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

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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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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).

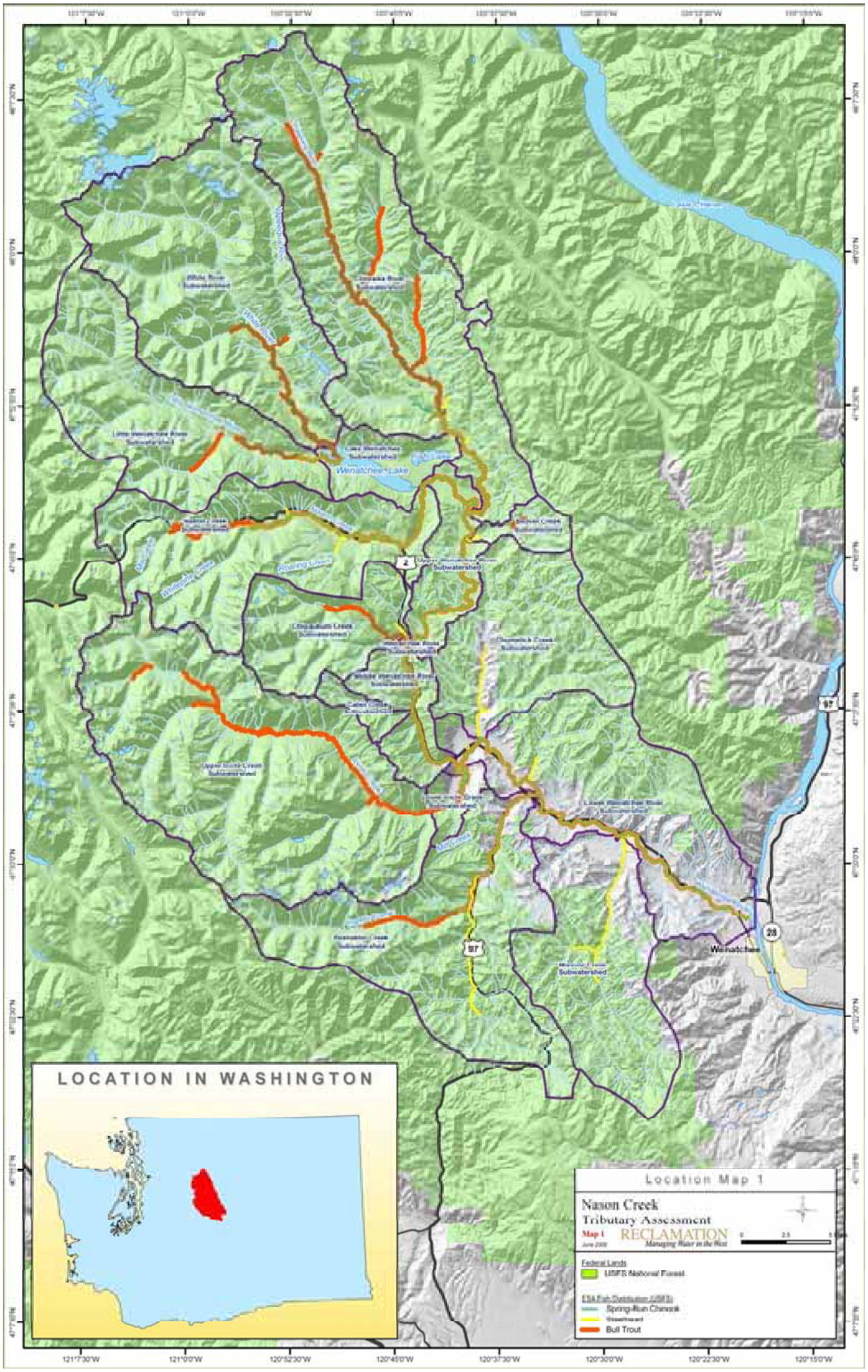


Figure 1. Location map for Nason Creek assessment area.

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.

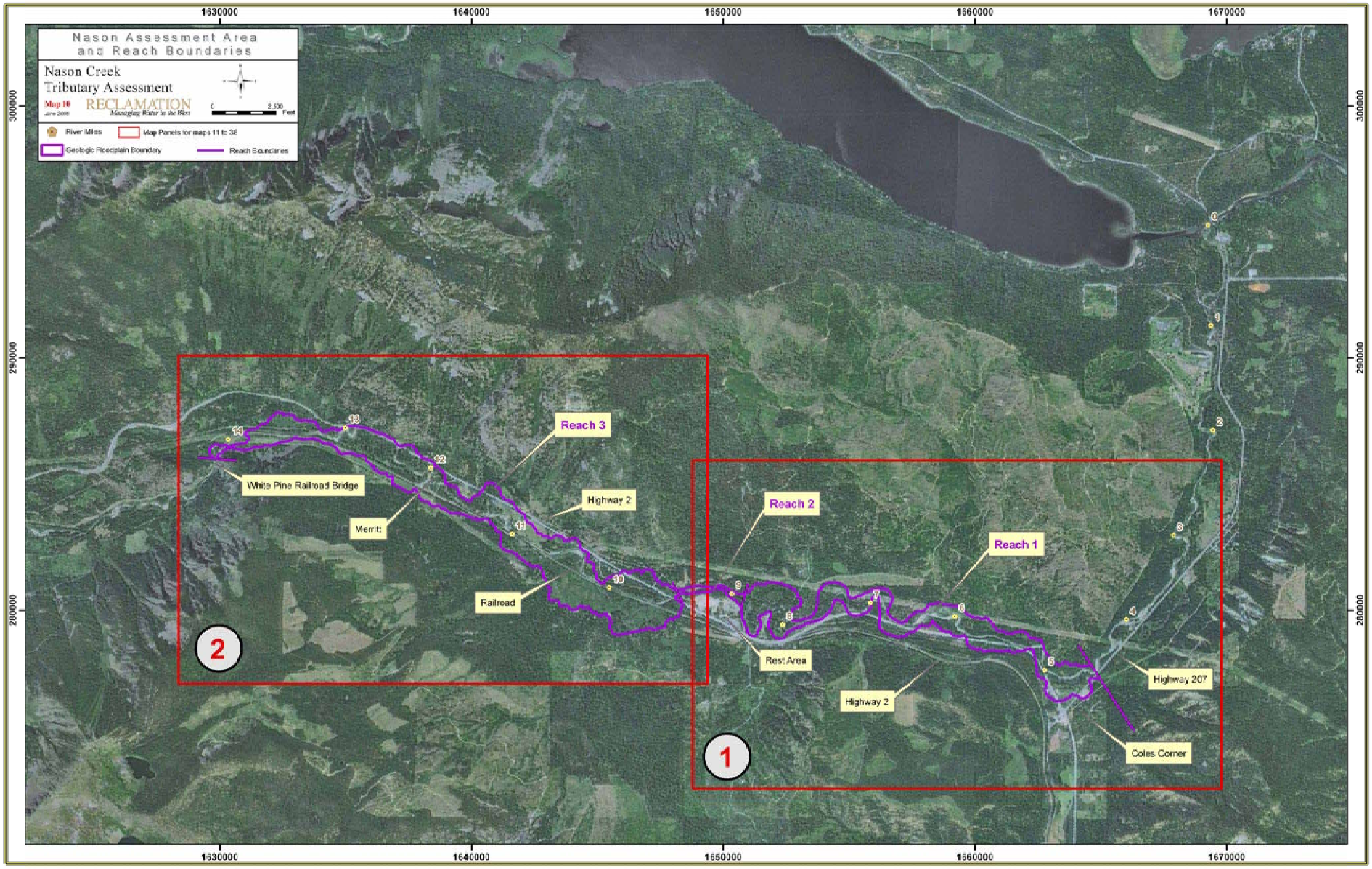


Figure 3. Location map for 10-mile assessment area, geomorphic reach breaks, and boundaries for map panels in atlas.

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.

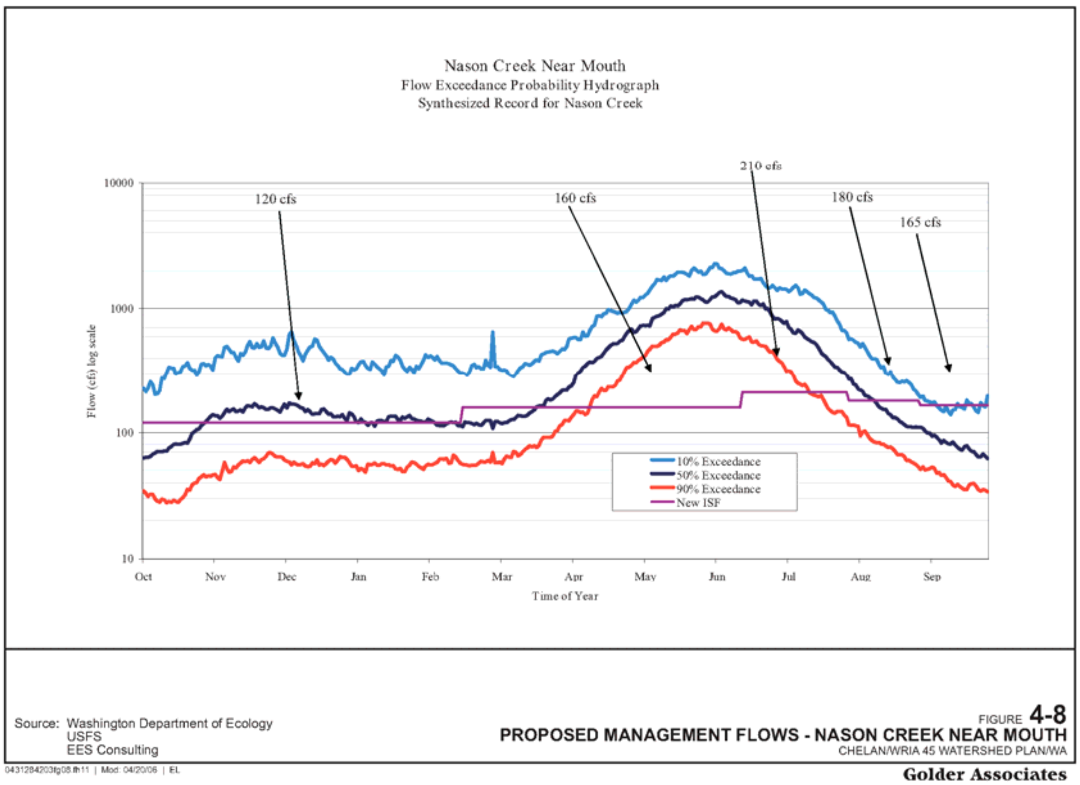


Figure 4. Summary of instream flow recommendations for Nason Creek near the mouth (WRIA Planning Unit 2006).

