Yakama Nation Fisheries

UPDATED

Lower Wenatchee River

REACH ASSESSMENT

TETRA TECH

December 2017

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Acronyms and Abbreviations

°C	degrees Celsius
BiOp	Biological Opinion
BNSF	Burlington Northern and Santa Fe
cfs	cubic feet per second
dbh	diameter at breast height
DEM	digital elevation model
DOZ	Disconnected Outer Zone
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
GIS	geographic information system
GLO	General Land Office
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HUC	Hydrologic Unit Code
IZ	Inner Zone
LiDAR	light detection and ranging
LWD	large woody debris
NMFS	National Oceanic and Atmospheric Administration National Marine Fisheries Service
OZ	Outer Zone
REI	Reach-based Ecosystem Indicators
RM	river mile
RUIP	Recovery Unit Implementation Plan
TMDL	Total Maximum Daily Load
UCHRP	Upper Columbia Habitat Restoration Program
UCRTT	Upper Columbia Regional Technical Team
UCSRB	Upper Columbia Salmon Recovery Board
USBR	U.S. Bureau of Reclamation
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Watershed Resource Inventory Area

1. INTRODUCTION

The Lower Wenatchee River Reach Assessment (this Project) evaluates existing conditions and impairments in the lower Wenatchee River to support the development of a habitat restoration strategy. The Wenatchee River subbasin, also referred to as the Assessment Area, covers approximately 1,330 square miles on the eastern slopes of the Cascade Mountains in Chelan County, joining the Columbia River near the town of Wenatchee, Washington. The reach of the lower Wenatchee River assessed for this Project is from the Columbia River confluence (River Mile [RM] 0.3) near Wenatchee, Washington, to the Icicle Road Bridge (RM 26.4), downstream of Tumwater Canyon, near Leavenworth, Washington, herein referred to as the Survey Area (Figure 1-1).

A history of channel modification, development, road and railway construction, and intensive land use practices along the lower Wenatchee River has resulted in degraded conditions for Endangered Species Act (ESA)-listed salmonids including Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and bull trout (*Salvelinus confluentus*), and other species.

The restoration strategy presented in this report includes a project ranking and evaluation process for potential project areas. This strategy evaluates potential habitat restoration actions based on current habitat conditions, geomorphic restoration potential, feasibility, infrastructure, and social constraints. Potential project areas are identified, described in detail, and their locations mapped. Future site-specific analyses will build upon this information to refine potential project areas, evaluate alternatives, and develop detailed designs for implementation. This reach assessment was developed by applying a number of novel approaches including the use of topobathymetric light detection and ranging (LiDAR) data collection (see Sections 3.1 and 4.1) to create a high-quality surface for visualization, analyses, and modeling; use of new and innovative tools including the TerEx tool for the identification, delineation, and characterization of terrace landforms.

This Project is being conducted by the Yakama Nation Department of Fisheries Resource Management Upper Columbia Habitat Restoration Program (UCHRP). The UCHRP is focused on identifying and implementing restoration projects in the Upper Columbia River Basin that benefit ESA-listed fish species. This reach assessment is one in a series of assessments that have been completed by the UCHRP and others in coordination with the Upper Columbia Regional Technical Team (UCRTT). Reach assessments are integral technical documents for subbasin restoration that inform reach-level restoration strategies. The reach assessment includes a synthesis of existing scientific information, field data collection, data analyses, and interpretation to describe geomorphic conditions, hydrology, aquatic habitat, and riparian conditions.

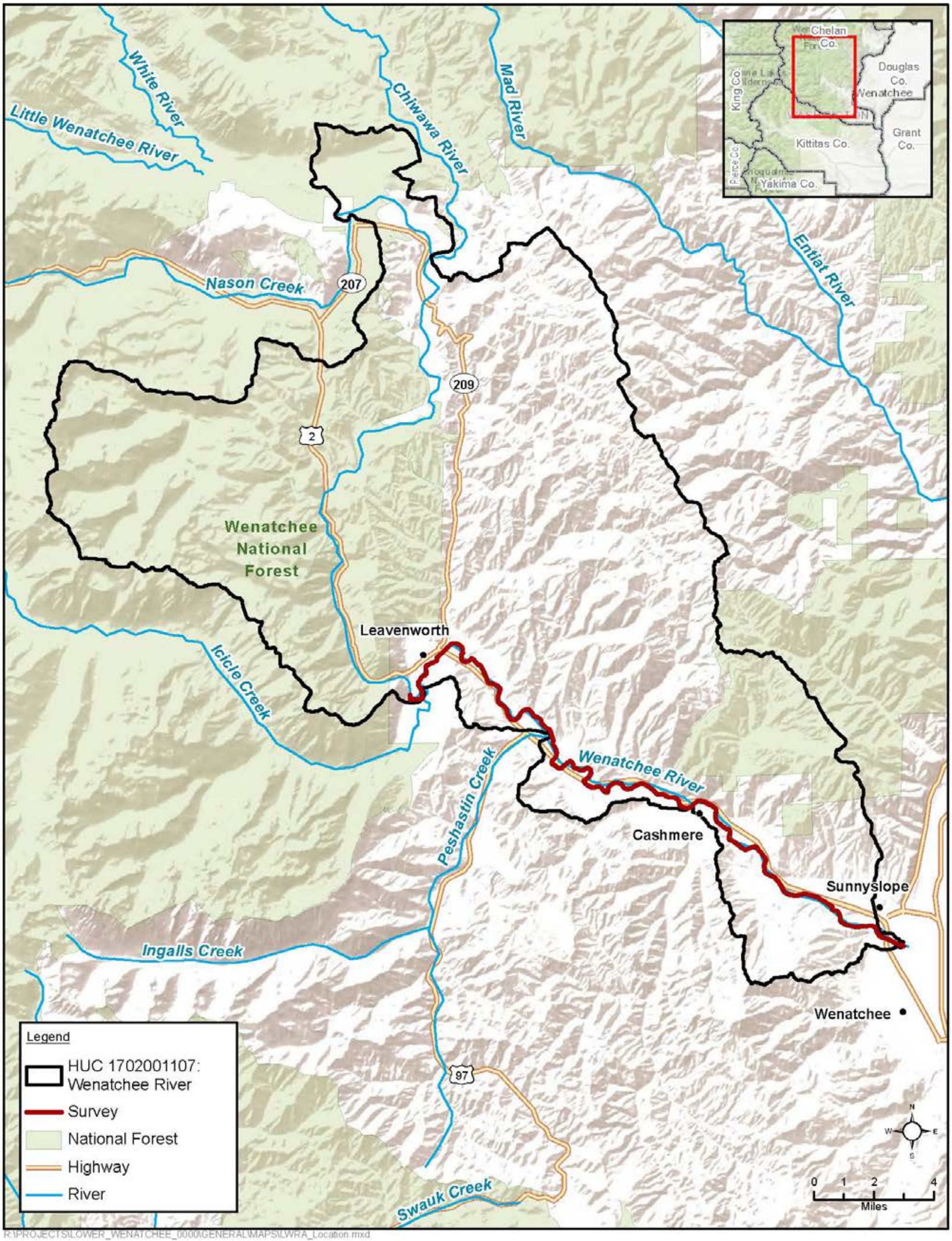


Figure 1-1. Project Location Map–Wenatchee River and Survey Area

1.1 Purpose

The purpose of this Project is to develop a science-based reach assessment and reach-based restoration strategy to address ecological concerns (also known as limiting factors) and improve habitat conditions for ESA-listed species in the lower Wenatchee River. This assessment documents and evaluates hydrologic processes, geomorphic processes, and aquatic habitat conditions that establish the technical basis for the restoration strategy. Evaluating the biological and physical traits is fundamental to identifying effective habitat restoration actions and priority areas. This restoration strategy is intended to assist habitat restoration practitioners with identifying and prioritizing restoration efforts.

1.2 Recovery Planning Context

Recovery planning for ESA threatened and endangered fish species in the upper Columbia River region has been robust, with this assessment serving as a next step in bringing prior guidance and action items forward for evaluation and implementation. Key recovery planning efforts that have addressed conditions in the Wenatchee River subbasin include the Wenatchee Subbasin Plan (NPCC 2005), the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSRB 2007), the Recovery Plan for the Coterminous United States Population of Bull Trout (USFWS 2015a), and the revised Biological Strategy (UCRTT 2014). Each of these is described briefly below.

The Yakama Nation and the Chelan County Natural Resources Department led the development of the Wenatchee Subbasin Plan (NPCC 2005) for the Northwest Power and Conservation Council, supporting their effort to meet ESA obligations under the 2000 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) issued by the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS). The Wenatchee Subbasin Plan included a technical assessment of subbasin conditions, an inventory of fish and wildlife activities and management plans within the subbasin, and a management plan laying out a vision for the subbasin with specific biological objectives and strategies to meet those objectives. For this assessment, the Subbasin Plan serves as a key resource for information regarding limiting factors in the lower Wenatchee River (see the Ecological Concerns discussion in Section 2.6) and restoration strategies most likely to help achieve broader subbasin goals.

The Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (Recovery Plan) established regional objectives for habitat restoration along streams that currently support or may support ESA-listed salmonids (UCSRB 2007). The following list of short-term objectives, long-term objectives, and general recovery actions identified in the Recovery Plan underpins the development of the restoration strategy in this assessment.

Short-Term Objectives

- Protect existing areas where high ecological integrity and natural ecosystem processes persist.
- Restore connectivity (access) throughout the historical range where feasible and practical for each listed species.
- Protect and restore water quality where feasible and practical within natural constraints.
- Increase habitat diversity in the short term by adding instream structures (e.g., large woody debris [LWD], rocks, etc.) where appropriate.
- Protect and restore riparian habitat along spawning and rearing streams and identify long-term opportunities for riparian habitat enhancement.

- Protect and restore floodplain function and reconnection, off-channel habitat, and channel migration processes where appropriate and identify long-term opportunities for enhancing these conditions.
- Restore natural sediment delivery processes by improving road network, restoring natural floodplain connectivity, riparian health, natural bank erosion, and wood recruitment.

Long-Term Objectives

- Protect areas with high ecological integrity and natural ecosystem processes.
- Maintain connectivity through the range of the listed species where feasible and practical.
- Protect and restore water quality where feasible and practical within natural constraints.
- Protect and restore off-channel and riparian habitat.
- Increase habitat diversity by rebuilding, maintaining, and adding instream structures (e.g., LWD, rocks, etc.) where long-term channel form and function efforts are not feasible.
- Reduce sediment recruitment where feasible and practical within natural constraints.

General Recovery Actions Specific to the Lower Wenatchee Assessment Unit

- Reduce water temperatures by restoring riparian vegetation along the river.
- Increase habitat diversity and quantity by restoring riparian habitat along the Wenatchee River, reconnecting side channels and the floodplain with the river, and increasing LWD in the side channels.

While the Recovery Plan outlined above was also intended to address bull trout, in September 2015 the U.S. Fish and Wildlife Service (USFWS) published an updated Recovery Plan for the Coterminous United States Population of Bull Trout (USFWS 2015a). This included a Mid-Columbia Recovery Unit Implementation Plan for Bull Trout (Mid-Columbia RUIP) (USFWS 2015b), within which the Wenatchee River subbasin is one of 24 bull trout core areas.

The Wenatchee River subbasin is one of four river subbasins identified as containing the healthiest and most stable bull trout populations within the recovery unit, where recovery focus should be on maintenance and prevention of new threats (USFWS 2015b). Nevertheless, the Mid-Columbia RUIP details recovery actions in the Wenatchee River core area to address habitat, demographic, and non-native fish threats. The restoration strategy in this assessment took the general and specific guidance of the Mid-Columbia RUIP into account.

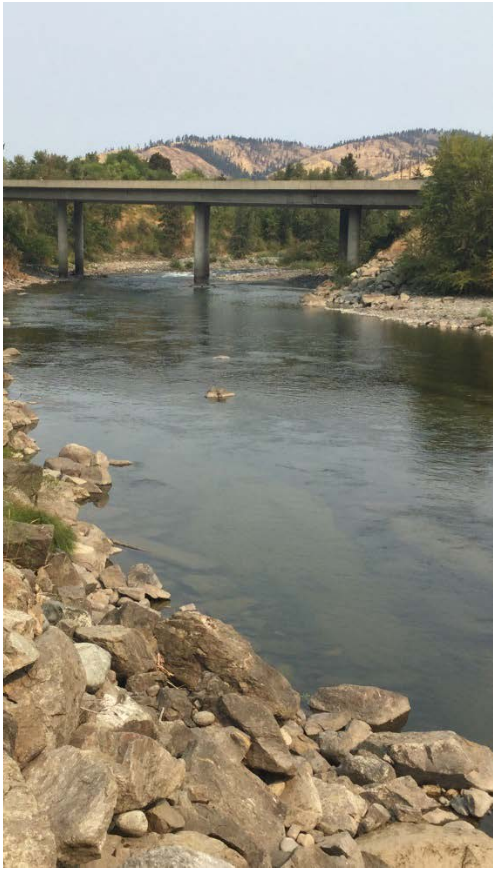
Lastly, the UCRTT was created to provide technical support to the Upper Columbia Salmon Recovery Board (UCSRB). The revised Biological Strategy provides specific support and guidance on implementing the 2007 Recovery Plan described above (UCRTT 2014). In the revised Biological Strategy, the lower Wenatchee River (in this case, the mouth to Tumwater Canyon) is designated as a Priority 2 area (on a scale of 1 to 4), with a restoration priority action type to restore natural geomorphic processes such as channel migration, floodplain interaction, and sediment transport (UCRTT 2014). The strategy also identified specific priority ecological concerns for the lower Wenatchee River as discussed in Section 2.6. As part of the revised Biological Strategy, a series of reference tables were also developed as a public resource (UCRTT 2013).

1.3 Report Organization

This report includes the following key components:

- Section 1: Introduction – Describes the purpose of the reach assessment and overview of document organization.

- Section 2: Assessment Area Conditions – Provides project context, relevant historical information, and existing background data used in the assessment.
- Section 3: Reach Assessment Methods – Describes assessment methods for topobathymetric LiDAR data collection, geomorphic and habitat field surveys, identification of potential project opportunities, reach assessment data analyses and Reach-based Ecosystem Indicators (REI) assessment.
- Section 4: Reach Assessment Results – Includes topobathymetric LiDAR output surface, hydrology, geomorphic reach descriptions, geomorphology, riparian vegetation, REI, and potential climate impacts.
- Section 5: Restoration Strategy – Describes existing and target habitat conditions, reach-scale restorations strategies, project opportunities and potential actions, and prioritization of potential opportunities.
- Section 6: Conclusion and Next Steps – Provides recommended follow-up actions for implementing the restoration strategy.
- Section 7: References – Lists all references cited in the report.



2. ASSESSMENT AREA CONDITIONS

The Assessment Area for this Project includes the entire Wenatchee River subbasin with a focus on the lower Wenatchee River drainage basin. Reach assessment results specific to the Survey Area are contained in Section 4.0.

This reach assessment builds on a large amount of previous data, analyses, effectiveness monitoring, and recovery planning efforts. As a critical first step in the development of this reach assessment, a search and review was conducted for relevant studies, assessments, and planning documents. As a component of the assessment, the essential background data and reports were indexed, relevance described, and archived to allow for convenient access and searchable content for stakeholders utilizing this assessment in the future. That index of existing reach assessment data is included as Appendix A.

The following subsections provide relevant background information to provide context and an increased understanding of current conditions in the lower Wenatchee River. The background information includes a description of the setting, status, geology, landscape history, human disturbance history, salmonid use and population, and recovery planning context.

2.1 Setting and Climate

The Wenatchee River drainage is referred to as Watershed Resource Inventory Area (WRIA) 45 and the Wenatchee River subbasin (8-digit Hydrologic Unit Code [HUC] 8 17020011). The lower Wenatchee River is located in the Wenatchee River HUC 10 watershed (10-digit HUC-10 1702001107) and specifically in the southern and eastern portion of the subbasin, within four subwatersheds (12-digit HUC) (downstream to upstream): Nahahum Canyon – HUC 170200110708 (47 square miles), Olalla Canyon - HUC 170200110707 (34 square miles), Derby Canyon - HUC 170200110706 (29 square miles), and Tumwater Canyon - HUC 170200110703 (33 square miles).

The elevation of the subbasin ranges from over 9,400 feet at the peak of Mount Stuart to 620 feet at the Columbia River confluence. The area is within the Columbia Cascade Ecological Province as identified by the Northwest Habitat Institute (NWHI 2016) and the Northern Cascades physiographic province and the Columbia Basin province in the lower reaches (NPCC 2005). There is a combination of federal, state, county, and private land throughout the subbasin with most of the upper elevations in U.S. Forest Service (USFS) ownership.

Average annual precipitation varies throughout the subbasin and is related to elevation and proximity to the crest of the Cascade Mountains. The upper elevations are characterized by heavy precipitation with considerable snow accumulation in winter months. Most precipitation occurs in fall and winter; however, powerful summer thunderstorms can occur periodically in summer months.

2.2 Geology and Glacial History

The topography of the Wenatchee River subbasin is a direct result of a complex series of geologic and glacial processes including deformation, uplift, erosion, and a complicated history of gigantic glacial floods down the Columbia River resulting in the formation of lakes, flood backwaters, and hillslope erosion by large and small landslides and debris flows (Tabor et al. 1982; Tabor et al. 1987). The following section contains an overview summary of the primary geologic characteristics and glacial history that define the lower Wenatchee River valley.

There are many comprehensive resources describing the geologic characteristics and glacial history of the area. The geologic mapping and the associated bulletin by Gresens et al. (1978) and Gresens (1983) and further mapping by Tabor et al. (1982) and Tabor et al. (1987) provide a detailed description of the geologic history of the area.

Extensive information has been compiled that describes the cataclysmic floods that profoundly affected the landscape in many parts of the Columbia Basin. There are resources available through the Ice Age Flood Institute and a number of geological field guides including Bjornstad (2006). The Eastern Washington University's John F. Kennedy Memorial Library also hosts the official archives of Ice Age Floods literature, including scientific articles and other materials.

The most dominant feature of the Study Area is the Chiwaukum Graben. A graben is a feature formed by geologic faulting in what is called a "horst and graben" landscape. In this process, the horst is the block of rock (i.e., mountains) that is lifted during fault slip and the graben is the block of rock that is dropped (i.e., valleys). Figure 2-1 shows the location of the Chiwaukum Graben relative to the Wenatchee River. Since the Chiwaukum Graben formed during the Eocene epoch, about 30 to 50 million years ago it has been filling with sediments that have created what is known as the Chumstick Formation (Gresens 1983). The Chumstick Formation is comprised primarily of sandstone (of alluvial and lacustrine origin) and can be observed many places along the lower Wenatchee River forming valley walls, bedrock outcrops, and the channel bed acting as a grade control.

Glacial activity during the ice age has altered the landscape of the lower Wenatchee River valley considerably. During the Pleistocene and on into the Holocene epoch, alpine glaciers extended down from the Mount Stuart range into the Wenatchee River valley. The town of Leavenworth is located on the terminal moraine (i.e., deposit at farthest advance of a glacier) of that alpine glacier (Tabor et al. 1987). Today, the Wenatchee River has deeply incised into the moraine deposit, as can be observed from the U.S. Highway 2 Bridge heading

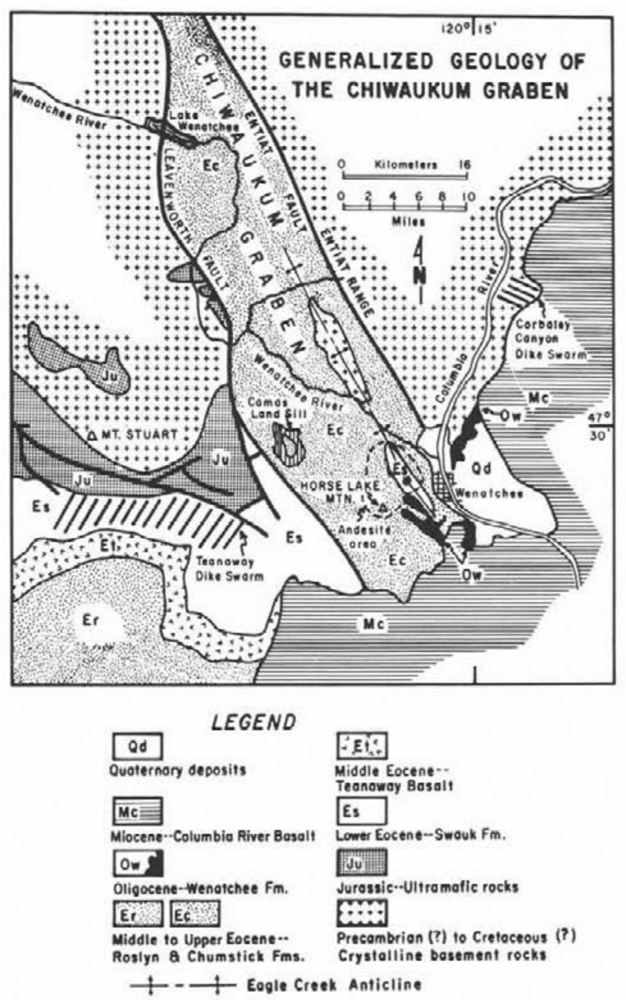


Figure 2-1. Generalized Geology of the Chiwaukum Graben (Source: Gresens 1983)

southeast from Leavenworth. Glacial erratics, or rocks transported and deposited by glaciers, can be observed throughout the lower Wenatchee River valley.

Glacial outburst floods during the last Ice Age (18,000 to 12,000 years ago) have also altered the landscape of the lower Wenatchee valley considerably. Flood flows were slowed considerably near Wenatchee because this area is relatively wide and unconfined compared to upstream and downstream reaches (IAFI 2015). The result was the formation of huge depositional features such as Pangborn Bar, a 600-foot-tall flood bar in East Wenatchee, and a backwater effect up into the Wenatchee River valley depositing layers of sediment, rocks, and boulders (Bjornstad 2006). The backwater effect extended up the valley to the toe of the alpine glacier at Leavenworth. The flood waters interacting with the toe of the glacier resulted in ice rafts that carried granitic erratics from the Mount Stuart batholith as far downstream as Dryden.

Since the last ice age, the Wenatchee River has gone through a period of post-glacial downcutting through glacial deposits. Current channel entrenchment in some reaches of the lower Wenatchee River is in part a result of this process (Jones & Stokes 2004). See Section 4.4 for a detailed description of the lower Wenatchee River geomorphology results.

The resulting landscape of the lower Wenatchee valley is a mosaic of glacial moraines and terraces, steep-sided valley hillslopes, bedrock outcrops, and stepped alluvial floodplains. The photograph in Figure 2-2 shows an exposed glacial terrace in Reach 2 near RM 1.7. Figures 2-3a and 2-3b contain geologic mapping of the lower Wenatchee River valley including bedrock geology and depositional features (Tabor et al. 1982; Tabor et al. 1987).

Figure 2-2. Photograph of Exposed Glacial Terrace in Reach 2 near RM 1.7

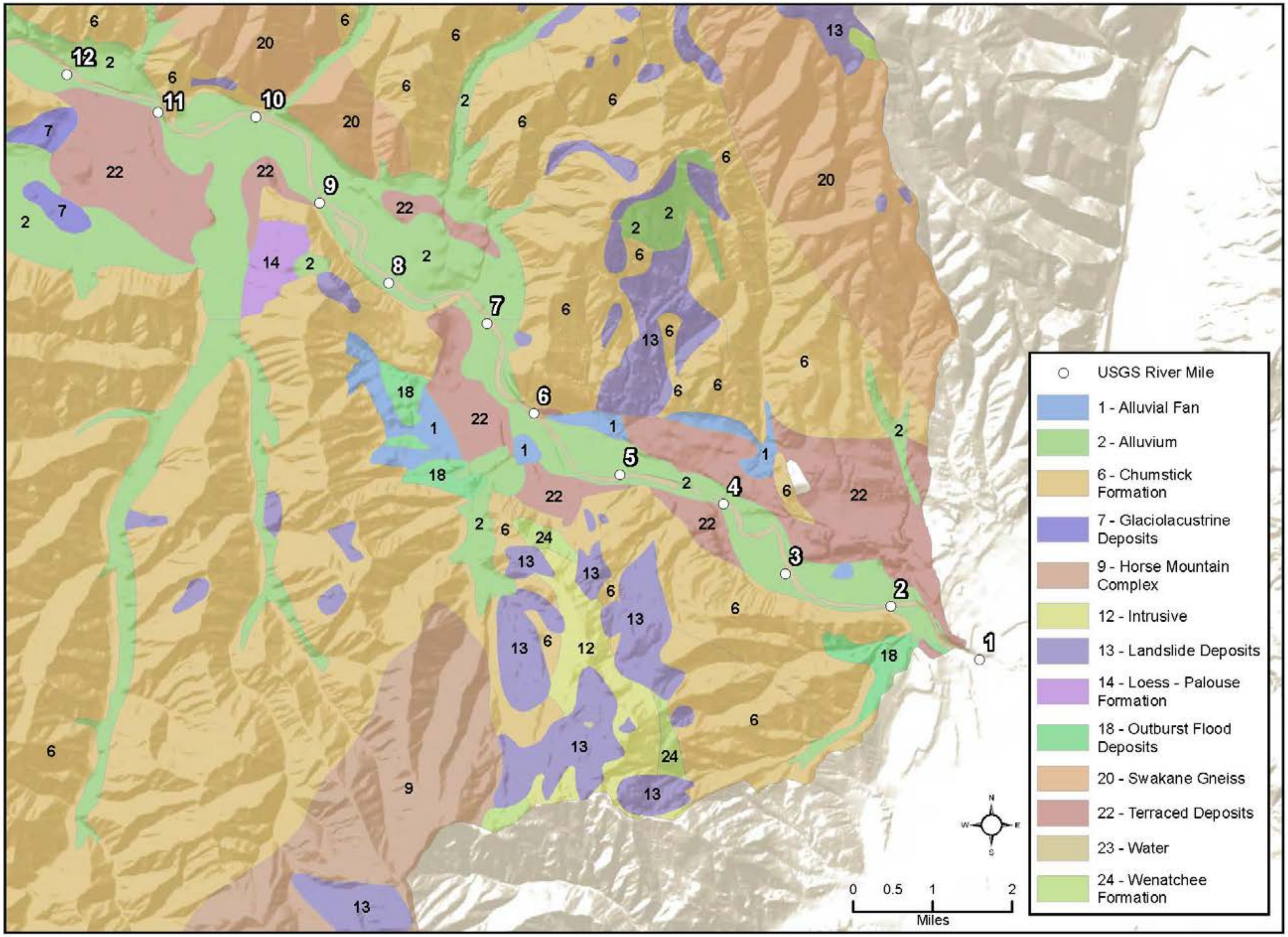


Figure 2-3a. Geologic Map of the Lower Wenatchee River Valley RM 0.0 to RM 12.0

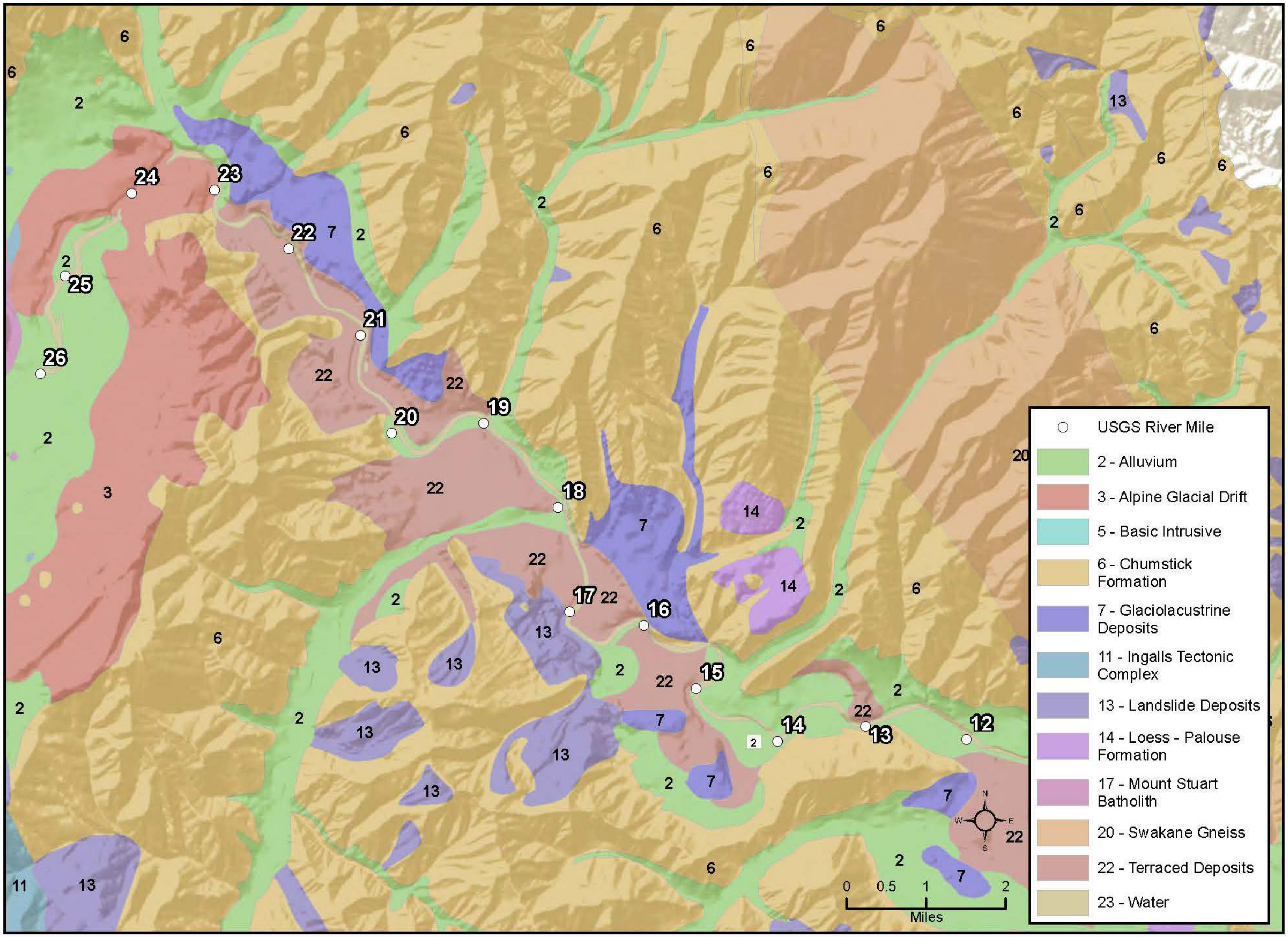


Figure 2-3b. Geologic Map of the Lower Wenatchee River Valley RM 12.0 to RM 26.4

2.3 Human History

Evidence suggests that human habitation of the Wenatchee valley goes back as far as 10,000 years (HistoryLink 2015a). Not until the most recent 150 years or so, however, did human activities begin to more substantially alter the form and function of the lower Wenatchee River. The following sections provide an overview of the central historical events and developments that have shaped the modern lower Wenatchee River and surrounding area.

