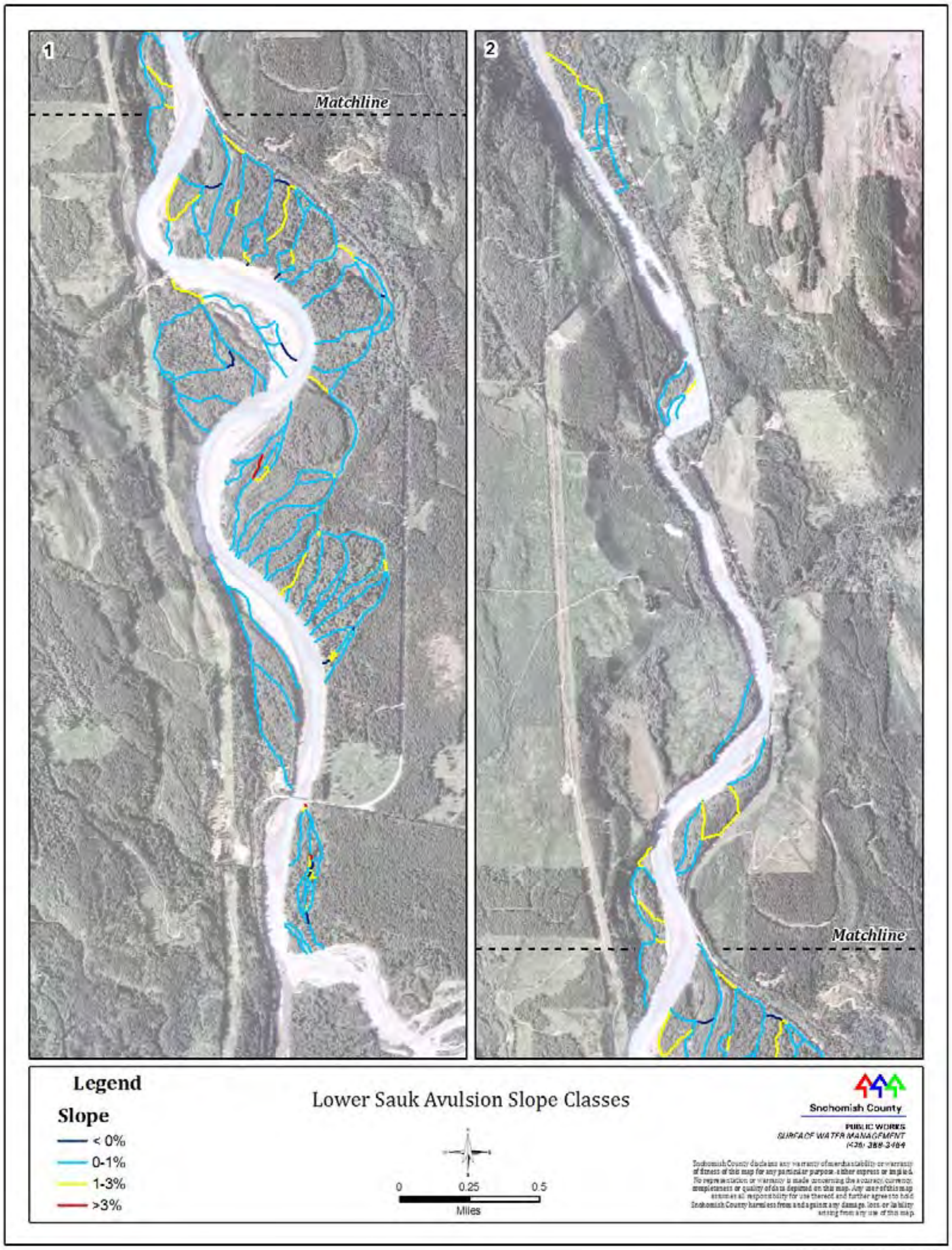


Figure 18. Risk ratings of potential avulsion pathways characterized according to average gradient along each pathway segment. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

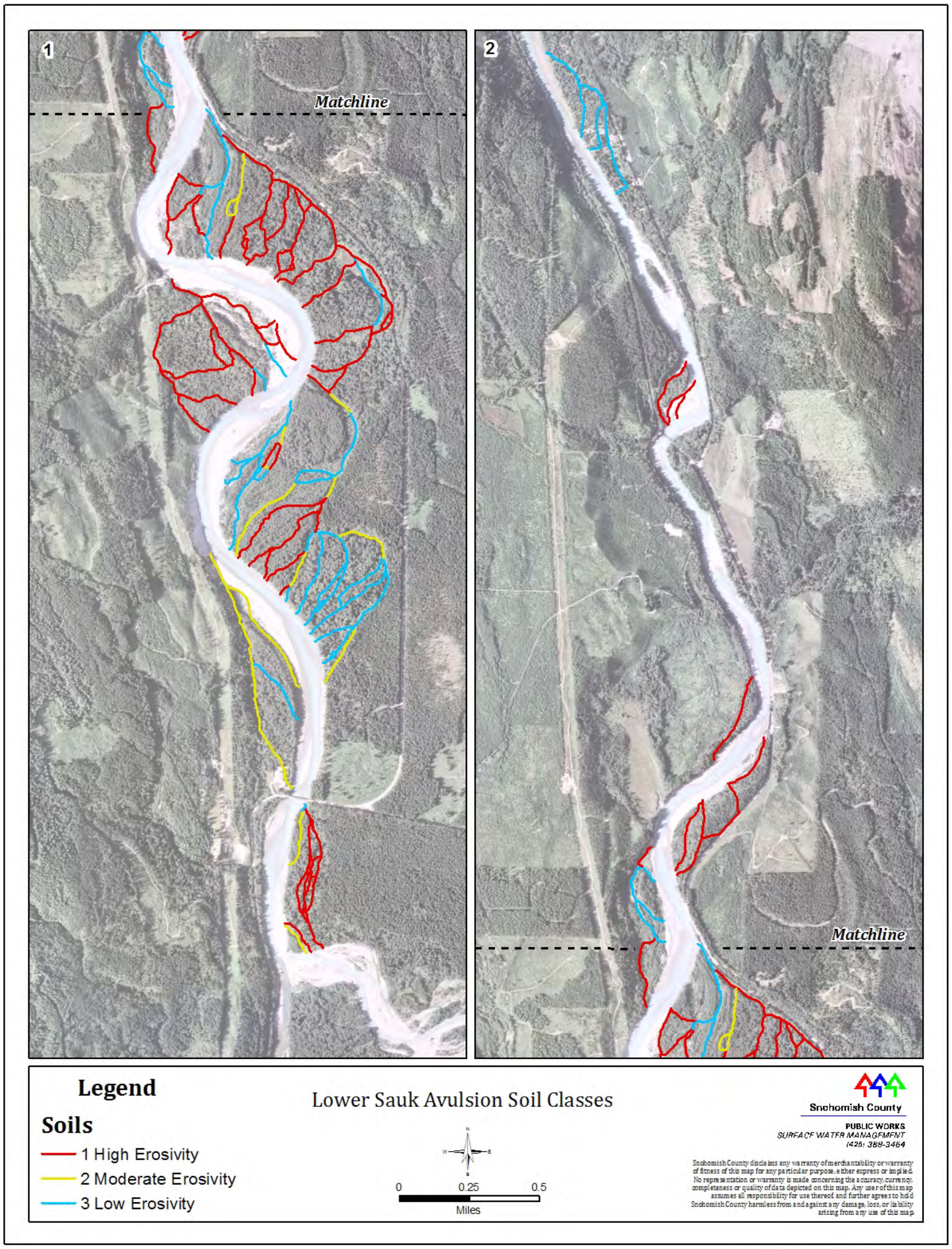


Figure 19. Risk ratings of potential avulsion pathways characterized according to floodplain soil K_w erodibility factors. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

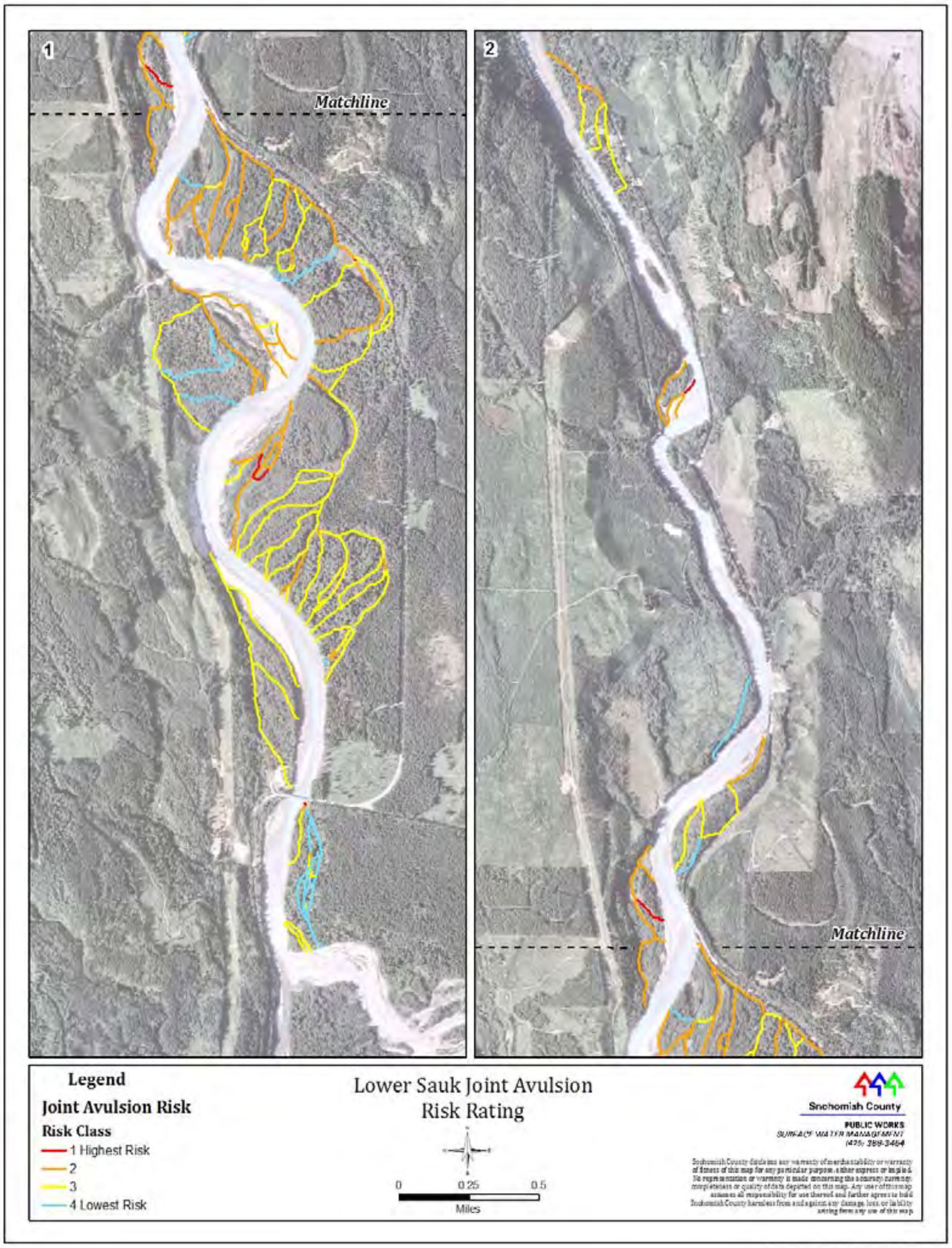


Figure 20. Joint avulsion risk ratings of potential avulsion pathways characterized according to weighted sums of flood flow level, longitudinal gradient, and floodplain soil K_w erodibility factor ratings depicted in Figures 1-3. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

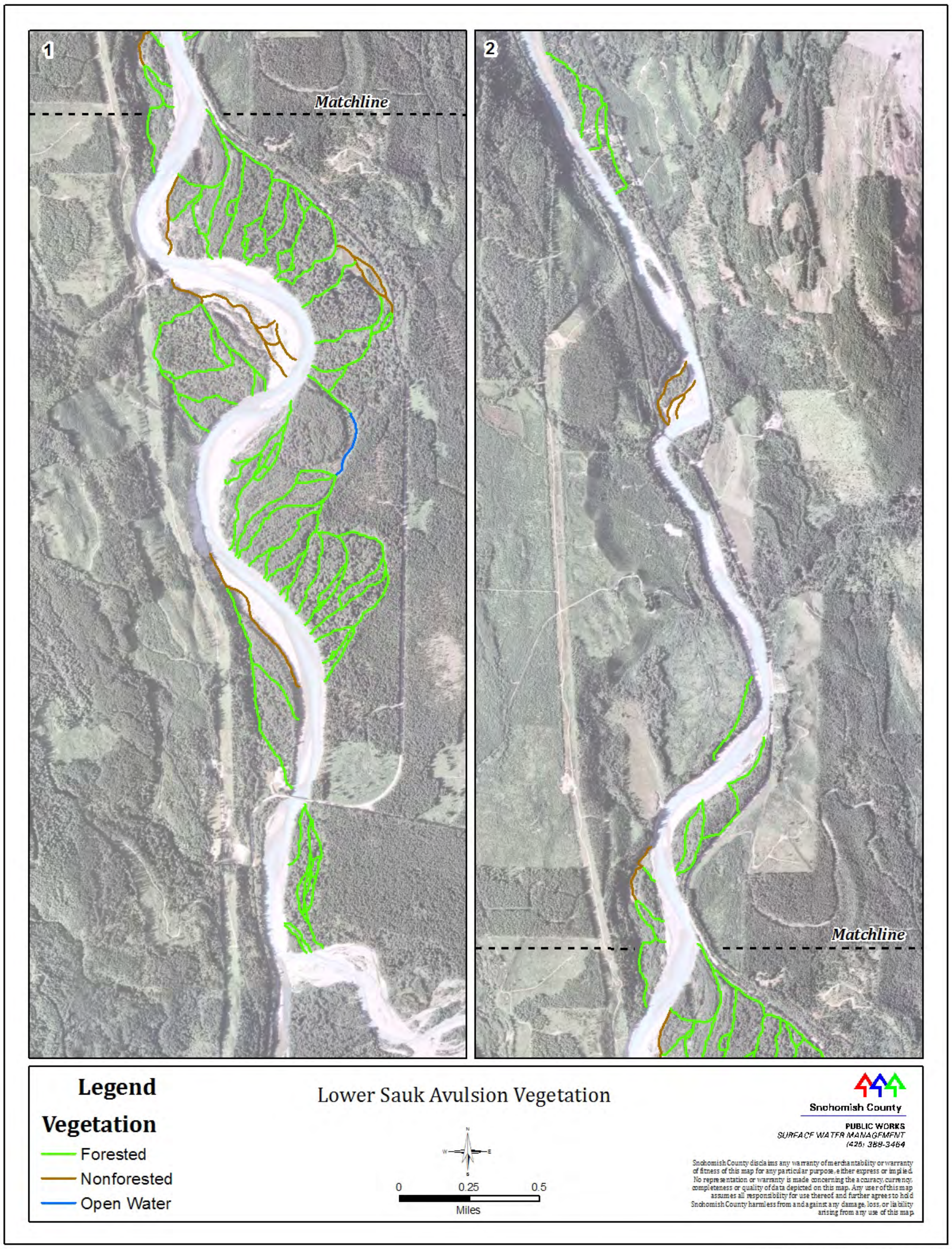


Figure 21. Joint avulsion risk mitigation ratings of potential avulsion pathways characterized according to whether a segment passes through forested land. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management.