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).

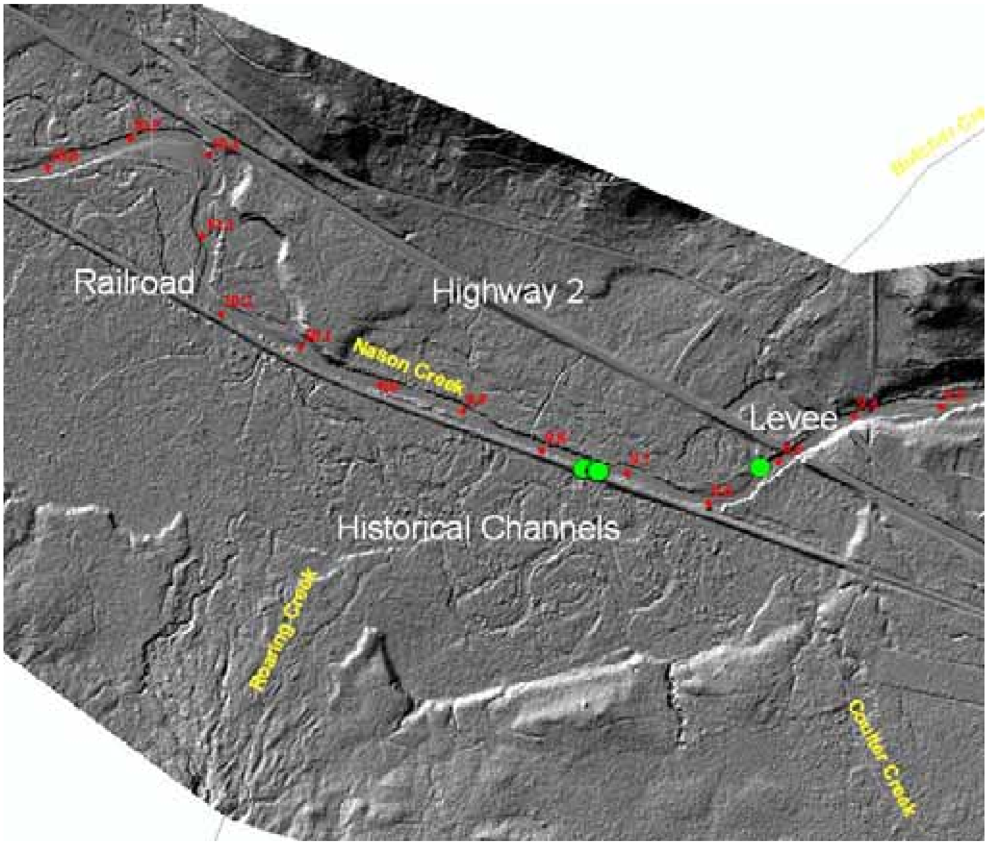


Figure 5. Example of railroad, highway, and levees cutting off flow connectivity between tributaries and present main channel. River miles from 2006 are shown in red text and existing culvert locations are green circles.

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

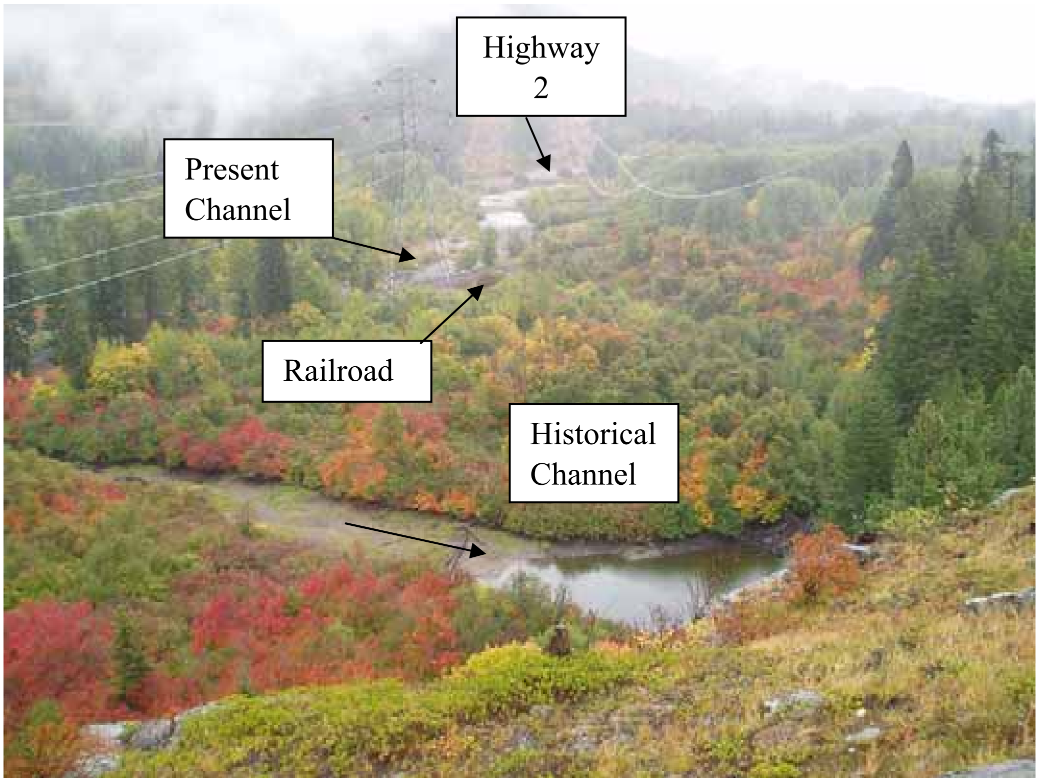


Figure 8. Looking across the valley at ponding in a historical channel of Nason Creek and the present channel between RM 10.7 to 11.1. The ponding has been observed to inundate the majority of the unvegetated historical channel. The river is flowing from left to right in the photograph. (Reclamation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

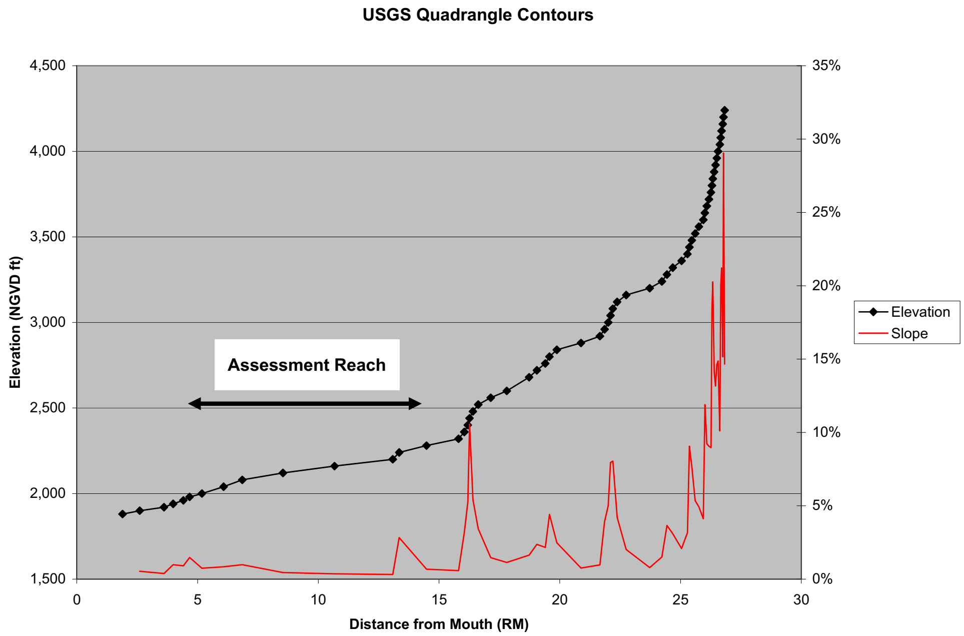


Figure 12. Longitudinal profile of slope and elevation of Nason Creek from the mouth to the headwaters based on USGS quadrangles. Elevation is shown in black with the y-axis on the left; slope (in percent of ft/ft) is shown in red with the y-axis on the right

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

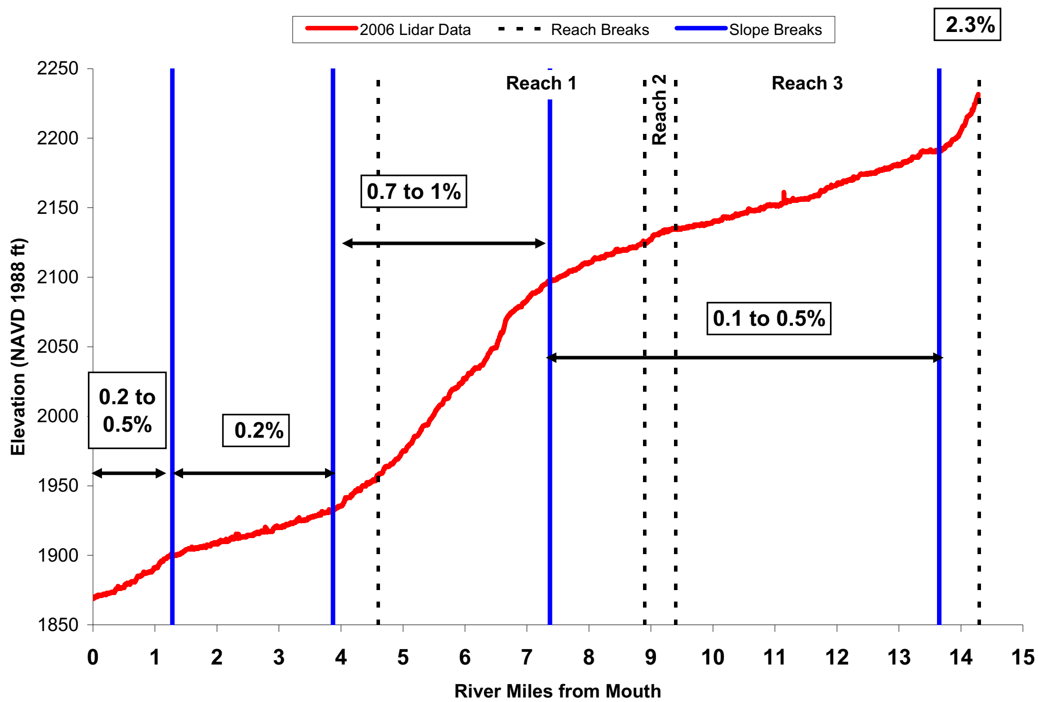


Figure 13. Longitudinal profile of bankfull slope within assessment area and lower 4 miles of Nason Creek (RM 14 to 0).