2.3.1 Early Settlement

As described in the Upper Wenatchee River Assessment (Inter-Fluve 2012), the first documented people of the region were members of the Wenatchi Tribe. The word “Wenatchee” in the local language may have had multiple meanings, one of which was most likely “great opening out of the mountains” (Hull 1929). The Lower Wenatchee area was home to the Sinpesquensi (or Sinkaensi or Sinpeskuensi) band of the Wenatchi, who lived off of plentiful traditional foods such as salmon, camas roots, berries, and game animals (HistoryLink 2015b). Estimates put the Wenatchi population in the broader region at about 1,400 in 1780; the Wenatchee River served as a major salmon fishery for Native Americans into the 1860s (Beckham 1995; HistoryLink 2015a). By the time of permanent white settlement in the late nineteenth century, the local population had already declined drastically from exposure to European diseases brought by earlier explorers and traders (HistoryLink 2015a).

European settlement within the Wenatchee River watershed began in about 1860 following the conclusion of the Yakima War. Settlement spread up the valley, more rapidly starting in the 1880s and after construction of the Great Northern Railroad (see Section 2.3.2 below). Gradually, settlers formed the small towns of Monitor (1880s), Cashmere (1880s), Dryden (1900s), Peshastin (1900s), and Leavenworth (1906), in addition to founding the city of Wenatchee (1893) (Beckham 1995; Hull 1929; Kinney-Holck and Upper Valley Museum 2011). The new towns cleared timber and established agriculture, particularly apple orchards, as the primary economic activity (Hull 1929). New agricultural activity was supported by development of irrigation systems withdrawing water from the Wenatchee River, as well as by the ability to ship goods along the Great Northern Railway (Beckham 1995). The historical photograph from 1904 in Figure 2-4 shows conditions in the lower Wenatchee Valley in the Sleepy Hollow area.

Figure 2-4. Historical (1904) Photograph from Chatham Hill Looking up the Wenatchee Valley into Sleepy Hollow Area (source: 1904 Photograph and Digital Image © Wenatchee Valley Museum and Cultural Center)

An early survey of the Wenatchee watershed was completed by the U.S. General Land Office (GLO) from 1894 to 1908, covering the area from the confluence with the Columbia River to Lake Wenatchee

(Beckham 1995). One of the surveyors, Charles Holcomb, described the Lower Wenatchee as "a beautiful stream of clear cold water running through the SW part of the township and emptying into the Columbia" (Beckham 1995). A prior railroad survey in 1870 observed great quantities of salmon in the Wenatchee River near the mouth of Tumwater Canyon, and concluded that the valley would be remarkably favorable for construction (Northwest Discovery 1981).

2.3.2 Great Northern Railroad

The Great Northern Railroad was spearheaded by builder James J. Hill, starting in St. Paul, Minnesota and gradually reaching westward (GNRHS 2015). The railroad made its way through Washington State in the early 1890s, reaching Seattle by 1893 (GNRHS 2015). Today, the rail line is part of the Burlington Northern and Santa Fe (BNSF) Railway.

Construction of the railway encouraged settlement along its route, which followed the Lower Wenatchee River through the valley as shown in Figure 2-5. As with many towns during the settlement of the American West, the communities along the lower Wenatchee River were greatly buoyed by the designation of railroad stops that connected them to the larger cities. This in turn increased development in the valley that permanently altered the landscape.

Construction of the railroad along the Wenatchee River required blasting out the road bed, which dumped massive debris piles into the river. In addition, from 1907-1908 the Great Northern Railway built a hydroelectric plant near the Tumwater Canyon, Tumwater Dam, one of the first major fish passage barriers on the Wenatchee River (Beckham 1995).

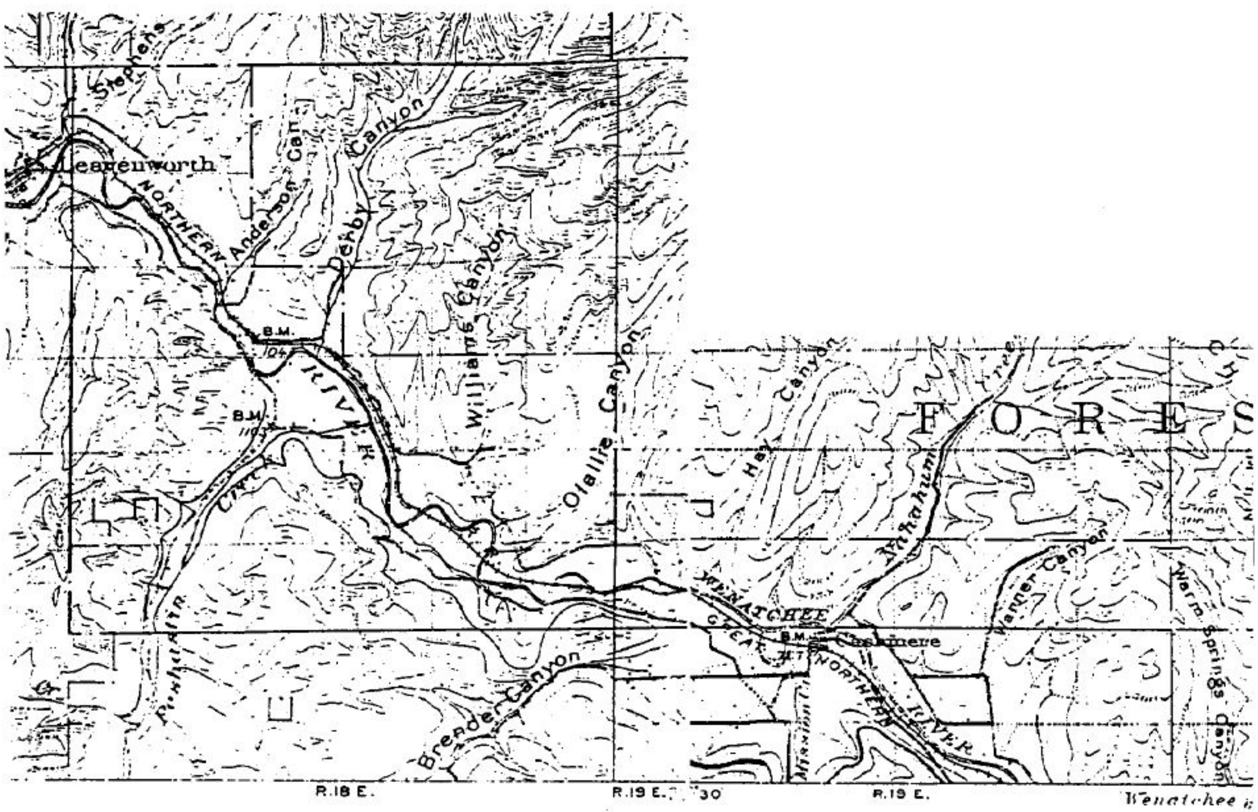


Figure 2-5. Route of the Great Northern Railroad in 1904 from Cashmere to Leavenworth, Washington, Through the Wenatchee Watershed (U.S. Geological Survey, in Beckham 1995)

2.3.3 Timber Harvesting

During the U.S. GLO survey noted above, it was observed that from Wenatchee to Cashmere, "A dense growth of pine, spruce and fir, with an occasional tamarack covers the township," and from Cashmere to Leavenworth the forest was described as "heavily timbered…with thick undergrowth of sage brush" (Beckham 1995). Much of this timber, including the riparian area of the lower Wenatchee River, was cleared and sold as a one-time venture, making way for ongoing agricultural production, primarily orchards. Ongoing timber harvest took place mainly in the upper portions of the Wenatchee basin, peaking in the 1980s with large-scale clear-cut logging (Inter-Fluve 2012). The Upper Wenatchee River Assessment discusses the history of timber harvesting in the area in further detail (Inter-Fluve 2012).

The main timber industry feature along the Lower Wenatchee River was the mill in Leavenworth. In 1903, the Lamb-Davis Lumber Company was incorporated, located on the banks of the river at the southern edge of town (Kinney-Holck and Upper Valley Museum 2011). The historical photograph in Figure 2-6 shows workers standing in front of the mill. The harvest for the mill took place upriver near Lake Wenatchee, and then logs were floated down to the mill for processing, often by splash damming. The historical photograph in Figure 2-7 shows the mill pond dam.

Figure 2-6. Workers Standing in Front of the Lamb-Davis Lumber Mill in Leavenworth, WA, circa 1903 (Source: Upper Valley Museum at Leavenworth)

By 1906, the Lamb-Davis company employed more than 250 men at the mill and as loggers (Kinney-Holck and Upper Valley Museum 2011). After a tragic accident in 1910 from an avalanche, the Great Northern Railroad decided to move the railway from Tumwater Canyon to Chumstick Valley, more than a mile away from Leavenworth. Without easy rail access, the Lamb-Davis sawmill closed in 1916, reopening as the Great Northern

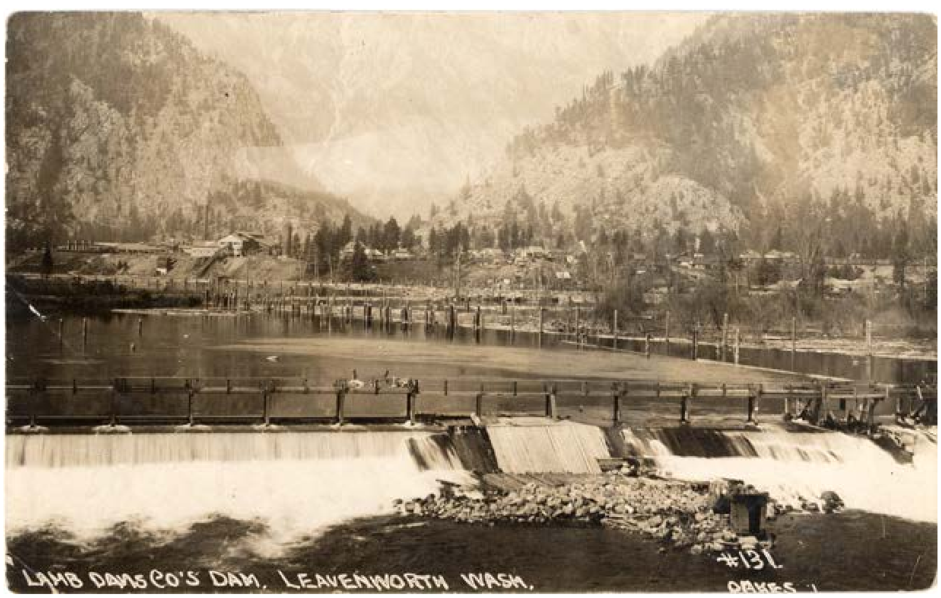


Figure 2-7. Lamb-Davis Lumber Company – Mill Pond Dam (Source: Upper Valley Museum at Leavenworth).

Lumber Company (not related to the railway), for a relatively short time, until the mill closed permanently in 1926 (Kinney-Holck and Upper Valley Museum 2011).

While the closure of the mill in Leavenworth did not halt timber harvest in the Wenatchee basin, it served to solidify the focus along the lower Wenatchee River on agriculture, leading eventually to tourism and agro-tourism as key economic drivers of the region. Riparian areas in some places were allowed to regenerate, perhaps most symbolically at the former mill site, now the forested Enchantment Park. Agricultural and residential/commercial development, however, have permanently transformed the banks and floodplains of the lower Wenatchee River away from the historical forest ecosystem.

2.3.4 Wildfires

In the area surrounding the lower Wenatchee River, the natural fire regime includes a low intensity fire every 5 to 10 years, as compared to high intensity stand replacing fires every 50 to 100 years in the upper portions of the Wenatchee basin (Andonaegui 2001). Fire suppression activities undertaken since European settlement have upended this pattern and led to overall less frequent, higher intensity fires throughout the basin (Inter-Fluve 2012). In some low elevation areas, fire suppression has led to an increase in tree density as well as greater abundance of more shade tolerant trees, such as grand fir (Andonaegui 2001).

In 2015, the fire season started earlier than usual, in late June, with the Sleepy Hollow Fire occurring west of the city of Wenatchee. The wildfire burned 2,950 acres, destroying 29 homes and several commercial buildings (InciWeb 2015). The oblique aerial photograph in Figure 2-8 shows fire damage from the Sleepy Hollow Fire.

Figure 2-8. Oblique Aerial Photograph of Recent (2015) Fire Damage in the Foothills near Wenatchee (source: Shane Wilder of Icicle TV, flight provided by Lighthawk and the UCSRB)

2.3.5 Development and Agriculture

As described above, the lower Wenatchee River and its floodplain have been significantly altered by settlement and development of the cities of Wenatchee, Monitor, Cashmere, Dryden, Peshastin, Leavenworth, as well as residential development and associated infrastructure. The photograph in Figure 2-9 shows an example of riverside residential development along the lower Wenatchee River.

Figure 2-9. Example of Current Riverside Residential Development

Along the river and in the floodplain, channel-confining features have been installed to protect infrastructure such as roads (particularly U.S. Highway 2), the Burlington Northern Railroad, as well as private and commercial properties. The historical photograph in Figure 2-10 shows an orchard along the banks of the river near Cashmere in 1920.

Figure 2-10. Historical Photograph of an Orchard near Cashmere in 1920 (source: Wenatchee National Forest, provided by the National Archives and Records Administration)

The impacts of continuing land use practices including agriculture, residential and urban development, infrastructure, and other similar features dominate the riparian area along much of the river. Previous analyses have found that approximately 35 percent of the lower Wenatchee River is confined by the railroad, 31 percent of the channel banks are entirely cleared of vegetation, 19 percent is rip-rapped, and only 16 percent is in a natural vegetated state (NPCC 2005). Upland and riparian development have been identified as important limiting factors for salmonids, potentially affecting channel migration, woody debris and gravel recruitment, peak/base flow regime, and stream temperatures (NPCC 2005).

Tomlinson et al. (2011) also examined the impact of development and growth on river floodplain dynamics at the watershed scale including the Wenatchee River, Little Wenatchee River, Chiwawa River, White River, and Nason Creek. They found that by 1949 approximately 55 percent of the Wenatchee River floodplain had been converted to agriculture, and that by 2006 62 percent of the floodplain had been modified by development, which included 20 percent growth due to expansion of urban areas. They concluded that conversion of floodplain to agricultural and urban land uses has likely contributed to declines in salmonid habitat along the Wenatchee River for many decades (Tomlinson et al. 2011). An important caveat to this research is that the floodplain was delineated from a 10-meter digital elevation model (DEM) and aerial photographs, which may have missed some smaller terrace features and over-estimated the total floodplain area (see Section 4.4.3 for more details).

2.3.6 Diversions and Dams

There are a series of dams on the mainstem Columbia River throughout the Upper Columbia region. The impoundment from the Rock Island Dam, which is located about 12 miles downstream from Wenatchee was completed in 1932 and was the first dam to span the Columbia River (CCPUD 2015). The impoundment from the dam creates the Rock Island Reservoir, which extends past the Wenatchee River confluence.

Figure 2-11. Photograph of Dead Chinook Fingerlings in an Unscreened Diversion Box at the End of the Rock Island Branch of Dryden Canal – 1940 (source: Oregon State University Libraries Special Collections & Archives Research

Starting in 1891, the lower Wenatchee River has been diverted for irrigation. Early diversions were unscreened for many decades, which was a considerable limiting factor for salmonids. The photograph in Figure 2-11 shows dead Chinook fingerlings in an unscreened diversion box on Rock Island Branch of Dryden Canal in 1940.

The photograph in Figure 2-12 shows an irrigation diversion in Reach 6. Although not shown in the photograph, the diversion is screened.

Figure 2-12. Example of an Irrigation Diversion near RM 13.7

The following contains a list of diversion dams from downstream to upstream and the year constructed (Andonaegui 2001; Beckham 1995):

- RM 6.6 – Pioneer Gunn water diversion (1891)
- RM 7.2 –Jones-Shotwell water diversion (1898)
- RM 10 – Pines Flat water diversion (1950)
- RM 17 – Dryden Diversion Dam, an 8-foot high irrigation diversion dam (1908)

In 1909, the Tumwater Dam was built by the Great Northern Railroad. The dam was built to provide hydroelectricity but is no longer in operation and is located in Tumwater Canyon, upstream of the lower Wenatchee River (Andonaegui 2001). Additionally, in 1904 the Lamb-Davis Lumber Company constructed a dam at the south edge of Leavenworth on the Wenatchee River to form a mill pond for their sawmill operations (on the site of the present-day Enchantment Park in Leavenworth, Washington). The mill pond dam no longer exists, though remnants such as log pilings and a boulder line are visible in the river. Prior to construction of this dam, Native American fishing grounds were near the mouth of Tumwater Canyon; after its construction they had to fish below the structure (Mullen 1992).

The USFWS documented as early as 1942 that salmon runs decreased rapidly after the dam was built in Leavenworth for the mill and the Tumwater Dam (Mullen 1992). The Dryden Diversion Dam, shown in Figure 2-13, has two functioning fish passage and trapping facilities (right and left bank) for broodstock collection with fish screens improved in 2001 (Andonaegui 2001).

Figure 2-13. Oblique Aerial Photograph of the Dryden Diversion Dam (source: Shane Wilder of Icicle TV, flight provided by Lighthawk and the UCSRB)

2.4 Water Quality and Quantity

Water quality and quantity have been extensively studied in the lower Wenatchee River. To comply with U.S. Environmental Protection Agency (EPA) requirements for the 1998 303(d) listing for stream temperature, the Washington State Department of Ecology (Ecology) completed a series of Total Maximum Daily Load (TMDL) studies for the Wenatchee River (Ecology 2005, 2006, 2007, 2009). The initial study included extensive field data collection, stream temperature modeling testing different temperature reduction strategies, and put forth recommendations for management activities (Ecology 2005). An additional groundwater data summary for the TMDL found that contamination may contribute to low dissolved oxygen values in the lower Wenatchee River (Redding 2007).

According to the most recent regulatory review, the 2014 Washington State Water Quality Assessment (Ecology 2016), portions of the lower Wenatchee River remain impaired for temperature, as well as for instream flow, pH, dissolved oxygen, and contaminants (polychlorinated biphenyls and dichlorodiphenyldichloroethylene). The contaminated portions reflect results from whitefish and sucker tissue samples and are the only segments on the current 2012 EPA-approved 303(d) list. TMDLs are in place for the areas along the lower Wenatchee River exceeding dissolved oxygen, pH, and temperature thresholds; while the lower Wenatchee River is still impaired, an active TMDL program removes the waterbody from the 303(d) list (Ecology 2016). Low summer instream flow is recognized as an impairment requiring complex solutions to restore more natural conditions (Ecology 2016).

Two wastewater treatment facilities in Peshastin and Cashmere are considered point sources of phosphorus into the lower Wenatchee River (Ecology 2009). The oblique aerial photograph in Figure 2-14 shows the sewage treatment facility near Cashmere. These facilities directly discharge treated water and may be able to implement improved treatment systems to reduce phosphorous. Non-point sources of pollution to the lower Wenatchee River area may include landfills, on-site septic systems on the floodplain, trash dumps in Dryden and Cashmere, the Dryden community septic drain field, agricultural runoff, and a number of other potentially leaking waste/sewer systems (Ecology 2009).

Figure 2-14. Oblique Aerial Photograph of the Sewage Treatment Facility near Cashmere (source: Shane Wilder of Icicle TV, flight provided by Lighthawk and the UCSRB)

To help manage water quantity issues, an Instream Flow Incremental Methodology (IFIM) study was completed to evaluate the effects of flow alteration on habitat availability in the lower Wenatchee River (EES and Payne 2005). This study modeled the "usable area" for salmonids at a range of flow levels, informing the establishment of minimum instream flows. In addition, the WRIA 45 Planning Unit, an extensive multi-stakeholder working group effort, developed the Wenatchee Watershed Management Plan, which provided instream flow recommendations as well as a host of potential management actions (WWPU 2006). Drawing on the available studies and recommendations, current instream flow regulations in WRIA 45 are included in the Washington Administrative Code (WAC) Chapter 173-545, last updated in 2007.

However, as noted above, low summer flows are an ongoing challenge in the lower Wenatchee River and remain on the agenda for management agencies and stakeholders.

See Section 4.7 for a discussion of the potential impacts of climate change on lower Wenatchee River temperatures and flow levels.

2.5 Fish Use and Population Status

The lower Wenatchee River is used by spring Chinook salmon, summer/fall Chinook salmon, sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), steelhead and resident trout (*O. mykiss*), cutthroat trout (*O. clarkia*), and mountain whitefish (*Prosopium williamsoni*). The lower Wenatchee River is also used by non-salmonid species of management interest including Pacific lamprey (*Entosphenus tridentatus*). Historical accounts of fish use in the lower Wenatchee River and early data sources include quantitative surveys by the Wenatchee River Physical Stream Surveys conducted by the U.S. Bureau of Fisheries in 1935 (USBF 1935), which were summarized in Bryant and Parkhurst (1950), and Chinook salmon abundance estimates by Fulton (1968). The following sections summarize salmonid fish use (Section 2.5.1) of the lower Wenatchee River and use by non-salmonid species of interest (Section 2.5.2).

2.5.1 Salmonids

Upper Columbia spring Chinook and summer steelhead are ESA listed, as are Columbia River bull trout. All three of these listed species can be found year-round in the lower Wenatchee River (EES and Payne 2005). Coho salmon were considered extirpated from the upper Columbia River and are maintained by hatchery populations and reintroduction efforts (Peven 2003). Wenatchee River sockeye salmon populations are considered "healthy" and are not listed under the ESA (Andonaegui 2001).

In response to declining Chinook salmon numbers, a hatchery on the Wenatchee River began operation in the late 1800s, but closed in 1904 (USFWS 2004). The Leavenworth National Fish Hatchery was constructed in 1940 to mitigate for fisheries losses due to construction of the Columbia River dams and has been operating since that time. Chinook salmon and coho salmon are raised at this facility. The historical photograph from 1940 in Figure 2-15 shows a fish truck unloading at the Leavenworth hatchery holding pond. The Rock Island Fish Hatchery complex was begun in 1989 as mitigation for the Rock Island Dam (Peven et al. 2004), and includes various acclimation facilities on the Wenatchee River (e.g., the Chiwawa acclimation pond for spring Chinook and the Dryden acclimation pond for summer Chinook). In addition, the Yakama Nation operates acclimation sites on Nason, Icicle, and Beaver creeks for coho salmon. The Peshastin facility raises coho and is operated by the Yakama Nation (Peven et al. 2004). Sockeye were captured for rearing in Lake Wenatchee in the mid-1900s (Gustafson et al. 1997); however, the Lake Wenatchee facility is now closed. The Yakama Nation is also working on efforts to improve Pacific lamprey abundance within the Wenatchee River,

Figure 2-15. Unloading Fish Truck at Leavenworth Hatchery Holding Pond – 1940 (source: Oregon State University Libraries Special Collections & Archives Research Center)

which has the potential to include supplementation at a later date. Additional information on hatchery facilities can be found in Appendix E of the Wenatchee River Subbasin Plan (Peven et al. 2004).

Coho salmon were extirpated from the upper Columbia River by the early 1900s (Andonaegui 2001), and earlier hatchery release efforts failed to establish self-sustaining populations. In 1999, the Yakama Nation began reintroductions that have resulted in substantial returns as well as increasing occurrences of natural reproduction (CRITFIC 2012). Coho use the lower Wenatchee River for migration, downstream movement, and rearing (EES and Payne 2005). The Hanford Reach fall Chinook hatchery program has recently led to excess hatchery fall Chinook in the upper Columbia River basin (WDFW 2015). Upper Columbia summer and fall Chinook are not listed under the ESA. The Wenatchee River stock is considered "healthy" and is one of the largest naturally produced Chinook populations in the Columbia River (Andonaegui 2001). Summer Chinook are known to use the lower Wenatchee River for spawning, rearing, and migration (Andonaegui 2001; EES 2005).

Upper Columbia spring Chinook were listed as endangered under the ESA on March 16, 1999. The Wenatchee River population of spring Chinook is classified as "very large" by the Interior Columbia Basin Technical Recovery Team based on historical habitat potential (ICTRT 2007). All of the five historical major spawning areas are currently occupied; however, spatial structure and diversity assessments resulted in an overall "high risk" rating for the population (ICTRT 2007). Descriptions of historical distribution for spring Chinook include "most of the main river" as well as Peshastin Creek and multiple tributaries to the upper Wenatchee River (Peven 2003). Spring Chinook are known to use the lower Wenatchee River for rearing and migration (Andonaegui 2001; EES and Payne 2005). This stock is "stream-type" (returning to freshwater several months prior to spawning), with juveniles rearing over the winter and out-migrating the following spring, resulting in year-round use of the lower Wenatchee River as shown in Table 2-1 (EES and Payne 2005; Hillman et al. 2008, 2010 and 2011; UCSRB 2014).

Upper Columbia summer steelhead were listed as endangered under the ESA on August 18, 1997. In 2006, this Distinct Population Segment was downlisted to threatened status (71 Federal Register 834). This decision was challenged in the U.S. District Court for the Western District of Washington, and in 2007, the district court agreed, returning the listing status to "endangered" in 2007. NMFS appealed the ruling, and in 2009, the district court revised their ruling, re-instating the "threatened" status (74 Federal Register 42605). This status was further upheld in the 2014 "Endangered and Threatened Wildlife; Final Rule To Revise the Code of Federal Regulations for Species Under the Jurisdiction of the National Marine Fisheries Service" (79 Federal Register 20802). Steelhead and resident rainbow trout are known to use the lower Wenatchee River for spawning, rearing, and migration (Andonaegui 2001), as well as incubation (EES and Payne 2005). Table 2-1 presents the life history timing for summer steelhead in the region (UCSRB 2014; EES and Payne 2005). Steelhead begin their upstream migration in the lower Wenatchee in July and are generally finished in March. Spawning occurs mid-February through mid-June, with incubation between mid-February and mid-August, and juvenile rearing year-round (EES and Payne 2005).