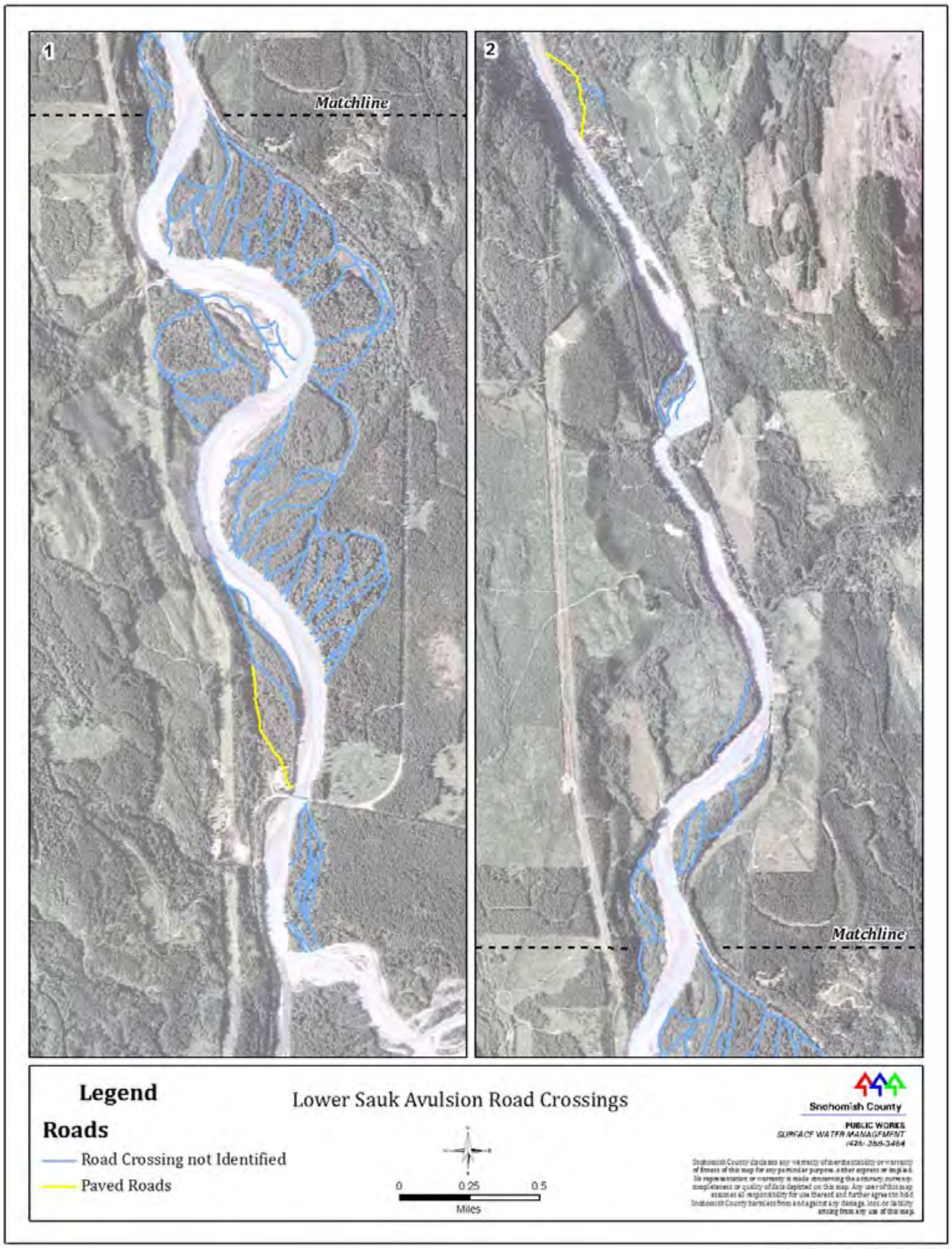


Figure 22. Joint avulsion risk mitigation ratings of potential avulsion pathways characterized according to whether a segment is intersected by a paved or gravel surfaced road. Tracings and ratings were based on pre-2006 flood event topography. GIS Data available from Snohomish County Surface Water Management. Road coverage may be incomplete and should be evaluated on a site-specific basis.

Class 3 segments could become higher risk segments after the river avulses through nearby class 1 or 2 segments. Class 4 segments have lowest relative risk. In general, the farther these two class segments are situated from the main channel, and the longer the total avulsion flow path, the lower the long term risk. Most of the pathways designated as Class 1 or 2 (i.e., relatively high risk) represent areas that the river has occupied at one time or another during the period spanned by available historic aerial photos (i.e., 1944 through 2006).

Forested vegetation is present along many of the potential avulsion pathways and in some cases may reduce the relative risk of avulsion. Forest stands consisting of relatively young deciduous species would not provide as much protection against avulsion as older coniferous forests, however. In the Sauk River, the forest age of specific stands on the floodplain generally reflects the last time the channel occupied that location. As noted above many of the potential pathways identified for this analysis coincide with former channel locations observed on air photos. However, even avulsion pathways that have not been occupied since 1949 appear to support relatively young deciduous vegetation. Continued growth and succession of conifer species should enhance the potential mitigative effect of vegetation, although it will not prevent the risk of avulsion.

Roads and bank hardening such as riprap tend to retard avulsion, often for sufficient time while the flood peak passes. However, these features can also eventually be associated with avulsion. In the case of bank hardening, the river may simply erode around the structure and connect with a potential avulsion pathway segment downstream. In the case of roads, the road may eventually wash out if there is sufficient flow overtopping the road, water on the downstream side of the road is sufficiently lower than upstream, and the flood lasts for a long time. Paved roads are more resistant that compacted gravel roads and may provide additional lead time for emergency erosion countermeasures.

SYNOPSIS OF ANALYSIS RESULTS

The following general patterns are indicated by the analysis results. The features indicated will likely lead to management prescriptions for fish habitat and land use that vary across the five geomorphic sub-reaches, reflecting characteristic river processes and erosion/deposition risks observed at the sub-reach scale. In particular, the channel migration and potential aggradation/degradation rate results may be combined into a joint erosion risk rating for each analysis segment, and evaluated in conjunction with avulsion risk and flood risk information as part of subsequent sub-reach scale risk assessments.

1. Large Scale Results:

Seven geomorphic sub-reaches have been delineated for the Sauk River as a result of the Phase I and II analyses, roughly delineated in vicinity of, and defined by breaks/longitudinal changes in the following physical attributes:

Darrington Bridge:
- Slope
- Channel widths
- Bar deposit grain size distribution
- Aggradation/degradation potential
- Degree of reworking of active gravel bars in main channel

~RM18:
- Channel widths
- Aggradation/degradation potential

~Dan Creek (N.B., used as geographic reference; Dan Cr likely has negligible geomorphic influence on Sauk R):
- Slope
- Channel widths
- Aggradation/degradation potential

~RM13:
- Channel widths

Bar deposit grain size distribution
Aggradation/degradation potential greater upstream
Degree of reworking of active gravel bars in main channel

RM 12.3
Suiattle River

~RM 8.45
Slope/Longitudinal Profile Inflection Point
Channel migration rates
Channel widths
Bar deposit grain size distribution
Aggradation/degradation potential
Area and degree of reworking of active gravel bars in main channel

2. Sub-Reach Results

The five geomorphic sub-reaches are distinguished as follows:

Sub-Reach I (Confined/Meandering): Above Darrington Bridge (Segments 1-19)

a. In Vicinity of eroding bank along Clear Creek Road and downstream properties (segments 3-6):
   - Strong degradation potential along segment 4 where road is adjacent to river
     - Tendency to downcut at bank toe, increasing erosion potential
   - Strong aggradation potential in adjacent upstream/downstream segments
     - Favors upstream avulsion and/or local meandering

b. Upstream of Darrington bridge (segments 16-19):
   - Strong aggradation tendency immediately upstream of bridge
     - Avulsion potential may be reduced/restricted
     - Local meandering may be more likely

Sub-Reach II (Wandering): Darrington Bridge to ~RM18 (Segments 19-26)

- Relatively mild aggradation/degradation potential
- Active channel width and annual main channel bank migration rates increasing downstream
- Side channels generally shorter, more transient than in sub-reach III
- Results suggest reach is primarily processing sediment downstream
- Primarily a wandering channel (single main channel with a few distributary branches; may move through meandering or avulsion)
- Side channel size tends to be smaller than downstream

Sub-Reach III (Transition): ~RM18 to Vicinity of Dan Cr (Segments 27-36)

- Stronger aggradation/degradation potential than upstream and downstream; potential greatest downstream of slope break, which occurs around segment 32
- Channel widths hold steady then continue increasing downstream
- Sub-reach = transition from wandering to braided channel

Sub-Reach IV (Braided): Vicinity of Dan Cr to ~RM13 (Segments 37-53)

- Low sediment transport capacity overall compared with upstream, favoring local deposition near Dan Creek
- No tendency toward either aggradation/degradation potential between analysis segments
- Channel widths are widest of entire Phase I reach
- Widest tendency in segments 41-50 (Bryson Road levee located within these segments)
- Greatest gains and losses in side channel area occur in this sub-reach, and side channel size tends to be large compared with upstream.
- Channel widening likely a response to reduced transport capacity in sub-reach, in which coarse sediments are likely deposited and stored for longer term compared with rest of river based on transport capacity, channel migration, and grain size distribution trends.
- Sub-reach channel is most closely described as braided (vs. wandering)

Sub-Reach V (Transition/Confined): ~RM13 to Suiattle River (Segments 53-59)

Channel narrows rapidly in downstream direction

Moderate variability in aggradation/degradation potential between analysis segments

Strong aggradation potential in segment 54 is indicative of backwater effect of further channel constriction downstream

Sub-Reach VI (Moderately Confined): Suiattle River to Upstream SR 530 Embankment (Segments 60-76)

Channel migrates primarily through planform meandering, avulsion less prominent than upstream

Similar grain size distribution as Sub-Reach IV (braided)

Moderate variability in aggradation/degradation potential between analysis segments

Sub-Reach VII (Confined): Upstream SR 530 Embankment to below USGS Gaging Station/Top of Delta Reach (Segments 77-93)

Narrow Channel

Similar grain size distribution as Sub-Reach I

Limited gravel bar area

Limited bank erosion

Upstream-downstream sediment transport in approximate equilibrium

Negligible variability in aggradation/degradation potential between analysis segments indicating sediment is transported relatively uniformly through reach

3. Level of Confidence in Analysis and Results

The longitudinal profiles of channel gradient, grain size, sediment transport analysis predictions of aggradation/degradation potential, flow depth channel migration rates, and size and extent of side channel changes over time, all consistently point to the five geomorphic sub-reaches outlined above. More site specific analysis and design will be required to evaluate erosion risk for specific projects and management actions, but the results presented here provide a quantitative estimate of reach scale hydraulic and erosion processes that will affect general suitability of specific measures. The information can be used to infer relative risk associated with different restoration activities (e.g., channel and floodplain connectivity, instream/bank stabilization structures, channel migration training, and bank revetment removal), with respect to whether projects would work against or with natural sedimentation and channel forming processes.

The level of uncertainty about each individual analysis varies depending on the type of data, and can be inferred in many cases from the scatter of data depicted in the graphs above. Specific cases are identified below:

- The flood level and sediment transport predictions should not be used to precisely delineate lateral flood extents and predict actual bed elevation changes. Field surveyed flood level data were not available to calibrate the HEC-RAS model at locations other than the USGS gage. The model does not simulate local hydraulic effects due the two bridges. Effort to get more accurate survey data would require higher level of funding. Typical sediment transport rate prediction errors range within an order of magnitude. However, the relative differences in sediment transport potential predicted for successive transects should be preserved and not meaningfully affect the results or general erosion risk determinations based on those results.
- Importantly, the river planform changed course at some locations after the November 2006 flood; the analysis results here are based on a blending of data from before and after that event. This is a common problem in active, dynamic, braided channels, where the location of even the 100-year flood extent can vary because of change in main channel location. It does not appear feasible to redo the analyses reported here every time the channel moves, but the general trends seen here at the sub-reach scale should be preserved in the foreseeable future, possibly within the next 20-50 years.
- The channel migration traces are generally accurate for the main channel and major side channels. Smaller side channels were delineated as part of the avulsion risk analysis using LIDAR data. The collective digitized channel traces for the present and avulsion risk analyses should provide for a reasonable delineation of the channel migration zone.

