Nason Creek Watershed Roads Assessment

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Table of Contents

List of Tables

List of Figures

Introduction

The concept of process-based river restoration has gained momentum in recent years, with many researchers and managers pressing for more holistic restoration efforts that better address root causes of ecosystem degradation and more cost-effectively restore river ecosystems (Beechie and Bolton 1999, Brierly et al. 2002, Wohl et al. 2005, Palmer and Allan 2006, Kondolf et al. 2006). Ecosystem processes are the biological, geochemical, and physical factors and components that take place or occur within an ecosystem. Therefore, the aim of process-based restoration is to re-establish normative rates and magnitudes of physical, chemical, and biological processes that create and sustain river and floodplain ecosystems (Beechie et al. 2010). Process-based restoration is guided by four basic principles (Beechie et al. 2010): 1) Target root causes of habitat and ecosystem change; 2) Tailor restoration actions to local potential; 3) Match the scale of restoration to the scale of physical and biological processes; and 4) Clearly define expected outcomes, including recovery time and durability of the restored state given location conditions.

Stream Process Groups

Beechie et al. (2013) provided a means of identifying and grouping key processes that influence stream ecosystems. We started with this classification and made minor modifications to meet our local needs. The stream process classification was used to describe the linkages between stream processes, watershed-scale assessments, and tools used to evaluate the condition of stream processes within subwatersheds. A brief description of the grouped processes is provided below.

Runoff, Infiltration, and Stream Flow

Stream flow regimes are defined by the magnitude, frequency, duration, timing, and rate of change of flow events (Poff et al. 1997). These components are primarily controlled by the timing and magnitude of precipitation or snowmelt events, but are also moderated by interception, infiltration, and evapotranspiration processes. There are three main runoff pathways: overland flow, subsurface flow, and groundwater flow. Annual patterns of stream flow, referred to as flow regimes, are controlled by annual patterns of precipitation and temperature. Cold regions receive most precipitation as snow, and most runoff occurs during spring snowmelt (Wohl 2000). Lundquist et al. (2013) conducted a meta-analysis using both a synthesis of other studies and modeling to show how forest cover influences snow cover and duration. They found that in regions with average December-January-February temperatures greater than -1^{0}C, forest cover reduces snow duration by 1-2 weeks compared to adjacent open areas (Lundquist et al. 2013). This occurs because the dominant effect of forest cover shifts from slowing snowmelt by shading the snow and blocking the wind to accelerating snowmelt from increasing longwave radiation. This is likely to become more widespread as climates continue to warm (Lundquist et al. 2013).

Stream Flow and Flood Storage

Stream flow and hydrologic regime exert strong influences on potential life history strategies and community structure of riparian and aquatic species and communities (Cushing and Gaines 1989, Schlosser 1985, Allan 1995, Doyle et al. 2005). The magnitude, frequency, duration, timing and rate of stream flow also influence a variety of physical and ecological functions in streams and floodplains (Karr 1991, Bertoldi et al. 2009). For example, low- and high-flow magnitudes influence riparian vegetation establishment and maintenance, development of floodplain habitats, formation of in-channel habitats, and structure of ecological communities (Cushing and Gaines 1989, Poff et al. 1997, Richter et al. 2003, Beechie et al. 2006).

Erosion and Sediment Supply

Erosion processes include soil creep, surface erosion, and mass wasting. We consider bank erosion under the Channel, Floodplain, and Habitat Dynamics process group. Mass wasting and surface erosion can be influenced by human activities such as logging, road building, grazing, and land clearing (Sidle et al. 1985, Bradford and Huang 1994, Imaizumi et al. 2008) as well as natural disturbance processes such as wildfire that alter characteristics of vegetation and soils. A multitude of factors influence rates and magnitudes of erosion and sediment supply, including landform, slope, parent geology, soil type, precipitation patterns, and vegetation.

Nutrient Delivery

Nutrient dynamics are governed by parent geology, landforms, precipitation and runoff, and vegetative cover (Beechie et al. 2013). Leaf-fall from riparian vegetation is a dominant process of nutrient delivery to streams in forested regions. Wildfire can reduce the uptake of nutrients to streams and increase rates of nutrient delivery to a stream channel (Nitschke 2005). Where anadromous fish are present, nutrient delivery from carcasses of post-spawning adults can be important in spawning areas, as well as downstream.

