Lower Wenatchee River Reach Assessment

Prepared for

CONFEDERATED TRIBES AND BANDS
YAKAMA NATION
TREATY OF 1855

Prepared by

TETRA TECH

May 2016

LOWER WENATCHEE RIVER REACH ASSESSMENT

Prepared for

YAKAMA NATION FISHERIES
401 Fort Road
Toppenish, WA 98948

Prepared by

TETRA TECH
19803 North Creek Parkway
Bothell, WA 98011

May 2016

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Acronyms and Abbreviations

°C	degrees Celsius
BiOp	Biological Opinion
BNSF	Burlington Northern and Santa Fe
BSR	biologically significant reach
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
lower Wenatchee River	Lower Wenatchee River reach assessment area
NMFS	National Oceanic and Atmospheric Administration National Marine Fisheries Service
OZ	Outer Zone
RBT	River Bathymetry Toolkit
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
WA	Washington
WAC	Washington Administrative Code
WRIA	Watershed Resource Inventory Area

1. INTRODUCTION

The Yakama Nation Department of Fisheries Resource Management Upper Columbia Habitat Restoration Program (UCHRP) is focused on implementing science-based restoration projects that benefit Endangered Species Act (ESA)-listed salmonids including Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and bull trout (*Salvelinus confluentus*), following the foundational recommendations set forth in the Upper Columbia Spring Chinook and Steelhead Recovery Plan (UCSRB 2007). In coordination with the Upper Columbia Regional Technical Team (UCRTT), the UCHRP has identified the lower reach of the Wenatchee River to be a high priority for restoration.

A history of channel modification, development, road and railway construction, and intensive land use practices along the lower Wenatchee River has resulted in degraded fish habitat that is limiting the productivity of ESA-listed salmonids. The Lower Wenatchee River Reach Assessment and Restoration Strategy is intended to provide a thorough understanding of the physical and biological impairments within this reach, and to present a habitat restoration strategy that will address ecological concerns, also known as limiting factors, and improve conditions to better support ESA-listed salmonids and non-listed species in the Upper Columbia region.

This reach assessment is one in a series of assessments that have been completed by the UCHRP, including for the lower Twisp River, Chewuch River, lower Peshastin Creek, lower Libby Creek, and the upper Wenatchee River. In addition, a number of reach assessments have been completed in the region by the U.S. Bureau of Reclamation (USBR). 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 (see Sections 3.4.2 and 4.4.3); and a technically advanced project opportunity prioritization process for targeting restoration actions (see Section 5.4).

The lower Wenatchee River reach assessment area (lower Wenatchee River) includes the mainstem of the Wenatchee River from its confluence with the Columbia River near Wenatchee, Washington (WA) to the Icicle Road Bridge, downstream of Tumwater Canyon, near Leavenworth, WA. This reach extends from river mile (RM) 0.0 to RM 26.4 referenced to the U.S. Geological Survey (USGS) river miles (USGS 2015a).

1.1 Purpose

Reach assessments are an important first step in the process of identifying effective habitat restoration actions in the highest priority areas. The reach assessment provides the scientific information, analyses, data synthesis, and interpretation focused on providing habitat improvements for target fish species. The purpose of this reach assessment is to create a document that identifies restoration opportunities based on a restoration strategy that incorporates existing data, site-specific field observations, and data analyses. It provides the technical basis to identify and conceptually develop potential restoration project opportunities to improve habitat and river processes important for listed salmonids and other species.

The restoration strategy presented in this report includes a project ranking and evaluation process for potential project opportunities to be evaluated according to restoration objectives, feasibility, and logistical factors. Potential project opportunities are identified, described in detail, and their location mapped. The restoration strategy is intended to assist habitat restoration practitioners to identify the most appropriate locations and a suite of potential restoration actions to evaluate for implementation. Site-specific analyses will need to be completed to refine potential project opportunities, evaluate alternatives, and develop detailed designs for construction as shown in Figure 1-1.

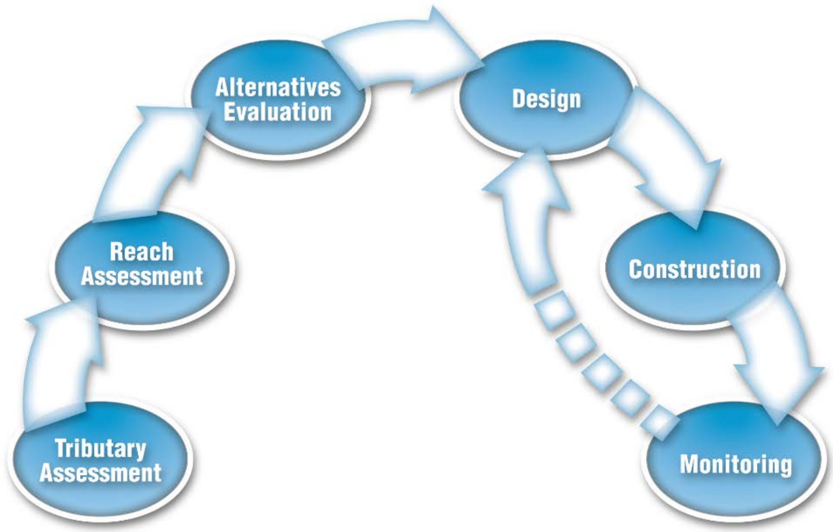
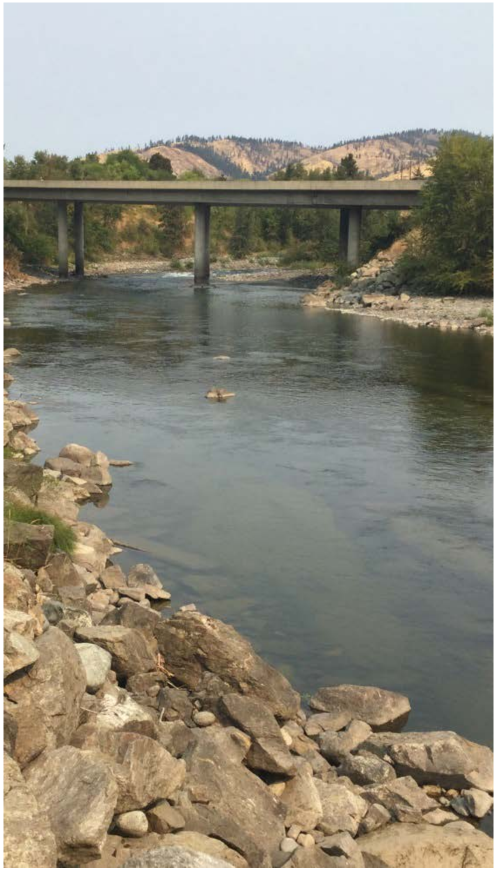


Figure 1-1. Flow Chart of Habitat Restoration Process Steps (adapted from USBR 2012)

1.2 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: Background – 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: Next Steps – Provides recommended follow-up actions for implementing the restoration strategy.



2. BACKGROUND

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 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

This reach assessment includes the lower Wenatchee River from the mouth at the Columbia River, near the city of Wenatchee, upstream to Icicle Creek Bridge near the city of Leavenworth (RM 0.0 to 26.4), referred to herein as the lower Wenatchee River. The Wenatchee River drainage area is approximately 1,330 square miles on the eastern slopes of the Cascade Mountains in Chelan County. The overview map in Figure 2-1 shows the Wenatchee River drainage and the lower Wenatchee River.

The elevation of the subbasin ranges from over 9,400 feet at the peak of Mount Stuart to 620 feet at the Wenatchee 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 ((NWPCC 2004). 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.

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 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), Ollala Canyon - HUC 170200110707 (34 square miles), Derby Canyon - HUC 170200110706 (29 square miles), and Tumwater Canyon - HUC 170200110703 (33 square miles).

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.

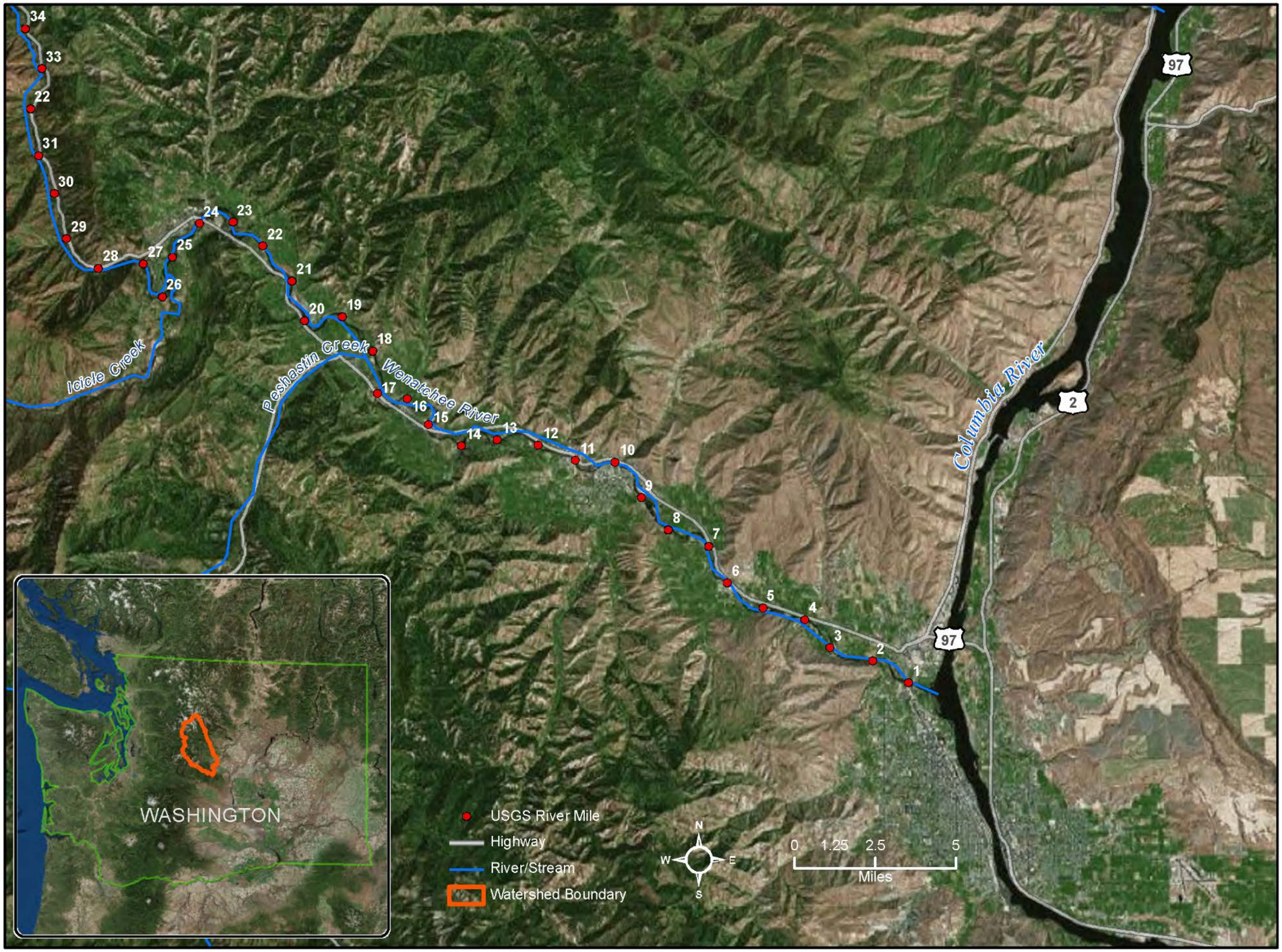


Figure 2-1. Lower Wenatchee River Location Map

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 Wenatchee River valley 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 2-2 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.

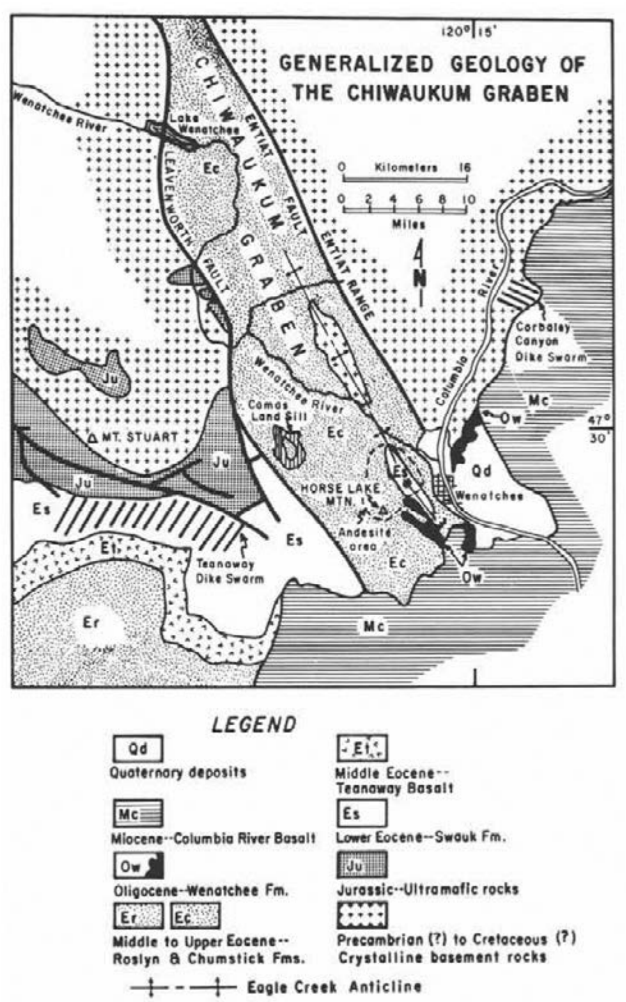


Figure 2-2. Generalized Geology of the Chiwaukum Graben (Source: Gresens 1983)

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 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 2-3 shows an exposed glacial terrace in Reach 2 near RM 1.7. Figures 2-4a and 2-4b contain geologic mapping of the lower Wenatchee River valley including bedrock geology and depositional features (Tabor et al. 1982; Tabor et al. 1987).

Figure 2-3. Photograph of Exposed Glacial Terrace in Reach 2 near RM 1.7

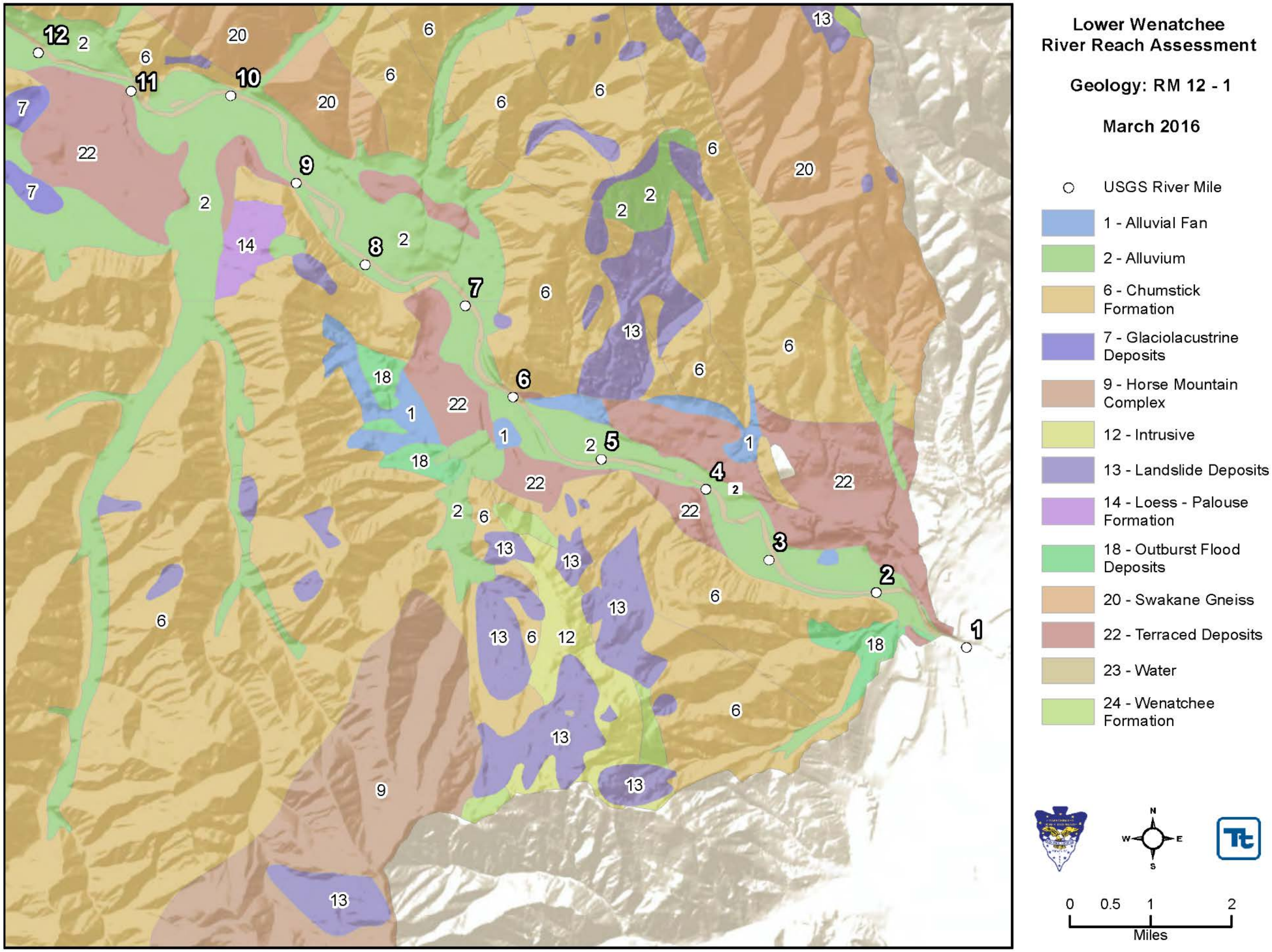


Figure 2-4a. Geologic Maps of the Lower Wenatchee River Valley RM 0.0 to RM 12.0

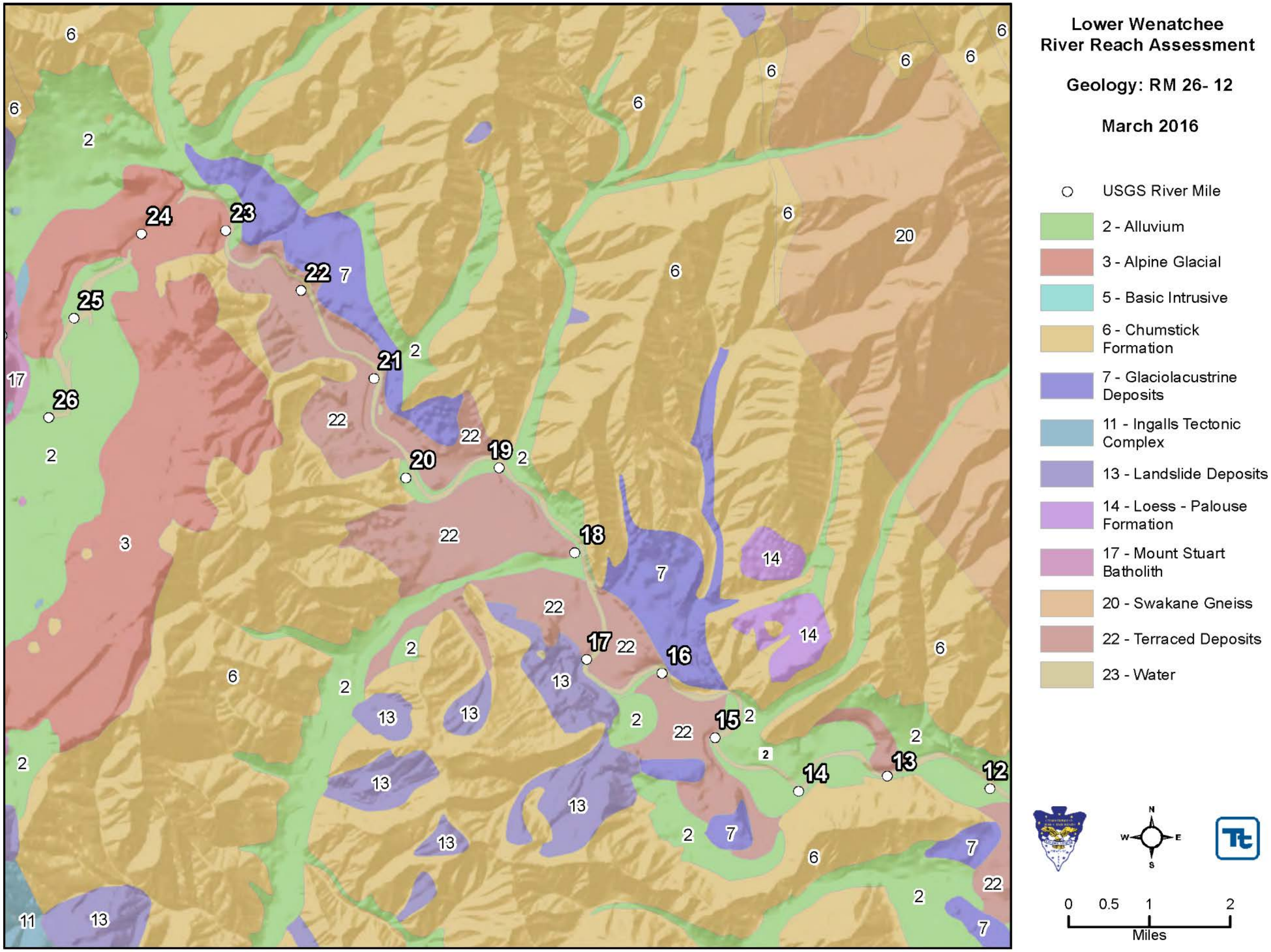


Figure 2-4b. Geologic Maps of the Lower Wenatchee River Valley RM 12.0 to RM 26.4

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 Watershed Assessment (Inter-Fluve 2012), the first documented people of the region were members of the Wenatchi Tribe. The word “Wenatchee” in the local language most likely meant “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 historic photograph from 1904 in Figure 2-5 shows conditions in the lower Wenatchee Valley in the Sleepy Hollow area.

Figure 2-5. Historic (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 2-6. 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).

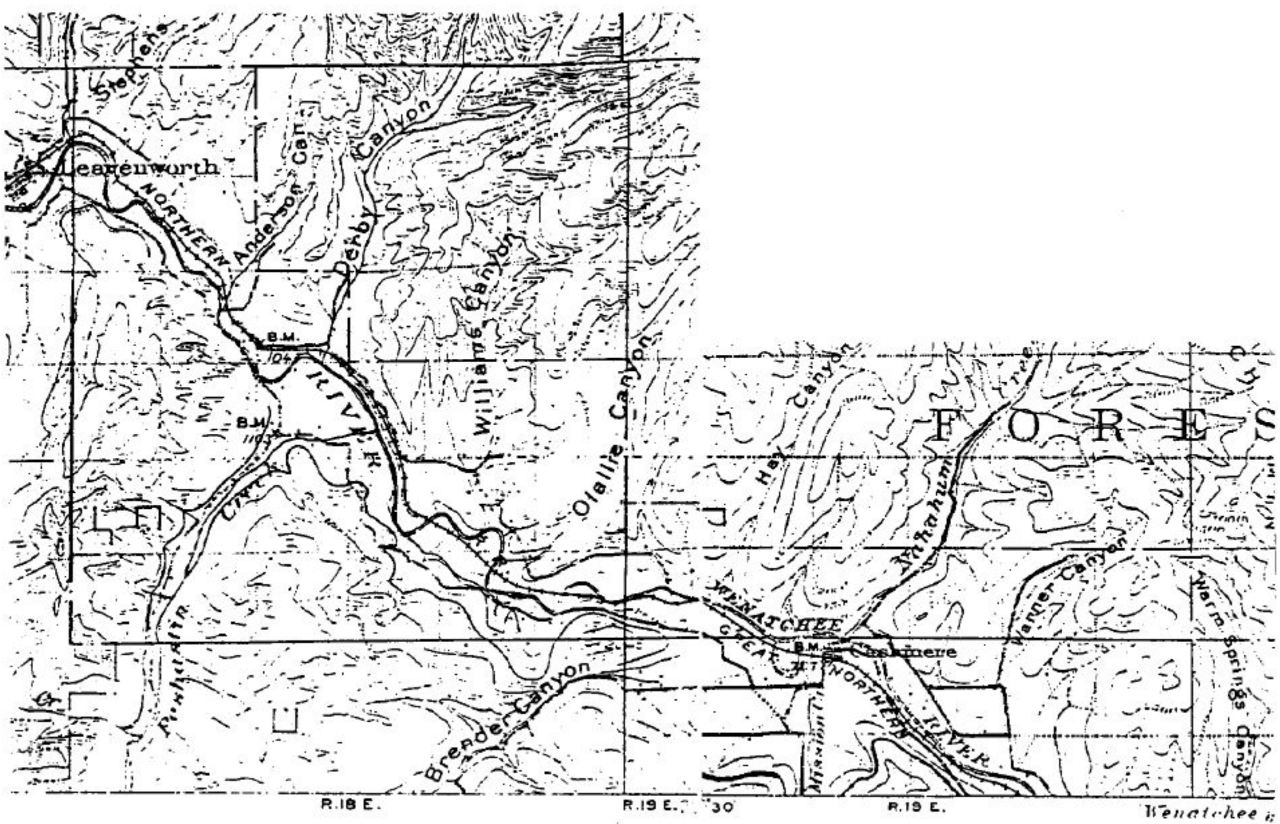


Figure 2-6. Route of the Great Northern Railroad in 1904 from Cashmere to Leavenworth, Washington, Through the Wenatchee Watershed (U.S. Geological Survey, in Beckham 1995)

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 historic photograph in Figure 2-7 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 historic photograph in Figure 2-8 shows the mill pond dam.

Figure 2-7. 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 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).

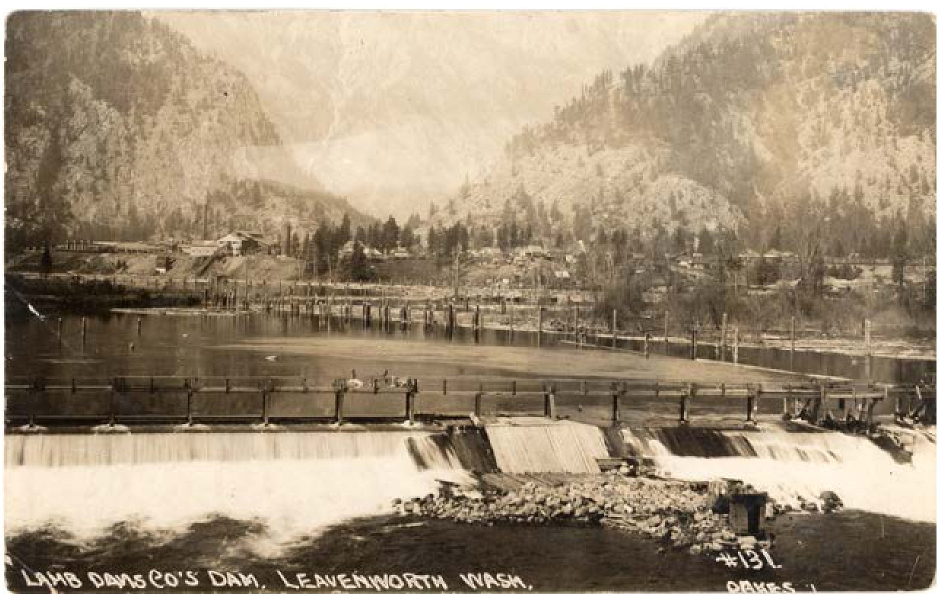


Figure 2-8. Lamb-Davis Lumber Company – Mill Pond Dam (Source: Upper Valley Museum at Leavenworth).

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 fire season started earlier than usual, in late June, with the Sleepy Hollow Fire 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 2-9 shows fire damage from the Sleepy Hollow Fire.

Figure 2-9. 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 2-10 shows an example of riverside residential development along the lower Wenatchee River.

Figure 2-10. Photograph Showing an 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 historic photograph in Figure 2-11 shows an orchard along the banks of the river near Cashmere in 1920.

Figure 2-11. Historic 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 (NWPCC 2004). 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 (NWPCC 2004).

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 was which extends past the Wenatchee River confluence.

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 2-12 shows dead Chinook fingerlings in an unscreened diversion box on Rock Island Branch of Dryden Canal in 1940.

Figure 2-12. 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 Center)

The photograph in Figure 2-13 shows an irrigation diversion in Reach 6. Although not shown in the photograph, the diversion is screened.

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)

Figure 2-13. Example of an Irrigation Diversion near RM 13.7

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, WA). 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 U.S. Fish and Wildlife Service (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 2-14, has two functioning fish passage and trapping facilities (right and left bank) for broodstock collection with fish screens improved in 2001 (Andonaegui 2001).

Figure 2-14. 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 2-15 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 2-15. 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 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 and discussed further in Section 2.7, 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 (Pevin 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 historic photograph from 1940 in Figure 2-16 shows a fish truck unloading at the Leavenworth hatchery holding pond. The Rocky Island Fish Hatchery complex was begun in 1989 as mitigation for the Rock Island Dam (Peven et al. 2004), and includes various acclimatization 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 acclimatization 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

Figure 2-16. Unloading Fish Truck at Leavenworth Hatchery Holding Pond – 1940 (source: Oregon State University Libraries Special Collections & Archives Research Center)

Wenatchee River, 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. 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 and 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

Lower Wenatchee River Fish Periodicity													
Species	**Lifestage**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Spring Chinook Salmon	Adult Immigration & Holding												
	Adult Spawning												
	Incubation/Emergence												
	Juvenile Rearing												
	Juvenile Emigration												
Summer Steelhead	Adult Immigration & Holding												
	Adult Spawning												
	Incubation/Emergence												
	Juvenile Rearing												
	Juvenile Emigration												
Bull Trout	Adult Immigration/Emigration												
	Adult Spawning												
	Incubation/Emergence												
	Juvenile Rearing												
	Juvenile Emigration												

Periods of most common use
Periods of lighter use
Periods of little 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, WA 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. Historic 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 historic 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. The Salmon, Steelhead, and Bull Trout Habitat Limiting Factors report for WRIA 45 (Andonaegui 2001) found that the following conditions were either not properly functioning or at risk along the lower Wenatchee: riparian condition, streambank condition, floodplain connectivity, entrenchment ratio, instream large woody debris (LWD), pool frequency, pool depth, off-channel habitat, temperature, and change in flow regime.

Similarly, the Wenatchee River Channel Migration Zone Study Phase II (Jones & Stokes 2004) identified two primary limiting factors and five secondary limiting factors as follows:

- Primary: Reduction of off-channel habitat and disconnection of valley flats, and degradation of riparian habitat.
- Secondary: Reduction of instream LWD and LWD recruitment; reduced quantities of habitat features such as pools; reduced instream flows; increased bank erosion and sedimentation; and high summer water temperature.

The Wenatchee Subbasin Plan (NWPCC 2004) also identified constrained channel migration, reduced LWD and gravel recruitment, lost or degraded riparian and off-channel habitat, low summer flows and high temperatures, and altered flow regime (extremes in the peaks and base flows) as important limiting factors.

More recently, the UCRTT identified five ecological concerns for the lower Wenatchee assessment unit, in priority order: 1) peripheral and transitional habitat (side channel and wetland connections), 2) riparian condition (including LWD recruitment), 3) water quantity (decreased water quantity), 4) water quality (temperature), and 5) channel structure and form (bed and channel form) (UCRTT 2013).

The Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) contains numerical ecological concerns data for the upper Columbia assessment area developed by the Expert Panel (FCRPS 2012). Figure 2-17 illustrates the limiting factors for spring Chinook and Figure 2-18 for summer steelhead. The ecological concerns, listed as limiting factors (LF) on the figures, are shown using pie charts and a bar graph with the pie chart size relative to the weight, or importance of a particular concern relative to other ecological concerns within the lower Wenatchee River. The prioritization of project opportunities in Section 5.4 uses these limiting factors as important criteria for ranking project effectiveness.

2.7 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 (NWPCC 2004), 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 Upper Columbia Regional Technical Team (UCRTT) 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 (NWPCC 2004) for the Northwest Power and Conservation Council, supporting their effort to meet ESA obligations under the 2000 FCRPS BiOp issued by the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS). The Wenatchee Subbasin Plan included a technical

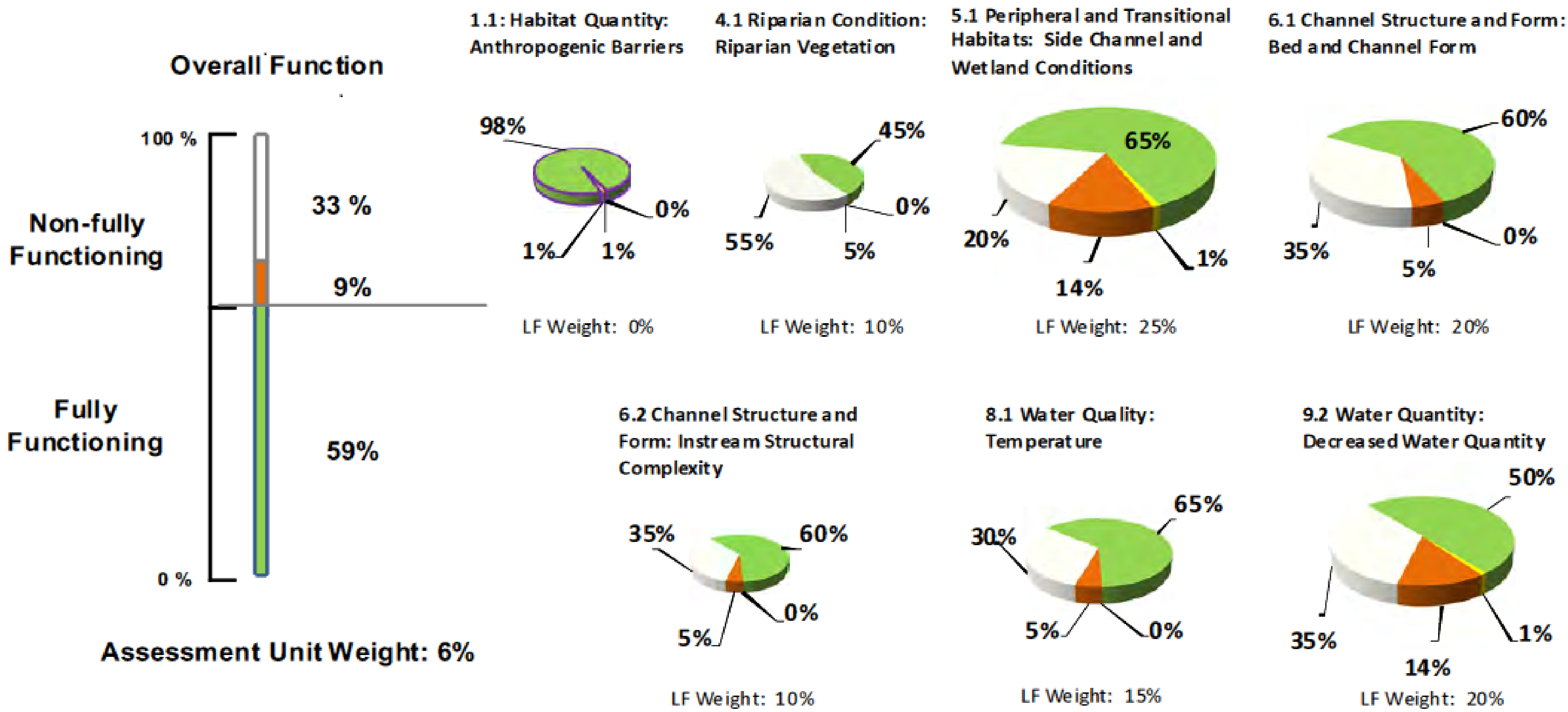


Figure 2-17. Lower Wenatchee (WEC5) Spring Chinook Ecological Concerns (a.k.a. limiting factors) Status (source: FCRPS 2012)

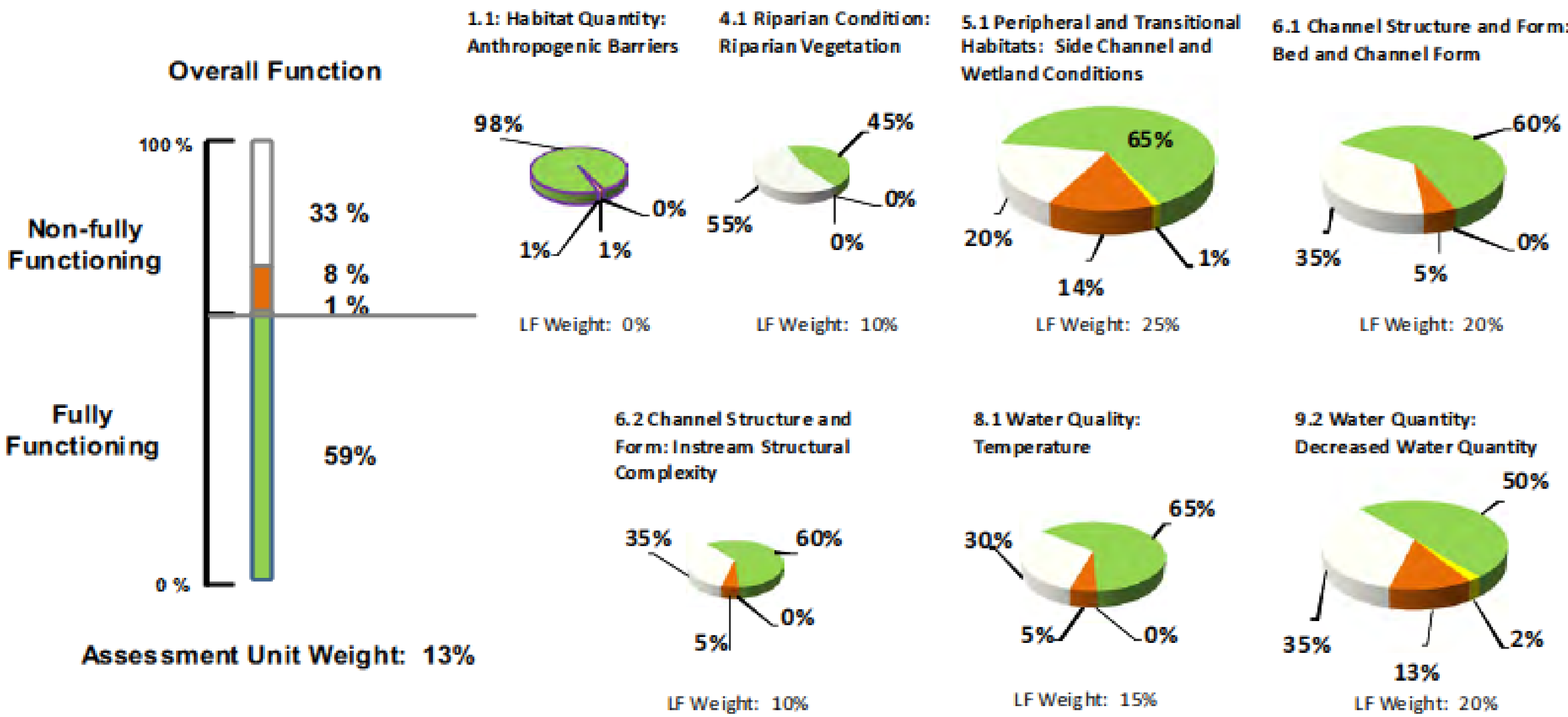


Figure 2-18. Lower Wenatchee (WEC5) Summer Steelhead Ecological Concerns (a.k.a. limiting factors) Status (source: FCRPS 2012)

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 (see preceding 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 historic 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, 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. large woody debris, 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

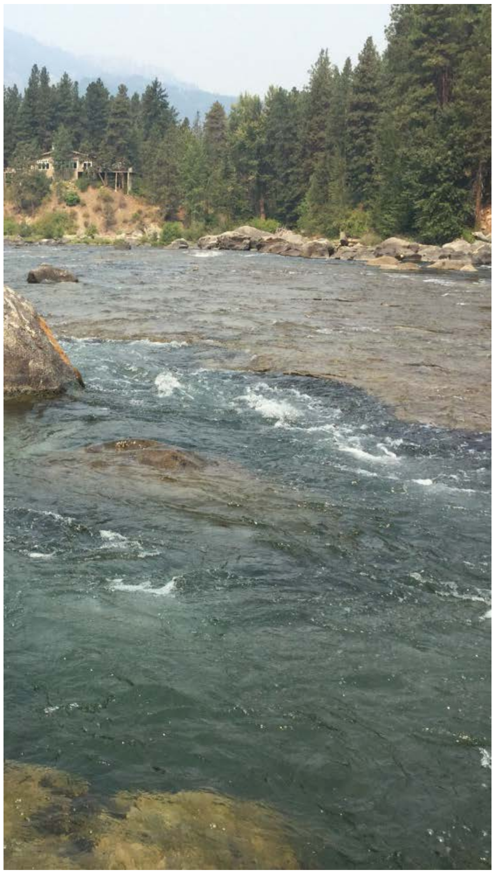
- Reduce water temperatures by restoring riparian vegetation along the river.
- Increase habitat diversity and quantity by restoring riparian habitat along the Wenatchee River, reconnecting side channels and the floodplain with the river, and increasing large woody debris in the side channels.

While the Recovery Plan outlined above was also intended to address bull trout, in September 2015 the USFWS published an updated Recovery Plan for the Coterminous United States Population of Bull Trout (USFWS 2015a).

This includes 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 UCRTT Biological Strategy provides specific support and guidance on implementing the 2007 Recovery Plan described above (UCRTT 2014). In the Biological Strategy, the lower Wenatchee River (in this case, the mouth to Tumwater Canyon) is designated as a Priority 2 area (on 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 as discussed above in Section 2.6. As part of the Biological Strategy, a series of reference tables were also developed as a public resource (UCRTT 2013).



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. 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 category of hydrology and hydraulics (Section 3.4.1) or 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 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 ungagged 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 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, 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. Historic 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.

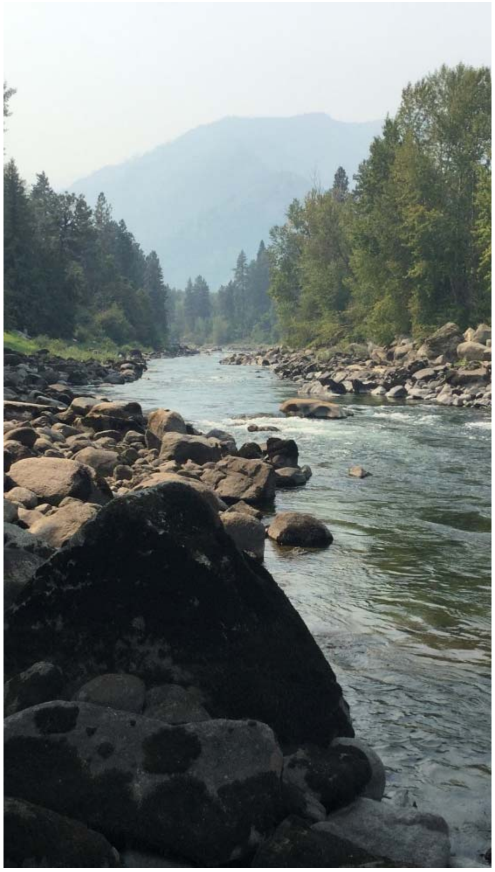
Hydraulic characteristics including shear stress, excess shear stress, unit stream power, and the threshold grain size were calculated throughout the lower Wenatchee River as measures of flow competence. Threshold of motion sediment size estimates were calculated with the Shields threshold of motion 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 USBR reach assessments (e.g., USBR 2009) as well as the Upper Wenatchee River Stream Corridor Assessment and restoration strategy (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 (RBT) 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 (DoD) comparison (Wheaton et al. 2010), was employed.

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.

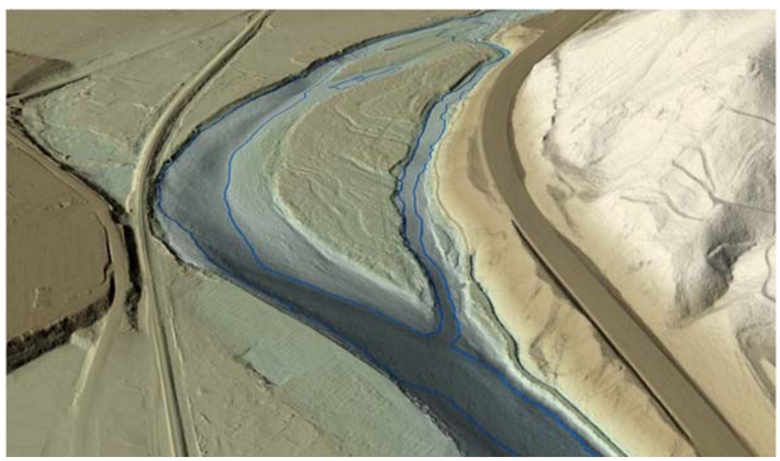


Figure 4-1. Bare-Earth Topobathymetric LiDAR (colored by elevation) Looking West near RM 6.5 Including Pioneer Side Channel

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.

