RECLAMATION
Managing Water in the West

NASON CREEK
TRIBUTARY ASSESSMENT
Chelan County, Washington

BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER, DENVER, CO,
AND
PACIFIC NORTHWEST REGIONAL OFFICE, BOISE, ID.

JULY 2008

U.S. DEPARTMENT OF THE INTERIOR

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

MISSION OF THE BUREAU OF RECLAMATION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover photo: View looking upstream at the railroad grade that defines the left bank. Nason Creek – Wenatchee River subbasin, Washington. (Reclamation photograph by R. McAffee, May 2, 2007).

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ACKNOWLEDGEMENTS

The authors of this report appreciate the support and input of a number of people and previous work that aided the completion of the Nason Creek tributary assessment. Prior to initiation of this assessment, research and analyses of portions of the Nason subwatershed were completed by other agencies, universities, and organizations which provided substantial information for this assessment. We gratefully acknowledge all of the individuals whose work facilitated a greater understanding of the physical processes being evaluated in this assessment.

Cameron Thomas at the U.S. Forest Service (USFS) was instrumental in establishing the initial scope and integration of geomorphic information with habitat conditions and goals. Cindy Raekes and Dave Hopkins from the USFS provided critical input to help link physical processes with habitat issues. Patrick Murphy, Jim Haberberger, and Tom Robinson from USFS were very helpful in obtaining aerial photography and ArcGIS information from previous efforts in the Nason Creek subwatershed. Jim Hadfield from the USFS provided important guidance for the vegetation assessment.

Steve Kolk (Reclamation's Wenatchee Subbasin Liaison), Mary Jo Sanborn, Joy Juelson, and Alan Schmidt (Chelan County Natural Resources Department), and members of the Wenatchee (WRIA 45) Habitat Subcommittee all assisted with passing on an abundance of local knowledge on past and present river conditions. The Cascadia Conservation District assisted with locating historical aerial photographs. The Wenatchee historical museum graciously provided access to copy historical photographs from settlers in the Wenatchee subbasin. Rick Wood from Washington Department of Transportation (WSDOT) shared historical flood knowledge and videos that were valuable to learn from. We are grateful to all of the landowners who allowed the Bureau of Reclamation or contractors access to their properties for the purpose of the assessment and provided local knowledge of flooding issues. A special thanks to all the other individuals not mentioned above that also contributed during meetings and field visits to help the team process and interpret findings.

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EXECUTIVE SUMMARY

The Bureau of Reclamation (Reclamation) completed an assessment of physical river processes and associated habitat for spring Chinook and steelhead listed under the Endangered Species Act (ESA) for approximately 10 river miles (RM) of Nason Creek, located in the Wenatchee subbasin in Chelan County, Washington. The purpose of this report is to develop a restoration and protection strategy based on a sound scientific assessment of channel processes. This report also includes a strategy that resource managers can use to sequence and prioritize reaches for protecting or restoring channel and floodplain connectivity and complexity.

Within this document, Reclamation describes a tributary reach-based approach to conduct geomorphic assessments and informs how this approach provides a platform that can be integrated with monitoring and adaptive management activities. The tributary reach-based approach employs a sequence of steps to focus funding and technical resources at telescoping geographic scales and to provide insight on the identification of potential project areas with the greatest biological benefits. This systematic, reproducible, and scientific approach includes stakeholder involvement to guide progress. Definition of discrete geographic areas (reaches) and the use of a modified Matrix of Pathways and Indicators (NOAA Fisheries 1996) provide an objective basis to integrate restoration strategies with implementation, status and trend, and effectiveness monitoring, and adaptive management at comparable geographic scales. Connections between project implementation, monitoring, and adaptive management can be potentially "rolled up" from smaller to larger scales to measure progress toward the NOAA Fisheries Biological Opinion (2008) and recovery plan goals in the Upper Columbia tributaries (UCSRB 2007).

Projects implemented with a clear understanding of the existing physical processes are more likely to provide both short- and long-term benefits to the ESA-listed and other culturally important fish species. The proposed strategy provides spatial linkages within the assessment area so that potential restoration activities can be conducted to expand and reconnect areas that are already functioning. Spatial linkages also ensure there are no critical limiting factors that need to be addressed before newly improved habitat can be accessed and utilized (e.g., barriers, flow limitations). In addition, understanding the existing physical processes will help minimize unanticipated impacts to presently functioning habitat, other potential restoration projects, infrastructure, and property, as well as maximize the sustainability of potential restoration projects.

Reclamation evaluated trends in physical processes over the last century and delineated reaches based on differences in geomorphic characteristics. The assessment area was broken into three geomorphic reaches, two of which are just under 5 miles long and the middle Reach 2 being 0.5 miles long. Restoration opportunities were identified based on the present conditions, and the potential for improvement to each reach. Prioritization of identified reaches is based on current habitat quality and potential habitat improvements through integration of results of the geomorphic assessment with established objectives for Nason Creek from the *Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan* (UCSRB 2007).

Analysis of historical impacts to flow, sediment, and topography within the assessment area revealed that:

- Nearly 360 acres of historical floodplain have been disconnected causing high energy channel sections with limited ability to sustain large woody debris (LWD) and spawning size sediments.
- Historical removal of LWD and present lack of ability to recruit LWD has reduced amounts of high quality LWD-formed pools and cover.
- Floodplain vegetation is recovering from turn-of-the-century logging, but is generally in good condition; the exception is the power and transmission line corridors, areas occupied by railroad and highway embankments, and localized pockets of development or agriculture where vegetation is repeatedly cleared.
- The channel length has been reduced by 2 miles through bypassing of historical channels with constructed, straight channels that are largely armored with riprap and devoid of habitat value.
- The availability and quality of off-channel habitat area is limited because of the straightened channel sections that prevent channel migration and reworking of the floodplain.
- Meandering sections could be enhanced to provide better habitat conditions because many are eroding into cleared terrace surfaces that are not recruiting LWD, or are running against in-channel features that affect the quality of pools in the meander bend.

The primary objective of recommended habitat actions is to recover long-term sustainable habitat function and availability by:

- Increasing the complexity of the main channel
- Increasing availability and quality of off-channel areas
- Increasing the amount of accessible floodplain

Achieving these restoration objectives would allow more recruitment of LWD and increased complexity in the main channel. Increased floodplain would reduce energy (velocity) in the system during high flows, improving the ability of the river to sustain recruited LWD and associated habitat complexity.

Based on a technical perspective from the findings of this assessment (Table 1), options for prioritizing restoration efforts in Reach 1 versus Reach 3 are presented below. Reach 2 is not included because there is no restoration actions proposed in this 0.5-mile area that is a single channel segment with functioning spawning habitat in the upstream end.

1. For implementation of restoration actions that build upon existing high quality habitat, Reach 3 offers the best opportunities, followed by Reach 1. This is because Reach 3 has limited, but more high quality habitat than Reach 1 and is immediately downstream of the mostly functioning habitat area above river mile (RM) 15.
2. For priorities based on the potential to increase available habitat area, Reach 3 would come first followed by Reach 1; Reach 3 has more opportunities to increase off-channel habitat, a key limiting factor identified, and has more potential tributary habitat segments that could be restored.
3. For restoration in the least impacted reach in terms of floodplain, channel migration, vegetation, and channel topography function, reach 1 would come first based on the findings of the geomorphic assessment.
4. For building upon existing restoration projects, prioritzation would start with Reach 1 and work upstream to Reach 3; this is to build upon the recently completed channel reconnection project in the lower 4 river miles.
5. For prioritizing based on the level of impacts to hillslope and tributaries, both reaches would be equally prioritized because the impacts are consistent.
6.

Table 1. Interpretation of overall present geomorphic conditions by geomorphic reach.

Reach	Existing High Quality Habitat	Opportunities to Increase and Enhance Habitat	Ranking: 5 (best) to 1 (worst)			
			Floodplain function	Channel migration	Riparian vegetation	In-channel complexity (LWD)
1 (RM 4.6 to 8.9)	Limited	Moderate	4	3	4	1
2 (RM 8.9 to 9.4)	RM 9.2 to 9.3 (spawning only)	Low	5	NA	5	4
3 (RM 9.4 to 14.3)	RM 11.1 to 11.4 and 12.8 to 13.3	High	2	2	4	2

The tributary assessment provides a good starting point for focusing restoration efforts and prioritization discussions within Nason Creek from RM 4.6 to RM 14.3. Based on findings of the tributary assessment, a finer resolution diagnostic investigation of local physical processes and habitat features is being conducted at the reach scale and will be issued as a separate report. The product of the reach assessment serves as the basis of an implementation strategy. Reach assessments include several primary goals:

a. diagnosing physical/environmental conditions at a more detailed spatial scale within the reach;

b. proposing a technical sequencing recommendation of habitat actions for a cumulative biological benefit; and

c. documenting baseline environmental conditions for future effectiveness monitoring.

Habitat actions are prioritized in the reach assessment based on the number of viable salmonid population (VSP) parameters and limiting factors addressed by an action and sequenced to maximize their cumulative benefits for the target species. Potential actions are also spatially linked in terms of which areas must be done concurrently to obtain restoration objectives.

1. INTRODUCTION

Nason Creek is located near the city of Leavenworth in Chelan County, Washington (Figure 1). It is approximately 27 miles in length, drains nearly 8,000 square miles, and is the first tributary to the Wenatchee River below Lake Wenatchee (about 0.6 mile below outlet at Wenatchee river mile 53.6). Elevations range from 1880 feet at the confluence with the Wenatchee to 4240 feet at the headwaters that originate in the eastern Cascades Mountain range. Just over 80 percent of the vegetation in the subwatershed consists of various fir and hemlock species (USFS 1996).

Much of the land ownership in the Nason Creek subwatershed is federally owned, of which 51 percent is non-designated recreational forest and 21 percent is part of the Alpine Lakes Wilderness Area (see map 2 in atlas). Privately-owned land makes up another 22 percent (14,000 of 69,000 acres total) of the subwatershed and includes a mixture of uses including rural home development, a golf course, small businesses, and corporate timber lands. The lower 15 miles, along with Kahler and Coulter Creek subdrainages, are dominated by privately-owned land (USFS 1996)

Anthropogenic land use activities in the riparian area include beaver trapping in the early to mid-800s, construction and maintenance for U.S. Highway 2 (1,250,000 vehicles a year), private homes, campgrounds, recreation, power and transmission line maintenance, and railroad activities (Appendix B – Historical Timeline) (USFS 1996). The railroad was completed in 1892. U.S. Highway 2, known as Stevens Pass, was present in the early 1900s and improved and relocated closer to the river in 1960. Highway 207, located downstream of the assessment area between RM 4 to RM 0, was also improved and relocated closer to the river in 1943. The power lines were present on 1930s maps but their initial construction date is unknown. Native Americans occupied the valley prior to the 1890s, and American pioneer settlements began with the railroad in the 1890s and increased thereafter. Housing and infrastructure is fairly spread out in the Nason subwatershed, but urban areas are present at the town of Merritt located at RM 12, Coles Corner at RM 4.5, a downhill ski area at the pass (Figure 2), and a Nordic center in the Mill Creek subdrainage. As of 1996, approximately 125 homes, businesses, and other structures were present within the Nason Creek subwatershed (USFS 1996).

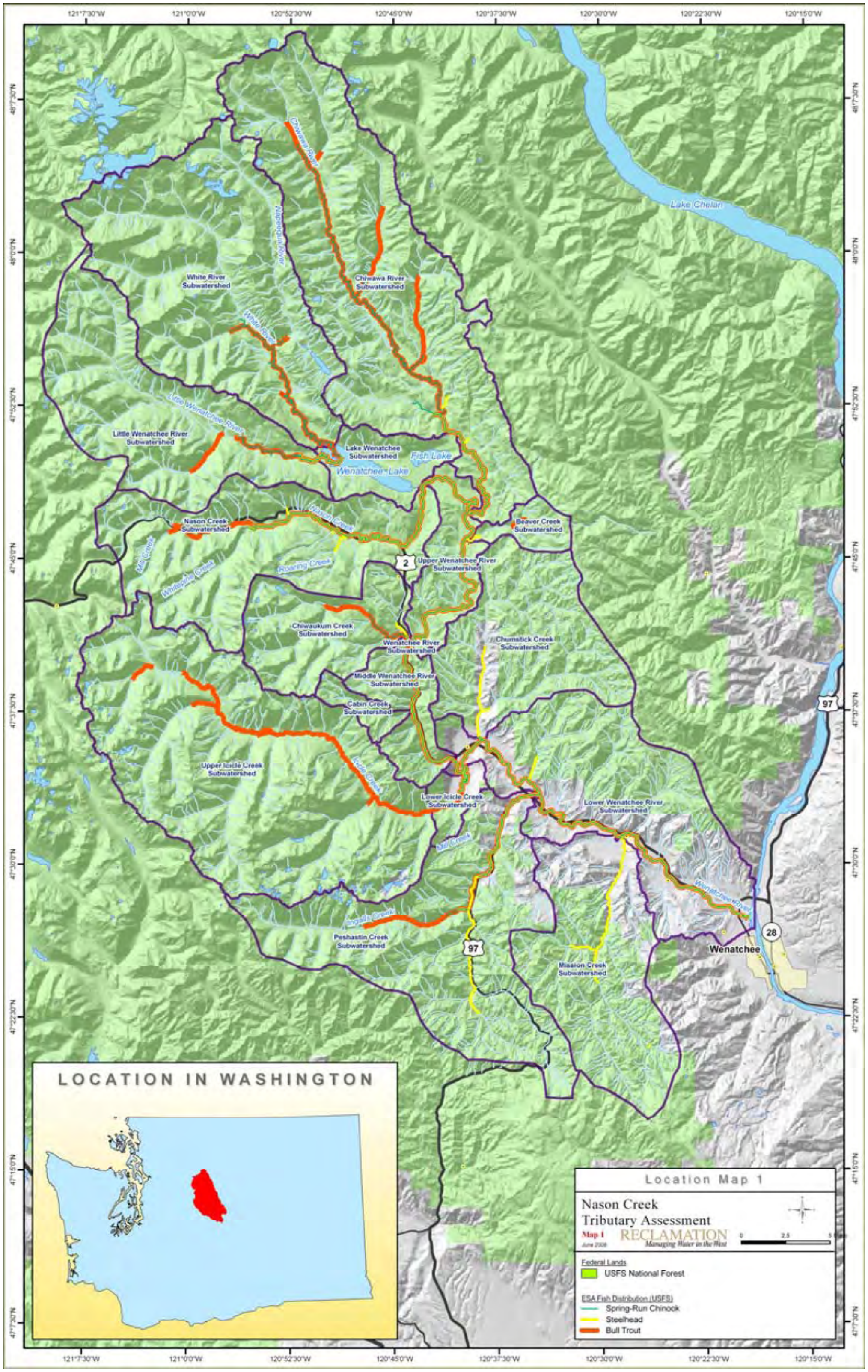


Figure 1. Location map for Nason Creek assessment area.

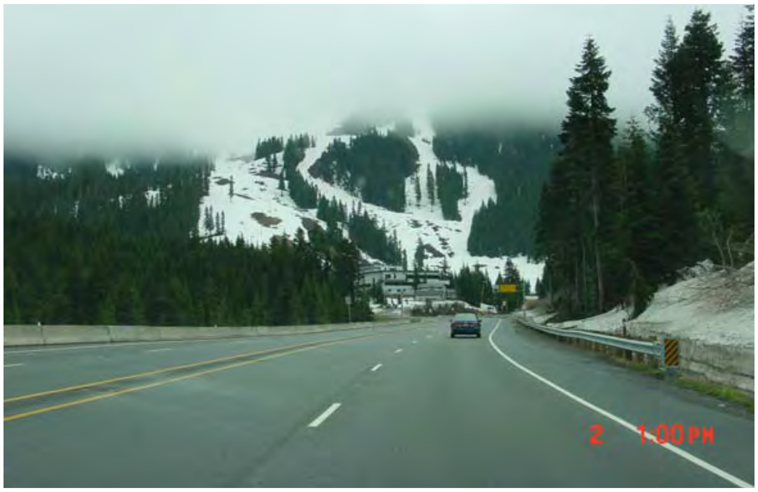


Figure 2. View of the Stevens Pass ski area and U.S. Highway 2.

Within the Nason Creek subwatershed, substantial changes to channel processes and resulting habitat have occurred since the 1800s (USFS 1996; Andonaegui 2001). As a result of both in- and out-of-subwatershed impacts, populations of several important fish species are now at risk and some species have been listed under the Endangered Species Act (ESA). Protection of existing aquatic habitat and restoration or improvement of altered habitat is generally an accepted method that benefits important fish species (UCSRB 2007). In order to make good decisions about where and how to implement aquatic habitat restoration projects, a strong understanding of river processes is necessary. This science-based tributary assessment provides decision makers with preliminary project implementation opportunities that will be elaborated on in more detail at the reach assessment scale.

1.1 Background and Need

In the Nason Creek subwatershed, changes in channel processes have reduced the quality and availability of habitat for spring Chinook salmon, steelhead, and bull trout. These impacts have affected the abundance, productivity, spatial structure, and diversity of Upper Columbia River (UCR) spring Chinook salmon, UCR steelhead trout, and UCR bull trout populations to such a degree that they were listed under the ESA. The UCR spring Chinook salmon was listed as endangered in 1999 (64 FR 14308). The UCR steelhead trout was listed as endangered in 1997; its status was upgraded to threatened in January 2006 and then it was reinstated to endangered in June 2007 (NOAA Fisheries Service 2007); this was in accordance with a U.S. District Court decision. Bull trout was listed as threatened in 1999 (USFWS 1998).

Recovery of the salmonid species to viable populations requires reducing or eliminating threats to the long-term persistence of fish populations, maintaining widely distributed and connected fish populations across diverse habitats within their native ranges, and preserving genetic diversity and life-history characteristics. Successful recovery of ESA-listed species means that populations have met certain measurable criteria (i.e., abundance, productivity, spatial structure, diversity), referred to as viable salmonid population (VSP) parameters (ICBTRT 2007; UCSRB 2007).

To achieve recovery, four sectors need to be addressed: harvest, hatchery, hydropower, and habitat (ICBTRT 2007; UCSRB 2007). The following biological guidance documents include recommendations for Nason Creek subwatershed and the Wenatchee subbasin on developing implementation frameworks, and types and prioritization of restoration activities needed to achieve recovery in these four sectors:

- Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs, Interior Columbia Basin Technical Recovery Team (ICTRT 2007)
- *Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan* (Upper Columbia Salmon Recovery Board (UCSRB) 2007); referred to as *Upper Columbia Recovery Plan* (UCSRB 2007) throughout this Nason Creek report
- *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region* (Draft) (Upper Columbia Regional Technical Team (UCRTT), 2007); referred to as Upper Columbia Biological Strategy (UCRTT 2007) throughout this Nason Creek report
- *Salmon, Steelhead and Bull Trout Habitat Limiting Factors (LFA), Water Resource Inventory Area* (WRIA) 45, Washington State Conservation Commission Final Report (Andonaegui 2001)
- *Nason Creek Watershed Analysis* (USFS 1996)
- *Wenatchee Watershed Planning Phase IV – Detailed Implementation Plan* (Wenatchee Watershed Planning Unit 2008)

Most biological guidance documents identify potential protection and restoration strategies that were based on available information and the professional judgment of a panel of scientists. Further technical investigation was necessary to refine protection and restoration strategies to the level of detail needed to implement projects, and to determine if the recommendations are sustainable and compatible with the geomorphic conditions in the river. In particular for Nason Creek, a stream channel migration study was recommended to assess the current channel confinement, the extent of the loss of channel migration and function, and the location of disconnected off-channel habitat (UCRTT 2007). It was also recommended to evaluate land-use impacts to understand the cumulative effects of timber harvest, development, and road densities on sediment delivery, large woody debris (LWD) levels, and stream channel function (UCRTT 2007).

1.2 Purpose and Scope

The purpose of this report is to describe technical results from a geomorphic assessment and to describe a strategy that resource managers can use to sequence and prioritize opportunities for protecting and restoring channel and floodplain connectivity and complexity in the assessment areas. The assessment covers RM 4.6 to RM 14.3, otherwise known as Coles Corner to the White Pine Railroad Bridge (Figure 3). This includes the Category 2 portion of the watershed below RM 15 that supports the second largest spring Chinook salmon spawning population (by redd count) in the Wenatchee subbasin, along with important steelhead and bull trout populations (Andonaegui 2001). Restoration opportunities have already been identified from RM 0 to 4.6 in a previous effort funded by Chelan County (Jones and Stokes 2004). Above RM 14.3 is land managed by the U.S. Forest Service (USFS) which is being assessed separately for restoration opportunities by the USFS. Additionally, at RM 16.8 (Gaynor Falls) on Nason Creek, there is a box canyon of bedrock falls and cascades that is a passage barrier to spring chinook and sockeye (USFS 1996). At RM 20.5 on Nason Creek (at Bygone Byways, approximately 0.5 mile above Mill Creek), there is a bedrock falls and cascades that are a barrier to steelhead, bull trout, and historically, coho (USFS 1996).

1.3 Authority

Reclamation established a Tributary Habitat Program to address tributary habitat improvement commitments for the Federal Columbia River Power System (FCRPS) Biological Opinions (BiOps). Objectives of the Tributary Habitat Program are to improve the survival of UCR salmon and steelhead listed under the ESA by ensuring fish screens meet current criteria, artificial fish passage barriers are replaced or removed to provide access to spawning and rearing areas, and instream flow and spawning and rearing habitat are improved in selected Columbia River tributary subbasins, including Nason Creek in the Wenatchee subbasin. Working closely with local partners and willing private landowners, Reclamation provides engineering and related technical assistance to meet mutual tributary habitat improvement objectives. Reclamation conducts the Tributary Habitat Program under authorities contained in the ESA, Fish and Wildlife Coordination Act, and Fish and Wildlife Act as delegated from the Secretary of the Interior in Secretarial Order No. 3274 dated September 11, 2007.

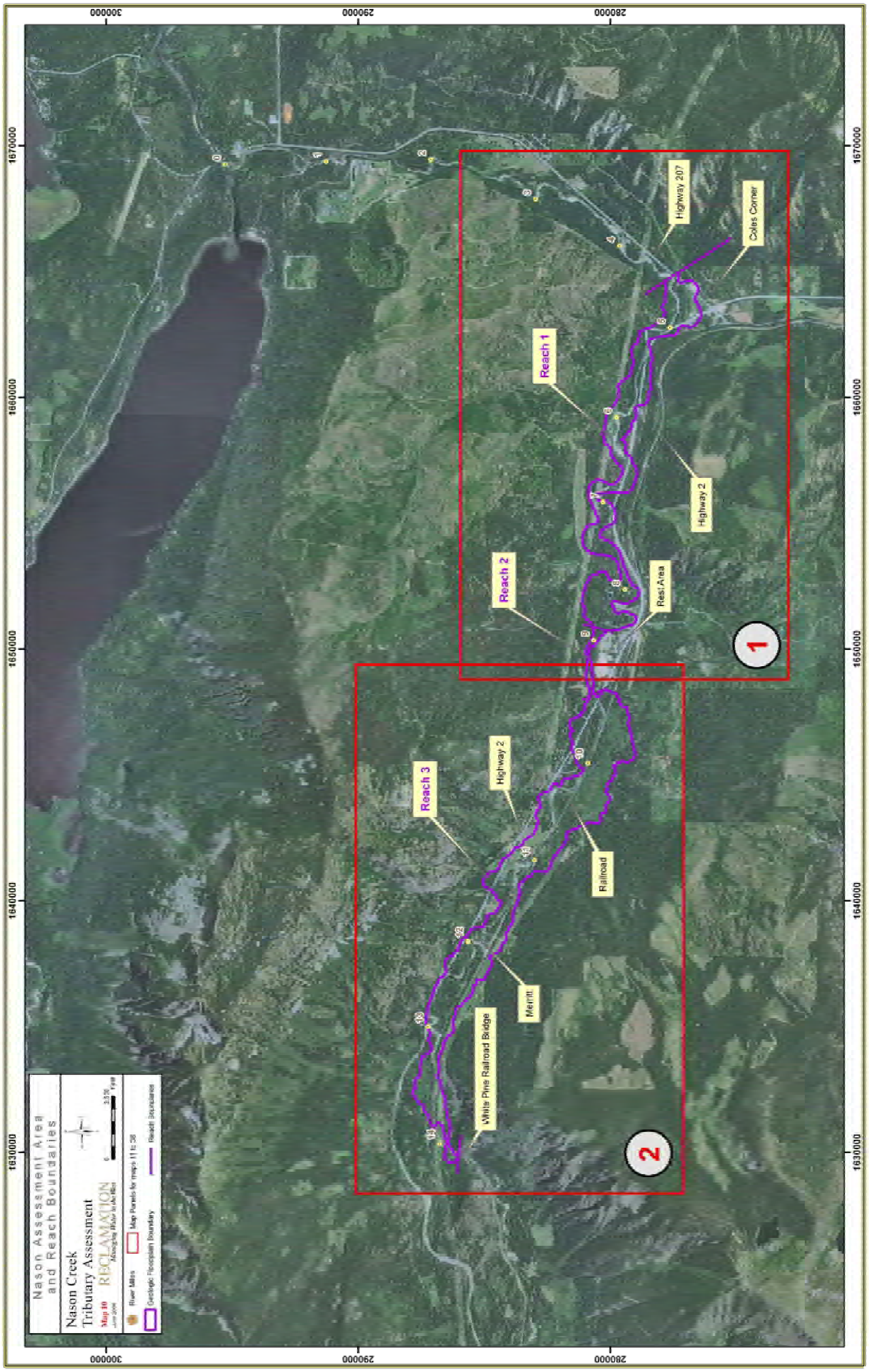


Figure 3. Location map for 10-mile assessment area, geomorphic reach breaks, and boundaries for map panels in atlas.

1.4 Federal Columbia River Power System Biological Opinion

BiOps on the operation and maintenance of the FCRPS issued by National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries Service) include measures to improve tributary habitat for salmon and steelhead listed under the ESA. The BiOps are addressed by the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers, and Reclamation, collectively referred to as the “Action Agencies.” These measures are addressed by the Action Agencies and consistent with subbasin plans developed through the Northwest Planning and Conservation Council (NPCC) and State recovery plans approved by NOAA Fisheries Service.

Reclamation commitments to tributary habitat improvement for the FCRPS BiOp (NOAA Fisheries 2008) began in 2000, and Reclamation has operated in nine Interior Columbia River tributary subbasins with over 50 ongoing project activities in various stages of development, implementation, or completion at any one time. This report was prepared to help identify, prioritize, and implement habitat projects that will meet FCRPS BiOp tributary habitat commitments in the Nason Creek subwatershed. The approach applied in this tributary assessment also provides a planning tool that can be used collectively by all partners to focus their resources in a systematic and scientifically reproducible way to identify and prioritize floodplain connectivity and channel complexity restoration/protection projects.

The tributary reach-based approach is a mechanism that can improve the delivery of services and products within schedule and budget parameters identified by partners and for Reclamation. This approach also provides a method that will help Reclamation managers anticipate upcoming workloads, assign people and allocate funding for that workload, and keep partners informed on the extent of available Reclamation resources for their near- and long-term planning purposes.

1.5 Report Methodology

Work described in this report was accomplished by a multidisciplinary team from Reclamation consisting of expertise in hydraulic and sedimentation engineering, geology and geomorphology, and vegetation. To incorporate local fisheries expertise on the team, technical services were provided through a contract with the USFS.

The scope, analyses, and protection and restoration strategies described in this tributary assessment were created in conjunction with those developed in the biological guidance documents. Variations in channel and floodplain processes were used to delineate and evaluate potential project areas in the assessment areas where habitat for focal fish species might be protected, enhanced, or restored. Prioritization of reaches were made based on the current habitat quality, potential habitat improvements, and how well proposed restoration actions meet established habitat objectives from recovery plan documents (see Section 1.1). At key milestones in this geomorphic assessment, presentations of completed and ongoing work were made to local Reclamation partners so they could provide input to this process.

The information from this assessment report also provides a current description of river processes operating within the assessment area, so that subsequent, more detailed assessments for smaller river sections can build upon and refine this information to successfully implement proposed actions. Restoration projects implemented with a clear understanding of the associated physical processes have a greater potential for sustainable short- and long-term habitat benefits for spring Chinook and steelhead.

Key steps to produce this report and the accompanying map atlas were to:

- Identify the recurrence intervals of natural and human-induced disturbances and how they affect understanding of and impose controls on channel processes and planform within the assessment area.
- Identify the habitat-forming physical processes and disturbance regimes working at the subbasin and reach scales from both historical and contemporary context.
- Delineate and characterize channel reaches on the basis of their geomorphic characteristics and biological opportunities and develop potential restoration strategies organized by a reach-based approach.
- Identify a technical sequencing of the reaches that can be used to prioritize the potential habitat protection and restoration areas within the assessment area based on linkage to primary limiting factors for salmon recovery.

For this assessment, methods included a mixture of quantitative and qualitative analyses to provide an acceptable level of certainty consistent with assessment objectives. Quantitative methods provide more certainty to results than qualitative methods, but cannot be used in all areas because they are more costly and time consuming to employ. Qualitative methods are faster and less costly, but can be difficult to repeat in a scientific manner and have less certainty. The approach taken was to meld multiple independent analysis tools that could be applied and compared to determine conclusions regarding channel processes within the scope described in this report. Quantitative data were collected to characterize and compare reach-level trends within the assessment areas. Refinement of this information with additional quantitative data and analysis can then occur at a smaller scale of the channel reach selected by stakeholders and project partners in which to implement restoration actions.

1.6 Report Organization and Products

Section 2 of this report summarizes the approach applied in conducting this assessment and describes the general direction of future assessments at refined spatial scales. This section also discusses linkages to monitoring and adaptive management. Section 3 describes the boundaries of the three reaches analyzed in this assessment and key terminology used throughout the report. Section 4 describes a biological overview of fish usage in the subwatershed and specific to the assessment area based on existing information and knowledge by local biologists. Section 5 presents an investigation of historical changes to geomorphic conditions based on changes in the flow regime, sediment regime, and topography of the channel and floodplain. In Section 6, existing geomorphic conditions relevant to restoration and protection actions are summarized by reach. Based on findings from the geomorphic assessment and biological guidance documents, a protection and restoration strategy is presented in Section 7. This section includes a prioritization tool of these reaches in terms of the potential to restore habitat. Section 8 presents a summary of the major conclusions of the assessment.

In addition to this report, existing and new information were synthesized into a ArcGIS database so that the information could be viewed spatially and readily transferred to design engineers, cooperators, and stakeholders. All ArcGIS data is presented in Washington State Plane North coordinate system, NAD 1983 and NAVD 1988 (feet). Detailed methods of the work described are typically contained in the appendices for this report. An atlas consisting of a series of maps showing the spatial relationships of the data compiled for this assessment accompanies this report. Additional supporting data such as ground topography, spreadsheet files, ground photographs, literature obtained, aerial photography and maps are also available upon request. A CD is located at the back of this report that contains the electronic versions of the main report, appendices, and map atlas.

2. Linkage To Implementation and Monitoring

The scope of this assessment originated in September 2005, based on input from local stakeholders and documents that provided both technical guidance on recovery strategies and legal authority to accomplish this work. The approach taken in the assessment, in particular the identification and preliminary prioritization of protection and restoration opportunities, evolved to incorporate new information as it became available. This report documents one stage of the tributary reach-based approach, a scaled assessment approach being utilized by Reclamation. The entire approach is described in Reclamation (2008) and summarized in Section 2.1, to provide the reader background of how this report fits in with the larger process.

2.1 Tributary Reach-based Approach

A tributary reach-based approach developed from discussions among participating scientists, managers, and local recovery planners who recognized a process-based geomorphic assessment would align well with the objectives and guidance expressed in NPCC subbasin plans and recent recovery planning documents. A tributary reach-based approach includes the following stages:

- A "tributary assessment" of a valley segment is made at a relatively coarse scale. A tributary assessment focuses on a large length of river, in this case 10 miles of Nason Creek. The purpose of the tributary assessment is to identify major geologic and hydraulic processes active within the valley segment, explore whether geomorphic and hydraulic conditions upstream and downstream from the valley segment affect conditions within the segment, and identify "geomorphic reaches" within the segment that share common geologic and hydraulic physical attributes.
- Near the conclusion of the tributary assessment, stakeholders review the results and include relevant social, political, and biological information, and prioritize which of the geomorphic reaches identified from the assessment possesses the greatest potential to implement projects that will obtain successful, sustainable, biological benefits and warrant a more detailed "reach assessment." A few project locations and concepts may be identified at this stage that will not require a reach assessment, particularly when the processes associated with the project are fairly localized and isolated.
- A "reach assessment" focuses on an individual reach identified in a tributary assessment, which is preferably less than 10 miles in length. The purpose of the reach assessment is to further refine understanding of the predominant processes that affect the reach, to establish a baseline of environmental habitat conditions, and

to provide technical recommendation of sequenced habitat actions. Analysis obtained previously from the tributary assessment provides information on upstream and downstream geomorphic and hydraulic conditions that could affect those physical conditions within the assessed reach. A reach assessment identifies project areas that are based on factors impacting channel processes and establishes a baseline of environmental habitat conditions using a modified "Matrix of Diagnostics/Pathways and Indicators" (MPI) (NOAA 1996). The modified MPI at a more detailed scale is referred to as a reach-based ecosystem indicator tool (REI) and is described in the reach assessment report, being produced as a separate document.

- At the conclusion of a reach assessment stakeholders review results; include more detailed social, political, and biological information; and prioritize project areas and specific projects with the greatest potential to obtain successful and sustainable biological benefits. After projects are identified and prioritized, partners typically take the next steps to design and implement alternatives, including landowner discussions, and secure funding for construction.

The tributary reach-based approach described above is used to identify potential habitat protection and restoration opportunities. The purpose of nesting reach assessments within a tributary assessment is to ensure the appropriate geomorphic and hydraulic information is obtained at the appropriate scale and timeframe for answering relevant questions or problems being investigated. In turn, this supports a collaborative decision process to seek ways to prioritize funding and resources as effectively as possible. The decision process further allows partners to systematically identify and prioritize areas with the greatest potential to implement protection or restoration projects that obtain successful and sustainable biological benefits, postpone investment in areas with less potential, and avoid investing in areas with little potential. This is a flexible approach and can be modified to accommodate smaller areas or the availability of pre-existing information. The approach may not be needed at all when partners conclude that biological benefits of protection or restoration projects are already clearly defined.

Use of the tributary reach-based approach could contribute to obtaining funds for project implementation. Funding proposals that conform to a systematic scientifically-based approach that identifies and prioritizes channel-complexity and floodplain-reconnection protection and restoration projects potentially could be more open to consideration for grants from entities that require sound justification for the proposals they choose to fund.

2.2 Potential for Linking the Tributary Reach-based Approach with Monitoring and Adaptive Management

Tributary habitat actions demand a strong understanding of the regional and watershed context. Three ultimate controlling factors at these coarser levels – physiography (geology and topography), vegetation, and climate – play an important role in assessing and identifying tributary habitat actions. These factors and their influences on rivers are essential in further understanding the effects of human disturbances on physical processes at the local level. When physical processes and their controlling factors are well understood and considered, habitat restoration has greater potential for success.

Monitoring efforts serve as a foundation for scientists, managers, and stakeholders to refine and improve upon future management decisions, restoration activities, and practices. Monitoring provides feedback on how individual projects are performing immediately after construction and over time by helping determine what changes occur after project implementation as compared to baseline conditions before initiating project implementation. Given that most habitat restoration occurs at the site and reach scale (Fausch et al. 2002; Montgomery and Bolton 2003), implementation and monitoring strategies need to be geared accordingly within an adaptive management framework.

Within the Interior Columbia Basin, Upper Columbia subbasins are developing strategies for monitoring and adaptive management which could be transferred as a model for monitoring efforts in other subbasins. Many different organizations including Federal, State, Tribal, local, and private entities implement tributary actions and have drafted integrated monitoring strategies intended to assess the effectiveness of restoration projects and management actions on tributary habitat and fish populations (Hillman 2006). Because of a multitude of ongoing activities in the Interior Columbia Basin, the Monitoring Strategy for the Upper Columbia Basin (Hillman 2006) includes recommendations for a monitoring plan that captures the needs of all entities, avoids duplication of sampling efforts, increases monitoring efficiency, and reduces overall monitoring costs.

The plan described in the Monitoring Strategy (Hillman 2006) is aimed at answering the following basic questions:

- Status monitoring—What are the current habitat conditions and abundance, distribution, life-stage survival, and age-composition of fish?
- Trend monitoring—How do these factors change over time?
- Effectiveness monitoring—What effects do tributary habitat actions have on fish populations and habitat conditions?

In the Upper Columbia Biological Strategy (UCRTT 2007), further guidance is provided on implementing monitoring activities specific to habitat restoration actions. Monitoring strategies are generally described in three categories:

- Implementation monitoring.
- Level 1 effectiveness monitoring.
- Level 2 and 3 effectiveness monitoring.

Implementation monitoring provides proof that the action was carried out as planned. Level 1 (extensive methods) is the next step up from implementation monitoring; it involves fast and easy methods that can be completed at multiple sites. Level 2 and 3 (intensive methods) includes additional methods beyond Level 1 that increase accuracy and precision but require more sampling time (Hillman 2006).

Information presented in this tributary assessment is intended to complement the monitoring protocols described above by providing historical and contemporary information on channel and floodplain functions. Subsequent reach assessments will provide a finer resolution diagnostic investigation on present biological use and habitat conditions, which are integrated with an understanding of local physical processes. Reclamation, their partners, and project sponsors will be conducting implementation monitoring to document restoration actions accomplished in the Nason Creek subwatershed. This information provides for near-term future assessment and monitoring efforts which can be used by entities working on status, trend, and effectiveness monitoring plans to test whether the river and habitat function responded as anticipated to implemented projects. Additionally, each restoration project implemented will have documented predictions based on hypotheses as to how processes and complexity are to improve (restore) as an outcome of the project(s).

This kind of overall framework is consistent with an “adaptive management framework” as described in *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance* (NOAA Fisheries 2007). Organizing implementation, monitoring, and adaptive management at a reach scale provides a “building block” structure that could be explored for meeting FCRPS BiOp and recovery goals at the population, major population group (MPG), evolutionary significant unit (ESU), and discrete population segment (DPS) levels. Project implementation and monitoring proposals that conform to a framework able to connect project implementation with monitoring and adaptive management could potentially also be more open to consideration for grants from entities that require sound scientific justification for the proposals they choose to fund.

3. GEOMORPHIC REACH DELINEATION

The Nason Creek assessment area is approximately 10 river miles beginning at Coles Corner (RM 4.5) and extending upstream to White Pine Railroad Bridge (RM 14.3). Three geomorphic reaches were identified within the 10-mile area on the basis of physical characteristics that dominate channel function and the formation and sustainability of habitat features (Table 1; map 10 in atlas). Examples of physical characteristics include lateral and vertical geologic controls, channel and valley slope, water, sediment, and LWD input and transport capacity, and topographic features. Examples of habitat characteristics include the availability of off-channel habitat, potential for LWD recruitment and pool formation, and abundance of spawning areas. Geomorphic processes and habitat conditions of the river are further evaluated for historical and present conditions in Chapters 4 through 6. The remainder of this chapter briefly describes methods for delineating the geomorphic reaches and typical geomorphic terms used in this report.

Table 2. List of geomorphic reaches for assessment area.

Reach	River Miles	Landmarks
1	4.6 to 8.9	Coles Corner to Rest Area
2	8.9 to 9.4	Rest area
3	9.4 to 14.3	Rest Area to White Pine Railroad Bridge; Merritt near RM 12

The longitudinal boundaries of the reaches (upstream and downstream ends) are located at natural constriction points, such as bedrock and large geologic deposits that provide lateral, and often vertical, limits to channel change. In bedrock-controlled areas, the channel must always pass through the constriction point such that channel position (or change in position) in one reach would not necessarily impact channel position in the adjacent reaches. However, other processes are not constricted at these points. Water, sediment, and LWD that are accumulated in one reach are typically transported to downstream reaches, although the timing will vary depending on the transport capacity of each reach. Where a boundary is located at a geologic deposit, channel position can translate from one reach to the next, but there is still a unique influence on physical properties at the boundary.

In this assessment, the lateral boundary of each geomorphic reach is defined by the cumulative extent of the historical channel migration zone (HCMZ) and overbank floodplain area. The HCMZ is composed of the active channel (main channel and unvegetated, frequently reworked sediment bars), side channels, wetlands, and vegetated islands within these areas. The HCMZ boundary can expand or contract over time where the river erodes the bounding banks or forms new terraces. The adjacent floodplain includes surfaces that are overtopped during floods and may include channels less-frequently inundated (referred to as “overflow” channels). The frequency at which the overbank surfaces are overtopped varies by geomorphic reach, but typically begins to occur between a 2- and 5-year flood. The floodplain boundary can also change over time due to erosion along the boundary. Reaches 1 and 3 have relatively wide HCMZ and floodplain areas. Reach 2 is naturally confined with limited to no off-channel and floodplain areas that can be distinguished from the active channel.

Within the report and mapping both the geologic and impacted floodplain and HCMZ boundaries are referred to for each geomorphic reach (see maps 23 and 26 in atlas). The geologic boundaries represent what is inferred as the historical condition in the late 1800s prior to the construction of the majority of human features in the valley such as the railroad, highway, areas with artificial fill, power lines, etc. This was determined based on field observations, historical maps and aerial photography, hydraulic model results, light distance and ranging (LiDAR) data, and local anecdotal accounts (see appendices H – Hydraulics and J – Geomorphic Map Methods and GIS Metadata).

The impacted condition represents the current boundary that results from large human-made embankments that block access to the geologic HCMZ and floodplain. Features used to draw the impacted boundary are the railroad, highway, and large levees that run adjacent to the river for more than a few channel widths. Small levees, roads, power line poles, houses, and other features that impact floodplain and off-channel processes to a lesser, more localized extent were noted, but were not used to draw the impacted boundaries. An example would be a small levee at the downstream end of a side channel that blocks water flow into and out of the side channel, but does not prevent lateral overbank flooding upstream and downstream of the feature.

4. BIOLOGICAL OVERVIEW FOR NASON

This section describes historical and existing biological use within the assessment area to document habitat processes that are and are not functioning adequately to contribute to the viability of ESA-listed populations of salmon and trout in the Wenatchee subbasin.

Currently there are three independent populations of spring Chinook salmon within the Upper Columbia Evolutionarily Significant Unit (Wenatchee, Entiat, and Methow) and five steelhead populations (Wenatchee, Entiat, Methow, Okanogan, and Crab Creek) within the Upper Columbia steelhead DPS. There are three "core" areas supporting bull trout populations (Wenatchee, Entiat, and Methow subbasins). The *Upper Columbia Recovery Plan* (UCSRB 2007) emphasizes recovery of all three listed species in the Wenatchee subbasin" (UCSRB 2007).

Status of listed populations in the *Upper Columbia Recovery Plan (2007)*, based on a variety of regulatory requirements and scientific sources, are described in terms of four viability parameters:

1. Abundance- effective population size large enough to survive disturbances observed in the past and expected in the future
2. Productivity- populations support at least 1:1 replacement ratio of spawner/returning adult
3. Spatial Structure- populations within a subbasin have widespread and complex spatial structures of naturally produced fish using major and minor spawning areas throughout the basin
4. Diversity- populations maintain phenotypic (physical traits, behavior, and life history traits) and genetic within population diversity.

Substantial anthropogenic modifications have occurred within the Nason Creek floodplain including transportation corridors (railroad and state highway), utility corridors (transmission and power lines), and private land development that affect current habitat condition (UCRTT 2003); a complete historical timeline is displayed in Appendix B. Extensive habitat field surveys suggest that human activities and historical land management activities in the Nason Creek floodplain have not only impacted current habitat conditions, but habitat resiliency to disturbance as well (USFS 1996).

The *Wenatchee Watershed Management Plan* (2006) and *Detailed Implementation Plan* (Wenatchee Watershed Planning Unit 2008) outline a watershed restoration program that is tiered to the actions in the *Upper Columbia Recovery Plan* (UCSRB 2007). The overriding goal for Nason Creek is to maintain and restore ecosystem functions and connectivity to sustain life history patterns and dispersal among salmonid populations in the upper Wenatchee subbasin (Andonaegui 2001).

The lower four miles of Nason Creek has already been assessed for restoration opportunities (Jones and Stokes 2003 and 2004). Chelan County Natural Resource Department (CCNRD), acting as the lead agency for Salmon Recovery Projects in the Wenatchee subbasin, is implementing up to three off-channel/floodplain reconnection projects between RM 0 and RM 4 based on the results of this work. Above RM 14 in mostly USFS managed lands, restoration planning at the Nason 5th field watershed scale is currently being drafted into a Watershed Action Plan. USFS is drafting the plan in cooperation with and to complement ongoing restoration efforts with WRIA 45 Habitat Subcommittee and Reclamation (Raekes 2008).

4.1 Historical Occurrence/Abundance of ESA Fish Species in the Nason Watershed

In Mullan et al. (1992), a number of affidavits obtained from long-time residents of Chelan County are documented regarding the extent, times, and locations of salmon runs, and the locations of spawning grounds with respect to the Wenatchee, Okanogan, and Methow Rivers:

> *"I, J.A. Adams, do herby certify that in the years previous the Lumber Company Dam at Leavenworth, which was built in 1904 and 1905, the salmon came up the Wenatchee River in very large numbers. Silvers, Chinooks, and Steelhead all came up about the same time, beginning about the first of September and continuing into November before they were all gone. All the creeks had their runs of Silvers and Steelheads. Nason was especially attractive to Silvers and Steelhead. Very few salmon however, were found in the Icicle Creek. As soon as the Leavenworth Dam was built, the salmon runs began to weaken and by the time the Dryden Dam was put into operation in 1908 the runs were practically at an end. The spring run was not considered of any importance and the Indians never came up in the spring but about September they came in large numbers and caught and dried all the salmon they needed for the winter supply."* (Page J-384 in Mullan et al. 1992).

Also from Mullen et al. (1992):

- Mean wild spring Chinook return to the Wenatchee during 1967-1987 was 4,465
- Historical steelhead return estimate of 7,300 to Wenatchee. Bryant and Parkhurst (1950) identified Nason Creek as the leading steelhead tributary in the Wenatchee subbasin (page H-286).
- Coho salmon return estimate of 3,900.

However, there is no historical estimate for bull trout; all life history forms (resident, fluvial, adfluvial) are believed to have occurred in the Wenatchee subbasin historically (UCSRB 2007).

4.2 Spatial Distribution of Present Fish Use

Spring Chinook, summer Chinook, steelhead/rainbow, sockeye, and bull trout are all present in the Wenatchee subbasin (see map 1 in atlas). Once in the Wenatchee subbasin, there are no barriers to fish passage on the mainstem Wenatchee River. Dryden Dam is located at RM 17 and Tumwater Dam at RM 31 on the mainstem Wenatchee, but both are documented to accommodate fish passage (Andonagui 2001). In 1905, a lumber mill dam (constructed by Lamb-Davis, LLC) was built at the downstream end of the city of Leavenworth, near RM 23. This dam may have impeded fish passage, but was removed in the 1930s and only the old foundation remains in the river (see Appendix B – Historical Timeline).

Along the mainstem of Nason Creek, there are no natural or artificial physical barriers to fish migration until RM 16.8 (Gaynor Falls) where there is a box canyon of bedrock falls and cascades that is a passage barrier to spring chinook and sockeye (USFS 1996). At RM 20.5 on Nason Creek (at Bygone Byways, approximately 0.5 mile above Mill Creek), there is a bedrock falls and cascades that are a barrier to steelhead, bull trout, and historically, coho (USFS 1996).

Significant Nason tributaries historically thought to be utilized by spring Chinook and sockeye include Kahler Creek at RM 6.1, Roaring Creek at RM 10 (and Coulter Creek, a tributary to Roaring Creek), Gill Creek at RM 10.7, and White Pine Creek at RM 15. Bull trout and steelhead also utilized these tributaries and Mill Creek near RM 20. Table 3 describes which channels are utilized for the various species and life stages. Coho is potentially being reintroduced to the Nason subwatershed but current usage is not known at this time. Additional information on artificial and natural barriers within these drainages is presented in Chapter 5.

Table 3. Current know salmon, steelhead, and bull trout use in the Nason Creek mainstem and tributary channels based on a limiting factors analysis completed by Andonaegui (2001).

Nason Creek Watershed	Spring Chinook			Summer Chinook			Steelhead/ Rainbow			Sockeye			Bull Trout		
	Spawning	Rearing	Migration	Spawning	Rearing	Migration	Spawning	Rearing	Migration	Spawning	Rearing	Migration	Spawning	Rearing	Migration
Nason Creek	X	X	X				X	X	X	X	X	X	X	X	X
Kahler Creek							X	X	X						
Roaring Creek							X	X	X						
Coulter Creek							X	X							
Gill Creek							X	X							
Whitepine Creek							X	X	X						
Mill Creek													X	X	

4.3 General Timing of Fish Use in Nason Creek by Species and Life Stage

Table 4 displays the general timing of different life stages of federally listed spring Chinook, steelhead, and bull trout in Nason watershed (Wenatchee Watershed Management Plan 2006, Appendix A) based on field studies and reports by USFS, Washington Department of Fish and Wildlife (WDFW), U.S. Fish and Wildlife Service (USFWS), Chelan Public Utility District (PUD), and NOAA Fisheries Service.

Table 4. Life history timing of steelhead, spring Chinook, and bull trout in Nason Creek.

Species **Life Stage**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Steelhead												
Spawning												
Incubation												
Rearing												
In-migration												
Spring Chinook												
Spawning												
Incubation												
Rearing												
In-migration												
Bull Trout												
Spawning												
Incubation												
Rearing												
In-migration												

Key for Table 3:

Black	Indicates periods of heaviest use
Grey	Indicates periods of moderate use
Blank areas	Indicate periods of little or no use

4.4 Biological Overview by Geomorphic Reach

Each of the three geomorphic reaches identified are Designated Critical Habitat for steelhead and spring Chinook and Essential Fish Habitat for Chinook and coho salmon. A variety of life stages for each of the ESA-listed species is dependent on Nason Creek to contribute to physical and biological connectivity within the Wenatchee subbasin, the Upper Columbia spring Chinook and steelhead ESUs, and the Columbia River DPS for bull trout. McIntosh et al. (1994) implied that the stability of anadromous fish runs in the Wenatchee River subbasin is tied to an abundance of high quality fish habitat, particularly a “wealth of intact headwater and floodplain areas.” To maintain the productivity of the Wenatchee River subbasin, the authors concluded that these features of the landscape must be maintained (McIntosh et al. 1994).

This section summarizes existing habitat conditions segregated by protection and restoration needs. The primary limiting factor to habitat in the assessment area is that large sections of historical channel and floodplain have been disconnected from the present channel by several human activities, primarily transportation and utility corridors. The present-day confined channel has increased flow and energy in the main channel and, as a result, the ability to create and maintain complex habitat that supports spawning and juvenile rearing is reduced. Constricted channel sections also reduce the availability of off-channel and backwater areas utilized for rearing, over-wintering, and high-flow refuge. High quality (functioning) habitat currently exists at RM 9.2-9.3, RM 11.1-11.4, and RM 12.8-13.3.

4.4.1 Habitat in Reach 1: Coles Corner to Rest Area (RM 4.6 to RM 8.9)

This 4.3-mile reach is low gradient (less than 1 percent) and comprised mainly of riffles and runs. U.S. Highway 2 parallels the right bank of the creek throughout this reach and reduces channel sinuosity. Very little side channel and off-channel habitat exist in this reach due to the highway, riprap placement to protect houses in the floodplain, and power line corridors. Instream large wood and quality pools (deep with hiding cover) are limited in this reach due in part to increased stream energy from channelization and fragmented or decoupled wood delivery processes from upstream wood delivery sources. Long-term wood recruitment is favorable despite the highway, houses, and power lines, as the immediate riparian area is often well forested with second-growth conifers and cottonwoods; this should be a protection emphasis in this reach.

Stream bottom substrates in the lower mile of this reach are generally too coarse for spawning gravel; however, the upper half mile of the reach is lower gradient and consists of gravel dominated with good spawning habitat. Pockets of good spawning habitat occur throughout the remainder of the reach. Rearing habitat is limited in this reach due to the lack of off-channel habitat, lack of side channels, and lack of fish hiding cover (wood, undercut banks, overhead cover). Boulders that are present in some areas of the reach and riprap that is protecting U.S. Highway 2 provide some hiding cover for rearing fish.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning, rearing, and migration
- Steelhead spawning, rearing, and migration
- Bull trout migration and foraging
- Coho spawning, rearing, and migration (estimated)

4.4.2 Habitat in Reach 2: Rest Area (RM 8.9 to RM 9.4)

This 0.5-mile stream segment is relatively straight, low gradient (less than 1 percent) and entrenched in glacial outwash deposits that form several terraces. Pool and riffle habitat is nearly equally split and there is no side channel habitat. The number of pools may be near natural levels in this reach.

Large instream wood is very scarce in this reach, likely due to the confined channel type that transports wood to downstream reaches rather than retains it. The long-term recruitment potential for large wood (to be delivered downstream as natural channel conditions are not favorable for retaining wood) is fair to good, with conifers found above both banks. Riparian protection should be an emphasis in this reach.

A bedrock constriction splits this reach at the mid-point; above this constriction the stream bottom is gravel dominated and pools are up to 450 feet long and 4.5 feet deep, contributing to very good spawning habitat. Juvenile rearing habitat is naturally limited due to the confined/transport nature of this reach where few off-channel and floodplain areas develop. Some rearing habitat is available among the larger boulder substrate in the lower half of the reach.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning, rearing, and migration
- Steelhead spawning, rearing, and migration
- Bull trout migration and foraging
- Coho spawning, rearing, and migration

4.4.3 Habitat in Reach 3: Rest Area to White Pine Railroad Bridge (RM 9.4 to RM 14.3)

The stream type in this reach is predominantly low gradient, moderately sinuous, and comprised mainly of pools with the exception of the last 0.9-mile segment of this reach (RM 13.4 to 14.3). This segment of the reach was rerouted and channelized during construction of the railroad beginning in the late 1800s resulting in a straight stream confined by the railroad bed on the right bank and riprap to protect power lines on the left bank. Both banks of Nason Creek in this area are isolated from its floodplain, instream large wood and long-term recruitment potential are low, pool quality is poor, juvenile rearing habitat is limited, and there is very little spawning habitat. Reconnection is a priority in this 0.9-mile long segment (RM 13.4-14.3).

Deep pools and spawning gravels are present in the remainder of the reach despite floodplain impacts from U.S. Highway 2 on the left bank, the railroad grade on the right bank, and the BPA power line corridor. In general, pools lack complexity but where large wood accumulates, deeper complex pool habitat forms. Pools greater than five feet deep were common at wood accumulations and spring Chinook redds were often found in pool crests of deep pools or riffles with wood accumulations. Long-term wood recruitment is poor due to transmission line vegetation maintenance in some cases, and in most cases due to fragmented or decoupled wood delivery processes from the floodplain and hillslope delivery. Juvenile rearing habitat is poor due to the lack of overhead (riparian vegetation) and instream cover (uniform stream bottom, lack of wood) in the current confined channel. Reconnection to the floodplain and historical channels is a restoration priority in this reach to restore processes that form and maintain channel complexity essential to spawning and juvenile rearing.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning, rearing, and migration
- Steelhead spawning, rearing, and migration
- Bull trout migration and foraging
- Coho spawning, rearing, and migration

4.5 Limiting Factors of Present Habitat Conditions

The existing habitat in Nason Creek has been degraded by several human activities, including highway and railroad construction through most of the floodplain in the assessment area. The Burlington Northern Railroad was completed across Stevens Pass in the 1890s, U.S. Highway 2 was completed in the 1920’s, and Highway 207 improvement occurred in 1943. In combination, these travel corridors have rerouted the channel in some locations, constricted the floodplain, cut off meanders, accelerated flows, and altered sediment routing. Power line placement and maintenance also has contributed to channel degradation. Logging and roading, on both private and public land, increased dramatically between 1967 and 1992 (USFS 1996). High road densities occur in the lower Nason Creek subwatershed (assessment area), as well as portions of the Gill, Roaring, and Coulter Creek tributaries (USFS 1996).

Although Nason Creek is morphologically and ecologically at risk due to human activities, it has not deteriorated past the point where restoration can be valuable and cost-effective. The presence of bull trout, steelhead and spring Chinook populations indicate that at least patches of adequate habitat exist and that, as habitat and water quality are restored, fish stocks exist to rebuild native aquatic communities (USFS 1996).

The following categories of habitat recovery actions to address limiting factors in Nason Creek (UCSRB 2007, page 206) relevant to the Nason Creek assessment area are:

- Re-establish connectivity throughout the assessment unit by removing or controlled breaching of artificial barriers.
- Increase habitat diversity and natural channel stability by increasing in-channel large wood complexes, restoring riparian habitat, and reconnecting side channels, wetlands, and floodplains to the stream.
- Reduce high water temperatures by reconnecting side channels and the floodplain and improving riparian habitat conditions.

4.5.1 Connectivity

Constructed human features were inventoried throughout the assessment area in addition to historical and present channel lengths (see Chapter 5). An estimated 1.5 miles of channel length has been reduced in the present active channel from Coles Corner to White Pine Creek. Human features, primarily railroad and road embankments, disconnect the current artificially-straightened channel from many historical channels. The largest impacts to channel and floodplain connectivity occur between RM 9.4 to 14.3.

The juvenile life history for all the ESA-listed fish in this assessment area is at the greatest risk for reduced abundance as passage into oxbows, wetlands, side channels, and other key habitat has been significantly reduced by isolation of these habitats from mainstem Nason Creek by constructed human features.

Re-establishing connection with historical channels and the Nason Creek floodplain is the primary restoration action to undertake as all other limiting habitat factors (temperature, water quality, habitat diversity) would benefit from improved channel and floodplain interaction. Channel migration across and within a floodplain is an important process for

LWD input. Migration also helps develop side channels, pools, and backwater areas, and wetland formation as channels are abandoned during the migration process. Through migration processes, riparian areas are both eroded from river banks and established on new bars and floodplain surfaces which help provide temperature regulation through shading.

4.5.2 Habitat Diversity

The disconnection of mainstem Nason Creek from its historical channels in the floodplain affects the quality and quantity of instream habitat and the ability to recruit and maintain quality habitat through a range of hydrologic conditions in normal seasons and also in extreme events.

A time series of instream habitat surveys (1989, 1991, and 1996) were conducted on Nason Creek by the USFS between the 1990 and 1996 historical flood events, estimated to be in the 200-to 500-year return interval. Surveyors in 1996 concluded that LWD abundance and percent pool area are strikingly correlated in Nason Creek and although LWD is normally an important pool-forming agent, it appears to be much more important in Nason Creek because of the reduced stream sinuosity (USFS 1996). The current channel cannot maintain or recruit LWD effectively due to the artificially straightened channel that flushes wood out of the system during flood events, the reduced interaction with the streambank (riprap, embankments, etc.) to recruit LWD, and the reduced riparian vegetation cover from floodplain disturbance throughout the assessment area.

Restoring channel function and floodplain/riparian processes is critical to restoring and maintaining habitat diversity in Nason Creek. In the long term, reconnection would increase habitat diversity through flood energy diffusion, recruitment and retention of LWD, increased channel length (sinuosity for pool formation), off-channel refugia, and stream channel resiliency to extreme flood events. LWD enhancement may be more effective once channel reconnection occurs.

4.5.3 Temperature

Periods of high water temperature are a concern for salmonid survival in Nason Creek and the Washington Department of Ecology lists Nason Creek waters as impaired (Cristea and Pelletier 2005). A Temperature Maximum Daily Load (TMDL) assessment was conducted on the Wenatchee River and tributaries in 2002 and 2003 (http://www.ecy.wa.gov/biblio/0503011.html). Temperature probes were placed throughout Nason Creek and data collected from those probes found that temperatures in Nason Creek during summer months exceed 303(d) criteria in the middle and lower Nason Creek reaches (see Appendix F – Water Quality Synopsis). The extent of exceedance varies depending on the climate and flow conditions for a given year, but generally occurs between July to September.

Potential causes of temperature increases are likely synergistic, as stream channel morphology and connectivity with floodplain and riparian ecosystems affect the temperature regime. Nason Creek loses valuable cool water inputs from valley wall springs and tributaries, hyporheic zones, and groundwater storage as a result of being disconnected from its floodplain. Channel decoupling from riparian and floodplain areas also affects the maintenance of streambed and streambank stability, riparian vegetation, and instream habitat features.

Protection of floodplain and restoration of channel processes across the floodplain are expected to reduce and regulate instream temperatures to benefit spawning, migrating, and rearing salmonids and bull trout.

5. Historical Changes To Geomorphic Conditions

The geomorphic analysis focuses on physical river processes that create and sustain habitat features important to spring Chinook, steelhead, and bull trout (see Chapter 4). Of particular focus are understanding changes in the three key elements of flow regime, sediment regime, and topography (including riparian vegetation) that dominate river morphology and channel processes. Disturbance to any of the three main elements can alter the form of the river and associated channel processes, which in turn can impact the availability of and the potential to restore salmonid habitat.

Evaluation of historical trends provides an understanding of how changes in river processes relate to geologic controls, historical floods and human activities, and whether the changes can be anticipated to continue in the future. A comparison of this knowledge to the present river setting helps determine which processes may not be functioning at their fullest potential today. Trends were evaluated from the late 1800s through the present day because this time period represents when the majority of detectable human impacts to the three key elements have occurred in the Nason Creek subwatershed. Interpretation of historical aerial photographs and maps, hydraulic and sediment modeling, vegetation mapping, geomorphic mapping, field observations, anecdotal accounts and existing literature was utilized to evaluate the historical changes to geomorphic conditions. The following sections describe historical impacts to the flow, sediment, and topography. Impacts within the subwatershed upstream of RM 14 (the assessment area boundary) are described first, followed by impacts within RM 4.6 to 14.3.

5.1 Flow Magnitude, Volume, and Timing

Flow processes within the Nason Creek subwatershed are discussed first in this section at a cursory scale with available information and field reconnaissance by the assessment team. Flow processes within the assessment area (RM 4.6 to RM 14.3) are discussed next. A quantitative analysis of flood frequency values for each river mile within the 10-mile assessment area was accomplished using available gage data; historical trends could not be evaluated because gage data has only been collected on Nason Creek at RM 0.2 since 2002 (gage operated by Washington State Department of Ecology (Ecology)).

5.1.1 Subwatershed Scale

Nason Creek drains 69,000 acres from the Cascade Crest at Stevens Pass to its confluence with the Wenatchee River at RM 53.6, slightly downstream of the Lake Wenatchee outlet (a natural lake). Nason Creek contributes approximately 18 percent of the low flow of the Wenatchee Subbasin (USFS 1996). High flows occur during winter months as flash storms and during longer-duration spring snowmelt periods. Minimum flows typically occur in late summer and early fall, and during winter baseflow. There are no areas along the main channel that have been documented to go dry (subsurface) during summer or fall low-flow periods, but ice formation periodically occurs in winter months.

Historically, there have been no large dams or water diversions constructed in the main channel within the subwatershed that would have the potential to significantly alter flood peak timing, volume, or duration during high-flow periods. Above RM 14.3 (the upstream boundary of the assessment area), the subwatershed is largely administered by the USFS (see Appendix E – Nason Creek Subwatershed Conditions and map 2 in atlas). Upstream of the White Pine Railroad Bridge at RM 14.3, a small amount of historical logging has occurred in the subwatershed. Logging was extensive downstream of RM 14. There is also infrastructure along Nason Creek such as the highway, railroad, and relatively isolated developed areas (see map 8 in atlas). The impact from these features on the timing of runoff in the upper subwatershed above RM 1.3 has not been evaluated, but would be expected to be small relative to total runoff volumes. Tributary crossings could be further investigated within the subwatershed to ensure adequate openings are present under the railroad and highway embankments.

Historically, large flood accounts for the Nason Creek subwatershed include:

1. 1948 flood of record in many areas; first high water event affecting the road next to Nason Creek; estimated at 5,270 cubic feet per second (cfs) in Federal Emergency Management Agency (FEMA) 2004 report (assumed to be near mouth)
2. November 1959, estimated at 6,860 cfs in FEMA report (assumed to be near mouth)
3. 1980 rain on snow with high water flooding Lake Wenatchee and Nason Creek, no estimated flow value (Thomas 2006)
4. December 26-27, 1990 rain on snow with high water flooding Lake Wenatchee and Nason Creek, no estimated flow value.(Thomas 2006; Wood 2007)
5. November 22 -25, 1995 rain on snow with high water flooding in Lake Wenatchee and Nason Creek, no estimated flow value (Thomas 2006; Wood 2007)
6. November 7, 2006 rain on snow with high water flooding Lake Wenatchee and Nason Creek (Ecology gage at RM 0.8 has not finalized a value for this flood).

There are several small diversions including water permits and certificates with a total potential of 3.5 cfs, claims with a total potential of 6.8 cfs, and applications with a total potential of 0.8 cfs, along with groundwater withdrawals (Andonaegui 2001). Potential future use through 2025 has been anticipated to increase as additional areas are developed (WRIA 45 Planning Unit 2006). Typically referred to is a small diversion at RM 0.75 on the main channel and a couple in the tributaries (Andonaegui 2001). The minimum mean daily flow recorded during the water years 2003 to 2007 at the Ecology gage at RM 0.8 has ranged between 16 to 34 cfs. The effects of the diversions and withdrawals, both individual and cumulative, on low-flow habitat conditions have been recently evaluated to provide recommendations on instream flows under the leadership of the Chelan County Watershed Program (WRIA 45 Planning Unit 2006). The proposed instream flow has been recommended to be a minimum of 120 cfs at the lowest streamflow periods with increasing recommended flow values as streamflows vary (Figure 4). The recommendations were based on an assessment of what flow is necessary for various life stages of fish utilizing the river channel throughout the year.

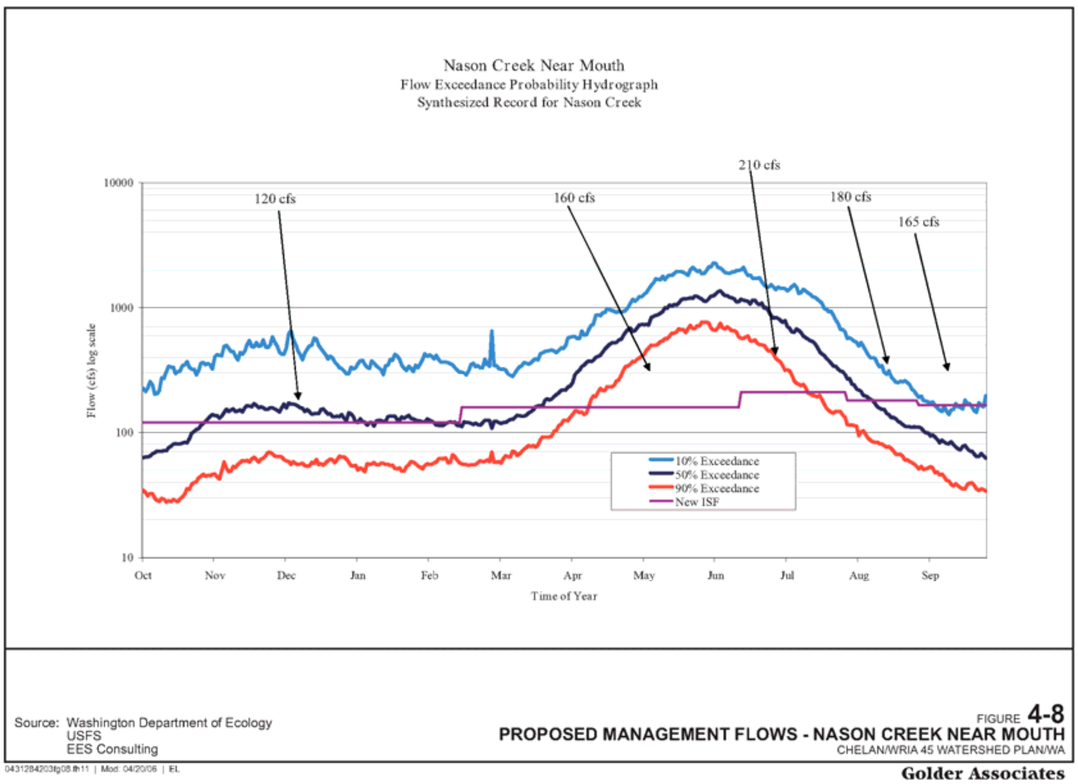


Figure 4. Summary of instream flow recommendations for Nason Creek near the mouth (WRIA Planning Unit 2006).

5.1.2 Assessment Area

Within the assessment area, several factors exist that have the potential to alter flow timing, magnitude, and duration of both low- and high-flow periods. Downstream of RM 14, both the left and right sides of the valley (looking downstream) of the assessment area have historically had large amounts of logging mostly between 1960s and 1990s, but many areas are now in a regrowth phase (see maps 11 to 16 in atlas for historical aerial photographs). Pockets of private land continue to harvest timber. No analysis has been done to date to quantitatively predict the impact of logging on flow timing and magnitude, either from tributaries or hillslope runoff. However, from this assessment, it is estimated that railroad and highway embankments that prevent connectivity between the hillslopes, floodplain, and tributaries with the main channel presently have more measurable, significant impacts on flow volume and timing in the main channel than logging, particularly between RM 9 and 14 (Reach 3).

Documentation on the tributary drainage size and impacts to flow connectivity were summarized in Table 6. Within geomorphic Reach 1, there is only one significant tributary (Kahler Creek) and it is presently connected with a side channel of Nason Creek. Geomorphic Reach 2 has no significant historical impacts to flow and there are no tributaries in this reach. The upper surface bounding Reach 2 has large amounts of paved ground. In geomorphic Reach 3, nearly all tributaries and hillslope runoff areas along the right side of the floodplain are partially or fully disconnected due to the railroad embankments, and a large portion of the left side from U.S. Highway 2 (looking downstream) (Figure 5; see maps 25 and 26 in atlas). Even though culverts are present in the railroad and highway embankments, many local biologist believe these are undersized and impact both flow connectivity and fish passage (Figure 7) (Andonaegui 2001). Elevations of ten culvert inverts were surveyed in 2007 and could be further evaluated at project scale evaluations. Most culverts are also thought to impede fish passage where historical fish use occurred (Andonaegui, 2001).

Ponded water has been observed to form in areas where the historical main channel has been cutoff by the railroad and highway embankment, and, in some cases, behind small levees (see cutoff areas on maps 23 and 24 in atlas and Figure 6and Figure 8). As ponded water on the non-river side of the embankment drains during summer months, it may be entering the main channel and elevating water temperatures. During field observations, the amount of ponding varied and appeared to reduce over time throughout the summer months. Water temperatures could be measured in the ponded areas and compared with main channel temperatures during the same time period to further evaluate the potential influence, along with utilizing airborne thermal infrared remote (TIR) sensing (often referred to as forward looking infrared or FLIR) collected in 2001 and 2003 (see Appendix F – Water Quality Synopsis).

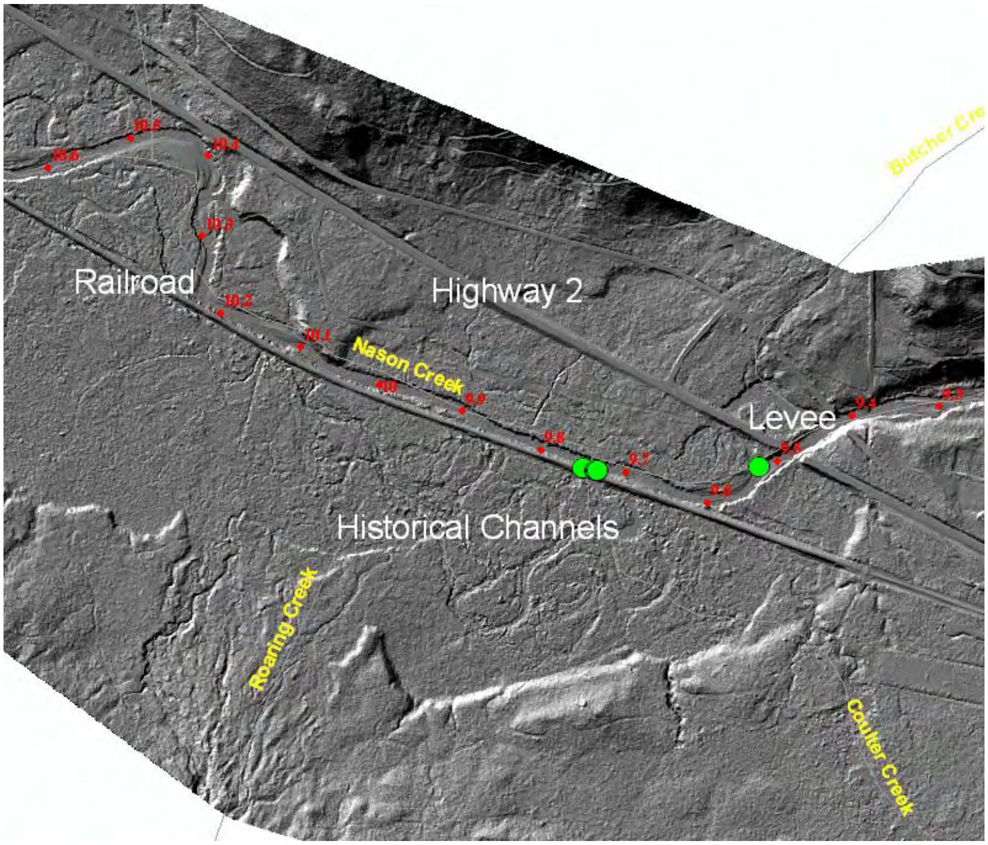


Figure 5. Example of railroad, highway, and levees cutting off flow connectivity between tributaries and present main channel. River miles from 2006 are shown in red text and existing culvert locations are green circles.

Figure 6. View to the north of ponding in the historical channel near RM 13.5. (Reclamation photograph by R. McAffee, May 2, 2007).

Figure 7. View to the south near RM 9.7 looking at the right river bank with concrete culvert inverts at water surface level. (Reclamation photograph by D. Bennett, August 8, 2007).

Table 5. Impacts to flow connectivity between main channel and significant tributaries within or near the 10-mile assessment area.

Tributary	Approximate confluence with Nason Creek (river mile)	Geomorphic Reach	Drainage Area (square miles)	Historical Impacts	Documented spring Chinook, steelhead, or bull trout use
White Pine	15.6	Just upstream of Reach 3	24.4	No significant impacts at confluence with Nason Creek	Yes (natural falls at RM 3.4)
Mahar	14.1	3	1.8	Unknown; passes under U.S. Highway 2 but confluence is just downstream of White Pine Railroad Bridge into existing main channel	Yes
Gill	10.7	3	1.7	On USFS Rd. 6930, there are three fish-blocking culverts at RM1.7, 2.5, and 2.7 (USFS Culvert Barriers Database 2000) (as referenced in Andonaegui 2001)	Yes
Roaring	10	3	7	Presently drains into historical main channel area blocked from present main channel by the railroad embankment; culverts in railroad	Yes (natural falls at RM 1.1)

Tributary	Approximate confluence with Nason Creek (river mile)	Geomorphic Reach	Drainage Area (square miles)	Historical Impacts	Documented spring Chinook, steelhead, or bull trout use
				embankment act as fish barriers (Andonaegui 2001)	
Coulter	9.6	3	5	Presently drains into historical main channel area blocked from present main channel by the railroad embankment; although often mapped as a tributary to Roaring Creek, based on the 2006 LiDAR data it would suggest historically it was an independent tributary flowing into a historical main channel of Nason Creek; culverts act as fish barriers at RM 0.4 at railroad embankment and at RM 3.0 on USFS Road 6930 (Andonaegui 2001)	Yes
Butcher	9.45	3	1.4	Presently drains into coho acclamation pond formed by a human-made levee; the pond is located in a historical main channel of Nason Creek; the connectivity with the main channel at the confluence is also impacted by the U.S. Highway 2 road embankment	No
Unnamed	8.6	1	Unknown	Culvert is present under U.S. Highway 2	No
Kahler	6.1	1	3.3	Presently drains into accessible side channel of Nason Creek; confluence area has been cleared of vegetation for a powerline crossing, but there are no embankments that prevent flow connectivity	Yes

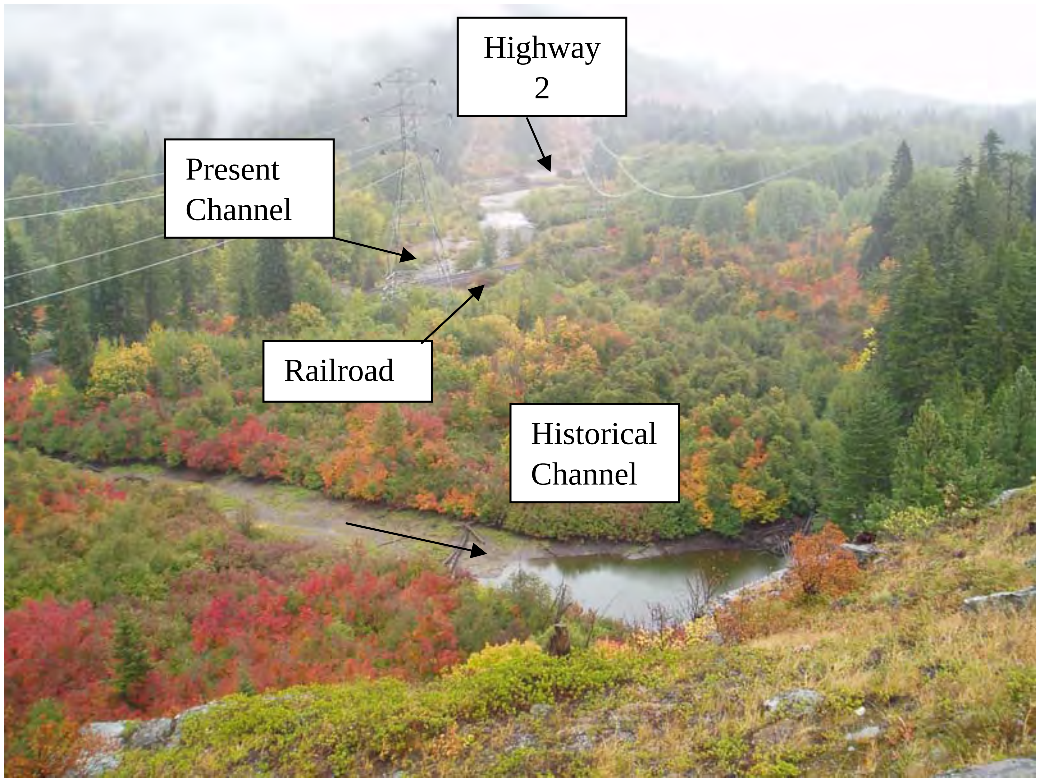


Figure 8. Looking across the valley at ponding in a historical channel of Nason Creek and the present channel between RM 10.7 to 11.1. The ponding has been observed to inundate the majority of the unvegetated historical channel. The river is flowing from left to right in the photograph. (Reclamation photograph by J. Bountry, October 2007)

A flood frequency estimate was computed by Reclamation incorporating the Ecology gage data at RM 0.8 with a correlation to the USGS gage data from Icicle Creek which has a longer period of record than Nason Creek (see Appendix D – Hydrology Analysis and GIS Data). There is still a lot of uncertainty associated with these estimates due to the limited data available, and because much of the Ecology data was still in provisional form as of June 2008 (Burkes 2008). Therefore, flood frequency values were also computed using only a correlation to the Icicle gage data with no use of the Nason data (see Appendix D for values). The 100-year estimates with the provisional Nason gage data are:

- 9,800 cfs near the mouth of Nason Creek,
- 8,400 cfs at RM 9 near the rest area, and
- 6,200 cfs near White Pine Railroad Bridge (RM 14.3)

The 100-year flood estimate at the mouth has a large estimated range of uncertainty due to the short period of record and provisional values (see Appendix D). These values should be recomputed once the Ecology gage data is finalized and as more data becomes available. For reference, the FEMA flood frequency estimates and Ecology gage data for Nason Creek and major streams in the Wenatchee subbasin are provided in Appendix H – Hydraulics and Sediment Analysis.

5.2 Historical Changes to Sediment Regime

Sediment regime components discussed in this section are sediment sources, transport capacity, and storage within both the subwatershed at a coarse, qualitative scale and at a more quantitative detailed scale within the assessment area. A sediment budget including detailed measurements of sediment input sources, suspended load, and bedload was beyond the scope of this effort.

5.2.1 Subwatershed Scale

Sediment sources in the Nason Creek subwatershed above RM 14.3 include mass wasting, tributaries, and reworking of the channel and floodplain (see Appendix E – Nason Creek Subwatershed Conditions for more details and ground photograph examples). Mass wasting includes bank erosion, landslides, debris flows, avalanches, and/or any other dislodgement and downslope transport under direct gravitational stresses. Input of fine sediment can also occur as a result of fire or roadways.

As mentioned in the flow section, there are no dams or in-channel sediment traps on Nason Creek upstream of RM 14 that would significantly reduce the incoming sediment load at RM 14. Infrastructure that would impact the sediment regime is also fairly limited in the upper subwatershed above RM 14.3. Small impacts to sediment loads may occur periodically due to mass wasting or blockage of sediment supply induced by the road, railroad embankments, localized campgrounds, or infrastructure. These impacts are estimated to be difficult to detect in a subwatershed-scale sediment budget. The largest observed impact during field observations was immediately upstream of the White Pine Railroad Bridge where the USFS road has been heavily armored with angular, loose riprap that could fall in the river (Figure 9). The riprap also reduces the floodplain width and likely increases the sediment transport capacity in the river through this section.

Figure 9. Downstream view to the north at riprap placed along USFS road and White Pine Railroad Bridge abutment near assessment area boundary (RM 14). (Reclamation photograph by R. McAffee, May 2, 2007).

Sediment sizes in the channel above RM 15 were observed in a few locations where accessible by the road, and a helicopter video of the channel from spring of 2006 was also obtained for this effort. In the locations viewed, gravel bars were common and the dominant sediment sizes on the surface of the channel bed and bars ranged from gravel to cobble (2 to 256 mm) (Figure 10 and Figure 11).

Figure 10. Upstream view of confluence of side and main channel in upper subwatershed near split in highway (vicinity of RM 20 to 22). (Reclamation photograph by J. Bountry, October 2007

Figure 11. Example of gravel and cobble size sediment near U.S. Highway 2 bridge crossing in upper subwatershed. (Reclamation photograph by P. Makar, October 2007).

The channel elevation in the headwaters has a steep slope followed by a stair step pattern downstream to RM 15 that is assumed to be formed from geologic controls (Figure 12). This pattern would be expected to result in altering sediment storage (flatter-sloped reaches) and transport reaches (higher-sloped reaches). Downstream of RM 13, the slope is consistently flat compared to the variations in the upstream subwatershed.

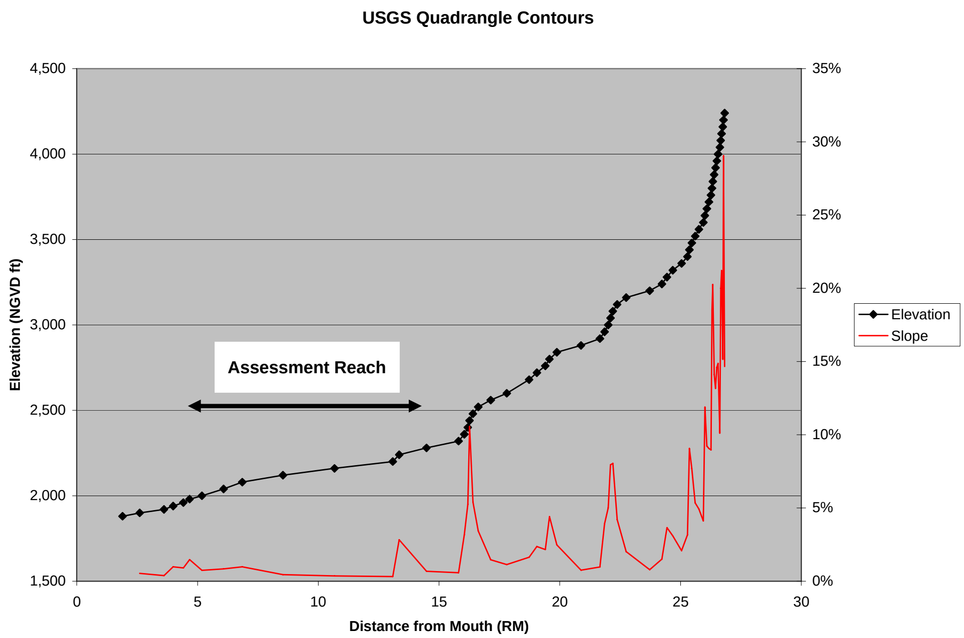


Figure 12. Longitudinal profile of slope and elevation of Nason Creek from the mouth to the headwaters based on USGS quadrangles. Elevation is shown in black with the y-axis on the left; slope (in percent of ft/ft) is shown in red with the y-axis on the right

5.2.2 Impacts to the Sediment Regime of Assessment Area

Within the assessment area, there has been no large-scale change to the balance between incoming water and sediment loads (at the upstream end) that would indicate a potential for incision or aggradation. However, several sections of the lower 14 miles of river have been artificially straightened and confined (reduced floodplain access) indicating there is a potential for increased sediment transport capacity and thus possibly incision. The potential for incision was evaluated by looking at the following:

- anthropogenic activities that impact the sediment regime,
- vertical channel bed controls that could limit the extent of incision,
- historical changes in bed elevation and slope to look for evidence of incision over time, and

- whether the impacts to sediment transport capacity are localized and limited to the confined areas or extend throughout the 10-mile assessment area.

Anthropogenic Activities

Within the assessment area, the biggest impact to sediment processes in the main channel is alteration to transport capacity and sediment storage due to artificial channel straightening from the construction of the railroad and widening and relocating of U.S. Highway 2 closer to the river. Additionally, several miles of bank along the main channel have been riprapped which reduces the ability of the river to recruit sediment. Many of the channel areas that can still meander have had vegetation clearing along the outside banks which has the potential to increase bank erosion rates and thus sediment recruitment. Channel migration is discussed in more detail in report Section 5.3.

Mass failures on hillslopes related primarily to roads and secondarily to timber harvest impact tributary and runoff sediment sources (USFS 1996). This has the potential to increase sediment loads to the valley floor and potentially to Nason Creek. However, as previously discussed tributary confluences have been altered and in several cases cutoff from Nason Creek by railroad or highway embankments. Therefore, since the construction of the railroad (1890s) and U.S. Highway 2 (1940s to 1960s), the sediment input from hillslope and tributary sources have likely been reduced. Reports from several decades ago to the present have documented how clear the water in Nason Creek is except for a few events associated with floods; turbidity is not considered a concern by regulating agencies at this time (Seabloom 1958; Cristea and Pelletier 2005).

Vertical Controls and Slope

Sediment storage and transport capacity is influenced by the slope of the river, which in turn is largely influenced by geologic controls within the Nason Creek subwatershed. The slope of the river in the assessment area ranges from 2.3 percent to 0.1 percent (Figure 13 and Table 6 see Appendix G for more details). There is not one consistent trend of increasing or decreasing slope, but rather a range of altering slopes in Reaches 1 and 2, and a trend of increasing and then decreasing slope in Reach 1 (Figure 14). Past glaciers that ran down the valley terminated around RM 9 leaving a large deposit of glacial sediment upstream. The river has not been able to cut down through these sediments between RM 9 and 14, thus resulting in a mildly sloped valley section relative to downstream Reach 1. Bedrock near the White Pine Railroad Bridge at RM 14.3 and large boulders between RM 8.9 and 9.4 (Figure 15) further limit downcutting of the river and may serve as elevation controls at the upstream- and downstream-most boundaries of Reaches 2 and 3. The boulders are interpreted to originate from a historical landslide that occurred as the glacier retreated up the valley based on geologic surface mapping for this assessment (see Appendix J – Geomorphic Map Methods and GIS Metadata).

Table 6. Slope data for geomorphic reaches.

Geomorphic Reach	RM Range	Reach-based Slope	Minimum Slope in Reach	Maximum Slope in Reach	Average Drop Per Mile (ft/mile)	Total Elevation Drop (ft)
1	4.6 to 8.9	0.7%	0.2%	2.2%	39	167
2	8.9 to 9.4	0.4%	0.1%	0.4%	20	10
3	9.4 to 14.3	0.4%	0.1%	2.3%	20	97

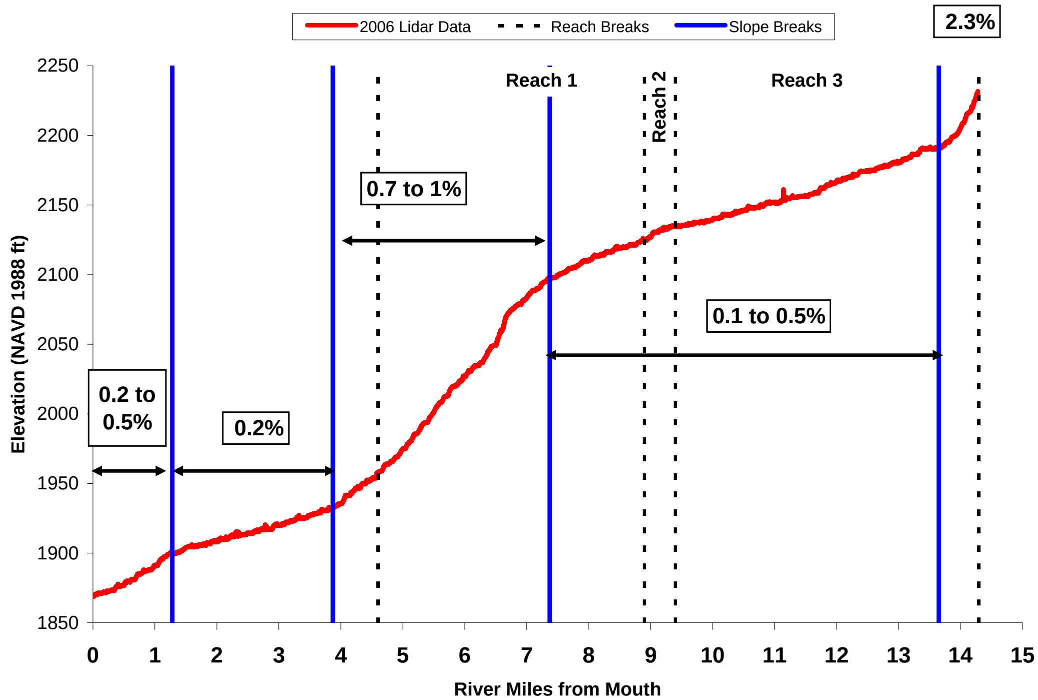


Figure 13. Longitudinal profile of bankfull slope within assessment area and lower 4 miles of Nason Creek (RM 14 to 0).

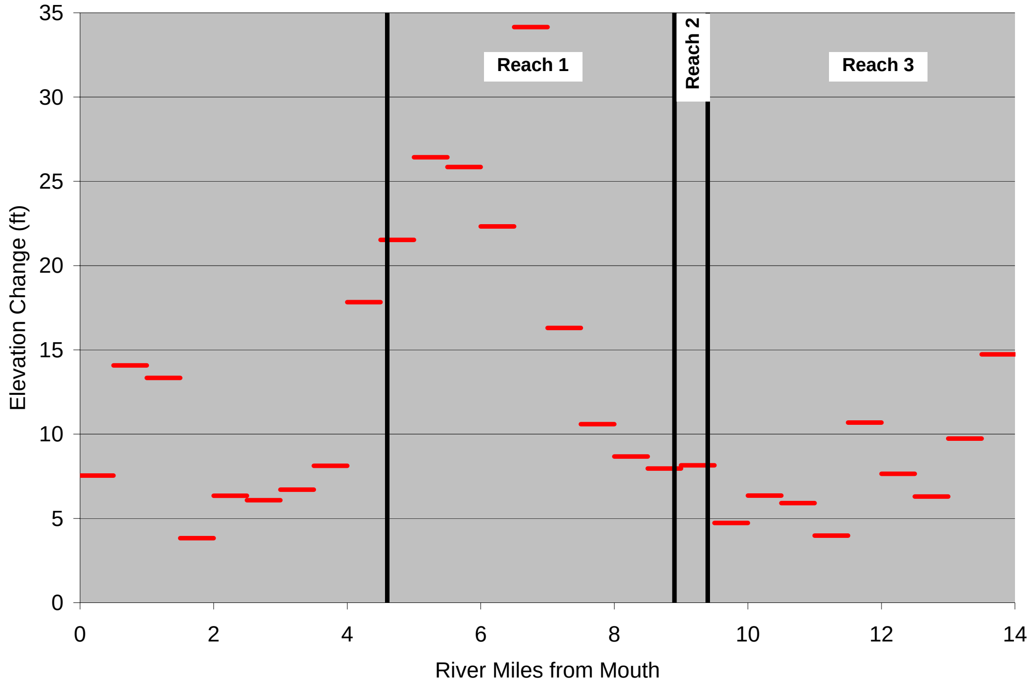


Figure 14. Elevation change per mile through assessment area showing trends in slope changes.

Figure 15. View is to the north looking downstream showing boulder field at downstream end of Reach 2 near RM 9. (Reclamation photograph by D. Bennett, August 9, 2007).

Downstream of RM 9, the river has a trend of increasing slope with the steepest section between RM 5 to 6. Within RM 6 to 9, sets of terraces can be observed adjacent to the river, indicating the river has over long geologic periods of time downcut through the valley in this section (see map 17 in atlas; see Appendix C and Section 4.7 in Appendix J). These features resulted as multiple alpine glaciers retreated and advanced within the Nason valley. Downstream of RM 6 to about 4, the river has a decreasing trend in slope. From RM 4 to the mouth, the slope increases and then decreases but over a shorter distance than the upstream reach. In this reach the slope may be largely due to a more extensive Lake Wenatchee that once existed in glacier times and backwatered up Nason Creek (see Appendix C and Section 4.7 in Appendix J). The elevation at the mouth is controlled by the present baseline elevation of the Wenatchee River.

LiDAR data was used to map conceptual alignments of historical channel paths for comparison to present channel alignments and lengths. Because of the confined channel sections, the present channel is about 2 miles shorter in length than before the construction of the railroad and U.S. Highway 2 embankments (Table 7). The channel shortening would be expected to increase the slope of the river, assuming the total change in elevation over the reaches remains the same due to the vertical controls present (e.g., bedrock and large cobbles). The increase in slope could be about 0.1 percent overall in Reaches 1 and 3, which is not significant at a reach scale.

Table 7. Estimate of change in slope due to channel straightening in assessment area.

Geomorphic Reach	River Miles	Slope (ft/ft)*	Historical Channel Length (average of 3 conceptual historical alignments)	Estimated Historical Slope
1	4.6 to 8.9	0.7%	4.9	0.6%
2	8.9 to 9.4	0.4%	NA	NA
3	9.4 to 14.3	0.4%	6.3	0.3%
* foot per foot				

A 1911 map and river contour survey was available that shows the channel was also shortened below RM 4.6. Between RM 0 to 5.4 (just upstream of Coles Corner) 0.9 miles of channel was lost due to relocation of the highway (Marshall 1914). This could also have resulted in channel incision that has the potential to headcut upstream into the assessment area. However, when the slopes of the longer 1911 channel were compared to 2006 conditions (Figure 160, the trends in slope were similar indicating geologic controls play a large role in controlling the Nason Creek slope (see Appendix G). Geologic interpretations for this reach are that the sediment in storage is much higher than the current transport capacity, making it unlikely that the river would incise over the last 100 years. Channel bed elevations from a 1980s FEMA analysis were also compared to 2006-7 elevations but showed the same trends in slope 30 years ago that exist today in RM 4 to 14 (FEMA 2004; see Appendix G for comparison).

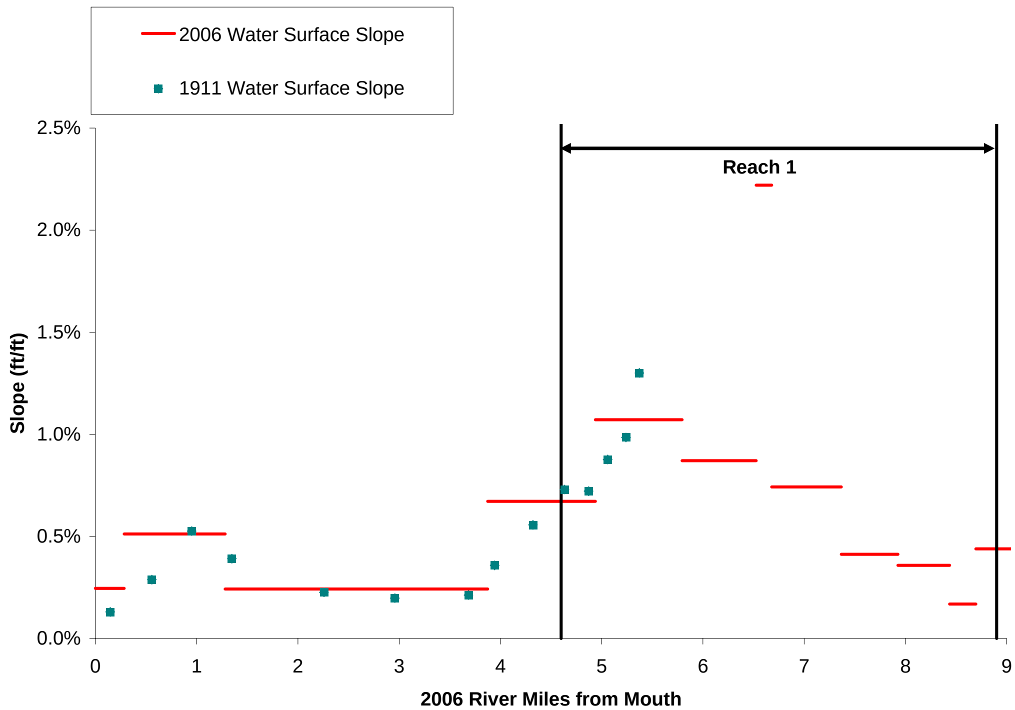


Figure 16. Comparison of present water surface slope with slope measured in 1911 by USGS (Marshall 1914).

Assessment of Sediment Transport Capacity

The previous section indicates geologic controls play a large role in forming channel slopes, but anthropogenic impacts have altered local energy in the channel. Additionally, the incoming sediment and water has not been changed, but locally within the reach it is likely altered. To better understand how significantly the sediment regime has been impacted, sediment transport capacity was evaluated between reaches and in localized areas where the channel has been confined and the floodplain reduced.

The first method to examine at variations in sediment transport potential involves looking at the balance between flow and slope, known as total stream power (see Appendix H for methods). Increasing flow in the downstream direction has the potential to increase sediment transport capacity. Generally, the slope is steeper in Reach 1 downstream of RM 9, than in the upstream Reaches 2 and 3 (RM 9 to 14). This steeper slope could also result in higher sediment transport capacity in the downstream direction. However, there is a lot of variation in slope in both reaches. The average active main channel width is about 65 to

80 feet within the assessment area. Multiplying slope and discharge together indicates that even with slope fluctuations, the river has a generally increasing potential to transport sediment in the downstream direction to RM 4.6. The slope of the river steepens and does not start increasing until downstream of RM 9, but the total stream power jump occurs between RM 9 and 10 where the Roaring and Coulter Creek drainages enter Nason Creek.

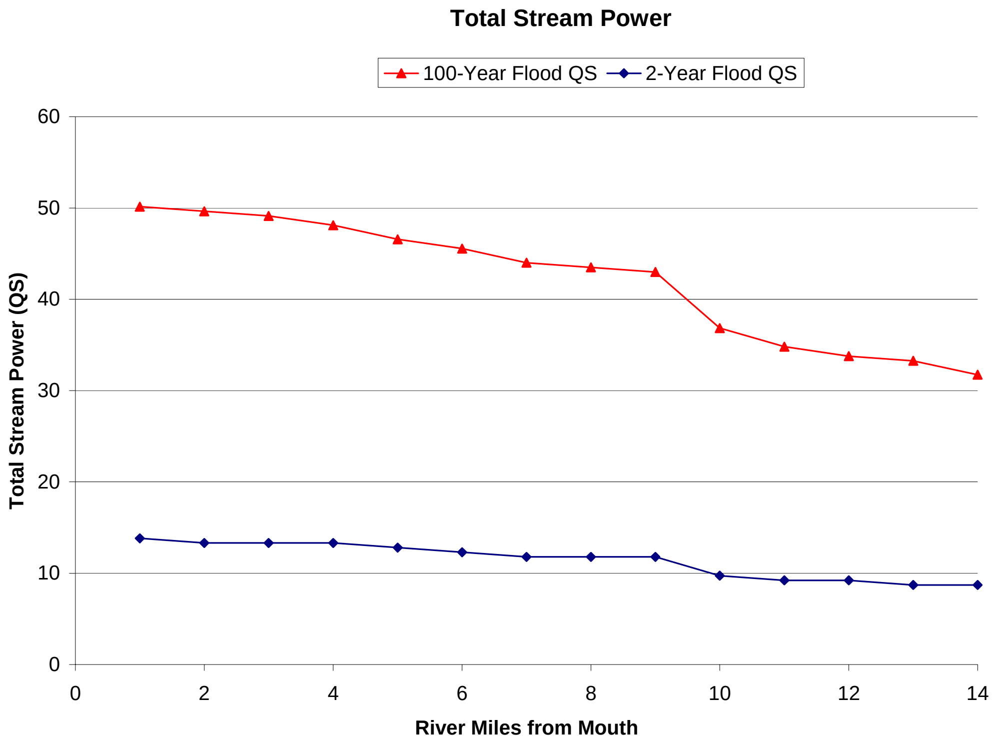


Figure 17. Total stream power (discharge times slope) for the assessment area.