Riparian Vegetation Functions and Dynamics

Colonization, succession, and natural disturbance dynamics are processes that structure riparian vegetation communities (Hughes et al. 1997). The interplay of physical, hydrological, and successional processes create a patchwork of forest ages and successional states within the riparian zone (Gregory et al. 1991, Corenblit et al. 2007, Osterkamp and Hupp 2010). For example, colonization and succession processes lead to predominately mature vegetation along headwater streams (Agee 1988). Conversely, on larger streams that migrate across their floodplains, floodplain forests predominately comprise colonizing species on braided channels, late successional species on straight channels, and a high diversity of both species and stand ages on meandering and island-braided channels (Beechie et al. 2006, Naiman et al. 2010). Riparian processes and functions that affect stream ecosystems include root reinforcement of banks, wood supply to streams, sediment retention, leaf litter supply, and shading (Beechie et al. 2013). Forest management, including road-related impacts, can reduce potential large wood available for in-channel wood and shade from riparian areas (Trombulka and Frissell 2000, Wondzell 2001, Meredith et al. 2014).

Sediment Transport and Storage

The rate of sediment transport relative to the rate of sediment supply determine whether any individual stream reach is accumulating sediment, exporting sediment, or is relatively stable (Beechie et al. 2013). Shifts in sediment transport capacity can result from changes in sediment supply or stream flow. Increases in sediment supply shift reaches to the oversupplied or aggrading state, whereas decreased sediment supply shifts reaches to the undersupplied or degrading state (Beechie et al. 2013). Increases in stream flow can result in relative sediment supply shifting to the undersupplied state, while decreases in stream flow can result in oversupply (Beechie et al. 2013).

Channel, Floodplain, and Habitat Dynamics

Dynamic processes and continuous change are characteristic of natural stream ecosystems (Jungwirth et al. 2002), and these dynamics create a shifting habitat mosaic (Ward et al. 2002). In a naturally shifting habitat mosaic, some habitats are lost while others are created, but the pattern and distribution of habitats remains more or less the same over time (Ward et al. 2002, Beechie et al. 2006). The most important processes that influence channel, floodplain, and habitat dynamics include lateral channel migration, avulsion, channel switching, floodplain building, variations in stream discharge, wood accumulation, and beaver dam building (Beechie et al. 2013).

Organic Matter Transport and Storage

The dynamics of organic matter transport and storage are influenced by channel structure and floodplain interactions in much the same way as sediments. Particulate organic matter is a key basal resource in stream ecosystems, and its storage within a reach affects local ecosystem productivity (Beechie et al. 2013). Fine organic particulates are trapped by filter-feeding organisms and processed through the food web (Vannote et al. 1980, Gaines et al. 1992, Beechie et al. 2013).

Instream Biological

A wide range of instream biological processes influence the structure and function of stream ecosystems including habitat selection, feeding, competition, and predation (Beechie et al. 2013). These processes influence the behavior of individuals, and, when viewed at larger scales, the collective behaviors of many species and individuals interact to structure biological communities and food webs (Beechie et al. 2013). The ability of stream organisms to exploit shifting habitat mosaics is essential to the full expression of potential species distributions and diversity in stream ecosystems (McGarvey and Hughes 2008). Instream biological processes vary with riparian conditions, stream flow, and habitat diversity, which can in turn, alter food webs and community structure. Food webs in streams are based on two key basal resources: materials that enter from the riparian area and primary production within streams (Vannote et al. 1980, Richardson et al. 2010).

Interactions between instream processes and riparian, sediment and hydrologic influences can be very complex and may result in unexpected changes to stream ecosystems. For example, when steelhead are present in sufficient numbers they can reduce the number of small fish through predation, which releases invertebrate populations who then consume most of the algae (Power 1990). Thus, changes at the top level of the food web can have influences several trophic steps away through cascading effects (Beechie et al. 2013). For the Nason Creek Roads evaluation, two aspects of in-stream biological processes were focused on: habitat connectivity and the current and potential distribution of listed fish species.