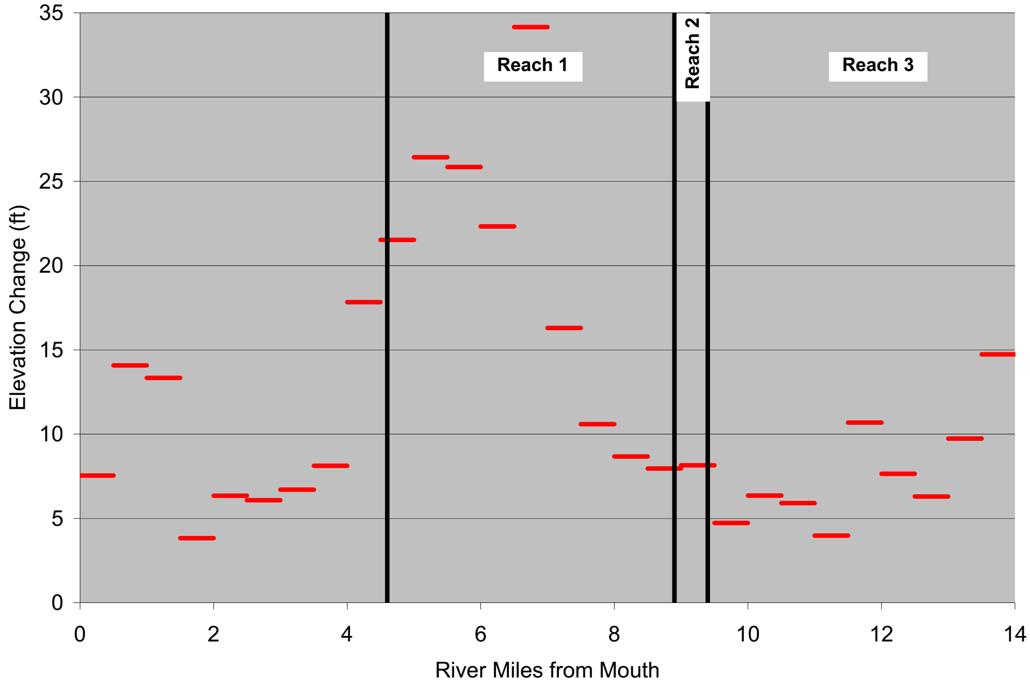


Figure 14. Elevation change per mile through assessment area showing trends in slope changes.

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).

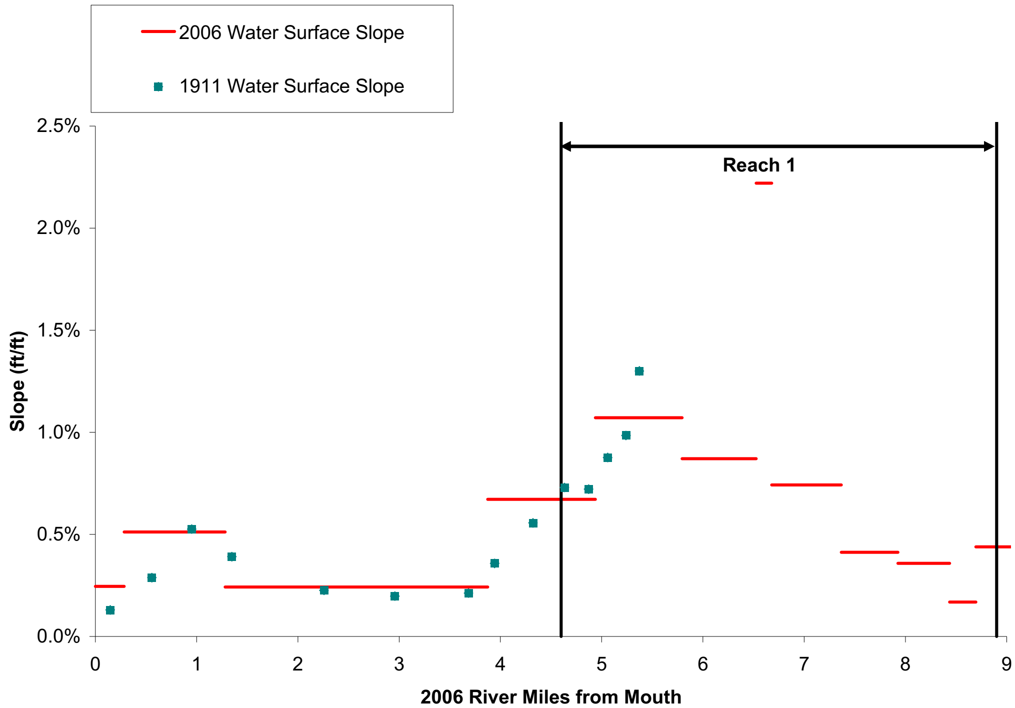


Figure 16. Comparison of present water surface slope with slope measured in 1911 by USGS (Marshall 1914).

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.

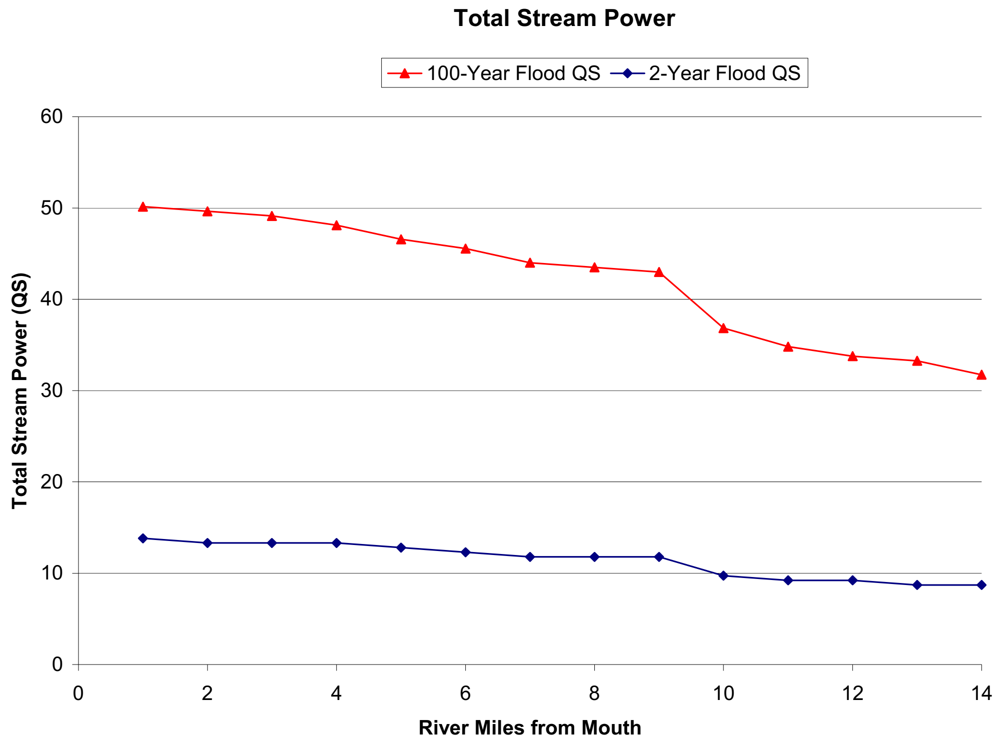


Figure 17. Total stream power (discharge times slope) for the assessment area.

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

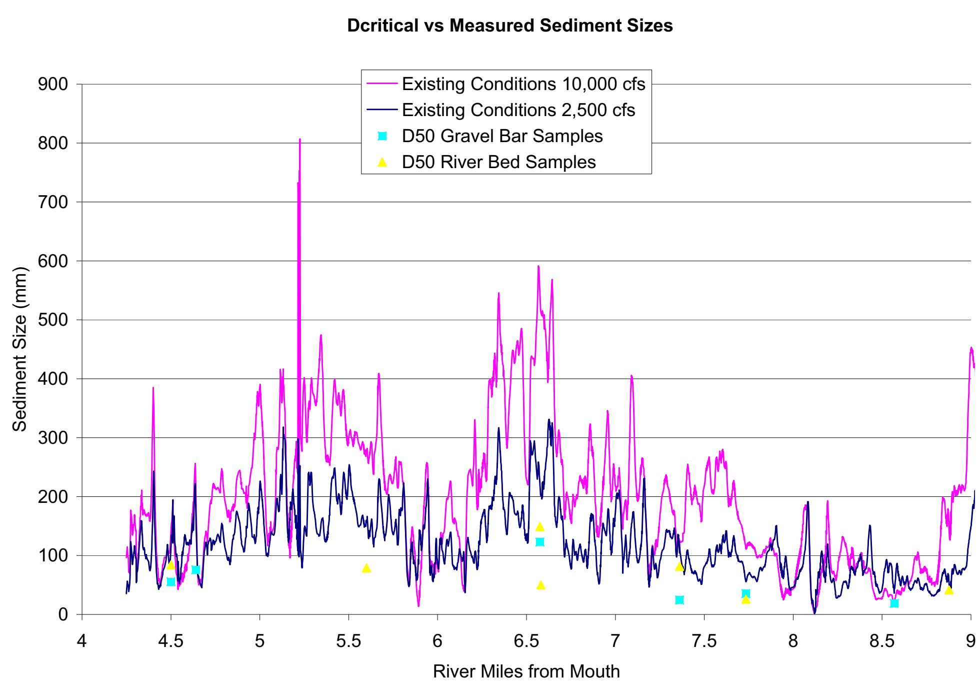


Figure 18. Comparison of computed sediment transport capacity versus measured sediment sizes in the bed and bar for Reach 1.