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Appendix: Definition of Channel Migration Classifications

Channel form may be classified according to degree of channel confinement by valley form, planform pattern, presence and extent of islands, types of depositional bars, and extent and character of lateral activity. The following types of channel are observed in the analysis reach, with classifications developed from Richards (1982), Leopold et al. (1995), and Galay et al. (1998):

- Confined/Meandering: Single, sinuous channel at low to bankfull flows with occasional islands and sediment deposits forming point and diagonal bars. Meander pattern sinuosity is generally contained between floodplain terraces and valley side walls. Meander migration in downstream direction is limited.
- Wandering: Channel is unconfined and free to move about floodplain. Slope is generally higher than for a purely meandering channel flowing through unconfined alluvial deposits. Plan form represents an intermediate state between meandering and braided condition, with a main channel and frequent islands and small channel splits. Main channel tends to move about the floodplain through a blend of meander bend migration and channel avulsion. Abandoned oxbows or prominent arcuate swales may be present on the floodplain.
- Braided: Irregular channel pattern, with few persistent, clearly defined islands. Flow is shallower than confined/meandering and wandering channels and is distributed more evenly among many channels. Channel tends to move about primarily through avulsion process. Sediment deposits distributed throughout channel net as mid-channel bars.

In both the wandering and braided cases, bedload constitutes a significant fraction of the total sediment transport load.

Sauk River

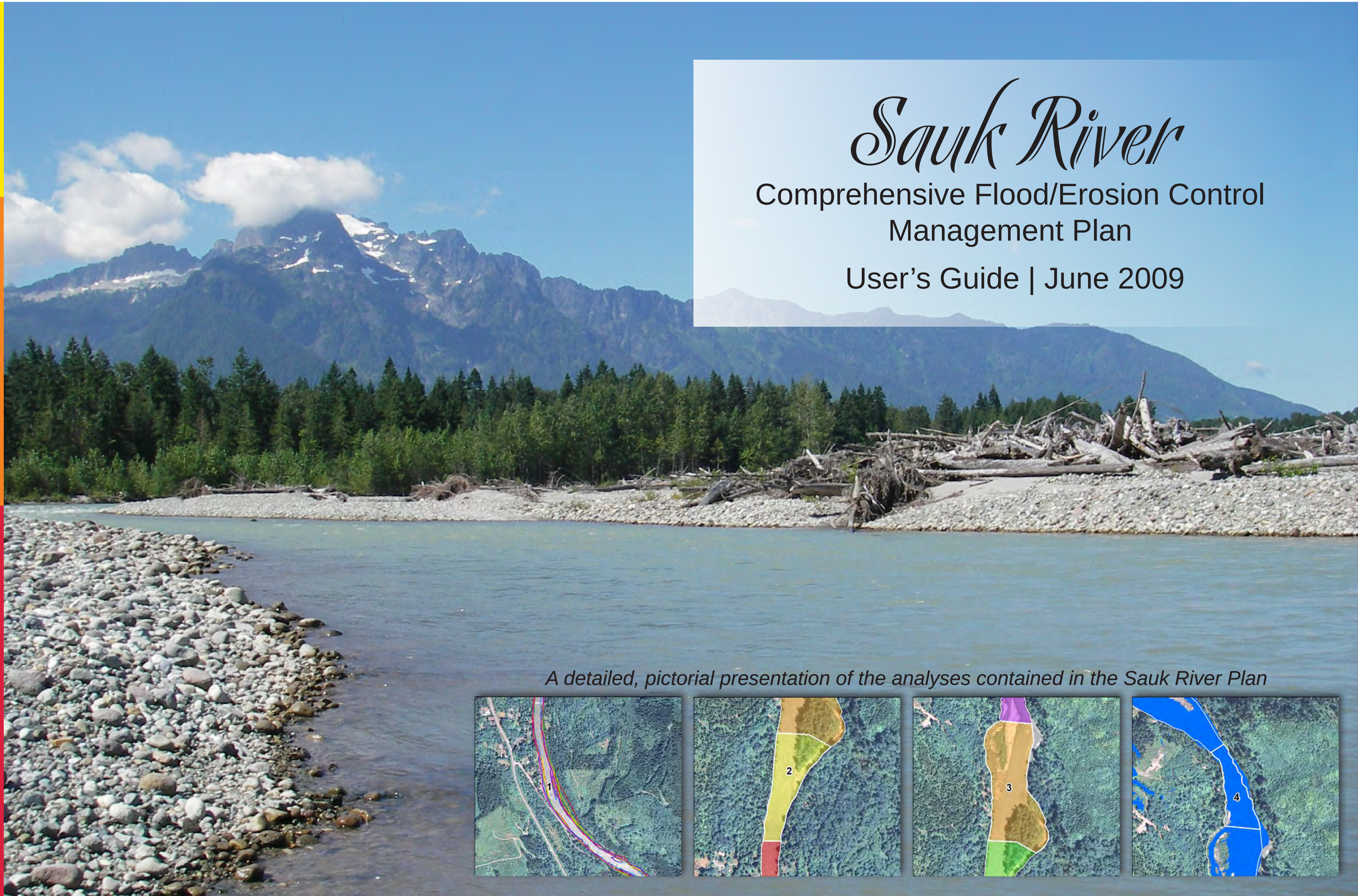
Comprehensive Flood/Erosion Control Management Plan

User's Guide | June 2009

HIGH

SIGNIFICANT

VOLATILE



A detailed, pictorial presentation of the analyses contained in the Sauk River Plan

Introduction

This Sauk River Plan User's Guide (Guide) is intended as a stand-alone document. It presents the analyses detailed in Appendix 4 of the Plan in a user-friendly, pictorial form for use by Stakeholders in making informed decisions about proposed river actions, particularly those designed for bank protection, fisheries enhancement, infrastructure protection and construction.

The entire Plan is designed to be an iterative document, from the ground up, quantifying the processes at work in each and every segment of the study reaches, information that can lead to informed decisions, and can aid and support any kind of design or permit action. At no time is it suggested in the Plan that Stakeholders are prevented from taking action, securing permits, protecting land from erosion and flooding. Likewise, agencies are not denied the opportunity of taking preventative actions as well.

Stakeholders are invited to use this Guide to locate their property, area of interest, or problem site, and view the components that created the risk rating for the particular property. The manual begins with several pages of maps and graphs that provide an overall view of the river. Figure 2 shows segment numbers 1 through 46 assigned to each river segment. Detailed information and maps for each numbered segment follow the overall maps.

Table of Contents

Figure 1. Vicinity map showing city boundaries, highways, and the river

This map details the extent of the Plan area, both upstream and downstream. In this map the river flows from south to north (as in all following maps).

Figure 2. Segment map overlaid on an aerial photograph of the entire river

This map details the numbered segments used throughout the Guide. To maintain consistency, the segments, which are composed of smaller segments with similar risk characteristics, are numbered starting at 1 in the most upstream segment and ending at 46 in the most downstream segment.

Figure 3. Joint Risk Graphic

The Joint Risk graphic is the result of the combination of several analyses and provides a picture of the risk from erosion and flooding inherent in each segment. It is worth noting that the original ratings, (Low, Medium, and High) were replaced at the request of the Stakeholders Committee, who felt that ratings that actually reflected the power of the Sauk River would be more appropriate. Thus, the original ratings were replaced with:

- High (=Low),
- Significant (=Medium), and
- Volatile (=High).

Essentially the Joint Risk rating is a combination of the migration rate of the river matched with the aggradation/erosion rate in the segment. (Aggradation is a term used to describe the process of sediment buildup in the bed of a river). The Risk Rating, combined with all other analysis factors, provides Stakeholders with a clear picture of river processes at work in the river.

Figure 4. 2-Year Inundation

The 2-Year Inundation provides a graphical interpretation of the results of the hydraulic modeling (HEC-RAS) and is detailed in Appendix 4. The graphic shows where the river would occupy during an event that would be representative of a two-year event; that is, an event that has the statistical probability of recurring every two years (although not that it happens once every two years).

Figure 5. 10-Year Inundation

The 10-Year Inundation provides a graphical interpretation of the results of the hydraulic modeling (HEC-RAS) and is detailed in Appendix 4. The graphic shows where the river would occupy during an event that would be representative of a ten-year event; that is, an event that has the statistical probability of recurring every ten years (although not that it happens once every ten years).

Figure 6. 100-Year Inundation

The 100-Year Inundation provides a graphical interpretation of the results of the hydraulic modeling (HEC-RAS) and is detailed in Appendix 4. The graphic shows where the river would occupy during an event that would be representative of a hundred-year event; that is, an event that has the statistical probability of recurring every hundred years (although not that it happens once every hundred years).

Figure 7. "Parker" Figure

This figure is the companion figure to the Main Channel figure (Figure 9). These two figures make up the risk analysis for each segment. Studying the figure, one begins to observe the "waves" of sediment that travel in a downstream direction, greatly influencing river behavior and morphology.

Figure 8. Geomorphic Reach Breaks

This figure depicts the geomorphic reach breaks in the Sauk; that is, the different reaches of the river that are determined by the differences in slope, channel migration, valley width, and other characteristics.

Figure 9. Main Channels

One graphic that is extremely valuable in understanding the volatile nature of the Sauk River is the position of the main channel. Earliest records start at 1949 and continue through 2004 (2007 is also available but was not flown in time for the study). Needless to say, the channel is dynamic and can move across the floodplain rapidly, sometimes in one event.

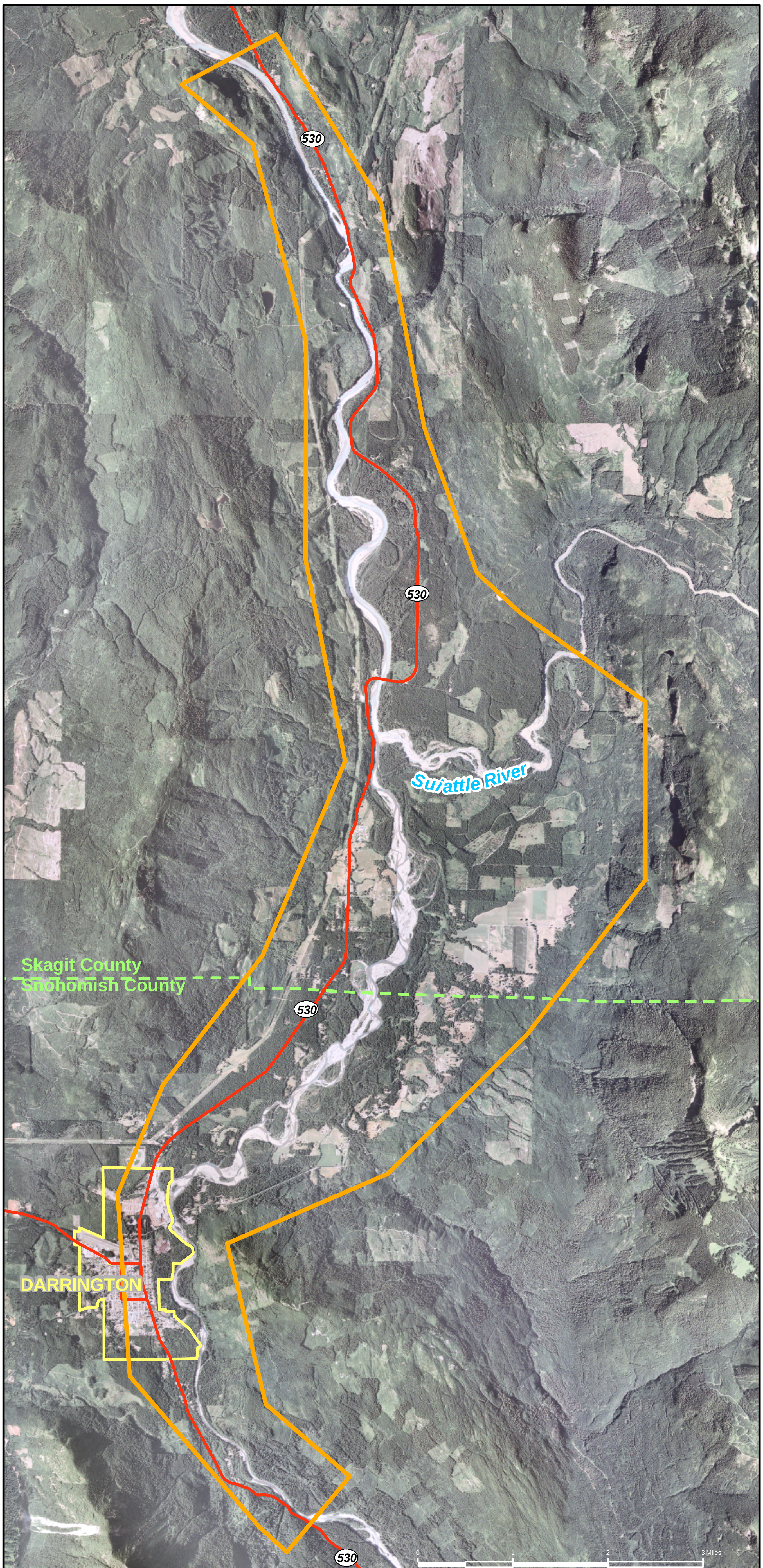
Figure 10. Agricultural and Forestry Land Use

This figure is not used in the analysis but is provided to show the extent of forest and agricultural land in the Sauk River basin. While this is by no means a comprehensive analysis of land use in the basin, it does demonstrate the respect that residents have paid to the river and its ability to move across the floodplain.