The two-dimensional (2D) hydraulic model results were used to take a more detailed look at sediment transport capacity by computing the critical sediment size that can be mobilized for a given flow, and then comparing it to the sediment presently on the surface of the channel and bars (Table 8, Figure 18 and Figure 19; see Appendix H for methods). A flow range of 2,500 to 10,000 cfs was used because this covers the 2- to 100-year flow range that typically could transport sediment in the channel bed and bars (see Appendix D – Hydrology Analysis and GIS Data). If the critical sediment size exceeds the measured sediment sizes, there is an excess capacity of sediment transport relative to the available sediment sizes in the bed, or in other words excess energy. Sediment sizes were not measured at all locations, but results can be inferred in areas that have similar geologic controls or anthropogenic impacts. In the steeper sections of Reach 1 between RM 5 and 8, there is naturally excess energy due to the relatively high slopes. At the upstream and downstream boundaries where the slope is milder, the transport capacity is more in balance with the sediment supply. In Reach 3, the transport capacity is in balance with the available sediment sizes except where the channel is artificially confined. In these areas, for example just downstream of White Pine Railroad Bridge, there is excess energy in the channel.

Table 8. Average (D_{50}) sediment sizes for bar surfaces and river bed for each reach based on pebble count data (see Appendix H). Sizes generally fall within the gravel and cobble range (the break between the two is 64 mm).

Reach	Feature	D_{35}	D_{50}	D_{84}	D_{95}
RM 4.6 to 8.9	Bar	37	56	135	211
	River	49	78	204	333
	Total	43	67	169	272
RM 8.9 to 9.4	Bar				
	River	21	33	97	204
	Total	21	33	97	204
RM 9.4 to 14.3	Bar	33	57	159	255
	River	38	54	137	254
	Total	35	56	147	255

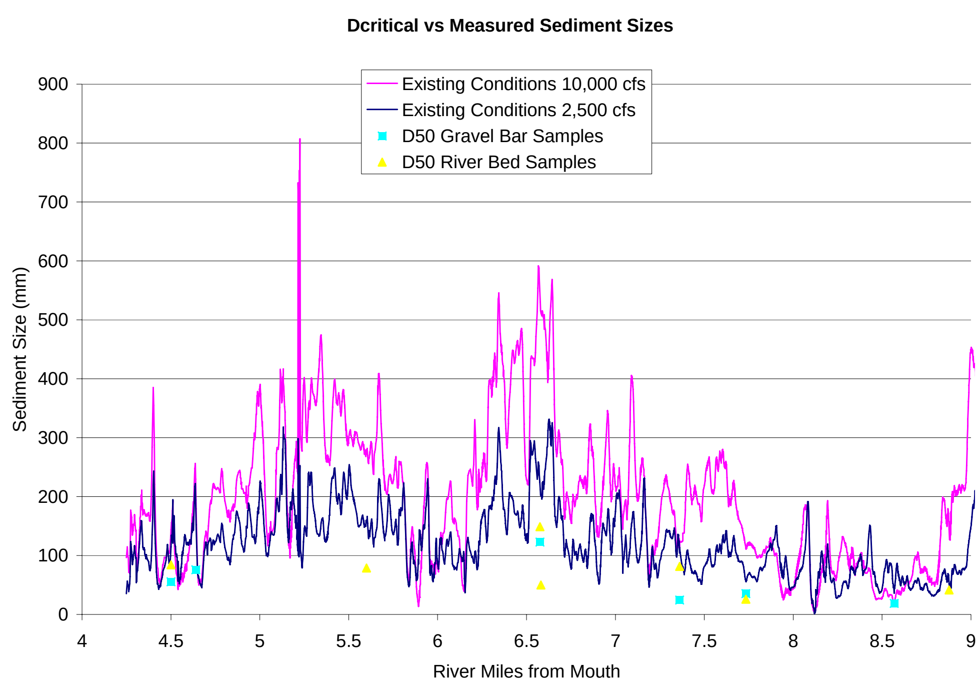


Figure 18. Comparison of computed sediment transport capacity versus measured sediment sizes in the bed and bar for Reach 1.

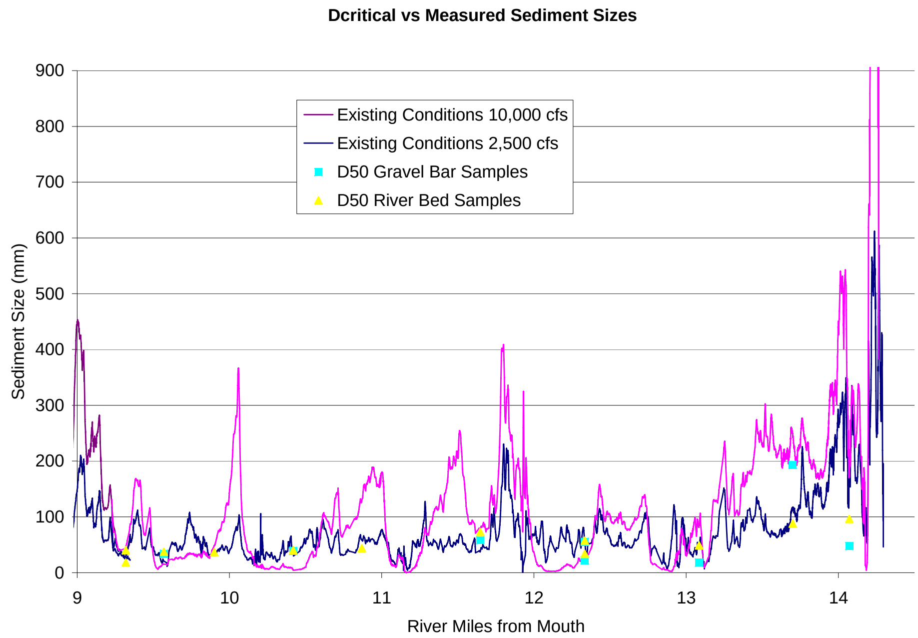


Figure 19. Comparison of computed sediment transport capacity versus measured sediment sizes in the bed and bar for Reach 3.

When looking at the critical sediment size in the previous section, it is evident that in some areas a higher flow of 10,000 cfs results in a lower energy in the river than 2,500 cfs, which is not intuitive. Explanation of this result and the relationship between artificially confined sections and excess energy can be made by overlaying geomorphic mapping results with unit stream power (Figure 20 and Figure 21). Unit stream power is an indicator of sediment transport capacity that incorporates effects of channel geometry and slope by multiplying velocity times slope (see Appendix H for methods). Figure 20 and Figure 21 show that within each geomorphic reach, artificially straightened and confined sections (dark blue/black lines) have higher energy than presently meandering sections (green lines). Good examples are artificially confined channels below White Pine Railroad Bridge, at Merritt, and at RM 8.3 where a bridge embankment confines the channel. However, exceptions occur where even though the channel is artificially confined, the energy is still low and furthermore reduces with an increase in flow (10,000 cfs has a lower unit stream power than 2,500 cfs). Examples are above RM 9.3, 10.1, and upstream of Merritt. The explanation of why the energy does not increase is that these areas are backwatered due to geologic or human-induced constriction points on the channel and floodplain width.

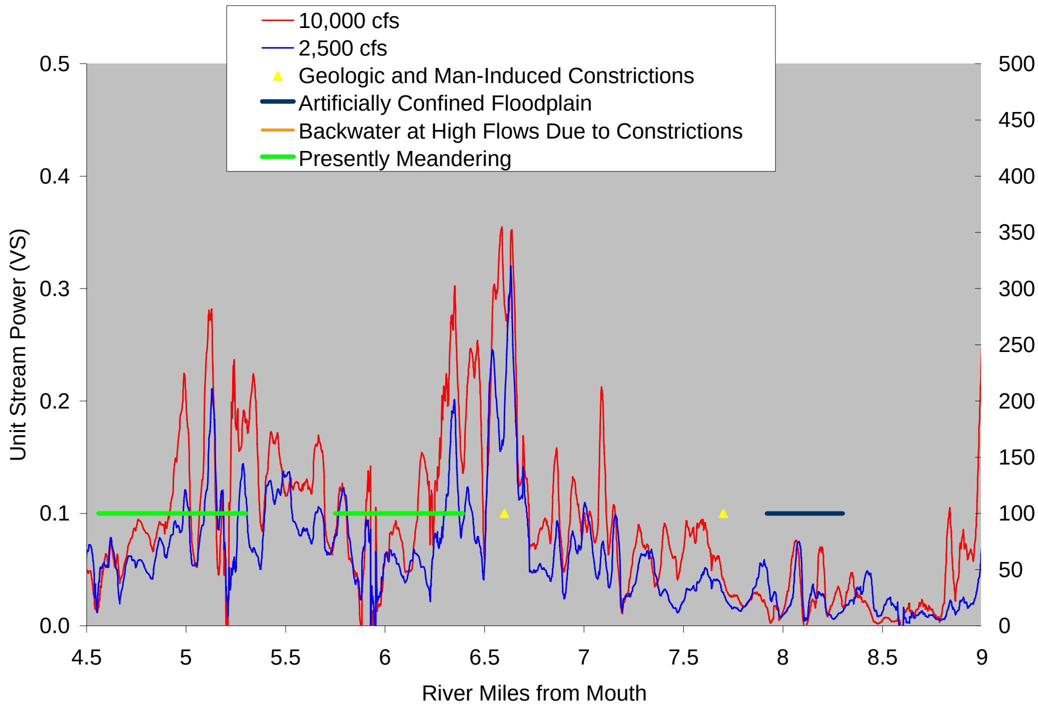


Figure 20. Overlay of geomorphic mapping and unit stream power from 2D hydraulic model for Reach 1.

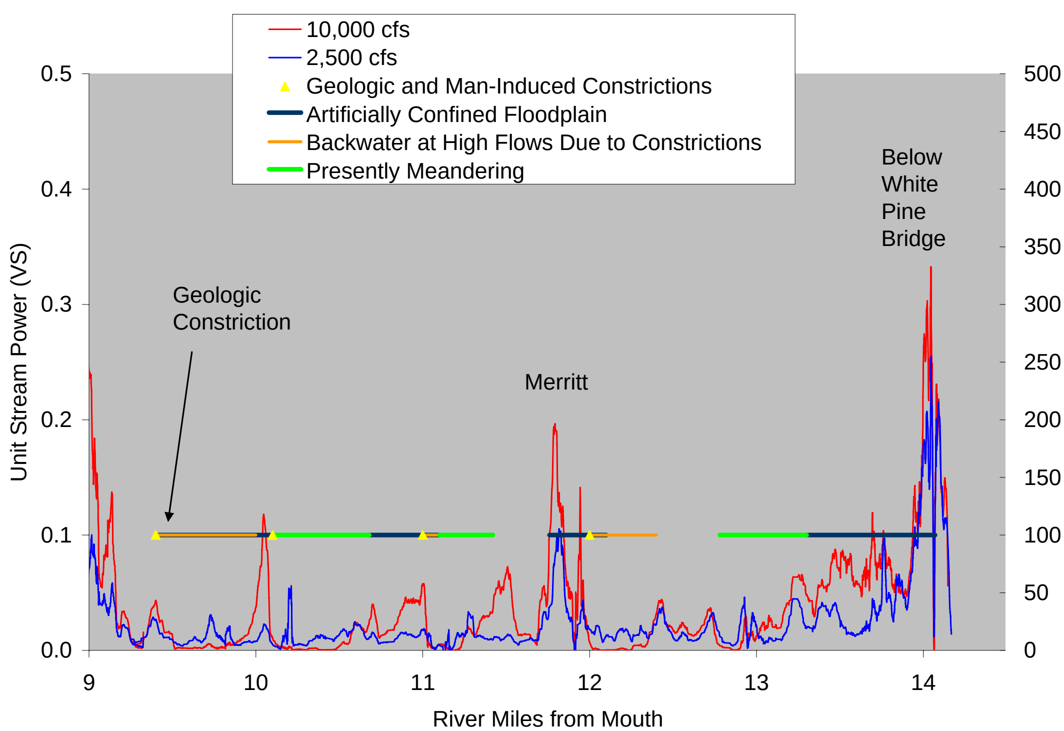


Figure 21. Overlay of geomorphic mapping and unit stream power from 2D hydraulic model for Reach 3.

5.3 Historical Changes to Topography

The previous section concluded that certain segments of the assessment area have higher stream energy either due to naturally steeper slopes or because of artificially confined and straightened channels. The exception was wide, unconfined floodplain areas that are backwatered by downstream confined floodplain sections that are within the same geomorphic reach and do not have a large change in slope. In confined areas, Nason Creek may try to dissipate excess energy by incising (lowering the channel bed), widening (increase width to depth ratio), or by becoming more sinuous (reduced slope). In backwater areas, Nason Creek may try and increase its energy by aggrading (raising the channel bed), narrowing and deepening (decreased width to depth ratio), or by reducing its sinuosity by straightening (increased slope). Evaluation of whether these changes have occurred is discussed in this report section.

Comparison used historical aerial photographs from 1962 to 2006, but unfortunately two of the most significant impacts, the railroad construction (1890s) and U.S. Highway 2 realignment and widening (1960) pre-date the earliest aerial photographs available. Historical maps date back to 1898 in some places, but there is more uncertainty in the channel position on maps because in some cases the channel position was not based on a detailed survey. These maps still postdate the construction of the railroad. The maps did provide some evidence of whether a channel section was migrating or occupying a different position prior to the realignment of U.S. Highway 2, even if the exact position of the channel was not entirely to scale. The 2006 LiDAR provides additional documentation of historical channel positions that help identify the historical condition of the channel planform, although the date the LiDAR channels were last active is unknown unless correlated with one of the historical aerials or maps. The geologic surface mapping was used to identify lateral and vertical controls that have been in place, for several hundreds to possibly thousands of years, which are linked to why certain channel planform types exist. Hydraulic modeling was also used to help identify areas of channel migration, changes to channel geometry and hydraulics, and impacts to floodplain topography.

5.3.1 Channel Planform

The first documented impacts by humans to planform on Nason Creek are anecdotal accounts of beaver trapping in the early to mid-1800s that presumably would have reduced the number of wetlands and backwater areas present (see Appendix B). There is no historical or present data available to quantitatively describe the locations or change in the number of beavers or associated ponded areas adjacent to the river. A 2007 survey indicates that beaver are present in Nason Creek and have created dams in a few off-channel areas (less than 5 locations).

The historical and present channel planform for unique sections along the assessment area were compared to identify areas of significant planform over the last century. There have been no major changes in the upstream sediment and flow supply to the assessment area, so hypotheses were focused on looking at the impacts from human features that have the potential to alter the channel planform. Where there are geologic controls limiting the width of the channel and floodplain, no detectable change in channel planform was observed (such as Reach 2 or steep, split flow sections like just downstream of White Pine Railroad Bridge). Meandering sections have experienced the most significant changes as a result of human features that have straightened the channel or altered the channel migration processes.

Historically, 50 percent of Reach 1 and 95 percent of Reach 3 were meandering channels (Table 9and Table 10). However, because of anthropogenic impacts, over half of these areas are no longer meandering. Most of the reduction in meandering channel area is due to channel straightening during the construction of the railroad and highway. In some cases, meandering characteristics have been indirectly impacted by a downstream confined section.

Table 9. Amount of meandering channel areas in each reach impacted under present conditions.

Reach	Historically meandering channel sections		Present (2006-07) meandering channel sections	
	river miles	percent of reach length	river miles	percent of reach length
1	2.4	56%	1.3	26%
2	0.0	0%	0.0	0%
3	4.7	95%	1.8	37%

Table 10. Conclusions from geomorphic mapping for historical channel migration versus present channel and bank condition for the assessment area.

Upstream RM	Downstream RM	Historical Channel Condition (prior to 1890s)	Present (2006-2007) Channel Condition	Channel banks
14.27	14.07	Split flow with log jam at head of side channel on river right	Same	Riprapped bridge embankment and road embankment just upstream
14.07	13.3	Evidence from LiDAR that pre-railroad main channel was cut off by railroad embankment	Human-made channel built at time of railroad construction	Riprap and levee embankments along both banks block migration and floodplain access;

Upstream RM	Downstream RM	Historical Channel Condition (prior to 1890s)	Present (2006-2007) Channel Condition	Channel banks
				upstream portion of banks inset in alluvial fan outside of defined HCMZ
13.3	12.78	Downstream and outward channel migration observed between 1962 and 2006	Meandering channel	One of the most active channel migration areas within assessment area; however, barbs and riprap along portions of the outside bends of channel where it runs against U.S. Highway 2 limit outward migration (built after 1990 and 1996 floods)
12.78	12.47	Evidence from LiDAR that channel was meandering prior to U.S. Highway	Straight channel locked agaisnt riprap	Riprapped bank on U.S. Highway 2 on river left
12.47	12.1	LiDAR suggests channel had more sinuous pattern prior to fill at Merritt being placed	Fairly straight channel with some sinuosity	Backwater conditions during high flows have altered sediment capacity and resulted in a less sinuous channel; one historical meander bend cutoff by U.S. Highway 2
12.1	11.76	Historical maps and field obervations indicate that fill was placed at Merritt in HCMZ and channel relocated to present position	Human-made channel	Artificially confined preventing migration and there is no access to floodplain; banks appear to be alluvial fan material
11.76	11.42	LiDAR and historical maps suggest it would have been more meandering; small meander cutoff and indirect impacts from upstream Merritt section	Straight channel	Riprap present
11.42	11.1	Downstream and outward channel migration between 1962 and 2006	Meandering channel	Artificially straightened channels upstream and downstream of this reach; migration rate may be altered because eroding into terrace bank cleared of vegetation
11.1	10.68	Evidence from LiDAR that channel was	Human-made channel	Due to railroad embankment, channel

Upstream RM	Downstream RM	Historical Channel Condition (prior to 1890s)	Present (2006-2007) Channel Condition	Channel banks
		meandering prior to railroad		cannot meander or access floodplain
10.68	10.1	Downstream and outward channel migration between 1962 and 2006	Meandering channel	Artificially straightened channels upstream and downstream of this reach; migration rate may be altered because eroding into terrace bank cleared of vegetation; meander is migrating toward U.S. Highway 2 but no bank protection currently in place
10.1	9.42	Evidence from LiDAR that channel was meandering prior to railroad	Human-made channel	Due to railroad embankment and U.S. Highway 2 embankment, channel cannot meander or access floodplain
9.42	8.9	Naturally confined channel	Same	Minimal
8.9	8.3	Naturally confined channel	Same	Minimal
8.3	7.92	Bridge evident since 1962 aerial photographs (construction date unknown)	Artificially confined channel	Bridge embankment prevents channel migration; historical side channels impacted by road crossings and possible fill at entrances
7.92	7.2	Naturally confined channel	Same	Powerline crossing has cleared vegetation along channel banks
7.2	7.08	Naturally confined channel with meander alignment	Meander bend has been cut off resulting in straighter channel	U.S. Highway 2 embankment with riprap on river right
7.08	6.61	Side channel on river right noted to enlarge in 1996 flood	Split flow	Banks have been cleared of vegetation in two locations where powerline crosses the channel
6.6	6.39	Meander bend cutoff by U.S. Highway 2 embankment preventing migration and limiting floodplain	Meander bend has been cut off resulting in straight channel	
6.39	5.75	Meandering channel with evidence of outward channel	Same	Channel meandering into cleared powerline crossing and lack of vegetation on

Upstream RM	Downstream RM	Historical Channel Condition (prior to 1890s)	Present (2006-2007) Channel Condition	Channel banks
		migration between 1975 to 1998, an enlarged side channel between 1998 to 2006		banks may be affecting migration rate and LWD recruitment
5.75	5.61	Meander bend cutoff by U.S. Highway 2 embankment preventing migration and limiting floodplain	Meander bend has been cut off resulting in straight channel	Narrow floodplain exists between channel and highway
5.61	5.41	Estimated to have historically been more sinuous based on LiDAR	Straight channel between two highway cutoffs	
5.41	5.3	Meander bend cutoff by U.S. Highway 2 embankment preventing migration and limiting floodplain	Meander bend has been cut off resulting in straight channel	Right bank of channel runs against riprap on U.S. Highway 2
5.3	4.56	Highway embankment, development, and riprap impacts channel migration and to a lesser degree limits floodplain access; sinuosity may be impacted by shortened channel section downstream to mouth	Meandering channel with some artificial constraints on migration along outside of meander bends	Abandoned bridge embankment is located on outside of meander bend on left bank (looking downstream)

5.3.2 Modifications to Floodplain Function and Connectivity

There are 953 acres of geologic floodplain within the assessment area of Nason Creek, which includes all channels and surfaces inundated by floods (see map 21 and 22 in atlas). This section describes the historical impacts to the floodplain utilizing geomorphic mapping and 2D hydraulic model results. The condition of floodplain vegetation along the boundary and within the floodplain is discussed in report section 5.3.5 and in Appendix I.

The geologic floodplain is bound by higher elevation geologic features including alluvial fans, glacial drift and outwash, landslides, talus, terraces, and bedrock which in places result in natural confinement of the floodplain width (Figure 22). The most extensive geologic unit along the floodplain boundary is glacial drift and outwash for Reaches 1 and 2, and alluvial fans in Reach 3, both of which can be eroded by the river. Geologic surfaces limit lateral expansion of the floodplain at RM 10.8 to 11.0 from bedrock on the right side and at 14.25 from bedrock on the left side and talus on the right side (see Appendix J for descriptions of surfaces). Boulders in a historical landslide at RM 8.9 to 9.4 also provide limits on lateral expansion. Glacial banks often have large cobbles that can line the toe of the bank when eroded by the river, thus in some cases limiting the rate of lateral expansion of the floodplain, but not preventing it.

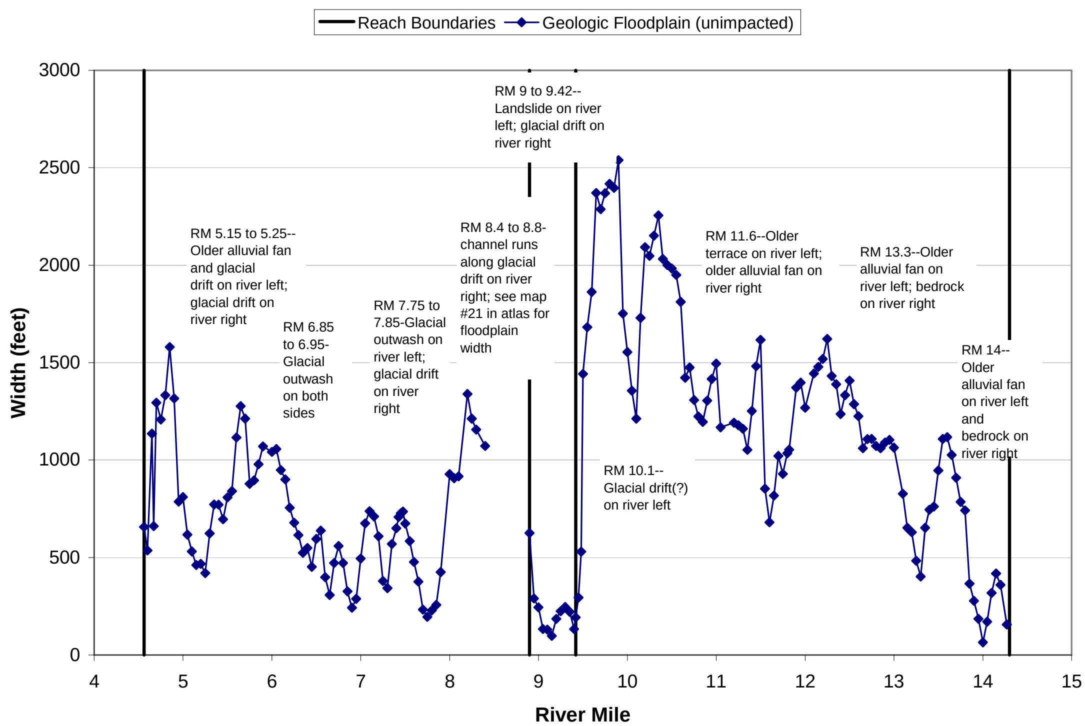


Figure 22. Geologic surfaces that narrow (confine) the historical floodplain width in the assessment area.

Historical floods and estimates of 2- to 100-year flood frequency values were documented in report section 5.1 and noted to have a lot of uncertainty due to a limited amount of gage data available on Nason Creek. A flow of near 5,650 cfs (provisional) measured at RM 0.8 was observed to come within a couple feet of the top of the bankfull channel between RM 5 to 9, but during the same day gravel bars in the upper portion of Reach 3 were partially exposed. Because of the uncertainty in flood frequency values and because there is variation longitudinally along the assessment area, flood inundation and stage results are discussed for 2,500, 5,000, 10,000 and 15,000 cfs to cover the range of uncertainty in flood values.

About 41 percent of the geological floodplain (369 acres) has been disconnected from the present channel as a result of 7.5 miles of embankments, levees, roads, and additionally from fill placed at Merritt near RM 12 (Table 12, Table 12, Figure 23; Figure 24, see map 25 and 26 in atlas). The present floodplain boundary is referred to as the "impacted" floodplain boundary in this report and map atlas. The disconnected areas are located in

Reaches 1 and 3, and in most cases are no longer inundated during high flows because of human features that block flow from accessing the disconnected areas. Occasional overtopping of low elevation spots in the embankments and levees can still occur. There is also a limited amount of connectivity through the embankments as a result of 19 culverts that are present, 15 of which are in Reach 3 (see maps 25 and 26 in atlas; see Figure 7 in Section 5.1.2). About 82 percent of the disconnected area occurs to the right of the 2006 channel (looking downstream). The majority of disconnectivity is due to the railroad and U.S. Highway 2 embankments (81 percent) and fill placed at the town of Merritt where there is a railroad turnaround and homes (9 percent). The remaining 10 percent of disconnected floodplain occurs from a few levees, bridges, and small road embankments. Approximately 39 percent (150 acres) of the disconnectivity is located within the historical channel migration zone (HCMZ). The remaining 61 percent is in areas located beyond the HCMZ that do not contain evidence of active channel reworking and migration but can still be overtopped and inundated during large floods. The overbank floodplain surfaces are generally raised 8 to 10 feet above the 2006 main channel bed elevation.

Table 11. Summary of geologic (historical) floodplain area cutoff by location.

Reach	Disconnected Floodplain Area (acres or percent)		Location of Disconnected Area (acres or percent)					
	Total Disconnected Area	Percent of Geologic (historical) Floodplain	Within HCMZ	Within Overbank Floodplain	Located on River Left	Located on River Right	Percent of Total on Left	Percent of Total on Right
1	50.5	15%	16.9	33.6	0.1	50.4	0 %	100%
3	335.4	56%	132.6	202.9	70.4	265.0	21 %	79%
Total	385.9	41%	149.5	236.4	70.5	315.4		

Table 12. Summary of geologic (historical) floodplain area cutoff based on human feature types.

Reach	Acres of disconnected floodplain by human feature type				
	Highway	Railroad	Levee	Estimated Fill at Merritt	Roads
1	47.9	0.0	0.0	0	11.0
3	43.1	230.9	27.7	33.7	0
Percent of Total	23%	59%	7%	9%	3%

Figure 23. Example of disconnected historical channels and floodplain between RM 9.6 to RM 9.9. Colors represent elevations relative to present main channel elevations, dark blue being the closest and green being the farthest (highest elevations). The railroad embankment can be seen in green running along the present channel identified by red river mile markers, flowing from upper left to right in the image.

Figure 24. View is to the south looking at the right bank showing original ground level with fill material on top at river bank adjacent to Merritt. (Reclamation photograph by D. Bennett, August 8, 2007).

The anthropogenic features also reduce the geological floodplain width in Reaches 1 and 3 as shown in Figure 25. Where there are reductions in the geologic floodplain width, the average reduction in width is 240 feet in Reach 1, and more than twice as much in Reach 3 (660 feet). The reduction in floodplain width in Reach 3 is nearly continuous along the river path, whereas the reduction in floodplain in Reach 1 is more isolated to five smaller areas.

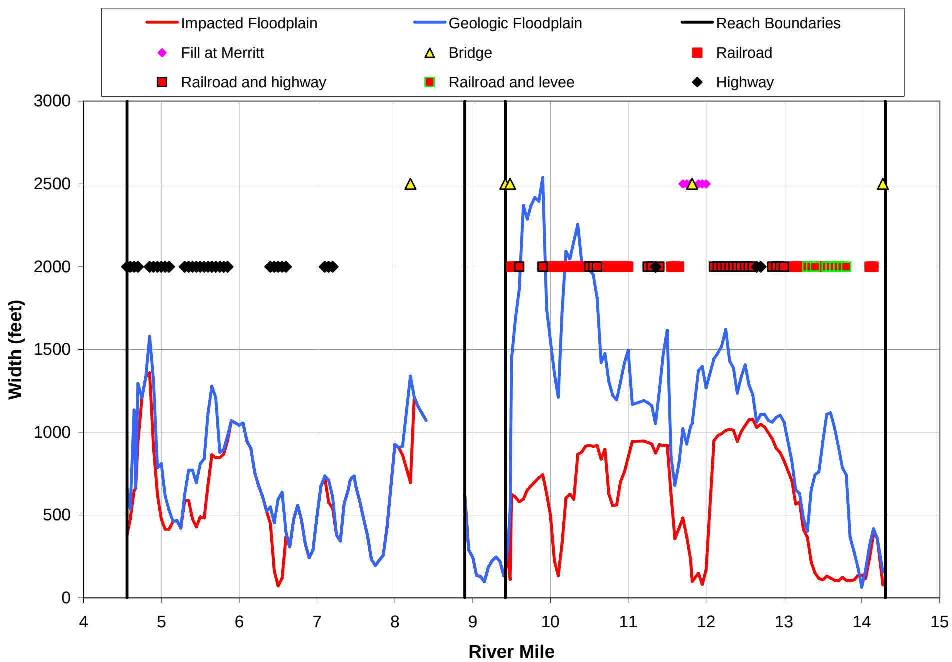


Figure 25. Reduction in floodplain width due to anthropogenic features with locations referenced as symbols that are identified in legend box.

Of the five bridges in the assessment area, the bridges at RM 8.2 and 9.48 have the most impact in reducing the floodplain width due to the associated approach embankment leading up to the bridge. The wooden bridge at RM 9.42 has recently fallen in the river, but the embankment remains in place. At RM 11.8, the fill at Merritt plays a larger role in the reduction of floodplain than the bridge itself. The bridge at RM 14.3 does not have much impact on constricting the floodplain width, but more impact on channel function from riprap as will be described in the next report section.

The maximum floodplain width reduction in Reach 1 is 520 feet, located near RM 6.5. Between RM 6.5 downstream to 4.6, the areas that have reduction in floodplain width correlate with disconnected floodplain areas caused by the U.S. Highway 2 embankment.

Between RM 6.5 to 9, the only impact to floodplain processes occurs where a bridge and road embankment have been constructed at RM 8.2. The embankment is located in the middle of the floodplain, so flow can still inundate areas around the embankment (Figure 26). The bridge has been in place since the 1962 aerial photographs, but may have been rebuilt since that time.

Floodplain inundation from the 2D model results were compared for impacted (existing) conditions and for historical conditions assuming the highway embankment had not been constructed (see maps 35 to 38 in atlas for results at 10,000 cfs as an example of model output). A modeled flow of 5,000 cfs is generally contained within the active channel and side channels in Reach 1, with a minimal amount of shallow overbank flow. At 10,000 cfs the majority of the present floodplain is inundated. The increase in stage from 2,500 to 10,000 cfs between both existing conditions and modeling with the human features removed modeling is approximately 3 to 4 feet. To look more quantitatively at impacts to water depth from disconnecting small portions of the historical floodplain, a model result of 10,000 cfs was used for comparison (Figure 27). The largest impacts to water depth are centered around the disconnected areas such that once connected, depths in the present floodplain are generally lowered. A few areas in the present floodplain would actually increase in depth due to the altered flow path alignment if the disconnected areas were reopened.

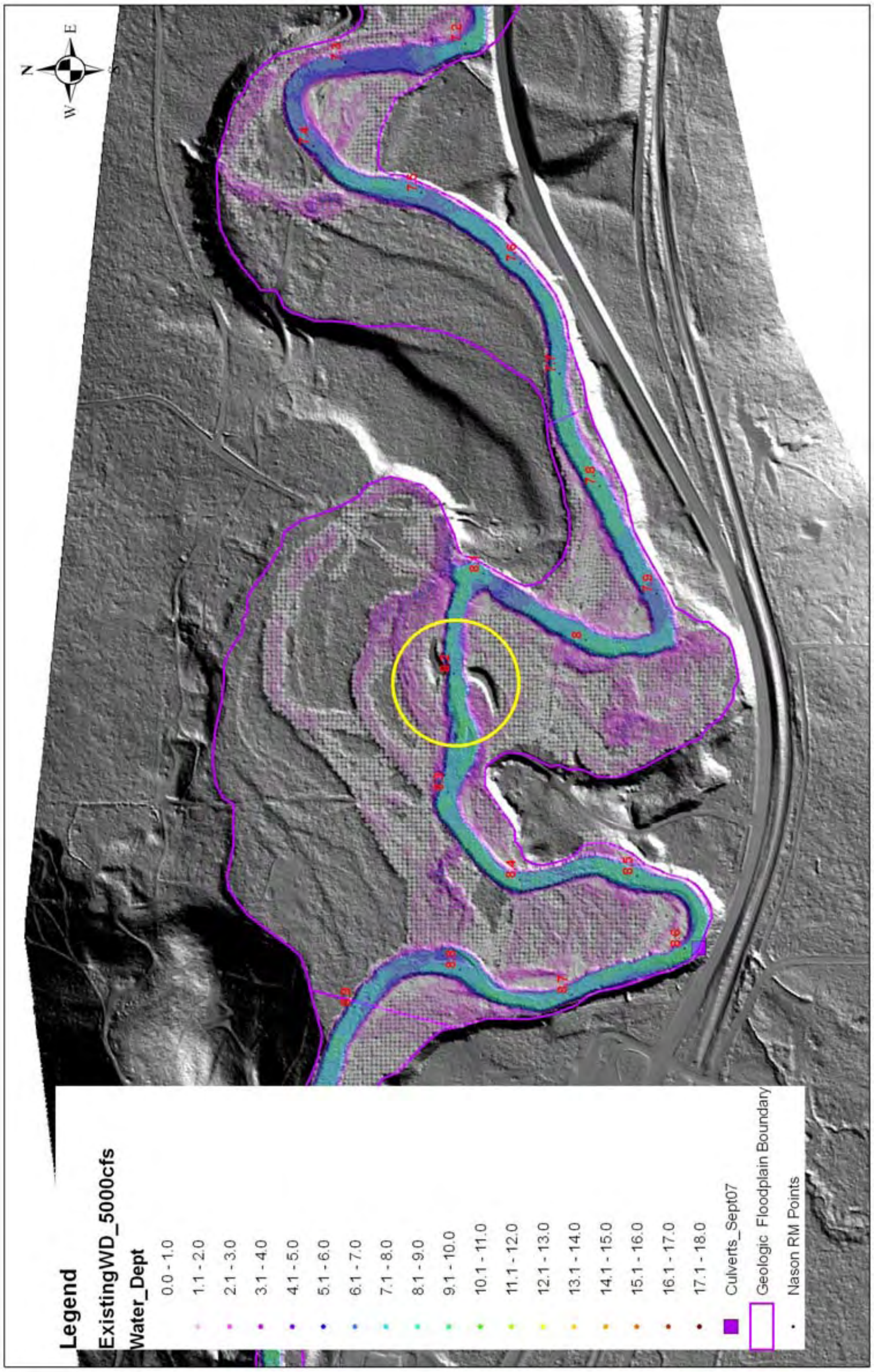


Figure 26. Impact to floodplain processes at RM 8 where flow can still go around embankment. Water depth (ft) results from the 2D model at a discharge of 5,000 cfs are shown, and are fairly shallow beyond the banks of the active channel.

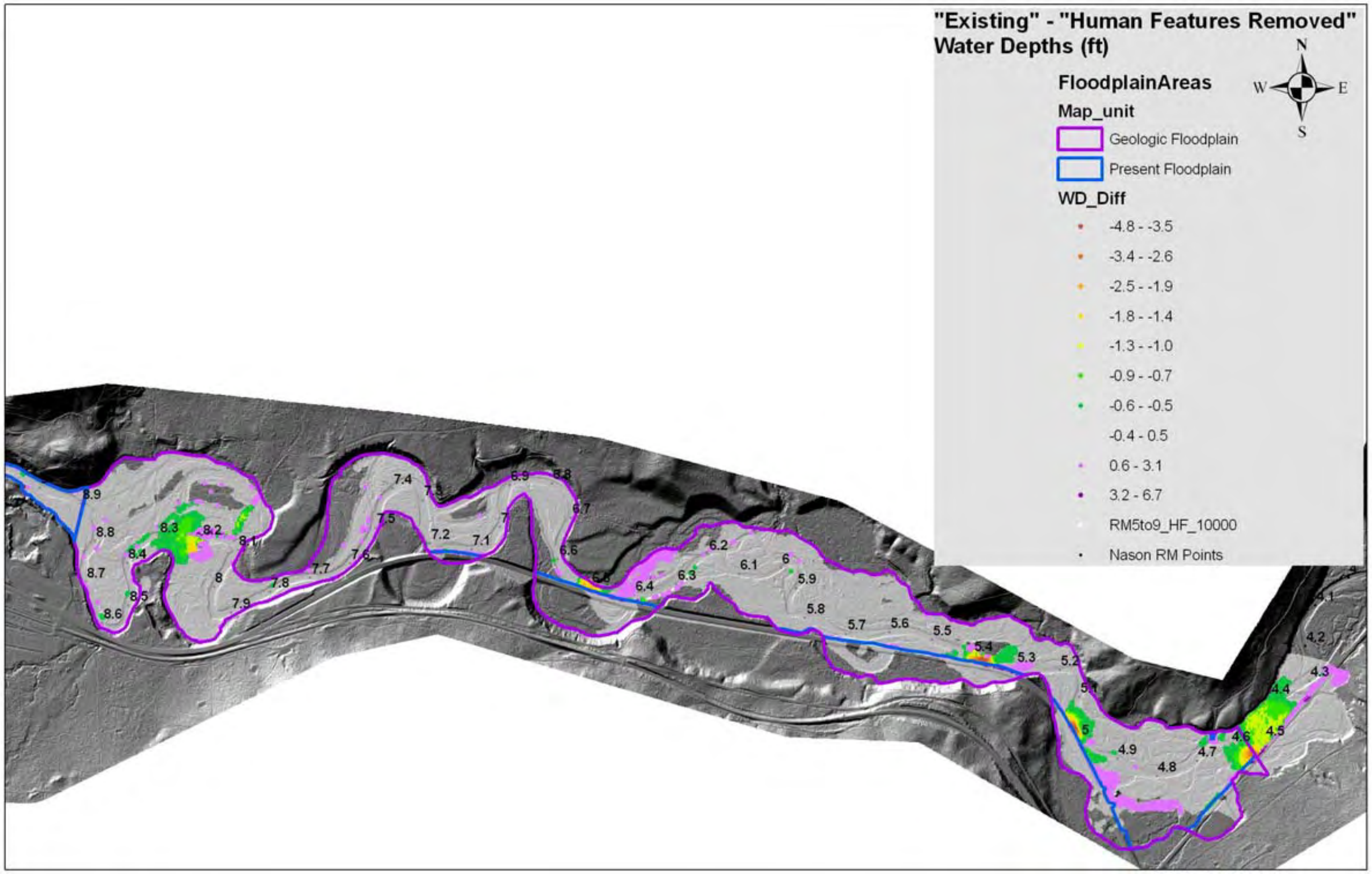


Figure 27. Difference in water depth between impacted present conditions at 10,000 cfs and presumed historical conditions had the highway and bridge embankments not been constructed. The white shading represents the extent of inundation under historical conditions, as compared to impacted conditions which cannot exceed the blue boundary line. The green (smallest reduction), yellow, orange, and red (largest reduction) show areas where water depth would be reduced by at least 0.5 feet if the historical floodplain were accessible. The pink and purple areas show where water depth would increase by at least 0.5 feet within the present floodplain.

The maximum floodplain width reduction in Reach 3 is 1,800 feet, but the impact to floodplain connectivity is almost continuous along the entire reach (see Figure 25). At the lower river flows such as 2,500 cfs, water begins to inundate side channels in meandering sections. At flows of 5,000 cfs and greater, the flow begins to spills out onto the floodplain. The majority of the floodplain is inundated at 10,000 cfs. Below White Pine and along Merritt in the artificially-confined sections, even 10,000 cfs is mostly contained within the active channel banks. In other artificially-confined channel sections, flooding of overbank surfaces occurs as low as 2,500 cfs. This is a result of backwater caused by rapid widening of the floodplain at the upstream end of constricted channel segments (Figure 28). The water depth is increased in backwater areas in Reach 3 by less than 1 foot at 2,500 cfs and about 3 to 5 feet at 10,000 cfs. When the railroad and highway embankments are conceptually removed to allow access to the historical floodplain for modeling purposes, the backwater is reduced and the slope is more consistent with other areas in the reach not impacted by backwater. The exception is just upstream of RM 9 which is a natural geologic constriction resulting in backwater, and above Merritt at RM 12 where fill was not removed from the model topography (historical floodplain topography could not be estimated for modeling purposes due to the extensive fill at this location). Between RM 13.5 to 14, the slope and water surface elevation reduces because in the modeling scenario, the present engineered channel was filled and the channel allowed to re-access the historical main channel. This changes the alignment, area, and location of flow inundation for this river segment which overall reduces the flood stage.

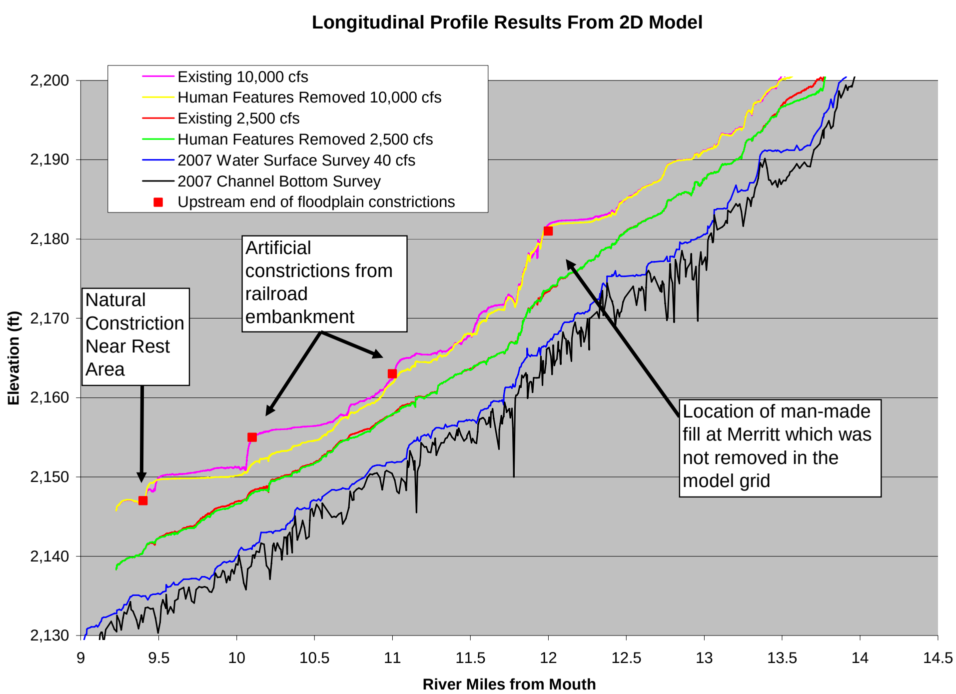


Figure 28. Backwater impacts from confined floodplain areas in Reach 3.

5.3.3 Modifications to Channel Geometry and Migration

For RM 4.6 to 14.3, human-made features that directly impact channel migration includes features that directly prevent lateral channel migration where it would otherwise meander. These can be the same features that prevent access to the floodplain, such as railroad and highway embankments, but in other cases may be different, such as riprap on the outside of an existing bank or barbs used to redirect the river away from a bank. The riprap and barbs limit migration, but are not a major impact to floodplain connectivity because they do not prevent overbank flooding onto the adjacent surface. Indirect effects to channel migration can also occur as a result of upstream or downstream features that result in an alteration of the channel sinuosity. The historical occurrence and impact of these features on channel migration for the assessment area are described below.

Channel migration is presently occurring in about one-fourth of Reach 1 and one-third of Reach 3, where historically it occurred in 50 percent of Reach 1 and nearly all of Reach 3 (see Table 9 and maps 29 and 30 in atlas for migration locations). Channel migration did not historically occur in Reach 2. The majority of reduction is due to railroad and highway embankments and fill placed at Merritt that result in straighter channel paths than historical conditions. This reduction also means a reduction in side channel and off-channel habitat areas historically available to fish. The total reduction in HCMZ is 150 acres, of which some portion would have contained off-channel habitat, wetlands, and backwater areas at any given time.

About 50 percent of the main channel in Reach 3 has riprap on at least one side of the main channel (Table 13). Less riprap is present in Reaches 1 and 2. The majority of riprap is associated with protecting the railroad and highway embankments from erosion, but an additional 9 percent is located along bridges, private property, and power and transmission line poles that reduce channel migration in additional areas beyond those confined by the railroad and highway (Figure 29 and Figure 30; also, see maps 23 and 24 for locations of riprap and human-made features that limit migration).

Table 13. Amount of bank protection along main channel.

Reach	Length of Riprap		Percent channel length with riprap on at least one bank
	left bank (feet)	right bank (feet)	
1 (Coles Corner to Rest Area)	300	2,700	13%
2 (Rest Area)	50	0	2%
3 (Rest Area to White Pine Bridge)	4,430	9,950	50%

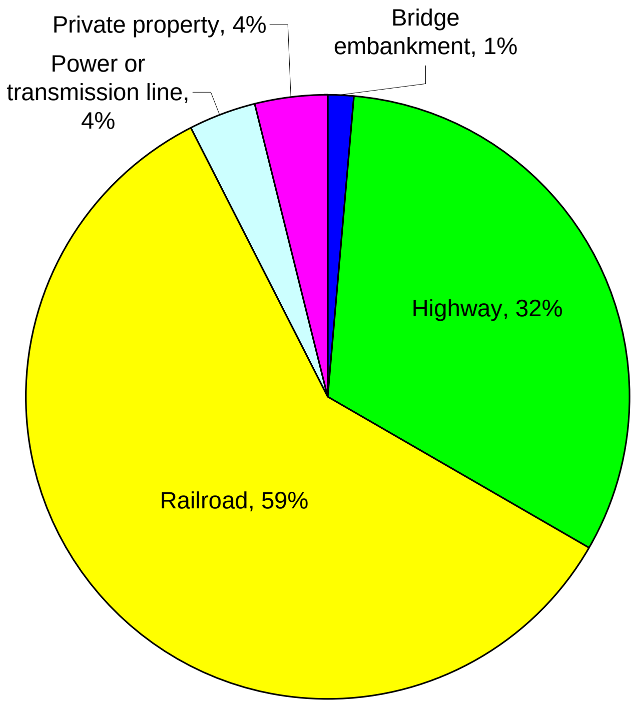


Figure 29. Purpose of bank protection along main channel by type of human feature in assessment area.

Figure 30. Downstream view to the east of sheet pilings that protect the power pole near RM 13.5

For the remaining sections that have actively migrated between 1962 and 2006, evidence of channel migration within the HCMZ has only been 0.5 acre in Reach 3, or about 0.1 percent of the reach and has not occurred in Reaches 1 or 2 (Table 14; see maps 29 and 30 in atlas for locations). An additional 13.3 acres in Reach 3 and 6.6 acres in Reach 1 have been eroded by channel migration, but the area eroded is terraces within the floodplain (in other words, expansion and widening of the HCMZ). Overall, the total amount of migration is presumed to be lower than historical values prior to all the channel confinements.

Table 14. Amount of channel reworking and expansion of the HCMZ (erosion into terraces) by reach.

Reach	HCMZ Reworking Area (acres)	Percent of Reach	HCMZ Expansion Area (acres)	Percent of Reach
1	0	0.0%	6.6	2.0%
2	0	0.0%	0.0	0.0%
3	0.5	0.1%	13.3	4.0%

The remaining area that is migrating encompasses 3.1 miles of channel and these areas are still impacted in terms of channel migration function. Each area is described below in order from upstream to downstream.

RM 12.78 to 13.3 (map 24 in atlas):

Active migration has occurred since at least 1962 and hydraulic model results indicate this reach has complexity in terms of varying velocity and water depth, which is essential for developing habitat and diversity in the ecosystem (Figure 31). However, barbs and riprap along the outside of the meander bends protect U.S. Highway 2, which impacts the lateral extent of migration (Figure 32). Because the upstream-most meander bend is not locked in with riprap, the channel may eventually cut off the present meander and start a new meander cycle despite the bank protection and in-channel features on river left. The position of the meander bend is impacted at the upstream end because of human-induced channel confinement just upstream.

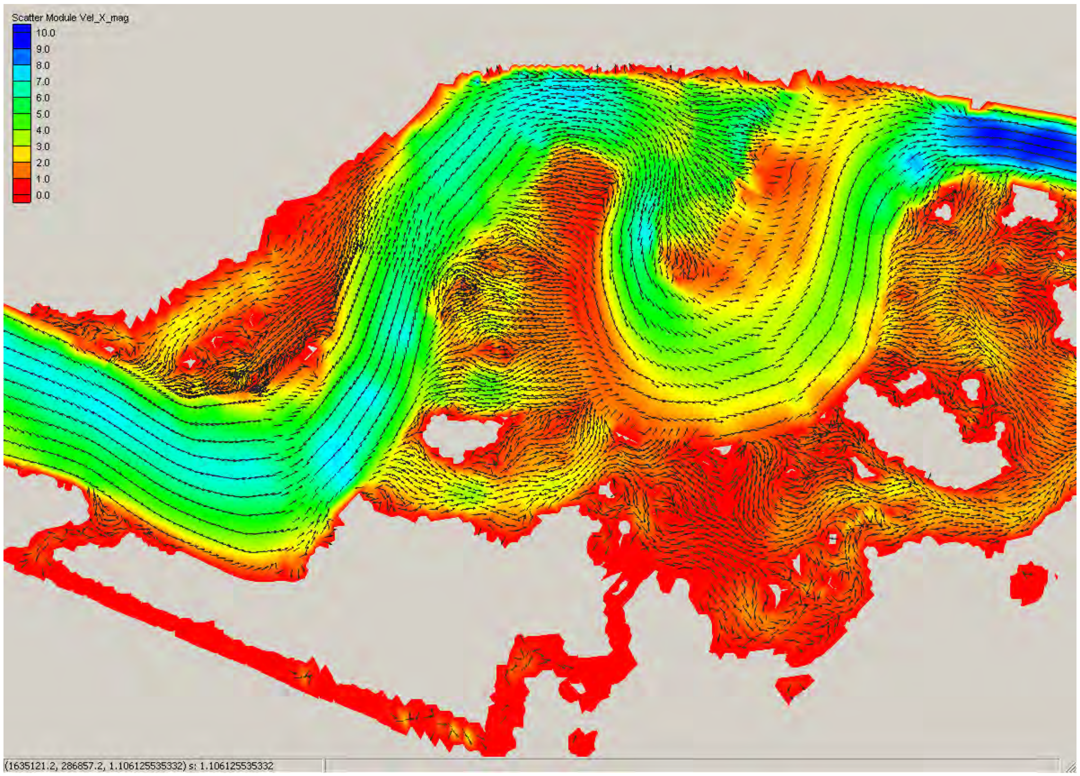


Figure 31. Example of 2D model velocity vectors (black arrows) and magnitude (color coded legend in feet per second (ft/s)) results around RM 12.7 to 13.3.

Figure 32. View is to the northeast looking downstream, showing riprap with two rock spurs into channel at RM 13.3. (Reclamation photograph by D. Bennett, August 7, 2007).

RM 12.47 to 12.1 (map 24 in atlas):

The channel upstream of the engineered channel around Merritt appears to have historically been more sinuous based on channel paths evident in the 2006 LiDAR data and historical maps (see map 28 in atlas for comparison of historical channel alignments). Although this channel section is not artificially confined, the sinuosity is reduced likely due to the backwater caused by the fill at Merritt during high flows. The backwater decreases the sediment transport capacity during high flows, so to increase energy the channel may have adjusted to a less sinuous, shorter and steeper path. Although it is less sinuous, the channel is still meandering rather than running completely straight or becoming braided, which indicates the energy still exceeds the sediment loads. Additionally, sediment capacity shows the bed and bars are frequently reworked (see Figure 19 in Section 5.2.2). There is also not any evidence of aggradation based on a comparison between 2007 and 1980s channel bottom data (see Appendix G). Sections of the historical main channel have been disconnected by U.S. Highway 2.

RM 11.42 to 11.1 and RM 10.68 to 10.1 (map 24 in atlas):

Between 1962 and 2006, the channel has migrated a fair amount in these two sections (Figure 33). The migrating channel areas are pinched between artificially confined sections upstream and downstream, which likely alters the channel position and migration rate. In both locations, the channel is now eroding outward into an unvegetated terrace of the floodplain. If the bank is eroding at an accelerated rate because it is cleared of vegetation, the sediment bar on the inside of the meander bend could be growing at an accelerated rate. This could hypothetically reduce the ability for seedlings to establish on the bar, and also impact channel geometry on the outside of the meander bend if sediment volumes from bank erosion locally overwhelm the river’s ability to maintain a scour pool on the outside of the meander bend. Further monitoring and survey data at this site would be useful at a project scale to more clearly understand impacts.

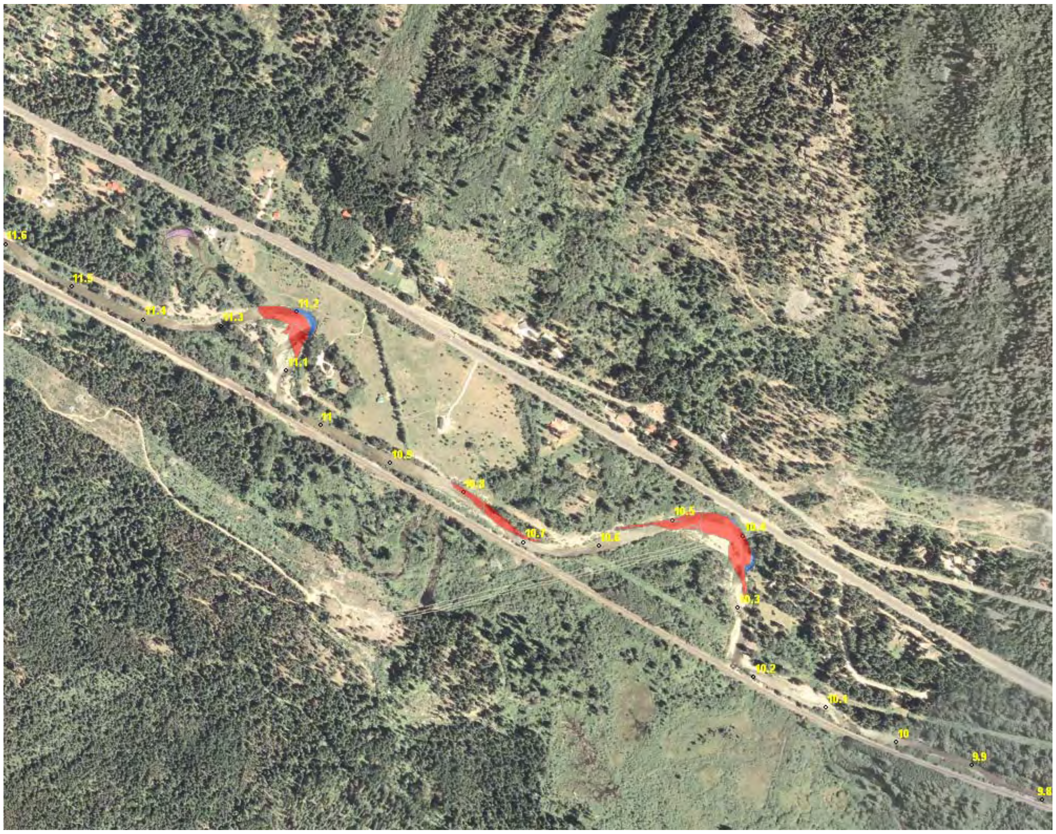


Figure 33. Example of two meandering channel locations (between artificially confined sections) where bank erosion along the outside of a meander bend at RM 10.4 and 11.2 occurred between 1962 and 2006 (colored polygons show erosion areas) (also see maps 29 and 30 in atlas for more locations of channel areas that have been reworked).

Between RM 10.1 and 10.48, the channel meander is progressing toward U.S. Highway 2 and, as of 2007, there was a narrow wedge of floodplain left between the highway and the river bank (see Figure 33). This is also a location where Roaring Creek and Coulter Creek drainages enter, although presently the confluence is blocked off by the railroad embankment with limited flow passage through culverts. This area has the potential to trap sediments that are flowing in from the tributary and hillslopes. The historical main channel downstream of RM 11.1 is believed to have been on the opposite side of the railroad. 2D modeling with the railroad removed shows the difference between the present channel meanders versus the historical channel path which were more sinuous (Figure 34). As discussed for Merritt, part of this change may be due to backwater caused upstream of the confined sections (see floodplain report section), which overlaps with these two meandering sections.

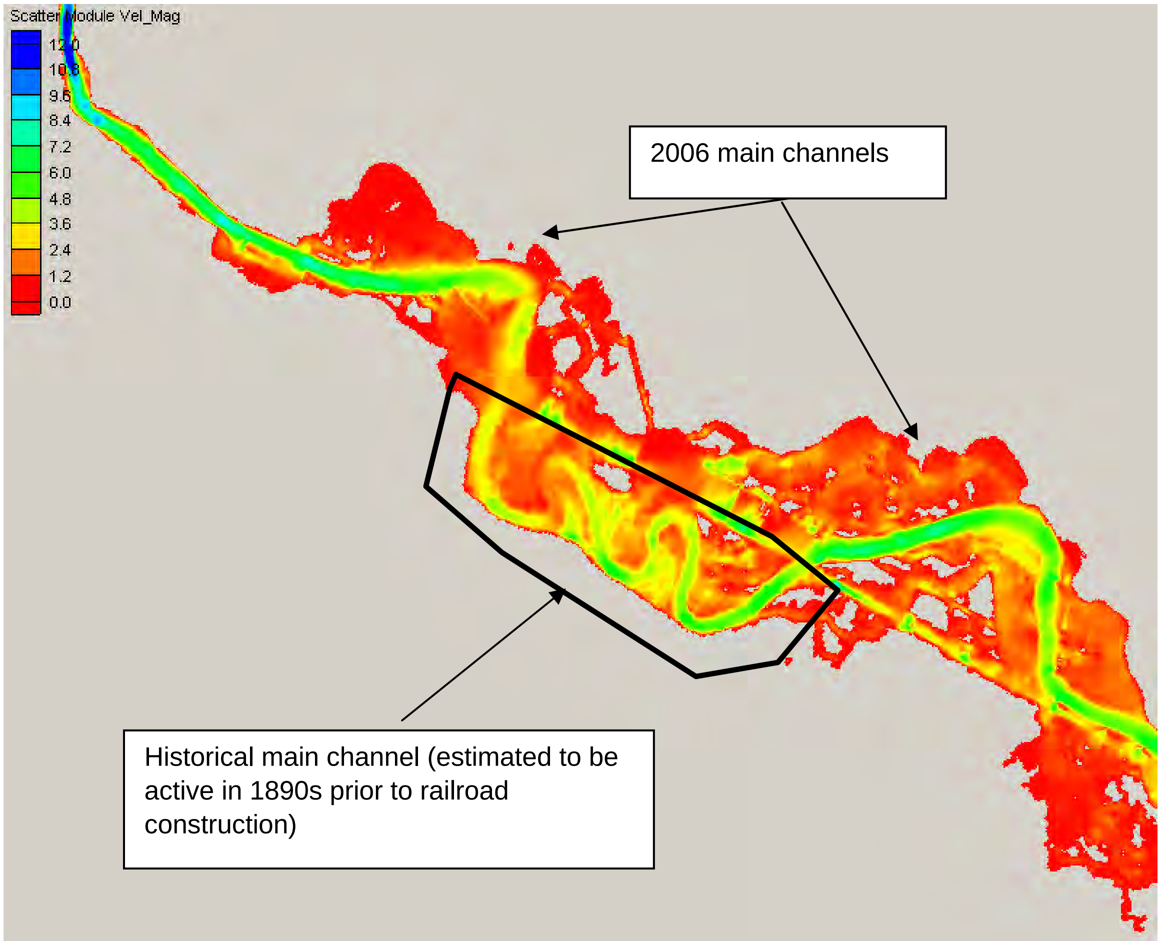


Figure 34. Image showing velocities and channel alignment of existing meanders and historical meander between RM 10.1 and 11.5. Note the tighter meander bends represented with the historical channel as compared to the two present (2006) meanders.

RM 6.39 to 5.75 (map 23 in atlas):

This section has a side channel that has developed through channel migration and reworking since 1962 near the confluence with Kahler Creek (Figure 35). The power line crossing presently runs through this side channel and vegetation has been cleared along its path. There is no bank protection currently, but the power line poles are at risk if further migration occurs. Because the banks have been cleared of vegetation, lateral bank erosion on the left side may be accelerated and altering the rate of migration.

Figure 35. Photograph of split flow at RM 6.

RM 5.3 to 4.56 (map 23 in atlas):

Channel migration impacts in this segment are not well understood. This segment is a transitional section between a steeper-sloped channel upstream and a flatter-sloped channel downstream. The valley makes a large bend in this section with a flatter slope relative to upstream sections. Two-dimensional computations show this causes a reduction in energy and sediment transport capacity. Because of this, the meanders are mildly sinuous. Impacts to present channel migration occur because a portion of the historical channel has been disconnected by the highway, but the channel has not been straightened and confined like in other segments. Additional impacts to channel migration may be occurring from upstream and downstream channel confinements (about 0.9 miles of channel was disconnected downstream when Highway 207 was realigned).

5.3.4 Modifications to Channel Geometry

Channel geometry has been impacted in the majority of channel areas along this section of Nason Creek. Some changes are obvious, such as in areas that have been artificially confined, and other impacts are more difficult to discern, such as areas that have been riprapped for many decades along road and railroad embankments (Figure 36).

Figure 36. Historical image labeled as "a spawning riffle on Nason Creek" that also shows the road embankment at an unknown location. Photograph by Alfred S. Witter from 1930s to 1940s timeframe reprinted with permission from Oregon State University Historical Photograph Collection.

As a result of the channel straightening, the length of the main channel has been shortened by 1.4 miles in Reach 3 and 0.6 miles in Reach 1 relative to conceptual channel lengths of historical conditions (Table 15; see Appendix J for methods). Channel bed elevations were compared to historical data where the channel has been straightened to look for signs of how the geometry has been altered. Two hypotheses on changes in channel geometry were that the channel may have incised below the historical channel bed level or the channel has widened to reduce excess energy caused by the shortened channel paths. Additionally, 2D hydraulic model results were used to compare hydraulics in presently meandering sections with confined sections to look for significant differences.

Table 15. Change in channel length due to artificial confinements.

Reach	2006 channel length (river miles)	Average length of 3 conceptual historical channels (river miles)	Average reduction in length (river miles)
1	4.3	4.9	0.6
2	0.5	0.5	0
3	4.9	6.3	1.4
Total	9.7	11.2	2.0

FEMA channel survey data from the 1980s was compared to 2006-07 data in confined sections to see if there were any signs of a trend of incision or widening over the last 20 to 30 years (Figure 37; more examples in Appendix G). Where the channel is in the same position as the 1980s data, the bed elevation or channel width has not appreciably changed over the last few decades. The LiDAR data indicates that the present channel is 2 to 3 feet lower than many historical channel elevations that may have been active prior to realignment and straightening. However, 2 to 3 feet of incision may be conservatively high because the historical channels may have filled in with finer sediments from hillslope runoff and tributaries and often have ponding such that the LiDAR would represent the water surface of the pond rather than the actual bottom elevation of the channel. Additional channel incision is not expected to continue based on preliminary investigation of geologic controls, sediment transport capacity, and observations of large cobble sizes present in the bed.

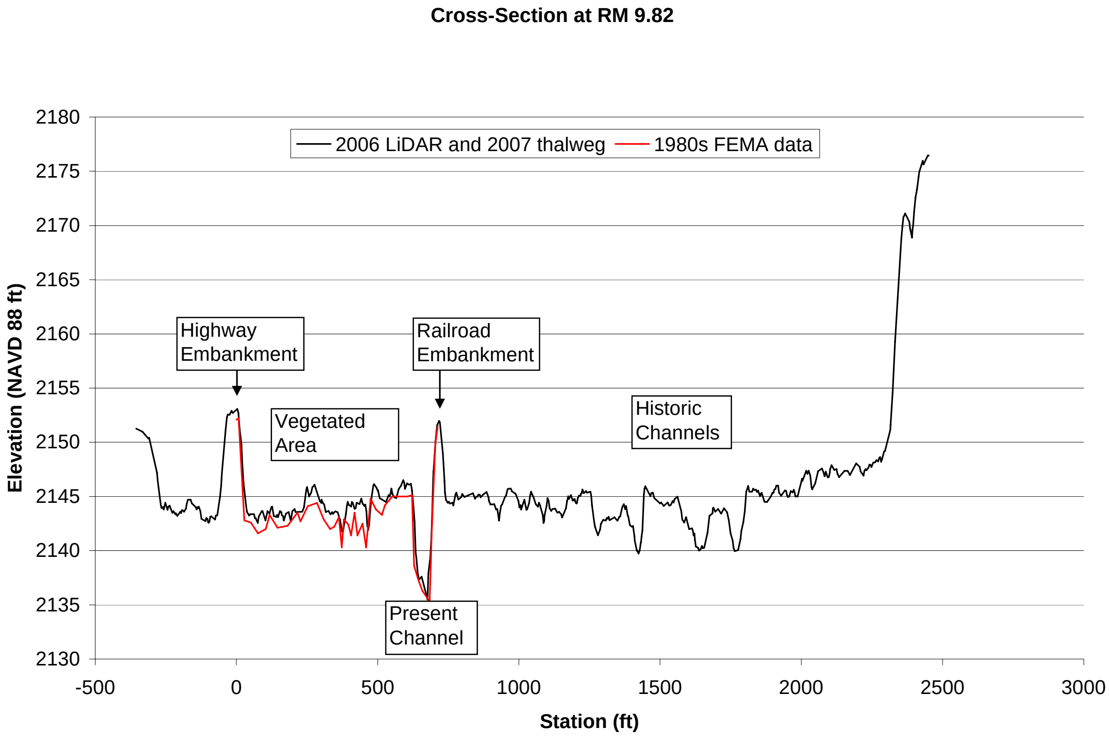


Figure 37. Nason Creek cross section at RM 9.82.

High quality rearing and holding habitat is often associated with areas that have water depths greater than 3 feet. Therefore, the locations of water depths greater than 3 feet from a 2007 survey at 40 cfs (low flow) were overlaid with mapping of areas that are presently meandering and areas that are confined and armored with riprap (Figure 38). Overall the density of 3 feet and greater depths was higher in Reach 3 than Reaches 1 and 2. Meandering sections generally contained a fair amount of the deeper depths, but confined sections also contained several areas of depths greater than 3 feet. It is hypothesized that many of the pools in confined sections are formed as scour pools to release energy so that although they are deep their quality is poor in terms of habitat value. Many of the deepest depths were associated with the presence of LWD (see maps 19 and 20 for LWD locations). The largest depth at RM 11.78 is located in a confined channel that runs along the fill at Merritt.

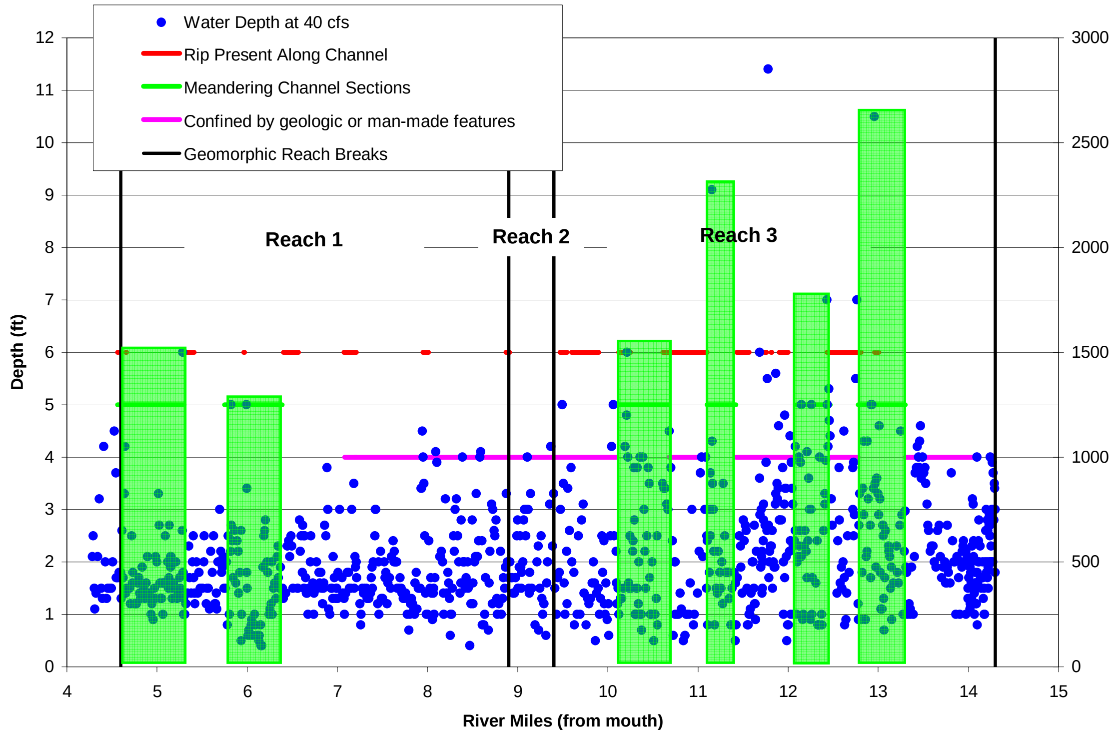


Figure 38. Plot of water depths greater than 3 feet in assessment area overlaid with meandering and confined sections and riprap.

To compare the meandering sections with confined sections, 2D model results for velocity were evaluated (Figure 39). Differences were more apparent in Reach 3 than Reach 1 because the disconnected areas are smaller in Reach 1 and the slope is in most places steeper. Confined sections had consistently higher velocities than meandering sections during a high flow of 10,000 cfs shown in Figure 39, but this was also true for all flows modeled. Areas that had backwater influences from downstream constrictions had lower velocities than confined sections that were not subjected to backwater. A close-up view of velocity vectors shows another impact to channel function. Confined, straight sections have uniform flow paths that contain little diversity in depth, velocity, or shear stress. However, meandering sections are more diverse in terms of channel hydraulics, showing variation in depth and velocity through the meander bend (Figure 40). This diversity in hydraulics is critical to supporting a range of habitat life stages of ESA-listed fish. For example, spawning areas are generally shallow, faster velocity sections compared to deep pools with LWD that offer holding and cover.

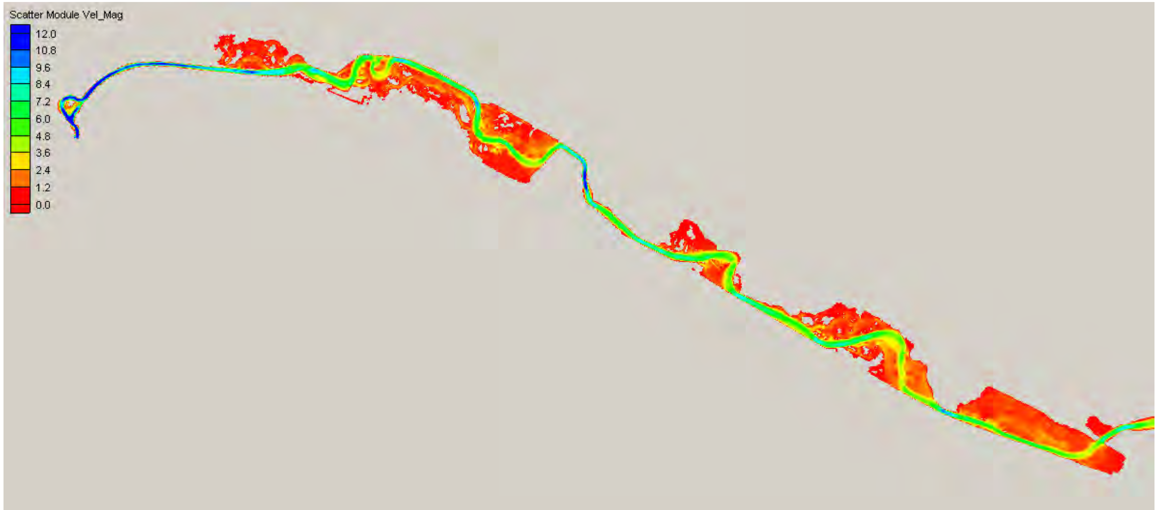


Figure 39. Velocity magnitude (ft/s) results from 2D model for RM 9 to 14 at 5,000 cfs.

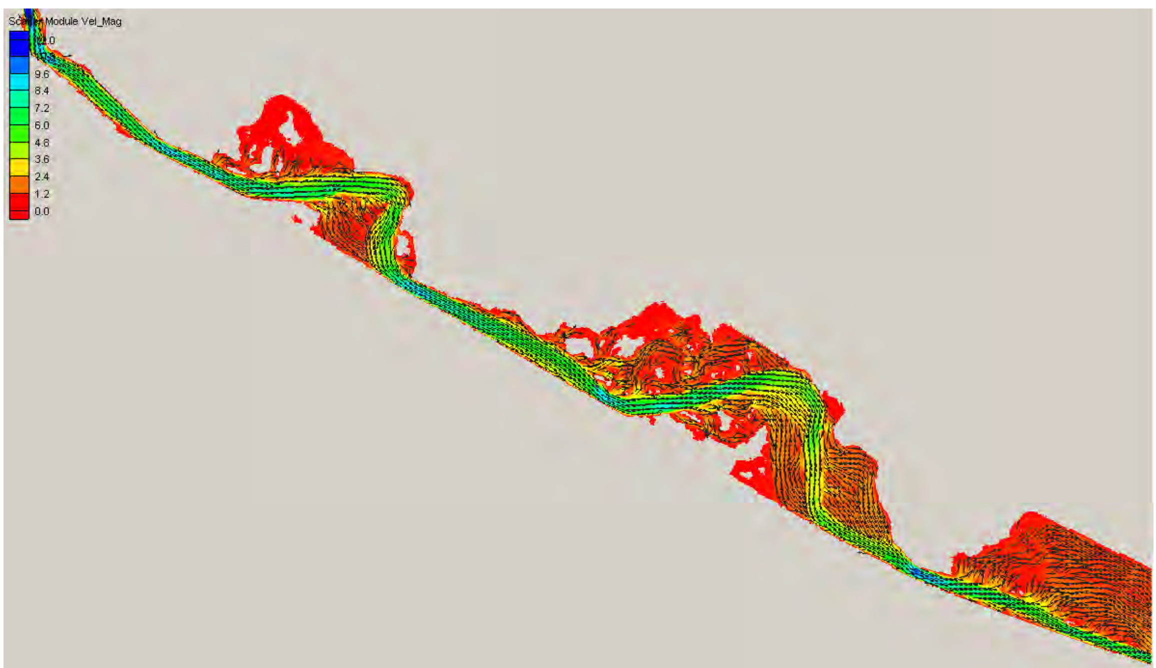


Figure 40. Example model result at 5,000 cfs of velocity magnitude (ft/s) and vectors between RM 9.5 and 11.1 (flow is from left to right in image).

5.3.5 Changes in Riparian Vegetation and LWD

Historical timber harvest and LWD clearing were evaluated based on anecdotal accounts and a literature review of historical documentation (Table 16, see maps 7 and 8 in atlas; Appendix B – Historical Timeline). Vegetation classification, maximum canopy age, and health condition were mapped in 2006 to assess general trends in vegetation condition following timber harvest activities (see Appendix I – Floodplain Vegetation Assessment; maps 7 and 8 in atlas). Areas that are presently cleared of vegetation for the power and transmission lines, development, or other reasons were noted. This information was linked to the ability of the vegetation to provide shade and cover, and whether it could be an adequate source of large woody debris if the river had access to it.

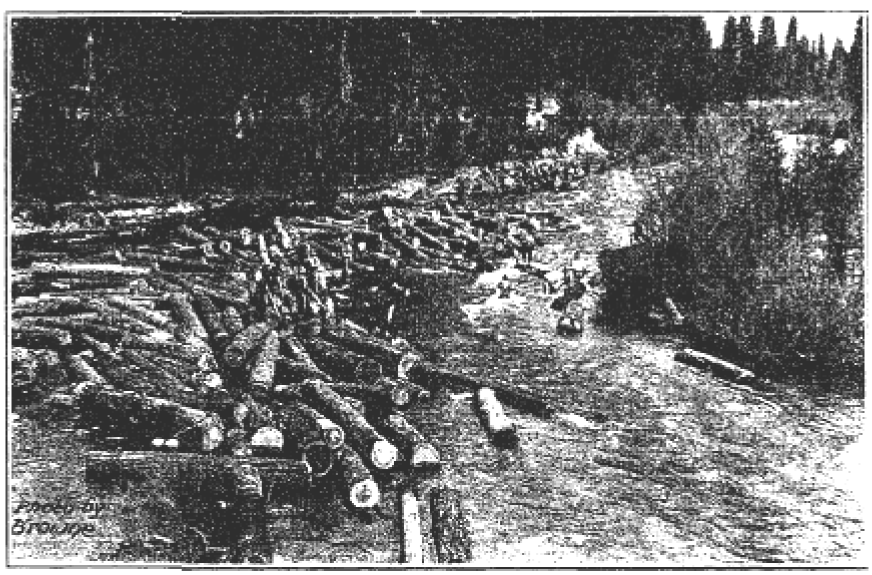
Table 16. Summary of Nason Creek vegetation analysis results by geomorphic reach.

Reach	Area (acres)	Presently impacted[1] (acres)	Natural species[2] (acres)	Percent Impacted	LWD potential area[3] (acres)	Percent LWD potential area	Percent shaded[4]
1	334.9	54.7	280.1	16%	206.2	62%	80%
2	13.6	0	13.6	0%	9.2	68%	96%
3	607.6	128.3	479.3	21%	255.4	42%	77%

[1] Impacted areas which are not potential natural community riparian vegetation but are anthropogenic land cover including railroad rights-of-way, roads, power line corridors, private and commercial property.
[2] Riparian areas which presently contain potential natural communities, even though many of these areas have been historically logged. Therefore, although native to the area, the structure, age, and species compositon may be different than historical conditions.
[3] Areas where over 50 percent is covered by trees of a height suitable to form LWD-based habitat in the main channel [trees over 40 feet (12 m) tall] which could be potentially recruited into Nason Creek by either high flows or active river migration.
[4] Percent of main channel which is presently shaded by vegetation (lateral extent of shading may vary). Note that this estimate is based on a buffer width along the stream of 82 feet (25 m).

The vegetation along Nason Creek is influenced by the topographic layout of the Cascade Mountains ranging from high elevation subalpine forests at approximately 5500 feet elevation to dry forest environments around 2000 feet in elevation (USFS 1996). Within the assessment area, Douglas-fir and grand fir are typically co-dominant in the canopy with vine maple being the common understory species (see Appendix I – Floodplain Vegetation Assessment; maps 31 and 32 in atlas). Black cottonwoods are present along the river and along abandoned river channels. Sand-bar willows and black cottonwood are present on gravel and cobble bars. Pacific willow and some alder species are found in wet areas. Very limited amounts of western red cedar are mixed throughout the reach.

Historical accounts note that timber harvest along the Nason Creek riparian corridor downstream of RM 14 started in the 1890s during railroad construction and early pioneer settlement and likely ramped up to an annual basis between 1905 to 1927 (Appendix B – Historical Timeline for references). Fires set to clear the right-of-way during railroad construction work spread over considerable areas of the entire valley and adjacent hills, and these, together with the cutting for railroad uses, greatly reduced the amount of standing timber (Plummer 1902). Additional fires were often started from the trains themselves and resulted in burning of adjacent hillslopes. Historical estimates in the early 1900s document that 17 to 35 million board feet a year were logged from several tributaries within the Wenatchee subbasin during the winter months, including Nason, Chiwawa, and the White River (see Appendix B – Historical Timeline for more references). Once harvested, the logs were stacked along the river banks and then driven down the river in spring snowmelt flows to a dam on the mainstem Wenatchee (Figure 41). During this process men were hired to literally “ride the logs” to ensure they did not get hung up and, if a log jam was encountered, it was dynamited or pulled apart. The log drives were so popular that locals and tourists were known to come watch the annual event each spring and the local newspaper often tracked the progress of the log drives. The logs were collected at the dam, and then taken to a lumber yard, and processed (Figure 42 and Figure 43).

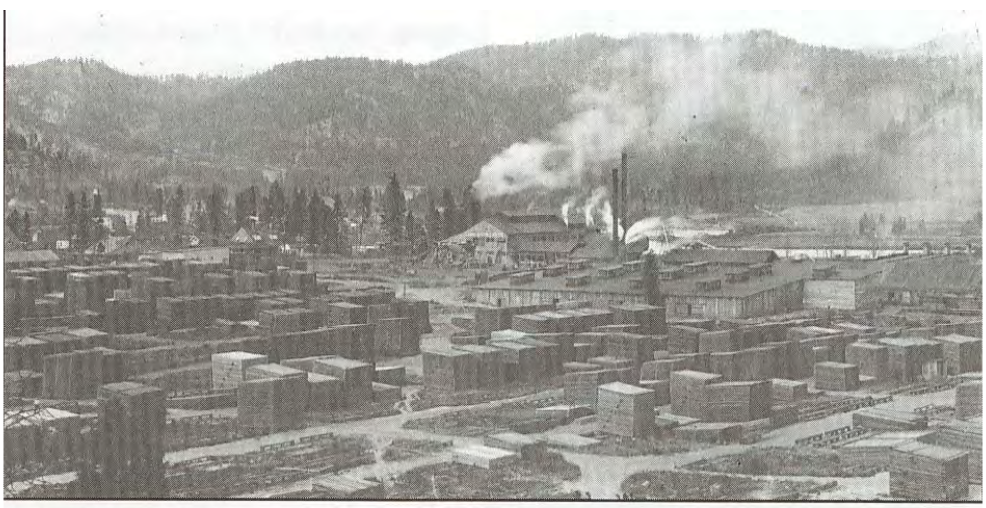


Log Drive on the Chewawa River. There are many million feet of fine timber in Chelan County

Figure 41. Log drive on Chiwawa River (early 1900s) thought to be similar to those that occurred on Nason Creek (image courtesy of Quintin Publications and Hull, 1929).

The Lamb Davis dam in Leavenworth, circa 1915
Courtesy Diane Muranke Collection

Figure 42. Photograph from 1915 of historical dam located on mainstem Wenatchee below Leavenworth (about RM 24) where logs were gathered from log drives down Nason, Chiwawa, and other tributaries of the Wenatchee River. Photograph courtesy of Wenatchee Historical Museum.



Vast yard of milled lumber, the Lamb Davis Co., Leavenworth
Courtesy Diane Muranke Collection

Figure 43. Photograph from unknown date of Lamb Davis Co. lumber mill in Leavenworth, Washington. Photograph courtesy of Wenatchee Historical Museum

Until the 1950s, timber harvest on public lands was largely limited to the harvest of large trees ("high grading") from the valley bottoms and adjacent hillslopes with little harvest on public lands until the 1960s (USFS 1996). From the mid-1970s to the present, clear cutting became a common practice with the volume of timber harvest increasing significantly as "high grading" techniques were replaced with large machinery (USFS 1996). The largest density of the timber harvesting on public lands occurred on hillslopes between White Pine Creek to the mouth of Nason (see map 7 and 8 in atlas).

In terms of historical fire suppression effects in federally managed lands, the USFS concludes the following: "Fire suppression has altered the species composition and density in some of the low inherent fire severity stands, increasing the risk of a high intensity fire, but these areas account for only 5.5 percent of the entire watershed" (USFS 1996). The Round Mountain Fire is the larger of two wild fires that have burned in the Nason Creek subwatershed in recent years. This 1994 fire was located on the ridge between Nason Creek and the Little Wenatchee River near the confluence of Nason Creek and burned approximately 3,407 acres (see map 4 in atlas and Appendix C – Watershed Conditions).

Another historical impact was beaver trapping that occurred in the early to mid 1800s. Beaver trapping is hypothesized by local biologists to have reduced the frequency of wetland areas (Thomas 2007). Quantitative documentation on the extent of beaver trapping or impact to processes at that time is not available, but anecdotal accounts suggest trapping was a widespread, common occurrence in the Wenatchee subbasin.

Within the valley floor of the assessment area, the forest appears to be recovering back to the historical grand fir forest. The floodplain vegetation connected to the river (where field checked) appeared to be in good health and normal vigorous growth was observed. Good lateral complexity was observed in some locations and was best at the few areas where active channel migration has occurred at least since the 1960s. Black cottonwoods occurred throughout the reach with the largest diameter at breast height of about 5.5 feet for the sample trees measured. Old growth (legacy) trees are absent from the assessment area and were most likely removed by logging.

Vegetation is not recovering in areas that remain clear for power and transmission line right-of-ways, highway and railroad embankments, roads, continued timber harvest, or where private development is present. Where channel migration has been hindered by railroad and highway embankments, vegetation growth is limited along the main channel because of reduced bar and floodplain development. On the opposite side of the embankments, ponding from runoff and groundwater sources can be observed as a result of the embankments blocking flow connectivity to the main channel. In these areas typical riparian forests that would have been present along the channel have been partially converted to species that can tolerate higher frequencies and extent of inundation.

Much of the river channel is well shaded by the riparian vegetation, but in some areas shading has been lost due to ongoing vegetation control under the power line corridors, residential clearing, and highway corridors. Although spatially there is a lot of shading, the quality and extent of shading relative to historical conditions is not known. Many of the trees are recovering from historical logging and may not be providing the same lateral extent of shading as historical vegetation communities. High water temperatures are a concern on Nason Creek and further study is recommended to better understand the contribution of riparian vegetation to the thermal regulation of the river (see Appendix F – Water Quality Synopsis).

Non-native vegetation and animal browsing do not appear to be a significant concern for vegetation health at this time. The most commonly found non-native examples were primarily in power line corridors and along roads. Small amounts of knapweed and toadflax were observed on bars.

5.4 Summary of Geomorphic Changes

Human activities that have had the most notable impacts to flow, sediment, and topography over the last 150 years within the assessment area are listed below:

- Beaver trapping is hypothesized to have reduced occurrence of wetlands (early to mid-1800s)
- Railroad and highway construction changed channel alignments, reduced channel migration, reduced access to the floodplain and off-channel areas, altered sediment and LWD transport, and also resulted in disconnection of tributaries and groundwater sources to the main channel
- Flood protection and bank armoring for residential areas, power and transmission poles, U.S. Highway 2, roads, the railroad, and infrastructure causes reduction in lateral migration and the ability to erode and create new channels and floodplain surfaces. Reworking of the floodplain is a vital process necessary for long-term, sustainable ecosystem function in areas that were historically meandering.
- Logging of riparian floodplain and log drives in the main channel estimated to occur from 1905 to 1927, reduced the occurrence of LWD in the channel and its potential future recruitment; this has reduced the number of LWD formed pools and cover in the main and side channels.
- Continued timber harvest on valley floors and hillslopes and clearing of log jams has impacted availability of LWD in the channel.
- The flow and fine sediment loads contributed from tributaries and hillslopes may be getting trapped behind railroad and highway embankments; the quantity and relative impact of this process was beyond the scope of this assessment.

- Extensive sections of straightened channel with riprapped banks have impacted vegetation adjacent to the river channel, reducing regrowth of trees and shrubs along with reducing the presence of LWD in the main channel. The confined channel results in limited bar development or floodplain surfaces for vegetation to colonize. Shading from vegetation is generally adequate but could be improved in riprapped and cleared areas.
- Sediment recruitment to the river from channel migration and bank erosion is likely reduced below historical levels due to the significantly reduced channel reworking area. In the few areas where the bank erosion is currently occurring, it is generally along a bank that has been cleared of vegetation and/or opposite a human feature in an artificially-constrained section of channel. From a sediment source perspective, the small amount of erosion occurring opposite human features is more than offset by the large amount of riprap on the banks in areas where natural bank erosion would be occurring.
- Very little off-channel habitat (side channels and accessible wetland areas) presently exists for rearing fish with the few locations centered near LWD present in the wetted low-flow channel. In locations where the channel is constrained, the channel banks are generally armored with riprap and/or boulders, and there is limited potential to recruit LWD from the adjacent riparian corridor. Because the constrained channel sections are often high in energy (velocity), it is also difficult for the river to sustain LWD transported into the reach from upstream reaches. The lack of wood has reduced both the quality and quantity of salmonid habitat in the main channel.
- Tributary and groundwater sources are not well connected to the main channel because of large embankments with few or undersized culverts the embankments result in ponding on the non-river side which may result in warmer water being contributed to Nason Creek and also presents a fish barrier
- Although deep depths and pools are frequent, very few pools have LWD associated with them and many are lacking riparian buffers along the margins of the wetted channel.
- These changes in geomorphic conditions can translate to impaired access to floodplain and off-channel habitat areas by fish and to a reduction in habitat features that depend on channel migration, recruitment of LWD, and reworking of the streambed.

6. EXISTING GEOMORPHIC CONDITIONS RELEVANT TO HABITAT RECOVERY ACTIONS

The previous chapter focused on historical changes to the of Nason Creek flow regime, sediment regime, and channel and floodplain topography at a coarse scale upstream of RM 14, and at a more detailed scale between RM 4 to 14. This chapter is intended to provide a general description of the geomorphic condition of each reach as it exists today, and the relevant geomorphic factors of flow, sediment, and topography that could influence the selection of restoration actions or protection areas. Within this section, factors are identified that may require further consideration in the reach assessment effort, where a more detailed assessment of each reach will be provided.

Upstream of Reach 3 (RM 14), geomorphic conditions are functioning fairly well and the USFS is working on restoration strategies for timber harvest and land use management. Toward the downstream end of Reach 1, the river transitions to a flatter slope that continues to the confluence with the Wenatchee River. Downstream of Reach 1 the river runs along Highway 207 and 0.9 miles of historical channel paths have been disconnected based on a USGS 1911 survey (Marshall 1914). Highway 207 blocks off historical channels, but during the 1990 flood was observed to be overtopped such that large flood water flows access the historical floodplain. The shortened main channel path does not appear to have increased energy enough to cause a headcut into Reach 1. Restoration opportunities for disconnected main channel and floodplain areas downstream of Reach 1 have been addressed in a separate analysis conducted by Jones and Stokes (2007). A reconnection of a historical main channel active in 1911 between approximately RM 3 and RM 4 to the present main channel was accomplished in 2007 by Chelan County.

6.1 Reach 1

In Reach 1 (RM 4.6 to 8.9), the channel slope generally ranges from 0.7 to 1.1 percent from RM 4.6 to 7.4, which is a relatively steeper section than upstream and downstream sections of the assessment area. From RM 7.5 to 8.9, the slope is milder ranging between 0.2 to 0.4 percent. The gravel and cobble-sized sediment in the channel bed and bars is frequently mobilized based on results of 2D modeling and field observations of unvegetated gravel bars that are present throughout the assessment area. The present high energy state of Nason Creek is mostly a result of steep slopes formed from geologic controls, but localized areas of human-induced disconnected main channel and floodplain have further increased the energy to a small degree. Restoration strategies aimed at lowering stream energy would not be expected to cause any aggradation issues (see Section 5.2) and would actually be beneficial by providing more opportunities to retain LWD and spawning-size sediment.

There are a few areas that presently provide opportunities for quality instream and off-channel habitat, but the availability of LWD in the main channel is overall limited and only a few LWD-formed pools exist. The amount of LWD present is likely much lower than it was historically because of timber harvest and log drives that removed all wood from the river in the early 1900s. Recruitment of new wood is limited in the upstream half of the reach because of limited channel migration (both historically and at present), but recruitment increases downstream of RM 6.4 where channel reworking occurs. Overall the vegetation is in good health and recovering from the historical logging, such that shading and future LWD recruitment will be available if channel migration can be restored between RM 7.9 to 8.3 and downstream of RM 6.4. The exception is the power line access corridor that has been cleared of vegetation and often crosses the path of the present channel in this reach (Figure 44). Where power lines cross the main channel, there is limited to no riparian vegetation along the river banks making the bank susceptible to accelerated erosion. These cleared areas offer good opportunities to replant riparian vegetation to help increase shade and LWD recruitment. Protection of both the power line roads and power poles will need to be addressed unless the power line can be set back farther away from the river.

Figure 44. View to the east (downstream) showing large woody debris and split flow located near RM 6.2. (Reclamation photograph by R. McAffee, May 4, 2007).

In-channel structures are limited to one bridge at RM 8.2 and an abandoned bridge embankment near RM 4.6, both of which limit channel migration resulting in a uniform channel section without much complexity. Channel function could also be improved at three locations where U.S. Highway 2 was placed in the outsides of bends in the historical main channel. In these areas, the channel is attempting to widen by eroding high terrace banks on the opposite side (Figure 45). The lateral erosion is limited and does not stand out as a critical item for addressing in restoration. In many areas, the sediment recruitment from channel migration has been reduced, so that bank erosion in these areas could be viewed as positive, although the contribution of the eroded areas to spawning size sediment is hard to quantify without further analysis. Where the river runs against the highway, there is a lack of overhanging vegetation and the channel is often lacking any cover or complexity from LWD. LWD in these steep, straight sections may be difficult to keep in place without a lot of careful design because the it could easily be washed out. In-channel features may also put the highway at risk for erosion or washing out and would need to be considered.

Figure 45. Looking at eroding glacial bank on left side of river in section where highway has cut off the historical meander bend near RM 6.6. (Reclamation photograph by D. Callahan, October 9, 2007).

6.2 Reach 2

In Reach 2 (RM 8.9 to 9.4), Nason Creek is naturally confined by a glacial terrace on river right and by a large landslide on river left. The lateral confinement results in a single thread channel with a limited, narrow floodplain. There are boulders in the downstream end of the reach that limit vertical incision. There were not identified any notable changes in flow, sediment, or topography over the last century from human features and activities within the reach. This reach mainly serves as a migration corridor for fish with spawning habitat also present in the upstream portion of the reach (Figure 32). The geologic controls in Reach 2 prevent any translation of topographic impacts from Reach 1 into Reach 3, or from Reach 3 into Reach 1. In other words, this reach serves to "reset" the river morphology because it must always pass through the confined, narrow corridor between the landslide and glacial deposit. The minimum vertical elevation of Reach 2 also is controlled by the large boulders in the channel bed.

Figure 46. Photograph of spawning habitat present between RM 9.2 to 9.3.

6.3 Reach 3

In Reach 3 (RM 9.4 to 14.3), geologic controls result in flatter slopes, wide valleys, and nearly continuous opportunities for lateral channel migration and for formation of rearing and off-channel habitat areas. The present channel slopes generally range from 0.1 to 0.5

percent from RM 9.4 to 13.7, and 0.6 to 2.3 percent at the upstream-most end from RM 13.7 to 14.3. Where the railroad and highway have constrained the channel and floodplain, the channel is straight with high velocities and minimal diversity in channel geometry and a lack of LWD. Most of these areas are lined with riprap. While vegetation beyond the riprap provides some shading, there is limited or no recruitment opportunities for LWD (Figure 47 and Figure 48). In three of these areas the historical main channel has been completely disconnected. Restoration concepts could focus on creating complexity in the existing channel, but this would not address the disconnected floodplain and reducing energy in the present channels.

Figure 47. Looking downstream at confined, high energy channel section along railroad embankment near RM 13.9 that provides little to no habitat value. (Reclamation photograph by D. Bennett, August 7, 2007).

Figure 48. Looking downstream at straightened channel near RM 11.6. (Reclamation photograph by D. Bennett, August 8, 2007).

The few remaining meandering sections do have more varied geometry and hydraulics than the straightened sections. Only one of the three meandering sections has ample vegetation along the outside of the meander banks and even this section still has barbs and riprap present in some portions of the meander bends. The two meandering sections that do not have vegetation are eroding into terraces at an accelerated rate and are not recruiting any LWD (Figure 49). Thus, although these sections meander, their ability to provide quality pools and habitat features is presently limited. Additionally, all three meandering sections are pinched between straightened sections. Both locations are meandering toward U.S. Highway 2, but no bank protection has been placed.

Figure 49. Looking downstream along meandering section near RM 11.2 that is eroding into an unvegetated bank about 8 to 10 feet high. (Reclamation photograph by D. Bennett, August 8, 2007).

Restoration strategies will need to consider possible future alignments and encourage channel reworking opportunities. Of particular consideration is how historical channel areas would be reconnected given the new, second main channel that has been created. Consideration will need to be given as to how flow should or would be split or whether portions or all of one of the channels is filled. Additionally, many of the areas would .likely have active migration of the channel, so land use and protection needs will have to be addressed given there is uncertainty in how fast and where the channel will migrate. The present channel is a few feet lower in elevation because of its straightened length. The meandering channels have lowered their sinuosity to increase energy where backwatered by downstream constrictions (Figure 50). At RM 12, Merritt provides a control that, if not altered as part of restoration strategies, would allow separate consideration of channel areas upstream and downstream of Merritt. The channel section through Merritt has high energy and may not be able to sustain in-channel features. Additionally, there are several homeowners along the channel banks that would need to be protected from losing land due to erosion.

Figure 50. Area near RM 13 that is presently meandering and contains some LWD-formed pools. (Reclamation photograph by D. Callahan, October 9, 2007).

6.4 Data Gaps

The tributary assessment fills a large data gap identified by watershed planning efforts, but future studies and design efforts will be needed to incorporate additional field data and quantitative analyses to refine reach-level conclusions. A reach assessment report is also being completed for the 10-mile assessment area and will include the following items not presented in the tributary assessment report:

- Linkage of baseline (existing) physical processes with habitat conditions through the utilization of a modified matrix of pathways and indicators relevant to ESA-listed fish species within Reaches 1 and 3 of the assessment area
- Expansion of reach-based restoration concepts presented in the tributary assessment to develop a list of specific potential restoration sites within each geomorphic reach
- Technical sequencing of the potential restoration actions within each reach based on the linkage of physical processes between project sites and relevant importance of actions to restoring sustainable habitat features
- Detailed existing conditions habitat data (such as wood levels, pool quality, depth and frequency, and spawning substrate) collected in 2007 that can be used as a baseline for comparing habitat conditions following implementation of restoration projects.

Additional data gaps not covered in the tributary or concurrent reach assessment efforts that may be relevant to address in determining project alternatives include, but are not limited to, the following:

- Refine geomorphic mapping
  - Validation of floodplain and HCMZ boundaries in areas that could not be accessed due to heavy vegetation or private land ownership;
  - In areas where proposed alterations to sediment contributions and resulting channel conditions are of interest, completion of additional bank profiles, dating of geomorphic surfaces, and refined analysis of sediment sizes to better understand localized processes important to habitat features; (e.g., restored connections to tributaries that are now cutoff, alterations to existing bank erosion rates)
- Validation of human feature locations and impacts
  - Identification of any new human features or modifications to existing features that may have been constructed since the writing of this report.
  - Further investigation to determine construction and maintenance history of features, and
  - Identification of land use concerns that may need to be addressed such as flooding and bank erosion.
- Hydraulic modeling
  - Refinement of the LiDAR grid (1-meter spacing available) with the 2007 longitudinal thalweg profile and possibly additional ground survey data may be needed at a project alternative or design scale depending on the questions that need to be addressed and the level of certainty required.
  - Evaluation of channel areas below the water surface at 40 cfs and low flow hydraulics, which was not done.
- Sediment computations
  - Additional sampling, which was limited to the ability of the river to rework the channel bed and bars.
  - Additional computations of sediment-transport-capacity and mobile-bed at a project scale if they are needed to predict amounts of incision or deposition within quantitative bounds.
- Streamflow
  - Continued collection of measured streamflow data on Nason Creek, which has only been recorded since 2002 at RM 0.8 by Ecology; operation of this gage should be continued to improve flood frequency estimates as more data

becomes available; additional flow measurements should be conducted at White Pine Railroad Bridge at high flows to understand the range in flood frequency between the two boundaries of the assessment area; a set of flow measurements could be collected longitudinally along the channel to better understand groundwater contributions at low flows. The USFS has started collecting a few measurements at the White Pine Railroad Bridge for Reclamation as of June 2008.