The Upper Columbia River bull trout Distinct Population Segment was listed as threatened under the ESA on June 12, 1998, and is known to use the lower Wenatchee River for rearing and migration. All populations of bull trout in the coterminous United States were listed as threatened under the ESA in November 1999 (USFWS 2015a). Bull trout are believed to have been historically present in the Wenatchee River (Peven 2003). The Wenatchee River bull trout population was listed as potentially "at risk" with a stable trend in the USFWS 5-year Review (USFWS 2008). The population contains all three life histories, or ecotypes, of bull trout (Peven 2003). Bull trout utilize the lower Wenatchee River year-round for juvenile rearing (EES and Payne 2005). Adult out- and in-migration occurs at various times through the year (Nelson et al. 2011; Nelson 2014; Ringel et al. 2014). Table 2-1 presents the times that various life-stages utilize the lower Wenatchee River.

Table 2-1. Periodicity Table for Spring Chinook, Summer Steelhead, and Columbia River Bull Trout in the Lower Wenatchee River

Species	Lifestage	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
Spring Chinook Salmon	Adult Immigration/Holding												
	Adult Spawning												
	Egg Incubation/ Fry Emergence												
	Juvenile Rearing												
	Juvenile Outmigration												
Summer Steelhead	Adult Immigration/Holding												
	Adult Spawning												
	Egg Incubation/Fry Emergence												
	Juvenile Rearing												
	Juvenile Outmigration												
Bull Trout	Adult Immigration/Outmigration												
	Adult Spawning												
	Egg Incubation/ Fry Emergence												
	Juvenile Rearing												
	Juvenile Outmigration												

Indicates periods of most common or peak use and high certainty that the species and life stage are present

Indicates periods of less frequent use or less certainty that the species and life stage are present

Indicates periods of rare or no use

Sources: EES and Payne 2005; Hillman et al. 2008, 2010, 2011, 2014; Ringel et al. 2014; UCSRB 2014

2.5.2 Non-Salmonid Species of Interest

Pacific lamprey are increasingly a species of management interest. Few targeted surveys have been conducted in the Wenatchee subbasin, and the majority of the information has been from their presence in smolt traps (Johnsen and Nelson 2012). Their presence and use of the lower Wenatchee has been documented, however, including the presence of ammocoetes and juveniles, as well as migrating adults (Peven 2003). Hillman et al. (2014) documented large numbers of Pacific lamprey in their smolt trap near Monitor, Washington, between 2000 and 2013, the most being caught in 2006 and 2007 at 1,933 and 2,876 individuals, respectively. The trap is run between February and August. Lamprey have not, however, been recorded in traps higher up in the subbasin (Hillman et al. 2014; Johnsen and Nelson 2012). Additionally, Johnsen and Nelson (2012) reported that 6,500 lamprey ammocoetes were recovered and released during dredging operations at the Highline Canal in 2009 and juveniles were captured by electrofishing downstream of Peshastin Creek in 2010. Historical distribution for Pacific lamprey is not well documented (Johnsen and Nelson 2012), but they are believed to have been present in the upper Wenatchee River historically (Peven et al. 2004; Johnsen and Nelson 2012).

In recent years, the Yakama Nation has been working on recovery efforts for Pacific lamprey, called the Pacific Lamprey Project. The objective of this project is to restore natural production of Pacific lamprey to a “level that will provide robust species abundance, significant ecological contributions and meaningful harvest within the Yakama Nations Ceded Lands and in the Usual and Accustomed areas” (Yakama Nation Fisheries 2016). Efforts include documenting historical occurrences and current presence, and working on artificial propagation and outplanting, in addition to developing a management action plan to identify threats and work to improve conditions for lamprey populations and migration (Yakama Nation Fisheries 2016).

2.6 Ecological Concerns

Ecological concerns, also referred to as “limiting factors,” serve to define and evaluate the habitat conditions inhibiting salmonid recovery. Multiple reports have identified ecological concerns affecting salmonid production in the Wenatchee River subbasin including the following:

- Salmon, Steelhead, and Bull Trout Habitat Limiting Factors report for WRIA 45 (Andonaegui 2001)
- Wenatchee River Channel Migration Zone Study Phase II (Jones & Stokes 2004)
- Wenatchee Subbasin Plan (NPCC 2005)
- 2008 Fish Accords (Three Treaty Tribes-Action Agencies 2008)
- FCRPS BiOp (FCRPS 2012)
- Upper Columbia Revised Biological Strategy (UCRTT 2014)

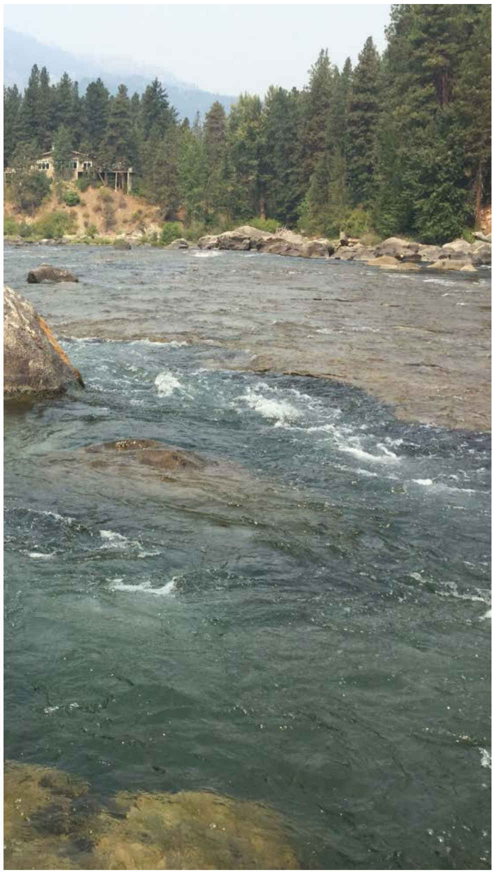
The revised Biological Strategy (UCRTT 2014) contains the most up-to-date ecological concerns information. The revised Biological Strategy identifies key biological considerations in protecting and restoring habitat, which are guided, in part, by the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSRB 2007), and are consistent with the Washington State-wide Steelhead Management Plan (WDFW 2008). The revised Biological Strategy identifies five ecological concerns for the lower Wenatchee assessment unit, in priority order (UCRTT 2014):

1. Peripheral and transitional habitat (side channel and wetland connections)
2. Riparian condition (riparian condition)
3. Water quantity (decreased water quantity)

4. Water quality (temperature)

5. Channel structure and form (bed and channel form)

The development of project opportunities in Section 5.3 uses these limiting factors as important criteria for ranking project effectiveness.



3. REACH ASSESSMENT METHODS

The methods employed in the development of the reach assessment included LiDAR data acquisition, field surveys, and analytical methods focused on identifying opportunities for providing habitat improvements for target fish species. The LiDAR data were acquired August 13 to 15, 2015, with data acquisition described below. Field surveys were conducted on foot during low flow conditions from August 13 to August 19, 2015. The field team, including a geomorphologist, fisheries biologist, and professional engineer (PE), walked the channel throughout the length of the lower Wenatchee River.

The following subsections provide the methods used to develop the reach assessment and restoration strategy: topobathymetric LiDAR data collection (Section 3.1), geomorphic and habitat field surveys (Section 3.2), field identification of restoration opportunities (Section 3.3), reach assessment analyses (Section 3.4), and Reach-based Ecosystem Indicators (Section 3.5).

3.1 Topobathymetric LiDAR Data Collection

The topobathymetric LiDAR survey was accomplished using traditional LiDAR and topobathymetric (or “green”) LiDAR collected simultaneously. While the traditional LiDAR laser pulses do not penetrate water surfaces, the topobathymetric sensor uses a narrow green beam laser that penetrates the water surface. The resulting surface was utilized for a detailed visualization of channel and floodplain features as well as for reach assessment analyses and calculations. The technical data report describing topobathymetric LiDAR acquisition, processing, and accuracy estimates is included as Appendix B.

3.2 Geomorphic and Habitat Field Surveys

Geomorphic and habitat field surveys were conducted to characterize current in-channel and riparian habitat and establish baseline conditions in the lower Wenatchee River. Specific attention was given during field surveys to making observations related to sediment transport and response conditions, channel incision and channel evolution trends (erosion and stability), substrate characteristics (e.g. size, distribution, supply), the abundance and influence of LWD, floodplain connectivity, surface and subsurface flow interactions, the influence of human activities, and the interaction of the stream with riparian ecological processes. Levees and other floodplain impairments were also documented during the surveys. Geomorphic conditions were observed and characteristics recorded during field surveys.

The field habitat surveys were completed generally following the USFS Level II protocol (USFS 2006). These methods were modified to adapt to the scale of the lower Wenatchee River by using a laser range finder for length and distance measurements and a personal floatation device for maximum pool depth. Channel units, also referred to as habitat units, were mapped and data collected continuously throughout the lower Wenatchee River. Mainstem channel units included pools (dam pool or scour pool), fast turbulent water (riffles), fast non-turbulent water (glides), and rapids. Side channels were identified as fast water (secondary channels) or slow water (off-channel habitat). Table 3-1 contains a list of the habitat data collected and a description of the measurement type.

Table 3-1. Stream Habitat Field Data Collection Description

Habitat Data	Measurement Type Description
Channel Unit Type and Number	Identify Channel unit type and assign numbers sequentially
Braids	Identify and map existing channel braids with GPS
Side Channels	Identify and map existing side channels with GPS
Tributary Junctions	Identify and map tributary junctions with GPS
Special Case Channel Units	Identify and map culverts, dams, marshlands, waterfalls and chutes
Maximum Depth	Measured for each channel unit
Average Depth	Measure average for each channel unit
Pool Tail Crest Depth	Measured for each channel unit
Channel Unit Length	Map with GPS points and measure for each channel unit
Channel Unit Width	Measured for each channel unit
Pieces of LWD	Tally in each channel unit and determine size class
Bankfull Width	Measured for each channel unit
Maximum Bankfull Depth	Measured for each channel unit
Bankfull Depth	Measured at 25%, 50%, and 75% of bankfull width
Unstable Banks	Map and measure the lineal distance of actively eroding banks
Bank Protection	Map and measure the lineal distance of bank protection
Riparian Vegetation	Classify by species, composition, and diameter class
Substrate Size	Pebble counts to document substrate differences, ocular estimates of substrate composition for each channel unit

Geomorphic reaches were delineated based on geomorphic characteristics, channel morphology classification, and riverine processes. The purpose of the delineation was to identify important functional differences in geomorphology in the lower Wenatchee River. Prior to the field surveys, a desktop analysis was conducted using existing data including aerial photos, LiDAR, and geology maps to preliminarily identify distinct geomorphic reaches. Previous reach delineations from the Chelan County Natural Resource Department Channel Migration Zone Study (Jones & Stokes 2004) were also reviewed. The final geomorphic reach delineations were field-verified during the survey, which included walking the entire lower Wenatchee River (see Section 4.3). Reach breaks were delineated based on physical characteristics such as channel gradient, sinuosity, geology, valley confinement, deposition, erosion, sediment size, channel dimensions (e.g., width-to-depth ratios), stream bed morphology, habitat, discharge, and other functional characteristics.

Sediment samples (pebble counts) were taken to document significant changes in bed sediment texture following the methods described in Bunte and Abt (2001). Ocular estimates of substrate composition were also collected for each channel unit.

3.3 Field Identification of Restoration Opportunities

Potential opportunities for restoration and habitat enhancement were initially identified during field surveys. This preliminary determination was further refined by utilizing the reach assessment analyses and other existing data.

The identification of potential restoration project opportunities was guided by a combination of site observations of geomorphology and field identification of specific opportunities for addressing habitat, riparian, and land-use impairments. Previously completed restoration projects identified through an evaluation of existing data and available information, were field reviewed to determine if there were potential restoration opportunities to be included in the restoration strategy (see Section 5.0). Potential restoration opportunities were selected that address the reach-scale restoration targets developed as part of the restoration strategy. The project opportunities and potential actions are discussed in Section 5.3.

3.4 Reach Assessment Analyses

The following subsections describe the methods for reach assessment analyses grouped into the categories of hydrology and hydraulics (Section 3.4.1) and geomorphic analyses (Section 3.4.2).

3.4.1 Hydrology and Hydraulics

The hydrologic analysis included evaluating characteristic flow data including monthly mean flows, base flow, low flow statistics and peak flows for the USGS gages on the lower Wenatchee River and gaged tributaries including the Wenatchee River at Peshastin gage (USGS 12459000), the Wenatchee River at Dryden (USGS 12461000), the Wenatchee River at Monitor gage (USGS 12462500), Icicle Creek (USGS 12458000), Mission Creek (USGS 12462000), and the Wenatchee Valley Canal (USGS 12460500). Characteristic flows for each of the USGS gages were obtained from USGS (2015b) and Wolock (2003). Base flows were calculated using the Web-based Hydrograph Analysis Tool (WHAT) following the methods of Lim et al. (2005).

The longitudinal variation of peak flows was calculated throughout the lower Wenatchee River for use in hydraulic modeling. The peak flow calculations were developed to account for changes in drainage area and tributary inputs. Peak flows were calculated using a Log Pearson Type III Analysis (USGS 1981) at both the Wenatchee River at Peshastin gage (USGS 12459000) which is currently active and has a period of record beginning in 1929, and the Wenatchee River at Monitor gage (USGS 12462500). Peak flows were adjusted for ungaged areas using the gage-transfer equations based on drainage area differences (USGS 2001). Peak flow rates were also adjusted for tributary inputs. A Log Pearson Type III Analysis was used to calculate peak flows for the Icicle Creek near Leavenworth gage (USGS 12458500) and the Mission Creek at Cashmere gage (USGS 12462000). The peak discharges for Peshastin Creek were previously developed in the Lower Peshastin Creek Tributary and Reach Assessment (Inter-Fluve 2010). Chumstick Creek peak discharges were calculated using the regional regression equations (Sumioka et al. 1998).

The peak discharges described above were used in a planning-level hydraulic model that was developed to determine flood inundation for a range of flows including the 2-year, 10-year, 50-year, and 100-year flood events. The hydraulic model was developed with the Hydrologic Engineering Centers River Analysis System (HEC-RAS), which is a cross section–based one-dimensional model developed by the USACE (USACE 2010) for computing velocity, flow depth, shears stress, and other hydraulic characteristics in riverine systems. Hydraulic model outputs were exported to HEC-GeoRAS, which is a custom interface between HEC-RAS and a geographic information system (GIS), for mapping HEC-RAS water surfaces, flow depths, and velocities. The flood inundation tool in HEC-GeoRAS interpolates the water surface elevations from HEC-RAS cross sections to two-dimensional geospatial data.

3.4.2 Geomorphic Analyses

The geomorphic analyses utilized metrics calculated from the topobathymetric LiDAR (see Section 3.1), existing aerial photography, historical information, geologic mapping, and floodplain inundation, among other data sources. The metrics were calculated at a series of 155 cross sections throughout the lower Wenatchee River.

The channel morphology of the lower Wenatchee River was analyzed using the classification systems of Church (1992), adapted from Kellerhalls et al. (1976), and Rosgen (1996). River form and process were described and channel morphology classified through a set of standard metrics such as channel dimensions (bankfull width and depth, gradient, etc.), sediment characteristics, channel pattern (e.g., single-thread, braided, anastomosing etc.) bed forms, channel meander process (stable, wandering, meandering etc.), and the presence of floodplain features (e.g., side-channels, vegetated islands, cutoffs, and oxbows).

The channel migration evaluation considered available data including aerial images, topobathymetric survey data, field identification of eroding banks, and other existing datasets to identify changes in the location and pattern of the lower Wenatchee River over time. Historical channel locations were evaluated by georeferencing the 1884 GLO survey maps (BLM 2015) and the 1911 plan and profile surveys of the Wenatchee River conducted by the USGS (USGS 1914). Existing evaluations of channel migration including the Chelan County Natural Resource Department Channel Migration Zone Study (Jones & Stokes 2004) were also considered in this analysis.

Hydraulic characteristics including shear stress, excess shear stress, unit stream power, and the threshold grain size were calculated throughout the lower Wenatchee River as measures of flow competence (Knighton 1984). Threshold of motion sediment size estimates were calculated with the Shields threshold of motion equation (Shields 1936). The equation is based on the Shields number, which is a non-dimensional number that relates the fluid force acting on sediment to the weight of the sediment.

The geomorphic reaches of the lower Wenatchee River were also mapped to identify sub-unit zones generally following the methods of U.S. Bureau of Reclamation (USBR) reach assessments (e.g., USBR 2009) as well as the Upper Wenatchee River Assessment (Inter-Fluve 2012). The zones identified were the Inner Zone (IZ), Outer Zone (OZ), and Disconnected Outer Zone (DOZ). The IZ was defined as the active river channel and included all areas that are regularly receive scouring flows including secondary channels and active bars. For the lower Wenatchee River, this closely approximates the area within the bankfull flow. The OZ was defined as the area outside the IZ that would be inundated with over-bank flows under a 100-year flood. The OZ was mapped utilizing the results of hydraulic modeling described above. The DOZ was defined as the area that would likely be inundated under a 100-year-flood event in the absence of human alterations such as levees, roads, bridges, agriculture and other development that restrict floodplain connectivity.

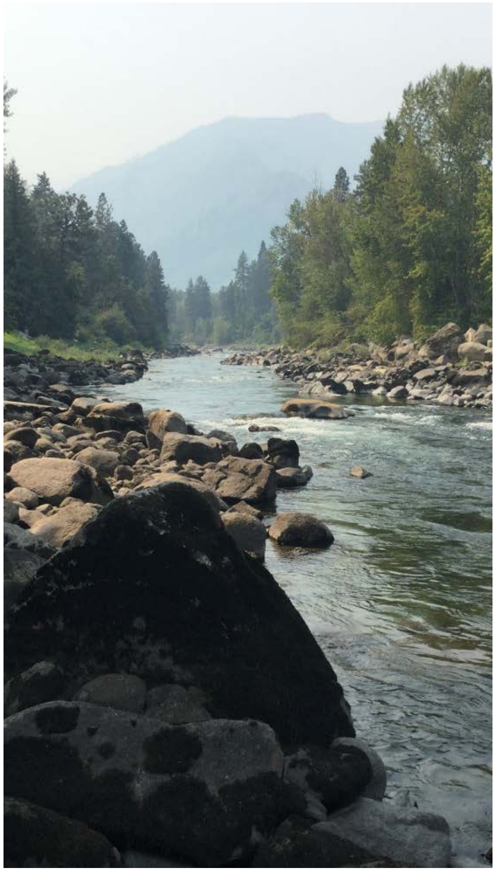
Specialized software was used for various aspects of the geomorphic analyses. For example, the TerEx Toolbox was utilized for semi-automated selection and calculating heights of terrace features from LiDAR (Stout and Belmont 2014). The River Bathymetry Toolkit software was utilized for processing stream channel topography, calculating metrics, and creating Relative Elevation Models with the slope of the valley removed (i.e., detrending) to reveal subtle changes in floodplain topography (McKean et al. 2009). In addition, geomorphic change detection software, which quantifies patterns erosion and deposition by developing a DEM of Difference comparison (Wheaton et al. 2010), was employed.

3.4.3 Canopy Height and Percent Cover

Canopy height and canopy cover were calculated using the 2015 LiDAR dataset (see Section 3.1). The calculation used both the bare earth and highest hit DEMs. The highest hit DEM comprises the LiDAR first returns that include the tree tops and are removed from the bare earth model by classification. To calculate canopy height, the bare earth DEM was subtracted from the highest hit DEM resulting in a DEM of canopy height above the bare earth surface. To remove the low understory vegetation from the canopy cover analysis, only tree heights of greater than 25 feet were included in the canopy cover area. The percentage canopy cover was based on the extent of canopy cover within the riparian area, which was represented by a 150-foot buffer from the river banks approximating one site-potential tree height.

3.5 Reach-based Ecosystem Indicators

The REI were used to characterize how the geomorphic and ecological processes are functioning within each reach of the lower Wenatchee River. The REI are based primarily on the "Matrix of Diagnostics/Pathways and Indicators" (USFWS 1998), the NMFS Matrix of Pathways and Indicators (NMFS 1996), and work conducted within the region by the USBR (USBR 2012) and the Yakama Nation (Inter-Fluve 2012). The REI process applies habitat survey data and other analysis results in order to assign reach-scale ratings of functionality (i.e. adequate, at risk, or unacceptable). This analysis is also used to help select restoration targets as part of the restoration strategy presented in Section 5.



4. REACH ASSESSMENT RESULTS

The reach assessment results provided in this section provide the scientific foundation and site-specific information needed to develop the project opportunities and potential restoration actions included in the restoration strategy (Section 5). The following subsections describe the reach assessment results including topobathymetric LiDAR (Section 4.1), hydrology (Section 4.2), geomorphic reach descriptions (Section 4.3), geomorphology (Section 4.4), riparian vegetation (Section 4.5), REI (Section 4.6), and climate change impacts (Section 4.7). Section 4.8 provides a summary of all the information provided in this section. The lower Wenatchee River existing conditions and results of the reach assessment are also shown in the Stream Habitat and Geomorphic Map Series River Mile 0.0 to 26.4 (Appendix C).

4.1 Topobathymetric LiDAR

The topobathymetric LiDAR, acquired in July 2015, fully integrated traditional near-infrared LiDAR with green wavelength (bathymetric) LiDAR in order to completely map both the topography and bathymetry of the lower Wenatchee River. Figure 4-1 shows an example of the topobathymetric LiDAR near RM 6.5. The topobathymetric LiDAR provided a highly detailed representation for visualization, technical calculations, and the modeling described in the subsections below.

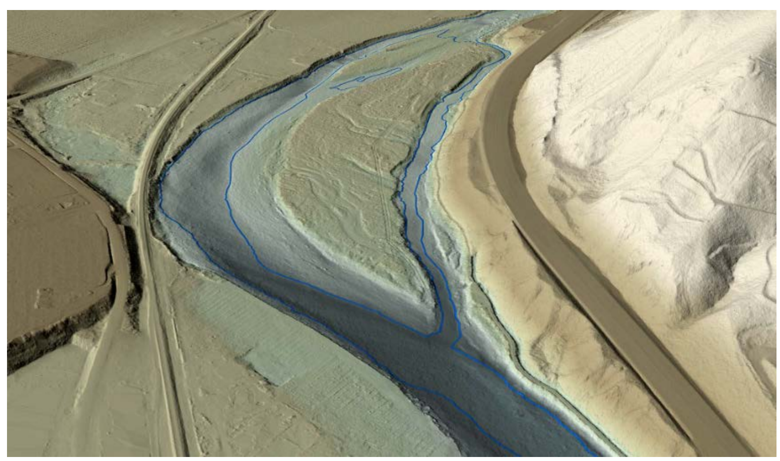


Figure 4-1. Bare-Earth Topobathymetric LiDAR (colored by elevation) Looking West near RM 6.5 Including Pioneer Side Channel

The topobathymetric LiDAR was evaluated for Fundamental Vertical Accuracy by guidelines presented in the Federal Geographic Data Committee National Standard for Spatial Data Accuracy (FGDC 1998) and, in the case of bathymetry, the percent of the total area with successful bathymetric depths including confidence levels. The absolute accuracy of the data ranged from an absolute vertical accuracy of 2.1 inches for topography and 3.2 inches for bathymetry. Bathymetric depths were successfully mapped for 96 percent of the Survey Area identified as water. Of the successfully mapped areas, 96 percent of those were mapped with high confidence and 4 percent were considered low confidence. Appendix B describes the topobathymetric LiDAR data and provides technical details about data acquisition procedures, processing methods, and analysis of the final dataset including LiDAR accuracy, depth penetration, and density.

4.2 Hydrology

Peak runoff in the Wenatchee River is driven largely by spring snowmelt and rain occurring from April through July and is commonly greatest in late June. Peak flows recede throughout the summer and baseflows typically return in August or September. Figure 4-2 shows the monthly mean flow for the Wenatchee River at Peshastin gage (USGS 12459000).

There are several tributaries draining into the lower Wenatchee River, the largest of which are Icicle Creek, Peshastin Creek, Chumstick Creek, and Mission Creek. Icicle Creek contributes the highest proportion of the lower Wenatchee River tributaries (nearly 30 percent), Peshastin Creek contributes approximately 10 percent, and the other tributaries each contribute less than 2 percent each. Figure 4-3 shows the location of lower Wenatchee River tributaries and USGS stream gages.

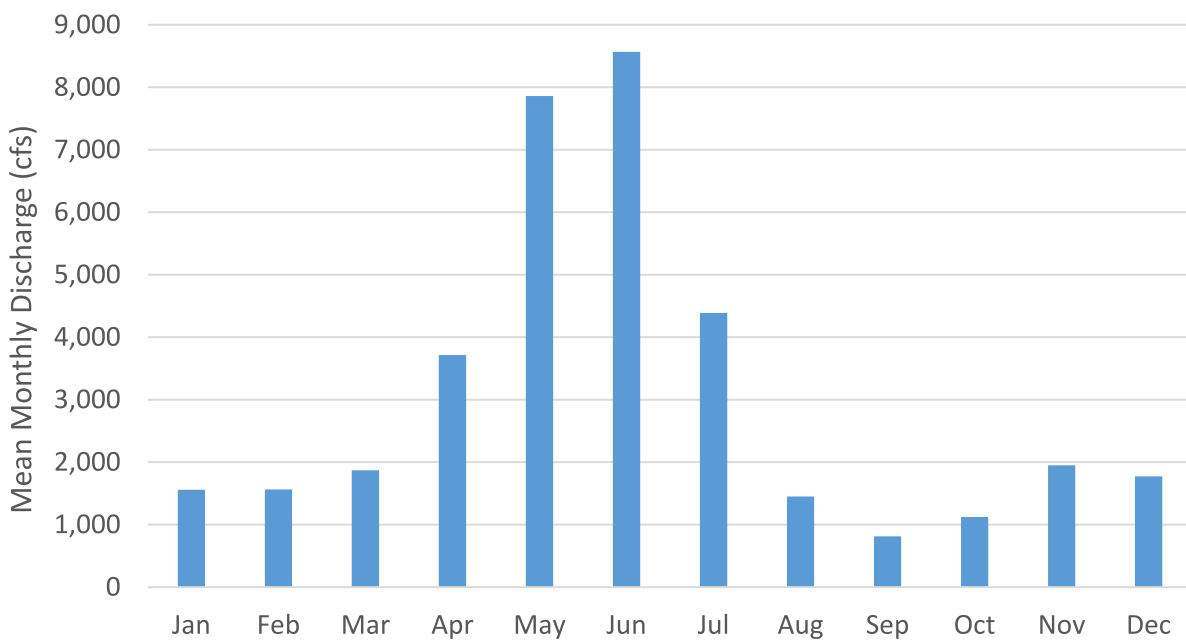


Figure 4-2. Lower Wenatchee River Monthly Discharge at Wenatchee River at Peshastin Gage (USGS 12459000)

Peak flows, monthly mean flows, base flows, and low-flow statistics were calculated for the Wenatchee River at Peshastin gage (USGS 12459000). The largest flood on record for this gage was 41,300 cubic feet per second (cfs) in 1996, exceeding the 100-year recurrence interval flood at that location. Figure 4-4 contains peak flows and minimum monthly base flows for the period of record. Section 4.7 includes further discussion of the potential impacts of climate change on the hydrology of the lower Wenatchee River.

Relatively extreme low flows occurred in the lower Wenatchee River in 2015 due to unusually low snowpack. Provisional data from the Wenatchee River at Peshastin gage recorded daily discharge below 400 cfs in late August and as low as 350 cfs in October of 2015. Flows over the field survey period (August 13 to August 19, 2015) ranged from 450 to 500 cfs at the Wenatchee River at Peshastin gage.