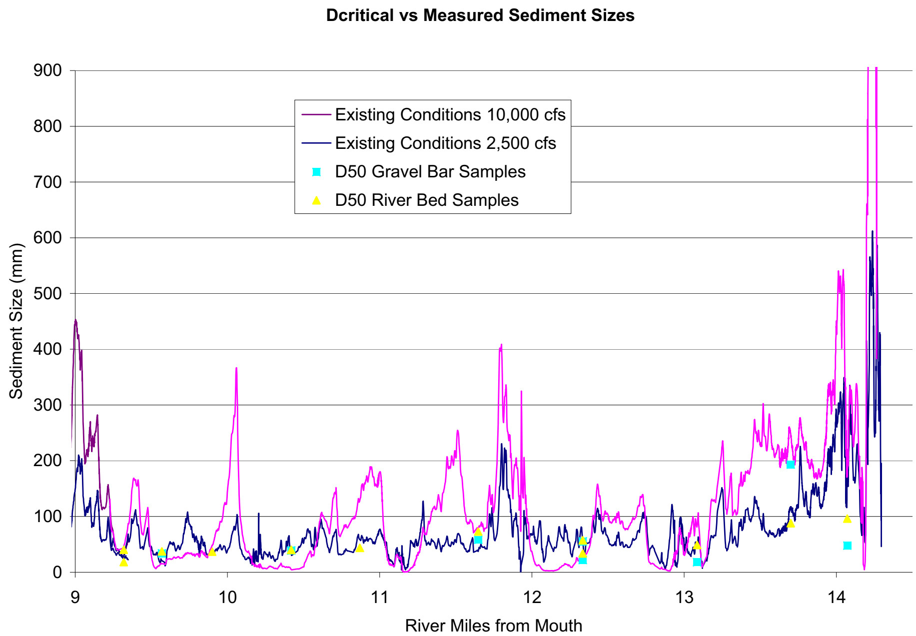


Figure 19. Comparison of computed sediment transport capacity versus measured sediment sizes in the bed and bar for Reach 3.

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.

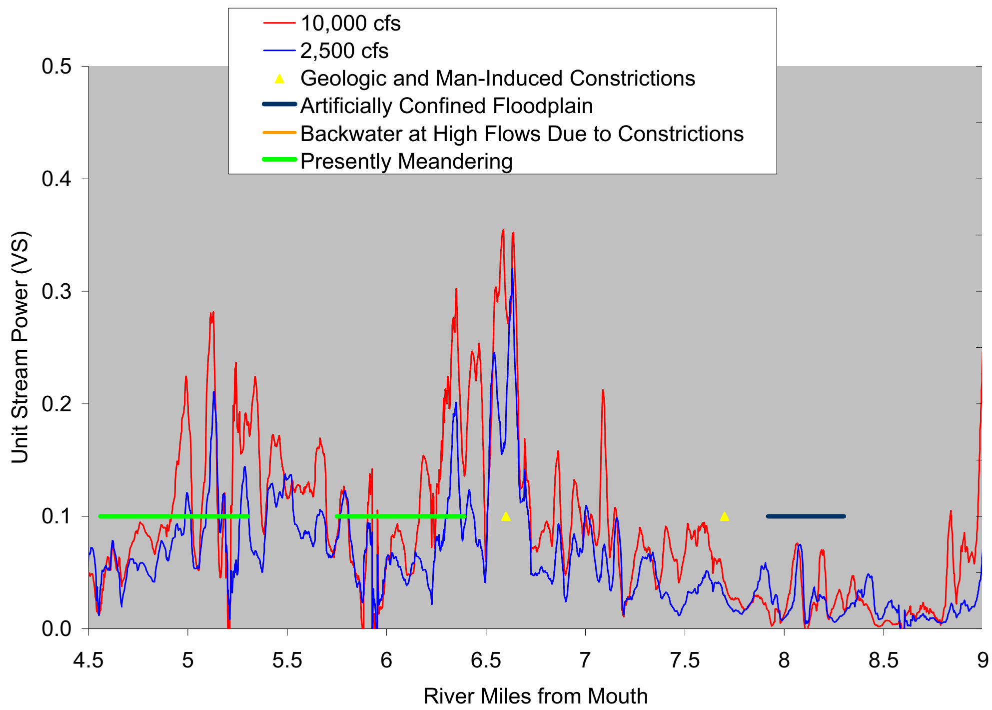


Figure 20. Overlay of geomorphic mapping and unit stream power from 2D hydraulic model for Reach 1.

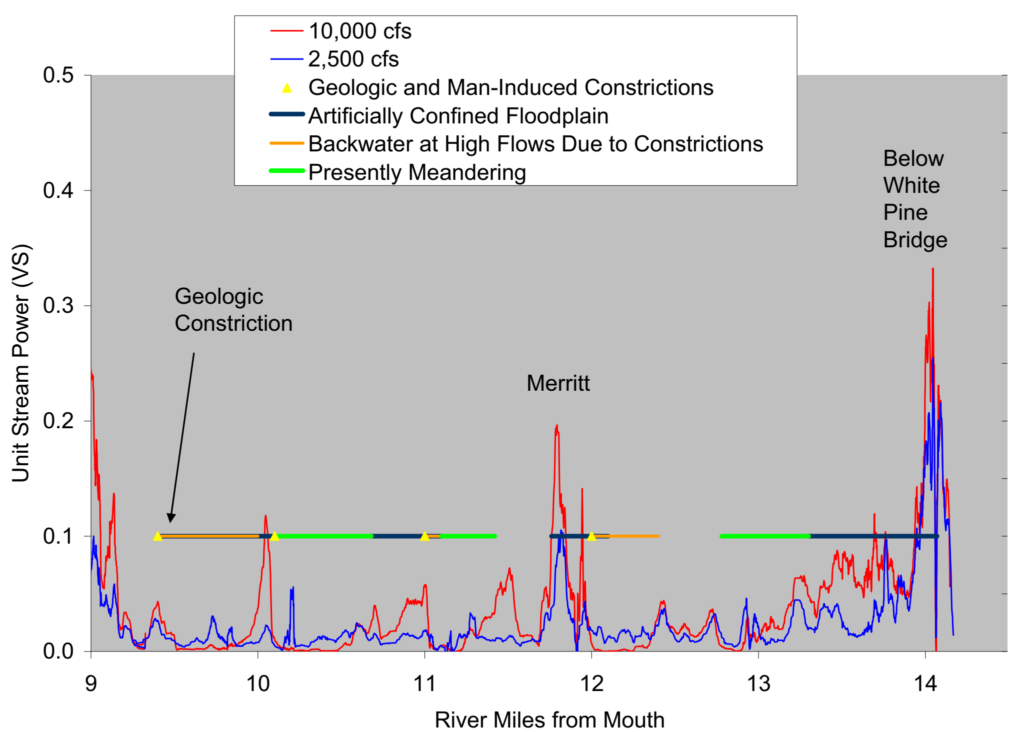


Figure 21. Overlay of geomorphic mapping and unit stream power from 2D hydraulic model for Reach 3.

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.

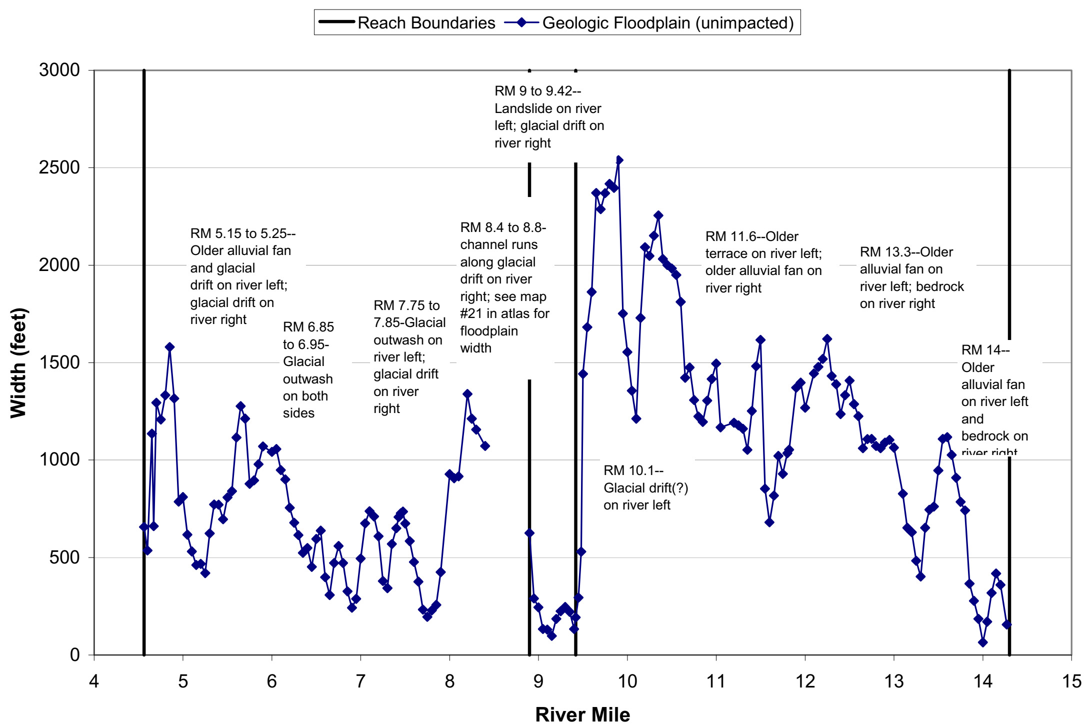


Figure 22. Geologic surfaces that narrow (confine) the historical floodplain width in the assessment area.