Road and Stream Interactions

Roads influence a wide range of stream and watershed processes. For example, the compacted surface of roads can lower infiltration capacity, alter and concentrate overland flow, and increase erosion and delivery of sediment to the stream system, which can degrade fish habitat quality (Dunham and Rieman 1999, Furniss et al. 1991, Luce and Black 1999, Jones et al. 2000, Luce et al. 2001, Trombulka and Frissell 2000, Meredith et al. 2014). Roads can also intercept subsurface flow and convert it to rapid surface runoff, extending channel networks and increasing watershed efficiency (Luce and Black 1999, Trombulka and Frissell 2000, Wondzell 2001). Roads reduce vegetative cover in streamside areas and result in the removal of large wood (Bunnell and Houde 2010, Meredith et al. 2014, Pollock and Beechie 2014). In addition, roads can accelerate delivery of water and increase erosion and sedimentation into streams (Trombulka and Frissell 2000, Wondzell 2001). Accelerated erosion, runoff, and sediment delivery from roads increases streambed fine sediment, which affects aquatic habitat and macroinvertebrates, and makes streambeds and banks more susceptible to erosion during high flow events (Luce and Black 1999, Wondzell 2001). The presence of roads can increase the drainage density 21-50% by altering flowpaths in a watershed (Wemple et al. 1996).

Effectively targeting road restoration opportunities in montane ecosystems requires spatially explicit disturbance information (i.e. road effects) and an understanding of how different disturbance processes, intensities, routing, and locations affect important attributes of aquatic ecosystems (Al-Chokhachy et al. 2016). The general understanding of road effects on aquatic ecosystems has been based largely on varied measures of road density and their associations with in-stream habitat or species/population status (Thurow et al. 1997, Hughes et al. 2004), but often lacks resolution on specific processes that drive the apparent response (Al-Chokhachy et al. 2016).

In this report, we present an approach used to assess road-stream interactions using a combination of GIS based tools (Benda et al. 2007, as suggested by Al-Chokhachy et al. 2016) and a complimentary field-based assessment of road conditions in order to identify areas to focus road restoration.

Objectives of this Assessment

The overall objective of this project was to assess the influence of roads within the Nason Creek watershed on a subset of the key ecological indicators (described above) in order to identify and prioritize potential road restoration or management actions to improve aquatic and riparian habitat conditions. To accomplish this, the following objectives were identified:

Objective 1. – Existing Conditions Roads Mapping

- Compile and catalog existing GIS data including USFS and DNR data layers
- Develop maps of existing GIS stream layers

Objective 2. - Field Inventory

- Field inventory existing mapped roads and document unmapped roads on public lands. Existing maps indicate there are 200-250 miles of forest roads in Nason creek with 162 miles on USFS lands.
- Document GPS locations for all stream crossings and road surface erosion

Objective 3. – Identify and Prioritize Actions to Improve Aquatic Habitat.

- Compile maps of field inventory and data points collected
- Assess impacts of roads on key ecological indicators using field inventory results and GIS data/tools.
- Identify project areas for restoration treatments based on potential risks and benefits to key indicators
- Develop maps of field inventory results, model results and potential project areas
- Summarize metrics associated with proposed treatments (ie. road density, stream crossings, sediment delivery).
- Document the assessment in a final report.

The Assessment Area

The Nason Creek assessment area includes two 6th Field subwatersheds (12th Code HUCs), Lower Nason Creek (31,671 Acres) and Upper Nason Creek (22,339 Acres) totaling 54,010 acres in size (Fig. 1). There are a total of 269.8 miles of road in the Nason Creek watershed, 66.1 mile in the Upper Nason Creek and 203.7 miles of road in Lower Nason Creek (Table 1). Road densities range from 0 to >5.0 miles/square mile and are highest in the valley bottom and eastern half of the watershed (Fig. 1).

Table 1. A summary of the available roads information for the Nason Creek watershed.

Landowner Category	**Miles of Road on DNR Roads Layer**	**Miles of Road on Forest Service Roads Layer**	**Miles of Road based on 2016 Inventory**
Public Lands	116.3	76.9	132.8
Private Lands	131.9	51.5	137
Totals	248.2	128.4	269.8

There are three federally listed fish species that occur within the Nason Creek watershed: steelhead (Endangered, *Oncorhynchus mykiss*), spring Chinook (Endangered, *Oncorhynchus tshawytscha*), and bull trout (Threatened, *Salvelinus confluentus*)(NMFS 2008, USFWS 2015). Approximately 27.7 miles of critical habitat has been designated in the Nason Creek watershed for steelhead, 15.7 miles of critical habitat for spring Chinook, and 23.9 miles of critical habitat for bull trout. The Nason Creek watershed has been identified as a high priority for restoration by the Okanogan-Wenatchee National Forest.