Individual Segment Maps 1 through 46

This section of the Guide includes information and maps on individual river segments, each identified by its assigned number. Segment numbers for the entire river section are shown in Figure 2.

Figure 1: Sauk River Comprehensive Flood Hazard Management Plan



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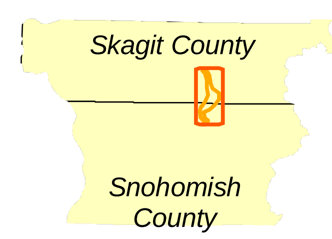
- Study Area
- City Boundary
- County Boundary
- Major Road



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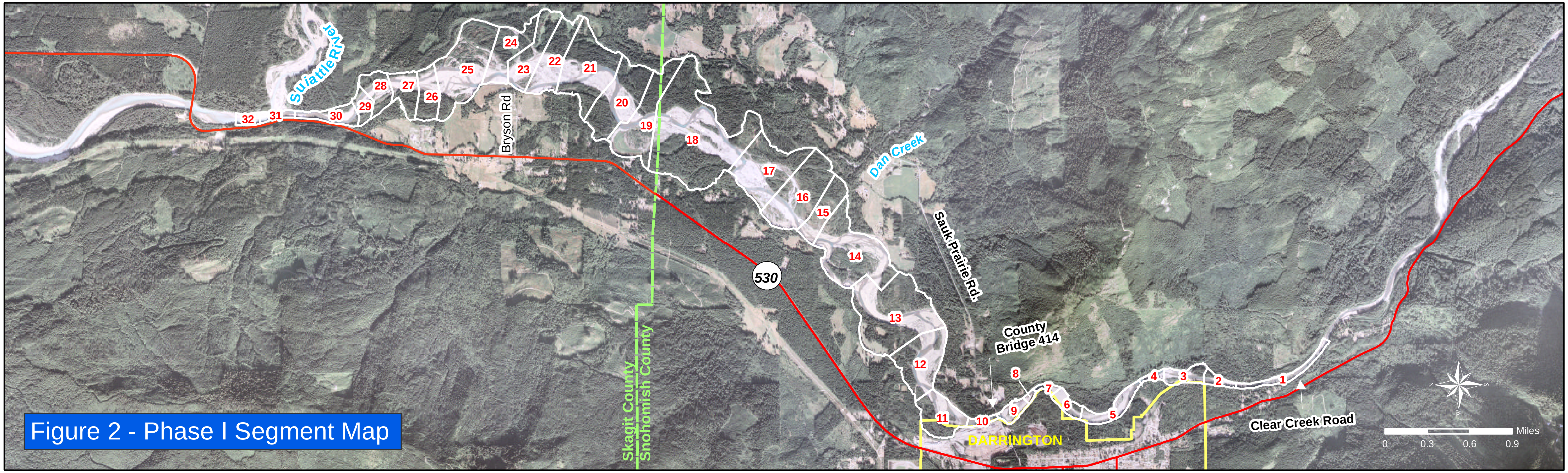