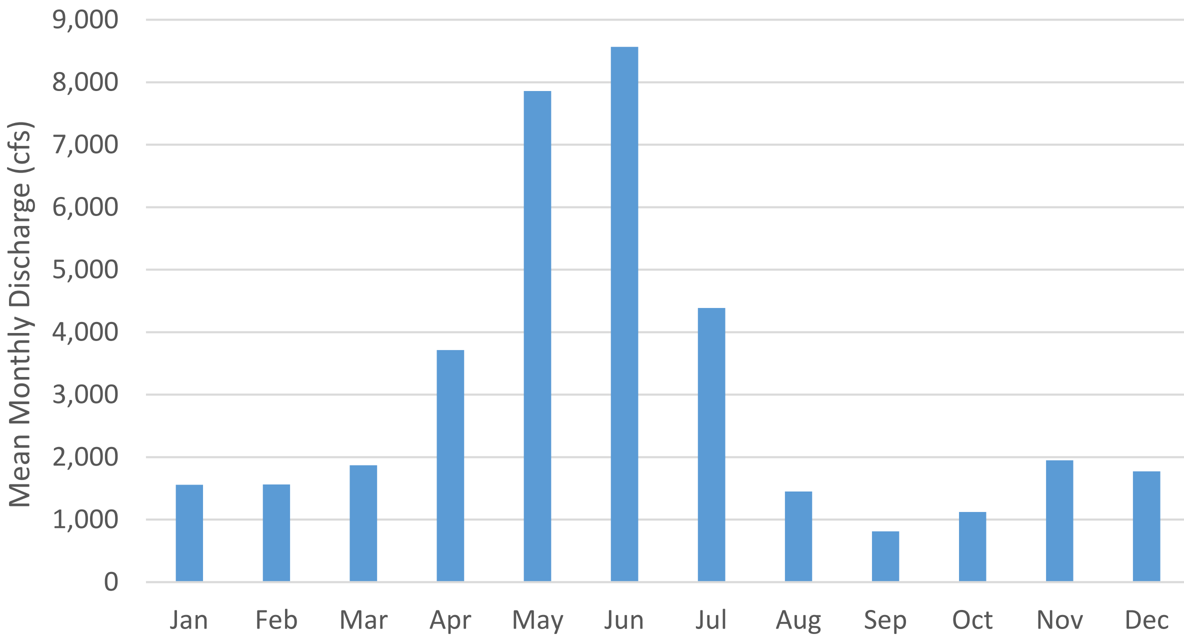


Figure 4-2. Lower Wenatchee River Monthly Discharge at Wenatchee River at Peshastin Gage (USGS 12459000)

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.

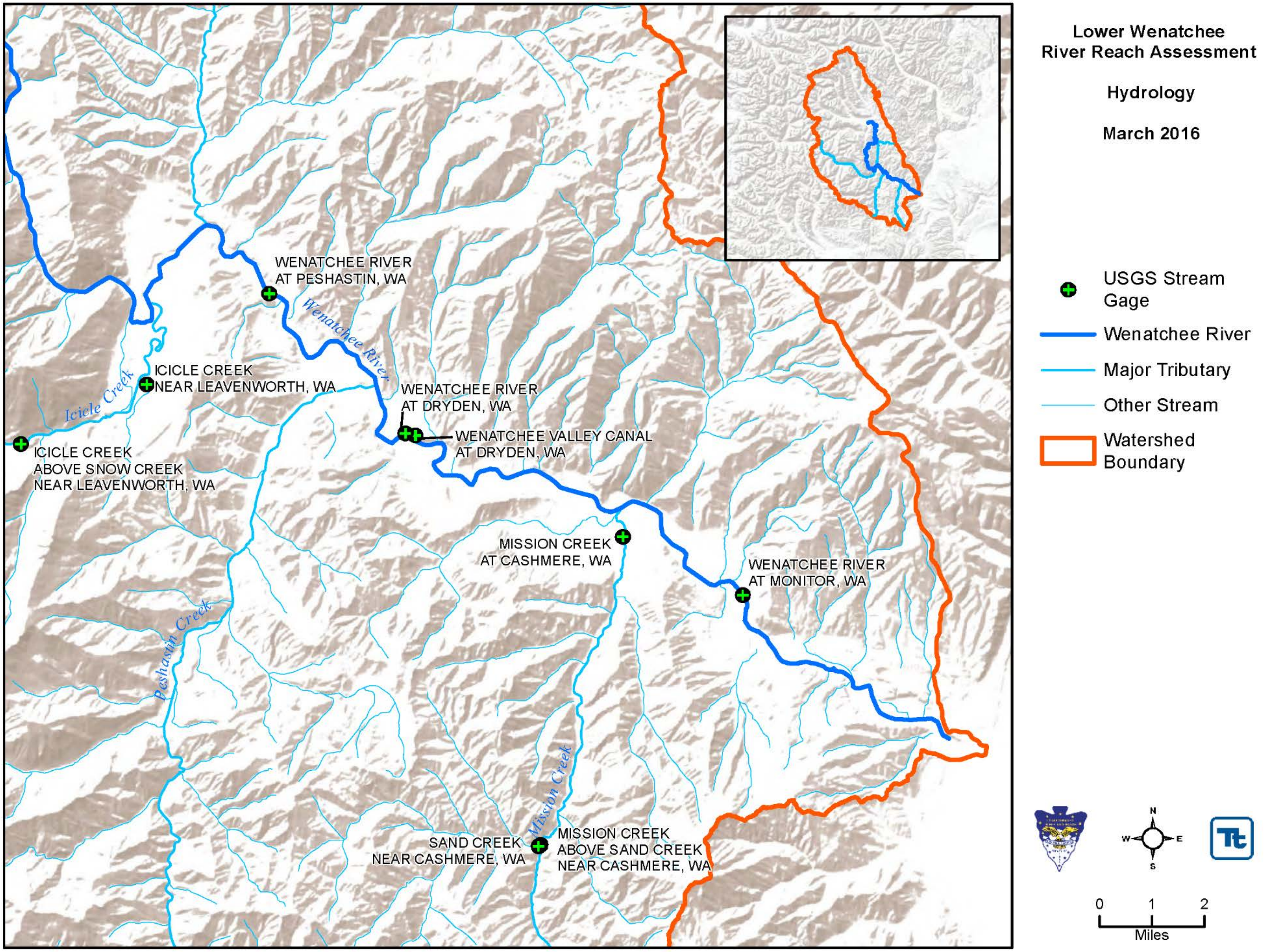


Figure 4-3. Lower Wenatchee River Hydrography and USGS Stream Gages

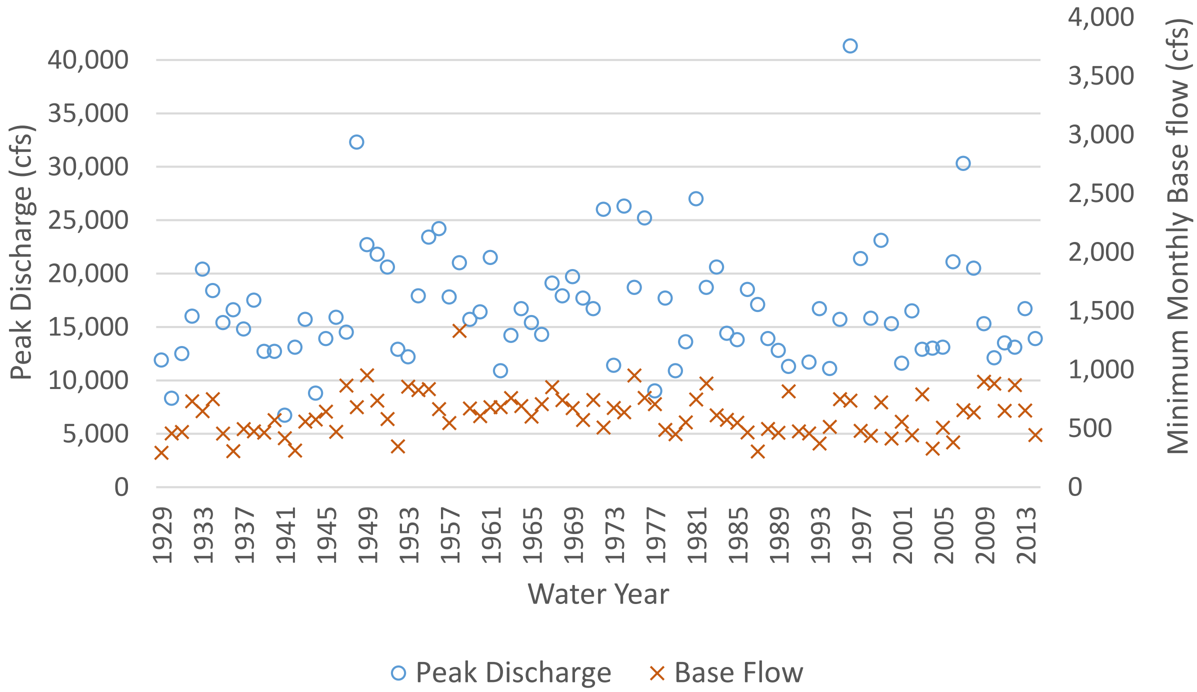


Figure 4-4. Peak Discharge and Baseflow for the Wenatchee River at Peshastin (USGS 12459000)

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 historic 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 areas 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 that 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 areas 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 if perched on high terraces. Small and large riparian trees are more frequent in this Reach.

Lower Wenatchee River Reach Assessment Geomorphic Reaches Overview

March 2016

USGS River Mile
Reach 1
Reach 2
Reach 3
Reach 4
Reach 5
Reaach 6
Reach 7
Reach 8
Reach 9
Reach 10
River/Stream
Geomorphic Reach Break

N
W E
S

0 1.25 2.5
Miles

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 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 historic 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 historic 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 historic 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

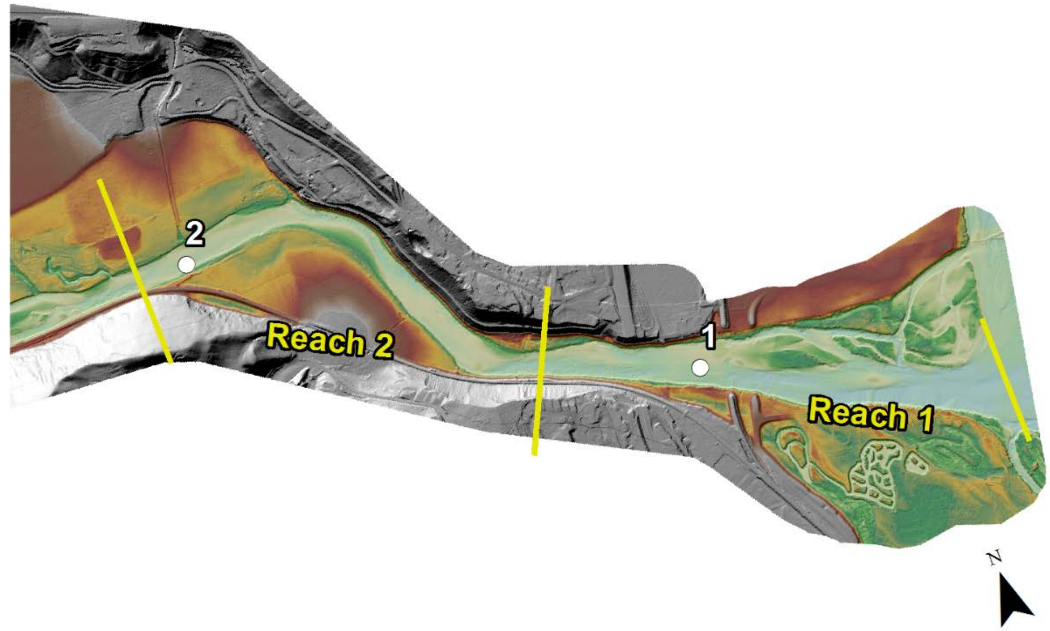


Table 4-3. Geomorphic Reach 2 Location and Existing Characteristics

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

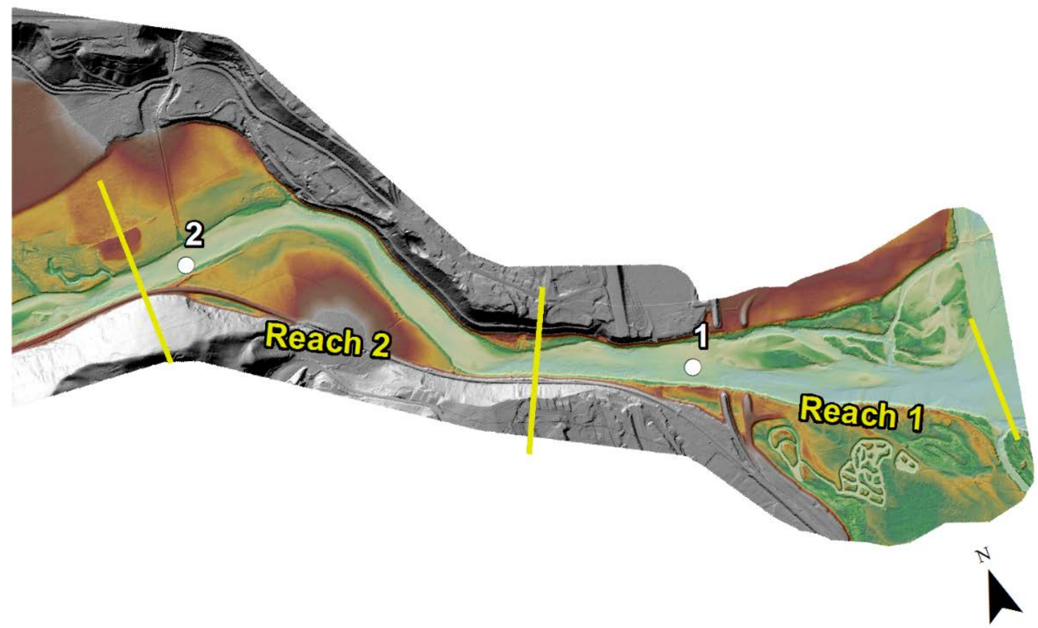


Table 4-4. Geomorphic Reach 3 Location and Existing Characteristics

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

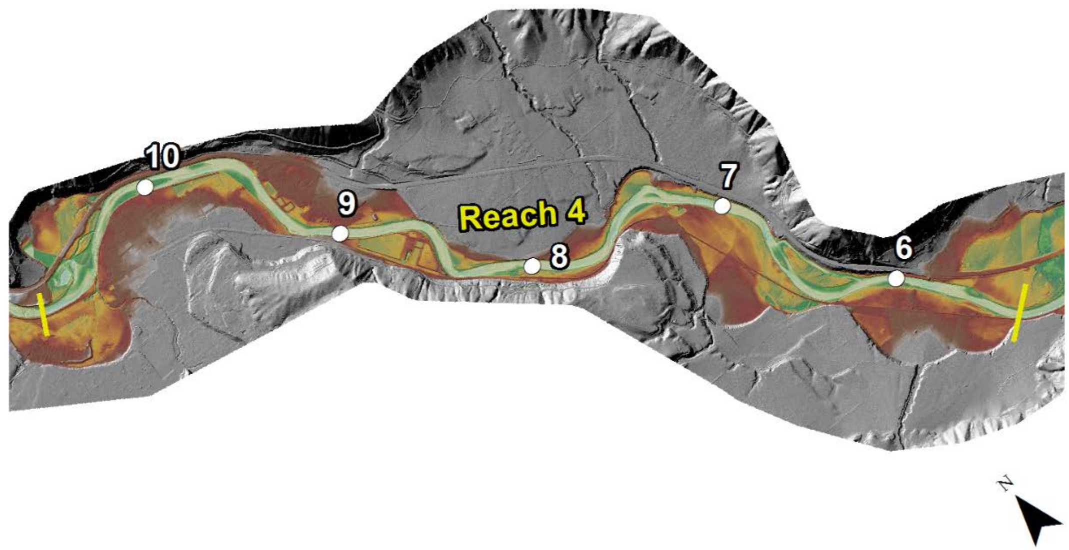


Table 4-6. Geomorphic Reach 5 Location and Existing Characteristics

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

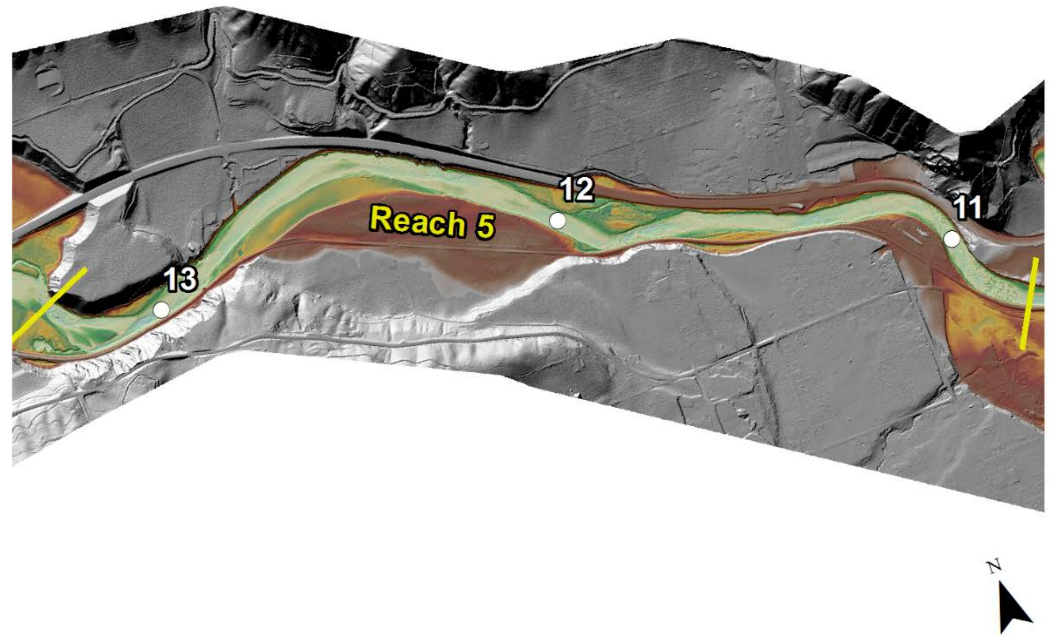
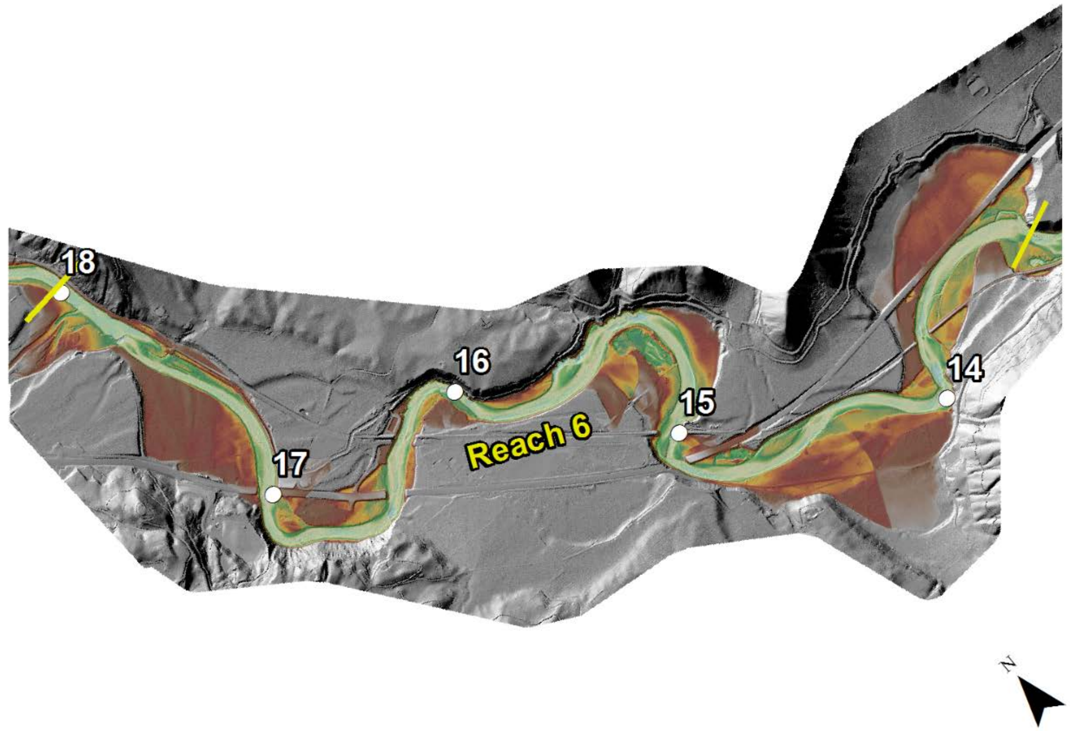


Table 4-7. Geomorphic Reach 6 Location and Existing Characteristics

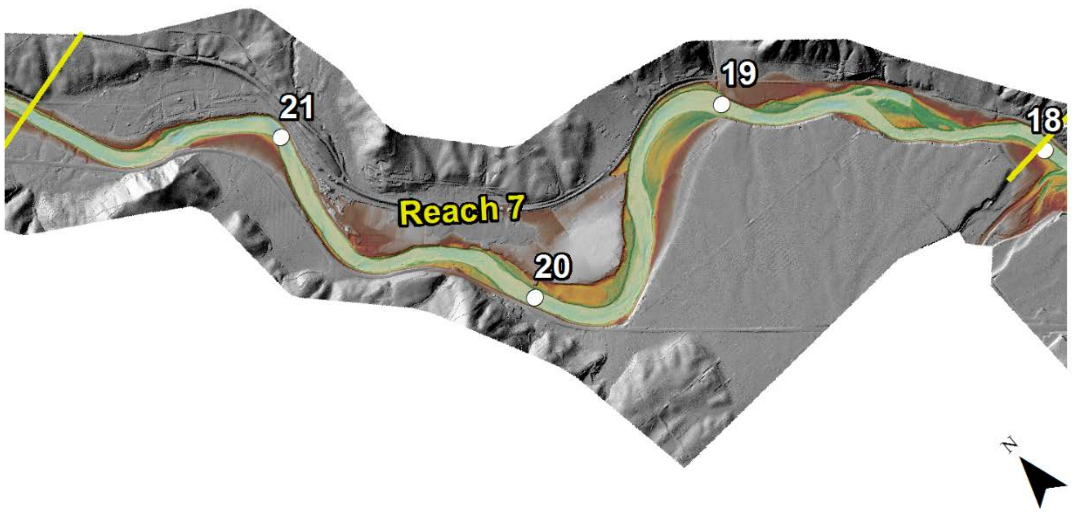
Reach Characteristics	
River Miles	13.25 to 18.0
Valley Setting	Broad, stepped terrace
Confining features	BNSF Railway, roads and highways, valley hillslopes, bedrock, and high terraces, Dryden Diversion Dam, residential and urban development
Channel Morphology	Irregular sinuous pattern, occasional islands, point, mid-channel, and lateral bars
Migration Process	None[1/]
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

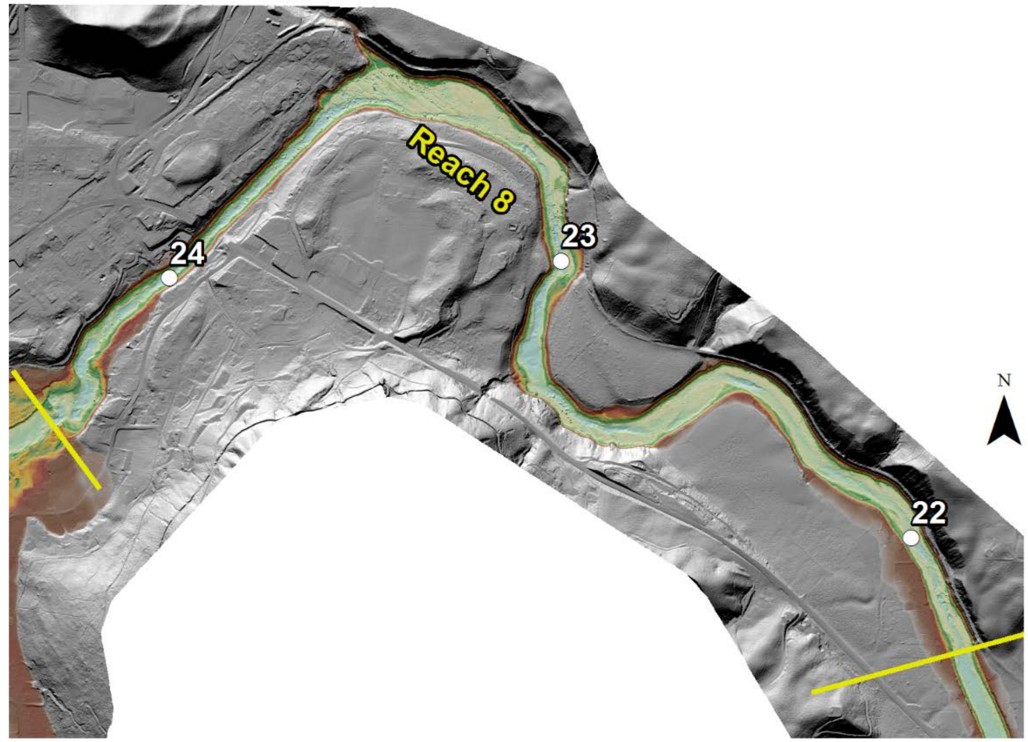
Reach Characteristics		Location Map and Photos
River Miles	18.0 to 21.80	
Valley Setting	Broad, stepped high terrace	
Confining features	High terraces, BNSF Railway, roads and highways, bedrock, and valley hillslopes	
Channel Morphology	Irregular sinuous pattern, occasional islands, infrequent point 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)	

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

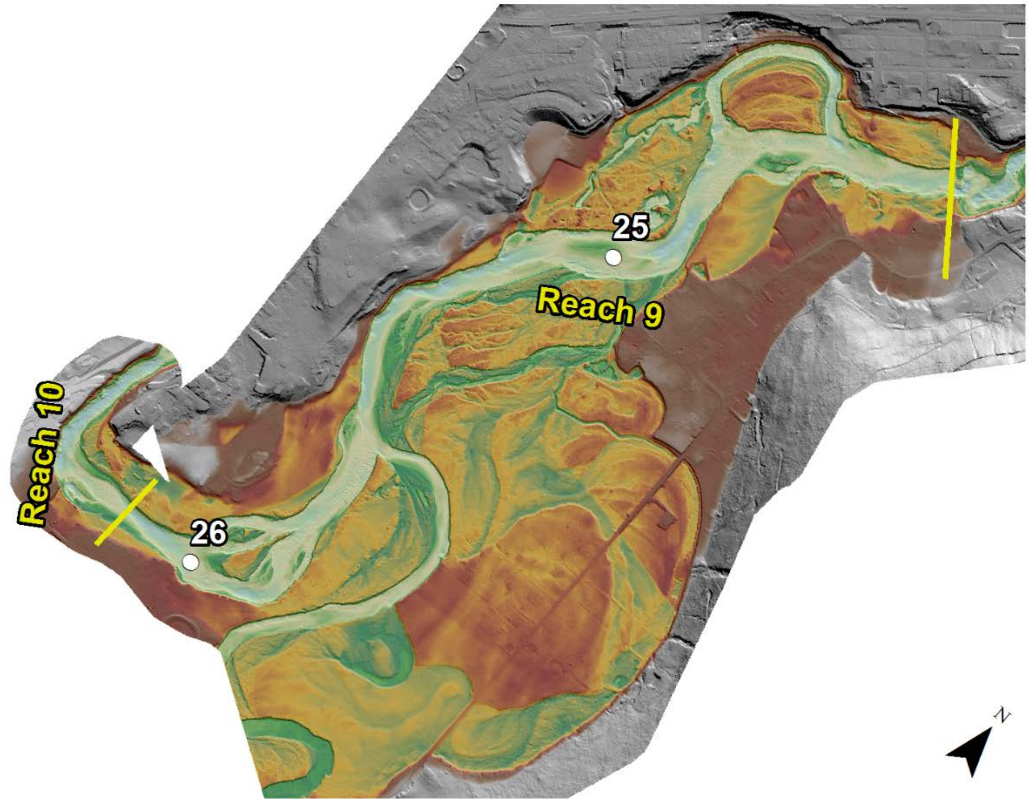
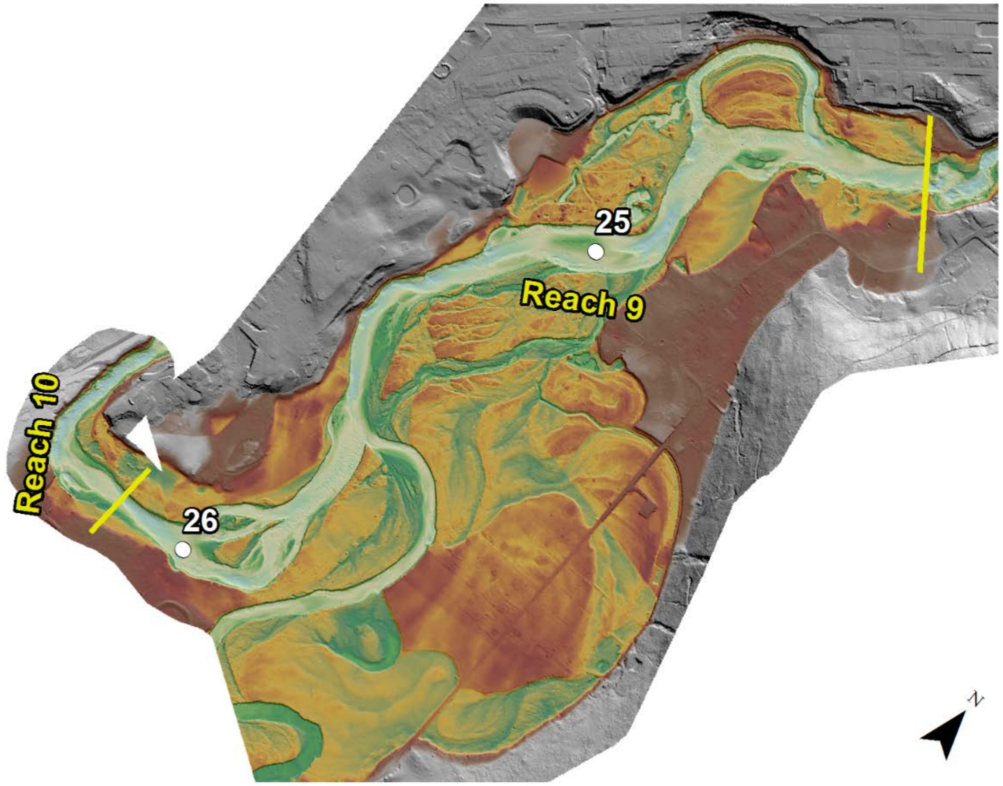


Table 4-11. Geomorphic Reach 10 Location and Existing Characteristics

Reach Characteristics		Location Map and Photos
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)	



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 C 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. 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, historic 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.

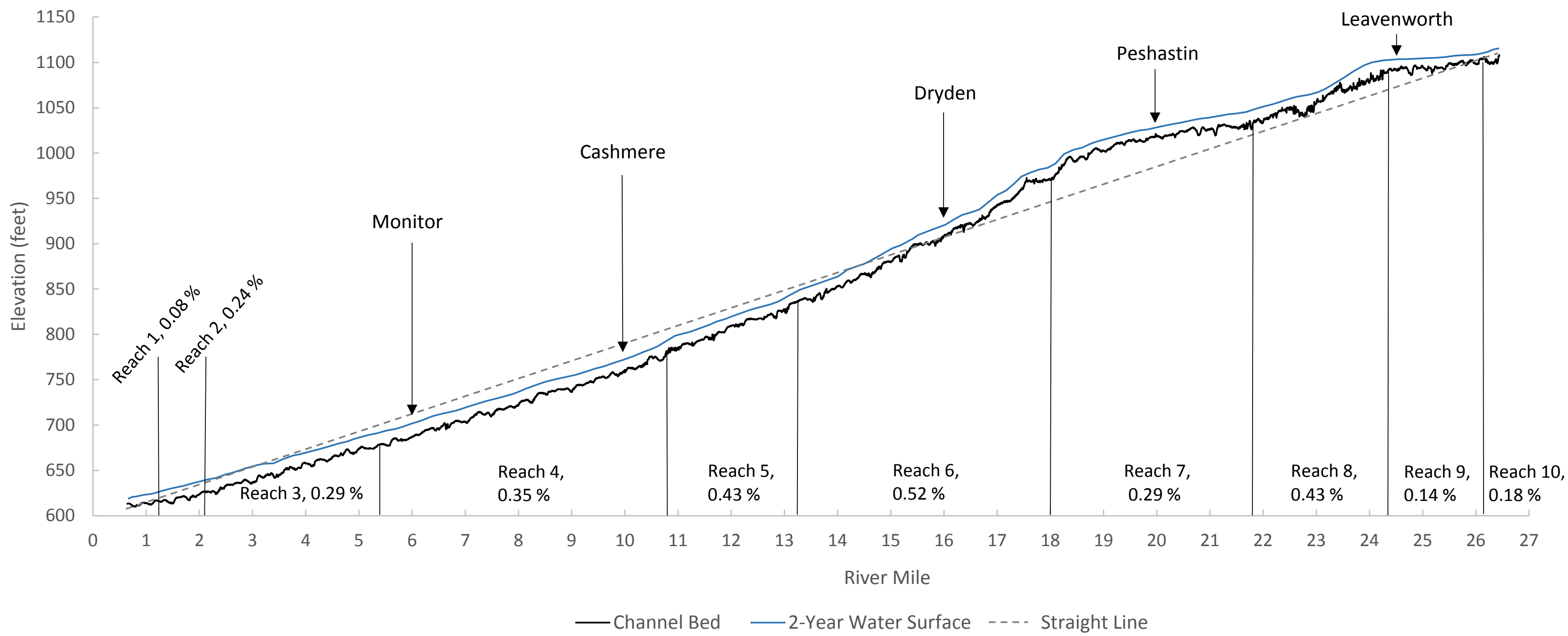


Figure 4-6. Longitudinal Profile and Channel Gradient for Geomorphic Reaches in the Lower Wenatchee River

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 historic 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 historic rates in areas with levees or artificially armored banks.

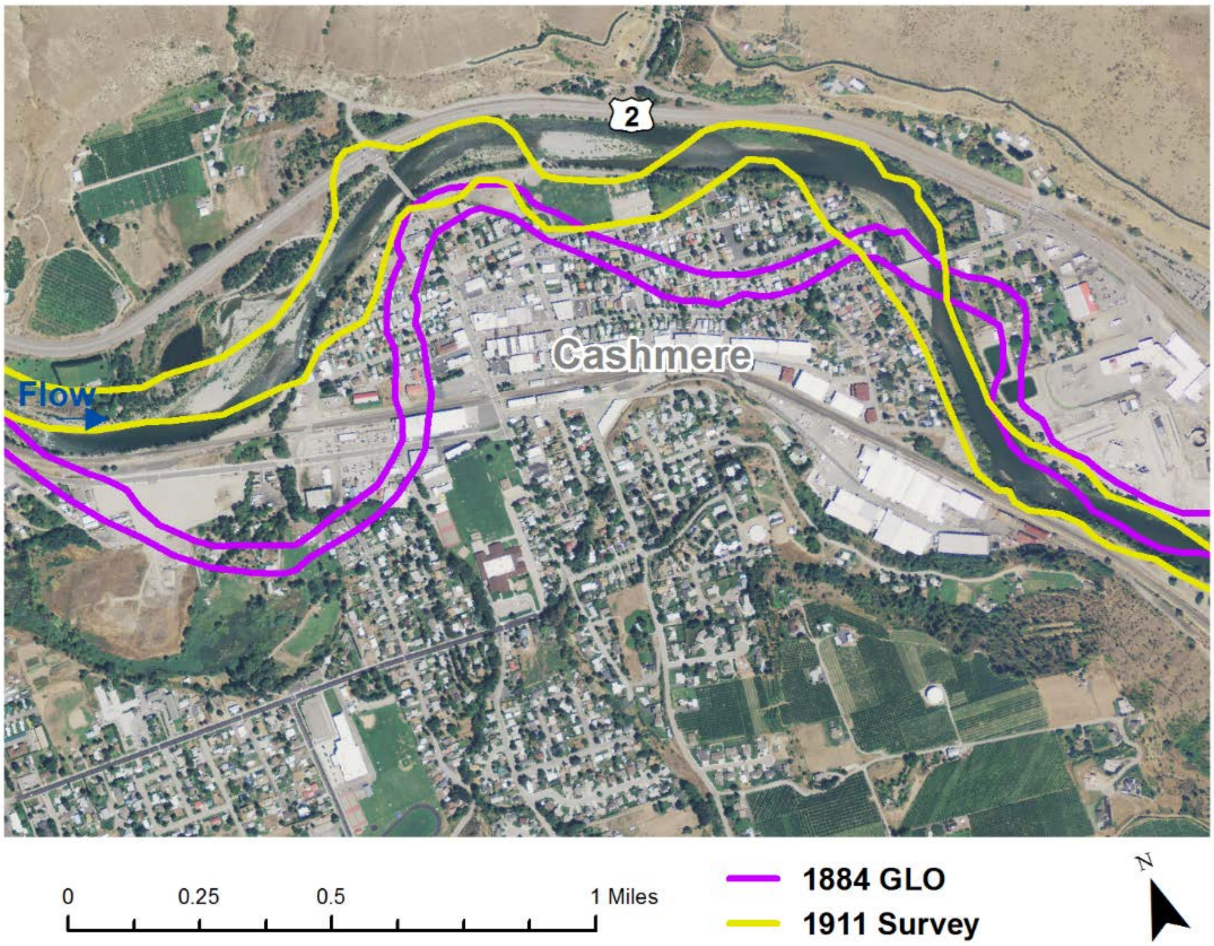


Figure 4-7. Historic Channel Location from 1884 GLO Map and 1911 USGS Plan View Survey of the Wenatchee River near the City of Cashmere (USGS 1914)

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 historic 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 B-2a through B-2k in Appendix B 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 historic 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 historic 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 4-6b, which shows that the bottom of profile concavity is in these reaches.

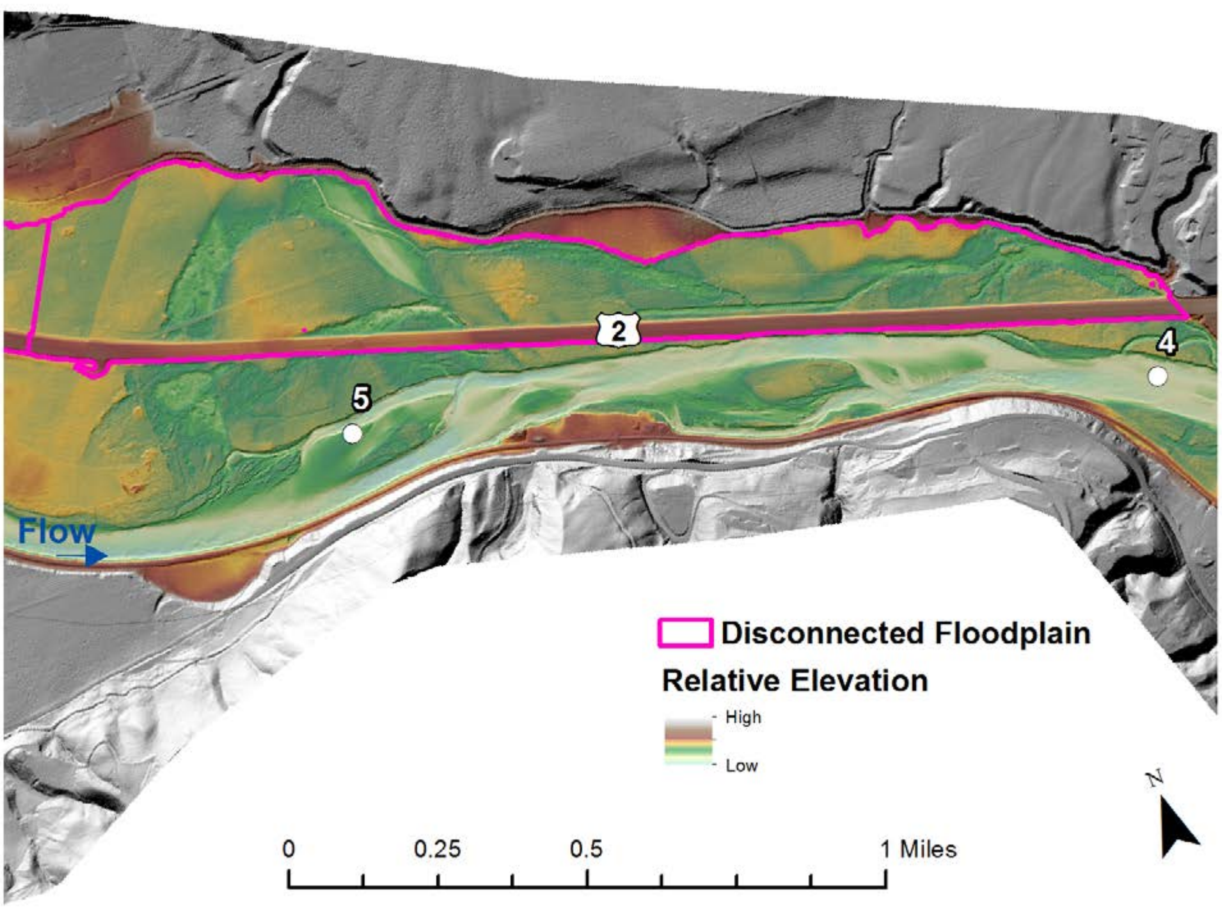


Figure 4-8. Example of Floodplain Disconnected Outer Zone by U.S. Highway 2, in Reach 3

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.

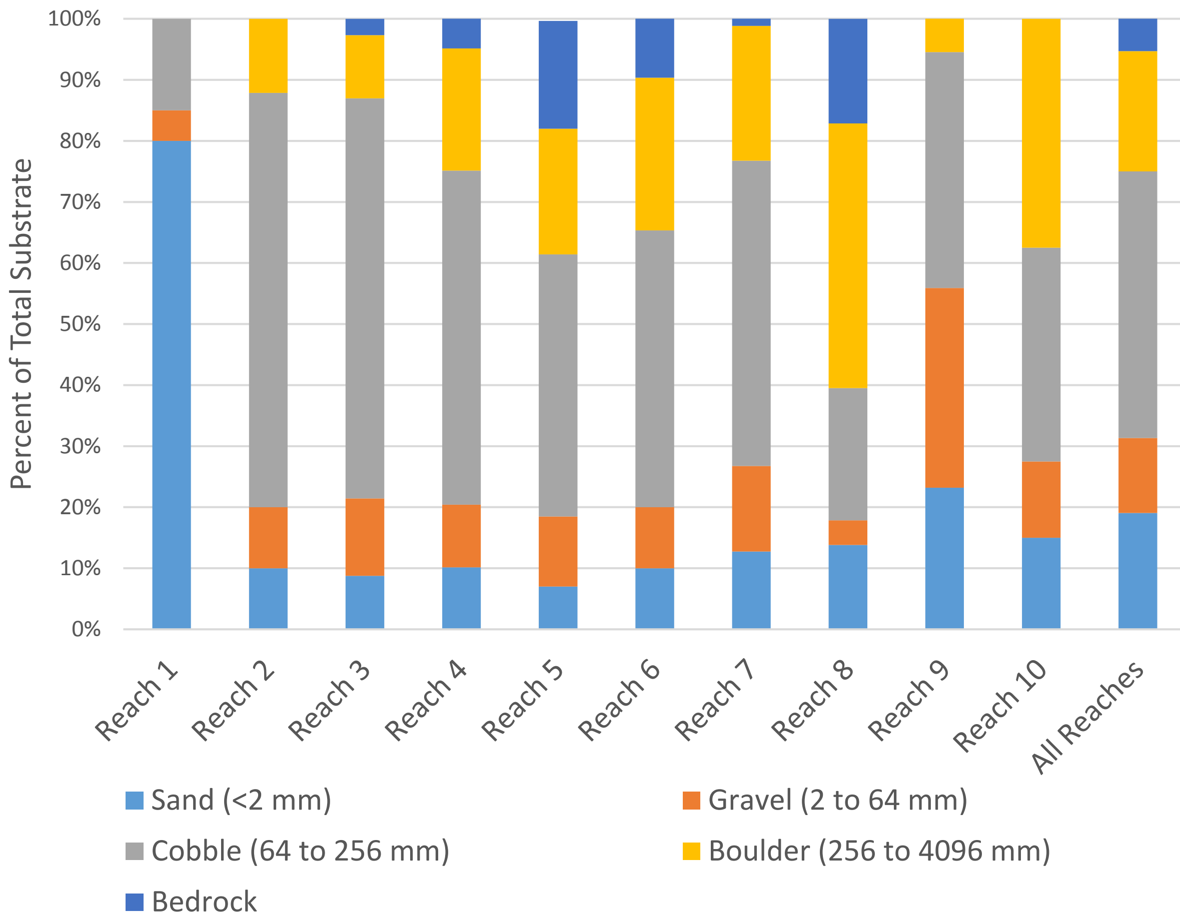


Figure 4-9. Distribution of Substrate Size Classes by Reach for the Lower Wenatchee River

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 4-6b, 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).

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

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).