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.

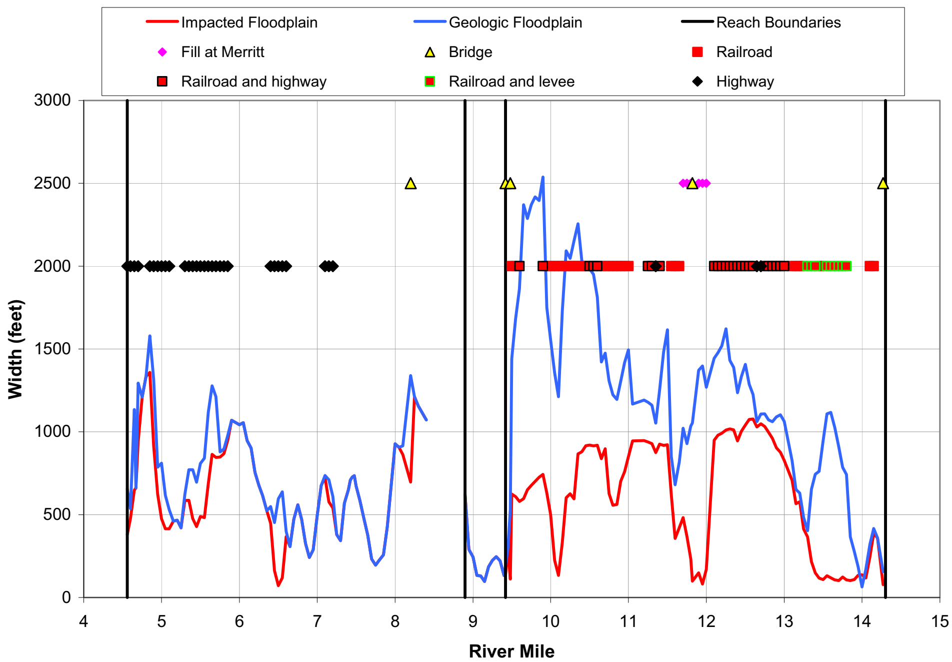


Figure 25. Reduction in floodplain width due to anthropogenic features with locations referenced as symbols that are identified in legend box.

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.

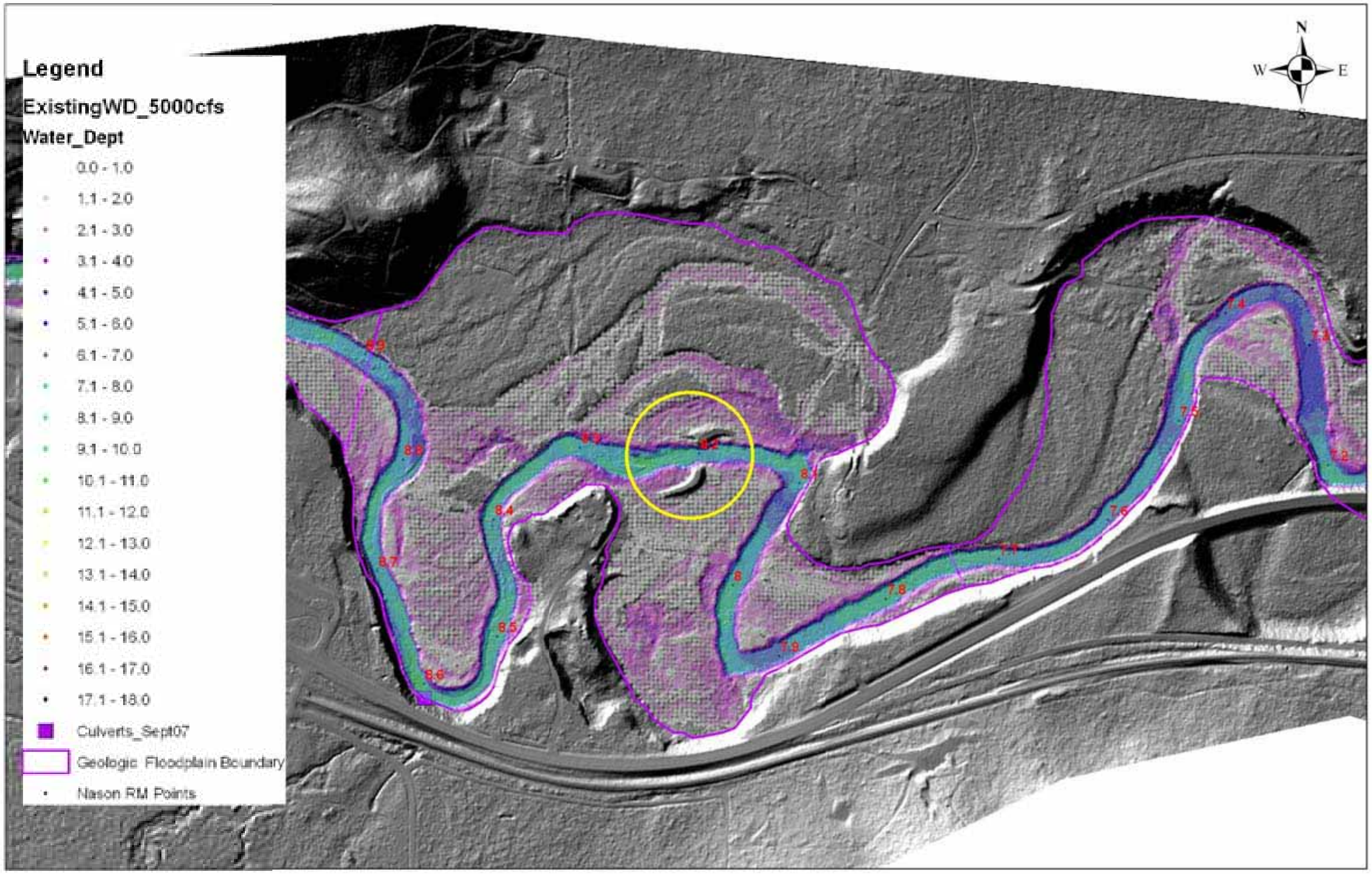


Figure 26. Impact to floodplain processes at RM 8 where flow can still go around embankment. Water depth (ft) results from the 2D model at a discharge of 5,000 cfs are shown, and are fairly shallow beyond the banks of the active channel.

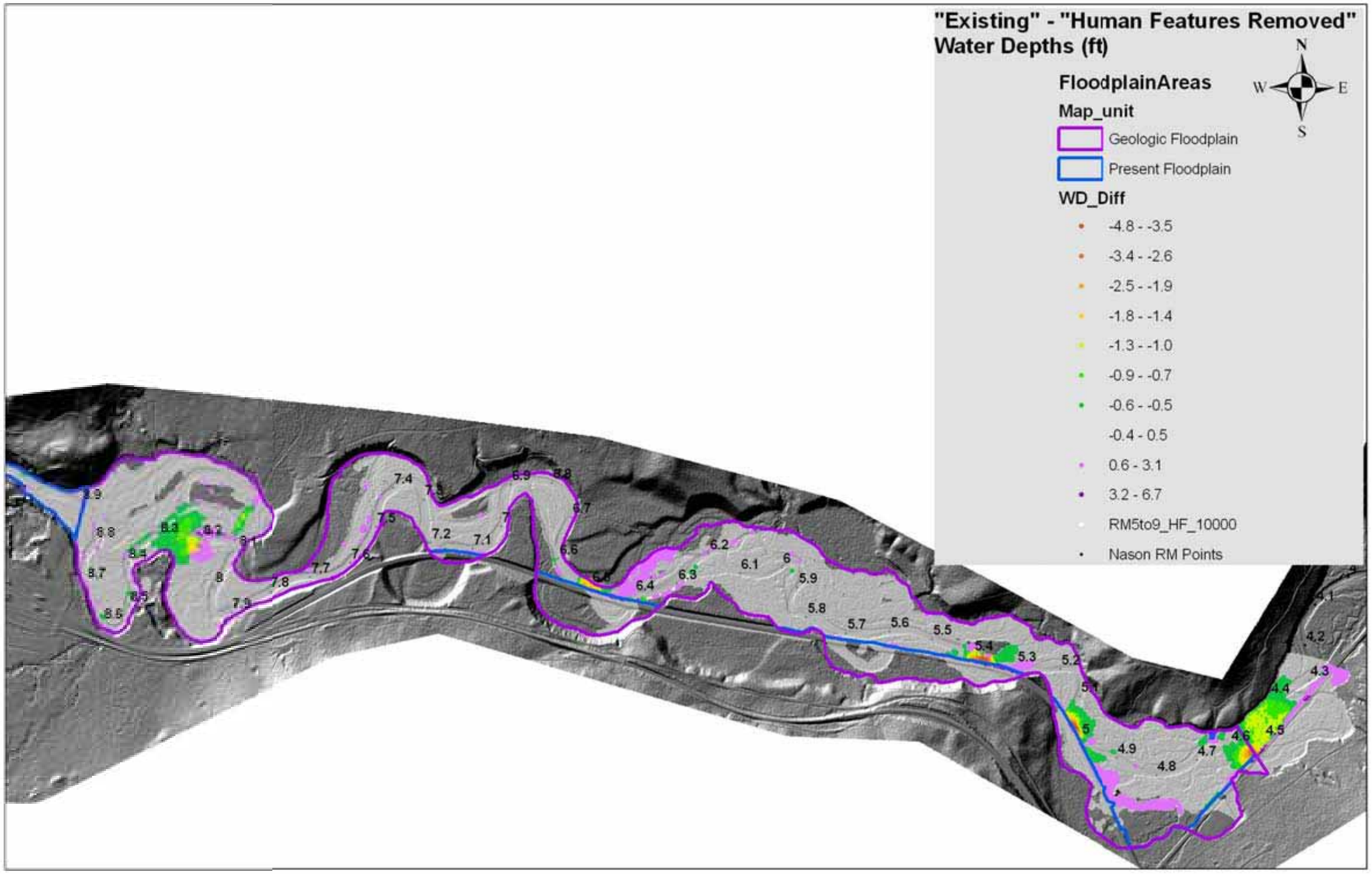


Figure 27. Difference in water depth between impacted present conditions at 10,000 cfs and presumed historical conditions had the highway and bridge embankments not been constructed. The white shading represents the extent of inundation under historical conditions, as compared to impacted conditions 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.