Figure 2 - Phase I Segment Map

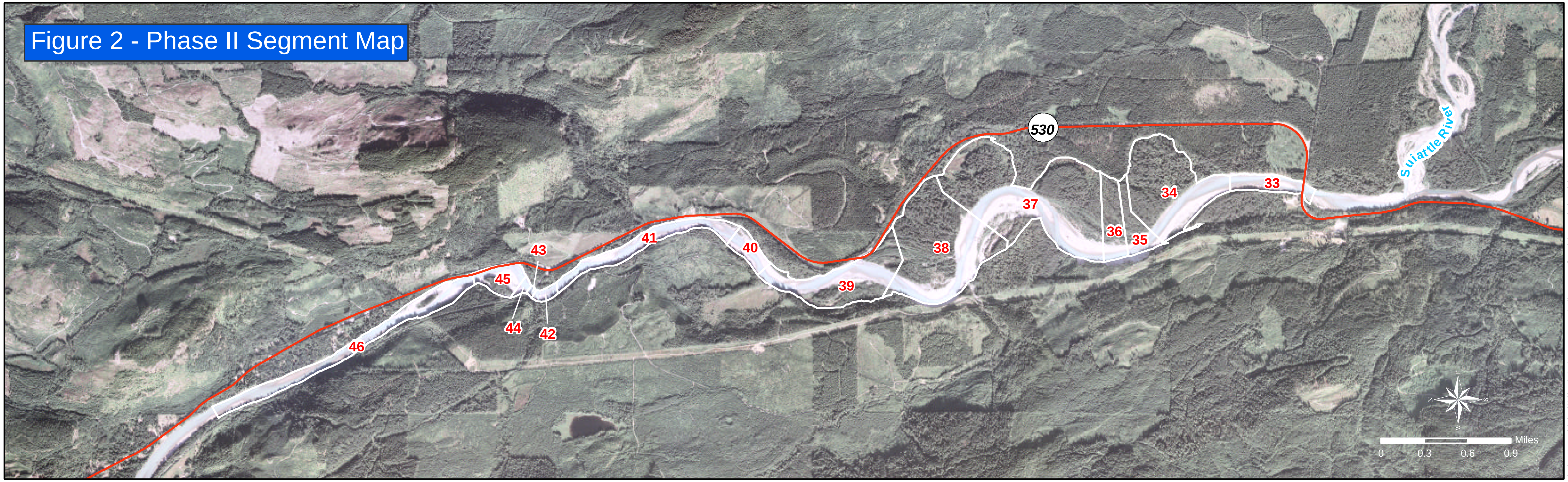

Figure 2 - Phase II Segment Map

Figure 3 - Joint Risk Phase I

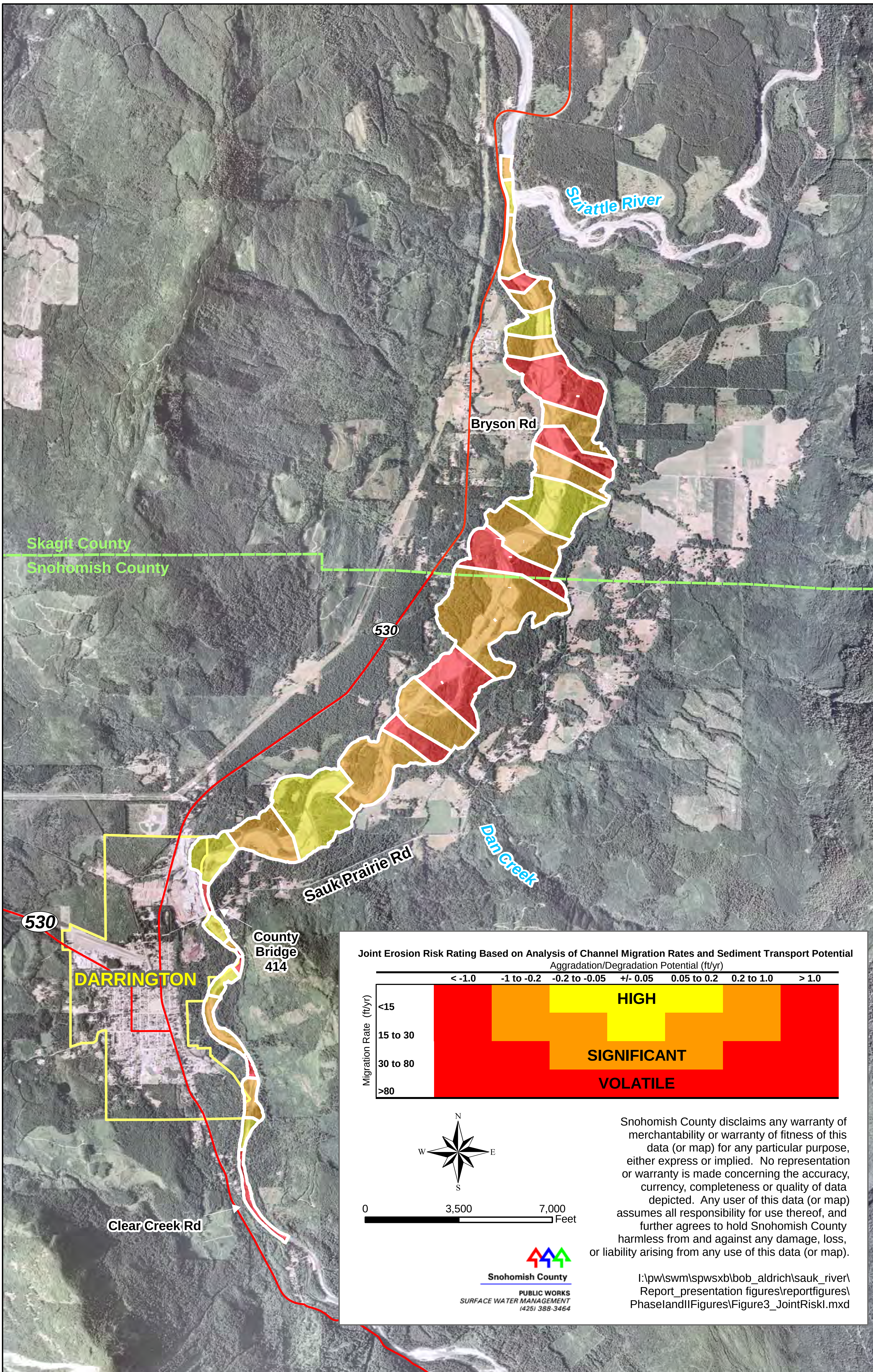

Figure 3 - Joint Risk Phase II

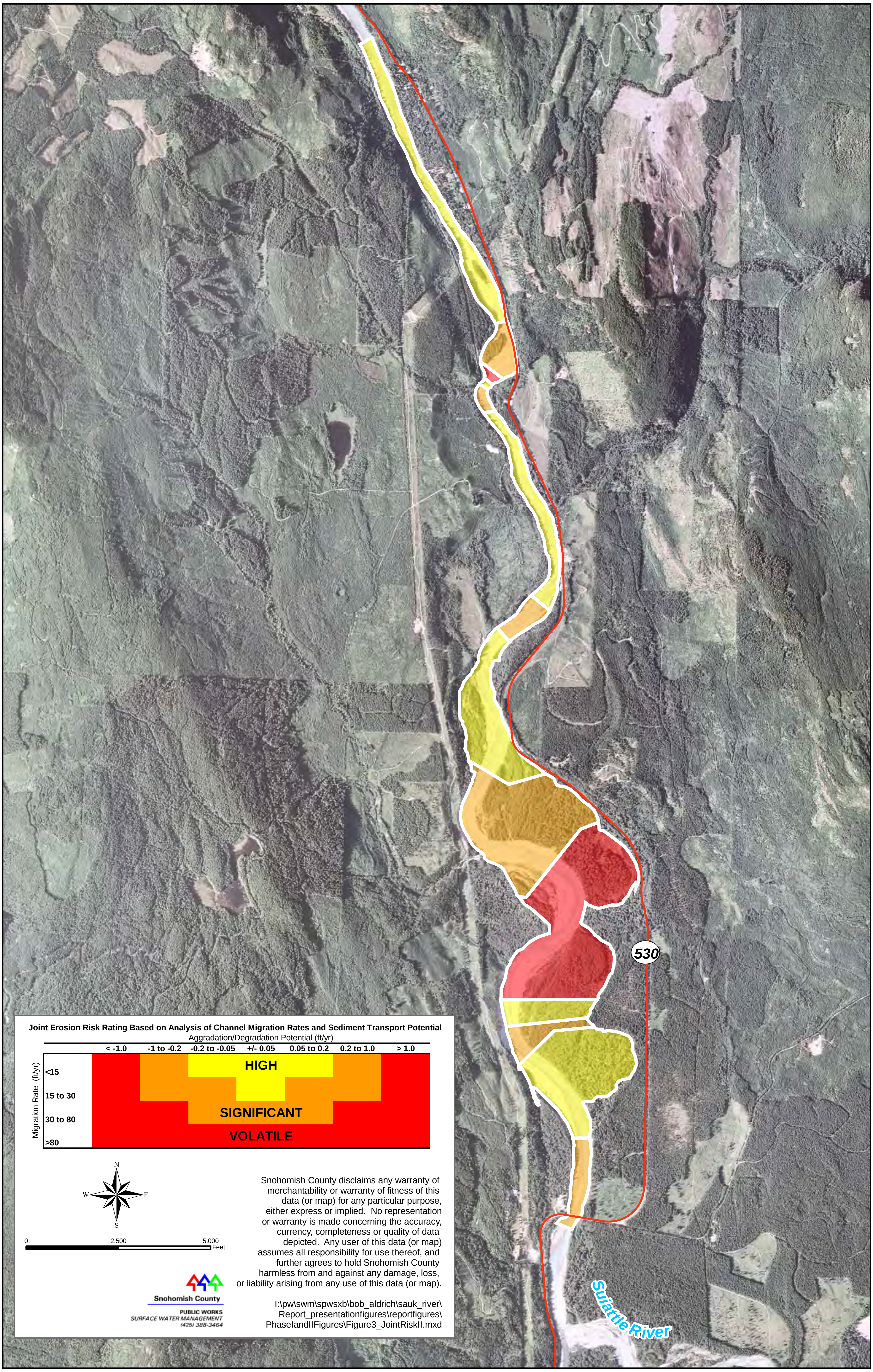

Figure 4 - Extent of Modeled Inundation for 2-year Flood Frequency Phase I

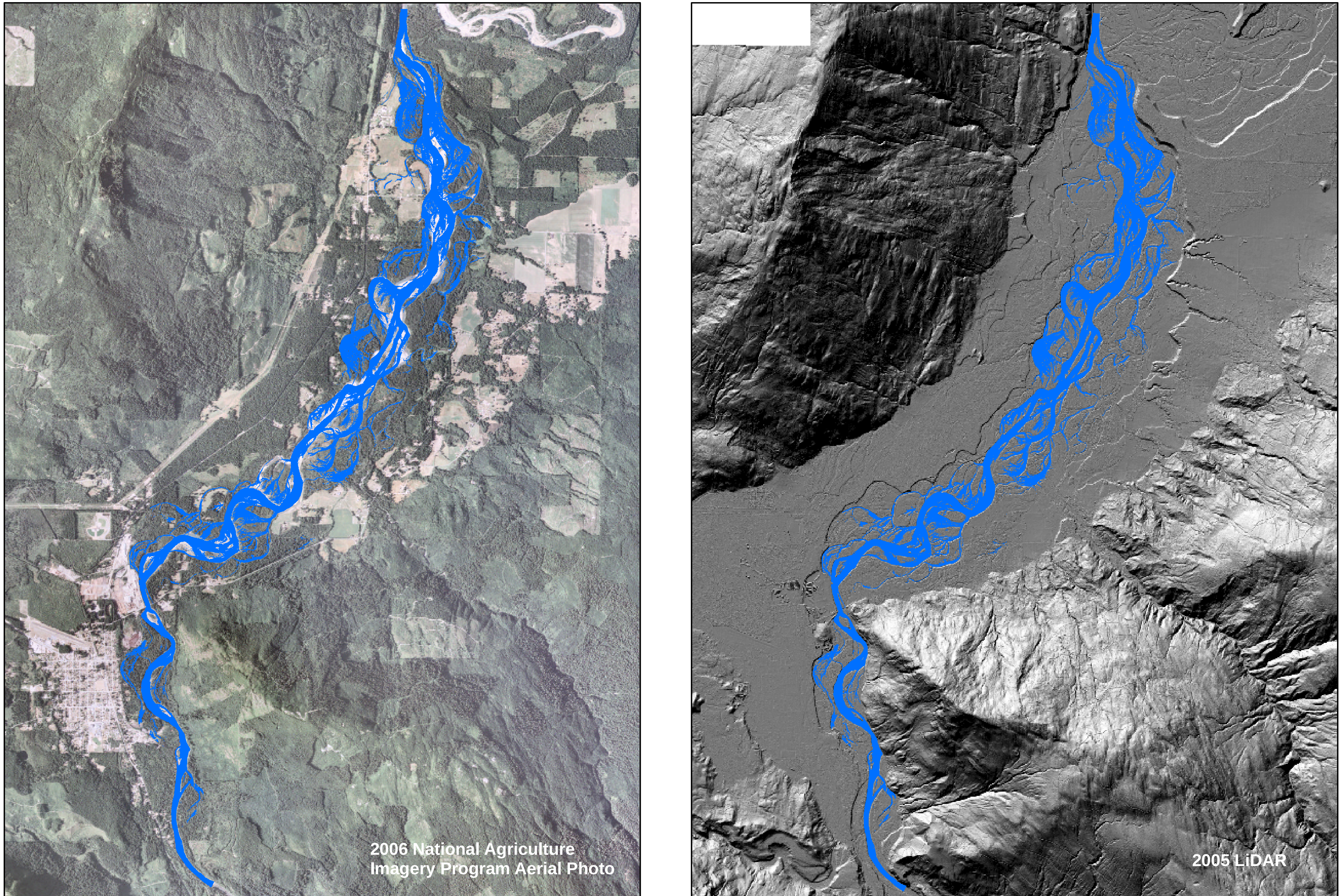

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Figure 4 - Extent of Modeled Inundation for 2-year Flood Frequency Phase II

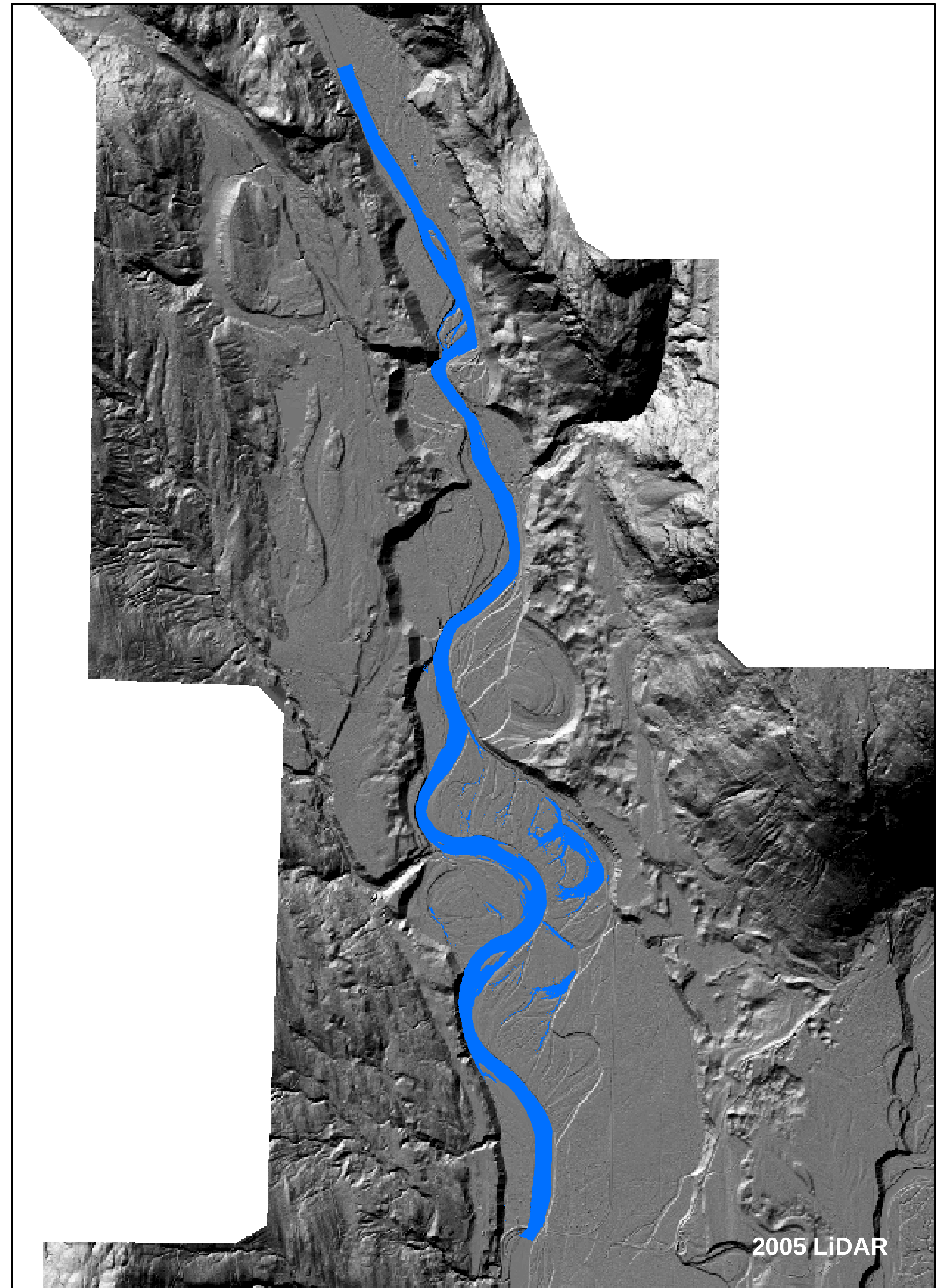

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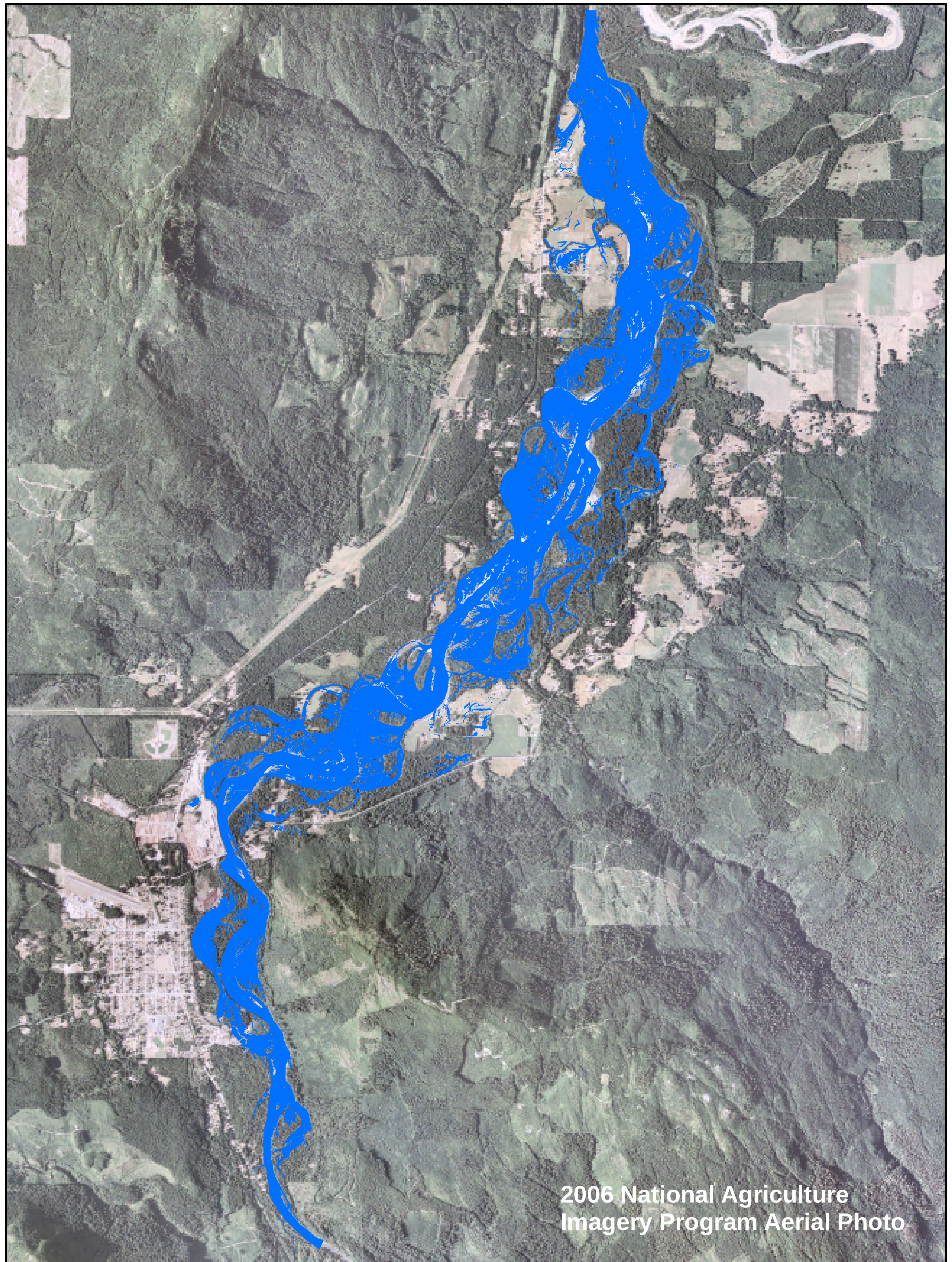
Figure 5 - Extent of Modeled Inundation for 10-year Flood Frequency Phase I