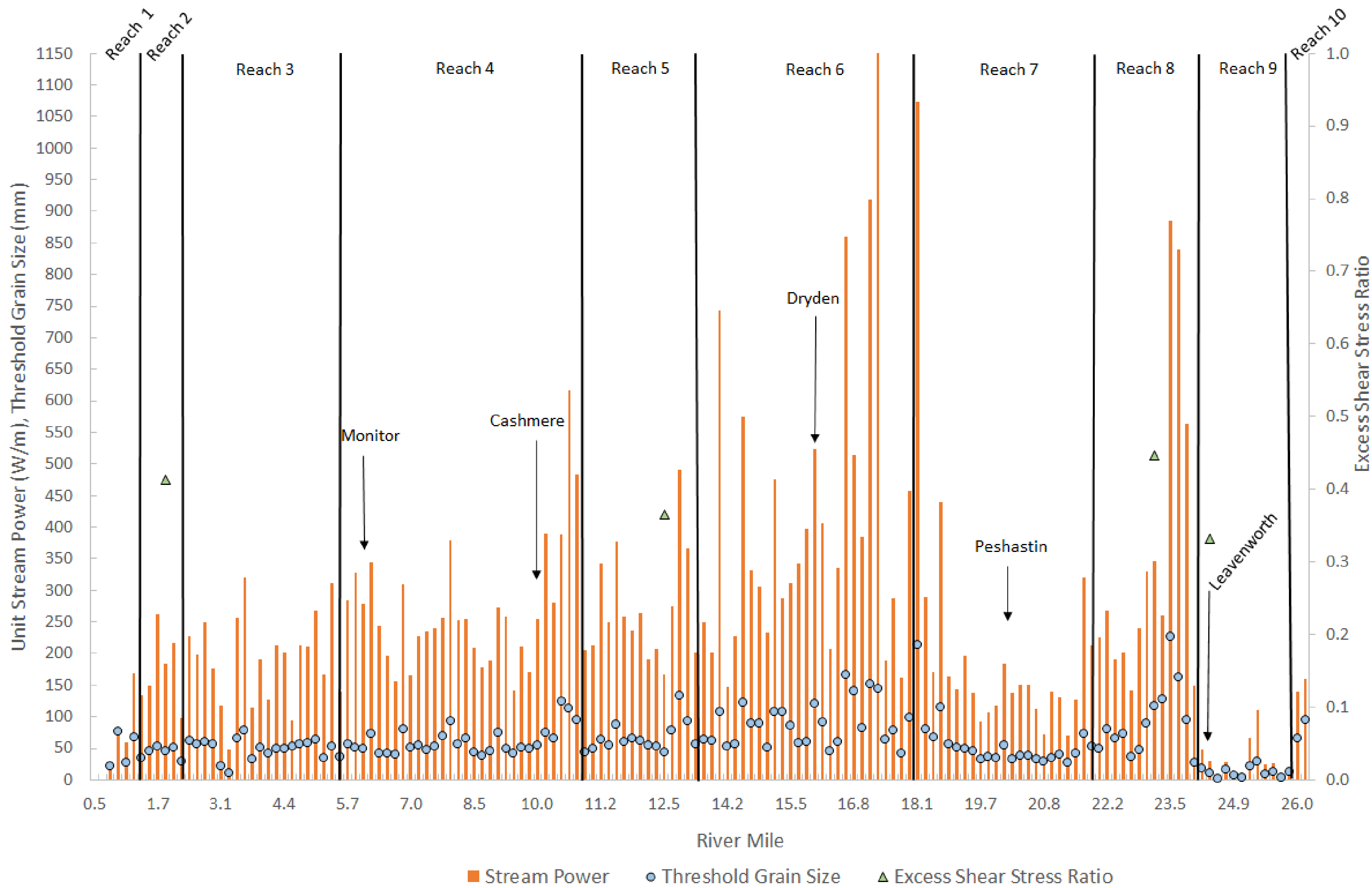


Figure 4-12. Unit Stream Power, Threshold Grain Size, and Excess Shear Stress by River Mile

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 bars and 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.

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

The amount of naturally occurring LWD in side channels and off-channel habitat is likely well below historic 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 historic accounts or other data sources reviewed for this assessment included information about the historic 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.

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.

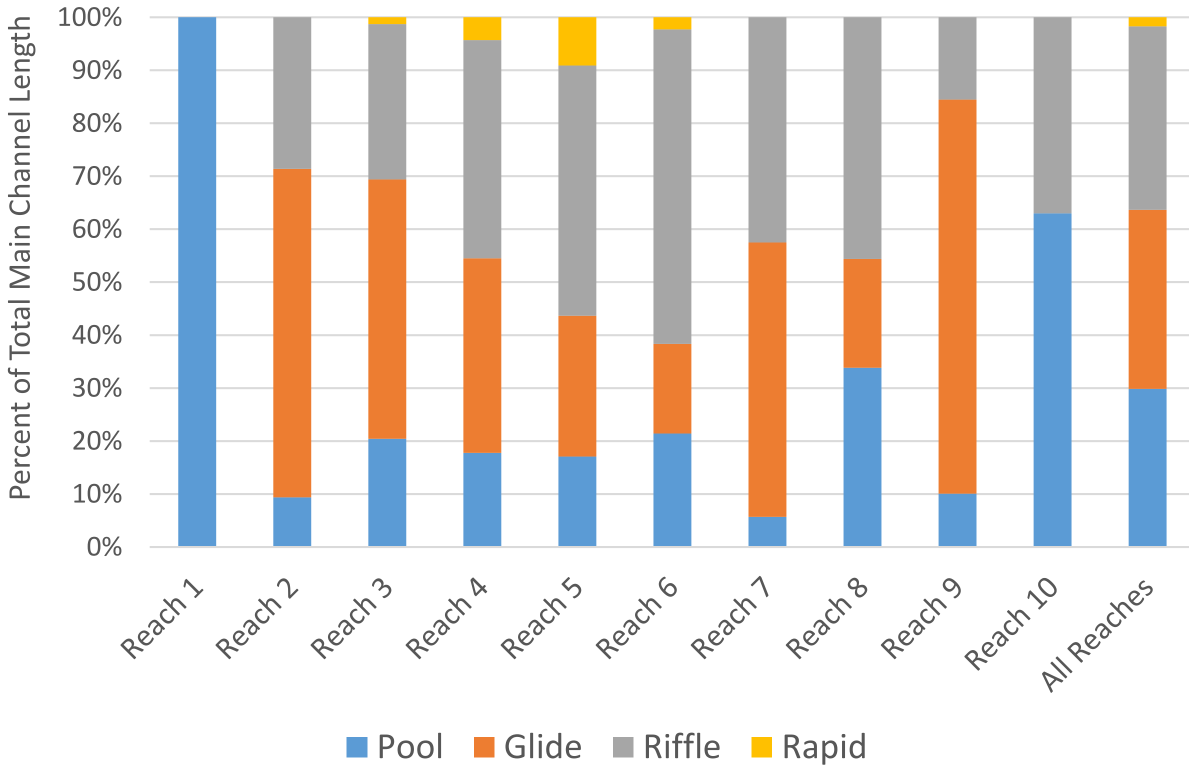


Figure 4-15. Distribution of Channel Units by Reach for the Lower Wenatchee River

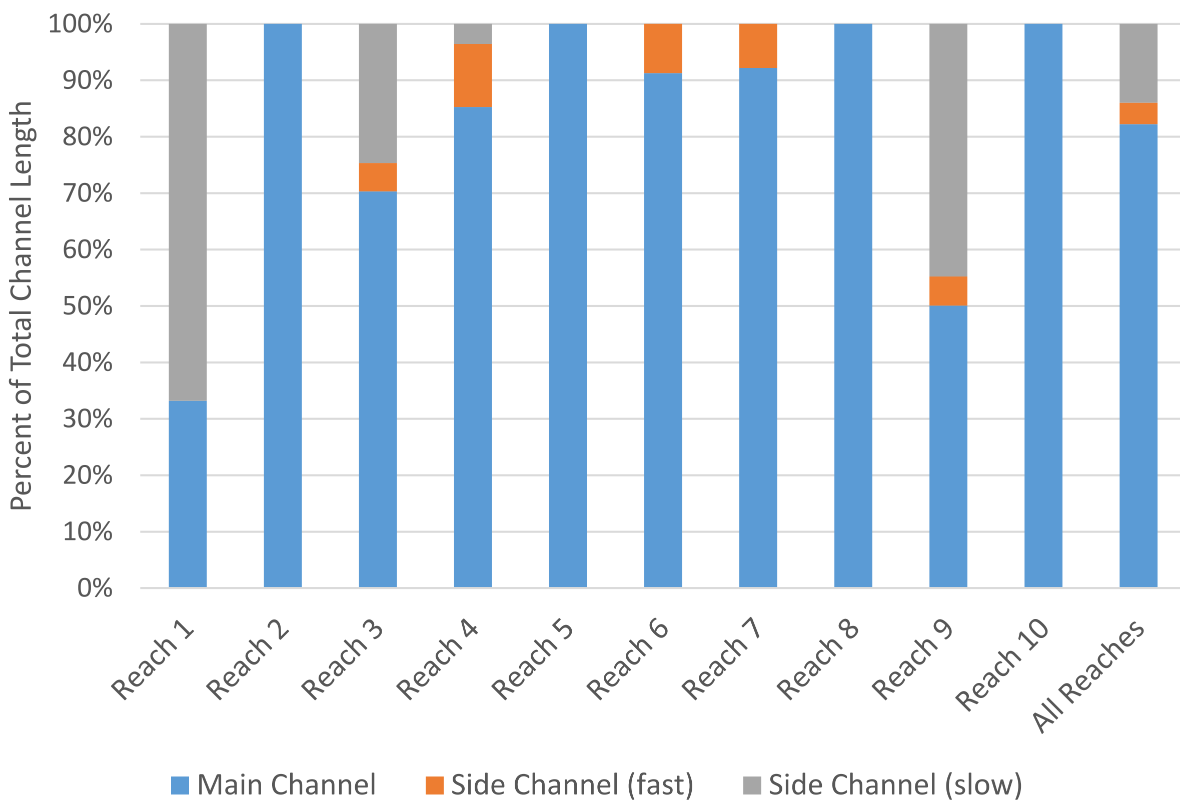


Figure 4-16. Distribution of Main Channel and Side Channel Units by Reach for the Lower Wenatchee River

4.5 Riparian Vegetation

Riparian vegetation data were collected during field habitat surveys following the USFS Level II protocols (USFS 2006). There are also existing reports describing the characteristics of riparian vegetation and canopy cover along the lower Wenatchee River as well as the absence of vegetation related to human disturbance (Andonaegui 2001; NWPCC 2004; 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). The REI analysis in Appendix D also contains riparian vegetation information including an analysis of percent canopy cover within the riparian area.

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

During field surveys for this assessment, riparian vegetation data was collected for each channel unit by 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.

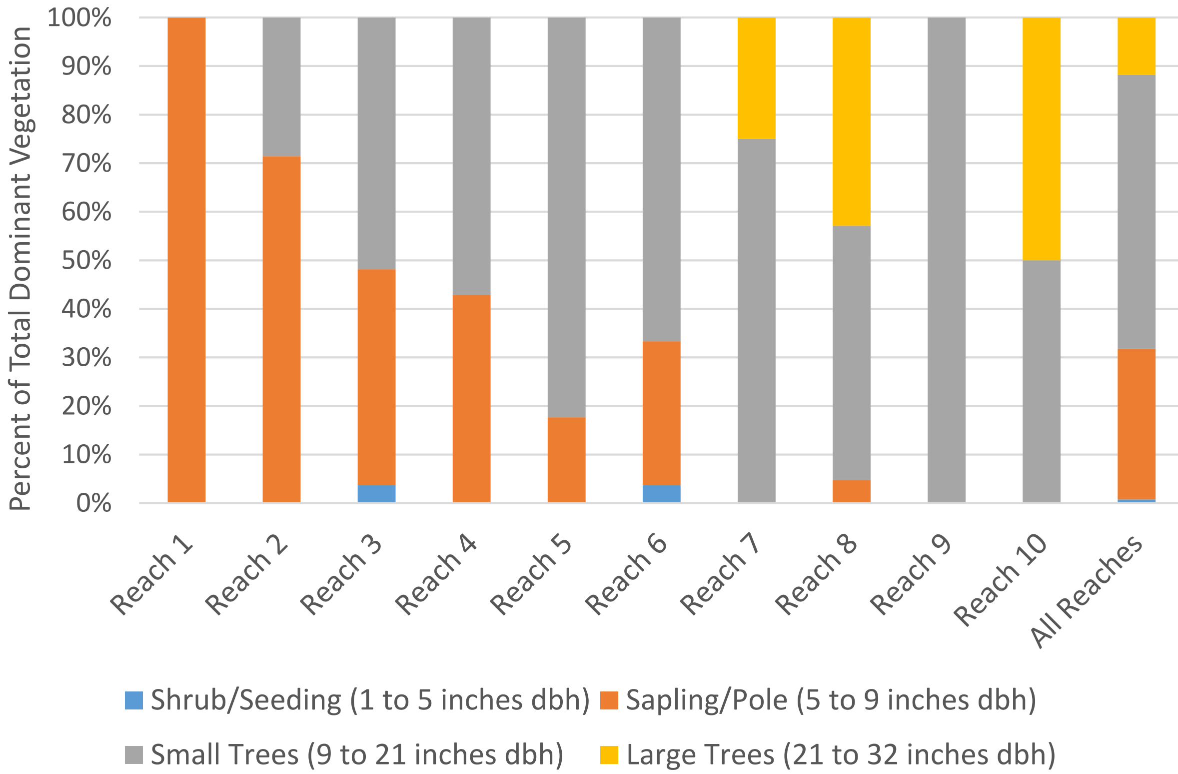


Figure 4-18. Distribution of Dominant Riparian Vegetation Diameter Class by Reach for the Lower Wenatchee River

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. Except for Reach 6, which includes Dryden Diversion Dam, the project area is 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 project 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 Reaches 9 and 10.

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

General Characteristics	General Indicators	Specific Indicators	Reach									
			1	2	3	4	5	6	7	8	9	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	Adequate	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 historic (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. 2012).

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. 2012). 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 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.

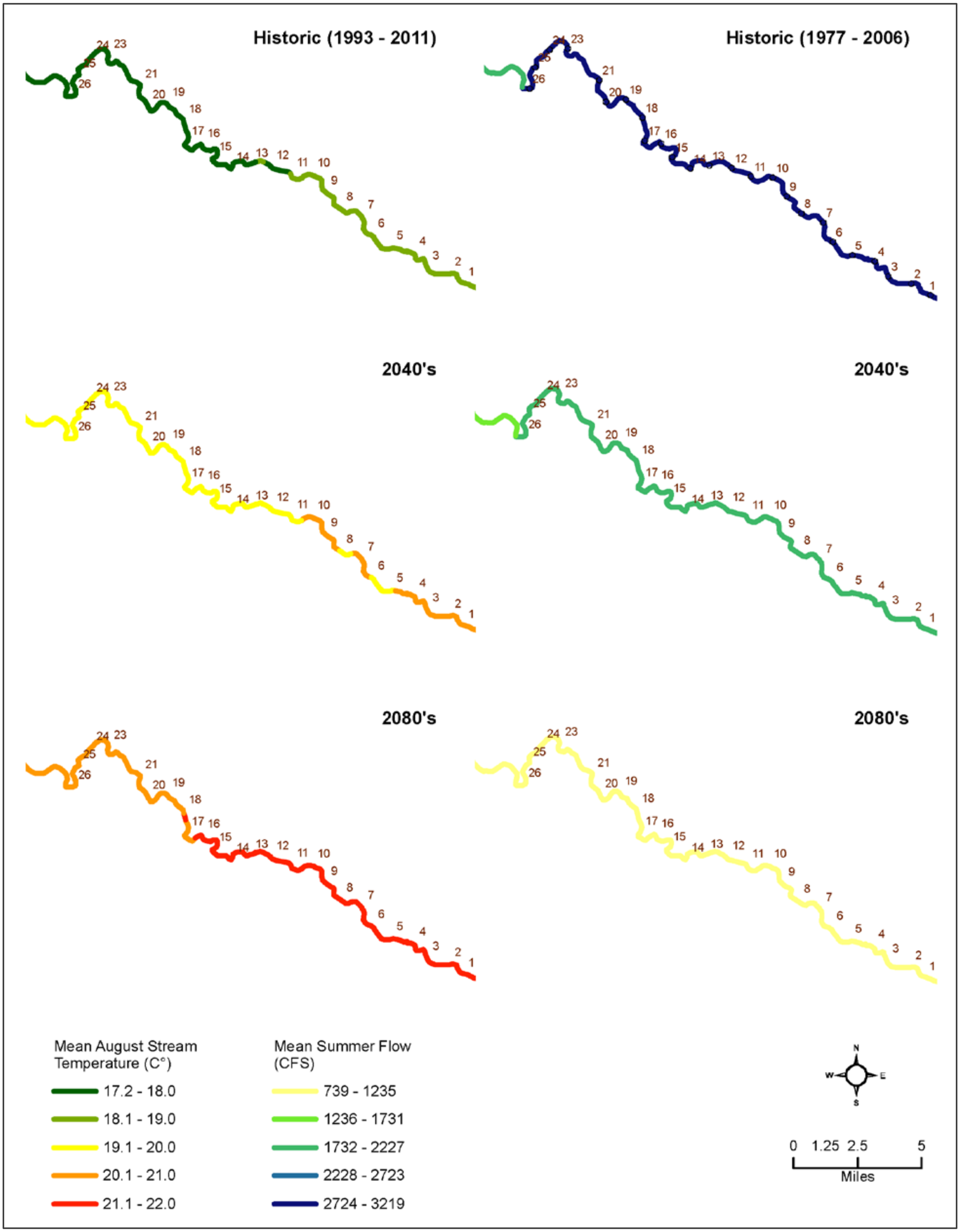


Figure 4-19. Modeled Historic and Future Climate Change Scenario Mean August Stream Temperatures and Mean Summer Flows along Lower Wenatchee River (Data Source: USFS 2015a, 2015b)

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 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 the following 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	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.	4.1 Riparian Condition: Riparian Vegetation 5.1 Peripheral and Transitional Habitats: Side Channel and Wetland Conditions	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.	9.2 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.	6.1 Channel Structure and Form: Instream Structural Complexity	Install 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.	6.1 Channel Structure and Form: Instream Structural Complexity	Install 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.	5.1 Peripheral and Transitional Habitats: Side Channel and Wetland Conditions 5.2 Floodplain Condition	Riparian Restoration, floodplain habitat reconnection, install habitat structures

Specific Indicator	Reaches Included	Existing Condition	Target Condition[2/]	Primary Ecological Concerns Addressed	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.	5.1 Peripheral and Transitional Habitats: Side Channel and Wetland Conditions 5.2 Floodplain Condition 8.1 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.	6.1 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.	6.1 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.	4.1 Riparian Condition: Riparian Vegetation	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 C).

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 39 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. This is due to the bank armoring and other 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 process are not maintained because they are disconnected from river flooding and occupation by native species. 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 historic 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 historic 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 historic 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 areas 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 historic 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 historic 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 8 should be to protect and maintain the existing functional riparian forests and riparian restoration. The existing riparian areas in this reach contain more conifers than in downstream reaches, and a larger proportion of big trees.

Reach 8: Reach 8 is highly confined, 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

This section provides a description of site-specific project opportunities and the potential restoration actions and overall action type that was identified for those sites. The site-specific project opportunities were identified during field surveys and further advanced based on the reach assessment results presented in Section 4.0. The identification of potential projects also considered previously completed restoration actions and potential actions that have been identified as part of past efforts. A total of 39 specific project opportunities were identified, a geodatabase created (Appendix F), and potential restoration actions listed for those sites. The 39 project opportunities and specific locations based on river miles are further described in Appendix E.

In addition to the specific project opportunities that have been identified, there are restoration actions that may be applied more generally throughout the lower Wenatchee River. These actions include efforts to preserve and increase instream flows, implementation of the TMDL Water Quality Implementation Plan (Ecology 2009) to improve water quality, planting native riparian vegetation and removing invasive species, preserving existing undeveloped areas, and acquiring key properties in the floodplain for protection measures. The potential to incorporate any or all of these actions into the specific project opportunities should also be considered, where applicable.

A list of potential restoration actions has been identified for each of the 39 project opportunities. Table 5-2 shows the number of sites that include each potential restoration action by geomorphic reach illustrating the potential restoration actions commonly identified on the lower Wenatchee River and what reaches have greatest restoration potential.

Table 5-2. Potential Restoration Actions Identified by Geomorphic Reach

	Number of Sites Identified by Geomorphic Reach[1/]								
Potential Restoration Actions	R1	R2	R3	R4	R5	R6	R7	R9	Total
Protection: (Acquisitions, Easements, Cooperative Agreements)	2	2	7	5	1	6	1	5	29
Reduce - Mitigate Point Source Impacts	--	--	--	2	--	--	--	--	2
Road Grading - Drainage Improvements	--	--	1	--	--	--	--	--	1
Road Decommissioning or Abandonment	--	--	--	--	--	1	--	--	1
Riparian Buffer Strip, Planting	--	2	6	5	--	2	--	1	16
Beaver Re-introduction or Management	1	--	--	--	--	1	--	--	2
Riparian Fencing	--	1	--	--	--	--	--	--	1
Bank Shaping and Stabilization	1	--	--	--	--	--	--	--	1
Removal of Bank Armoring	1	--	--	--	--	--	--	--	1

	Number of Sites Identified by Geomorphic Reach[1/]								
Potential Restoration Actions	R1	R2	R3	R4	R5	R6	R7	R9	Total
Restore Banklines with LWD - Bioengineering	1	--	4	1	--	1	--	--	7
Boulder Placements	--	--	2	5	--	--	--	--	7
LWD Placements - Individual Pieces or Trees, Log jams, etc.	2	2	9	5	1	7	1	5	32
Weirs for Grade Control (side channel)	--	--	--	--	--	1	--	--	1
Levee Modifications: Removal, Setback, Breach	--	--	--	1	--	1	--	--	2
Remove and/or Relocate Floodplain Infrastructure	--	--	1	3	--	1	1	1	7
Restoration of Floodplain Topography and Vegetation	1	1	6	4	1	3	--	2	18
Floodplain Excavation: Benching	1	--	1	--	--	--	--	--	2
Improve Thermal Refugia	--	--	2	--	--	1	--	--	3
Perennial Side Channel	--	--	5	3	1	4	--	2	15
Secondary Channel (non-perennial)	1	--	4	2	1	2	--	2	12
Wetland	--	--	--	--	--	2	--	--	2
Alcove	1	1	3	3	--	4	--	1	13
Hyporheic, Off-Channel Habitat (Groundwater)	--	--	2	1	1	1	--	1	6
Pool Construction (side channel or tributary)	--	1	--	1	--	1	--	--	3
Riffle Construction (side channel or tributary)	--	1	--	1	--	1	--	--	3
Meander (Oxbow) Re-connect - Reconstruction	--	--	2	--	--	--	--	--	2
Channel Reconstruction (side channel or tributary)	--	1	--	1	--	2	--	--	4
Structural Passage (Diversions)	--	--	--	--	--	1	--	--	1
Barrier or Culvert Replacement or Removal (side channel or tributary)	--	--	1	--	--	--	--	1	2

1/ No potential restoration opportunities were identified in Reaches 8 or 10.

The overall restoration action type was also identified for each of the 39 project opportunities. A description of the main restoration action types that were identified for the lower Wenatchee River is provided in the subsections below and included with the description of the project opportunities in Appendix D.

5.3.1 Protect and Maintain Habitat

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.

5.3.2 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 has also previously identified a number of site-specific areas where riparian restoration opportunities exist (Jones & Stokes 2003).

5.3.3 Floodplain Habitat Reconnection

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.

5.3.4 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.

5.3.5 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 historic floodplains and enhance floodplain habitat.

5.3.6 Install Habitat Structures

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. In some instances, these actions may also include some minor pool excavation to complement the installation of these habitat structures.

5.4 Prioritization of Project Opportunities

The importance of project prioritization is increasingly being recognized by river restoration practitioners. During recent Independent Scientific Review Panel evaluations of habitat projects funded by the Bonneville Power Administration, considerable emphasis has been placed on developing a strategic framework to ensure that funding entities direct efforts toward the most important restoration priorities; restoration projects should be conducted in the right locations and in the right order centered on a process-based, landscape-scale approach (ISRP 2013). Past efforts have often not considered or did not have adequate information available to make determinations of how and where priority work should occur, particularly at the watershed level or finer geographic scales. To that end, project opportunities in the lower Wenatchee River were ranked by applying a scoring matrix (Appendix G) that uses existing and new information gathered during the reach assessment. Rankings first take into consideration several biological and physical habitat attributes considered to have the most impact on improving fish population performance, followed by project feasibility and constraints. The biological and physical scoring categories and descriptions are as follows:

Biological Rankings:

- Restoration Actions Score – assigns a score to proposed restoration actions based on their ability to provide benefits to key lifestages of target fish species, and whether an action should be implemented in the immediate (1-3 years), intermediate (4-15 years), or long-term (15 years or more) future. Higher numbers of near-term restoration actions result in higher scores.
- Action Effects on Limiting Factors Score – scoring of this category is based on the ability of each restoration action to address known limiting factors, and whether or not an action directly or indirectly affects a limiting factor.
- Lifestages Present Score – assigns a score based current production areas and on the raw count of the number of lifestages of the focal fish species present from periodicity tables (Table 2-1).
- Lifestage Utilization Score – targets areas based on the number of lifestages present and their relative importance, with higher scores assigned to areas with multiple lifestages, and those lifestages that are in need of immediate action to improve fish population performance.

Physical Processes Rankings:

- Natural Processes Score – assigns a score based on if the proposed project as a whole qualifies as full restoration, partial restoration, or short-term habitat based on the definitions from Beechie et al. (2010).
- Geomorphic Potential Score – targets areas based on the physical ability to affect change, and under the assumption that moderately confined or unconfined reaches present more physical opportunities to implement restoration actions that can increase both habitat quantity and quality.
- Current Conditions Score – scores are based on the overall evaluation of current habitat conditions as described through the REI as discussed in Section 4.6. Scores reflect expected improvements if all restoration actions were implemented, and are based on the assumption that areas with fair to good habitat provide the most opportunity for improvement, while areas with poor habitat would require larger investments for minimal improvement, and areas with excellent habitat provide little opportunity for improvement beyond their current condition.
- Current Temperature Score – considered as a separate but important subcategory of the Current Conditions Score, whereby a score of “Poor” would flag lethal temperatures and would serve as a

warning that a project opportunity may not be worthwhile despite possible high scores in other categories.

- Project Scale and Connectivity Score – scores project opportunities based on scale (stream miles or acres of floodplain), connectivity with adjacent projects, and whether or not the project provides upstream or downstream benefits (e.g., provides increased flow, reduces summer temperatures).

5.4.1 Project Opportunity Scoring Matrix

The first step in the development of the project opportunity scoring matrix (Appendix G) was to determine fish distribution and timing of the ESA-listed focal species of concern (Chinook salmon, steelhead, and bull trout), as described in Section 2.5, and decide if there were enough differences between any of the geomorphic reaches to separate them into biologically significant reaches (BSRs). A BSR would be defined as a stream reach with similar fish use and limiting factor characteristics. An example of two very distinct BSRs would be where one reach had fish use that occurred mostly during migration periods, had high summer water temperatures, and where very limited spawning or rearing occurred, while another reach, perhaps higher in the watershed, contained spawning and rearing habitat for multiple species, and year-around use for all lifestages. In this example, the latter reach would warrant a higher initial ranking based on higher overall fish utilization and fewer limiting factors present.

Based on examination of fish periodicity in the lower Wenatchee River (Table 2-1), only subtle differences in fish utilization and limiting factors were found; therefore, the study area was not broken into separate BSRs. The differences that were found would be accounted for in other project opportunity ranking categories.

The next step was to determine the relative importance of the lifestages of each of the focal species based on current fish use and assign rankings based on the following definitions:

High (H): High-priority lifestage use in need of *immediate to short-term action* (1-3 years) to improve fish population abundance, productivity, distribution, and sustainability.

Medium (M): Medium-priority lifestage use in need of *intermediate-term action* (4-15 years) to improve fish population abundance, productivity, distribution, and sustainability.

Low (L): Low-priority lifestage use in need of *long-term action* (15 or more years) but is currently minimally affected by existing conditions; could improve future fish population performance.

N/A: Lifestage not present and therefore not applicable.

Using these definitions, rankings were assigned to each lifestage of the focal fish species as shown in Table 5-3, with comments indicating the rationale behind the rankings. These qualitative rankings are converted to numerical scores within the prioritization matrix spreadsheet (Appendix G), and can be automatically updated if new information comes forth that would indicate the need to change any rankings.

Table 5-3. Fish Lifestage Utilization Rankings for the Lower Wenatchee River

Lifestage	Spring Chinook	Steelhead	Bull Trout	Comments
Adult Immigration & Holding	M	L	L	Pools for Chinook staging are important in low-flow years.
Adult Spawning	L	M	N/A	Most steelhead spawning above RM 18.
Incubation/Emergence	N/A	M	N/A	No Chinook salmon or bull trout. Most steelhead spawning above RM 18.
Summer Rearing	M	H	M	Data gap on bull trout use.
Winter Rearing	H	H	M	Data gap for all species.
Juvenile Emigration	H	H	N/A	Off-channel and velocity refugia important at higher flows.

NMFS's standardized limiting factors (also known as ecological concerns) were then entered into the scoring matrix (Appendix G). These determinations were made from the FCRPS (2012) BiOp Expert Panel process for the lower Wenatchee River assessment unit. The Expert Panel assigned weightings to each of the limiting factors, and those were assigned qualitative rankings of high, medium, or low using definitions based on urgency for addressing very similar to those listed for fish lifestages above. The results are shown in Table 5-4 below. These qualitative rankings are also converted to numerical scores within the prioritization matrix spreadsheet in Appendix G.

Table 5-4. Limiting Factors Rankings for the Lower Wenatchee River

Limiting Factors Rankings: from Expert Panel1/				
Weight	No.	NOAA Standardized Limiting Factor Description/2	Score	Comments
0%	1.1	Habitat Quantity: Anthropogenic Barriers	H	Limiting Factor Weight indicates barriers have been addressed.
10%	4.1	Riparian Condition: Riparian Vegetation	M	Most important in unconfined reaches.
25%	5.1	Peripheral and Transitional Habitats: Side Channels & Wetland Conditions	H	Provide thermal and velocity refugia; habitat diversity.
20%	6.1	Channel Structure and Form: Bed and Channel Form	H	Most habitat is very long riffles and glides.
10%	6.2	Channel Structure and Form: Instream Structural Complexity	M	Low quantities of large wood and complex pools.
15%	8.1	Water Quality: Temperature	H	Reduced summer temperatures.
20%	9.2	Water Quantity: Decreased Water Quantity	H	Increasing summer flows was considered high priority.
Source Data: FCRPS (2012) Expert Panel [X] Sub-Basin [ ] Recovery Plan [ ]				

1/ The Expert Panel limiting factors and weights were essentially identical for spring Chinook and steelhead in Lower Wenatchee assessment units (WEC5 and WES5).

2/ NMFS uses the term "ecological concern" instead of "limiting factor," but the two are used interchangeably by the Expert Panel and others.

The overall impacts of implementing restoration actions were evaluated next. Potential restoration actions are generally arranged in order from passive (e.g., protection or land management) to highly active (e.g., channel reconstruction or dam removal) restoration actions. Each opportunity was assigned a qualitative ranking of high, medium, low, or N/A based on an action's ability to address key fish lifestages, and general comments were noted. These qualitative rankings are also later converted to numerical scores within the prioritization matrix spreadsheet (Appendix G), but not until after they have been assigned to specific potential project areas.

The previous steps set the stage for ranking individual project opportunities, which was completed within a separate worksheet. Individual project opportunities that were identified during field surveys or through additional investigation were assigned a description based on location along the river that included reach number, river mile(s), and left or right banks. The restoration actions that were most appropriate for the lower Wenatchee River were then assigned, regardless of costs, constraints, or other feasibility criteria. Restoration actions could be designated as a passive effect or a direct action, but these had no impact on scores. The opportunity scoring matrix would then automatically calculate the Restoration Actions Score and the Action Effects on Limiting Factors Score. The Lifestages Present Score is also automatically calculated after entering the BSR number from a drop-down menu (note that only one BSR was included in the lower Wenatchee River). The Lifestage Utilization Score is automatically calculated based on previously entered information. Since the totals of the Restoration Actions, the Action Effects on Limiting Factors, and the Lifestage Utilization scores were large numbers, each was divided by various factors (5 or 10). The resulting subtotal of the Biological Rankings portion of the scoring matrix was intended to represent approximately 50 percent of the total possible score.

The five Physical Processes Rankings were chosen by selecting qualitative rankings from drop-down menus. The rankings were selected based on a combination of site-specific data for the lower Wenatchee River and professional opinion. Each of those scoring categories was also automatically converted to numerical scores, with the resulting subtotal score representing approximately 50 percent of the total possible score. An example of the scoring of an individual project opportunity is illustrated in Table 5-5. The results of all 39 project opportunity rankings were sorted into a separate worksheet, arranged from highest to lowest ranking, and are included in Appendix G.

5.4.2 Project Feasibility Criteria

A project feasibility evaluation system was developed using 10 criteria, followed by an overall summary column. Estimated cost and benefit/cost ratios were the only categories converted to numerical scores. Other categories were assigned quantitative high, moderate, low, or to be determined (TBD) rankings using limited professional judgement. For example, some categories, such as landowner willingness, would be difficult to evaluate until the potential project was farther along in the planning process. In addition, quantitative scoring would make little sense if a single category (e.g., an unwilling landowner, or inaccessibility) would limit the chance of a project opportunity from becoming an actual project. For those reasons, the feasibility criteria were kept as a separate component of the biological/physical scores. Table 5-6 illustrates the feasibility criteria used for the lower Wenatchee River, and includes the preliminary feasibility rankings for the 10 highest scoring project opportunities.

5.5 Restoration Strategy Summary

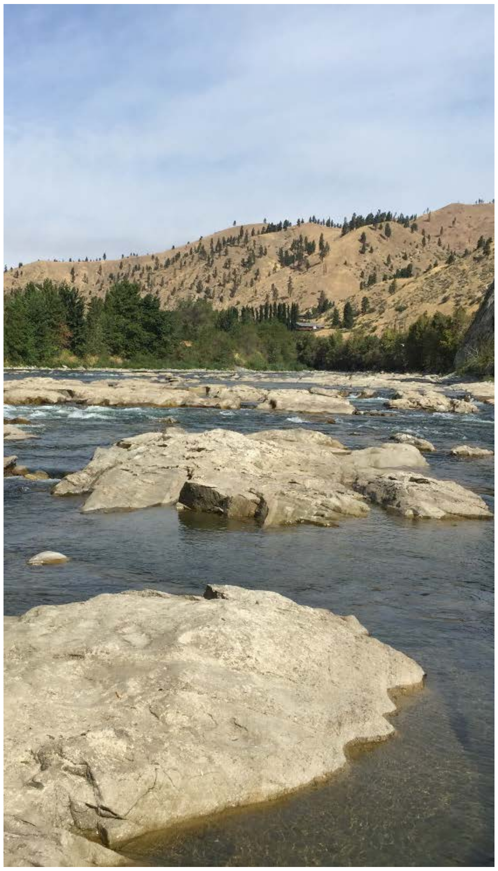
The restoration strategy described above, along with details included in Appendix E, identified restoration project opportunities, their locations, and associated restoration actions and action types. A project opportunity geodatabase (Appendix F) was also developed. The project geodatabase will facilitate in 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 has 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.

Table 5-5. Example Scoring of an Individual Project Opportunity

Project Descriptions and Actions			Biological Rankings					Physical Processes Rankings							
	Opportunity Location (Reach No. & RM's)/Project Name		BSR ranking	Restoration Actions Score	Action Effects on Limiting Factors Score	Lifestages Present Score	Lifestage Utilization Score	Natural Processes Score	Geomorphic Potential Score	Current Conditions Based on REI Scoring	Current Temperature	Project Scale and Connectivity	Subtotal Biological Scores	Subtotal Physical Scores	TOTAL PROJECT SCORE
Activity No.	Reach 3, RM 3.0, Right Bank	Action Type	Tier II	50	36	BSR 1	46	Partial Restoration	Good	Fair	Fair	Good			
1	Protection: (Acquisitions, Easements, Cooperative Agreements)	Passive Effect		10	0										
12	Riparian Buffer Strip, Planting	Direct Action		10	9										
20	LWD Placements - Individual Pieces or Trees, Logjams, etc.	Direct Action		10	6										
24	Restoration of Floodplain Topography and Vegetation	Direct Action		10	9										
31	Alcove	Direct Action		10	12										
Reach 3, RM 3.0, Right Bank		Scores:	0	10	4	10	9	5	15	15	0	7	33	42	75

Table 5-6. Project Opportunity Summary Table with Feasibility Criteria

Lower Wenatchee River Project Opportunities Summary Table				Feasibility Criteria												
General Information																
Reach	Opportunity Location (Reach No. & RM's)/Project Name	TOTAL PROJECT SCORE	RANK	Estimated Cost	Benefit/Cost Ratio	Landowner Willingness	Design Effort	Construction Effort	Site Access Effort	Site Management - Dewatering and Erosion Control Effort	Risk & Uncertainty (Goals and Objectives Achieveable?)	Risk & Uncertainty (Public Safety, Infrastrucure)	Regulatory Requirements, Permitting Effort	Overall Feasibility Constraints	Comments
3	Reach 3, RM 2.2 - 3.0, Left Bank	106	1	6	18	TBD	MODERATE	MODERATE	LOW	LOW	LOW	LOW	LOW	LOW	Highest ranked project.
3	Reach 3, RM 4.0 to 5.2, Left Bank	104	2	10	10	TBD	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	Very high costs.
6	Reach 6, RM 13.8, Right Bank	100	3	8	13	TBD	MODERATE	HIGH	LOW	LOW	MODERATE	HIGH	HIGH	HIGH	Roads & railroad infrastructure.
4	Reach 4, RM 9.2 to 10.7, Left Bank	100	4	10	10	TBD	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	Levee setback with residences involved.
9	Reach 9, RM 25.0 to 26.6, Right Bank	98	5	6	16	TBD	MODERATE	MODERATE	LOW	LOW	LOW	MODERATE	MODERATE	MODERATE	Improves CMZ 20.
6	Reach 6, RM 18.0, Right Bank	97	6	6	16	TBD	MODERATE	MODERATE	LOW	LOW	LOW	MODERATE	MODERATE	MODERATE	Lower Peshastin realignment.
4	Reach 4, RM 6.5, Left Bank	92	7	4	23	TBD	LOW	MODERATE	LOW	LOW	LOW	LOW	LOW	LOW	High potential to improve Pioneer SC.
9	Reach 9, RM 24.7, Left Bank	90	8	2	45	TBD	LOW	LOW	MODERATE	MODERATE	LOW	MODERATE	LOW	LOW	Blackbird Island, very high benefit/cost.
2	Reach 2, RM 2.0, Left Bank	84	9	6	14	TBD	MODERATE	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	HIGH	MODERATE	Tributary realignment.
4	Reach 4, RM 8.6, Right Bank	83	10	10	8	TBD	HIGH	HIGH	LOW	HIGH	MODERATE	HIGH	HIGH	HIGH	Very high cost to relocate wastewater site.
1	Reach 1, RM 0.8 Right Bank	82	11												
9	Reach 9, RM 24.4, Right Bank	81	12												
3	Reach 3, RM 5.2, Left Bank	80	13												
3	Reach 3, RM 3.8, Right Bank	80	14												



6. 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 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 project opportunity geodatabase (Appendix F), the potential project opportunities list (Appendix E), and the project opportunity prioritization matrix spreadsheet (Appendix G). The tools provided in this report are flexible and adaptable. Updates can be made as limiting factors or river conditions change, new empirical data and research evidence become available, or as projects are implemented (i.e., removed from the rankings list), thus contributing to adaptive management of habitat restoration programs in years ahead. The project opportunity prioritization provided in this report should be viewed therefore not as static or fixed but rather as adaptable, meant to assist watershed managers in ensuring the correct restoration activities are implemented in the areas that can address the most limiting factors, and produce the highest potential benefits for salmonid population performance. This approach was taken with the understanding that conditions can change over time or based on new information as it becomes available.

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.

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APPENDIX A

Index of Existing Reach Assessment Data

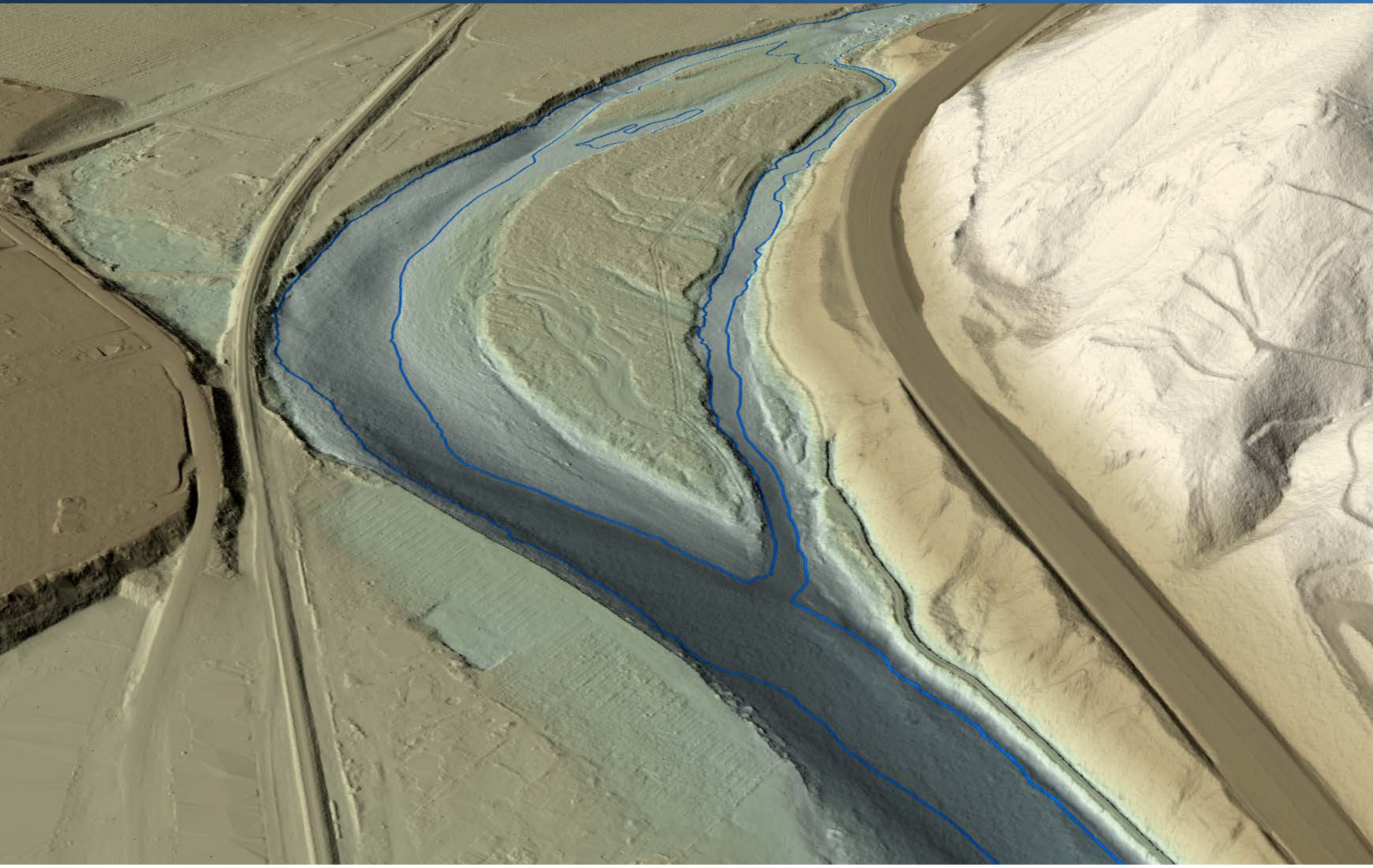
(provided on DVD)

This appendix is provided separately.

APPENDIX B

Lower Wenatchee River Topobathymetric LiDAR Technical Data Report

November 11, 2015



Lower Wenatchee River Topobathymetric LiDAR

Technical Data Report

TETRA TECH

Tricia Gross
Tetra Tech, Inc.
19803 North Creek Parkway
Bothell, WA 98011
PH: 360-336-3071

QSI Corvallis
517 SW 2nd St., Suite 400
Corvallis, OR 97333
PH: 541-752-1204

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Cover Photo: A view looking west along the Lower Wenatchee River outside of Monitor, WA. The image was created from the gridded LiDAR bare earth, colored by elevation, and overlaid with the water's edge breakline.

INTRODUCTION

A photo taken by QSI acquisition staff showing a view looking upstream on the Lower Wenatchee River.

In July 2015, Quantum Spatial (QSI) was contracted by Tetra Tech to collect topo-bathymetric Light Detection and Ranging (LiDAR) data in the summer of 2015 for the Lower Wenatchee River site in Washington. The Lower Wenatchee area of interest stretched from the river mouth upstream to Icicle Road Bridge in Leavenworth, WA (river miles 0 to 26.4). Traditional near-infrared (NIR) LiDAR was fully integrated with green wavelength (bathymetric) LiDAR in order to completely map both the topography bathymetry of the site. Data were collected to aid Tetra Tech in assessing the topographic and geophysical properties of the study area.

This report accompanies the delivered topobathymetric LiDAR data and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including LiDAR accuracy, depth penetration, and density. Acquisition dates and acreage are shown in Table 1, the project extent is shown in Figure 1 and a complete list of contracted deliverables provided to Tetra Tech is shown in Table 2.