    - Evaluation of groundwater and surface water connectivity was beyond the scope of this tributary assessment, but hypotheses on historical impacts of recharge from groundwater to the main channel are presented that could be further analyzed in future scope of works.

- Additional mapping of vegetation to supplement the vegetation mapping was done using aerial photographs and only limited field verification where public access was available. For projects with riparian components, localized field validation and riparian planting plans will be needed. More field measurements of tree age and species health may be of particular use at these smaller scales.
- Integration of any new information on biological use as it becomes available.
- Additional monitoring of flow, sediment, and topographic processes and changes to connectivity with the main channel in order to predict the impacts of reconnection to presently cutoff areas of the HCMZ and floodplain, where vegetation, ponding, and channel conditions have changed since the areas have been disconnected for several decades or more.

7. Reach – Based Protection and Restoration Opportunities

This section describes restoration opportunities that encourage lateral, vertical, and longitudinal connectivity between the river and floodplain of physical processes important to habitat. Lateral connectivity between the floodplain and river is critical for access and viability of off-stream habitat and refuge areas. Vertical connectivity is critical for water quality and quantity in habitat areas (groundwater flow, water temperature). Longitudinal connectivity is critical for salmon, steelhead, and bull trout migration, genetic exchange between populations, and re-founding of populations following events such as a forest fie or large debris flow. The section first describes potential restoration actions, and then provides a comparison between geomorphic reaches for local resource managers to use for prioritization discussions. Finally, this section discusses general considerations for restoration success and sustainability specific to Nason Creek in the assessment area.

7.1 Potential Restoration Action

The *Upper Columbia Recovery Plan* (UCSRB 2007) provides a list of potential habitat actions for Upper Columbia subbasins, and how these actions link to VSP parameters and limiting factors identified for steelhead, spring Chinook, and bull trout. Proposed habitat restoration actions were summarized for each reach based on terminology used in the *Upper Columbia Recovery Plan* (UCSRB 2007) to be consistent with terminology used by other resource planners and entities involved in restoration and monitoring of ESA-listed fish within the Upper Columbia Basin (Table 17). The *Upper Columbia Recovery Plan* descriptions were slightly modified to link with detailed findings from this tributary assessment to make the list of habitat restoration actions more specific to Nason Creek between RM 4.6 to 14.3 (Table 18). Reaches 1 and 3 have identical recommendations for habitat actions; however, the spatial extent of restoration needed and the type of habitat gained for each of these actions varies between the two reaches. These differences are further discussed in the next report section. Reach 2 does not have any restoration actions recommended in

Table 18 because it is functioning appropriately with minimal disturbance from historical human activities or constructed features.

Of the potential habitat actions listed, there are several sequencing strategies that could be used to prioritize and achieve the restoration goals. Overall, the primary objective of any combination of the habitat actions is to recover long-term, sustainable habitat function and availability by:

- increasing the complexity of the main channel
- increasing availability and quality of off-channel areas
- increasing the amount of accessible floodplain

Achieving these restoration objectives will allow more recruitment of LWD and increased complexity in the main channel. Increased floodplain access will reduce energy (velocity) in the system during high flows, improving the ability of the river to sustain recruited LWD and associated habitat complexity. More work is needed to understand the benefit of these actions to water temperature, but many of these actions have the potential to increase cold groundwater sources to the river to help reduce warm temperatures in Nason Creek, particularly during late summer and early fall.

Table 17. Summary of proposed restoration types for each reach based on findings of geomorphic assessment.

Geomorphic Reach	River Miles	Habitat Action Class [1/]							VSP Parameters Addressed [2/]	
		Riparian restoration within HCMZ	Riparian restoration within floodplain	Side-channel reconnection	Obstruction reconnection	Road Maintenance	Floodplain Restoration	LWD Restoration	A/P	D/SS
1	4.6 to 8.9	X	X	X	X	X	X	X	X	X
2	8.9 to 9.4									
3	9.4 to 14.3	X	X	X	X	X	X	X	X	X

[1/] Habitat action classes and associated VSP parameters addressed referenced from Table 5.9 in *Proposed Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (UCSRB, 2006)
[2/] A/P = abundance and productivity; D/SS = diversity and spatial structure as described in *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* (ICBTRT, 2007)

Table 18. Potential habitat action classes for assessment area and linkage to limiting factors and VSP parameters; adapted from Table 5.9 in the *Upper Columbia Recovery Plan* (UCSRB 2007); note that additional potential habitat actions may be identified by the reach assessment being conducted by Reclamation for Reaches 1 and 3.

Habitat Action Class	Limiting Factors Addressed	VSP Parameters Addressed[1]	Potential Habitat Actions
Restoration of Floodplain and Channel Migration	Channel incision, increased temperature, loss of natural stream channel and habitat complexity, sinuosity, stream length, unnatural width to depth ratios, embeddedness, unstable banks, increased fine sediments, loss of pool and riffle formation, and spawning gravel and LWD recruitment	Productivity Abundance Diversity Structure	1- Use dike, road, and railroad removal, setback, and/or breaching to increase flood-prone areas to reduce lateral scour and flow volume in main channel and protect or improve existing spawning habitats.
			2- Abandon or reduce usage of human-made channels by reconnecting to the historical channel and channel migration zone area to create viable spawning and/or off-channel habitat areas.
			3- Restore and reconnect wetlands and floodplains to the riverine system where appropriate to restore flow connections.
			4- Decommission, modify, or relocate roads, the railroad and highway, low-priority dikes, bridges, and culverts to enhance lateral channel migration.
Side-Channel Reconnection	Loss of channel sinuosity and length, decreased habitat refugia and diversity, loss of hyporheic function associated with floodplains, increased bed scour by concentrating river energy, loss of bank stability, elevated temperature, depressed invertebrate production, loss of natural LWD recruitment	Productivity Abundance	1-Restore and/or reconnect side channel habitats, islands, spawning areas, and oxbows to increase off-channel habitat.
			2-Re-establish groundwater sources to side channels, particularly where ponding occurs due to railroad and highway embankments; in many cases this needs to be done in conjunction with reconnection of the actual side channels also.
			3-Establish wetland , backwater habitats by improving connectivity between oxbows (abandoned channels) and the floodplain with the main channel.

[1] VSP parameters refer to four parameters identified by McElhany et al (2000) that form the key to evaluating population viability status. They are abundance, population growth rate, population spatial structure, and diversity. The NOAA Fisheries Service focuses on these parameters for three reasons: first, they are reasonable predictors of extinction risk (viability); second, they reflect general processes that are important to all populations of all species; third, the parameters are measurable.

Habitat Action Class	Limiting Factors Addressed	VSP Parameters Addressed[1]	Potential Habitat Actions
Obstruction Restoration	Remove barriers to address loss of habitat quantity, habitat fragmentation, decreased habitat refugia and diversity, and increased density-dependent mortality from concentrating populations into small habitat units	Abundance Diversity Structure	1-Where only partial or no flow and fish passage access is available, design and construct openings in the railroad and highway embankment, ensuring screens consistent with the newest standards and guidelines.
			2-Remove, modify, or replace culverts that prevent or restrict access to habitat and/or cause loss of habitat connectivity.
LWD Restoration	Loss of natural stream channel complexity, refugia and hiding cover, sinuosity, stream length, loss of floodplain connectivity, unnatural width to depth ratios, embeddedness, unstable banks, increased fine sediments, loss of pool and riffle formation, and spawning gravel and natural LWD recruitment	Productivity Abundance	1-Add key pieces of wood to stabilize banks, provide hiding cover, and jump-start the re-establishment of historical levels of LWD-formed pools; this could be part of a restoration to historical conditions or as part of enhancement to existing channels that may not have the opportunity to be restored in the near future.
			2-Create side-channel habitats, islands, and reconnect back channels to increase LWD deposition channel complexity and riparian areas to re-establish normative processes
Riparian Restoration	Loss of bank stability, elevated temperatures, loss of natural LWD recruitment	Productivity Abundance	1-Repair cleared riparian zones by re-establishing native vegetation communities, particularly along stream channel banks where the powerline crossings are present or development.
			2-Replace invasive or non-native vegetation with native vegetation in powerline corridors.
Road Maintenance	Loss of natural stream channel complexity, sinuosity, stream length, loss of floodplain connectivity, unnatural width to depth ratios, embeddedness, unstable banks, increased sediment, loss of pool and riffle formation, and spawning gravel and LWD recruitment	Productivity Abundance	1-Establish and protect riparian buffers to avoid increased mass wasting and modified runoff during rainfall events; this is of particular importance on the hillslopes where fire has occurred or recent logging
			2-Implement road abandonment or decommissioning plans where roads are no longer utilized, potentially in areas with old logging roads or where bridges have deteriorated and fallen apart but the embankments still remain in place

Habitat Action Class	Limiting Factors Addressed	VSP Parameters Addressed[1]	Potential Habitat Actions
			3-Decommission, modify, or relocate (setback) roads, bridges, and culverts to decrease stream confinement to the extent practicable
			4-Manage the placement of new dikes and other structures that may confine or restrict side channels and disconnect habitat in floodplains

7.2 Technical Prioritization of Restoration for Geomorphic Reaches

The entire 10-mile stretch of Nason Creek evaluated has already been established by the FCRPS BiOP and the *Upper Columbia Recovery Plan* (2007) as a high priority for protecting existing habitat and for increasing habitat through restoration projects. However, in practicality a prioritization plan is needed to help focus available resources. The three reaches were compared in terms of presently functioning habitat, level of impact to physical processes, and the opportunities available for improving physical processes responsible for creating ESA-listed steelhead and spring Chinook habitat features.

Local USFS biologists have identified existing high quality fish habitat segments only at RM 9.2 to 9.3 (riffle spawning area in Reach 2) and RM 11.1 to 11.4, and RM 12.8 to 13.3 (meandering channels with LWD-formed pools in Reach 3). High quality habitat is loosely defined by local biologists as areas that presently support one or more life stages for spring Chinook and steelhead and have limited impacts to physical processes from human activities or features.

Table 19 and Table 20 provide quantitative results for present geomorphic conditions based on the results of this geomorphic assessment. For easier comparison, this information was summarized in Table 21 using a ranking system based on a general interpretation using all of the more detailed results.

Technical prioritization of Reaches 1 and 3 are presented below in terms of sequencing potential habitat restoration efforts. Reach 2 is not included because there is no restoration actions proposed in this area.

1. If it is desired to implement restoration actions that build upon existing high quality habitat, Reach 3 offers the best opportunities followed by Reach 1. This is because Reach 3 has limited, but more high quality habitat than Reach 1 and is immediately downstream of the mostly functioning habitat area above RM 15.
2. If it is desired to prioritize based on the potential to increase available habitat area, Reach 3 would come first followed by Reach 1; Reach 1 has more opportunities to increase off-channel habitat, a key limiting factor identified, and has more potential tributary habitat segments that could be restored.
3. If it is desired to start restoration in the least impacted reach in terms of floodplain, channel migration, vegetation, and channel topography function, reach 1 would come first based on the findings of the geomorphic assessment.
4. If it is desired to build upon existing restoration projects, prioritzation would start with Reach 1 and work upstream to Reach 3; this is to build upon the recently completed channel reconnection project in the lower four river miles.
5. If it is desired to prioritize based on the level of impacts to hillslope and tributaries, both reaches would be equally prioritized because the impacts are similar.

Table 19. Summary of channel migration, in-channel habitat, and off-channel habitat conditions by geomorphic reach.

Reach	Percent disconnected or impacted HCMZ area	Length of disconnected main and side channels (miles)	Total historical channel area (acres)	Percent of HCMZ reworking (1962 to 2006)	Percent present main channel with riprapped banks	Reduction in main channel length (miles)	Potential off-channel habitat area (percent of main channel habitat area)	Number of LWD-formed pools (2006)	Number of log jams (2006)
1 (RM 4.6 to 8.9)	16%	3.8	36	2%	13%	0.6	6 to 22%	2	4
2 (RM 8.9 to 9.4)	0%	0.0	0	0%	2%	0	0%	0	0
3 (RM 9.4 to 13.3)	49%	9.4	66	2%	50%	1.4	9 to 31%	8	4

Table 20. Summary of floodplain connectivity and vegetation condition by geomorphic reach.

Reach	Percent of disconnected floodplain	Percent impacted vegetation (cleared)	Percent floodplain with LWD sized trees	Percent shading on present channel banks	Tributaries with historical fish use
1 (RM 4.6 to 8.9)	15%	16%	62%	80%	Kahler
2 (RM 8.9 to 9.4)	0%	0%	68%	96%	None
3 (RM 9.4 to 13.3)	56%	21%	42%	77%	Mahar, Gill, Roaring, Coulter

Table 21. Interpretation of overall present geomorphic conditions by geomorphic reach.

Reach	Existing High Quality Habitat	Opportunities to Increase and Enhance Habitat	Ranking: 5 (best) to 1 (worst)			
			Floodplain function	Channel migration	Riparian vegetation	In-channel complexity (LWD)
1	Limited	Moderate	4	3	4	1
2	RM 9.2 to 9.3 (spawning only)	Low	5	NA	5	4
3	RM 11.1 to 11.4 and 12.8 to 13.3	High	2	2	4	2

7.3 Restoration Success and Sustainability

Using restoration concepts that are guided by understanding of the river geomorphic processes helps ensure project objectives are sustainable in that they work with existing river processes rather than against them. This understanding allows biologists and resource managers to evaluate the reasonability of their expectations for a project achieving complexity objectives, and the time interval that may be necessary before the objectives are realized. In cases where projects are designed without consideration of river processes, project objectives are less likely to be achieved. Further, unanticipated risks, or even negative impacts to land use habitat can occur.

An ideal approach to achieve the objectives would be to re-establish or reconnect historical HCMZ and floodplain areas and allow river processes to form habitat features over time. This approach could be supplemented with replanting of cleared vegetation areas. However, it may not always be possible to fully reconnect the HCMZ and floodplain unless significant road, railroad, and power line setbacks occur, and modifications are made to existing engineered channel sections. To accomplish primary restoration actions, several secondary actions may be needed which are also listed inTable 18. If full or partial access to historical channel and floodplain areas cannot be accomplished due to landowner or land use constraints, other alternative actions could still provide enhancement (improvement) to current conditions. Because alternative actions typically require that rock or LWD structures be placed in the river, these actions may require more maintenance over the long term and a careful consideration of local impacts to land use and infrastructure.

Restoration concepts presented are only initial ideas based on the information available from this geomorphic assessment. Restoration areas should be viewed cumulatively with other potential project areas in a given reach to fully understand the potential benefits and issues that need to be addressed. For example, opening the floodplain on one side of the river will alter the energy and hydraulics on the opposite side. Additionally, opening up one section of floodplain may allow the river to be more fully connected with currently functioning areas (protection areas), creating a larger reach of viable habitat. These concepts also need to consider upstream and downstream processes, and be integrated with biological evaluation of habitat complexity benefits to fully understand the sustainability of restoration actions at each site.

8. CONCLUSIONS

Historical changes to flow, sediment, and topography over the last 150 years were evaluated to identify habitat protection and restoration opportunities on Nason Creek between RM 4.6 (Coles Corner) to 14.3 (White Pine Railroad Bridge). Local USFS biologists have identified existing high quality fish habitat segments only at RM 9.2 to 9.3 (riffle spawning area in Reach 2), RM 11.1 to 11.4, and RM 12.8 to 13.3 (meandering channels with LWD-formed pools in Reach 3). High quality habitat is loosely defined by local biologists as areas that presently support one or more life stages for spring Chinook and steelhead and have limited impacts to physical processes from human activities or features.

The largest impact to physical processes and habitat is from railroad construction in the 1890s and U.S. Highway 2 realignment and widening in 1960. These impacts straightened channel alignments, reduced channel migration, reduced access to the floodplain and off-channel areas, altered sediment and LWD availability and transport, and also resulted in disconnection of tributaries and groundwater sources from the main channel. Bridges, small levees, and the power and transmission line corridors also impact physical processes but to a lesser, more localized degree.

The channel length has been reduced by 2 miles from bypassing historical meandering channels with constructed, straight channels that are largely armored with riprap and devoid of habitat value. These straightened reaches have scour pools, but based on 2D modeling and field observations these reaches generally lack any diversity of hydraulics and are much higher in energy and velocity than channel sections within the assessment area that have not been straightened and confined. Upstream of these confined channels, backwater occurs causing a reduction in sinuosity and change in hydraulics. This is particularly evident for two of three remaining meandering sections between RM 9 and 14 and upstream of the fill placed at Merritt. The most noticeable impact to hydraulics and channel function is in a stretch below White Pine Railroad Bridge. A backwater does not occur upstream of this confined section because the river is much steeper through the White Pine Railroad Bridge than it is in the downstream confined section. Backwater is also limited between RM 9 and 5 because the slope is steeper and the confined sections are shorter.

Very little off-channel habitat (side channels and accessible wetland areas) presently exists for rearing fish with the few locations centered near LWD present in the wetted low-flow channel. About one-third of the historical channel migration zone has been disconnected, which accounts for 168 acres of area that could be providing backwater channels, side channels, and other off-channel habitat components.

Logging of riparian floodplain and log drives in the main channel reduced the occurrence of LWD in the channel and its potential future recruitment (estimated to have occurred from 1905 to 1927). This historical depletion of LWD has reduced the number of LWD-formed pools and cover in the main and side channels. Logging still occurs today, but at a much smaller scale. Overall the vegetation is recovering from logging impacts fairly well in the riparian floodplain. The exception is corridors that are continually cleared for power and transmission lines, area occupied by highways and railroad embankments, and small localized pockets of development.

Nearly 360 acres of historical floodplain have been disconnected which causes more concentrated flow in the remaining floodplain area. Flood protection and bank armoring for residential areas, power and transmission poles, U.S. Highway 2, roads, the railroad, and infrastructure have resulted in 31 percent (3 miles) of the present channel length being armored with riprap. This reduces lateral migration and the ability to erode and create new channels and floodplain surfaces, a vital process necessary for long-term, sustainable ecosystem function. The riprap also reduces the ability to recruit new LWD in the confined sections. The few meandering sections that remain are eroding into floodplain banks, but limited LWD is being recruited because these areas are still cleared of vegetation. Because the constrained channel sections are often high in energy (velocity), it is also difficult for the river to sustain LWD transported into the reach from upstream reaches. The lack of wood has reduced both the quality and quantity of salmonid habitat in the main channel.

Sediment recruitment to the river from channel migration and bank erosion is reduced below historical levels due to artificially confined sections. Bank erosion occurring in the human-induced confined sections is assumed to occur because the channel may be widening to dissipate energy. Where bank erosion is occurring in floodplain deposits (less than 8 feet above the channel bed), erosion may be accelerated due to local clearing of vegetation. In other artificially-constricted sections, the channel cannot re-establish a meander bend or significantly widen because of large cobbles in the glacial deposits being eroded. From a sediment source perspective, the small amount of erosion occurring opposite human features is more than offset by the large amount of riprap on the banks in areas where natural bank erosion would occur.

Tributary and groundwater sources are not well connected to the main channel because of large embankments with few or undersized culverts. The embankments also limit fish access to tributaries such as Roaring and Coulter creeks.

These changes in geomorphic conditions result in impaired fish access to floodplain and off-channel habitat areas and in a reduction in habitat features that depend on channel migration, recruitment of LWD, and reworking of the streambed. The primary objective for habitat restoration actions is to recover long-term, sustainable habitat function and availability by:

- increasing the complexity of the main channel topography,

- increasing availability and quality of off-channel areas, and
- increasing the amount of accessible floodplain.

Achieving these restoration objectives would allow more recruitment of LWD and increased complexity in the main channel. Increased floodplain access would reduce energy (velocity) in the system during high flows, improving the ability of the river to sustain recruited LWD and associated habitat complexity.

The assessment area was broken into three geomorphic reaches, two of which are just under 5 miles long and the middle reach (Reach 2) that is 0.5 miles long. Similar types of restoration actions are needed for both Reaches 1 and 3, but the extent of restoration needed and the potential to increase habitat differs between the two reaches. Technical prioritization of Reaches 1 and 3 was accomplished in terms of sequencing potential habitat restoration efforts. Reach 2 is not included because there are no restoration actions proposed in this naturally confined area that has had minimal impacts to physical processes. Restoration options include the following:

1. If it is desired to implement restoration actions that build upon existing high quality habitat, Reach 3 offers the best opportunities followed by Reach 1. This is because Reach 3 has limited, but more high quality habitat than Reach 1 and is immediately downstream of the mostly functioning habitat area above RM 15.
2. If it is desired to prioritize based on the potential to increase available habitat area, Reach 3 would come first followed by Reach 1; Reach 3 has more opportunities to increase off-channel habitat, a key limiting factor identified, and has more potential tributary habitat segments that could be restored.
3. If it is desired to start restoration in the least impacted reach in terms of floodplain, channel migration, vegetation, and channel topography function, Reach 1 would come first based on the findings of the tributary assessment.
4. If it is desired to build upon existing restoration projects, prioritzation would start with Reach 1 and work upstream to Reach 3; this is to build upon the recently completed channel reconnection project in the lower four river miles.
5. If it is desired to prioritize based on the level of impacts to hillslope and tributaries, both reaches would be equally prioritized because the impacts are similar.

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10. ABBREVIATIONS

Abbreviation	Definition
BiOp	biological opinion (under the ***ESA***)
cfs	cubic feet per second, a measure of flow volume
D_{50}	The median particle-size diameter for a sediment sample, such that 50 percent of the sample is larger than this value.
DPS	discrete population segment
DS	downstream
ESA	Endangered Species Act
ESUs	evolutionarily significant units
FCRPS	The FCRPS comprises the Bonneville Power, the Army Corps of Engineers, and the Bureau of Reclamation. ACOE and Reclamation operate Federal hydroelectric dams in the Columbia River Basin and BPA markets the power.
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GPS	global positioning system
ICBTRT	Interior Columbia Basin Technical Recovery Team
LFA	Limiting Factors Analysis
LiDAR	Light Detection and Ranging (LiDAR) is a remote sensing system used to collect topographic data.
LWD	large woody debris
MPG	major population group
NAD 1983	The North American Datum of 1983 (NAD 83) is the horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980.

Abbreviation	Definition
NAVD 1988	The North American Vertical Datum of 1988 (NAVD 88) is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations
NMFS	National Marine Fisheries Service of ***NOAA***
NOAA	National Oceanic and Atmospheric Administration of the U.S. Department of Commerce
NOAA Fisheries Service	NOAA National Marine Fisheries Service (**aka NMFS**)
Reclamation	Bureau of Reclamation of the U.S. Department of the Interior
RM	river mile
TRT	Technical Recovery Team
UCRTT	Upper Columbia Regional Technical Team
UCSRB	Upper Columbia Salmon Recovery Board
Upper Columbia Biological Strategy	*A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board* (UCRT 2007)
Upper Columbia Recovery Plan	*Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan* (UCSRB 2007)
US	upstream
USFS	U.S. Forest Service of the Department of Agriculture
USFWS	U.S. Fish and Wildlife Service of the Department of the Interior
USGS	U.S. Geological Survey of the Department of the Interior
VSP	viable salmonid populations
WRIA	Water Resource Inventory Area

11. GLOSSARY

Term	Definition
adaptive management	A management process that applies the concept of experimentation to design and implementation of natural resource plans and policies.
aggrading stream	A stream that is actively building up its channel or floodplain by being supplied with more bedload than it is capable of transporting.
alluvial fan	A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases; it is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with a gradually decreasing gradient (Neuendorf et al. 2005).
alluvium	A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream, as a sorted or semi-sorted sediment on the river bed and floodplain (Neuendorf et al. 2005).
anadromous (fish)	A fish, such as the Pacific salmon, that spawns and spends its early life in freshwater but moves into the ocean where it attains sexual maturity and spends most of its life span (Owen and Chiras 1995).
bar (in a river channel)	Accumulations of bed load (sand, gravel, and cobble) that are deposited along or adjacent to a river as flow velocity decreases. If the sediment is reworked frequently, the deposits will remain free of vegetation. If the surface of the bar becomes higher than the largest flows, vegetation stabilizes the surface making further movement of the sediment in the bar difficult.
bedload	The sediment that is transported intermittently along the bed of the river channel by creeping, rolling, sliding, or bouncing along the bed. Typically includes sizes of sediment ranging between coarse sand to boulders (the larger or heavier sediment).

Term	Definition
bed-material	Sediment that is preserved along the channel bottom and in adjacent bars; it may originally have been material in the suspended load or in the bed load.
bedrock	A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material (Neuendorf et al., 2005). The bedrock is generally resistant to fluvial erosion over a span of several decades, but may erode over longer time periods.
canopy cover (of a stream)	Vegetation projecting over a stream, including crown cover (generally more than 1 meter (3.3 feet) above the water surface) and overhang cover (less than 1 meter (.3 feet) above the water).
Category 2	Category 2 watersheds support important aquatic resources, and are strongholds for one or more listed fish species. Compared to Category 1 watersheds, Category 2 watersheds have a higher level of fragmentation resulting from habitat disturbance or loss. These watersheds have a substantial number of subwatersheds where native populations have been lost or are at risk for a variety of reasons. Connectivity among subwatersheds may still exist or could be restored within the watershed so that it is possible to maintain or rehabilitate life history patterns and dispersal. Restoring and protecting ecosystem functions and connectivity within these watersheds are priorities. Adapted from UCRTT (2007).
centerline	A line drawn along the center of the active or unvegetated channel; visually placed to be at the center of all channel paths.
channel morphology	The physical dimension, shape, form, pattern, profile, and structure of a stream channel.
channel planform	Characteristics of the river channel that determine its two-dimensional pattern as viewed on the ground surface, aerial photograph, or map.
channel remnant (wet)	Same as an ***old channel*** (wet) for channels on the ***USGS*** topographic maps from the middle 1980s. Mapped as a channel remnant (wet), because this is how they appear on the topographic maps.
channel sinuosity	The ratio of length of the channel or thalweg to down-valley distance. Channel with a sinuosity value of 1.5 or more are typically referenced as meandering channels (Neuendorf et al. 2005).

Term	Definition
channel stability	The ability of a stream, over time and under the present climatic conditions, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern, and profile without either aggrading or degrading.
channelization	The straightening and deepening of a stream channel to permit the water to move faster, to reduce flooding, or to drain wetlands.
core habitat	Habitat that encompasses spawning and rearing habitat (resident populations), with the addition of foraging, migrating, and overwintering habitat if the population includes migratory fish. Core habitat is defined as habitat that contains, or if restored would contain, all of the essential physical elements to provide for the security of allow for the full expression of life history forms of one or more local populations of salmonids.
depositional areas (stream)	Local zones within a stream where the energy of flowing water is reduced and sediment settles out, accumulating on the streambed.
discharge (stream)	With reference to streamflow, the quantity of water that passes a given point in a measured unit of time, such as cubic meters per second or, often, cubic feet per second (cfs).
diversity	All the genetic and phenotypic (life history traits, behavior, and morphology) variation within a population.
ecosystem	A unit in ecology consisting of the environment with its living elements, plus the non-living factors, which exist in and affect it (Neuendorf et al. 2005).
embeddedness	The degree to which large particles (boulders, gravel) are surrounded or covered by fine sediment, usually measured in classes according to percentage covered.
fine sediment (fines)	Sediment with particle sizes of 2.0 mm (0.08 inch) or less, including medium to fine sand, silt, and clay.
floodplain	The surface or strip of relatively smooth land adjacent to a river channel constructed by the present river in its existing regimen and covered with water when the river overflows its banks. It is built on alluvium, carried by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current. A river has one floodplain and may have one or more terraces representing abandoned floodplains (Neuendorf et al. 2005).
flow regime	The quantity, frequency, and seasonal nature of water flow.

Term	Definition
geomorphic province	A geomorphic province is comprised of similar land forms that exhibit comparable hydrologic, erosional, and tectonic processes (Montgomery and Bolton, 2003); any large area or region considered as a whole, all parts of which are characterized by similar features or by a history differing significantly from that of adjacent areas (Neuendorf et al. 2005); also referred to as a basin. An example would be the Upper Columbia Basin.
geomorphic reach	A geomorphic reach, represents an area containing the active channel and its floodplain bounded by vertical and/or lateral geologic controls, such as alluvial fans or bedrock outcrops, and frequently separated from other reaches by abrupt changes in channel slope and valley confinement. Within a geomorphic reach, similar fluvial processes govern channel planform and geometry through driving variables of flow and sediment. A geomorphic reach is comprised of a relatively consistent floodplain type and degree of valley confinement. Geomorphic reaches may vary in length from 100 meters in small, headwater streams to several miles in larger systems (Frissell et al.., 1986). An example in this assessment would be geomorphic reach M10 (river miles 55 to 65) on the Upper Methow River valley segment, locally known as the Big Valley reach.
geomorphology	The study of the classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes caused by the actions of flowing water.
GIS	Geographical information system. An organized collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.
glacial deposits (undifferentiated)	Consists primarily of glaciofluvial deposits of sand, gravel, cobbles and boulders deposited by retreat and melting of the Okanogan Lobe of the Cordilleran Ice Sheet and most likely glacial deposits from alpine glacial advances post-dating and/or contemporaneous with the retreat of the Okanogan Ice Sheet. Unit also includes glacial outburst flood, lacustrine, delta, till and moraine deposits. The materials are generally unconsolidated and susceptible to fluvial erosion.

Term	Definition
habitat action	Proposed restoration or protection strategy to improve the potential for sustainable habitat upon which endangered species act (ESA) listed salmonids depend on. Examples of habitat actions include the removal or alteration of project features to restore floodplain connectivity to the channel, reconnection of historic side channels, placement of large woody debris, reforestation of the low surface, or implementation of management techniques.
habitat connectivity (stream)	Suitable stream conditions that allow fish and other aquatic organisms to access habitat areas needed to fulfill all life stages.
habitat unit	A habitat unit is defined as a morphologically distinct area within a geomorphic reach comprising floodplain and channel areas; typically less than several channel widths in length (Montgomery and Bolton, 2003). Individual habitat units may include pools, riffles, bars, steps, cascades, rapids, floodplain features, and transitional zones characterized by relatively homogeneous substrate, water depth, and cross-sectional averaged velocities.
headwaters	The source of a river. Headwaters are typically the upland areas where there are small swales, creeks, and streams that are the origin of most rivers. These small streams join together to form larger streams and rivers or run directly into larger streams and lakes.
hyporheic zone	In streams, the region adjacent to and below the active channel where water movement is primarily in the downstream direction and the interstitial water is exchanged with the water in the main channel. The boundary of this zone is where 10 percent of the water has recently been in the stream (Neuendorf et al., 2005).
ICBTRT	Interior Columbia Basin Technical Recovery Team. Expert panel formed by ***NMFS*** (NOAA Fisheries) to work with local interests and experts and ensure that ICBTRT recommendations for delisting criteria are based on the most current and accurate technical information available.
incipient motion	The initiation of mobilizing a single sediment particle on the streambed once threshold conditions are met.
incision	The process where by a downward-eroding stream deepens its channel or produces a relatively narrow, steep-walled valley (Neuendorf et al., 2005).

Term	Definition
landslide	Consists of a heterogeneous mixture of silt, sand, gravel, cobbles and boulders. Occur predominantly along glacial terrace deposits and valley walls. Mass wasting along the active river channels typically result in a "self-armoring" bank in that the finer materials are transported by the fluvial system and the larger materials are retained along the toe of the slope protecting the slope except during flood events.
large woody debris (LWD)	Large downed trees that are transported by the river during high flows and are often deposited on gravel bars or at the heads of side channels as flow velocity decreases. The trees can be downed through river erosion, wind, fire, or human-induced activities. Generally refers to the woody material in the river channel and floodplain whose smallest diameter is at least 12 in and has a length greater than 35 ft in eastern Cascade streams.
levee	A natural or artificial embankment that is built along a river channel margin; often a human-made structure constructed to protect an area from flooding or confine water to a channel. Also referred to as a dike.
limiting factor	Alternate definition: Any factor in the environment of an organism, such as radiation, excessive heat, floods, drought, disease, or lack of micronutrients, that tends to reduce the population of that organism (Owen and Chiras, 1995).
low-flow channel	A channel that carries flow during base flow conditions.
mass wasting	General term for the dislodgement and downslope transport of soil and rock under the influence of gravitational stress (mass movement). Often referred to as shallow-rapid landslide, deep-seated failure, or debris flow.
moraine	A mound or ridge of unstratified glacial drift deposited by direct action of glacial ice.
nonnative species	Species not indigenous to an area, such as brook trout in the western United States. Sometimes referred to as an exotic species.
orthorectified photograph	An aerial photograph that has been corrected for the geometries and tilt angles of the camera when the image was taken and for topographic relief using a digital elevation model, flight information, and surveyed control points on the ground.
overbank deposits	Fine sediment (medium to fine sand, silt, and clay) that is deposited outside of the channel on the floodplain or terrace by floods.

Term	Definition
overflow channel	A channel that is expressed by no or little vegetation through a vegetated area. There is no evidence for water at low stream discharges. The channel appears to have carried water recently during flood event. The upstream and/or downstream ends of the overflow channel usually connect to the main channel.
peak flow	Greatest stream discharge recorded over a specified period of time, usually a year, but often a season.
planform	The shape of a feature, such as a channel alignment, as seen in two dimensions, horizontally, as on an aerial photograph or map.
project area	A project area is a distinct geographic location with potential implementation opportunities for habitat restoration and protection actions. Project areas are at a comparable level of organization as a habitat unit within a geomorphic reach and typically bounded by geomorphic features (e.g. river channel, floodplain, or terrace).
project feature	A project feature is an individual structure or component of an active floodplain of a project area; examples include levees, roadway embankments, bridges, or culverts.
redd	A nest constructed by salmonid species in the streambed where eggs are deposited and fertilized. Redds can usually be distinguished in the streambed by a cleared depression and associated mound of gravel directly downstream.
riparian area	An area with distinctive soils and vegetation community/composition adjacent to a stream, wetland, or other body of water.
riprap	Large angular rocks that are placed along a river bank to prevent or slow erosion.
salmonid	Fish of the family *salmonidae*, including trout, salmon, chars, grayling, and whitefish. In general usage, the term most often refers to salmon, trout, and chars.
scour	Concentrated erosive action by flowing water, as on the outside curve of a bend in a stream; also, a place in a streambed swept clear by a swift current.

Term	Definition
side channel	A channel that is not part of the main channel, but appears to have water during low-flow conditions and has evidence for recent higher flow (e.g., may include unvegetated areas (bars) adjacent to the channel). At least the upstream end of the channel connects to, or nearly connects to, the main channel. The downstream end may connect to the main channel or to an overflow channel. Can also be referred to as a secondary channel.
slough	A sluggish channel of water, such as a side channel of a river, in which water flows slowly through, swampy ground, such as along the Columbia River, or a section of an abandoned river channel, containing stagnant water and occurring in a floodplain (Neuendorf et al., 2005).
smolt	A juvenile salmon or steelhead migrating to the ocean and undergoing physiological and behavioral changes to adapt its body from a freshwater environment to a saltwater environment.
spawning and rearing habitat	Stream reaches and the associated watershed areas that provide all habitat components necessary for adult spawning and juvenile rearing for a local salmonid population. Spawning and rearing habitat generally supports multiple year classes of juveniles of resident and migratory fish, and may also support subadults and adults from local populations.
subbasin	A subbasin represents the drainage area upslope of any point along a channel network (Montgomery and Bolton, 2003). Downstream boundaries of subbasins are typically defined in this assessment at the location of a confluence between a tributary and mainstem channel. An example would be the Twisp River Subbasin.
suspended load	The part of the total stream load that is carried for a considerable period of time in suspension, free from contact with the streambed, it consists mainly of silt, clay, and fine sand (Neuendorf et al., 2005).
suspended sediment	Solids, either organic or inorganic, found in the water column of a stream or lake. Sources of suspended sediment may be either human induced, natural, or both.

Term	Definition
terrace	A relatively stable, planar surface formed when the river abandons the floodplain that it had previously deposited. It often parallels the river channel, but is high enough above the channel that it rarely, if ever, is covered by water and sediment. The deposits underlying the terrace surface are alluvial, either channel or overbank deposits, or both. Because a terrace represents a former floodplain, it can be used to interpret the history of the river.
tributary	A stream feeding, joining, or flowing into a larger stream or lake (Neuendorf et al., 2005).
valley segment	A valley segment is a section of river within a subbasin. Within a valley segment, multiple floodplain types exist and may range between wide, highly complex floodplains with frequently accessed side channels to narrow and minimally complex floodplains with no side channels. Typical scales of a valley segment are on the order of a few to tens of miles in longitudinal length. An example in this assessment would be the Middle and Upper Methow River valley segments.
watershed	The area of land from which rainfall (and/or snow melt) drains into a stream or other water body. Watersheds are also sometimes referred to as drainage basins. Ridges of higher ground form the boundaries between watersheds. At these boundaries, rain falling on one side flows toward the low point of one watershed, while rain falling on the other side of the boundary flows toward the low point of a different watershed.

RECLAMATION
Managing Water in the West

NASON CREEK
TRIBUTARY ASSESSMENT
Chelan County, Washington
TECHNICAL APPENDICES

BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER, DENVER, CO,
AND
PACIFIC NORTHWEST REGIONAL OFFICE, BOISE, ID.

JULY 2008

U.S. DEPARTMENT OF THE INTERIOR

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

MISSION OF THE BUREAU OF RECLAMATION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover photo: View looking upstream at the railroad grade that defines the left bank. Nason Creek – Wenatchee River subbasin, Washington. (Reclamation photograph by R. McAffee, May 2, 2007).

Appendix Title

A	Biological Setting
B	Historical Timeline
C	Geologic Setting
D	Hydrology Analysis and GIS Data
E	Nason Creek Subwatershed Conditions
F	Water Quality Synopsis
G	Channel Slope and Survey Data
H	Hydraulics and Sediment Analysis
I	Floodplain Vegetation Assessment
J	Geomorphic Map Methods and GIS Metadata

APPENDIX A.

BIOLOGICAL SETTING

CONTENTS

Tables

1. INTRODUCTION

This appendix focuses on documenting data available that describes present biological use within the assessment area. Biological data available in Arc geographic information system (ArcGIS) was plotted on the map atlas. Note that river miles presented in the tables in this appendix were generated from separate studies and may have slightly different numbers than presented in other sections of this geomorphic assessment report (based on 2006 aerial photography).

Also note, Coho usage and distribution within Nason Creek is being evaluated by Yakama Indian Nation and is not covered in this report.

1.1 Present Spring Chinook Use in Nason

Adult spring Chinook salmon migrate into the Columbia River in the early spring (peak migration in mid-May), move into upper Columbia River tributaries from April through July, and hold until spawning begins in the late summer (UCSRB 2007). In Nason Creek, spawning occurs from mid-August through mid-September, with the majority of spring Chinook redds located in the lower 15.8 river miles (RM). Chelan County Public Utility District (PUD) established an index reach on Nason Creek (RM 8.3 to 15.8) and has conducted redd surveys since 1958 with assistance from Washington Department of Fish and Wildlife (WDFW) and the Yakama Indian Nation. The entire anadromous reach of Nason (mouth to Gaynor Falls at RM 16.9) has been surveyed for redds since 1981.

Returning hatchery spring Chinook (Chelan County PUD Chiwawa River integrated hatchery program) stray to other non-target major spawning areas (MaSAs) in the upper Wenatchee and commonly make up greater than 10 percent of the spawner composition in Nason Creek and the White and Little Wenatchee Rivers, based on comprehensive data collected in 2001 and 2002 (Tonseth 2003; Tonseth 2004). Of the 186 redds tallied in Nason Creek in 2005, a split of about 3 to 1 of hatchery to natural females were identified on the redds.

Adult Chinook salmon die within a short time after spawning and carcasses can often be observed in close proximity to newly constructed redds. Decomposition of carcasses contributes nutrients back into the stream where their eggs have just been deposited; thereby contributing nutrients back to the streams in which their young will rear. Spring Chinook salmon eggs remain in the gravel until hatching in December and fry emergence occurs in January and/or February (Mullan et al. 1992). Juveniles spend approximately 1 year in fresh water before smolting and migrating to the Pacific Ocean between April and June.

Studies of juvenile rearing and migration have identified three major juvenile life history patterns within the Wenatchee spring Chinook population: summer and overwinter rearing within natal spawning areas; fall pre-smolt migration and overwintering in the mainstem Wenatchee downstream of natal tributaries; and early summer emigration to downstream areas for summer rearing and overwintering. An on-going study to estimate juvenile spring Chinook densities and abundance in the Chiwawa River (Hillman and Miller 2002) found that that the distribution of age-0 Chinook salmon correlated positively with the distribution of Chinook redds in the river the previous fall. In all years of the study, age-0 Chinook were most abundant in multiple channel and pool habitats, and least abundant in riffles and glides. Within both the Chiwawa River and its reference areas, which includes a moderately confined segment on Nason Creek (RM 0.62 to 1.7) habitat types with woody debris consistently had the highest densities of age-0 Chinook.

The dominant life history strategy for salmon is to “home” in on their natal streams for spawning, thus subpopulations are generally thought to be fairly isolated from other subpopulations despite occasional straying. However, based on expanded carcass recoveries from spawning ground surveys, strays from other watersheds in the Wenatchee subbasin have comprised 3 to 27 percent of the spring Chinook spawners in the Wenatchee River above Tumwater Canyon (UCSRB 2005). The nearest source populations of spring and summer Chinook salmon exist in the Entiat, Methow, and Okanogan drainages. Unfortunately, spring Chinook salmon populations have also declined to very low levels in those locations. Consequently, contributions from other populations in the Upper Columbia are expected to be minimal.

Based on factors that determine diversity and spatial structure, the Wenatchee population is at high risk of extinction because of the loss of naturally produced spring Chinook spawning in tributaries downstream from Tumwater Canyon. Abundance and productivity for spring Chinook is also not considered viable with a less than 25 percent chance of extinction in 100 years (UCSRB 2007).

Table 1. Summary of spring Chinook redd counts in Nason Creek 1998-2007. (Percentage of redds per survey area and total within the basin are in parenthesis)

Year	Above Index (RM 15.8-16.9)	Index (RM 8.3-15.8)	Below Index (RM 0.0-8.3)	Total
1998	0 (0)	20 (70)	9 (30)	29 (30.8)
1999	0 (0)	1 (12.5)	7 (87.5)	8 (14.8)
2000	2 (2)	50 (50)	48 (48)	100 (28.6)
2001	7 (1.9)	170 (45.5)	197 (52.6)	374 (17.7)
2002	6 (2)	175 (59.5)	113 (38.4)	294 (25.8)
2003	0 (0)	56 (67.5)	27 (32.5)	83 (25.7)
2004	0 (0)	79 (49.7)	80 (50.3)	159 (27.4)
2005	0 (0)	44 (23.7)	142 (76.3)	186 (21.1)
2006	0 (0)	74 (50.3)	73 (49.6)	147 (27.8)
2007	0 (0)	40 (44.0)	51 (56.0)	91 (20.7)
Source: Chelan County PUD and WDFW				

1.2 Present Steelhead Use in Nason

Wenatchee River steelhead are inland (vs. coastal) steelhead of the “stream maturing” reproductive ecotype (NOAA Fisheries 1996). Steelhead enter and begin to ascend the Columbia River in June and July, arriving near their spawning grounds from August to November. Recent research with 395 radio tagged adult steelhead showed that the peak in upstream steelhead movements nearest the Wenatchee River (i.e., at Rock Island and Rocky Reach) occurs in early September (English et al. 2001). Most adult steelhead moved into tributary streams by November; however, some adults held in the mainstem Columbia River until February or March before moving into natal streams to spawn (English et al. 2001). Spawning survey data from the WDFW show that numbers of steelhead redds within Nason Creek subwatershed have ranged from 27 to 412 from 2001 to 2005, with an average of 152 redds per year (Tonseth 2005). The majority of steelhead redds are found in the mainstem of Nason Creek between Roaring Creek (RM 9.3) and Whitepine Creek (RM 15.4) (Tonseth 2008). Steelhead also spawn within Roaring Creek and near the mouth of Mahar Creek near Nason RM 14.0. In general, WDFW concludes that steelhead in Nason Creek utilize more of the mainstem available spawning habitat than steelhead in the Chiwawa River because few suitable first and second order tributaries are accessible (Tonseth 2005). Juvenile rearing lasts approximately 2 to 7 years prior to ocean emigration. Mean smolt age is considered to be 2.65 years with migration generally occurring from April through June with peak migration in early May (Mullan et al. 1992).

Naturally produced steelhead have been supplemented in the Wenatchee subbasin by hatchery smolt releases for many years, at varying levels. Approximately 10 to 25 percent of steelhead crossing Priest Rapids dam (the third Columbia dam downstream of Wenatchee River) are wild fish (Peven 1991). In the Wenatchee subbasin, hatchery steelhead disperse throughout the basin and spawn in streams in which no releases have occurred, suggesting that hatchery rearing and release methodology may have an influence on stray rates (Murdoch and Viola 2003). Beginning in 1992, WDFW closed the Wenatchee subbasin to angler retention of wild steelhead. Also, in the early 1990s, stocking of catchable size rainbow into Wenatchee subbasin tributaries (Chiwawa, Nason, and Little Wenatchee) was discontinued.

Based on redd counts and using a conservative spawner-to-redd ratio of 2.0, the average number of steelhead returning to Nason Creek for spawning has averaged 304 fish in the last 5 years (Tonseth 2005).

Based on factors that determine diversity and spatial structure, the Wenatchee steelhead population is at high risk of extinction. Based on abundance and productivity, naturally produced steelhead population is also not viable and has a greater than 25 percent rate of extinction in the next 100 years. When hatchery fish are considered along with naturally produced fish, the risk of immediate extinction is low (UCSRB 2007).

Table 2. Summary of steelhead redd counts in Nason Creek 2001-2007. (Percentage of redds per survey area and total within the basin are in parentheses)

Year*	Mouth to Kahler Creek Bridge (RM 0.0-4.0)	Kahler Creek Bridge to Merritt Bridge (RM 4.0-10.6)	Merritt Bridge to Lower Railroad Bridge (RM 10.6-13.6)	Lower Railroad Bridge to White Pine (RM 13.6 to 14.6)	Total
2001					27 (13.4)
2002	3 (3.8)	69 (86.2)		8 (10.0)	80 (15.9)
2003	36 (29.7)	65 (53.7)		20 (16.5)	121 (25.6)
2004	45 (30.4)	20 (13.5)	55 (37.2)	28 (18.9)	148 (32.0)
2005	76 (18.5)	81 (19.8)	195 (47.6)	58 (14.1)	410 (14.2)
2006					77 (19.5)
2007	11 (14.1)	25 (32.0)	35 (44.9)	7 (9.0)	78 (49.1)

Source: WDFW

* Survey years 2001-2003 combined the Merritt to Lower RR Bridge with Lower RR Bridge to Whitepine Reach; the survey results for this reach are recorded in the Lower RR Bridge to Whitepine column. Year 2006 data not available by reach.

1.3 Present Bull Trout Use in Nason

Bull trout in the Upper Columbia basin have both resident and migratory life history patterns. Resident bull trout complete their entire life cycle in a tributary stream. Migratory bull trout spawn in tributary streams where juveniles rear for up to 4 years before migrating to a river or lake. Migrating bull trout return to spawning tributaries from the end of June into October. Spawning occurs between mid-September and early November. Resident and migratory bull trout can be found together in spawning grounds and can spawn together. Offspring can express either life history. Bull trout can live longer than 12 years, and of the three ESA-listed species, prefer the coldest water (typically 15^{o} C or less). All life stages of bull trout are associated with complex forms of cover and pools (UCSRB 2007).

Three groups of bull trout were identified during a recent study by Kelly-Ringel and DeLaVernge (2005), with the Nason Creek population belonging to the Upper Wenatchee-Columbia River group (spawn in the Chiwawa River system and Nason Creek and over-winter in the Columbia River). Bull trout typically overwinter from December to May and migrate up the Wenatchee River to spawning grounds from May to mid-October with adult bull trout migrating back to overwintering habitat from October to December (Kelly-Ringel and DeLaVergne 2005). Bull trout are known to spawn in the Chiwawa River and its tributaries (RM 48.5), Nason Creek (RM 53.5), Chiwaukum Creek (RM35.8), Icicle Creek (RM 25.5) and Peshastin Creek (RM 17.8) (UCSRB 2005). Spawning also occurs in the Little Wenatchee River and the White River, both of which are tributaries to Lake Wenatchee.

The Wenatchee River bull trout subpopulation is one of the stronger subpopulations within the Upper Columbia River. The Wenatchee River basin bull trout redd counts have averaged 498 redds for the past 10 years (1998 to 2007), with the Chiwawa watershed forming the strong-hold for bull trout in the upper Wenatchee with a 10-year average of 309 redds in index reaches (U.S. Fish and Wildlife Service (USFWS) and U.S. Forest Service (USFS) annual bull trout spawning surveys). However, the bull trout population within the Nason Creek subwatershed is depressed and typically has less than 15 redds each year (Kelly-Ringel and DeLaVernge 2005). Bull Trout are known to spawn in Nason Creek from Mill Creek (RM 20.5) upstream to a series of barrier falls near RM 22.4 and in Mill Creek from the mouth to a barrier falls approximately 0.6 miles upstream. Bull trout have also been observed in Henry Creek, a tributary of Nason about one mile downstream of Mill Creek (USFS 1996) and may be able to access the lower reaches of Coulter, Roaring, Gill, and Whitepine Creeks, below barrier falls.

Migration is important to the persistence of bull trout populations because it facilitates gene flow between populations and allows extirpated populations to be re-established and small populations to expand (Rieman and McIntyre 1993; Rieman, Lee, and Thurow 1997; Rieman and Allendorf 2001). Persistence of migratory life history forms and maintenance or re-establishment of stream migration corridors is crucial to the viability of bull trout populations (Reiman and McIntyre 1993). Connectivity within the upper Wenatchee subbasin subpopulation appears excellent. However, most of the population seems to be concentrated in the upper Wenatchee watersheds, with the Chiwawa River being the strongest.

Recent telemetry research by the Chelan County PUD to define the migratory patterns of bull trout that pass through Rocky Reach, Rock Island, and Wells Dam indicates that bull trout in the Wenatchee subbasin migrate to and from the mainstem Columbia River and are physically connected with bull trout populations in the Entiat River and the Methow River (BioAnalysts, Inc. 2003).

However, given the distances and unknown extent of altered fluvial dynamics of the mainstem Columbia River, the persistence and genetic integrity of the Wenatchee subpopulation is presumed to be functioning at risk (Thomas 2007).

Table 3. Summary of bull trout redd counts in Nason Creek 1996-2007. (Percentage of redds per survey area and total within the basin are in parenthesis)

Year	Nason Creek Mill Creek to Falls (RM 20.5-22.4)	Nason Creek Whitepine to Mill (RM 15.8-20.5)	Mill Creek Mouth to Falls RM (0.0-0.6)	Total
1996	n/a	n/a	3 (100)	3 (0.8)
1997	0	n/a	1 (100)	1 (0.3)
1998	6 (67)	n/a	3 (33)	9 (2.3)
1999	5 (33)	n/a	10 (67)	15 (2.9)
2000	5 (38)	3 (24)	5 (38)	13 (2.7)
2001	1 (33)	n/a	2 (67)	3 (1.0)
2002	1 (14)	n/a	6 (86)	7 (1.2)
2003	0 (0)	n/a	3 (100)	3 (0.6)
2004	2 (13)	n/a	13 (87)	15 (3.2)
2005	0 (0)	n/a	3 (100)	3 (0.9)
2006	0 (0)	n/a	17 (100)	17 (2.3)
2007	0 (0)	n/a	0 (0)	0 (0)
Source: USFWS				

2. REFERENCES

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APPENDIX B.

HISTORICAL TIMELINE

CONTENTS

1. INTRODUCTION

This appendix presents a timeline of the human activities with the Wenatchee subbasin in order to assess their impacts to river processes based on the timing, duration, and extent of the activities. The following sections document historical information obtained from various literatures for early settlement, historical floods, vegetation, transportation, logging activities, land ownership and use, and fisheries.

2. EARLY ACCOUNTS OF BASIN AND HUMAN SETTLEMENT

Settlement in Nason Valley began with the Wenatchi Indians and colonists who moved to the area from Icicle to be near the Great Northern Railroad tracks (Roe 2002). Nason Creek was named after a member of the Wenatchi Tribe whose son homesteaded in Dryden in 1910 (Roberts 1996). Available historical accounts are somewhat vague and sparse. However, the information obtained from available literature is documented in the timeline below.

Pre-settlement	History shows that in early spring the Indians would pick up camp and move to Ephrata, returning to a big campground in Icicle Valley in the late spring for the return of salmon (Roberts 1996).
Early 1800s	Evidence exists of white trappers present in the Wenatchee basin who were most likely associated with the Hudson Bay Fur Company (Roberts 1996).
1800s	Many Indian trails were present in the lower Wenatchee Valley that were used by settlers from the Walla Walla and Puget Sound area (Kelley 1940).
1850s to 1890s	Europeans explored the Wenatchee watershed. In 1855, the Yakima Treaty was developed to initiate discussion on the division of land among the natives and settlers; however, before decisions were made, miners began settling in the Wenatchee Valley (Roe 2002).
1863	Father Respari came into the Wenatchee Valley to do missionary work with the Indians in an area later founded and named Cashmere (Kelley 1940).

1869	In the mining town of Biewett, gold prospectors first to settle in Upper Wenatchee (Roberts1996).
1870	July 8 is the first reference to Nason Creek in recorded history during Linsley expedition between Lake Wenatchee to Tumwater (Linsley and Majors 1981).
1884	First wave of pioneer families arrived in Icicle Valley (Roberts 1996).
1892	160 acres of heavily timbered land filed for homestead in 1892; wood cabin built; Merritt was a post office and flag station; post office existed until 1943; Merritt Inn built on land and burned down around 1980; 1904 Merritt Hotel built and later a grocery store was added; residents of the area walked the railroad track because it was the easiest path through the dense woods (Roe 2002).
1899	March 12, the state legislature passed a bill forming the new county of Chelan from parts of Kittitas and Okanogan counties, its boundaries the same as today; Governor John R. Rogers issued a proclamation on December 7, 1899; a May 1900 census put the new county's population at 776 (Roe 2002).
Early 1900s	Sheep grazing on the rise due to grazing rights on newly established national forestlands (Roe 2002).
1907	In November, 35,000 sheep were documented in Mount Stuart area, 25,000 in Icicle, and 6,500 around the White River (Roe 2002).
1925 to 1928	Railroad built camps to house and feed workers for rights of way and tracks toward Stevens Pass, the Cascade switchbacks, the Cascade Tunnel, and Eight-Mile Tunnel. After railroad work was completed, the camps became scheduled stops; each settlement averaged 100 to 200 residents in early century (Roe 2002). Villages began after construction of the railroad.
1928	New longer tunnel went in near Yodelin in 1928-location of existing fan house for tunnel (Thomas 2007)
Late 1920s	A ski hill was promoted and the first winter sports tournament occurred in 1929. A ski hut was built at Stevens Pass by the Civilian

	Conservation Corps (CCC) in 1938. A ski area was dedicated March 13, 1938. These two ski areas stayed open during World War II. The government considered recreation essential, so it sent soldiers and sailors to the area for the railroad. The government also provided gas to run the rope tow. The highway was kept plowed by the military. Many other lodges, T-bars, and chairlifts were built during the decade (Roe 2002).
1920 and 1930 census	Shows in 1920 about 60 people and in 1930 about 30 people located in Merritt.
1935 to 1936	In a fisheries survey of Nason Creek, the U.S. Bureau of Fisheries (USBF) noted that small farms principally devoted to hay and grain were scattered throughout the lower valley; the upper valley was too rugged for cultivation (Bryant and Parkhurst 1935-36).
1940	Report notes sparse settlement in Wenatchee basin which was typically confined along streams where associated lowlands lended to irrigated agriculture; documents 21,000 persons in Wenatchee region; report notes agriculture is leading industry supporting a third of the population (fruit being 85 percent of total farms), followed by Wholesale Retail trades, the Building Industry, the Professional Group, and the establishments such as Hotels.
1950s to 1960s	Ski hills and jumping clubs existed (Roberts 1996).
	Approximately 125 homes, businesses and other structures are within the Nason Creek subwatershed, and the number increases each year with new construction (USFS 1996).

3. Historical Flood

The occurrence of floods since 2002 is based on a stream gage operated by Department of Ecology (Ecology) near the mouth of Nason Creek (45J070). Documentation on historical floods for pre-2002 floods is based on local knowledge of U.S. Forest Service (USFS), a Federal Emergency Management Agency (FEMA) report, and Washington State Department of Transportation (WSDOT) personnel interviewed by Reclamation. Occurrence of historical floods was validated by examining streamflow data available from nearby gages on the mainstem Wenatchee River and Icicle Creek, a nearby tributary to the Wenatchee River.

Water Year (WY)	Event
1948	Upper Columbia basin areas; flood of record; high water event affecting highway in Nason (Thomas 2007; USFS 2007)); FEMA (2004) notes U.S. Geological Survey (USGS) estimated 5,270 cfs flood at the mouth of the river
November 1959	FEMA (2004) notes USGS estimated 6,860 cfs flood at mouth of the river (larger than the 1948 event)
1980	Rain on snow event, high water flooding Lake Wenatchee and Nason Creek (Thomas 2007; USFS 2007)
December 26-27, 1990	Rain-on-snow event, high water flooding Lake Wenatchee and Nason Creek (Thomas 2007)
November 22-25, 1995	Rain on snow event, high water flooding Lake Wenatchee and Nason Creek (Thomas 2007; USFS 2007)
1996	Flood damage to roads (Ribson 2007; Wood 2007) resulting in: • At least one section of Highway 207 between Coles Corner to the confluence of Nason Creek and the Wenatchee River was overtopped and washed out about a mile from the Highway 2/207 junction • Highway 2 washout near river mile (RM) 13; bank protection and barbs were subsequently placed to protect the road • Several washouts on hillslope roads as noted by USGS (USFS 1996)
May 2002 - present	Annual peaks from an Ecology gage at RM 0.8 on Nason Creek (data recorded from May 2002 to present; drainage area of 107.8 square miles): • As of June 2008, discharge values are currently being revised by Ecology and actual values are not available

4. VEGETATION

Year	Event
1880	Linsley expedition noted soil well covered with timber in Wenatchee

	valley below Tumwater Canyon; timber changed rapidly when nearing the Columbia River; fir was replaced by yellow pine with the quantity steadily decreasing; passed considerably good white pine before reaching Lake Wenatchee (Linsley and Majors, 1981)
Pre-railroad	Noted that when Stevens found railroad route there was little evidence of snow slides; destruction of timber above the railroad by fire (from sparks) was thought to cause more excessive slides on hillslope (Anderson 1952); photo of burned hillslope (Roe 2002, p.37)
Post-railroad and logging	Historical logging done adjacent to tracks on hillslopes; noted that major historical avalanches and landslides were thought by locals to be in part caused by reckless logging on hillslopes before consequences of mass logging on local processes were understood (Roe 2002) Where logged, locals noted that vine maple and scrub brush overtook (Johnson 2002)
1902	USFS maps vegetation in the Wenatchee subbasin
1930s	During a fisheries survey of Nason Creek in 1935 and 1936, the USBF noted that the watershed drained by Nason Creek was rugged and heavily forested and that conifers thrived on the slopes. However, the survey also noted that conifers were not found in great numbers on the streambanks except in the upper reaches; the stream was well shaded and protected by a thick growth of willow, cottonwood, and underbrush (Bryant and Parkhurst 1935-36)

5. TRANSPORTATION

The following historical information was collected from the book *The Story of Railroading and Recreation in the North Cascades* (Roe 2002) unless otherwise noted.

Year	Event
1870	D.C. Linsley expedition to find route for railroad (Linsley and Majors 1981)
1890	John F. Stevens discovered Stevens Pass and designed railroad route down Nason Creek

1891 to 1893	Railroad construction; Great Northern railroad (GNR) had no financial support or land grants from government to complete tracks across the Cascades; therefore, railroad company built switchbacks on west side of the Cascades until funds could be secured for tunnels (Anderson 1952)
1893	GNR ran directly up Tumwater Canyon; tracks relocated in 1920s to Chumstick Creek (Anderson 1952)
1893	GNR completed, switch backing up to and over Stevens pass. Railroad bed was considered some of the finest built in mountainous terrain in the State of Washington. One of the toughest sections to build was located in a narrow section of the valley below White Pine Creek confluence, known as the "Gap" (Thomas 2007)
1893	June – first scheduled railroad service, with a station at Nason Creek located at present ghost town of Winton
1890s to early 1900s	Switchback trail existed on which wagons crossed west side of Cascades contributing to the onset of tourism
1905	Great Northern Railroad renamed Great Northern Railway
1908	Tumwater Dam built in Tumwater Canyon on mainstem Wenatchee for power generation for electric trains; plant replaced and dismantled later because tracks were relocated; dam remains today (Roberts 1996)
1913 to 1917	The majority of the East Cascades portion of road was completed except for railroad underpass
1925	Stevens Pass Scenic Highway opened on July 11 but much of it was dirt and parts of it were dangerous. The USFS wanted expansion because campers, anglers, hunters, and berry pickers wanted access to the wilderness. Fortuitously, the Great Northern rerouted its track through the Chumstick Valley. This left the old roadbed for the highway.
1929	Automobile route completed through Tumwater utilizing former railroad grade (Anderson 1952) New Stevens Pass highway route opened September 1. More improvements were made in the 1930s by the Works Progress Administration.

1931	Legislation authorized Stevens Highway, primary state highway (P.S.H.) No. 15, from Peshastin (P.S.H. 2) via Stevens Pass to Everett (WSDOT web site 1931)
1937	Stevens highway designated State Highway 15, then US 2 in 1948. It was later changed to SR 2 to comply with Federal highway numbering standards.
1943	Highway 207 straightened and improved for higher speed traffic (Coles Corner to mouth). Installed turnpike sections that cut off oxbows, also created new channel near Beaver Creek Highway (Highway 209 going to the town of Plain, near the south entrance of the State Park on Lake Wenatchee). River fan where Nason joined Wenatchee forced upstream above existing bridge. Historically, river flows went overland where current development exists on east side of Highway 207. (Thomas 2007)
1960	State Highway 2 realigned and improved for high speed traffic. Road moved east and north, away from Winton, and further constrained Nason Creek (Thomas 2007); new and old highway alignments are visible in 1962 aerial photographs

6. Logging Activities

Logging activities appeared to have started in the early 1900s. Logging drives were completed under Tumwater Canyon to a dam owned by Great Northern Railroad. There are historical accounts of river men darting back and forth over logs (Johnson 2002). Literature describes accounts of loggers from the Great Northern Lumber Company along Nason Creek, Lake Wenatchee, and near big bend of Chiwawa, and the Wenatchee River (Johnson 2002). During winter, the loggers would cut, skid, and haul logs to be amassed in great decks adjacent to the stream. Decks would be 30 feet or higher and stretched along the river bank waiting for high water to make the drive to the mill (Johnson 2002). During April to June of each year when the water rose, the decks were dumped into the river and the “river rats” would boat down the river and dynamite or throw chains into logs to pull and loosen any jams that may have formed that blocked the log drive (Johnson 2002). Each week the Leavenworth Echo would report the location of jams and describe how far down the tributaries and river the drive had reached. Mill officials estimated 15 million board feet of logs reached the mill by late April of 1926 (Johnson 2002). Drives often started in April and men frequently had to shovel snow off the jams before they could dynamite (Johnson 2002). The following timeline displays the logging activities that continued during the 1900s.

1900s	No bridges on the Wenatchee River as it was usually too deep to ford easily; locals bound for Ellensburg or Wenatchee traveled along the north bank of the river to the Peshastin ferry (Roe 2002)
1903	Lam Davis Lumber Company (LDLC) filed for 34,000 acres of prime forest land and bought river front property near town (Roberts 1996); they incorporated for $250,000 and built a mill in Leavenworth (Roe 2002). LDLC eventually built a dam across the Wenatchee River, below today's hospital, to act as a storage pond for logs. In memoirs at the Leavenworth Ranger Station, James Fromm, a pile driver for LDLC in 1907, recalled that he and other lads rode peeled cedar logs down the river into the millpond as a lark; the small dam could be opened to release water when log storage was not required (Roe 2002) LDLC set aside 400 feet of riverbank above and below the dam for local Indians to do subsistence fishing (Roe 2002)
1905 to 1929	Logs floated down spring waters of Wenatchee from Nason, Chiwawa, and Lake Wenatchee to lumber mill in Leavenworth (Roberts 1996; Hull 1929)
1906	On July 28 Leavenworth became an incorporated town, population 1,000, largely supported by the mill, railroad, and a handful of miners (Roe 2002) LDLC had a daily capacity of 100,000 to120,000 board feet of lumber and 20,000 to 25,000 board feet of lath; its box factory consumed an additional 30,000 board feet of lumber to provide boxes for local fruit orchards (Roe 2002) Lumber mill opened at Peshastin (Roe 2002)
1907	LDLC created the Wenatchee Valley & Northern Railroad (WVNR) to transport logs from forest to mill; 20 miles of the WVNR was in place by 1909 with an additional 10 miles created; a large amount of lumber used to build this railway (Roe 2002)
1908	Built Peavine Railroad up Chumstick to Lake Wenatchee; operated

	until 1920s when returned to river-driving the logs (Roberts 1996)
1909	Kelly & Lapp, a local lumber mill, purchased by S.B. Hathaway; LDLC dominated lumber business in area; logs taken from the Nason Creek area and heavy forest of upper Wenatchee Valley; LDLC owned 50,000 acres of timberland; much of logging was performed by Adams & Costello, which built substantial camps and barns for its crews and teams in remote areas (Roe 2002)
	Big logs were cut on the White and Wenatchee rivers during fall and winter and stacked in huge piles until spring runoff; loggers dynamited the piles to roll them into the rivers; a crew of river-drivers then followed the logs downstream all the way to the mills; small logs taken above Lake Wenatchee were processed at local mill; large logs were floated down the Wenatchee to the LDLC mill at Leavenworth (Roe 2002)
1910	Mount Stewart Mining Company began mining asbestos on Ingalls and Allen Creek; Adams & Costello brought in 20 million board feet of lumber at mills (Roe 2002)
	Tunnel construction for a 2.5 mile tunnel begun in 1899, in use by 1910. Tunnel entrance in Nason subwatershed located, current name of town on USFS map is Bern. (Thomas 2007)
1911	Log camp noted at mouth of Lake Wenatchee on a survey map (Marshall 1914)
1913	One contractor, Adams & Costello, drove 17 million board feet on (3,400 loaded logging trucks, 1,400 houses) (Roberts 1996)
1914 to 1916	Lumber mill operated by C.A. Harris and son Arden made ties for Great Northern Lumber Co. (Roe 2002); in 1892 Harris was in Entiat with lumber equipment; moved back to Entiat in 1917 near Ardenvoir (Roe 2002)
1915	Lamb Davis Dam constructed; 25 logging camps along the river and 250 men employed (Roberts 1996)
1916	Mill closed during WWI (Roberts 1996)

1917	Mill reopened under Great Northern Lumber Company (Roberts 1996) LDLC sold to Great Northern Lumber Company (GNLC) including 650 million board feet; more advanced logging methods began including donkey engines and cable to get logs to railsway; logs in valley were beginning to be depleted and logging moved into higher land using skid ways or flumes to bring logs to railroads; GNLC had holding pond at Chiwaukum to release logs during high water downstream to Leavenworth; flooding in May 1921 caused 18 to 20 million board feet of logs to go down Wenatchee over GNLC dam and wound up on Wenatchee River shores all the way to the Columbia (Roe 2002)
1920s	Logging trucks came about (Roe 2002)
1922	GNLC closed down due to reduced profits because of price reductions in lumber (Roe 2002)
1925	River drive featured in early 1925 Paramount Pictures film “The Ancient Highway” directed by Sam Nelson (Roberts 1996)
1926	June 11, 35 million board feet of logs brought down Nason, Chiwaukam, Chiwawa, Wenatchee and other rivers; 1926 log drive thought to be last one by locals, but there was one additional drive in 1927 (Johnson 2002)
1927	Mill closed doors because the river’s accessible timber tracts had been logged off (Roberts 1996) GNLC railway closed due to depletion of forests adjacent to railway (Roe 2002) 1927 Drive (Johnson 2002) o Camp at Chiwawa River Bridge noted o Boats taken up both Chiwawa and Nason Creek o Logs said to be in river and will be set afloat as soon as there is sufficient water

1929	"Great Depression" ended log drives Blueprint for snow sheds on tracks – No.1 Douglas fir came from mills between Skykomish and Everett
1930s	Dam on Wenatchee River mysteriously dynamited; fishermen claimed it interfered with fish runs (Roberts 1996) Logging operations confined largely to ponderosa pine types, but some cutting in better quality Douglas fir stands along the Stevens Pass highway (Nason drainage) noted: o On private land the practice was to remove all merchantable pine timber, but young trees often remained o Horses and tractors were used for skidding, while motor trucks used for transporting logs to the sawmill; logs were trucked for nearly 50 miles
1931	Nason Creek Mill Company began operation; early cuts sold for fruit boxes (Roberts 1996) Chancy Lamb, a mill operator since the mid-1800s in Clinton, Iowa, sent his son to Lafayette to purchase several fine stands along Nason Creek toward Stevens Pass at prices reportedly as low as $10 per acre (Roe 2002) Several small saw mills continued until the 1980s with one pole mill still located at Winton (Roberts 1996)

7. LAND OWNERSHIP AND USE

7.1 Ownership

Currently, 22 percent of the watershed is in private ownership and concentrated in the lower half of the Nason Creek subwatershed; this includes private timberland holdings mostly in the Kahler (RM 5.1), Roaring (RM 8.4), Gill (RM 9.3), and Coulter Creek (tributary to Roaring Creek) drainages. Matrix allocations, which are where most timber harvest takes place on USFS land, and privately-owned land together, constitute 90 percent of Butcher-Kahler drainage, 85 percent of Gill-Roaring-Coulter, and 80 percent of lower Nason (Andonaegui 2001).

The floodplain of Nason Creek below RM 15.0 has largely been converted to rural residential and recreational development and a substantial portion of the watershed below RM 15.0 has experienced road building and timber harvest. The upper watershed has experienced less of these impacts (Andonaegui 2001).

Small portions of the Alpine Lakes and Henry M. Jackson Wilderness areas lie the headwaters and 68 percent of the Upper Nason subwatershed is Late Successional Reserve (LSR) or administratively withdrawn, with only 24 percent matrix. Wilderness, LSR, and administratively-withdrawn lands make up 94 percent of headwaters at Nason, and 99 percent of white pine (USFS 1996).

7.2 Land Use

Historically, land use during the 1930s consisted of general farming on Nason near RM 3 to 4 and also along a portion of the area between Coles Corner and Merritt. During this era, general farming consisted of dry farming, sub-irrigated areas, or through small cooperative irrigation projects (Kelley 1940). Further noted during this era was undeveloped graphite running 32 percent pure at Nason Creek (Kelley 1940).

Currently, recreational use in Nason Creek subwatershed is high and is traveled by approximately 1,250,000 vehicles per year (USFS 1996).

Most of the other development in Nason Creek, including the majority of the harvest, harvest-related roads, and private land development, has occurred since 1967 (USFS 1996).

7.2.1 Natural Barriers

As previously noted, there were no diversions on Nason Creek in the mid-1930s; however, a natural falls barrier (Gaynor Falls), approximately 11 to 12 feet high, was noted 1,700 paces above the confluence with White Pine and documented to be impassable at low water and most probably impassable at all times (Bryant and Parkhurst 1935-1936).

Natural barriers were located on:

- Nason Creek at Gaynor Falls at RM 16.8
- Roaring Creek (confluence at RM 8.4) a naturals falls at RM 1.1
- White Pine Creek (confluence with Nason at RM 14.6) a natural falls at RM 3.4 (Andonaegui 2001).

7.2.2 Diversion Dams

During 1935 to 1936, no diversions were noted on Nason Creek (Bryant and Parkhurst 1935-36). The Nason Drainage included:

- Kahler Glenn Golf Course pump diversion at RM 0.75 on Nason Creek (Golder 2003)
- Water diversion, Butcher Creek at RM 0.4 (Golder 2003)
- Mill Creek Nordic Center diversion dam on Lanham Creek at RM 0.5 (Golder 2003)

On the mainstem Wenatchee River the diversions noted were Dryden Dam at RM 17 and Tumwater Dam at RM 31 (Andonaegui 2001).

7.2.3 Fisheries

During the Linsley expedition in July 1870, it was noted that at the mouth of Tumwater Canyon salmon collected in great quantities resulting in the arrival of Indians in mass. Linsley noted that between 200 and 300 Indians camped along Tumwater Canyon (Linsley and Majors 1981). It was also documented that Native Americans spear fished in Tumwater Canyon into the 1900s (Roberts 1996).

During a 1935-1937 USBF survey, no salmon were noted in the stream; however, excellent spawning opportunities did exist (Bryant and Parkhurst 1935-36). In 1939, it was documented that thousands of salmon were trapped at Rock Island and transported into the Wenatchee River, Nason Creek, and Lake Wenatchee so that they might begin perpetuating themselves in new waters. Observations noted that salmon spawned out satisfactorily (Kelley 1940).

The Leavenworth Fish Hatchery was constructed between 1939 and 1941 as part of the mitigation measures for the Bureau of Reclamation's construction of Grand Coulee Dam (Roberts 1996).

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APPENDIX C.

GEOLOGIC SETTING

CONTENTS

Tables

Figures

Photographs

1. TECTONIC SETTING OF THE PACIFIC NORTHWEST

Four geologic belts mark the evolution of the Columbia and Pacific mountain building events along western United States, known as orogens. These belts include the Omineca Belt, Intermontane Zone, Coast Crystalline Complex, and the Insular Belt in northern Washington, United States, and into British Columbia, Canada (Figure 1). Each of these belts contains a sequence of tectonic terranes that record the geologic history of the northern Pacific Northwest. The term tectonic terrane is used in the context of Beck and others (1980), “a tectonic terrane is defined as a fault-bounded geologic entity characterized by a distinctive stratigraphic sequence and a structural history differing markedly from those of adjoining neighbors”. Readers should also note that reference to the Pacific oceanic plate in the text is generalized and does not recognize the multiple smaller plates (i.e., Juan de Fuca plate, Gorda plate, etc.) that are, in themselves, very significant to understanding the Pacific Northwest’s tectonic regime. The tectonic terranes for the Wenatchee subbasin are discussed in more detail in the Regional Geologic Setting for the Wenatchee subbasin section of this report, and further refined for the Nason Creek tributary assessment in the Site Geology of Nason Creek Valley section.

Within the Omineca Belt and Intermontane Zone the Okanogan-Shuswap terrane are interpreted to define the Columbia orogen (Figure 1). The Okanogan-Shuswap terrane is comprised of Late Paleozoic-Early Mesozoic metamorphic rocks that were intruded by igneous rocks (plutonism) between Late Triassic and Middle Jurassic time (Hibbard 1971; Rinehart and Fox 1972; Miller and Engels 1975). Additionally, during most of Jurassic time these crystalline rocks were mantled by extrusive volcanic rocks (volcanism) along what is commonly referred to as the Columbia arc. This event occurred as a result of the North American continental plate and Pacific oceanic plate colliding in an east-west motion along a subduction zone resulting in uplift and volcanism along the Columbia arc. As the arc uplifted, erosion transported and deposited the sediments westward into an ancient ocean along the continental margin (Tennyson and Cole 1987).

During Mesozoic time the sediments derived from the uplift of the Columbia arc were deposited westward into the Tyaughton Trough forming the Methow-Pasayten belt. The Methow-Pasayten belt is comprised mostly of Jurassic and Lower Cretaceous marine and volcanic sedimentary rocks deposited over a basement of Triassic ocean ridge basalt (Ray 1986). Studies completed in the Methow basin, an element of the Methow-Pasayten belt, show that the Methow basin ceased to be a sedimentary basin in Late Cretaceous time due to infill and folding as the North Cascades Core were uplifted walling off the western side of the basin during the Pacific orogen (McGroder 1988; Tennyson and Cole 1987).

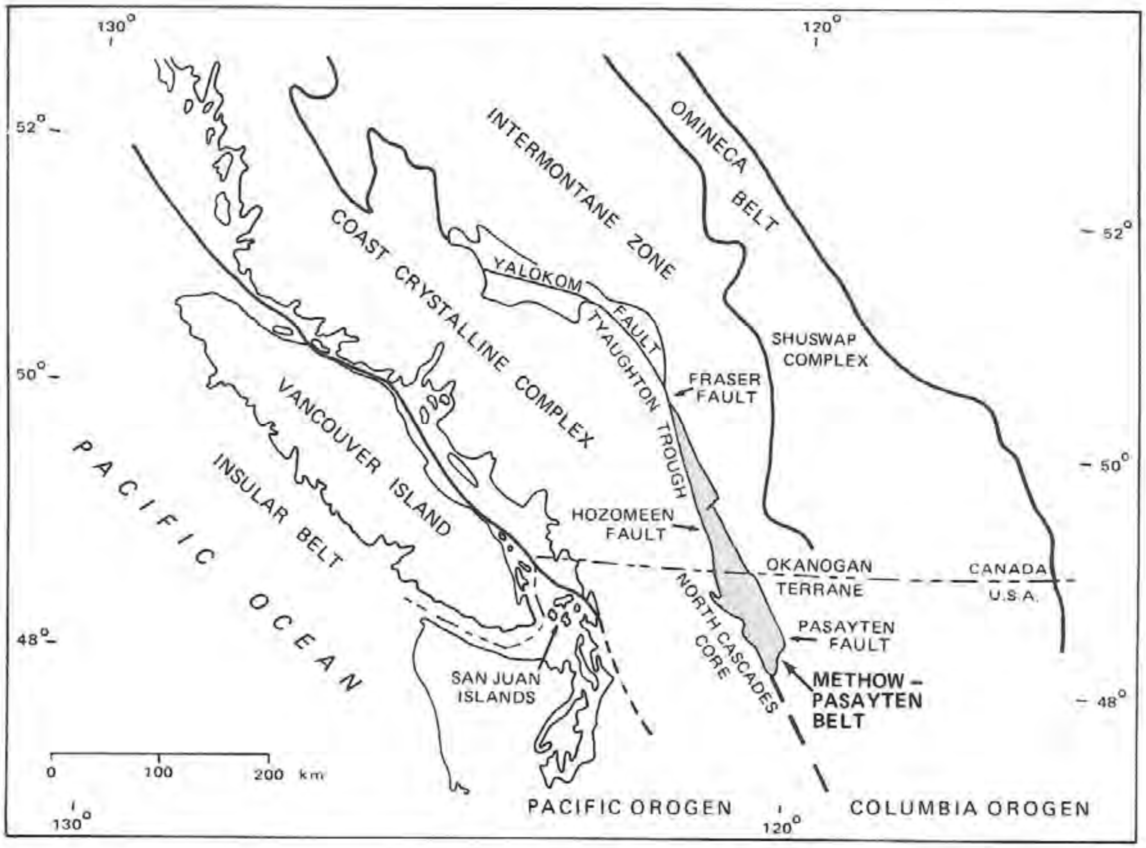

Figure 1. Tectonic map of the four tectonic belts and their primary elements recording the Columbia and Pacific orogens for the northern Pacific Northwest as delineated by Tennyson and Cole (1987).

The North Cascades Core, an element of the Coast Crystalline Complex, is comprised of Late Paleozoic to Early Mesozoic marine sedimentary and volcanic rocks that were accreted as blocks or microplates to the North American plate in Cretaceous time (Tennyson and Cole 1987; Haugerud 1989; Frizzell et al. 1987). During Middle Cretaceous time, regional compression between the oceanic and continental plates deformed the terranes resulting in uplift, metamorphism (recrystallization of the rocks) and thrust faulting (McGroder 1989, 1988; Misch 1966; Brandon et al. 1988). This event is recognized as the beginning of the Pacific orogen. During the Late Cretaceous and into the Tertiary plutonism accompanied the metamorphism as a broad arc began to develop (Tennyson and Cole 1987).

The westernmost structural element in the Pacific orogen is known as the Wrangellia terrane that underlies Vancouver Island (McGroder 1989). Crustal contraction or thickening occurred during the collision between the North American plate as Wrangellia and other terranes that compose the Insular Belt were accreted during the Late Cretaceous

(Frizzell et al. 1987; McGroder 1989; Tennyson and Cole 1987). These terranes probably evolved independently prior to their accretion to the North American plate and were most likely adjacent to the continental margin by Late Jurassic time (Brandon et al. 1988).

In the Cenozoic the collision or convergence between the Pacific and North American plates shifted from an east-west direction to a northeast-southwest and volcanic activity shifted westward. During the Middle Eocene to Late Miocene the convergence between the plate boundaries were relocated westward and the direction of convergence shifted to a northeast-southwest direction (Wells, Weaver, and Blakely 1998; Armentrout 1987). The overall regional stress regime changed to mostly extensional with local compression (Armentrout 1987). Associated with this new stress regime was the onset of volcanism along the Cascade arc, and regional folding and tensional rifting. During Eocene and Oligocene time active volcanism occurred along the Cascade arc accompanied by tensional rifting inland (i.e., initiation of the Chiwaukum graben).

In Miocene time the regional stress regime became less extensional with increasing compression. North- to northwest trending fissures opened in southeastern Washington, northeast Oregon and western Idaho extruding flood basalts of the Columbia River Basalt Group (Anderson and Vogt 1987). In addition, clockwise rotation of microplates or smaller crustal blocks along the west coast occurred (Wells, Weaver, and Blakely 1998; Armentrout 1987). This stress regime still persists to the present.

2. REGIONAL GEOLOGIC SETTING OF THE WENATCHEE SUBBASIN

The Wenatchee subbasin is located in the North Cascades Core, an element of the Coast Crystalline Complex belt as delineated by Tennyson and Cole (1987). The regional geology (Figure 2) is comprised of five tectonic terranes described in more detail below:

1. Swakane terrane
2. Mad River terrane
3. Chelan Mountains terrane
4. Nason terrane
5. Ingalls Tectonic Complex.

There is also one structural basin known as the Chiwaukum graben, and extrusive volcanic rocks of the Columbia River Basalt Group (Tabor et al. 1987a).

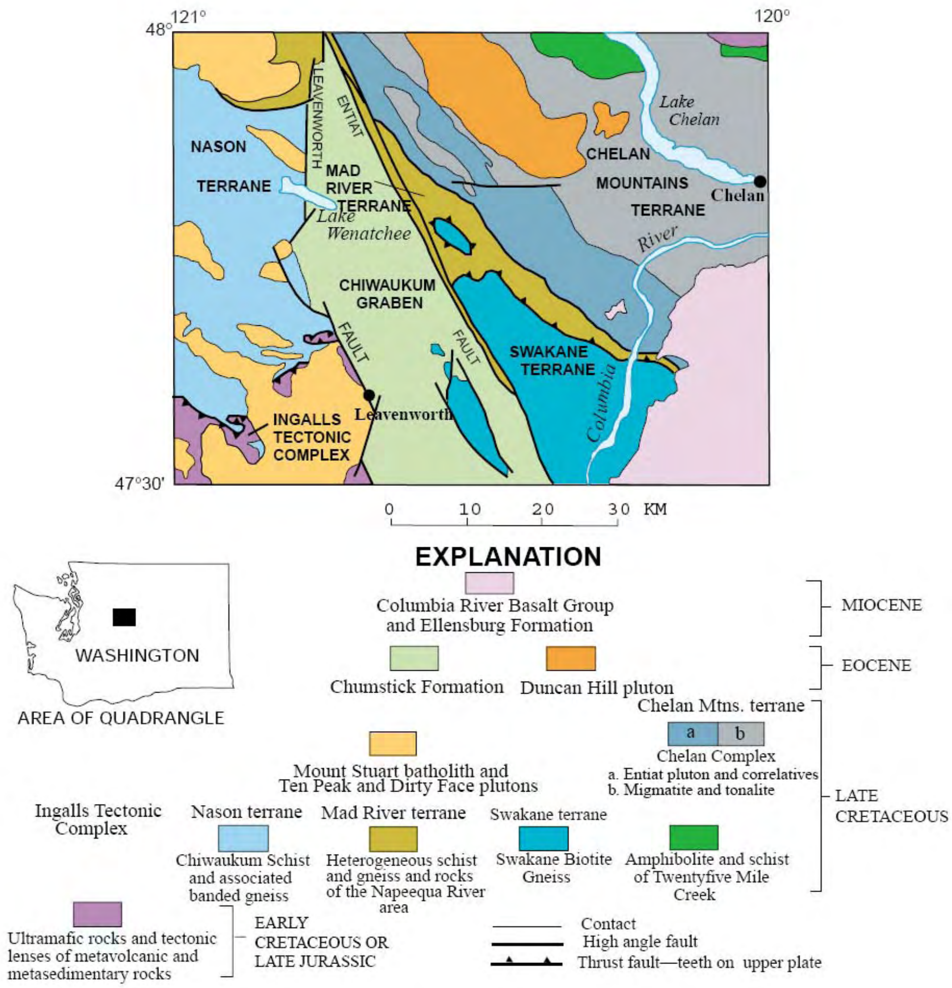

Figure 2. Generalized geologic map for the Wenatchee subbasin and surrounding area from Tabor et al. (1987a).

2.1 Swakane Terrane

The Swakane terrane is comprised of metamorphic rocks (Swakane Biotite Gneiss unit) (Tabor et al. 1987a). The original rock was emplaced or deposited at least by Pre-Cretaceous and presumably during the Precambrian (Mattinson 1972). The Swakane terrane is in thrust fault contact or tectonically overlain by the Mad River terrane (Tabor et al. 1987a). Dikes and sills intruded the terrane during a period of regional metamorphism in Late Cretaceous time (Mattinson 1972).

2.2 Mad River Terrane

The Mad River terrane is comprised of a heterogeneous mixture of metamorphic rocks (schist and gneiss units) (Tabor et al. 1987a). The original rock or protolith for the Mad River terrane is probably Paleozoic age or older. The terrane tectonically overlies or thrusted over the Swakane terrane. Dikes and sills intruded the terrane during a period of regional metamorphism in Late Cretaceous time (Mattinson 1972). The Mad River terrane is separated from the Nason and Ingalls terranes by the Chiwaukum graben that is fault bounded by the Entiat fault on the northeast and the Leavenworth fault on the southwest (Tabor et al. 1987a).

2.3 Chelan Mountains Terrane

The Chelan Mountains terrane is comprised of metamorphic marine and sedimentary rocks, and igneous intrusions or plutons. The terrane contains igneous and metamorphic rocks from the Late Cretaceous regional metamorphism and the presence of older rocks. Although not conclusive, the supracrustal or surface rock of both the Mad River and Chelan Mountains terranes may have been depositionally continuous and then thrust over the Swakane terrane suggesting that they may be the same rock (Tabor et al. 1987a; Tabor, Zartman, and Frizzell 1987b).

2.4 Nason Terrane

The Nason terrane is comprised of metamorphic rocks (Chiwaukum Schist and gneiss) derived from sedimentary and igneous rocks. The terrane is bounded by the Leavenworth fault and others on the east and the Straight Creek fault zone on the west. The Nason terrane juxtaposes the Mad River terrane to the northeast and is in fault contact or overthrust by the Ingalls Tectonic Complex to the south. The terrane has undergone a high degree of metamorphism, presumably during the Late Cretaceous (Tabor et al. 1987a; Tabor, Zartman, and Frizzell 1987b).

2.5 Ingalls Tectonic Complex

The Ingalls Tectonic Complex is comprised of a mixture of marine sedimentary and volcanic rocks (dismembered ophiolite complex) that were accreted to the North American plate (Hopson and Mattinson 1973; Miller 1977, 1980; Miller and Frost 1977). The terrane is predominantly Late Jurassic or Early Cretaceous in age and is primarily metamorphic rocks (serpentinite, serpentinized pridotite and metaperidotite) (Tabor et al. 1987a). The Ingalls Tectonic Complex has been thrust over the Chiwaukum Schist of the

Nason terrane (Miller 1977). The terrane was tectonically emplaced or accreted prior to the Late Cretaceous intrusion by the Mount Stuart batholith (Tabor et al. 1987a).

2.6 Chiwaukum Graben

The Chiwaukum graben is a structural basin bounded by the Entiat fault on the northeast and the Leavenwork fault on the southwest. The graben was initiated during Eocene time when the regional stress regime was extensional and filled with sediments eroded from the surrounding area that form the sedimentary rocks of the Chumstick Formation (Gresens 1987b; Tabor et al. 1987a). The active life of the graben was from about 46 my to 40 my (Gresens 1987a).

2.7 Columbia River Basalt Group

The Columbia River Basalt Group is comprised of a series of flood basalts that poured out of fissures in southeastern Washington, northeast Oregon, and western Idaho. The basalt flows form the Columbia Plateau and lap onto the rocks of the Mad River terrane and the Chelan Mountains terrane (Tabor et al. 1987a). The uplift of the Cascade Range in Pliocene time tilted the Columbia River Basalt Group eastward and eventually raised the range enough to nourish alpine glaciers during Pleistocene time (Tabor et al. 1987a).

2.8 Quaternary Deposits

The Quaternary age deposits in the Wenatchee watershed reflect the following conditions:

1. advances and retreats of alpine glaciers
2. flood deposits in the lower drainage from glacial outburst floods flowing down the Columbia River,
3. formation of lakes in the Wenatchee river valley by landslides and flood backwaters,
4. recent alluvium from streams reworking surficial deposits
5. landslides and debris flow deposits (Tabor et al. 1987a)

2.9 Glacial Geology

The Cascade Range forms a topographic barrier causing orographic uplift as Pacific air flows eastward and effectively divides Washington into two climatic regions. West of the Cascade Range the climate has moisture maritime conditions and east of the range has drier continental conditions (Porter 1976). In Pleistocene time glaciers east of the

Cascade Range most likely developed in a relatively drier climate as compared to those that developed west of the range.

During the Late Pleistocene there were at least two glaciations, known as the Salmon Springs Glaciation and the Fraser Glaciation (Table 1). These glaciations involved the development of both continental and alpine glaciers in the Pacific Northwest. The older Salmon Springs Glaciation is believed to have occurred between about 140,000 and 130,000 years before present (B.P.) and the younger Fraser Glaciation occurred between about 18,000 and 11,500 years B.P. (Porter 1976; Waitt 1979).

During the last glacial cycle, the Fraser Glaciation, there were at least one continental phase and most likely three alpine phases. Waitt and Thorsen (1983) noted that the expansion of the glacial lobes from the continental ice sheet did not fluctuate in phase or with the advance of the alpine glaciers.

Table 1. Regional alpine glacial stages correlated by Waitt (1977).

Location	Glacial stage 130-140 ky B.P.	Glacial stage 18 ky B.P.	Glacial stage 14-15 ky B.P.	Glacial stage 11.5 ky B.P.
Yakima Valley (Porter 1976)	Kittitas drift Indian John and Swauk Prairie members	Lakedale drift Ronald and Bullfrog members	Lakedale drift Domerie member	Lakedale drift Hyak member
Peshastin Valley (Hopkins 1966)	Unrecognized	Outer member	Unrecognized	Inner member
Wenatchee Valley (Page 1939; Porter 1969)	Peshastin drift	Leavenworth drift stages I-III	Leavenworth drift stage IV	Leavenworth drift stage V

Alpine glaciers advanced about 18,000 years B.P. during the Evans Creek Stade of the Fraser Glaciation prior to the arrival of the continental ice sheet (Cordilleran Ice Sheet). The alpine glaciers are responsible for the development of U-shaped cross valley profiles.

The Cordilleran Ice Sheet expanded southward from the Canadian border about 17,000 to 13,500 years B.P. during the Vashon Stade of the Fraser Glaciation (Burtchard, 1998). During its maximum stand the ice sheet buried much of the northeastern North Cascade Range (Barksdale 1941; Waitt 1972). The Okanogan Lobe of the ice sheet flowed south from Canada overriding prominent mountain ranges and converged into ice streams down the Skagit, Chelan, Methow, Okanogan, and Columbia valleys (Barksdale 1941; Waitt and Thorsen 1983). At its maximum, the Okanogan Lobe reached the Chelan trough (Waitt 1972; Waitt and Thorson 1983).

During the retreat of the Cordilleran Ice Sheet, the Okanogan Lobe impounded glacial Lake Columbia east of Grand Coulee in Washington (Bretz 1923 and 1932; Flint 1935 and 1936; Flint and Irwin 1939). This ice dam failed at least once releasing a catastrophic glacial outburst flood as deep as 215 meters that flowed down the Methow-Chelan segment of the Columbia River Valley (Waitt 1972, 1980, and 1982).

After the retreat of the Cordilleran Ice Sheet there was a period of time, known as the Everson Interglacial of the Fraser Glaciation, when there were no glacial advances or expansions. Following the Everson Interglacial the alpine glaciers re-advanced in the Cascade Range during the Sumas Stade of the Fraser Glaciation between about 15,000 and 11,500 years B.P. It should be noted that in the areas affected by Cordilleran Ice Sheet there are no known alpine glacial deposits predating the last glacial episode (Tabor et al. 1987a). However, there are erosional features (i.e., changes in cross valley geometry) that most likely predate the arrival of the Cordilleran Ice Sheet.

3. SITE GEOLOGY OF THE NASON CREEK VALLEY

Nason (tectonic) terrane forms the bedrock in the upper drainage of Nason Creek. The terrane is comprised of metamorphic rocks that are crystalline and very hard. Physiography of the upper drainage is steep mountainous (physical) terrain with both jagged and rounded peaks, and over-steepened valley walls with large accumulations of talus along their bases (Photograph No. 1). Nason Creek has a steep gradient or channel slope as it flows from the headwaters and decreases in slope as it flows downstream. It is unlikely that Nason Creek has incised to any great depth in the crystalline rock, and more likely that the creek follows the relative path of Pleistocene alpine glaciers from their zone of accumulation in the headwater area to where the glaciers scoured the valley. The creek is basically confined by bedrock and talus slopes upstream of White Pine Campground. Below White Pine Campground the valley has been scoured by the alpine glaciers and the creek is predominantly unconfined and has been able to re-work the glacial deposits along a broad valley bottom.

Photograph 1. Typical view of the upper Nason Creek drainage where the alpine glaciers over-rode or surmounted bedrock outcrops rounding their profile and talus accumulation at the base of the outcrop. (Reclamation photograph by E. Lyon, June 18, 2008).

The Chumstick Formation juxtaposes the Nason terrane along the Leavenworth fault, the southwest structural boundary of the Chiwaukum graben. Nason Creek flows across the Leavenworth fault and the Chumstick Formation in the lower drainage. The Chumstick Formation is comprised of sedimentary rocks that are relatively soft and less resistant to weathering and erosion than the Nason terrane. The terrain of the lower drainage is predominantly hills and subdued mountains (Photograph No. 2). Alpine glaciers mapped as glacial stages Plain I and II by Nimick (1977) in Figure 3, have scoured the lower valley and are most likely from the Salmon Springs Glaciation (130-140 ky B.P.) based on correlated regional alpine glacial stages (see Table 1). Glaciers from the Fraser Glaciation (18-11.5 ky B.P.) are mapped as glacial stages Plain III and IV (Nimick, 1977) in Figure 3. A landslide that is seated in the left abutment of a terminal moraine between river miles (RM) 8.9 and 9.3 is interpreted to be equivalent to the Evans Creek Stade of the Fraser Glaciation. The valley bottom is broad and the creek is unconfined except were it has incised into the tremendous amount of glacial outwash deposits.

Photograph 2. View is from the left abutment of a terminal moraine over 200 feet above the valley floor believed to be of Evans Creek age looking downstream at the lower Nason Creek drainage area. The moraine is just downstream of the Leavenworth fault and contains clasts from both the Nason terrane and Chumstick Formation. (Reclamation photograph by E. Lyon, June 18, 2008).

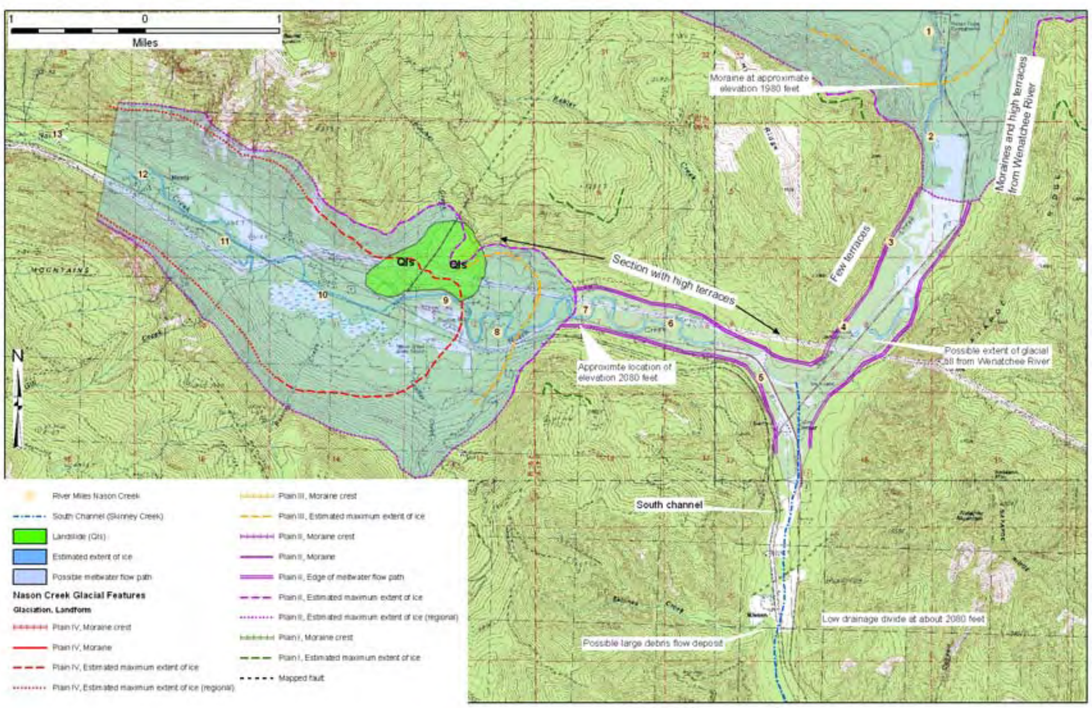

Figure 3. Map of lower Nason Creek valley showing glacial features as mapped by Nimick (1977).

The terminal moraine of probable Evans Creek age does not continue across the valley bottom, but is breached and probably had released a glacial outburst flood. Where exposed downstream of the moraine along Nason Creek there is a stratigraphic sequence of boulders in a relatively fine matrix that fines upward to silt and sand that is overlain by younger glacial outwash deposits. It was beyond the scope of this assessment to further investigate this phenomenon. However, if such a catastrophic outburst flood event did occur the flows would have been through Skinny Creek and the Tumwater Canyon as the adjacent valley would have been filled with the alpine glacier that built the terminal moraine that impounds Lake Wenatchee. The relatively narrow opening through the Skinney Creek and Tumwater Canyons would have temporarily ponded or restricted the flows and large amounts of sediment would have been deposited.

The boulders (up to 10 feet in dimension) contained in the terminal moraine were deposited downstream of the breach most likely forming a wedge from between about RM 6.7 and Rm 8.5 (Photograph No. 3). Following the breach, copious amounts of glacial outwash were deposited by the receding glacier (and probably by subsequent younger glaciers). Nason Creek has incised through the glacial outwash deposits as evidenced by the flight of terraces that are perched over 60 feet above the active stream channel. Nason Creek continued to incise through the glacial deposits until it reached the wedge of boulders that provide a vertical grade control.

Photograph 3. View is looking downstream at boulders up to 10 feet in dimension deposited during the failure of the terminal moraine. At the base of the cutbank near center of photograph the boulder deposit and subsequent glacial outwash deposit can be observed in-place. (Reclamation photograph by E. Lyon, June 18, 2008).

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Waitt 1979	Waitt, R., Jr. 1979. "Late Cenozoic deposits, landforms, stratigraphy, and tectonism in Kittitas Valley, Washington." U.S. Geological Survey Professional Paper 1127, 18 p
Waitt 1977	Waitt, R., Jr. 1977. *Guidebook to Quaternary geology of the Columbia, Wenatchee, Peshastin, and Upper Yakima Valleys, West-Central Washington*. Geological Society of America 1977 Annual Meeting (Seattle), Field Trip no. 13, 10-11 November, 1977; Open-file Report 77-753, 25 p
Waitt 1972	Waitt, R.B., Jr. 1972. "Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade Range, Washington." University of Washington Ph.D. thesis, 154 p.
Waitt and Thorson 1983	Waitt, R., Jr., and R. Thorson. 1983. "The Cordilleran Ice Sheet in Washington, Idaho, and Montana;" *In* Wright, Jr., H., and Porter, S., editors, Late-Quaternary environments of the United States, Volume 1, The Late Pleistocene, University of Minnesota Press, Minneapolis, Minnesota, p. 53-70.
Wells et al. 1988	Wells, R., C. Weaver, and R. Blakely. 1998. "Fore-arc migration in Cascadia and its neotectonic significance." *Geology*, v. 26, no. 8, p. 759-762.
Wheeler and others 1972	Wheeler, J., and others. 1972. "The cordilleran structural province." *In* Price, R., and Douglas, R., Variations in tectonic styles in Canada: Geological Association of Canada Special Paper 11, p. 1-81.