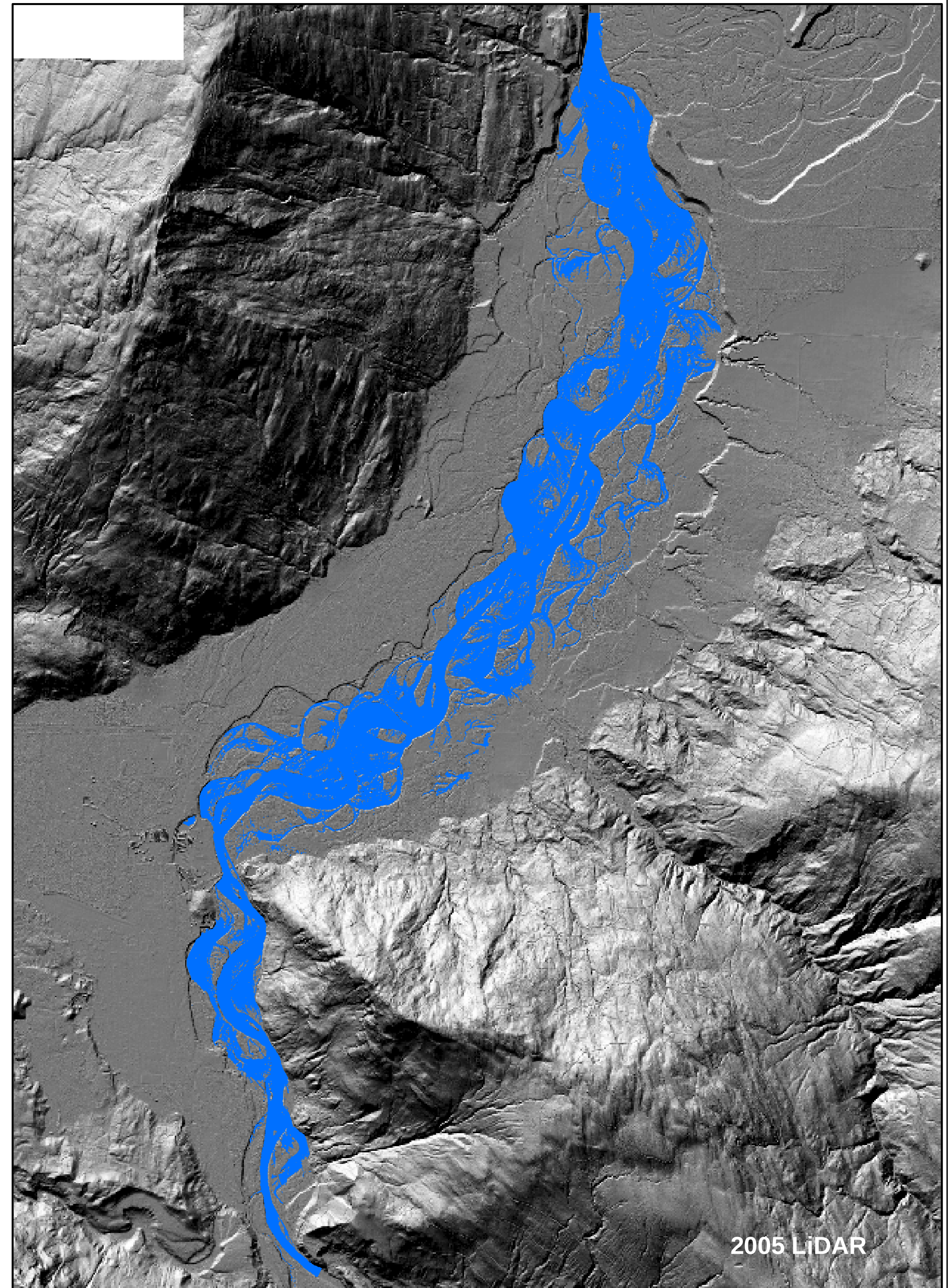


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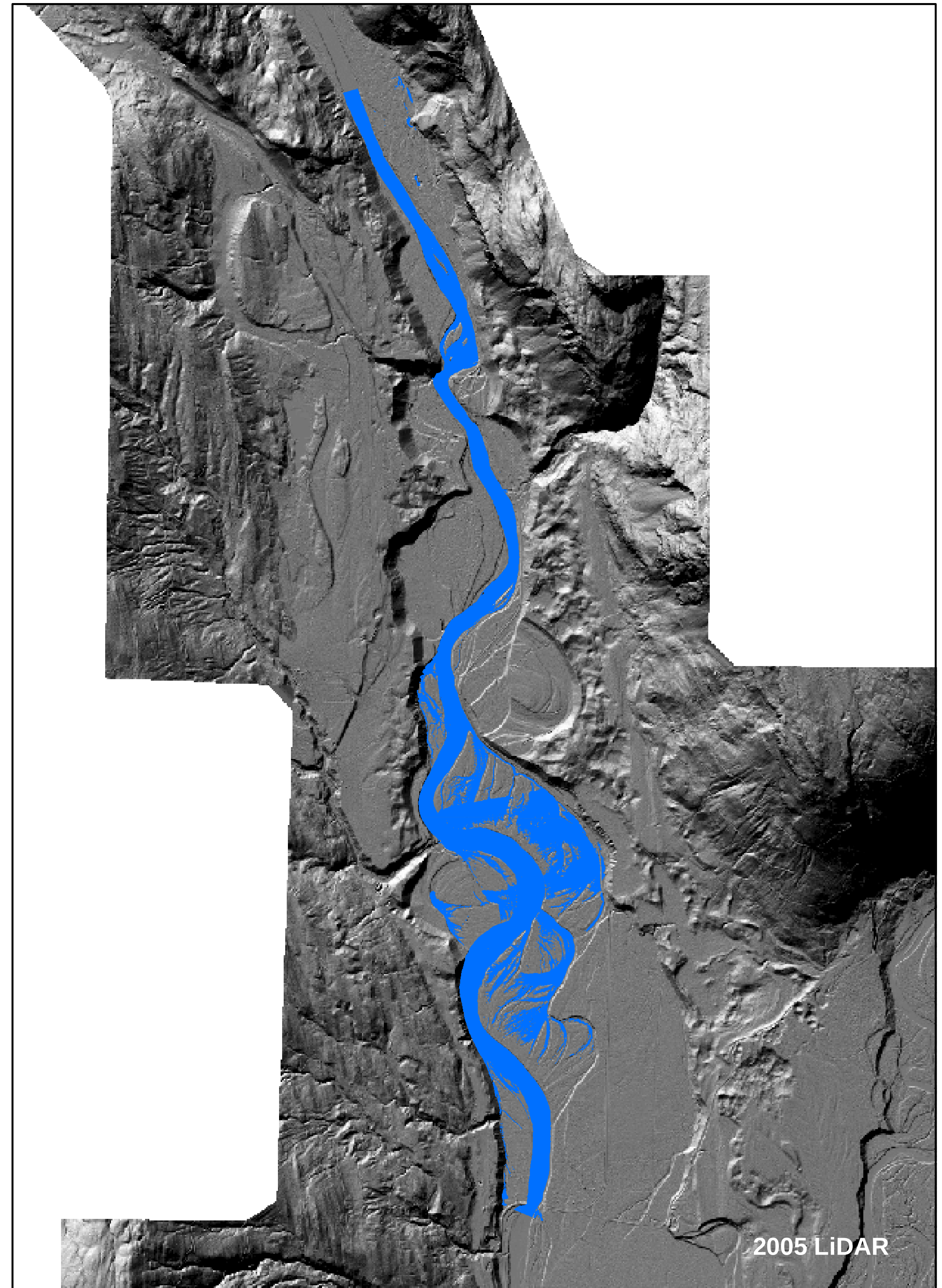
Figure 5 - Extent of Modeled Inundation for 10-year Flood Frequency Phase II



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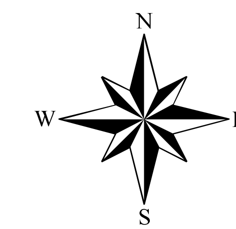

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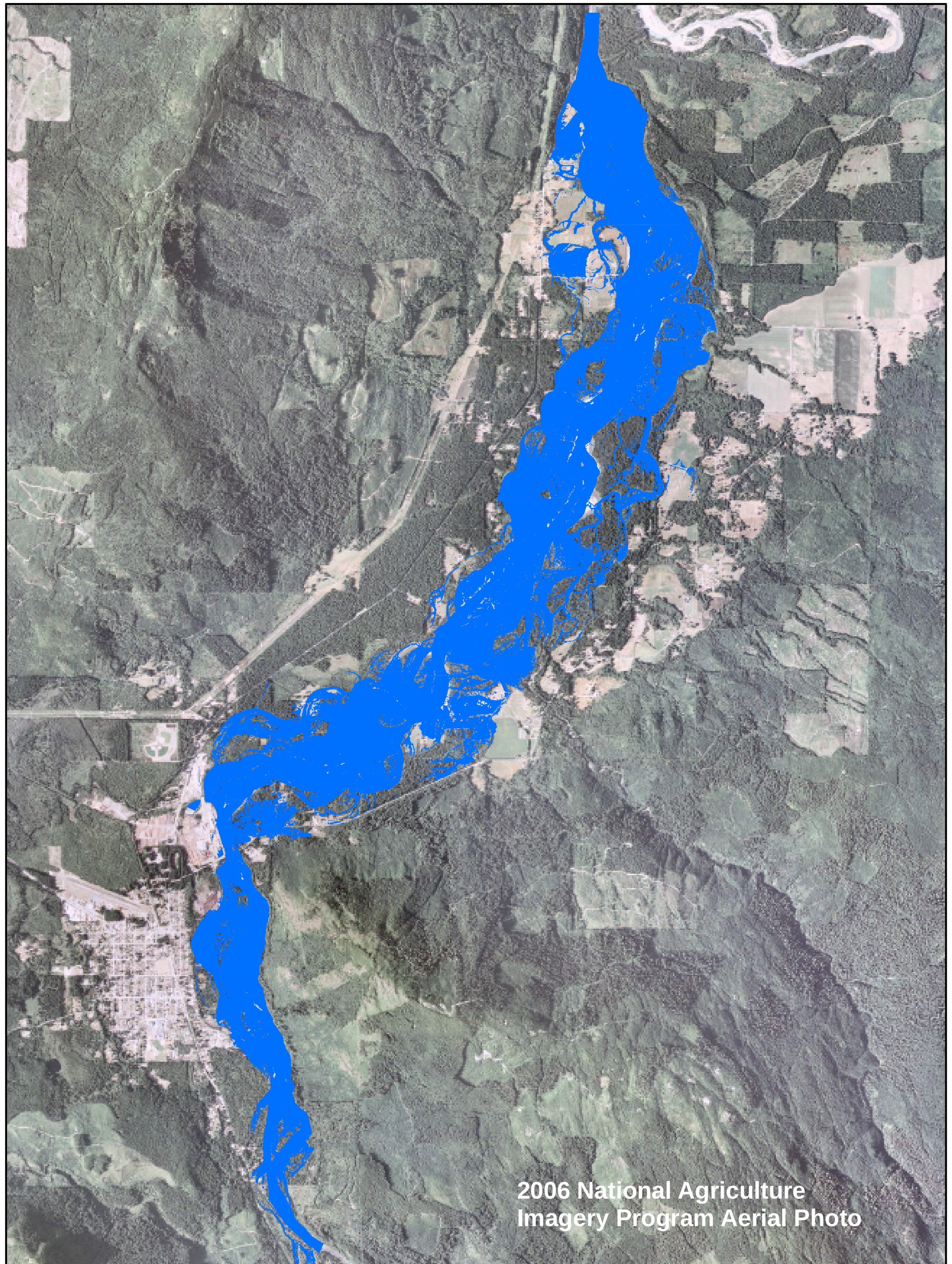
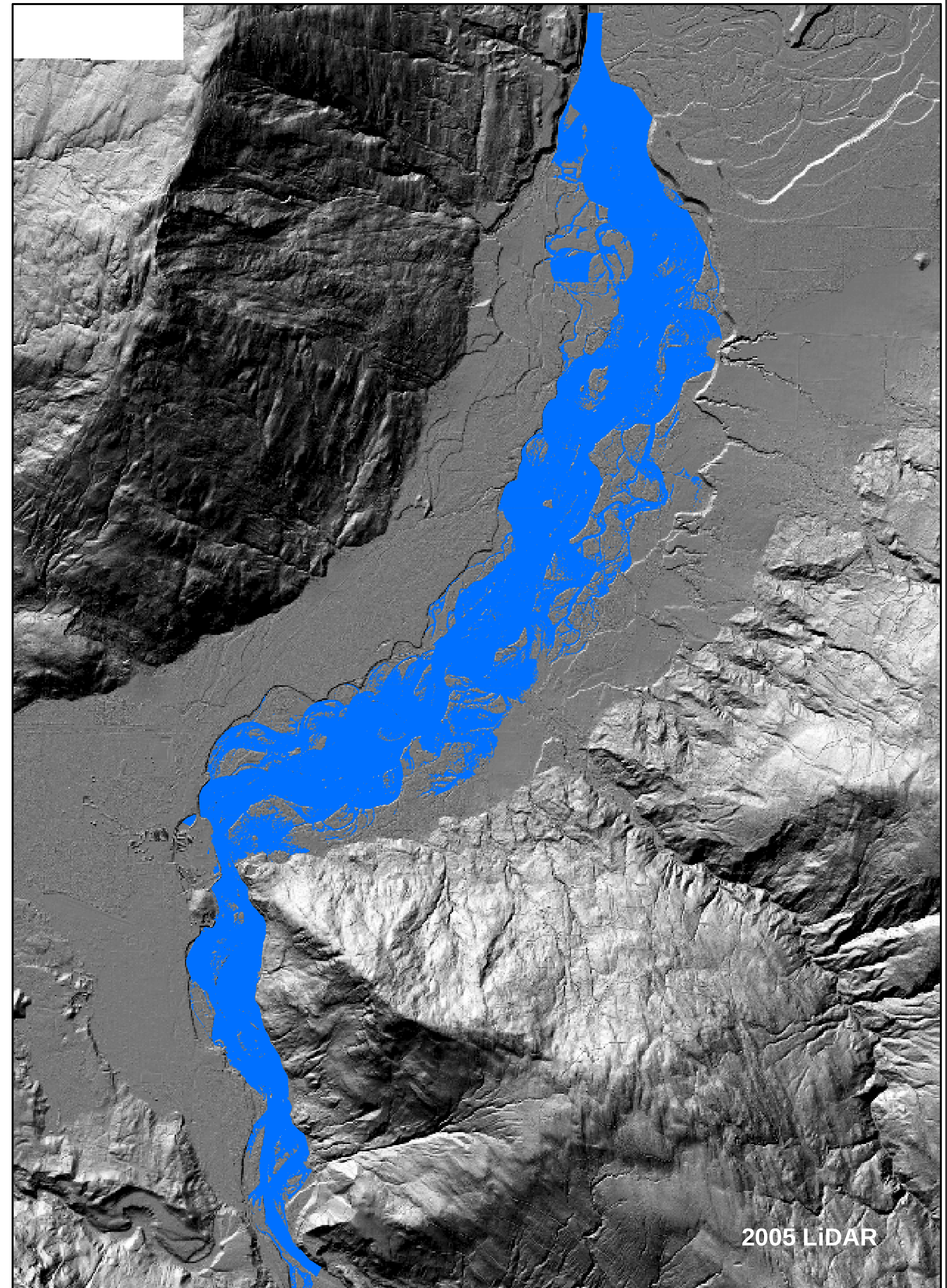
Figure 6 - Extent of Modeled Inundation for 100-year Flood Frequency Phase I





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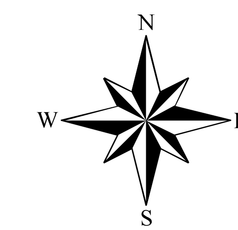