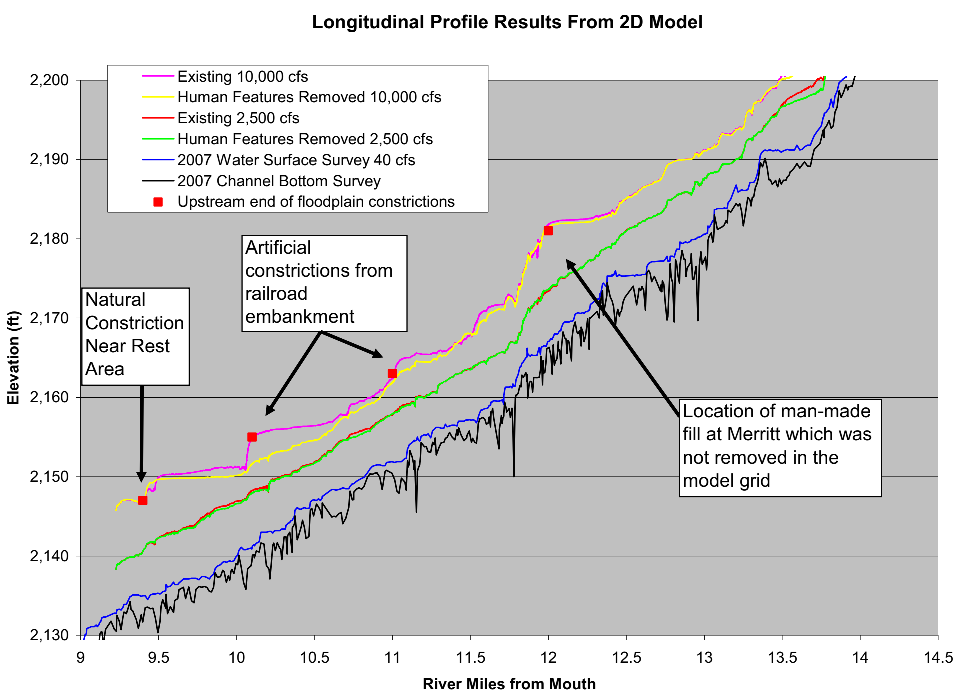


Figure 28. Backwater impacts from confined floodplain areas in Reach 3.

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%

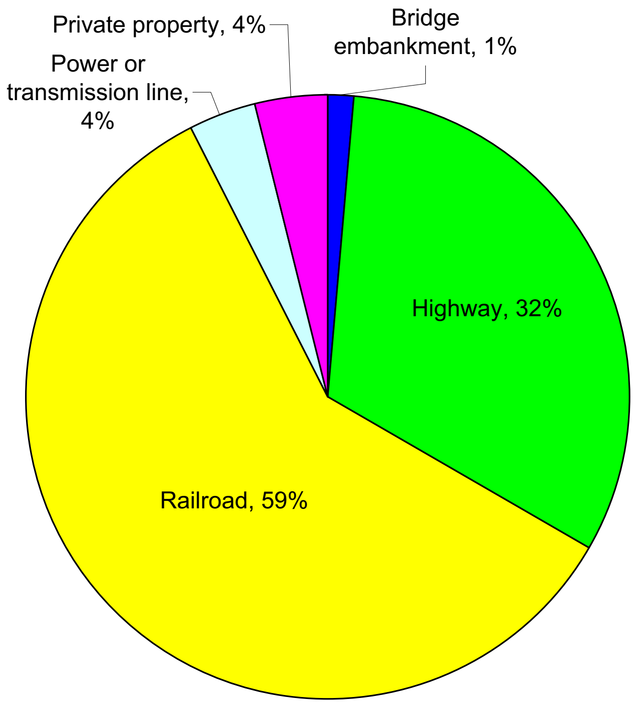


Figure 29. Purpose of bank protection along main channel by type of human feature in assessment area.

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.

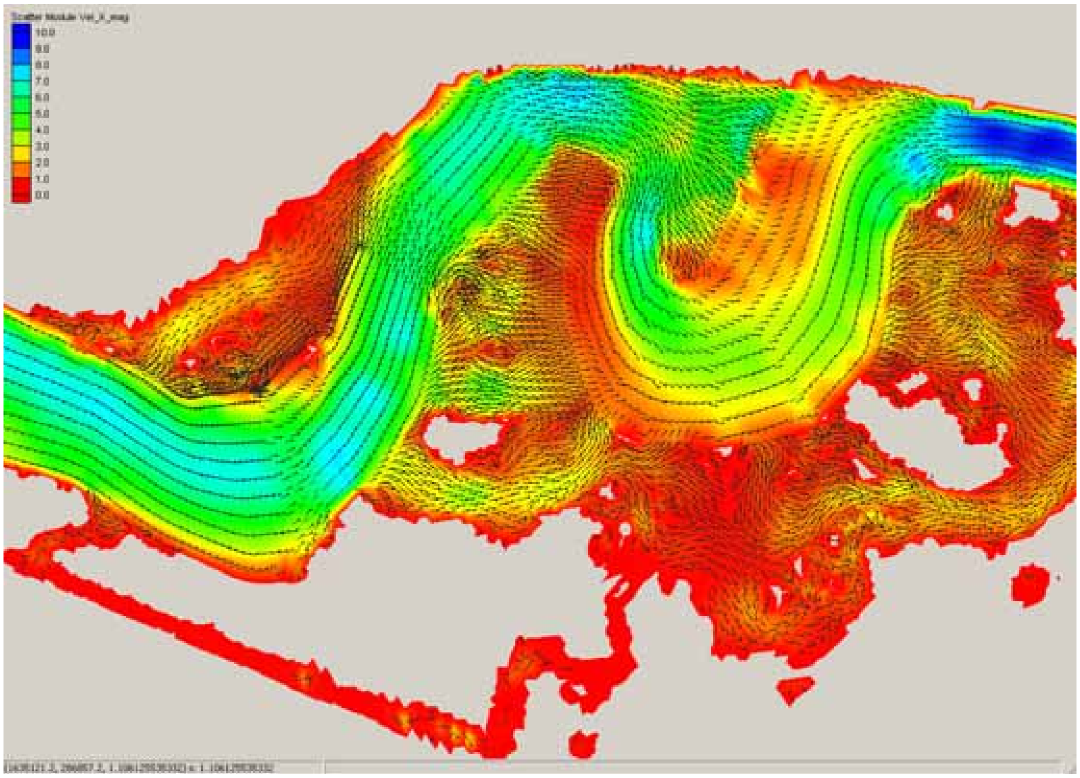


Figure 31. Example of 2D model velocity vectors (black arrows) and magnitude (color coded legend in feet per second (ft/s)) results around RM 12.7 to 13.3.

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.

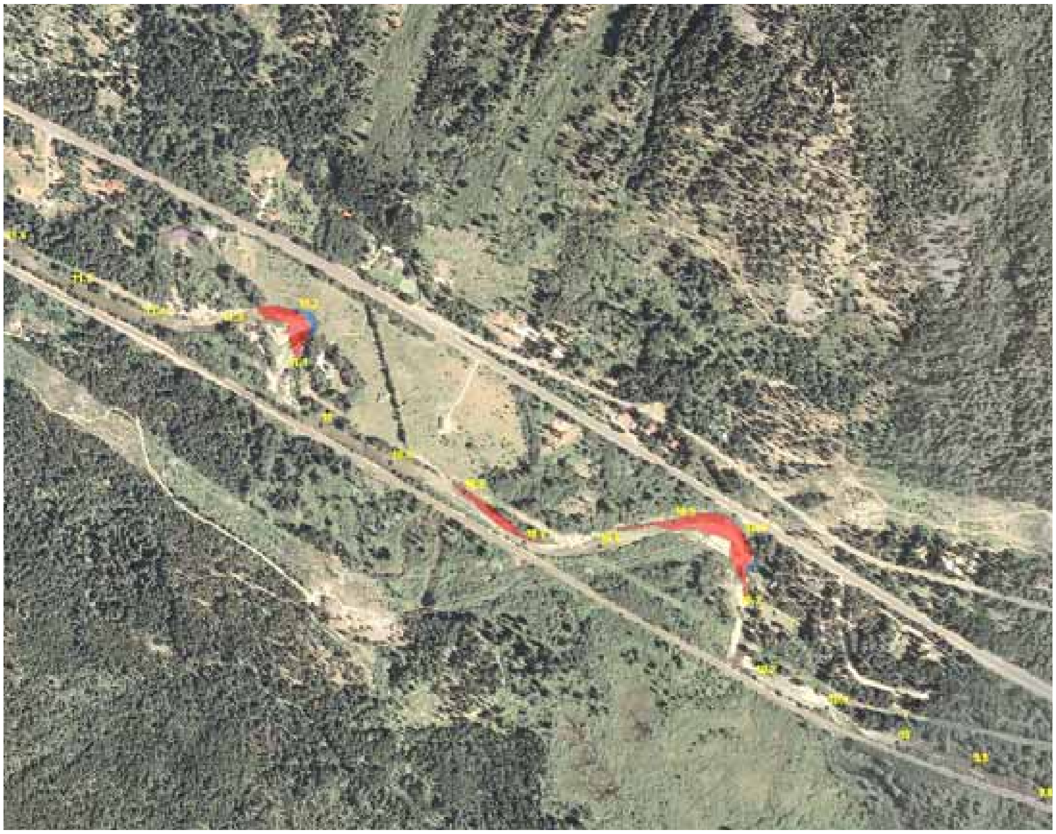


Figure 33. Example of two meandering channel locations (between artificially confined sections) where bank erosion along the outside of a meander bend at RM 10.4 and 11.2 occurred between 1962 and 2006 (colored polygons show erosion areas) (also see maps 29 and 30 in atlas for more locations of channel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