Methods

Prior to going into the field, maps were prepared that contained all known mapped roads. Roads layers were obtained from US Forest Service and Department of Natural Resources. All known roads were driven or walked. Any new roads found were also driven or walked. Field staff kept a running GPS unit (Garmin 64 ST) to document line work for roads walked or driven. Field data was also collected to document evidence of road surface erosion, evidence of sediment delivery to streams, stream crossings, road end, road junctions, ditches, culverts (streams or ditch relief), water bars, bridges, rolling dips, skid trails, tank traps, and water on the road. Streams were characterized as a stream at the road crossing if there was a defined bed and bank (evidence of bank scour and unvegetated cobble bed), however, field staff did not walk up or downstream from the road to fully verify whether or not this stream flows into Nason Creek. There was not sufficient funding to follow the DNR stream typing protocols and produce the associated paperwork to update DNR stream typing as part of this project. The field inventory collected GPS data at 1960 points (Appendix D). Approximately 300 data points were included as part of the modeled evaluation. Those 300 points were selected if the data points were coded as surface erosion or the notes contained comments that indicated the point may have surface sediment delivery to a stream, surface erosion, blocked, buried, or failed culvert, fords, and/or evidence of water on the road (ruts, seeps). The field track road line work was also evaluated in comparison to aerial photographs to determine if any road segments were missed during the field inventory. Roads in Sections 3 and 5 (Township 26 North Range 15 East) were added based upon aerial photograph interpretation.

As described above, roads can influence a wide-variety of stream processes. In order to focus our assessment, we identified key ecological indicators, management questions, and analysis tools in order to assess how roads influenced a subset of key stream processes and functions (Table 2).

Table 2. Key indicators, key questions, datalayers and assessment tools used in the Nason Creek Watershed Roads Assessment.

Key Indicator	Key Questions	Datalayers	Assessment Tools
Erosion and Sediment Supply	Which roads are contributing fine sediment to streams? Which roads interrupt wood and coarse sediment delivery to streams?	Roads, stream, high-res. DEM, Land-type Associations	Graip-Lite, Erosion Potential Delivered, Field Inventory of Roads
Floodplain Functions	How have human activities impacted the amount and function of floodplains?	Floodplains, DEM, Roads, other human developments	Floodplain mapping, LIDAR, Remote Sensing, Field Inventory of Roads
Habitat Connectivity	How have human developments affected aquatic organism passage? Do barriers prevent access to current and future cold water?	Road-stream crossings, barrier inventory, current and potential fish habitat, cold water	Barrier data, field inventory, intrinsic habitat potential, cold water projections
Habitat for Listed Fish Species	What is the current distribution of listed fish? Where is the potential habitat?	Current fish distribution, potential habitat	Intrinsic habitat potential

Erosion and Sediment Supply

Our assessment of the influences of roads on erosion and sediment supply included two primary components (Beechie et al. 2013). First, we assessed roads and road segments for their potential to deliver fine sediment to streams. Second, we assessed road segments that were located in landscape positions that make them prone to the risk of failure. This assessment also identified locations on the landscape where roads could interrupt the delivery of wood and coarse sediments to streams.

Erosion from road surfaces can increase streambed fine sediment, which affects aquatic habitat, macroinvertebrate populations, and fish spawning habitats (Luce and Black 1999, Wondzell 2001). In addition, fine sediment from roads can make streambeds and banks more susceptible to erosion during high flow events (Luce and Black 1999, Wondzell 2001). We used the GRAIP-Lite (Geomorphic Road Analysis and Inventory Package) tool in NetMap (Benda et al. 2007) to identify roads and road segments that were deemed to be hydrologically-connected and had the highest potential to deliver fine sediments to streams. In addition, field surveys of road conditions conducted in the summer and fall of 2016 identified erosion points, where there was visual evidence of erosion of the road surface and other erosional issues (e.g., failed culverts, gullies, landslides). These data were used in combination with the GRAIP-Lite analyses to identify and prioritize road segments for maintenance, rehabilitation, and restoration.