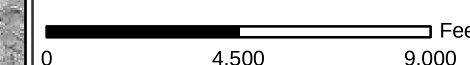

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Figure 6 - Extent of Modeled Inundation for 100-year Flood Frequency Phase II

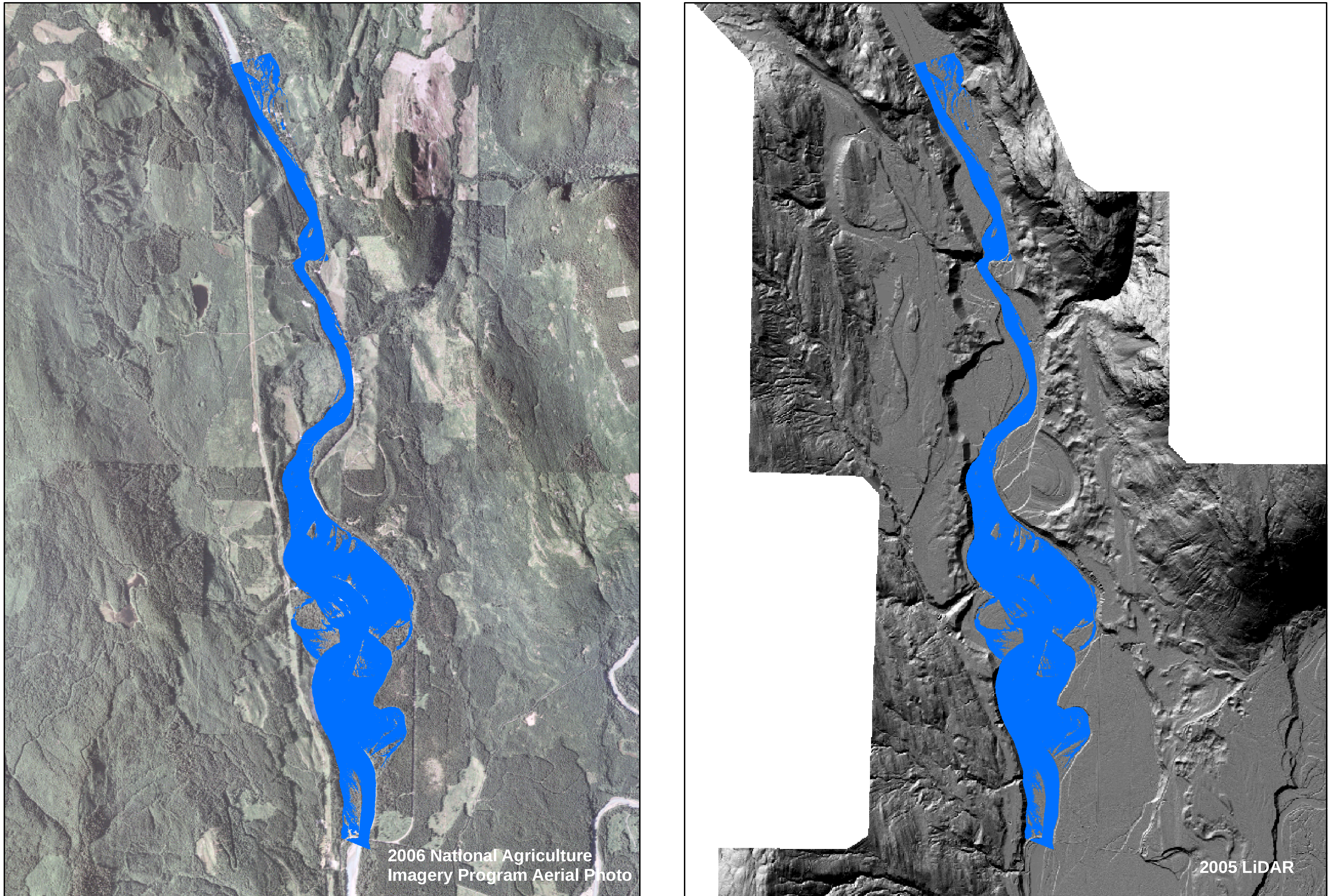

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Figure 7 - Aggradation/Degradation Potential (Parker) Phase I