APPENDIX D.

HYDROLOGY ANALYSIS AND GIS DATA

This appendix provides documentation on a hydrologic analysis for the Wenatchee subbasin based on U.S. Geological Survey (USGS) gaging station data. An additional section is provided on Nason Creek incorporating provisional Washington Department of Ecology (Ecology) gage data available since 2002. As of June 2008, Ecology determined the upper range of peak flow values at this gage will need to be revised and likely lowered. Therefore, the Nason Creek estimates will need to be revised once this gage data has been finalized.

CONTENTS

Tables

Figures

1. INTRODUCTION

This report documents hydrology data and an Arc geographic information system (ArcGIS) database developed for the Wenatchee River Restoration Project being accomplished by the Technical Service Center for the Pacific Northwest Region of the Bureau of Reclamation. The report contains the following information:

- Basin characteristics
- Historical flood accounts and annual trends
- Flood frequency computations for peak flows at USGS gage station locations
- Flood frequency computations with GIS integration for ungaged locations
- Maximum, average, and minimum daily flow values at gaging stations for the period of record

2. BASIN CHARACTERISTICS

The Wenatchee River drainage basin is located in western Chelan County, Washington. The drainage basin above the mouth of the Wenatchee River is 1,335 mi^2 which accounts for 45 percent of the total area of Chelan County. All runoff generated from the Wenatchee River Drainage basin empties into the Columbia River just north of Wenatchee, Washington.

Figure 1 shows the Wenatchee watershed and its component sub-watersheds. The headwaters of the Wenatchee River originate in the Cascade Mountain range as the Little Wenatchee and White rivers. These rivers feed into Lake Wenatchee, the source of the Wenatchee River. The tributaries shown in Figure 1 add significant volume to the Wenatchee River. The Chiwawa River, White River, Little Wenatchee River, Nason and Icicle Creeks are the source of over 90 percent of the surface water within the watershed (WRIA 45 2006).

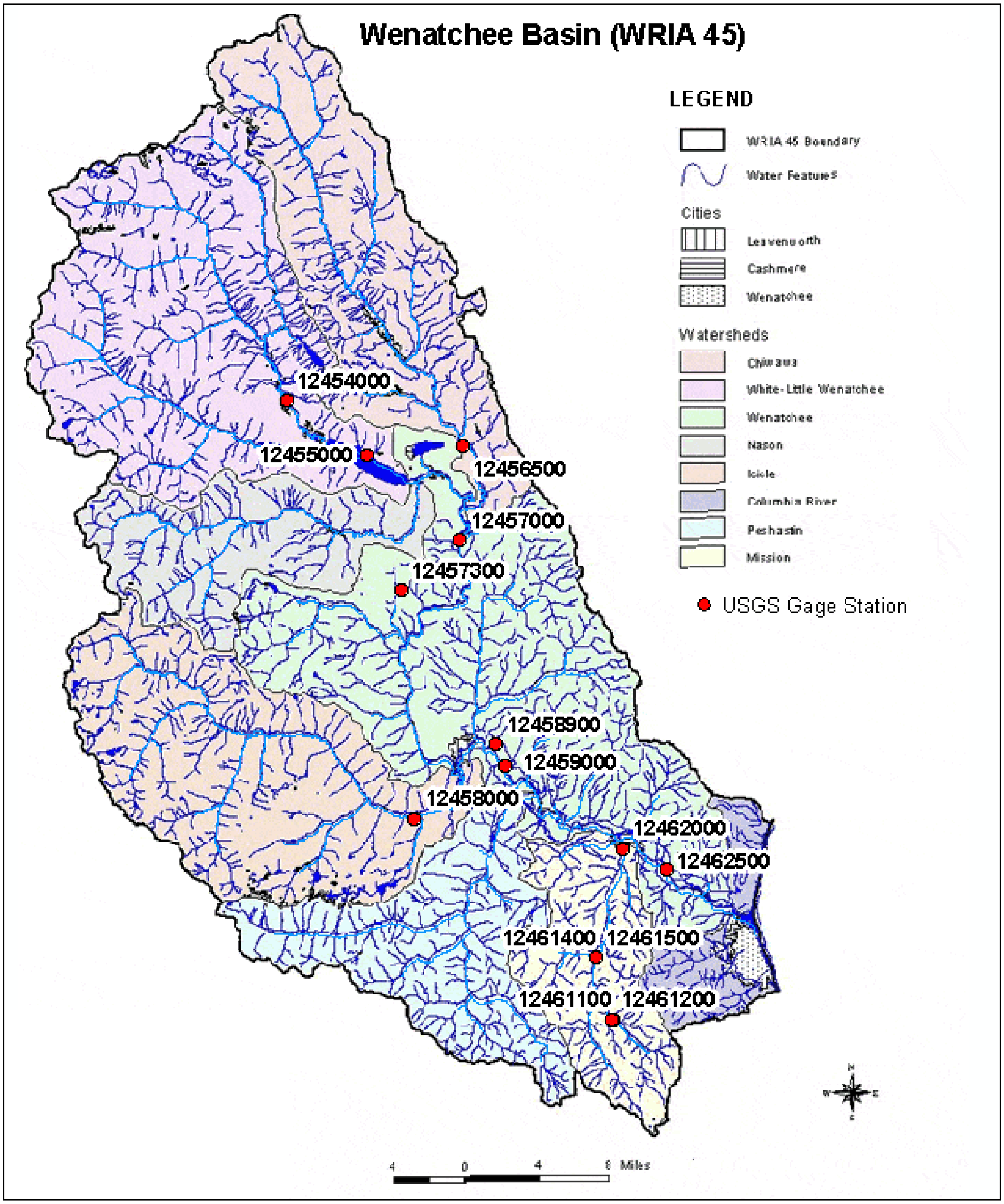


Figure 1. Wenatchee River drainage basin (WRIA 45 2006).

The topography of the basin varies significantly. The mouth of the Wenatchee River is approximately 610 feet above sea level. The highest point at elevation 9400 feet is located just above the headwaters of Ingalls Creek in the Peshastin Creek watershed.

The USGS maintains stream gage stations throughout the Wenatchee River drainage basin which provide mean daily flow data and instantaneous annual peak flow data. Of the nineteen gages, 14 have at least 20 years of record (Table 1).

Table 1. USGS stream gage information for gages with at least 20 years of record in owl pellets Wenatchee River basin.

USGS Gage No.	Description	Date of Peak Discharge	Years of Record	Drainage Area (mi^2)
12454000	WHITE RIVER NEAR PLAIN WA	12/26/1981	29	150
12455000	WENATCHEE RIVER BELOW WENATCHEE LAKE WA	5/29/1948	48	273
12456500	CHIWAWA RIVER NEAR PLAIN WA	11/30/1996	32	170
12457000	WENATCHEE RIVER AT PLAIN WA	11/30/1996	83	591
12457300	SKINNEY CREEK AT WINTON WA	4/22/1956	20	2.6
12458000	ICICLE CREEK ABOVE SNOW CREEK NEAR LEAVENWORTH WA	11/29/1996	58	193
12458900	POSEY CANYON NEAR LEAVENWORTH WA	3/18/1972	20	1.4
12459000	WENATCHEE RIVER AT PESHASTIN WA	11/30/1996	77	1000
12461100	EAST BRANCH MISSION CREEK NEAR CASHMERE WA	1/16/1974	20	15.4
12461200	EAST BRANCH MISSION CREEK TRIB NEAR CASHMERE WA	1/16/1974	34	2.5
12461400	MISSION CREEK ABOVE SAND CREEK NEAR CASHMERE WA	1/16/1974	21	39.8
12461500	SAND CREEK NEAR CASHMERE WA	8/15/1956	20	18.6
12462000	MISSION CREEK AT CASHMERE WA	3/13/1972	21	81.2
12462500	WENATCHEE RIVER AT MONITOR WA	11/30/1996	43	1301

3. HISTORICAL FLOOD ACCOUNTS AND ANNUAL TRENDS

Based on the USGS gage records, the basin is subject to large late spring and early summer floods caused by melting snow at high elevations. However, the majority of peak floods of record have occurred during winter months. The largest recorded flood in the last 100 years occurred on November 30, 1996 at the Wenatchee River at Monitor, WA gage (USGS 12462500). It was measured at 47,500 ft^3/s. The largest recorded flood relative to drainage area occurred on December 26, 1981 at the White River near Plain, WA gage (USGS 12454000). A peak discharge of 19,100 ft^3/s was recorded for the 150 mi^2 basin. The most recent flood in the Wenatchee River basin occurred on November 7, 2006. At the Wenatchee River at Monitor, WA gage (USGS 12462500), an average daily discharge of 30,600 ft^3/s was recorded. This magnitude has been estimated as a 25-year flood.

Figures 2 and 3 show the annual peak discharges at the two gages within the Wenatchee River drainage basin with the longest periods of record.

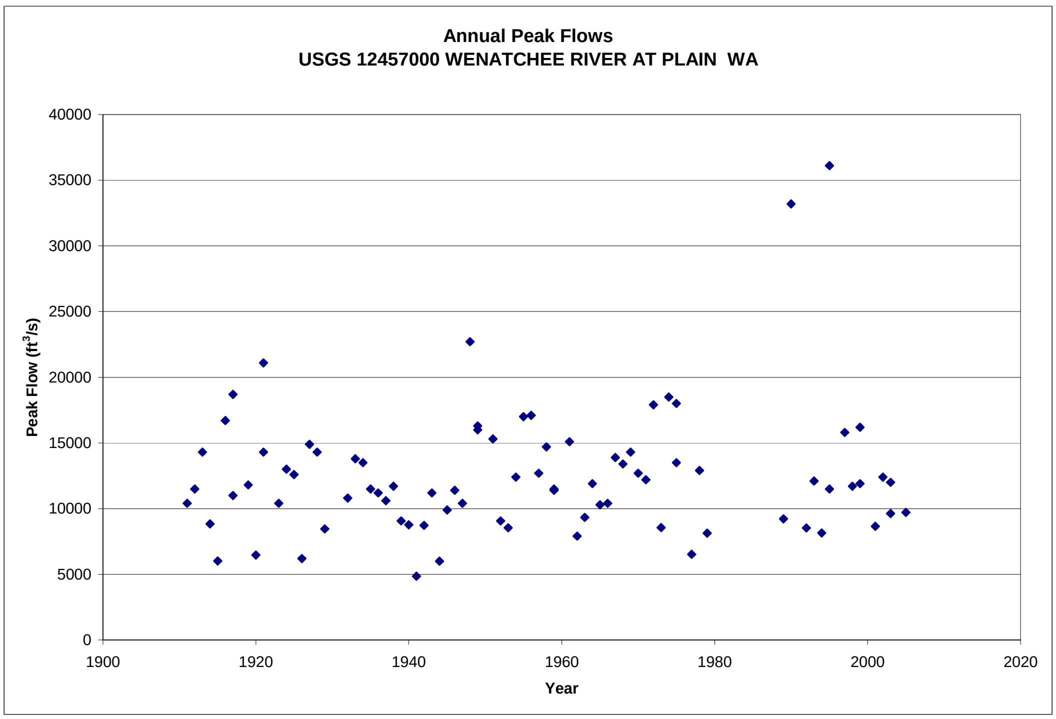


Figure 2. Annual peak flow data for the Wenatchee River at Plain, Washington.

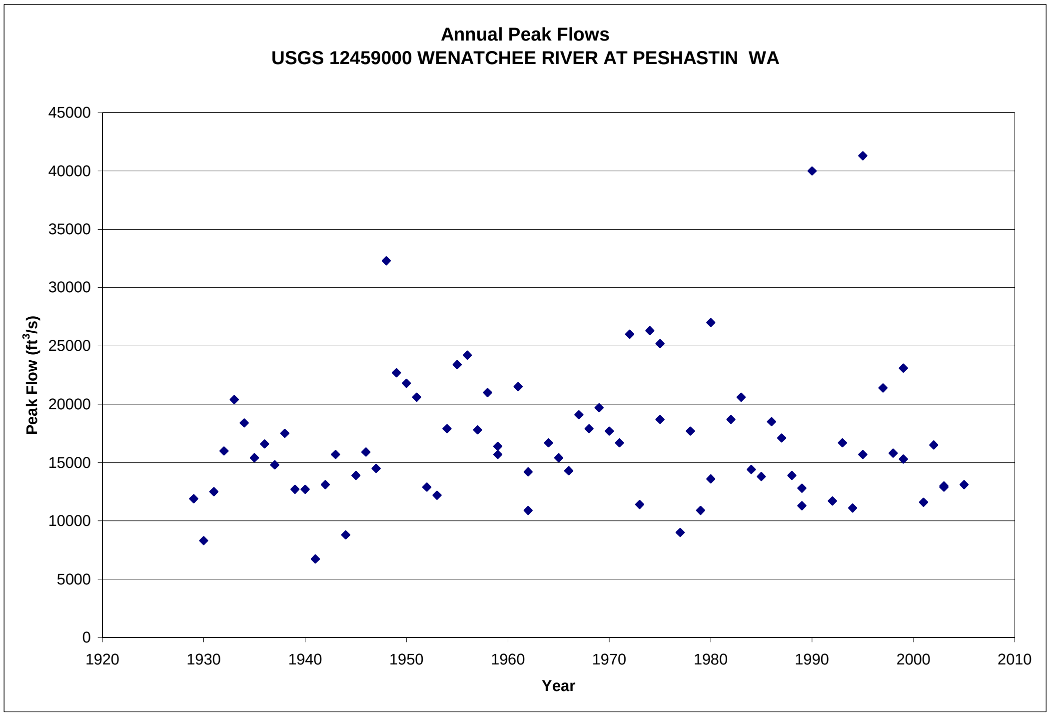


Figure 3. Annual peak flow data for the Wenatchee River at Peshastin, Washington.

Regarding flooding in Chelan County, R.W. Beck and Associates (1974) notes the following:

> "Rain storms, in the past, resulted in extremely high and sudden runoffs from many of the smaller drainage areas in Chelan County, sometimes resulting in loss of life as well as property. Peak flow may be reached from less than one hour to several hours after the rain begins, depending on the particular drainage area. When the water emerges from the mouth of the deeply incised canyons, it spreads out on the alluvial fans, many of which have been settled and/or developed in orchards. In some instances, local residents have not given proper attention to flooding hazards, probably because most of the stream courses are normally dry and because flooding is a relatively unusual event. There are some homes and other developments within areas that are subject to flooding."

Figures 4 and 5 show the annual discharge trends at the two gages within the Wenatchee River drainage basin with the longest periods of record. The annual instantaneous peak discharges were normalized by the average of the annual peaks. The annual mean discharges were normalized by the average of the mean discharges. This resulted in a dimensionless scale for the y-axis. Bounds have also been placed at +/- 20% in order to easily identify years with significantly above/below average discharges. The behavior of the annual instantaneous peaks relative to the annual mean discharges can be easily observed because the y-axis is dimensionless. It was determined that a year with an above average peak will not always occur when the mean annual discharge is also above average.

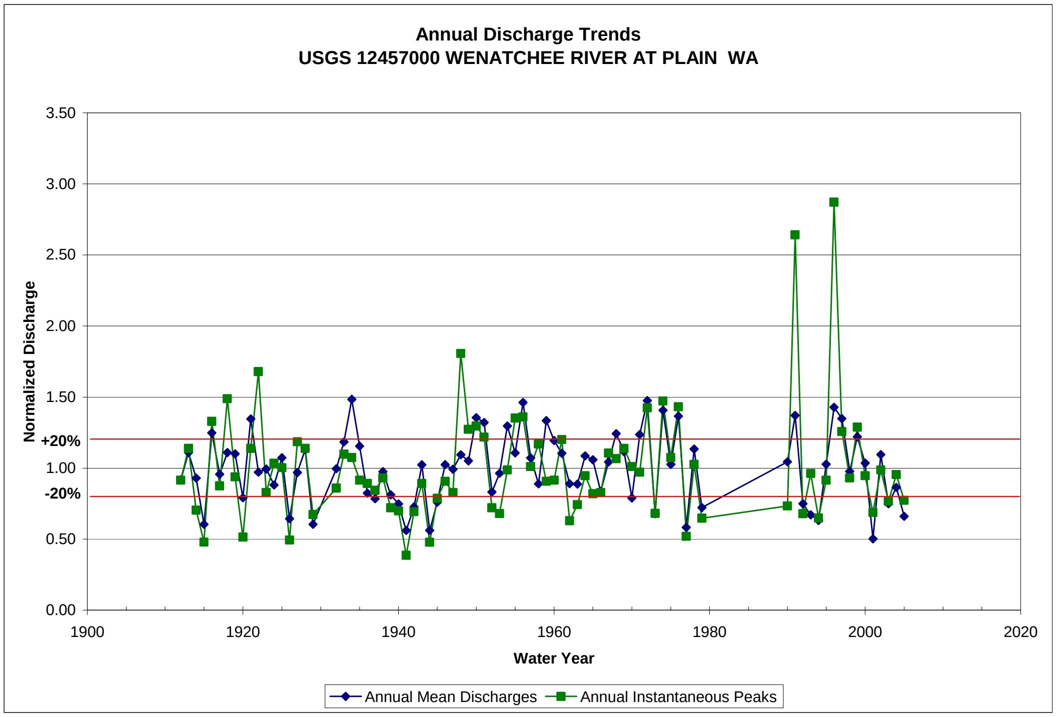


Figure 4. Annual peak flow trends for the Wenatchee River at Plain, Washington.

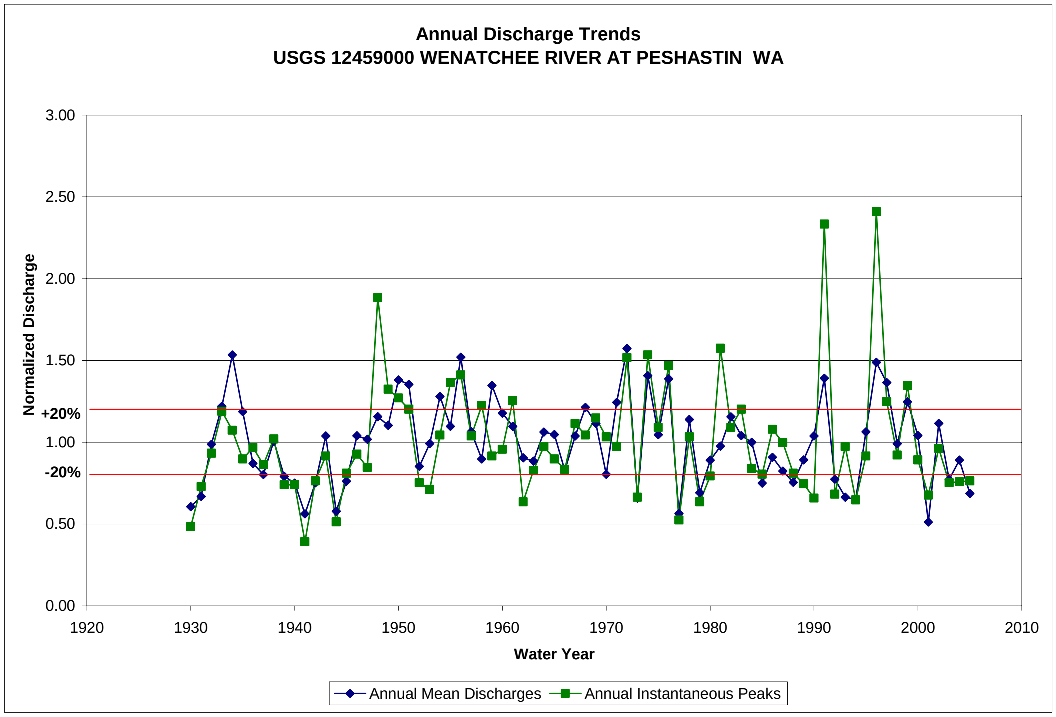


Figure 5. Annual peak flow trends for the Wenatchee river at Peshastin, Washington.

4. PEAK FLOW CALCULATIONS AT USGS GAGE STATION LOCATIONS

The annual flow data for the fourteen selected USGS stream gages were obtained from the USGS NWIS web site. A Log-Pearson III distribution was fit to the gaged record of peak flows using the method of moments to develop the 2-, 5-, 10-, 25-, 50-, and 100-year flood frequency values. This process is consistent with the procedure described in the Guidelines for Determining Flood Flow Frequency, Bulletin 17B (USWRC 1981). Figure 6 is a frequency plot of the peak discharge versus annual exceedance probability (AEP) for the Peshastin gage. Table 2 provides the results of the statistical analysis for all gages. The ranked data statistics, flood frequency results, and 95 percent confidence limits are located in the appendix. Applying confidence limits to the flood frequency values provides and understanding of the level of uncertainty associated with predicting flood magnitudes and frequencies.

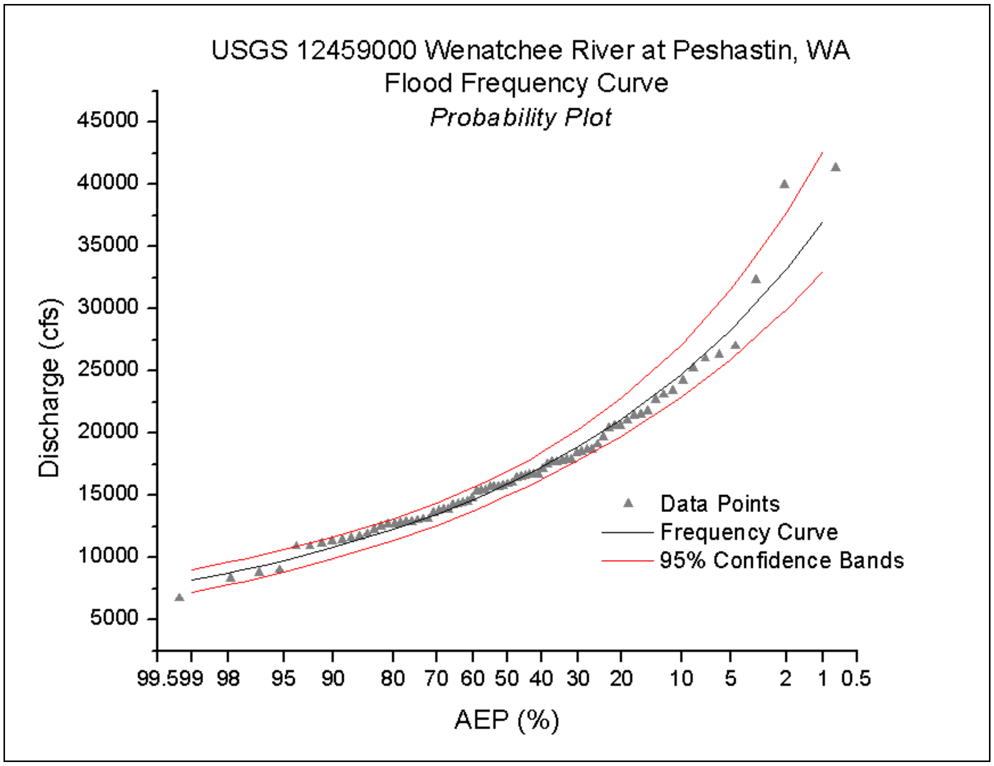


Figure 6. Wenatchee River flood frequency curve.

Table 2. Peak flow data computed for USGS stream gages in the Wenatchee basin.

USGS Gage No.	Description	Q2 (ft^3/s)	Q5 (ft^3/s)	Q10 (ft^3/s)	Q25 (ft^3/s)	Q50 (ft^3/s)	Q100 (ft^3/s)
12454000	WHITE RIVER NEAR PLAIN WA	4540	5660	6530	7780	8820	9960
12455000	WENATCHEE RIVER BELOW WENATCHEE LAKE WA	7030	8870	10000	11400	12500	13500
12456500	CHIWAWA RIVER NEAR PLAIN WA	3160	4450	5310	6410	7240	8060
12457000	WENATCHEE RIVER AT PLAIN WA	9830	13400	16400	20800	24600	29000
12457300	SKINNEY CREEK AT WINTON WA	28	44	55	69	79	90
12458000	ICICLE CREEK ABOVE SNOW CREEK NEAR LEAVENWORTH WA	4310	6230	7700	9800	11600	13500
12458900	POSEY CANYON NEAR LEAVENWORTH WA	3	6	9	13	15	18
12459000	WENATCHEE RIVER AT PESHASTIN WA	15900	21100	24700	29500	33200	37000
12461100	EAST BRANCH MISSION CREEK NEAR CASHMERE WA	21	42	62	94	124	160
12461200	EAST BRANCH MISSION CREEK TRIB NEAR CASHMERE WA	7	14	20	28	34	40
12461400	MISSION CREEK ABOVE SAND CREEK NEAR CASHMERE WA	171	341	522	865	1230	1730
12461500	SAND CREEK NEAR CASHMERE WA	62	115	165	251	335	440
12462000	MISSION CREEK AT CASHMERE WA	182	290	386	544	692	870
12462500	WENATCHEE RIVER AT MONITOR WA	14400	19200	23500	30200	36300	43500

5. PEAK FLOW CALCULATIONS AT UNGAGED SITES WITH GIS INTEGRATION

Because a stream channel restoration project site could potentially be located along any reach within the Wenatchee basin, peak flow calculations were also computed over the entire basin and incorporated into a geographic information system. The user of the Wenatchee GIS database can easily acquire the desired peak flow information by simply clicking on a potential project site within the basin. This system was created using the watershed processing tools in ESRI's ArcHydro and the USGS publication: Methods for Estimating Flood Magnitude and Frequency in Washington (USGS 2001). Three methods were used for computing peak flows at ungaged locations which will be described in further detail below. The results from each computation method can vary at individual sites and should be considered tools to represent a range of possible flood frequency values.

A GIS was created, in order to quickly access specific peak flow information associated with potential project sites. This system incorporates digital elevation models (DEM's) of the topography, aerial photography, existing stream networks, existing project locations, and a graphical database that contains the peak flow information for the Wenatchee River drainage basin's individual subwatersheds or subbasins. Once the DEM of the basin is imported into the GIS, ArcHydro delineated all of the subbasins. For this system, a minimum subbasin size of 5 mi^2 was selected because most stream channel restoration projects have subwatersheds greater than this size. After the watershed processing was complete, ArcHydro had created 129 subbasins within the entire Wenatchee subbasin. For each of these subbasins peak flows for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were calculated based on a local gage data analysis and a regional gage data analysis.

5.1 Peak Flows at Ungaged Locations along the Wenatchee River Mainstem

The mainstem of the Wenatchee River is approximately 60 miles long. Along this reach there are four USGS stream gages that contain at least 40 years of instantaneous peak flow data. Table 3 and Figure 7 display the information and location of the USGS gages used along the Wenatchee River mainstem.

Table 3. USGS Gages along the Wenatchee River Mainstem

USGS Gage No.	Description	Date of Peak Discharge	Years of Record	Drainage Area (mi^2)
12455000	WENATCHEE RIVER BELOW WENATCHEE LAKE WA	5/29/1948	48	273
12457000	WENATCHEE RIVER AT PLAIN WA	11/30/1996	83	591
12459000	WENATCHEE RIVER AT PESHASTIN WA	11/30/1996	77	1000
12462500	WENATCHEE RIVER AT MONITOR WA	11/30/1996	43	1301

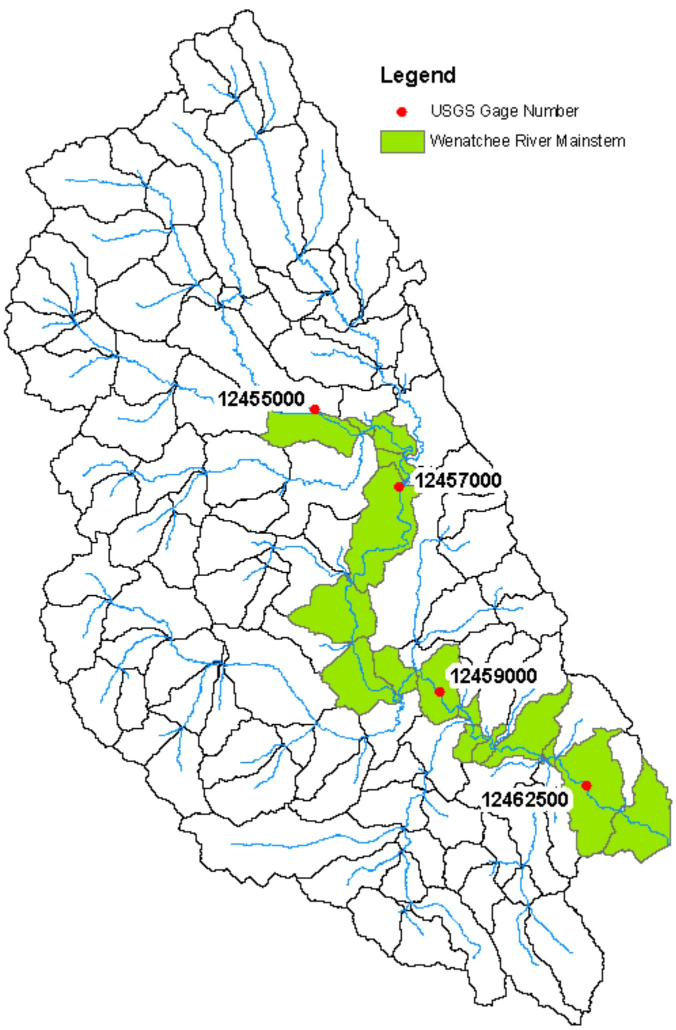


Figure 7. Highlighted subbasins along the Wenatchee River mainstem with peak flows computed using the USGS gages in Table 3.

Using the annual peak flow data from these gage stations, parameters for the log skewness and log variance were computed. Then a linear trendline was added to the log mean flow versus log area data. This yielded equation 1 which had a correlation coefficient of 0.9547.

$$Y = 0.5514*X + 2.5047 \qquad \text{(Eq. 1)}$$

X is the log of the subbasin area, and Y is the log mean flow. The log mean flows for the remaining subbasins were computed using the above equation, and finally a Log Pearson III analysis was performed to compute the peak flows for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Table 5 lists the parameters of each gage used in the analysis as well as an example of the peak flow computations for a 1,000 mi^2 subbasin.

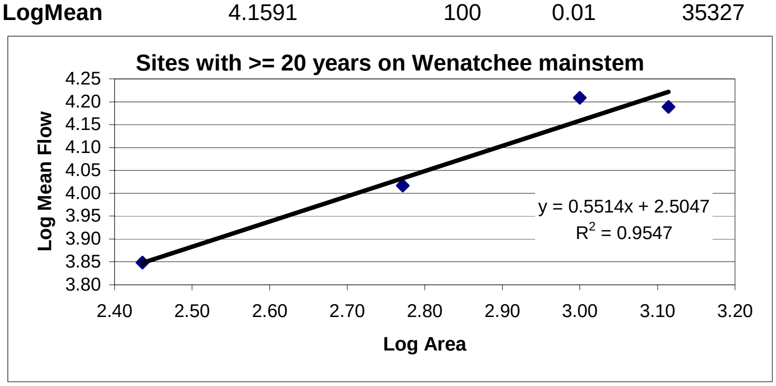
Table 4. Wenatchee Mainstem gage data analysis for a 1,000 mi^2 subbasin.

Site ID	Area (mi^2)	LogArea	LogMean	N	LogSkew	N*LogSkew	LogVar	n*LogVar
12455000	273.0	2.44	3.85	48	0.06	2.861	0.119	5.693
12457000	591.0	2.77	4.02	83	0.99	82.411	0.148	12.267
12459000	1000.0	3.00	4.21	77	0.31	23.565	0.141	10.851
12462500	1301.0	3.11	4.19	43	1.46	62.771	0.136	5.848
					Sum	**171.608**		**34.660**

LogSkew	0.6837
LogVar	0.1381
Slope	0.551
Intercept	2.505
Effective N	63
Sub-basin Area	1000
LogArea	3.0000
LogMean	4.1591

Regional Analysis

Return Period	Probability	Peak Flow
2	0.5	13917
5	0.2	18540
10	0.1	22015
25	0.04	26908
50	0.02	30941
100	0.01	35327



5.2 Peak Flows at Ungaged Locations Based on a Single Gage Analysis for Chiwawa, Icicle, and White Rivers

Using the guidelines specified in the USGS publication (USGS 2001), the peak flows at the USGS gages were used to compute the flows for the appropriate subbasins. Equation 2 was used to estimate the ungaged peak flows at the ungaged subbasin outlets.

$$Q_u = Q_g \left(\frac{A_u}{A_g} \right)^{0.97} \qquad \text{(Eq. 2)}$$

Qu is the peak discharge, in ft^3/s, at the ungaged site for a specific recurrence interval, Qg is the peak discharge, in ft^3/s, at the gaged site for a specific recurrence interval, Au is the contributing drainage area, in mi^2, at the ungaged site, Ag is the contributing drainage area, in mi^2, at the gaged site, and, 0.97 is the regional exponent for Chelan County, Washington. Of the 129 subbasins, 47 basins' peak flows were computed using this method. Below, Figure 8 highlights the subbasins with peak flows computed using a single gage analysis.

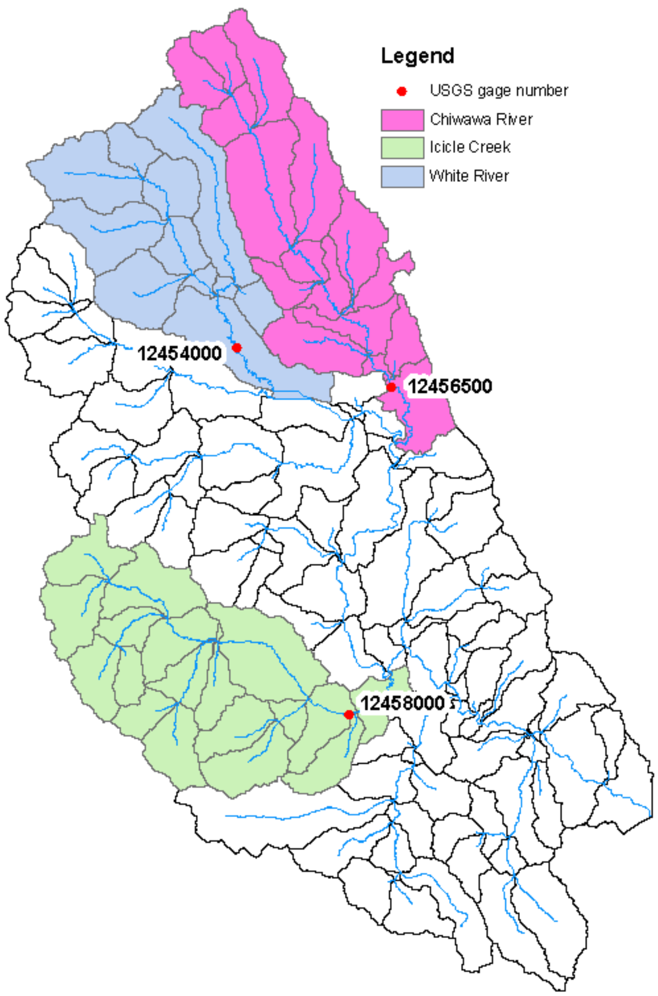


Figure 8. Highlighted subbasins within the Wenatchee River watershed with peak flows computed using single USGS gages.

5.3 Peak Flows at Ungaged Locations Based on a Synthesized Gage Analysis for Nason Creek

The Nason Creek watershed contains 9 of the 129 subbasins in the Wenatchee River basin (Figure 9). The Department of Ecology (Ecology) gage 45J070 contains provisional peak flow data from 2002 to 2007. The gage is located near the mouth of Nason Creek at RM 0.8 and has a drainage area of 107.8 mi^{2}. The overall margin of error for discharge data is estimated at 5 percent, and the margin of error for flows greater than 1,200 ft^3/s is estimated at 15 percent (Springer 2005). However, as of June 2008 Ecology had discovered that high flows at the Nason gage were influenced by backwater from a downstream gage. The reported peak flow values will be revised and potentially lowered once the backwater influence is removed. Additionally, the rating curve at the gage may not be accurate for high flows due to the limited amount of measured flow data in the field at this site. The following analysis used the original provisional values and should be updated once finalized values are available

The Nason Creek watershed is very similar to the Icicle Creek watershed. As a result, the annual peaks from the USGS gage on Icicle Creek (12485000) were adjusted using Equation 2, so they could be applied to Nason Creek. A synthesized gage record was created combining the annual peaks from 2002-2007 and the adjusted annual peaks from 1912-2001 on Icicle Creek. The result was 60 years of synthesized annual peak flow data at the Ecology gage on Nason Creek.

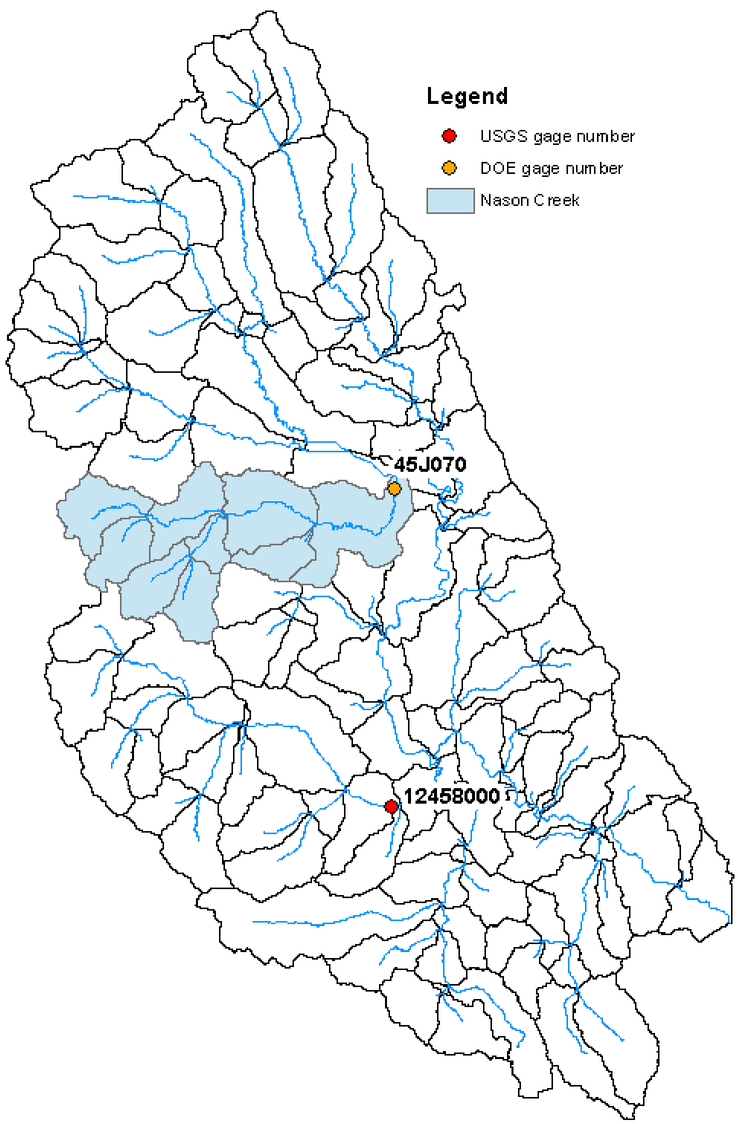


Figure 9. Highlighted subbasins within the Wenatchee River watershed with peak flows computed using a synthesized gage analysis.

A Log-Pearson III distribution was fit to the synthesized gage record of annual peak flows using the method of moments to develop the 2-, 5-, 10-, 25-, 50-, and 100-year flood frequency values. The ranked data statistics, flood frequency results, and 95 percent confidence limits are located in the appendix. Applying confidence limits to the flood frequency values provides and understanding of the level of uncertainty associated with predicting flood magnitudes and frequencies. Following the procedure in the previous section, Peak Flows at Ungaged Locations Based on a Single Gage Analysis, the flood frequency values at the Ecology gage were used to compute the flood frequency flows for the Nason Creek subbasins and at river miles 1-14 (Table 5). Because of the uncertainty in the provisional Ecology values, a second set of flood frequency values were computed for comparison based only on a correlation with the Icicle gage data with no use of the Ecology gage data on Nason Creek (Table 6). The values are slightly lower than when the provisional Ecology gage data are used.

Table 5. Flood frequency flows at RM 1 through RM 14 on Nason Creek using a correlation to Icicle Creek gage and incorporating provisional Ecology gage data since 2002.

Analysis of synthetic gage record – Ecology gage (2002-2007) and Icicle Creek gage							
River Mile	Drainage Area (mi)	Q2 (ft^3/s)	Q5 (ft^3/s)	Q10 (ft^3/s)	Q25 (ft^3/s)	Q50 (ft^3/s)	Q100 (ft^3/s)
1	108.31	2700	4000	5100	6800	8200	9800
2	107.26	2600	4000	5100	6700	8100	9700
3	105.70	2600	3900	5000	6600	8000	9600
4	103.72	2600	3900	4900	6500	7900	9400
5	99.67	2500	3700	4700	6300	7600	9100
6	98.16	2400	3700	4700	6200	7500	8900
7	94.22	2300	3500	4500	5900	7200	8600
8	93.03	2300	3500	4400	5900	7100	8500
9	92.10	2300	3400	4400	5800	7000	8400
10	78.12	1900	2900	3700	4900	6000	7200
11	74.43	1800	2800	3600	4700	5700	6800
12	71.68	1800	2700	3400	4500	5500	6600
13	70.31	1700	2700	3400	4500	5400	6500
14	67.29	1700	2500	3200	4300	5200	6200

Table 6. Flood frequency flows at RM 1 though Rm 14 using a correlation to Icicle Creek gage.

Analysis of synthetic gage record - Icicle Creek gage only							
River Mile	Drainage Area (mi^2)	Q2 (ft^3/s)	Q5 (ft^3/s)	Q10 (ft^3/s)	Q25 (ft^3/s)	Q50 (ft^3/s)	Q100 (ft^3/s)
1	108.31	2500	3600	4600	6000	7300	8700
2	107.36	2400	3600	4500	6000	7200	8600
3	105.70	2400	3500	4500	5900	7100	8500
4	103.72	2400	3500	4400	5800	7000	8300
5	99.67	2300	3300	4200	5500	6700	8000
6	98.16	2200	3300	4200	5500	6600	7900
7	94.22	2100	3200	4000	5300	6300	7600
8	93.03	2100	3100	4000	5200	6300	7500
9	92.10	2100	3100	3900	5100	6200	7400
10	78.12	1800	2600	3300	4400	5300	6300
11	74.43	1700	2500	3200	4200	5000	6000
12	71.68	1600	2400	3100	4000	4900	5800
13	70.31	1600	2400	3000	4000	4800	5700
14	67.29	1500	2300	2900	3800	4600	5500

5.4 Peak Flows at Ungaged Locations Based on a Regional Gage Analysis

Because 56 of the 129 subbasins could not be associated with a single USGS gage location, a regional gage analysis was implemented to fill the gaps. Using annual peak flow data from 13 USGS gage stations within the Wenatchee basin, regional parameters for the log skewness and log variance were computed. Then a linear trendline was added to the regional log mean flow versus log area data. This yielded equation 3 which had a correlation coefficient of 0.9423.

$$Y = 1.3216*X + 0.2802 \qquad \text{(Eq. 3)}$$

X is the log of the subbasin area, and Y is the log mean flow. The log mean flows for the remaining subbasins were computed using the equation 3, and finally a Log Pearson III analysis was performed to compute the peak flows for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Table 6 lists the parameters of each gage used in the analysis as well as an example of the peak flow computations for a 150 mi^2 subbasin.

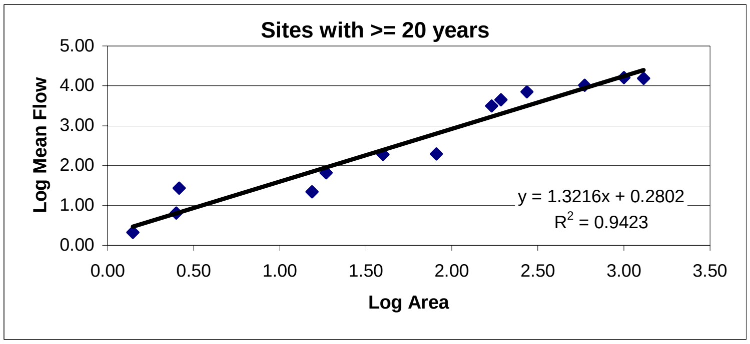
Table 7. Example regional gage data analysis for a 150 mi^2 subbasin.

Site ID	Area (mi^2)	LogArea	LogMean	N	LogSkew	N*LogSkew	LogVar	n*LogVar
12455000	273.0	2.44	3.85	48	0.06	2.861	0.119	5.693
12456500	170.0	2.23	3.50	32	-0.04	-1.189	0.177	5.677
12457000	591.0	2.77	4.02	83	0.99	82.411	0.148	12.267
12457300	2.6	0.41	1.44	20	-0.20	-4.066	0.237	4.744
12458000	193.0	2.29	3.65	58	0.49	28.292	0.180	10.423
12458900	1.4	0.15	0.33	20	-0.73	-14.537	0.524	10.472
12459000	1000.0	3.00	4.21	77	0.31	23.565	0.141	10.851
12461100	15.4	1.19	1.34	20	0.24	4.717	0.344	6.889
12461200	2.5	0.40	0.81	34	-0.51	-17.218	0.404	13.746
12461400	39.8	1.60	2.28	21	0.85	17.745	0.329	6.899
12461500	18.6	1.27	1.82	20	0.62	12.329	0.296	5.927
12462000	81.2	1.91	2.29	21	0.87	18.343	0.220	4.626
12462500	1301.0	3.11	4.19	43	1.46	62.771	0.136	5.848
					Sum	**216.024**		**104.063**

LogSkew	0.4347
LogVar	0.2094
Slope	1.322
Intercept	0.280
Effective N	38
Sub-basin Area	150
LogArea	2.1761
LogMean	3.1560

Regional Analysis

Return Period	Probability	Peak Flow
2	0.5	1383
5	0.2	2119
10	0.1	2704
25	0.04	3563
50	0.02	4298
100	0.01	5119



5.5 Using the GIS Database

Once the computations for all of the subbasins were completed, they were integrated into the GIS. The information tool is used to access the data by simply clicking on the subbasin of interest (Figure 10). Figure 11 is a close up of the attributes displayed for a specific subbasin. Table 7 lists the descriptions of each attribute in the GIS database.

It is important to note that if the REF_GAGES field is blank, then the regional gage data analysis was used to calculate the peak flows for the selected subbasin.

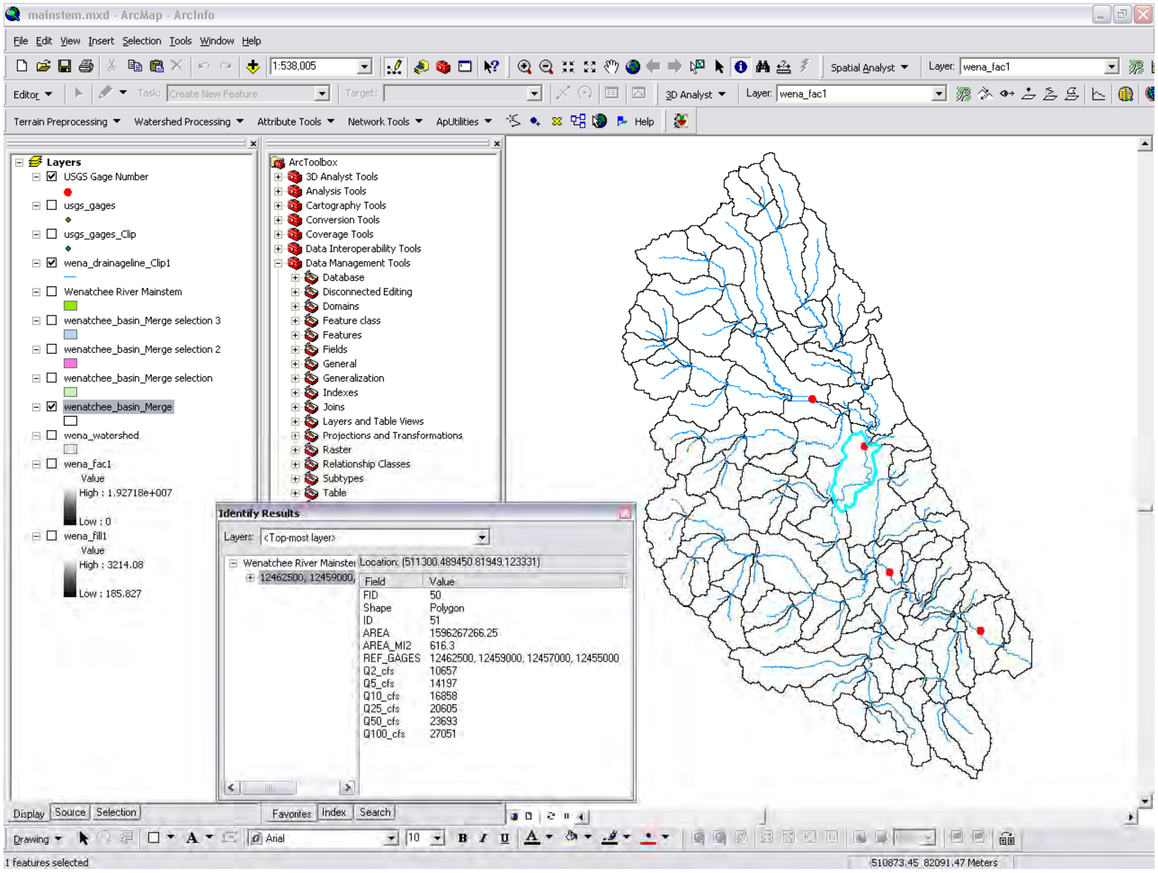


Figure 10. Accessing the peak flow data in ArcGIS.

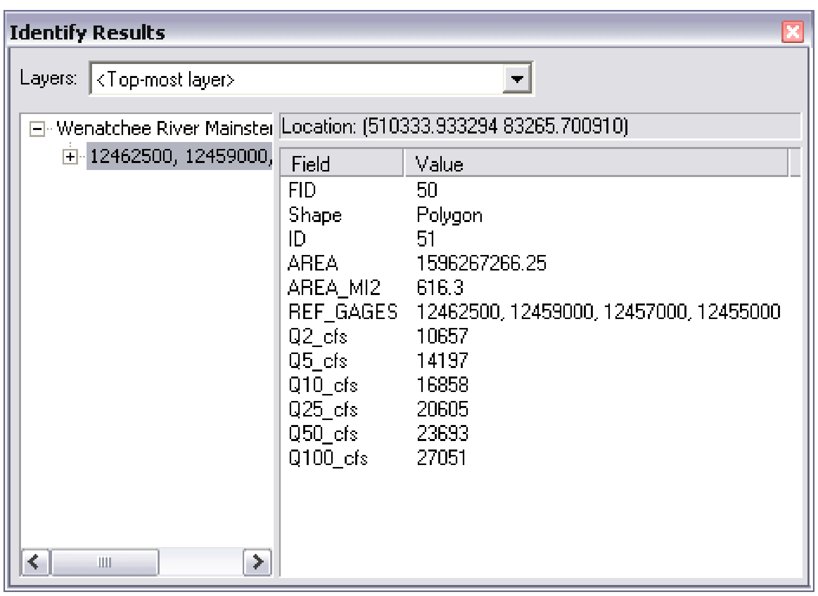


Figure 11. Output summary example for an ungaged subbasin.

Table 8. GIS output description.

Field	Description
AREA_MI2	Sub-basin area in square miles
REF_GAGES	USGS stream gages used for peak flow calculations (blank if regional analysis is used)
Q2_cfs	2 year peak flow in cubic feet per second
Q5_cfs	5 year peak flow in cubic feet per second
Q10_cfs	10 year peak flow in cubic feet per second
Q25_cfs	25 year peak flow in cubic feet per second
Q50_cfs	50 year peak flow in cubic feet per second
Q100_cfs	100 year peak flow in cubic feet per second

5.6 Maximum, Average, and Minimum Daily Flows

Figures 12 through 18 represent a summary hydrograph analysis of the mean daily flows for seven major USGS gages in the Wenatchee River drainage basin. Maximum, mean, median, minimum and the upper and lower quartiles of daily flow values are presented for each day. A simple routine was developed in Microsoft Excel's Visual Basic editor to compute the above statistics for each calendar day of a gage's period of record and output them in a graphical format.

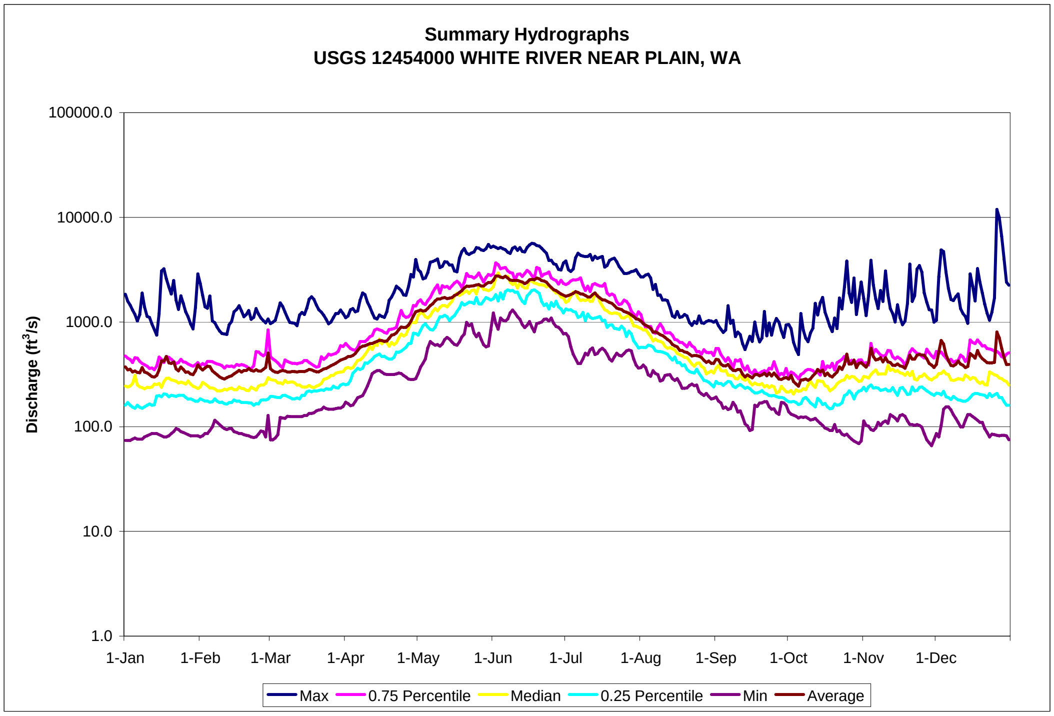


Figure 12. Mean daily flow statistics for White River near Plain, Washington.

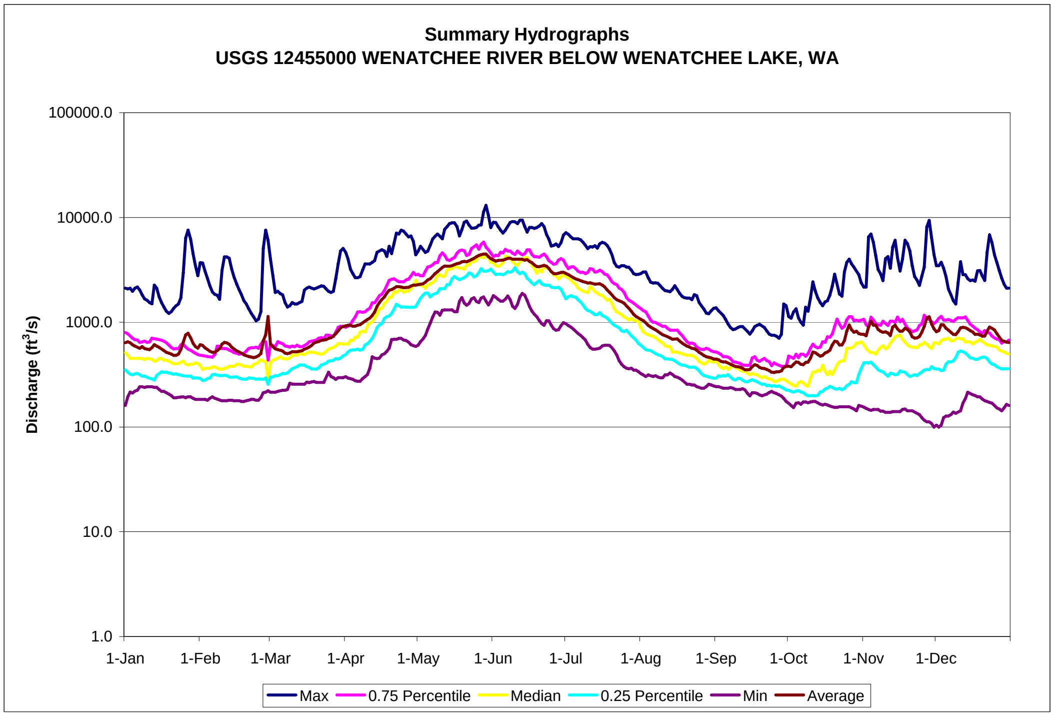


Figure 13. Mean daily flow statistics for Wenatchee River below Wenatchee Lake, Washington.

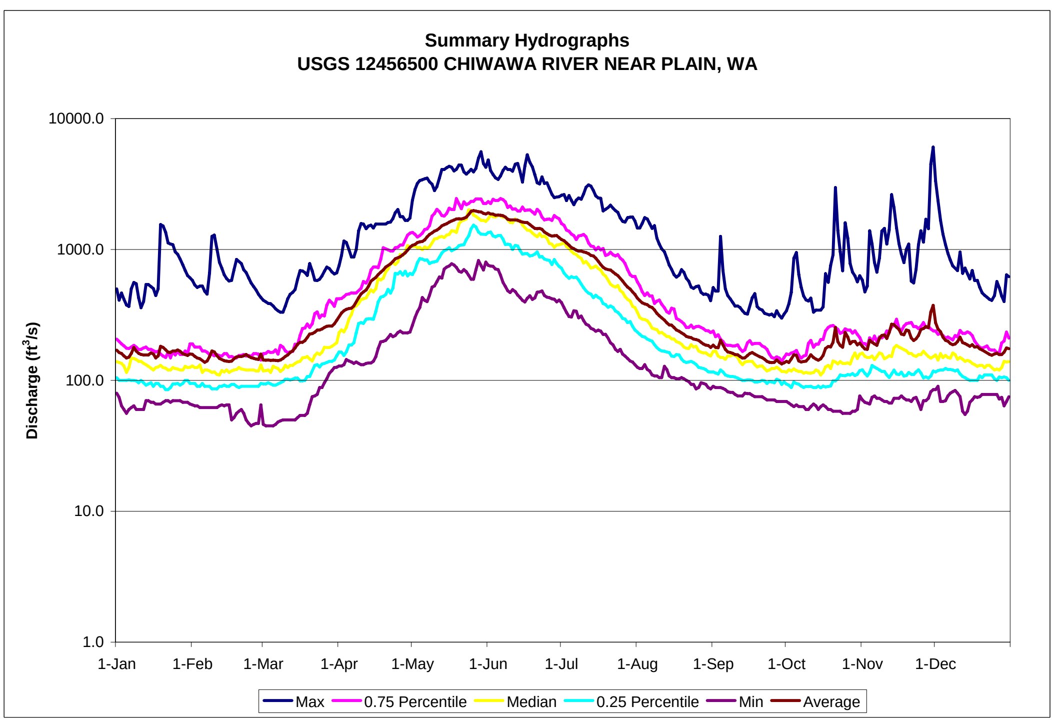


Figure 14. Mean daily flow statistics for Chiwawa River near Plain, Washington.

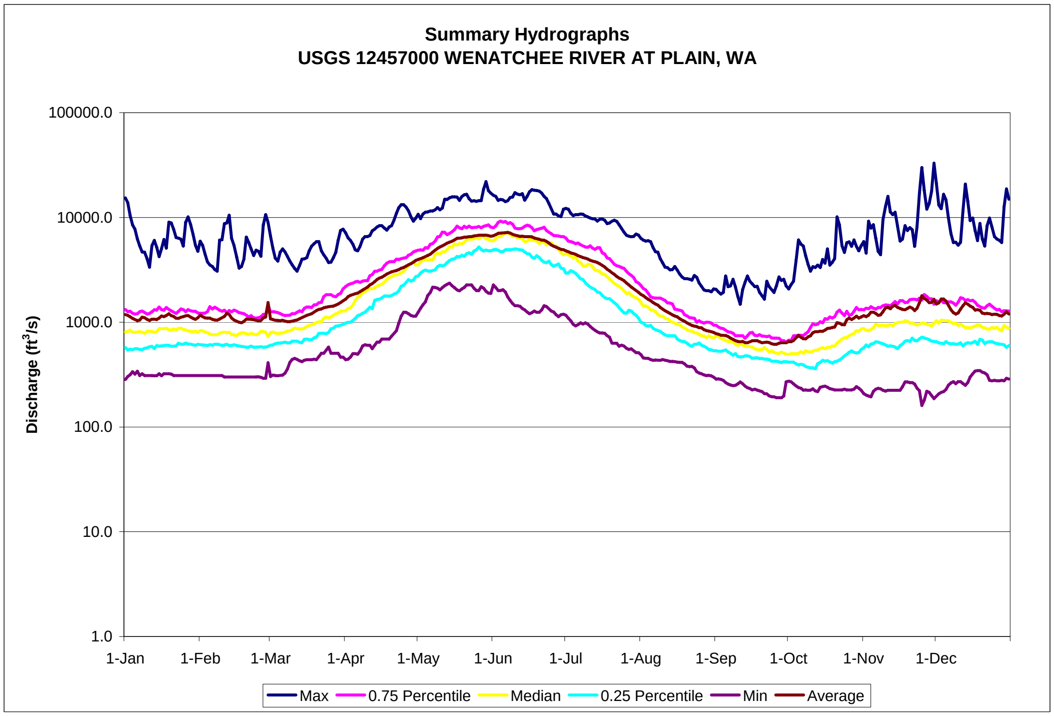


Figure 15. Mean daily flow statistics for Wenatchee River at Plain, Washington.

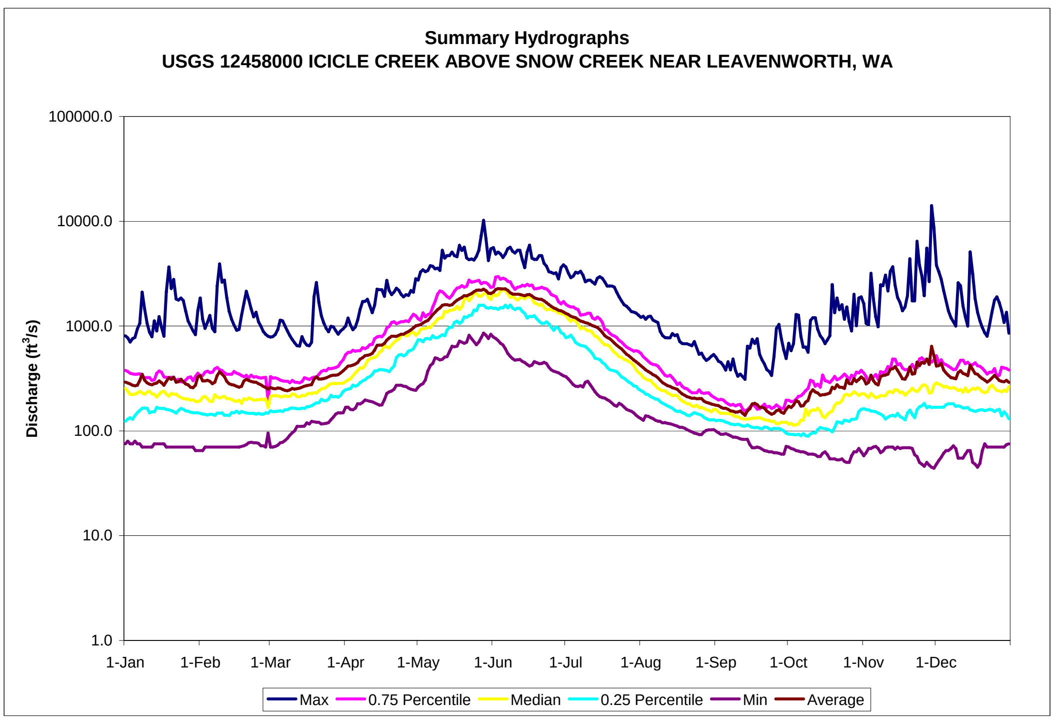


Figure 16. Mean daily flow statistics for Icicle Creek above Snow Creek near Leavenworth, Washington.

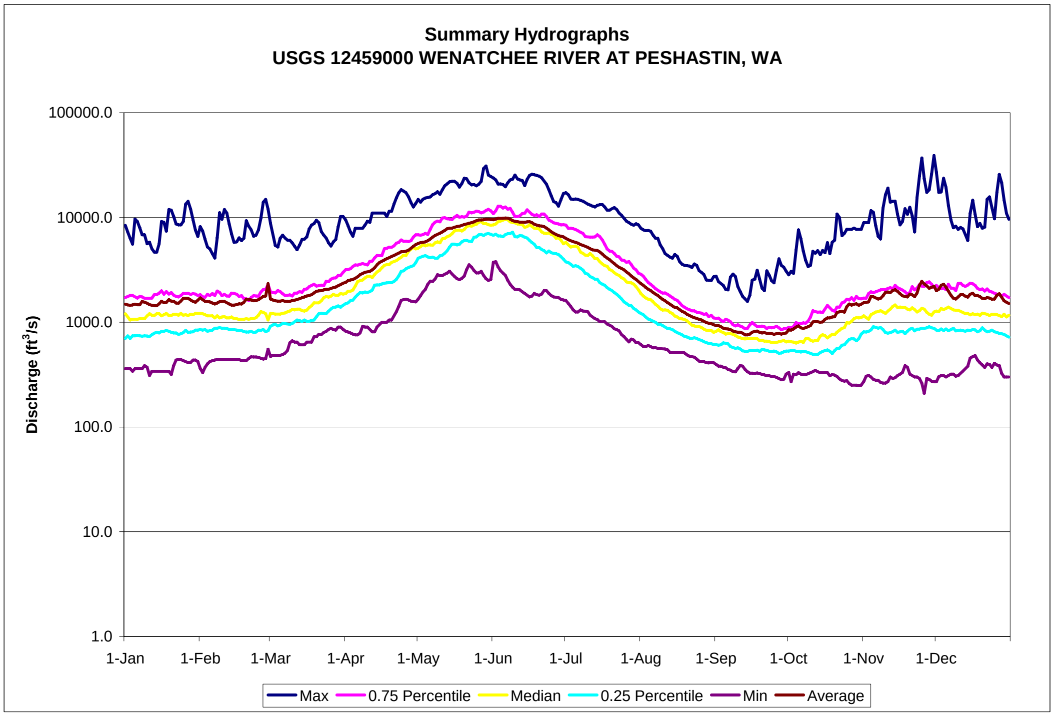


Figure 17. Mean daily flow statistics for Wenatchee River at Peshastin, Washington.

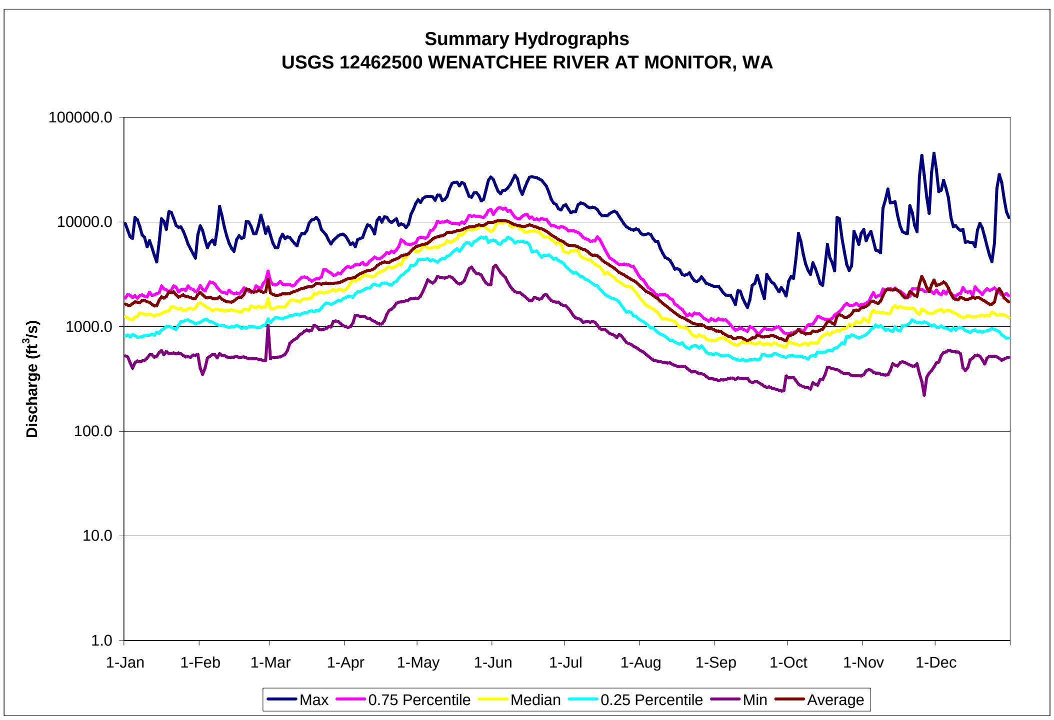


Figure 18. Mean daily flow statistics for Wenatchee River at Monitor, Washington.

6. REFERENCES

Parenthetical Reference	Bibliographic Citation
WRIA 45 2006	WRIA 45. 2006. Wenatchee Watershed Management Plan. Chelan County, Washington. Washington State Department of Ecology. Publication No. 043-1284.203
Beck 1974	Beck, R.W. and Associates. 1974. *Flood Information Study, Chelan County, Washington.* Washington State Department of Ecology. Olympia, Washington.
USWRC 1981	U.S. Department of the Interior. United States Water Resources Council. 1981. *Guidelines for Determining Flood Flow Frequency*. Bulletin #17B of the Hydrology Committee.
USGS 2001	U.S. Geological Survey. 2001. *Methods for Estimating Flood Magnitude and Frequency in Washington.* USGS Fact Sheet 016-01.
Springer 2005	Springer, Chuck. June 2005. *Flow Summary for Gaging Stations on the Wenatchee River and Selected Tributaries*. Washington State Department of Ecology. Publication No. 05-03-015.

4/3/2007

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Date

ATTACHMENT 1 – USGS GAGE STATIONS

Table 9. USGS Gage Station 1254000 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.6758	0.104	1.9075	0.4347	1.1218

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00696	1980	19100	0.99	3312	2909	3636
2	0.03037	1983	5900	0.98	3371	2972	3694
3	0.06559	1974	5890	0.975	3397	3000	3718
4	0.1008	1958	5780	0.96	3460	3067	3780
5	0.13602	1956	5700	0.95	3496	3106	3814
6	0.17124	1968	5700	0.9	3640	3261	3956
7	0.20646	1961	5430	0.8	3870	3506	4184
8	0.24167	1982	5390	0.7	4081	3729	4398
9	0.27689	1955	5360	0.6	4298	3954	4625
10	0.31211	1972	5310	0.5704	4366	4024	4697
11	0.34732	1967	5240	0.5	4537	4197	4882
12	0.38254	1969	5200	0.4296	4727	4385	5095
13	0.41776	1975	5160	0.4	4816	4471	5195
14	0.45297	1962	5030	0.3	5167	4803	5609
15	0.48819	1970	5020	0.2	5662	5245	6223
16	0.52341	1975	4780	0.1	6533	5976	7379
17	0.55863	1959	4590	0.05	7464	6715	8690
18	0.59384	1971	4580	0.04	7780	6958	9148
19	0.62906	1964	4480	0.025	8474	7484	10178
20	0.66428	1957	4460	0.02	8818	7741	10699
21	0.69949	1959	4320	0.01	9955	8573	12464
22	0.73471	1978	4200	0.005	11203	9464	14473
23	0.76993	1966	4150	0.002	13050	10746	17564
24	0.80515	1965	3980	0.001	14614	11805	20284
25	0.84036	1979	3760	0.0005	16341	12948	23384
26	0.87558	1977	3560	0.0001	21078	15979	32355
27	0.9108	1973	3490				
28	0.94601	1962	3270				
29	0.98123	1979	2970				

Table 10. USGS Gage Station 12455000 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.8482	0.1186	0.0596	0	0.0596

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.01245	1948	13700	0.99	3780	3268	4215
2	0.0332	1975	13000	0.98	4059	3554	4488
3	0.05394	1949	11000	0.975	4161	3658	4587
4	0.07469	1974	10500	0.96	4396	3901	4817
5	0.09544	1972	10200	0.95	4521	4030	4939
6	0.11618	1955	9620	0.9	4978	4504	5388
7	0.13693	1956	9400	0.8	5599	5148	6007
8	0.15768	1949	9030	0.7	6098	5659	6516
9	0.17842	1961	8910	0.6	6563	6125	7002
10	0.19917	1958	8490	0.5704	6700	6260	7149
11	0.21992	1969	8420	0.5	7032	6583	7509
12	0.24066	1933	8310	0.4296	7381	6917	7897
13	0.26141	1967	8190	0.4	7536	7063	8073
14	0.28216	1959	8100	0.3	8120	7601	8748
15	0.3029	1951	7990	0.2	8865	8264	9640
16	0.32365	1935	7700	0.1	10022	9255	11081
17	0.3444	1968	7600	0.05	11099	10148	12470
18	0.36515	1975	7560	0.04	11436	10423	12912
19	0.38589	1932	7550	0.025	12134	10987	13840
20	0.40664	1934	7550	0.02	12462	11249	14279
21	0.42739	1970	7400	0.01	13469	12046	15648
22	0.44813	1977	7190	0.005	14467	12825	17029
23	0.46888	1959	7160	0.002	15783	13838	18882
24	0.48963	1957	7040	0.001	16782	14598	20312
25	0.51037	1954	6990	0.0005	17788	15355	21770
26	0.53112	1964	6970	0.0001	20163	17116	25280
27	0.55187	1978	6910				
28	0.57261	1936	6640				
29	0.59336	1938	6630				
30	0.61411	1971	6520				
31	0.63485	1946	6520				
32	0.6556	1943	6490				
33	0.67635	1937	6290				
34	0.6971	1966	6250				
35	0.71784	1947	6120				
36	0.73859	1939	6090				
37	0.75934	1962	6020				
38	0.78008	1940	5690				
39	0.80083	1945	5680				
40	0.82158	1965	5670				
41	0.84232	1952	5180				
42	0.86307	1973	5110				
43	0.88382	1953	5050				
44	0.90456	1942	5010				
45	0.92531	1979	4700				
46	0.94606	1962	4560				
47	0.9668	1944	3490				
48	0.98755	1941	2750				

Table 11. USGS Gage Station 12456500 – Fequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.4987	0.1774	-0.0372	0	-0.0372

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.01863	1995	7030	0.99	1206	905	1471
2	0.04969	1990	6810	0.98	1352	1042	1623
3	0.08075	1948	5880	0.975	1406	1094	1679
4	0.1118	1999	5550	0.96	1534	1217	1811
5	0.14286	1956	5080	0.95	1604	1284	1883
6	0.17391	1955	4730	0.9	1865	1541	2152
7	0.20497	1997	4370	0.8	2238	1910	2541
8	0.23602	1949	4250	0.7	2550	2217	2876
9	0.26708	2003	3730	0.6	2850	2507	3209
10	0.29814	1995	3700	0.5704	2940	2593	3312
11	0.32919	1998	3600	0.5	3161	2800	3570
12	0.36025	2002	3470	0.4296	3398	3016	3854
13	0.3913	1957	3460	0.4	3505	3112	3986
14	0.42236	1938	3210	0.3	3913	3469	4502
15	0.45342	1993	3130	0.2	4450	3918	5214
16	0.48447	1943	3060	0.1	5313	4606	6427
17	0.51553	1946	3060	0.05	6146	5241	7661
18	0.54658	1947	3000	0.04	6412	5439	8065
19	0.57764	2003	2950	0.025	6971	5849	8931
20	0.6087	1937	2880	0.02	7236	6041	9350
21	0.63975	1999	2780	0.01	8064	6632	10683
22	0.67081	1945	2700	0.005	8902	7217	12072
23	0.70186	1940	2540	0.002	10031	7988	13998
24	0.73292	1942	2510	0.001	10904	8574	15530
25	0.76398	1992	2470	0.0005	11796	9163	17129
26	0.79503	1914	2400	0.0001	13948	10553	21115
27	0.82609	2001	2260				
28	0.85714	1994	2260				
29	0.8882	1939	2170				
30	0.91925	2005	1570				
31	0.95031	1944	1360				
32	0.98137	1941	1360				

Table 12. USGS Gage Station 12457000 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
4.0164	0.1478	0.9929	0	0.9929

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0073	1995	36100	0.99	6039	5447	6574
2	0.01954	1990	33200	0.98	6242	5652	6778
3	0.03156	1948	22700	0.975	6322	5732	6857
4	0.04357	1921	21100	0.96	6518	5930	7054
5	0.05559	1917	18700	0.95	6629	6041	7165
6	0.0676	1974	18500	0.9	7072	6489	7610
7	0.07962	1975	18000	0.8	7772	7193	8317
8	0.09163	1972	17900	0.7	8416	7837	8975
9	0.10365	1956	17100	0.6	9084	8498	9666
10	0.11566	1955	17000	0.5704	9293	8704	9885
11	0.12768	1916	16700	0.5	9825	9222	10447
12	0.13969	1949	16300	0.4296	10424	9798	11091
13	0.15171	1999	16200	0.4	10703	10064	11395
14	0.16372	1949	16000	0.3	11827	11115	12639
15	0.17574	1997	15800	0.2	13441	12580	14486
16	0.18775	1951	15300	0.1	16384	15151	17992
17	0.19977	1961	15100	0.05	19657	17909	22043
18	0.21178	1927	14900	0.04	20795	18851	23481
19	0.2238	1958	14700	0.025	23346	20934	26752
20	0.23581	1921	14300	0.02	24635	21976	28427
21	0.24783	1969	14300	0.01	28995	25448	34195
22	0.25985	1913	14300	0.005	33960	29323	40926
23	0.27186	1928	14300	0.002	41609	35165	51583
24	0.28388	1967	13900	0.001	48351	40208	61224
25	0.29589	1933	13800	0.0005	56034	45857	72453
26	0.30791	1934	13500	0.0001	78378	61824	106337
27	0.31992	1975	13500				
28	0.33194	1968	13400				
29	0.34395	1924	13000				
30	0.35597	1978	12900				
31	0.36798	1970	12700				
32	0.38	1957	12700				
33	0.39201	1925	12600				
34	0.40403	2002	12400				
35	0.41604	1954	12400				
36	0.42806	1971	12200				
37	0.44007	1993	12100				
38	0.45209	2003	12000				
39	0.4641	1964	11900				
40	0.47612	1999	11900				
41	0.48813	1919	11800				
42	0.50015	1998	11700				
43	0.51217	1938	11700				
44	0.52418	1959	11500				
45	0.5362	1995	11500				
46	0.54821	1935	11500				
47	0.56023	1912	11500				
48	0.57224	1946	11400				
49	0.58426	1959	11400				
50	0.59627	1943	11200				
51	0.60829	1936	11200				
52	0.6203	1917	11000				
53	0.63232	1932	10800				
54	0.64433	1937	10600				
55	0.65635	1911	10400				
56	0.66836	1947	10400				
57	0.68038	1966	10400				
58	0.69239	1923	10400				
59	0.70441	1965	10300				
60	0.71642	1945	9900				
61	0.72844	2005	9710				
62	0.74046	2003	9630				
63	0.75247	1963	9330				
64	0.76449	1989	9220				
65	0.7765	1952	9060				
66	0.78852	1939	9060				
67	0.80053	1914	8840				
68	0.81255	1940	8770				
69	0.82456	1942	8720				
70	0.83658	2001	8650				

Table 13. USGS Gage Station 12457300 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
1.4382	0.2372	-0.2033	0	-0.2033

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0297	1956	75	0.99	7.1	4.1	9.9
2	0.07921	1972	64	0.98	8.4	5.2	11.5
3	0.12871	1960	51	0.975	8.9	5.6	12
4	0.17822	1959	43	0.96	10	7	13
5	0.22772	1971	39	0.95	11	7	14
6	0.27723	1954	36.6	0.9	13	10	17
7	0.32673	1965	35	0.8	17	13	22
8	0.37624	1969	33	0.7	21	16	26
9	0.42574	1968	31	0.6	24	19	30
10	0.47525	1961	31	0.5704	25	20	31
11	0.52475	1966	25	0.5	28	23	34
12	0.57426	1962	25	0.4296	31	25	38
13	0.62376	1957	24.5	0.4	32	26	40
14	0.67327	1955	23.8	0.3	37	30	47
15	0.72277	1958	21.3	0.2	44	35	58
16	0.77228	1964	20	0.1	55	43	77
17	0.82178	1962	14	0.05	65	50	96
18	0.87129	1967	11.4	0.04	69	53	103
19	0.92079	1970	11	0.025	76	57	117
20	0.9703	1973	6	0.02	79	59	124
				0.01	90	66	147
				0.005	101	73	171
				0.002	116	81	205
				0.001	127	88	232
				0.0005	138	94	260
				0.0001	166	109	332

Table 14. USGS Gage Station 12458000 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.6488	0.1797	0.4878	0	0.4878

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00587	1995	19800	0.99	1976	1656	2267
2	0.01943	1948	11600	0.98	2129	1804	2423
3	0.03677	1975	9250	0.975	2186	1860	2482
4	0.05411	1959	8620	0.96	2324	1995	2623
5	0.07145	1972	8040	0.95	2400	2069	2700
6	0.08878	1949	8020	0.9	2691	2356	2998
7	0.10612	1974	8000	0.8	3125	2786	3446
8	0.12346	1999	7230	0.7	3508	3162	3847
9	0.1408	1962	6610	0.6	3892	3535	4257
10	0.15814	1956	6470	0.5704	4010	3649	4385
11	0.17547	1951	6110	0.5	4307	3931	4712
12	0.19281	1978	6090	0.4296	4636	4238	5081
13	0.21015	1975	6090	0.4	4788	4378	5254
14	0.22749	1955	6010	0.3	5387	4920	5954
15	0.24482	1970	5920	0.2	6225	5652	6969
16	0.26216	1968	5850	0.1	7698	6884	8840
17	0.2795	1997	5570	0.05	9269	8147	10928
18	0.29684	1961	5530	0.04	9803	8567	11655
19	0.31418	1999	5310	0.025	10976	9478	13280
20	0.33151	1969	5250	0.02	11558	9925	14100
21	0.34885	1967	5130	0.01	13484	11377	16865
22	0.36619	1949	5110	0.005	15602	12940	19993
23	0.38353	1958	5040	0.002	18738	15201	24769
24	0.40087	1954	4910	0.001	21397	17077	28936
25	0.4182	1966	4520	0.0005	24332	19111	33646
26	0.43554	1913	4430	0.0001	32373	24526	47058
27	0.45288	1912	4380				
28	0.47022	1964	4380				
29	0.48755	1937	4320				
30	0.50489	1971	4150				
31	0.52223	2005	4150				
32	0.53957	1938	4080				
33	0.55691	1957	4020				
34	0.57424	1947	4000				
35	0.59158	2002	3970				
36	0.60892	1959	3900				
37	0.62626	1943	3880				
38	0.6436	1995	3870				
39	0.66093	1965	3850				
40	0.67827	1998	3750				
41	0.69561	1939	3630				
42	0.71295	1946	3530				
43	0.73028	1945	3530				
44	0.74762	1972	3380				
45	0.76496	1942	3310				
46	0.7823	1940	3170				
47	0.79964	1952	3000				
48	0.81697	2003	2940				
49	0.83431	2001	2940				
50	0.85165	1953	2940				
51	0.86899	1914	2920				
52	0.88633	1994	2820				
53	0.90366	1962	2780				
54	0.921	1979	2630				
55	0.93834	2003	2450				
56	0.95568	1944	2400				
57	0.97301	1977	2370				
58	0.99035	1941	1640				

Table 15. USGS Gage Station 12458900 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
0.3267	0.5236	-0.7268	0	-0.7268

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0297	1972	11	0.99	0.1	0	0.2
2	0.07921	1958	7.5	0.98	0.1	0	0.2
3	0.12871	1969	7.1	0.975	0.1	0	0.3
4	0.17822	1955	5.6	0.96	0.2	0.1	0.4
5	0.22772	1957	5.5	0.95	0.2	0.1	0.4
6	0.27723	1954	5.3	0.9	0.4	0.2	0.7
7	0.32673	1971	4.5	0.8	0.8	0.4	1.3
8	0.37624	1959	4	0.7	1.3	0.8	2
9	0.42574	1963	3.7	0.6	1.8	1.1	2.8
10	0.47525	1966	3.6	0.5704	2	1.2	3.1
11	0.52475	1960	3	0.5	2.5	1.6	3.9
12	0.57426	1964	2.3	0.4296	3	1.9	4.9
13	0.62376	1962	2	0.4	3.3	2.1	5.4
14	0.67327	1961	2	0.3	4.4	2.8	7.6
15	0.72277	1965	1	0.2	6	3.7	11.2
16	0.77228	1968	0.6	0.1	8.8	5.3	18.1
17	0.82178	1970	0.5	0.05	12	7	26
18	0.87129	1967	0.3	0.04	13	7	29
19	0.92079	1973	0.3	0.025	15	8	35
20	0.9703	1955	0.2	0.02	15	9	38
				0.01	18	10	47
				0.005	21	11	56
				0.002	24	13	68
				0.001	27	14	78
				0.0005	29	15	87
				0.0001	34	17	106

Table 16. USGS Gage Station 12459000 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
4.209	0.1409	0.306	0	0.306

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00777	1995	41300	0.99	8186	7236	9036
2	0.02073	1990	40000	0.98	8773	7824	9621
3	0.03368	1948	32300	0.975	8989	8042	9836
4	0.04663	1980	27000	0.96	9499	8557	10344
5	0.05959	1974	26300	0.95	9774	8834	10617
6	0.07254	1972	26000	0.9	10804	9878	11646
7	0.08549	1975	25200	0.8	12267	11358	13117
8	0.09845	1956	24200	0.7	13495	12590	14371
9	0.1114	1955	23400	0.6	14679	13762	15603
10	0.12435	1999	23100	0.5704	15036	14111	15979
11	0.13731	1949	22700	0.5	15914	14962	16917
12	0.15026	1950	21800	0.4296	16861	15865	17946
13	0.16321	1961	21500	0.4	17290	16269	18418
14	0.17617	1997	21400	0.3	18938	17797	20268
15	0.18912	1958	21000	0.2	21134	19775	22807
16	0.20207	1951	20600	0.1	24748	22924	27132
17	0.21503	1983	20600	0.05	28337	25960	31568
18	0.22798	1933	20400	0.04	29503	26931	33033
19	0.24093	1969	19700	0.025	31988	28981	36191
20	0.25389	1967	19100	0.02	33186	29960	37729
21	0.26684	1975	18700	0.01	36992	33039	42680
22	0.27979	1982	18700	0.005	40953	36196	47921
23	0.29275	1986	18500	0.002	46465	40525	55352
24	0.3057	1934	18400	0.001	50869	43936	61393
25	0.31865	1968	17900	0.0005	55494	47479	67826
26	0.33161	1954	17900	0.0001	67183	56279	84448
27	0.34456	1957	17800				
28	0.35751	1978	17700				
29	0.37047	1970	17700				
30	0.38342	1938	17500				
31	0.39637	1987	17100				
32	0.40933	1993	16700				
33	0.42228	1971	16700				
34	0.43523	1964	16700				
35	0.44819	1936	16600				
36	0.46114	2002	16500				
37	0.47409	1959	16400				
38	0.48705	1932	16000				
39	0.5	1946	15900				
40	0.51295	1998	15800				
41	0.52591	1959	15700				
42	0.53886	1995	15700				
43	0.55181	1943	15700				
44	0.56477	1935	15400				
45	0.57772	1965	15400				
46	0.59067	1999	15300				
47	0.60363	1937	14800				
48	0.61658	1947	14500				
49	0.62953	1984	14400				
50	0.64249	1966	14300				
51	0.65544	1962	14200				
52	0.66839	1988	13900				
53	0.68135	1945	13900				
54	0.6943	1985	13800				
55	0.70725	1980	13600				
56	0.72021	2005	13100				
57	0.73316	1942	13100				
58	0.74611	2003	13000				
59	0.75907	1952	12900				
60	0.77202	2003	12900				
61	0.78497	1989	12800				
62	0.79793	1940	12700				
63	0.81088	1939	12700				
64	0.82383	1931	12500				
65	0.83679	1953	12200				
66	0.84974	1929	11900				
67	0.86269	1992	11700				
68	0.87565	2001	11600				
69	0.8886	1973	11400				
70	0.90155	1989	11300				

Table 17. USGS Gage Station 12461100 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
1.3426	0.3444	0.2358	0	0.2358

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0297	1974	114	0.99	4	2	6.2
2	0.07921	1972	75	0.98	4.8	2.5	7.2
3	0.12871	1956	49.7	0.975	5.1	2.7	7.6
4	0.17822	1957	44	0.96	5.9	3.3	8.6
5	0.22772	1969	40	0.95	6.3	3.6	9.2
6	0.27723	1968	36	0.9	8.1	5	11.4
7	0.32673	1959	29	0.8	11	7	15
8	0.37624	1960	28	0.7	14	10	19
9	0.42574	1961	28	0.6	17	13	23
10	0.47525	1973	26	0.5704	19	13	25
11	0.52475	1962	24	0.5	21	16	29
12	0.57426	1958	22	0.4296	25	18	34
13	0.62376	1971	13	0.4	26	19	36
14	0.67327	1967	13	0.3	33	24	46
15	0.72277	1962	13	0.2	42	31	64
16	0.77228	1955	10.9	0.1	62	44	102
17	0.82178	1966	9	0.05	85	58	155
18	0.87129	1970	8	0.04	94	63	176
19	0.92079	1965	7	0.025	114	74	226
20	0.9703	1964	7	0.02	124	79	253
				0.01	160	97	354
				0.005	202	118	485
				0.002	271	150	718
				0.001	334	178	951
				0.0005	408	209	1244
				0.0001	631	297	2244

Table 18. USGS Gage Station 12461200 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
0.8136	0.4043	-0.5064	0	-0.5064

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.01754	1974	35	0.99	0.5	0.3	0.9
2	0.04678	1972	30	0.98	0.8	0.4	1.2
3	0.07602	1982	26	0.975	0.8	0.5	1.3
4	0.10526	1956	21	0.96	1.1	0.6	1.6
5	0.1345	1981	18	0.95	1.2	0.7	1.8
6	0.16374	1983	15	0.9	1.9	1.2	2.6
7	0.19298	1975	14	0.8	3.1	2.2	4.1
8	0.22222	1979	12	0.7	4.3	3.1	5.5
9	0.25146	1959	12	0.6	5.5	4.2	7.2
10	0.2807	1978	11.8	0.5704	6	4.5	7.8
11	0.30994	1968	9.9	0.5	7	5.4	9.2
12	0.33918	1962	9.3	0.4296	8.3	6.4	11
13	0.36842	1987	9.2	0.4	8.8	6.8	11.8
14	0.39766	1971	8.5	0.3	11	9	15
15	0.4269	1969	8.5	0.2	14	11	21
16	0.45614	1960	8.3	0.1	20	15	30
17	0.48538	1986	7.5	0.05	26	19	41
18	0.51462	1961	6.3	0.04	28	20	45
19	0.54386	1980	6.2	0.025	32	22	53
20	0.5731	1970	5.8	0.02	34	23	57
21	0.60234	1958	5.7	0.01	40	27	69
22	0.63158	1957	5	0.005	46	31	82
23	0.66082	1984	4.7	0.002	54	35	100
24	0.69006	1966	3.8	0.001	60	39	114
25	0.7193	1967	3.8	0.0005	66	42	128
26	0.74854	1975	3.6	0.0001	80	49	162
27	0.77778	1955	3.6				
28	0.80702	1963	3.4				
29	0.83626	1973	3				
30	0.8655	1965	3				
31	0.89474	1964	1.5				
32	0.92398	1985	1.2				
33	0.95322	1986	0.6				
34	0.98246	1977	0.3				

Table 19. USGS Gage Station 12461400 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
2.2787	0.3285	0.845	0	0.845

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00748	1974	2090	0.99	53	30	75
2	0.03834	1975	670	0.98	57	34	82
3	0.08759	1979	630	0.975	59	36	84
4	0.13685	1975	620	0.96	64	39	90
5	0.1861	1978	520	0.95	67	42	93
6	0.23535	1972	310	0.9	79	51	108
7	0.2846	1971	299	0.8	99	68	133
8	0.33385	1959	240	0.7	120	85	158
9	0.3831	1968	172	0.6	143	105	188
10	0.43236	1962	155	0.5704	151	111	198
11	0.48161	1959	144	0.5	171	128	225
12	0.53086	1965	140	0.4296	195	148	259
13	0.58011	1961	137	0.4	207	157	276
14	0.62936	1977	125	0.3	258	197	354
15	0.67862	1969	114	0.2	341	257	493
16	0.72787	1973	114	0.1	522	377	837
17	0.77712	1967	108	0.05	769	526	1376
18	0.82637	1962	101	0.04	865	581	1605
19	0.87562	1966	96	0.025	1103	712	2205
20	0.92488	1964	83	0.02	1233	781	2555
21	0.97413	1970	65	0.01	1730	1032	3998
				0.005	2398	1346	6169
				0.002	3638	1888	10761
				0.001	4944	2418	16219
				0.0005	6653	3071	24148
				0.0001	13161	5309	60341

Table 20. USGS Gage Station 12461500 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
1.8237	0.2964	0.6165	0	0.6165

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0297	1956	325	0.99	19	11	26
2	0.07921	1972	242	0.98	21	12	29
3	0.12871	1959	120	0.975	22	13	30
4	0.17822	1905	115	0.96	24	15	32
5	0.22772	1957	112	0.95	25	16	34
6	0.27723	1973	82	0.9	29	19	39
7	0.32673	1971	74	0.8	37	26	48
8	0.37624	1955	71	0.7	45	33	57
9	0.42574	1958	68.5	0.6	53	40	68
10	0.47525	1954	67.4	0.5704	55	42	71
11	0.52475	1968	62	0.5	62	48	80
12	0.57426	1966	61	0.4296	70	54	91
13	0.62376	1969	56	0.4	74	57	97
14	0.67327	1965	54	0.3	90	70	121
15	0.72277	1961	42	0.2	115	88	162
16	0.77228	1964	38	0.1	165	122	256
17	0.82178	1970	37	0.05	228	161	388
18	0.87129	1962	36	0.04	251	175	441
19	0.92079	1967	23	0.025	306	207	572
20	0.9703	1962	22	0.02	335	223	646
				0.01	440	279	928
				0.005	571	344	1314
				0.002	793	449	2044
				0.001	1007	545	2823
				0.0005	1271	657	3866
				0.0001	2140	997	7825

Table 21. USGS Gage Station 12462000 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
2.2921	0.2203	0.8735	0	0.8735

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0283	1972	560	0.99	84	58	106
2	0.07547	1971	470	0.98	89	63	112
3	0.12264	1956	463	0.975	91	64	114
4	0.16981	1948	408	0.96	95	69	119
5	0.21698	1973	290	0.95	98	71	122
6	0.26415	1959	235	0.9	109	82	134
7	0.31132	1955	215	0.8	127	98	154
8	0.35849	1968	208	0.7	144	114	173
9	0.40566	1957	192	0.6	162	131	194
10	0.45283	1969	182	0.5704	167	136	201
11	0.5	1954	168	0.5	182	150	219
12	0.54717	1962	153	0.4296	199	165	241
13	0.59434	1958	151	0.4	207	172	251
14	0.64151	1964	150	0.3	240	200	297
15	0.68868	1959	141	0.2	290	240	371
16	0.73585	1962	140	0.1	386	311	530
17	0.78302	1967	136	0.05	502	389	742
18	0.83019	1965	123	0.04	544	416	824
19	0.87736	1961	114	0.025	641	477	1022
20	0.92453	1970	114	0.02	692	508	1130
21	0.9717	1966	103	0.01	870	614	1531
				0.005	1087	736	2057
				0.002	1444	927	3006
				0.001	1780	1097	3977
				0.0005	2177	1290	5209
				0.0001	3475	1878	9758

Table 22. USGS Gage Station 12462500 – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
4.1889	0.136	1.4598	0	1.4598

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.0073	1995	47500	0.99	10344	9152	11384
2	0.01368	1990	45900	0.98	10483	9295	11523
3	0.03742	1980	29600	0.975	10542	9355	11582
4	0.06115	1975	29200	0.96	10698	9515	11738
5	0.08489	1972	28700	0.95	10792	9611	11831
6	0.10863	1974	27600	0.9	11199	10029	12241
7	0.13237	1999	25000	0.8	11921	10767	12973
8	0.1561	1997	24300	0.7	12645	11502	13717
9	0.17984	1983	22700	0.6	13437	12299	14546
10	0.20358	1982	20900	0.5704	13693	12553	14817
11	0.22732	1969	20500	0.5	14356	13207	15529
12	0.25105	1975	20400	0.4296	15123	13951	16369
13	0.27479	1986	19500	0.4	15486	14299	16775
14	0.29853	1967	19400	0.3	16982	15699	18487
15	0.32227	1978	19200	0.2	19211	17695	21163
16	0.346	1987	18800	0.1	23460	21284	26588
17	0.36974	1993	18700	0.05	28407	25244	33290
18	0.39348	1970	18600	0.04	30174	26620	35762
19	0.41722	1964	18200	0.025	34211	29706	41542
20	0.44095	2002	18000	0.02	36290	31268	44583
21	0.46469	1962	17900	0.01	43495	36569	55425
22	0.48843	1998	17800	0.005	51996	42638	68745
23	0.51217	1971	17800	0.002	65635	52057	91119
24	0.5359	1995	17600	0.001	78137	60424	112558
25	0.55964	1999	16600	0.0005	92902	70042	138855
26	0.58338	1965	16400	0.0001	138309	98314	225146
27	0.60712	1966	15700				
28	0.63085	1968	15500				
29	0.65459	1984	15400				
30	0.67833	1988	15000				
31	0.70207	1980	14800				
32	0.7258	1985	14600				
33	0.74954	1989	14000				
34	0.77328	2003	13900				
35	0.79702	2005	13800				
36	0.82075	2003	13700				
37	0.84449	1992	12400				
38	0.86823	2001	12200				
39	0.89196	1973	12000				
40	0.9157	1989	12000				
41	0.93944	1994	12000				
42	0.96318	1979	11600				
43	0.98691	1977	9410				

Table 23. Synthetic Gage Record (Ecology 45J070 and USGS 12458000) – Frequency Analysis

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.4413	0.2018	0.5482	0.0000	0.5482

RANK	PlotPos	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00593	1995	11254	0.99	1132	935	1315
2	0.01924	2007	9940	0.98	1225	1023	1411
3	0.03599	1948	6593	0.975	1260	1057	1448
4	0.05274	2006	6450	0.96	1345	1139	1536
5	0.06949	2003	5780	0.95	1392	1184	1585
6	0.08624	1975	5258	0.9	1575	1362	1775
7	0.10298	2005	4960	0.8	1855	1634	2067
8	0.11973	1959	4900	0.7	2107	1879	2333
9	0.13648	1972	4570	0.6	2364	2126	2611
10	0.15323	1949	4559	0.5704	2445	2202	2699
11	0.16998	1974	4547	0.5	2648	2393	2924
12	0.18673	1999	4109	0.4296	2876	2604	3181
13	0.20347	1962	3757	0.4	2982	2701	3303
14	0.22022	1956	3678	0.3	3407	3082	3802
15	0.23697	1951	3473	0.2	4014	3608	4545
16	0.25372	1975	3462	0.1	5115	4520	5958
17	0.27047	1978	3462	0.05	6333	5487	7599
18	0.28721	1955	3416	0.04	6755	5815	8183
19	0.30396	1970	3365	0.025	7698	6536	9513
20	0.32071	1968	3325	0.02	8173	6895	10195
21	0.33746	1997	3166	0.01	9775	8082	12545
22	0.35421	1961	3143	0.005	11586	9392	15289
23	0.37096	2003	3140	0.002	14354	11341	19628
24	0.3877	1999	3018	0.001	16771	13002	23542
25	0.40445	1969	2984	0.0005	19506	14844	28094
26	0.4212	1967	2916	0.0001	27315	19931	41684
27	0.43795	1949	2904				
28	0.4547	1958	2865				
29	0.47144	1954	2791				
30	0.48819	1966	2569				
31	0.50494	1913	2518				
32	0.52169	1964	2490				
33	0.53844	1912	2490				
34	0.55519	1937	2455				
35	0.57193	2002	2390				
36	0.58868	1971	2359				
37	0.60543	1938	2319				
38	0.62218	1957	2285				
39	0.63893	1947	2274				
40	0.65567	1959	2217				
41	0.67242	1943	2205				
42	0.68917	1995	2200				
43	0.70592	1965	2188				
44	0.72267	1998	2131				
45	0.73942	1939	2063				
46	0.75616	1945	2006				
47	0.77291	1946	2006				
48	0.78966	1972	1921				
49	0.80641	1942	1881				
50	0.82316	1940	1802				
51	0.8399	1952	1705				
52	0.85665	2001	1671				
53	0.8734	1953	1671				
54	0.89015	1914	1660				
55	0.9069	1994	1603				
56	0.92365	1962	1580				
57	0.94039	1979	1495				
58	0.95714	1944	1364				
59	0.97389	1977	1347				
60	0.99064	1941	932				

APPENDIX E.