Aquatic habitats are structured by interactions among terrestrial and aquatic processes and climate (Bisson et al. 2003). For example, wildfires influence hillslope erosion, stream sedimentation, and woody debris recruitment to streams (Benda et al. 2003, Miller et al. 2003). Certain types of disturbances, such as fires and landslides are essential in the creation and maintenance of channel and riparian landforms (Benda et al. 2003, Miller et al. 2003, Bisson et al. 2009). When human activities such as stream cleaning, log drives, diking, riparian logging, and damming have simplified channels, disturbances such as fires and landslides may be a benefit in the long term because they may increase physical and biological diversity (Benda et al. 2003, Bisson et al. 2009, Flitcroft et al. 2016). Land uses such as timber harvest, fire suppression, and road networks, can alter the frequency and magnitude of natural disturbances (Benda et al. 2003, Rieman et al. 2010).

We used the General Erosion Potential-Delivered (GEPdel) model in NetMap (Benda et al. 2007) with landslide hazard ratings for Land-Type Associations (Davis et al. 2004) to identify landscape conditions (gullies, steep drainages, etc.) that are prone to landslides and slope failures. These are areas where there is potential for the delivery of wood and coarse sediment to streams. We then intersected these areas with the roads datalayer to identify road segments that are at risk of failure and/or that may interrupt the delivery of wood and coarse sediment to streams.

Floodplain Function

The most important processes that influence channel, floodplain, and habitat dynamics include lateral channel migration, avulsion, channel switching, floodplain building, variations is stream discharge, wood accumulation, and beaver dam building (Beechie et al. 2013). Floodplain processes can be disrupted by a variety of land and water uses including dams, installation of dikes and riprap to control flooding, and roads that bisect floodplains and isolate floodplain channels (Beechie et al. 1994, 2008). However, the assessment methods for identifying altered floodplain conditions or processes are often the same regardless of the cause of change (Beechie et al. 2013).

We used LiDAR floodplain mapping (100 year event) from the Bureau of Reclamation Reach Assessments for the lower 14 miles of mainstem Nason Creek. The floodplain mapping tool in NetMap (2 X bank full width) to approximate the floodplain area in the remainder of the Nason Creek watershed. We then used our roads inventory data and remote imagery to identify portions of the floodplains that are no longer connected to the main stream channel.

Habitat Connectivity

The role of physical and biotic connectivity in freshwater ecosystems is widely acknowledged to be essential for maintaining habitat dynamics and species responses (Lowe et al. 2006, Bisson et al. 2009, Waples et al. 2009). Connectivity includes migratory pathways along rivers and their tributary systems (longitudinal connectivity) as well as unimpeded lateral connections between main channels, secondary channels, and floodplains (Bisson et al. 2009). Ecological connectivity is critical for processes and functions that include a wide variety of complex aquatic and terrestrial interactions that influence channel dynamics, food webs, and water quality (Naiman and Bilby 1998, Power and Dietrich 2002). Removing barriers to movement and improving natural linkages between terrestrial and aquatic ecosystem processes to re-create normative riverine conditions is an important conceptual foundation for salmon restoration (Williams et al. 2006, Bisson et al. 2009). Excessive flow velocities and undersized culverts at road-stream crossings can alter stream channel function and fragment fish habitat (Furniss et al. 1998). The primary objective of this component of the assessment was to identify and prioritize the most influential barriers to aquatic organisms for restoration of habitat connectivity (Dunham et al. 2003, Fausch et al. 2009).

We used road and stream datalayers to identify road-stream crossings that intersected current or potential habitat for steelhead (see Distribution of Current and Potential Habitat for Listed Fish Species below). In addition, during field surveys of road conditions, a preliminary assessment of the road-stream crossing was made. Finally, we obtained cold-water projections for streams from 2040 from NorWeST (www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). Detailed descriptions of how stream temperature projections were developed are available in Ver Hoef et al. (2006) and Isaak et al. (2015). We then categorized the portions of the streams in the assessment area as "favorable" in the mean August stream temperatures were currently or projected to be $<17^0$C, "stressful" if mean August stream temperatures were currently or projected to be 17-21^0C, and "fatal" in mean August stream temperatures were currently or projected to be $>21^0$C (based on Mantua and Raymond 2014). The field data and spatial data were used to identify potential barriers to fish passage with the greatest potential to access additional potential habitat and cold water. Additional fish inventories may need to be completed to fully assess the barrier potential, impacts, and restoration.

Distribution of Current and Potential Habitat for Listed Fish Species
The current distribution of listed fish species and the identification of areas that are potential habitat but not currently occupied provides an assessment of the ability of streams to contribute to the recovery of listed fish species (NMFS 2008, USFWS 2015). In addition, site-specific data from fish surveys, monitoring, or research may be used to identify important spawning reaches or other attributes that may be important in determining restoration opportunities and priorities.