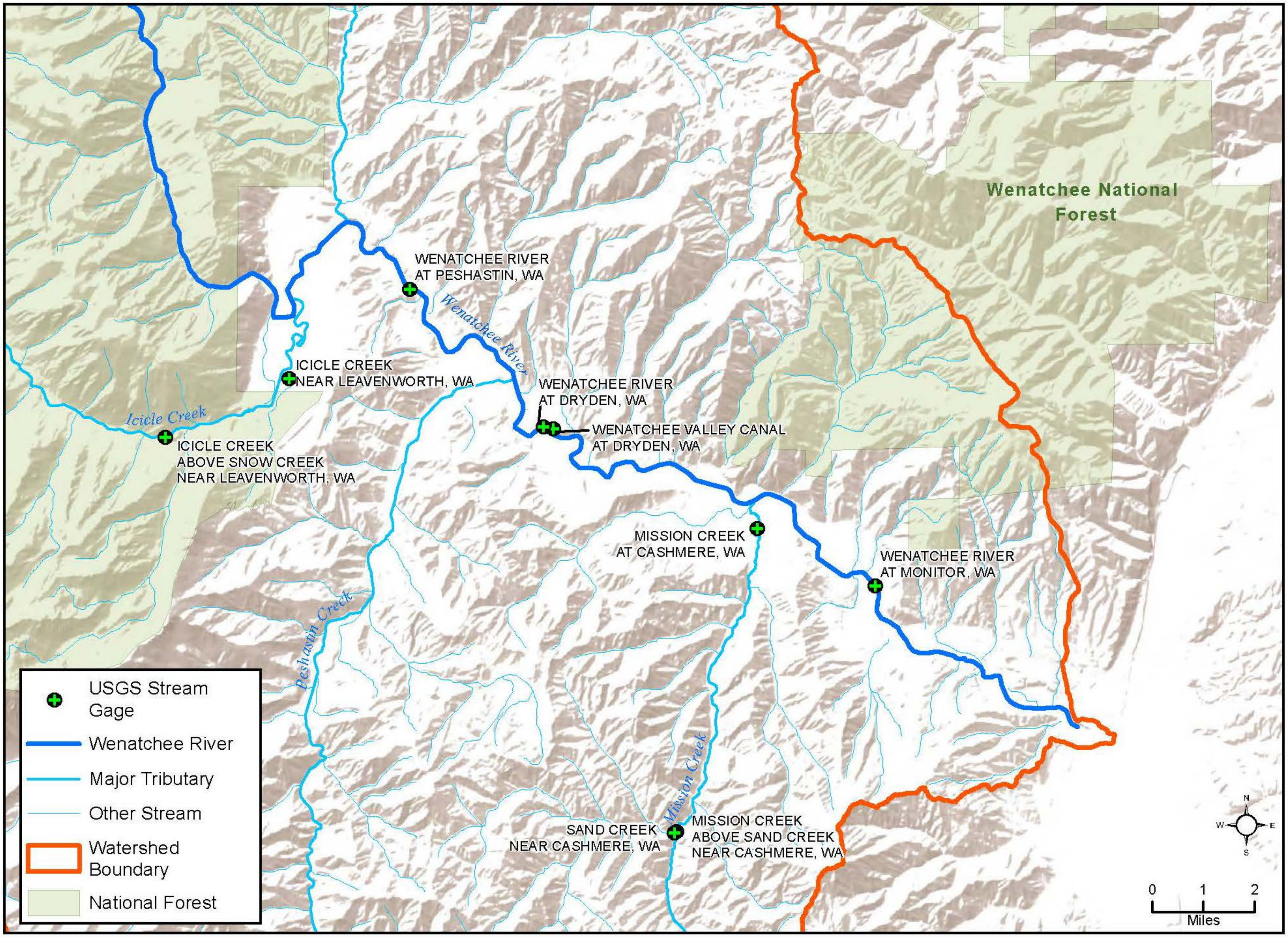


Figure 4-3. Lower Wenatchee River Hydrography and USGS Stream Gages

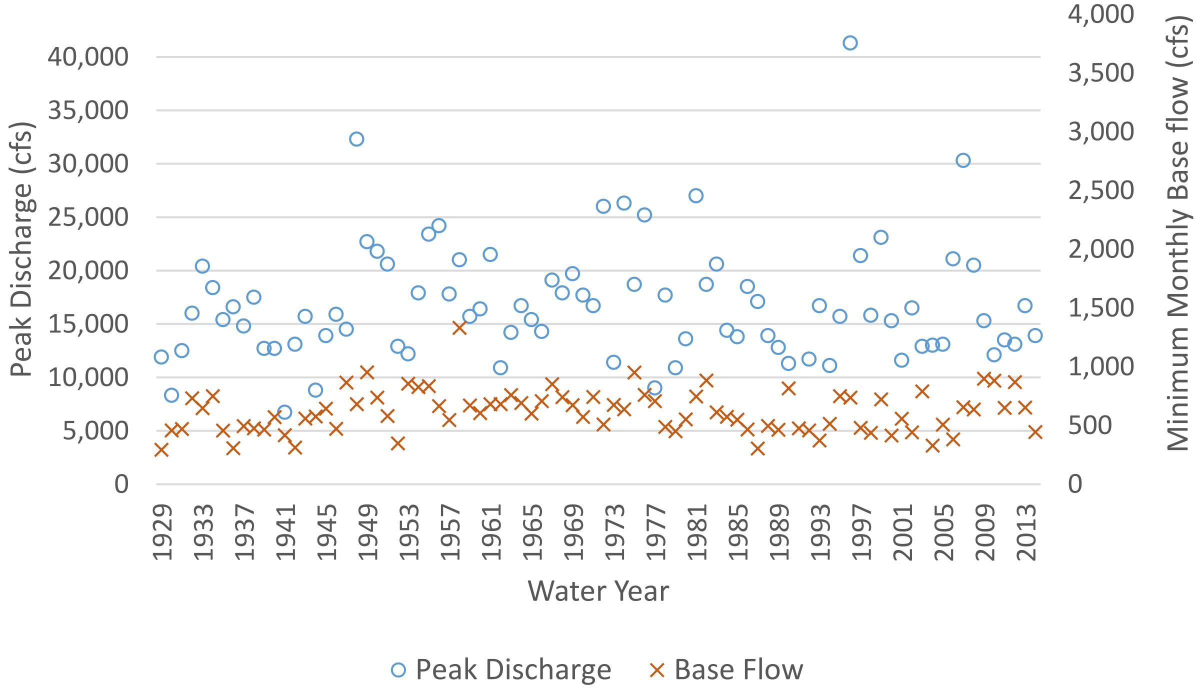


Figure 4-4. Peak Discharge and Baseflow for the Wenatchee River at Peshastin (USGS 12459000)

Peak discharges were calculated for the length of the lower Wenatchee River for use in developing a planning-level hydraulic model. Table 4-1 contains peak flow estimates for the 2-year, 10-year, 50-year, and 100-year flood events accounting for tributary inflows and drainage area differences along the lower Wenatchee River. Hydraulic model outputs were used to develop water surfaces, flow depths, and velocities for the floodplain connectivity and inundation analysis in Section 4.4.3. The REI analysis in Appendix D also contains additional hydrologic information.

Table 4-1. Peak Discharges for the 2-Year, 10-Year, 50-Year, and 100-Year Flood Events

	Lower Wenatchee River Peak Discharge			
Location Range	2-year (cfs)	10-year (cfs)	50-year (cfs)	100-year (cfs)
Icicle Road Bridge (RM 26.4) to Icicle Creek (RM 25.6)1/	11,318	17,342	22,812	25,210
Icicle Creek (RM 25.6) to Chumstick Creek (RM 23.5)2/	15,697	23,840	31,206	34,419
Chumstick Creek (RM 23.5) to Peshastin Creek (RM 18.0)3/	16,063	24,613	32,376	35,779
Peshastin Creek (RM 18.0) to RM 15.02/	17,275	26,982	36,141	40,264
RM 15.0 to Mission Creek (RM 10.6)2/	17,331	27,516	37,883	42,736
Mission Creek (RM 10.6) to RM 4.03/	17,668	28,127	38,793	43,793
RM 4.0 to Columbia River confluence1/	18,037	28,714	39,602	44,707

1/ Discharge calculated by gage transfer methods from nearest Wenatchee River gage (USGS 2001).
2/ Discharges adjusted for tributary inputs using existing gage data or regional regression equations (Sumioka et al. 1998).
3/ Discharge at gages estimated using the Log Pearson Type III analysis (USGS 1981).

4.3 Reach Descriptions

Ten distinct geomorphic reaches were delineated within the lower Wenatchee River. The reaches ranged from less than 1 mile in length to 5.5 miles in length. The differentiating characteristics of each of the reaches are qualitatively summarized below, the location shown in Figure 4-5. A more detailed description of lower Wenatchee River geomorphology is included in Section 4.4. Tables 4-2 through 4-11 include a table quantifying reach characteristics, a reach map showing relative elevation maps, and representative photographs. The relative elevation maps in Tables 4-2 through 4-11 are colored by the difference in elevation compared to the water surface elevation at the time of survey (August 13 to 15, 2015).

Reach 1: Reach 1 consists entirely of a single, continuous, low gradient, and low velocity pool created by the backwater effect of the Columbia River due to the Rock Island Dam and reservoir. The main channel pattern is nearly straight. There is a network of distributary channels on the left bank providing high quality rearing habitat but with limited cover. Anthropogenic modifications on the right bank throughout the lower portion of this reach have disconnected distributary channels. The bed sediments in this reach transition rapidly from sand-dominated to cobble-dominated in the upstream direction. Large riparian trees are infrequent in Reaches 1 to 6.

The majority of the historical floodplain in Reach 1 is contained in the Wenatchee Confluence State Park, which occupies land on both the right and left bank. The park has done work in this area to create a set of constructed wetlands and a system of trails for hikers, bikers, and bird watchers. Historically, the primary ecologic function of this reach would have been the result of frequent flooding with dynamic distributary channels depositing LWD and sediment, and likely considerable habitat modification due to beaver activity.

Reach 2: The defining characteristic of Reach 2 is that the valley is relatively narrow, comprising hillslopes on the right bank and a high glacial terrace on the left bank. The reach is relatively short with a mixture of low gradient pool, riffle, and glide habitat with no side channels, off-channel habitat, or islands. Bed surface sediments are cobble-dominated from Reaches 2 to 7.

The BNSF Railway is adjacent to the river for short segments at the upper and lower ends of this reach; however, it is along the base of the hillslope so the level of confinement is expected to be similar to natural conditions.

Reach 3: The valley in Reach 3 is broad with low stepped terraces. The bankfull channel width and floodplain width are greater than in adjacent reaches. The reach contains a mixture of low gradient pool, riffle, and glide habitat with relatively abundant side channels and off-channel habitat, some of which is the result of previous restoration actions. The channel pattern is irregular and sinuous with occasional islands, some of which are vegetated. Point, lateral, and diagonal bars are frequent. The channel bed lacks complexity and is relatively uniform and featureless in many parts of the reach. The floodplain in this reach is marked by abandoned meander bends and an extensive network of channel scars suggesting that historically, this area was dynamic and complex with abundant side-channel and off-channel habitat.

Roads, residential development, agriculture, and the BNSF Railway are confining features in Reach 3. In particular, U.S. Highway 2 bisects and disconnects a considerable portion of the floodplain in the upstream portion of Reach 3.

Reach 4: Reach 4 is also in a broad valley with low stepped terraces. Reach 4 has the greatest amount of development and bank armoring. Nearly 30 percent of the channel banks are armored in this reach. Side channels and off-channel habitat are not as abundant as in Reach 3. The channel pattern is irregular and sinuous with occasional islands, which are smaller and less frequent than in Reach 3. Point and lateral bars are frequent but smaller than in Reach 3. The channel bed lacks complexity and is relatively uniform and featureless in many parts of the reach.

Reach 4 is more incised and disconnected from its floodplain than Reach 3. The BNSF Railway, roads, U.S. Highway 2, residential and municipal development, and agriculture are confining features in Reach 4. In particular, levees protecting the city of Cashmere and the Wastewater Treatment Facilities confine the channel and limit channel migration.

Reach 5: Most of Reach 5 is naturally confined by bedrock outcrops and high terraces. The BNSF Railway and U.S. Highway 2, which both parallel the river in parts of the reach, further confine the channel. The amount of armored banks is relatively high in this reach. Side channels and off-channel habitat are relatively limited in Reach 5 including previous restoration actions. There are no islands in Reach 5 and sediment storage in bars is relatively limited. Floodplain connectivity in Reach 5 is less than in adjacent upstream and downstream reaches.

Exposed bedrock on the channel bed is more abundant in this reach than downstream reaches and floodplain areas are limited to isolated pockets in Reach 5 and are small relative to downstream reaches.

Reach 6: Reach 6 has the steepest gradient on the lower Wenatchee River and has a considerably higher sinuosity than reaches downstream. The series of stepped terraces adjacent to the river indicate this pattern is the result of progressive lateral migration as the river incised into glacial deposits. The current channel appears to be very stable with no observed bank erosion, and limited bank armoring. Side channels and off-channel habitat are relatively limited in Reach 6 including previous restoration actions and those downstream of the Dryden Diversion Dam. There are occasional islands and sediment is stored in relatively frequent point, mid-channel, and lateral bars.

There are frequent areas of exposed bedrock on the channel bed in Reach 6 acting as grade control and a greater abundance of boulders than downstream reaches although bed sediments are similarly cobble-dominated. The frequent river crossings of the BNSF Railway and U.S. Highway 2 disconnect portions of the limited floodplain that is available in Reach 6.

Reach 7: The valley narrows considerably in Reach 7 with high terraces still present. The sinuosity is less; however, similar to Reach 6, terraces adjacent to the river indicate lateral migration and incised into glacial deposits. The current channel appears to be very stable with no observed bank erosion, limited bank armoring, and frequent exposed bedrock grade controls on the channel bed. There are two notable side channels in the downstream portion of the reach the largest of which is well vegetated and appears very stable. Off-channel habitat is very limited, bars are infrequent, and the channel lacks complexity throughout most of this reach comprised of mostly long rifle and glide channel units.

Although the BNSF Railway and U.S. Highway 2 parallel the river throughout most of Reach 7 the impact of development is less than in downstream reaches because there are limited crossings and most of the development is perched on high terraces. Small and large riparian trees are more frequent in this Reach.

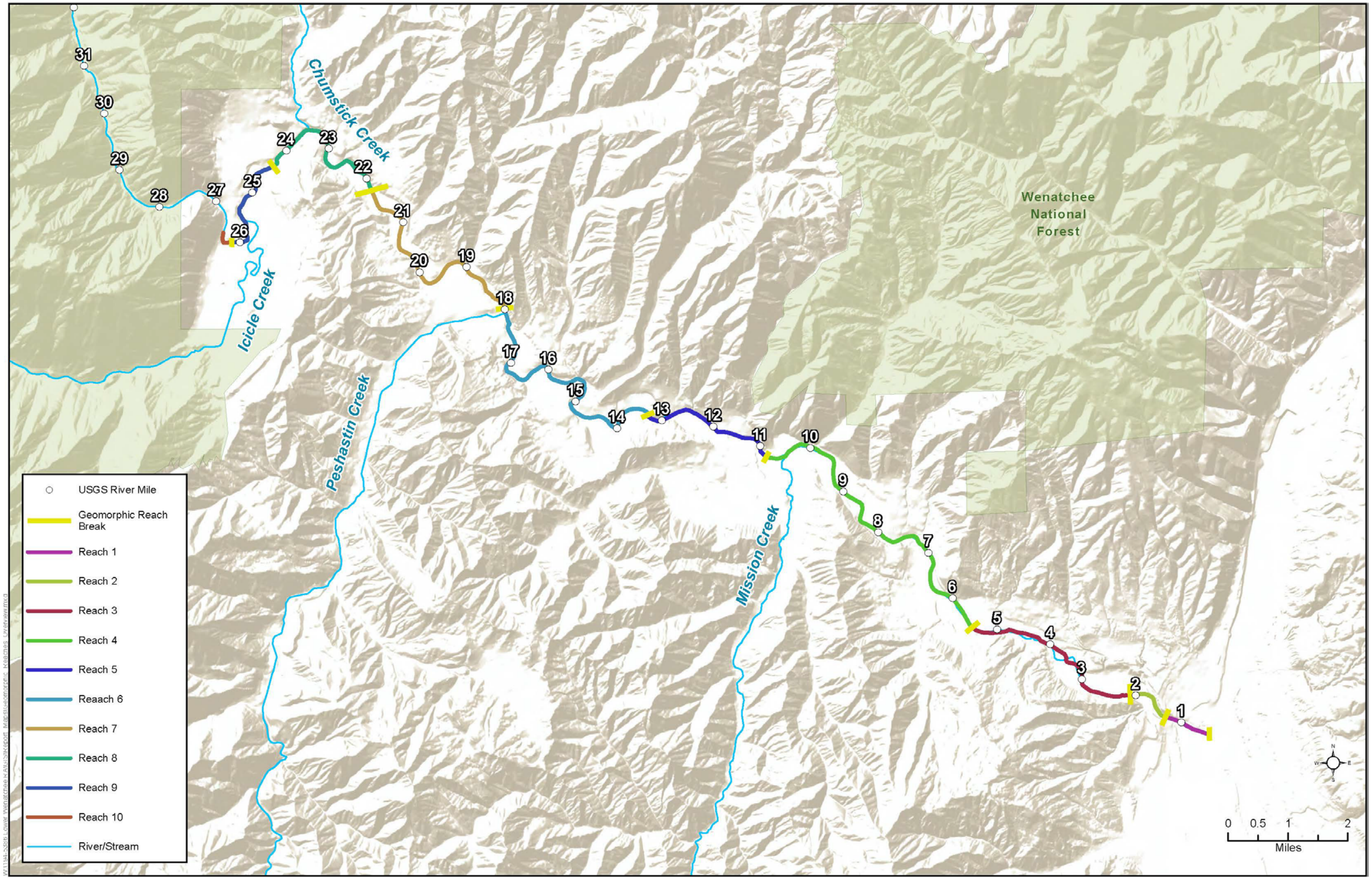


Figure 4-5. Geomorphic Reaches Location Map

Reach 8: Reach 8 is the most confined reach with the least amount of floodplain, side channels, and off-channel habitat in the lower Wenatchee River. The river is deeply incised into glacial deposits throughout this reach. The channel appears to be very stable with coarse substrate, no observed bank erosion, no artificial armoring, and frequent exposed bedrock grade controls. Bars are very infrequent. The channel pattern is irregular sinuous but this pattern is the result of post-glacial incision and geologic controls rather than channel meandering or migration.

Small and large trees are more frequent in the riparian zone of this Reach. It is expected that existing development and other human actions do not have a significant impact on the geomorphology of Reach 8.

Reach 9: Reach 9 is in a very broad valley with low stepped terraces and contains the greatest amount of off-channel habitat in the lower Wenatchee River excluding the distributary channels in Reach 1. The reach also contains the greatest proportion of gravel with large bars comprised of spawning sized gravel deposits and frequent islands. The largest island, Blackbird Island, is heavily vegetated and appears to be the result of a channel avulsion. The channel pattern of Reach 9 is sinuous and the floodplain is well-developed connected. The floodplain is marked by historical meander scrolls and channel scars demonstrating the dynamic nature of this reach.

There have been a number of previous restoration actions completed in this reach. Naturally and anthropogenic confining features are relatively limited in this Reach 9. The historical mill pond and sawmill operations at this site have impacted this reach considerably. There are remnants from the operations including boulders at the location of the historical dam, as well as log pilings and saw logs found throughout the reach. Large riparian trees are infrequent in this reach.

Reach 10: Reach 10 is a short transitional reach as the lower Wenatchee River exits Tumwater Canyon. The valley is narrow and confined by hillslopes and high terraces. Bed surface sediments are cobble-dominated and side channel and off-channel habitat are very limited. The habitat consists primarily of a single large pool that extends upstream beyond the extent of the survey. There is a residential property bank armoring on the right bank near the downstream extent of the reach.

Table 4-2. Geomorphic Reach 1 Location and Existing Characteristics

Reach Characteristics	
River Miles	0.5 to 1.25
Valley Setting	High glacial terrace (upstream), delta (downstream)
Confining features	Glacial terrace, roads and highways, and bank protection
Channel Morphology	Straight pattern, frequent irregular islands, lateral bars
Migration Process	Irregular lateral
Rosgen Type	F5
Gradient	0.08%
Sinuosity	1.00
Bankfull Width (ft)	602
Floodplain Width (ft)	1,930
Bank Condition	Armored (14%), eroding (0%)
Floodplain Disconnected	87%
Sediment	Sand (80%), gravel (5%), cobble (15%), boulder (0%), bedrock (0%)
LWD (pieces/mile)	2.5
Channel Units	Backwater pool (100%)
Off Channel Habitat (percent of total)	67%
REI Score	18 (fair)

Location Map and Photos

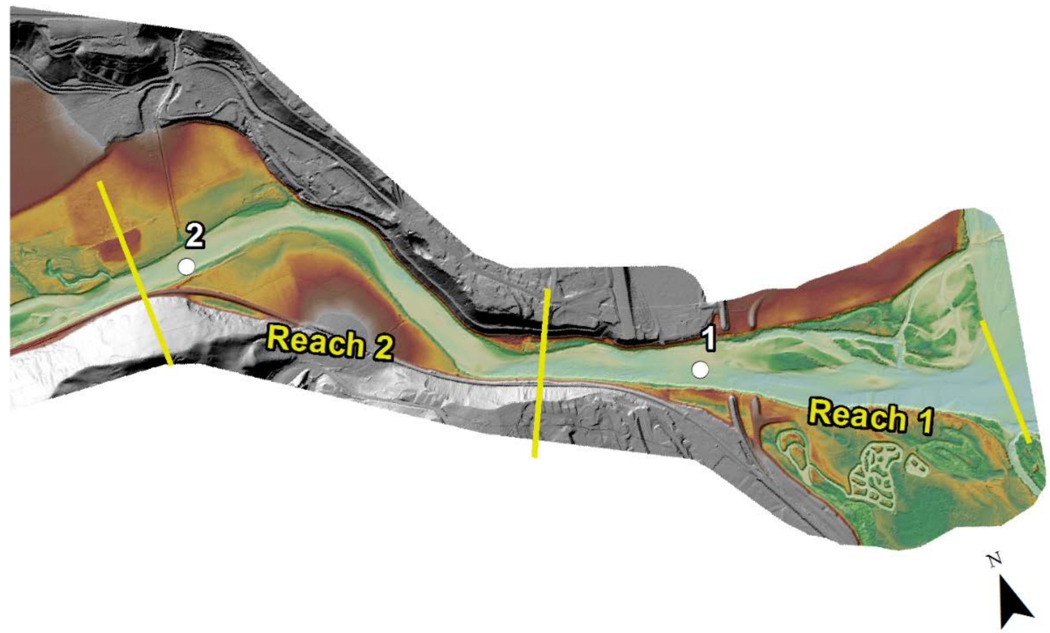


Table 4-3. Geomorphic Reach 2 Location and Existing Characteristics

Reach Characteristics	
River Miles	1.25 to 2.10
Valley Setting	Relatively narrow, high glacial terrace, valley hillslopes
Confining features	High glacial terrace and BNSF Railway
Channel Morphology	Irregular sinuous pattern, no islands, and point bars
Migration Process	Irregular lateral
Rosgen Type	F3
Gradient	0.24%
Sinuosity	1.15
Bankfull Width (ft)	248
Floodplain Width (ft)	869
Bank Condition	Armored (0%), eroding (0%)
Floodplain Disconnected	4%
Sediment	Sand (10%), gravel (10%), cobble (68%), boulder (12%), bedrock (0%)
LWD (pieces/mile)	0
Channel Units	Pool (9%), Glide (62%), Riffle (29%), Rapid (0%)
Off Channel Habitat (percent of total)	0%
REI Score	22 (fair)

Location Map and Photos

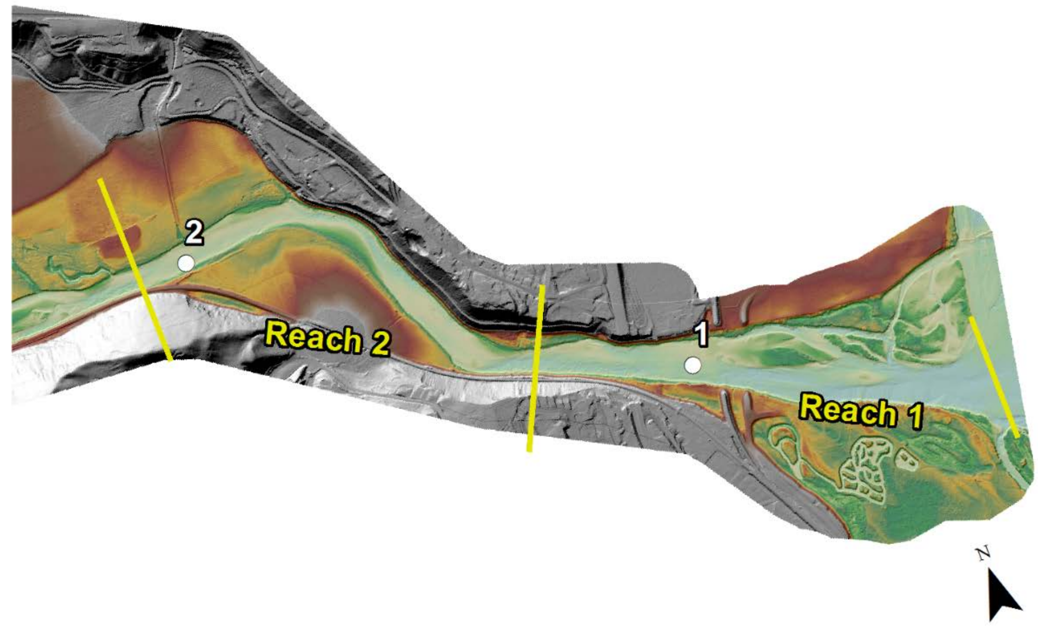


Table 4-4. Geomorphic Reach 3 Location and Existing Characteristics

Reach Characteristics	
River Miles	2.10 to 5.40
Valley Setting	Broad, stepped terrace
Confining features	BNSF Railway, roads and highways, residential development, and agriculture
Channel Morphology	Irregular sinuous pattern, occasional islands, point, lateral, and diagonal bars
Migration Process	Irregular lateral
Rosgen Type	C3
Gradient	0.29%
Sinuosity	1.11
Bankfull Width (ft)	262
Floodplain Width (ft)	1542
Bank Condition	Armored (14%), eroding (4%)
Floodplain Disconnected	43%
Sediment	Sand (9%), gravel (13%), cobble (66%), boulder (10%), bedrock (3%)
LWD (pieces/mile)	4.7
Channel Units	Pool (20%), Glide (49%), Riffle (29%), Rapid (1%)
Off Channel Habitat (percent of total)	25%
REI Score	19 (fair)

Location Map and Photos

Table 4-5. Geomorphic Reach 4 Location and Existing Characteristics

Reach Characteristics	
River Miles	5.40 to 10.80
Valley Setting	Broad, stepped terrace
Confining features	BNSF Railway, roads and highways, residential and urban development, bank protection, and agriculture
Channel Morphology	Irregular sinuous pattern, occasional islands, point and lateral bars
Migration Process	Irregular lateral
Rosgen Type	F3
Gradient	0.35%
Sinuosity	1.24
Bankfull Width (ft)	223
Floodplain Width (ft)	1,111
Bank Condition	Armored (27%), eroding (0%)
Floodplain Disconnected	66%
Sediment	Sand (10%), gravel (10%), cobble (55%), boulder (20%), bedrock (5%)
LWD (pieces/mile)	1.1
Channel Units	Pool (18%), Glide (37%), Riffle (41%), Rapid (4%)
Off Channel Habitat (percent of total)	4%
REI Score	17 (fair)