NASON CREEK SUBWATERSHED CONDITIONS

This appendix describes general characteristics of the Nason Creek subwatershed to serve as a context for the river mile (RM) 4 to 14 assessment area. This information is used in the main report to explore whether any upstream, downstream, or hillslope processes have potential influences on physical river processes and habitat within the assessment area. The information is based on a literature review of a 1996 U.S. Forest Service (USFS) watershed analysis and other historical documents. Hydrology and water quality data at the subwatershed scale are presented in separate appendices.

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Tables

Figures

1. LAND USE AND OWNERSHIP

The primary zoned land classifications in the Wenatchee subbasin are forest and residential with a small percentage of agriculture. Eighty-six percent of the watershed is classified as forest (Table 1).

Table 1. Land use zoning in the Wenatchee watershed.

Land Use Classification	Totals	Percent of Watershed
Commercial Agricultural	8,195	1.0%
Forest	732,209	86.0%
Public	1,226	0.1%
Rural Residential /Resource 2.5	4,411	0.5%
Rural Residential /Resource 5	19,227	2.3%
Rural Residential /Resource 10	14,619	1.7%
Rural Residential /Resource 20	59,576	7.0%
Total Rural Residential /Resource	97,833	11.5%
Rural Village	1,860	0.2%
Rural Commercial	236	0.0%
Rural Industrial	376	0.0%
Rural Recreational and Resource	853	0.1%
Rural Waterfront	1,484	0.2%
Urban Residential 1	8	0.0%
Urban Residential 3	2	0.0%
Total Urban Residential	10	0.0%
Peshastin Village Commercial	2	0.0%
General Commercial	5	0.0%
Industrial	4	0.0%
Commercial Mineral	241	0.0%
City Urban Growth Area	2,669	0.3%
Open Water	4,325	0.5%
Totals	**851,527**	**100.0%**

Source: Chelan County Planning Parcel Database

Within the Wenatchee subbasin, the Nason Creek subwatershed is a mix of developed (mainly along the valley floor) and undeveloped areas (USFS 1996; see map 2 in attached atlas). The following breakdown is from the Nason Creek Biological Assessment (USFS 1999a).

- 28 percent wilderness
- 19 percent Late Successional Reserve (areas managed to protect and enhance conditions of late-successional and old-growth forest ecosystems, no scheduled timber harvest)

- 10 percent Administratively Withdrawn (areas not scheduled for timber harvest, include recreation areas, lands not technically suitable for timber production, visual retention, protection of locally endemic species, in Nason; the Administratively Withdrawn area is for a not-yet designated Inventoried Roadless Area).
- 20 percent Matrix (areas designated for long-term growth and production of commercially valuable wood products)
- 22 percent private ownership

There are a few urban nodes spread throughout at Stevens Pass ski area, Merritt, and Coles Corner. In a 1940 report, the only population precinct noted in the Nason Creek subwatershed was Merritt, listed as having 60 persons in 1920 and 40 in 1930; general farming was noted to occur in one location below Coles Corner and for a large portion of the Coles Corner to Merritt reach. As of 1996, approximately 125 homes, businesses, and other structures were within the Nason Creek subwatershed (USFS 1996).

Anthropogenic land use activities in the riparian area include construction and maintenance for U.S. Highway 2 (1,250,000 vehicles a year); private homes; campgrounds; recreation; power and transmission line maintenance; and railroad activities (Appendix B – Historical Timeline) (USFS 1996). The railroad was constructed in the 1890s and increased therafter. The highway (known as Stevens Pass Highway) was present in the early 1900s and improved and relocated closer to the river in the 1940s to 1960s. The power lines were present by 1930s maps (construction date unknown); settlement began with the railroad. A downhill ski area is present at the pass and a Nordic center located in the Mill Creek subdrainage.

2. VEGETATION

Nason Creek vegetation ranges from high elevation subalpine forests at approximately 5500 feet elevation to dry forest environments around 2000 feet in elevation (USFS 1996). Within the 68,164 acre watershed, 18 percent of the total acreage is composed of non-forest habitat such as hardwoods and shrubs, wetlands, alpine meadows, rock, and water (Table 2). Processes which influence the pattern and distribution of vegetative development include human and natural disturbances, such as timber harvest, roads, fire, snow avalanche, flooding, and wind (USFS 1996). Note that more detailed vegetation mapping within the assessment area is discussed in an Appendix I – Vegetation.

Table 2. Plant series distribution in Nason Creek subwatershed from USFS 1996 analysis.

Plant Series	Acres	Percent of Total Area
Pacific silver fir	22,893	33.6%
Grand fir	18,083	27.0%
Mountain hemlock	2,138	3.1%
Western hemlock	4,828	7.1%
Subalpine fir	4,727	6.9%
Douglas-fir	2,858	4.2%
Subalpine larch	723	1.1%
Whitebark pine	44	< 0.1%
Ponderosa pine**	4	< 0.1%
hardwoods	1,233	1.8%
slide community	3,125	4.6%
Non-forested wetland	225	0.3%
subalpine meadow	3,245	4.8%
rock	3,537	5.2%
water	501	0.7%

** Ponderosa pine occurs as a seral species in some Douglas-fir and grand fir habitats, and is much more prevalent as a species within the Nason Creek subwatershed than this plant series data suggests. A community which exists prior to the climax community is referred to as seral or successional; a given site on the landscape may have a number of seral communities present over time following a disturbance (USFS 1996).

The 1996 USFS watershed analysis documented that while there are some areas of concern in the drainage, the overall condition of the vegetation in the Nason Creek subwatershed is stable and vigorous.

Vegetation areas of concern within the Nason subwatershed are in the Coulter and Kahler Creek drainages, which are predominantly early successional at this time due to past wild fires and harvest activities on public and private lands. The dry forest communities at the east end of the subwatershed, which have missed at least two cycles of fire, are becoming dense (USFS 1996). Seven species of noxious weeds can be found near roads and powerline corridors in the Nason Creek subwatershed. Endemic levels of insects and pathogens are found throughout the subwatershed.

3. TIMBER HARVEST

In the last decade, timber harvest permits on public lands have been reduced and vegetation is returning in many areas. Timber harvest continues on privately-owned land but is not well documented (Haberberger 2008). Historical timber harvest and present clearings on public lands has been documented by the USFS (see map 8 in attached atlas). Historical timber harvest is a database that is continually updated by the USFS and includes timber activities on Federal lands from 1949 to the present. It does not include all private land timber harvest activities. A separate mapping effort by the USFS on aerial photography documented all present clearings, noted to be continually updated (Haberberger 2008). This database does not describe when the timber harvest occurred but rather that the land still remains cleared. Matrix allocations, where most timber harvest takes place on USFS land, and privately-owned land together make up 90 percent of the Butcher-Kahler drainage, 85 percent of Gill-Roaring-Coulter drainage, and 80 percent of lower Nason drainage (Andonaegui 2001). Information on historical timber harvest activities in the Nason Creek subwatershed from the late 1800s to the present are documented below.

Nason Creek, before the advent of the Great Northern Railway in 1891, would have had a relatively undisturbed forest and riparian corridor. Around the turn of the century, the best timber was found in the vicinity of the Cascade tunnel in the upper subwatershed, and consisted of fir, Patton hemlock, and Engelmann spruce, with some red cedar (Plummer 1902). Fires set to clear the right of way during railroad construction spread over considerable areas of the valley and adjacent hills, and these, together with the cutting for railroad uses, greatly reduced the amount of standing timber (Plummer 1902). The U.S. Geolocial Survey (USGS) land classification map of 1902 (Figure 1) shows active logging at this time (Plummer 1902). Plummer states that "*Near Nason Creek station a mill having a daily capacity of 10,000 feet is in operation, and ships lumber to Wenatchee*" (Plummer 1902).

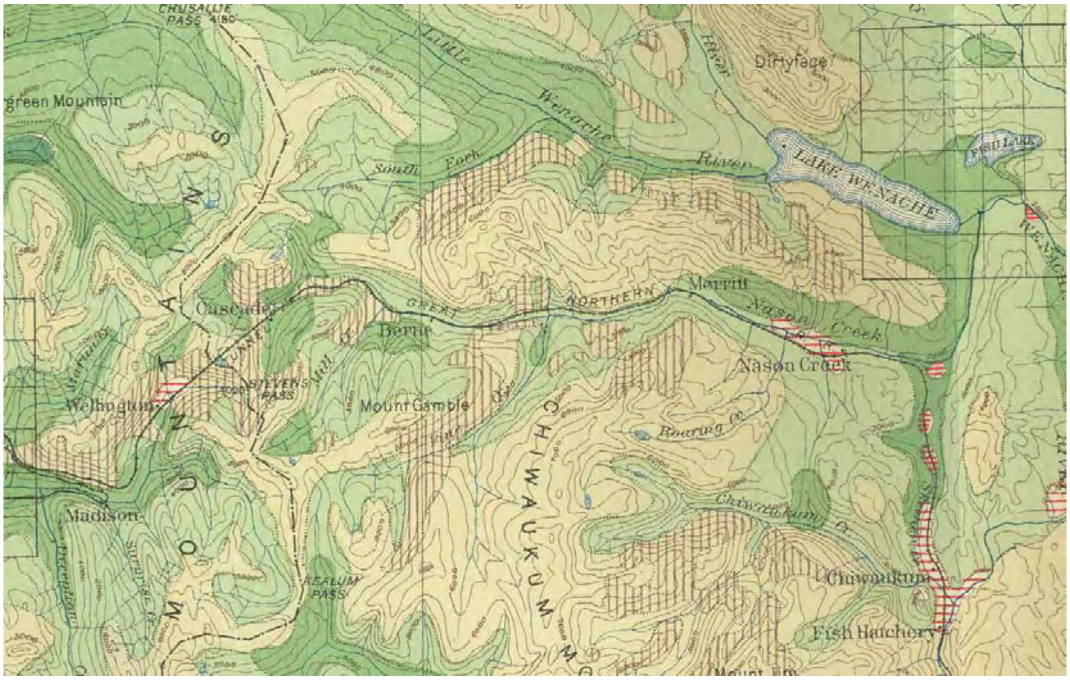


Figure 1. The USGS land classification map of 1902 shows fires identified as vertical black-striped areas and logged areas as horizontal red-striped areas (Plummer 1902).

Following this 1902 documentation, there are several references to nearly annual clear cutting for log drives on Nason Creek and down the Wenatchee River between 1905 and 1927. A map documenting the extent of clear cutting associated with the 1905 to 1927 log drives has not been found; however, many references are available on the general capacity and size of logging facilities in the Wenatchee subbasin (Figure 2); also see Appendix B – Historical Timeline appendix for further information). Ponderosa pine was the most commonly logged species in the Wenatchee subbasin, but it was noted that Douglas fir stands along the Stevens Creek highway (Nason drainage) were logged (Kelley 1940).

THE LUMBER MANUFACTURERS - ANNUAL PRODUCTION*

Companies	Location	Cut in M. board feet
Peshastin Lumber and Box Co.	Peshastin	12,000
Schmitten Lumber Co.	Cashmere	8,000
Wenatchee Box Corp.	Wenatchee	5,000
Landreth Bros.	Wenatchee	3,000
C. A. Wright	Blewett	3,000
Cole's Corner	Winton	1,000
Total		32,000

*Manager, Pine Box Sales, Wenatchee

Figure 2. Example of lumber company production in the Wenatchee subbasin documented in the 1940 Kelley report.

Typically, the log drives would occur during spring snowmelt when the water was higher and it was easier to float logs down the creek. In the prior winter months, timber along the river corridor would be harvested and stock piled along the river bank for the log drives. Logs were floated down Nason Creek to the Wenatchee River and collected behind a dam on the mainstem Wenatchee River. The log drives were also a recreational event to which local citizens came to watch men hired to float down river with the logs to ensure they did not get hung up on log jams or other obstacles in the river. The newspaper in the local city of Leavenworth is believed to have documented the log drives during the time period they occurred, and additional research may reveal more details regarding the extent and duration of activity on Nason Creek.

Until the 1950s, timber harvest on public lands was largely limited to the harvest of large trees (“high grading”) from the valley bottoms and adjacent hillslopes (Smith 1993) with little harvest on public lands until the 1960s. From the mid-1970s to the present, clear cutting became a common practice with the volume of timber harvest increasing significantly (USFS 1996). Accompanying these practices were substantial increases in road building (McIntosh et al. 1994). Most of the timber harvesting on public lands occurred on hillslopes between White Pine Creek to the mouth of Nason.

4. FIRE REGIME

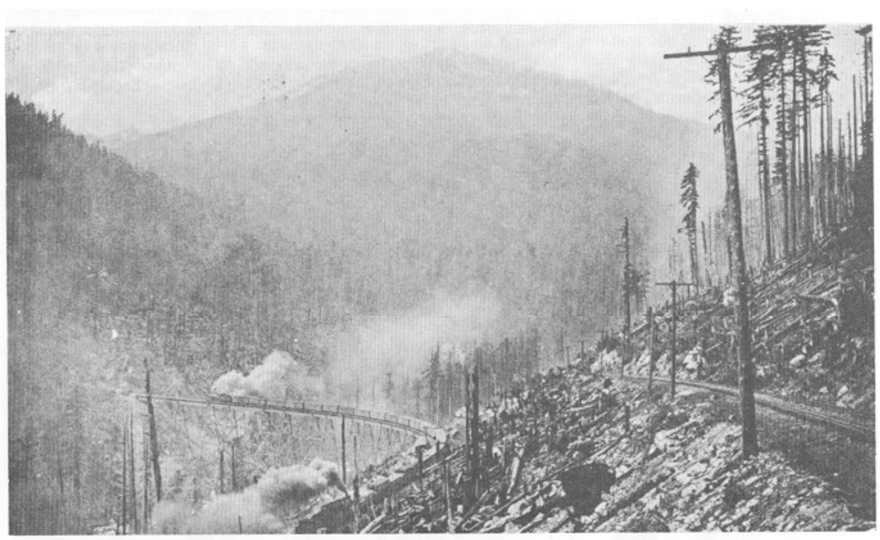
The USFS 1996 Nason Creek subwatershed analysis examined the role of fire and its effects on vegetation patterns (see map 4 in attached atlas). Historically, fire is believed to have had the largest impacts on vegetation patterns in the eastern side of the subwatershed where it is drier with a lack of rock outcroppings or avalanche chutes that serve as natural barriers. In these areas, fires may have burned as often as 2 to 25 years on average caused from burning by Native Americans or lightning strikes (USFS 1996). Slightly less than 70 percent of the subwatershed is occupied by high elevation, moist forest stands that can have high severity fires, but would naturally occur infrequently (USFS 1996). The potential historical fire regime (severity and frequency) was mapped in geographic information system (GIS) by Davis et al. (2004) and is provided on map 4 in the attached atlas for comparison to recorded fire areas. The historical fire regime represents possible fire disturbance in an unmanaged setting but is not based on actual data. Davis et al. (2004) notes that historical fire regimes are believed to have changed about 100 years ago with the onset of forest management. Available data on historical fires in the Nason subwatershed and an interpretation of existing conditions fire regimes from the USFS (1996) is provided below.

As European settlers moved into the area, burning occurred from construction of the railroad in the 1890s and later from the trains themselves (Figure 3). In addition, the railroad right-of-way has been burned repeatedly to maintain passage, which undoubtedly had a large effect on riparian vegetation (Mullan et al. 1992; McIntosh et al. 1994). A 1902 USGS Land Classification map shows areas identified as burned (Plummer 1902) less than a decade after railroad construction (see Figure 1). Fire suppression in the first half of the century became more aggressive as the USFS began using lookouts and crews from the Civilian Conservation Corps (USFS 1996). A 1940 report documents only one fire occurrence in the vicinity of the Nason subwatershed (Kelley 1940; burn area not rectified in ArcGIS, Figure 4).

Figure 5 shows documented wild fires by USFS from approximately the last decade within the Nason Creek subwatershed as well as wild fires within the surrounding area. The Round Mountain Fire in 1994 was the larger of two wild fires that have burned in the Nason Creek subwatershed in recent years burning approximately 3, 407 acres. This wild fire was located on the ridge between Nason Creek and the Little Wenatchee River near the confluence of Nason Creek.

In terms of fire suppression effects, the USFS concludes the following:

> "Fire suppression has altered the species composition and density in some of the low inherent fire severity stands, increasing the risk of a high intensity fire, but these areas account for only 5.5 percent of the entire watershed (USFS 1996). Nearly 69 percent of the watershed is occupied by high elevation or moist forest stands, which have high severity, low frequency fire regimes. These ecosystems are relatively stable and fire suppression has done little at this time to alter the successional trends and current conditions (USFS 1996). In moderate fire regimes, which account for approximately 26 percent of the acres in the Nason Creek subwatershed, fire suppression may have wrought a change in the size and distribution of early and mid seral stands, but the extent and ecological significance of such a change is not well understood (USFS 1996)."



In the days before the completion of the eight-mile tunnel through the Cascades, Great Northern trains zig-zagged along the mountainside and skimmed along trestles over high canyons. One of the short, sharply curved tunnels on the old route was the Horseshoe Tunnel near Scenic. This photo shows a train crossing the trestle at the mouth of the Horseshoe Tunnel.

Figure 3. Example showing a burned hillside along railroad tracks. Photo taken between 1893 and 1929. (Anderson 1952)

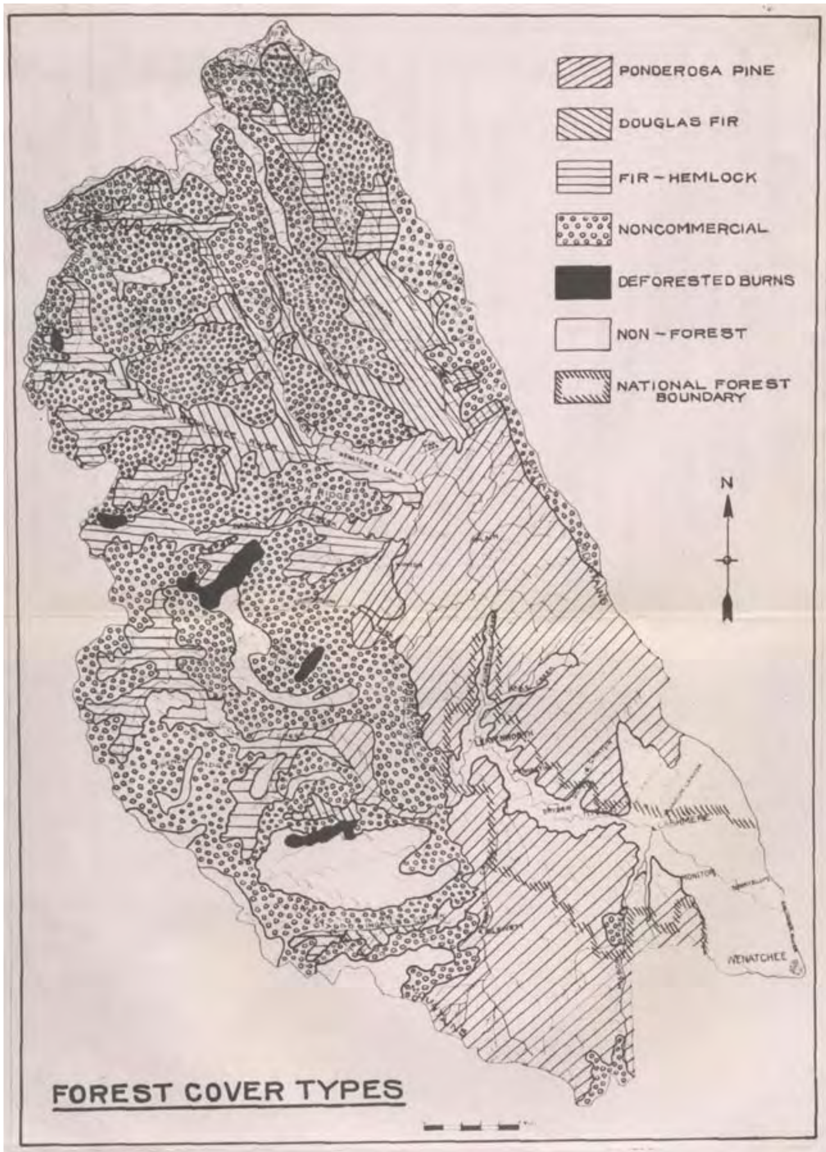


Figure 4. Document of fire in upper Nason Creek in the 1940 Kelley report.

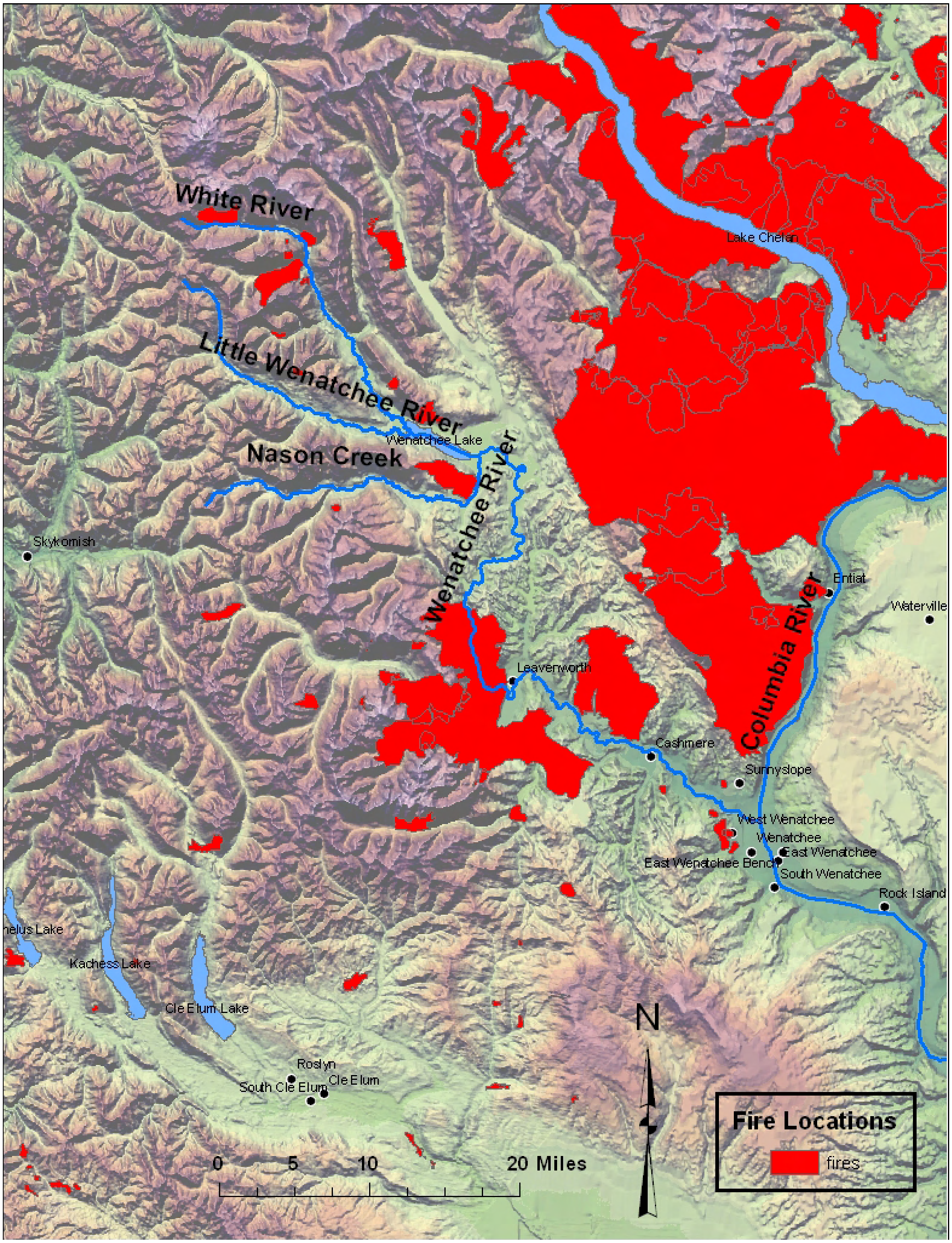


Figure 5. Fire locations within the Nason Creek subwatershed and surrounding areas. The fire polygons document historical fires in the Wenatchee watershed provided by USFS, Okanogan Wenatchee National Forest (P. Murphy, 2008, written communication of ArcGIS file).

5. SEDIMENT SOURCES

The types of sediment recruitment to Nason Creek were qualitatively evaluated based on available literature, historical aerial photographs, and field observations. Sediment in the Nason Creek subwatershed naturally originates from mass wasting (Figure 6 and Figure 7), tributaries, and reworking of the channel and floodplain (Figure 8). Mass wasting includes bank erosion, landslides, debris flows, avalanches, and/or any other dislodgement and downslope transport under direct gravitational stresses. Input of fine sediment can also occur as a result of fire, either catastrophic or managed, that removes the duff layer and damages the soil properties so that runoff from these soils is extensive, causing erosion from hill slopes and delivered to channel systems (USFS 1999b). Roadways are another sediment source from surface erosion (generally fine sediment) and/or mass failings of the roadway prism or bank protection (fine or coarse sediment).

There are no dams or sediment traps on Nason Creek, but in many instances the frequency and volume of sediment delivery has been altered. Mass failures related primarily to roads and secondarily to timber harvest are believed to be the dominant management-induced sediment source and mechanism of delivery for Nason Creek (USFS 1996). Tributary confluences have been altered and in several cases cutoff from Nason Creek by railroad or highway embankments. Bank erosion rates may be reduced in several areas where the channel has been riprapped and accelerated in other areas where vegetation has been cleared along the bank. Channel storage and reworking rates may be altered in localized areas due to channelization by riprap and highway and railroad embankments. Generally, these impacts are more easily observed below the White Pine Railroad Bridge near RM 14.

A quantitative sediment budget and sediment load measurements were beyond the available resources for this assessment, but could be done in future studies to confirm this qualitative assessment. A sediment budget would require sampling of bedload and suspended load at key locations along the river at a range of low-to-high flows to develop a sediment-rating curve. It would also require bulk sampling of sediment contributed from landslides, bank erosion, and floodplain and riverbed sediment to develop a particle size distribution for each source area. The rate of delivery (frequency) and volume of sediment from each of these sources would then need to be estimated. This information could be coupled with a sediment transport or budget model that would route the sediment along the assessment area and adjust the sediment in storage in the channel bed and floodplain based on an input hydrograph. Some general observations on sediment sources are provided below.

Figure 6. Example of slope failure on right side of river just upstream of White Pine Railroad Bridge. (Reclamation photograph taken by J. Bountry, June 2005).

Figure 7. Example of terrace bank erosion along left side of channel between RM 4 and RM 9 on Nason Creek. (Reclamation photograph taken October 2007).

Figure 8. Example of sediment present in Nason Creek channel bed in upper portion of subwatershed. (Reclamation photograph taken by P. Makar, October 2007)

5.1 Avalanches

Avalanches are prevalent in the upper watershed due to large snow fall. Most precipitation occurs as snowfall, with an average of 540 inches falling at the Cascade crest and 140 inches at Lake Wenatchee; the record snow depth at Stevens Pass is 219 inches on the ground at one time (USFS 1996). A local resident, writing on the railroad construction, observed that the destruction of timber by fire above the railroad is thought to have increased the volume of avalanches cascading down from the heights onto the railroad tracks (Anderson 1952). Extensive review of avalanche data was not done for this geomorphic assessment, but avalanches are recognized as a sediment source, particularly in the upper portion of the basin.

5.2 Slope Stability

Maps from Davis et al. (2004) are included in the map atlas that document potential hazard areas for shallow landslides (map 5), deep-seated landslides (map 6), and soil erosion overlaid with timber harvest (map 7). No mapping of actual landslides at the subwatershed scale has been done, other than some limited mapping of road washouts, scour areas, and slides that the USFS observed during and following the 1990 flood. Mapping within RM 4.6 to 14.3 included one landslide near RM 9 (see Appendix J - Geomorphic Map Methods and GIS Metadata).

In general, the potential for shallow landslides is greatest above RM 9 and occurs on both sides of the drainage basin. The potential for deep-seated landslides is less frequent overall and is more typical below RM 9. Areas of high potential for deep-seated landslides occur for a stretch along the left side of the river between RM 4 and 9 and between RM 14 to 15. The area along Kahler and Butcher Creek is affected by faulting and folding of the bedrock which increases the risk of landslides (USFS 1996). Soil erosion hazard varies throughout the subwatershed. Other information available from Davis et al. (2004) is bedrock exposure, depth of bedrock, and slope gradient. Methods and definitions of these features based on Davis et al. (2004) are provided in Attachment 2 of this appendix.

5.3 Roads

Roads have been identified as a key part of reducing fine sediment levels in Nason Creek subwatershed (Andonaegui 2001). Nason Creek itself is paralleled from its mouth to RM 4.0 by State Highway 207 where it is then paralleled by State Highway 2 almost to its headwaters near Stevens Pass. The USFS documented road density of public roads as 3.88 miles per square mile in RM 0 to RM 12.2 and 1.1 miles per square mile for RM 12.2 to the headwaters (Raekes 2008; see map 3 in attached atlas). The highest densities are concentrated in the lower portion of the subwatershed and along tributary drainage paths. Areas with high density have the potential to change flow runoff timing and magnitudes and can increase fine sediment loads in the runoff. Road density numbers include hillslope and valley-bottom roads; however, the data represents a minimum value since it does not include all logging roads, power line roads, private roads, or railroad grades. The USFS has concluded that road densities have increased, mostly between 1975 and 1985, as a result of increased logging/access roads and an increase in private and public roads that reflect the increase in devolvement (USFS 1996).

Between 1985 and 1992, the USFS observed slope failures within timber harvest units and adjacent to roads. Many of these failures may have occurred during the 1990 flood (USFS 1996). Timber harvest is assumed to have resulted in increased surface erosion, mass failures, and surface runoff, but no quantitative analysis has been done. These changes conceptually could contribute to increased sediment delivery to stream systems and changes in the timing and duration of stream flow (USFS 1996). However, in many areas on Nason Creek, the tributaries have been disconnected from the mainstem river by railroad and highway embankments. Additionally, many hillslope areas are becoming revegetated. In these instances, the sediment runoff that reaches Nason Creek is limited.

The USFS has proposed potential mitigation measures where there are high road densities including culvert re-sizing, hardening of road channel crossings, anchoring of culvert and drainage feature outlets, planting of alders or other phreatic vegetation on cutslope seeps, and/or improved drainage (USFS 1996). The USFS also notes that reducing road densities is the best long-term strategy to reduce impacts in terms of sediment delivery to streams.

5.4 Tributaries

Of the Nason Creek tributaries, those nearest the mouth of Nason Creek have experienced the greatest negative habitat impacts, particularly those below RM 14. Impacts to both flow and sediment from tributaries are further discussed in the main report, but generally revolve around the following issues: 1) historical logging has occurred which may have resulted in increased mass wasting and sediment delivery to Nason Creek; and 2) many of the drainages are not presently connected to Nason Creek because the railroad and highway embankments do not have adequate culverts to pass the incoming flow and sediment.

6. LARGE WOODY DEBRIS SOURCES

The USFS Nason Creek Watershed Analysis (USFS 1996) documented the potential of large woody debris (LWD) recruitment along the channel bank and LWD that is already present in the channel for Nason Creek (Table 3). The following paragraphs were summarized from the USFS report. The report describes the recruitment potential as a function of reaches and segments as defined by the USFS. These reaches are different than those defined by Reclamation for this geomorphic assessment; therefore, the reach designation given by the USFS has been removed to avoid confusion and is listed by river mile (RM) only. Reclamation's assessment area (RM 4.6 to RM 14.2) is located entirely within the first "reach" of the USFS' report. The areas identified by the USFS for fair to good LWD recruitment are essentially upstream of the Reclamation assessment area.

- From the mouth of Nason Creek (RM 0 to RM 15.4 or 0.25 miles above Whitepine Creek), the outlook for LWD recruitment is poor. With 75 percent of this section in private ownership, options to improve this situation will be very limited. Past disturbances (highway construction, private cottages, campgrounds, powerline construction, and railroad activities) have changed the character of the creek and severely limited the land's ability to produce riparian tree vegetation. Oxbows and wetlands have been cut off from the main flow of Nason Creek, depriving it from its natural sources of LWD.
- Beginning about 0.25 miles above Whitepine Creek where the creek enters a narrow "V" shaped valley and ending about 300 feet above the Burlington Railroad tunnel, this area is naturally deficient in LWD due to the steepness of the slope and large amount of bedrock adjacent to the creek (0.5 mile in length). This section of the creek has poor recruitment potential.

- The next section of the creek extends for 5.5 miles and begins 300 feet above the Burlington Northern Railroad (BNR) tunnel and ends about 0.5-mile below Mill Creek. As was the case in the first 15 miles of Nason Creek, this area has also been heavily impacted by the highway and railroad. However, it has a fair prognosis for LWD recruitment even though there has been some channelization from highway, railroad, and private land activities. It has been most heavily impacted by the Bonneville Power Administration (BPA) powerlines, BNR and U.S. Highway 2.
- The next section is 0.7 miles in length and begins 0.5 miles above Mill Creek and extends to 1/2 mile below USFS Road 6700. This area has a good probability for LWD recruitment. It was the only reach to currently meet forest standards for LWD. There is only a small area of this segment that has been altered by the highway.
- The next section runs from 0.5-mile below USFS Road 6700 (Smithbrook) for 2.8 miles to the beginning of Stevens Creek (2.8 miles in length). This area also has a fair probability for LWD recruitment. This reach is the least impacted by the highway and railroad and has most of its natural characteristics. Some areas could be affected by avalanches as this section lies in close proximity to several avalanche chutes. The south side of the remaining areas have been affected by the highway and may be limited for future LWD recruitment.
- From Stevens Creek to the headwaters, there are alternating sections that are naturally deficient of LWD due to avalanche zones and areas that have large trees along the bank but limited wood in the channel.

Table 3. List of USFS survey results for LWD available in the streambanks and found in the channel (USFS 1996).

USFS Reach	Adequate streamside wood and existing wood in channel	Adequate streamside wood but existing wood in channel below target	Inadequate streamside wood and existing wood in channel below target (100 pieces per mile)	Cause
RM 0 to RM 15.4 (.25 miles above White Pine)		32 %	68%	Disturbance by railroad, highway, power lines, vegetation clearing
RM 15.4 to 300 feet above BNR tunnel (0.5 mile)		49%	51%	Naturally deficient

USFS Reach	Adequate streamside wood and existing wood in channel	Adequate streamside wood but existing wood in channel below target	Inadequate streamside wood and existing wood in channel below target (100 pieces per mile)	Cause
300 feet above BNR tunnel to ½ mile below Mill Creek (5.5 miles)		86%	14%	Disturbance by railroad and highway
Mill Creek to ½ mile below FS Road 6700 (0.7 miles)	100%			
½ mile below FS Road 6700 to Stevens Creek (2.8 miles)		82%	18%	Lack of influence from highway and railroad
Stevens Creek to Headwaters		Ranges by section (47 to 100%)	Ranges by section (49 to 100%)	Avalanche zone naturally deficient in LWD mixed with flatter areas

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ATTACHMENT 1 – FIRE REGIME CATEGORIES

The following fire regime categories are presented in the associated map atlas for this geomorphic assessment and originate from:

Davis, C., M. Karrer, B. Kovalchik, T. Lillybridge, and C. Narsico. 2004. *Landtype associations of north-central Washington*. U.S Department of Agriculture Forest Service. Wenatchee, Washington. 114 p.

Unit 1

Frequency
0 to 35 years

Severity
Low

Fire regime
Large stand-replacing fire can occur under certain weather conditions, but are a rare event (i.e., every 200+ years)

Plant communities
Include ponderosa pine, eastside/dry Douglas fir, pine-oak woodlands, Jeffery pint on serpentine soils, oak woodlands, very dry white fir

Relative disturbance and response
Very low

- Low-severity fire likely a major contributor to nutrient cycling, converting forest floor to available nutrients
- Frequent historical fires kept fuels from accumulating, which would have caused higher severity
- Natural wood debris ranged between 5 and 15 tons per acre
- Forest floor duff ranged from non-existent to no more than 1 inch depth

Unit 3a

Frequency
Less than 50 years

Severity
Mixed

Fire regime

Lower severity fire tends to predominate in many events

Plant communities

Include mixed conifer, very dry westside Douglas-fir, and dry grand fir

Relative disturbance and response

Moderate

- Effects from a range of non-lethal to lethal fire causes diversity of disturbances
- Downed wood debris somewhat common (10 to 15 tons per acre)
- Mixed severity fires caused some tree mortality, which contributed to cycling of down woody debris
- Forest floor duff ranged from 0.5 to 1 inch thick depending upon fire intervals (thicker layers maintained with lower frequency of fire returns)

Unit 4

Frequency

35 to 100+ years

Severity

Stand-replacing

Fire regime

Natural ignitions within this regime resulting in large fires may be relatively rare

Category separated into subcategories having different potential climax plant communities

Relative disturbance and response

High

- High-severity fire common with a variety of short-term and long-term effects to soils and forest structure
- Highly variable patterns of age class and density somewhat controlled by fire extent and regeneration response
- Downed woody debris common and may have been extensive as a result of tree mortality

- "Reburns" in areas of high debris accumulation would have reduced fuel levels and caused severe heating of soils and removal of duff layers
- Down woody debris average ranged 15 to 25 tons per acre or higher
- Forest floor duff layers ranged 0.5 to 1.5 inches thick depending on severity and frequency of fires

Subunit 4a

Frequency
    35 to 100+ years

Severity
    Stand-replacing, juxtaposed

Fire regime
    Lower severity fire tends to predominate in many events

Plant communities
    Located upslope from a plant community with a shorter fire regime interval

Experiences a shorter fire interval than would be expected due to association with a plant community with a more frequent fire interval downslope

Subunit 4b

Frequency
    100+ years

Severity
    Stand-replacing, patchy arrangement

Plant communities
    Include subalpine fir and mountain hemlock parkland and white pine north of 45 degrees latitude

Subunit 4c

Frequency
    100 to 200 years

Severity
    Stand-replacing

Plant communities

Include subalpine mixed conifer (e.g., spruce-fir), western larch, and western white pine

Can have mountain hemlock in Cascades and Pacific silver fir north of 45 degrees latitude

Unit 5

Frequency

Greater than 200 years

Severity

Stand-replacing

Fire regime

Occurs at the environmental extremes where natural ignitions are very rare or virtually non-existent or environmental conditions rarely result in large fires

Sites tend to be very cold, very hot, very wet, very dry, or some combination of these conditions

Relative disturbance and response

Very High

- High severity fire in plant communities less adapted to fire disturbance
- Downed woody debris abundant and often exceeded 30 tons per acre
- Coarse woody debris substantially contributed to biomass of forest floor duff layers
- Duff layers often more than 2 inches thick and composed of about 50 percent decaying wood
- After fires, characteristics reset

ATTACHMENT 2 – LAND TYPE CATEGORIES

The following land type categories are presented in the associated map atlas for this geomorphic assessment and originate from:

Davis, C., M. Karrer, B. Kovalchik, T. Lillybridge, and C. Narsico. 2004. Landtype Associations of North-Central Washington: Wenatchee, Washington, U.S Department of Agriculture Forest Service. 114 p.

Deep-seated landslides:

- Rotational slumps or translational movement that is either sporadic or slow involving thick masses of material over a relatively large area
- Ratings based on observations of existing landslides, empirical observations of geomorphic processes associated with each landtype association, and research relating site indicators of slope stability hazards (see Davis et al. 2004)
- Low hazard
  - Landtype association unit has very few of the properties associated with landslide probability
  - Little evidence of landslides observed
- Moderate hazard
  - Landtype association unit has properties commonly associated with landslide probability, but properties occur over a small extent of unit area
  - Evidence of landslides have been observed over most of the unit area

Slope stability hazard (shallow-rapid landslides):

- Debris slides, such as debris avalanche, debris flow, or debris torrents, involving relatively shallow masses over a relatively small area
- Ratings based on observations of existing landslides, empirical observations of geomorphic processes associated with each landtype association, and research relating site indicators of slope stability hazards (see Davis et al. 2004)
- Low hazard
  - Landtype association unit has very few of the properties associated with landslide probability
  - Little evidence of landslides observed
- Moderate hazard
  - Landtype association unit has properties commonly associated with landslide probability, but properties occur over a small extent of unit area

  - Evidence of landslides has been observed, but is not common
- High hazard
  - Landtype association unit has most of the properties associated with landslide probability
  - Evidence of landslides has been observed over most of the unit area

Soil erosion:

- Relative interpretation for surface or hillslope erosion hazard
- Rating represents the susceptibility of the bare, unvegetated surface to erosion by water and wind
- Ratings developed from site characteristics:
- Soil texture
- Surface rock fragments
- Slope relief
- Rate of vegetation establishment after disturbance
- Climatic conditions (precipitation timing, intensity, and duration)
- Low hazard
  - landtype association units generally contain site features that limit the probability of sheet erosion
  - Generally site conditions include sufficient rock fragments to armor surfaces, irregular and complex slope shapes with less than 20 percent gradients, cohesive soils with moderately fine and fine textures, rapid vegetation recovery, and/or surface runoff is seldom concentrated
- Moderate hazard
  - Landtype association units generally contain site features that limit sheet erosion to rilling
  - Generally the site conditions include some rock fragments, but insufficient to fully armor the surface, long straight slopes with 20 to 45 percent gradients, medium and moderately coarse textured soils, moderate rapid vegetation recovery (2 to 5 years), and/or some probability of concentrated runoff
- High hazard
  - Landtype association units generally contain site features that develop extensive rilling, which can enlarge into gullies

  - Generally the site conditions include long straight slopes with gradients exceeding 45 percent, coarse to moderately coarse textured soils, vegetation recovery is slow (more than 5 years), and/or a high probability of concentrated surface runoff

Bedrock exposure:

- Average range of bedrock exposed
- Based on field observations and NCSS soil survey map unit descriptions

Depth of bedrock:

- Empirical interpretation of depth of unconsolidated soil or surficial deposits to consolidated bedrock
- Based on field observations and NCSS soil surveys

Slope gradient:

- Range of average range or predominant slope gradient for map unit
- Based on field observations and NCSS soil survey map unit descriptions

APPENDIX F.

WATER QUALITY SYNOPSIS

CONTENTS

Tables

Figures

1. WATER QUALITY DATA

Water temperatures vary along the stream gradient due to topography, channel morphology, substrate composition, riparian vegetation, groundwater exchanges, tributary influences, and, in some cases, anthropogenic influences. This section evaluates available water temperature data for Nason Creek from both recent and historical data sets. Limited historical water quality data is also presented. Recently collected water quality data (e.g., turbidity, alkalinity) should also be available from Total Maximum Daily Load (TMDL) assessments but was unavailable within the timeframe of this report documentation.

1.1 Washington State Department of Ecology Temperature Data (1998 to 2004)

The Washington State Department of Ecology (Ecology) uses data from monitoring stations to compile the 303(d) report, a list of water bodies that do not meet state clean water standards. Ecology submits this report to the U.S. Environmental Protection Agency (EPA) and must prepare a TMDL for each listed water body as required in section 303(d) of the Federal Clean Water Act. TMDLs, also known as Water Clean-Up Plans, specify the maximum amount of pollutants that can be discharged into a water body without degrading water quality below state standards and allocates that discharge amount among various sources (Bilhimer et al. 2003).

The Wenatchee River from the Wenatchee National Forest boundary (RM 27.1) to its headwaters is considered Class AA (extraordinary). Because Nason Creek discharges to the AA portion of the Wenatchee River, it is considered Class AA as well (Bilhimer et al. 2003).

From 1998 through 2004 (the 2005 through 2008 listings have not yet been released), Nason Creek has consistently exceeded the standard for temperature, but been acceptable in all other standards. From river mile (RM) 4.5 to RM 14.4, approximately 70 percent of the river exceeds the temperature standard (Figure 1). Much of the lower 4 miles also exceeded the temperature standard. Current standards for temperature are listed in Attachment 1, and can be found on the Ecology web site (http://www.ecy.wa.gov).

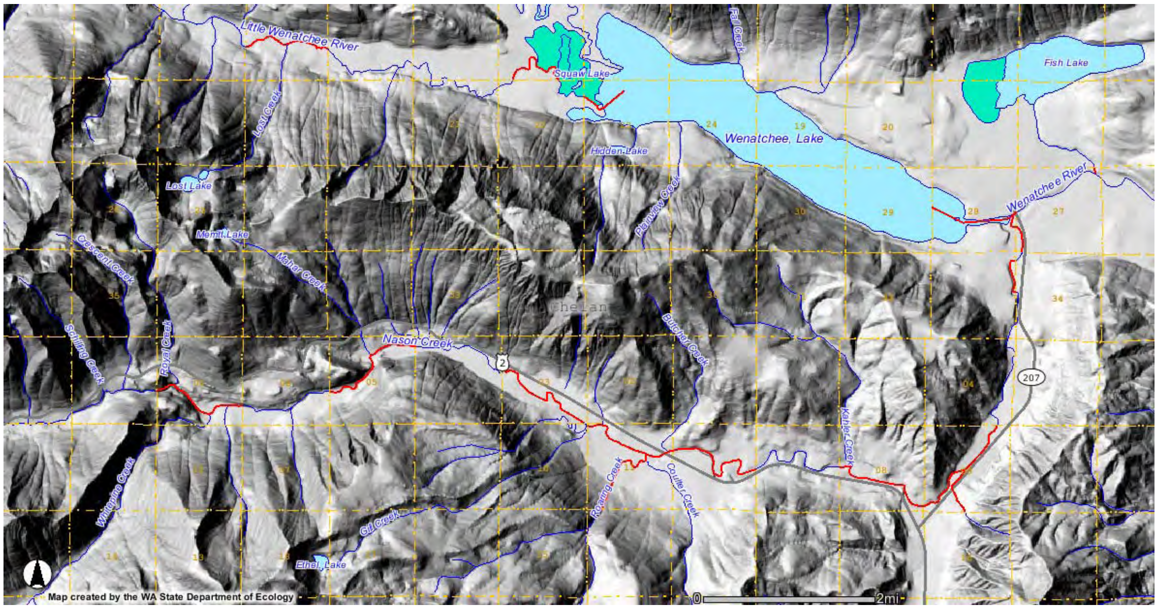

Figure 1. 303(d) Water Quality Assessment for Nason Creek from the 2002-2004 Ecology Report. The red highlights show where Nason Creek exceeds the water quality standard for temperature (http://apps.ecy.wa.gov/wqawa/viewer.htm?trs=26N16E11&lstid=42921&category=5).

A network of continuous temperature data loggers was installed in the Wenatchee River watershed by Ecology as described by Bilhimer et al. (2003). Data from 2002 and 2003 show that water temperatures in excess of the current Class A or AA standards and proposed core/non-core standards are common throughout the watershed (Billhimer et al. 2003). Water temperatures for Nason Creek from July to September 2003 are shown in Figure 2, and for some of the tributaries to Nason Creek in Figure 3 (Cristea and Pelletier 2005).

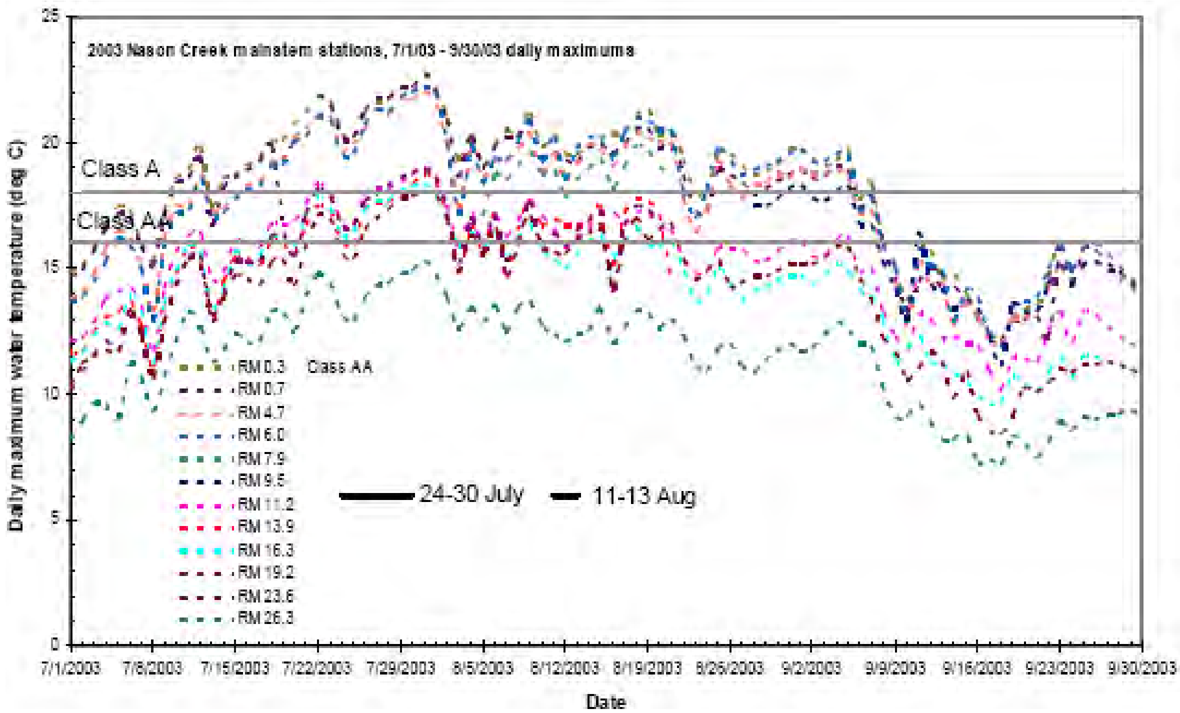

Figure 2. Water temperatures for Nason Creek from July to September 2003. Reproduced from the Wenatchee River Temperature Total Maximum Daily Load Study, August 2005, Publication No. 05-03-011 (Ecology 2008).

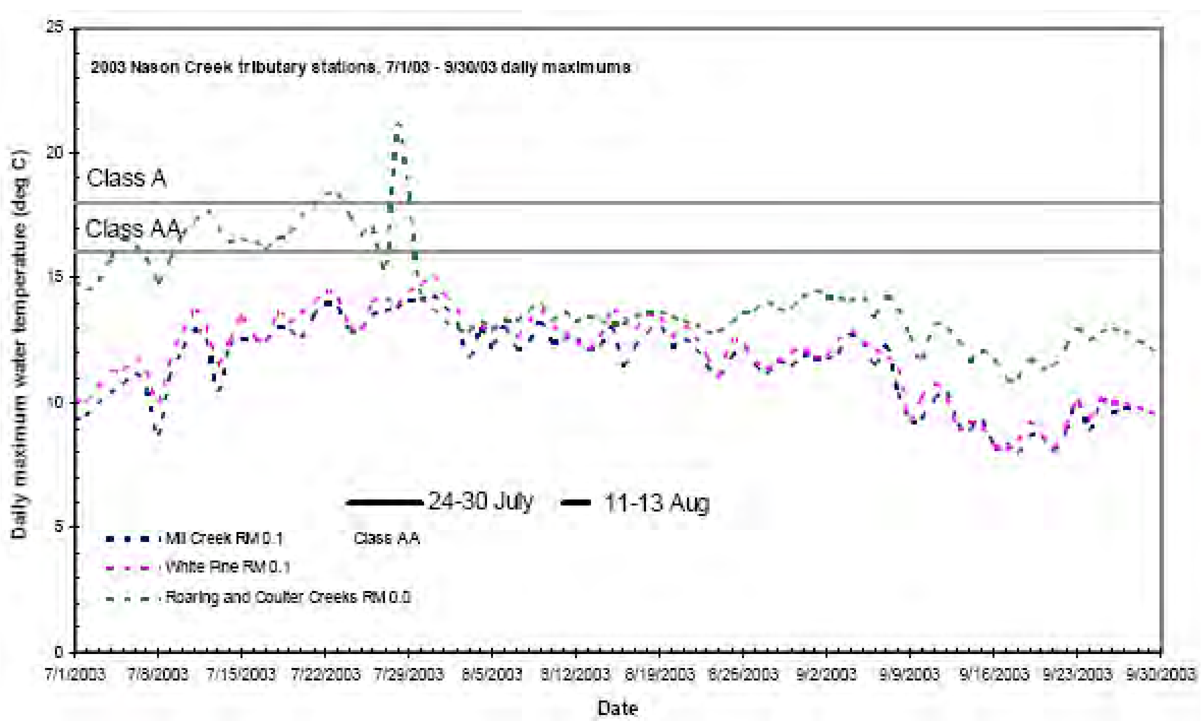

Figure 3. Water temperatures for Mill Creek, White Pine, and Roaring and Coulter Creeks from July to August 2003. Reproduced from the Wenatchee River Temperature Total Maximum Daily Load Study, August 2005, Publication No. 05-03-011. (Ecology 2008)

1.2 Airborne Thermal Infrared Remote Sensing Surveys (2001 and 2003)

Watershed Sciences, LLC, conducted airborne thermal infrared (TIR) remote sensing surveys in 2001 and 2003 on selected streams in the Wenatchee subbasin, including Nason Creek (Watershed Sciences, LLC. 2003). The objective of the project was to collect TIR and color video imagery in order to characterize the thermal regime of the river and support ongoing TMDL analysis. TIR images provide information about spatial stream temperature variability and can illustrate changes in the interacting processes that determine stream temperature (Figure 4).

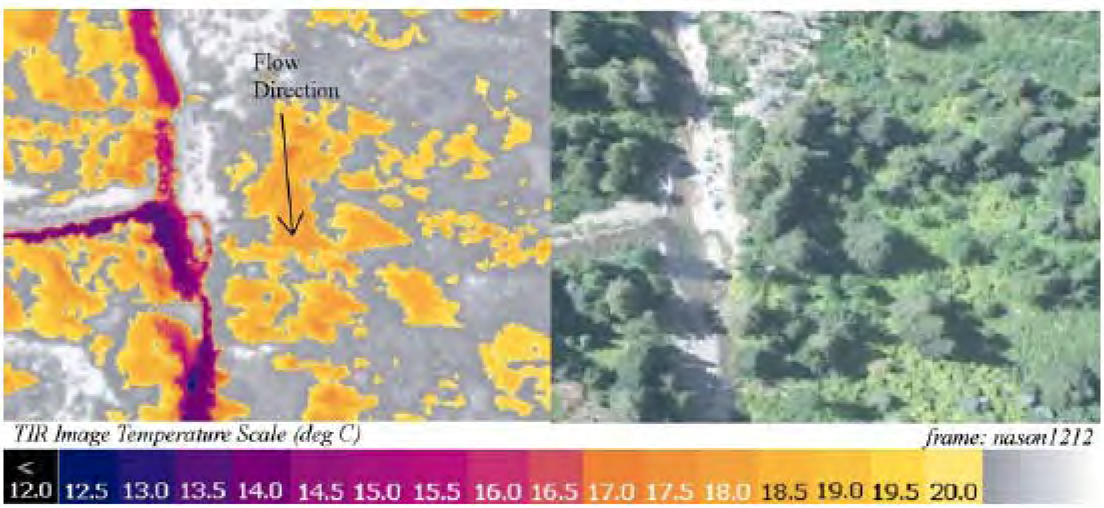

Figure 4. Example of TIR and color video images showing the confluence of Mill Creek and Nason Creek.

Median radiant temperatures were plotted versus river mile for Nason Creek by Watershed Sciences, LLC, from 2003 data (Figure 5). Tributaries and other sampled inflows (i.e., springs, side channels) are labeled by river mile on the profile with their name and temperature summarized in Table 1. The profile also shows the location of tributaries that were detected during the image analysis, but were not visible enough to obtain an accurate radiant temperature sample. These locations were included to provide additional context for assessing observed spatial temperature patterns (Watershed Sciences, LLC. 2003).

Figure 5. Median channel temperatures versus river mile for Nason Creek (August 12, 2003) (Watershed Sciences, LLC. 2003)

Table 1. Tributary and other surface water inflows for Nason Creek. (Watershed Sciences, LLC. 2003)

Name	Image	Km	Mile	Tributary °C	Nason Cr. °C	Difference °C
			Tributary			
Wenatchee R. (LB)	nason0018	0.3	0.2	18.6	17.9	0.7
Butcher Cr. (LB)	nason0470	13.8	8.6	16.0	16.8	-0.8
Whitepine Cr. (RB)	nason0891	24.6	15.3	12.8	15.2	-2.4
Unnamed Trib. (RB)	nason1092	29.7	18.4	9.9	13.8	-3.9
Mill Cr. (RB)	nason1212	33.2	20.6	13.3	15.2	-1.9
			Spring			
Spring (RB)	nason0283	7.7	4.8	13.2	17.8	-4.6
Spring (RB)	nason0638	18.6	11.6	13.0	15.1	-2.1
Spring (RB)	nason0808	23.4	14.5	10.2	14.6	-4.4
Spring (LB)	nason1024	27.8	17.3	13.5	15.3	-1.8
Spring (RB)	nason1096	29.8	18.5	12.1	13.9	-1.8
Spring (LB)	nason1338	36.5	22.7	12.5	12.6	-0.1
			Side Channel			
Side Channel (RB)	nason0210	5.6	3.5	18.8	19.4	-0.6

The Watershed Science, LLC. report describes the following interpretation of the August 12, 2003 data:

> *Overall, Nason Creek exhibited a general pattern of downstream warming with thermal variability occurring at multiple scales along the profile. At the upstream end of the survey, water temperatures were cool (<11.0°C @ river mile 25.0) and increased rapidly reaching ≈13.9°C at river mile 23.2. A sharp decrease (-1.7°C) was observed at river mile 22.9. Although the source of cooling at this location was not directly apparent from the imagery, a spring sampled at river mile 22.7 and Smith Brook Creek (not sampled) mapped at river mile 22.7 may have contributed to this decrease. Moving downstream, water temperatures increased rapidly reaching 14.6°C at river mile 22.0 before remaining relatively consistent with only local thermal variability (±0.7oC) to river mile 20.6. At river mile 20.6, the inflow of Mill Creek (13.3°C) dramatically lowers the water temperatures in Nason Creek.*
>
> *Downstream of Mill Creek, water temperatures in Nason Creek exhibited fewer dramatic fluctuations and more distinct reach scale patterns of warming and cooling. Local warming trends were observed between river miles 18.8 and 17.6 and between river miles 15.0 and 13.6. The reach with the most sustained longitudinal heating occurred between river miles 10.6 and 3.5 where stream temperatures, at the time of the survey, increased from 15.3°C to 19.1°C. Local cooling was observed in two reaches. Stream temperatures decreased from 15.7°C to 13.9°C between river miles 16.5 and 15.0. The inflow of Whitepine Creek at river mile 15.3 contributed in part to the observed temperature minimum. However, the cooling trend started upstream of the Whitepine Creek suggesting that other factors contributed to the overall trend. Another area of localized cooling (-1.5°C) was observed between river mile 3.2 and 2.6. The factors contributing to this trend were not apparent from the imagery. Between river mile 20.6 and the mouth, three distinct reaches had relatively consistent temperatures throughout.*
>
> *Water temperatures in each of these reaches were much less than measured air temperatures and one may expect some level of longitudinal heating in the absence of some buffering process. Factors controlling stream temperatures through these reaches are an area for further analysis.*

Nason Creek was flown using similar methods and instrumentation on August 14, 2001. The data from the two surveys presents a unique opportunity to compare spatially continuous temperature patterns from different years (Figure 6). Visual inspection of the two profiles shows that, although absolute temperatures were warmer during the 2001 survey by 1 to 3 degrees Celsius, broad scale spatial temperature patterns were consistent. Reaches that exhibited longitudinal heating in 2001 were the same reaches that showed heating in 2003. However, the profiles also show that in the warmer year (2001), the rates were generally higher (i.e., degrees Celsius per river mile) resulting in more dramatic local temperature maximums. The 2001 data was collected at a slightly different time of day, but

2001 was referenced by local biologists as a dry, hot year with low flows in the river that may also have played a role in the different temperature magnitudes. Locally cool areas were consistent between the two years.

Watershed Sciences, LLC. (2003) suggests that future studies look at the following questions:

- Are cool areas consistent between years and are these temperatures stable with regard to the thermal requirements for salmonids?
- Have stream reaches changed with regard to channel and habitat conditions?

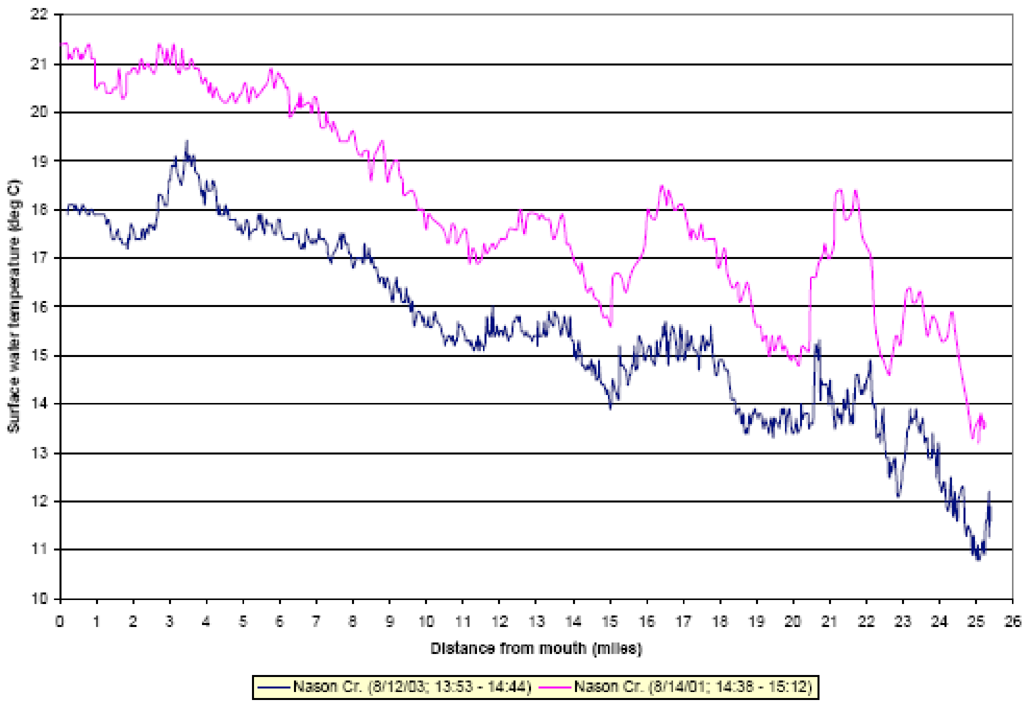

Figure 6. Comparison of longitudinal temperature profiles derived from airborne TIR Imagery collected on Nason Creek on August 12, 2003 (blue) and August 14, 2001 (fuchsia). (Watershed Sciences, LLC. 2003)

1.3 Historical Temperature and Water Quality Data

Single point temperature measurements were collected during a habitat survey in 1935 and 1936 conducted by the U.S. Fish and Wildlife Service (USFWS) (Bryant and Parkhurst 1950; Table 2). The data below White Pine Bridge was collected in October and November, where as the data upstream of White Pine was collected in July. The limited single point samples and varying dates are difficult to compare to the more detailed Ecology report (see report section 1.1, Bilhimer et al. 2003) and TIR imagery (see report section 1.2, Watershed Sciences, LLC. 2003); the data suggest that water temperatures varied along Nason Creek due to local influences in the 1930s also.

Table 2. Water temperature data from 1935 and 1936 habitat surveys (Bryant and Parkhurst 1950).

Location	Approximate 2006 RM	Water Temp (°F)	Water Temp (°C)	Temp Date
Wenatchee Lake Hwy Bridge	0.78	46	7.8	10/12/1936
Sawmill Bridge	4.02			No data
First Highway Bridge	8.84			No data
Merritt Bridge	10.84	34.5	1.4	11/6/1935
GNRR Bridge (Merritt GS)	13.09	34	1.1	11/6/1935
Confluence White Pine	15.19	52	11.1	7/21/1936
Highway Bridge	16.15	61	16.1	7/21/1936
Mill Creek Confluence	18.92	62	16.7	7/21/1936
Stevens Creek Forks	22.08	55	12.8	7/21/1936

Collection of water samples for chemical and physical analyses was done at Nason Creek near the mouth at the State Park Bridge (estimated at RM 0.8) in 1955 and 56 (Figure 7; Seabloom 1958). Methods used an average of two samples at the site collected in 1 to 2 week intervals between June through September of 1955, and monthly samples during winter and spring of 1955-56 (when weather permitted). Data presented in the report are reproduced in Table 3, Table 4, Figure 8, Figure 9, Table 5, and Table 6. The 1958 report summarized the data as follows:

- Nason Creek contained very little suspended sediment or dissolved oxygen in the water except for one occasion during heavy runoff
- Water was neutral and very soft
- Waters were practically saturated with dissolved oxygen
- Temperature was subject to significant diurnal variations during the warm weather months
- A comparison to physical and chemical data collected in May to November of 1940 by the USFWS showed similar water quality results (no temperature data was collected)
- Water quality parameters were similar on the Chiwawa River (near the mouth at State Highway 15C bridge) except for temperature; the average, minimum, and maximum temperatures were all higher on Nason Creek; however, the average monthly diurnal variation was the same

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Figure 7. Photograph of 1956 water temperature sampling location (Seabloom 1958).

Table 3. Summary statistics for water quality data from Seabloom 1958 report.

Table 4.--Nason Creek--Water quality, physical characteristics, 1955-1956.

	Average	Minimum	Maximum
Temperature (° F.)	47	32	63
Turbidity (units)	5	2	150 1/
Color (units)	7	5	100 1/
Specific conductance (micromhos/cm at 25° C.)	34	17	43

1/ Abnormal due to heavy surface runoff and not considered in the average value

Table 4. Summary water temperature data in monthly form from Seabloom 1958 report.

Table 5.--Nason Creek--Water quality, water temperature 1956

Month	Average daily Maximum temperature °F.	Average daily minimum temperature °F.	Average diurnal variation °F.
August	61	52	9
September	55	50	5
October	44	41	3
November	35	34	1
December	33	32	1

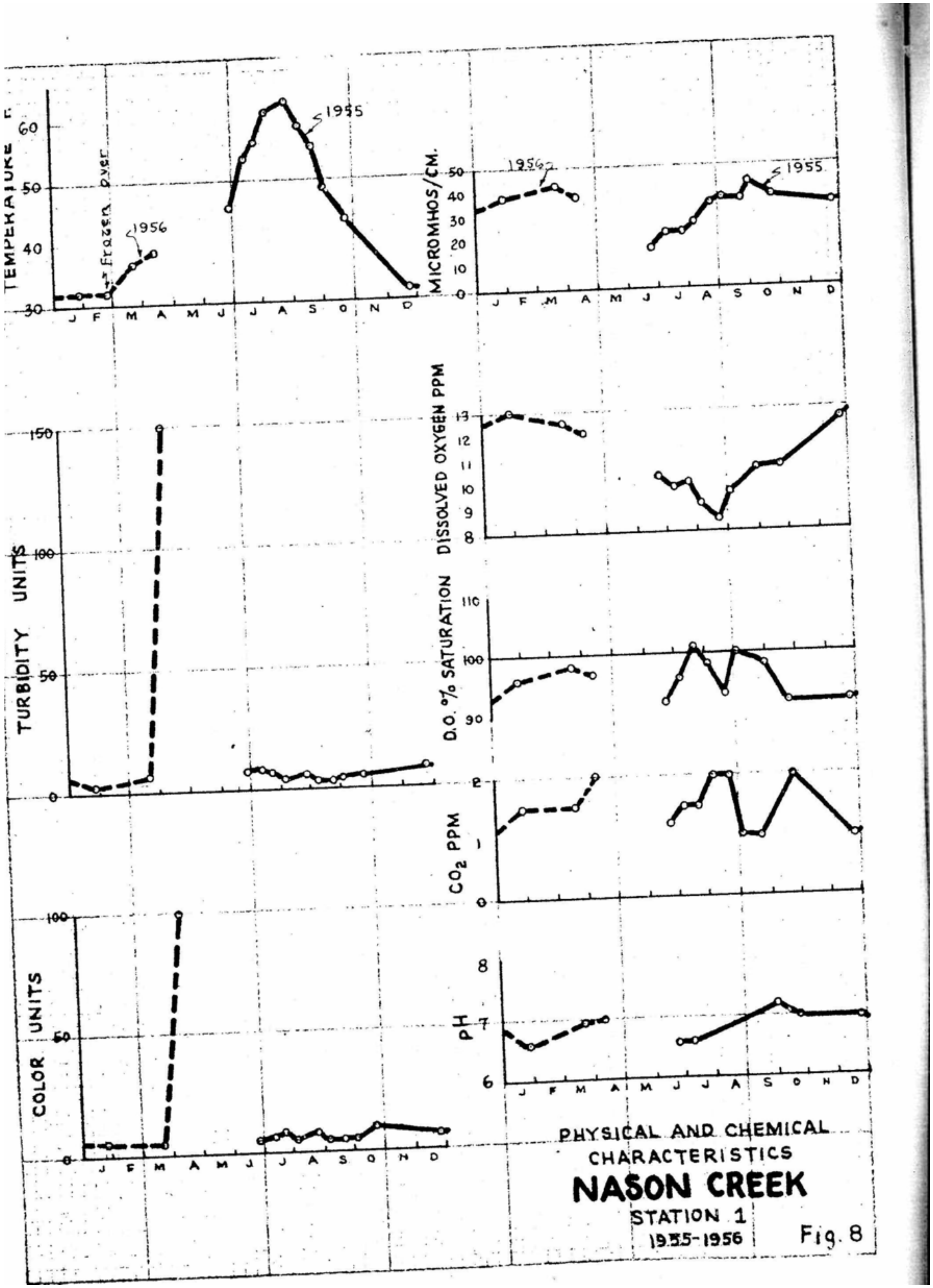

Figure 8. Charts of physical and chemical characteristics from Seabloom 1958 report.

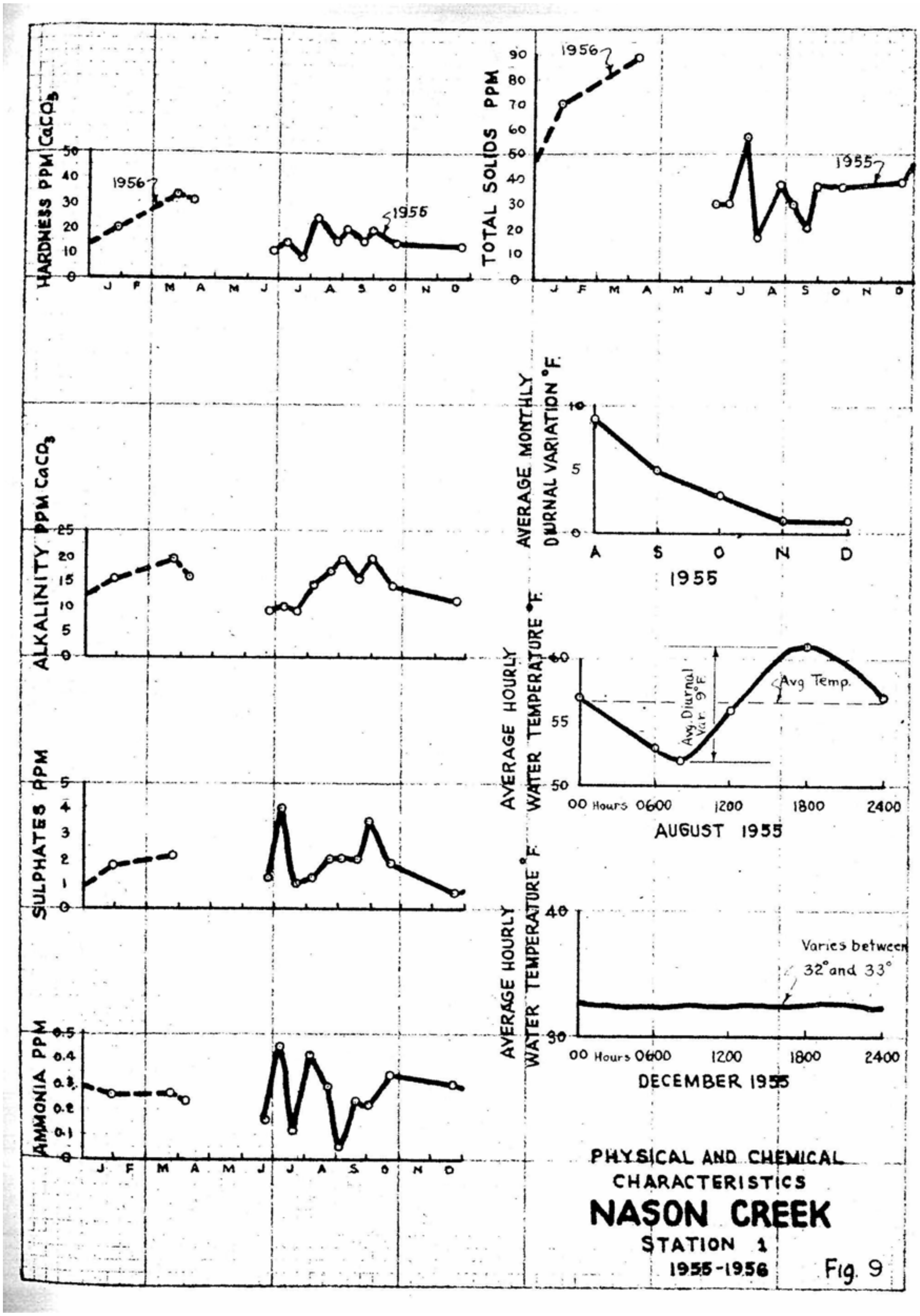

Figure 9. Additional charts of physical and chemical characteristics from Seabloom 1958 report.

Table 5. Summary statistics for water quality data from Seabloom 1958 report.

Table 6.--Nason Creek--Water quality, chemical characteristics, 1955-1956 1/

	Average	Minimum	Maximum
Dissolved oxygen	10.7	8.55	13.0
Percent saturation D.O.	96	92	101
Carbon dioxide	1.5	1.0	2.0
pH	6.9	6.6	7.2
Total hardness	19	9	33
Alkalinity	15	9	19
Sulfates	1.9	0.6	4.0
Ammonia	0.25	0.05	0.45
Total solids	41	17	89
Iron	0.05	-	-
Copper	0.00	-	-
Aluminum	0.20	-	-
Calcium	10.00	-	-
Magnesium	0.60	-	-
Sodium	1.50	-	-
Potassium	1.60	-	-
Chloride	0	-	-

1/ All units are ppm except pH and percent saturation.

Table 6. Comparison of 1940 and 1955-56 water quality data provided in Seabloom 1958 report.

Table 7.--Nason Creek--Water quality 1940 and 1955-1956.

	1940	1955-1956
Average dissolved oxygen (ppm)	10.9	10.7
Average percent saturation D.O.	96	96
Average carbon dioxide (ppm)	1.9	1.5
Average pH	6.9	6.9
Average total alkalinity (ppm)	13	15

2. LITERATURE REVIEW OF PHYSICAL INFLUENCES ON WATER TEMPERATURE IN FORESTED STREAMS

The following information is taken from Bilhimer et al. (2003) which addresses the issue of temperature exceedance. The Wenatchee River subbasin TMDL will be developed for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. The transport and fate of heat in natural waters has been the subject of extensive study. Edinger, Brady, and Geyer (1974) provide an excellent and comprehensive report of this research. Thomann and Mueller (1987) and Chapra (1997) have summarized the fundamental approach to the analysis of heat budgets and temperature in natural waters that will be used in this TMDL.

Figure 10 shows the major heat energy processes or fluxes across the water surface or stream bed. Adams and Sullivan (1989) reported that the following environmental variables were the most important drivers of water temperature in forested streams:

- **Stream depth**. Stream depth is the most important variable of stream size for evaluating energy transfer. Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.
- **Air temperature**. Daily average stream temperatures are strongly influenced by daily average air temperatures. When the sun is not shining, the water temperature in a volume of water tends toward the dew-point temperature (Edinger, Brady, and Geyer 1974).
- **Solar radiation and riparian vegetation**. The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily average temperatures are less affected by removal of riparian vegetation.
- **Groundwater.** Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative the flow in the stream and the difference in temperatures between the groundwater and the stream.

The heat exchange processes with the greatest magnitude are as follows (Edinger, Brady, and Geyer 1974):

- **Short-wave solar radiation**. Short-wave solar radiation is the radiant energy which passes directly from the sun to the earth. Short-wave solar radiation is contained in a wavelength range between 0.14 microns (μm) and about 4 μm. Daily average solar radiation measured at the Washington State University Public Agricultural Weather System (PAWS) station in Wenatchee during July to August 2002 was 277 watts per square meter (Watts/m^2). The peak values during daylight hours are typically about three times higher than the daily average. Short-wave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear.

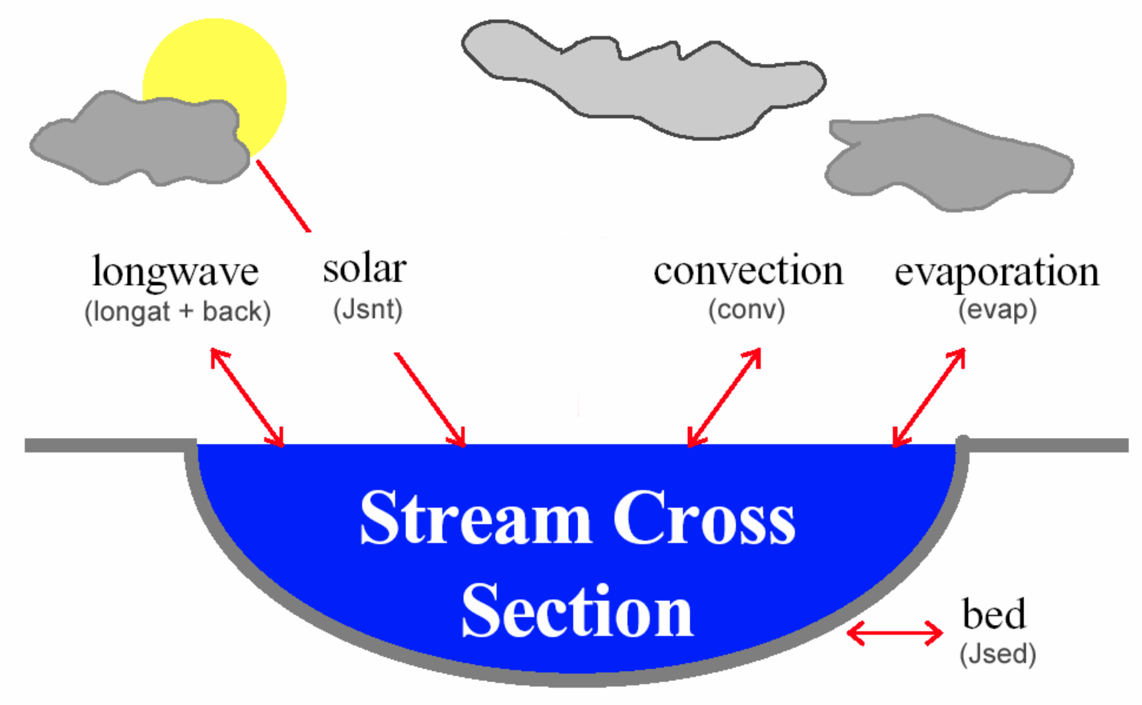

Figure 10. Surface heat transfer processes in the QUAL2K Model that affect water temperature (net heat flux = Jsnt + longat – longback ± conv - ± Jsed) (Edinger, Brady, and Geyer 1974).

- **Long-wave atmospheric radiation.** The long-wave radiation from the atmosphere varies in wavelength range from about 4 μm to 120 μm. Long-wave atmospheric radiation depends primarily on air temperature and humidity and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from long-wave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid-latitudes (Edinger, Brady, and Geyer 1974).
- **Long-wave back radiation from the water to the atmosphere**. Water sends heat energy back to the atmosphere in the form of long-wave radiation in the wavelength range from about 4 μm to 120 μm. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from long-wave back

radiation typically ranges from about 300 to 500 W/m^2 (Edinger, Brady, and Geyer 1974).

3. Role of Riparian Vegetation on Water Temperature in Forested Streams

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation are well documented (for example see Holtby 1988; Lynch, Rishel, and Corbett 1984; Rishel, Lynch, and Corbett 1982; Patric 1980; Swift and Messer 1971; Brown, Swank, and Rothacher 1971; and Levno and Rothacher 1967).

These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al. 1992; Beschta et al. 1987; Bolton and Monahan 2001; Castelle and Johnson 2000; CH_2M Hill 2000; GEI 2002; Ice 2001; and Wenger 1999.

All of these summaries recognize that the scientific literature indicates that riparian vegetation plays an important role in controlling stream temperature. The list of important benefits that riparian vegetation has upon the stream temperature includes:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.

The warming of water temperatures as a stream flows downstream is a natural process. However, the rates of heating can be dramatically reduced when high levels of shade exist and heat flux from solar radiation is minimized. The overriding justification for increases in shade from riparian vegetation is to minimize the contribution of solar heat flux in stream heating.

There is a natural maximum level of shade that a given stream is capable of attaining. The importance of shade decreases as the width of a stream increases. The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system and inflows of surface water and groundwater. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection.

Dispersion results from turbulent diffusion that mixes the water column. Due to dispersion, flowing water is usually well mixed vertically. Stream water mixing with inflows from surface tributaries and subsurface groundwater sources also redistributes heat within the stream system.

These processes (advection, dispersion, and mixing of surface and subsurface waters) redistribute the heat of a stream system via mass transfer. Turbulent diffusion can be calculated as a function of stream dimensions, channel roughness, and average flow velocity. Dispersion occurs in both the upstream and downstream directions. Tributaries and groundwater inflows can change the temperature of a stream segment when the inflow temperature is different from the receiving water.

4. SUMMARY

From 1998 through 2004, Nason Creek has consistently exceeded the TMDL standard for water temperature in portions of the stream, but been acceptable in all other standards (Bilhimer et al. 2003). Based on TMDL data from Ecology, from RM 4.5 to RM 14.4 approximately 70 percent of the river exceeds the temperature standard in the warmest recorded periods of late summer during low flows. Other sections downstream of RM 4.5 also exceed the standards. Longitudinal temperature profiles derived from August 2001 and 2003 airborne TIR imagery show an overall increasing trend in water temperature in the downstream direction for Nason Creek; however, many areas have localized cooling potentially due to groundwater or tributary sources (Watershed Sciences, LLC. 2003). The TIR data suggest maximum temperatures can vary from year to year, but longitudinal trends of increasing and decreasing temperature zones are fairly consistent. The duration and rate of temperature rises may also have variability depending on localized influences on temperature.

Available literature suggests there are multiple influences on water temperature that can either cool or warm the water such as air temperature, solar radiation, contributing groundwater and tributary water temperature, flow magnitude, riparian vegetation, and water depth. Further data collection of in-stream temperature variations both longitudinally and through time would improve understanding of where local cooling occurs and from what source. Integration of this information with riparian vegetation mapping and air temperature could further understanding of temperature flux. This information could potentially be used to help prioritize habitat restoration actions.

5. REFERENCES

Parenthetical Reference	Bibliographic Citation
Adams and Sullivan 1989	Adams, T.N., and K. Sullivan. 1989. "The Physics of Forest Stream Heating: A Simple Model. Timber, Fish, and Wildlife." Report Number TFW-WQ3-90-007. Washington Department of Natural Resources, Olympia, Washington.
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ATTACHMENT 1 – CURRENT STANDARDS FROM WASHINGTON STATE DEPARTMENT OF ECOLOGY WATER QUALITY

The following current water quality standards are taken from the Washington State Department of Ecology Water Quality web site at http://www.ecy.wa.gov/programs/wq/swqs/criteria.html

Temperature

173-201A-200
Fresh water designated uses and criteria**.**

The following uses are designated for protection in fresh surface waters of the state. Use designations for water bodies are listed in WAC 173-201A-600 and 173-201A-602.

(1) **Aquatic life uses**. Aquatic life uses are designated based on the presence of, or the intent to provide protection for, the key uses identified below in (a). It is required that all indigenous fish and nonfish aquatic species be protected in waters of the state in addition to the key species described below.

(a) The categories for aquatic life uses are:

i. **Char spawning and rearing**. The key identifying characteristics of this use are spawning or early juvenile rearing by native char (bull trout and Dolly Varden), or use by other aquatic species similarly dependent on such cold water. Other common characteristic aquatic life uses for waters in this category include summer foraging and migration of native char; and spawning, rearing, and migration by other salmonid species.

ii. **Core summer salmonid habitat**. The key identifying characteristics of this use are summer (June 15 through September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids.

iii. **Salmonid spawning, rearing, and migration**. The key identifying characteristic of this use is salmon or trout spawning and emergence that only occur outside of the summer season (September 16 through June 14). Other common characteristic aquatic life uses for waters in this category include rearing and migration by salmonids.

iv. **Salmonid rearing and migration only**. The key identifying characteristic of this use is use only for rearing or migration by salmonids (not used for spawning).

v. **Non-anadromous interior redband trout**. For the protection of waters where the only trout species is a non-anadromous form of self-reproducing interior redband trout (O. mykis), and other associated aquatic life.

vi. **Indigenous warm water species**. Protection for waters where the dominant species under natural conditions would be temperature tolerant indigenous nonsalmonid species.

Examples include dace, redside shiner, chiselmouth, sucker, and northern pikeminnow.

(b) **General criteria**. General criteria that apply to all aquatic life fresh water uses are described in WAC 173-201A-260 (2)(a) and (b), and are for:

i. Toxic, radioactive, and deleterious materials.
ii. Aesthetic values.

(c) **Aquatic life temperature criteria**. Except where noted, water temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax). Table 200 (1)(c) lists the temperature criteria for each of the aquatic life use categories.

Table 200 (1)(c) Aquatic Life Temperature Criteria in Fresh Water

Category	**Highest 7-DADMax**
Char Spawning	9°C (48.2°F)
Char Spawning and Rearing	12°C (53.6°F)
Salmon and Trout Spawning	13°C (55.4°F)
Core Summer Salmonid Habitat	16°C (60.8°F)
Salmonid Spawning, Rearing, and Migration	17.5°C (63.5°F)
Salmonid Rearing and Migration **Only**	17.5°C (63.5°F)
Non-anadromous Interior Redband Trout	18°C (64.4°F)
Indigenous Warm Water Species	20°C (68°F)

i. When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

ii. When the background condition of the water is cooler than the criteria in Table 200 (1)(c), the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted as follows:

   A. Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge).
   B. Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F).

iii. Temperatures are not to exceed the criteria at a probability frequency of more than once every ten years on average.

APPENDIX G.

CHANNEL SLOPE AND SURVEY DATA

CONTENTS

Tables

Figures

1. INTRODUCTION

This appendix describes channel slope computation methods and results, and results of a historical survey data comparison. Existing conditions channel data for Nason Creek is available from 2006 light detecting and ranging (LiDAR) data and 2007 (ground survey profile of main channel). Historical data is available for portions of the assessment area from a 1911 map (water surface contours) and a 1980s Federal Emergency Management Agency (FEMA) study (cross-section data). This data is utilized in combination with geomorphic mapping to look for any trends of channel incision, aggradation, or widening between periods of available data.

2. CHANNEL SLOPE METHODS

Channel slope was computed for river mile (RM) 0 to RM 27 at the headwaters using U.S. Geoligcal Survey (USGS) quadrangle contours. The channel sections are based on 1963 aerial photography with limited revisions in 1985. The quad maps provide 20 foot contour intervals for the river between RM 0 to RM 5 and 40-foot contour crossings between RM 5 to RM 27.

Between RM 0 to 14, a second set of channel slope measurements were made based on 2006 LiDAR elevations measured along the centerline of the active channel at a low flow of approximately 40 cubic feet per second (cfs). LiDAR data did not penetrate water unless it was very shallow, and therefore, elevations generally represent points along the active channel bars or just offset from the edge of water. Breaks in slope were estimated by hand drawing straight lines connected along the tops of hydraulic controls (riffles and rapids). Where the straight line no longer crossed the hydraulic controls because of a channel flattening or steepening, a new line was drawn and a slope break identified. Slopes were computed between the break points by dividing the change in elevation of the water surface by the distance between points.

A water surface and channel bottom profile was collected in August 2007 using ground survey techniques between RM 4 to 14 at a similar flow of 40 cfs (recorded at the Washington State Department of Ecology (Ecology) gage at RM 0.8). This data was plotted along the estimated water surface elevations generated from LiDAR. Generally, the LiDAR is very similar or slightly lower than the water surface elevation recorded in the ground survey (Figure 1). Therefore, no updates were made to slope computations.

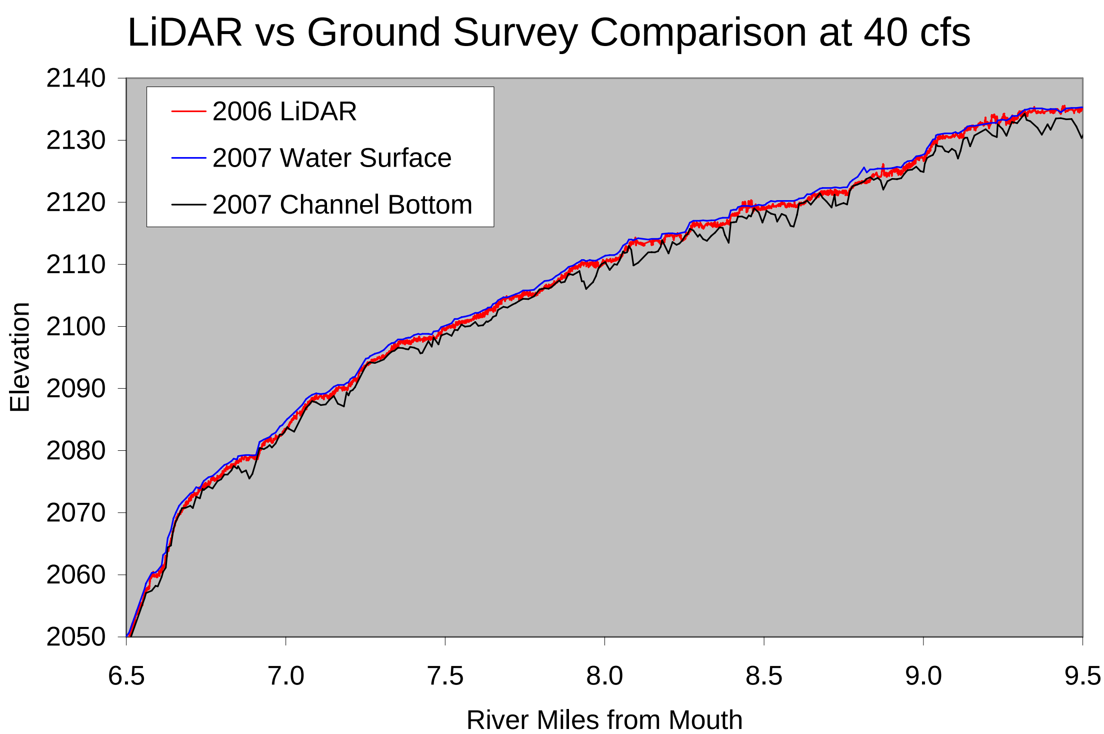


Figure 1. Example of comparisons of LiDAR with ground survey data.

2.1 USGS Quadrangle Slope Results for RM 0 to RM 27

The slope is steep in the headwaters with an overall decreasing trend from RM 27 to RM 25 of 30 percent to 2 percent (Figure 2). From RM 25 to RM 15.8, the slope has a stair step pattern of steeper and flatter sections ranging from 1 to 10 percent. From RM 15.8 to the mouth, the slope is relatively flat compared to the rest of the watershed, with all slopes less than 2 percent based on the USGS quadrangle contours.

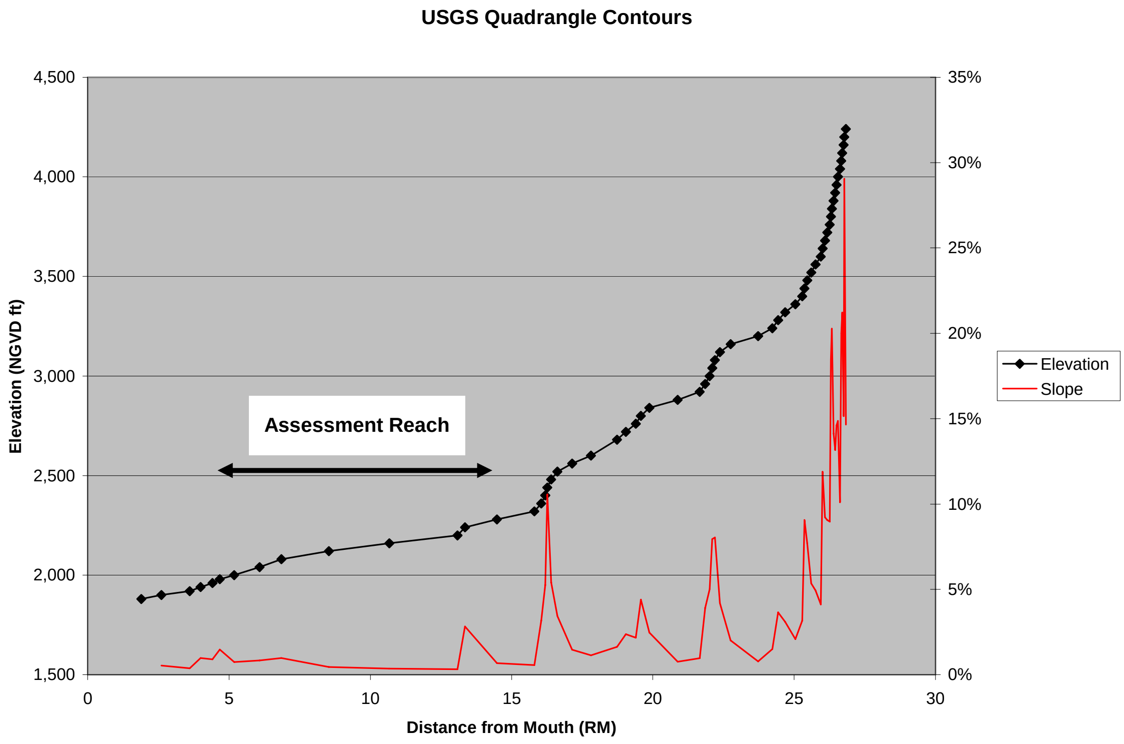


Figure 2. Slope and elevation along Nason Creek from RM 0 to the headwaters based on USGS quadrangle maps.

2.2 2006 LiDAR and 2007 Ground Survey Slope Results for RM 0 to RM 14

Geomorphic reach boundaries were defined where there are geologically controlled changes in floodplain widths. If reach boundaries are used to compute a slope, the slope in the upstream-most geomorphic reaches 2 and 3 are slightly flatter than in reach 1 (Table 1). However, locations where there are major changes in slope do not directly coincide with the boundaries of the geomorphic reaches (Figure 3), and there are several slope fluctuations within each reach (Figure 4). From the mouth at RM 0 to RM 14, the computed slopes range from 0.1 to 2.2 percent or about 4 to 34 feet of drop per mile (Table 2 and Table 3). To evaluate if there are longitudinal trends in slope, the change in elevation was plotted for ½-mile increments (Figure 5 and Table 3). Longitudinally, the slope can be described as follows:

- In the vicinity of the White Pine Bridge at RM 14.3, the slope is steep at 2.2 percent; this section has a natural constriction by bedrock and has been further constricted to a small degree by the bridge embankment and riprap.

- Between RM 9 and RM 14, slopes fluctuate up and down in a sporadic pattern;
- Between RM 4 and RM 9 there is more of a trend of increasing than decreasing slope in the downstream direction;
- Downstream of RM 4 the slope is 0.5 percent or less.

Table 1. Slope data for geomorphic reaches.

Geomorphic Reach	RM Range	Reach-based Slope	Minimum Slope in Reach	Maximum Slope in Reach
1	4.6 to 8.9	0.7%	0.2%	2.2%
2	8.9 to 9.4	0.4%	0.1%	0.4%
3	9.4 to 14.3	0.4%	0.1%	2.3%

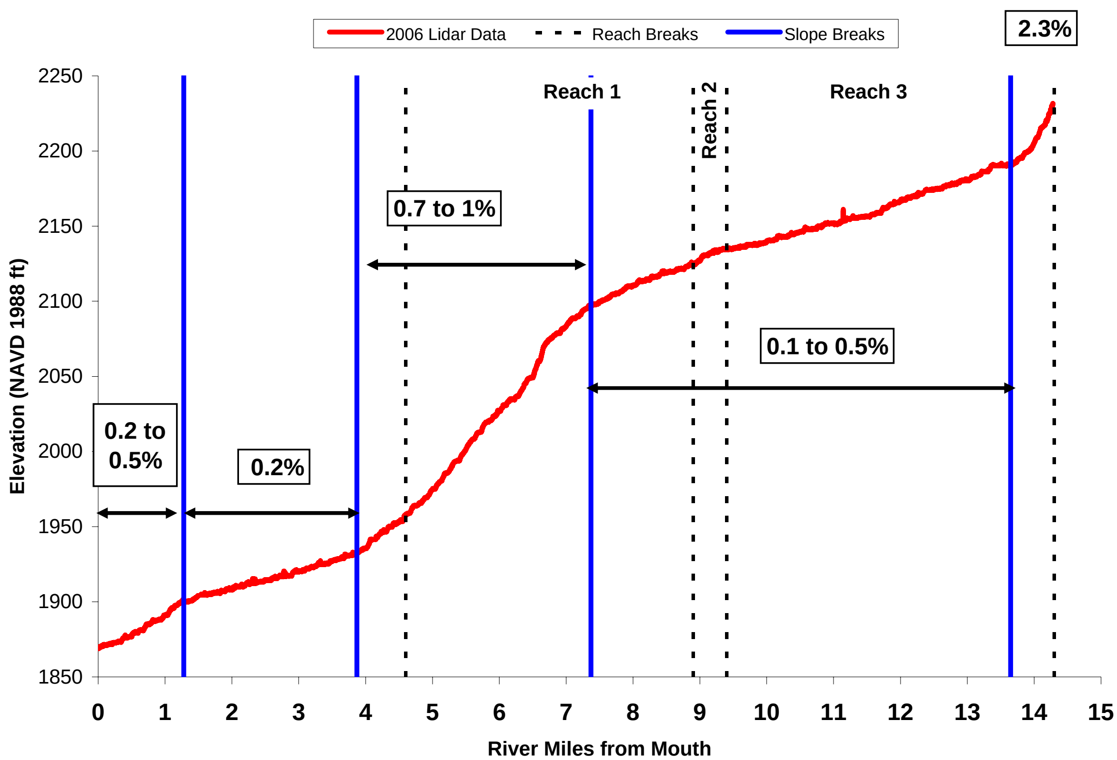


Figure 3. Longitudinal profile of channel elevation and range of slopes (ft/ft) from RM 0 to 14.