Table 1: Acquisition dates, acreage, and data types collected on the Lower Wenatchee River site

Project Site	Contracted Acres	Buffered Acres	Acquisition Dates	Data Type
Lower Wenatchee River	1,501	3,610	08/13/2015 – 08/15/2015	NIR Wavelength LiDAR
			08/13/2015 – 08/15/2015	Green Wavelength LiDAR

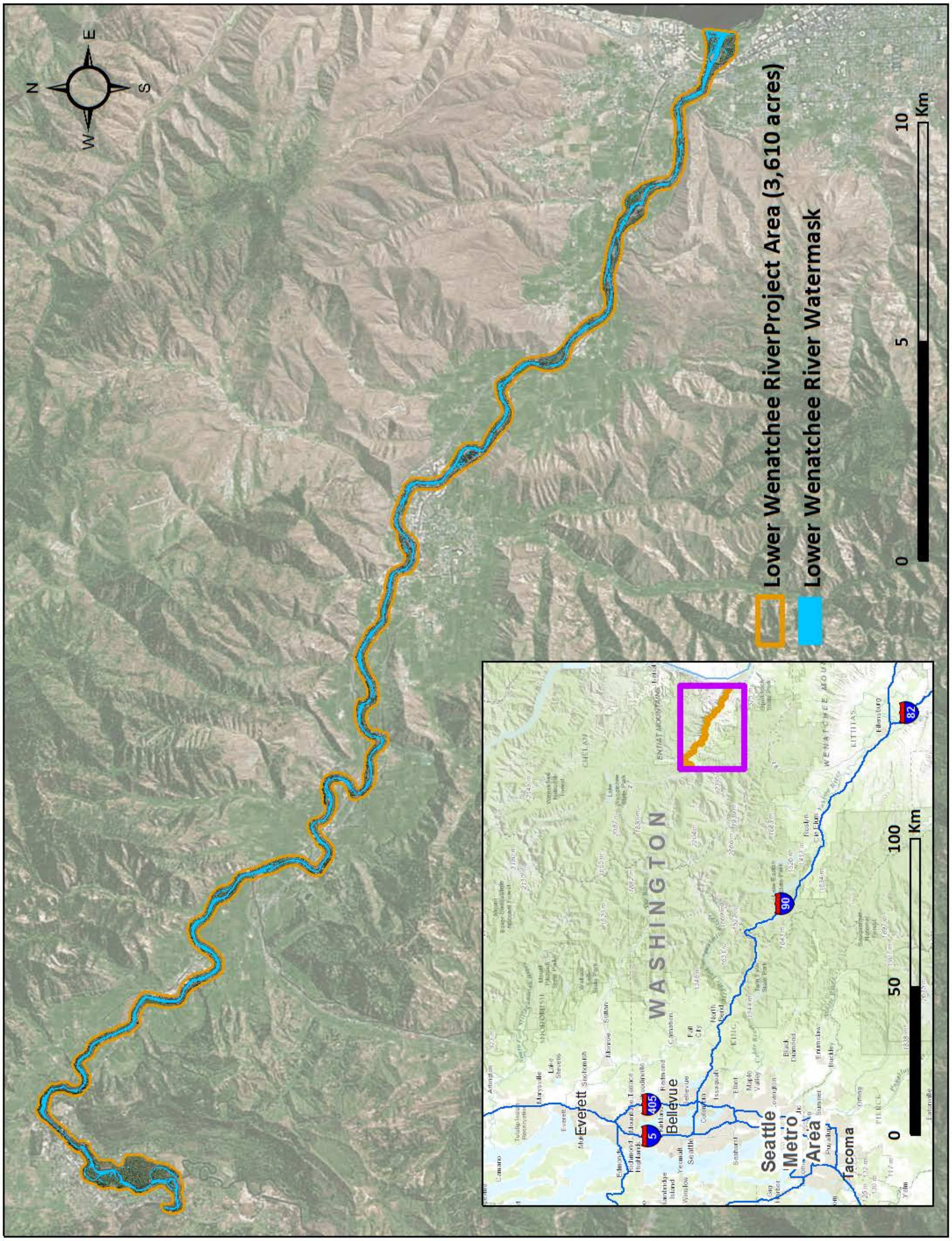

Figure 1: Location map of the Lower Wenatchee River site in Washington

Deliverable Products

Table 2: Products delivered to Tetra Tech for the Lower Wenatchee River site

Lower Wenatchee River Products **Projection: UTM Zone 10 North** **Horizontal Datum: NAD83 (2011)** **Vertical Datum: NAVD88 (GEOID12A)** **Units: Meters**	
Topobathymetric LiDAR	
Points	LAS v 1.2 • All Returns
Rasters	1.0 Meter ESRI Grids • Combined topo-bathymetric Bare Earth Model • Highest Hit Model 0.5 Meter GeoTiffs • Intensity Images
Vectors	Shapefiles (*.shp) • Site Boundary • LiDAR Tile Index • Water Breaklines • Submerged Topographic Density

QSI's ground acquisition equipment set up over monument LOW_WEN_02 in the Lower Wenatchee River LiDAR study area.

Sensor Selection: the Riegl VQ-820-G

The Riegl VQ-820-G was selected as the hydrographic airborne laser scanner for the Lower Wenatchee River project based on fulfillment of several considerations deemed necessary for effective mapping of the project site. A high repetition pulse rate, high scanning speed, small laser footprint, and wide field of view allow for seamless collection of high resolution data of both topographic and bathymetric surfaces. A short laser pulse length allows for discrimination of underwater surface expression in shallow water, critical to shallow and dynamic environments such as the Lower Wenatchee River. The Riegl system has demonstrated hydrographic depth ranging capability up to 1 Secchi depth on bright reflective surfaces. Sensor specifications and settings for the Lower Wenatchee River acquisition are displayed in Table 6.

Planning

In preparation for data collection, QSI reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Lower Wenatchee River LiDAR study area at the target point density of ≥4.0 points/m^2 for green LiDAR returns, and ≥6.0 points/m^2 for NIR LiDAR returns (determined by the altitude required for flying topobathymetry). Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flight were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access and potential air space restrictions, channel flow rates (Figure 2 through Figure 5), and water clarity were reviewed.

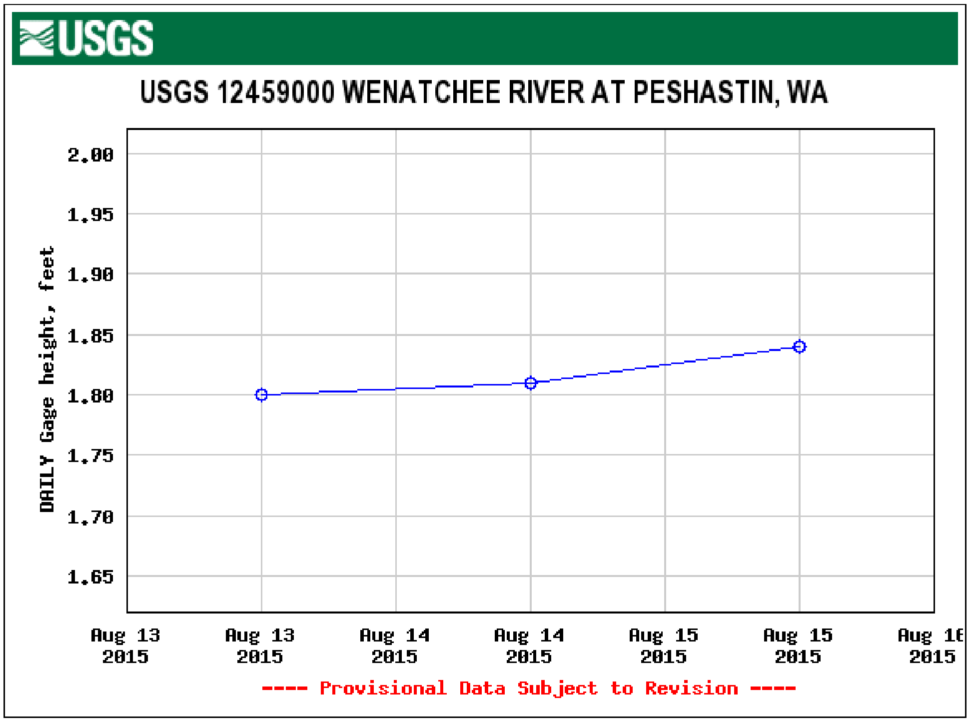

Figure 2: USGS Station 12459000 gauge height along the Lower Wenatchee River at the time of LiDAR acquisition.

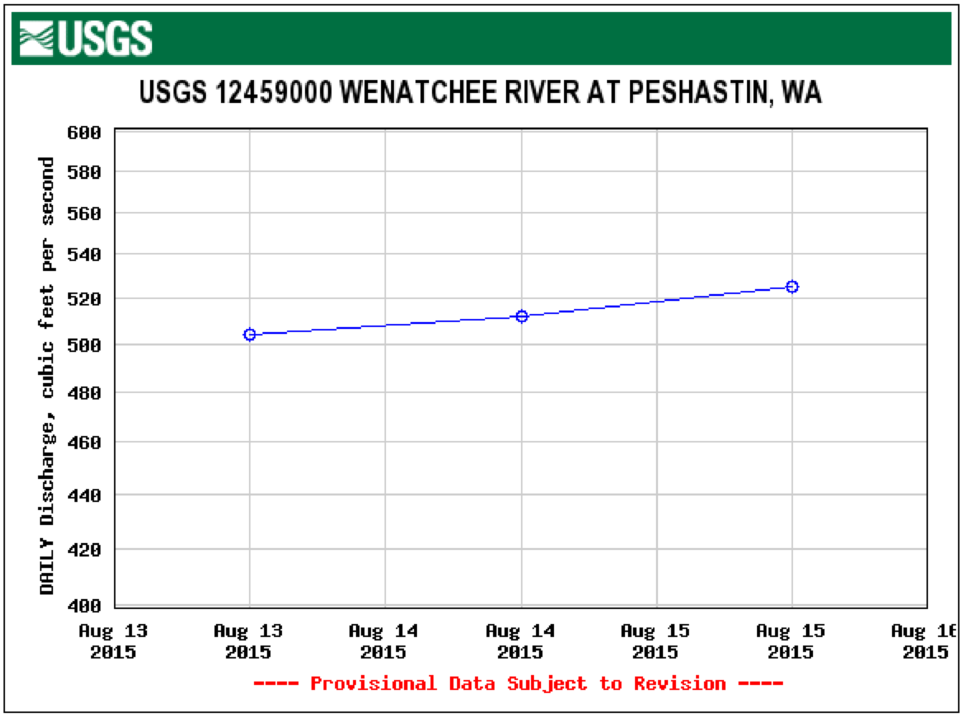

Figure 3: USGS Station 12459000 flow rates along the Lower Wenatchee River at the time of LiDAR acquisition.

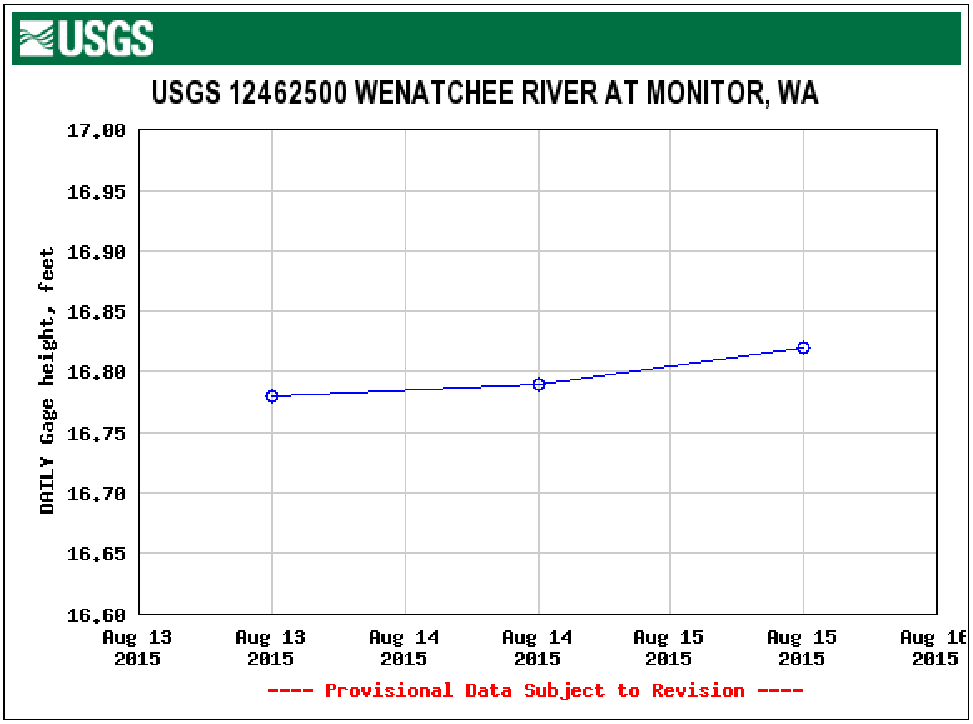

Figure 4: USGS Station 12462500 gauge height along the Lower Wenatchee River at the time of LiDAR acquisition.

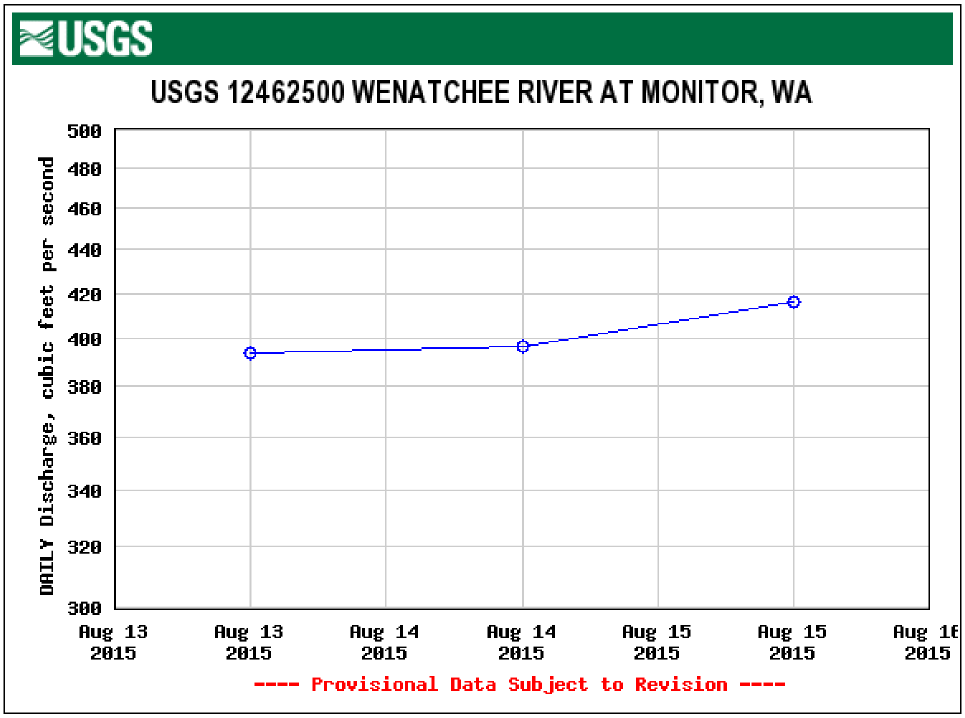

Figure 5: USGS Station 12462500 flow rates along the Lower Wenatchee River at the time of LiDAR acquisition.

This photo taken by QSI acquisition staff displays water clarity conditions in the Lower Wenatchee River near the town of Monitor, WA.

Airborne Survey

LiDAR

The LiDAR survey was accomplished using a Leica ALS80 system dually mounted with a Riegl VQ-820-G topobathymetric sensor in a Cessna Caravan. The Riegl VQ-820-G uses a green wavelength (λ=532 nm) laser that is capable of collecting high resolution vegetation and topography data, as well as penetrating the water surface with minimal spectral absorption by water. The recorded waveform enables range measurements for all discernible targets for a given pulse. The typical number of returns digitized from a single pulse range from 1 to 7. The Leica laser system can record unlimited range measurements (returns) per pulse, but typically does not record more than 5 returns per pulse. It is not uncommon for some types of surfaces (e.g., dense vegetation or water) to return fewer pulses to the LiDAR sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset. Table 3 summarizes the settings used to yield an average pulse density of ≥4 pulses/m^2 for the Riegl VQ820G and ≥6 pulses/m^2 for Leica ALS80 over the Lower Wenatchee River project area.

Table 3: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications		
Sensor	**Leica ALS80**	**Riegl VQ-820G**
Acquisition Dates	August 13 – 15, 2015	August 13 – 15, 2015
Aircraft Used	Cessna Caravan	Cessna Caravan
Survey Altitude (AGL)	600 m	600 m
Target Pulse Rate	400 kHz	284 kHz
Pulse Mode	Single Pulse in Air (SPiA)	Single Pulse in Air (SPiA)
Laser Pulse Footprint Diameter	16 cm	60 cm
Mirror Scan Rate	66.3 Hz	N/A
Field of View	40°	44°
GPS Baselines	≤13 nm	≤13 nm
GPS PDOP	≤3.0	≤3.0
GPS Satellite Constellation	≥6	≥6
Maximum Returns	Unlimited, but typically not more than 5	Unlimited, by typically no more than 7
Intensity	8-bit	16-bit
Resolution/Density	Average 6 pulses/m^2	Average 4 pulses/m2
Accuracy	$RMSE_Z$ ≤ 15 cm	$RMSE_Z$ ≤ 30 cm

All areas were surveyed with an opposing flight line side-lap of ≥60% (≥100% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

Ground Control Survey

QSI-Established Monument LOW-WEN 01

Ground control surveys, including monumentation, and ground survey points (GSPs), were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data

Monumentation

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK) and post processed kinematic (PPK).

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI established two new monuments for the Lower Wenatchee River LiDAR project (Table 4,Figure 6). New monumentation was set using 5/8” x 30” rebar topped with stamped 2-1/2" aluminum caps. QSI’s professional land surveyor, Christopher Glantz (WA PLS #48755) oversaw and certified the establishment of all monuments.

Table 4: Monuments established for the Lower Wenatchee River acquisition. Coordinates are on the NAD83 (2011) datum, epoch 2010.00

Monument ID	Latitude	Longitude	Ellipsoid (meters)
LOW_WEN_01	47° 30' 34.25135"	-120° 26' 05.14046"	236.289
LOW_WEN_02	47° 33' 26.48335"	-120° 35' 20.77425"	308.677

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS[1]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Monuments were established according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[2] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project is shown in Table 5.

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[1] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions. http://www.ngs.noaa.gov/OPUS.

[2] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

Table 5: Federal Geographic Data Committee monument rating for network accuracy

Direction	Rating
1.96 * St Dev $_{NE}$:	0.020 m
1.96 * St Dev $_{z}$:	0.050 m

For the Lower Wenatchee River LiDAR project, the monument coordinates contributed no more than 5.4 cm of positional error to the geolocation of the final ground survey points and LiDAR, with 95% confidence.

Ground Survey Points (GSPs)

Ground survey points were collected using real time kinematic and post-processed kinematic (PPK) techniques. A Trimble R7 base unit was positioned at a nearby monument to broadcast a kinematic correction to a roving Trimble R6 GNSS receiver. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. When collecting RTK and PPK data, the rover records data while stationary for five seconds, then calculates the pseudorange position using at least three one-second epochs. Relative errors for any GSP position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. See Table 6 for Trimble unit specifications.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however the distribution of GSPs depended on ground access constraints and monument locations and may not be equitably distributed throughout the study area (Figure 6).

Table 6: Trimble equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R6	Integrated GNSS Antenna R6	TRM_R6	Rover
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static

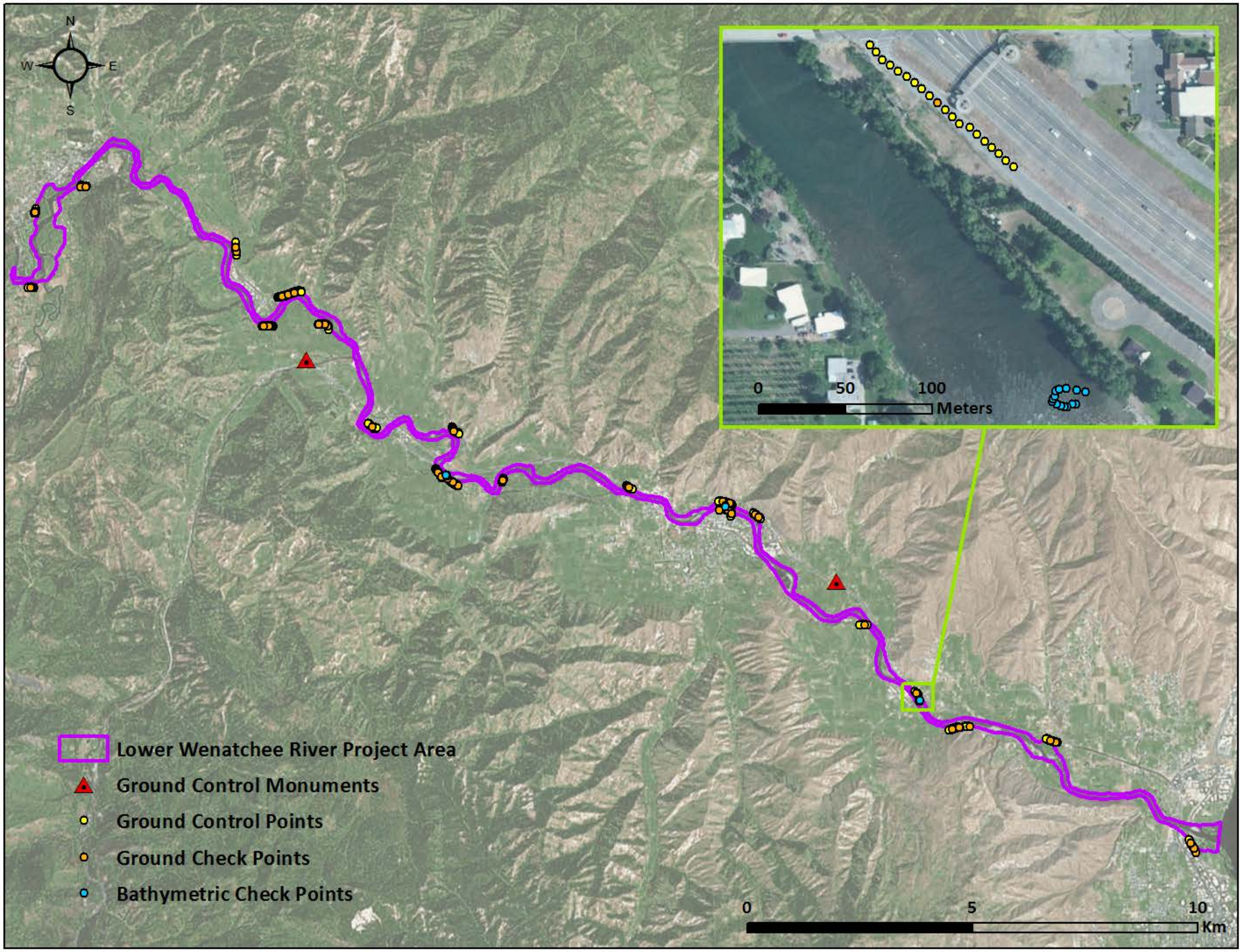
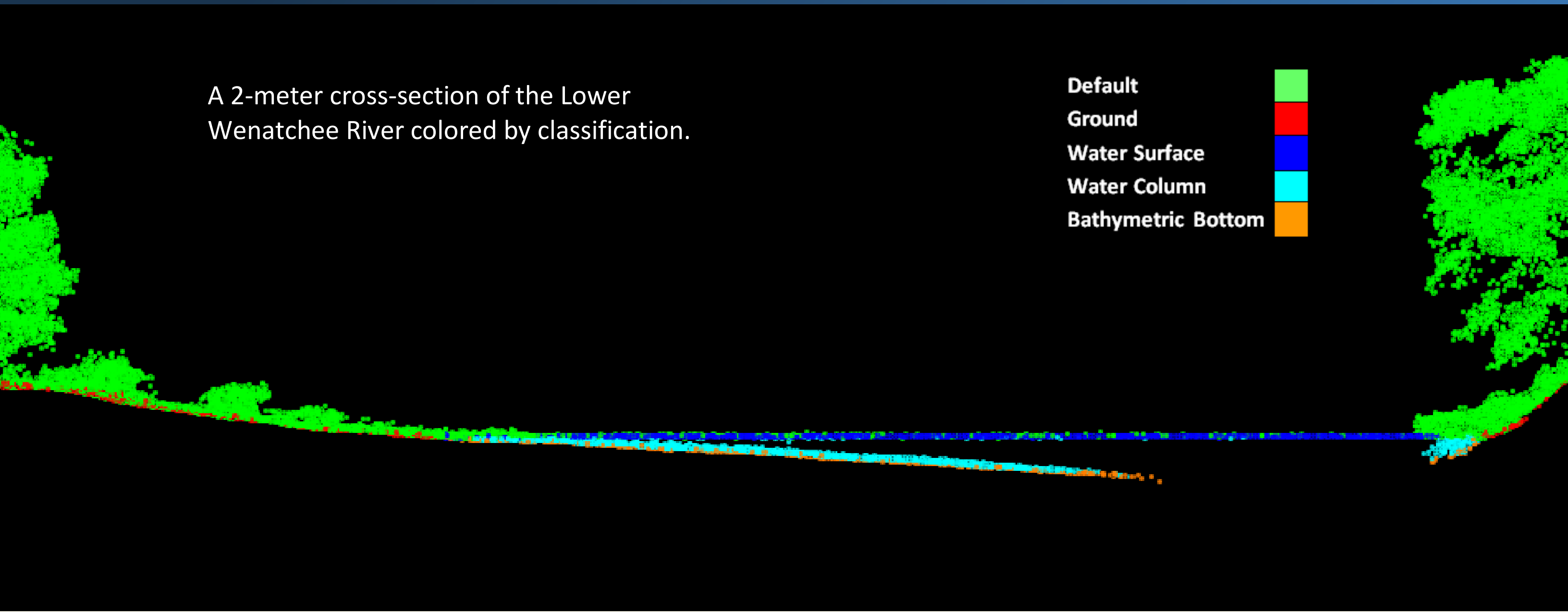


Figure 6: Ground control location map of the Lower Wenatchee River project area



A 2-meter cross-section of the Lower Wenatchee River colored by classification.

Topobathymetric LiDAR Data

Upon completion of data acquisition, QSI processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, sensor and data calibration for optimal relative and absolute accuracy, and LiDAR point classification (Table 7). Riegl's RiProcess software was used to facilitate bathymetric return processing. Once bathymetric points were differentiated, they were spatially corrected for refraction through the water column based on the angle of incidence of the laser. QSI refracted water column points using QSI's proprietary LAS processing software, LAS Monkey. The resulting point cloud data were classified using both manual and automated techniques. Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 8.

Table 7: ASPRS LAS classification standards applied to the Lower Wenatchee River dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and man-made structures
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
9	Water Surface	Laser returns that are determined to be water using automated and manual cleaning algorithms.

Classification Number	Classification Name	Classification Description
25	Water Column	Refracted Riegl sensor returns that are determined to be water using automated and manual cleaning algorithms.
26	Bathymetric Bottom	Refracted Riegl sensor returns that falls within the water's edge breakline which characterize the submerged topography.

Table 8: LiDAR processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	IPAS TC v.3.1 Waypoint Inertial Explorer v.8.6 POSPac MMS v6.2
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Convert data to orthometric elevations by applying a geoid12a correction.	ALS Post Processing Software v.2.75 RiProcess v1.6.4 Waypoint Inertial Explorer v.8.6 Leica Cloudpro v. 1.2.1 TerraMatch v.15
Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.15
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	TerraMatch v.15 RiProcess v1.6.4
Apply refraction correction to all subsurface returns.	LAS Monkey
Classify resulting data to ground and other client designated ASPRS classifications (Table 7). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.15 TerraModeler v.15
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface models as ESRI GRIDs at a 1 meter pixel resolution.	TerraScan v.15 TerraModeler v.15 ArcMap v. 10.1
Export intensity images as GeoTIFFs at a 0.5 meter pixel resolution.	TerraScan v.15 TerraModeler v.15 ArcMap v. 10.1

Bathymetric Refraction

The water surface model used for refraction is generated using NIR points within the breaklines defining the water's edge. Points are filtered and edited to obtain the most accurate representation of the water surface and are used to create a water surface model TIN. A tin model is preferable to a raster based water surface model to obtain the most accurate angle of incidence during refraction. The refraction processing is done using Las Monkey; QSI's proprietary LiDAR processing tool. After refraction, the points are compared against bathymetric check points to assess accuracy.

LiDAR Derived Products

Because hydrographic laser scanners penetrate the water surface to map submerged topography, this affects how the data should be processed and presented in derived products from the LiDAR point cloud. The following discusses certain derived products that vary from the traditional (NIR) specification and delivery format.

Topobathymetric DEMs

Bathymetric bottom returns can be limited by depth, water clarity, and bottom surface reflectivity. Water clarity and turbidity affects the depth penetration capability of the green wavelength laser with returning laser energy diminishing by scattering throughout the water column. Additionally, the bottom surface must be reflective enough to return remaining laser energy back to the sensor at a detectable level. Although the predicted depth penetration range of the Riegl VQ-820-G sensor is one Secchi depth on brightly reflective surfaces, it is not unexpected to have no bathymetric bottom returns in turbid or non-reflective areas.

As a result, creating digital elevation models (DEMs) presents a challenge with respect to interpolation of areas with no returns. Traditional DEMs are "unclipped", meaning areas lacking ground returns are interpolated from neighboring ground returns (or breaklines in the case of hydro-flattening), with the assumption that the interpolation is close to reality. In bathymetric modeling, these assumptions are prone to error because a lack of bathymetric returns can indicate a change in elevation that the laser can no longer map due to increased depths. The resulting void areas may suggest greater depths, rather than similar elevations from neighboring bathymetric bottom returns. Therefore, QSI created a water polygon with bathymetric coverage to delineate areas with successfully mapped bathymetry. This shapefile was used to control the extent of the delivered clipped topobathymetric model to avoid false triangulation (interpolation from TIN'ing) across areas in the water with no bathymetric returns.

Intensity Images

In traditional NIR LiDAR, intensity images are often made using first return information. For bathymetric LiDAR however, it is most often the last returns that capture features of interest below the water's surface. Therefore, a first return intensity image would display intensity information of the water's surface, obscuring the features of interest below.

With bathymetric LiDAR a more detailed and informative intensity image can be created by using all or selected point classes, rather than relying on return number alone. If intensity information of the bathymetry is the primary goal, water surface and water column points can be excluded. However, water surface and water column points often contain potentially useful information about turbidity and submerged but unclassified features such as vegetation. For the Lower Wenatchee River project, QSI created one set of intensity images from NIR laser first returns, as well as one set of intensity images from green laser returns. Green laser intensity images were created using first returns over terrestrial areas only, as well as bathymetric bottom points in order to display more detail in intensity values (Figure 7).

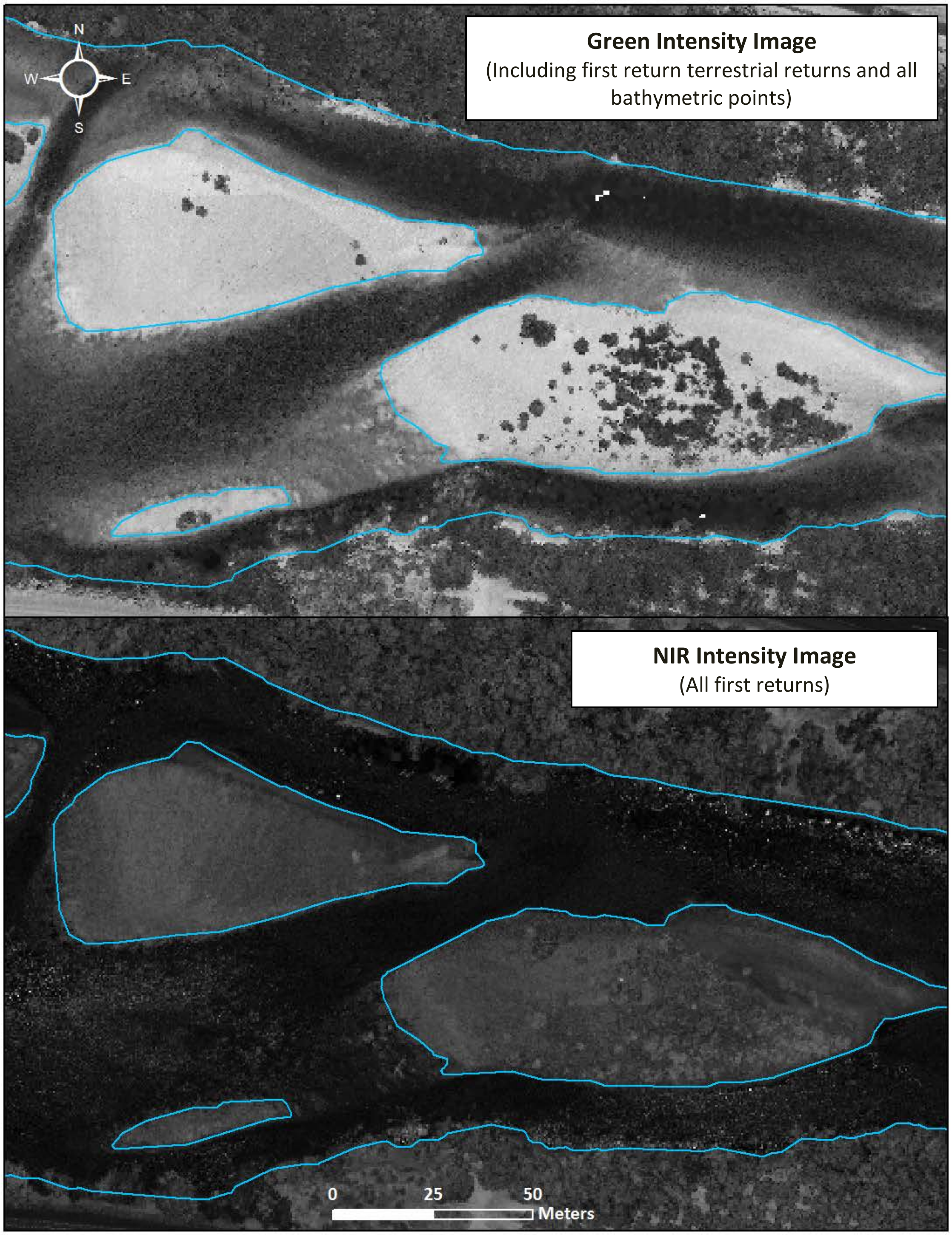
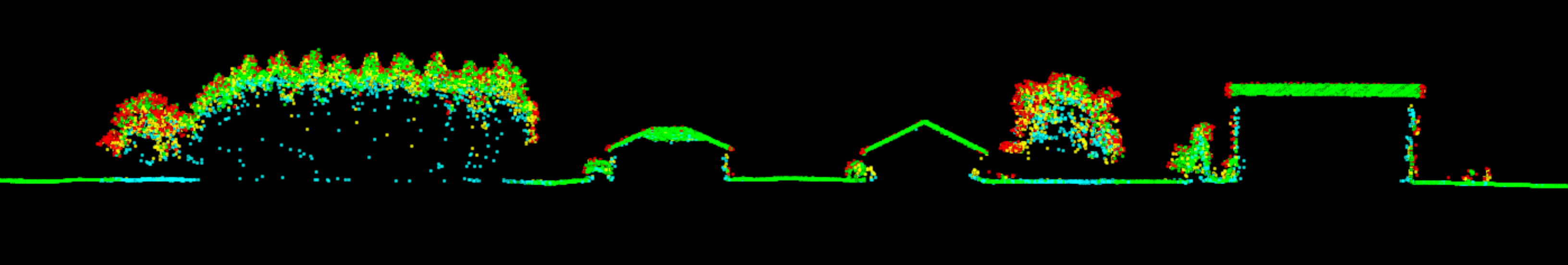


Figure 7: A comparison of Intensity Images from Green and NIR returns in the Lower Wenatchee River project area

A 1-meter cross-section of buildings and vegetation in the Lower Wenatchee River project area, colored by echo.



Bathymetric LiDAR

An underlying principle for collecting hydrographic LiDAR data is to survey areas that can be difficult to collect with other methods, such as multi-beam sonar, particularly over large areas. In order to determine the capability and effectiveness of the bathymetric LiDAR, several parameters were considered; depth penetrations below the water surface, bathymetric return density, and spatial accuracy.

Mapped Bathymetry and Depth Penetration

The specified depth penetration range of the Riegl VQ-820-G sensor is one secchi depth; therefore, bathymetry data below one secchi depth at the time of acquisition is not to be expected. To assist in evaluating performance results of the sensor, a polygon layer was created to delineate areas where bathymetry was successfully mapped.

This shapefile was used to control the extent of the delivered clipped topo-bathymetric model and to avoid false triangulation across areas in the water with no returns. Insufficiently mapped areas were identified by triangulating bathymetric bottom points with an edge length maximum of 4.56 meters. This ensured all areas of no returns > 9 m^2 were identified as data voids. Within the Lower Wenatchee study area, bathymetry was mapped for 95.93% of areas identified as water. Of the areas successfully mapped, 48.11% had a calculated depth of 0 – 0.5m, 33.22% had a calculated depth of 0.51 -1.0 m, 12.53% had a calculated depth of 1.01 – 1.5m, and the remaining 6.15% had a calculated depth between 1.51m and 4.0m (Table 9).

Confidence

In bathymetric LiDAR collection, there are generally fewer returns at greater depths and uncertainty exists as to whether the return is actually a bottom return or part of the water column. In order to more closely assess the depths mapped, bathymetric point density was considered. The distribution of the point density within the mapped area varied depending on depth. Confidence in bathymetric elevation data was assessed by looking at average point density within an area of $9m^2$ radiating out from the center of any given 1 meter cell (r = 1.69 m). If the $9m^2$ search area around the 1 m cell had an average point density of ≤ 1 point/m^2, the cell was considered an area of low confidence due to a lack of surrounding data to confirm bathymetric elevations. Cells whose search area had an average point density of ≥$1m^2$ were considered adequately covered with high confidence in the bathymetric data elevations represented (Figure 8). Of the successfully mapped areas, 96.3% were mapped with high confidence and 3.7% were considered low confidence (Figure 9, Table 9). The confidence attribute within the mapped area shapefile provided was created based on this information. It should be noted that confidence levels are designed for assessing the overall model of topography at a spatial resolution of $1m^2$.

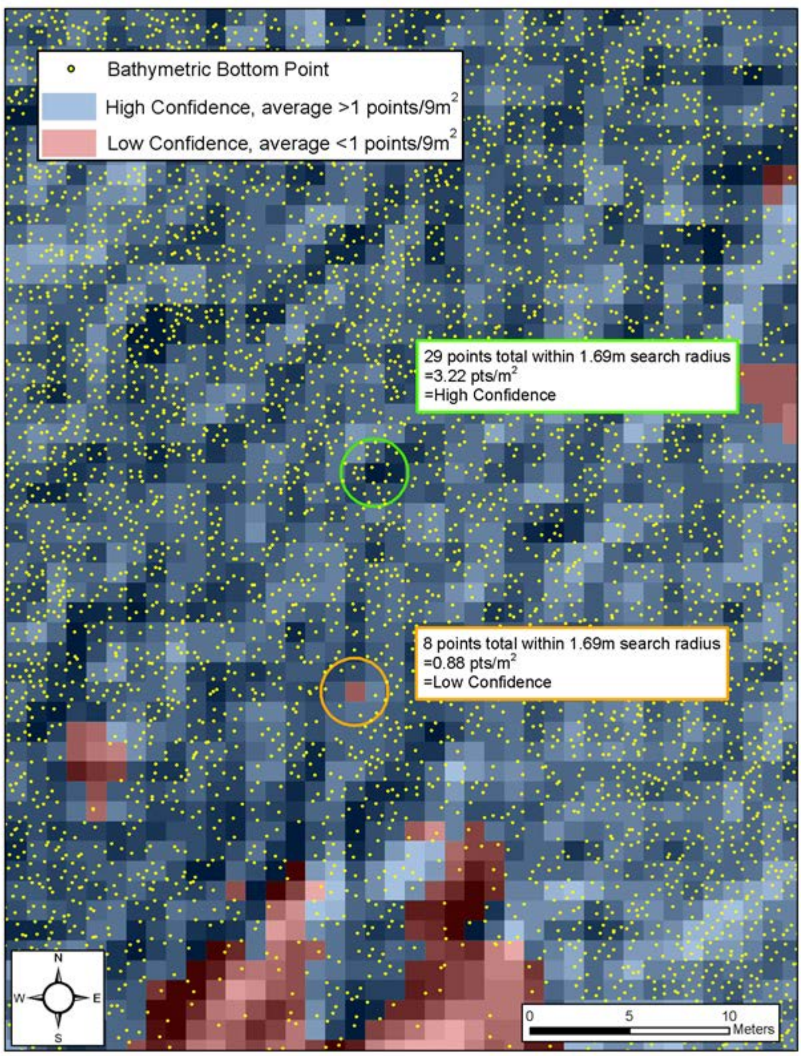


Figure 8: Sample plot of low and high confidence in bathymetric returns

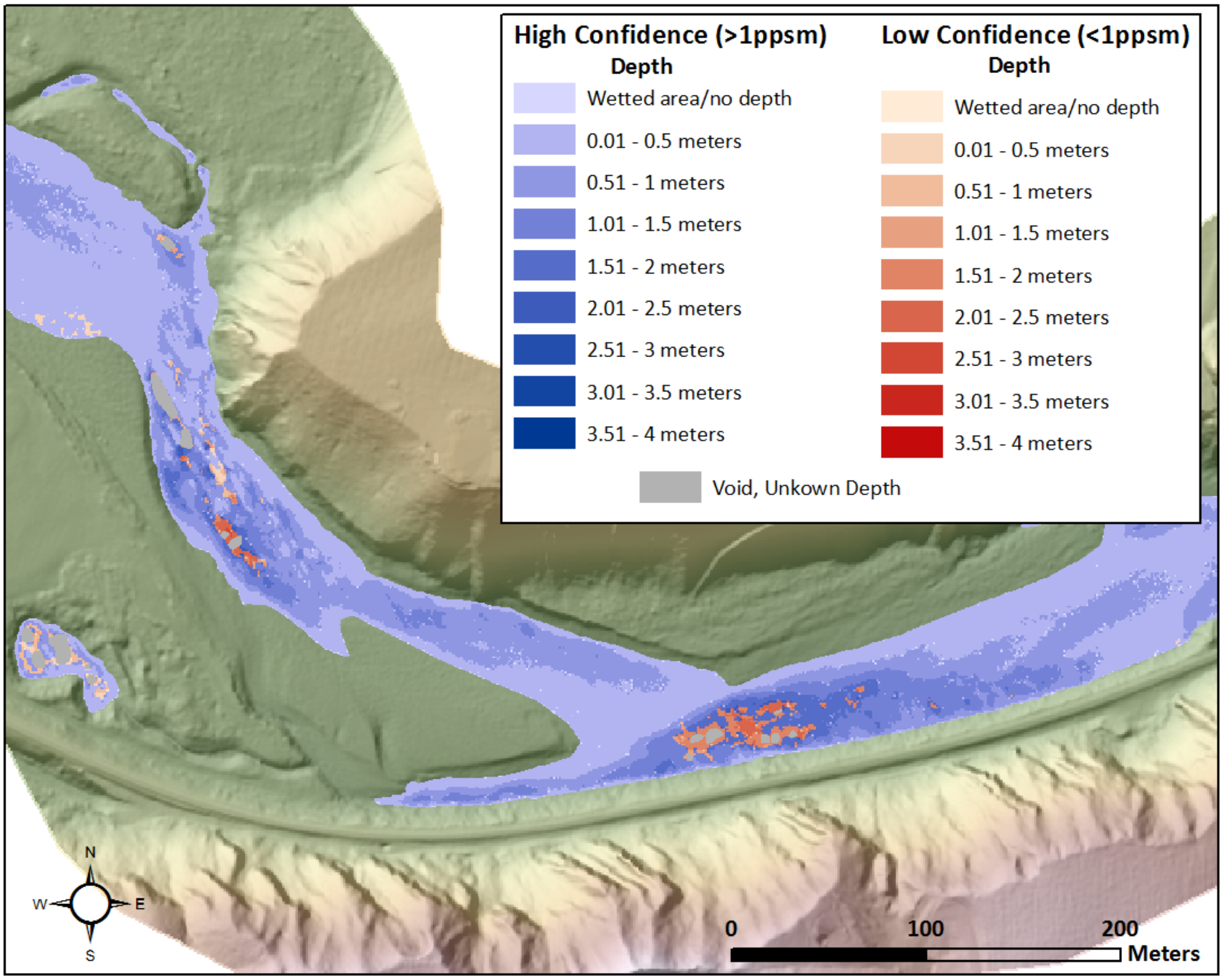


Figure 9: Sample image from the Lower Wenatchee River project showing confidence values and data voids

Table 9: Percentage of successfully mapped bathymetry by depth and confidence

Depth Range	Percentage of Successfully Mapped Areas	Percentage Identified as High Confidence	Percentage Identified as Low Confidence
No Measurable Depth	1.06%	98%	2%
0.01 - 0.50 meters	47.05%	99%	1%
0.51 - 1.00 meters	33.22%	97%	3%
1.01 - 1.50 meters	12.53%	93%	7%
1.51 – 4.00 meters	6.15%	75%	25%

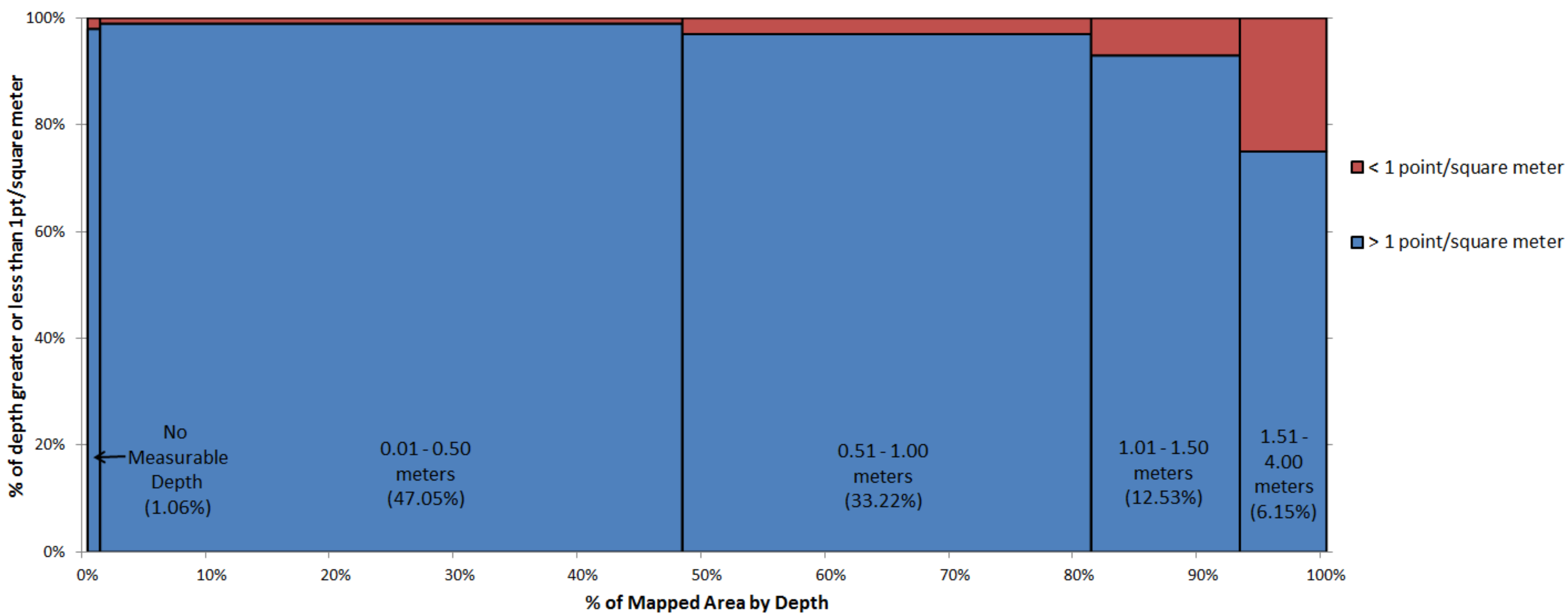


Figure 10: Depth percentages and point density by depth percentages for the Lower Wenatchee River project

LiDAR Point Density

First Return Point Density

The acquisition parameters were designed to acquire an average first-return density of ≥4 points/m^2 for the topobathymetric LiDAR data, and ≥6 points/ m^2 for the NIR LiDAR data. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water and steep slopes) may have returned fewer pulses than originally emitted by the laser.