There are three federally listed fish species that occur within the Nason Creek watershed: steelhead (Endangered, *Oncorhynchus mykiss*), spring Chinook (Endangered, *Oncorhynchus tshawytscha*), and bull trout (Threatened, *Salvelinus confluentus*). Chelan County NRD (J. Hadersberger) provided information on the current distribution of listed fish in the watershed based on StreamNet. We then used the species-specific intrinsic potential tool from NetMap (Benda et al. 2007) to identify the distribution of potential habitat within the watershed.

Summary of Road Assessment Results

Erosion and Sediment Supply

The road inventory (both field and remote imagery) resulted in a considerable increase in the amount of roads compared to existing databases (9% more than the State DNR layer, 53% more than the Forest Service layer). This indicates the importance of updating and rectifying roads inventories prior to conducting analyses of road-stream interactions.

There are 2 miles of road (1.4 miles on public lands and 0.6 miles on private lands) and 5 erosion points that occurred in areas identified high erosion potential based on the General Erosion Potential-Stream Delivered module in TerrainWorks (Table 3). The roads identified as occurring in moderate and high erosion potential areas occurred widely across the watershed. This assessment provides information to identify roads that are in high erosion potential areas where fine sediments could be delivered to streams.

Table 3. Miles of roads and erosion points (from field surveys) that were located within areas identified as low, moderate, or high erosion potential.

Road/Erosion Point	Low Erosion Potential	Moderate Erosion Potential	High Erosion Potential
Public Roads	104.4 miles	1.4 miles	1.4 miles
Private Roads	110.6 miles	51.1 miles	0.6 miles
All Roads	215 miles	52.5 miles	2 miles
Erosion Points	284 points	86 points	5 points

We identified 25.7 miles of road that contributed 63% of the potential sediment delivery to streams (Table 4). The catchments with the highest potential sediment delivery to stream estimates included 8,10,11, and 12 (Fig. 2). There are 28.6 miles of roads within these catchments that are identified as medium or higher potential for sediment delivery to streams accounting for 34% of the overall potential sediment delivery. This assessment provides a means to identify and prioritize road segments for rehabilitation to reduce sediment delivery from roads to streams.

Table 4. The miles of road, mean road density, and relative sediment budget (kg/yr) from roads within the Nason Creek watershed that have the potential to contribute sediment to streams and summarized by catchment.

Catchment (acres)	Miles of Road	Mean Road Density (mile/sq.mi)	Relative Sediment Production (kg/year)	Relative Sediment Delivery (kg/year)	Proportion of Relative Sediment Delivery

1 (6,149)	15.6	1.6	269,616.5	78,030.6	6.4%
2 (6,263)	15.7	1.5	158,977.3	37,727.9	3.1%
3 (3786)	19.1	3.0	267,645.5	104,634.1	8.5%
4 (3588)	11.2	2.1	184,840.6	68,063.1	5.6%
5 (2591)	3.3	0.8	50,348.0	24,756.7	2.0%
6 (5040)	18.8	2.3	294,247.1	93,726.5	7.7%
7 (4653)	15.7	2.1	161,383.1	55,542.2	4.5%
8 (6827)	32.4	3.1	572,119.5	169,668.7	13.9%
9 (3056)	24.1	4.9	354,365.4	92,070.5	7.5%
10 (5243)	55.4	6.4	846,205.1	247,922.2	20.3%
11 (3274)	26.3	4.9	393,077.2	132,926.6	10.9%
12 (3543)	31.6	5.1	357,608.3	118,987.6	9.7%
Total 54, 013	269.1		**3,910,433.6**	**1,224,056.7**	100%

The final assessment of the potential for sediment delivery from roads to streams included identification of roads that were located in high erosion potential areas connected to streams and also occurred within landtype associations with high hazard ratings for slope failure (Fig. 3). This assessment show areas where roads are in a location that may result in sediment delivery to streams but also shows areas where roads may interrupt coarse sediment and wood delivery to stream. The delivery of coarse sediment and wood is an important natural process that greatly influences the quality of fish habitats. This assessment can be used to identify areas for rehabilitation work to restore this important process.

Another way to evaluate surface erosion and sediment delivery is to review the field data collected. Figure 4 depicts the 278 surface erosion points documented in the field. This data is overlaid onto the General Erosion Potential map. A combination of this modeling data and field data was used to develop potential future project areas as described at the end of this report. It is important to note that not all documented road surface erosion points deliver sediment directly to streams. At the design stage of this project, each surface erosion data point would be evaluated to determine whether or not it delivers sediment to streams.