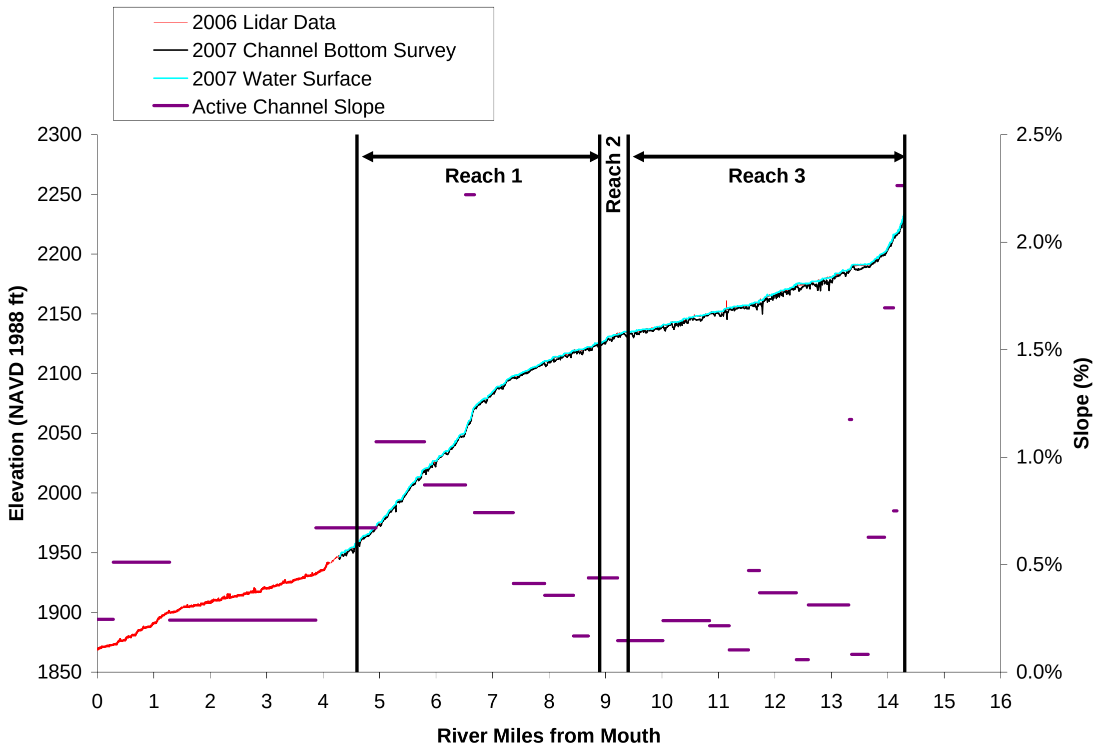


Figure 4. Longitudinal profile of channel elevation and slope data (percent) from RM 0 to RM 14.

Table 2. Channel slope data for RM 0 to RM 14.

Upstream RM	Downstream RM	Elevation (NAVD 88 feet)	Distance (feet)	Elevation Change (feet)	Slope (feet)	Slope (percent)
14.28	14.16	2231.2	612	13.8	0.0226	2.3%
14.16	14.10	2217.4	318	2.4	0.0075	0.8%
14.10	13.94	2215.0	834	14.1	0.0169	1.7%
13.94	13.65	2200.9	1543	9.7	0.0063	0.6%
13.65	13.36	2191.2	1556	1.3	0.0008	0.1%
13.36	13.32	2189.9	203	2.4	0.0118	1.2%
13.31	12.59	2186.4	3782	11.8	0.0031	0.3%
12.59	12.38	2174.6	1128	0.7	0.0006	0.1%
12.38	11.73	2173.9	3434	12.7	0.0037	0.4%
11.73	11.53	2161.3	1035	4.9	0.0047	0.5%
11.53	11.19	2156.4	1803	1.9	0.0010	0.1%
11.19	10.85	2154.5	1825	3.9	0.0022	0.2%
10.85	10.02	2150.6	4381	10.5	0.0024	0.2%
10.02	9.22	2140.1	4220	6.2	0.0015	0.1%

Upstream RM	Downstream RM	Elevation (NAVD 88 feet)	Distance (feet)	Elevation Change (feet)	Slope (feet)	Slope (percent)
9.22	8.70	2133.9	2751	12.1	0.0044	0.4%
8.70	8.44	2121.8	1367	2.3	0.0017	0.2%
8.44	7.93	2119.5	2696	9.6	0.0036	0.4%
7.93	7.37	2109.8	2951	12.2	0.0041	0.4%
7.37	6.68	2097.7	3635	27.0	0.0074	0.7%
6.68	6.53	2070.7	811	18.0	0.0222	2.2%
6.53	5.79	2052.7	3862	33.6	0.0087	0.9%
5.79	4.94	2019.1	4514	48.4	0.0107	1.1%
4.94	3.87	1970.7	5620	37.7	0.0067	0.7%
3.87	1.28	1933.0	13691	33.1	0.0024	0.2%
1.28	0.28	1899.9	5263	26.9	0.0051	0.5%
0.28	0.00	1873.0	1502	3.7	0.0025	0.2%

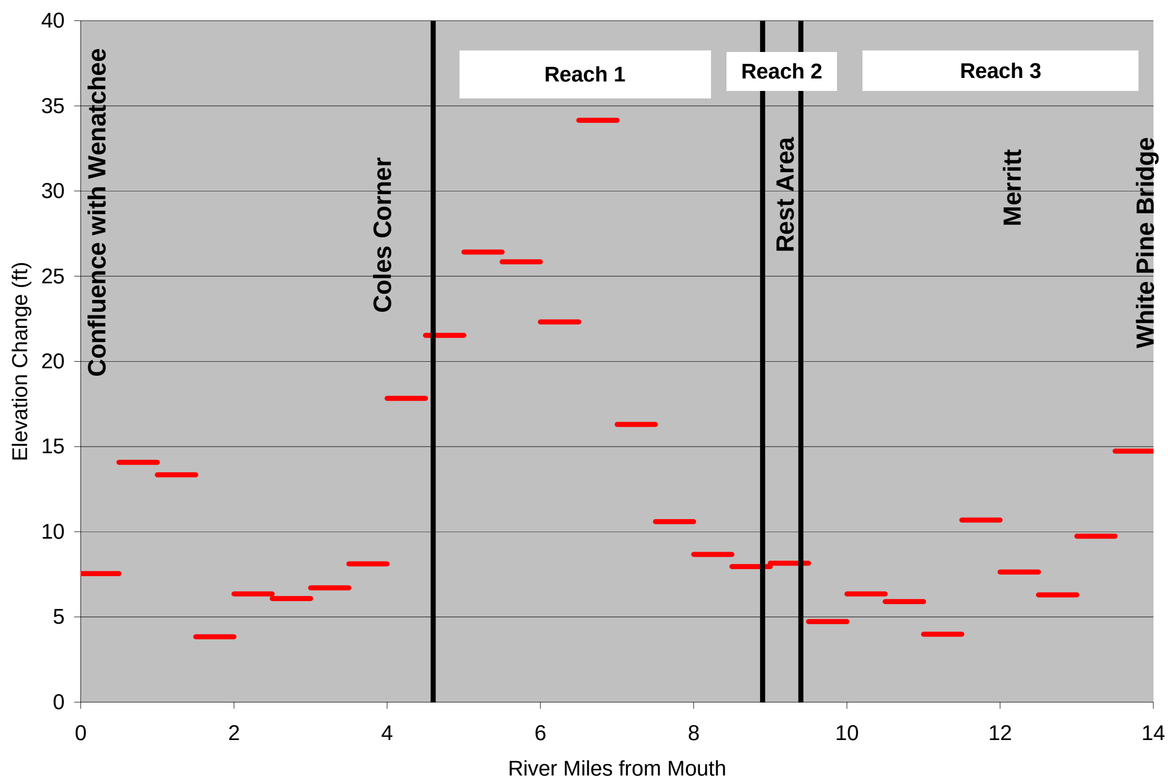


Figure 5. Drop in elevation by ½-mile increments of Nason Creek for RM 0 to RM 14.

Table 3. Drop in elevation per every ½-mile of river for RM 0 to RM 14.

RM	Elevation (feet)	Change (feet)
14.0	2205.2	14.7
13.5	2190.4	9.7
13.0	2180.7	6.3
12.5	2174.4	7.6
12.0	2166.8	10.7
11.5	2156.1	4.0
11.0	2152.1	5.9
10.5	2146.2	6.4
10.0	2139.8	4.7
9.5	2135.1	8.1
9.0	2127.0	8.0
8.5	2119.0	8.7
8.0	2110.3	10.6
7.5	2099.7	16.3
7.0	2083.4	34.2
6.5	2049.3	22.3
6.0	2027.0	25.8
5.5	2001.1	26.4
5.0	1974.7	21.5
4.5	1953.2	17.8
4.0	1935.3	8.1
3.5	1927.2	6.7
3.0	1920.5	6.1
2.5	1914.4	6.3
2.0	1908.1	3.8
1.5	1904.2	13.3
1.0	1890.9	14.1
0.5	1876.8	7.5
0.0	1869.3	

2.3 Water Depths at Low Flow

Water depth was computed for the 2007 survey data by subtracting the measured channel bottom from the measured water surface. The channel bottom was intended to follow the thalweg of the active main channel, but in some cases local scour pools may have been present that were not captured in the survey. Geomorphic reach 3 had the largest amounts of recorded depths greater than 3.3 feet (1 meter), a threshold value often used to define habitat availability (Table 4 and Figure 6). In both reaches the most frequently occurring depths were from 1 to 2 feet. Only a few depths 5 feet or greater were recorded and the majority were in reach 1 (Table 5).

In addition to the depth, the formation mechanism and the quality of a pool are also important factors in relating to potential habitat. Locations both meandering channels and riprap present on one or both sides of the active channel bank, were plotted against the depths to determine if there are any correlations with locations of larger depths. Based on this plot and a field survey performed by the U.S. Forest Service in 2007, the majority of pools 5 feet or deeper were either associated with large woody debris (LWD) and/or formed on the outside of meander bends. A few pools were formed in artificially constricted sections and assumed to occur from local scour. There was not a clear relationship between deep pools and riprap locations at the reach scale, but local impacts could be occurring that would need to be evaluated in the field.

Table 4. Number of pools greater than 3.3 feet (1 m) by geomorphic reach

Reach	RM	Number of deeper pools greater than 3.3 feet (1 m)	Number per mile
1	4.56 to 8.9	13	3
2	8.9 to 9.42	2	4
3	9.42 to 14.27	38	8

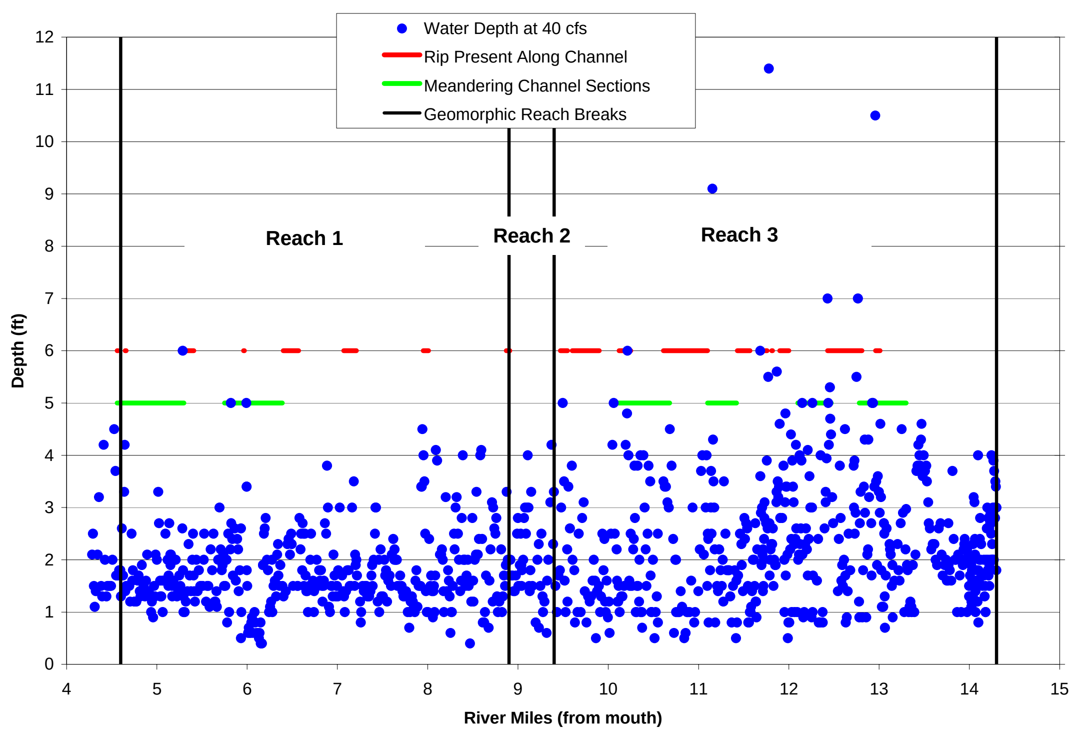


Figure 6. Longitudinal profile of water depths measured in 2007 at a river flow of 40 cfs.

Table 5. Histogram data for Reach 1 and 3 water depths recorded in 2007 at a flow of 40 cfs.

Depth Bin (feet)	Reach 1 Frequency	Reach 3 Frequency
0-0.5	5	5
0.5-1	48	74
1-1.5	135	71
1.5-2	102	104
2-2.5	54	75
2.5-3	24	63
3-3.5	13	37
3.5-4	5	38
4-4.5	4	15
4.5-5	2	13
5-5.5	0	3
5.5-6	1	3
6-6.5	0	0
6.5-7	0	2
7-7.5	0	0
7.5-8	0	1
8-8.5	0	1
8.5-9	0	0
9-9.5	0	1
9.5-10	0	0
10-10.5	0	1
10.5-11	0	0
11-11.5	0	1
11.5-12	0	0

3. HISTORICAL SURVEY COMPARISON

3.1 USGS 1911 Survey

A 1914 map generated by USGS shows a 1911 survey that provides 10-foot contour intervals for the creek's water surface during summer flows (Marshall 1914). This data was compared to channel bottom elevations and slope computations between RM 0 to RM 5.4. This map represents the river channel after impacts from the construction of the railroad in 1890s, but prior to the channel cutoffs due to highway improvements in the 1940s to 1960s. The 1911 survey provides contour data from RM 0 to what in 1911 was RM 6.3. Due to highway construction, the 2006 channel (RM 0 to RM 5.4) is 0.9 miles shorter that it was in 1911.

The map was available in hard copy and was rectified into geographical information system (GIS) using township boundaries present on both the 1914 map and modern USGS 7.5 minute quadrangles. Contour lines were identified in GIS and a centerline of both the 1911 channel and 2006 channel used to determine river miles for comparison to 2006 vertical data. The 1914 map is documented to be in a mean sea level vertical datum (prior to establishment of 1929 vertical datum). A datum conversion could not be determined because the benchmarks used in the 1911 survey have not been resurveyed in a known datum. However, in a similar map produced in the early 1900s in the Methow subbasin, a vertical conversion from mean sea level to 1988 NAVD of 0.5 feet was determined. An unknown vertical datum conversion, unknown flow at time of 1911 water surface elevation survey, and approximation of contour line locations introduces error to this comparison that make it difficult to conclude absolute changes in elevations. An assumption was made that the 1911 survey was also completed at low flow because it was done in the summer, and that the vertical datum conversion from mean sea level to NAVD 88 feet is less than 1 foot.

Based on these assumptions, a general analysis of trends in vertical elevations was made between 1911 and 2006 (Figure 7). From RM 0 to RM 4, the water surface appears to not have had significant changes since 1911. From RM 4 to RM 5.4, the water surface differences range from negligible to approximately 2 feet lower in elevation in 2006 than 1911. The two largest differences are at RM 3.9 and RM 5.4, where the 2006 water surface is approximately 6 feet lower in elevation. At RM 3.9, there was a nearly 1-mile section of channel in 1911 that was cut off by the highway resulting in the 1911 channel being 800 feet to the right of the present 2006 channel. The different channel locations and lengths may in part explain the large difference in elevation at this location. The channel slopes were computed for both 2006 and 1911 surveys based on respective channel lengths and elevation data (Figure 8). The two were compared using 2006 river miles for plotting purposes. Water surface elevation slope results between 1911 and 2006 are similar, although localized differences do occur.

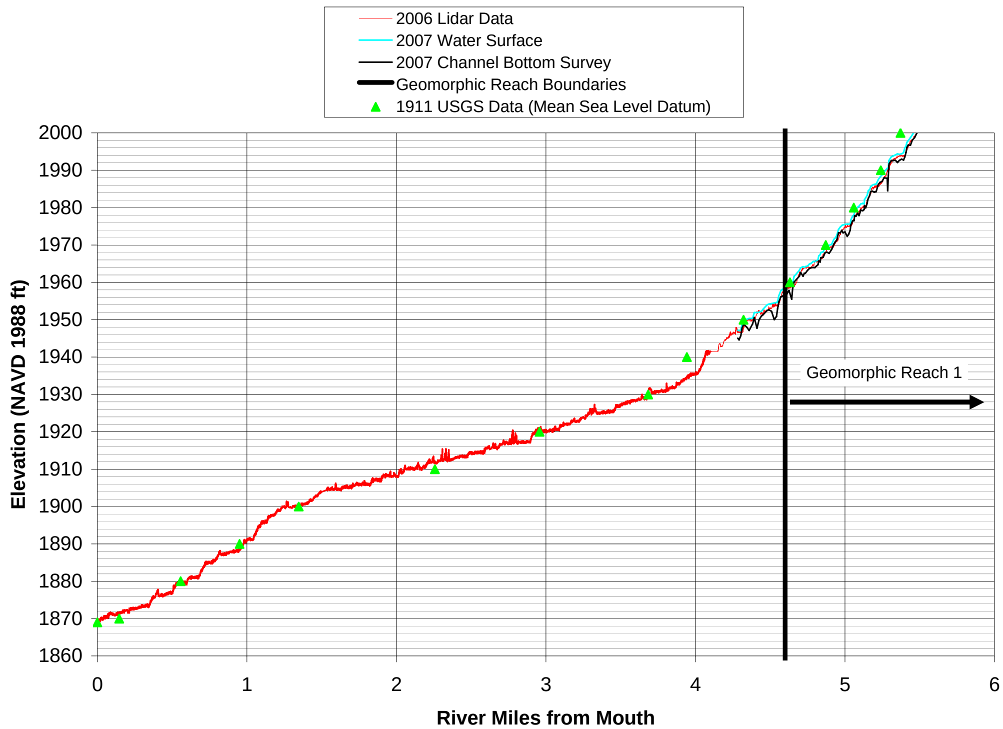


Figure 7. Comparison of 1911 & 2006 water surface elevations between RM 0 and RM 5.3.

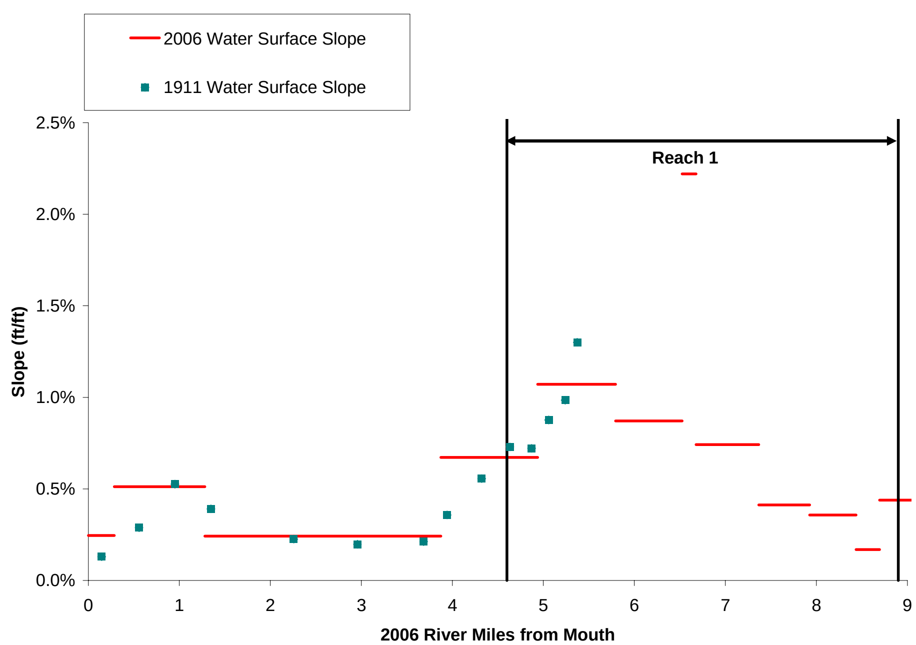


Figure 8. Comparison of 1911 & 2006 water surface elevation slopes.

3.2 1980s FEMA Survey

A set of cross-section data was obtained between RM 4 to RM 14 that was collected for a FEMA floodplain study conducted by a private consultant firm (FEMA 2004; Baker 2007). The report notes that the data was based on ground survey in the channel supplemented by topographic maps (4 foot contour) compiled from 1986 aerial photographs (1:4800). The vertical datum was converted from the original 1929 (NGVD ft) to 1988 datum (NAVD ft) by adding 4.1 feet. FEMA could not verify the data because it was in a non-standard computer program format used by the consultant. However, the data appeared to be in station-elevation format similar to the HEC-2 program used at that time period. The original survey data was not available; therefore, locations of the data had to be estimated based on rectifying maps showing the cross-section lines where survey data was collected. There is an unknown potential horizontal error in using this method, but the highway and railroad, roads, river position (where not meandering), and bridges were used where possible to ensure data was generally in the right location. Once the maps were in a known datum in GIS, a 2006 river mile was associated with each cross-section to allow comparison of cross-sections and channel thalweg data between the 1980s set and 2007 data.

The thalweg comparison plots indicate no large changes in channel slope over the last two decades (Figure 9 and Figure 10). When comparing actual elevations, differences range between +/- 4 feet (Table 6). Because of the method used to place the data and potential changes in the locations of pools and riffles, it is very possible that even less change in channel bottom elevation has occurred. Many of the areas that show the largest differences are pool locations that could be easily explained by a slightly wrong horizontal position or downstream migration of the pool location.

Cross-section plot comparisons were made in locations where the channel has not changed position since the 1980s. In particular, locations that are artificially confined by the highway or railroad were compared to look for evidence of incision. The plots indicate small changes in bars and bed elevations in the main channel (see Attachment 1 for plots). The one exception is at RM 8.18 near a bridge location. It is unknown if the bridge was reconstructed between the 1980s and 2006 survey, but an embankment appears to be present in 2006 that was not there in the 1980s.

Table 6. Summary of elevation differences between 2007 and 1980s channel data.

Geomorphic Reach	Channel Bottom Difference (feet)			
	Minimum	Maximum	Average	Absolute Average
1	-3.8	4.0	0.0	1.6
2	-2.3	1.4	-0.4	1.8
3	-2.0	3.8	0.1	1.0

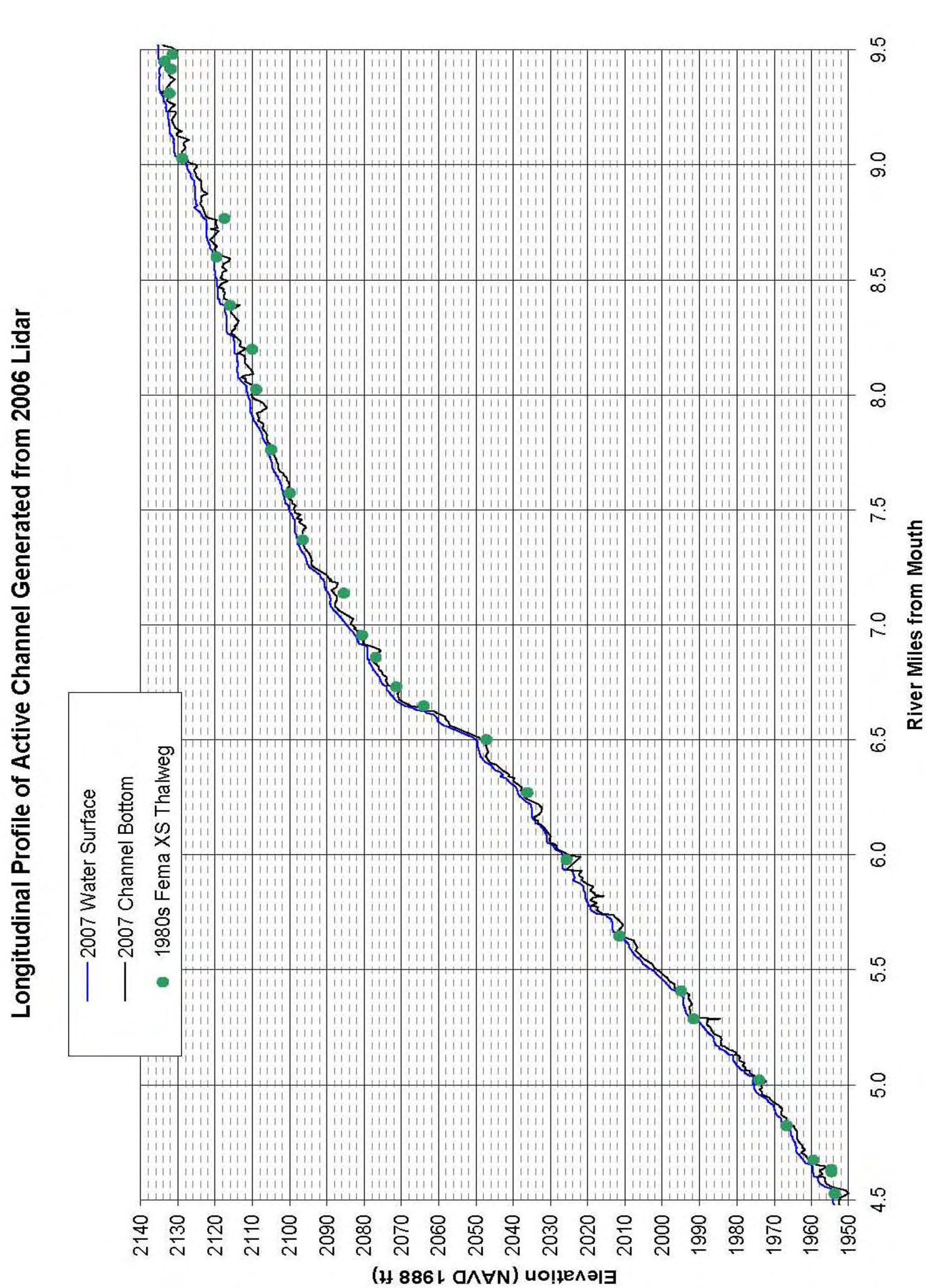


Figure 9. Longitudinal profile comparison of 2007 and 1980s channel bottom from RM 4.5 to RM 9.5.

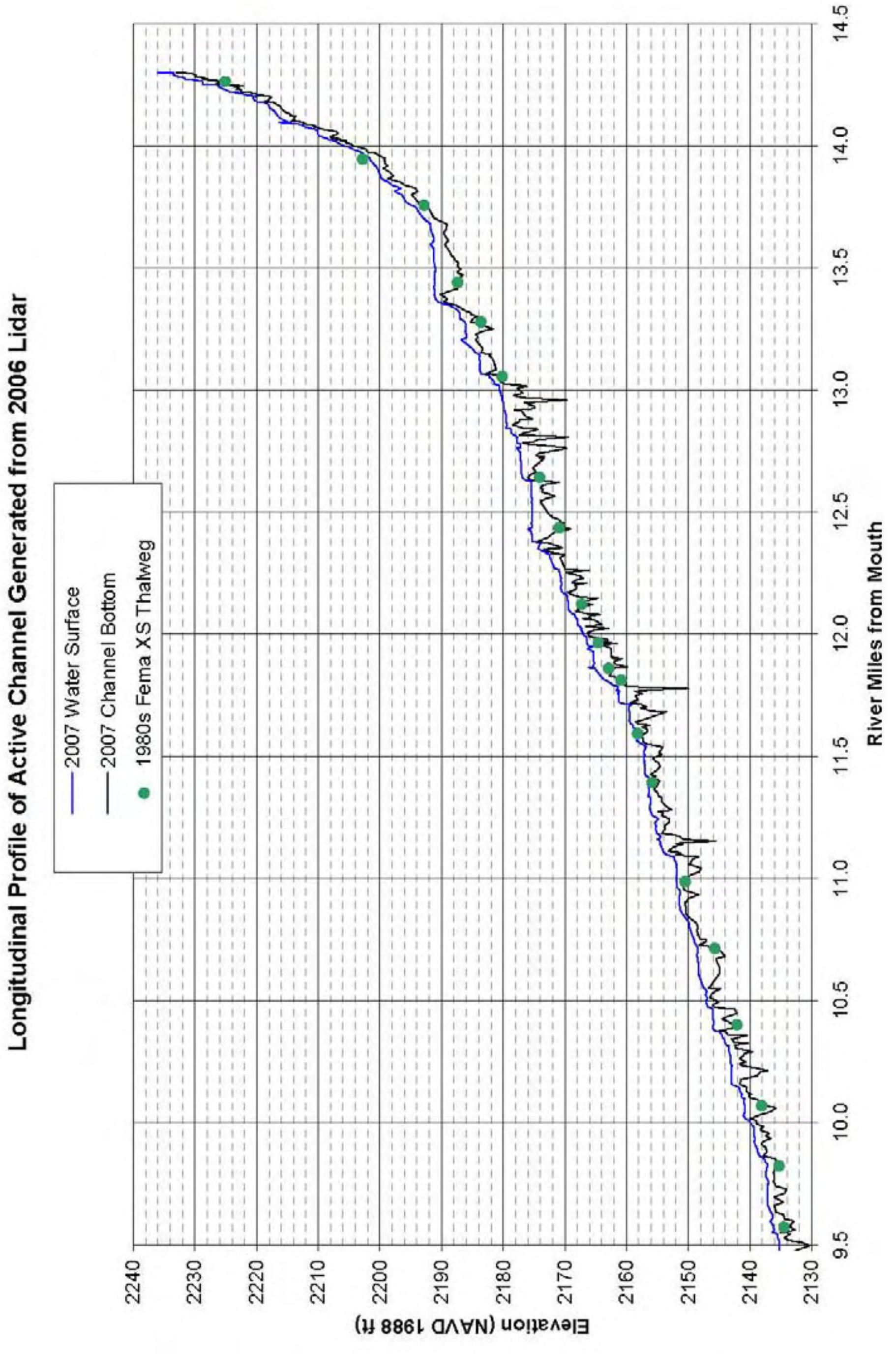
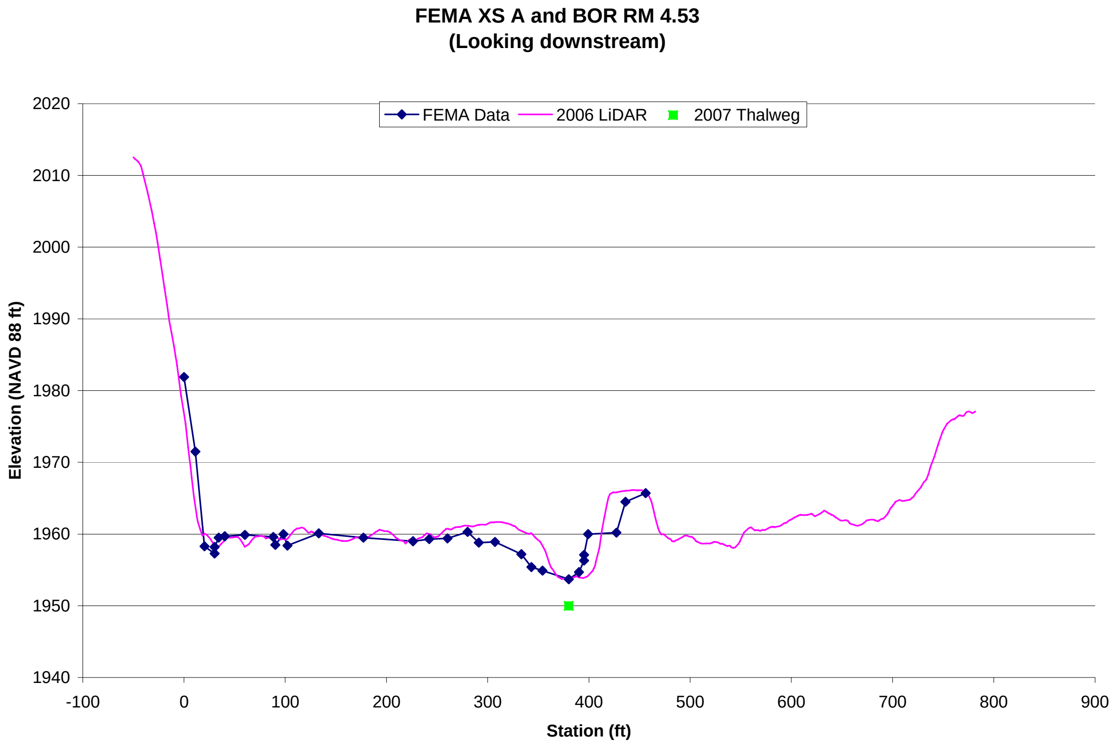


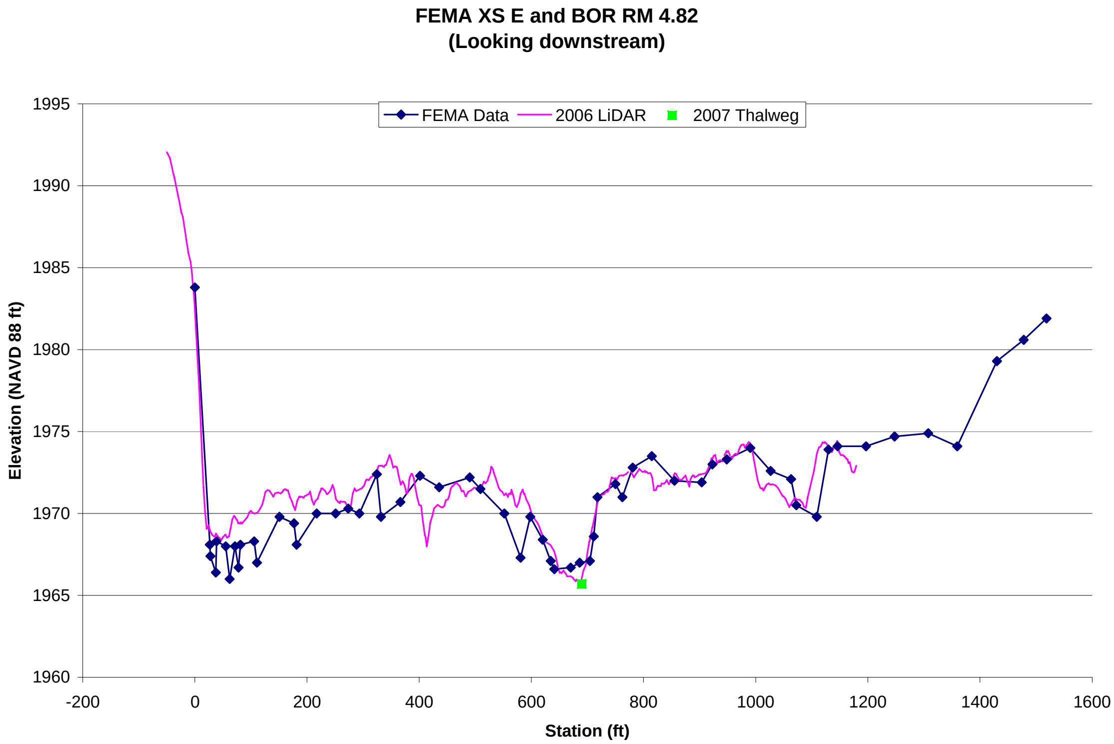
Figure 10. Longitudinal profile comparison of 2007 and 1980s channel bottom from RM 9.5 to RM 14.5.

4. REFERENCES

Parenthetical Reference	Bibliographic Citation
Baker 2007	Baker, Michael. 2007. Michael Baker Consultants. April. Personal communication.
FEMA 2004	Federal Emergency Management Agency. 2004. Flood Insurance Study: Chelan County, Washington Unincorporated Areas. Flood Insurance Study Number 530015V000B: 173.
Marshall 1914	Marshall, R.B. 1914. Profile surveys in Wenatchee River basin Washington. United States Geological Survey, Water Supply Paper. 368.

ATTACHMENT 1 – Cross-section Plots Comparing 2006-2007 Data with 1980s FEMA Data


FEMA XS A and BOR RM 4.53
(Looking downstream)
FEMA Data
2006 LiDAR
2007 Thalweg
Elevation (NAVD 88 ft)
Station (ft)
2020
2010
2000
1990
1980
1970
1960
1950
1940
-100
0
100
200
300
400
500
600
700
800
900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(Looking downstream)
FEMA Data
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2007 Thalweg
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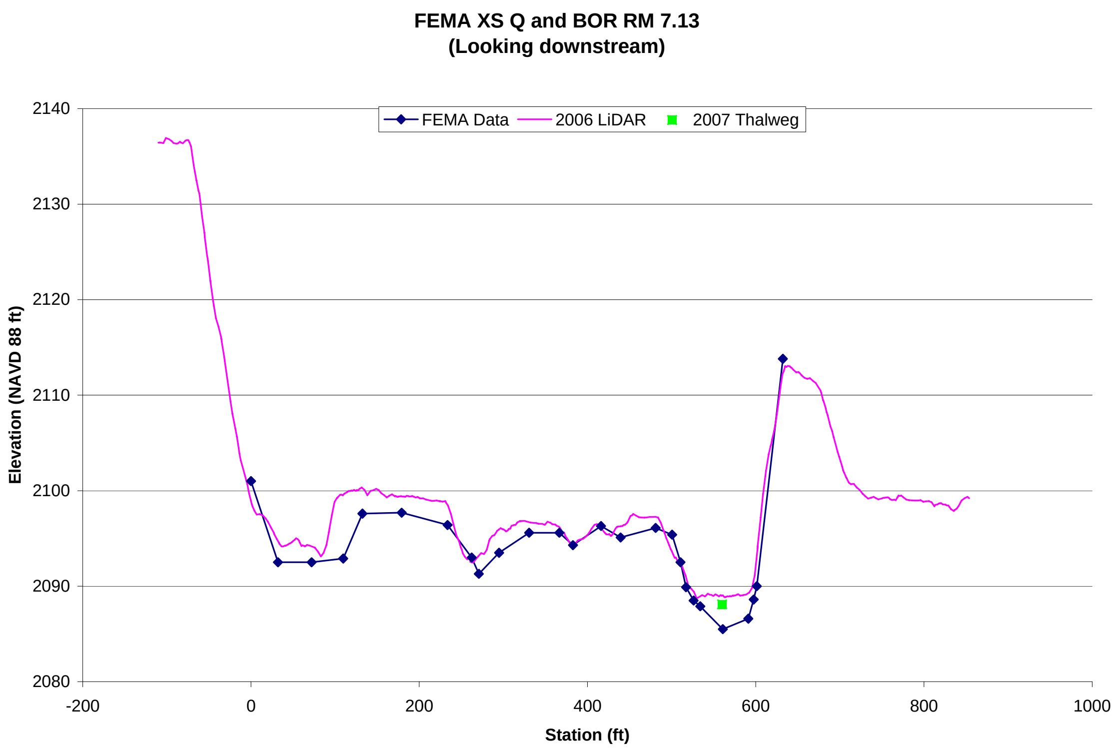
1975
1970
1965
1960
-200
0
200
400
600
800
1000
1200
1400
1600
Station (ft)


FEMA XS Q and BOR RM 7.13
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2007 Thalweg
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2120
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2100
2090
2080
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200
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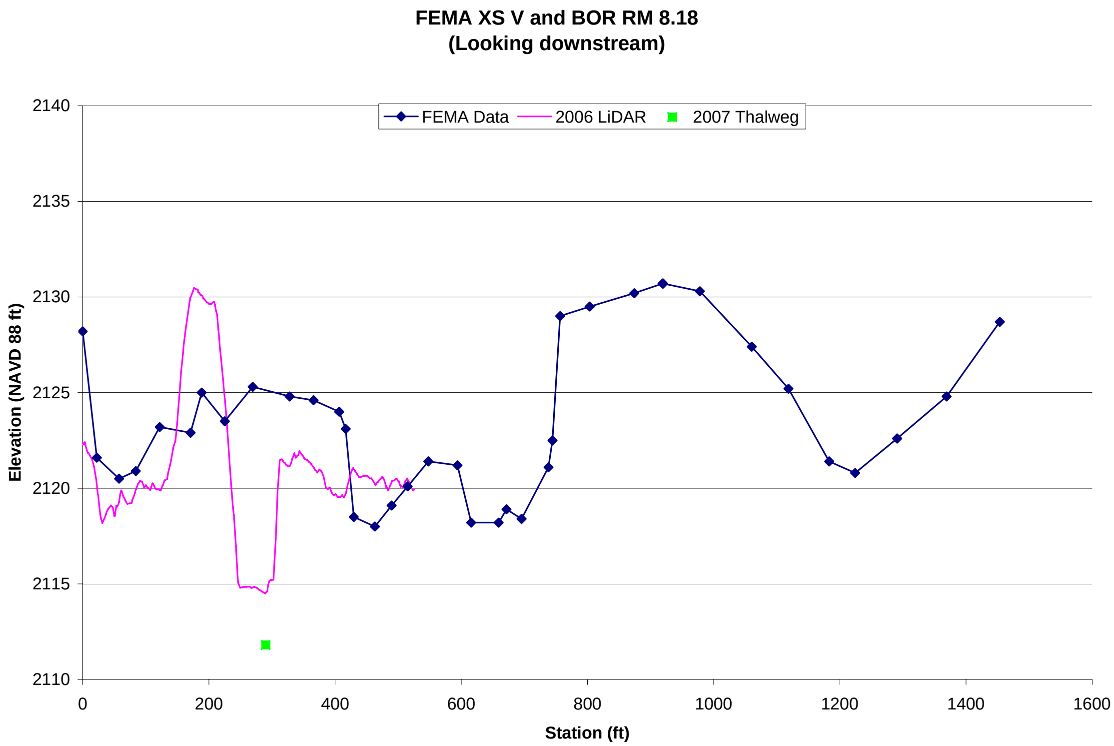
600
800
1000
Station (ft)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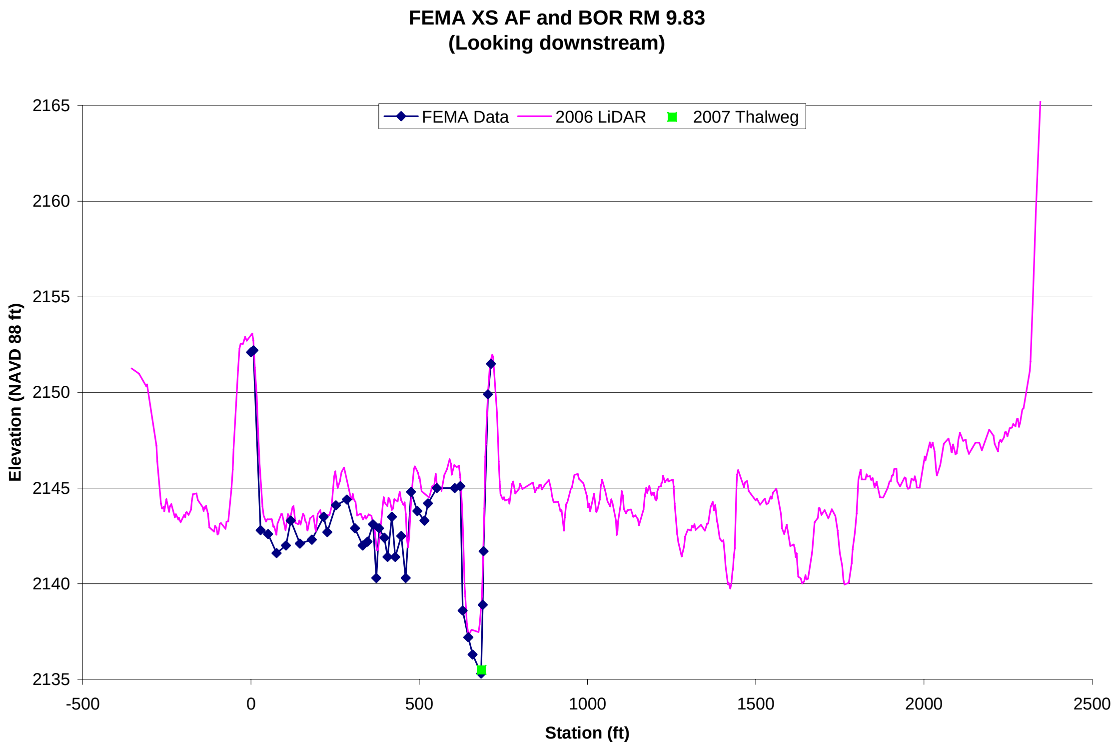
1200
1400
1600
Station (ft)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2007 Thalweg
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2135
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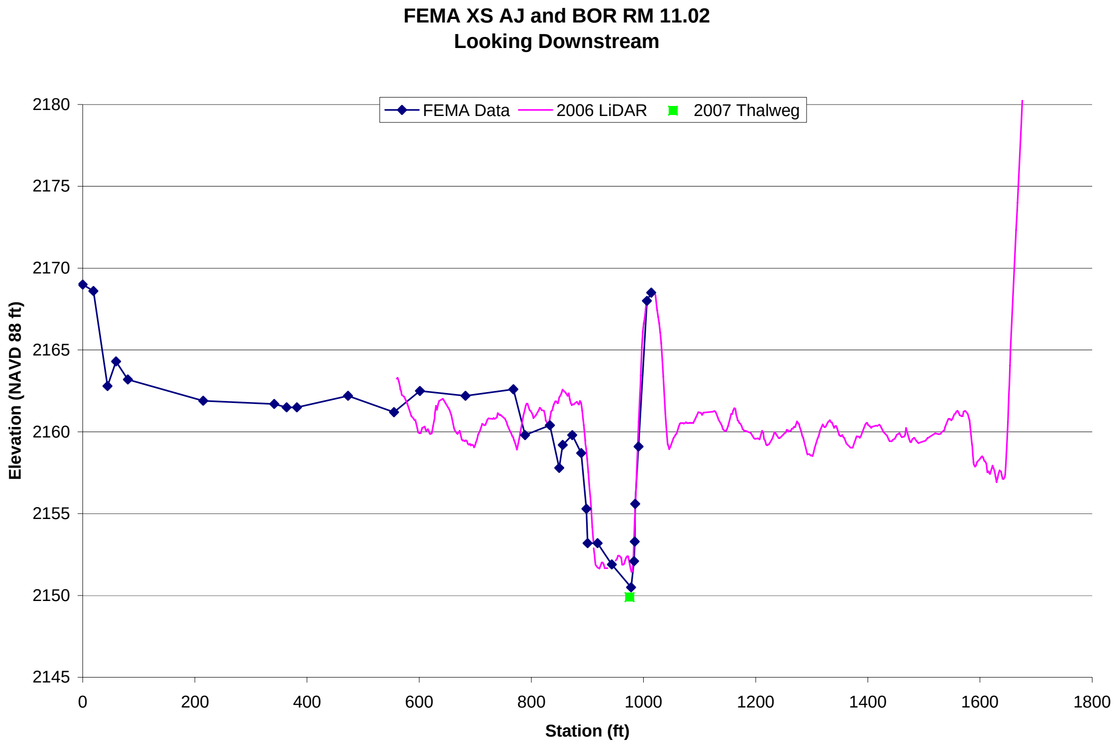
0
500
1000
1500
2000
2500
Station (ft)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800
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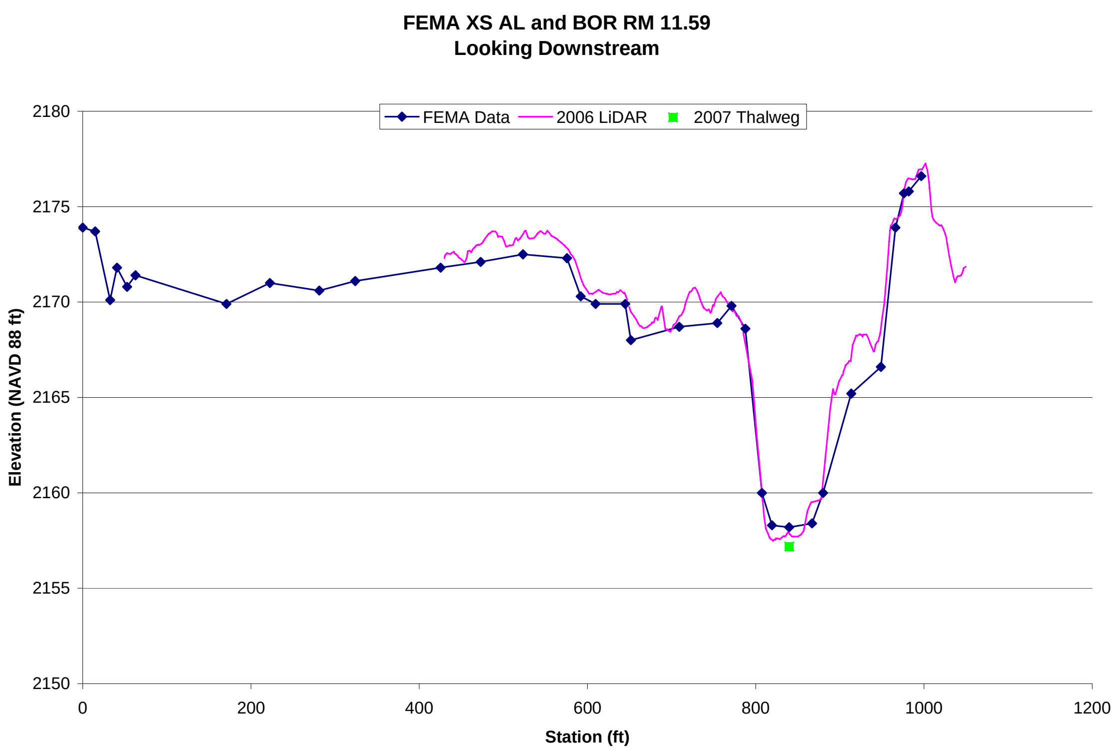
1200
1400
1600
1800
Station (ft)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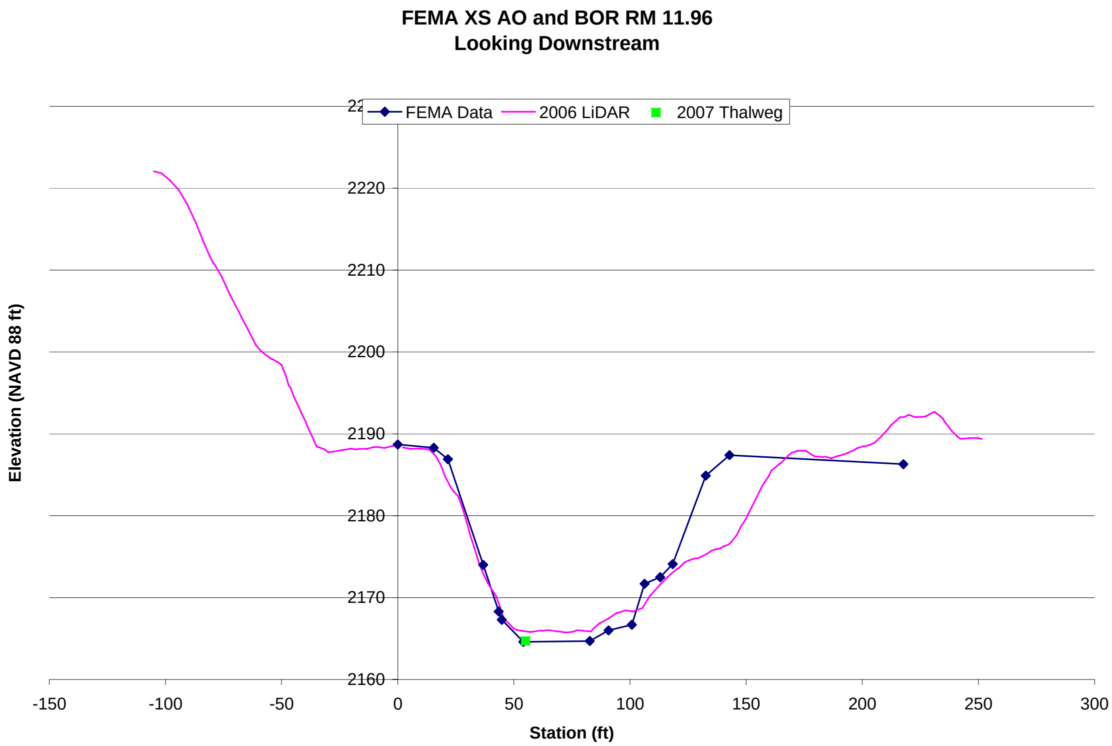
400
600
800
1000
1200
Station (ft)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2007 Thalweg
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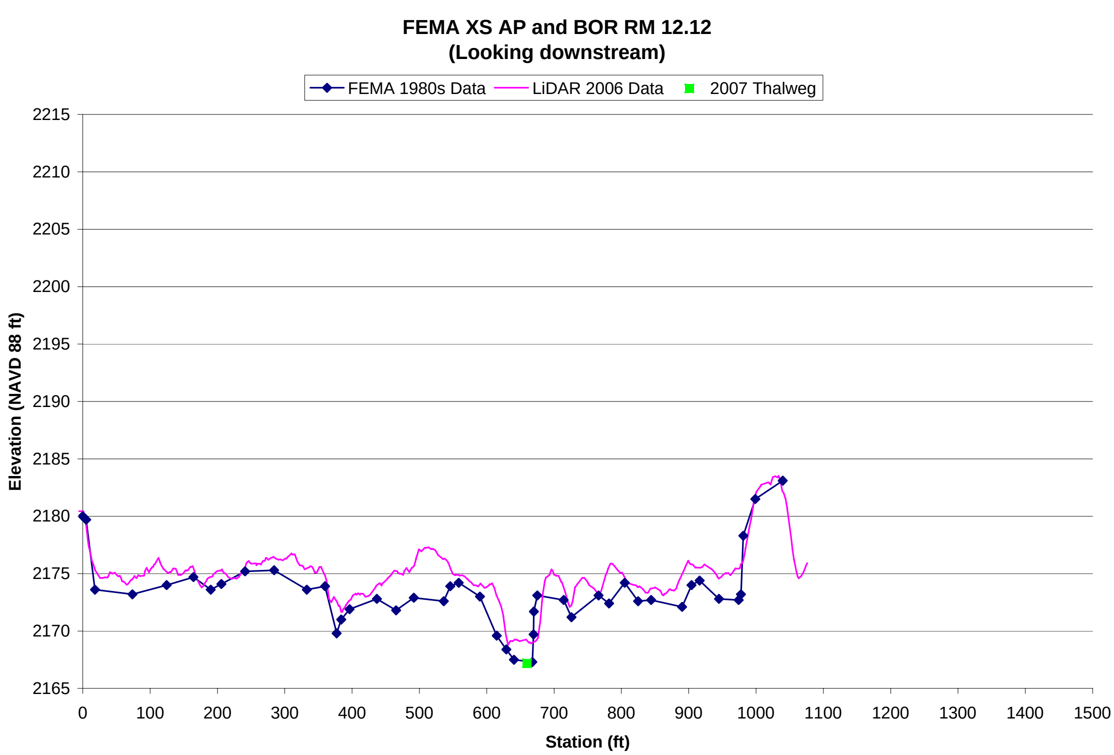
50
100
150
200
250
300
Station (ft)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(Looking downstream)
FEMA 1980s Data
LiDAR 2006 Data
2007 Thalweg
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2175
2180
2185
2190
2195
2200
2205
2210
2215
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400
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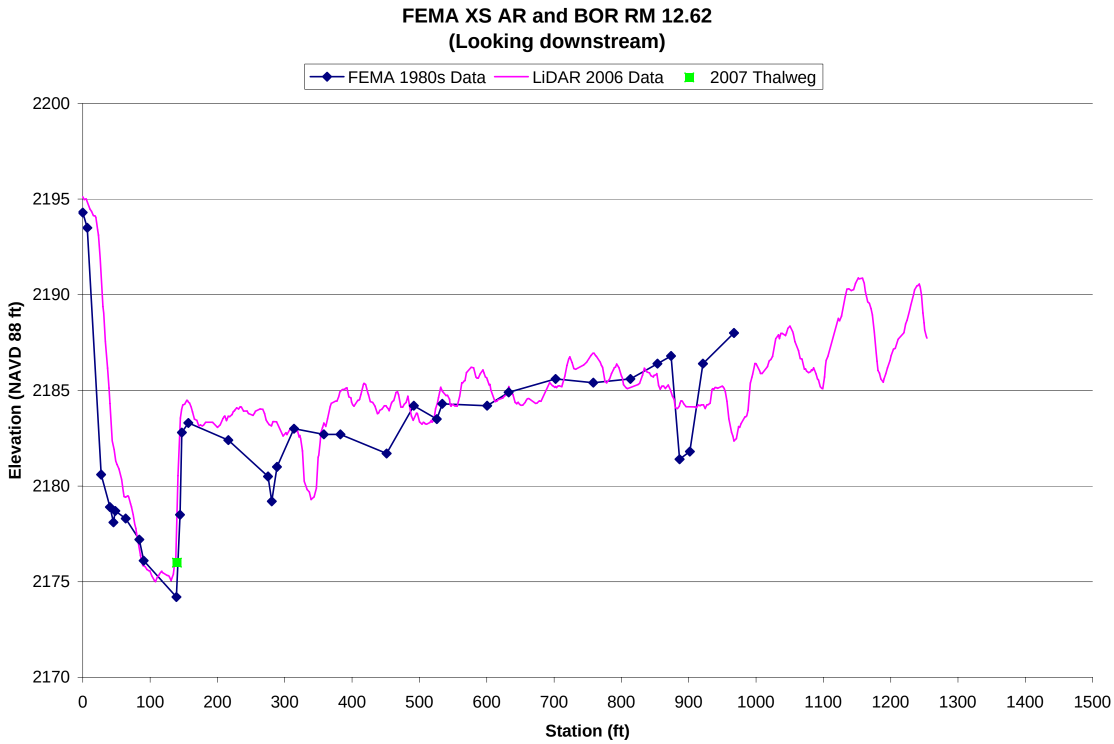
700
800
900
1000
1100
1200
1300
1400
1500
Station (ft)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(Looking downstream)
FEMA 1980s Data
LiDAR 2006 Data
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2185
2180
2175
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500
600
700
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900
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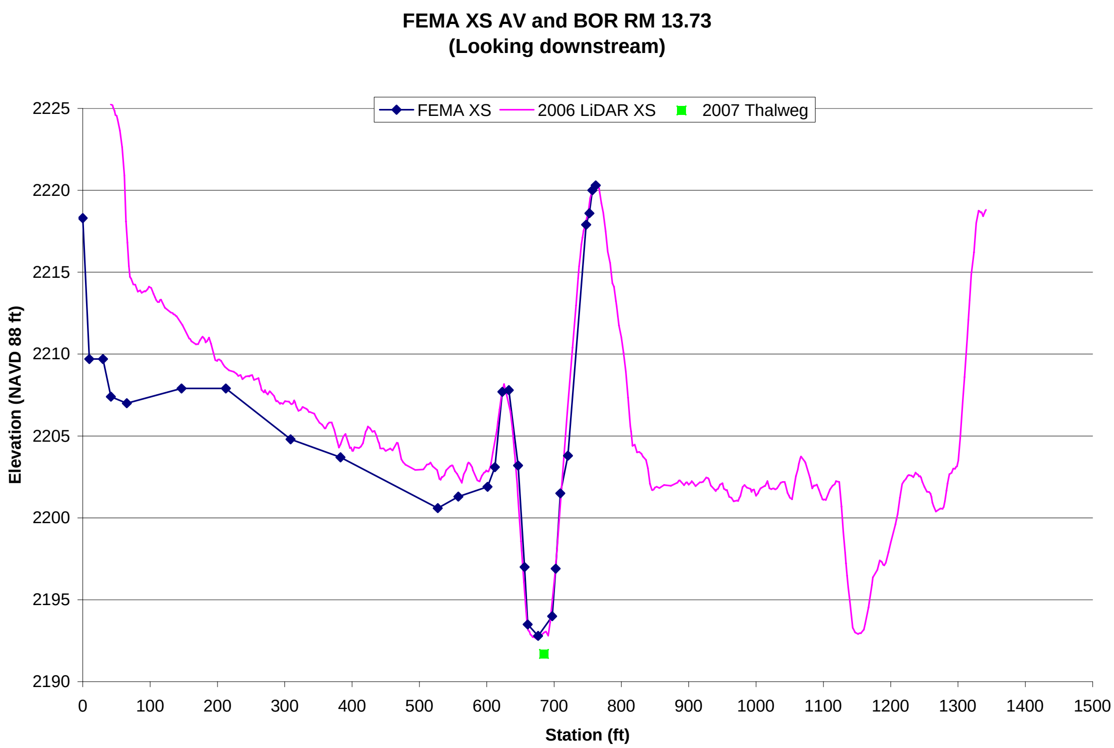
1100
1200
1300
1400
1500
Station (ft)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(Looking downstream)
FEMA XS
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2007 Thalweg
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2215
2210
2205
2200
2195
2190
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Station (ft)

APPENDIX H.

HYDRAULICS AND SEDIMENT ANALYSIS

This appendix includes the methodology for development of a two-dimensional (2D) numerical hydraulic model applied to the assessment area and an analysis of relative sediment transport capacity among reaches. The 2D model was developed using existing topography and topography with human features removed. The removed human features removed from the modeling surface prevent flow from accessing the floodplain in localized portions of the floodplain. The objective of the hydraulic modeling effort was to assist with delineation of the geologic floodplain and historical channel migration zone, and evaluate flow connectivity impacts from embankments or other man-made constructs that prevent channel – floodplain connectivity. Additionally, relative sediment capacity among geomorphic reaches is compared. The model was based solely on 2006 LiDAR data collected at 40 cfs and is most applicable for drawing conclusions regarding off-channel and floodplain connectivity at near bankfull and higher flows. If localized channel hydraulics or sediment predictions are needed, particularly at low flows, additional modeling should be employed that incorporates survey data below the water surface elevation corresponding to a discharge of 40 cubic feet per second (cfs). The type of model needed at project scales will be dependent on the project level questions of interest, and could potentially range from a one-dimensional to three-dimensional numerical model, a physical model, or a channel migration model.

CONTENTS

Tables

Figures

1. INTRODUCTION

The two dimensional (2D) numerical model, SRH-W v1.1 (Lai 2006; http://www.usbr.gov/pmts/sediment/model/srh2d/index.html), was used for hydraulic and sediment analysis on Nason Creek from river mile[1] (RM) 4.6 to 14.3. A 2D model was utilized for its improved representation of complex hydraulic flow features and its ability to determine hydraulic conditions on a continuum. Examples of complex flow features are lateral overtopping onto adjacent floodplains and interaction between the main channel and side channels. Both conditions can result in non-uniform flow distribution (Figure 1). A 1D HEC-RAS model (built with GEORAS in ARCGIS) was also used for visualization of topography in cross-section format and for generating boundary conditions for the 2D model (Figure 2). Limited calibration data was available that included water surface elevation at 40 cfs, ground photographs during a spring snowmelt flood that did not overtop the active channel banks, anecdotal accounts during a 1990 and 1996 flood that did overtop the active channel banks, and FEMA floodplain boundaries. Steady flows modeled ranged from 2,500 to 15,000 cfs, which includes the range of estimated 2- to 100-year flood values between RM 4 to 14.

The following is a list of major features of SRH-W (Lai 2006):

- SRH-W solves the 2D depth-averaged form of the diffusive wave or the dynamic wave equations. The dynamic wave equations are the standard St. Venant depth-averaged shallow water equations;
- Both the diffusive wave and dynamic wave solvers use the implicit scheme to achieve solution robustness and efficiency;
- Both steady or unsteady flows may be simulated;
- All flow regimes, i.e., subcritical, transcritical, and supercritical flows, may be simulated simultaneously without the need of a special treatment;
- Solution domain may include a combination of main channels, side channels, floodplains, and overland;
- Solved variables include water surface elevation, water depth, and depth averaged velocity. Output information includes above variables, plus flow inundation, Froude number, and bed shear stress.

[1] All river miles in this appendix refer to the centerline length along the 2006 active, unvegetated channel starting at river mile 0 at the mouth of Nason Creek where it enters the Wenatchee River.

- A development version of the code was also utilized to compute sediment capacity, Shields number, and incipient motion for a limited number of model runs.

The 2D model was applied to existing topographic conditions and to topographic conditions with human features removed that block flow access within the floodplain. The objective was to assist with delineation of the geologic floodplain and historical channel migration zone, and evaluate flow connectivity impacts from embankments or other human features that prevent the channel from interacting with the floodplain at bankfull discharges and higher. Additionally, sediment capacity between geomorphic reaches is compared. The model was based solely on 2006 LiDAR data collected at 40 cfs and is most applicable for looking at off-channel and floodplain connectivity at near bankfull and higher flows.

All data presented in this report are in the horizontal projection of Washington State Plane North, NAD 1983 feet and vertical projection of NAVD 1988 feet. Model results are available in ASCII (comma delimited) format for each model run, SMS format (a post processing software), and also as ARCGIS shape files.

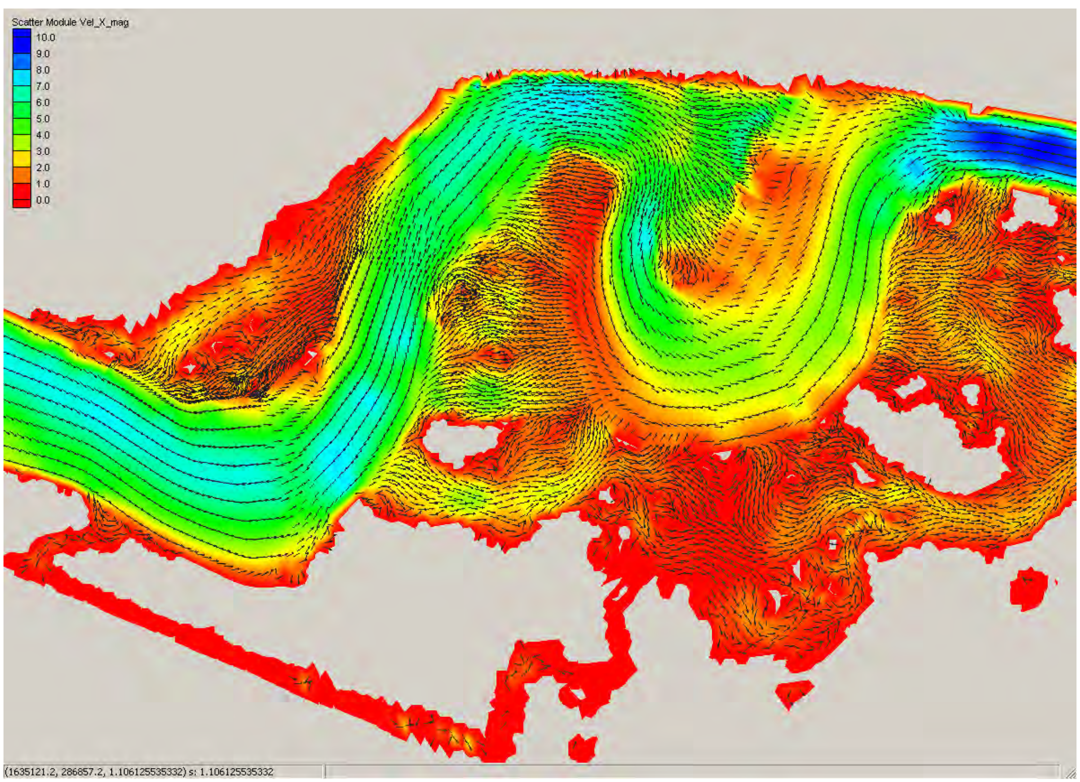

Figure 1. Example of 2D model velocity vectors (black arrows) and magnitude (color coded legend in ft/s) results around RM 12.7 to 13.3 where flow path along channel and floodplain differ.

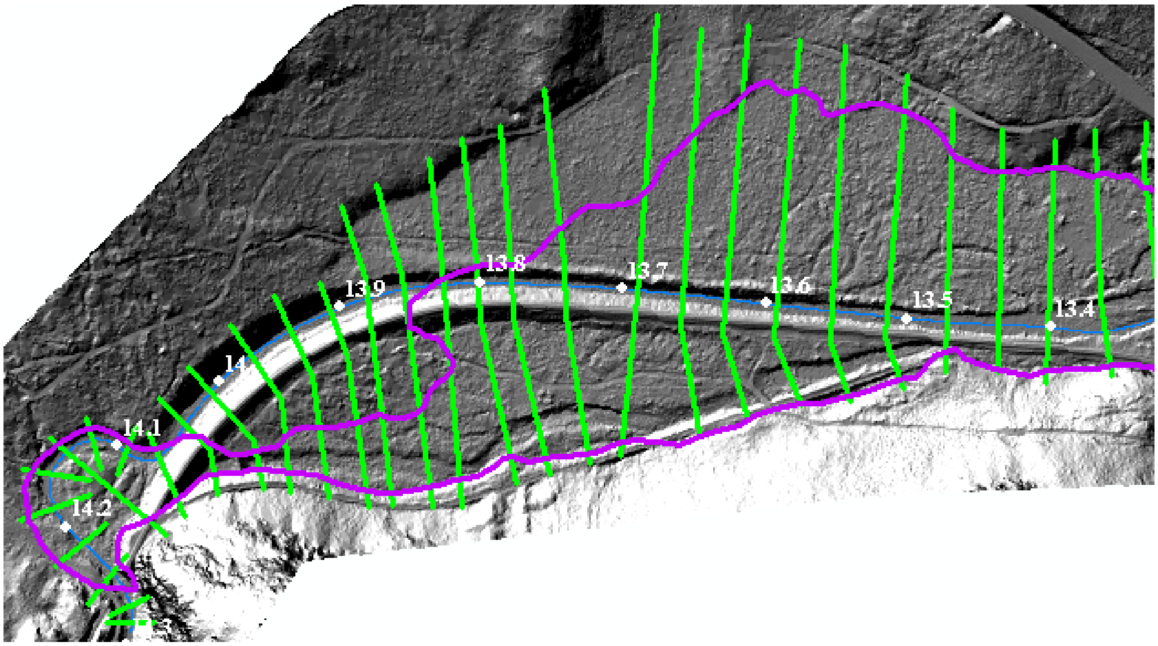

Figure 2. Example of 1D model cross-sections generated (green lines) along with geologic floodplain boundary (purple) for RM 13.4 to 14.3 shown on hillshade from 2006 LiDAR.

2. MODEL SETUP

Hydraulic analysis includes the following steps:

1. Selection of the solution domain (model boundaries)
2. Mesh generation for the solution domain
3. Delineation of Manning's roughness parameters on mesh
4. Topographic representation of the mesh (transforms mesh to a "grid" by applying elevations of input survey data)
5. Selection of computation parameters and boundary conditions

2.1 Solution Domain (Model Boundaries)

Two independent model meshes were generated to capture each of the two geomorphic reaches 1 and 3 that contain complex off-channel areas and floodplain (Table 1). LiDAR data was available from RM 0 to 14.4. The upstream and downstream boundaries were chosen where there is a naturally confined section with fairly uniform hydraulics. The exception was the downstream end of the reach 1 model, where the floodplain was more extensive. Because there was not an ideal location to cutoff the model, the model boundary went slightly downstream of the geomorphic reach boundary to help eliminate any errors associated with the boundary. The lateral boundaries of the solution domain were selected based on geologic features that limit the extent of flood inundation such as alluvial fans, terraces, bedrock, etc.

Table 1. Summary of solution domains for both 2D models.

Geomorphic Reach Represented	1D and 2D Model Extent	Upstream Boundary	Downstream Boundary	Model Reference Name
1 (RM 4.6 to 8.9)	RM 4.3 to 9.4 (5.1 miles)	Naturally confined section (geomorphic reach 2)	Moderately confined section with highway embankment	RM 5 to 9 Model
3 (RM 9.4 to 14.3)	RM 9.2 to 14.3 (5.1 miles)	Bedrock constriction just upstream of White Pine Bridge	Naturally confined section (geomorphic reach 2)	RM 9 to 14 Model

2.2 Mesh Generation

SRH-W uses a combination of structured and unstructured mesh cells. For Nason Creek, a combination of quadrilateral and triangular meshes was utilized. A pre-processor program SMS (version 8.1) was used to generate the mesh for existing and human feature removed conditions. The following web site link provides more information for the software: www.scientificsoftwaregroup.com. The SRH-W user's manual (Lai 2006) provides an in-depth discussion on how to use SMS to prepare a 2D mesh for use by SRH-W.

The mesh was broken into unique polygons based on an iterative procedure. Polygons were initially based on roughness variations (e.g., main channel, vegetated floodplain, and unvegetated floodplain). Polygons were then further sub-divided to allow proper representation of flow lines, such as in meander bends. The final iteration was to sub-divide polygons in areas where tighter mesh cell density was needed such as along road and railroad embankments where it was important to capture absolute maximum elevations that could impact flow connectivity within the floodplain. The existing conditions mesh was also utilized to represent the human features removed conditions.

The mesh has the following features:

- Combined structured and unstructured mesh with quadrilateral and triangular element configurations
- Number of elements
    - 118,349 elements (mesh cells) for RM 5 to 9
    - 296,441 elements (mesh cells) for RM 9 to 14
- Number of nodes
    - 110,711 nodes for RM 5 to 9
    - 161,580 nodes for RM 9 to 14
- 20 cells generally used across active, unvegetated 2006 channel
- Tightest density of cells used in channel areas and areas with rapid changes in elevation with respect to horizontal distance
- Lesser density of cells was used in floodplain areas where there is less elevation change (topographic relief)

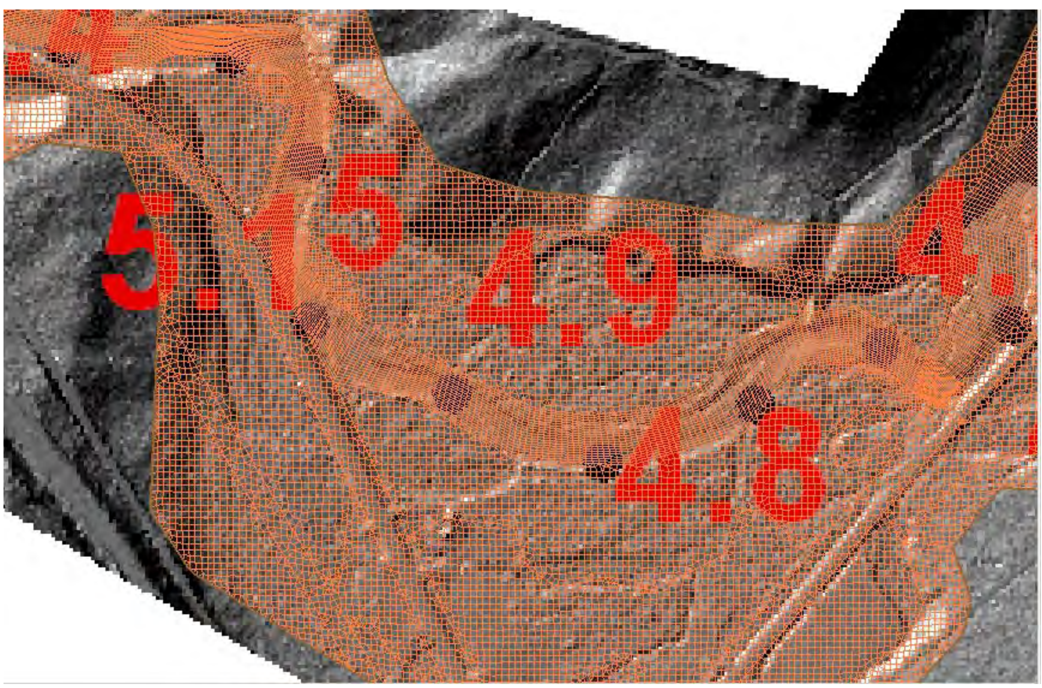

Figure 3. Example of mesh solution with river miles shown in red text and brown circles (background is 2006 LiDAR hillshade).

2.3 Roughness Delineation

Flow resistance is quantified in SRH-W using the Manning's roughness coefficient, and as such is one of the model inputs. Manning's coefficient is usually distributed spatially, according to the surface roughness type in the solution domain. Delineation of roughness polygons was done in ARCGIS version 9.2 using a 2006 aerial photograph generated from the U.S. Department of Agriculture "National Agriculture Imagery Program" (NAIP), 2006 aerial photography collected by Watershed Sciences for this geomorphic effort, and a vegetation model from 2006 LiDAR data illustrating canopy heights. Because the model objectives are focused on off-channel and floodplain connectivity and each model is 5-miles in length, roughness polygons were broken into four general categories: 1) unvegetated channel area, 2) cleared, 3) densely vegetated floodplain, and 4) sparsely vegetated floodplain (example shown in Figure 4 and Figure 5). Roughness value selection is discussed in the calibration section of the report.

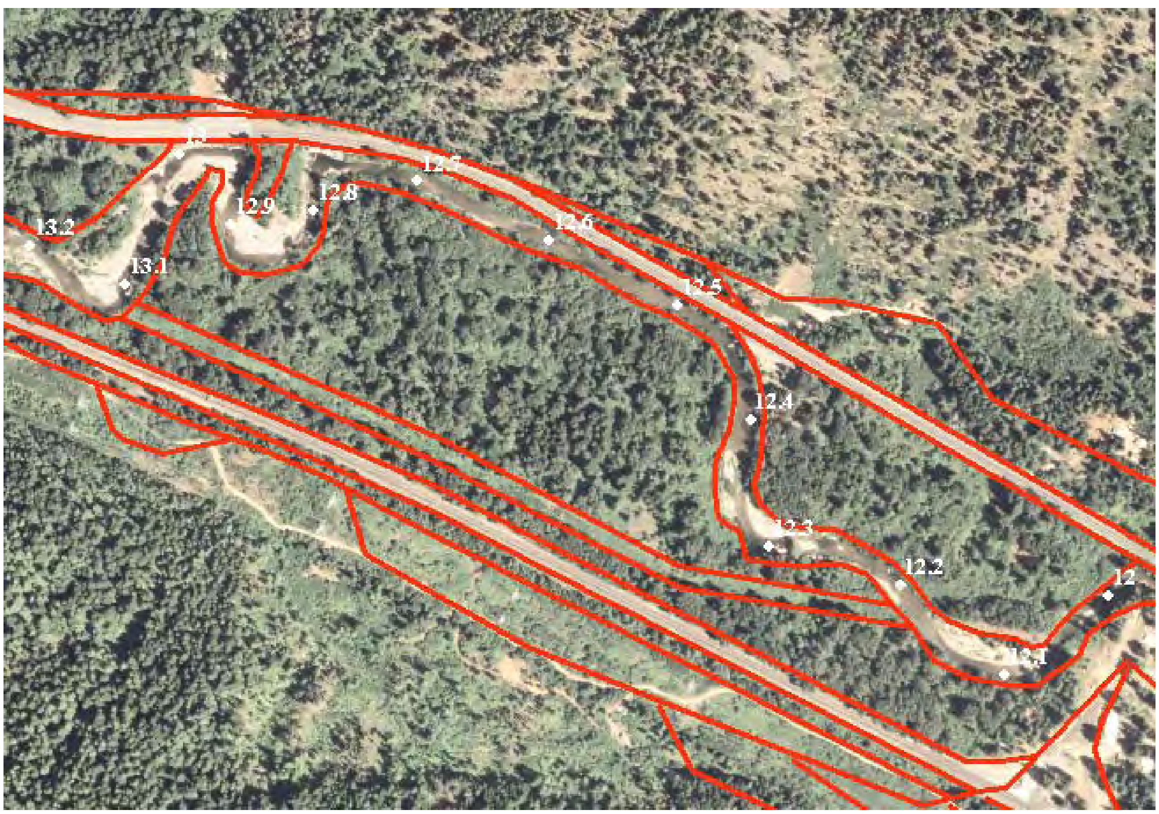

Figure 4. Example of roughness delineation for 2D model mesh for the extent of the model boundary.

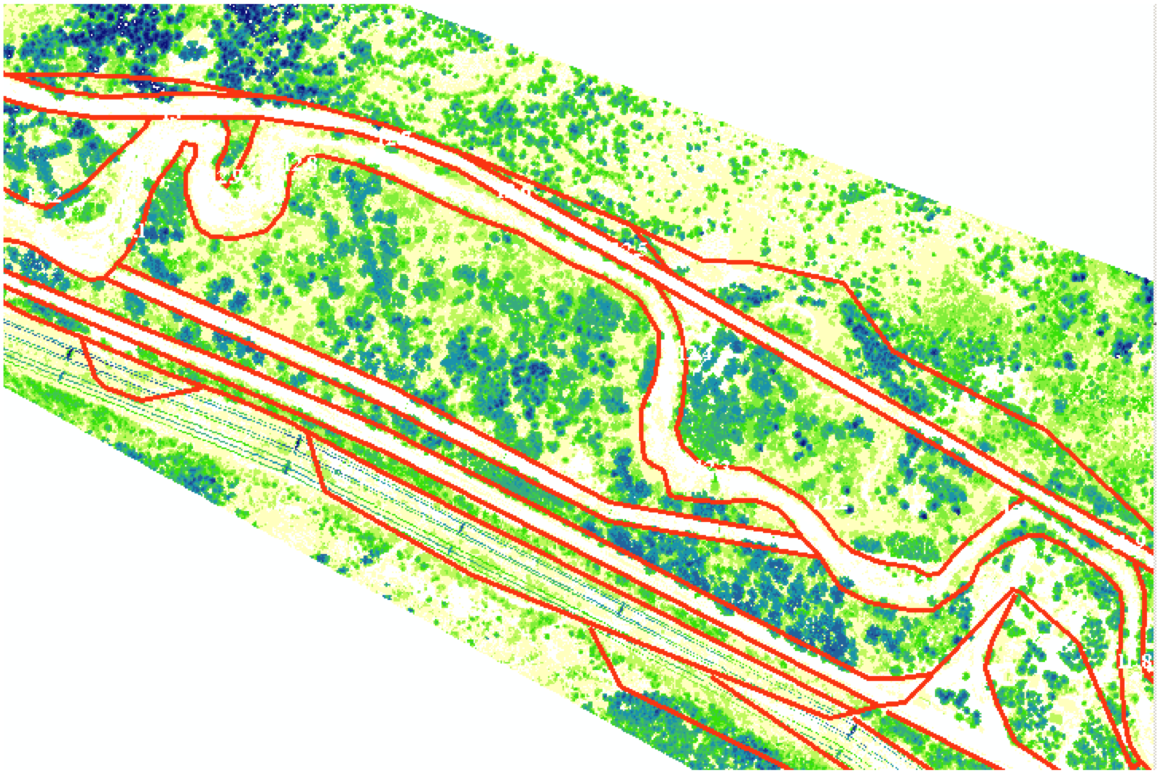

Figure 5. Example of vegetation height model from 2006 LiDAR data used for roughness delineation.

2.4 Topographic Representation of Mesh

The terrain grids generated for 2D modeling of geomorphic reaches 1 and 3 are listed in Table 2. Topography data used to populate the existing conditions grid with elevations was a 10-foot grid derived from bare-earth 2006 LiDAR data collected at a flow of 40 cfs. The bare-earth LiDAR elevation points had to be reduced from a 3.3-foot grid to a 10-foot grid to accommodate processing limitations of SMS, a program used to develop the mesh and grid for input to SRH-W. In the RM 9 to 14 grid, embankment areas were supplemented with original LiDAR data to ensure crest heights of embankments that limit flow connectivity were captured correctly. For the human features removed grid, features were removed that were raised above the nearby ground such that they would impact flow connectivity between the main channel and floodplain (e.g. levees, road embankments, railroad embankments). Houses, infrastructure, and features such as power line poles were not removed.

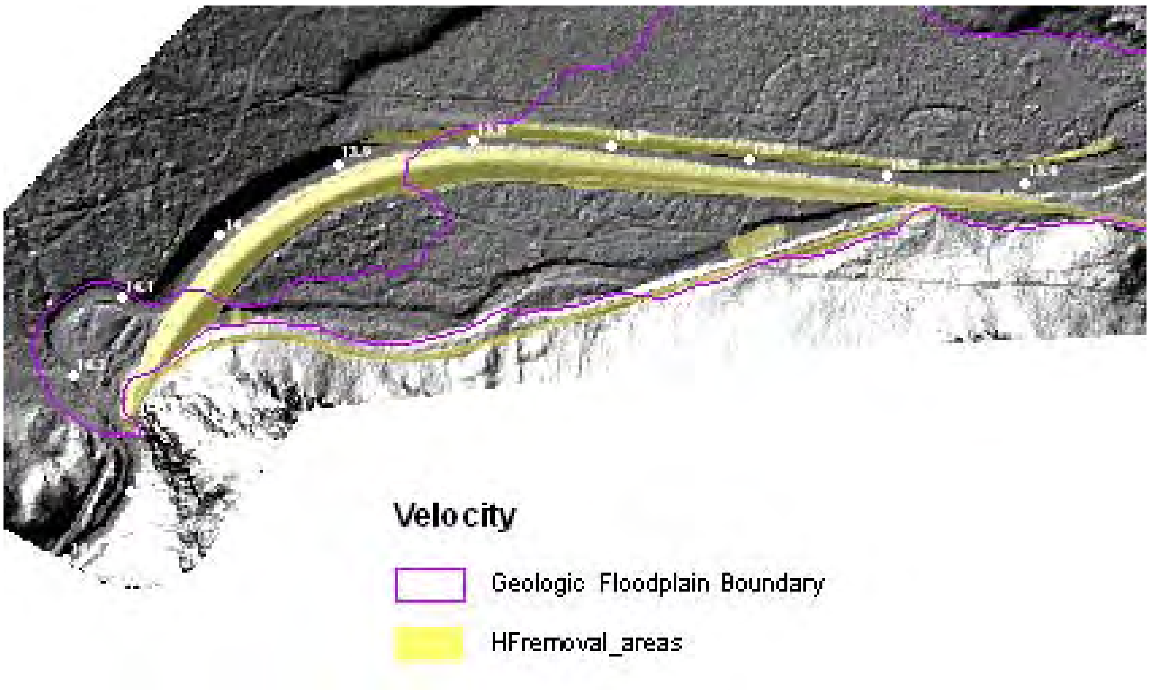

Figure 6. Example of human features removed that impede flow connectivity within the geologic floodplain boundary.

Bare-earth LiDAR data does not represent the true ground elevation of wetted areas during the survey (Figure 7); however, bed elevations in very shallow portions of the river such as riffles were determined to be properly represented because a significant portion of the bed material was exposed in these areas. A longitudinal profile of the channel bottom (thalweg) was later surveyed by foot (combination of RTK GPS and total station) in 2007 and could be incorporated into the grid development for future modeling efforts. A comparison of the LiDAR and ground surveys in very shallow areas indicates that elevations are within one foot of each other. More details of this comparison can be found in Appendix G (Channel Slope and Survey Data). No ground elevation data were collected in ponded areas outside of the main channel during the 2007 ground survey. In deep pools the LiDAR is unreliable for determining bed elevations due to the inability of red light to penetrate the water column. Even though the thalweg is not represented in deep pools, the hydraulic controls that have the greatest impact on water surface elevations (riffles) are properly represented, thus the water surface elevations and off-channel and floodplain connectivity is well represented in model results at discharges greater than 40 cfs. Although the water surface elevations are within a few tenths of a foot in pool areas, localized model results for depth, velocity, Froude number, and shear stress are not well represented. Due to the lack of detailed channel bottom data, model results at discharges less than 40 cfs will be unreliable.

Table 2. List of grids created for 2D modeling.

Reach	Scenario	Grid Name	Topographic Data Notes	Elevation Range (NAVD 88 ft)
RM 5 to 9 (Geomorphic Reach 1)	Existing	NC_RM5to9_Existing.2dm (Figure 8)	10 foot grid from bare earth 2006 LiDAR data	1946 to 2256
RM 5 to 9 (Geomorphic Reach 1)	Human Features Removed	NC_RM5to9_HFRemoved.2dm (Figure 9)	Delineated human features in ARCGIS where elevations are higher than natural ground (e.g. levees, roads, railroad); removed these elevation points from model input data and allowed the tin to connect natural ground from either side of the feature to create new surface	1946 to 2256
RM 9 to 14 (Geomorphic Reach 3)	Existing	NC_RM9to14_Existing4.2dm (Figure 10)	10 foot grid from bare earth 2006 LiDAR data; delineated human features in GIS where elevations are higher than natural ground (e.g. levees, roads, railroad); supplemented 10 ft grid in these areas with original 1 m bare earth LiDAR data to capture crest heights of features; used for higher flows to ensure overtopping was correctly captured	2132 to 2468
RM 9 to 14 (Geomorphic Reach 3)	Human Features Removed	NC_RM9to14_HFRemoved3.2dm (Figure 11)	Delineated human features in ARCGIS where elevations are higher than natural ground (e.g. levees, roads, railroad); removed these elevation points from model input data and allowed the tin to connect natural ground from either side of the feature to create new surface	2132 to 2468
RM 9 to 14 (Geomorphic Reach 3)	Human Features Removed and Channel Modifications	NC_RM9to14_ChanMod3.2dm (Figure 12and Figure 13)	Modified channel to fill in engineered channel areas and reconnect historical main channel to present channel at RM 13.3 to 14.3 and RM 10.7 to 11;	2132 to 2468

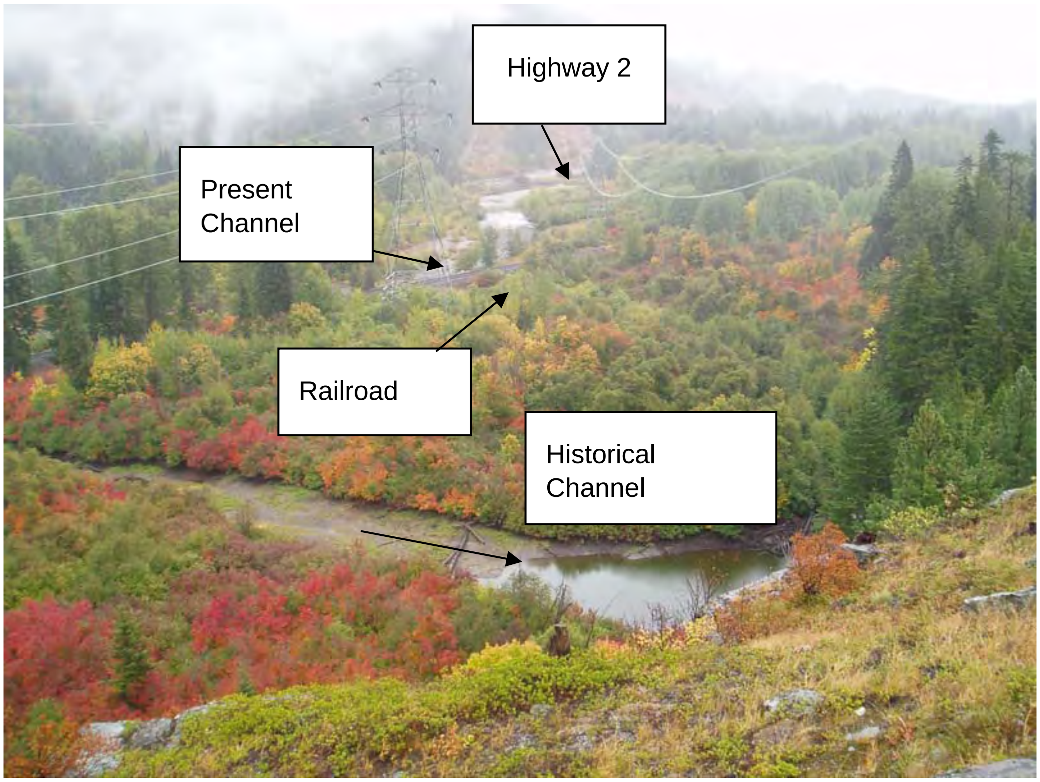

Figure 7. Example showing wetted channel and ponded areas where underwater elevations are not represented in 2D model grid.

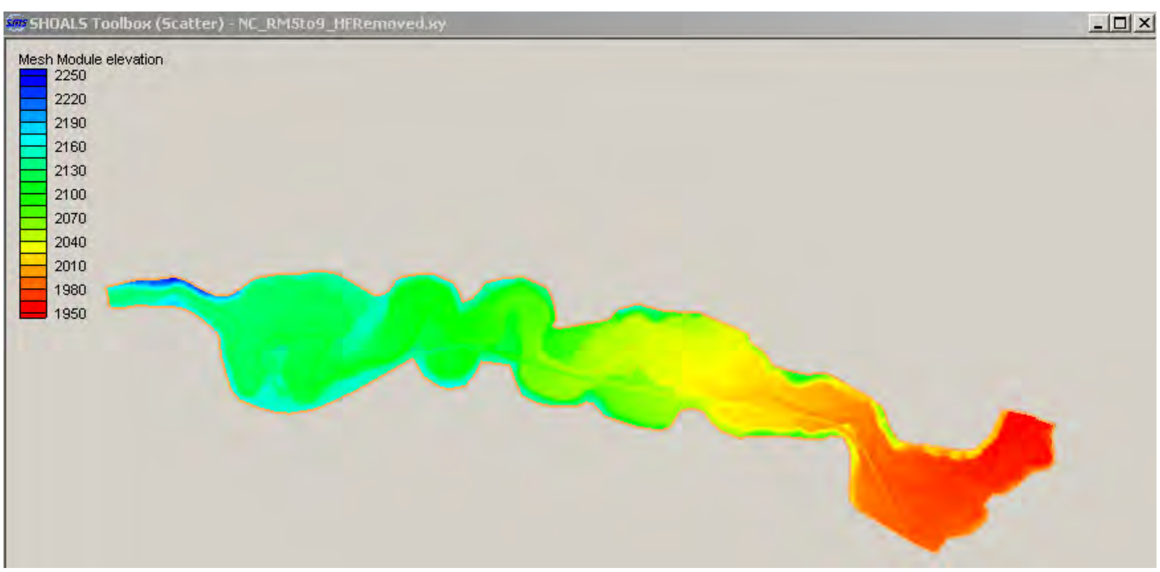

Figure 8. Existing conditions grid for RM 5 to 9.

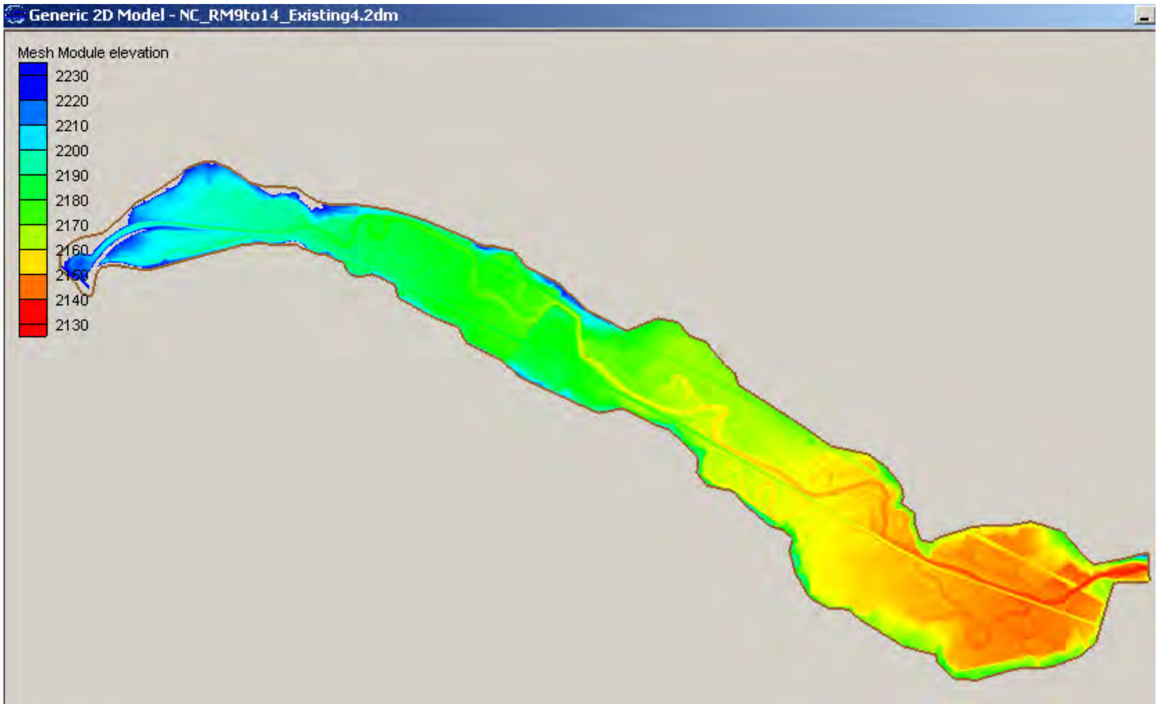

Figure 9. Existing conditions grid for RM 9 to 14.

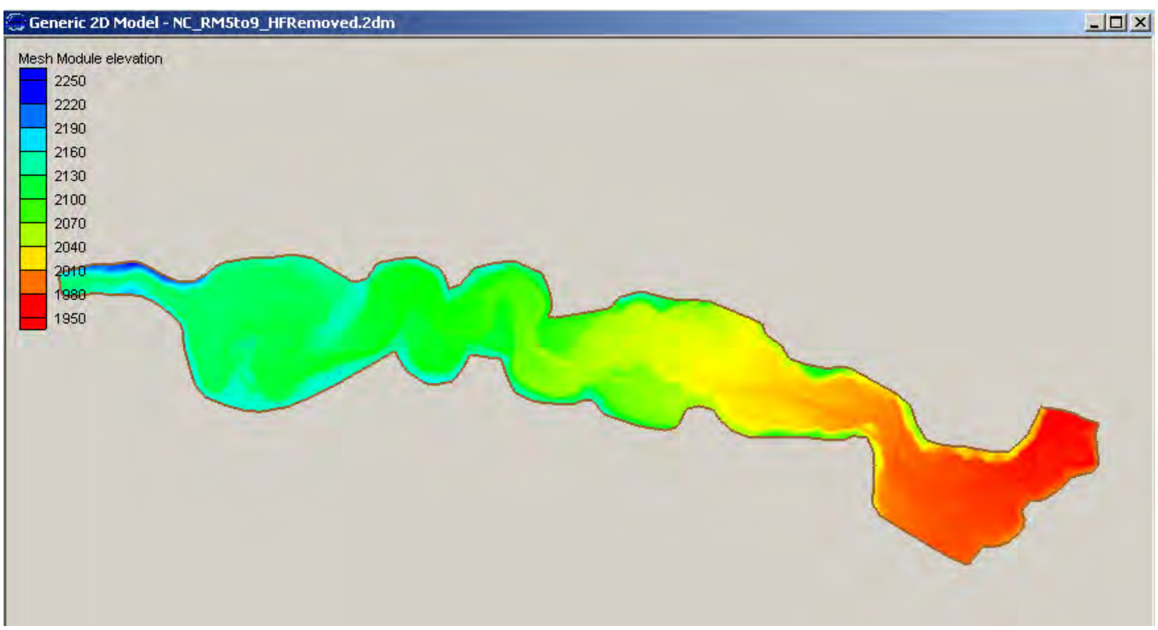

Figure 10. Human features removed grid for RM 5 to 9.

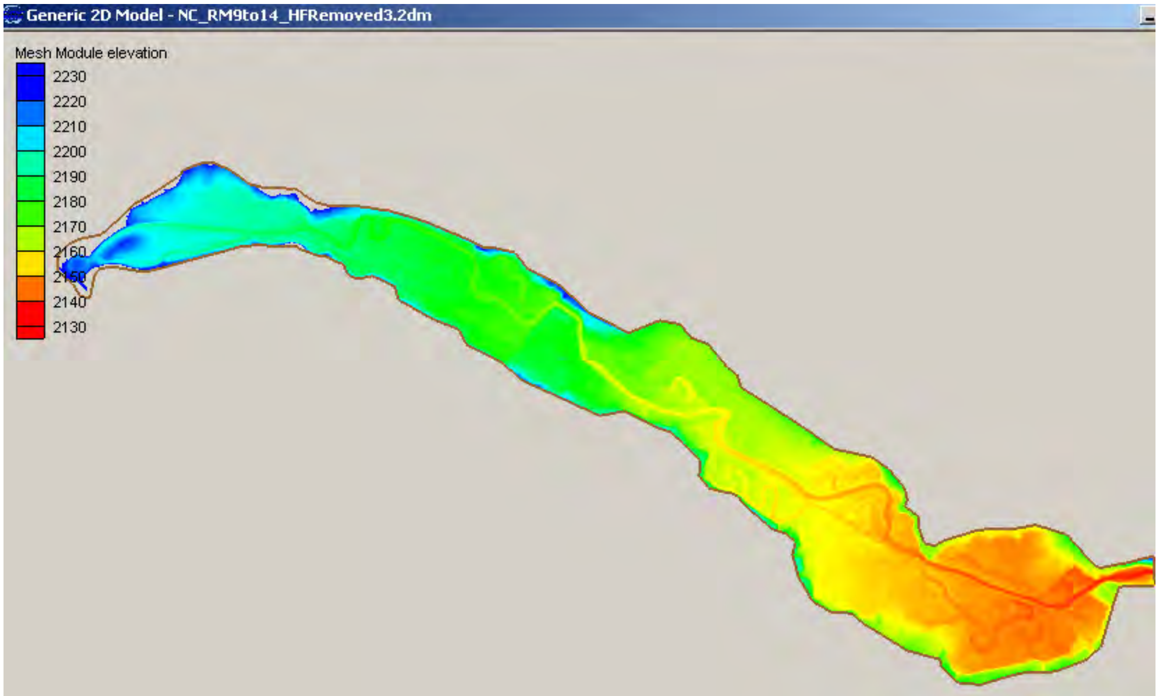

Figure 11. Human features removed grid for RM 9 to 14.