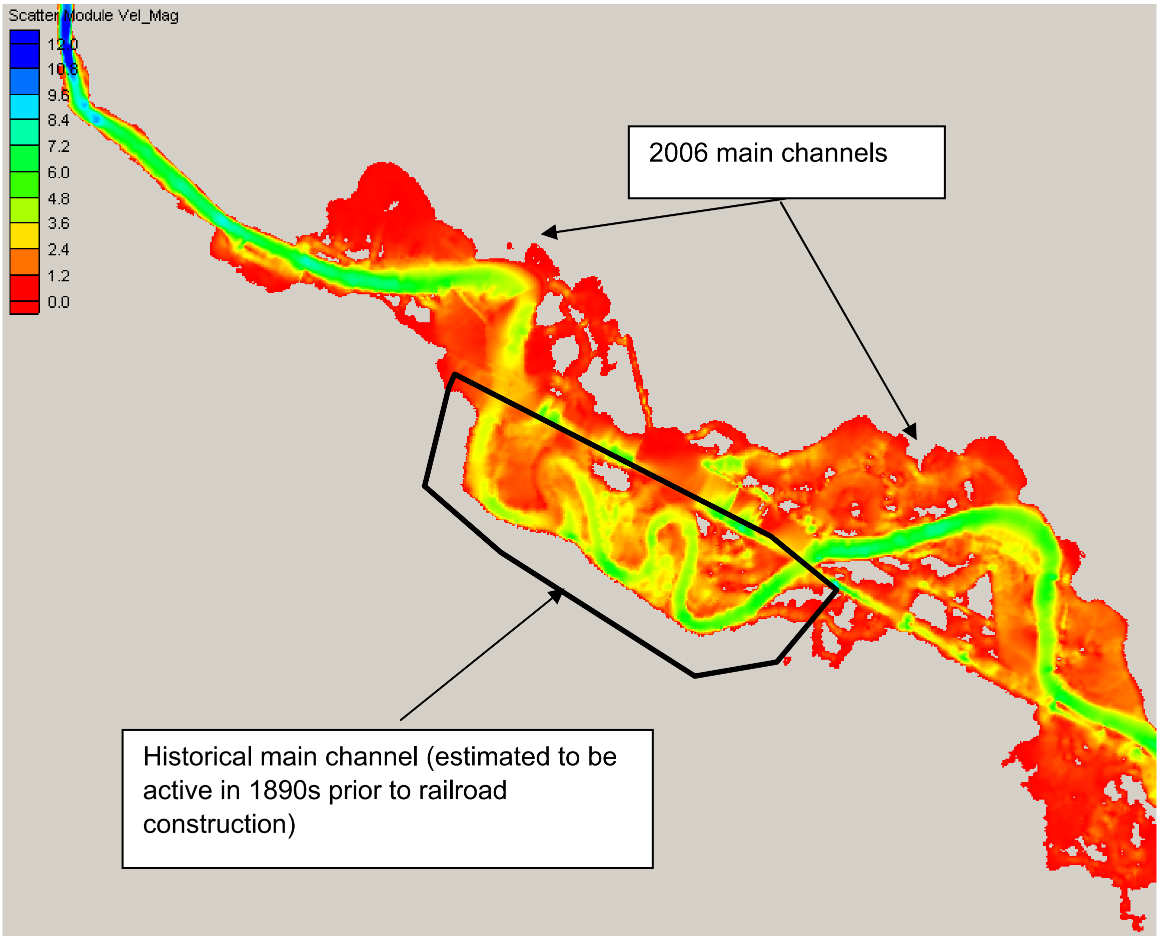


Figure 34. Image showing velocities and channel alignment of existing meanders and historical meander between RM 10.1 and 11.5. Note the tighter meander bends represented with the historical channel as compared to the two present (2006) meanders.

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.

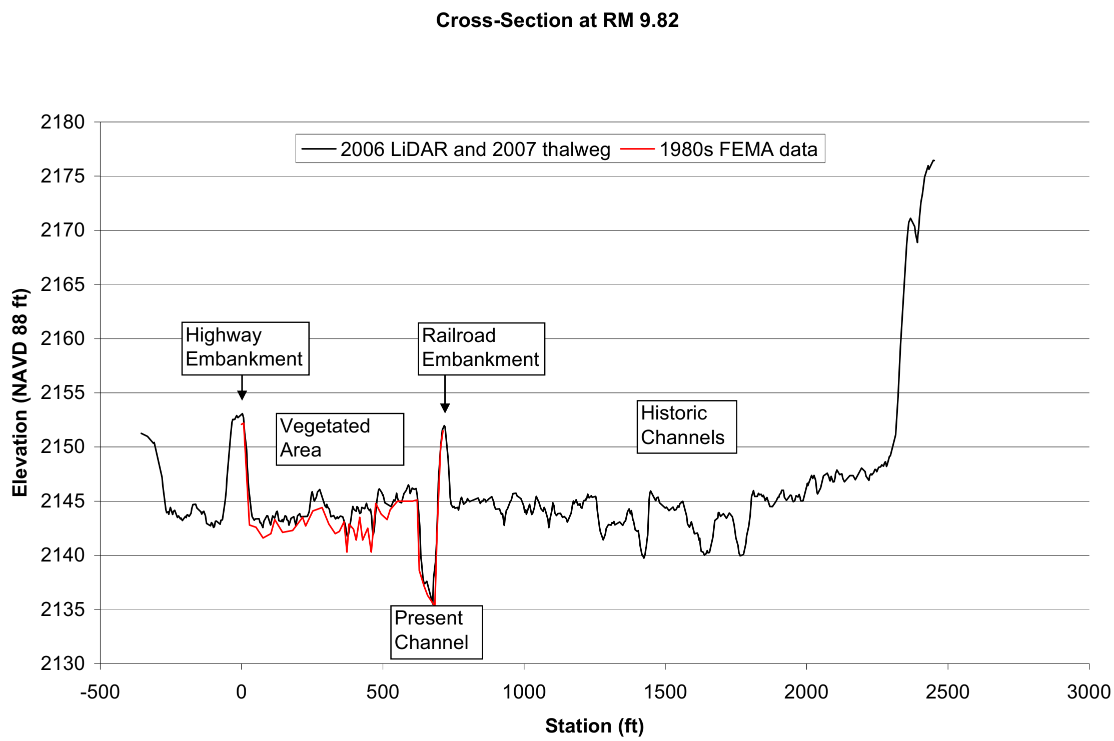


Figure 37. Nason Creek cross section at RM 9.82.

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.

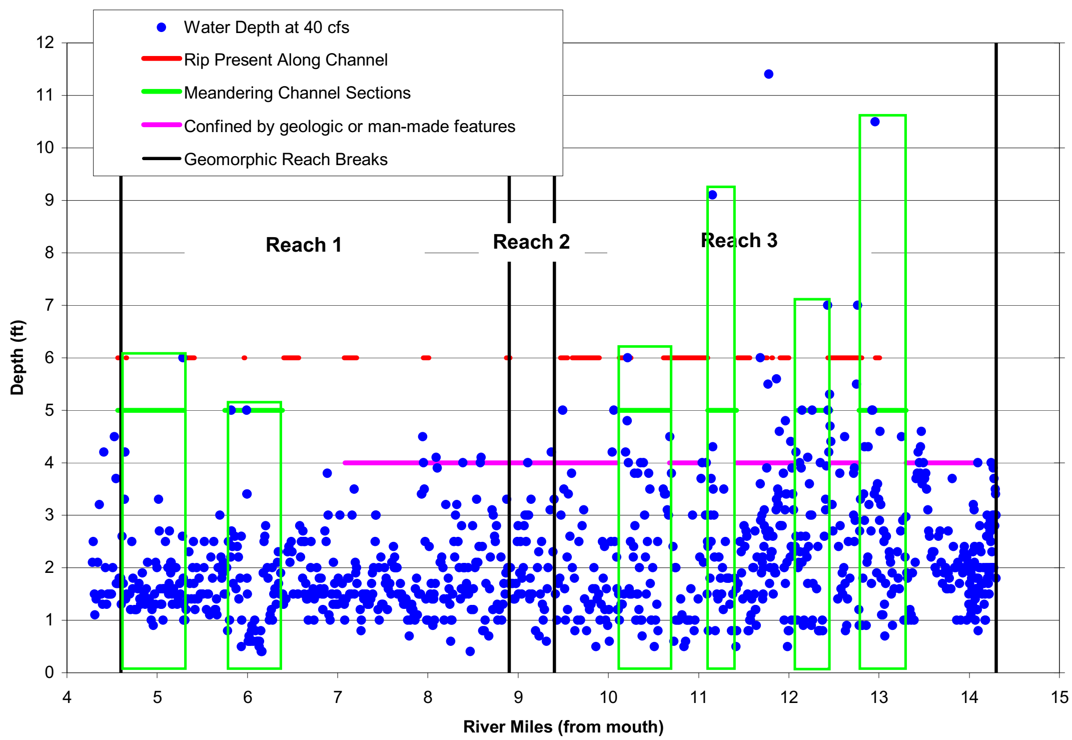


Figure 38. Plot of water depths greater than 3 feet in assessment area overlaid with meandering and confined sections and riprap.

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.