The average first-return density of the green wavelength LiDAR data for the Lower Wenatchee River project was 19.44 points/m^2 while the average first-return density of the NIR wavelength LiDAR data was 53.76 points/m^2 (Table 10). In total, 73.20 points/m^2 were achieved for the Lower Wenatchee LiDAR acquisition. The statistical and spatial distributions of first return densities per 100 m x 100 m cell are portrayed in Figure 9 through Figure 13.

Table 10: Average First Return LiDAR point densities

First Return Type	Point Density
Green Sensor First Returns	19.44 points/m^2
NIR Sensor First Returns	53.76 points/m^2
Cumulative First Returns	73.20 points/m^2

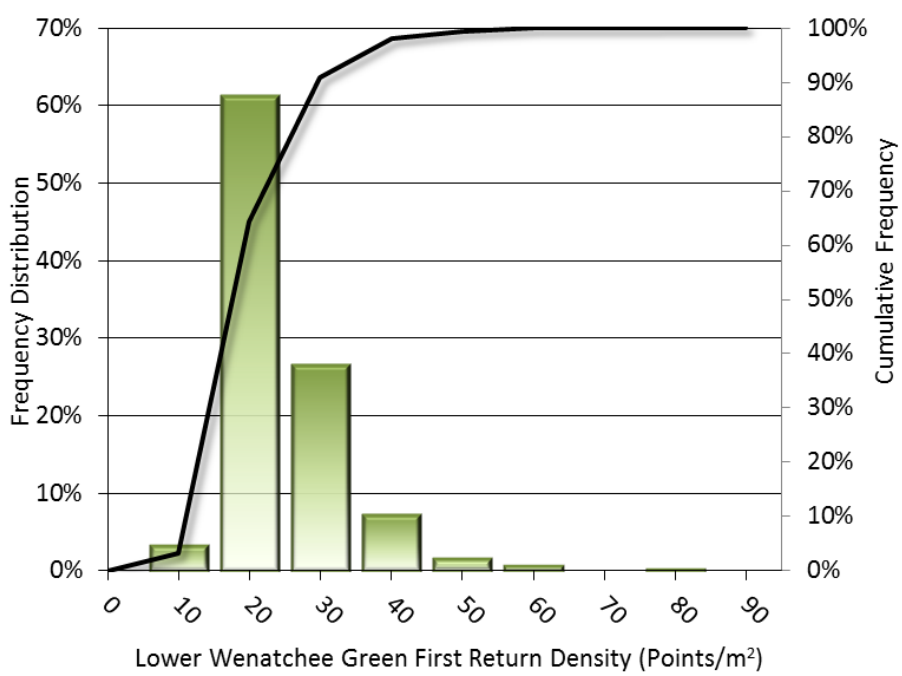


Figure 11: Frequency distribution of Green LiDAR first return densities per 100 x 100 m cell

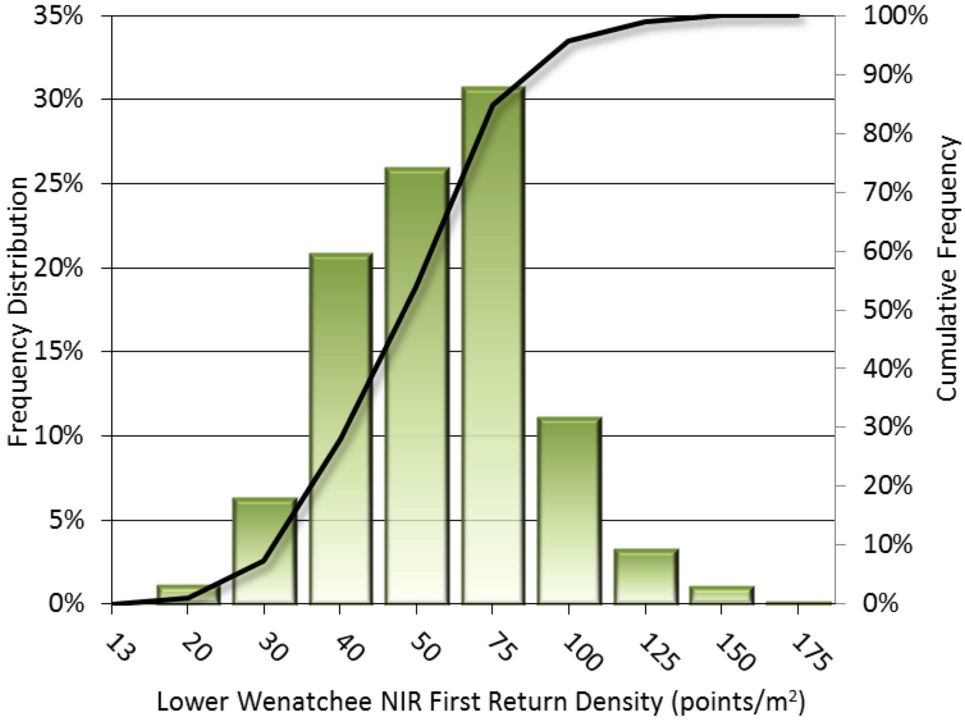


Figure 12: Frequency distribution of NIR LiDAR first return densities per 100 x 100 m cell

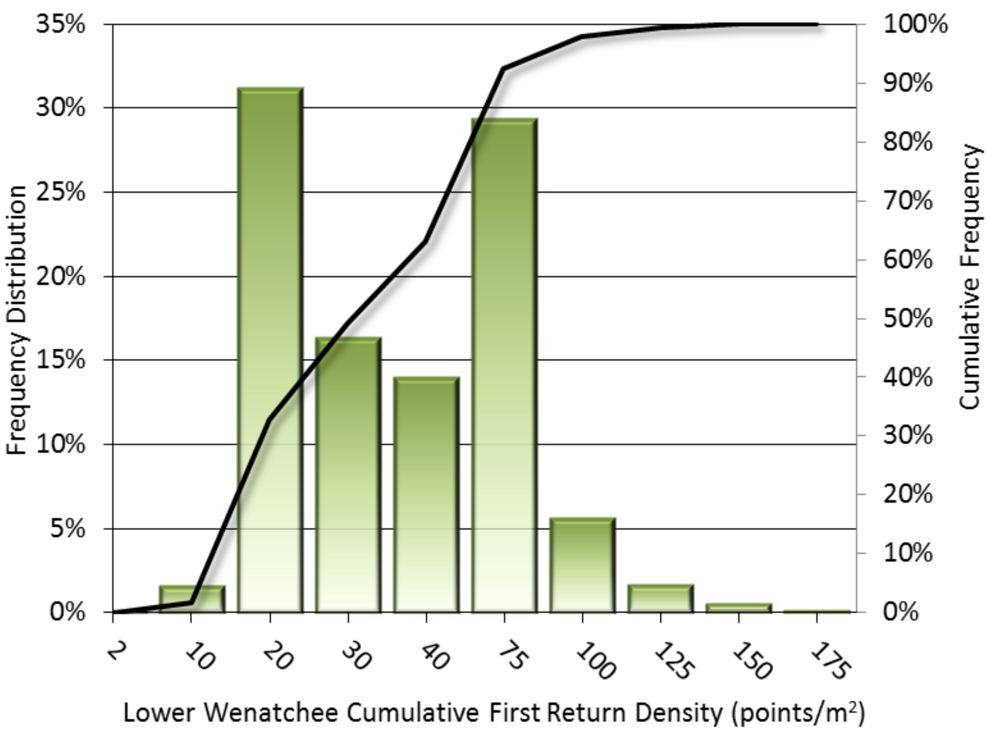


Figure 13: Frequency distribution of cumulative first return densities per 100 x 100 m cell

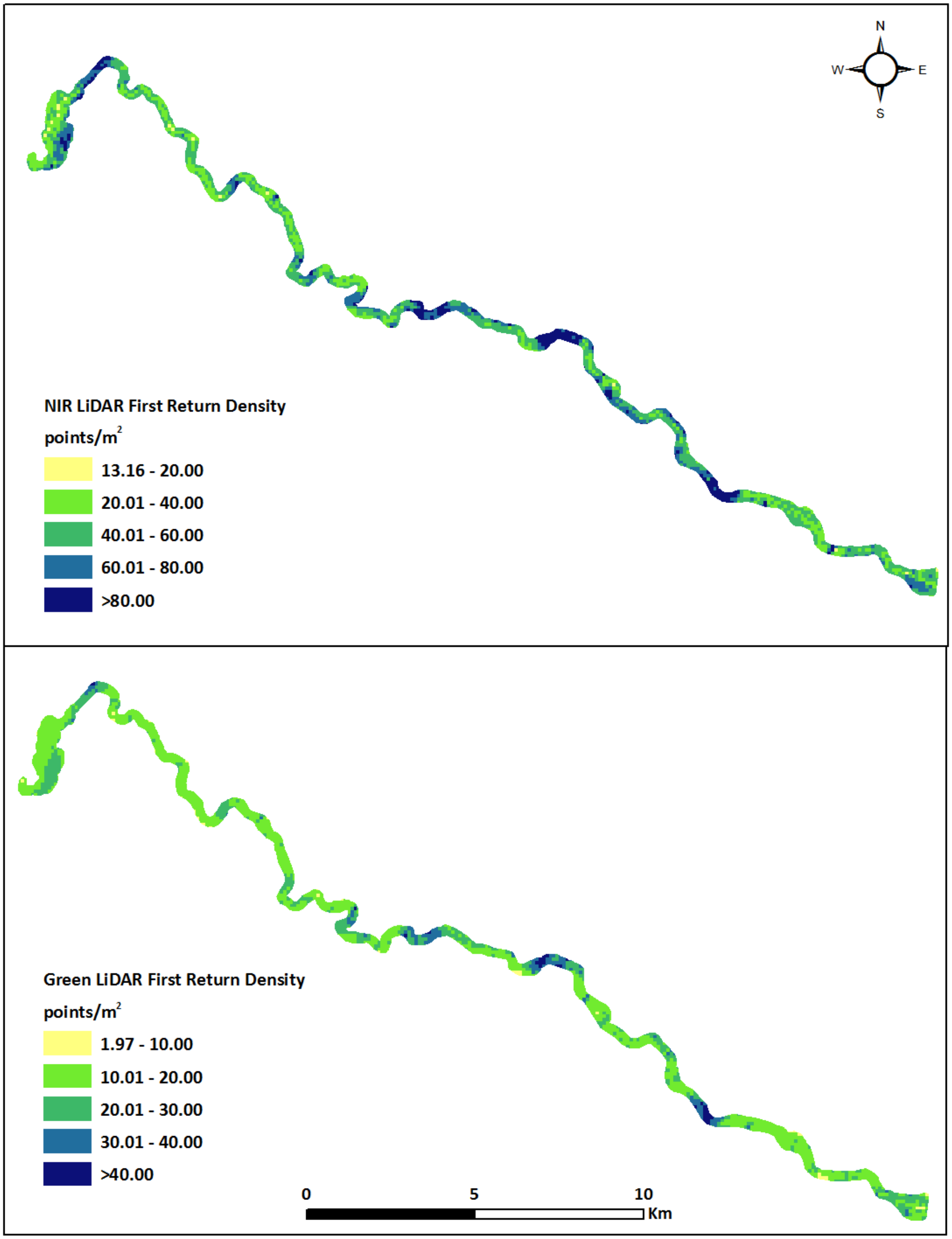


Figure 14: NIR and Green LiDAR first return density maps for the Lower Wenatchee River site (100 m x 100 m cells)

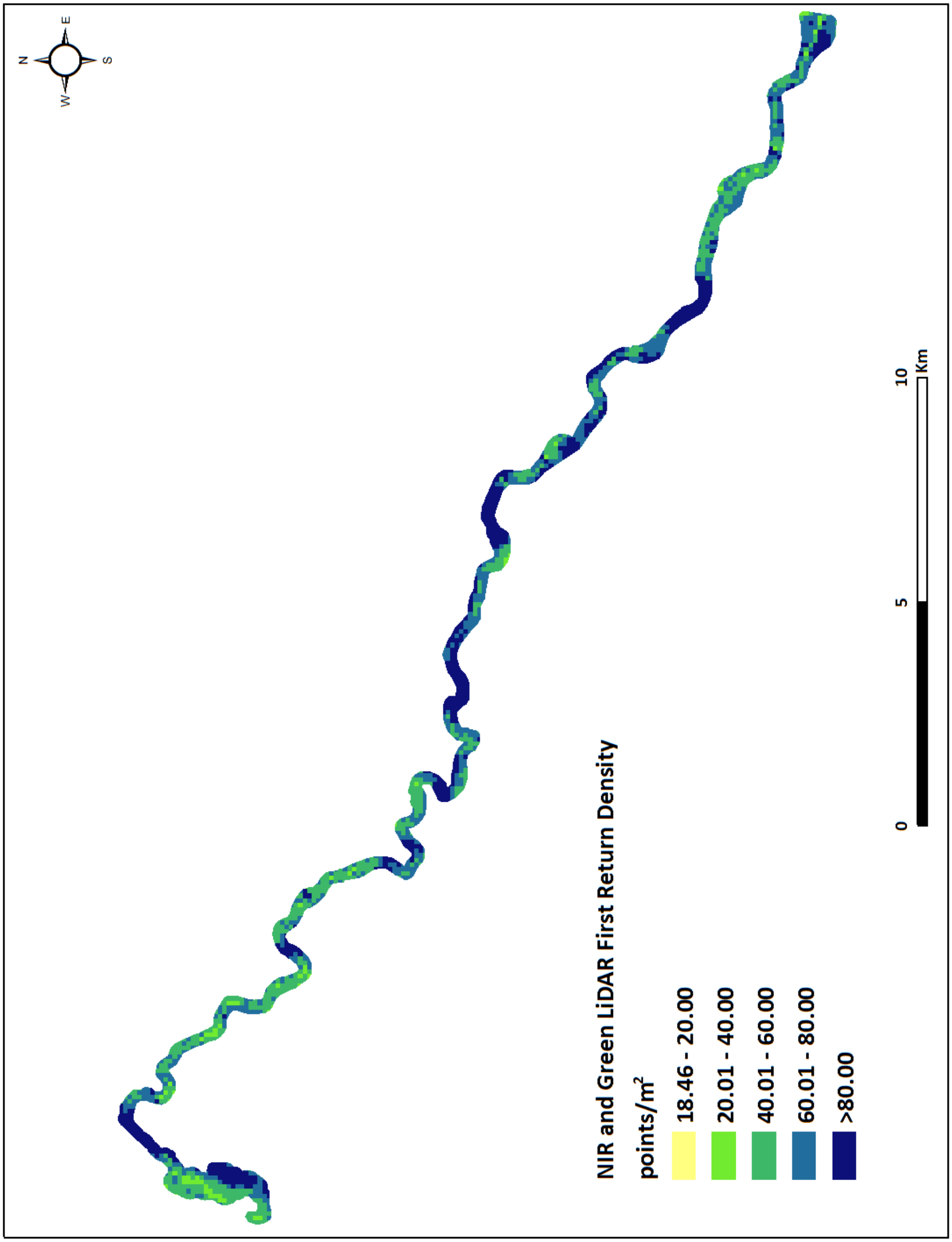


Figure 15: Cumulative first return density map for the Lower Wenatchee River site (100 m x 100 m cells)

Bathymetric and Ground Classified Point Densities

The density of ground classified LiDAR returns and bathymetric bottom returns were also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may have penetrated the canopy, resulting in lower ground density. Similarly, the density of bathymetric bottom returns was influenced by turbidity, depth, and bottom surface reflectivity. In turbid areas, fewer pulses may have penetrated the water surface, resulting in lower bathymetric density.

The ground and bathymetric bottom classified density of LiDAR data for the Lower Wenatchee River project was 12.84 points/m^2(Table 11). The statistical and spatial distributions ground classified and bathymetric bottom return densities per 100 m x 100 m cell are portrayed in Figure 16 and Figure 17.

Table 11: Average Ground and Bathymetric Classified LiDAR point densities

Classification	Point Density
Ground and Bathymetric Bottom Classified Returns	12.84 points/m^2

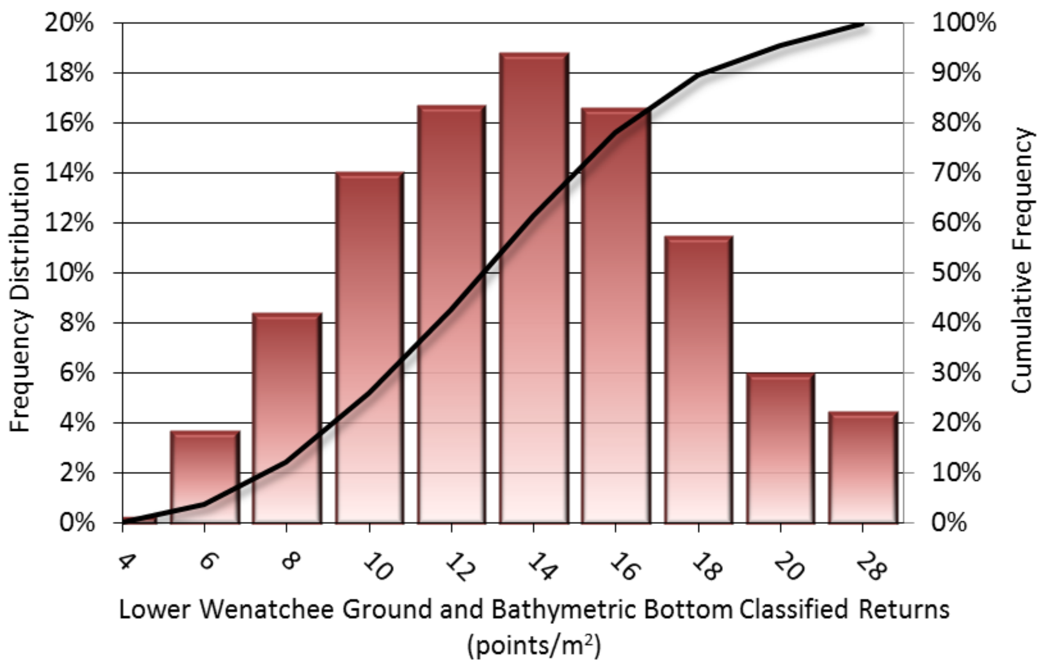


Figure 16: Frequency distribution of ground and bathymetric bottom classified densities per 100 m x 100 m cell

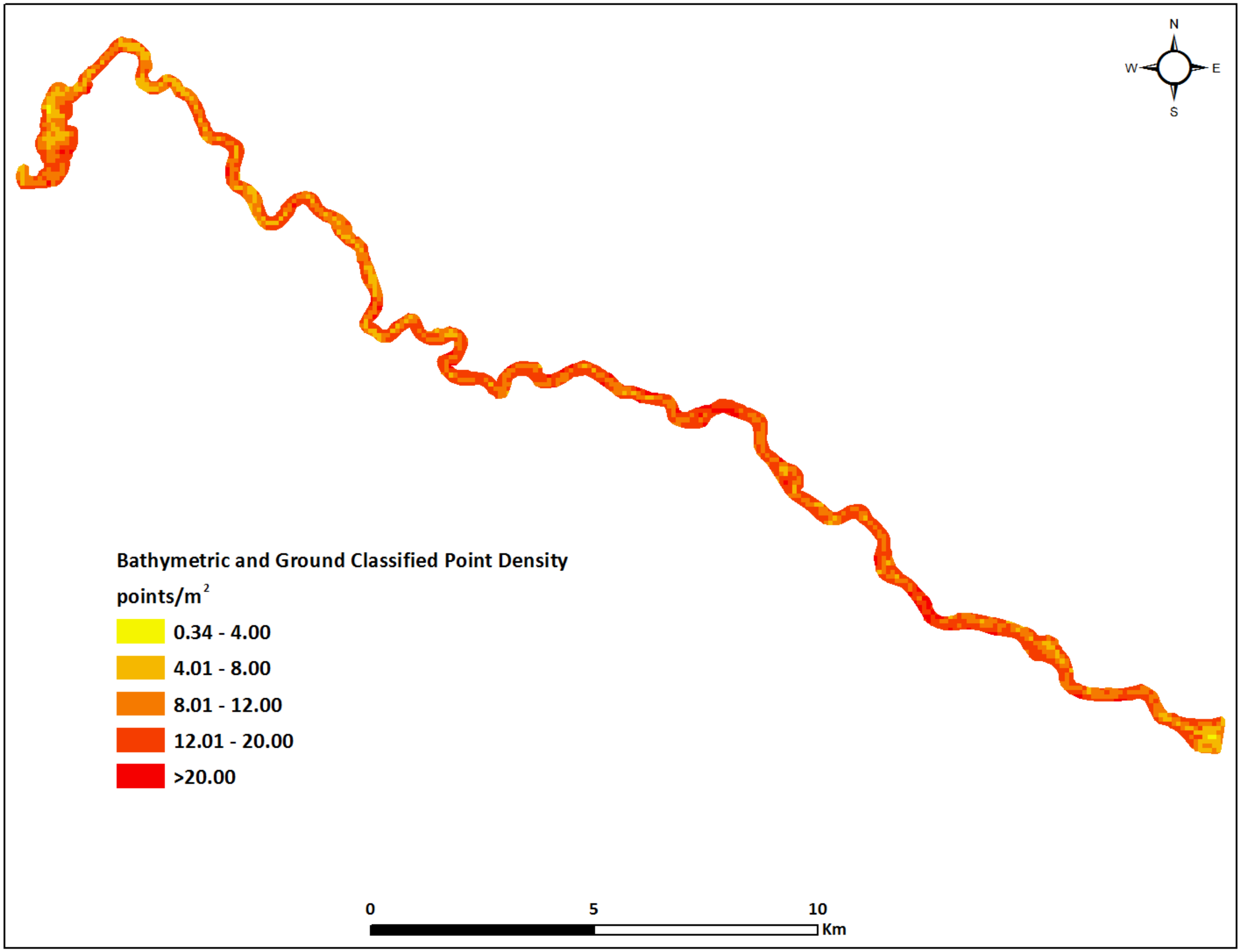


Figure 17: Ground and bathymetric bottom density map for the Lower Wenatchee River site (100 m x 100 m cells)

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

LiDAR Absolute Accuracy

Absolute accuracy was assessed using Fundamental Vertical Accuracy (FVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[3]. FVA compares known RTK ground check point data collected on open, bare earth surfaces with level slope (<20°) to the triangulated surface generated by the LiDAR points. FVA is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 12. The mean and standard deviation (sigma σ) of divergence between the ground surface model and the ground survey point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of the distribution is also evaluated. For the Lower Wenatchee River survey, 43 ground checkpoints were collected in total resulting in a Fundamental Vertical Accuracy of 0.054 meters (Figure 18). Additionally, 37 bathymetric check points were collected, resulting in an average vertical accuracy of 0.082 meters in submerged or near-shore areas (Table 12,Figure 19).

QSI also assessed accuracy using 34 ground control points. Although these points were used in the calibration and post-processing of the LiDAR point cloud, they still provide a good indication of the overall accuracy of the LiDAR dataset, and have been provided in Table 12.

Table 12: Absolute accuracy

Absolute Accuracy			
	Ground Check Points	**Bathymetric Checks Points**	**Ground Control Points**
Sample	43 points	37 points	812 points
FVA (1.96*RMSE)	0.054 m	0.082 m	0.051 m
Average	-0.004 m	-0.009 m	-0.002 m
Median	-0.003 m	-0.016 m	-0.003 m
RMSE	0.028 m	0.042 m	0.026 m
Standard Deviation (1σ)	0.028 m	0.041 m	0.026 m

[3] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.3-1998). Part 3: National Standard for Spatial Data Accuracy. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3

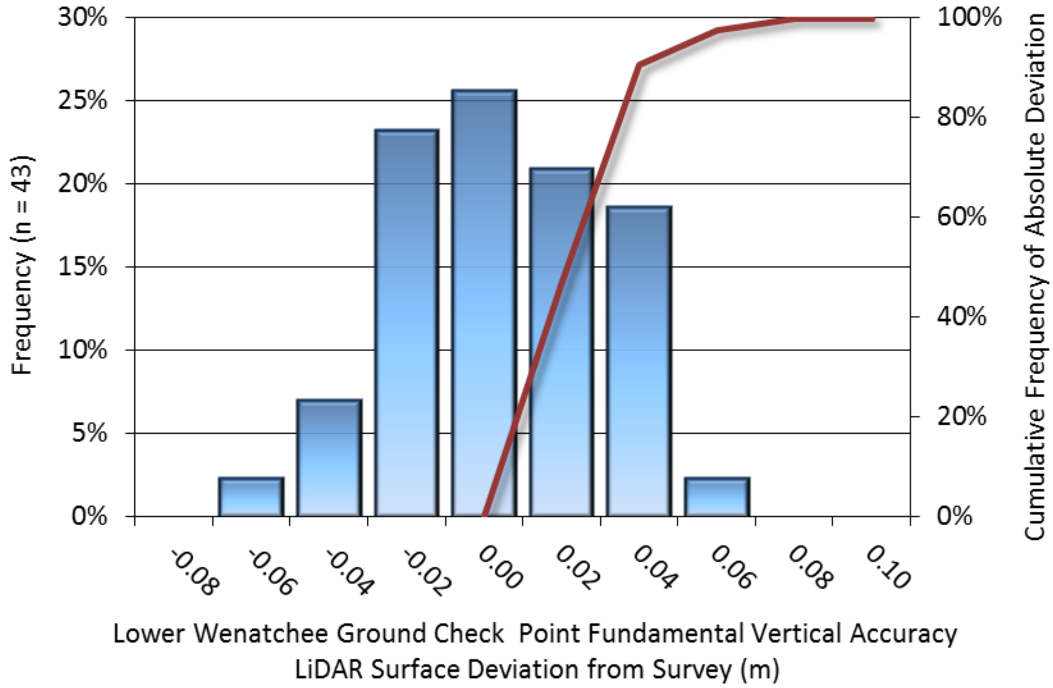


Figure 18: Frequency histogram for LiDAR surface deviation from ground check point values

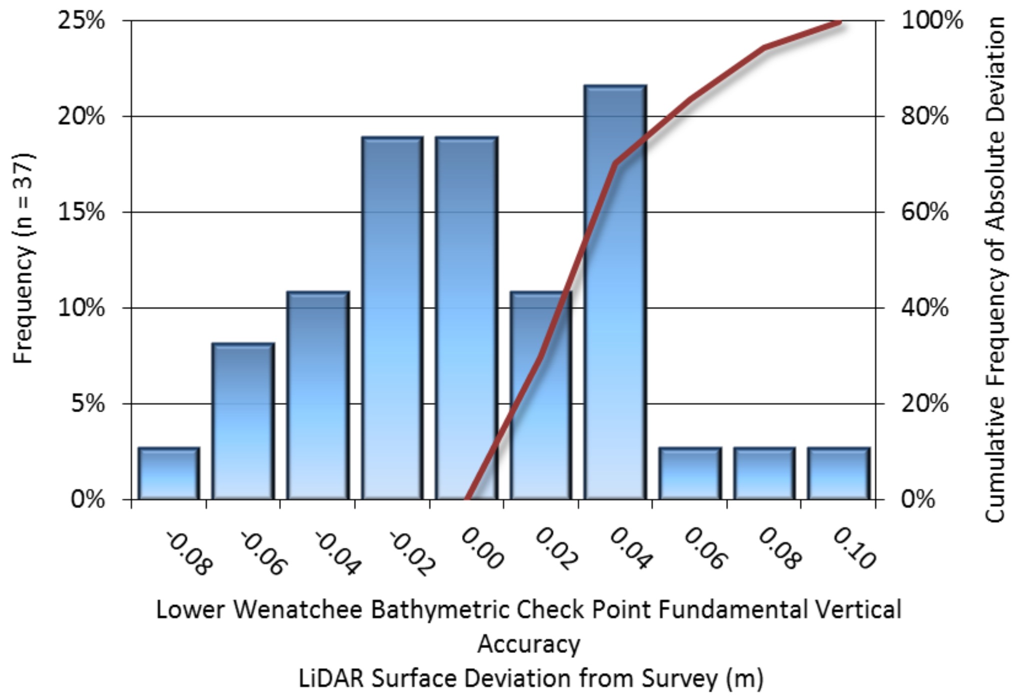


Figure 19: Frequency histogram for LiDAR surface deviation from bathymetric check point values

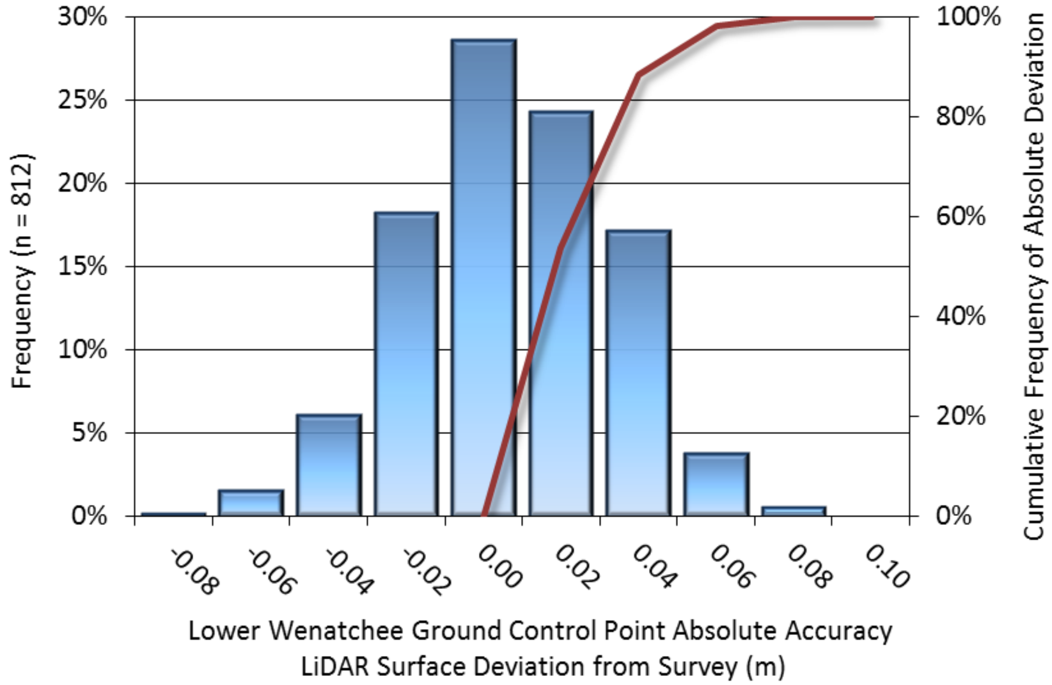


Figure 20: Frequency histogram for LiDAR surface deviation from ground survey point values

LiDAR Vertical Relative Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the LiDAR system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Lower Wenatchee River LiDAR project was 0.039 meters (Table 13, Figure 21).

Table 13: Relative accuracy

Relative Accuracy	
Sample	140 surfaces
Average	0.039 m
Median	0.038 m
RMSE	0.039 m
Standard Deviation (1σ)	0.006 m
1.96σ	0.012 m

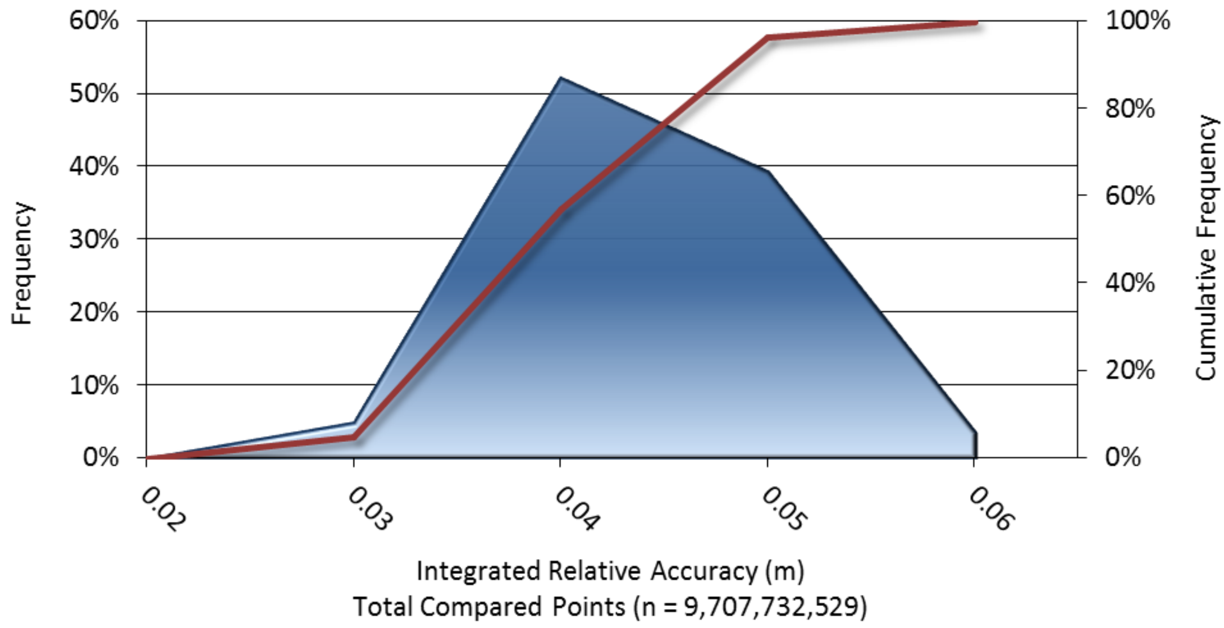


Figure 21: Frequency plot for relative vertical accuracy between flight lines

Quantum Spatial provided LiDAR services for the Lower Wenatchee River project as described in this report.

I, Mousa Diabat, PhD, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

____

Mousa Diabat, PhD
Project Manager
Quantum Spatial, Inc.

I, Christopher Glantz, PLS, being duly registered as a Professional Land Surveyor in and by the state of Washington, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between August 13, 2015 and August 15, 2015.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

11/11/2015

Christopher Glantz, PLS
Land Survey Manager
Quantum Spatial, Inc.

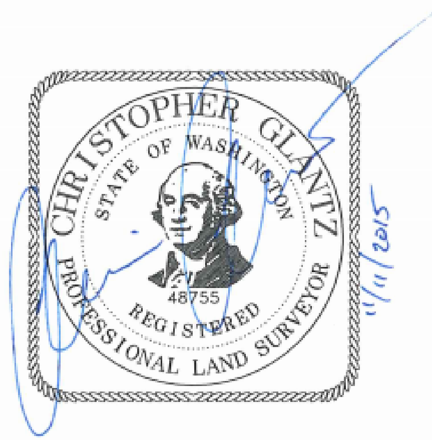


Figure 22: View looking west over Wenatchee River Confluence State Park. The image is created from the gridded, topobathy bare earth model overlaid with the vegetation point cloud and water breaklines.

Figure 23: A view looking west over the Lower Wenatchee River near West Wenatchee. The image is created from the gridded topobathy bare earth model colored by elevation.

Glossary

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Fundamental Vertical Accuracy (FVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Absolute Accuracy:** The vertical accuracy of LiDAR data is described as the mean and standard deviation (sigma σ) of divergence of LiDAR point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.
>
> **Relative Accuracy:** Relative accuracy refers to the internal consistency of the data set; i.e., the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. Affected by system attitude offsets, scale and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm).
>
> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echos) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native LiDAR Density: The number of pulses emitted by the LiDAR system, commonly expressed as pulses per square meter.

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±15^{o} from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

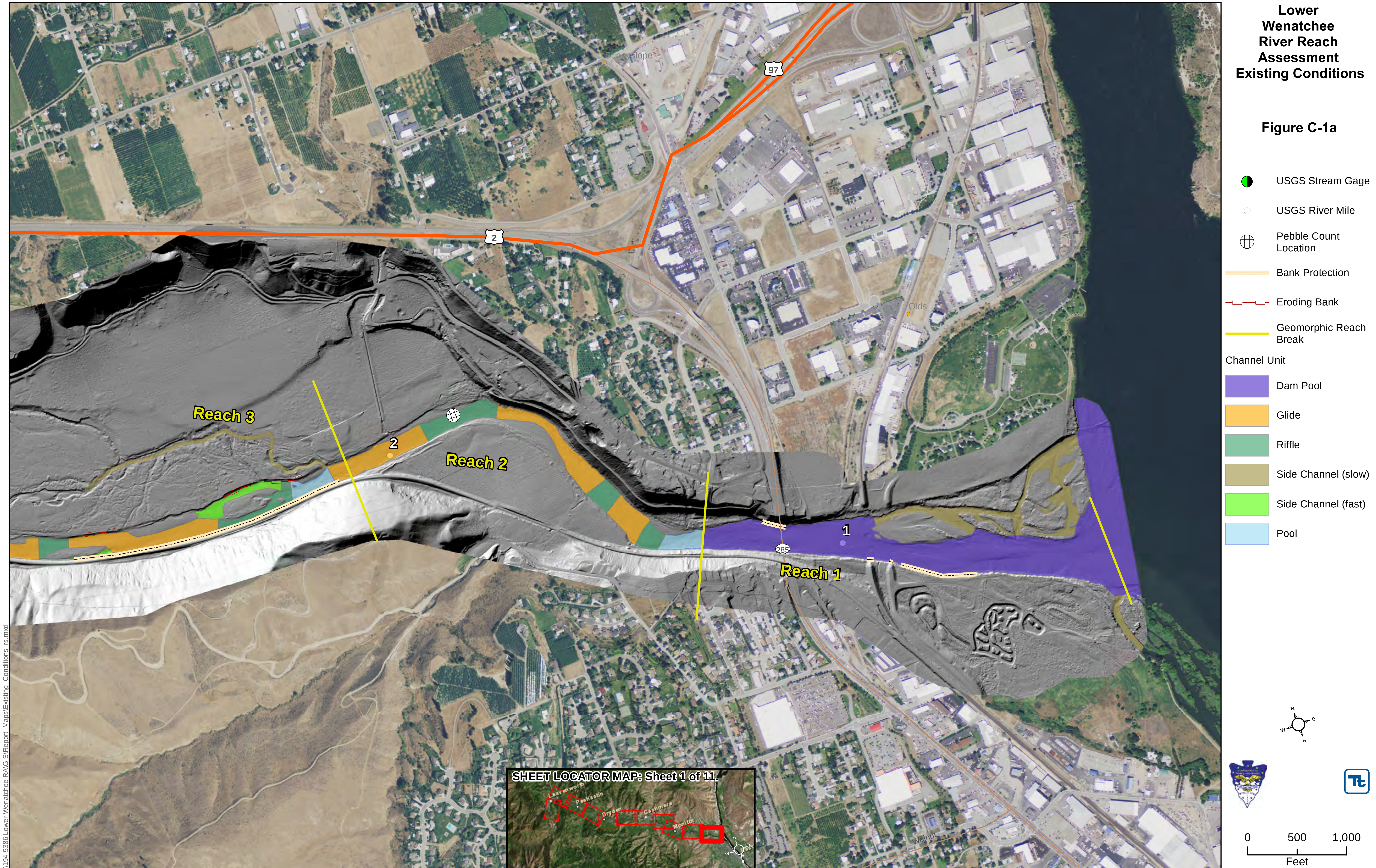
APPENDIX C

Stream Habitat and Geomorphic Map Series River Mile 0.0 to 26.4

List of Figures

Lower Wenatchee River Reach Assessment Existing Conditions

Figure C-1a



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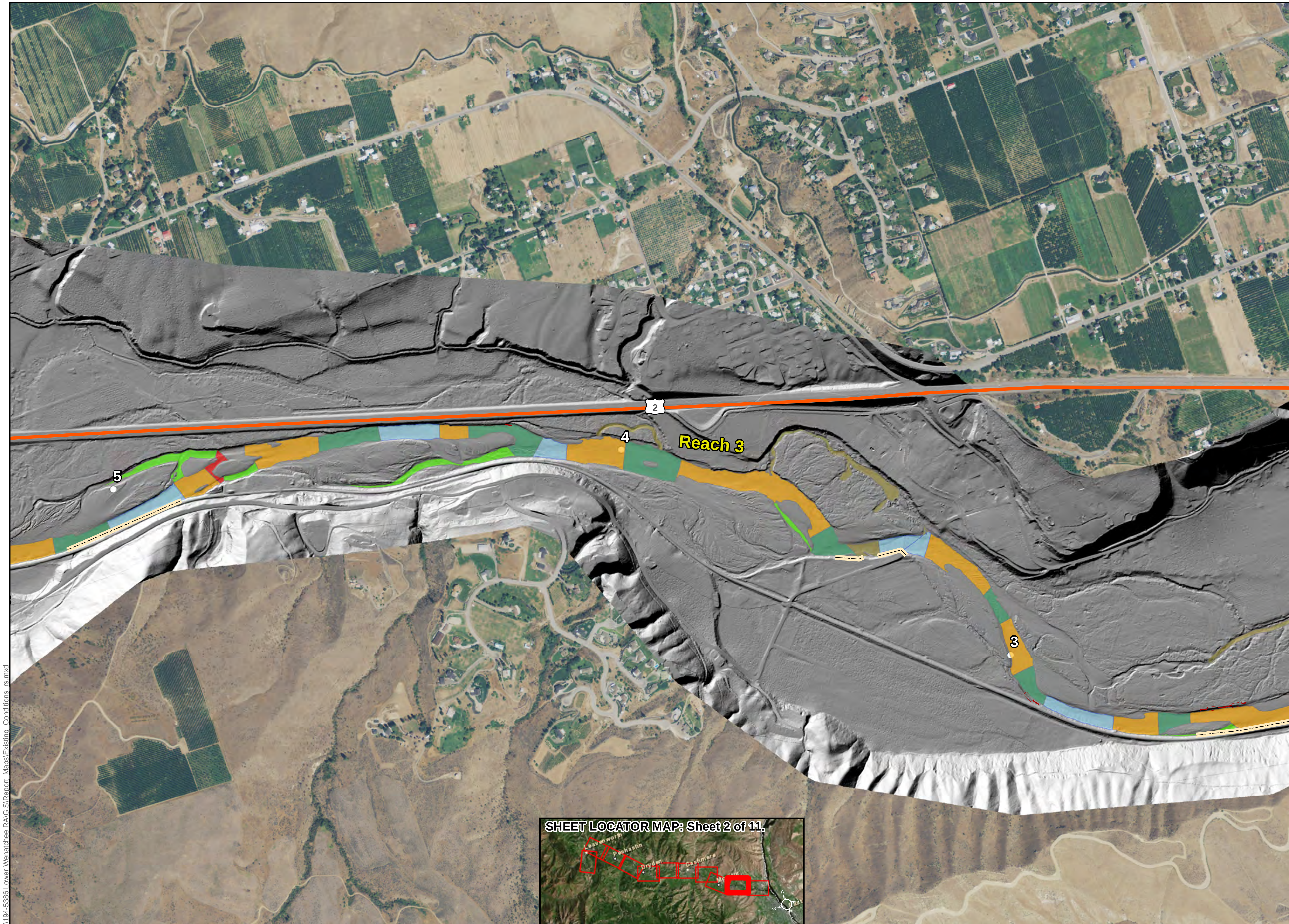

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Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1b

- USGS Stream Gage
- USGS River Mile
- Pebble Count Location
- Bank Protection
- Eroding Bank
- Geomorphic Reach Break