Location Map and Photos

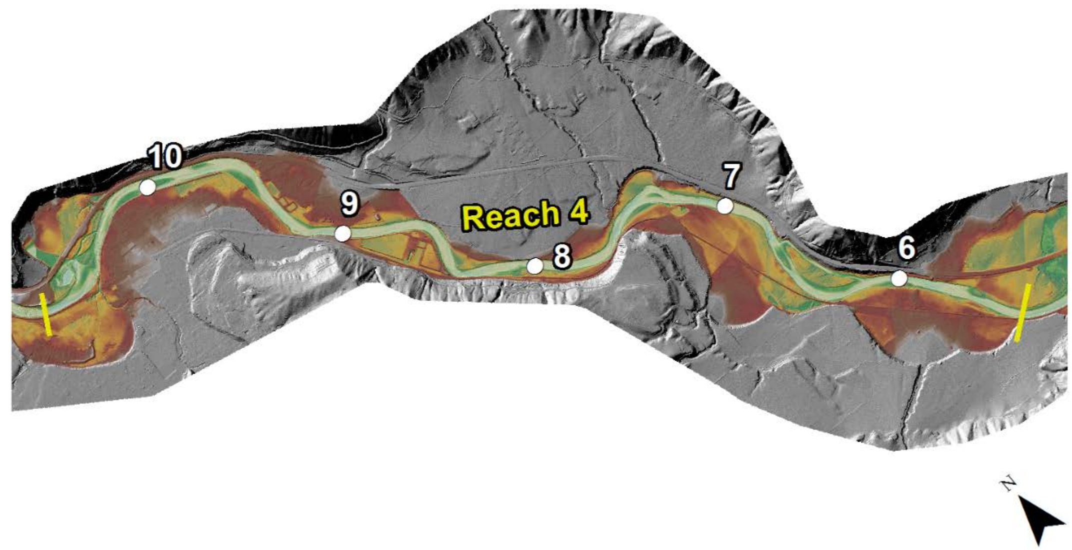


Table 4-6. Geomorphic Reach 5 Location and Existing Characteristics

Reach Characteristics	
River Miles	10.80 to 13.25
Valley Setting	Broad, stepped terrace
Confining features	BNSF Railway, roads and highways, bedrock, terraces, hillslopes, bank protection, and agriculture
Channel Morphology	Irregular sinuous pattern, occasional islands, point, mid-channel, and lateral bars
Migration Process	Irregular lateral
Rosgen Type	F3
Gradient	0.43%
Sinuosity	1.13
Bankfull Width (ft)	237
Floodplain Width (ft)	513
Bank Condition	Armored (18%), eroding (0%)
Floodplain Disconnected	54%
Sediment	Sand (7%), gravel (11%), cobble (43%), boulder (21%), bedrock (18%)
LWD (pieces/mile)	0
Channel Units	Pool (17%), Glide (27%), Riffle (47%), Rapid (9%)
Off Channel Habitat (percent of total)	0%
REI Score	17 (fair)

Location Map and Photos

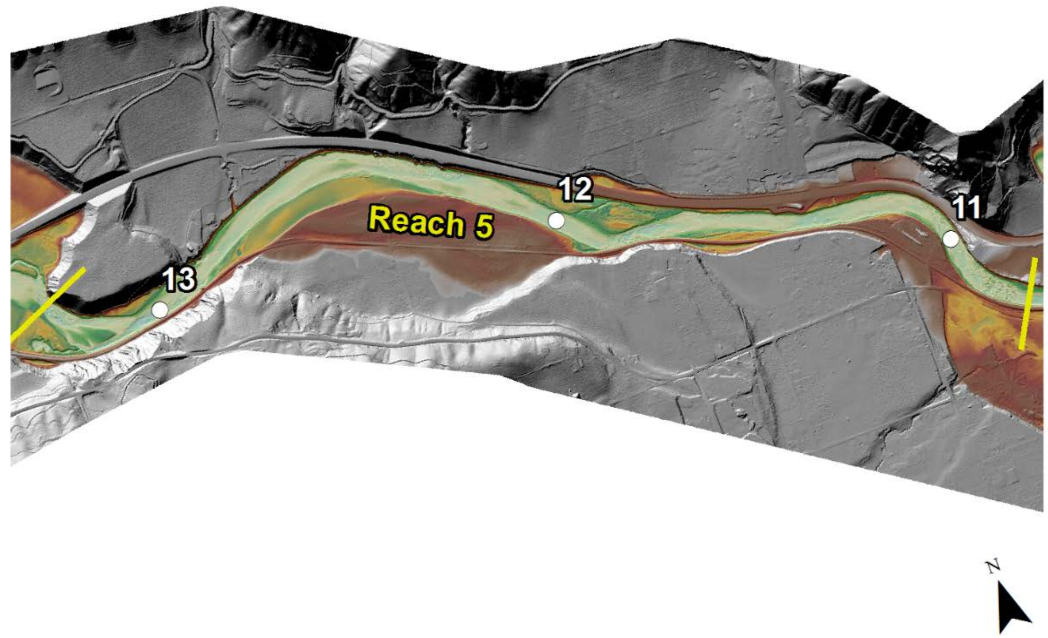
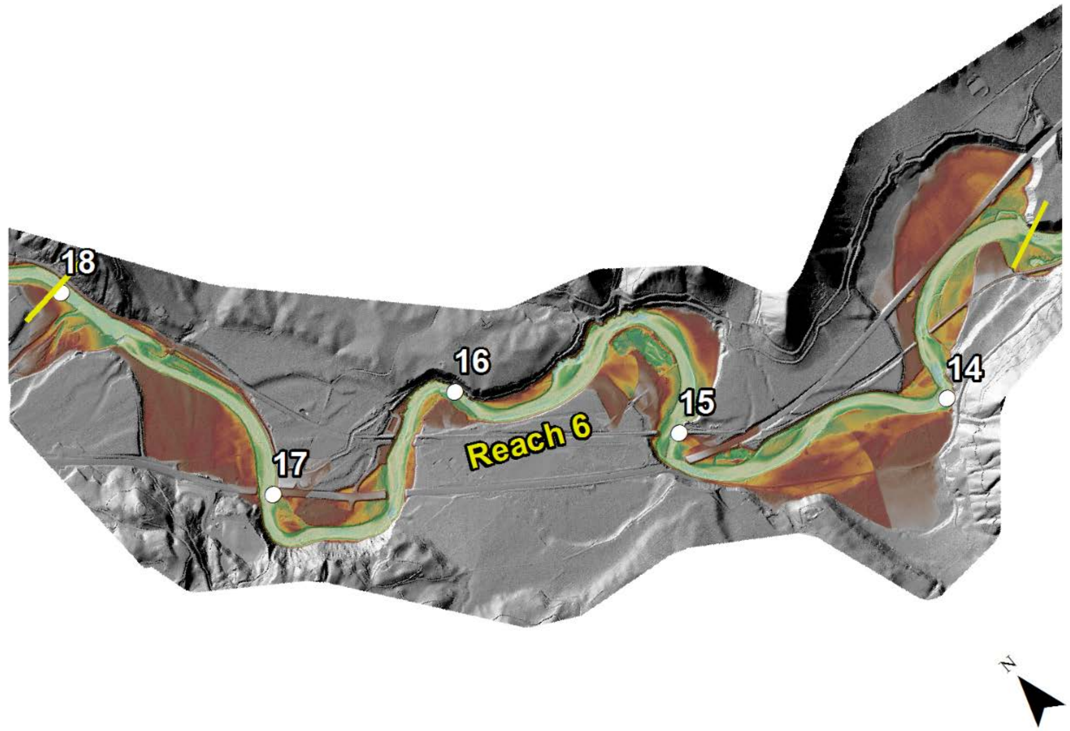


Table 4-7. Geomorphic Reach 6 Location and Existing Characteristics

Reach Characteristics	
River Miles	13.25 to 18.0
Valley Setting	Broad, stepped terrace
Confining features	BNSF Railway, roads and highways, valley hillslopes, bedrock, and high terraces, Dryden Diversion Dam, residential and urban development
Channel Morphology	Irregular sinuous pattern, occasional islands, point, mid-channel, and lateral bars
Migration Process	None1/
Rosgen Type	F3
Gradient	0.52%
Sinuosity	1.65
Bankfull Width (ft)	235
Floodplain Width (ft)	566
Bank Condition	Armored (10%), eroding (0%)
Floodplain Disconnected	62%
Sediment	Sand (10%), gravel (10%), cobble (45%), boulder (25%), bedrock (10%)
LWD (pieces/mile)	1.4
Channel Units	Pool (21%), Glide (17%), Riffle (59%), Rapid (2%)
Off Channel Habitat (percent of total)	0%
REI Score	17 (fair)

Location Map and Photos

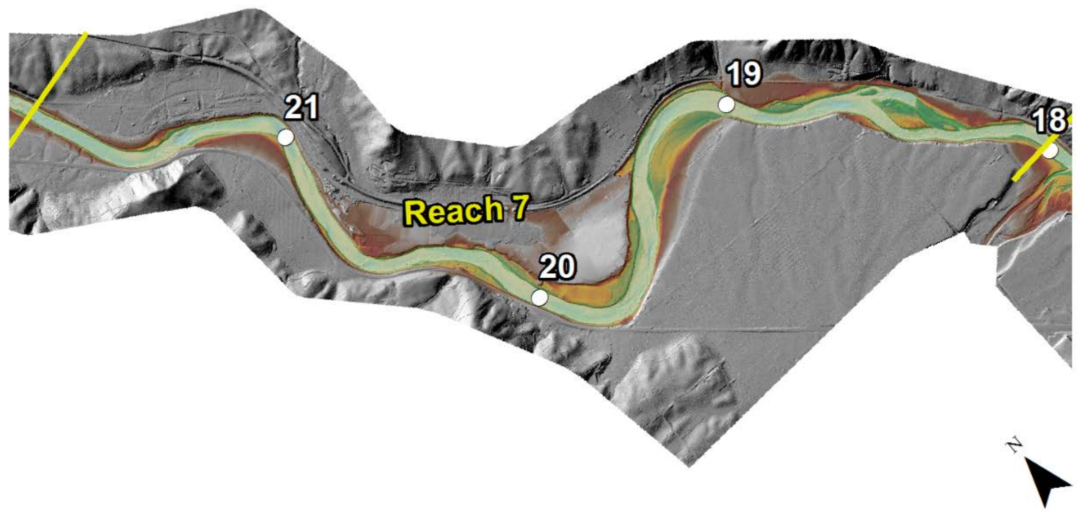


1/ The presence of naturally confining features results in very little to no channel migration.

Table 4-8. Geomorphic Reach 7 Location and Existing Characteristics

Reach Characteristics	
River Miles	18.0 to 21.80
Valley Setting	Broad, stepped high terrace
Confining features	High terraces, BNSF Railway, roads and highways, bedrock, and valley hillslopes
Channel Morphology	Irregular sinuous pattern, occasional islands, infrequent point bars
Migration Process	None[1/]
Rosgen Type	F3
Gradient	0.29%
Sinuosity	1.32
Bankfull Width (ft)	230
Floodplain Width (ft)	391
Bank Condition	Armored (6%), eroding (0%)
Floodplain Disconnected	9%
Sediment	Sand (13%), gravel (14%), cobble (50%), boulder (22%), bedrock (2%)
LWD (pieces/mile)	9.9
Channel Units	Pool (6%), Glide (52%), Riffle (42%), Rapid (0%)
Off Channel Habitat (percent of total)	0%
REI Score	22 (fair)

Location Map and Photos

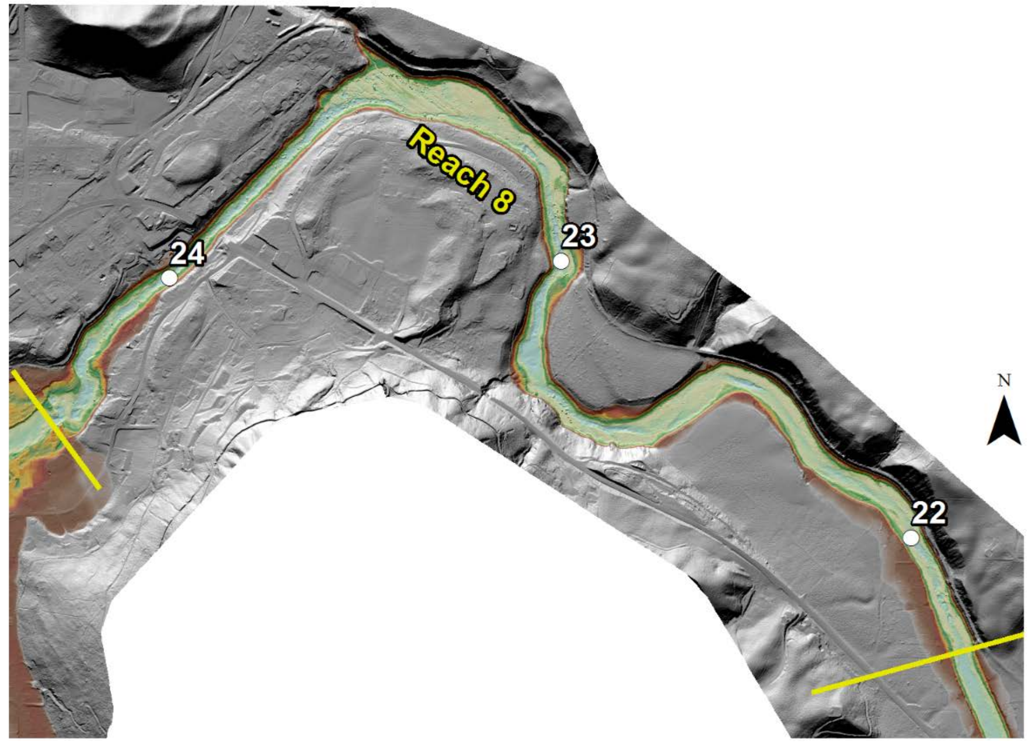


1/ The presence of naturally confining features results in very little to no channel migration.

Table 4-9. Geomorphic Reach 8 Location and Existing Characteristics

Reach Characteristics	
River Miles	21.8 to 24.35
Valley Setting	Broad, stepped high terrace
Confining features	High terraces, bedrock, and valley hillslopes
Channel Morphology	Sinuous pattern, no islands, infrequent point bars
Migration Process	None[1/]
Rosgen Type	F2
Gradient	0.43%
Sinuosity	1.62
Bankfull Width (ft)	207
Floodplain Width (ft)	271
Bank Condition	Armored (1%), eroding (0%)
Floodplain Disconnected	0%
Sediment	Sand (14%), gravel (4%), cobble (22%), boulder (43%), bedrock (17%)
LWD (pieces/mile)	2.2
Channel Units	Pool (34%), Glide (21%), Riffle (46%), Rapid (0%)
Off Channel Habitat (percent of total)	0%
REI Score	25 (good)

Location Map and Photos

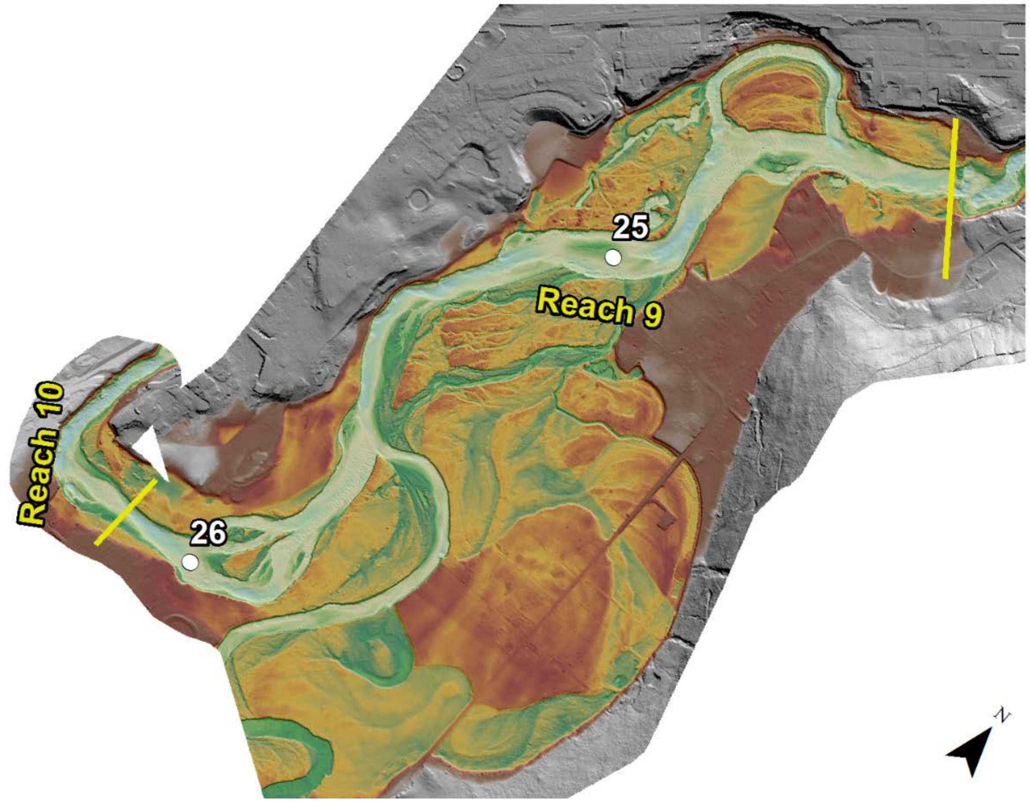


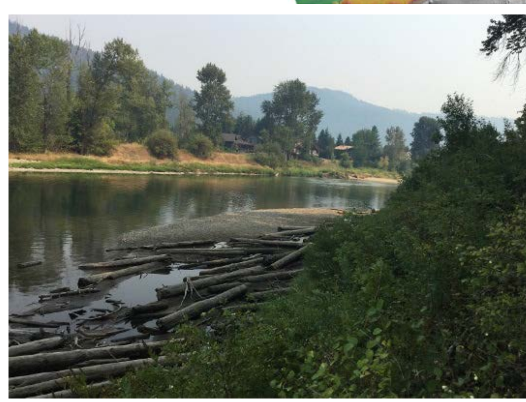
1/ The presence of naturally confining features results in very little to no channel migration.

Table 4-10. Geomorphic Reach 9 Location and Existing Characteristics

Reach Characteristics	
River Miles	24.35 to 26.15
Valley Setting	Very broad, low stepped terrace
Confining features	Low terraces, residential and commercial development
Channel Morphology	Irregular sinuous pattern, frequent irregular islands, point and lateral bars
Migration Process	Irregular lateral
Rosgen Type	C4
Gradient	0.15%
Sinuosity	1.28
Bankfull Width (ft)	344
Floodplain Width (ft)	1,566
Bank Condition	Armored (1%), eroding (0%)
Floodplain Disconnected	13%
Sediment	Sand (23%), gravel (33%), cobble (39%), boulder (6%), bedrock (0%)
LWD (pieces/mile)	5.4
Channel Units	Pool (10%), Glide (74%), Riffle (16%), Rapid (0%)
Off Channel Habitat (percent of total)	45%
REI Score	23 (good)

Location Map and Photos





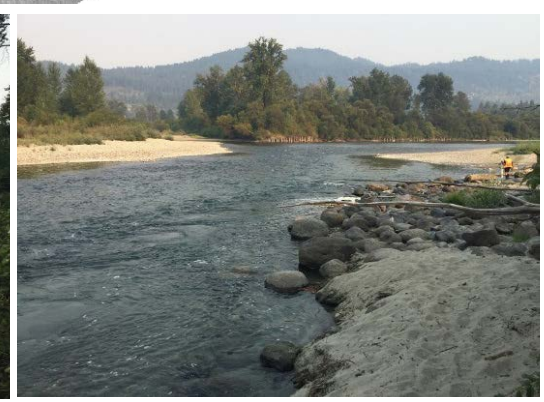
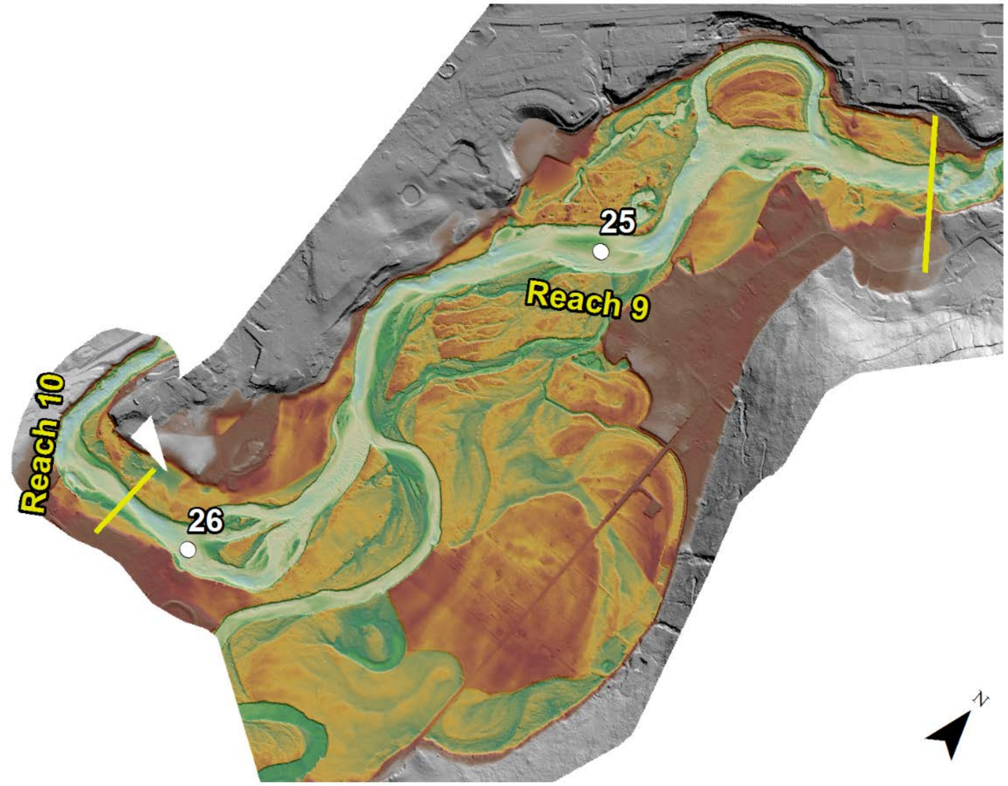


Table 4-11. Geomorphic Reach 10 Location and Existing Characteristics

Reach Characteristics	
River Miles	26.15 to 26.40
Valley Setting	Narrow, right bank valley hillslope
Confining features	Valley hillslope, roads, and residential bank protection
Channel Morphology	Sinuous planform, no islands, point and lateral bars
Migration Process	Irregular lateral
Rosgen Type	F2
Gradient	0.18%
Sinuosity	1.44
Bankfull Width (ft)	196
Floodplain Width (ft)	217
Bank Condition	Armored (16%), eroding (0%)
Floodplain Disconnected	7%
Sediment	Sand (15%), gravel (13%), cobble (35%), boulder (38%), bedrock (0%)
LWD (pieces/mile)	3.3
Channel Units	Pool (63%), Glide (0%), Riffle (37%), Rapid (0%)
Off Channel Habitat (percent of total)	0%
REI Score	23 (good)

Location Map and Photos



4.4 Geomorphology

Geomorphic conditions in the lower Wenatchee River were recorded during field surveys, and desktop analyses were conducted to characterize conditions with respect to channel migration and channel evolution, floodplain connectivity, sediment transport dynamics, the role of LWD, and the impact of land use practices (historical and current) on reach-scale processes and habitat availability. Risks and constraints associated with land-uses were also documented and described. The geomorphology analyses utilized aerial photography, topographic data, historical information, geologic mapping, and other data sources. The following paragraphs provide an overview of geomorphic conditions in the lower Wenatchee River.

The geomorphic conditions of the lower Wenatchee River are tightly linked to the glacial history. As described in Section 2.2, the lower Wenatchee River has gone through a period of post-glacial downcutting through a patchwork of deposits. In some areas, particularly between Leavenworth and Cashmere, the river has eroded through glacial deposits down to bedrock. The current geomorphic conditions are, in large part, a direct result of this process and the interaction with geologic controls. The role of land use practices has also had an impact on geomorphic conditions particularly in reaches that are more sensitive to disturbance.

An important concept to consider for understanding the geomorphology of the lower Wenatchee River is that of an alluvial river. Many of the basic principles of fluvial geomorphology are based on the properties of alluvial rivers. Alluvial rivers flow in self-formed channels in which the bed and the banks are made up of sediment that was deposited by the river and has the potential to be mobilized given the right combination of hydraulics, sediment characteristics, and bank conditions. Reach 9 is a good example of an alluvial river. There is direct evidence of active channel migration processes and a well-developed floodplain. Reaches 1 through 6 also exhibit properties of an alluvial river, although there are segments within these reaches where processes are constrained, referred to herein as mixed alluvial. For example, Reach 6 has areas with glacial boulders that were deposited after being rafted downstream on icebergs that calved off the toe of the alpine glacier in location of present day Leavenworth during a glacial outburst floods (Bjornstad 2006). The alluvial areas of these reaches are more dynamic, have complex channel form, are sensitive to disturbance, and in general have more active restoration potential.

Patterns of bed material transport and storage in alluvial reaches are determined by a complex interaction between the sediment supply, transport capacity (i.e. the ability to transport the incoming sediment supply), the availability for sediment storage in bars and islands, and the potential for the channel to adjust laterally or vertically. Alluvial reaches with high sediment storage availability and lateral mobility are commonly referred to as storage, or response reaches, whereas reaches with limited sediment storage areas and limited lateral mobility are referred to as transport reaches. Reach 9 is a good example of a storage reach. Sediment transport patterns and process are described further in Section 4.4.4.

In contrast to alluvial rivers, a number of circumstances can lead to river channels that are immobile, to varying degrees. This limits natural migration, sediment transport processes, and floodplain development. The presence of bedrock, over-sized (non-alluvial) sediments, and confining features can result in rivers with constrained geomorphic processes. For example, during the post-glacial period, the river in Reach 8 has incised through an alpine glacier end moraine landform. The result of this is that the river channel is confined in a deep, narrow gorge and reworking of the moraine deposits has resulted in frequent large boulders and glacial erratics. Reaches 7 and 10 also have relatively immobile conditions to varying degrees.

The subsections below describe the results of the geomorphic field survey data and analyses in terms of longitudinal profile (Section 4.4.1) channel migration (Section 4.4.2), floodplain connectivity and inundation

(Section 4.4.3), sediment characteristics and flow competence (Section 4.4.4), LWD (Section 4.4.5), and channel units (Section 4.4.6). The REI analysis in Appendix D also contains geomorphological data and analysis.

4.4.1 Longitudinal Profile

A longitudinal profile of the lower Wenatchee River was derived from the topobathymetric LiDAR data. Figure 4-6 illustrates the longitudinal profile of the channel thalweg and the 2-year flow event water surface. The location of the 10 geomorphic reaches and their average channel gradient, and the location of cities are shown for reference. The slope breaks in the profile from Leavenworth to Dryden shows the strong influence of bedrock grade controls in these reaches where the concavity of the profile from Dryden to the mouth indicates channel incision. The straight gray dashed line in Figure 4-6 highlights these features in the longitudinal profile.

There are likely a number of factors causing the observed profile concavity. At the geologic time scale, profile concavity may be related to tectonic factors such as uplift or subsidence (i.e., drop in elevation) or changes in base level. Post-glacial fluvial incision, downstream fining of sediment, or increasing discharge can also increase profile concavity. Straightening of the channel, armoring channel banks, and otherwise artificially confining the channel can cause further incision. The change in base level due to the construction of the Rock Island Dam may also be a contributing factor and this process may still be unfolding as the reservoir was raised 6.1 feet in 1979. Given the observed bedrock grade control at the low point in the profile concavity (near Cashmere), shown in Figure 4-6, and frequent bedrock grade controls upstream of there, further channel incision will not likely occur in the lower Wenatchee River upstream of Cashmere.

4.4.2 Channel Migration

The channel migration analyses built on the previous work of the Wenatchee River Channel Migration Zone Study (Jones & Stokes 2004), which included an analysis of channel migration from aerial photographs and the delineation of channel migration zones. The analysis also takes into consideration observations of bank conditions and bank armoring during field surveys, effectiveness monitoring of exiting restoration projects, historical channel locations identified from aerial imagery, the 1884 GLO survey maps, and the 1911 plan and profile surveys of the Wenatchee River conducted by the USGS (USGS 1914).

The presence of bank erosion is a key indicator for active channel migration. The locations of eroding banks, armored banks, and levees were mapped during field surveys. The existing conditions map series Figures C-1a through C-1k in Appendix C show these mapped banks and levees for the lower Wenatchee River. The proportion of eroding banks was low throughout the lower Wenatchee River with a maximum of 4 percent in Reach 3. As described above, the channel banks are coarse and highly erosion-resistant and the channel is confined in many areas between Cashmere and Leavenworth. These observations are in agreement with the findings of Jones & Stokes (2004).

Although bank erosion is generally low, bank erosion rates of up to 15 feet per year have been observed in Reach 3 from 2007 to 2011 at the Goodfellow Project site near RM 2.2 and likely occur in other isolated areas within the alluvial and mixed alluvial reaches (i.e., Reaches 1, 2, 3, 4, and 9). At this site, the development of a mid-channel bar is constricting flow and promoting lateral migration.

The highest proportion of armored banks was in Reaches 4 and 5 with 21 percent and 18 percent, respectively. There are three sections of USACE levees near the city of Cashmere on the right bank. The two levee segments protecting the city of Cashmere (USACE ID G3-208 and G3-095) and the third levee (USACE ID G3-096) is downstream of Cashmere and surrounds the Cashmere Wastewater Treatment Facilities.