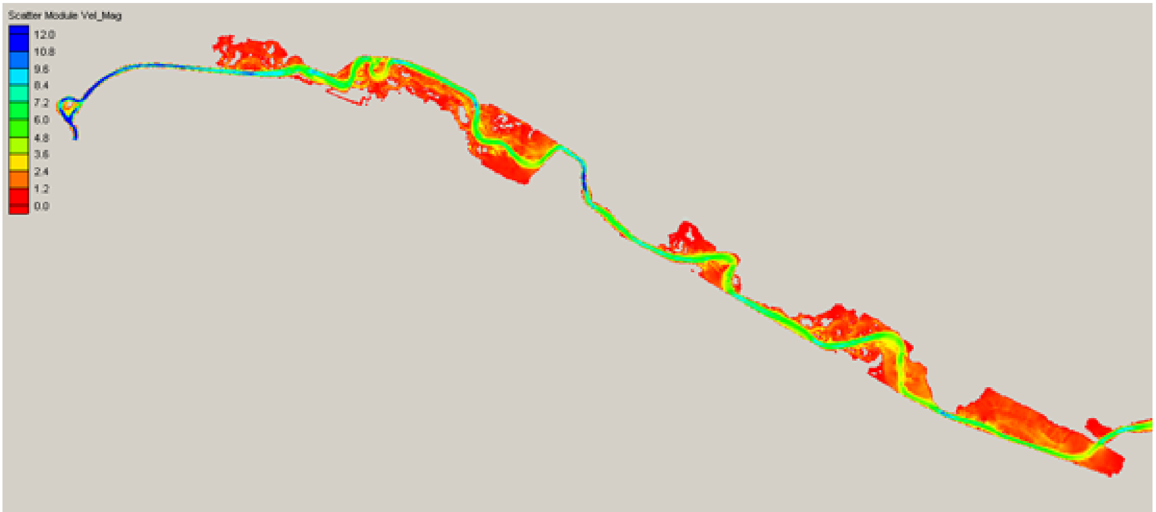


Figure 39. Velocity magnitude (ft/s) results from 2D model for RM 9 to 14 at 5,000 cfs.

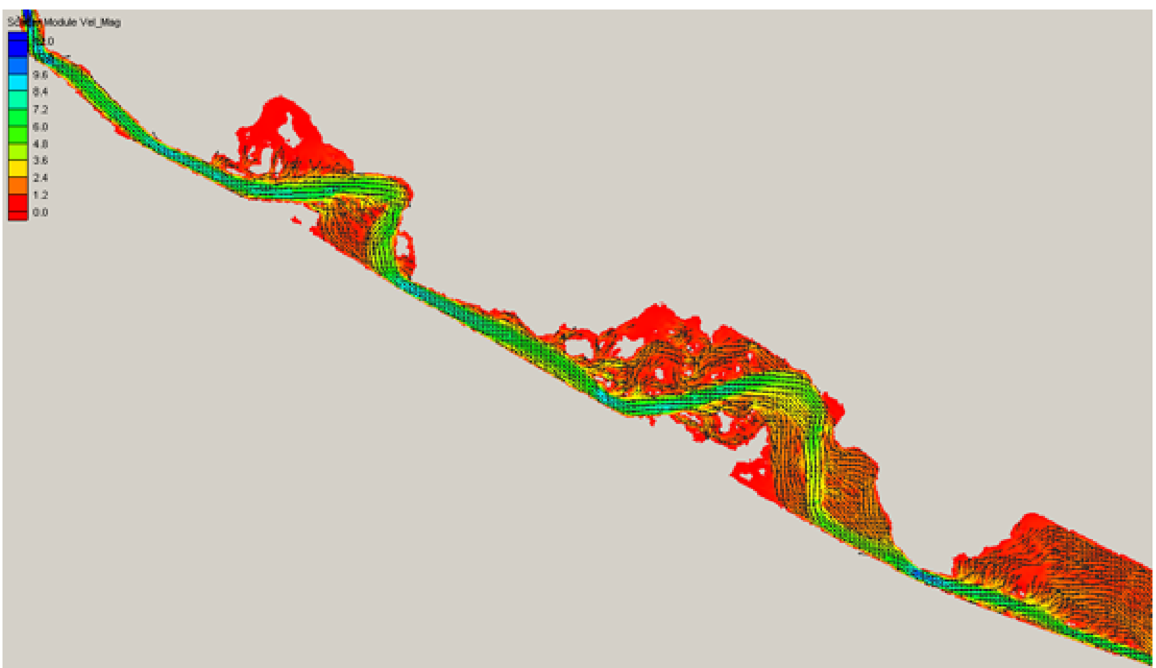


Figure 40. Example model result at 5,000 cfs of velocity magnitude (ft/s) and vectors between RM 9.5 and 11.1 (flow is from left to right in image).

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.

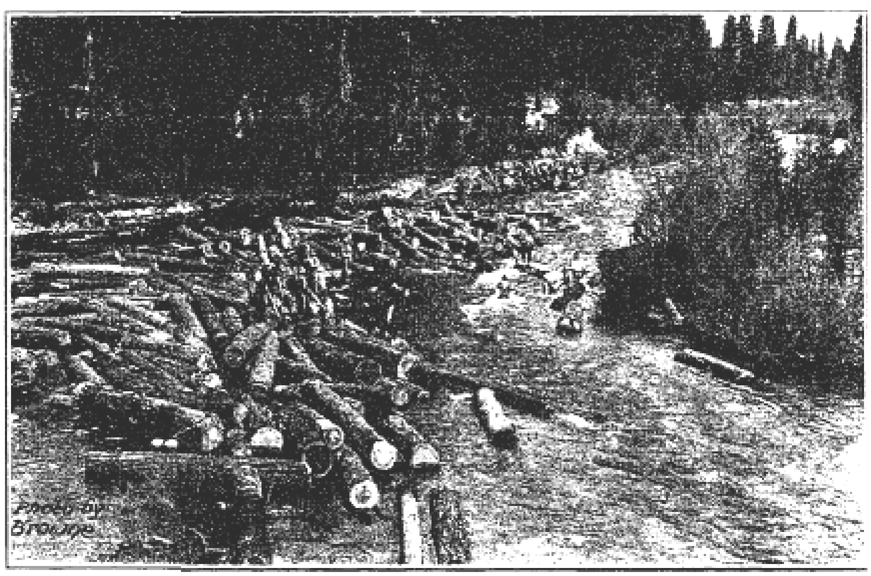
Table 16. Summary of Nason Creek vegetation analysis results by geomorphic reach.

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).

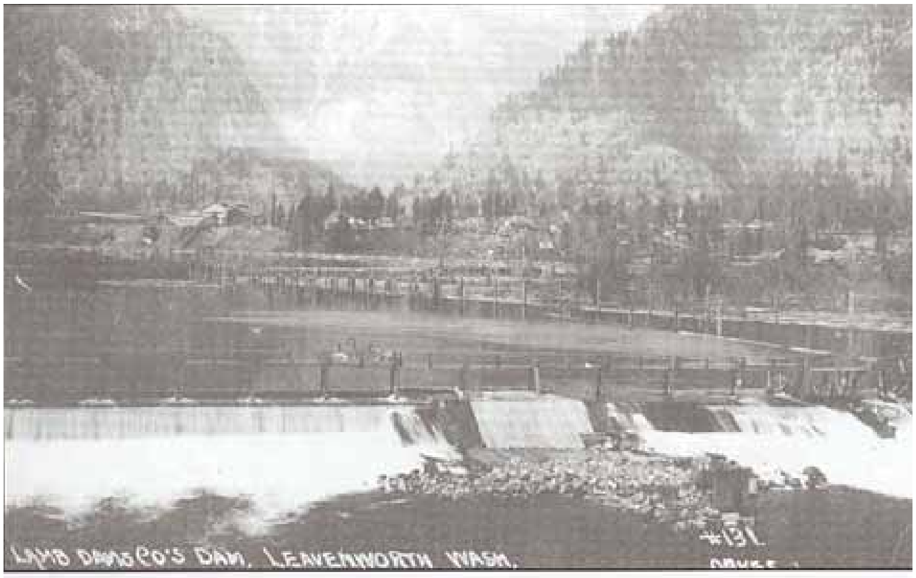
The vegetation along Nason Creek is influenced by the topographic layout of the Cascade Mountains ranging from high elevation subalpine forests at approximately 5500 feet elevation to dry forest environments around 2000 feet in elevation (USFS 1996). Within the assessment area, Douglas-fir and grand 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).



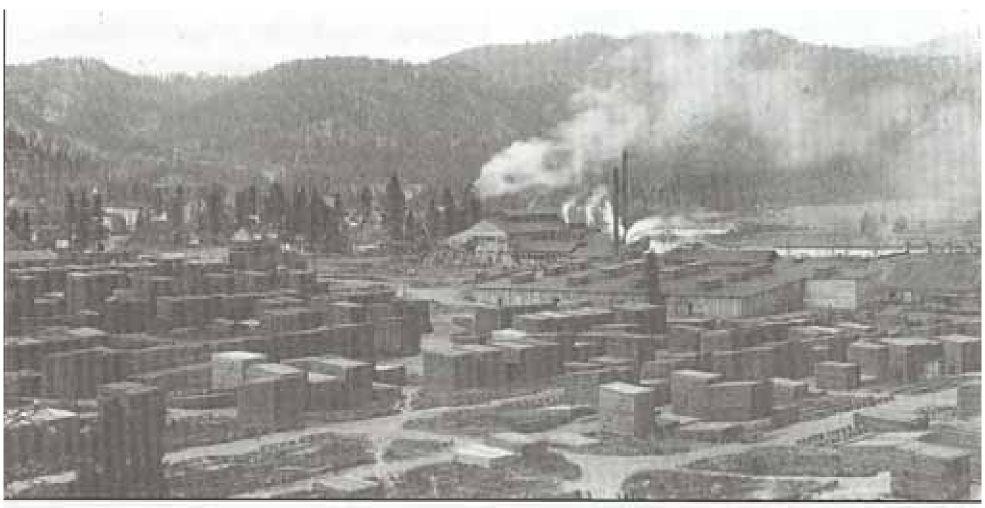
Log Drive on the Chewawa River. There are many million feet of fine timber in Chelan County

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.