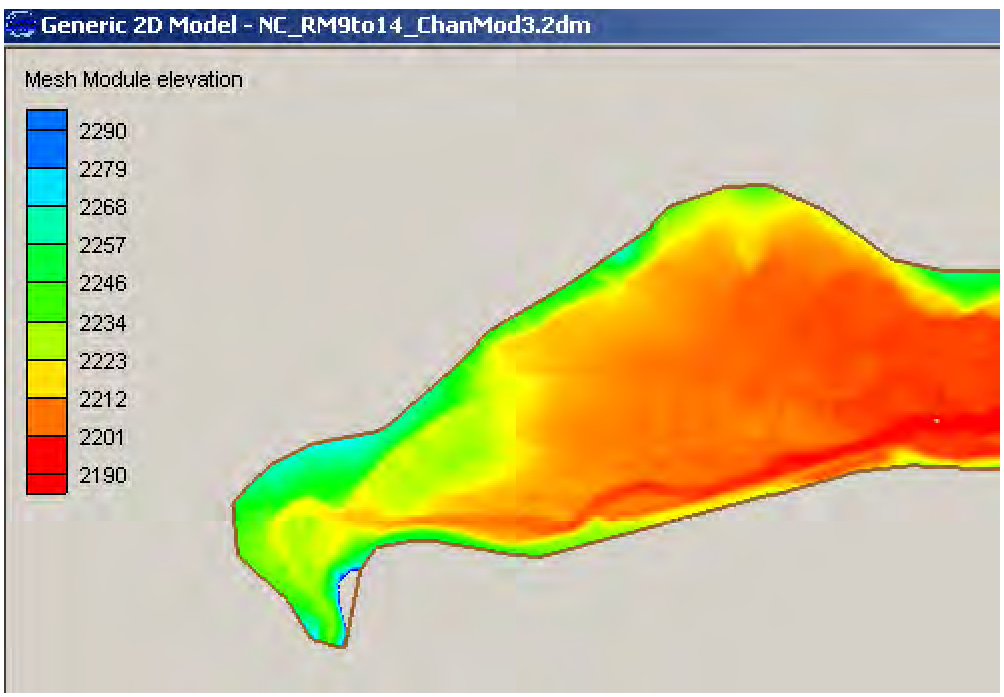

Figure 12. RM 13.3 to 14.3 where present channel was filled in to evaluate flow connectivity if only historical channel were inundated.

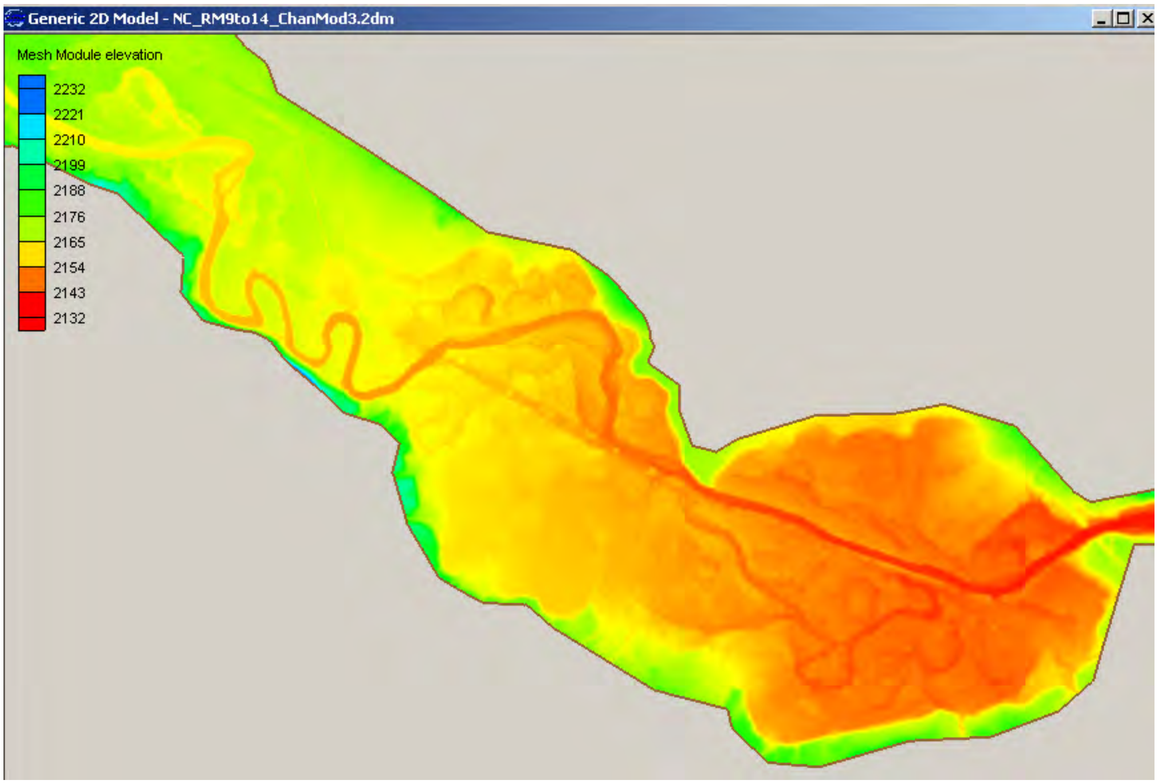

Figure 13. RM 10.7 to 11.0 where present channel was filled in to evaluate flow connectivity if only historical channel were inundated.

2.5 Computation Parameters and Boundary Conditions

A time step, total computation time, upstream boundary condition of discharge, and downstream boundary water surface elevation must be input to SRH-W prior to running a simulation. Selection of these parameters is discussed in this section.

2.5.1 Time Step and Duration

A time step of 5 seconds was chosen and initially ran for 86,400 time steps (432,000 seconds or 120 hours). Model results were output at intervals of 900 or 1800 time steps, which equals every 1.25 to 2.5 hours. A computation time duration was chosen that was long enough such that results appeared to be hydraulically stable and were not significantly changing with additional computation time. A hydraulically stable result was defined as having no unrealistic values of velocity or Froude number from both an absolute magnitude and relative to location in the main channel or floodplain (e.g., smaller velocities in shallow overbank areas, higher velocities around outside of meander bends, etc.). To test the model run times, results were compared for a flow of 2,500 and 15,000 cfs in the RM 5 to 9 reach for existing conditions at different durations (example comparison shown in Figure 14). The results were nearly identical at half the total computation time, so subsequent runs were often shortened to be more efficient in computer processing time.

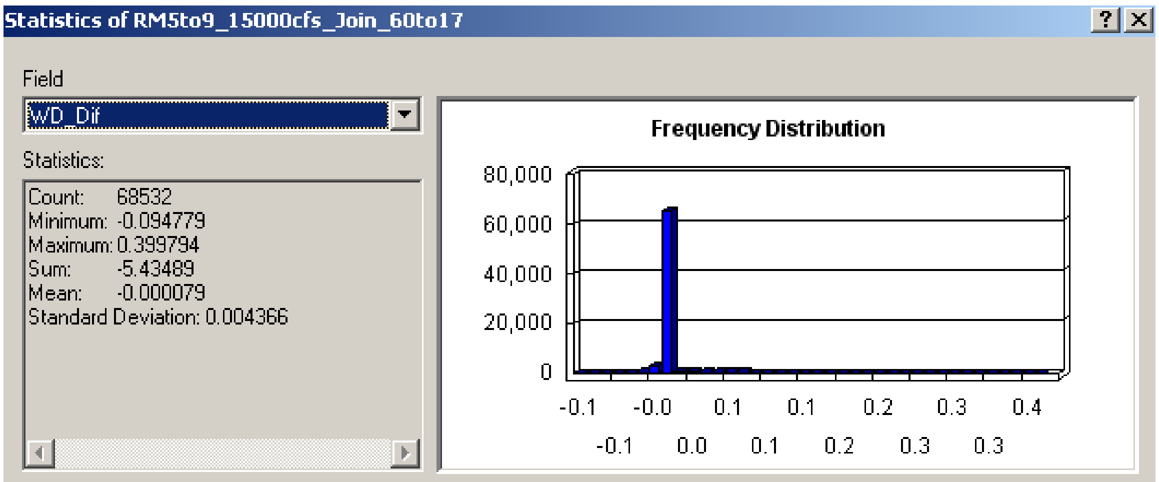

Figure 14. Comparison of model results at two computation intervals for 15,000 cfs for RM 5 to 9 existing conditions grid.

2.5.2 Modeled Discharges

USGS gage data from Icicle Creek and the Washington Department of Ecology (DOE) gage data at RM 0.8 was used to develop flood frequency values to help choose the discharges modeled. However, flow data at this gage has only been collected since 2002, which provides about 5 years of data. The highest flow recorded was slightly less than 10,000 cfs. Additionally, discharge varies with drainage area and generally increases in the downstream direction, so that a 100-year flood value at RM 0.8 is much different than at the upper end of the 2D modeling near RM 14. Upstream flow reduction for each flood frequency value was estimated using a relationship of flow and drainage area (see Hydrology appendix for methods; Figure 15). Because modeling was done with steady flows and not hydrographs, a series of flows were used in 5,000 cfs increments ranging from 2,500 to 15,000 cfs, which covers the range of 2- to 100-year estimated flood values for RM 4 to 14.

The DOE suggests that the margin of error is 5 percent for flows measured below 1,200 cfs and 15 percent for flows measured above 1,200 cfs; stage measurements are noted to have a 0.02 foot margin of error (Springer 2005). Additionally, the flood frequency values also have uncertainty of up to 30 percent for the 100-year flood because of limited gage data available on Nason Creek (Appendix D – Hydrology). Therefore, a combination of model results should be used when thinking of a 10- or 100-year flood result depending on the location.

For comparison, the 100-year flood reported in the 1980s FEMA study for Nason Creek was 6,200 cfs near RM 6, and about 4,100 cfs at the White Pine railroad bridge (RM 14.3) (Figure 16). These flood frequency values were not based on any gage data from the Nason Creek watershed, and are lower than values updated with DOE gage data. The DOE gage at RM 0.8 (107.8 sq miles) has estimated values for the following peak flows;

- Water Year 2007: November 2006, 9,940 cfs instantaneous peak (peak under review at DOE and may be changed; as of June 2008 new November peak listed as 4,960 cfs)
- Water Year 2006: May 2006, 6,440 cfs instantaneous peak (estimated value)
- Water Year 2005: January 2005, 4,950 cfs instantaneous peak (estimated value)
- Water Year 2004: November 2003, 3,150 cfs estimated instantaneous peak
- Water Year 2003: January 2003, 5,780 cfs instantaneous peak (estimated value)

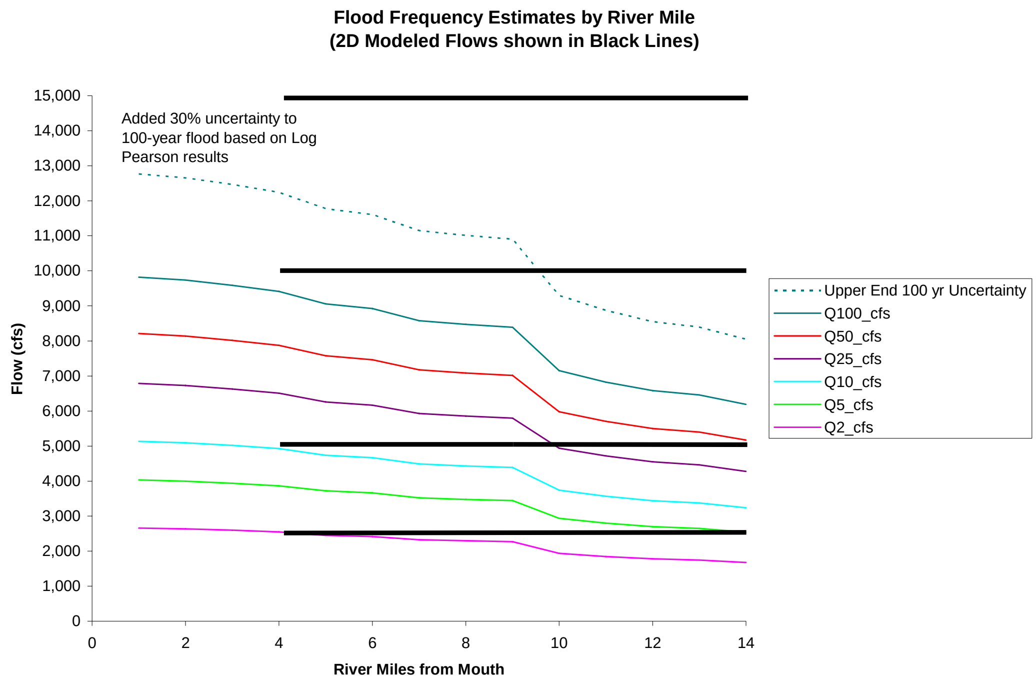

Figure 15. Comparison of modeled flows of 2,500, 5,000, 10,000, and 15,000 cfs (black lines) for RM 4 to 14 versus computed flood frequency estimates (e.g. Q 100_cfs is 100-year flood) that change longitudinally by river mile.

Table 1. Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second (cfs)) 10-Year	50-Year	100-Year	500-Year
Wenatchee River					
At Monitor Gage	1,301	26,500	38,500	48,700	82,000
At Dryden Gage	1,155	25,700	36,863	46,372	78,289
At Peshastin Gage	1,000	24,300	34,000	42,300	71,800
At South Line S34, T26N, R17E	606	17,600	21,500	23,000	26,000
At Plain Gage	591	17,500	26,500	34,100	62,800
At Lake Gage	273	10,000	12,100	13,000	14,800
Mission Creek					
At Southern City Limits of Cashmere	82	660	1,780	2,600	5,700
Peshastin Creek					
At Mouth	143	1,980	3,210	3,790	5,130
Icicle Creek					
At Mouth	213	7,930	11,000	12,360	15,650
Chumstick Creek					
At Mouth	82	900	1,430	1,720	2,810
At Eagle Creek Road	50	560	900	1,200	1,820
At Cross Section AP	41	470	760	930	1,520
At Sunitsch Canyon Road	31	400	640	770	1,250
Chiwawa River					
At Mouth	190	4,900	6,500	7,200	8,800
Nason Creek					
At Kahler Creek Bridge	98.6	4,270	5,860	6,590	8,250
Above Kahler Creek Confluence	91.2	3,990	5,490	6,170	7,720
Below Butcher Creek Confluence	87.5	3,850	5,290	5,960	7,460
Below Roaring Creek Confluence	76.3	3,430	4,720	5,320	6,670
Above Gill Creek Confluence	70.8	3,220	4,440	5,000	6,260
At Merritt	67.5	3,090	4,270	4,810	6,020
At Burlington Northern RR Bridge	64.2	2,960	4,090	4,610	5,780

Figure 16. Flood frequency values reported in 1980s FEMA analysis on Nason Creek.

2.5.3 Downstream Boundary Water Surface Elevation

A downstream boundary condition of water surface elevation is needed for each upstream boundary of discharge (Table 3). Preferably, a known rating curve of water surface elevation versus discharge is used for the downstream boundary, but was not available in this case except at RM 0.8 at a gaging station which is too far downstream to be used for either model. For the RM 9 to 14 model boundary, the output results from the RM 5 to 9 2D model were used to generate a downstream water surface elevation value. The boundary for the RM 5 to 9 model had to be generated from a 1D model as described below. Because both models had estimated boundary conditions, model results in the vicinity of the boundaries may not be accurate and should be used with caution.

Table 3. Boundary conditions for modeling.

Upstream Flow Input (cfs)	RM 5 to 9 Downstream Boundary Water Surface Elevation		RM 9 to 14 Downstream Boundary Water Surface Elevation	
	(m)	(ft)	(m)	(ft)
40	593.69	1947.79	650.53	2134.30
2500	594.96	1951.98	651.74	2138.25
5000	595.38	1953.34	652.80	2141.73
5666	595.45	1953.59	653.74	2144.81
10000	595.84	1954.85	654.01	2145.70
15000	596.20	1956.03	654.98	2148.90

The water surface elevation for the RM 5 to 9 model was based on a normal depth assumption using a 0.0067 slope derived from the water surface elevation slope (Appendix G – Channel Slope and Survey Data). A downstream boundary of water surface elevation is needed for the 2D model, so this slope assumption was input into a 1D HEC-RAS model also created from the 2006 LiDAR data. The 1D model was used to generate a water surface elevation for input to SRH-W. A 1D HEC-RAS model was also available from a previous effort funded by Chelan County with topography based on cross-section data. Because the LiDAR data was utilized to generate the grid for the 2D model, it was assumed the new 1D model based on LiDAR would be more accurate to develop downstream boundary conditions. To improve the accuracy of the downstream boundary input data, the 1D model could be extended so its boundary was at the DOE gage. The established discharge-elevation rating curve at the gage could be used for the boundary of the 1D model instead of slope, and then the computed elevation at the point of interest used for the 2D model downstream boundary.

A sensitivity analysis was performed for the RM 5 to 9 model at 5,000 cfs (near bankfull) with the boundary raised and lowered an arbitrary value of 1 foot to estimate the extent of influence on model results. At 5,000 cfs, the extent of river where the water surface elevation differed by more than 0.1 feet was limited to about 1/10 of a mile upstream from the downstream boundary. Other discharges were not tested.

3. MODEL CALIBRATION AND VALIDATION

Calibration of the model is an iterative process used to adjust roughness parameters and the topographic representation of the grid (if needed) to match measured data at a range of flows and scenarios. The measured data typically represents existing (or very recent) conditions, but in some cases may represent historical conditions with a different grid. Measured data can include water surface elevations, inundation boundaries, velocities, or water depths. The calibrated model is then validated by running at one or more flows with additional measured data not used in the calibration process. Both processes should cover the range of flows of interest.

Within the Nason Creek modeling boundaries, limited hydraulic data was available to either calibrate or validate the hydraulic model results. Additionally, the discharge is estimated to change longitudinally, and is only measured at RM 0.8, downstream of both models. Measured water surface elevation and depth was collected in 2007 at a low flow of 40 cfs, but this flow does not represent the majority of flows modeled (2,500 to 15,000 cfs). Additionally, because the 2D model grid was based on LiDAR and did not incorporate the 2007 channel thalweg, the modeled water surfaces are slightly higher in elevation than measured values (because the channel bottom is approximately modeled as water surface elevation at 40 cfs). The only data available to calibrate with were six photographs taken during May 2006 which are described in Section 3.2. No data was available to validate the model.

3.1 Selection of Roughness Values

Roughness values were based on past modeling experience in similar channel environments. A slightly higher roughness value was used in the channel for 40 cfs because of the shallower depths where coarse sediment would have more influence. For comparison purposes, the FEMA report documents Manning's n values for the Nason Creek 1D modeling in the 1980s ranged from 0.038 to 0.050 for the channel and 0.080 to 0.100 for overbank areas (FEMA 2004).

Table 4. Roughness values selected for 2D modeling.

Description	40 cfs	2,500 to 15,000 cfs
Unvegetated Main Channel	0.05	0.04
Cleared Overbank	0.03	0.03
Densely Vegetated Overbank	0.08	0.08
Sparsely Vegetated Overbank	0.06	0.06

3.2 Inundation Comparison during May 2006 Snowmelt Runoff

Six high flow photographs were available that show inundation from a May 19, 2006 spring snowmelt flood at RM 0.8 (location not modeled), 5.5, 6.6, 10.5, 13.2, and 14.2 (Table 5). The estimated mean daily flow at the DOE gage (RM 0.8) on the day of the photographs was 5,650 cfs, which is between a 10- and 25-year flood (Appendix D – Hydrology). The flood started on May 15 and went into June. Estimates of flow reduction by river mile were made for the May 19th flood based on a drainage area relationship with discharge (Appendix D – Hydrology). This approach suggests the flow was approximately 4,900 cfs at RM 9, and only 3,600 cfs at RM 14.

Model inundation results from 5,000 cfs were reasonably matched with the photographs between RM 5 to 9 (Figure 17 and Figure 18). For the sites above RM 9, the 5,000 cfs model results showed more inundation than observed in the field, and the 2,500 cfs model results showed less inundation. This would be expected given the predicted reduction in flow. Further calibration of roughness should be done using additional field measured water surface elevation data at higher flows if possible for future modeling efforts.

Table 5. Summary of model observations versus field notes for ground photographs during May 2006 flood.

Photograph	Approximate RM	Estimated Q based on drainage area	2,500 cfs model notes	5,000 cfs model notes	Field Notes
N6	0.85	5,600	No data	No data	Flow almost as high as bridge deck near DOE gage;
N1	5.5	5,200		Flow contained in banks; about 2 feet of freeboard to top of right bank	Flow contained in banks; can't see any backchannels

Photograph	Approximate RM	Estimated Q based on drainage area	2,500 cfs model notes	5,000 cfs model notes	Field Notes
N2	6.6	5,100		Less than 0.5 feet flow on parts of island; did not overtop Hwy 2	Flow partially inundating island in split flow; does not overtop Hwy2
N3	10.5	4,100	Gravel bar partially wet	Gravel bar wet	Gravel bar not inundated in photos
N4	13.2	3,700	Gravel bar dry	Gravel bar wet	Gravel bar not inundated in photos; can't see back channels
N5	14.2	3,600	Flow confined to banks	Flow confined to banks	Confined under RR bridge; looks like going into backchannel beyond log jam but hard to see

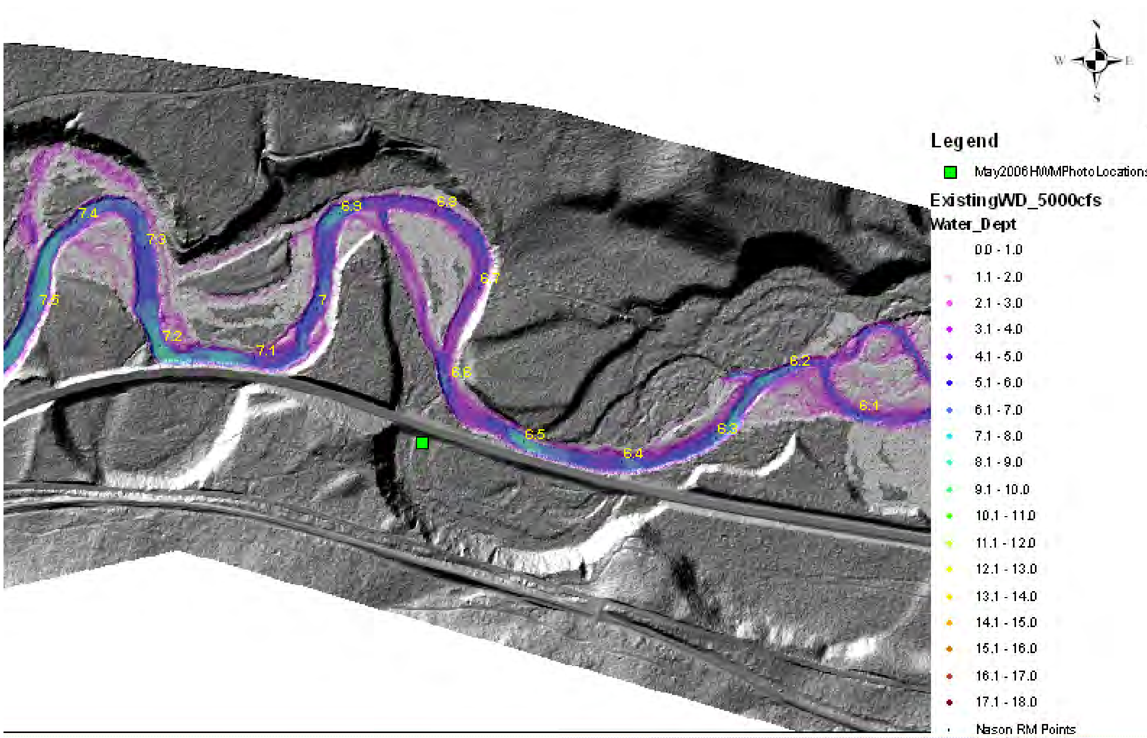

Figure 17. Existing conditions grid with modeled flow of 5,000 cfs for comparison to ground photograph (green square) during May 2006 flood. Flow on the island between the split flow was typically less than 0.5 foot.

Figure 18. Looking upstream at May 2006 flood from locations shown in previous figure (near RM 6.6).

3.3 Comparison with FEMA Floodplain

For comparison, the 100-year flood inundation boundary reported in the 1980s FEMA 1D model study for Nason Creek was compared to 2D model results. The FEMA study reported the 100-year flood as 6,200 cfs near RM 6, and about 4,100 cfs at the White Pine railroad bridge (RM 14.3) (see Figure 16). The model result of 5,000 cfs fell in the middle of these values and was used for comparison. Some areas were very close, but other areas were different. The main differences in results are attributed to use of a dense topographic data set and 2D model approach compared with a 1D model utilizing only cross-section data that may have missed hydraulic controls such as riffles and rapids. Results from the 2D model were based on existing conditions and did not account for backwater through culverts or tributary inflow. The FEMA floodplain boundary between RM 9 to 14 has several areas that show inundation for existing conditions due to backwater from culvert openings or tributary input that is blocked by embankments from reaching the mainstem river.

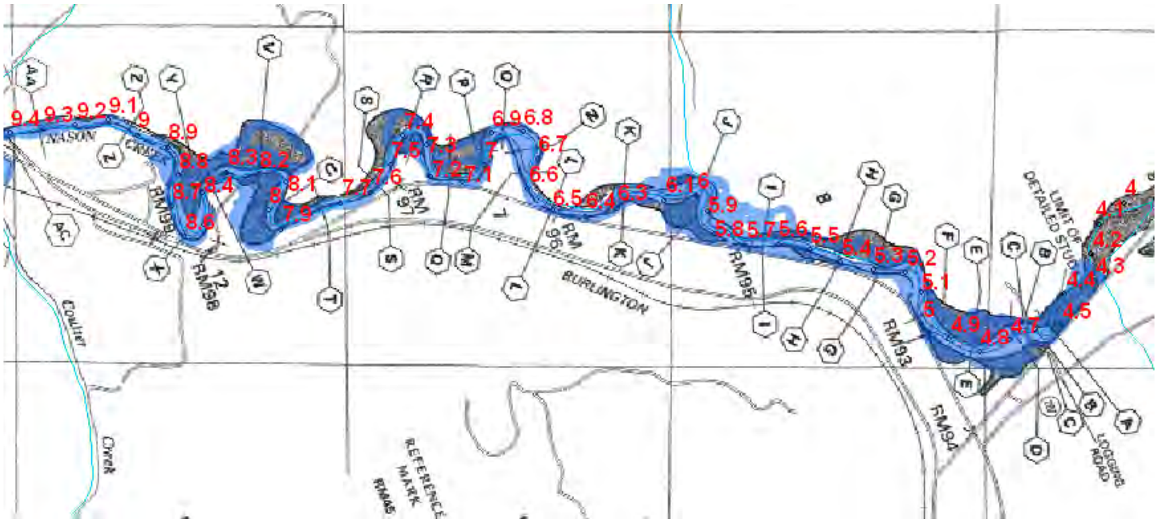

Figure 19. Inundation comparison in geomorphic reach 1 (RM 5 to 9) of 2D model results with FEMA 1D model result.

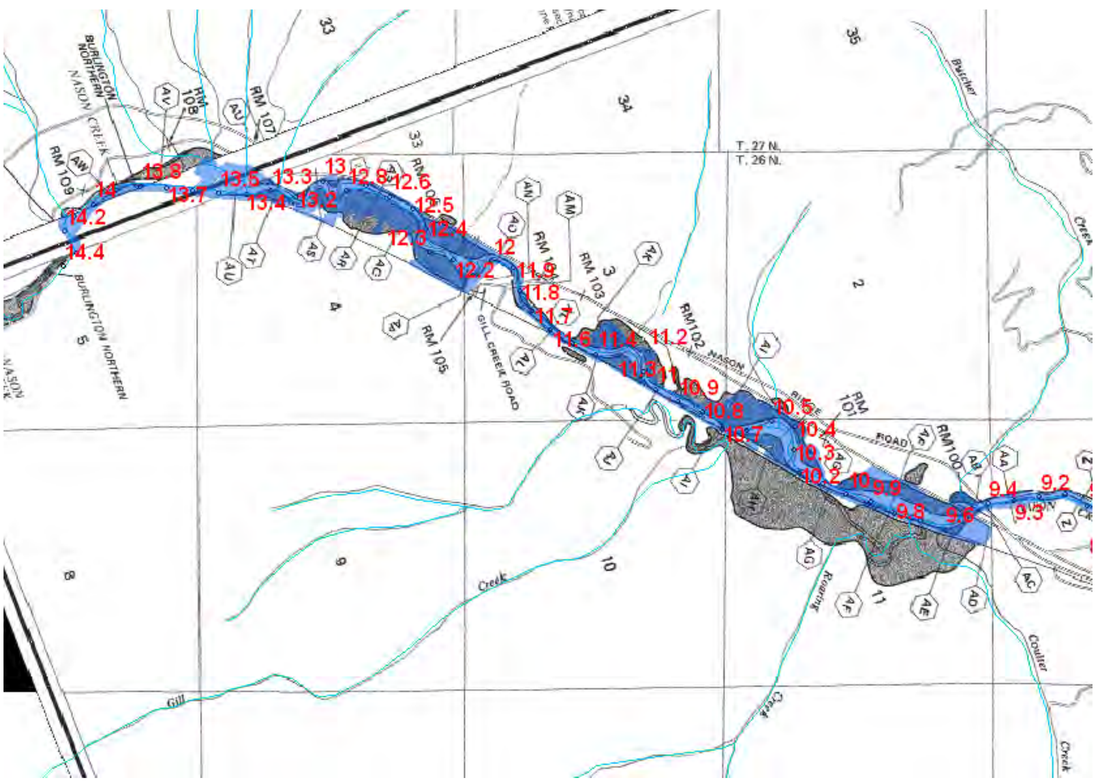

Figure 20. Inundation comparison in geomorphic reach 3 (RM 9 to 14) of 2D model result with FEMA 1D model result.

3.4 Roughness Uncertainty

The impact of uncertainty in roughness was examined by adjusting a Manning's n value of 0.04 by +/- 0.01. A flow of 5,000 cfs was used for the comparison, which is largely contained within the active channel. A change in roughness of +/- 0.01 resulted in a mean change in water surface elevation of +/- 0.3 foot for all inundated grid cells (based on comparison of 2d model result grids in GIS) (Figure 21). Inundation area was slightly larger with a larger roughness but would not change reach-level conclusions of off-channel and floodplain connectivity (Figure 22).

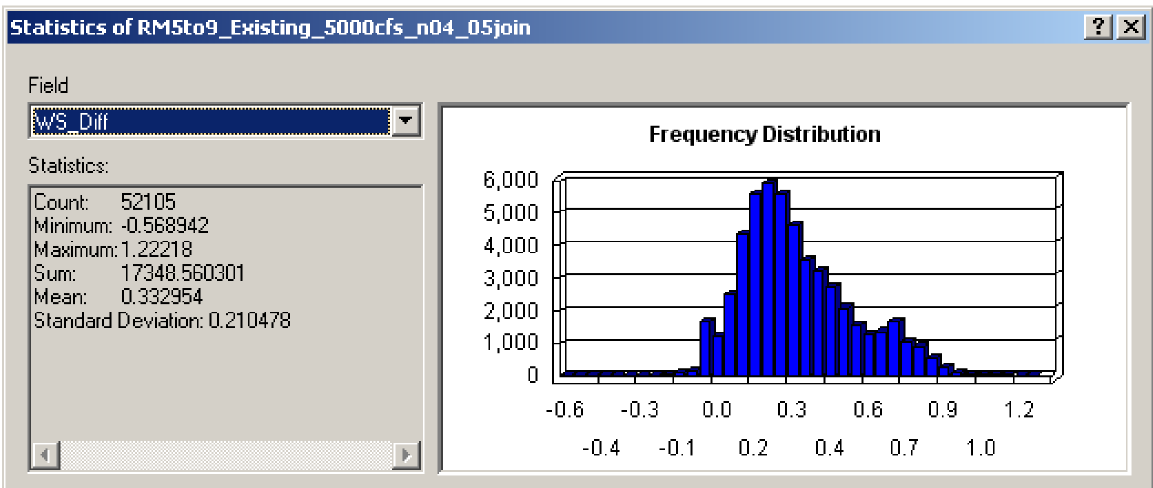

Figure 21. Comparison of water surface elevation difference between 5,000 cfs run with roughness of 0.04 versus 0.05.

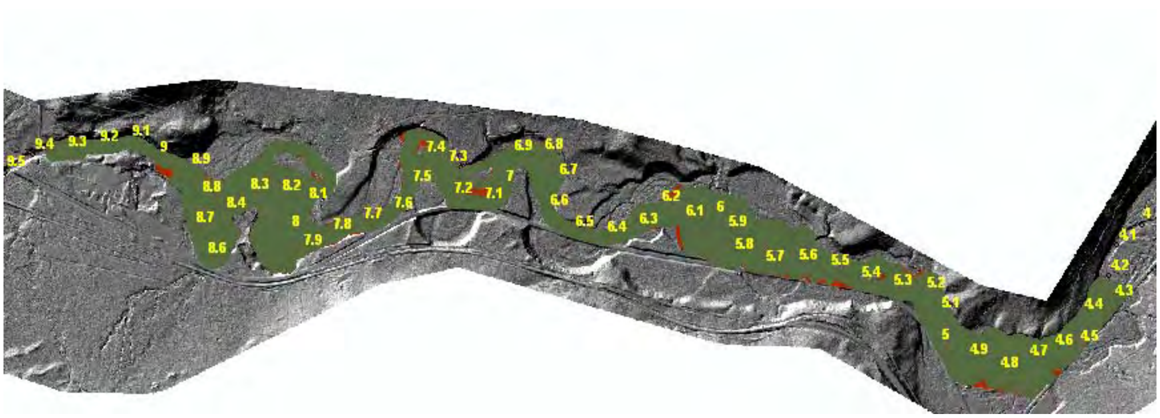

Figure 22. Inundation comparison of roughness of 0.04 (green) versus 0.05 (red) in geomorphic reach 1 for existing conditions. Areas in red represent the additional inundation caused by the higher roughness value in the active channel.

4. MODEL SCENARIOS AND OUTPUT

Two model grids were used that cover RM 5 to 9 (geomorphic reach 1) and RM 9 to 14 (geomorphic reach 3) independently (see Section 2). Modeling was done to represent existing conditions for a range of flows that cover near bankfull conditions to inundation of the majority of the geologic floodplain (Table 6). The purpose of modeling existing conditions was to evaluate current hydraulic conditions and relatively compare geomorphic reaches 1 and 3. Modeling was also done with all human features removed that are raised above the floodplain and block connectivity of flow between the main channel and off-channel and floodplain areas. One additional model run was done with the human features removed grid at 5,000 cfs in RM 9 to 14 that also has two sections of the artificial channel filled in. The purpose of this run was to assist with visualization of potential inundation and hydraulic characteristics if the historical channels and floodplain are reconnected.

Interpretation of inundation, backwater effects and sediment transport capacity results are documented in the main report so they can be integrated with conclusions from the geomorphic mapping. For each model run, a raw output file from SRH-W is available with results for all cells along with a GIS file containing results only in wetted cells.

Hydraulic model result files contain the following parameters:

1. X (easting position of cell value) (ft)
2. Y (northing position of cell value) (ft)
3. Bed elevation from input topography (ft)
4. Water surface elevation (ft)
5. Water depth (ft)
6. Velocity in the X-direction (ft/s)
7. Velocity in the Y-direction (ft/s)
8. Velocity magnitude (ft/s)
9. Froude number ($V/\sqrt{gh}$) (dimensionless)
10. Bed shear stress (lb_f/ft^2)

A few additional runs were done with a newer version of the SRH-W code that compute sediment capacity and incipient motion of sediment (Table 7). Additional model results obtained with the sediment code are:

1. Sediment capacity (lb/ft/s)
2. Critical D50 (mm)
3. Shields parameter

Table 6. List of 2D model runs for RM 5 to 9 (geomorphic reach 1) and RM 9 to 14 (geomorphic reach 3).

Scenario	Model Mesh Name	SRH-W Output File Name	GIS Output File name	Upstream Flow Input (cfs)
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist40cfs_SMS96.txt	RM5to9_Existing_40cfs	40
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist2500cfs_SMS96.txt	RM5to9_Existing_2500cfs	2,500
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist5000cfs04_SMS96	RM5to9_Existing_5000cfs	5,000
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist10000cfs_SMS73.txt	RM5to9_Existing_10000cfs	10,000
Existing	NC_RM5to9_Existing.2dm	RM5to9_Existing_15000cfs_SMS60.txt	RM5to9_Existing_15000cfs	15,000
HF Removed	NC_RM5to9_HFRemoved.2dm	RM5to9_HF40cfs_SMS96.txt	RM5to9_HF_40cfs	40
HF Removed	NC_RM5to9_HFRemoved.2dm	RM5to9_HF2500cfs_SMS96.txt	RM5to9_HF_2500	2,500
HF Removed	NC_RM5to9_HFRemoved.2dm	RM5to9_HF5000cfs_SMS96.txt	RM5to9_HF_5000	5,000
HF Removed	NC_RM5to9_HFRemoved.2dm	RM5to9_HF10000cfs_SMS36.txt	RM5to9_HF_10000	10,000
HF Removed	NC_RM5to9_HFRemoved.2dm	RM5to9_HF15000cfs_SMS45.txt	RM5to9_HF_15000	15,000
Existing	NC_RM9to14_Existing2.2dm	RM9to14_Exist40cfs_SMS96.txt	RM9to14_Exist40cfs	40
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist2500cfs_SMS96.txt	RM9to14_Exist2500cfs	2,500
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist5000cfs_SMS41.txt	RM9to14_Exist5000cfs	5,000
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist7500cfs_SMS35.txt	RM9to14_Exist7500cfs	10,000
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist10000cfs_SMS35.txt	RM9to14_Exist10000cfs	15,000
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist15000cfs_SMS27.txt	RM9to14_Exist15000cfs	40
HF Removed	NC_RM9to14_HFRemoved3.2dm	RM9to14_HF2500cfs_SMS96.dat	RM9to14_Exist2500cfs	2,500
HF Removed	NC_RM9to14_HFRemoved3.2dm	RM9to14_HF5000cfs_SMS96.txt	RM9to14_Exist5000cfs	5,000
HF Removed	NC_RM9to14_HFRemoved3.2dm	RM9to14_HF10000cfs_SMS67.dat	RM9to14_Exist10000cfs	10,000
HF Removed	NC_RM9to14_HFRemoved3.2dm	RM9to14_HF15000cfs_SMS62.txt	RM9to14_Exist15000cfs	15,000

Table 7. List of 2D model runs with sediment capacity for RM 5 to 9 (geomorphic reach 1) and RM 9 to 14 (geomorphic reach 3).

Scenario	Model Mesh Name	SRH-W Output File Name	GIS Output File name	Upstream Flow Input (cfs)
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist2500SEDSRH_SMS48.txt	RM5to9_Exist2500SEDSRH	2,500
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist5000SEDSRH_SMS48.txt	RM5to9_Exist5000SEDSRH	5,000
Existing	NC_RM5to9_Existing.2dm	RM5to9_Exist10000SEDSRH_SMS48.txt	RM5to9_Exist10000SEDSRH	10,000
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist2500SEDSRH_SMS48.txt	RM9to14_Exist2500SEDSRH	2,500
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist5000SEDSRH_SMS48.txt	RM9to14_Exist5000SEDSRH	5,000
Existing	NC_RM9to14_Existing4.2dm	RM9to14_Exist10000SEDSRH_SMS48.txt	RM9to14_Exist10000SEDSRH	10,000

5. MODEL APPLICABILITY AND LIMITATIONS

The SRH-W model utilized is state-of-the-art and provides one of the best available methods to simulate river hydraulics. However, even the most advanced modeling has uncertainties due to assumptions related to the theoretical model development (e.g., depth-averaged flow equations used and numerical discretization errors) and the input data used (e.g., uncertainty in topography data and roughness values).

The results are applicable for looking at the relative change in hydraulics and flow distribution between the two geomorphic reaches 1 and 3. The model results are useful for looking at existing and potential off-channel and floodplain connectivity to historical areas currently cut-off (either partially or completely). The model results were also utilized to assist with refining boundaries of historical channel migration zone areas and floodplain areas based on the extent of inundation, depth, and velocity. The water surface elevations computed by the model have an estimated uncertainty of up to 1 foot at high flows based on professional experience.

Future model improvements should consider incorporating 2007 channel bottom data and obtaining additional underwater topography in areas where more accuracy is needed. Detailed hydraulic results at a project scale may require a denser grid than the 10-foot grid used at the reach scale. Model accuracy could be validated and potentially improved if more calibration and validation data is obtained to check against the model results. All of the models were run with steady flows (no hydrographs) and static beds. Additional modeling will be needed if channel migration rates, or bed scour and aggradation prediction is of interest.

6. SEDIMENT ANALYSIS METHODS

Sediment characteristics and the likelihood of future incision were addressed through an analysis of surrogate sediment transport parameters (stream power) and by comparing measured sediment sizes in the channel bed with incipient motion computations. Comparison with incipient motion indicates the ability of the river to mobilize the present channel bed and bars. The locations and general characteristics of sediment sources to the assessment reach were identified as part of the geologic investigation, but were not quantified or measured. Sensitivity of the channel bed to a change in sediment supply and/or sediment transport capacity as a result of construction of individual or multiple projects could be considered for future analysis if required. Field observations and channel survey comparisons suggested localized areas of a few feet of channel incision, particularly in areas where engineered straight channels had replaced historically meandering sections of river. The limitations of not using a predictive, quantitative sediment transport model in this assessment include losses in analysis resolution such as magnitude of incision or deposition of sediment, changes in bar and channel sediment storage as a result of proposed project construction, interactions of sediment supply and storage between proposed projects in close proximity, and changes in bed character.

Sediment transport capacity was also computed for 5,000 cfs existing conditions model runs to compare relative transport capacity between geomorphic reach 1 and 3. Sediment transport capacity was computed using the Meyer-Peter Muller equation in a version of SRH-W that computes sediment transport capacity at each grid cell based on hydraulic results for the input steady flow. In addition, the critical (largest) sediment size that can be mobilized for the modeled flow was computed using the Shields equation and the D_{50}, which had an average sediment size of 60 mm. These values were compared to sediment sizes measured on the bed surface to see if the typical bed sizes are mobilized within the range of potential flows.

Results are presented in the main report so they can be integrated with other information. Details on the stream power and pebble count methods are provided below.

6.1 Stream Power

Generally, discharge tends to increase in the downstream direction in river basins as additional tributaries and runoff provide more flow. Increasing discharge provides more potential energy to transport sediment and large woody debris if hydraulic conditions are otherwise comparable. Increasing the slope can also increase the river’s ability to transport sediment and large woody debris while decreasing the slope can reduce the transport capacity.

The total stream power computation shows how the combination of discharge and slope vary along the river from a reach-based perspective. The total stream power is computed by multiplying the product of discharge, slope and the specific weight of water for a given reach length (γQSX with units of power) (Bagnold 1966). Stream power is typically computed per unit length, X = 1. In this report, total stream power is simply computed as discharge multiplied by slope without the constant of specific weight of water or reach length. Discharge values were based on flood frequency output documented in the hydrology appendix D. Slopes were based on water surface slopes generated from hydraulic controls surveyed in 2007 (Appendix G – Channel Geomoety and Slope).

Total stream power is often used to indicate and compare the relative magnitude of sediment loads a stream is capable of transporting between reaches. It does not provide quantitative information as to the actual quantities or sizes transported. If the total stream power increases or decreases in a downstream direction, the sediment transport potential of the stream would also be expected to increase or decrease, respectively. Increases or decreases in sediment transport potential can indicate the likelihood of a reach to trend towards deposition or incision. If changes in slope and discharge are balanced out by the river, total stream power will remain relatively constant along the river's length and the reach would be expected to be in dynamic equilibrium. Computations utilized the 2- to 100-year discharge combined with bankfull slopes and did not differentiate between in-channel and floodplain flows.

The "unit stream power" is defined as the rate of potential energy expenditure per unit weight of water (Yang 1996). It is often used as an indicator of the relative energy required to transport a given sediment load among various cross-sections.

The unit stream power is computed by multiplying the friction slope and velocity (typically depth-averaged) for a given cross-section (VS with units of ft/s). Friction slope was computed by taking an average difference of the velocity head between model cell results for a given discharge along the centerline of the main channel. Velocity was the velocity magnitude output at a grid cell along the centerline of the active channel for a given discharge. Velocity incorporates the impact of channel geometry on sediment transport. Unit stream power provides a way to compare the relative ability of the stream to transport sediment at various cross-sections. By using a series of cross sections to represent a range of hydraulic conditions within each geomorphic reach, unit stream power can be used to look at relative comparisons of sediment transport capacity between reaches. It does not provide quantitative information as to the actual quantities or sizes transported. The depth-averaged velocity was computed using the normal depth assumption and did not differentiate between floodplain areas and the active channel.

6.2 Pebble Counts

Reclamation contracted with the USFS to collect pebble count samples during low flow periods at typical channel and bar sections located throughout the assessment reach. The sediment sample was collected with the intention of measuring surface coarse bed-material that must be mobilized by the river before the channel and bar sediment can be transported. This is the sediment sizes most closely linked with channel form, potential aggradation, and potential incision. In some channel areas the pebble count represents an armor layer on the channel bottom that may not be mobilized except for extremely high flood events. Ground photographs, particle size distributions, and field notes are available for each site. The D35, D50, and D90 at each site were computed (Figure 23, Figure 24, and Figure 25).

The method employed was to count 100 pebbles in approximately 1-foot intervals either across the wetted channel or along the unvegetated portions of sediment bars. Lines across channel sections were repeated if the channel width was less than 100 feet. Bar locations were chosen generally such that the grid was adjacent to the water edge and in the middle of the point or longitudinal bars (as opposed to upstream or downstream end). On bars, up to 4 lines were used in a grid format to capture the 100 piece count because most bars were less than 100 feet in width. Areas for pebble counts were chosen based on typical channel and bar sections without any localized influence that would cause local fining or coarsening of the sediment. Bank material was not included in the counts. If the bank sediment being eroded is coarse enough it will not be mobilized far from the erosion site and will be represented in the bar and channel samples. On the other hand, finer-sized sediment in the bank may be easily suspended and mobilized downstream and, therefore, would improperly skew the particle size distribution representing surface bed-material sizes.

The USFS crews noted the following regarding methods for collecting pebble counts:

- A written summary for each survey site was done, including whether the sample was located across the wetted channel or on a gravel bar.
- At sites where there was a river survey and grid survey performed, in some instances only one “largest substrate” measurement was taken. In this case the “largest substrate” was entered for both survey summaries for that site. If there were two “largest substrates” on the data sheets for river and grid surveys at one site, then two were entered in the database.
- The location of large wood was documented if it fell in a river or bar grid; if the wood spanned both areas, the location was based on whether it was mostly located in the river line or on a bar grid, but was never entered in both.

- Some "wetted widths" were recorded in feet with decimals, where others were recorded in feet and inches.
- In the ground photographs for each site, the following abbreviations were used: LB= left bank, RB= right bank, XS= cross-section.
- Grid type on the "pebble_count_bar" worksheet includes dimensions of the grid.
- At most sites several passes were made across a stream in order to gain 100 data points. These are designated by pass 1, 2, 3…etc., and #s meaning each unique data point gathered.

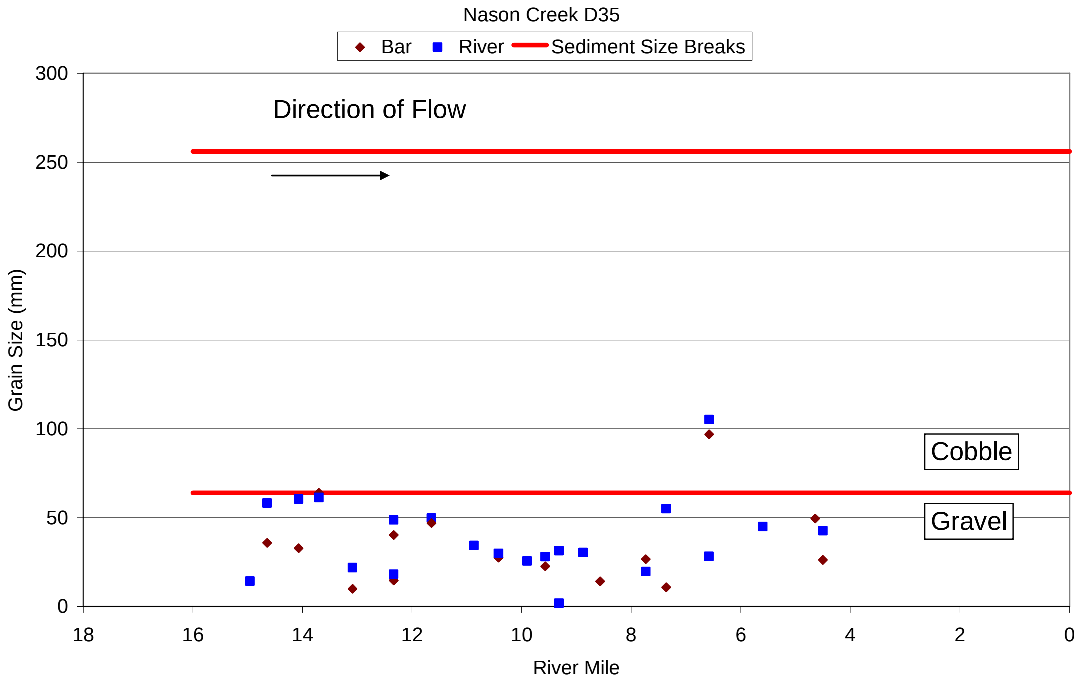

Figure 23. Results of D_{35} at pebble count sample sites.

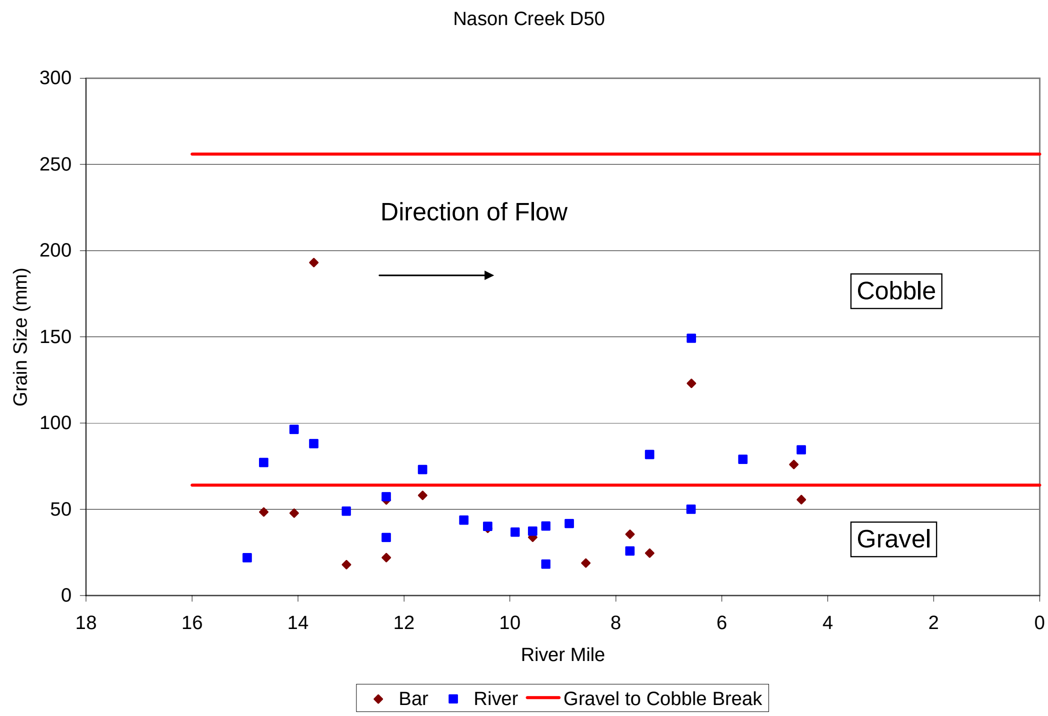

Figure 24. Results of D_{50} at pebble count sample sites.

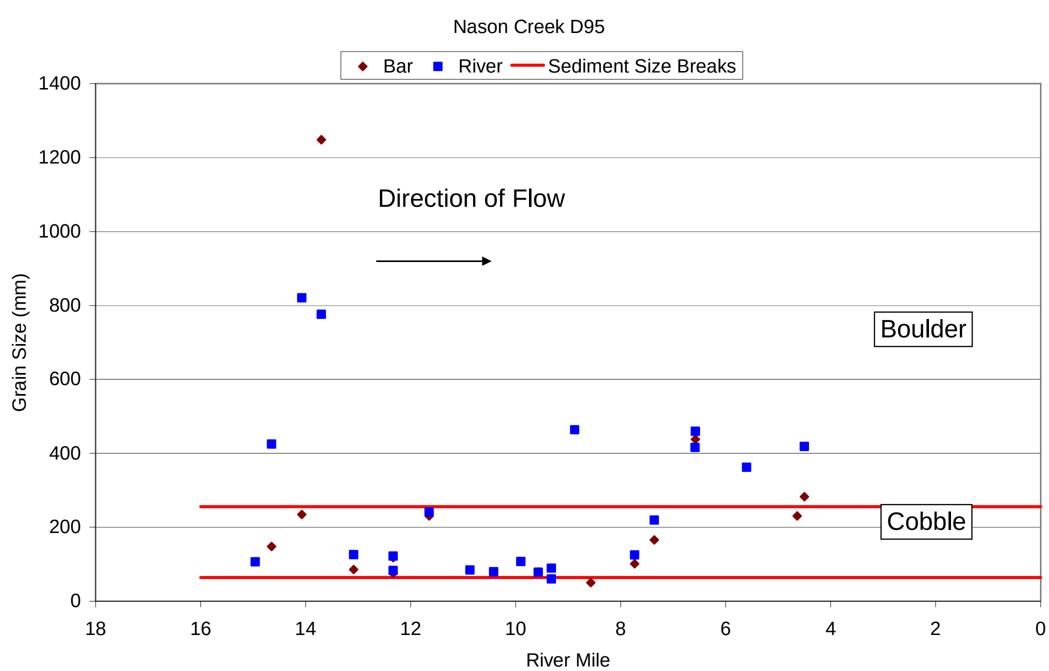

Figure 25. Results of D_{95} at pebble count sample sites.

7. REFERENCES

Parenthetical Reference	**Bibliographic Citation**
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APPENDIX I.

FLOODPLAIN VEGETATION ASSESSMENT

CONTENTS

Tables

Figures

EXECUTIVE SUMMARY

The objective of the 2007 riparian vegetation assessment is to provide an understanding of the present vegetation conditions to be utilized for the Nason Creek tributary- and reach-scale assessments. A team of ecologist conducted field sampling and geographic information system (GIS) analyses of remotely sensed data to create a GIS file containing polygons of vegetation units. Data from the vegetation assessment, along with other components of the geomorphic assessment, will be used for planning and prioritizing salmon recovery efforts in Nason Creek between river miles (RM) 4 and RM 14.

In August 2007 riparian vegetation was sampled throughout the assessment reach. Data collected included canopy cover and height for overstory and understory species and herbaceous species. These data were used in a GIS along with aerial photography and light detecting and ranging (LiDAR) data to interpret riparian vegetation and create vegetation units within the reach. The vegetation units were classified into the Oregon/Washington U.S. Forest Service (USFS) vegetation units for consistency with previous mapping available for lower Nason Creek RM 0 to RM 4.

Utilizing GIS, vegetation units were analyzed for the potential contribution of riparian vegetation for healthy salmon habitat. Analyses included natural species presence (potential natural community), large woody debris (LWD) trees, and shading (Table 1**)**. Areas of presently functioning vegetation were identified for potential easement or protection strategies. Presently functioning was generally defined as areas with native vegetation species that were at least several decades old (most areas were historically logged). Acres of LWD-sized trees—trees over 40 feet (12 meters) tall—from the riparian vegetation mapping were compiled for the entire floodplain and for an 82-foot (25-meters) buffer adjacent to the stream. Potential for thermal shading by the riparian vegetation within the 82-foot buffer was also quantified. Vegetation units were also ranked, based on professional judgment, for the level of effort needed to restore vegetation to a hypothesized natural condition.

The riparian vegetation along Nason Creek is generally in good health, and species are of potential naturally occurring species. Douglas-fir and grand fir are typically co-dominant in the canopy with vine maple being the common understory species. Black cottonwoods are present along the river and along abandoned river channels. Sand-bar willows and black cottonwood are present on gravel bars and cobble bars. Pacific willow and some alder species are found in wet areas. Limited amounts of western red cedar are mixed throughout the reach. Old growth (legacy) trees are absent from the reach and were most likely logged. A large amount of logging of the floodplain and log drives down the river occurred along Nason Creek in the early 1900s, but the exact extent and impact is not documented. The riparian forest appears to be recovering back to the historic grand fir forest. Ponded areas containing wetland indicator plants were observed in the reach; however, wetlands delineation was not a part of this scope. A limited amount of mammalian herbivory was observed, most likely from deer. Tree diseases were not evaluated but do not appear to be a limiting factor for healthy riparian vegetation. The majority of the forest is recovering and appears to be trending back to historical conditions. However, localized areas of the floodplain vegetation have been completely cleared due to construction of the highway, railroad, power lines, and commercial and residential development. Active residential development is also occurring in the reaches and would further impact the riparian vegetation if it continues to expand. Noxious weeds were found in limited areas such as under power lines and may increase over time if not controlled.

Table 1. Summary of Nason Creek vegetation analysis results by geomorphic reach.

Reach	Area (acres)	Presently impacted[1] (acres)	Natural species[2] (acres)	Percent Natural	Percent Impacted	LWD potential area[3] (acres)	Percent LWD potential area	Percent shaded[4]
1	334.9	54.69	280.1	84%	16%	206.2	62%	80%
2	13.6	0	13.6	100%	0%	9.2	68%	96%
3	607.6	128.27	479.3	79%	21%	255.4	42%	77%

[1] Impacted areas which are not potential natural community riparian vegetation but are anthropogenic land cover including railroad rights-of-way, roads, power line corridors, private and commercial property.
[2] Riparian areas which contain potential natural communities.
[3] Areas where the over 50 percent is covered by canopy of trees of LWD height [trees over 40 ft (12 m) tall] which could be potentially recruited into Nason Creek by either high flows or active river migration.
[4] Percent of main channel which is presently shaded by vegetation. Note that this estimate is based on a buffer width along the stream of 82 feet (25 meters).

Where riparian forest vegetation is present along the river, trees of adequate LWD size are available for future and immediate recruitment into the river if river migration processes are restored. Although cleared areas adjacent to the river had inadequate shading, aerial photography shows the majority of the river was shaded by tall trees. Further analyses should be completed to determine if the riparian vegetation provides adequate shading for the river. Large historical channel and floodplain areas presently cut off by the railroad and highway are now ponded. For example, the area to the south of the railroad between RM 9 and RM 11 is now disconnected from the river and contains several wetland-type species and naturally broken-off stumps where tall trees used to be present. This area might require major vegetation restoration efforts to restore it to historical conditions on a short timeframe of years.

High energy floods are also a concern in the reach, and have impacted vegetation adjacent to the river channel, reducing regrowth of trees and shrubs along with the presence of LWD in the main channel. In artificially confined reaches, there is limited bar development or floodplain surfaces for vegetation to establish. Most banks in these areas are riprap.

Additional analyses may be needed at the project-level scale to further develop riparian restoration strategies. More field measurements of tree age and species health may be of particular use at these smaller scales. High water temperatures are a concern on the river, and further study is recommended to better understand the contribution of riparian vegetation to the thermal regulation of the river.

1. BACKGROUND AND OBJECTIVES

The Nason Creek watershed is located on the eastern slope of the Cascade Mountains in central Washington. The headwaters of Nason Creek are at the crest of the Cascades Mountain Range and flow east for approximately 21 miles (34 kilometers) and then turn north for another 5 miles (8 kilometers) before emptying to the Wenatchee River at Lake Wenatchee. Past U.S. Forest Service (USFS) vegetation assessments indicated that the watershed is a vegetative transition zone, stretching from high elevation sub-alpine forest to dry forest environments.

The Nason Creek floodplain is currently occupied by successional coniferous forest. A mean annual precipitation of over 60 inches (1.5 meters) a year supports a grand fir/vine maple series as defined by Lillybridge et al. 1995. Douglas-fir and grand fir are typically co-dominant in the canopy with vine maple being the common understory species. Black cottonwood is present along the creek and along abandoned creek channels. Western red cedar is mixed throughout the floodplain. Ponderosa pine is scattered in the upstream portion of the watershed and becomes more dominate in the downstream direction. Monotypic ponderosa stands exist on higher and drier sites adjacent to the floodplain. A smaller percentage of the riparian vegetation is composed of riparian non-forest habitats consisting of hardwood stands, shrubs, wetlands, and meadow.

The objective of the 2007 vegetative assessment was to fill data gaps on the Bureau of Reclamation's (Reclamation) Nason Creek tributary and reach assessments (two stages of analysis) in the vegetation component for river mile (RM) 4 to RM 14 (Coles Corner to White Pine Campground). For these analyses, the following vegetation products were needed:

1. Vegetation composition and structure of present (2006 to 2007) site conditions within the area of active channel migration and floodplain processes (low surface)
    a. Utilize initial vegetation mapping for Nason Creek by the USFS done solely with aerial photography
    b. Refine and expand USFS vegetation mapping to cover the newly mapped low surface
    c. Include mapping of impacted or cleared areas (e.g., power lines, developments), and of ponded and river areas
2. A conceptual model (hypothesis) of historic vegetation conditions prior to European settlement in the late 1800s for comparison to present conditions.
3. Identification of riparian reserves – defined as areas of functioning or at least semi-functioning vegetation that could provide a good source of shade, cover, and potential LWD.

4. Potential for the present vegetation to serve as a LWD source if eroded into the river through channel migration processes or windfall along Nason Creek.
5. Ranking of vegetation condition in terms of shade and cover along a defined buffer zone of 98 feet (30 meters) along the present main channel.
6. Restoration recommendations and quantification of level of effort for restoration to be used in ranking and prioritizing of potential projects.

Data collected included information on LWD, LWD recruitment, diameter of LWD, types of conifers and deciduous trees, percentage of canopy coverage, and relative foliage coverage in specific non-assessed area. The 2007 vegetation assessment covered low surface sites utilizing both 2006 global positioning system (GPS) vegetation mapping (orthophotos and hardcopy aerial photographs) and LiDAR data. In addition, field validations (ground truthing) were conducted to verify vegetation on GPS maps and photographs based on LiDAR technology.

2. METHODS

A limited field inventory and mapping project was conducted to collect data on riparian vegetation for Nason Creek. Field assessments were conducted from August 6 to August 10, 2007, and from October 1 to October 4, 2007. Interpretation of aerial photographs and LiDAR data were used to create a GIS vegetation community map. Data will be used for analyses and project areas ranking within the assessment area for salmon recovery efforts.

2.1 Vegetation Community Classification

A classification system was selected which would best assess riparian vegetation for ecosystem health, creation, and restoration. This classification is based on various studies done by Robert D. Ohmart (Hink and Ohmart 1984). The classification method included categorizing vegetation polygons into community types and structure classes using an alphanumeric descriptive code. Each woody riparian plant species was assigned a letter code (the species code). The classification code (described in Figure 1) consisted of species codes for the canopy layer, species codes for the understory layer, and a number signifying the height of the canopy and thickness of the understory. This detailed classification was rolled into the more general USFS classification used for the lower Nason Creek study (RM 0 to 4) which was completed by Jones and Stokes for Chelan County (2003). See Figure 2 showing an example map.

Example:

Canopy Layer / Understory Layer+Type Number (1-4)

Example: PP-GF/VM1

Ponderosa pine dominant with grand fir in overstory with understory of vine maple

TYPE DEFINITIONS:

Type 1- Tall trees with well developed understory. Tall or mature to mixed-aged trees [**>40 feet (12 meters)**] with canopy covering **>50 percent of area** of the community (polygon) **and** understory layer [**5 to 40 feet (1.5 to 12 meters)**] with covering **>25 percent of area** of the community (polygon).

Type 2 – Tall tree canopy with little or no understory vegetation. Tall or mature trees **[>40 feet (12 meters**)] with canopy covering **>50 percent of area** of the community (polygon) **a** understory layer [**5 to 40 feet (1.5 to 12 meters)**] with covering **<25 percent of area** of the community (polygon).

Type 3 – Intermediate-sized canopy with dense understory vegetation. Intermediate-sized trees [**(15 to 40 feet (4.6 to 12 meters)]** with canopy covering **>50%** of area of the community (polygon) **with** understory layer [**(5 to15 feet (1.5 to 4.5 meters)]** with canopy covering **>25 percent** of the area of the community (polygon).

Type 4 –Intermediate-sized trees openly spaced with little understory. Intermediate-sized t [**15 to 40 feet (4.6 to 12 meters)]** with canopy covering > **50 percent** of the area of the commun (polygon) understory [**5 to 15 feet (1.5 to 4.5 meters)**] layer covering **< 25 percent** of the area c community (polygon)

Figure 1. Alphanumeric descriptive code and type definitions used to categorize vegetation polygons.

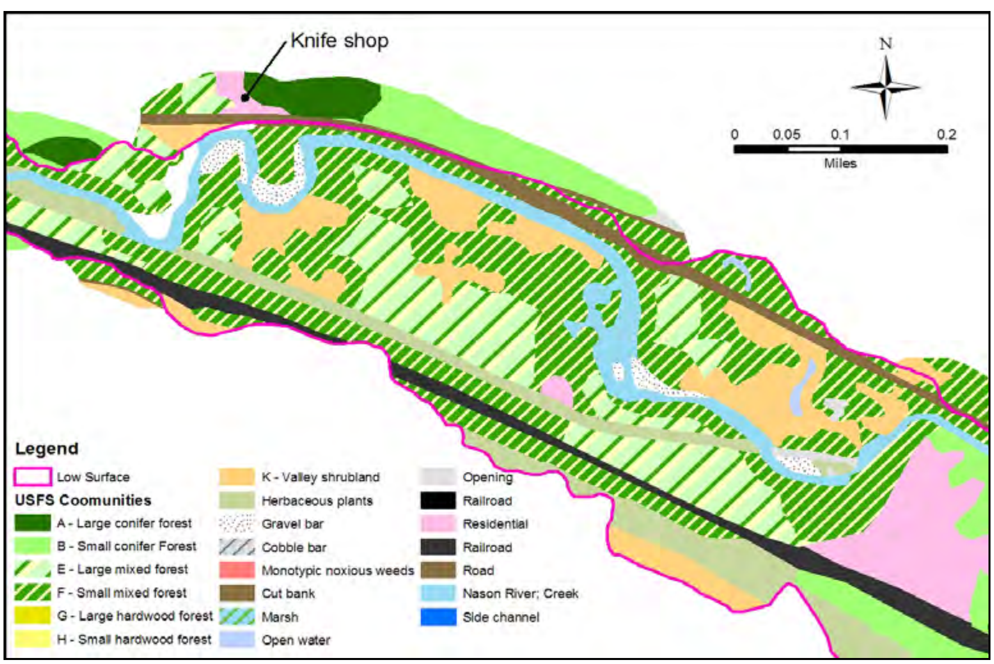

Figure 2. Example map showing USFS vegetation classes.

2.2 Preparatory Field Work

Prior to going to the field, orthophotos from October 2006 and hardcopy aerial photos were used to select vegetation data collection sites. Sites were selected which appeared to represent all possible vegetation communities, and focus was on areas which showed potential for reconnection of the floodplain to the creek. Coordinates for the points were generated using the ArcGIS program and loaded into GPS devices for use in the field.

2.3 Field Work

During the August field work, an attempt was made to navigate as close as possible to each point using GPS and hardcopy aerial photos. An evaluation form (Figure 3) was completed to document percent cover, heights, and species of the canopy, herbaceous understory, woody debris and litter, wetland features, and hydrologic indicators. At each field site a photograph(s) was taken to document the vegetation species and structure. Table 2 lists the vegetation species observed and designated species code. In some instances where access was not possible due to thick vegetation, open water, and private lands, evaluations were conducted from a high overlook or from public roads.

Field data were entered in a spreadsheet (Attachment 1) for later use in developing alphanumeric classification codes. Plant species were recorded according to the relative abundance of the species cover within two layers. Species within a layer were separated by a "-." Canopy and understory layers were separated by a "/." Typically one or two species were recorded for each layer, but as many species as qualified (up to four) were recorded. For a species to be recorded in the code, they had to have 25-percent relative abundance. Plant species dominance (or relative abundance) was determined by visual estimation. Tree and shrub height, as well as plant cover, were also determined by visual estimates.

This detailed vegetation community class was rolled into the Oregon/ Washington/USFS watershed analysis model vegetation units (Table 3). The authors added additional fields for other land areas such as gravel bars. Using this classification maintains consistency with the lower Nason Creek mapping done in 2003 for Chelan County. This classification was linked to the polygons in the GIS and added as an attribute field.

During the October 2007 field assessment, 2 days were spent measuring tree diameters at breast height (DBH) and tree heights for a sampling of the largest cottonwoods and conifers. Tree height was measured using a TruPulse Professional Laser Rangefinder (Laser Technology, Inc.). A meter tape was used to measure circumference from which the diameter was calculated. Tree height information was used in the interpretation of the tree LiDAR data to determine trees that had the required diameter for LWD potential. Thirty-eight trees were measured for DBH and 14 trees for height from various GPS locations.

Vegetation Classification Form						
Date						
Recorder, Phone #						
Polygon ID				**Photo Number**		
UTM WGS84 Coordinates	**X**					
	Y					
Waypoint #			**Time**			
Riparian Vegetation						
Species Codes	**Canopy**	**Height and Cover**				
		Canopy Cover	>40 Ft	1-25%	25-75%	75-100%
			20-40 Ft	1-25%	25-75%	75-100%
		%Dead	1-25%	25-50%	50-75%	75-100%
		Species (Relative foliage cover) - Circle one for each species				
			1-25%	25-50%	50-75%	*75-100%*
			1-25%	25-50%	50-75%	*75-100%*
	Understory	**Height and Cover**				
		Height	5-15 Ft	1-25%	25-75%	75-100%
			<5 Ft	1-25%	25-75%	75-100%
		%Dead	1-25%	25-50%	50-75%	75-100%
		Species (Relative foliage cover) - Circle one for each species				
			1-25%	25-50%	50-75%	*75-100%*
			1-25%	25-50%	50-75%	*75-100%*
			1-25%	25-50%	50-75%	*75-100%*
Ground Litter			1-25%	25-50%	50-75%	*75-100%*
Notes						
Wetland						
CM- Cattail Marsh		OW-Open Water		GM - Grass Meadow		
Other						
OA - Open Area		Ag-Agricultural		Road		
Hydrology Indicators (circle all that apply)						
Surface water present		Debris in vegetation			Watermarks on vegetation	
Sediment deposits		Drainage patterns			Back channel	

Figure 3. Evaluation form for Nason Creek vegetation assessments.

Table 2. Vegetation inventory from 2007 Nason Creek field assessment.

Conifer/Deciduous Tree	**Scientific Name**	**Species Code**
Aspen	*Populus tremuloides*	A
Black cottonwood	*Populus balsamifera*	BC
Big Leaf maple	*Acer macrophyllum*	BM
Douglas-fir	*Pseudotsuga menziesii*	DF
Englemann spruce	*Picea engelmannii*	ES
Grand fir	*Abies grandis*	GF
Ponderosa pine	*Pinus ponderosa*	PP
Red cedar	*Thuja plicata*	RC
Sita alder	*Alnus crispa* spp.	SA
Shrubs/Terrestrial		
Bitter cherry	*Prunus emarginata*	BC
Black elderberry	*Sambucus racemosa* spp	BE
Black hawthorn	*Crataegus douglasii*	BH
Red-Osier dogwood	*Cornus stolonifera*	RD
Snowbrush	*Ceanothus velutinus*	NU*
False solomon	*Smilacina racemosa*	NU
Hardhack	*Spiraea douglasii*	Hh
Ocean spray	*Holodiscus discolor*	NU
Oxeye daisy	*Chrysanthemum leucanthemum* L.	NU
Sand bar willow	*Salix ssp.*	SBW
Pacific willow	*Salix lucida* spp. *lasiandra*	PW
Scouler willow	*Salix scouleriana*	SW
Skunk cabbage	*Lysichiton americanum*	NU
Timbleberry	*Rubus parviflorus*	NU
Vine maple	*Acer circinatum*	VM
Riparaian/Emergent Plants		
Duckweed	*Lemna* spp.	NU
Pondweeds	*Potomogeton* spp	NU
Vallsinera	*Vallisneria* spp.	NU
Reed canarygrass	*Phalaris arundinacea* L.	NU
Sedges	Family Cyperaceae	NU
Various grasses		NU
* Not Used		

Table 3. Oregon/Washington/USFS vegetation type unit descriptions for Nason Creek

Designation	Unit Name	Description
A	Large conifer forest	Mean DBH greater than 12 inches (30.4 centimeters). Mixed stands often include Douglas-fir, ponderosa pine, western red cedar, grand fir, or western larch. Crown closure usually greater than 50 percent
B	Small conifer forest	Same as large conifer forest but with smaller trees
E	Large mixed forest	Mean DBH greater than 12 inches (30.4 centimeters). Stand dominants almost always black cottonwood and mixed conifers, with an understory of smaller trees and shrubs
F	Small mixed forest	Same as large mixed forest but with smaller trees
G	Large hardwood forest	Mean DBH greater than 12 inches (30.4 centimeters). Nearly always consists of black cottonwood stands
H	Small hardwood forest	Comparable to large hardwood forest but with smaller trees
K	Valley shrub land	Dominated by deciduous woody vegetation (usually willows) less than 40 feet (12 meters) tall
Additional fields identified by Reclamation (authors)		
Co	Cobble bar	Riverine bar dominated by cobble sized material
Creek	Nason Creek	Main stem Nason Creek
Cutbank	Cutbank	Large bank cut by the creek during high flows
Go	Gravel bar	Gravel bar with less than 25 percent shrub cover
Garish	Gravel bar/shrub	Gravel bar with more than 25 percent scattered willow stands
Herb	Herbaceous	Dominated by herbaceous vegetation
MHz	Marsh	Wetted area containing marsh plants
NN	Noxious weeds	Area dominated by noxious weeds
Op	Opening	Open area, usually cleared areas adjacent to residential or commercial development
OW	Open water	Open water, usually ponded areas, which are now disconnected from the river by either the road or railroad
Railroad	Railroad	Railroad tracks and associated embankment
Res	Residential	Dominated by residential development
Riprap	Riprap	Bank dominated by riprap along the river
Road	Road	Highway
Side-Channel	Side channel	Creek side channel which contains, or may contain, water during high flows

Measurements of tree height were limited by denseness of tree stands, making it difficult to see both the top and the lower portions of trees. In addition, rain interfered with the laser rangefinder and limited the number of measurements taken.

2.4 Post Field Work Aerial Photograph and LiDAR Data Interpretation

Aerial photography was flown for the project in October 2006 and then orthorectified for the project (average flow in river of 40 cubic feet per second (cfs)). LiDAR data were captured in October 2006, and first and second returns were used to create a grid containing tree height values. The LiDAR data and color aerial photography were used in GIS to interpret map vegetation not mapped in the field. The October aerial photos were useful for delineating hardwoods because yellow foliage was visible.

In ArcGIS 9.2, a 300-foot (91-meter) buffer from the rivers edge (as seen October 2006 photography) was created and merged with the geologic low surface provided by Reclamation hydrologists to create the study area polygon. The existing vegetation (provided by USFS) was incorporated. LiDAR data were grouped into height classifications, made semi-transparent, and overlain on 2006 aerial photography (Figure 4). Polygons of dominate canopy cover were created using heads-up (on screen) digitizing. Field assessment points were overlain on the photography. Data and detailed vegetation classification from the field assessments were tied to the polygons and used to visually interpret the areas not field assessed. Polygons were attributed with USFS unit and LWD categories (trees, small trees and shrubs, and low vegetation/openings) (Figure 4). Approximately 20 percent of the study area was assessed in the field, and the remaining 80 percent was visually interpreted using aerial photography and LiDAR data.

2.5 LWD and Shading Interpretation Methods

Thirty-foot-long (9.1-meter-long) logs are the generally accepted minimum size for LWD in the stream. Forty feet (12 meters) was used in this study as a minimum size which, with accounting for some breakage of the tree or the small size of the top 5 feet (1.5 meters) of the trees, would provide LWD to the stream.

LiDAR data were symbolized to group vegetation into areas with greater than 50 percent canopy cover of:

- Trees with potential LWD tree size over 40 feet tall (12 meters) = T
- Small trees and shrubs 5 to 40 feet (1.5 to 12 meters) = S
- Low vegetation (crops, herbaceous, low shrubs, and open areas) 1 to 5 feet (30.4 centimeters to 1.5 meters) tall = O

Polygons were attributed with the appropriate letter to be used in analysis.

In order to estimate shading and short-term (decades), LWD contribution of the riparian vegetation adjacent to the river, a buffer of 82 feet was chosen. McDade et al. (1990) used an 82-foot (25-meter) buffer as the minimum distance from the river that trees contributed LWD to the river. An 82-foot buffer from the river was created in GIS and intersected with the vegetation classification. Acres were calculated for all polygons and added as an attribute. The attribute table was exported to an Excel file. The Excel file was then imported into an Access database for summary reporting by reach. The summary reports were exported to an Excel spreadsheet for distribution and formatting for reports.

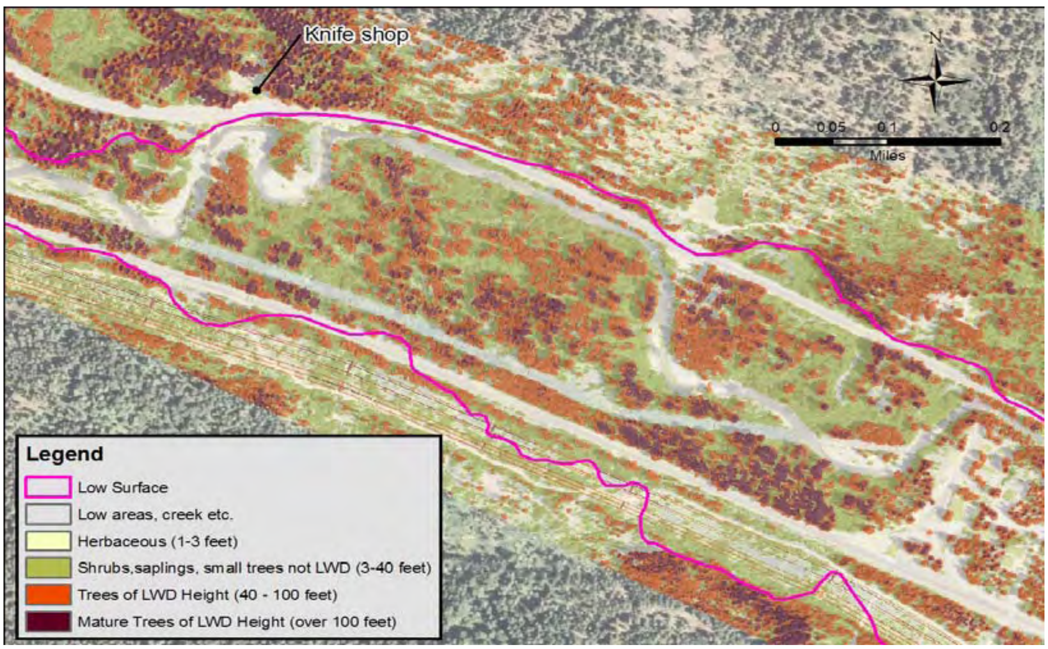

Figure 4. Example map showing LiDAR data shaded for tree heights and overlain on aerial photography.

3. VEGETATION SUMMARY AND RESULTS

The vegetation along Nason Creek is heavily influenced by the Cascade Mountains. Douglas-fir and grand fir are typically co-dominant in the canopy with vine maple being the common understory species. Black cottonwoods are present along the river and along abandoned river channels. Sand-bar willows and black cottonwood are present on gravel bars and cobble bars. Pacific willow and some alder species are found in wet areas. Limited amounts of western red cedar are mixed throughout the reach. Old growth (legacy) trees are absent from the reach and were probably logged in the 1900s for the railroad and for the fruit industry. The forest appears to be recovering back to the historic grand fir forest. Ponded areas containing wetland indicator plants were observed in the reach; however, wetlands delineation was not a part of this scope. A very limited amount of mammalian herbivory was observed, mostly likely from deer. Few deer tracks and limited amounts of deer scat were observed. One set of moose tracks was observed near White Pine. Signs of bear were observed at three locations during field surveys. Limited beaver activity was observed in the reach. Table 4 shows the acres of each USFS unit type for each reach (see Nason Creek tributary assessment).

Table 4. Acres of USFS units (see Table 3 for USFS type description)

USFS	Reach		
Unit	N1	N2	N3
A	46	6	14
B	88	4	27
E	15	0	33
F	25	0	120
G	13	0	6
H	20	0	56
K	32	0	164
Herb	16	0	39
Marsh	0	0	6
Gravel bar	5	0.2	7
Gravel bar/shrub	2	0.2	3
Noxious weed	4	0	2
Op	5	0	5
Railroad	0	0	20
Res	10	0	38
Co	4	0	0
Cutbank	1	0	0

3.1 Nason Geomorphic Reach 3

The forest in the low surface of reach 3 has good vertical and lateral complexity in the sites visited. Douglas-fir, ponderosa pine, and grand fir are often mixed in the canopy. The understory is dominated by vine maple. Few high flow channels were observed in this area. Black cottonwood and aspen are found in abandoned river channels.

3.2 Nason Geomorphic Reach 2

In reach 2, the geology constrains the floodplain, keeping it narrow and in places where the soils are relatively dry. The dominate conifer tree is ponderosa pine, but in general the presence of vegetation is limited.

3.3 Nason Geomorphic Reach 1

The riparian vegetation in reach 1 tends to have less lateral and vertical complexity than in reach 3. The forest adjacent to the low surface at the meander at RM 6.6 has low vertical structural complexity due to dry soil conditions, and the dominate conifer trees is the ponderosa pine. The two meanders at RM 5.1 and RM 5.9 near Coles Corner contain older average age class trees including intermediate to mature grand fir, black cottonwood, and red cedar resulting in approximately 75 percent canopy closure. Young and intermediate age class trees were lacking, which may have been stripped in the 1990 flood. At those two sites there was extensive evidence of a high flow event forming many high flow channels. Piles of large woody debris were observed on the downstream portion of the meander.

3.4 Floodplain Cut-off Areas

Areas of floodplain presently cut off by railroad and highway embankments or other manmade features were specifically evaluated for vegetation condition. The majority of these areas are located in reach 3. Many of these areas contain small- to-medium size wetlands (in the former main channels) and are dominated by large shrubs extending in some cases up to 25 feet (7.6 meters) in height. Conifers, which at one time existed in this area, have died (visual observations) because they do not tolerate the wet and standing water conditions. These shrubs are found either occupying the channel within the oxbows or found at the edge of open water (pond or oxbow) where they could potentially provide some shading. Shrubs and wetlands that currently exist in the cutoff areas would not contribute to short-term LWD recruitment if these areas are reconnected and accessed by the river. However, over longer time periods, riparian vegetation would be expected to re-establish if natural migration processes are restored, reconnecting these areas to the presently accessible channel and floodplain. Riparian and aquatic vegetation found in and surrounding these sites included equisetum, bulrush, pondweed species, vallisneria, duckweed, and grasses. At higher elevations on the perimeters of some of these moist sites are mature to intermediate deciduous and conifer trees.

There are additional moist sites outside the low surface, which were cut off by channelization. These areas are fed by seepage and groundwater flows where there are intermediate to mature conifers and deciduous trees including black cottonwood and grand fir. Understory in these areas is comprised mainly of various types of shrubs including vine maple up to 15 feet (4.5 meters) in length. In one particular area, there was a large monoculture of spyrea ranging up to 6 feet (1.8 meters) in height which was surrounded mainly by Pacific willow.

3.5 Power Line Corridors

Power and transmission lines run nearly parallel to the channel throughout the Nason assessment area, and often cross the main channel. Floodplain vegetation within these corridors and the vegetation adjacent to the corridors have been severely impacted by consistent clearing done to maintain the access right-of-way. Vegetation tends to be monocultures of differing species depending on the sites. Some areas are dominated by non-native and noxious weeds such as spotted knapweed and less desirable native plants such as common tansy. Other areas on the edges of these corridors have native vegetation such as black cottonwoods and aspen that are being limited in height by mowing to allow access into these corridors for operation and maintenance of the power lines. These trees are generally intermediate in height and are density packed (dog hair stands) which are an unnatural condition limiting diameter and tree height. In some areas, dense shrub growth is found to the edge of the river but does not extend substantially over the river to provide adequate shading for fish.

Soils in these corridors appear more xeric with more cobbles due to removal of endemic soils for the development of the corridor and right-of-way. This results in encroachment by non-native plants which were potentially transferred to the area from heavy equipment or by some other vector. These drier sites do not appear to be sustaining shrubs and tree growth. On the edge of the river within the power line corridor there are some areas that have limited amounts of LWD that could be recruited. Overall, when the power line corridor passes over Nason Creek potential LWD recruitment has been greatly reduced as is shading on the river.

4. GIS Analysis of Natural Community, Potential LWD Sources and Shading

This report section documents methods used to accomplish GIS-based vegetation and LWD analysis needed to help populate a reach-based ecosystem indicator (REI) table, presented in a separate report.

4.1 Potential Natural Community (REI Structure Criteria)

Riparian vegetation which is consistent with its potential natural community is the desired condition for the riparian area. The potential natural community is a biotic community that would be established if all successional sequences were completed without the interference of human activities (Winward 2000). Table 5 shows the acres of the riparian area of potential natural community (natural species) and the acres of impacted areas which are anthropogenic land cover such as railroad rights-of-way, roads, power line corridors, and private and commercial property.

Table 5. Potential natural community vegetation analysis results by geomorphic reach.

Reach	Area (acres)	Natural Species (acres)	Percent Natural	Impacted (acres)	Percent Impacted
1	334.9	280.1	84%	54.69	16%
2	13.6	13.6	100%	0	0%
3	607.6	479.3	79%	128.27	21%

4.2 LWD Contribution and Shading

Two important components riparian vegetation contributes to salmon habitat are LWD and shading for the river channel. LWD creates and maintains spawning, rearing, and holding habitat for salmon and is part of the nutrient exchange necessary in a river system. Shading of the river channel has been shown to contribute by reducing water temperatures during hot summer months, particularly during low flow conditions.

These data were generated from the GIS analysis:

- Trees which could be potentially recruited into the stream and provide LWD by active river meanders accessing the trees at some point in the future (acres of polygons classified as dominated by trees within the low surface - LWD potential analysis.
- LWD which is accessible to the stream in the short-term because they are within a close proximity to the present river channel; the impact on present river channel migration rates due to levees, riprap, etc., was not taken into account in this analysis [acres of trees within 82 feet (25 meters) of the wetted river on 2006 aerial photography - LWD accessible analysis]
- Shading by trees and shrubs adjacent to the river [acres within 82 feet (25 meters) of the wetted river on 2006 aerial photography - shading analysis]

4.3 LWD Potential Analysis

Figure 5 was produced with LWD classification of all vegetation in the study area.

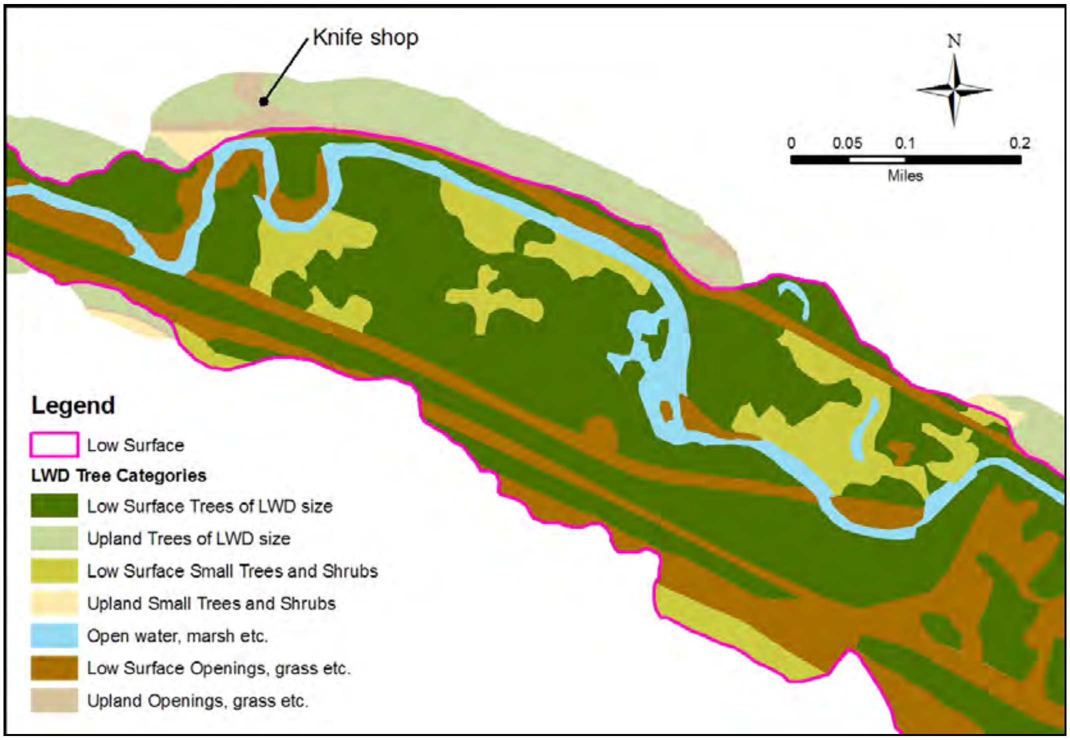

Figure 5. Example map showing LWD tree classifications.

Fifty-six percent of the assessment area (Table 6) has polygons which are dominated by LWD-sized trees. Polygons classified as LWD trees contain an average of 40 trees per acre. In areas cut-off from the river by the railroad, shrubs dominated areas make up 23 percent of the study area. Twenty-two percent of the study area is classified as low vegetation/openings. Much of this area is private land.

Table 6. Summary of vegetation classification for study area.

Acres LWD trees	Acres small trees/ shrubs	Acres low vegetation/ openings	Total acres*
476	196	185	857
56%	23%	22%	100%

4.4 LWD Potential Analysis by Reach

Table 7 shows acres of trees that are currently of adequate size to provide LWD within the low surface (floodplain) for each reach. This represents the acres of LWD-sized trees that could be recruited if the river accessed them either through lateral erosion, flooding, or wind throw. Reach 2 is a very short, narrow reach and is constrained by the geology.

Table 7. Acres and percent of area of LWD-sized trees within the low surface by reach.

Reach	LWD Trees (acres)
N1	208
N2	9
N3	259

4.5 LWD Accessible Analysis

The LWD accessibility analysis includes three general spatial areas: vegetation within 82 feet (25 meters) of the river centerline, the remaining low surface, and areas outside the low surface but still within a 300-foot (91-meter) distance from the river centerline. These areas could provide trees which could be recruited into the stream (Figure 6).

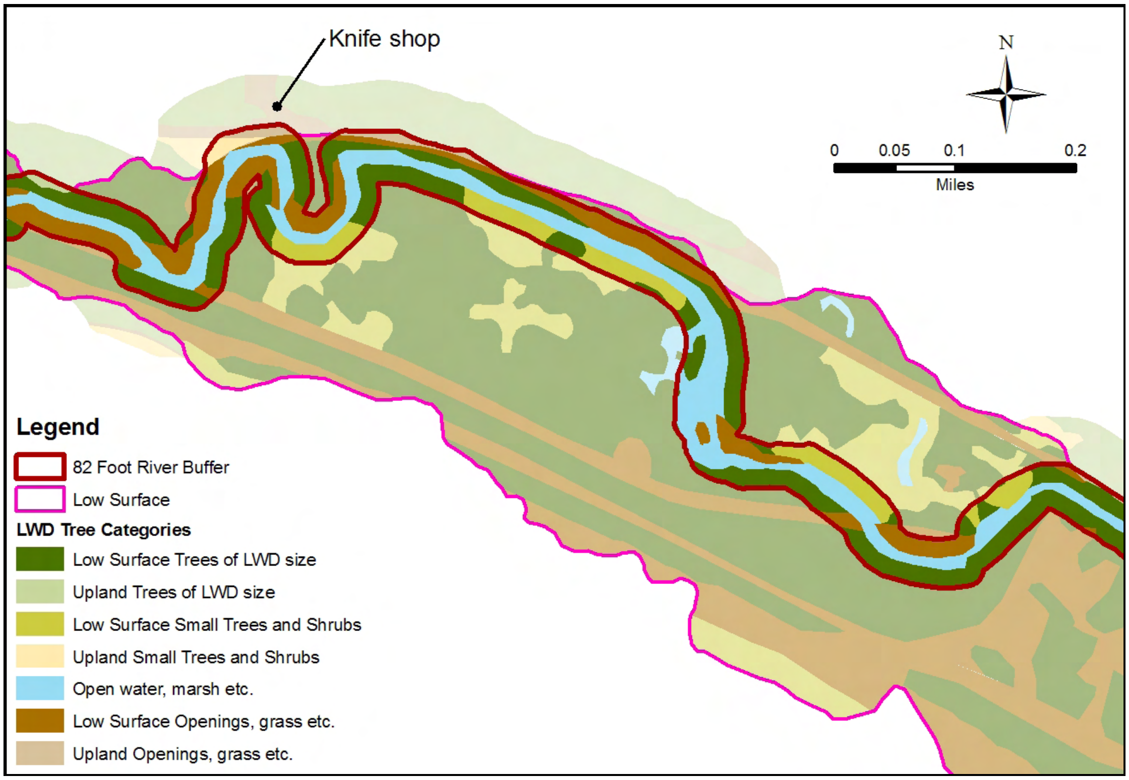

Figure 6. Example map showing buffer adjacent to the river and LWD tree categories.

LWD-sized trees adjacent to the river could be recruited into the river in the short term. Table 8 shows acres for each reach. Some acres are larger than the low surface LWD trees because of area outside the low surface, but within 82 feet (25 meters) of the river.

Table 8. Acres of LWD-sized trees within 82 feet (25 meters) of Nason Creek reach within 82 feet of the river.

Reach	LWD Trees (acres)
N1	64
N2	10
N3	51

4.6 Shading Analysis

Seventy-eight (672 acres) percent of the study area is shaded by the riparian vegetation. The majority of this shading is by shadows of tall trees falling across the river. Table 9 shows the percent of the strip 82 feet (25 meters) wide along both sides of the river which contains trees and/or shrubs and which could provide shade to the river. Trees and shrubs outside the low surface, but within 82 feet (25 meters) are included.

Table 9. Percent of stream shaded by trees/shrubs by reach.

Reach	Percent of stream shaded
N1	80%
N2	96%
N3	77%

5. Limitations and Future Work Recommendations

Future work should include more ground assessments to increase GIS mapping accuracy. If desired, measurements of large down wood per cubic foot would yield information of the riparian area's ability to provide filtering of sediment and nutrients to the river. Additional analyses are needed to better understand the linkage between shading along the river by the riparian vegetation and influence on water temperature. Aerial photography or field surveys could be completed during the hottest times of the year, and measurements of actual shading by the vegetation would enhance the understanding of the contribution of the vegetation for thermal cover for the fish. Continued monitoring of vegetation structure could be done on a decadal scale to track recovery of logging from the turn of the century. Additional, more detailed vegetation mapping and monitoring may be important at a project scale as part of restoration actions and adaptive management.

6. References

Parenthetical Reference	Bibliographic Citation
Hink and Ohmart 1984	Hink, V.C., and R.D. Ohmart. 1984. *Middle Rio Grande Biological Survey*. U.S. Army Corps of Engineers. Final Report.
Jones and Stokes 2003.	Jones and Stokes. 2003. "Channel Migration Zone Study, Wenatchee River Riparian Vegetation Conditions and River Restoration Opportunities." Prepared for Chelan County Natural Resources Program. Bellevue, Washington.