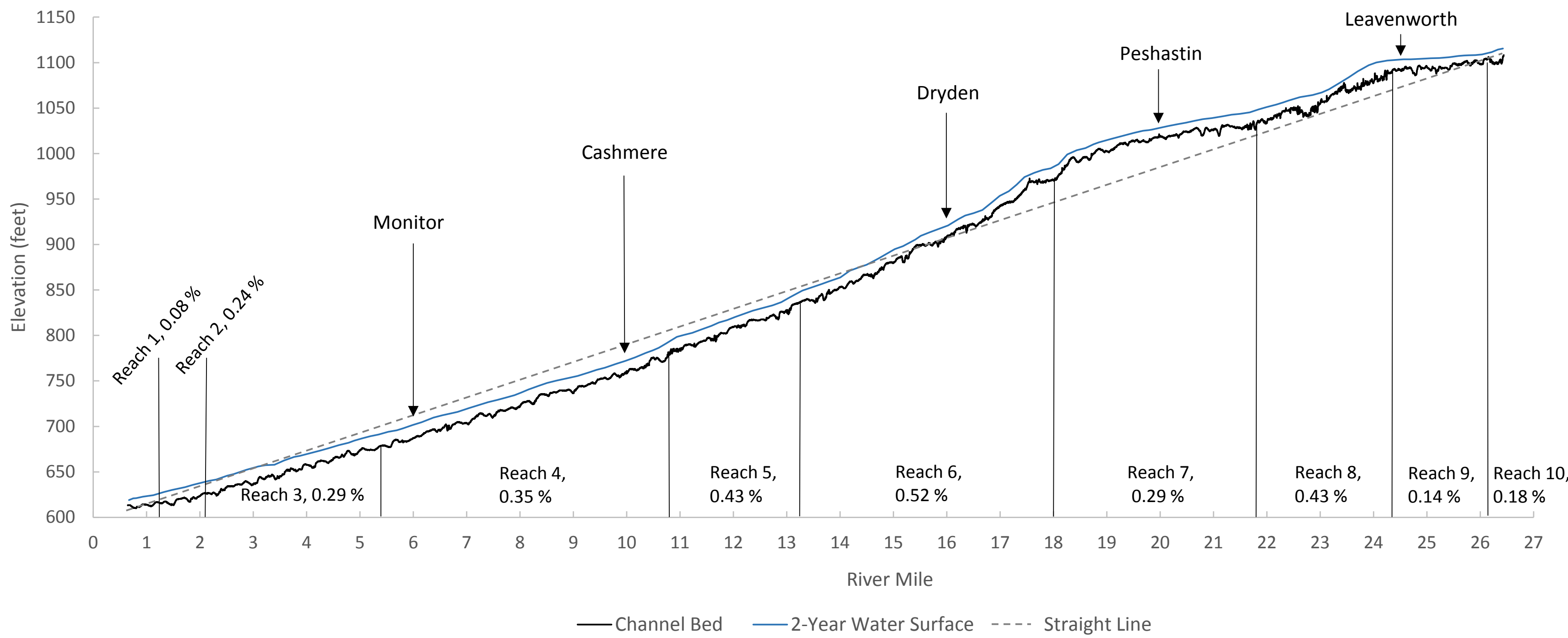


Figure 4-6. Longitudinal Profile and Channel Gradient for Geomorphic Reaches in the Lower Wenatchee River

Based on available aerial imagery, the 1884 GLO survey maps, and the 1911 plan and profile surveys the lower Wenatchee River is generally stable in most areas and has a similar general alignment for at least the last 100 years. This observation is in agreement with the findings of Jones & Stokes (2004). However, there are isolated areas where there appears to have been considerable channel movement that may have been associated with human activities. Figure 4-7 shows the mapped historical channel location from 1884 and 1911 compared with an aerial image of the present location near the City of Cashmere. Current channel migration rates and processes likely only differ from historical rates in areas with levees or artificially armored banks.

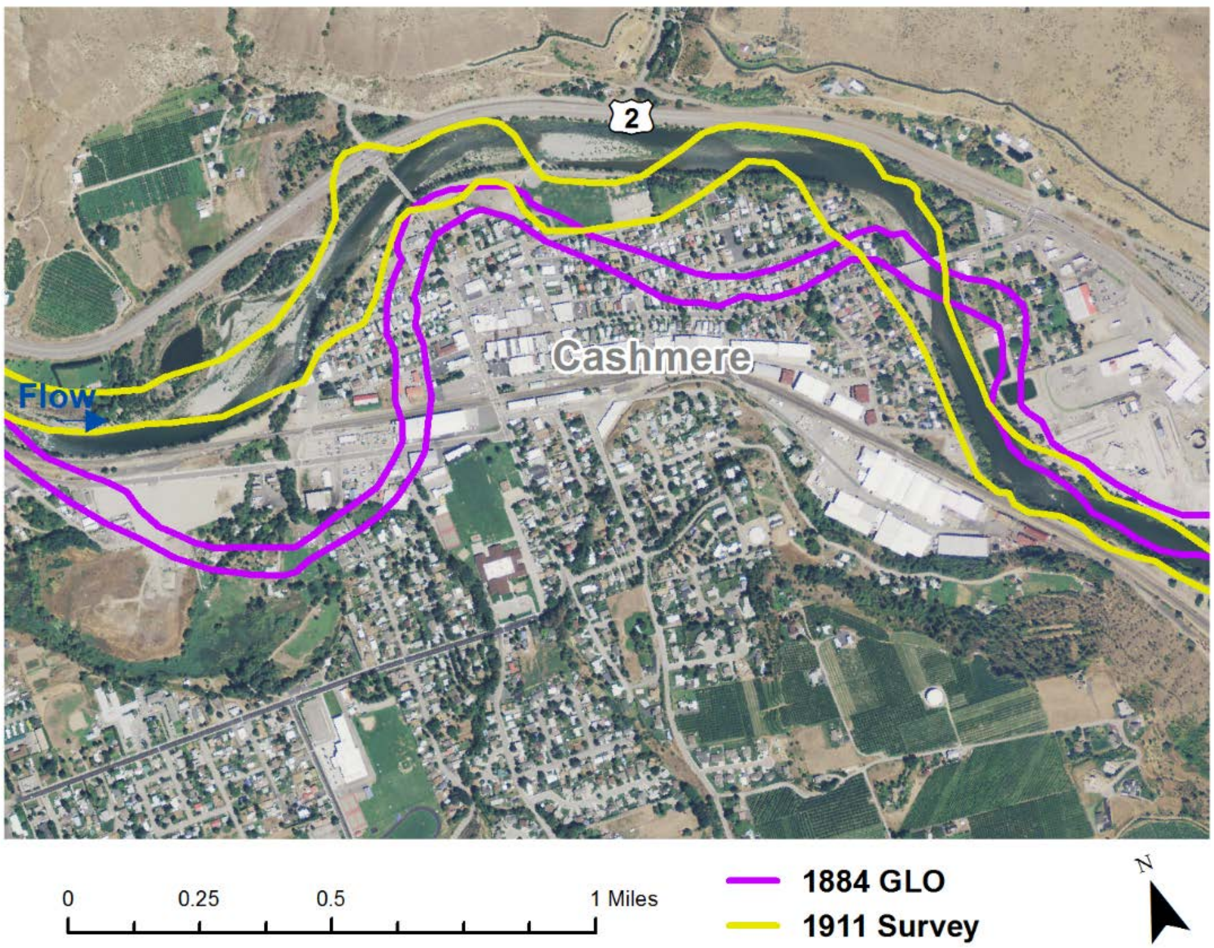


Figure 4-7. Historical Channel Location from 1884 GLO Map and 1911 USGS Plan View Survey of the Wenatchee River near the City of Cashmere (USGS 1914)

4.4.3 Floodplain Connectivity and Inundation

Floodplain connectivity and floodplain inundation were evaluated based on the results from the hydraulic modeling, floodplain inundation mapping, and the geomorphic sub-unit mapping described in Section 3.4.2.

Hydraulic model outputs of water surface elevation, flow depth, and velocity were used to map floodplain inundation and evaluate floodplain connectivity for the 2-year, 10-year, 50-year, and 100-year flood events. The inundation map series Figures C-2a through C-2k in Appendix C show the water surface extent at the time of survey (August 13 to 15, 2015), the flood inundation extent for the 100-year flood, and the depth for the 2-year event for the lower Wenatchee River. The figures illustrate that the alluvial Reaches 3 and 9 have the greatest amount of floodplain inundated in the 2-year and 100-year floods under existing conditions while floodplain connectivity is relatively restricted in the remaining reaches.

Floodplain connectivity throughout the lower Wenatchee River is severely limited compared to historical conditions by the BNSF Railway, roads and highways, residential and urban development, agriculture, and other infrastructure. As previously described, the presence of glacial terraces, bedrock, and valley hillslopes also confine the river and limit floodplain availability. Reaches 6 through 8 and 10 have only isolated areas of floodplain due primarily to these natural constraints. In addition to floodplain inundation, Figures C-2a through C-2k in Appendix C show the presence of terrace landforms and their average elevation above the channel bed.

Reaches 1, 3, 4, and 6, in particular, have a considerable amount of historical floodplain that is disconnected due roads, levees, bank protection, residential development, agriculture, the BNSF Railway, and other development. The sub-unit geomorphic mapping in Figures C-3a through C-3k in Appendix C show the areas of disconnected floodplain, referred to as the DOZ. Figure 4-8 shows an example of a large area of historical floodplain in Reach 3 bisected and disconnected by U.S. Highway 2. Inundation and connectivity are also limited in some areas due to channel incision into the floodplain. Reaches 4 and 5 are more incised than upstream and downstream reaches. This result is in agreement with the longitudinal profile in Figure 4-6, which shows that the bottom of profile concavity is in these reaches.

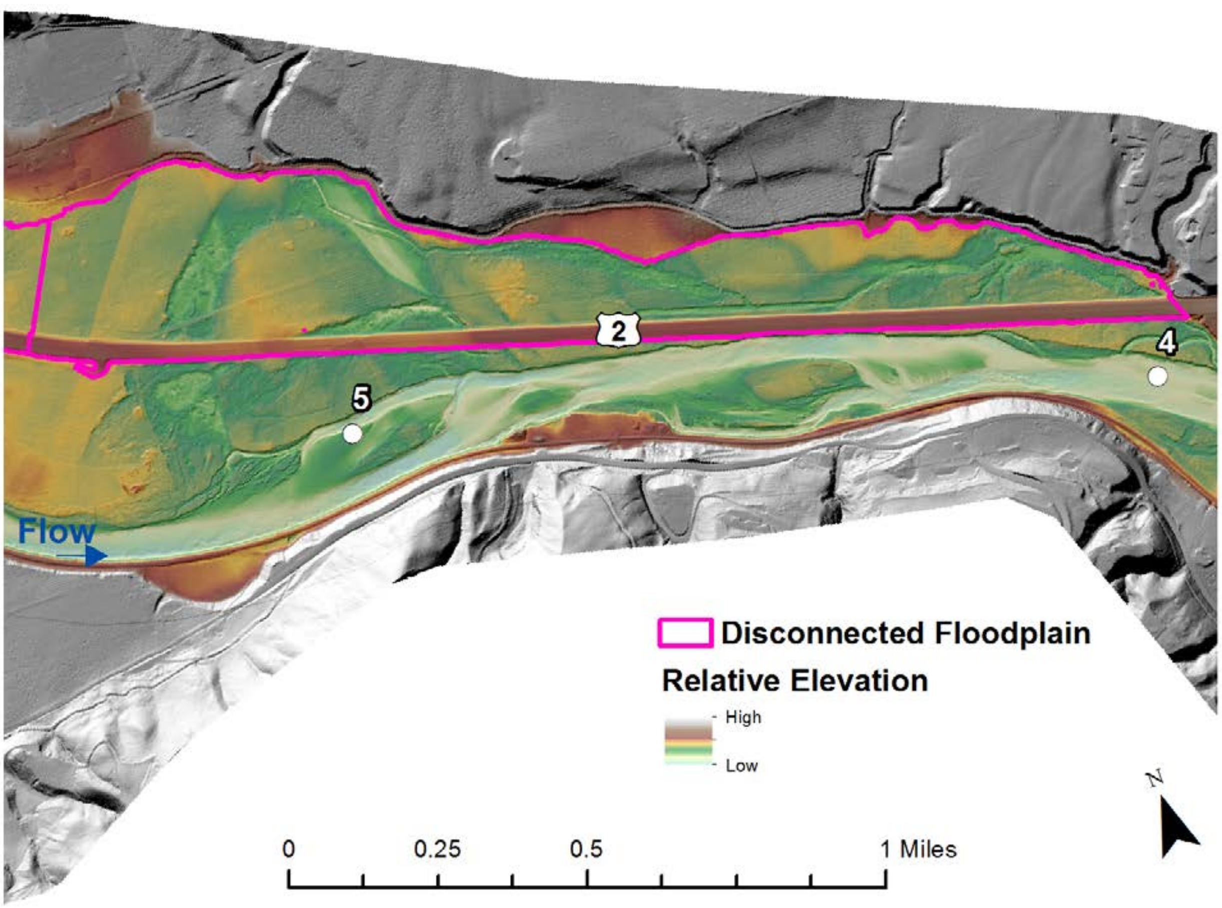


Figure 4-8. Example of Floodplain Disconnected Outer Zone by U.S. Highway 2, in Reach 3

4.4.4 Sediment Characteristics and Flow Competence

Sediment mobility and flow competence were evaluated based on field observations of sediment size distributions (i.e., pebble counts and ocular estimates) and the hydraulic characteristics calculated at hydraulic model cross sections. The existing conditions map series Figures C-1a through C-1k in Appendix C show the location of the four pebble counts taken during field surveys. Ocular estimates of percent sand, gravel, cobble, boulder, and bedrock were also taken at each channel unit during field surveys. Those estimates are summarized by reach in Figure 4-9.

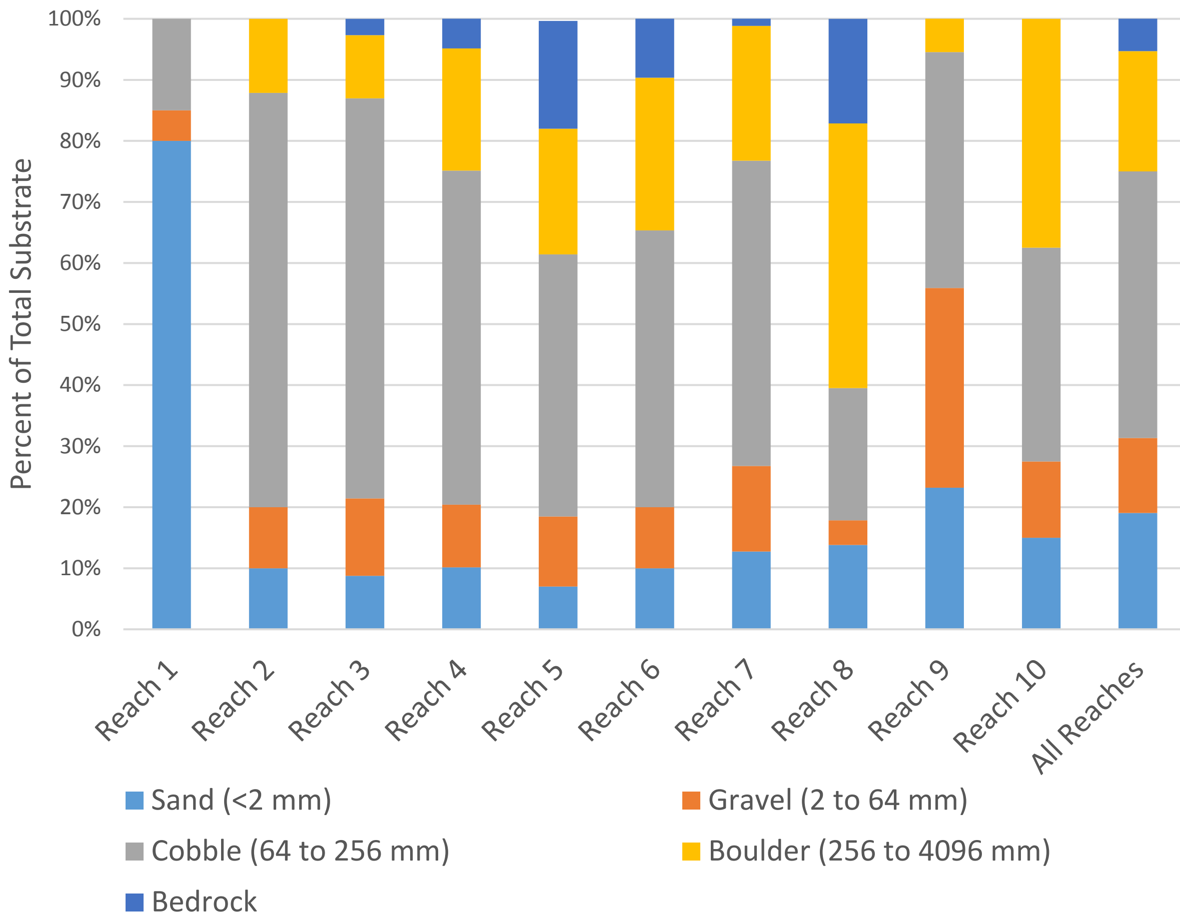


Figure 4-9. Distribution of Substrate Size Classes by Reach for the Lower Wenatchee River

In general, the lower Wenatchee River is cobble-dominated with the exception of Reach 1, where bed sediments transition rapidly from cobble- to sand-dominated, and Reach 9, which transitions from cobble- to gravel-dominated, both in the downstream direction. From Reach 8 downstream, there is a gradual trend of decreasing size in the cobble-dominated substrate. The three field photographs in Figure 4-10 show typical bed sediments in Reach 2, Reach 7, and the downstream end of Reach 9.

Figure 4-10. Photos of Typical Channel Substrate Conditions at 3 Locations Including RM 2.0 in Reach 2 (left), RM 19.1 in Reach 7 (middle), and RM 24.6 in Reach 9

The abrupt sediment size transition in Reach 1 is expected due to the backwater effects of the Columbia River confluence while the transition in Reach 9 is somewhat more complex. As shown in the longitudinal profile in Figure 4-6, Reach 9 is low gradient (0.14 percent), and has a broad, functioning floodplain with little to no confinement. In addition, Reach 9 is directly downstream of a steep transport reach through Tumwater Canyon and has significant flow and sediment inputs from Icicle Creek as well. The result is a high sediment supply and a strongly responsive storage reach with a considerable amount of gravel bars and islands. Reach 9 also exhibits dune-ripple type bedforms, which can be seen in the topobathymetric LiDAR data in some areas. These bedforms are relatively rare in gravel-bed channels but more commonly seen in sand-bed channels. They indicate high flows relative to flow resistance and significant sediment transport at most stages (Montgomery and Buffington 1997).

Boulders are relatively frequent in Reaches 5 through 7, likely deposited in part from ice-rafted glacial sediments, and in Reach 8 where the Wenatchee River has incised through the glacial end moraine deposit at Leavenworth. The photograph in Figure 4-11 shows large instream boulders and bedrock in Reach 8. There are intermittent bedrock grade controls exposed on the river bed, particularly from Cashmere in Reach 4 (RM 10.0) to Leavenworth in Reach 8 (RM 24.5).

Flow competence was evaluated by calculating hydraulic conditions at model cross sections including unit stream power, shear stress, excess shear stress, and threshold of motion grain size, also referred to as incipient motion. Figure 4-12 shows the longitudinal variation in hydraulic conditions throughout the lower Wenatchee River with geomorphic reach breaks and cities shown for context. The hydraulic characteristics are in agreement with the observed sediment size distributions and sediment storage area results described above. Considerable sediment storage in bars and islands is associated with areas of reduced channel confinement and reduced flow competence, particularly in Reaches 1 through 3, 7, and 9 (Figure 4-12).

Figure 4-11. Boulders and Bedrock near RM 22.7 in Reach 8

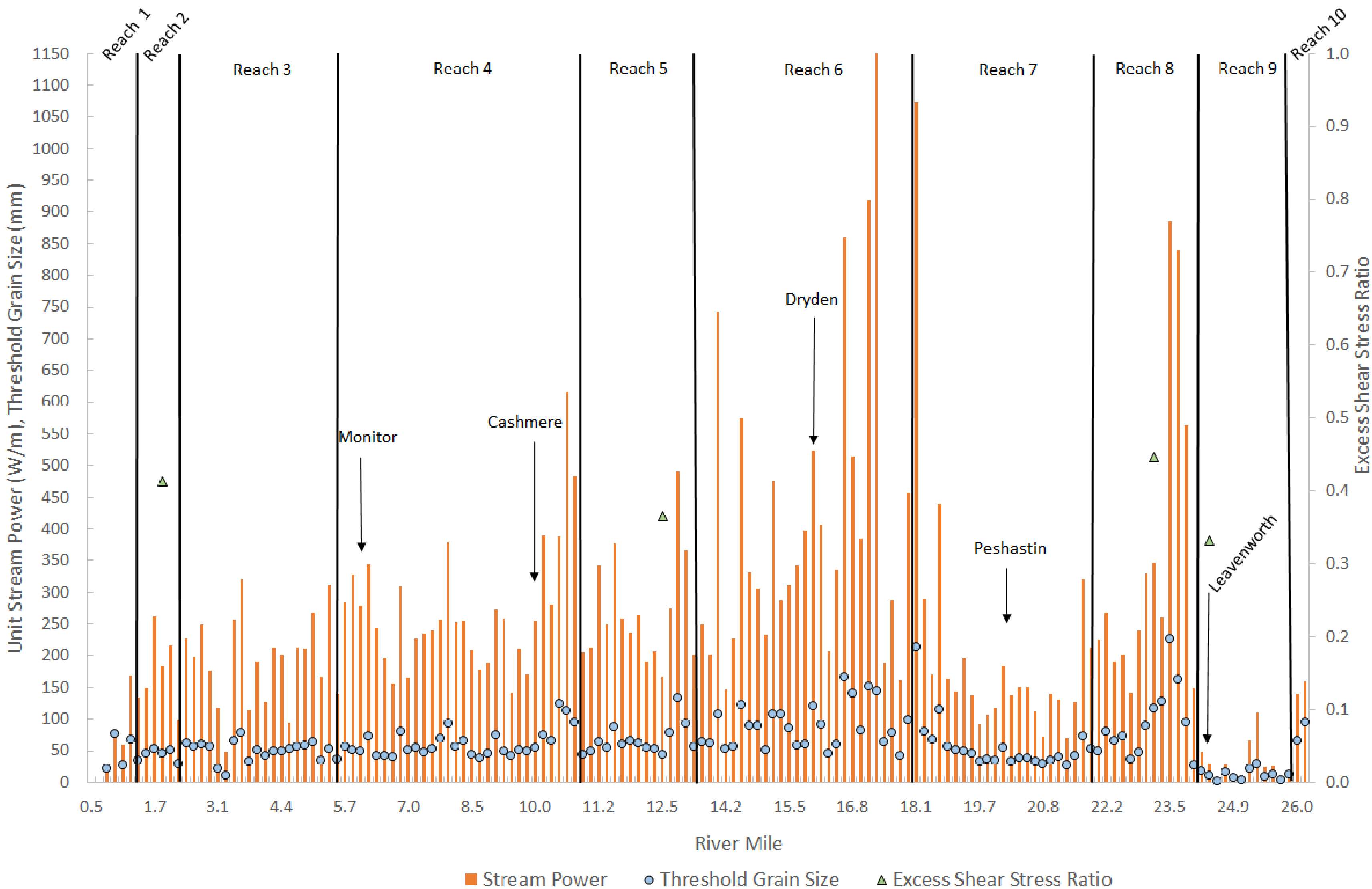


Figure 4-12. Unit Stream Power, Threshold Grain Size, and Excess Shear Stress by River Mile

4.4.5 Large Woody Debris

During field surveys, LWD within the bankfull channel was inventoried following the USFS Level II protocols (USFS 2006). All medium (greater than 12 inches in diameter and 35 feet in length) and large (greater than 20 inches in diameter and 35 feet in length) LWD was tallied within each channel unit. In general, the quantity of LWD is low throughout the lower Wenatchee River and log jams are nearly non-existent.

The quantity of LWD ranged from 1.1 pieces per mile in Reach 2 to 9.9 pieces per mile in Reach 7 (see the REI results for LWD in Appendix D). The quantity of LWD in all reaches was well below the federal target of 20 pieces per mile (USFWS 1998). In addition, Fox and Bolton (2007) determined that standard was low for larger eastern Washington streams (16 to 164 feet bankfull width) in unmanaged forested basins which had an average of over 40 pieces per mile. The Upper Wenatchee River Stream Corridor Assessment found LWD quantities higher than 40 pieces per mile in several reaches with a maximum of over 140 pieces per mile (Inter-Fluve 2012). For the purposes of this analysis, the criterion of 40 pieces per mile for adequate conditions was applied.

Over 95 percent of the LWD inventoried was in the medium size class. Typically, individual pieces of LWD were found intermittently along the bankfull channel margins occasionally in small groups but not in jam configurations. One exception to this was the log jam shown in Figure 4-13 within Reach 8 that was racked on a crossing abutment in a narrow, bedrock controlled part of the river.

Figure 4-13. Photograph of Rare Log Jam Racked on a Crossing Abutment in Reach 8, near RM 22.8

There is considerably more LWD along the lower Wenatchee River stored on the floodplain, on islands, and in abandoned channels than within the bankfull channel. This pattern has been observed in other large river systems (Lassettre and Harris 2001). The floodplain LWD occurs in the greatest abundance in the alluvial reaches with a relatively broad unconfined floodplain, particularly in Reach 3. This LWD is either buried in the floodplain, perched well above the bankfull elevation, or both, and is only engaged at relatively extreme flood events. The photograph in Figure 4-14 shows an example floodplain jam at the inlet of a left bank side channel.

The amount of naturally occurring LWD in side channels and off-channel habitat is likely well below historical levels due to riparian clearing, instream wood removal, and limited upstream recruitment potential. The quantity of LWD historically present in the mainstem lower Wenatchee River is uncertain, however. None of the historical accounts or other data sources reviewed for this assessment included information about the historical abundance of mainstem LWD or log jams.

Previous studies have found that the abundance of instream LWD decreases with basin area in large rivers as a result of increased transport potential (Bilby and Bisson 1998). However, the current conditions in most large rivers of the Pacific Northwest do not accurately represent historical conditions due to widespread modification, riparian clearing, and snag removal (Collins et al. 2002). Qualitative historical records indicate that extensive log jams, sometimes miles in length and channel-spanning, were historically present on many large rivers across North America (Wohl 2013). These jams are believed to have created stable, multi-thread channels and complex floodplain and wetland networks.

Figure 4-14. Photograph of Floodplain Jam at a Side Channel Inlet in Reach 5 at RM 12.0

4.4.6 Channel Units

As described in Section 3.2, Channel unit, or habitat unit, data was collected during field surveys following the USFS Level II protocols (USFS 2006). There are also other existing habitat data sources available, including a recent unpublished field survey completed in 2014 that included detailed geomorphic unit mapping from the Icicle Creek Road Bridge (RM 26.4) downstream to approximately RM 23 and edge habitat mapping throughout the entire lower Wenatchee River (Terraqua 2015). The REI analysis in Appendix D also contains additional channel unit information.

During field surveys for this assessment, mainstem channel units identified included rapids, riffles, glides, scour pools, and dam pools. Side channels were identified as slow water or fast water. In recreational whitewater terminology, much of the lower Wenatchee River between Leavenworth and Cashmere (Reaches 4 through 8) contains class III rapids (American Whitewater 2016). However, habitat data collection protocols define rapids as being greater than 3 percent channel gradient. Channel gradient throughout the lower Wenatchee River is less than 1 percent (see Figure 4-6) except for short sections which are typically still less than 2 percent gradient. The channel units identified as rapids in this survey contained rapid habitat characteristics (e.g. steeper gradient, turbulent flows, exposed obstructions, and whitewater) and were near the gradient threshold. Other short sections of rapid-like habitat that were less than the channel width in Reaches 4 through 8 were not delineated separately.