Floodplain Function

We mapped a total of 2,410.7 acres of floodplains within the assessment area, 1074.3 acres on public lands and 1336.4 acres on private lands. The floodplains are distributed in the lower half of the watershed and have been considerably impacted by roads, highways, railways, and powerlines. Approximately 225 acres have been directly impacted by these activities. Because of the importance of Nason Creek to list fish recovery efforts, several projects have been implemented or are in progress to reconnect floodplains to the main stream channel and restore some floodplain functions. There are 15.9 miles of roads in the identified floodplains of which 6.9 miles are on public lands and 9 miles of private lands (Fig. 5).

Habitat Connectivity
We identified a total of 423 road-stream crossings, 250 on public lands and 173 on private lands. Of these, 3 occurred within current steelhead habitat, 194 on perennial streams, and 226 on seasonal streams. Twenty-three road-stream crossing are located in mapped floodplains, 10 of which occur on public lands.

Field inventory showed that 170 of the stream crossings were noted as 'problematic' because the notes identified issues such as delivery of sediment directly to a stream, blocked pipes and water flows across the road, or the stream is flowing in a roadside ditch. There are 25 stream crossings that occur within 300 feet of a stream identified as current or potential steelhead habitat (Fig. 6). This information can be used to assess the potential of stream crossings to prevent fish passage and also to identify stream crossings that deliver sediment to streams.

Current and Potential Habitat for Listed Fish Species
The three listed fish species that occur within the Nason Creek watershed all have substantial miles of current, critical habitat, and potential habitat (Table 5). This information can be used to identify road rehabilitation projects that are most directly influencing habitat for listed fish species.

Table 5. Miles of current habitat, designated critical habitat, and potential habitat for steelhead, Spring Chinook, and bull trout in the Nason Creek watershed.

Listed Fish Species	Miles of Current Habitat (StreamNet)	Miles of Designated Critical Habitat	Miles of Additional Potential Habitat (IP 25%+)
Steelhead	27.7	27.7	8.3
Spring Chinook	15.7	15.7	0.4
Bull trout	23.9	23.9	NA

Potential Road Rehabilitation Projects to Restore Key Watershed Processes in the Nason Creek Watershed

Luce et al. (2001) and Al-Chokhachy et al. (2016) identified the need to conduct spatially explicit watershed assessments to inform road-related rehabilitation and stream restoration. The focus of these assessments should be to determine which roads are the most damaging to aquatic resources so that limited resource are used to address most significant problems (Luce et al. 2001, Al-Chokhachy et al. 2016). In the Nason Creek watershed roads assessment, the following text describes the process to identify potential projects that address key indicators for restoring watershed processes as described in Table 2 above.

<u>Erosion and Sediment Supply</u>
In order to identify projects that reduce sediment delivery from roads to streams, the whole watershed was divided into project areas. Sections of road that were

identified as having moderate to high General Erosion Potential (Figure 7) were grouped into 23 project areas. Each project area is further characterized in Table 6 (Appendix B) and there are two maps per project area (Appendix C). Table 6 describes the location of the project area, provides a list of the field data collected within that project area, and there has been an initial attempt to crosswalk this project area with the description of this road in the 2011 USFS Nason Creek Minimum Roads Analysis. The first map for each project area depicts the GPS waypoint number of the field data collected overlaid on an aerial photo base; a complete list of all of the field data collected is included as Appendix D to this report. The second map for each project area depicts the comment field from the field inventory to characterize the actual conditions that exist in the field at any given location.

Floodplain Functions

Figure 5 depicts the 15.9 miles of roads located within floodplains of the Nason Creek watershed. This road network has disconnected 225 acres of floodplain. Some of these roads depicted on Figure 4 include State Highway 2 and 207. Part of the next phase of this project will be to work with landowners to determine the feasibility of removing or re-locating any forest roads located within floodplain areas.

Habitat Connectivity and Barriers

Figure 6 depicts 25 road-stream crossings that were identified within 300' of mapped intrinsic potential for steelhead habitat. Out of the 423 road-stream crossings identified, these crossings that lie closest to steelhead habitat would likely be the highest priority for implementation. There is potential to add approximately 8 miles of steelhead habitat through barrier removal.

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