Lillybridge et al. 1995	Lillybridge, T.R.; B.L. Kovalchik, C.K. Williams, and B.G. Smith. 1995. “Field guide for forested plant associations of the Wenatchee National Forest.” Gen. Tech. Rep. PNW-GTR-359. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 335 p. In cooperation with: Pacific Northwest Region, Wenatchee National Forest.
McDade et al. 1990	McDade, M.H., F.J. Swanson, W.A. McKee, J.F. Franklin, and J. Van Sickle. 1990. “Source distances for coarse woody debris entering small streams in western Oregon and Washington.” Can. J. For. Res. 20:326-330
Winward 2000	Winward, Alma H. 2000. “Monitoring the vegetation resources in riparian areas.” Gen. Tech. Rep. RMRS-GTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p

ATTACHMENT 1 – FIELD DATA SPREADSHEET AND PEER REVIEW DOCUMENTATION

Appendix 1. Field Form Data

SurveyPt	Photo	Comments	Canopy Avg Hight	Canopy % Cover	% Canopy Dead	Canopy Species 1	Canopy 1 Species % abundance	Canopy Species 2	Canopy 2 Species % abundance	Canopy Species 3	Canopy 3 Species % abundance	Canopy Species 4	Canopy 4 Species % abundance	Understory Avg Height	% understory cover	% understory dead	Recruitment species	understory species 1	% understory species 1 abundance	understory species 2	% understory species 2 abundance	understory species 3	% understory species 3 abundance	understory species 4	% understory species 4 abundance	understory species 5	% understory species 5 abundance	understory species 6	% understory species 6 abundance	understory species 7	% understory species 7 abundance	understory species 8	% understory species 8 abundance	understory species 9	% understory species 9 abundance	Wetted area plants	Wetted area characteristics
01A	DSCN1275.JPG	Black Cottonwood, Intermediate age	>40 FT	25-75%	1.25%									5-15 FT	25-75%	1.25%		D.W.		Willow		black cottonwood															
01B	DSCN1278.JPG	Underneath Power Lines, no trees, brush species, area approx. 200 yds long x 40 yds wide, spotted knapweed and grasses found underneath power lines. Small,bc, maples dw and elderberry												5-15 FT	1.25%	1.25%		BC	25-50%	Vine Maple	25-50%	D.W.	1.25%	Spotted Knapweed	75-100%	grasses	25										
02A	DSCN1280.JPG	Looking downstream, Mixed conifers, mixed shrubs, this view some cottonwoods taller than conifers	>40 FT	75-100%	1.25%	DF	25-50%	BC	25-50%																												
02B	DSCN1283.JPG	Looking upstream, Mixed conifers, mixed shrubs, this view conifer taller than cottonwoods	>40 FT	75-100%	1.25%	BC	25-50%	BC																													
03A	DSCN1288.JPG	G.F., BC site, Intermediate, Moist	>40 FT	75-100%	1.25%	GF	25-50%	BC	25-50%					5-15 FT	25-75%	1.25%		VM																			
03B	DSCN1305.JPG	Looking north to 03A site, open water, tall grasses,moist soils, dead trees			1.25%																															grasses	open pond
04A	DSCN1292.JPG	Good BC recruitment in creek channel, Intermediate age BC both side of creek	>40 FT	75-100%	1.25%	BC	50-75%	PP	25-50%	DF	25-50%			5-15 FT	25-75%	1.25%		S.W.	25-50	Dogwood	25-50																
04B	DSCN1290.JPG	BC lining both sides of right of way ,BC approx 40-60 year old	>40 FT	75-100%	1.25%	BC	50-75 %	GF	1.25%	RC	1.25%	Aspen	1.25%	5-15 FT	75-100	1.25%																					
05A	DSCN1302.JPG	Open area 2 acres approx.with dense spyrea shrubs up to 6 ft tall, area wet														1.25%		Spyrea	75-100%	Pacific Willow	25-50%	Hawthorne	1.25%														
05B	DSCN1307.JPG	Oxbow on north side of road with pondweed(P.S), standing water	>40 FT	75-100%	1.25%	F.S.	25-50%	PP	25-50%	GF	1.25%	RC	1.25%	5-15 FT	75-100%	1.25%		VM	25-50 %	Dogwood	25-50%	Hawthorne	1.25%	Spyrea	1.25%												
06A	DSCN1311.JPG	Site appears to flood periodically, with cobble and woody debris BC recruitment high for this area	>40 FT	75-100%	1.25%	BC	75-100%	GF	1.25%	PP	1.25%			5-15 FT	75-100%	1.25%		Willow Sandbar	25-50%	VM	25-50%	D.W.	1.25%														
06B	DSCN1315.JPG	Oxbow evaluated from high point on south side, looking east	>40 FT	1.25%	1.25%	BC	1.25%	DF	1.25%	PP	1.25%	GF	1.25%	5-20 FT	75-100%	1.25%		S. Willow	50-75%	VM	25-50%	BC	1.25%	Hawthorne	1.25%											grasses, PS, vallisneria	
07A	DSCN1320.JPG	Looking west to oxbow, photo from high overlook on south side of oxbow	>40 FT	25-75%	1.25%	BC	25-50%	GF	1.25%	F.S.	1.25%	DF	1.25%	5-20 FT	75-100%	1.25%		VM	25-50%	Dogwood	25-50%	Bitter Cherry	1.25%	Willow (P,S)	1.25%											grasses,PS, vallisneria	
07B	DSCN1321.JPG	Looking north into woods from Highway 2 , some dead LWD, private property	>40 FT	25-75%	1.25%	BC	50-75%	RC	1.25%	Aspen	1.25%			5-15 FT	75-100%	1.25%		Dogwood	50-75%	BC	25-50%	Spyrea	1.25%	Aspens	1.25%												
08A	DSCN1324.JPG	Standing water between Highway 2 and dirt road to the north	>40 FT	1.25%	1.25%	BC	25-50%	PP	25-50%	DF	1.25%			5-15 FT	75-100%	1.25%		Dogwood	1.25%	Hawthorne	1.25%															grasses,PS, vallisneria	open pond
08B	DSCN1326.JPG	Dense tree and shrub growth,tree young intermediate, ferns	>40 FT	25-75%	1.25%	BC	25-50%	VM	25-50%	BC	1.25%	Aspen	1.25%	5-15%	25-75%	1.25%		VM	50-75% %	Ferns	25-50%	Wild Rose	1.25%	False Solomon Seal	1.25%												
09A	DSCN1328.JPG	Open pond area, riparian plants on edge, trees & shrubs on west,north,east	>40 FT	25-75%	1.25%	PP	50-75%	BC	1.25%	GF	1.25%			5-15 FT	25-75%	1.25%		Dogwood	25-50%	VM	25-50%	Hawthorne	1.25%	False Solomon Seal	1.25%	Spyrea	1.25%									grasses,equisteum,reed canarygrass, bulrush	Yes, open pond,1 acre
09B	DSCN1329.JPG	Looking at WP 160 (9A) from paved road, looking north from Highway 2	9A & 9B same site																																		
10A	DSCN1331.JPG	site off of gravel bar,mature BC,dead BC, young bc recruitment area	>40 FT	25-75%	1.25%	BC	25-50%	Aspen	25-50%					5-15 FT	25-75%	1.25%		BC	25-50%	VM	25-50%	aspen	1.25%	Red elderberry	1.25%	snow Berry	1.25%	Ferns	1.25%	Tansy	1.25%	fireweed	1.25%	golden rod	1.25%		
10B	DSCN1332.JPG	Oxbow to south of wypt, off of RR,	>40 FT		1.25%	BC	50-75%	RC	1.25%	PP	1.25%	GF	1.25%	5-15 FT	50-75%	1.25%		Willow(P)	50-75%	Dogwood	1.25%	BC	1.25%	hawthorne	1.25%	spyrea	1.25%									grasses, equisteum, PS,cat tails	Yes, open pond
11A	DSCN1336.JPG	Old beaver dam, dense monotypic willows,	>40 FT	1.25%	1.25%	BC	1.25%							5-15 FT	75-100%	1.25%		Willows (P)	75-100%	Spyrea	1.25%	Hawthorne	1.25%													PS	Yes, standing water
11B	DSCN1337.JPG	Decommissioned bridge,	20-40 FT	25-50%	1.25%	PP	25-50%	BC	1.25%					5-15 FT	1.25%	1.25%	Willow on sandbar	Willows (P)	25-50%	Alder(white, mountain)	1.25%	BC	25-50%	spyrea	1.25%	dogwood	1.25%	hawthorne	1.25%								
12A	DSCN1340.JPG	I02 Bridge	>40 FT	1.25%	1.25%	PP	25-50%	GF	25-50%					5-20 FT	25-75%	1.25%		VM	25-50%	Willows(S)	25-50%	Dogwood	25-50%														
12B	DSCN1341.JPG	LBC	>40 FT	50-75%	1.25%	PP	50-75%	BC	25-50%	DF	1.25%	RC	1.25%	5-15 FT	75-100%	1.25%		VM	75-100%	Oregon Grape	1.25%	Snowberry	1.25%														
13A	DSCN1344.JPG	Power line cutting across Nason 2X, large mature aspens	>40 FT	25-75%	1.25%	PP	50-75%	BC	25-50%	DF	1.25%	GF	1.25%	5-15 FT	25-50%	1.25%		dogwood	30-50%	VM	30-50%	hawthorne	1.25%	ferns	1.25%	black elderberry	1.25%	snowberry	1.25%								
13B	DSCN1346.JPG	LWD (BC), Moist site	>40 FT	50-75%	1.25%	DF	50-75%	BC	25-50%	Aspen	1.25%	GF	1.25%	5-25 FT	25-75%	1.25%		VM	75-100%	Giant Skunk Cabbag	1.25%	willow(S)	1.25%	dogwood	1.25%	snowberry	1.25%										yes
14A	DSCN1348.JPG	Shrub area, moist site, trees in semi-circle	>40 FT	75-100%	1.25%	PP	75-100%	DF	25-50%					5-20 FT	50-75%	1.25%		willow(P)	50-75%	Alder(white, mountain)25-50%	1.25%	Hawthorne	1.25%	service berry	1.25%	spyrea	1.25%										
14B	DSCN1350.JPG	Wypt on edge of creek,cobble,s and	>40 FT	50-75%	1.25%	PP	50-75%	BC	50-75%	Aspen	1.25%	GF	1.25%	5-20 FT	25-50 %	1.25%	Willow on sandbar	Dogwood	25-50%	VM	1.25%	willow(S)	1.25%	alder	1.25%	black elderberry	1.25%	BC	1.25%								
15A	DSCN1354.JPG	West wypt to island, LBC	>40 FT	25-50%	1.25%	BC	25-50%	PP	25-50%	DF	1.25%			5-25 FT	25-75 %	1.25%		Willow (P)	25-50 %	Alder	50-75%	Dogwood	1.25%														
15B	DSCN1356.JPG	Under power lines,s & n views	>40 FT	1.25%	1.25%	PP	25-50%	DF	25-50%	BC	1.25%			5-20 FT	75-100%	1.25%		Sitka Alder	50-75%	Willow (P)	50-75%	Dogwood	1.25%	VM	1.25%	snowberry	1.25%	marestail	1.25%								
16A	DSCN1360.JPG	wypt174 looking north from northside of N.C.,significant amounts of cobble on site	>40 FT	25-75%	1.25%	PP	50-75%	BC	50-75%	DF	1.25%	RC	1.25%	5-15 FT	25-75%	1.25%		G.F	50-75%	Dogwood	1.25%	Service berry	1.25%	VM	1.25%	RC	1.25%										
16B	DSCN1361.JPG	Wypt looking sw to island, r.o.w. through island, open ground on island, plants seem stressed	>40 FT	25-75%	1.25%	PP	50-75%	BC	25-50%	DF	1.25%			5-20 FT	25-75%	1.25%		Sitka Alder	50-75%	BC	25-50%	Dogwood	1.25%	PP	1.25%	Tansy	1.25%	Bitter Cherry	1.25%	Ocean Spray	1.25%						
17A	DSCN1368.JPG	Trees,shrubs on south side of power line, dry high flow channel, little gd cover in low site	>40 FT	50-75%	1.25%	DF	25-50%	PP	25-50%					5-15 FT	1.25%	1.25%	Potential for Willow	0	1.25%	Kikinknick	1.25%	ceanothus	1.25%	DF	1.25%												
17B	DSCN1369.JPG	Wypt taken underneath power line, looking north, decline of large BC, potential BC recruitment	> 40 FT	25-75%	1.25%	PP	25-50%	BC	25-50%	DF	1.25%			5-20 FT	25-75%	1.25%	I	Sitka Alder	25-50%	Dogwood	25-50%	Spyrea	1.25%	Willow (S)	1.25%	BC	1.25%	VM	1.25%								
18A	DSCN1373.JPG	old channel on west side of creek, willow, BC intermediate tree growth	>40 FT	25-75%	1.25%	PP	25-50%	BC	25-50%	DF	1.25%			5-20 FT	25-75%	1.25%		VM	1.25%	BC	1.25%	Dogwood	1.25%	Willow (S)	1.25%	Ferns	1.25%										
18B	DSCN1377.JPG	Some grass, fairly bare below shrub/tree canopy, LWD on inside of stream curve, willow recruitment	>40 FT	50-75%	1.25%	PP	25-50%	BC	25-50%	GF	1.25%			5-15 FT	50-75%	1.25%	Potential for Willow	Sitka Alder	25-50%	Dogwood	25-50%	Willow(S, P?)	1.25%	VM	1.25%	Spyrea	1.25%	Service Berry	1.25%	RC	1.25%						
19A	DSCN1380.JPG	Site a mixture of PP and DG and ground cover predominately service berry and snowberry	>40 FT	25-75%	1.25%	PP	50-75%	DF	25-50%	Aspen	1.25%	BC	1.25%	5-15 FT	25-75%	1.25%		Service berry	25-50%	Snowberry	25-50%	Wild Rose	1.25%	False Solomon Seal	1.25%												
19B	DSCN1381.JPG	Site contains signif amounts of down woody debris, I&M BC. Site of potential recruitment of BC &DF, older side canal fills during runoff(photo 1383)?	>40 FT	25-75%	1.25%	PP	25-50%	DF	25-50%	BC	25-50%	Aspen	1.25%	5-20 FT	50-75%	1.25%		Sitka Alder	50-75%	Dogwood	25-50%	BC	25-50%	Spyrea	1.25%	Black elderberry	1.25%	DF	1.25%	PP	1.25 %	snowberry	1.25%				

Appendix 1. Field Form Data

SurveyPt	Photo	Comments	Canopy Avg Hight	Canopy % Cover	% Canopy Dead	Canopy Species 1	Canopy 1 Species % abundance	Canopy Species 2	Canopy 2 Species % abundance	Canopy Species 3	Canopy 3 Species % abundance	Canopy Species 4	Canopy 4 Species % abundance	Understory Avg Height	% understory cover	% understory dead	Recruitment species
20A	DSCN1385.JPG	Major old meander (east side), thickly covered with shrubs, standing water in meander.	>40 FT	25-75%	1-25%	DF	25-50%	GF	25-50%	PP	1-25%	BC	1-25%	5-15 FT	50-75%	1-25%	
20B	DSCN1386.JPG	Major old meander (west side), thickly covered with shrubs, standing water in meander. Large dia alders (8 inch)	>40 FT	25-75%	1-25%	DF (I)	50-75%	PP(I)	25-50%					5-25 FT	25-75%	1-25%	
21A	DSCN1387.JPG	Site contain signif amounts of down wood limbs and tree trunks, bits of woody debris from flooding, very little undergrowth	>40 FT	50-75%	1-25%	GF (I&M)	25-50%	B.C (I&M).	1-25%	RC(I&M)	1-25%	DF	1-25%	5-20 FT	25-75%	1-25%	
21B	DSCN1393.JPG	Young GF/PP /DF on edge of river, I&M BC, old bridge structure at this site.	>40 FT	25-50%	1-25%	BC	25-50%	PP	25-50%					5-20 FT	25-75%	1-25%	
22A	DSCN1396.JPG	Broken standing PP &BC trees close to water one dead (DF) fairly tall, some bank erosion, small trib	>40 FT	25-75%	1-25%	BC	50-75%	PP	50-75%	GF	1-25%	DF	1-25%	5-15 FT	75-100%	1-25%	
22B	DSCN1397.JPG	I &M BC, wet soil at this site, sign amount of young willow, dense vegetation	>40 FT	25-75%	1-25%	BC	25-50%	GF	1-25%	DF	1-25%	RC	1-25%	5-20 FT	50-75%	1-25%	
						I = Intermediate											
						M=Mature											

SurveyPt	understory species 1	% understory species 1 abundance	understory species 2	% understory species 2 abundance	understory species 3	% understory species 3 abundance	understory species 4	% understory species 4 abundance	understory species 5	% understory species 5 abundance	understory species 6	% understory species 6 abundance	understory species 7	% understory species 7 abundance	understory species 8	% understory species 8 abundance	understory species 9	% understory species 9 abundance	Wetted area plants	Wetted area characteristics
20A	VM	25-50%	Dogwood	25-50%	Sitka Alder	25-50%	Ferns	1-25%	snowberry	1-25%									water hemlock,equisetum, cattail	yes
20B	Sitka Alder	25-50%	Spyrea	1-25%	Water Hemlock	1-25%	Skunk Cabbage	1-25%	bulrush	1-25%	Equisteum	1-25%	VM	1-25%					water hemlock, equisetum,cattail	yes
21A	VM	25-50%																		
21B	Sitka Alder	50-75%	Willows(P)	25-50%	BC	1-25%	Tanzy	1-25%	Spyrea	1-25%										
22A	Dogwood	25-50%	Sitka Alder	25-50%	VM	1-25%	BC	1-25%	Bitter Cherry	1-25%										
22B	Sitka Alder	50-75%	Willows (P&S)	25-50%	Skunk Cabbage	1-25%	VM	1-25%	Ferns	1-25%	snowberry	1-25 %	service berry	1-25%	Timble berry	1-25%				

PEER REVIEW DOCUMENTATION
PROJECT AND DOCUMENT INFORMATION

Project Name: Wentachee Watershed Plan

WOID: WEWAP

Document: 2007 Nasson Creek Floodplain Vegetation Assessment

Date: March 26, 2008 Date Transmitted to March Client: March 27,2008

Team Leader: David Sisneros Leadership Team Member___________
(Peer Reviewer of Peer Review/QA Plan)

Document Author(s)/Preparer(s): David Sisneros, John Boutwell, Debra Callahan

Peer Reviewer: Denise Hosler

REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain____

Part B: Document Requires Peer Review: SCOPE OF PEER REVIEW
Peer Review restricted to the following Items/Section(s): Reviewer:
Entire
Entire

REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: Denise M Hosler Review
Date: March 26, 2008 Signature

Reviewer:______________________ Review
Date:______________________ Signature

Preparer - I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: David Sisneros
Date: April 2, 2008 Signature

APPENDIX J.

GEOMORPHIC MAP METHODS AND GIS METADATA

This appendix provides documentation on the geomorphic mapping data and methods accomplished in the assessment area, along with metadata for the GIS database that was generated both in the assessment area and within the Nason Creek subwatershed.

CONTENTS

Tables

Figures

1. AVAILABLE DATA

Materials used for geomorphic mapping include historical maps and aerial photographs to assess channel changes over time (Table 1 and Table 2). The majority of historical photographs were provided by the U.S. Forest Service (USFS). Photographs that were not already rectified[1] were put in a geographic information database (GIS) in a known datum by the Bureau of Reclamation (Reclamation) (see Section 2 following for methods). Coverage of each map and photo set varied, but the earliest aerial photography found was 1962 and the oldest documentation of river position on a map was from 1898. Channels originating from historical maps have less certainty because methods used for generating the maps are undocumented and can vary.

Survey data available in a known datum included historical water surface profiles from the United States Geological Survey (USGS) maps (Table 2), cross-section data from the 1970s, a longitudinal profile of the channel bottom and water surface collected in 2007, and light distance and ranging (LiDAR) data collected in fall of 2006 (Table 3). Sediment data has been collected to look at average conditions in designated reaches throughout the subwatershed by the USFS (locations not specified). New pebble count data were collected in 2008 (Table 4; methods documented in Appendix H – Hydraulics and Sediment Analysis).

The USFS provided vegetation mapping of conditions within the last decade at the subwatershed scale (Table 5). New vegetation mapping was accomplished for the assessment area by Reclamation at a detailed scale; however, additional field investigation will likely be needed at project-level implementation. Historical vegetation mapping was also located for the subwatershed that was accomplished at a fairly coarse scale.

Streamflow measurements are limited, but have been collected since 2002 by the Washington Department of Ecology (Ecology) (Table 6). Ground photographs were collected by Reclamation where land was publically accessible (Table 7). Habitat data has been collected mostly by the USFS (Table 8). Additional spawning data has been collected by the Washington Department of Fish and Wildlife (WDFW) and the Yakama Nation.

To evaluate water temperature patterns, thermal infrared and color videography (TIR) data is available for low-flow periods in 2001 and 2003 (Table 9). Additional water temperature data is known to exist from Ecology, but was not acquired for this assessment.

[1] The process of "orthorectification" or placing an image over a known reference point or datum.

Table 1. List of aerial photographs utilized in geomorphic assessment.

Date	Source	River Coverage	Type
October 11 to 13, 2006; October 20, 2006	Reclamation (collected by Watershed Sciences, LLC. 2007)	RM 0 to 14	Color orthophoto
2006	U.S. Department of Agriculture (USDA) NAIP	Nason Creek subwatershed	Color orthophoto
July 2, 2006	USFS		Hard copy color
1998	USGS	Nason Creeksubwatershed	B&W orthophoto (see maps 15 and 16 in atlas)
1993 (no mapping done)	USFS	RM 0 to 3; RM 11 to 14	B&W
1974	USFS	RM 4 to 14	Color hard copies rectified into GIS (see maps 13 and 14 in atlas)
1962	USFS	RM 4 to 14	B&W hard copies rectified into GIS (see maps 11 and 12 in atlas)

Table 2. List of historical maps utilized in geomorphic assessment.

Date	Source	River Coverage	Type
Revised 1989	Federal Emergnecy Management Agency (FEMA)	RM 4 to 14	Floodplain map
Channel sections based on 1963 aerial photography with limited revisions in 1985	USGS	Nason subwatershed	7.5 minute quadrangle
1936	Chelan County (Washington Department of Transportation Archives)		Subwatershed
Unknown, found in 1932 folder	Chelan County (Washington State Archives)	RM 11 to 13	Township and land plots
1914 (channel survey noted in 1911)	USGS (Marshall 1914)	RM 0 to 5	Plan and profile map; 10-ft contours; 1” = 400 ft
1905 (meanders not noted; survey May to June 1903 by Muirhead)	Surveyor Generals Office (Bureau of Land Management BLM))	RM 8 to 14.5	Township and range map (GLO)
1901 (survey noted in 1900 by Farmer)	USGS (Plummer 1902)	Nason Creek subwatershed	1:125,000; 100 ft contour map
1900 (meander survey noted July to September 1898 by Whitham)	Surveyor Generals Office (BLM)	RM 4 to 8	Township and range map (GLO)

Table 3. List of available topographic data in a known survey datum for assessment area.

Date Collected	Type	Source	Approximate River Coverage	Method
August 27 to September 14, 2007	Longitudinal profile of channel bottom and water surface; also includes invert elevations of 10 culverts along main channel	Reclamation (collected by Pacific Geomatics Services, Inc; Seattle, WA)	RM 4 to 14	GPS and total station (WA State Plane North, NAD 1983 ft, NAVD 1988 ft)
2006	Bare earth and first return ASCII data; 1-m grid and 0.5 m contours	Reclamation (collected Watershed Sciences, LLC. 2007))	RM 0 to 14	LiDAR Data (UTM Zone 10, meters)
October 2005 and September 2006	Cross sections and topography	Chelan County (collected by Jones and Stokes 2007)	RM 0 to 4	Ground survey (WA State Plane North, NAD 1983 ft, NGVD 1929 ft)
1970s	Cross sections	FEMA (2004) (Nason Creek modeling done by CH_2MHILL)	RM 4 to 14	Ground survey (station-elevation data only; NGVD 1929 ft)

Table 4. List of sediment data collected for geomorphic assessment.

Date Collected	Source	River Coverage	Type
October and November 2005; September and October 2006	Reclamation (collected by USFS)	RM 4 to 14	Bar surface and riverbed pebble counts
1989, 1991, 1996	USFS	Nason Creek subwatershed	Bank to bank pebble counts for habitat surveys

Table 5. List of vegetation data available for Nason subwatershed.

Date	Source	River Coverage	Type
2006-07	Reclamation	RM 4 to 14	Vegetation species polygons along valley floor (see Appendix I)
1949 to 2002	USFS	Nason subwatershed	Vegetation species, timber harvest and management, fire areas
1998 (also available for 1981 and 1992)	Chelan County (Jones and Stokes 2003)	RM 0 to 4	Vegetation species
1902	(Plummer 1902)	Nason subwatershed	Vegetation species, clear cut, and fire area mapping

Table 6. List of available streamflow data.

Collection Period	Location	Source	Type
May 2002 to present	RM 0.8 on Nason at Cedar Brae Road Crossing (Bridge)	Ecology (Gage # 45J070)	Flow; continuous telemetered, peak flow data still provisional
2002-present	White Pine Creek near mouth	Ecology (Gage #45P050)	Manual stage height
October 1992 to September 1993	RM 0.75 on Nason Creek	Chelan County Conservation District	20 manual flow measurements

Table 7. Ground photographs collected during field visits.

Date	Mean Daily Flow at Ecology Gage (average if multiple days)	Source	River Coverage	Purpose
September 30 to October 2, 2007	62 cfs	Reclamation	Varies	Upper watershed reconnaissance and peer review
August 7-9, 2007	61 cfs	Reclamation	RM 4 to 14 (locations in GIS)	Human features and geologic features in present main channel
May 2-7, 2007	710 cfs	Reclamation	RM 4 to 14 (locations in GIS)	Human features and geologic features in floodplain
May 19, 2006	5,666 cfs	Reclamation	6 locations between RM 0 to 14	High flow documentation
June 30, 2005	43 cfs	Reclamation	RM 0 to 15	

Table 8. Habitat data either acquired or referenced in geomorphic assessment.[2]

Date	Source	River Coverage	Type	Spatial Representation
August 2007	USFS	RM 4 to 14	Level 2 habitat survey	GIS data; shown on maps 19 and 20 in atlas
2001-2007	WDFW	RM 0 to 14.6	Steelhead spawning	Reach-averaged, no GIS data
2000-2007	Yakama Nation	RM 0 to 14.6	Coho spawning	Reach-averaged, no GIS data
1998-2007	Chelan County PUD,WDFW	RM 0 to 16.9	Spring Chinook spawning	Reach-averaged, no GIS data
1989, 1991, 1996	USFS	RM 0 to 16.8	Habitat survey	Reach-averaged, no GIS data
1935-1936	U.S. Bureau of Fisheries (Oregon State University)	Watershed	Habitat survey	Reach-averaged; no GIS data

[2] Note that additional habitat data exists from USFS reach assessments, WDFW, and Yakama Nation that is known to exist and referenced, but was not acquired for this assessment

Table 9. List of known water temperature data collected in Nason subwateshed.

Date	River Flow	Source	River Coverage	Type
1998 to 2004	Unknown	Ecology (Bilhimer 2003)	Varies	303d studies
August 12, 2003	49 cfs at Washington Department of Ecology (Ecology) Gage	Pacific Watershed Institute (Watershed Sciences, LLC. 2003)	RM 0 to 26	TIR
August 14, 2001	98.5 cfs at Ecology Gage	Pacific Watershed Institute (Watershed Sciences, LLC. 2002)	RM 0 to 26	TIR
1955-1956	Unknown	Seabloom 1958	7 spot measurements between RM 0 to 26	Water measurement
October and November 1935 and July 1936	Unknown	USBF 1935		Water measurement

2. HISTORICAL PHOTOGRAPH AND MAP RECTIFICATION

Historical aerial photographs from 1962 and 1975 were acquired and scanned from the USFS office near Wenatchee, Washington. The scanned images were rectified, which means the images can be displayed and used for GIS mapping in a known set of coordinates. The coordinate system used was Washington State Plane NAD 1983 feet. Orthophotography from 2006 was used for the rectification because it has been corrected to produce an accurate image of the Earth by removing tilt and relief displacements which occurred when the photo was taken. The rectification process involved identifying a series of ground control points that link locations on the scanned image with locations on the spatially referenced orthophotography. Control points are locations that can be accurately identified on the scanned images and in real-world coordinates. Many different types of features were used to identify locations, including road and stream intersections, the mouth of a stream, rock outcrops, the corner of an established field, and street corners. The control points were used to build a first-order transformation that converted each scanned image into a spatially-correct raster[3] dataset. RMS[4] error for each rectified image was kept at a maximum of 20 feet.

Historical maps from 1901 to 1989 were also rectified to a known coordinate system (Washington State Plane NAD 1983 feet). The historical maps were rectified by matching control points along township and range boundaries from the historical maps with the most recent available USGS 7.5 minute quadrangles in digital form. A digital raster graphic (DRG) is a scanned image of the standard series topographic maps, including all map collar[5] information. The image inside the map is georeferenced to the surface of the earth and fit to the Universal Transverse Mercator projection (reprojected in this case to Washington State Plane NAD 1983). The maps have varying degrees of errors depending on the scale of the map and the original methods, which are not well documented. Most maps were found in historical archives but did not include detailed metadata on methods or presumed accuracy. The 1901 to 1905 maps appear to have the most error, particularly in river alignment because in places the rectified map shows the river running through bedrock. However, the map area is still useful for general indications of river position and alignment that can be compared to other river positions over time. Of particular interest for comparison are areas where the map creators took the time to indicate a channel meander rather than just showing a straight channel path. The historical maps also document settlement activities and, in some cases, historical logging and fire areas.

3. LIDAR DATA PROCESSING

The LiDAR data collected in 2006 can be used to produce color-coded maps that represent the change in elevation across the valley floor. There is a wide range of LiDAR elevation values between the upstream and downstream ends of the assessment area, and between the valley walls and the valley floors. A typical color-coded image of the surface elevation produced in ArcGIS does not show the localized changes in elevation that are of interest for this assessment. Of particular focus are having visual images that can be used to evaluate the elevation of historical channels and adjacent surfaces compared to the present main channel. The difference in elevation is in part used to distinguish between historical channels and floodplain surfaces, and also to evaluate whether the present river has signs of incision because it is lower or higher than historical channel areas. This is of particular value in meandering sections where it is difficult to know how to draw a cross-section alignment that is a fair representation for elevation comparison between two channels of differing alignments and lengths. Therefore, an image was produced from the LiDAR data that shows the elevation of historical channels and floodplain surfaces relative to the

[3] A raster is a commonly used GIS image made up of rows of pixels. A raster image is a data file or structure representing a generally rectangular grid of pixels, or points of color. Each pixel has a single value

[4]. Determined by calculating the deviations of points from their true position, summing up the measurements, and then taking the square root of the sum.

[5] The map collar is the area around the map that contains information such as projection, quadrangle location, latitude/longitude and UTM tick marks, map scale, etc.

present main channel (see maps 17 and 18 in atlas). The relative elevation surface model is a fairly quick process for which the methods are described below.

A channel bottom profile survey from 2007 was used to develop a three-dimensional river centerline representing the main channel of Nason Creek. Main-channel elevation values were extended across the valley by creating evenly spaced valley-wide cross sections perpendicular to the centerline, then populating the cross section elevations with values extracted from the centerline to create a series of flat cross sections. The elevation values of the cross sections were used to create an ESRI TIN surface and subsequently converted to an ESRI GRID that was used as the main channel elevation model in the calculation. Relative elevation values were calculated by subtracting the main channel elevation model ESRI GRID from a valley-wide LiDAR Bare Earth ESRI GRID. LiDAR data was not combined with the 2007 profile data to create a continuous surface that could be utilized for hydraulic modeling. This could be done in future efforts and may require additional elevation data in wetted channels and off-channel ponds and in heavily vegetated areas where the LiDAR could not penetrate below the water or through the vegetation.

4. GEOMORPHIC MAPPING

The section below describes methods and terms utilized in the geomorphic mapping which are summarized in the main report and presented in visual form in the accompanying map atlas. All of the mapping data is available in a GIS database (see next section). Mapping described below includes:

- Historical channel migration zone
- Floodplain
- Historical channels
- Human features
- Bank erosion
- Geologic surfaces

Methods for vegetation mapping are described separately in Appendix I.

4.1 Historical Channel Migration Zone

The historical channel migration zone (HCMZ) includes the main channel plus side channels, islands, and all other areas that have evidence of channel migration for a period of at least the last 100 years and probably several hundred years. The HCMZ includes the area where the majority of coarse sediment (sand, gravel, and cobbles) is transported during high flows over this century timeframe. The HCMZ is part of the river’s floodplain, but the floodplain includes additional areas as described in Section 4.2 below. Therefore, the HCMZ boundary is not associated with a specific flood interval. The typical surface height within the HCMZ ranges from 2 to 8 feet above the present channel bed.

The HCMZ boundary was defined by the extent of present and historical channels based on 2006 LiDAR elevations, 2006 and 2007 field observations and bank profiles (see Attachment 1), historical maps (1901, 1911, 1932, and 1936), and aerial photographs (1962, 1974, 1998, and 2006). The HCMZ boundary was validated by using depth and velocity results from a two-dimensional (2D) hydraulic model of existing conditions and with a model that removed all human features that block flow access (features with an elevation above the natural ground). In some areas, channels are present on higher elevation surfaces. The channels are not well defined and are inferred to not have been reworked by the river in at least the last several hundred years. To determine if these channels should be mapped within the HCMZ boundary, 2D model results were used to help identify channels that had significant depth and appeared to be well connected with the main channel.

In a few of the assessment areas, there was still uncertainty in the boundary of the HCMZ because of modifications that have been made to the topography. For this reason, a second HCMZ boundary was mapped that included channels that were questionable. The HCMZ with greater confidence is referred to as the high-confidence HCMZ and used in the majority of report discussions. The HCMZ with less confidence is referred to as the moderate-confidence HCMZ.

4.2 Geologic Floodplain

The geologic, or historical, floodplain for Nason Creek includes the HCMZ, but also extends beyond the HCMZ to include additional surfaces that are only inundated during large floods. These additional surfaces are typically 8 to 10 feet above the active channel (Attachment 1). In some cases the boundary of the HCMZ and floodplain coincide, such as along bedrock valley walls or steep alluvial fans. There is not a specific flood interval associated with the floodplain boundary but it should incorporate the majority of inundation areas associated with flooding, in many cases up to the 100-year flood. During large floods, minor inundation areas may extend beyond the boundaries of the geologic floodplain. Geomorphic surfaces of several relative heights are present within the floodplain, interpreted to represent surfaces formed over different periods of time. The majority of surfaces are less than 12 feet above the present river bed elevation.

There are primarily two types of deposits within the floodplain: channel deposits and floodplain (or overbank) deposits. The deposits are composed of sediments from silt to boulders; however, the channel deposits are predominantly sand through cobbles and the overbank deposits are sand and silt. The unconsolidated character of these deposits makes them highly susceptible to erosion. The sources for the deposits within the floodplain are reworked older fluvial deposits, glacial deposits, alluvial-fan deposits, and landslide deposits.

To draw the geologic floodplain boundary, the first draft was done using a combination of the extent of historical channels (main, side, and overflow) and natural breaks in elevation where geologic features are present. Elevation breaks may be along bedrock, alluvial fans, or along more subtle features such as glacial terraces. In other areas, the boundary was estimated on a surface that has a gradual sloping elevation. The 2D model results were also used to help validate the areamapped as floodplain was inundated at flows between 2,500 and 10,000 cubic feet per second (cfs), the range of predicted flood frequency values for the assessment area. In some places, the model showed inundation beyond the boundary drawn from geomorphic surface interpretation. In these cases, the geologic boundary was extended only if the surface had significant inundation. A general rule of thumb for extending the geologic floodplain boundary was that the surface had to have more than 0.5 foot of depth or 0.5 feet per second (ft/s) of velocity at 10,000 cfs.

The floodplain boundary was then refined using results from 2D hydraulic modeling with human features removed that presently impede access between the main channel and floodplain. Once delineated, the floodplain boundary was compared to previously mapped floodplain areas and local accounts of flooding to see if any significant areas had been excluded. The Federal Emergency Management Agency (FEMA) defined 100-year and 500-year floodplains for the Nason Creek within the assessment area that were used for comparison (FEMA 2004). A few high water ground photographs were taken by Reclamation in May 2006, along with a helicopter video of that spring snowmelt. Also utilized, were local accounts from Washington State Department of Transportation that noted flooding from the winter 1990 and 1995 floods which were said to be two of the largest documented floods in the subwatershed. The majority of major flooding accounts were along RM 12 to RM 13, and downstream of RM 4 to the mouth.

4.3 Historical Main Channels

Historical channels were mapped to assist with delineation of the HCMZ, identifying areas of present and historical channel migration, and identification of potential restoration opportunities. Reconnection of historical channels is most often identified by recovery planning efforts as having the highest potential to improve habitat availability and quality for spring Chinook and steelhead on Nason Creek between RM 4 and Rm 14 (Andonaegui 2001; USFS 1996; UCSRB 2007). Therefore, it is of interest to know how well defined the historical channels are, and whether they are inferred to be historical main channels or smaller side channels. This is important in identifying restoration strategies, both in terms of the benefit of reconnection, how it links with presently accessible channels, and in terms of the level of effort that may be needed to restore the channel function.

Centerlines for the main channel were mapped on all of the years of available maps and aerial photographs to identify where the main channel has changed position, and to compare the sinuosity of the present channel relative to historical channel alignments. Channels were mapped in ArcGIS on rectified historical maps and aerial photographs spanning the early 1900s to 2006 (see Table 1 and Table 2). This can be overlaid with the mapping of human features (next report section) to identify impacts to channel function and migration.

In many sections of Nason Creek (downstream of RM 14), the historical main channel has been disconnected and is now bypassed by a human-made channel running along the railroad and highway embankment. These disconnected areas have been identified as a priority for focusing restoration efforts by Upper Columbia recovery planning efforts (UCSRB 2007). These historical main channels along with side channels, overflow channels, and backwater areas were difficult to identify on historical aerial photographs and maps with any confidence because of dense vegetation, poor quality, and the lack of elevation data to discern the channel boundaries. Field mapping or surveying all of these areas would have been time consuming and expensive, and may have had access limitations, making it difficult to get a detailed map.

Because of these limitations, 2006 LiDAR data was used to map the historical main channels, side channels, and backwater areas. Channels were then categorized based on their topographic expression (depth and width) in groups of “good,” “moderate,” or “poor” to help determine whether they were main or side channels, or in some cases to show evidence of possible human-placed fill. “Good” channels are those that are well expressed with a clear alignment. Channels in this category are generally assumed to have been main channels based on interpretation of how the railroad and highway was constructed. Most “good” channels are relatively wide and include historical main channels, although some well-expressed narrower channels (interpreted to be side channels) are included in the good category. “Moderately” expressed channels are somewhat less well expressed, and are usually narrower than channels in the good category. “Moderately” expressed channels also might have been main channels. “Poor” channels were not well defined either because they are shallow overflow channels that are only inundated during floods, or because they have been modified by land use or from placement of fill.

Due to the extensive channel confinement, it was of interest to evaluate the reduction in channel sinuosity and length to historical (early 1800s) conditions. There isn’t any way to tell which of the historical channels that are visible on the LiDAR hillshade were active at any one time and, as mentioned earlier, the historical photographs and maps do not go back far enough in time. To look at a comparison to present channel length, the good and moderately expressed LiDAR channels that are estimated to have been main channel paths were used to generate three possible historical main channel paths based on professional judgment (Table 10; Figures 2, 3, and 4 in Attachment 2). Interpretation was made by using meanders that might be somewhat realistic given the size of Nason Creek and the width of the HCMZ. In some cases, the same historical paths were used for more than one conceptual main channel alignment. Where multiple historical paths exist, the alignment was varied to cover the range of uncertainty in main channel occupation at any given time. Two of the possible historical main channel paths (paths 1 and 2) were kept within the high-confidence HCMZ boundary as the limit of channel migration. The third possible main channel path (path 3) was drawn within the moderate-confidence HCMZ boundary as the limit of channel migration, so that the entire possible HCMZ could be considered.

Table 10. Lengths of main channels for conceptual paths 1 and 2 (within the high-confidence HCMZ) and 3 (within the moderate-confidence HCMZ).

Reach	Conceptual Main Channel 1 Length (feet)	Conceptual Main Channel 2 Length (feet)	Conceptual Main Channel 3 Length (feet)
1	25,375	24,203	27,948
3	32,055	33,811	33,970

4.4 Historical Side Channels

It was of interest to determine how the present availability of side channel and off-channel areas compares to historical conditions. This helps set a potential target for restoration of what is possible by working within the conceptual model of historical conditions for RM 4.6 to RM 14.3. This also helps distinguish how far departed present side channel availability is at a reach scale, and how the reaches relatively compare.

In order to determine what the historical side channel and off-channel area may have been, the total area of wetted side channels as compared to the total area of wetted main channel was computed. In order to compute this value, the length (described in Section 4.3), width, and area had to be computed for both historical main and side channels as described below.

4.4.1 Historical Side Channel Lengths

For each of the three conceptual historical main channel paths, three potential sets of side channel paths (lines) were mapped using the channel expression areas delineated on the hillshade (e.g., good, moderate, poor). The cumulative length of each set of side channels was computed in ArcGIS for each reach (Table 11; Figures 2, 3, and 4 in Attachment 2). Side channels mostly consist of moderately-defined and poorly-defined LiDAR channels that would not have been expected to be main channels, although some well-defined channels (good category) were included that were narrow and adjacent to a likely main channel. The side channel paths were drawn such that they always connect to the historical main channel path at both upstream and downstream ends. The side channel paths follow mapped channels from the LiDAR except for short sections where a channel may not be visible, such as where railroad and highway embankments exist. Some of the channels mapped on the LiDAR were main channel for one conceptual path and side channel for another conceptual path. Not all areas had side channels. This information was used to look at the potential availability of off-channel habitat at a reach scale.

Table 11. Lengths of side channels for conceptual paths 1 and 2 (within the high-confidence HCMZ) and 3 (within the moderate-confidence HCMZ).

Reach	Conceptual Side Channels 1 Length (feet)	Conceptual Side Channels 2 Length (feet)	Conceptual Side Channels 3 Length (feet)
1	7,362	5,417	4,639
3	8,086	13,485	9,525

4.4.2 Historical Channel Widths

In order to estimate main and side channel areas, historical channel widths are also needed to multiply by the mapped channel lengths. Because of the uncertainty in mapping the area of each conceptual main channel and side channel, widths of several of the channels mapped on the LiDAR hillshade were measured in ArcGIS to get minimum, average, and maximum values (Figures 2, 3, and 4 in Attachment 2). The measured widths were divided into four categories for comparison purposes:

1. active, unvegetated main channel in 2006;
2. historical main channels based on channels in the good, or well-expressed LiDAR mapping category;
3. channels interpreted to be side channel paths.

Using the measured channel widths, a minimum and maximum width was estimated for the conceptual (historical) channels: 65 to 80 feet for the main channels and 30 to 50 feet for the side channels. These values appeared to encompass the variability in average width measurements of the main or side channels for the entire assessment area.

4.4.3 Estimation of Historical Channel Area

The mapped lengths of the conceptual main and side channel paths were multiplied by the ranges in main or side channel widths to estimate the wetted area covered by the three main channel paths and the possible side channels related to each alignment. The same widths were used for all of the conceptual channel paths, but different values could be estimated at a more detailed scale in future reach assessment phases.

4.4.4 Estimation of Side Channel Area as Percent of Main Channel Area

Biologists often estimate the available rearing habitat in a river by what percent of the wetted channel is composed of side channel and backwater areas as opposed to just the main channel. The cumulative area of the side channels for each reach was calculated as a percent of the total area of the associated main channel path (Figure 1). The minimum percent of side channels was calculated using the minimum side channel area and the maximum main channel area. The maximum percent of side channels was calculated using the maximum side channel area and the minimum main channel area. This resulted in a potential range of historical side channel areas of 6 to 22 percent for Reach 1, and 9 to 31 percent for Reach 3.

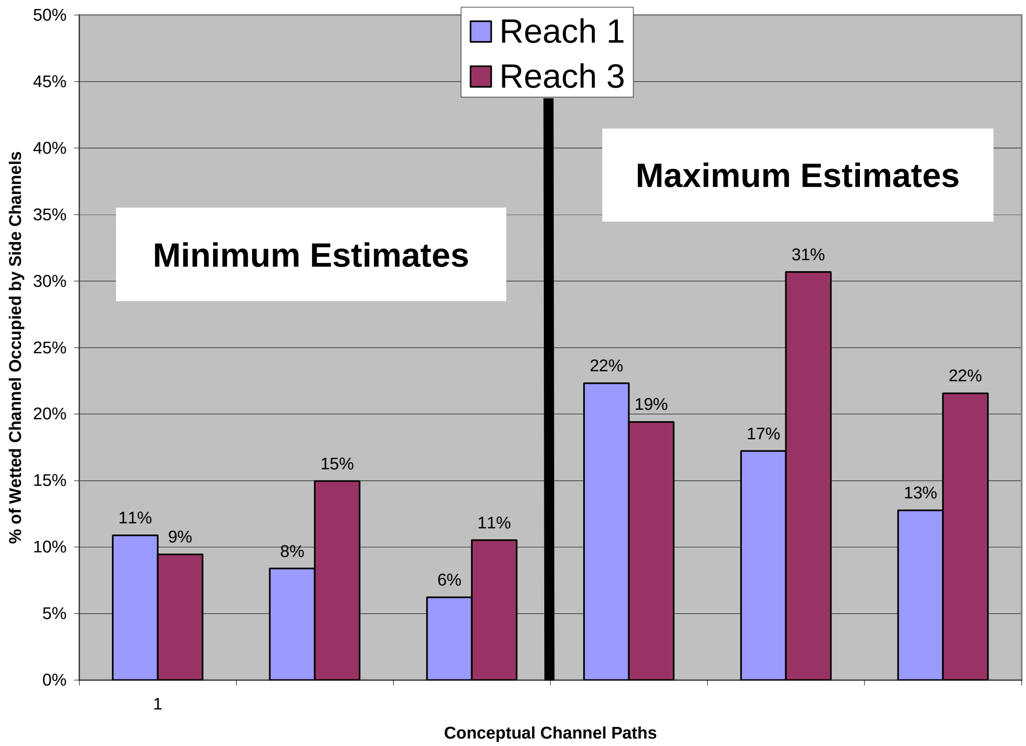

Figure 1. Estimates for historical percent of active, wetted channel area occupied by side channels.

4.5 Human Features Along and Within the Floodplain Boundary

The human-constructed features that are present along and within the floodplain boundary were mapped from aerial photographs and LiDAR collected in 2006 and from field reconnaissance. Features were further identified by field checking areas where 2D hydraulic modeling results showed an interruption of flow connectivity between the main channel and floodplain. Human features were mapped in GIS as points, lines, and polygons. Points represented features such as barbs, culverts, and sheet pile where it was difficult at this mapping scale to show a longitudinal extent or area occupied by the feature. Lines represented features that did not have an extensive area occupied, but did extend longitudinally for some distance, for example riprap. Polygons represented features where the footprint of the feature could be delineated such as railroad and road embankments and large levees. In some cases, lines were generated of the features represented by areas to determine the length of the feature in addition to the area.

Additional human features may exist where they could not be detected remotely or checked in the field due to limited field access. Over time, human features either may be washed out, replaced, or new features constructed and this mapping could be updated at a specified interval of interest. Of particular interest may be updates following new construction and after flooding.

Human features were characterized in GIS not only by location and quantity, but also by whether they impact channel function and migration, floodplain access, or both. The objective was to clearly identify the benefits of modifying or removing the features in proposed habitat restoration strategies discussed in the main report for this assessment. Maps 23 and 24 in the atlas show the locations and types of features that impact channel migration. Maps 25 and 26 in the atlas show the locations and types of features that impact floodplain access. Each is described in a little more detail below.

Features that impact floodplain access were identified as those that physically block water from flowing between the main channel and some portion of the adjacent floodplain. This results because the feature is raised above the typical ground surface. Examples include levees, railroad and road embankments, and culverts where they are located within these raised features. In some cases, the features can be overtopped at large floods, but were still included in this category because they impact floodplain access at least a portion of the time. Floodplain areas that are disconnected due to human features were separated by whether they are located within the HCMZ or in the extended floodplain. Floodplain areas within the boundary of the HCMZ that are disconnected due to these features are referred to as “impacted HCMZ” areas; impacted floodplain areas that are outside of the HCMZ are referred to as “disconnected floodplain.”

Features such as riprap along the HCMZ boundary limit further expansion of the HCMZ and floodplain because they armor the boundary (assuming the bank protection is maintained). They may also limit vegetation cover and recruitment of LWD. Features along the floodplain boundary (mostly riprap) were identified by whether they were located on the left or right (looking downstream) boundary. Features on the floodplain boundary that were also located along the 2006 wetted main channel were noted. The lengths of the human features along the floodplain boundary were calculated in ArcGIS. The lengths were used to calculate the percent of the floodplain boundary that is protected by human features in each geomorphic reach.

Human features were also identified that impact channel migration and channel geometry. In some cases, these are the same features that block access to the floodplain, such as railroad and road embankments and levees. In other cases, features that limit channel migration may still allow overtopping into the floodplain, such as riprap that is on existing ground where no berm or levee is present, cabled logs, sheetpile along power and transmission line poles, and developed areas that are anticipated to be protected if river erosion was ever initiated.

4.6 Bank Erosion

Bank erosion along the unvegetated channel was documented using field observations by Reclamation and USFS personnel. In some cases, the entire length of erosion was documented. In other areas, a point was marked to locate the erosion, but no extent was documented. Historical areas of bank erosion along the main channel between 1962, 1974, and 2006 were mapped using polygons at a few locations where channel migration has noticeably occurred. In other instances a small amount of erosion is occurring but the lateral extent of erosion is not measurable between aerial photographs within the bounds of the error associated with rectification of the 1962 and 1974 sets.

4.7 Geologic Surfaces

In addition to mapping the boundary of the HCMZ and floodplain, the types and extent of geologic surfaces that bound the floodplain were mapped (Figure 2 and maps 21 and 22 in atlas). The purpose of this mapping was to identify vertical controls in the river bed that can limit incision, lateral controls along the boundary of the HCMZ and floodplain that can limit expansion of these boundaries, and the potential erodibility and sediment contribution of these surfaces based on their underlying composition exposed to the river.

Expansion can occur as part of a normal river process, or because upstream or adjacent human features are redirecting the river (with possibly more energy) into a surface that may not have otherwise eroded. The composition and potential erodibility of the underlying material in these surfaces is also used to examine the potential erodibility in areas where historical channels may be reactivated as part of a restoration process. This helps inform future efforts as to whether there is a risk of bank erosion, particularly in areas occupied by highways and development. In places extension of these surfaces into the present main channel also forms vertical controls that limit incision, such as bedrock formations or boulders from historical debris flows and landslides. Additionally, mapping of these surfaces can help qualitatively estimate potential sediment contributions based on their composition.

The surface types identified on Nason Creek in the assessment area and included in the GIS database are included as Attachment 3. Methods used to identify these surfaces included literature review of existing geologic information and maps (see Appendix C), relative elevations of surfaces compared to the main channel from 2006 LiDAR data and collection and interpretation of bank profiles to distinguish characteristics among the varying surfaces (see Attachment 1). Although beyond the scope of this assessment, it is also possible to date terraces and alluvial fans to refine understanding of how long it has been since the main channel occupied these areas, and how often they might be actively contributing sediment to the river. This is of particular interest in river areas that are actively migrating into cleared terrace banks. The dating can help establish if the terrace surface is only hundreds of years or less in age, or if it is thousands of years old. This helps qualify whether it may be appropriate to slow the rate of erosion down in areas that took thousands of years to form and are presently rapidly eroding.

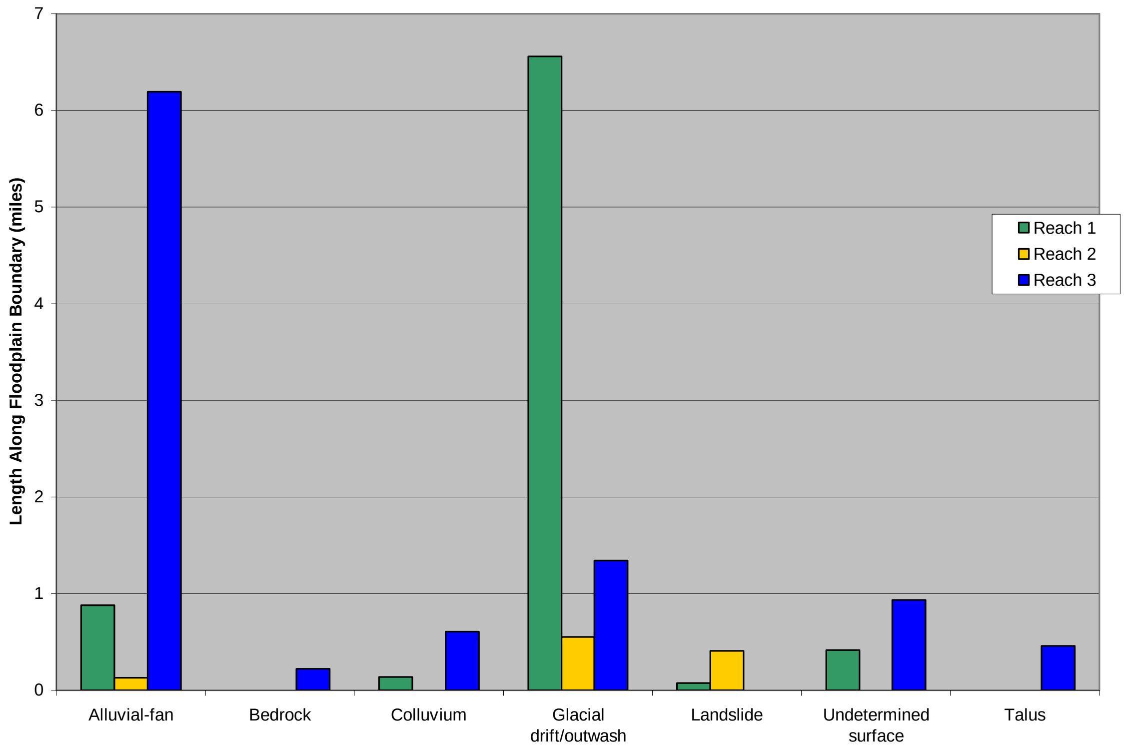

Figure 2. Length of each geologic surface type that occurs along the floodplain boundary within the assessment area reaches.

4.8 Channel Slope

The channel slope in the Nason Creek tributary assessment area varies markedly (Figure 3). The slope is relatively flat upstream of about river mile (RM) 7.2 and downstream of RM 4.7. In between these two flatter sections is a very steep section. These slope changes are most likely the result of glacial scour and deposition that occurred thousands of years ago, and the markedly different rock types of the Nason terrane and Chumstick Formation.

Glacial ice occupied the Nason Creek valley (Figure 4) several times during the Salmon Springs Glaciation (130-140 ky BP.) and the Fraser Glaciation (18-11.5 ky B.P.) (refer to Appendix C for further discussion). Upstream of locality A (refer to Figures 3 and 4), the bedrock is comprised of hard, metamorphic rocks of the Nason terrane that are resistant to fluvial erosion. The valley has been widened and deepened by advancing glaciers, and subsequently filled by their retreat during Pleistocene time. Nason Creek is predominantly unconfined in this reach and has been able to re-work the glacial deposits along the broad valley bottom.

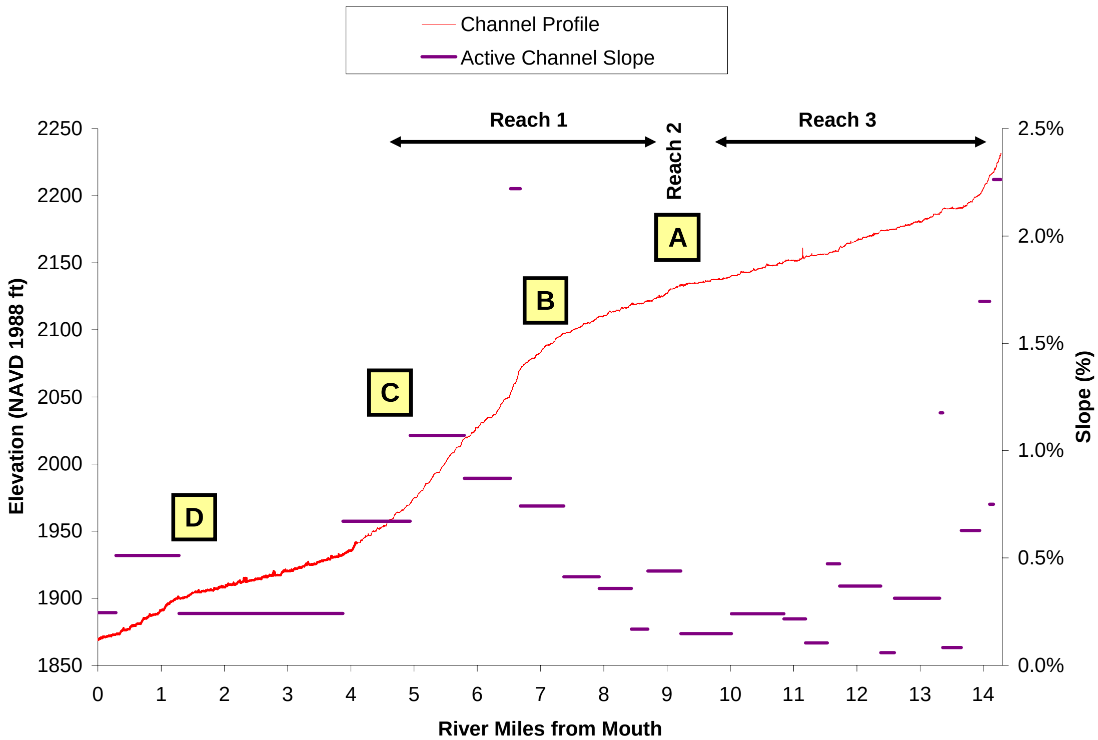

Figure 3. Longitudinal profile of channel slope and bed elevation along with points of discussion (A, B, C, D) for text in Section 4.7.

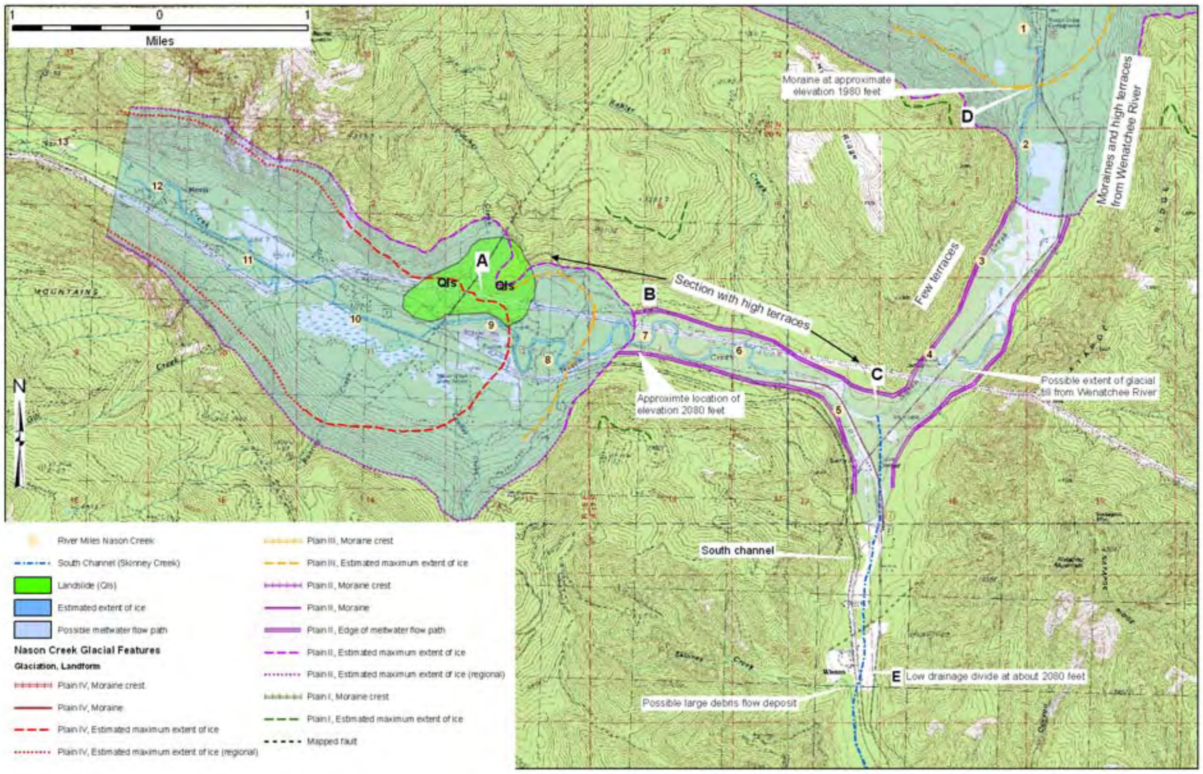

Figure 4. Map of lower Nason Creek valley showing glacial features as mapped by Nimick (1977). Localities shown by letters are discussed in text.

At locality A the metamorphic rocks of the Nason terrane are juxtaposed by the sedimentary rocks of the Chumstick Formation along the Leavenworth fault. There is also a landslide that is seated in the left abutment of a terminal moraine between river miles (RM) 8.9 and 9.3. This moraine is interpreted to be correlative to the Evans Creek Stade of the Fraser Glaciation. The terminal moraine of does not continue across the valley bottom, but is breached and probably released a glacial outburst flood. If a catastrophic glacial outburst flood did occur, the flood would have flowed down Skinney Creek and Tumwater Canyon (locality E) as a glacier would have occupied the Lake Wenatchee valley.

The boulders (up to 10 feet in dimension) contained in the terminal moraine were deposited downstream of the breach (between locality A and B) probably forming a wedge between about RM 6.7 and RM 8.5. Following the breach, copious amounts of glacial outwash were deposited by the receding glacier (and probably by subsequent younger glaciers) between locality B and C. Nason Creek has incised through the glacial outwash deposits as evidenced by the flight of terraces that are perched over 60 feet above the active stream channel. The creek continued to incise through the glacial deposits until it reached the wedge of boulders that provide a vertical grade control.

The reaches between localities B, C, and D have been influenced by interactions between the Nason Creek glacier and the Lake Wenatchee glacier. Between about RM 1.5 and 4.0 the slope of Nason Creek is relatively flat. In this area the creek is predominantly unconfined and is reworking the thick glacial deposits. From about RM 1.5 to Lake Wenatchee the slope of the creek becomes somewhat steeper. This is probably an erosional artifact from the Lake Wenatchee glacier flowing up the Nason Creek valley.

5. GIS DATABASE

Two GIS databases were generated to document information utilized from external sources and to document information generated by Reclamation for this assessment. For the Reclamation database, metadata were generated for each file that documents the methods and pertinent information in developing the file. For the non-Reclamation database, metadata may or may not be available; most of the external data is publically available, but in some cases distribution may be limited and the original source will need to be contacted to get a copy of the data. The majority of Reclamation-developed GIS data is in the Washington State Plane NAD 1983 and NGVD 1988 coordinate system.

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ATTACHMENT 1 – Nason Creek Bank Profile Descriptions (RM 6 to RM 14)

Date described: August 7, 2007 Characteristic		Reach:3 Location: RM 12.875 on outside of active meander bend within floodplain	Reach:3 Location: RM 12.06 along constructed fill at Merritt	Reach:3 Location: RM 11.96 along constructed fill at Merritt
Overall assessment of erodibility	Extreme High Moderate Low to none	Extreme High Moderate Low	Extreme High Moderate Low	Extreme High Moderate Low
Bank	Right Left	Right Left	Right Left	Right Left
Road or building visible	Yes No	Yes No	Yes No	Yes No
Landform	Floodplain Terrace(?) Moraine Valley edge	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Fill(?) Moraine Valley edge
Relationship to channel	Outside of bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section
Bank height - Measured				
Bank height - Estimated	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5
Bank material	Rock Boulder Gr Riprap Cobble Gr Pebble Gr Sand/Silt "Blue" clay	Rock Boulder Gr Cobble Gr B4' Pebble Gr Sand/Silt T3' "Blue" clay	Rock Boulder Cobble Gr Pebble Gr Sand/Silt Brown clay	Rock Boulder Gr Cobble Gr Pebble Gr Sand/Silt "Blue" clay
Geologic origin	Rock Glacial Channel Overbank Landslide	Rock Glacial Channel Overbank Landslide	Rock Glacial-Fluvio Channel Overbank Landslide	Rock Glacial Fill(?) Channel Overbank Landslide
Consolidation 0=loose; 5=hard (rock)	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Slope (degrees)	<25 25-45 45-90 90	<25 25-45 45-90 90	<25 25-45 45-90 90	<25 25-45 45-90 90
Dominant vegetation on surface (Estimate percent of each)	Grass 10 Shrubs Alder 90 Deciduous Conifer Mixed	Grass Shrubs40 Alder Deciduous30 Conifer Mixed	Grass Shrubs Alder 90 Deciduous Conifer 10 Mixed	Grass Shrubs Alder 60 Deciduous Conifer 40 Mixed
Clear cut to surface edge	Yes No	Yes No	Yes No	Yes No
Roots in bank – Percent of visible bank	<5 10 25 50 >50	<5 10 25 50 >50	<5 10 25 50 >50	<5 10 25 50 >50
Roots – Density 0=few; 5=abundant	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Root size	Fine Medium Large Very large	Fine Medium Large Very large	Fine Medium Large Very large	Fine Medium Large Very large
Protection	LWD Riprap	LWD Riprap	LWD Riprap	LWD Boulder Armor

Date described: August 7, 2007 Characteristic		Reach:3 Location: RM 12.875 on outside of active meander bend within floodplain	Reach:3 Location: RM 12.06 along constructed fill at Merritt	Reach:3 Location: RM 11.96 along constructed fill at Merritt
Evidence of active landslide	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank
Evidence of active erosion	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots
Photographs taken	8-7-07, #7	8-7-07, #29	8-7-07, #45	8-7-07, #48

Photograph No.7. View is to the north at bank profile site of left bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 7, 2007)

Photograph No.29. View is to the south at bank profile site of right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 7, 2007)

Photograph No.45. View is to the east looking at bank profile site on right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 8, 2007)

Photograph No.48. View is to the south looking at bank profile site on right bank. **Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 8, 2007)**

Date described: August 7, 2007 Characteristic	Reach:3 Location: RM 11.86 along constructed fill at Merritt	Reach:3 Location: RM 11.22 along outside of meander bend	Reach:3 Location: RM 10.95 along engineered channel bank	Reach:3 Location: RM 9.95 along engineered channel within floodplain
Overall assessment of erodibility	Extreme High Moderate Low	Extreme High Moderate Low	Extreme High Moderate Low	Extreme High Moderate Low
Bank	Right Left	Right Left	Right Left	Right Left
Road or building visible	Yes No	Yes No	Yes No	Yes No
Landform	Floodplain Terrace Fill (?) Moraine Valley edge	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Fill(?) Moraine Valley edge
Relationship to channel	Outside of bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section
Bank height - Measured				
Bank height - Estimated	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5
Bank material	Rock Boulder Gr Cobble Gr Pebble Gr Sand/Silt "Blue" clay	Rock Boulder Gr Cobble Gr Pebble Gr B4' Sand/Silt T4' "Blue" clay	Rock Boulder Cobble Gr(few) Pebble Gr Sand/Silt Brown clay	Rock Boulder Gr Cobble Gr Gravel B3' Sand/Silt T5' "Blue" clay
Geologic origin	Rock Glacial/ Fill? Channel Overbank Landslide	Rock Glacial Channel Overbank Landslide	Rock Glacial-Fluvio Channel Overbank Landslide	Rock Glacial Fill(?) Channel B Overbank T Landslide
Consolidation 0=loose; 5=hard (rock)	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Slope (degrees)	<25 25-45 45-90 90	<25 25-45 45-90 90	<25 25-45 45-90 90	<25 25-45 45-90 90
Dominant vegetation on surface (Estimate percent of each)	Grass 10 Shrubs 30 Alder 60 Deciduous Conifer Mixed	Grass 100 Shrubs Alder Deciduous Conifer Mixed	Grass10 Shrubs Alder 20 Deciduous70 Conifer Mixed	Grass Shrubs 20 Alder 80 Deciduous Conifer Mixed
Clear cut to surface edge	Yes No	Yes No	Yes No	Yes No
Roots in bank – Percent of visible bank	<5 10 25 50 >50	<5 10 25 50 >50	<5 10 25 50 >50	<5 10 25 50 >50
Roots – Density 0=few; 5=abundant	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Root size	Fine Medium Large Very large	Fine Medium Large Very large	Fine Medium Large Very large	Fine Medium Large Very large
Protection	LWD Boulder Armor	LWD Riprap	MWD(light) Riprap	LWD Boulder Armor
Evidence of active landslide	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank

Date described: August 7, 2007 Characteristic	Reach:3 Location: RM 11.86 along constructed fill at Merritt	Reach:3 Location: RM 11.22 along outside of meander bend	Reach:3 Location: RM 10.95 along engineered channel bank	Reach:3 Location: RM 9.95 along engineered channel within floodplain
Evidence of active erosion	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots
Photographs taken	8-7-07, #50	8-8-07, #13, 14 and 15	8-8-07, #23	8-8-07, #44

Photograph No.50. View is to the west looking at bank profile site on right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 7, 2007)

Photograph No.13. View is to the east looking downstream showing both banks. Nason Creek - Wenatchee Subbasin, Washington. Downstream view. (Reclamation photograph by D. Bennett, August 8, 2007).

Photograph No.14. View is to the north at bank profile site of left bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 8, 2007).

Photograph No.15. View is to the west looking upstream, showing close-up of left bank near bank profile site. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 8, 2007).

Photograph No.23. View is to the north at bank profile site of left bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 8, 2007).

Photograph No.44. View is to the north at bank profile site of left bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 8, 2007).

Date described: August 9, 2007 Characteristic	Reach:1 Location: RM 8.8 on right bank within floodplain	Reach:1 Location: RM 8.68 on terrace forming floodplain boundary	Reach:1 Location: RM 8.35 on left bank of terrace within floodplain	Reach:1 Location: RM 7.56 on right bank of terrace forming floodplain boundary
Overall assessment of erodibility	Extreme High **Depo Zone?** Moderate Low	Extreme High Moderate **Low**	Extreme High Moderate **Low**	Extreme High **Moderate** Low
Bank	**Right** Left	**Right** Left	Right **Left**	**Right** Left
Road or building visible	**Yes** No	**Yes** No	**Yes** No	Yes **No**
Landform	**Floodplain** Terrace Moraine Valley edge	Floodplain **Terrace** Moraine Valley edge	Floodplain **Terrace** Moraine Valley edge	Floodplain **Terrace** Moraine Valley edge
Relationship to channel	**Inside of bend** Into bank at high angle Straight section	**Inside of slight bend** Into bank at high angle Straight section	**Outside of bend** Into bank at high angle Straight section	**Outside of Slight bend** Into bank at high angle Straight section
Bank height - Measured				
Bank height - Estimated	Feet: <3 **3**-6 6-15 >15 Meters: <1 **1**-2 2-5 >5	Feet: <3 3-6 6-15 **>15** Meters: <1 1-2 2-5 **>5**	Feet: <3 3-6 **6-15** >15 Meters: <1 1-2 **2-5** >5	Feet: <3 3-6 6-15 **>15** Meters: <1 1-2 2-5 **>5**
Bank material	Rock Boulder Gr Cobble Gr Pebble Gr **Sand** "Blue" clay	Rock **Boulder Gr** **Cobble Gr** **Pebble Gr** Sand/Silt "Blue" clay	Rock **Boulder Gr** **Cobble Gr** **Pebble Gr** Sand/Silt "Blue" clay	Rock Boulder Gr Cobble Gr Pebble Gr Sand/Silt "Blue" clay
Geologic origin	Rock Glacial **Channel** Overbank Landslide	Rock **Glacial** Channel Overbank Landslide	Rock **Glacial** Channel Overbank Landslide	Rock **Glacial** Channel Overbank Landslide
Consolidation 0=loose; 5=hard (rock)	0 1 **2** **3** 4 5	0 1 2 **3** 4 5	0 1 2 3 **4** 5	0 1 2 3 **4** 5
Slope (degrees)	**<25** 25-45 45-90 **90**	<25 25-45 **45-90** 90	**<25 B1'** **25-45 T7'** 90	<25 **25-45** 45-90 90
Dominant vegetation on surface (Estimate percent of each)	**Grass Tr** **Shrubs 50** **Alder 40** Deciduous **Conifer 10** Mixed	Grass **Shrubs 40** **Alder 30** Deciduous **Conifer 30** Mixed	**Grass 10** **Shrubs 10** **Alder 10** Deciduous **Conifer 70** Mixed	**Grass 20** **Shrubs 20** Alder Deciduous **Conifer 10** Mixed
Clear cut to surface edge	Yes **No**	Yes **No**	Yes **No**	Yes **No**
Roots in bank – Percent of visible bank	**<5** 10 25 50 >50	**<5** 10 25 50 >50	<5 10 25 **50** >50	<5 10 25 **50** >50
Roots – Density 0=few; 5=abundant	**0** 1 2 3 4 5	**0** 1 2 3 4 5	0 1 2 3 **4** 5	0 1 2 **3** 4 5
Root size	**Fine** **Medium** Large Very large	**Fine** **Medium** **Large** Very large	**Fine** **Medium** **Large** Very large	**Fine** **Medium** **Large** **Very large**
Protection	**LWD Nat** Riprap	LWD Riprap	**Boulder/Cobble Armor**	LWD Riprap

Date described: August 9, 2007 Characteristic	Reach:1 Location: RM 8.8 on right bank within floodplain	Reach:1 Location: RM 8.68 on terrace forming floodplain boundary	Reach:1 Location: RM 8.35 on left bank of terrace within floodplain	Reach:1 Location: RM 7.56 on right bank of terrace forming floodplain boundary
Evidence of active landslide	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank
Evidence of active erosion	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots
Photographs taken	8-9-07, #12	8-9-07, #15	8-9-07, #21	8-9-07, 34

Photograph No.12. View to the west looking at bank profile site on the right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August, 9, 2007).

Photograph No.15. View to the west looking at bank profile site on the right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 9, 2007).

Photograph No.21. View to the northwest looking at bank profile site on the left bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 9, 2007).

Photograph No.34. View is to the east showing bank profile site on right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 9, 2007).

Date described: August 9-10, 2007 Characteristic	Reach:1 Location: RM 7.51 on right terrace bank forming floodplain boundary	Reach:1 Location: RM 7.45 on right bank within floodplain	Reach:1 Location: RM 6.735 on left terrace bank forming floodplain boundary	Reach:1 Location: RM 6.54 on left terrace bank forming floodplain boundary
Overall assessment of erodibility	Extreme High Moderate Low	Extreme High Moderate Low	Extreme High Moderate Low	Extreme High Moderate Low
Bank	Right Left	Right Left	Right Left	Right Left
Road or building visible	Yes No	Yes No	Yes No	Yes No
Landform	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Moraine Valley edge	Floodplain Terrace Moraine Valley edge
Relationship to channel	Outside of bend Into bank at high angle Straight section	Inside of slight bend Into bank at high angle Straight section	Outside of bend Into bank at high angle Straight section	Inside of bend Into bank at high angle Straight section
Bank height - Measured			50 Approx	40 Approx
Bank height - Estimated	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 3-6 6-15 >15 Meters: <1 1-2 2-5 >5
Bank material	Rock Boulder Gr Cobble Gr Pebble Gr Sand "Blue" clay	Rock Boulder Gr Cobble Gr Pebble Gr Sand/Silt "Blue" clay	Rock Boulder Gr Cobble Gr Pebble Gr Sand/Silt "Blue" clay	Rock Boulder Gr Cobble Gr Pebble Gr Sand/Silt "Brown" clay
Geologic origin	Rock Glacial Channel Overbank Landslide	Rock Glacial Channel Overbank Landslide	Rock Glacial Channel Overbank Landslide	Rock Glacial Channel Overbank Landslide
Consolidation 0=loose; 5=hard (rock)	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Slope (degrees)	25-45 B6' 45-90 T45'	<25 25-45 45-90 90	<25 B1' 25-45 T7' 90	<25 25-45 45-90 90
Dominant vegetation on surface (Estimate percent of each)	Grass 5 Shrubs 20 Alder Deciduous 5 Conifer 20 Mixed	Grass 30 Shrubs 10 Alder 30 Deciduous Conifer 30 Mixed	Grass 10 Shrubs 30 Alder 30 Deciduous Conifer Trc Mixed	Grass Shrubs Alder Deciduous Conifer Mixed
Clear cut to surface edge	Yes No	Yes No	Yes No	Yes No
Roots in bank – Percent of visible bank	<5 10 25 50 >50	<5 10 25 50 >50	<5 10 25 50 >50	<5 10 25 50 >50
Roots – Density 0=few; 5=abundant	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Root size	Fine Medium Large Very large	Fine Medium Large Very large	Fine Medium Large Very large	Fine Medium Large Very large
Protection	LWD Nat Riprap	LWD Riprap	Boulder/Cobble Armor	Boulder/Cobble Armor

Date described: August 9-10, 2007 Characteristic	Reach:1 Location: RM 7.51 on right terrace bank forming floodplain boundary	Reach:1 Location: RM 7.45 on right bank within floodplain	Reach:1 Location: RM 6.735 on left terrace bank forming floodplain boundary	Reach:1 Location: RM 6.54 on left terrace bank forming floodplain boundary
Evidence of active landslide	Headscarps? Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank
Evidence of active erosion	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots
Photographs taken	8-9-07, #36	8-9-07, #41	8-10-07, #1	8-10-07, 2

Photograph No.36. View is to the east showing bank profile site on right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 9, 2007).

Photograph No.41. View is to the east showing bank profile site on right bank. Nason Creek - Wenatchee Subbasin, Washington. (Reclamation photograph by D. Bennett, August 9, 2007).

Photograph No. 1. A view to the north, looking upstream along the left bank at location of bank profile measurement. Nason Creek – Wenatchee subbasin, Washington –(Reclamation photograph by R. McAffee, August 10, 2007).

Photograph No. 2. A view to the north looking at the different deposits that is visible in the left bank at a location of a bank profile. Nason Creek – Wenatchee subbasin, Washington – (Reclamation photograph by R. McAffee, August 10, 2007).

Date described: August 10, 2007 Characteristic	Reach:1 Location: RM 6.48 on left terrace forming floodplain boundary	Reach:1 Location: RM 6.44 on right bank within floodplain	Reach:1 Location: RM 6.33 on right bank of terrace within floodplain	
Overall assessment of erodibility	Extreme High **Moderate** Low	Extreme High **Moderate Low**	Extreme High **Moderate** Low	
Bank	Right **Left**	Right **Left**	**Right** Left	
Road or building visible	**Yes** No	**Yes** No	**Yes** No	
Landform	Floodplain **Terrace** Moraine Valley edge	**Floodplain** Terrace Moraine Valley edge	**Floodplain Terrace(?)** Moraine Valley edge	
Relationship to channel	**Inside of slight bend** Into bank at high angle Straight section	**Inside of slight bend** Into bank at high angle Straight section	**Outside of bend** Into bank at high angle Straight section	
Bank height - Measured	20 Approx	2-3 approx		
Bank height - Estimated	Feet: <3 3-6 6-15 **>15** Meters: <1 1-2 2-5 **>5**	Feet: **<3** 3-6 6-15 >15 Meters: <1 1-2 2-5 >5	Feet: <3 **3-6** 6-15 >15 Meters: <1 1-2 2-5 >5	
Bank material	**Rock Boulder Gr** **Cobble Gr Pebble Gr** **Sand** "Blue" clay	Rock Boulder Gr **Cobble Gr Pebble Gr** **Sand/Silt** "Blue" clay	Rock Boulder Gr **Cobble Gr Pebble Gr** **Sand/Silt** "Blue" clay	
Geologic origin	Rock **Glacial** Channel **Overbank** Landslide	Rock **Glacial** Channel **Overbank** Landslide	Rock **Glacial** **Channel Overbank** Landslide	
Consolidation 0=loose; 5=hard (rock)	0 1 2 **3** 4 5	0 1 2 3 **4** 5	0 1 2 **3** 4 5	
Slope (degrees)	<25 25-45 **45-90** 90	<25 25-45 45-90 **90**	<25 **25-45** 90	
Dominant vegetation on surface (Estimate percent of each)	**Grass Tr Shrubs 10** Alder **Deciduous 20** **Conifer 10** Mixed	**Grass 40** Shrubs Alder Deciduous Conifer **Mixed 20**	**Grass 10** Shrubs **Alder 20** Deciduous **Conifer 30** Mixed	
Clear cut to surface edge	Yes **No**	Yes **No**	Yes **No**	
Roots in bank – Percent of visible bank	<5 **10** 25 50 >50	<5 **10** 25 50 >50	<5 **10 25** 50 >50	
Roots – Density 0=few; 5=abundant	0 1 **2** 3 4 5	0 1 **2** 3 4 5	0 **1** 2 3 4 5	
Root size	**Fine Medium** **Large** Very large	**Fine Medium** Large Very large	**Fine Medium** Large Very large	
Protection	**Boulder/Cobbler Armor**	**Cobble Armor**	**Cobble Armor**	

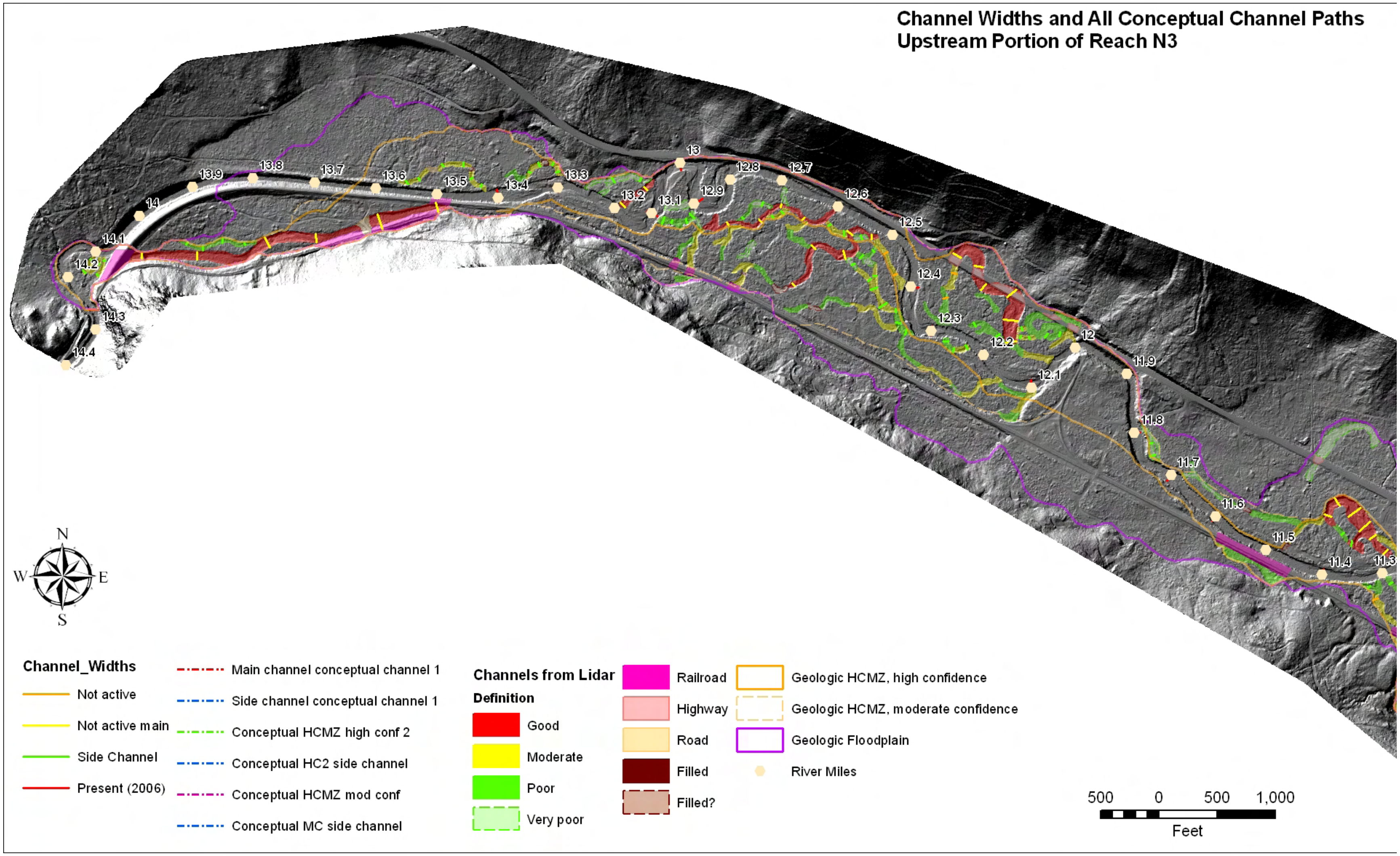
Date described: August 10, 2007 Characteristic	Reach:1 Location: RM 6.48 on left terrace forming floodplain boundary	Reach:1 Location: RM 6.44 on right bank within floodplain	Reach:1 Location: RM 6.33 on right bank of terrace within floodplain	
Evidence of active landslide	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	Headscarps Slumps Disturbed vegetation Water out of bank	
Evidence of active erosion	Undercut Exposed roots	Undercut Exposed roots	Undercut Exposed roots	
Photographs taken	8-10-07, #3	8-10-07, #4	8-10-07, #5	

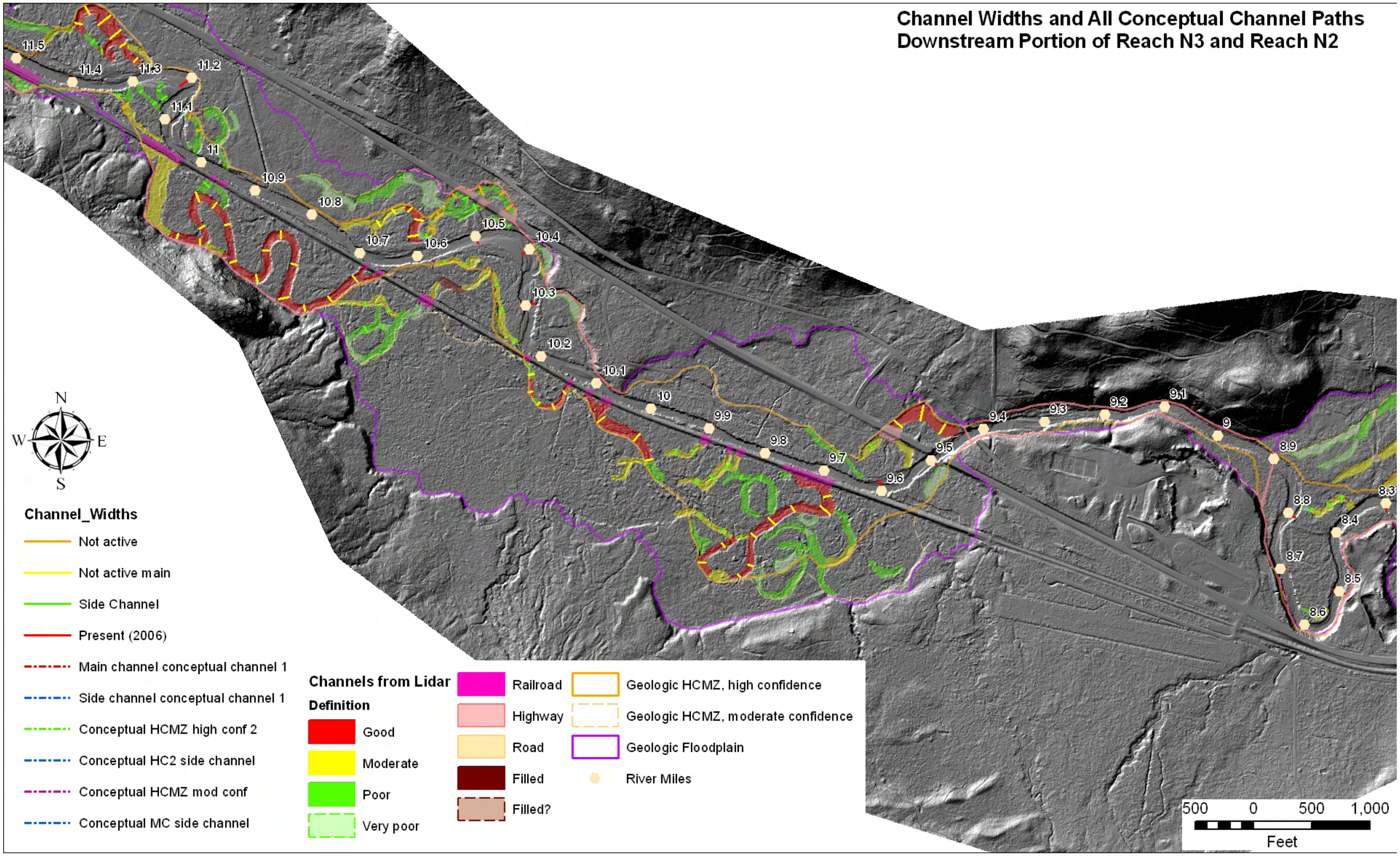
Photograph No. 3. A view to the north showing the middle surface in a succession along the left bank of the river. Nason Creek – Wenatchee subbasin, Washington (Reclamation photograph by R. McAffee, August 10, 2007).

Photograph No. 4. A view to the north showing the lowest surface in a succession of terraces along the left bank of the river. Nason Creek – Wenatchee subbasin, Washington. (Reclamation photograph by R. McAffee, August 10, 2007).

Photograph No. 5. A view to the east showing the right bank which is comprised of finer material over cobbles and boulders. Nason Creek – Wenatchee subbasin, Washington. (Reclamation photograph by R. McAffee, August 10, 2007).

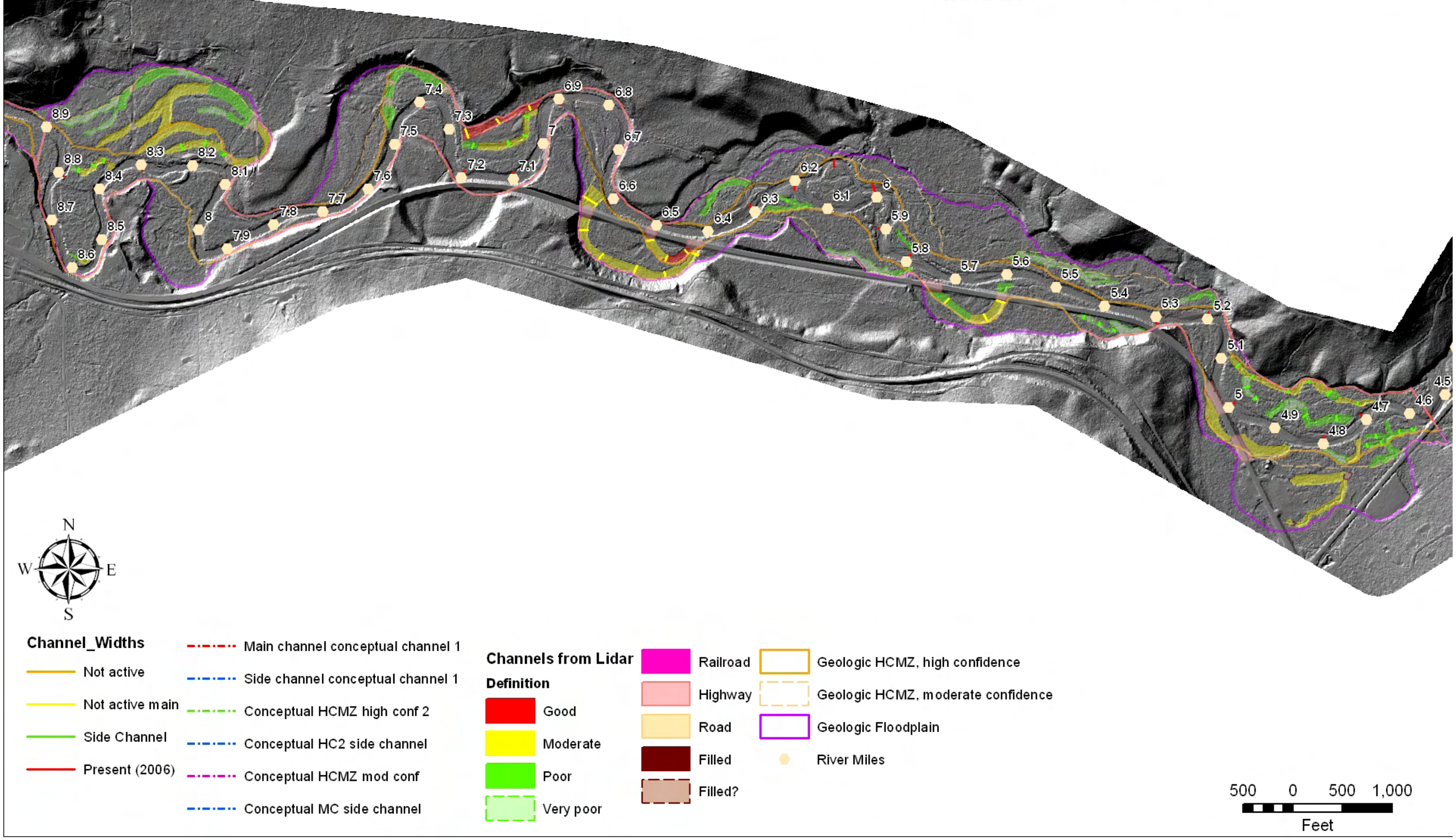
ATTACHMENT 2 – Supporting Figures for GIS-based Estimations of Historical Channel Lengths and Widths from 2006 LiDAR


Channel Widths and All Conceptual Channel Paths
Upstream Portion of Reach N3
14.4
14.3
14.2
14.1
14
13.9
13.8
13.7
13.6
13.5
13.4
13.3
13.2
13.1
13
12.9
12.8
12.7
12.6
12.5
12.4
12.3
12.2
12.1
12
11.9
11.8
11.7
11.6
11.5
11.4
11.3
N
S
E
W
Channel_Widths
Not active
Not active main
Side Channel
Present (2006)
Main channel conceptual channel 1
Side channel conceptual channel 1
Conceptual HCMZ high conf 2
Conceptual HC2 side channel
Conceptual HCMZ mod conf
Conceptual MC side channel
Channels from Lidar
Definition
Good
Moderate
Poor
Very poor
Railroad
Highway
Road
Filled
Filled?
Geologic HCMZ, high confidence
Geologic HCMZ, moderate confidence
Geologic Floodplain
River Miles
500
0
500
1,000
Feet



Channel Widths and All Conceptual Channel Paths
Downstream Portion of Reach N3 and Reach N2
11.5
11.4
11.3
11.2
11.1
11
10.9
10.8
10.7
10.6
10.5
10.4
10.3
10.2
10.1
10
9.9
9.8
9.7
9.6
9.5
9.4
9.3
9.2
9.1
9
8.9
8.8
8.7
8.6
8.5
8.4
8.3
N
W
E
S
Channel_Widths
Not active
Not active main
Side Channel
Present (2006)
Main channel conceptual channel 1
Side channel conceptual channel 1
Conceptual HCMZ high conf 2
Conceptual HC2 side channel
Conceptual HCMZ mod conf
Conceptual MC side channel
Channels from Lidar
Definition
Good
Moderate
Poor
Very poor
Railroad
Highway
Road
Filled
Filled?
Geologic HCMZ, high confidence
Geologic HCMZ, moderate confidence
Geologic Floodplain
River Miles
500
0
500
1,000
Feet

Channel Widths and All Conceptual Channel Paths
Reach N1



ATTACHMENT 3 – Description of Surface Types identified in the Nason Creek Assessment Area

Alluvium (QA)

Fluvial units composed two main types of deposits:

> Channel deposits that consist of unconsolidated, primarily rounded to well-rounded, well-bedded to poorly bedded cobbles through sand; bed composition varies between nearly all cobbles to nearly all sand; channel deposits include boulders in places, especially adjacent to glacial deposits; channel deposits are up to about 3 m thick where exposed in banks; maximum thickness unknown
>
> Overbank deposits that consist of fine sand through clay; primarily massive to weakly bedded; overbank deposits often overlie channel deposits; may be up to about 3 foot thick, but deposits are mostly <1 foot thick

Alluvium includes the present and abandoned channels and intervening surfaces that constitute the geologic floodplain, which includes the area of channel migration and the most floodprone areas; some flooding occurs outside of the geologic floodplain

> Channels are well defined to very poorly defined on the hillshade created from Lidar data; channels are main, side, and overflow channels of various ages; some channels are presently active; some have been active historically (interpreted from historical aerial photographs from 1962, 1975, 1998); when other channels were active is not known, but some could be a few hundred years old, or possibly older
>
> Intervening surfaces are different heights above the active channel; surfaces are <10 feet above the active channel; most surfaces are <8 feet above the active channel of Nason Creek; some surfaces are up to about 12 feet above the active channel (RM 12.4 to RM 12.9, river right; RM 11.5 to RM 11.0, river left; RM 9.3 to RM 9.2, river right; RM 8.4 to RM 8.2, river left; RM 7.6 to RM 7.5, river left)
>
> Surfaces range in age from presently active to probably a few hundred years, to possibly a few thousand years; for presently active surfaces, some are overtopped and reworked frequently (e.g., annually); others are overtopped and reworked only rarely (e.g., every few tens of years)
>
> Surfaces have not been subdivided on the basis of their height or activity

Alluvium is derived primarily from reworking of older alluivium and glacial deposits

Alluvium is unconsolidated and susceptible to fluvial erosion

Older Suface (QTO)

Deposits are similar to those described for the alluvium

Older surfaces are generally higher than 10 feet above the active channel of Nason Creek; older surface between RM 11.7 and RM 11.2 (river left) is greater than 12 feet above the active channel

Older surfaces do not generally exhibit channels; exception is the older surface between RM 6.4 and RM 6.15, which has poorly defined channels; older surface between RM 11.7 and RM 11.2 has been artificially altered, and any channels that may have been present have been modified or destroyed

Older surfaces are preserved where they have been protected from fluvial erosion by projections of alluvial-fan or glacial deposits into the valley

Older surfaces have been eroded by fluvial processes as indicated by their scalloped contacts with alluvium (Qa)

Older surfaces likely represent a range in age, but their absolute ages are not known; the position of the older surfaces above the alluvium indicates that the older surfaces are older

Older surfaces are mapped in four places in the assessment reach: RM 13.9 to RM 13.6, river left, reach N3; RM 11.7 to RM 11.2, river left, reach N3; RM 8.25 to RM 8.25, river left, reach N1; RM 6.4 to RM 6.15, river left, reach N1

Older surface deposits are unconsolidated and susceptible to erosion

Alluvial Fan Deposits (QAF)

Unconsolidated, poorly sorted, weakly bedded cobbles through sand preserved in small, gently to moderately sloping, fan-shaped surfaces at the mouths of mostly smaller tributary drainages; alluvial fans are generally graded to the alluvium (Qa); drainages with alluvial-fan deposits are unnamed except for Kahler Creek (near RM 6, river left); alluvial-fan deposits are unconsolidated and susceptible to erosion; scalloped contacts between the alluvial-fan deposits and the alluvium indicates that the toes of the alluvial fans have been eroded, especially at Kahler Creek and the alluvial fans between RM 13.45 and RM 13.25 and between RM 9.6 and RM 9.5 (river right); alluvial-fan deposits are likely of several ages; most are probably less than a few thousand years old.

Alluvial Fan Deposits Older (QAFO)

Deposits similar to those described for alluvial-fan deposits, but may be consolidated in part; deposits form a fairly steep, nearly continuous apron along most of the floodplain boundary in reach N3, but are preserved only along a section of the floodplain boundary in the upstream portion of reach N1 (between RM 8.8 and RM 8.1, river left); includes large alluvial-fan deposits from the larger drainages, such as Mahar Creek (RM 14.1, river left), Gill Creek (RM 10.6, river right), Roaring Creek (RM 9.9, river right), Butcher Creek (RM 9.5, river left), and Coulter Creek (RM 9.3, river right); includes alluvial-fan deposits (Qaf) along the present drainages; older alluvial-fan deposits are preserved up to tens of feet above alluvium (Qa) of Nason Creek, unit includes alluvial-fan deposits of several ages; some deposits grade to glacial drift (Qd) (e.g., deposit at Coulter Creek); most of the unit is inset into the estimated limit of glacial drift (Nimick, 1977) and extend to nearly the elevation of the alluvium (Qa); older alluvial-fan deposits are unconsolidated and susceptible to erosion; scalloped contact between the older alluvial-fan deposits and the alluvium indicate that the toes of the alluvial fans have been eroded; includes areas of colluvium (Qc).

Glacial Drift or Till (QD)

Unconsolidated, poorly sorted, massive deposits of boulders through silt; deposited by alpine glaciers that once filled Nason Creek valley and extended into the assessment reach; includes moraines, or hummocky ridges, as described by Nimick (1977); moraines of at least three relative ages are preserved in the assessment reach, an older one between RM 7.2 and RM 7.1, a middle one between RM 7.8 and RM 7.7, and a younger one between RM 9.4 and RM 8.8 (Nimick,1977); glacial drift makes up most of the geologic floodplain boundary on river right between RM 9.9 and RM 5 and a section of the boundary on river left between RM 8.3 and RM 4.56; glacial drift is primarily unconsolidated and is susceptible to erosion; outwash deposits (Qoo, Qoy) are inset into the glacial drift downstream of RM 8.9 and are interbedded with glacial drift near the upstream extent of the outwash deposits; one possible deposit of glacial drift is preserved on river left between RM 10.4 and RM 9.9 (shown as Qd?); glacial ice also extended from the Wenatchee River upstream into the Nason Creek valley to at least about RM 2 and perhaps as far as RM 3.9, just downstream of the assessment reach (Tabor and others, 2005; Chelan geologic quad digital database).

Glacial Outwash Younger (QUY)

Deposits are similar to those described as alluvium (Qa), except that the glacial outwash generally includes a higher percentage of large cobbles and boulders than the alluvium; form nearly flat to gently sloping surfaces between about 15 feet and 30 feet above the active channel of Nason Creek; younger of two main levels of glacial outwash that are preserved downstream of RM 8.9 (reach N1) in the assessment reach; unit probably correlates with the ice limit between RM 9.4 and RM 8.8; makes up discontinuous sections of the floodplain boundary on both side of the valley downstream of RM 8.9; one surface between RM 7.1 and RM 6.8 (river left) is slightly lower than the other younger glacial outwash surfaces (height of about 10 to 20 feet), so it is shown as glacial outwash younger(?); when ice from the Wenatchee River valley extended upstream into the Nason Creek valley, outwash from the glaciers in both valleys likely flowed south from Cole's Corner into an unnamed valley that currently lacks through-going drainage; deposits are unconsolidated and susceptible to fluvial erosion, which may winnow the fines from the deposits and leave cobbles and boulders to armor the toes of eroding banks.

Glacial Outwash Older (QOO)

Deposits are similar to those described as glacial outwash younger (Qoy); form nearly flat to gently sloping surfaces between about 25 feet and 35 feet above the active channel of Nason Creek; some surfaces are up to 50 feet above the active channel; older of two main levels of glacial outwash that are preserved downstream of RM 8.9 (reach N1) in the assessment reach; unit may correlate with either the ice limit between RM 7.2 and RM 7.1 or the one between RM 7.8 and RM 7.7, or both; makes up discontinuous sections of the floodplain boundary on both sides of the valley between RM 8.2 and RM 5.7; deposits are generally unconsolidated and susceptible to fluvial erosion, which may winnow the fines from the deposits and leave cobbles and boulders to armor the toes of eroding banks.

Landslide (QLS)

One landslide deposit is mapped in the assessment reach: on river left between RM 9.3 and RM 8.9 in reach N2; unconsolidated, unsorted deposit of boulders to silt; derived from bedrock and glacial drift upslope of the landslide deposit.

Colluvium (QC)

Unconsolidated, generally unsorted, angular boulders through sand forming moderately steep and steep slopes along the sides of the valley; mapped separately only in reach N3 on river right between RM 13.7 and RM 12.8 and between RM 12.3 and RM 12.1, and in reach N1 on river left between RM 5.5 and RM 5.3; in the rest of the assessment reach, colluvium is included within the bedrock (BR) and the older alluvial-fan deposits (Qafo); lithology, size, and characteristics of colluvium vary with the adjacent bedrock; deposited primarily by slope processes; ages of the deposits are unknown, but may range between presently active to a few thousand years; depending on the sizes of clasts and characteristics of the colluivium, deposits may or may not be susceptible to fluvial erosion.

Talus (QCT)

Deposits are similar to those described as colluium (Qc), except that talus may be coarser and have a smaller percentage of fine sizes; mapped separately only in reach N3 on river right between RM 14.27 and RM 13.4, where bedrock is present near the floodplain boundary; ages of the deposits are unknown, but may range between presently active to a few thousand years; deposited by slope processes; sizes of the clasts in the talus are generally too large to be easily transported by fluvial processes.

Bedrock (BR)

Bedrock forms the upper slopes of the valley, Nason Ridge to the north and the Chiwaukum Moutains to the south; mapped only along the floodplain boundary in two locations in reach N3: on river right between RM 14.27 and RM 13.3 and between RM 11.0 and RM 10.8; major change in the bedrock type (not differentiated on map) occurs in reach N2 (RM 9.5 to RM 8.9); upstream of this point, rocks are primarily metamorphic types (Chiwaukum Schist), such as schists, gneisses, and amphibolites, which are relatively resistant to erosion; downstream of this point, rocks are primarily sandstone with some conglomerate, shale, and tuff (Chumstick Formation), which are generally erodible.