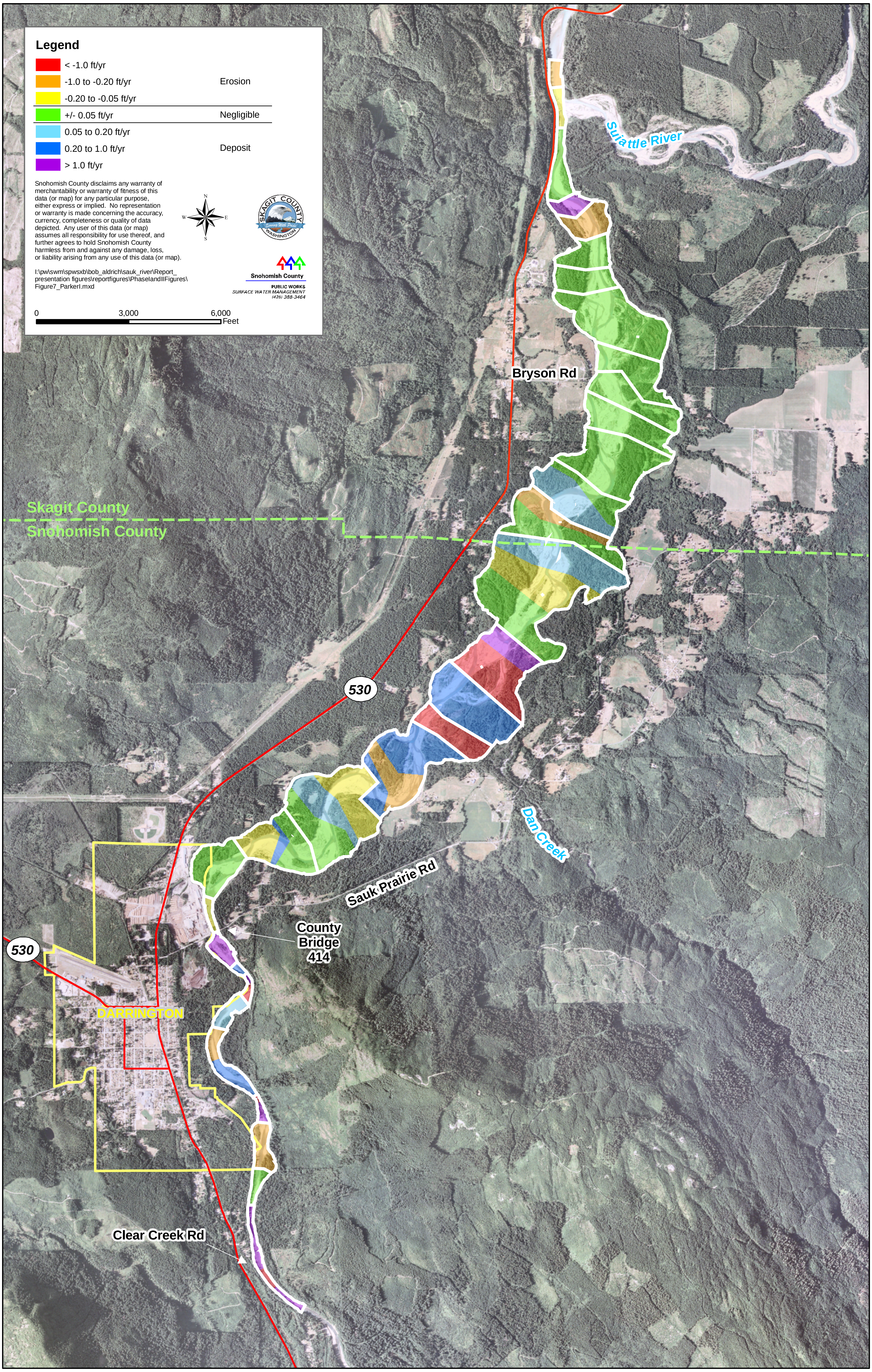

Figure 7 - Aggradation/Degradation Potential (Parker) Phase II

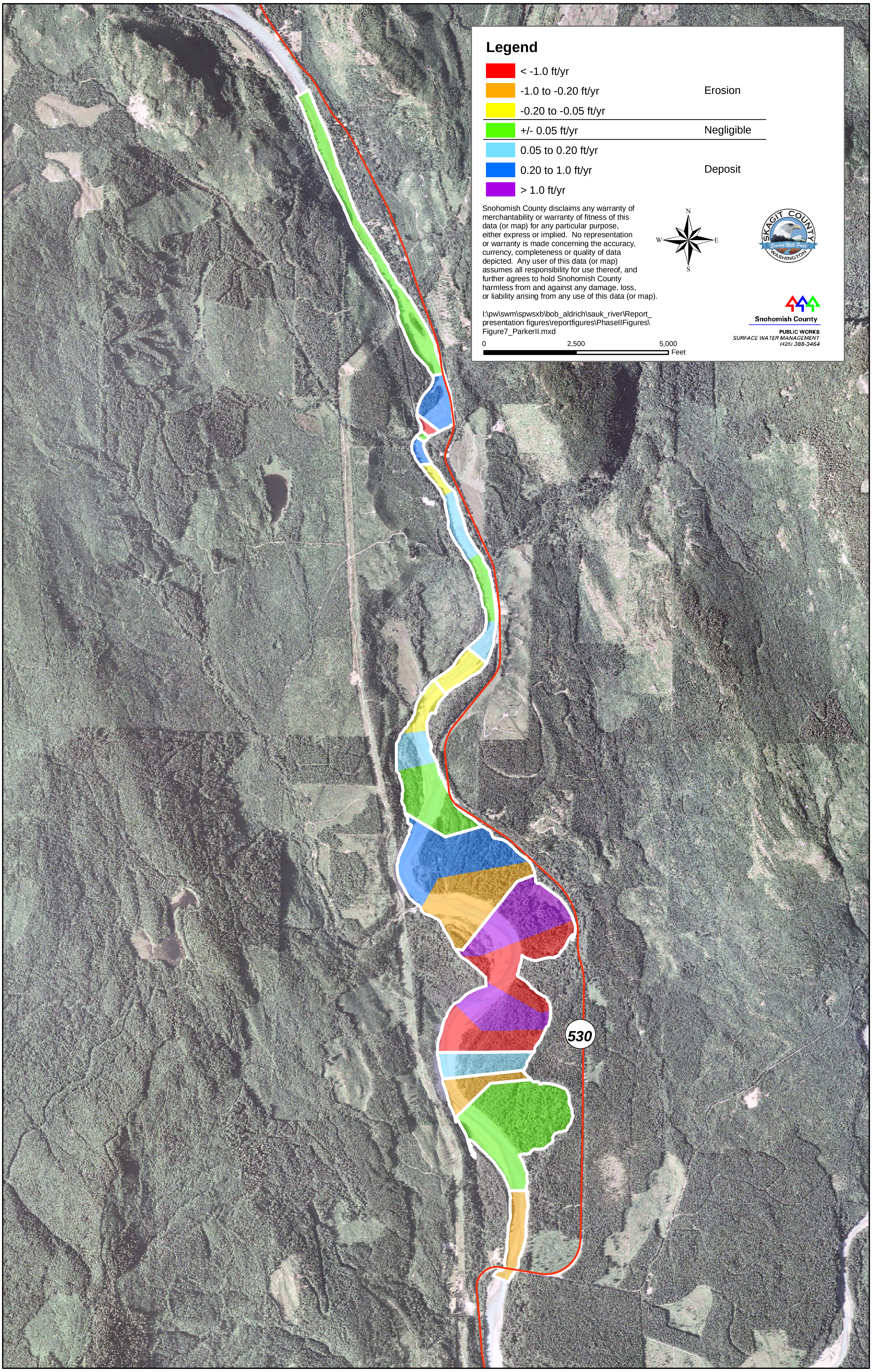

Figure 8 - Geomorphic Reach Breaks Phase I

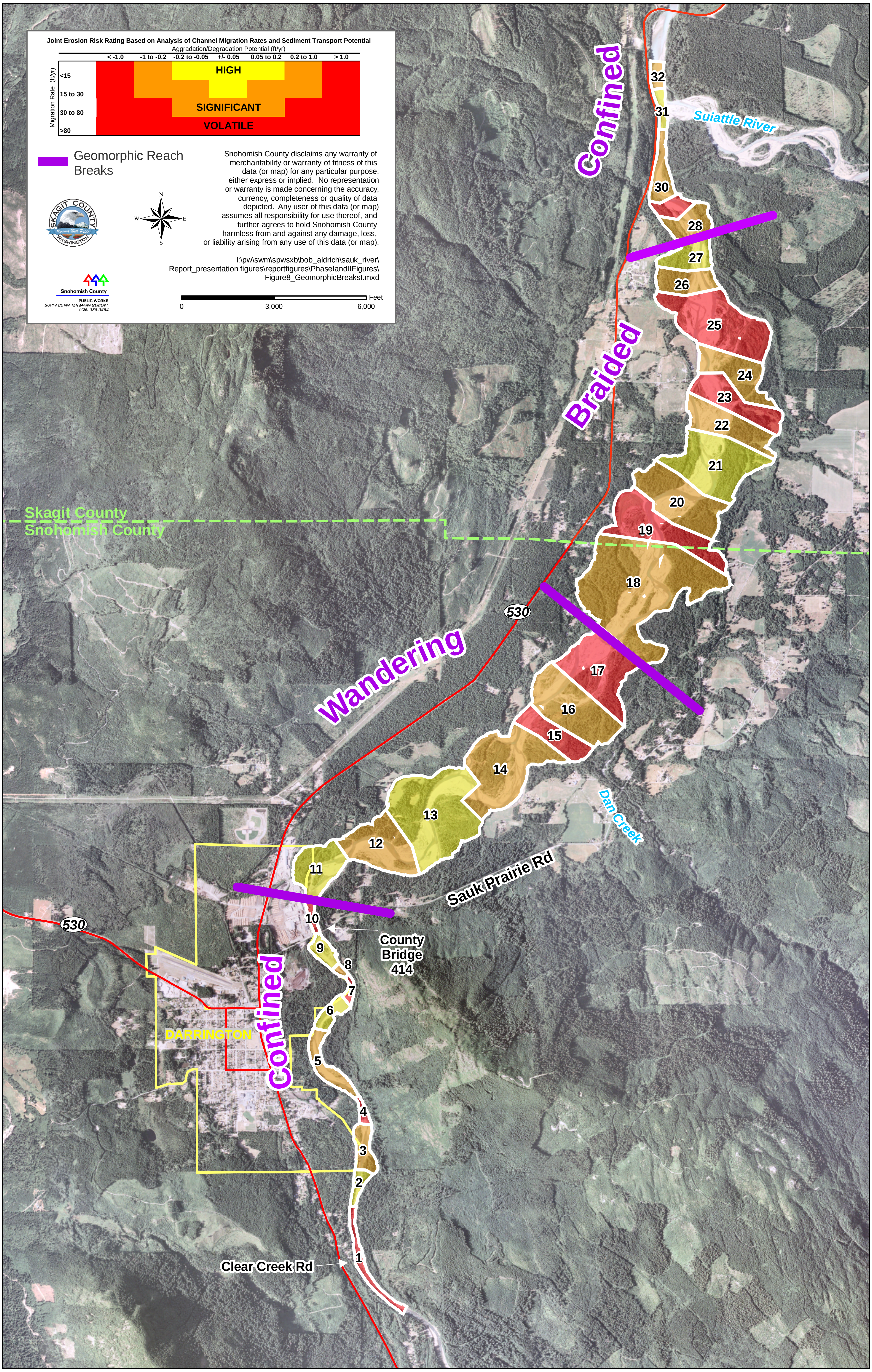

Figure 8 - Geomorphic Reach Breaks Phase II

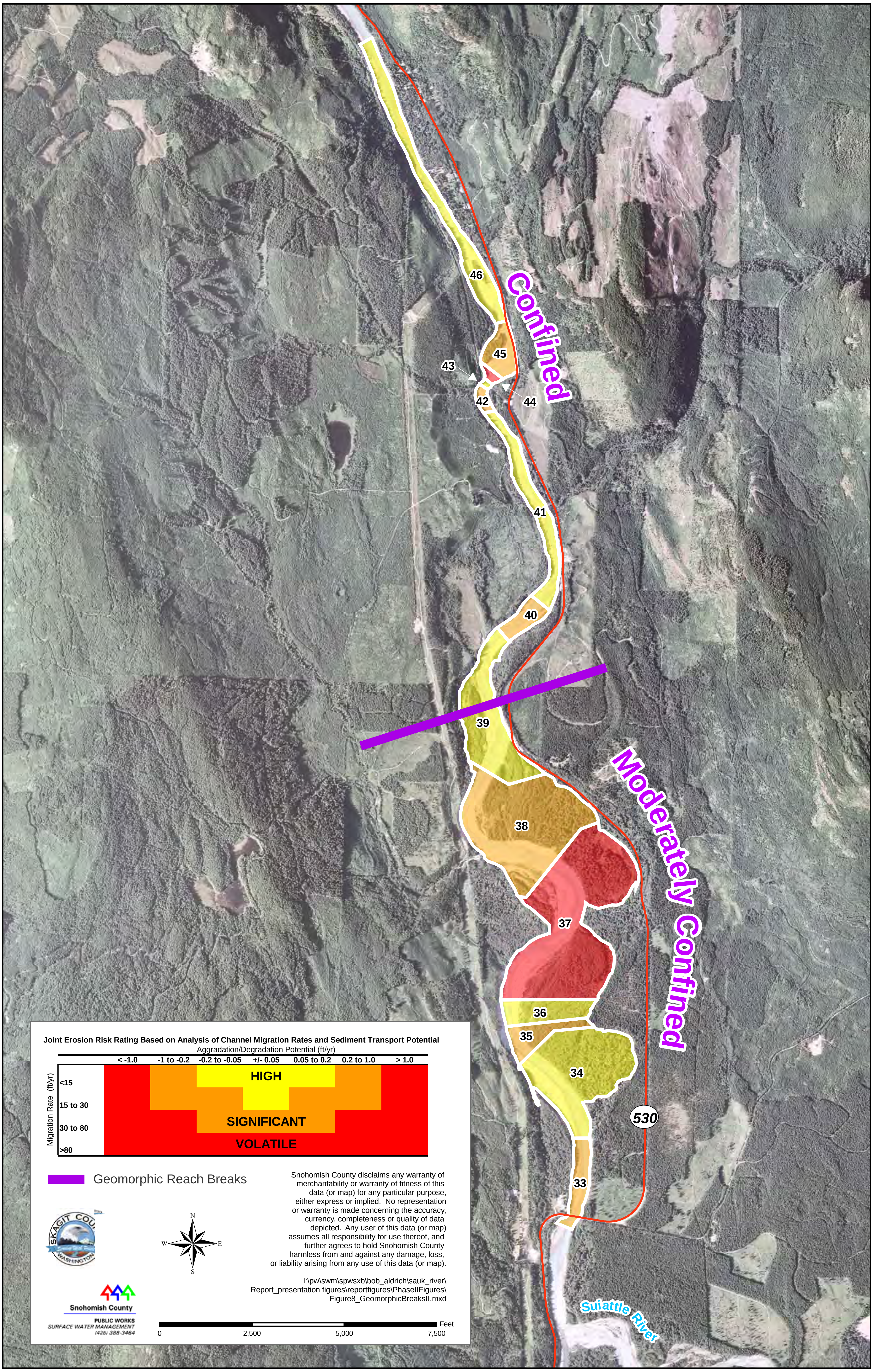

Figure 9 - Main Channels Phase I

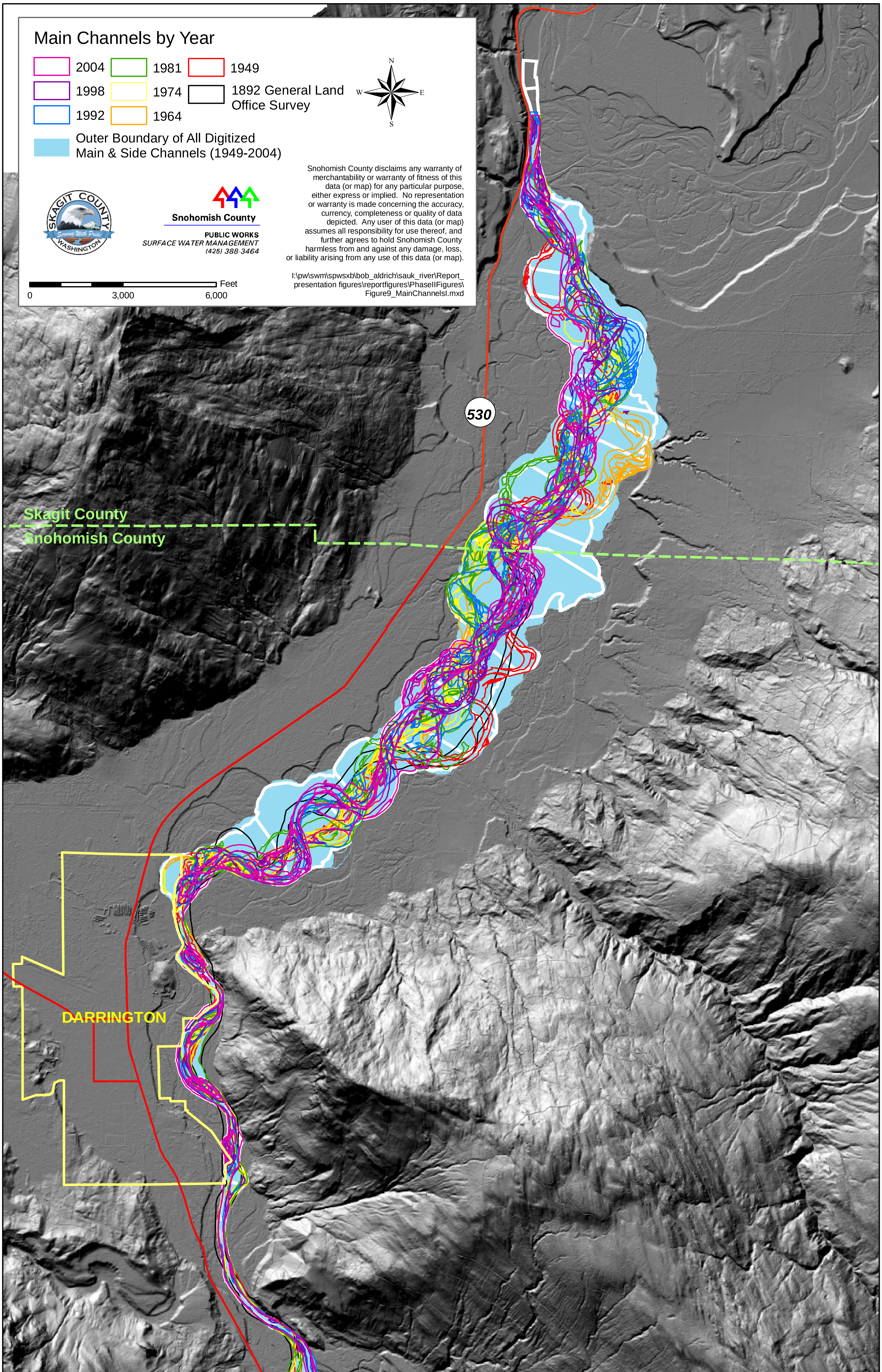

Figure 9 - Main Channels Phase II

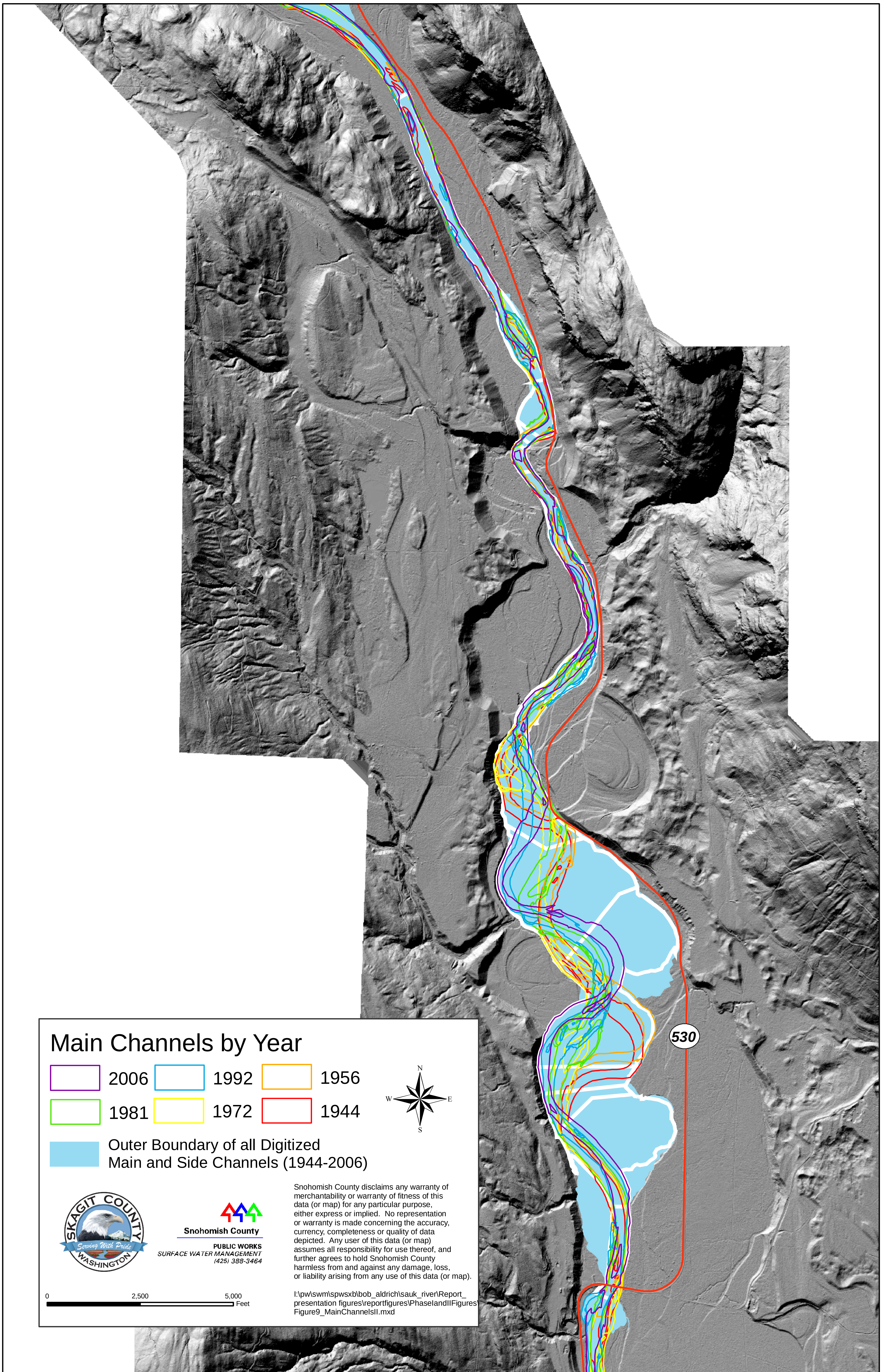

Figure 10 - Land Use Phase I & II