Most of the lower Wenatchee River is dominated by long riffle and glide channel units. Figure 4-15 shows the distribution of channel units by geomorphic reach. Pool frequency in the lower Wenatchee River ranged from 0.5 to 3.3 pools/mile (see the REI results for pool frequency and quality in Appendix D). As shown in Figure 4-15, Reaches 1 and 10 had the largest percentage of pool habitat; however, that is because Reach 1 is effectively one large backwater dam pool at the confluence with the Columbia River and Reach 10 is short and is dominated by a single, large, scour pool. Reach 8 has the next largest proportion of pool habitat at 34 percent, respectively. Many of the pools in Reach 8 were bedrock-forced pools in this tightly confined reach. Reaches 6 and 8 have the greatest number of pools with residual pool depths exceeding 3 feet.

Even considering the low-flow conditions during field surveys (approximately 400 cfs), a wetted pool depth of over 20 feet was recorded and there were a total of 18 pools over 10 feet deep. Approximately 17 percent of total pools were relatively shallow with residual depths of less than 3 feet. The primary limitation for pool habitat quality in the lower Wenatchee River is a lack of sufficient fish cover associated with pools (e.g., overhanging vegetation, LWD), rather than pool frequency or depth.

The distribution of side channels (fast and slow) varies greatly throughout the lower Wenatchee River, as shown in Figure 4-16. Reaches 2, 8, and 10 contain no side-channel units. Reaches 3 and 9 contain the greatest amount of side-channel habitat, which is expected since they also have more available floodplain and greater floodplain connectivity than the other reaches (see Section 4.4.3). In Reach 9, side channels represent approximately 50 percent of the total channel length. In contrast, side channels represent less that 15 percent of the total channel length in Reaches 4, 6, and 7.

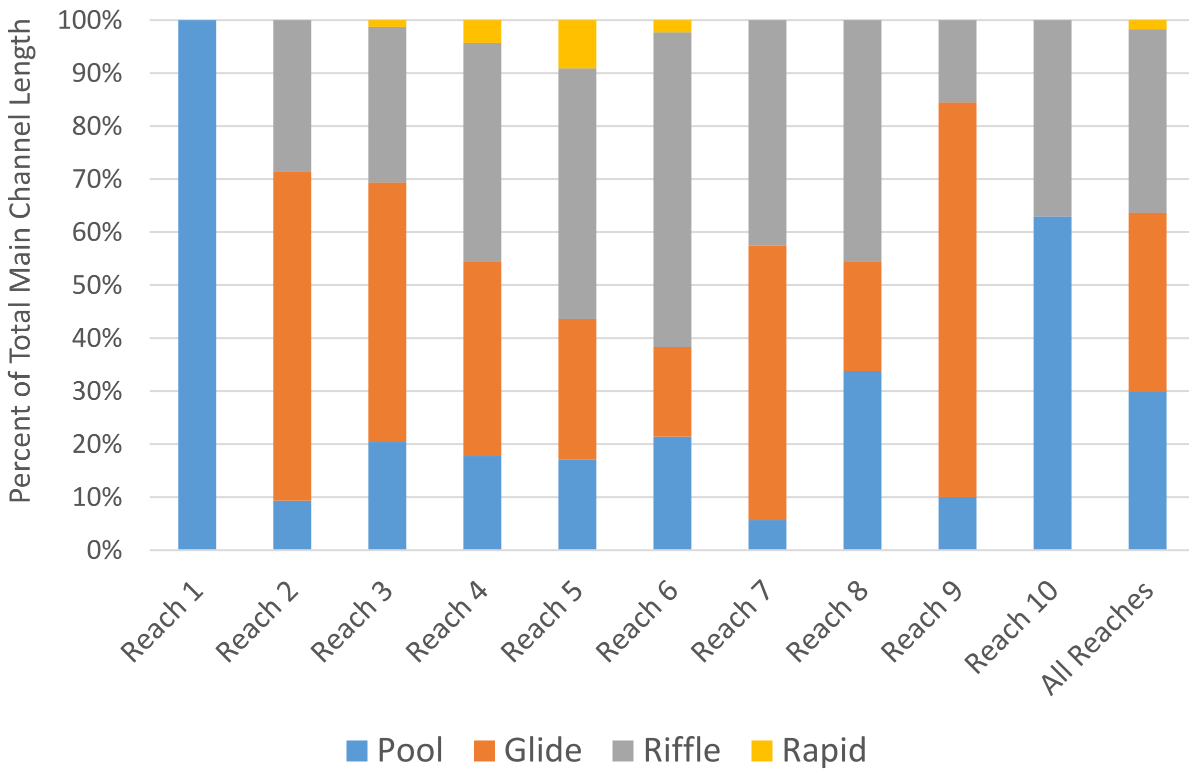


Figure 4-15. Distribution of Channel Units by Reach for the Lower Wenatchee River

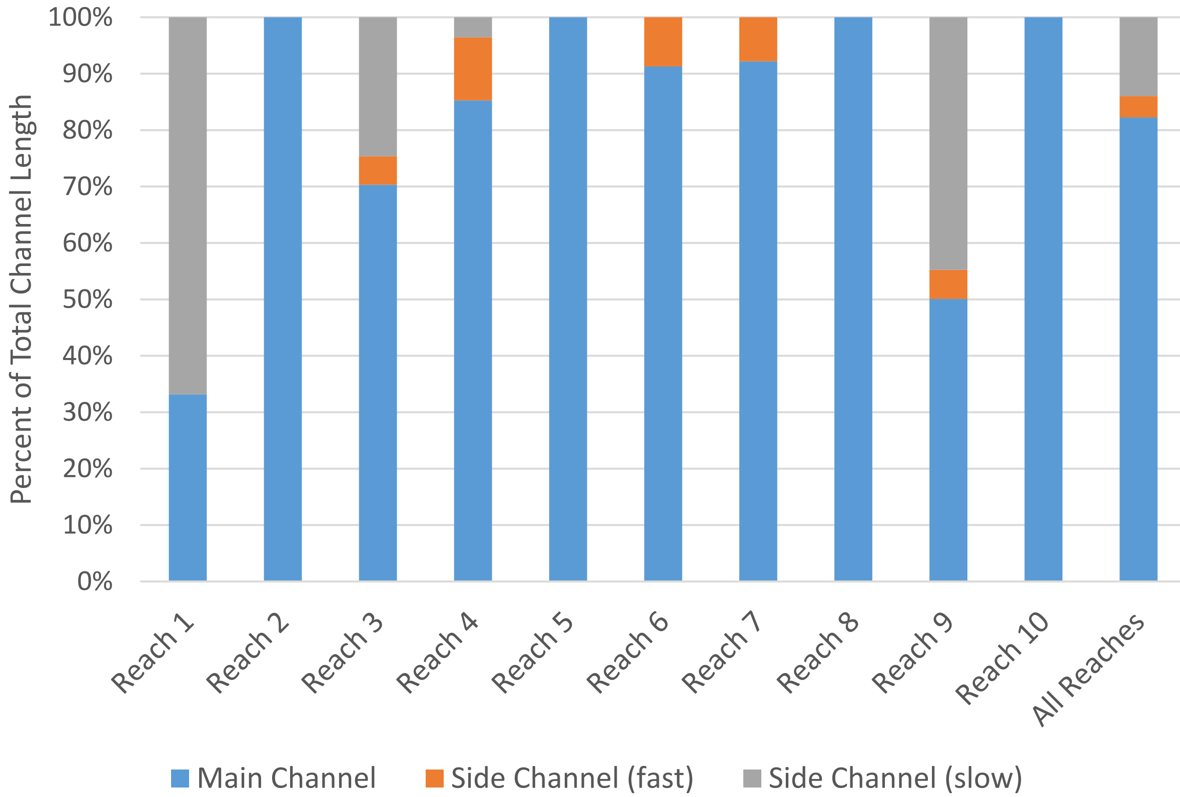


Figure 4-16. Distribution of Main Channel and Side Channel Units by Reach for the Lower Wenatchee River

4.5 Riparian Vegetation

There are several existing reports describing riparian vegetation characteristics and canopy cover along the lower Wenatchee River as well as the absence of vegetation related to human disturbance (Andonaegui 2001; NPCC 2005; Tomlinson et al. 2011). In addition, the aerial photograph analysis included in the Wenatchee River Riparian Vegetation Conditions and River Restoration Opportunities Study (Jones & Stokes 2003) also mapped vegetation conditions, including vegetation type, along the lower Wenatchee River to better understand the change in vegetation conditions over time. They found that human-modified land use dominates the majority of the riparian area including orchards, urban cover, and other similar features (Jones & Stokes 2003). The photograph in Figure 4-17 shows an example of an orchard in the riparian area in Reach 3. The vegetation communities identified in the forested riparian areas were mixed forests, hardwood forest, and valley shrubland (Jones & Stokes 2003).

Figure 4-17. Example of an Existing Orchard in the Riparian Area near RM 7.7 in Reach 4

Riparian vegetation data were collected for each channel unit during field habitat surveys following the USFS Level II protocols (USFS 2006). The data collected included identifying dominant and subdominant vegetation types for overstory and understory, noting if vegetation existed, and estimating size classes based on diameter at breast height (dbh). Figure 4-18 shows the percent of total dominant vegetation that was found to be shrub/seedling, sapling/pole, small trees, or large trees by geomorphic reach. There is a trend of increasing dominant vegetation size in the upstream direction. Saplings and small hardwoods (less than 9 inches dbh) dominate the lower reaches (Reach 1 through 6) with mixed forests and conifers including small (9 to 21 inches dbh) and large trees (21 to 32 inches dbh) dominating in the upper reaches (Reaches 7 through 10). These results indicate very little recruitment potential for large functional trees in the lower Wenatchee River.

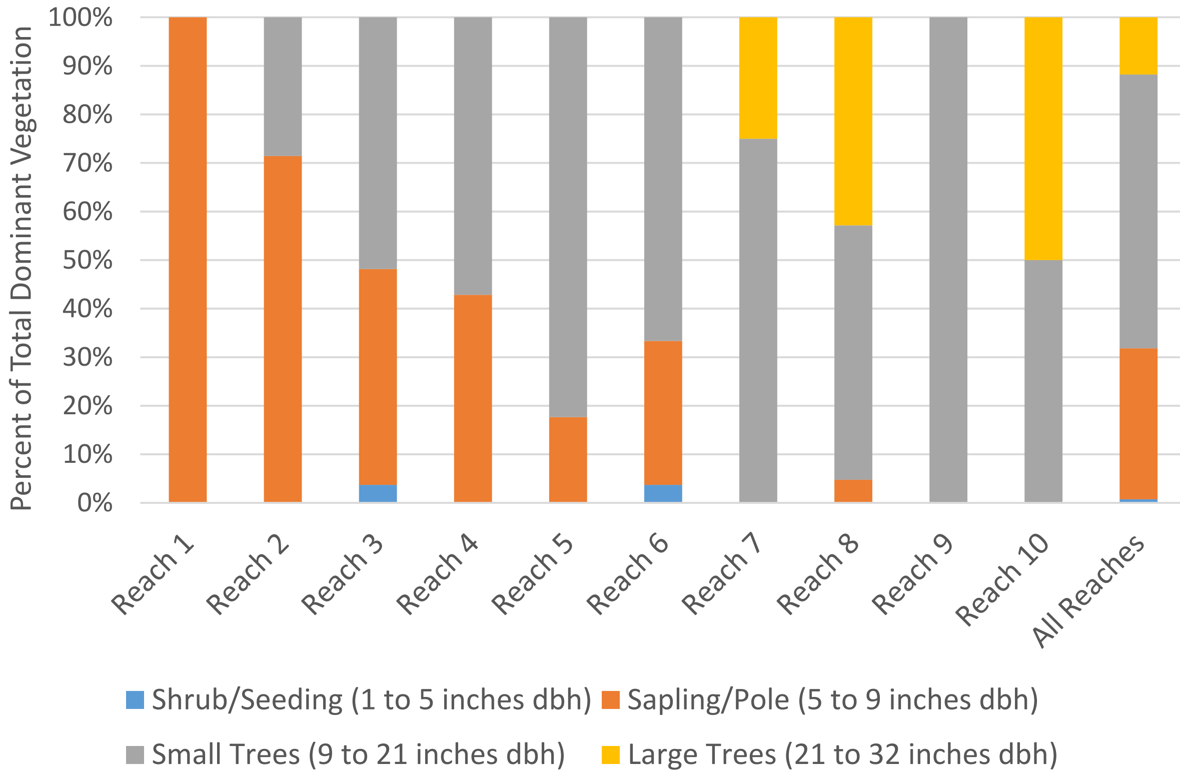


Figure 4-18. Distribution of Dominant Riparian Vegetation Diameter Class by Reach for the Lower Wenatchee River

The REI analysis in Appendix D also contains riparian vegetation information including an analysis of percent canopy cover within the riparian area. The percent canopy cover was low in all reaches, ranging from 11.8 percent in Reach 2 to 30.1 percent in Reach 10. The map series Figures C-4a through C-4k in Appendix C show the highest hit LiDAR difference representing riparian vegetation height for the entire Survey Area.

4.6 Reach-based Ecosystem Indicators

This section presents an overview of the REI results, which are presented in detail in the REI Report (Appendix D). The REI analysis provides a standardized method to summarize habitat impairments and compare geomorphic and ecosystem functionality. Each metric is evaluated against USFWS and USBR criteria and rated adequate, at risk, or unacceptable.

At the watershed scale, the REI includes an assessment of road density, natural and human-caused disturbance regime, and alteration of the natural hydrologic regime (peak/base flow). For road density, the Wenatchee River watershed is rated unacceptable, and is rated at risk for the disturbance and hydrologic regime metrics. This is a reflection of historical and ongoing human activities and development in the area (Appendix D).

Reach-scale results for 11 specific indicators are summarized in Table 4-12. All reaches in the Survey Area are considered adequate for main channel barriers. Pool frequency and quality is considered at risk across the board, and both LWD pieces/mile and canopy cover are rated unacceptable throughout the Survey Area. Overall, Reaches 4 and 5 have the most unacceptable ratings (7 out of 11), followed closely by Reaches 1 and 6. Conversely, Reach 8 has the most adequate (5) and fewest unacceptable (2) REI ratings, followed by Reach 10.

Table 4-12. Reach-Based Ecosystem Indicator (REI) Ratings

General Characteristics	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Habitat Assessment	Physical Barriers	Main Channel Barriers	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
Habitat Quality	Substrate	Dominant substrate/Fine sediment	Unacceptable	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	At risk	Adequate	At risk
	LWD	Pieces/mile at bankfull	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	Pools	Pool frequency and quality	At risk	At risk	At risk	At risk	At risk	At risk	At risk	At risk	At risk	At risk
	Off-Channel Habitat	Connectivity with main channel	At risk	Unacceptable	At risk	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Adequate	At risk	Adequate
Channel	Dynamics	Floodplain connectivity	Unacceptable	Adequate	At risk	At risk	At risk	At risk	Adequate	Adequate	At risk	Adequate
		Bank stability/Channel migration	Unacceptable	Adequate	Unacceptable	Unacceptable	Unacceptable	Unacceptable	At risk	Adequate	Adequate	Unacceptable
		Vertical channel stability	Adequate	At risk	Unacceptable	Unacceptable	Unacceptable	At risk	Adequate	Adequate	At risk	Adequate
Riparian Vegetation	Condition	Structure	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	At risk	Unacceptable	At risk
		Disturbance (human)	At risk	At risk	At risk	Unacceptable	Unacceptable	Unacceptable	At risk	At risk	At risk	At risk
		Canopy cover	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable

Adequate At risk Unacceptable

4.7 Climate Change Impacts

Washington State has already experienced long-term warming, a longer frost-free season, more frequent nighttime heat waves, declining glacial area and spring snowpack, and earlier peak stream flows than historically seen. By the 2050s, the average annual temperature in Washington is expected to increase by 2 to 8.5°F, and by the 2040s average April 1 snowpack could decrease by 38 to 46 percent relative to historical (1916-2006) conditions. Changes in the timing of water availability are expected to have broad ecological and socioeconomic consequences due to numerous competing demands in the state, including for instream flow management for salmonids and agriculture (Snover et al. 2013).

Results from the Columbia Basin Climate Change Scenarios Project indicate dramatic changes in spring snowpack and a shift from snow and mixed-rain-and-snow to rain-dominant systems across most of the Pacific Northwest (Hamlet et al. 2013). Corresponding shifts in streamflow from spring and summer to winter are likely for basins that currently experience large winter snow accumulation (Hamlet et al. 2013). For the Wenatchee River subbasin specifically, models show it shifting to a mixed rain-snow system (Tohver et al. 2014). For areas on the east side of the Cascades, such as the lower Wenatchee River, climate models do not show a significant decrease in late summer base flows; however, this is due to the very low late summer flows that occur under current conditions, therefore increasing drought stress cannot significantly decrease base flows in the simulations (Tohver et al. 2014).

In most rivers in the Pacific Northwest, stream temperatures are expected to increase, and the threat to salmon recovery is high where temperatures are currently near tolerance thresholds for salmon. Changes in stream flow and temperature will effect species differently as they occupy different habitats and vary in timing of life history events, leading to varied exposure to altered conditions (Beechie et al. 2013).

In a 2010 study specifically focused on the Wenatchee River, model results indicate that the average daily maximum temperature could increase by 1 to 1.2 degrees Celsius (°C) by the 2020s, by 2°C in the 2040s, and 2.5 to 3.6°C in the 2080s, peaking at 27 to 30°C in the warmest reaches (Cristea and Burges 2010). This is well above Washington State fresh water temperature limits for fish, which range from 12°C to 20°C (highest 7-day average of daily maximum temperatures), depending on lifestage and species (WAC 173-201A-200).

Figure 4-19 presents recent modeling results for changes in mean August stream temperature and mean summer flows along the lower Wenatchee River. Both datasets use the global climate model A1B emissions scenario for the future periods, representing a medium warming scenario (USFS 2015a, 2015b; Cristea and Burges 2010). The trend toward warmer stream temperatures and lower summer flows is clear, and will compound existing ecological concerns for threatened and endangered fish species.

However, analysis of the combined effects of climate change and habitat restoration indicates that restoration projects are likely to result in a net benefit to salmonids even with future shifts in temperature and hydrology (Battin et al. 2007). Restoration actions that increase habitat diversity so that salmon are able to follow alternative life history strategies could potentially increase the resilience of populations to climate change (Beechie et al. 2013). The strategies presented in Section 5 were developed with an understanding of the predicted local climate change impacts described above.

4.8 Reach Assessment Results Summary

This reach assessment utilized aerial photography, topobathymetric LiDAR data, historical information, geologic mapping, hydrology and hydraulic modeling, geomorphic analyses, REI analyses, a climate change assessment, and other data sources to evaluate historic, current, and potential future conditions in the lower Wenatchee River. The data and analyses were used to characterize conditions with respect to channel migration, channel evolution, floodplain connectivity, sediment transport dynamics, the role of LWD, and the impact of land use practices (historical and current) on reach-scale processes.

In general, the results demonstrate the primary drivers on the processes and form of the lower Wenatchee River are post-glacial downcutting of the river through moraine, glacial outwash, and outburst-flood deposits, and channel and floodplain modifications related to riparian clearing, instream wood removal, road-building, levees, bank protection, urban and residential development, agriculture, the BNSF Railway, and other development.

The results illustrate that there are unique characteristics in each of the 10 distinct geomorphic reaches of the lower Wenatchee River that can be used to evaluate potential restoration actions to develop effective, long-lasting solutions to address limiting factors for ESA-listed species. In general, purely alluvial reaches with more available floodplain, relatively low levels of natural confinement, and existing floodplain areas identified as being suitable for potential restoration actions were found to have the most restoration potential. Restoration potential was more limited in confined reaches with limited floodplain and large substrate. These results were used to identify and refine the project opportunities and the potential restoration actions described in the restoration strategy (Section 5). Reach-scale restoration strategies are described in Section 5.2.

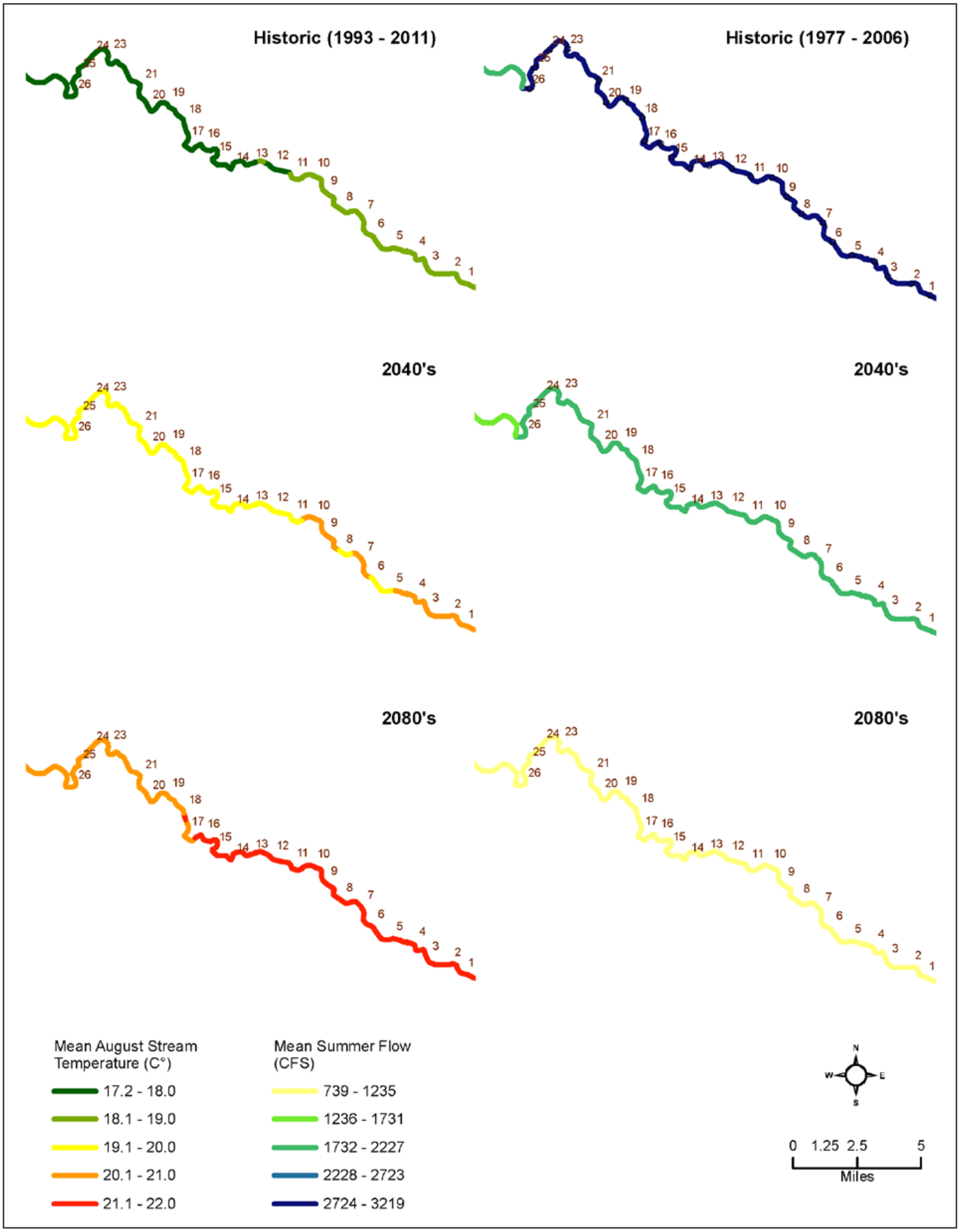


Figure 4-19. Modeled Historical and Future Climate Change Scenario Mean August Stream Temperatures and Mean Summer Flows along Lower Wenatchee River (Data Source: USFS 2015a, 2015b)

5. RESTORATION STRATEGY

The restoration strategy described below provides the framework for targeted and effective habitat restoration in the lower Wenatchee River. The strategy utilizes the technical information gathered from the stream habitat, geomorphic, hydraulic, and REI analyses to identify and prioritize specific project opportunities and effective restoration actions at those sites. The restoration strategy describes existing and target conditions based on historical information, habitat needs of the fish species of concern, and properly functioning conditions identified by the REI analysis. Project opportunities and restoration actions identified are those that could achieve target habitat conditions.

The following subsections describe specific elements of the restoration strategy including existing and target habitat conditions (Section 5.1), reach-scale restorations strategies (Section 5.2), identifying project opportunities and potential actions (Section 5.3), and prioritization and scoring of project opportunities (Section 5.4). Section 5.5 provides a summary of the information provided in this section. The next steps for implementing the restoration strategy are discussed in Section 6.0.

5.1 Existing and Target Habitat Conditions

Existing geomorphic and habitat conditions for the lower Wenatchee River were described in Section 4.0 of this document. Target habitat conditions have been developed based on the REI assessment in Appendix D, the Matrix of Diagnostics/Pathways and Indicators (USFWS 1998), the NMFS Matrix of Pathways and Indicators (NMFS 1996), as well as more recent work conducted within the region by the USBR and their adaptation of these indicators (USBR 2012). Table 5-1 includes brief a summary of existing and target REI conditions, identifies the primary ecological concerns (also commonly referred to as limiting factors), and lists the recommended restoration action types that would address the ecological concerns and lead to target conditions. Restoration action types are described in Section 5.3.

Table 5-1. Summary of Existing and Target Conditions, Restoration Actions and Ecological Concerns Addressed

Specific Indicator	Reaches Included	Existing Condition	Target Condition[2/]	Primary Ecological Concerns Addressed (UCRTT 2014)	Restoration Action Type[3/]
Disturbance (human)	All Reaches	Land use actions have degraded channel complexity and habitat availability.	High quality habitat and watershed complexity providing refuge and rearing space for all lifestages or multiple life-history forms. Natural processes are stable.	Riparian Condition Peripheral and Transitional Habitats (side channel and wetland connections)	Riparian restoration, floodplain habitat reconnection, tributary restoration, modify existing levees and bank protection, Install habitat structures
Change in Peak/Base Flows	All Reaches	Water diversions and potential climate change impacting peak/base flows.	Magnitude, timing, duration and frequency of peak/base flows are not altered relative to natural conditions.	Water Quantity (decreased water quantity)	Protect and maintain habitat, riparian restoration, floodplain habitat reconnection, tributary restoration
Main Channel Barriers	All Reaches	Functioning fish passage facilities at Dryden Diversion Dam. No other manmade mainstem barriers.	No manmade barriers present in the mainstem that limit upstream or downstream fish passage at any flows.	N/A	No action
Dominant substrate/Fine sediment	1, 8, and 10	Fine sediment dominates substrate in lower Reach 1. Reaches 8 and 10 have coarse boulder substrate.	Dominant Substrate is gravel or cobble (interstitial spaces clear), or embeddedness < 20%, <12% fines (<0.85 mm) in spawning gravel or <12% surface fines of <6 mm.	N/A	No action[1/]
Pieces/mile at bankfull	All Reaches	LWD quantities ranging from 0 to 10 pieces/mile.	Greater than 20 pieces/mile >12" dbh > 35' length; and adequate sources of woody debris available for both long- and short-term recruitment.	Channel Structure and Form (instream structural complexity)	Install LWD habitat structures, riparian restoration
Pool frequency and quality	All Reaches	Pools are relatively abundant and deep but lack cover.	Pools have good cover and cool water and only minor reduction of pool volume by fine sediment; each reach has many large pools > 1 m deep with good cover.	Channel Structure and Form (instream structural complexity)	Install LWD habitat structures
Off-channel Habitat	Reaches 1 through 7 and 9	Channel incision and development have considerably reduced the amount of adequate off-channel habitat available.	Reach has ponds, oxbows, backwaters, and other low-energy off-channel areas with cover; similar to conditions that would be expected in the absence of human disturbance.	Peripheral and Transitional Habitats (side channel and wetland conditions)	Riparian Restoration, floodplain habitat reconnection, install LWD habitat structures

Table 5-1. Summary of Existing and Target Conditions, Restoration Actions and Ecological Concerns Addressed (continued)

Specific Indicator	Reaches Included	Existing Condition	Target Condition[2/]	Primary Ecological Concerns Addressed (UCRTT 2014)	Restoration Action Type[3/]
Floodplain connectivity	Reach 1 and 3 through 6	Floodplain connectivity has been considerably reduced due to land use activities and development.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession.	Peripheral and Transitional Habitats (side channel and wetland conditions) Water quality (temperature)	Riparian Restoration, floodplain habitat reconnection, modify existing levees and bank protection, install habitat structures
Bank stability/Channel migration	Reach 1, 3 through 7, and 10	The presence of levees, roads, highways, and railways, and other bank protection limit channel migration.	Channel is migrating at or near natural rates.	Channel Structure and Form (bed and channel form)	Modify or enhance existing levees and bank protection, install habitat structures
Vertical channel stability	Reaches 1 through 6	Land use, development, and natural post-glacial incision.	No measurable trend of aggradation or incision and no visible change in channel planform.	Channel Structure and Form (bed and channel form)	Riparian restoration, modify existing levees and bank protection
Riparian Structure and Canopy Cover	All Reaches	Riparian clearing for agriculture and development have dramatically reduced functional riparian area.	Greater than 80% species composition, seral stage, and structural complexity are consistent with potential native community. Trees and shrubs within one site potential tree height distance have >80% canopy cover that provides thermal shading to the river.	Riparian Condition	Riparian Restoration

1/ No action restoration actions were developed for dominant substrate fine sediment because in Reach 1 fine sediment the result of the backwater effect from the Rock Island Dam on the Columbia River, and in Reaches 8 and 10 they are believed to be natural conditions.

2/ Target conditions was defined as the “adequate” condition for REI criteria (see Appendix D).

3/ See Sections 5.3.1 to 5.3.7 for full descriptions of restoration actions types.

5.2 Reach-Scale Restoration Strategies

This section provides a narrative overview of the reach-scale restoration strategies within each of the geomorphic reaches. Appendix E contains a description and rationale for each of the 38 individual project opportunities including potential restoration actions and project opportunity rankings, which are described in Section 5.4.

Reach 1: There are two site-specific project opportunities and many potential restoration actions suitable for Reach 1, a number of which have been previously documented in Wooten and Morrison (2008). This reach has the highest percent of disconnected floodplain of all the reaches on the lower Wenatchee River, which is primarily due to floodplain modifications on the right bank at Confluence State Park. Although the current series of constructed wetlands in the park do provide an asset for the community, they are limited in that natural hydrological and ecological processes are not maintained because they are disconnected from river flooding and occupation by native species. Additional wetlands have been created by inundation of the area resulting from the Rock Island Dam reservoir, which do provide some habitat to wildlife (Wooten and Morrison 2008). A focus of the restoration strategy for this reach should be reconnecting this floodplain habitat with distributary channels and installing habitat structures. This would increase the movement of water, nutrients, and sediment in the system and recover natural processes. The reintroduction of beavers could also increase complexity and provide cover. Riparian restoration should also be a focus in this reach including removing invasive species and supplemental planting of beneficial native species.

Reach 2: Reach 2 has only two project opportunities identified because the reach is short and relatively confined by steep hillslopes on the right bank and high glacial terrace on the left bank. However, there are floodplain habitat reconnection opportunities in the upper extent of the reach and tributary restoration potential. The Highline Ditch return is within this reach and currently flows in a straight, concrete canal across the Wenatchee River floodplain. Restoration action alternatives to be considered for this opportunity are removing the canal and reconstructing a more natural channel or using the return flows to feed an off-channel habitat project. There are also riparian restoration opportunities in this reach.

Reach 3: With 10 project opportunities identified, Reach 3 likely has the greatest potential for restoration in the lower Wenatchee River. There is high geomorphic potential and existing conditions are considerably impacted based on the reach assessment and REI results. The restoration strategy for Reach 3 should be focused on actions that reconnect historical floodplains that are currently disconnected and enhancing off-channel and side channel habitat where connectivity has been reduced due to channel incision. In addition to off-channel and side channel creation or enhancement, the restoration actions identified to reconnect floodplain habitats in the reach include the potential for groundwater collection fed off-channel habitat, and reconnecting historical meanders. Protecting the floodplain from future development through acquisitions, easements, or cooperative agreements should also be a focus within this reach. The primary restoration action types for this reach are protect and maintain habitat, riparian restoration, floodplain habitat reconnection, modify existing levees and bank protection, and install habitat structures.

Reach 4: There are 10 project opportunities identified in Reach 4, and the geomorphic potential is relatively high although the potential constraints tend to be higher. Because the reach includes the cities of Monitor and Cashmere, a considerable amount of urban development and infrastructure occurs within the historical floodplain. The reach has the second highest percent of floodplain disconnected at 66 percent, and the highest percent of armored banks at 27 percent. In addition, there are existing levees protecting the city of Cashmere and its wastewater treatment facilities. The restoration strategy in Reach 4 should be focused on protecting the floodplain from future development through acquisitions, easements, or cooperative agreements, and modifying or removing bank protection and levees, were feasible. Riparian restoration should also be a focus of the restoration strategy in this reach. The channel bed lacks complexity and is relatively uniform and featureless in many parts of the reach. Installing habitat structures to create local scour pools and increase the instream habitat complexity should also be considered.

Reach 5: Limited restoration opportunities exist in Reach 5. Bedrock grade controls, as well as the combination of natural and artificial channel confinement, result in a stable channel with a limited historical floodplain in isolated areas resulting. Overall, geomorphic potential in Reach 5 is low. The focus of the restoration strategy in Reach 5 should primarily be riparian restoration. However, there was one project opportunity in Reach 5 for floodplain habitat reconnection that is relatively small but has good potential for improving off-channel habitat in a reach where it is very limited.

Reach 6: Similar to Reach 5, Reach 6 is laterally confined by a combination of natural (including high glacial terraces), and artificial features (roads, railroads). Bedrock controls vertical grade, resulting in a stable channel. However, there is greater geomorphic potential and several project opportunities identified to reconnect floodplain habitat in Reach 6. The stepped-terrace landforms in this reach suggest lateral migration during post-glacial incision in this reach, which has resulted in accessible floodplain habitats, particularly on the inside of meander bends. Multiple crossings of U.S. Highway 2 and the BNSF Railway limit floodplain connectivity in this reach. Although potential project opportunities tend to be smaller in Reach 6 than in other reaches, a total of eight project opportunities were identified that cover a wide range of potential restoration actions. The focus of the restoration strategy in Reach 6 should include: protecting the floodplain from future development through acquisitions, easements, or cooperative agreements; reconnecting historical floodplains that are currently disconnected and enhancing off-channel and side channel habitat (which may require modification of infrastructure in the floodplain); riparian restoration; and installing habitat structures. Reach 6 also includes a project opportunity on lower Peshastin Creek at the confluence.

Reach 7: Restoration opportunities are somewhat limited in Reach 7 and geomorphic potential is relatively low. This reach is confined by high glacial terraces and hillslopes with relatively small, infrequent areas of floodplain. Development and infrastructure have much less of an impact on the geomorphology of Reach 7 than in downstream reaches as they are primarily located on high terraces. Two project opportunities have been identified in this reach. The focus of the restoration strategy in Reach 7 should be to protect and maintain the existing functional riparian forests and riparian restoration. The existing riparian areas in this reach contain more conifers and a larger proportion of large trees than in downstream reaches.

Reach 8: Reach 8 is highly confined and stable, and the substrate is dominated by boulders and bedrock, and therefore, the geomorphic potential is naturally low. No site-specific project opportunities were identified in this reach. The focus of the restoration strategy in Reach 8 should be to protect and maintain the existing functional riparian forests, and possibly expand them where encroachment by agriculture occurs. Reach 8 has the second largest proportion of large trees in the lower Wenatchee River and the forests are dominated by conifers. These forests have the potential to provide much needed LWD recruitment in the future.

Reach 9: Reach 9 has several project opportunities and high geomorphic potential as illustrated by the floodplain connectivity and inundation, and sediment results from the reach assessment. The conditions in Reach 9 are notably different from all the other reaches on the lower Wenatchee River. This reach is a low-gradient response reach downstream of Tumwater Canyon that has a broad, well-connected floodplain, gravel-dominated substrate, and a more complex network of side channels and off-channel habitat. The primary focus of the restoration strategy in Reach 9 should be to enhance and/or reconnect off-channel and side-channel habitat and install habitat structures. The restoration strategy in this reach should also focus on protecting the floodplain from future development (through acquisitions, easements, or cooperative agreements) and riparian restoration.

Reach 10: Reach 10 is a short, stable transport reach where the Wenatchee River exits Tumwater Canyon. Geomorphic potential is low in this reach and no site-specific project opportunities were identified. Potential exists for general restoration activities as described in Section 5.3, but at a small scale. The focus of the restoration strategy in Reach 10 should be to protect and maintain the existing functional riparian forests. Reach 10 has the greatest proportion of large trees in the lower Wenatchee River and the forests are dominated by conifers. These forests have the potential to provide much needed LWD recruitment in the future.

5.3 Project Opportunities and Potential Actions

Potential restoration projects and project actions are grouped into resource preservation and land management, described in Section 5.3.1, and instream and floodplain restoration, described in Section 5.3.2. Resource preservation and land management actions identified for the lower Wenatchee River include land and water preservation, instream flow and water quality management, and beaver management. Instream and floodplain actions identified for the lower Wenatchee River include riparian restoration, floodplain restoration and reconnection, side channel and off-channel habitat restoration, tributary restoration, modifying existing levees and bank protection, and installing habitat structures.

5.3.1 Resource Preservation and Management

In addition to the specific instream and floodplain restoration projects that have been identified, there are restoration actions that may be applied more generally throughout the lower Wenatchee River. The following sections contain a description of the types of proposed preservation and management actions identified for the lower Wenatchee River. The potential to incorporate any or all of these actions into the specific project opportunities should also be considered, where applicable.

Land and Water Preservation

Protection and maintenance actions involve preservation of existing functional floodplain and riparian habitats. These actions may be accomplished through purchase of lands or acquisition of conservation easements from the landowners in areas containing existing functional habitat and/or physical processes. Purchases or easements would be achieved to limit or eliminate anthropogenic activities within riparian areas and adjacent uplands. These actions generally would not include areas where floodplain and riparian habitat and/or physical processes have previously been compromised by human influence. In some cases, protection and maintenance objectives might be achieved through long-term management plans.

Instream Flow and Water Quality Management

Decreased water quantity was identified as a priority ecological concern for the lower Wenatchee River in the revised Biological Strategy (UCRTT 2014). Restoration actions to address decreased water quantity include irrigation efficiency improvements, water storage, and water right negotiations. Instream flow management can also address injury and mortality (mechanical injury) by eliminating or reducing mechanical injury to target fish species at diversion structures. The following recommendations for increasing water quantity were identified in the revised Biological Strategy (UCRTT 2014):

- Water right purchase and lease
- Water banking

- Conversion of small pumps to wells
- Improving irrigation efficiencies
- Changing point of diversion to Columbia River, where feasible (e.g., Wenatchee Irrigation District)

Water quality, specifically temperature, was also identified as a priority ecological concern for the lower Wenatchee River in the revised Biological Strategy (UCRTT 2014). Restoration actions to improve water quality include the implementation of the TMDL Water Quality Implementation Plan (Ecology 2009), planting native riparian vegetation and removing invasive species, preserving existing undeveloped areas, and acquiring key properties in the floodplain for protection measures.

Other restoration actions to reduce point and non-point sources of pollution in the lower Wenatchee River should be considered, where feasible. Those sources include the two wastewater treatment facilities in Peshastin and Cashmere (which are considered point sources of phosphorus) as well as landfills, on-site septic systems on the floodplain, trash dumps in Dryden and Cashmere, the Dryden community septic drain field, agricultural runoff, and a number of other potentially leaking waste/sewer systems.

Beaver Management

Historically, beaver were very abundant throughout the lower Wenatchee River floodplain and contributed considerably to habitat diversity and ecosystem function. The reintroduction of beavers may assist in addressing several of the ecological concerns identified in the revised Biological Strategy (UCRTT 2014), including side channel and wetland connections, water quantity and quality, and riparian condition.

The reintroduction of beavers is complicated, particularly in populated areas with significant infrastructure and development. Beaver reintroduction may be addressed through the development of a beaver restoration management plan. Such a plan should include analysis of potential flooding concerns when infrastructure is present, along with possible impacts to newly planted riparian areas.

5.3.2 Instream and Floodplain Restoration

Instream and floodplain restoration project actions were identified during field surveys and further refined throughout the reach assessment development process. The identification of potential projects also considered previously completed restoration actions and potential actions that have been identified as part of past efforts. Within the Survey Area, a total of 38 distinct instream and floodplain restoration and enhancement project areas were identified. Appendix E contains a description and rationale for each of the 38 project areas including potential restoration actions and project rankings, which are described in Section 5.4. Project area extents and potential restoration actions are included in the Project geodatabase (Appendix F). The following subsections contain a description of the types of proposed restoration actions identified for the project areas.

Riparian Restoration

Riparian restoration actions are identified in areas that have been significantly impacted by agricultural, or residential and urban development. These areas contain native riparian vegetation that has been compromised or is no longer properly functioning. The intent of these actions is to enhance or re-establish riparian vegetation communities along the stream, to increase riparian habitat diversity, restore canopy cover to increase stream shading, and increase the likelihood of large wood recruitment. These actions may be accomplished through removal of invasive plant species, replanting with native riparian plants, and providing protection where needed. The Wenatchee River Riparian Vegetation Conditions and River Restoration Opportunities Study (Jones & Stokes 2003) has also previously identified a number of site-specific areas where riparian restoration opportunities exist.

Floodplain Restoration and Reconnection

As previously noted, decreased water quantity in the lower Wenatchee River was identified as a priority ecological concern in the revised Biological Strategy (UCRTT 2014). A properly functioning floodplain acts as an extension of the alluvial aquifer, attenuating stream flows as floodwaters disperse onto the floodplain and discharging stored water during drier months. Connected floodplains regulate stream flows, water temperature, and water quality. Floodplain groundwater discharge to streams provides cool water areas for rearing fish, and floodplain groundwater storage has also been shown to attenuate peak flows (Acreman et al. 2003).

Where possible, floodplain infrastructure should be relocated or removed to eliminate physical features disconnecting the floodplain. Restoring or enhancing wetlands and springs is also an important aspect of floodplain restoration. Since wetlands store water during periods of heavy precipitation and then release it slowly, they provide important buffering of both water quantity and quality (Hammersmark et al. 2008). This slow release of cooled water during summer periods of low flow and warm temperatures provides thermal refugia for target fish species. Beaver reintroduction may also assist with restoring and reconnecting the floodplain.

Side Channel and Off-Channel Habitat Restoration

Side channel and wetland connections in the lower Wenatchee River were identified as the highest priority ecological concern in the revised Biological Strategy (UCRTT 2014). Side channels and off-channel areas provide important rearing habitat for target fish species. Martens and Connolly (2014) found higher densities of salmonids in seasonally disconnected, partially connected, and fully connected side channels than in mainstem channels. Restoration actions to restore or enhance side channel and off-channel habitat include reconnecting or constructing perennial side channels, secondary channels, floodplain ponds, wetlands, alcoves, and groundwater-fed off-channel habitat.

The removal of constraining features on the floodplain may allow for natural inundation of existing perennial and ephemeral side channels and wetlands. Roni et al. (2002) found that projects involving reconnection of existing off-channel habitats had a higher probability of success than projects creating entirely new off-channel habitat. These types of restoration actions might be classified as full restoration because they restore natural processes (Beechie et al. 2010).

The focus of actions related to floodplain habitat reconnection is to identify and restore areas where existing floodplain habitat, including side-channels, off-channel habitat, abandoned meanders, and other features have been disconnected from the main stream channel. These areas provide an immediate increase in habitat quantity, complexity, and diversity by reestablishing previously inaccessible or under-utilized habitat. These actions may be accomplished through site-specific excavations intended to reconnect relic side channels, or grading of floodplain topography, and normally would also include associated actions such as large wood placements and riparian plantings. Floodplain habitat reconnection actions may include modifications to existing restoration project sites to increase instream flow connectivity, habitat diversity, and riparian habitat complexity.

Alcoves, which are off-channel habitat areas connected to the main channel only at the outlet, also provide high-quality off-channel habitat for juvenile salmonids, refugia during flood flows, and year-round thermal refuge. They also have a propensity for fine material deposition, which may also support lamprey habitat. Tributary junctions and groundwater seeps and springs are ideal locations for alcoves because of the consistent source of cooled groundwater.

Tributary Restoration

Tributary restoration actions may be located at the confluence with existing tributary channels where there is potential of significantly increasing the quantity and quality of instream habitat complexity. These projects can be achieved through any combination of channel realignment, habitat creation or reconnection, large wood placement, and riparian plantings. The goals of these actions are to improve access and provide increased rearing capacity and refugia in close proximity to the mainstem river.

Modify Existing Levees and Bank Protection

These restoration actions may be located in areas where existing levees and/or bank protection structures are providing bank stability or flood control, but otherwise provide little to no habitat benefit to the system and limit natural channel processes. The objective of the modification actions is to increase the instream habitat complexity and cover through incorporation of large wood and other habitat elements. Levee modification actions may include the excavation of existing levees or replacing existing levees with setback levees to reconnect historical floodplains and enhance floodplain habitat.

Install Habitat Structures

Instream structural complexity in the lower Wenatchee River was identified as an ecological concern in the revised Biological Strategy (UCRTT 2014). Restoration actions of this type may be located in areas where the main channel severely lacks instream habitat, and where geomorphic processes are not functioning at full potential. Installing habitat structures involves placing large wood and/or boulder habitat structures to increase habitat complexity and cover. A variety of habitat structures can be used to accomplish this including simple large wood structures, complex large wood structures or log jams, and individually placed boulders or boulder clusters. The size of LWD to be used should be determined during development of project designs, and LWD should consist of durable species (generally conifers). In some instances, these actions may also include some minor pool excavation to complement the installation of these habitat structures.

The overall strategy for habitat structures should include designs to minimize risks to boaters and recreational users. These design aspects may include locating projects in areas with good sight lines, designing structures that do not protrude too far into channel, adding bumper logs to minimize racking and to shed unwanted debris and boaters, and signage to warn boaters and recreational users of habitat structures. Scour and stability calculations will likely also be necessary during the design development process to create stable features.

5.4 Project Prioritization and Scoring

The importance of project prioritization is increasingly being recognized by river restoration practitioners as a necessary step to focus restoration efforts. The intent of project scoring and prioritization is to guide efforts to further investigate and develop projects based on the information that is known about factors such as current conditions, ecological concerns, and potential project benefit. It also allows restoration practitioners to consider related information that could affect the likelihood of project implementation and success, such as benefit-to-cost, feasibility, and climate change.

The projects proposed for the lower Wenatchee River were prioritized primarily based on a total benefit score calculated for each project type or project area, then ranked into three tiers. Tier 1 ranked projects received the highest total benefit scores, followed by Tier 2, and so forth. Proposed projects included both resource protection and management projects and the 38 instream and floodplain restoration project areas identified throughout the lower Wenatchee River. Table 5-2 summarizes the project prioritization scoring and the projects ranked into the three priority tiers. The complete prioritization matrix, including supplemental information used for prioritization and scoring rationale, is included in Appendix G.

Table 5-2. Project Prioritization, Scoring, and Tier Rank

Tier	Project Name	Project Prioritization Scoring and Tier Rank1/			
		Total Benefit Score	Benefit-to-Cost Score	Feasibility Designation	Climate Change Impact
1	Project Area 11 – RM 4.0 to 5.2 Left Bank	12	4.0	Low	High
	Project Area 21 – RM 8.4 to 9.0 Right Bank	12	4.0	Low	High
	Project Area 23 – RM 9.2 to 10.6 Right Bank	12	4.0	Low	High
	Project Area 26 – RM 13.5 to 13.9 Right Bank	12	4.0	Low	High
	Project Area 4 – RM 2.2 to 3.0 Left Bank	11	5.5	Moderate	High
	Project Area 7 – RM 3.6 to 4.0 Right Bank	11	5.5	Moderate	High
	Project Area 31 – RM 17.8 to 17.9 Right Bank	11	5.5	Moderate	Moderate
	Project Area 38 – RM 24.9 to 25.6 Right Bank	11	5.5	High	Moderate
	Project Area 2 – RM 0.3 to 0.9 Right Bank	11	3.7	Moderate	High
	Project Area 16 – RM 6.4 to 6.5 Right Bank	11	3.7	Low	High
	Project Area 24 – RM 11.7 to 12.1 Left Bank	10	10.0	High	Moderate
	Beaver Management	10	10.0	Low	High
	Project Area 3 – RM 1.8 to 2.0 Left Bank	10	5.0	Moderate	Moderate
	Project Area 36 – RM 24.6 to 24.7 Right Bank	10	5.0	Moderate	Low
	Project Area 17 – RM 6.2 to 6.6 Left Bank	10	3.3	High	High
2	Project Area 5 – RM 3.1 to 3.2 Right Bank	9	9.0	Moderate	Moderate
	Project Area 20 – RM 8.0 to 8.2 Right Bank	9	9.0	Moderate	Moderate
	Project Area 25 – RM 13.3 to 13.4 Left Bank	9	9.0	High	Moderate
	Project Area 29 – RM 15.0 to 15.1 Right Bank	9	9.0	Moderate	Moderate
	Project Area 34 – RM 24.5 to 24.6 Right Bank	9	9.0	High	Low
	Project Area 10 – RM 4.4 to 4.7 Right Bank	9	4.5	Moderate	Moderate
	Project Area 12 – RM 4.9 to 5.4 Left Bank	9	4.5	High	Moderate
	Project Area 32 – RM 18.3 to 18.6 Left Bank	9	4.5	Moderate	Low
	Instream Flow and Water Management	9	4.5	Moderate	High
	Land Acquisition	9	3.0	Moderate	Moderate
	Project Area 8 – RM 3.9 to 4.1 Left Bank	8	8.0	High	Moderate
	Project Area 28 – RM 14.4 to 14.8 Left Bank	8	8.0	High	Moderate
	Project Area 30 – RM 15.2 Right Bank	8	8.0	High	Moderate
	Project Area 37 – RM 24.7 to 24.9 Left Bank	8	8.0	High	Low
	Project Area 35 – RM 24.6 to 24.7 Left Bank	8	4.0	Moderate	Low
3	Project Area 1 – RM 0.3 to 0.8 Left Bank	6	3.0	Moderate	Low
	Project Area 6 – RM 3.3 to 3.4 Right Bank	5	2.5	Moderate	Low
	Project Area 9 – RM 4.3 to 4.6 Left Bank	5	2.5	Moderate	Low
	Project Area 14 – RM 5.7 to 6.0 Left Bank	5	2.5	Moderate	Low
	Project Area 15 – RM 6.2 to 6.4 Mid-channel	5	2.5	Moderate	Low
	Project Area 18 – RM 6.8 to 7.0 Mid-channel	5	2.5	Moderate	Low
	Project Area 19 – RM 7.8 to 8.0 Mid-channel	5	2.5	Moderate	Low
	Project Area 22 – RM 9.0 to 9.2 Mid-channel	5	2.5	Moderate	Low
	Project Area 27 – RM 14.4 to 14.7 Right Bank	5	2.5	Moderate	Low
	Project Area 13 – RM 4.9 to 5.5 Right Bank	5	1.7	Moderate	Low
	Project Area 33 – RM 20.5 Left Bank	4	4.0	Moderate	Low

1/ Project prioritization scoring methods and rationale are included in Appendix G.

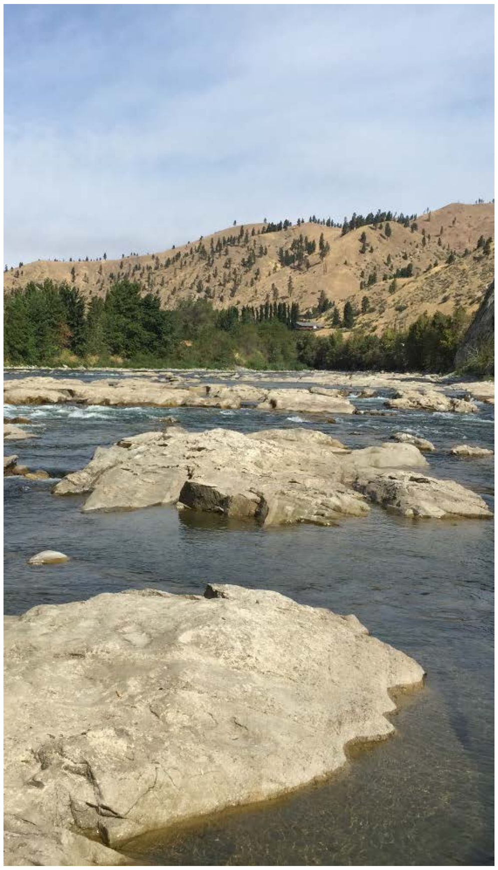
The scoring of project benefit included an evaluation of the potential recovery gap, fish use potential, and the ability to address root causes and ecological concerns. The potential recovery gap represents the difference in ecological functions between existing and target conditions that can be gained through restoration measures. Projects were also evaluated based on a benefit-to-cost score, which is a relative value used to compare potential project benefits. The cost score is a categorical ranking of relative cost based on construction techniques, access, and project requirements. Projects were ranked first by project benefit and secondarily by the benefit-to-cost score.

In addition to the benefit and benefit-to-cost scores, feasibility was also evaluated for all projects. The feasibility was assessed based on the likelihood of being able to implement the project within a 10-year timeframe. This assessment was based on landownership and other known constraints that could potentially impact feasibility including economic, regulatory, political, social, and permitting considerations. Feasibility was not used as part of the project prioritization and scoring because feasibility may change drastically over time based on landownership and other factors.

The ability of projects to ameliorate climate change effects and increase salmon resilience was also evaluated based on the analysis of Beechie et al. (2013). The assessment identified the relative potential for proposed project actions to ameliorate climate change related temperature increases, flow changes, and the ability of proposed actions to increase salmon resilience.

5.5 Restoration Strategy Summary

The restoration strategy described above, along with details included in Appendix E, identified restoration project opportunities, their locations, and associated restoration actions and action types. A project opportunity geodatabase (Appendix F) was also developed. The project geodatabase will facilitate the tracking of future projects, providing restoration planners with a tool to evaluate which areas are being under-represented, and aid in identifying how various restoration projects interact with each other and important features. In addition, available implementation data on completed restoration projects have been incorporated into the project opportunity geodatabase to document past efforts. The restoration strategy includes a prioritization of project opportunities (Appendix G) that incorporates field data, analyses of physical and biological data, restoration objectives based on the needs of fish species of concern, feasibility, and logistical factors. The restoration strategy helps document and predict project impacts, and aids in planning of allocation of financial resources within the lower Wenatchee River.



6. CONCLUSION AND NEXT STEPS

This reach assessment and restoration strategy provides a scientific foundation and identifies potential project alternatives to assist habitat restoration practitioners in identifying the most appropriate project locations and restoration actions within those locations proposed for further evaluation and implementation. This report sets the baseline for future adaptive management and can be used as a reference to determine if potential project actions are appropriate for specific sites based on landscape history, geomorphic and biological conditions, predicted climate impacts, and other relevant data presented. It also provides an objective scoring rationale that can be used in communications with landowners who may choose to participate in habitat restoration.

There are several resources included in this report that will be most useful in the planning process for habitat restoration practitioners, including the reach assessment map series (Appendix C), the potential project opportunities list (Appendix E), the project opportunity geodatabase (Appendix F), and the project opportunity prioritization matrix spreadsheet (Appendix G). The intent of these resources is to provide the necessary information for making informed and effective habitat restoration decisions in a format that is clear, concise, and user-friendly.

For each project opportunity site, this report has identified a number of proposed restoration actions that will assist with project planning and design development; however, the actions listed should not be considered an exhaustive list. The potential restoration actions listed in this report can also be modified and adapted to refine projects during design development. Site-specific analyses would be needed to refine these potential projects, evaluate design alternatives, and develop detailed designs for construction.

Next steps were identified throughout the development of this Project. These include ongoing data collection and research efforts, developing site-specific project designs, implementing projects, and monitoring completed projects. The preliminary list of next steps identified for the lower Wenatchee River are provided below:

- Continue to perform stakeholder outreach and communicate the results of this geomorphic assessment and restoration strategy.
- Continue to implement the prioritized projects identified in the restoration strategy.
- Identify opportunities to fill data gaps, including those identified in the revised Biological Strategy (UCRTT 2014):
    - Assess the extent to which the lower Wenatchee River could be used for juvenile over-winter rearing if habitat conditions were improved.
    - Assess groundwater surface water interaction.
    - Assess the effects of temperature in the lower Wenatchee River through the TMDL process.

- Incorporate recommendations and continue to evaluate potential opportunities for future habitat improvement and habitat preservation based on predicted climate changes.
- Continue to integrate the results of ongoing research, monitoring, and data collection and evaluation into the restoration strategy.

The resources provided in this report are flexible and may be adapted to fit changing circumstances. This approach was taken with the understanding that conditions can change over time and new data are being collected. This strategy allows for effective planning and prioritization of resources for habitat restoration programs for year to come.

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