Channel Unit

- Glide
- Riffle
- Rapid
- Side Channel (slow)
- Side Channel (fast)
- Pool

N E S W

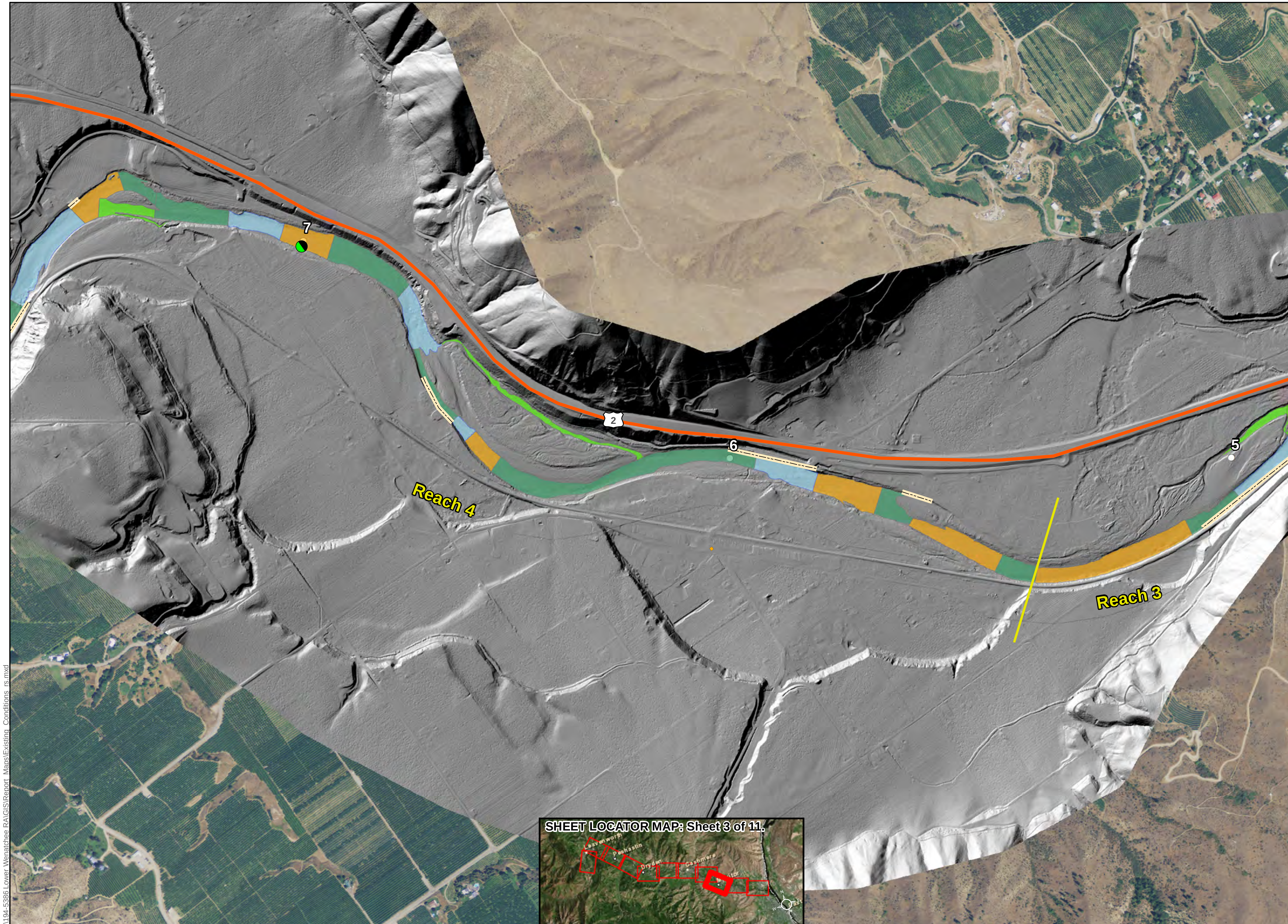
0 500 1,000

Feet

Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1c



- USGS Stream Gage
- USGS River Mile
- Pebble Count Location
- Bank Protection
- Eroding Bank
- Geomorphic Reach Break

Channel Unit

- Glide
- Riffle
- Side Channel (fast)
- Pool

0 500 1,000
Feet

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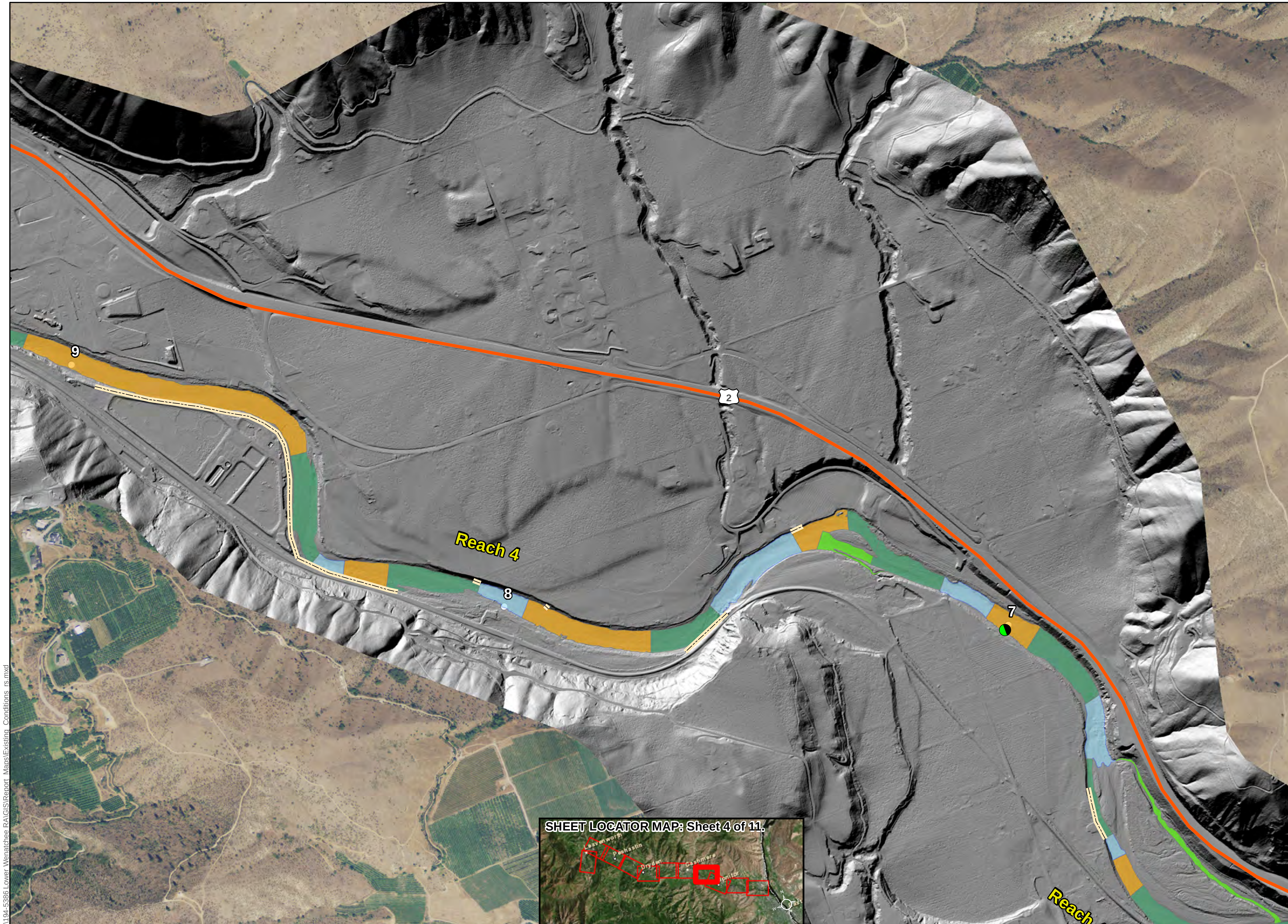
Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1d



USGS Stream Gage

USGS River Mile

Pebble Count Location

Bank Protection

Eroding Bank

Geomorphic Reach Break

Channel Unit

Glide

Riffle

Side Channel (fast)

Pool

0 500 1,000

Feet

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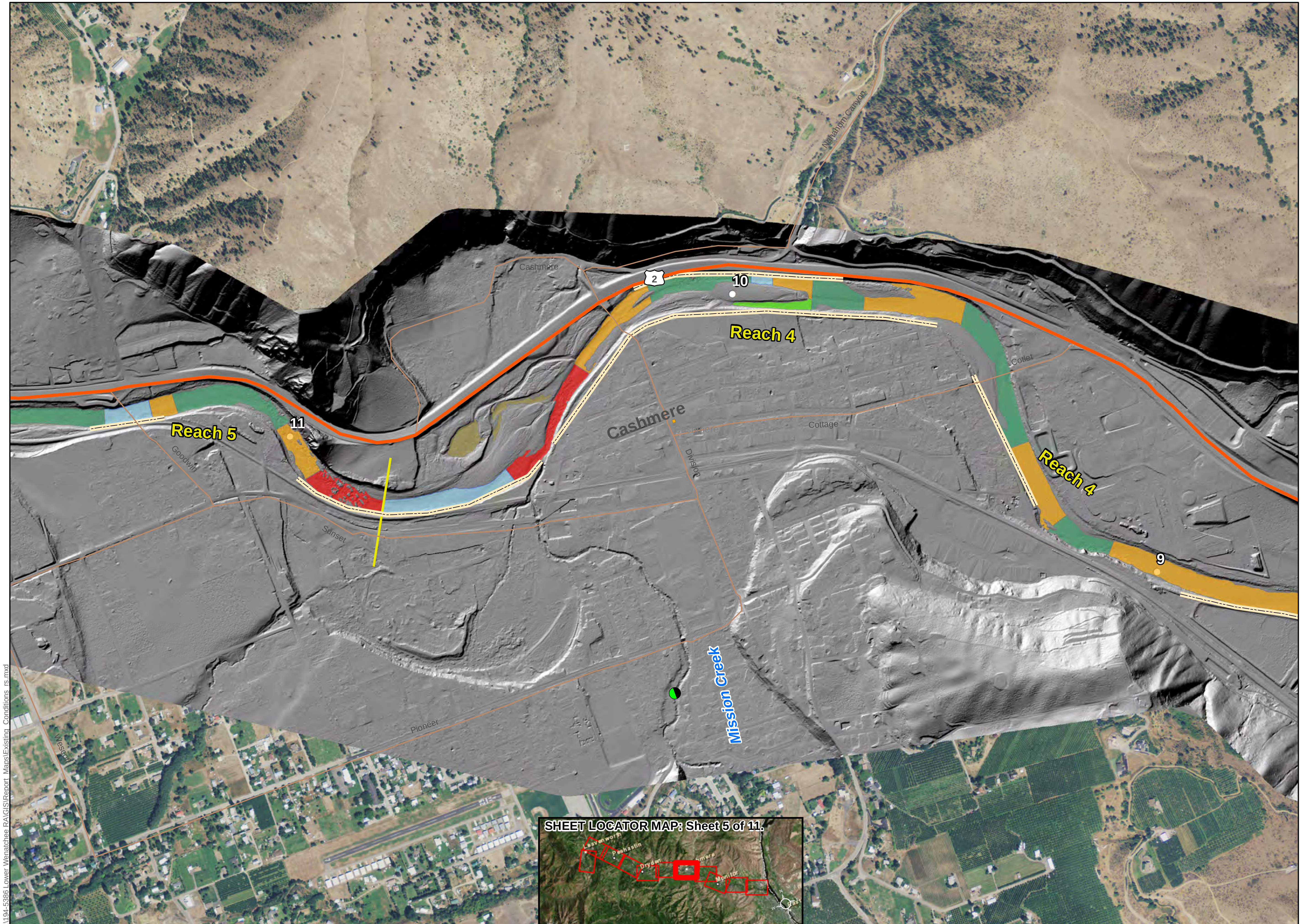

Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1e

USGS Stream Gage

USGS River Mile

Pebble Count Location

Bank Protection

Eroding Bank

Geomorphic Reach Break

Channel Unit

Glide

Riffle

Rapid

Side Channel (slow)

Side Channel (fast)

Pool

0 500 1,000

Feet

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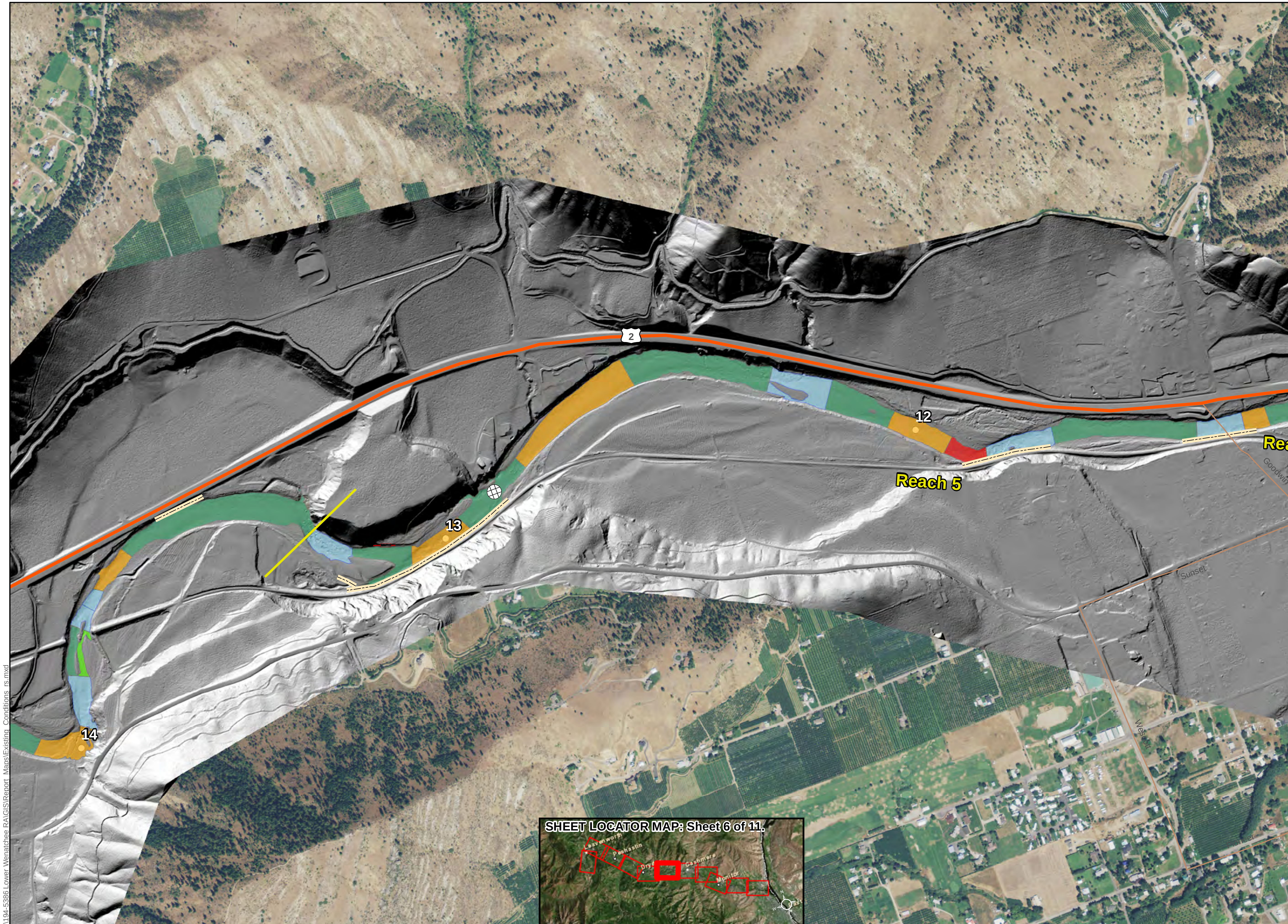
Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1f



USGS Stream Gage

USGS River Mile

Pebble Count Location

Bank Protection

Eroding Bank

Geomorphic Reach Break

Channel Unit

Glide

Riffle

Rapid

Side Channel (fast)

Pool

0 500 1,000

Feet

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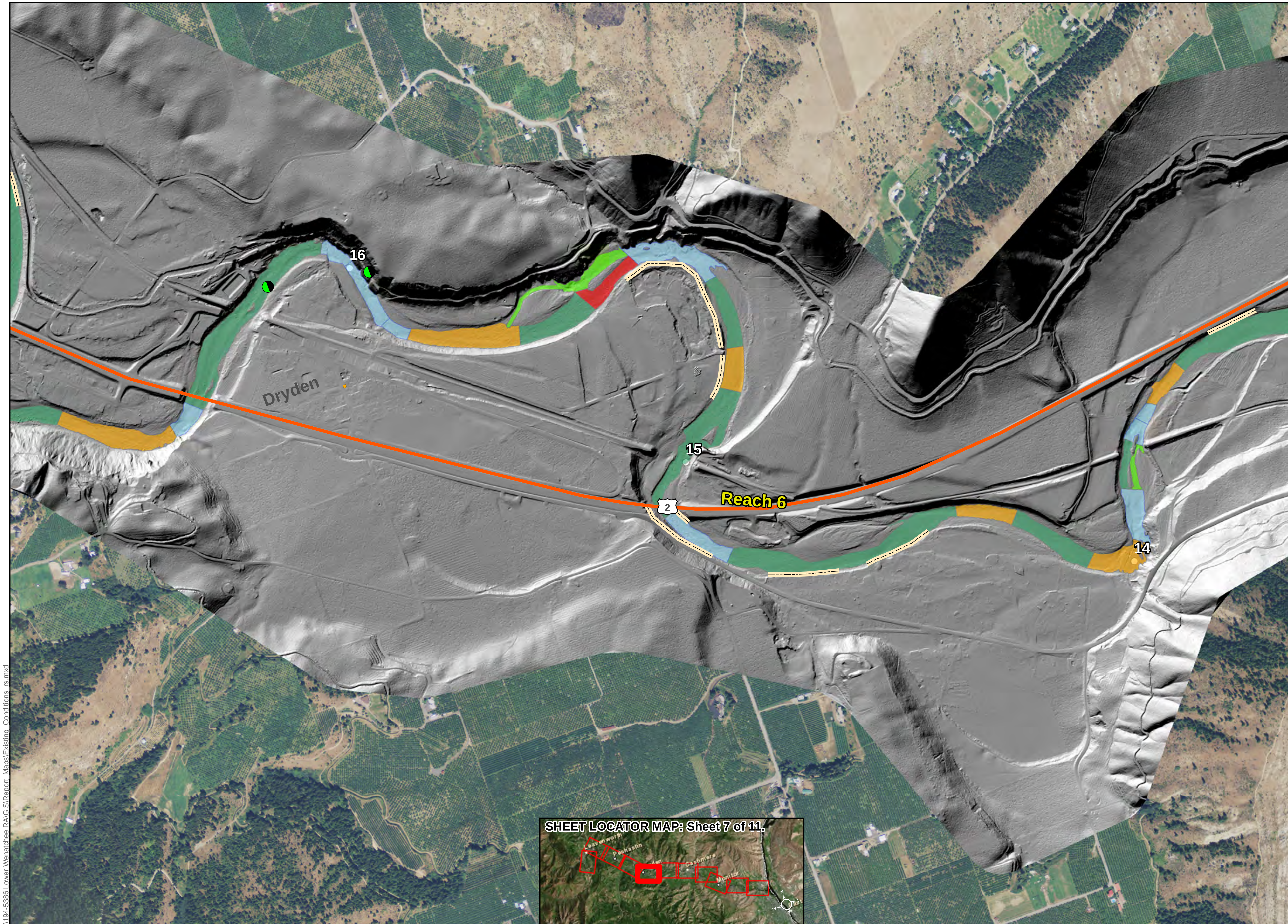
Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1g



USGS Stream Gage

USGS River Mile

Pebble Count Location

Bank Protection

Eroding Bank

Geomorphic Reach Break

Channel Unit

Glide

Riffle

Rapid

Side Channel (fast)

Pool

N E S W

0 500 1,000

Feet

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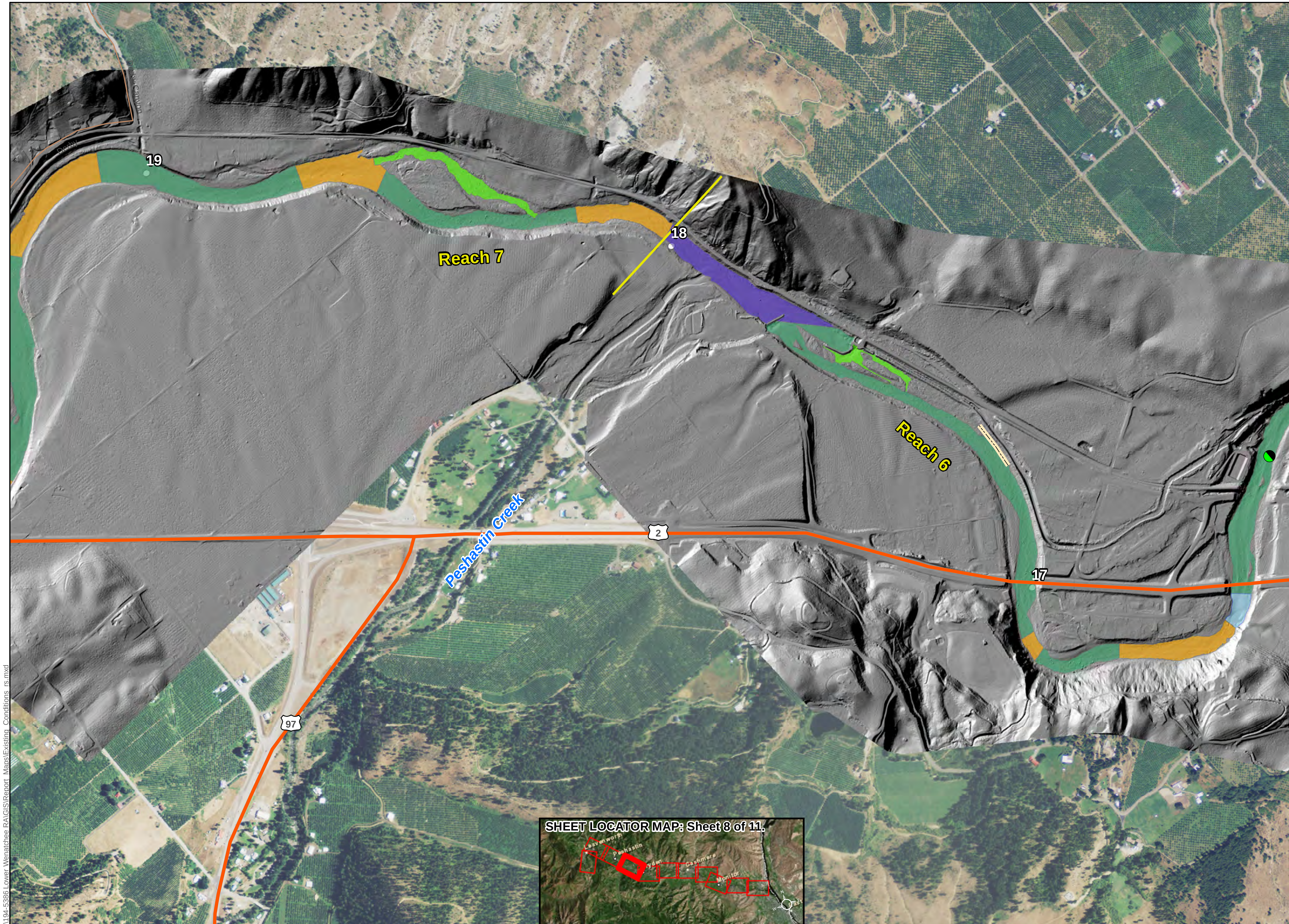

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Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1h

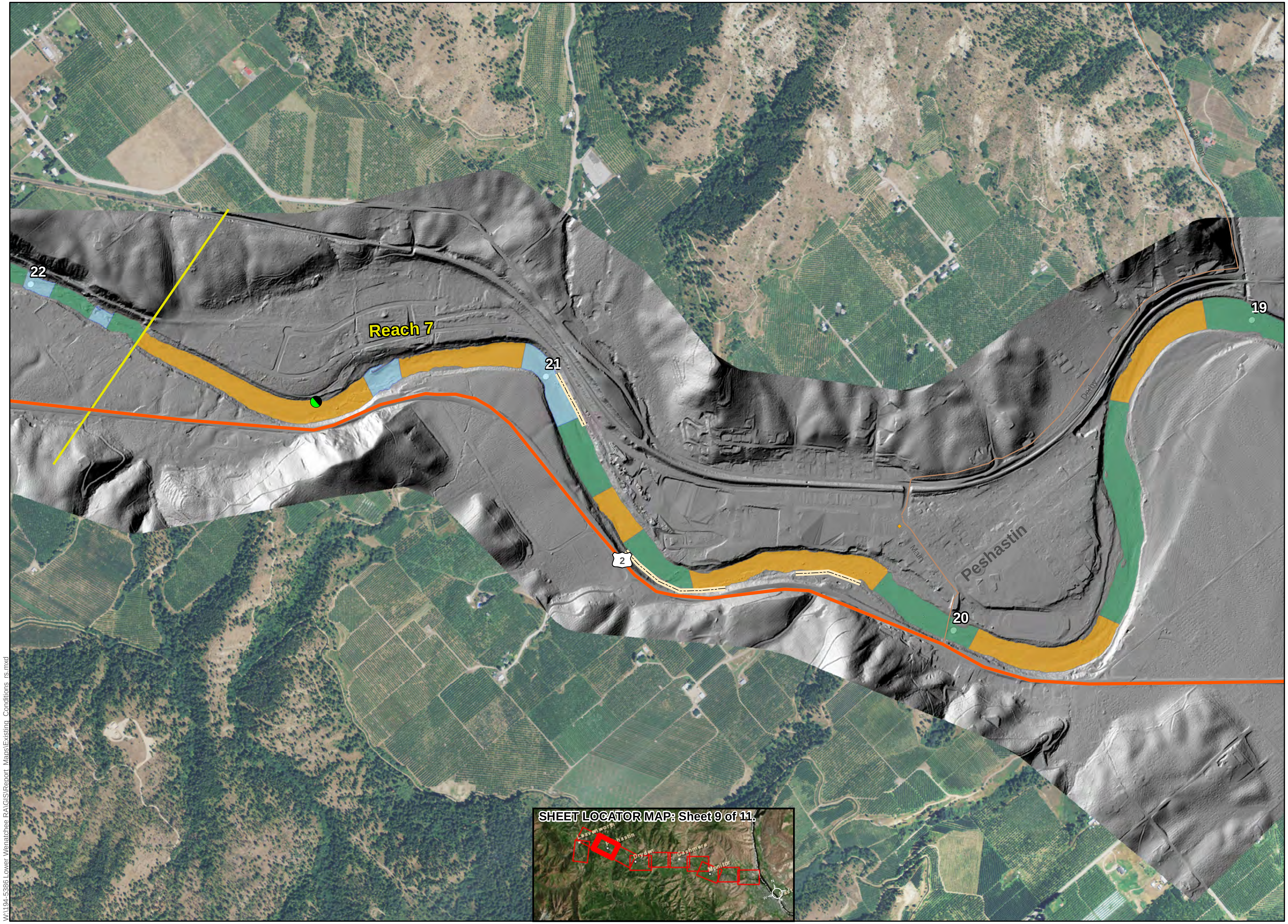
- USGS Stream Gage
- USGS River Mile
- Pebble Count Location
- Bank Protection
- Eroding Bank
- Geomorphic Reach Break

Channel Unit

- Dam Pool
- Glide
- Riffle
- Side Channel (fast)
- Pool

0 500 1,000

Feet



Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1i

USGS Stream Gage

USGS River Mile

Pebble Count Location

Bank Protection

Eroding Bank

Geomorphic Reach Break

Channel Unit

Glide

Riffle

Pool

0 500 1,000

Feet

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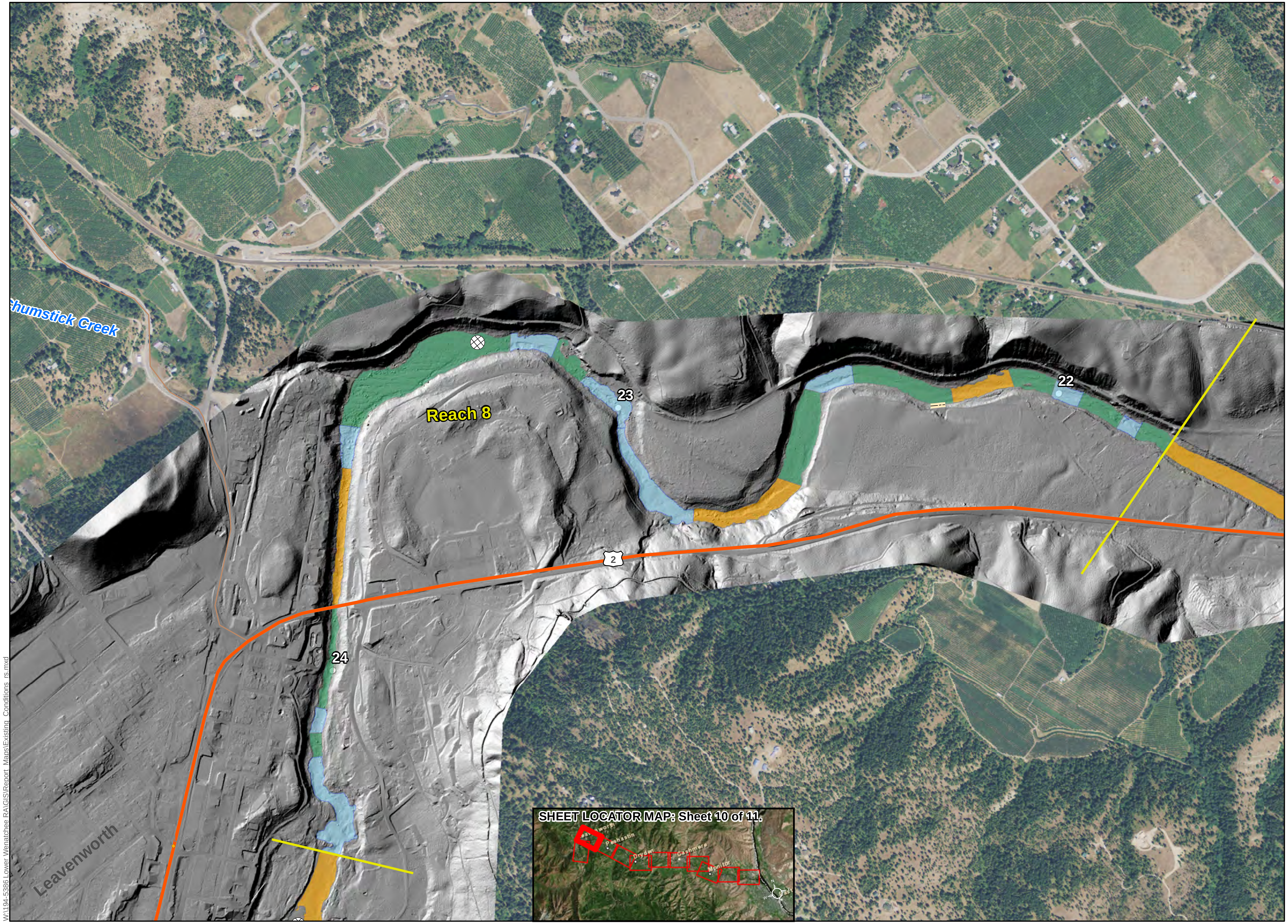
Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1j



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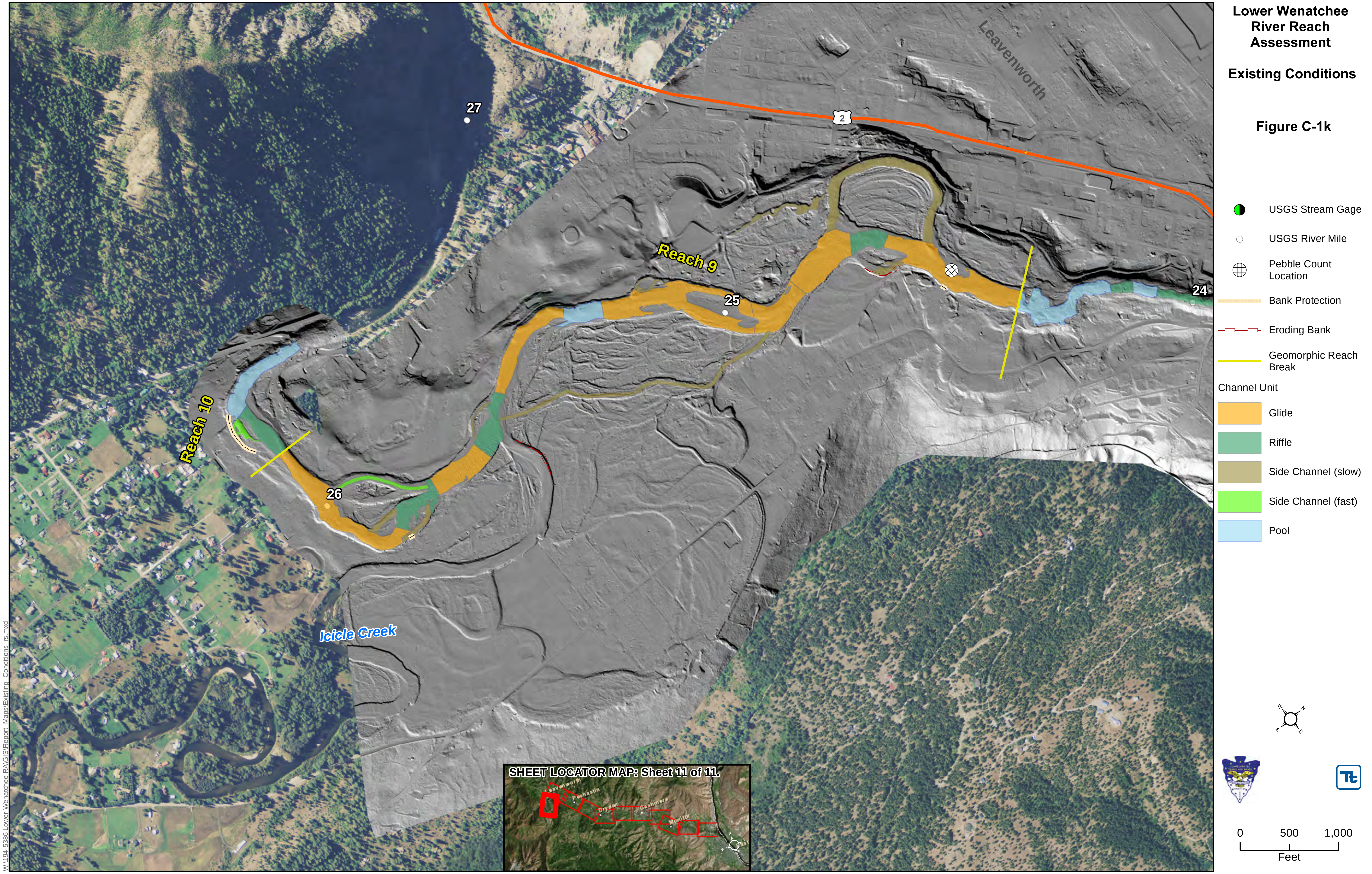
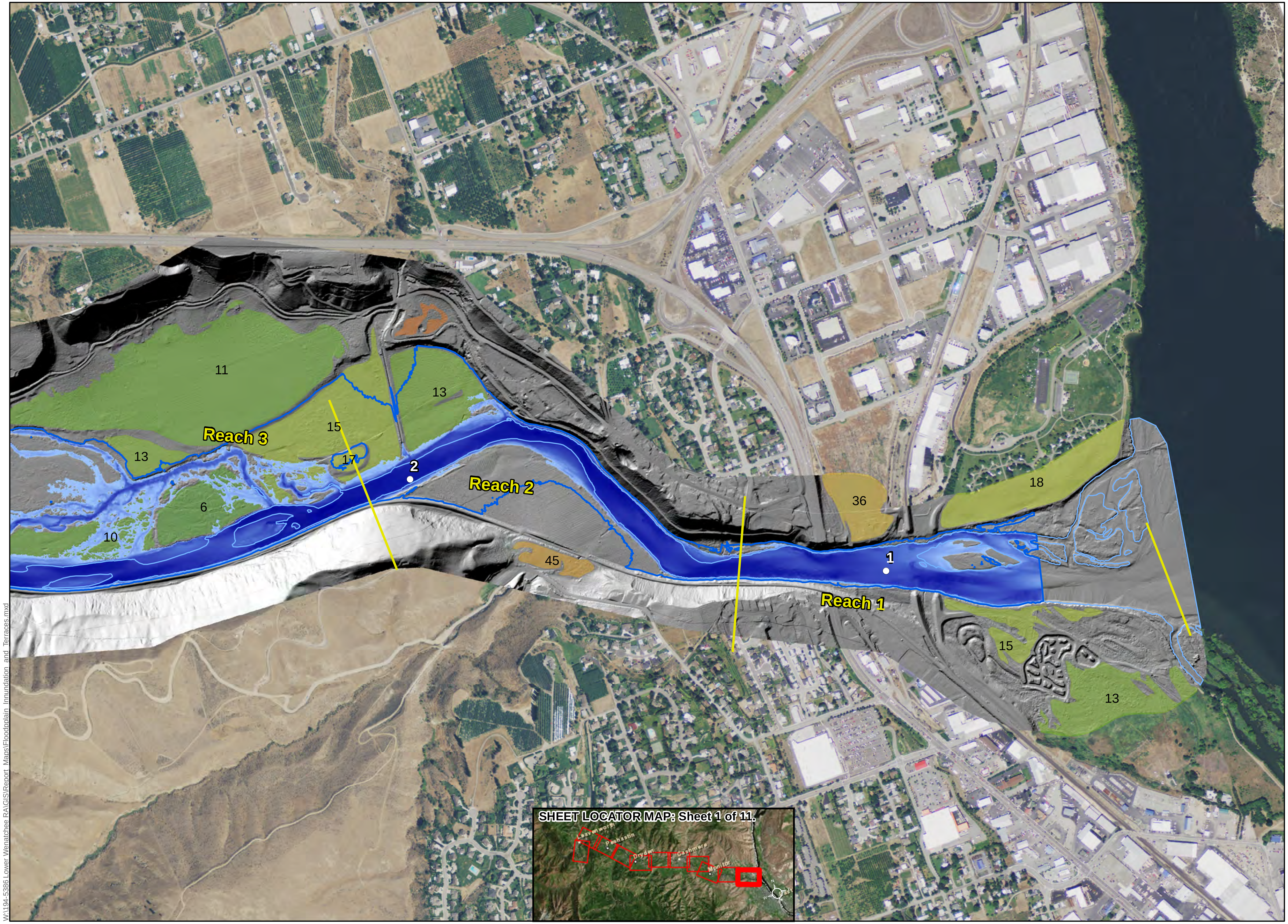
Lower Wenatchee River Reach Assessment

Existing Conditions

Figure C-1k





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Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2a

USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

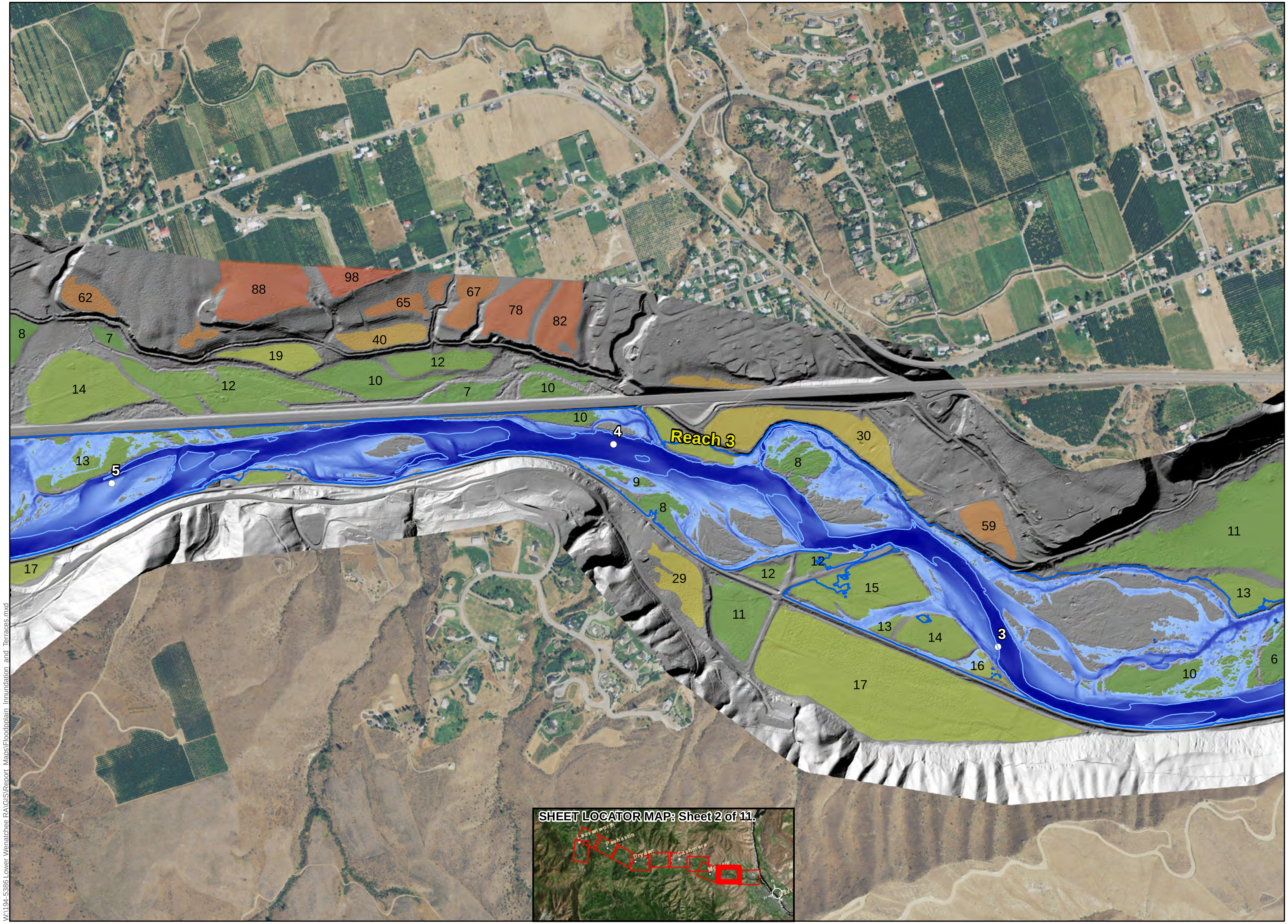
High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

N E S W

0 500 1,000
Feet



Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2b

USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

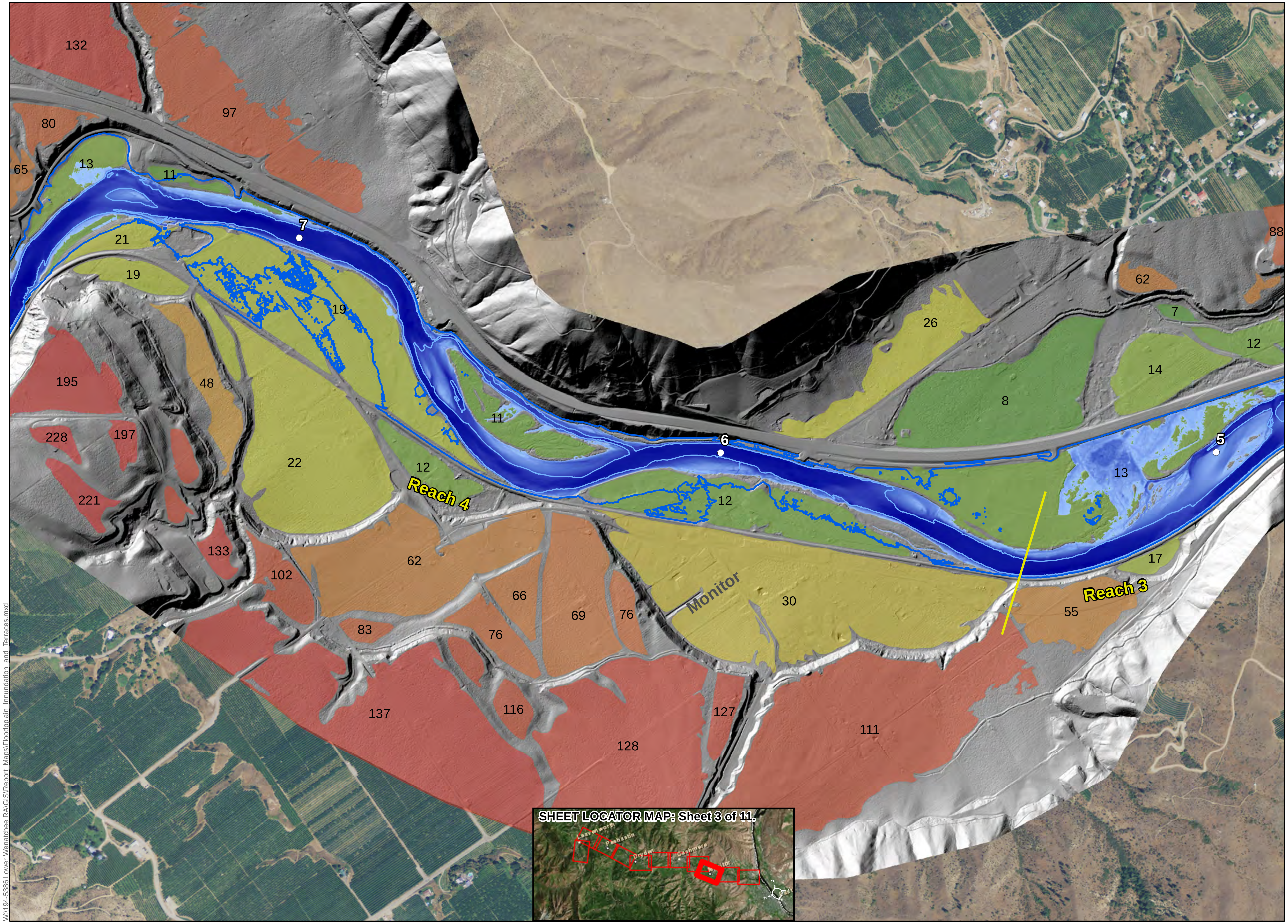
Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet



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Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2c

USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

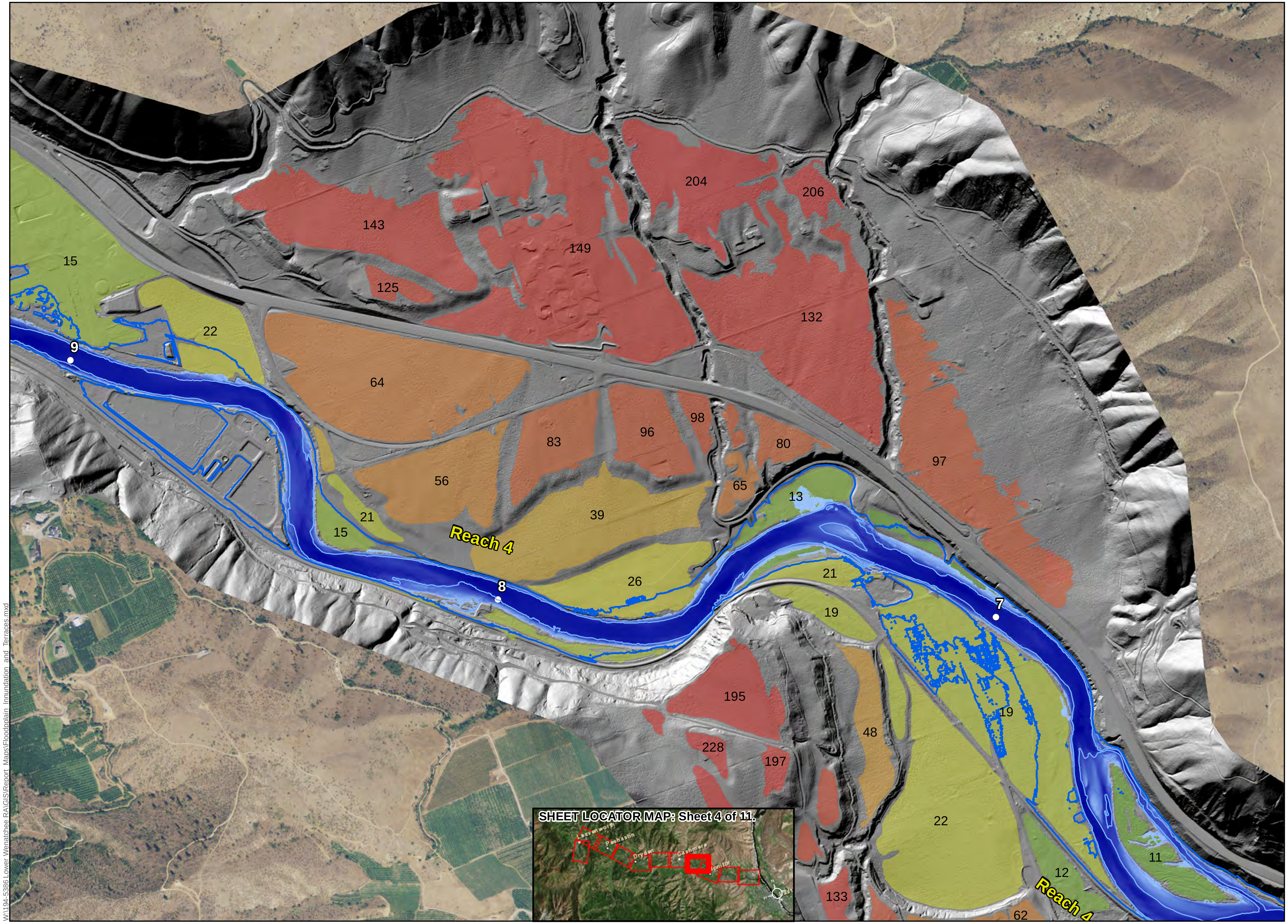
Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet



Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2d

○ USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

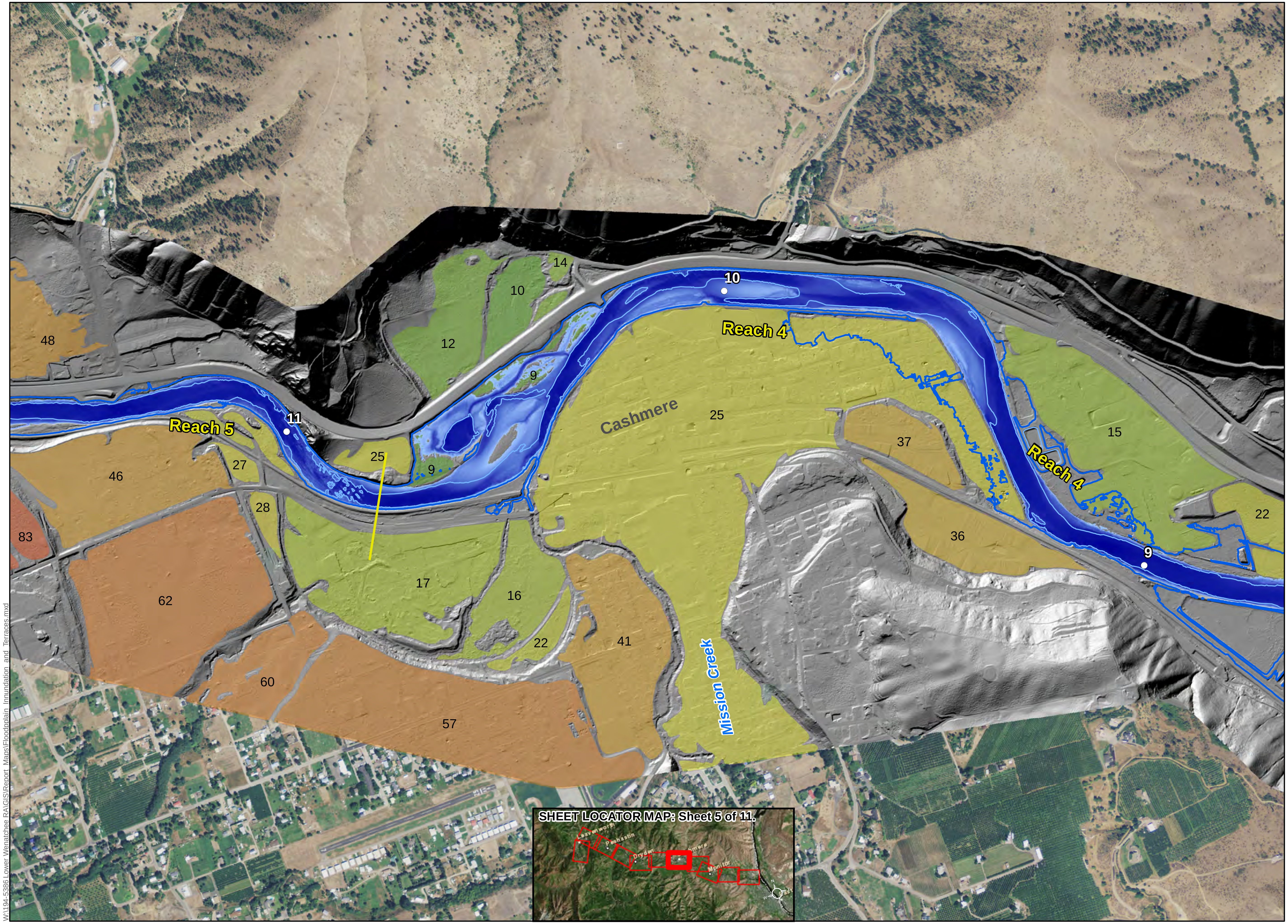
0 500 1,000
Feet

W:\194-5386 Lower Wenatchee RA\GIS\Report Maps\Floodplain Inundation and Terraces.mxd

Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2e



USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

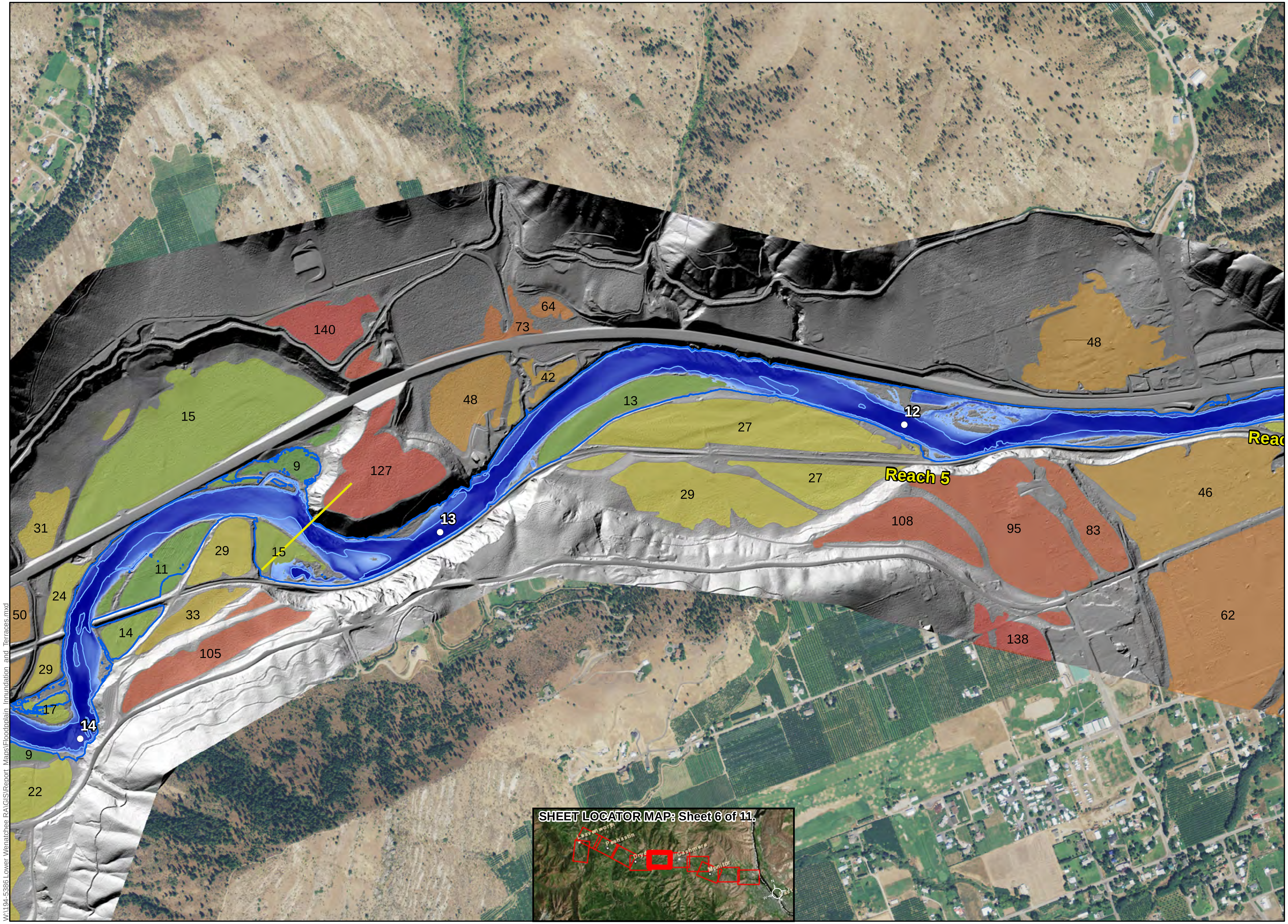
Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2f



USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

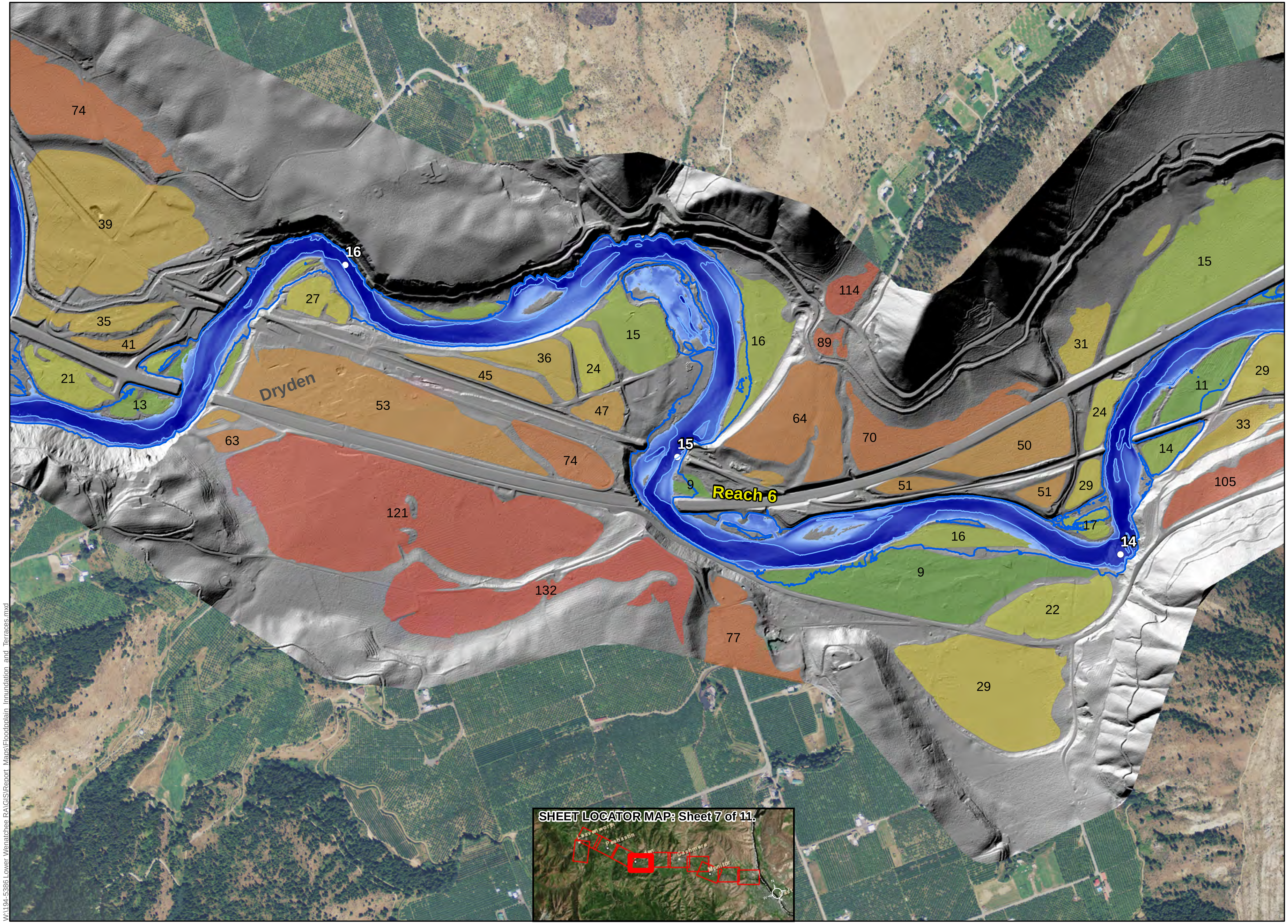
Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2g



USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

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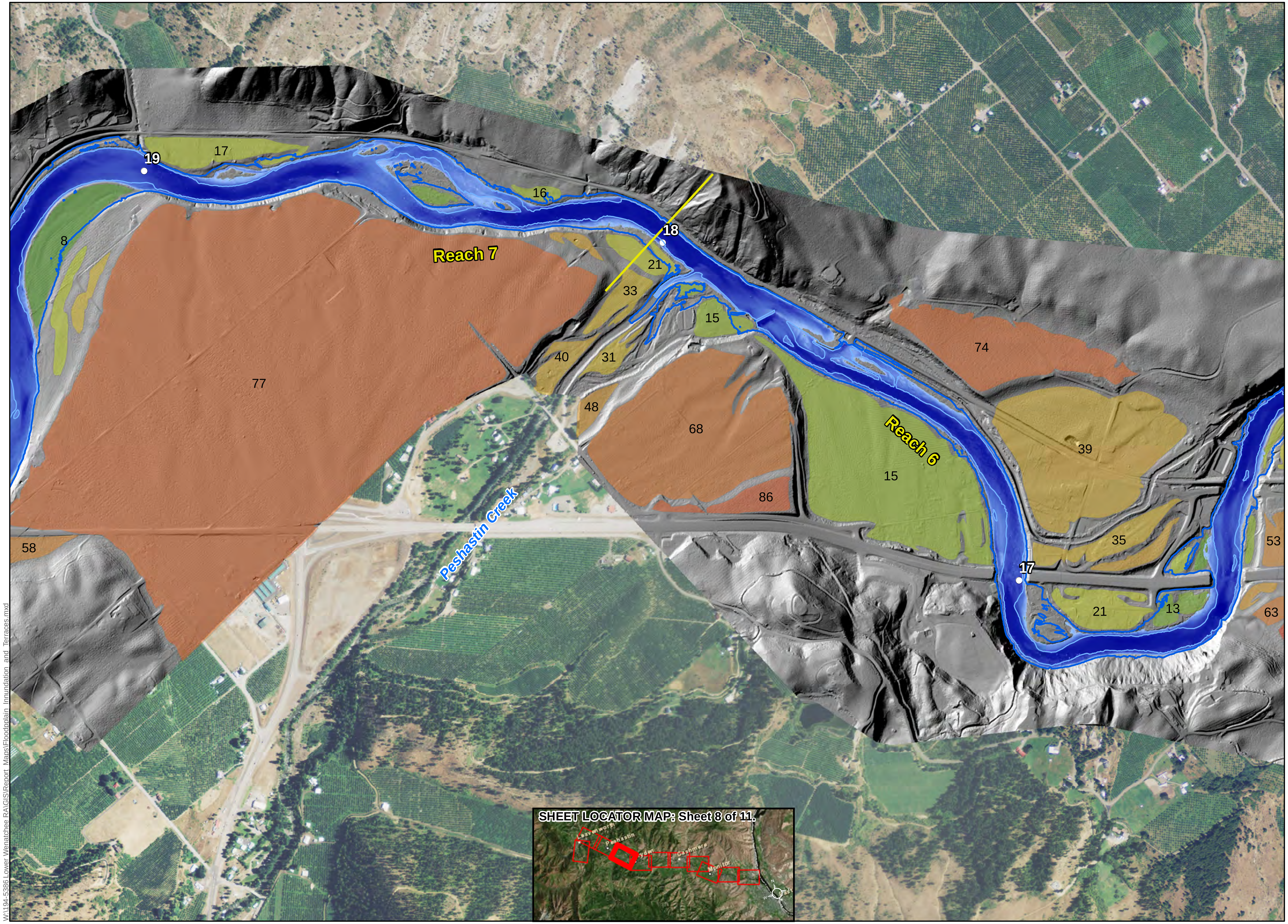

Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2h

USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

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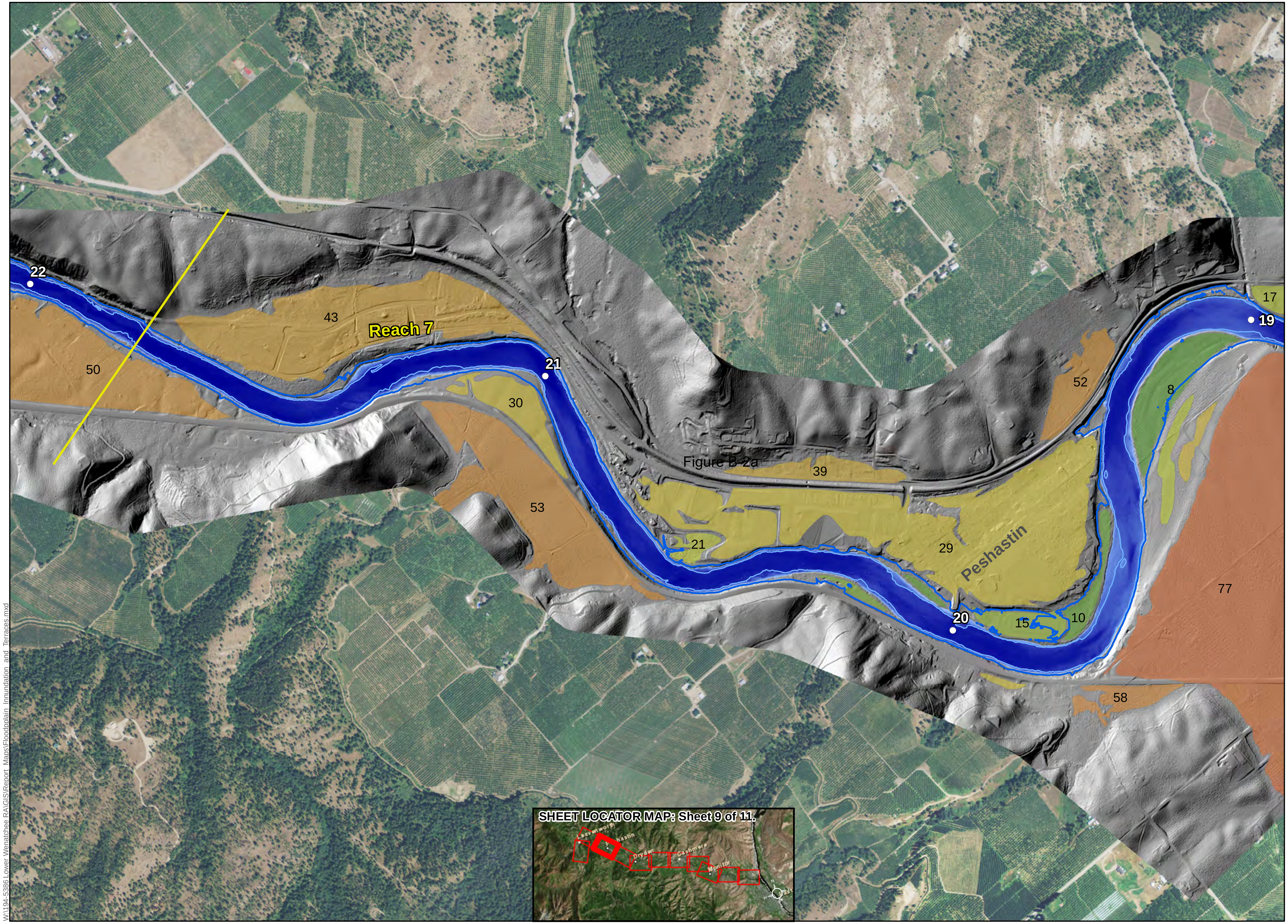


Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2i

o USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

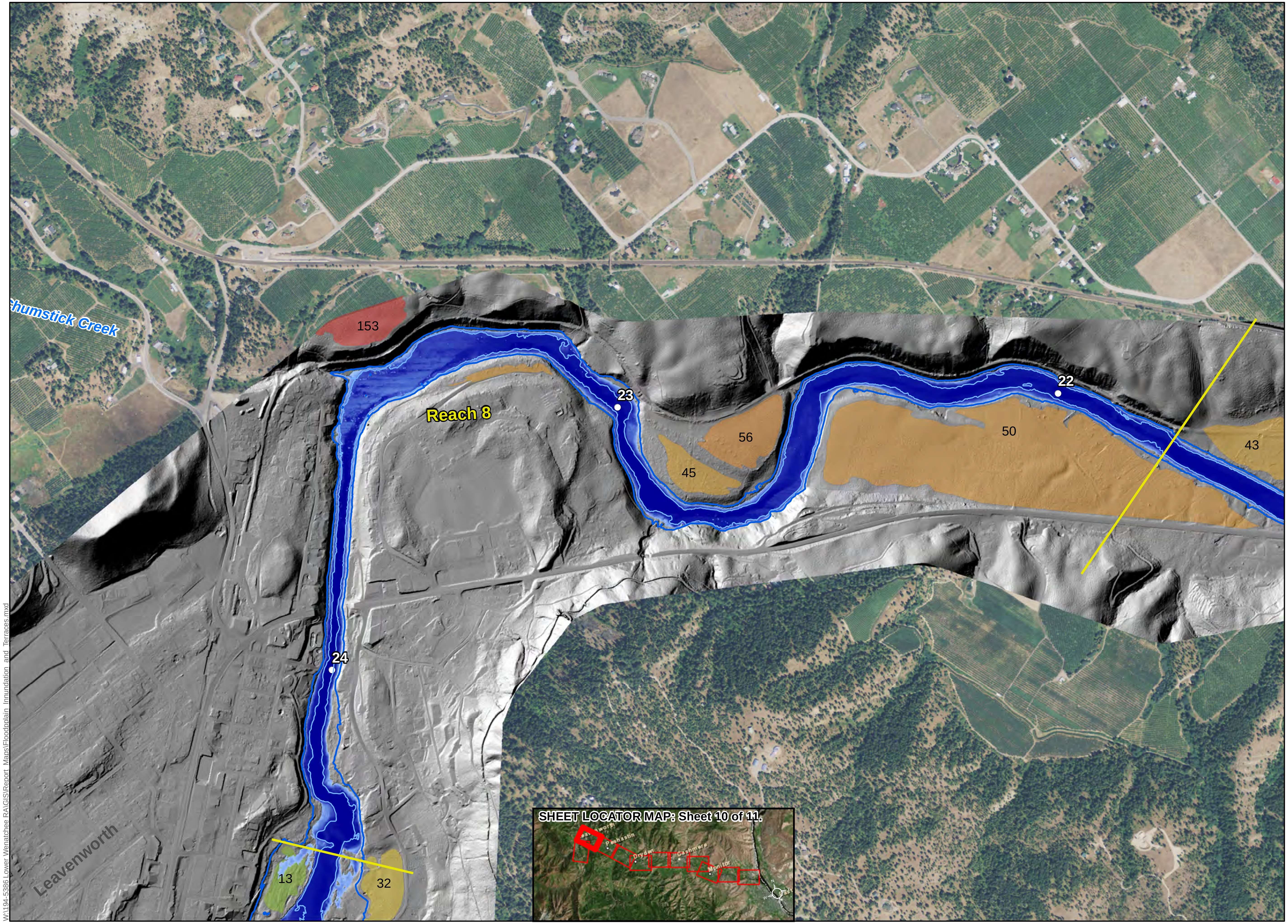
High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

W:\194-5386 Lower Wenatchee RA\GIS\Report Maps\Floodplain Inundation and Terraces.mxd



Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2j

USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

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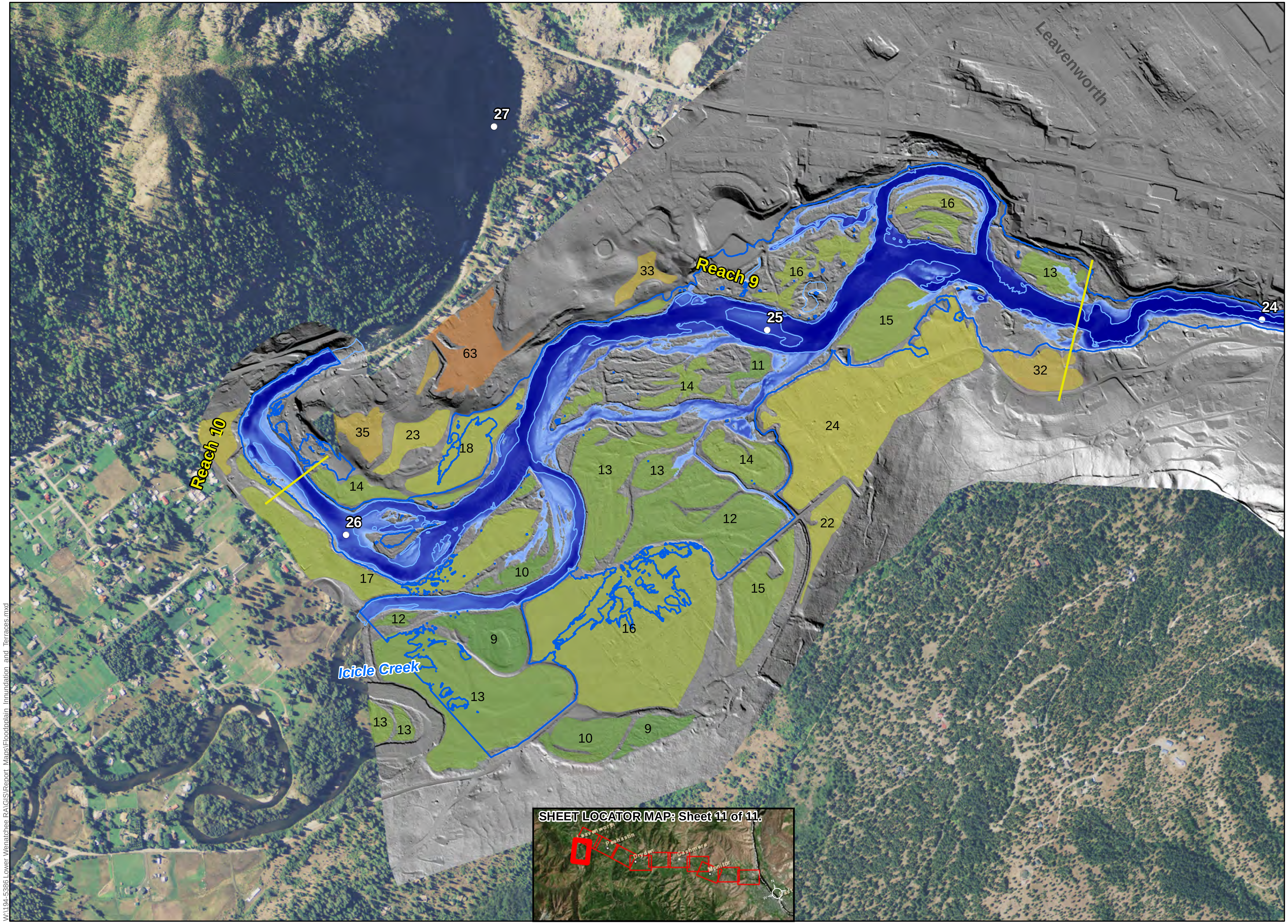


Lower Wenatchee River Reach Assessment

Inundation and Terrace Mapping

Figure C-2k

USGS River Mile

Geomorphic Reach Breaks

Survey Flow Wetted Extent

100-Year Extent

2-Year Depth (ft)

24
19
15
10
5
0

Terrace Relief (ft)

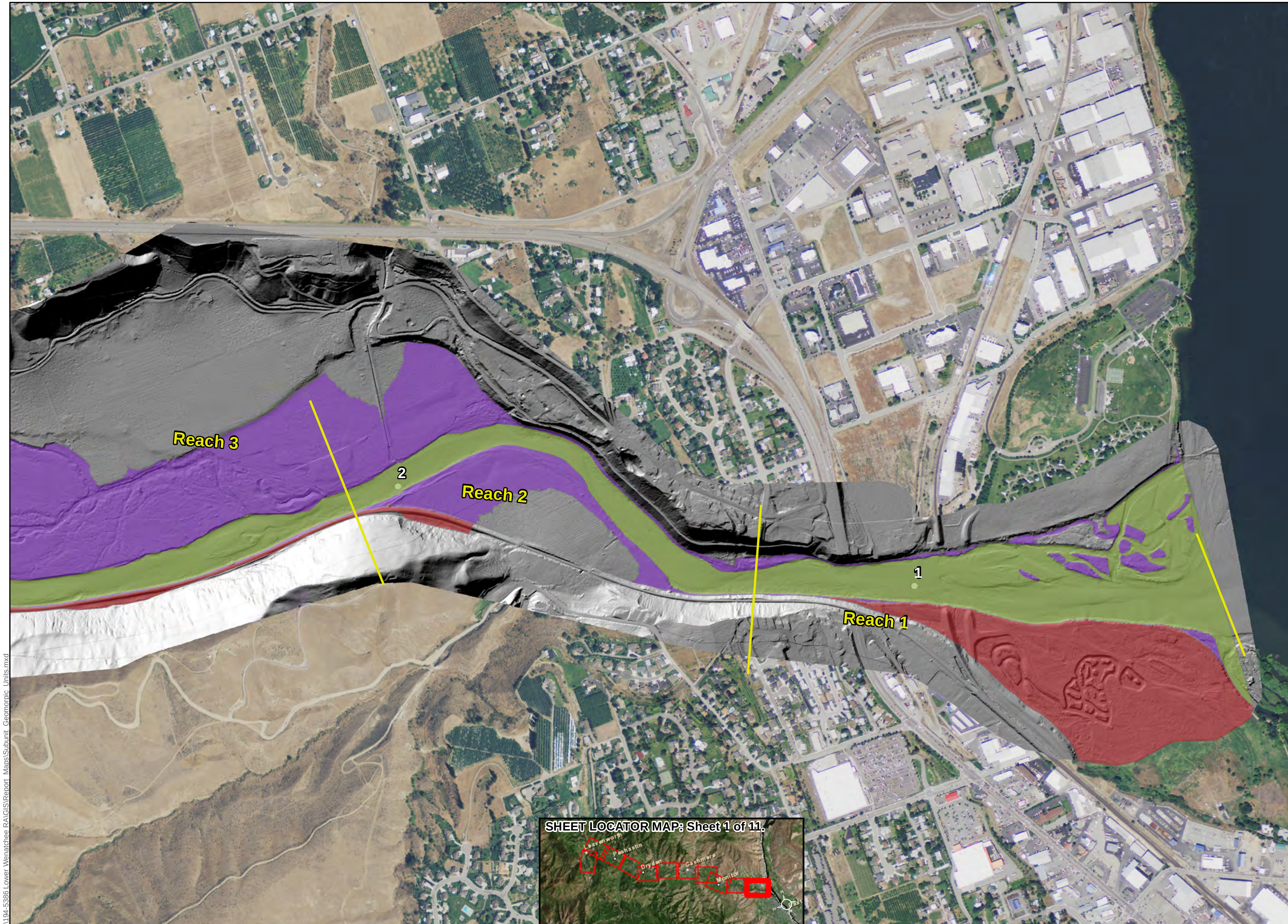
High : 228
Mid : 30
Low : 6

Average terrace relief is measured relative to the average elevation of the adjacent channel bed. See values labeled on map.

Base layers: combined topo-bathymetric hillshade (2015) and 2013 National Agriculture Imagery Program (NAIP) aerial imagery.

0 500 1,000
Feet

W:\194-5386 Lower Wenatchee RA\GIS\Report Maps\Floodplain Inundation and Terraces.mxd



Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3a

USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 360 720 Feet

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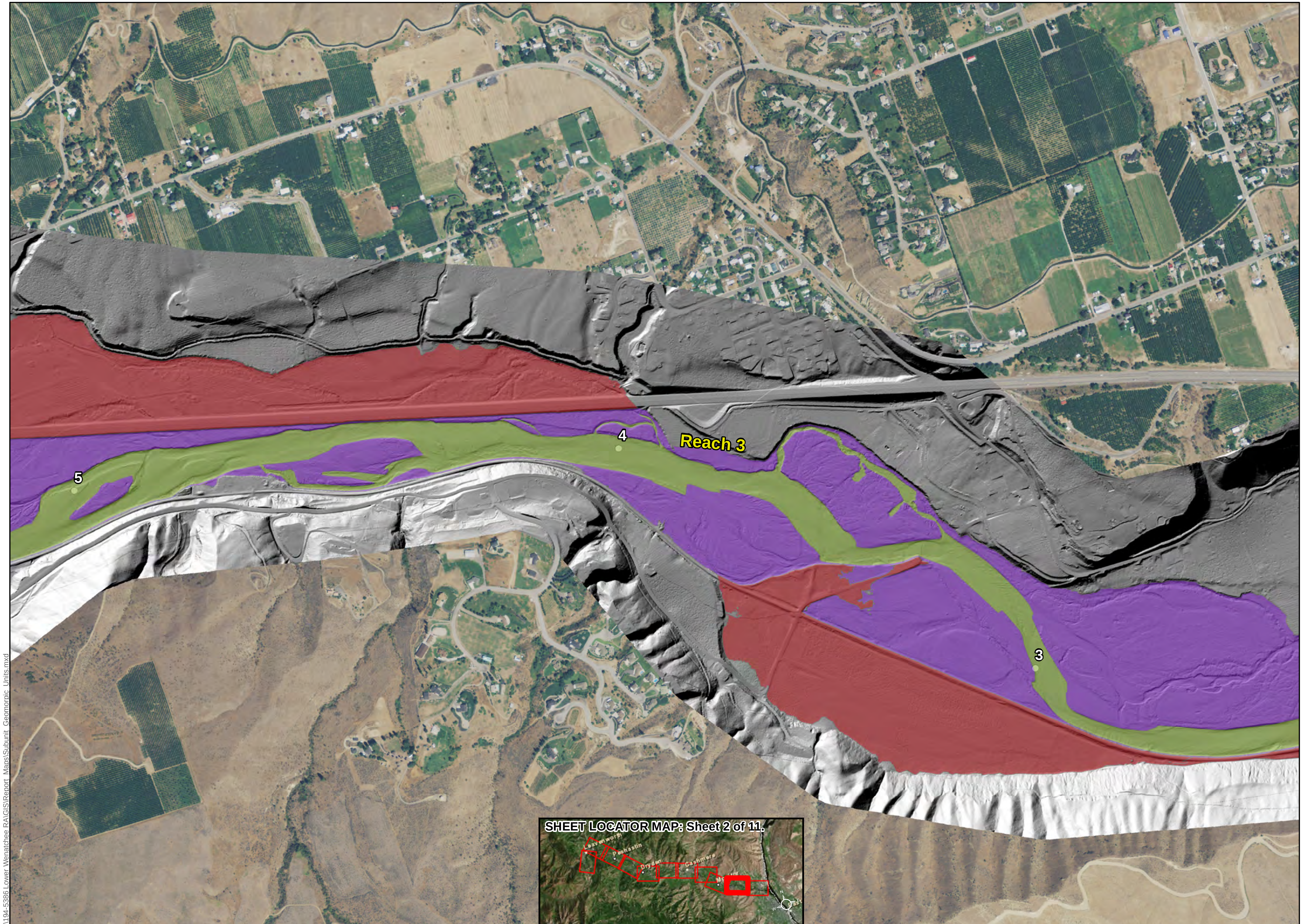
Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3b



USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

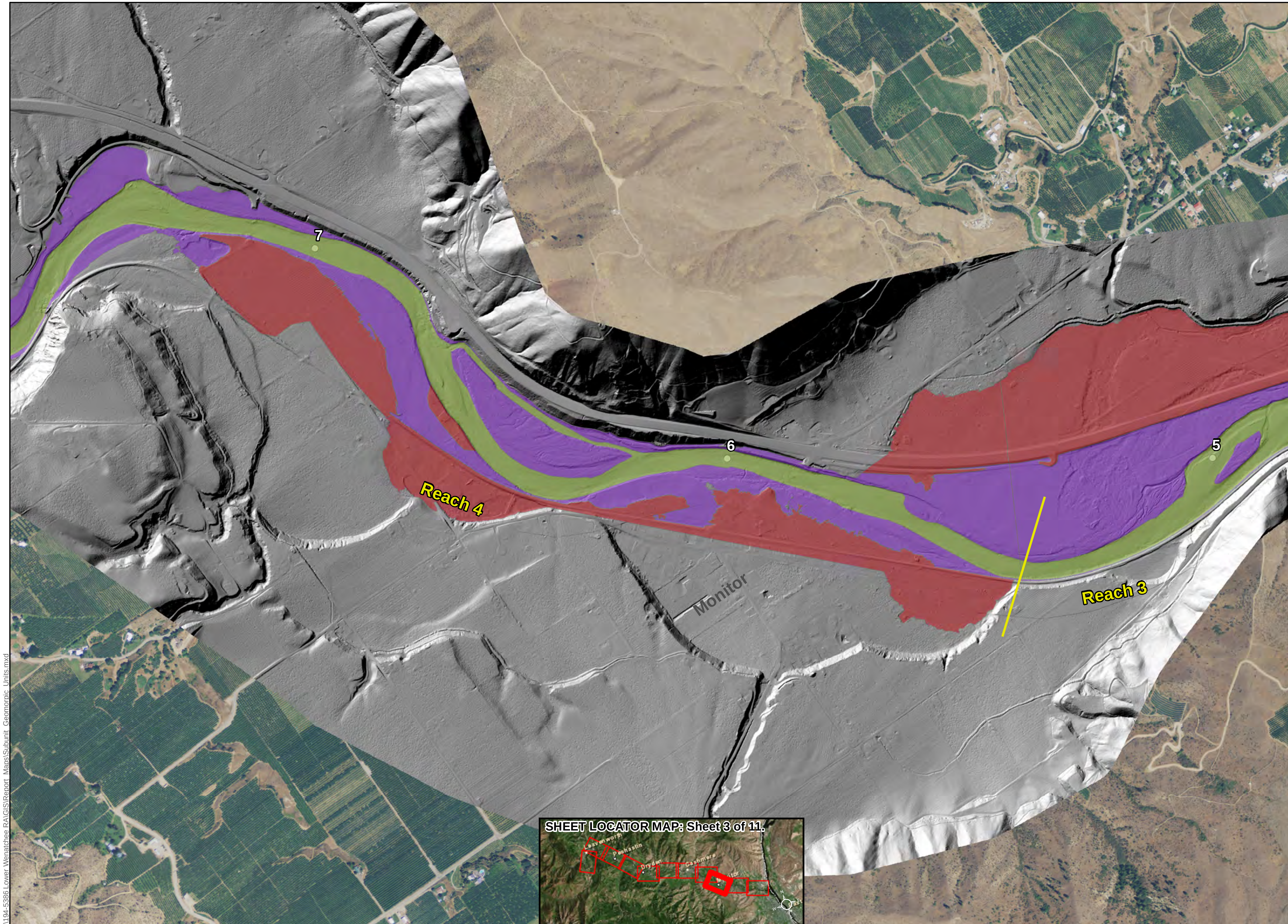
Outer Zone

0 360 720 Feet

Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3c



USGS River Mile

Geomorphic Reach Break

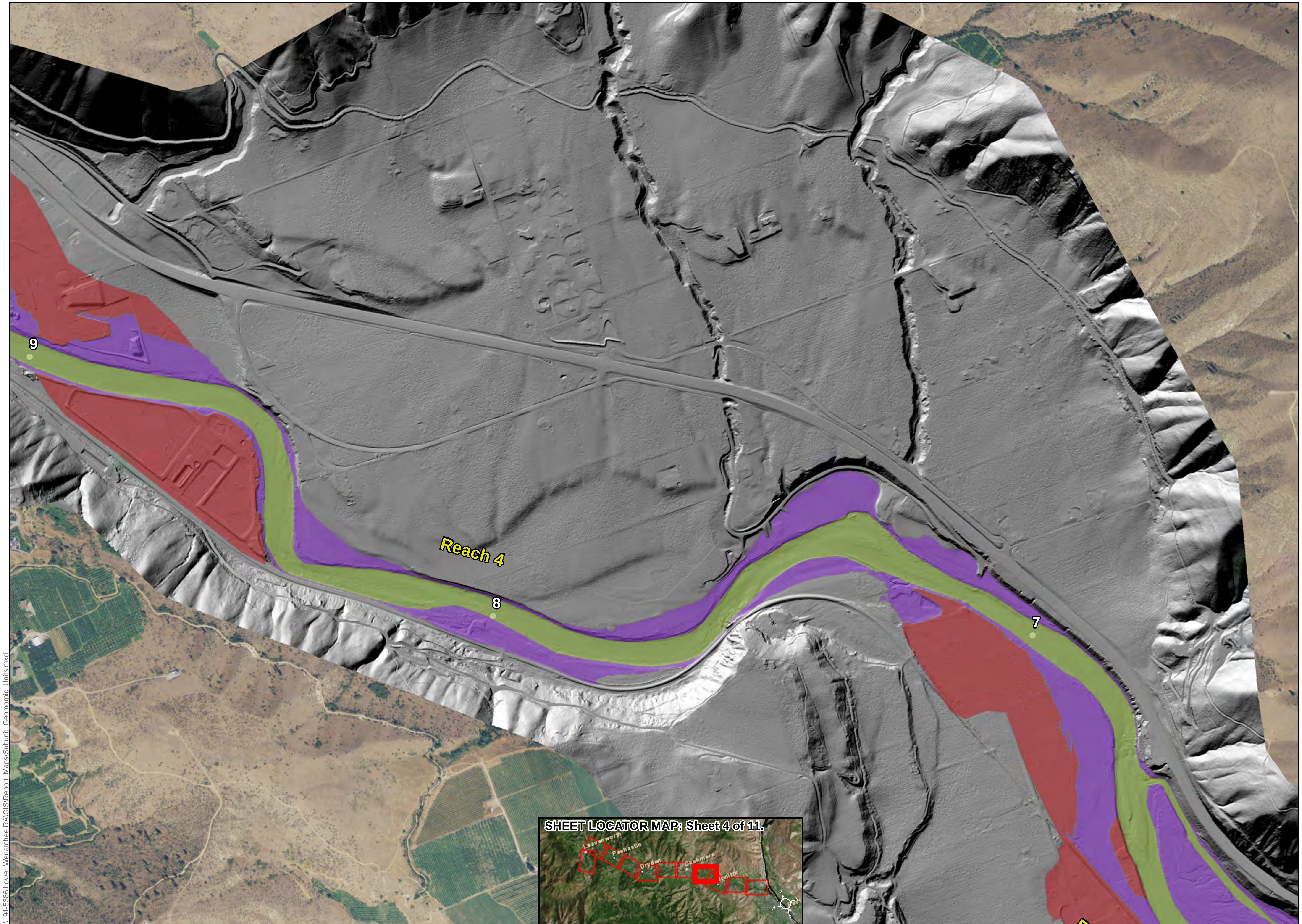
Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 400 800 Feet



Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3d

USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 360 720 Feet

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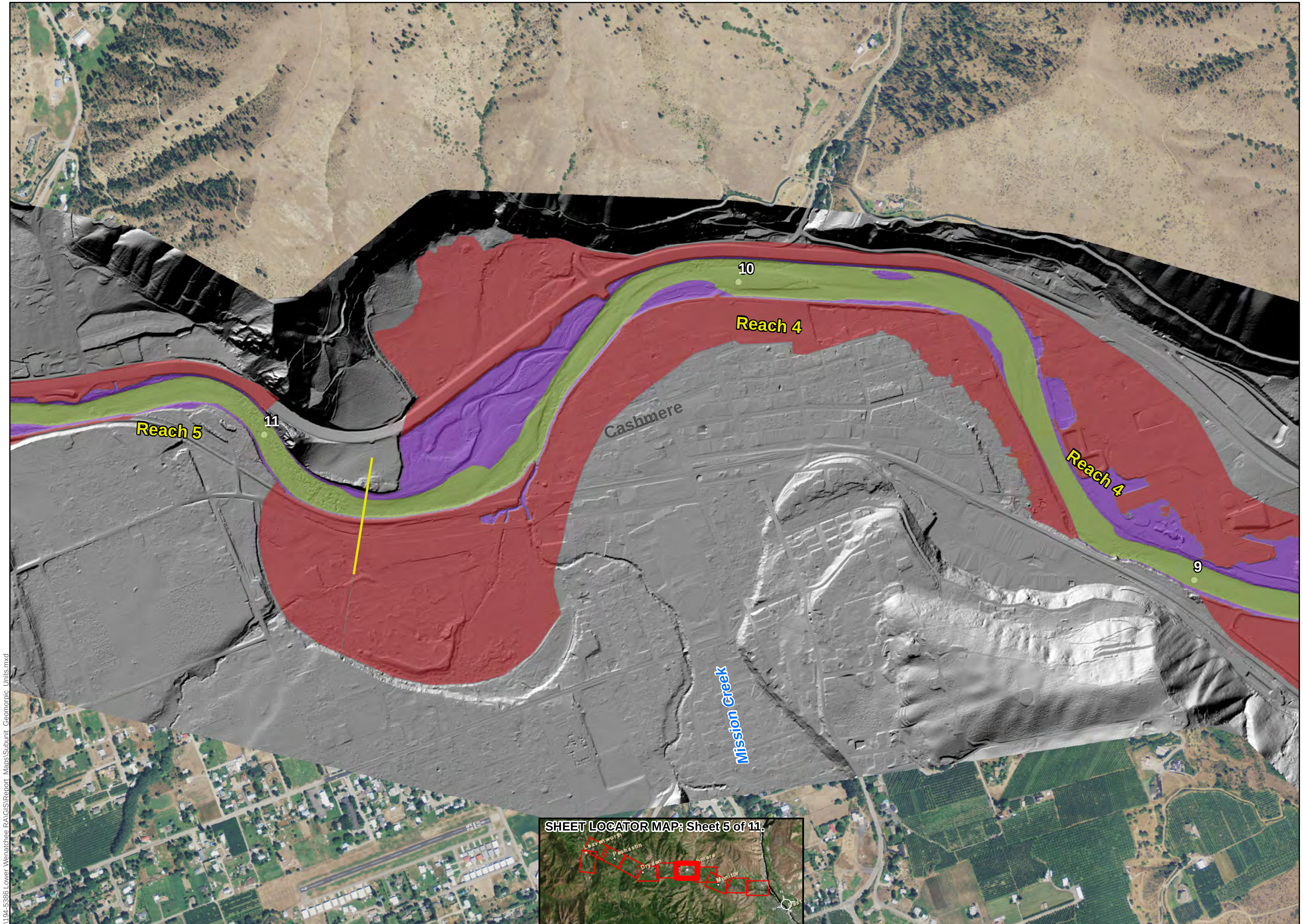
Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3e



USGS River Mile
Geomorphic Reach Break
Zone
Disconnected Outer Zone
Inner Zone
Outer Zone

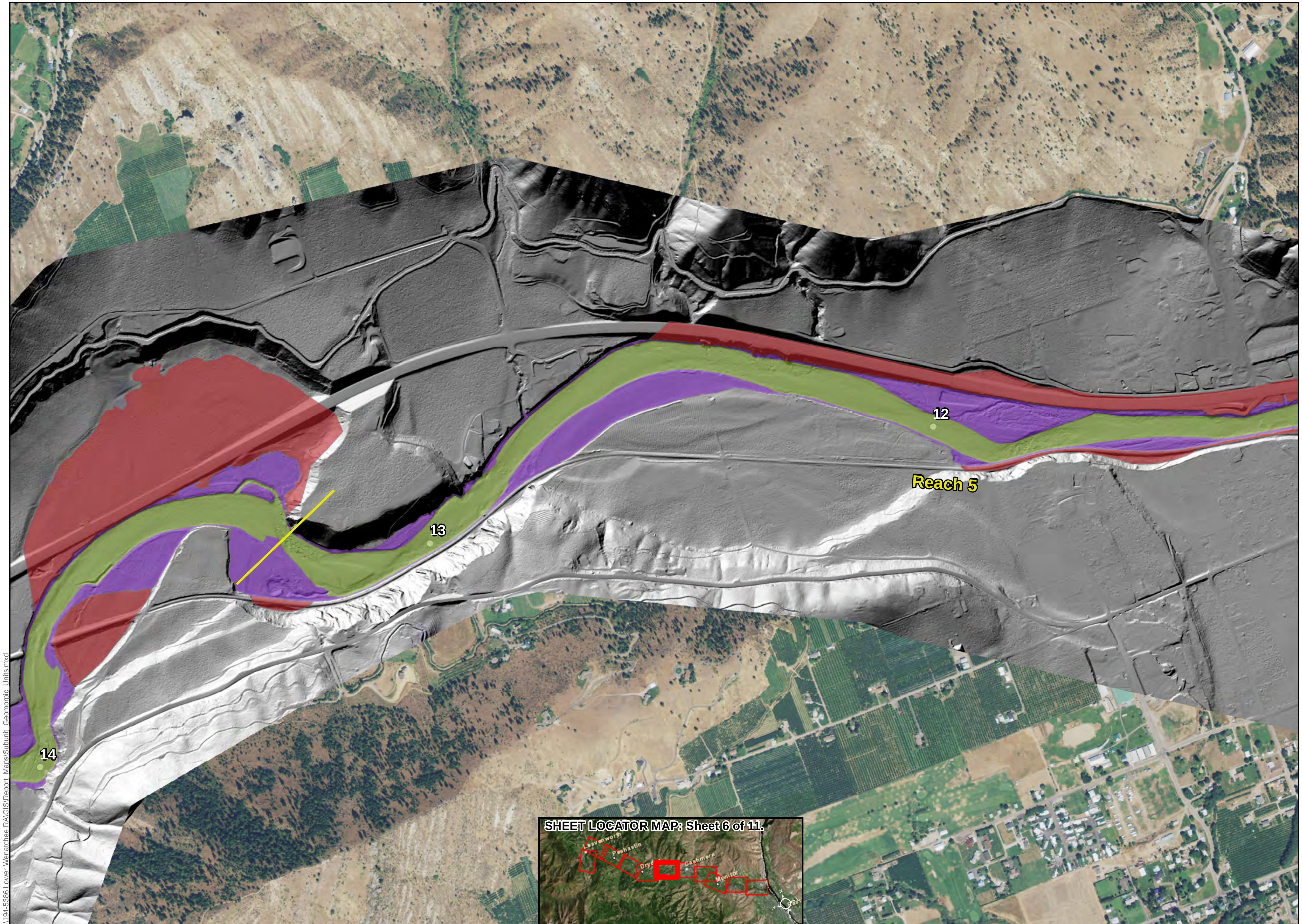
0 360 720 Feet

W:\194-5386 Lower Wenatchee RA\GIS\Report_Maps\Subunit_Geomorphic_Units.mxd

Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3f



USGS River Mile

Geomorphic Reach Break

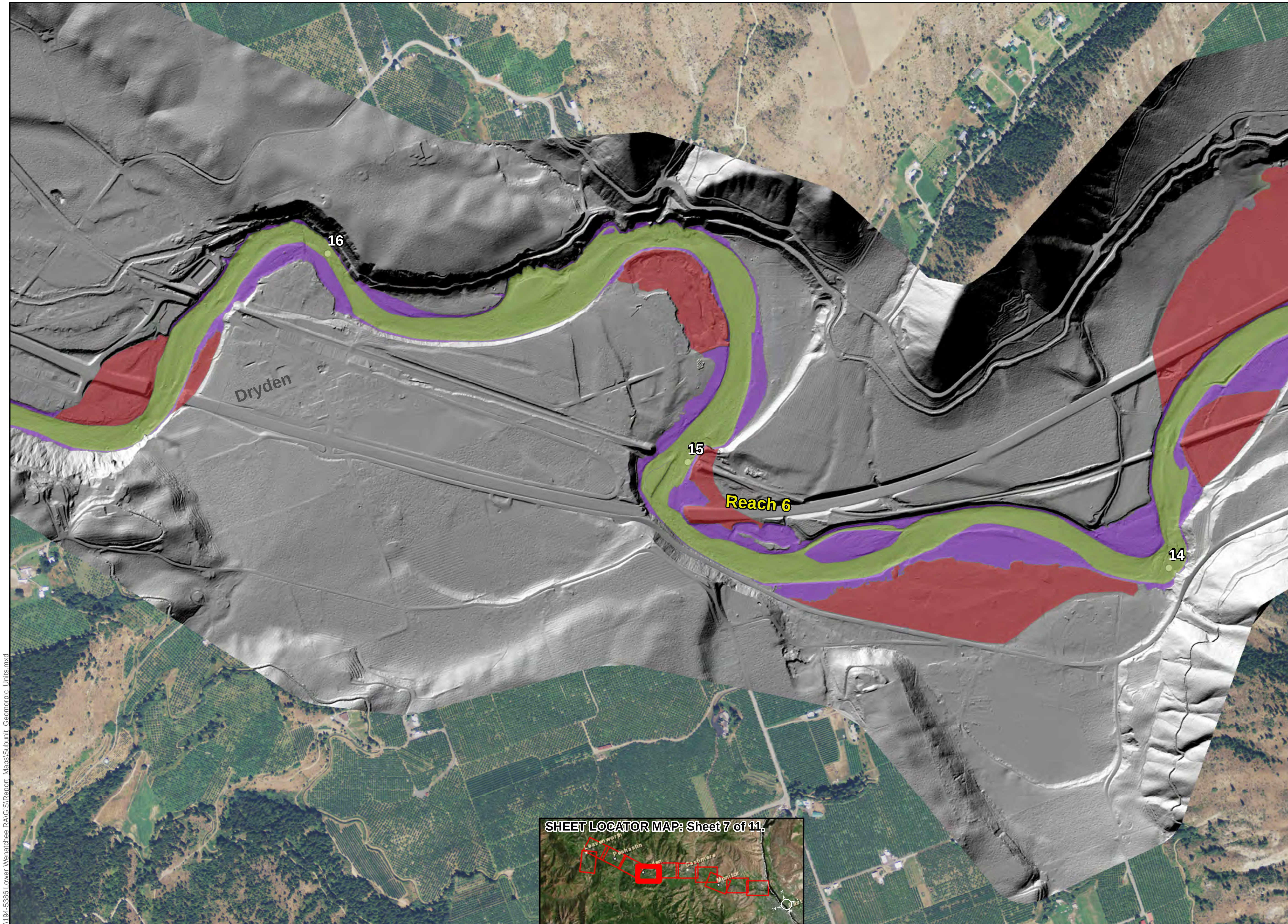
Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 360 720 Feet



Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3g

USGS River Mile

Geomorphic Reach Break

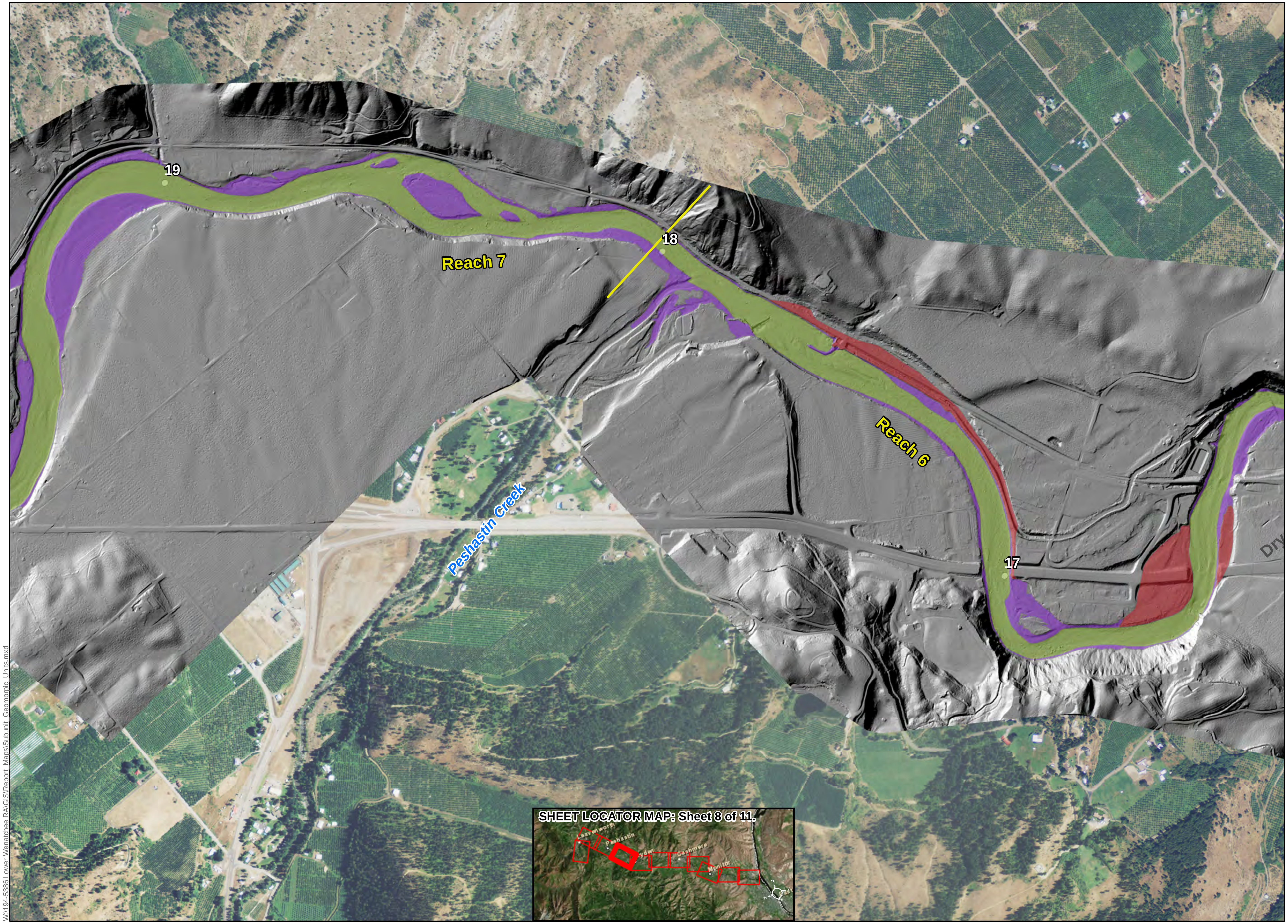
Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 360 720 Feet



Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3h

USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 400 800 Feet

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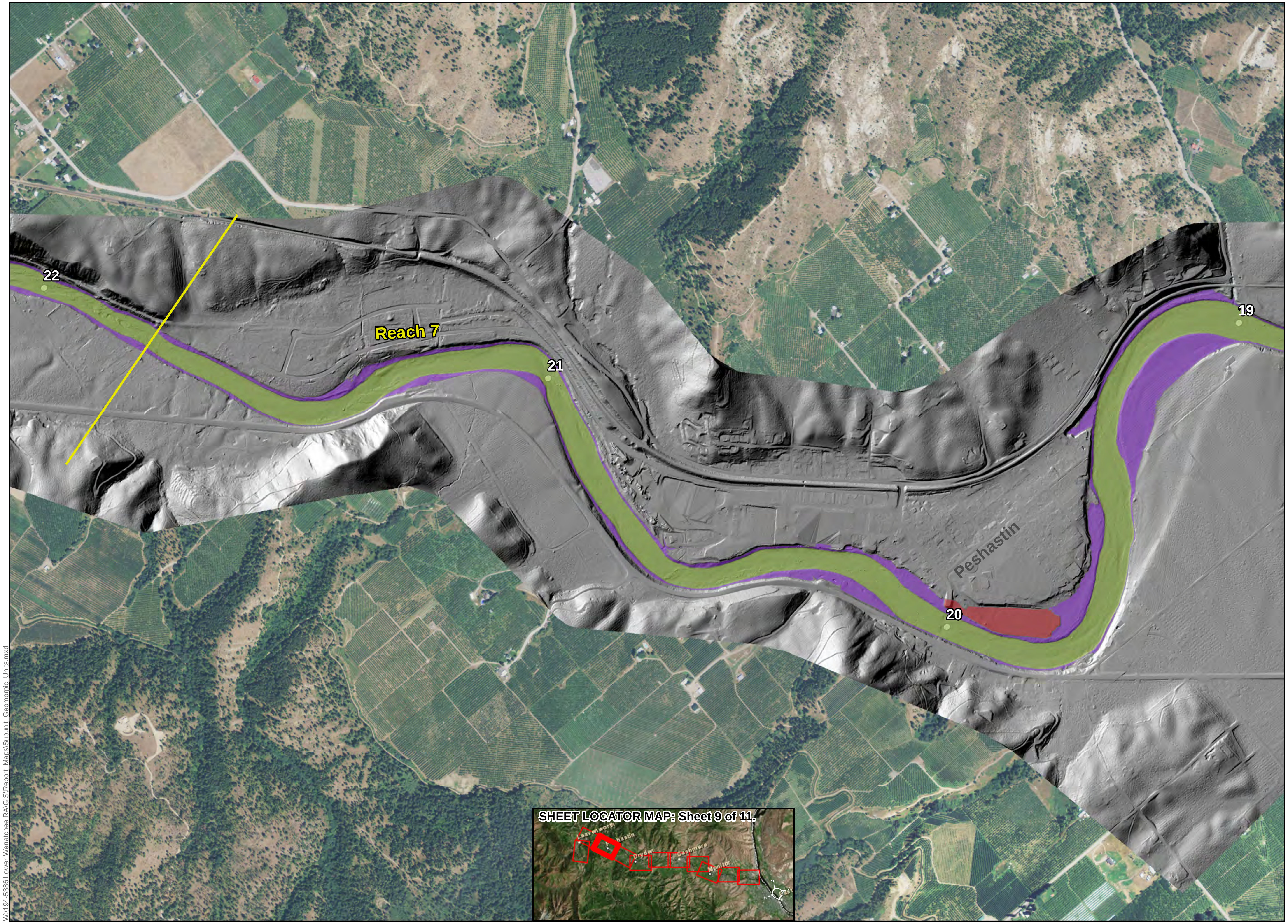
Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3i



USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 395 790 Feet

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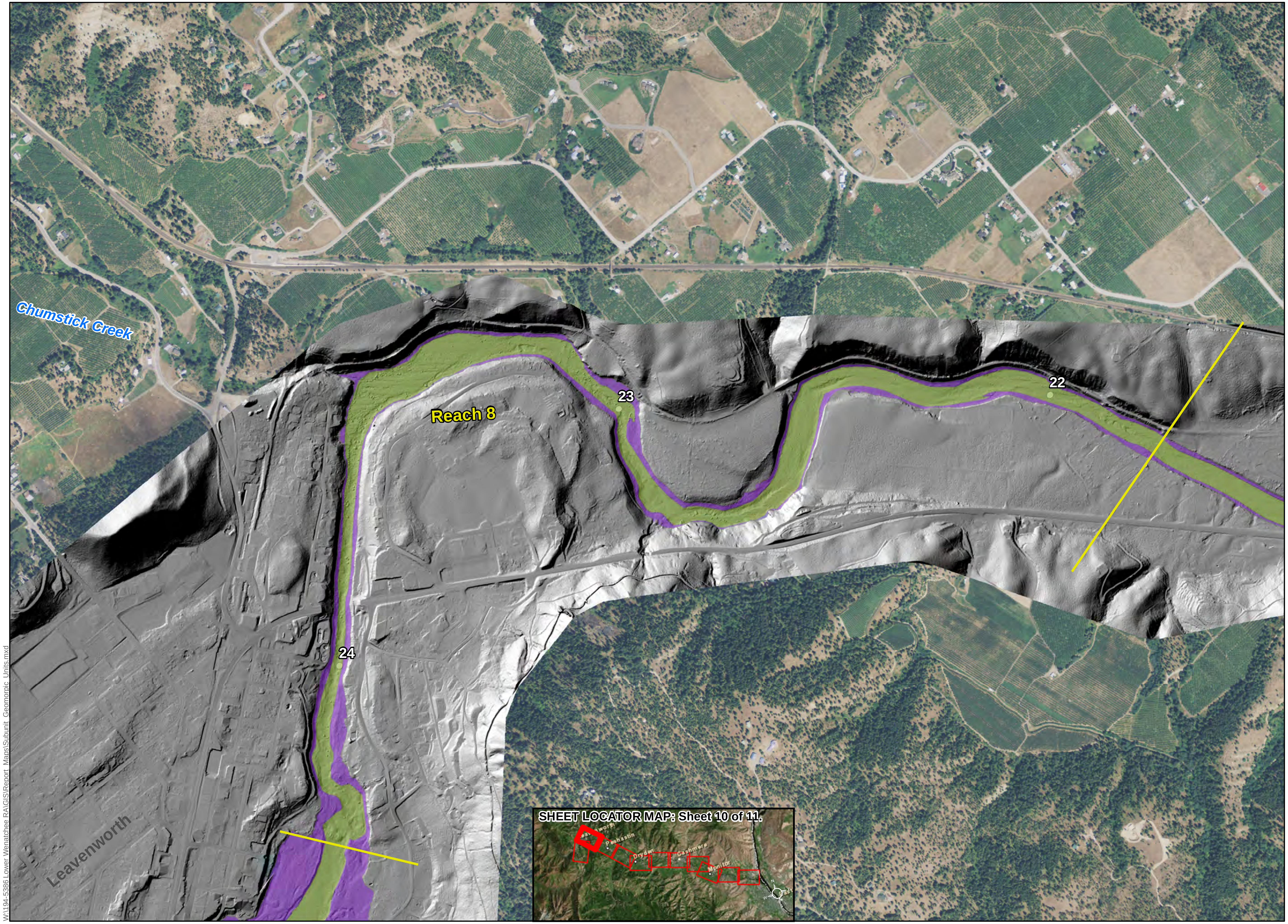
Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3j



USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 395 790 Feet

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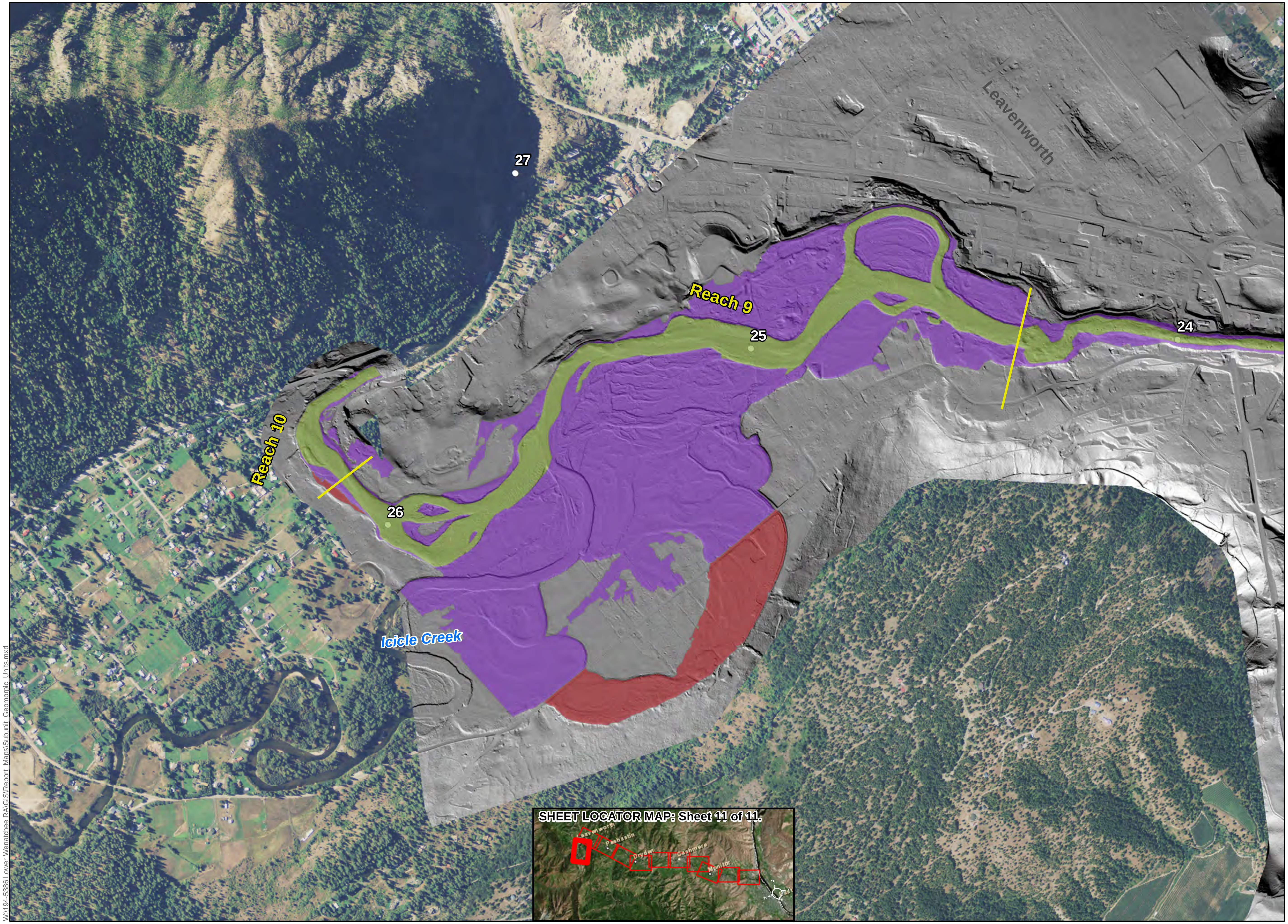
Lower Wenatchee River Reach Assessment

Sub-unit Geomorphic Units

Figure C-3k



USGS River Mile

Geomorphic Reach Break

Zone

Disconnected Outer Zone

Inner Zone

Outer Zone

0 450 900 Feet

W:\194-5386 Lower Wenatchee RA\GIS\Report Maps\Subunit Geomorphic Units.mxd

APPENDIX D

Reach-Based Ecosystem Indicators (REI)

1. INTRODUCTION

This Reach-based Ecosystem Indicator (REI) assessment characterizes the state of geomorphic and ecological processes within the Wenatchee River watershed and within each of the 10 project area reaches. The REI criteria used in this assessment are based on the Matrix of Diagnostics/Pathways and Indicators (USFWS 1998), the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS) Matrix of Pathways and Indicators (1996), as well as more recent work conducted within the region by the Bureau of Reclamation and their adaptation of these indicators (USBR 2012).

Data collected during the habitat survey, geomorphic assessment, and hydraulic analysis informed this REI assessment. Specific analysis results are presented and discussed for each metric, and are used to assign a condition rating of “adequate”, “at risk”, or “unacceptable.” The criteria for rating categories are explained in detail for each indicator below.

2. PATHWAY: WATERSHED CONDITION

GENERAL INDICATOR: WATERSHED ROAD DENSITY AND EFFECTIVE DRAINAGE NETWORK

Metric Overview

Road density can be a good indicator of watershed condition, as it has been shown that high road density can result in altered drainage networks (Montgomery 1994; Wemple et al. 1996) which in turn often increases fine sediment load to streams and rivers (Reid and Dunne 1984; Goode et al. 2011). In addition, increased road density can result in greater mass wasting events and erosion than in a less disturbed watershed (Montgomery 1994; Wemple et al.1996). Increased sediment delivery to streams can have significant effects on aquatic systems, such as reducing suitable spawning habitat; smothering salmon eggs (Lisle 1989); clogging hyporheic flow paths (Boulton et al. 1998); reducing substrates for aquatic plants, biofilms, and aquatic invertebrates (Henley et al. 2000); as well as impacting channel morphology and water clarity (Waters 1995; Wood and Armitage 1997).

Criteria: From USFWS (1998), modified by USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Effective Drainage network and Watershed Road Density	Increase in Drainage Network/Road Density	Zero or minimum increase in active channel length correlated with human-caused disturbance **And** Road density <1 *miles/mile*^{2}	Low to moderate increase in active channel length correlated with human-caused disturbance **And** Road density 1 to 2.4 *miles/mile*^{2}	Greater than moderate increase in active channel length correlated with human-caused disturbance **And** Road density >2.4 *miles/mile*^{2}

Assessment Results

Road density was calculated using an ArcGIS layer developed by the Chelan County Conservation District (Walker 2008). Road density was assessed for the Wenatchee River watershed (HUC-10 1702001107) which is within the Wenatchee River subbasin (HUC-8 17020011). Road density for the HUC-10 Wenatchee River watershed was 2.8 miles per square mile. Based on the rating criteria the watershed is functioning at an **unacceptable** condition;

however, the impact of watershed road density and the effective drainage network is greater on smaller tributary streams than it has on the mainstem lower Wenatchee River.

REI Rating

Watershed Rating: **Unacceptable**

INDICATOR: DISTURBANCE REGIME (NATURAL & HUMAN-CAUSED)

Metric Overview

Disturbance is an integral part of natural systems (Ward 1998). Natural disturbance regimes create habitat and biological diversity (Nakamura et al. 2000; Ward 1998) that maintain the larger ecosystem processes. Natural disturbance regimes include events such as landslides, fire, flood, drought, and windstorms. Human activities such as flow regulation, channelization, bank stabilization, road construction, and land-use modifications (conversion to agriculture, development, etc.) can change how systems respond to natural events, frequency of events, and ability to recover (Waples et al. 2009).

Criteria: From USFWS (1998)

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Disturbance Regime	Natural/Human Caused	Environmental disturbance is short lived; predictable hydrograph; high quality habitat and watershed complexity providing refuge and rearing space for all lifestages or multiple life-history forms. Natural processes are stable.	Scour events, debris torrents, or catastrophic fires are localized events that occur in several minor parts of the watershed. Resiliency of habitat to recover from environmental disturbance is moderate.	Frequent flood or drought producing highly variable and unpredictable flows, scour events, debris torrents, or high probability of catastrophic fire exists throughout a major part of the watershed. The channel is simplified, providing little hydraulic complexity in the form of pools or side channels. Natural processes are unstable.

Assessment Results

The Upper Wenatchee Watershed Assessment (Inter-Fluve 2012) determined that the disturbance regime for the upper portion of the Wenatchee River watershed is functioning at an **at risk** condition. This rating was determined based on historical accounts of riparian timber harvest, splash damming, log drives, and development in and around the floodplain (Inter-Fluve 2012). Similar alterations in the lower watershed include past human disturbance as well as on-going disturbances that limit the resiliency of habitat to recover from disturbance events. For example, along the lower Wenatchee River roads and railroads as well as other land use development has constrained river channel migration, disconnected habitat, and decreased woody debris abundance (WWPU 2006).

REI Rating

Watershed Rating: **At Risk**

INDICATOR: STREAMFLOW (CHANGE IN PEAK/BASE FLOW)

Metric Overview

The magnitude, timing, duration, and frequency of stream flows within a watershed are important drivers within the ecological system. Stream discharge and channel morphology are directly linked to these processes and largely controlled by climate, vegetation, geology, and human alterations and impacts. Alterations to the natural hydrology of a watershed can affect timing and magnitude of peak flow and low flow events. The frequency of high-flow events can also be dramatically affected by human actions, potentially decreasing due to flow regulation (e.g., dams) and water withdrawals (e.g., for irrigation), or increasing from widespread timber harvest, increased impervious surfaces, or extensive road networks.

Criteria: From USFWS (1998), modified by USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Streamflow	Change in Peak/Base flows	Magnitude, timing, duration and frequency of peak flows within a watershed are not altered relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Some evidence of altered magnitude, timing, duration and frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Pronounced evidence of altered magnitude, timing, duration and frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.

Assessment Results

In the Wenatchee River watershed, precipitation falls mostly as snow; the snowmelt in spring and early summer is the primary source of surface water (MWG et al. 2003). Spring snowmelt dominates the seasonal flow pattern in the watershed, with peak runoff from April through July, with the highest rates in May and June (Figure 1).

Top flood events have not noticeably increased in frequency or magnitude since 1929 (Table 1), with the largest 20 events spread out over the 1940s through 2000s. Figure 2 shows base flows and peak flows calculated for the Wenatchee River at Peshastin gage (USGS 12459000) since 1929. While human alterations to the watershed may have contributed to a change in peak flows, determining this causal relationship would require more complex analysis than is possible for this assessment (Hall et al. 2014).

Climate change projections indicate that rainfall may increase 1 to 2 percent by 2040, and 4 percent by 2080 (e.g., Mote and Salanthe 2009). Climate change models (synthesized by CIG 2009) also predict an increase in winter stream flows, earlier and lower peak runoff, and lower summer baseflows (Figure 3). These analyses suggest that human-induced climate change is likely to alter the magnitude, timing, duration, and frequency of streamflows.

Therefore, based on the potential effects of climate change on watershed hydrology, this metric is rated **at risk**.

REI Rating

Watershed Rating: **At Risk**

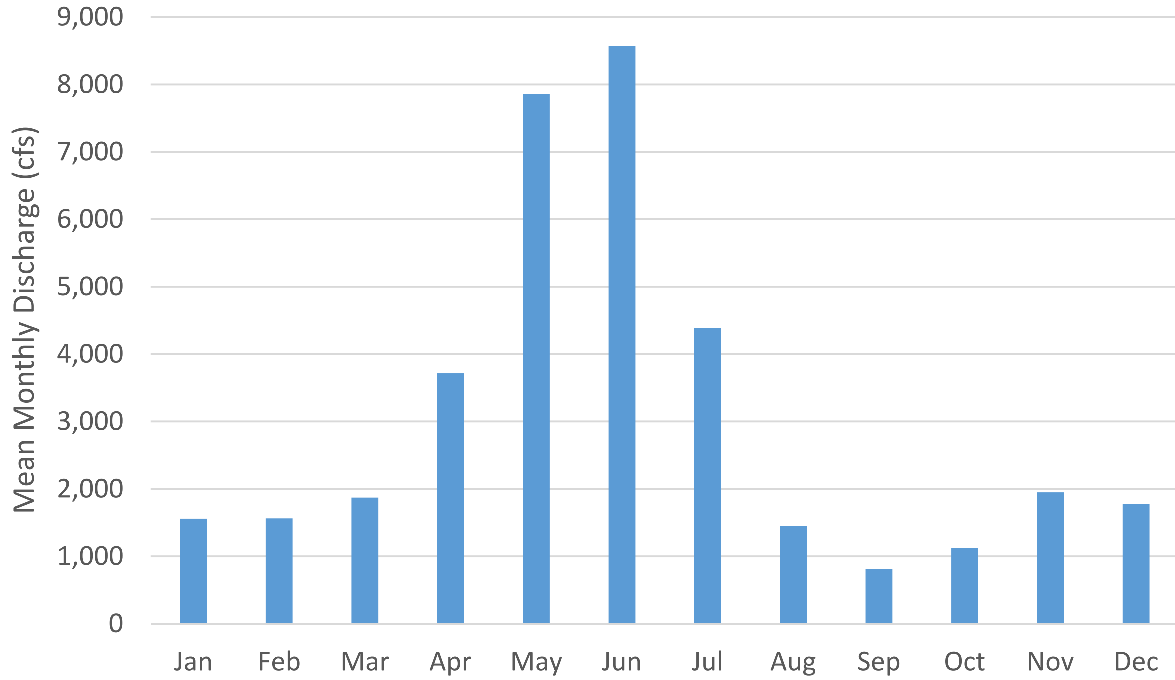


Figure 1. Mean Monthly Discharge at Peshastin for period 1929 to 2014 (USGS Gage 12459000)

Table 1. Top 20 Flood Events since 1929

Event Rank	Water Year	Discharge (cfs)
1	1996	41300
2	1991	40000
3	1948	32300
4	2007	30300
5	1981	27000
6	1974	26300
7	1972	26000
8	1976	25200
9	1956	24200
10	1955	23400
11	1999	23100
12	1949	22700
13	1950	21800
14	1961	21500
15	1997	21400
16	2006	21100
17	1958	21000
18	1951	20600
19	1983	20600
20	2008	20500

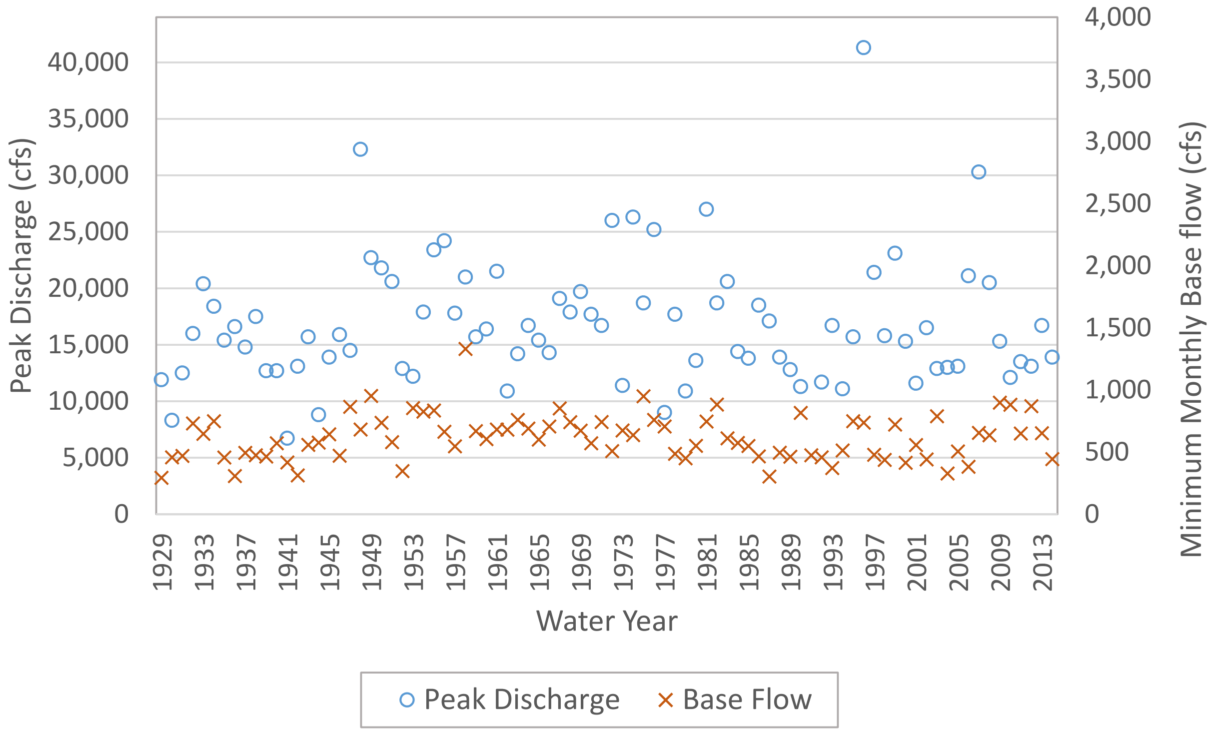


Figure 2. **Peak and Base Flows of the Wenatchee River at Peshastin from 1929 to 2013 (USGS Gage 12459000).**

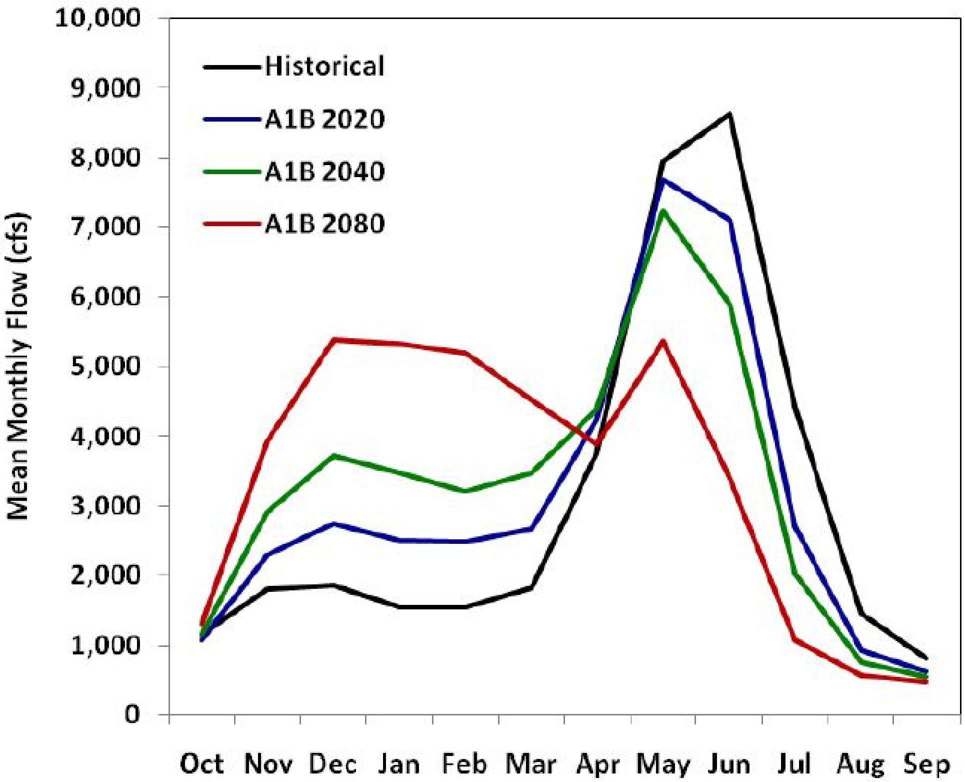


Figure 3. Projected Impacts of Climate Change on Mean Monthly Flows of Wenatchee River at Peshastin (CIG 2009; Elsner 2011)

3. PATHWAY: REACH-SCALE HABITAT ACCESS

INDICATOR: PHYSICAL BARRIERS – MAIN CHANNEL BARRIERS

Metric Overview

Physical barriers restrict movement of aquatic species, such as salmonids, throughout a watershed. This can result in reduced genetic diversity within populations and reduced distribution of marine derived nutrients throughout the system, and may also impact transport of woody debris material downstream from source areas. This metric evaluates the presence or absence of fish passage barriers in the lower Wenatchee River.

Criteria: From USFWS (1998), modified by USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Access	Physical Barriers	Main Channel Barriers	No manmade barriers present in the mainstem that limit upstream or downstream fish passage at any flows	Manmade barriers present in the mainstem that prevent upstream or downstream migration at some flows that are biologically significant	Manmade barriers present in the mainstem that prevent upstream or downstream migration at multiple or all flows

Assessment Results

No complete fish passage barriers are present on the lower Wenatchee River. Dryden Diversion Dam, located on the mainstem (just downstream of the Peshastin Creek confluence), has two functioning fish passage and trapping facilities (right and left bank) for broodstock collection with improved and updated fish screens in 2001 (Andonaegui 2001). Therefore, all reaches are considered **adequate**.

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Physical Barriers	Main Channel Barriers	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate

4. PATHWAY: REACH-SCALE HABITAT QUALITY

INDICATOR: SUBSTRATE – DOMINANT SUBSTRATE FINE SEDIMENT

Metric Overview

Stream substrate is important for salmon spawning, egg incubation, and rearing. High-quality spawning areas generally include gravel/cobble dominated substrates with relatively low amounts of interstitial fine sediments. These factors provide conditions suitable for egg incubation (proper aeration and not smothered by fines) and young-of-the year rearing (available interstitial spaces for cover and refuge).

Criteria: Modified from USFWS (1998) and USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Substrate	Dominant Substrate/Fine Sediment	Dominant Substrate is gravel or cobble (interstitial spaces clear), or embeddedness < 20%, <12% fines (<0.85mm) in spawning gravel or <12% surface fines of <6mm	Gravel and Cobble is subdominant, or if dominant, embeddedness is 20-30%; 12-17% fines (<0.85mm) in spawning gravel or 12-20% surface fines of <6mm	Bedrock, sand, silt, or small gravel dominant, or if gravel and cobble dominant, embeddedness > 30%; >17% fines (<0.85mm) in spawning gravel or >20% surface fines of <6mm

Assessment Results

Streambed substrate was based on complete pebble counts to document substrate differences, and ocular estimates of substrate composition for each channel unit. Reaches 2 through 7 and 9 are considered **adequate** due to dominant cobble and gravel substrate. However, Reaches 2 through 7 are dominated by coarse cobbles with very few areas with spawning sized gravels whereas Reach 9 has abundant spawning sized gravels. Reaches 8 and 10 are considered **at risk** due to a higher incidence of boulders. Reach 1, the mouth of the Wenatchee River, is rated **unacceptable** with respect to substrate due to the dominance of sand/fines. However, this is the expected condition in Reach 1 given the backwater effects of the Columbia River.

Table 2. Substrate Size Class Distribution by Reach

Substrate Size Class	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Sand (<2 mm)	80%	10%	9%	10%	7%	10%	13%	14%	23%	15%
Gravel (2 to 64 mm)	5%	10%	13%	10%	11%	10%	14%	4%	33%	13%
Cobble (64 to 256 mm)	15%	68%	66%	55%	43%	45%	50%	22%	39%	35%
Boulder (256 to 4096 mm)	0%	12%	10%	20%	21%	25%	22%	43%	6%	38%
Bedrock	0%	0%	3%	5%	18%	10%	2%	17%	0%	0%

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Substrate	Dominant Substrate/ Fine Sediment	unaccept-able	adequate	adequate	adequate	adequate	adequate	adequate	at risk	adequate	at risk

INDICATOR: LARGE WOODY DEBRIS (LWD)

Metric Overview

Large woody debris (LWD) provides critical habitat structure and helps create and sustain channel complexity over time. Large pieces and log jams can generate quality pools, offer refuge, and provide potential food sources for salmonids. This metric evaluates the quantity of LWD in pieces per mile. Although the federal targets for properly functioning are 20 pieces per mile (USFWS 1998), Fox and Bolton (2007) determined that standard was low since larger eastern Washington streams (16 to 164 feet bankfull width) surveyed in unmanaged forested basins had an average of over 40 pieces per mile. In addition, 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 was chosen.

Criteria: Modified from USFWS (1998) and Fox and Bolton (2007)

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Large Woody Debris (LWD)	Pieces per mile at bankfull	>40 pieces/mile >12" dbh > 35' length; and adequate sources of woody debris available for both long- and short-term recruitment.	Current levels meet piece frequency standard for **Adequate**, but lacks potential sources from riparian areas for wood debris recruitment to maintain that standard.	Does not meet standards for **Adequate** and lacks potential large woody material recruitment.

Assessment Results

All of the reaches in the Assessment Area are considered **unacceptable** due to a general lack of LWD. Future LWD recruitment is also limited by insufficient riparian vegetation (see Pathway: Riparian Condition below). The quantity of LWD historically present in the mainstem lower Wenatchee River is uncertain. Previous studies have found that the abundance of instream LWD does decrease with basin area in large rivers as a result increased transport potential. 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).

Table 3. Large Woody Debris Pieces per Mile

Large Woody Debris (LWD)	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Pieces/mile	2.5	0.0	4.7	1.1	0.0	1.4	9.9	2.2	5.4	3.3

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
LWD	Pieces per mile at bankfull	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable

INDICATOR: POOLS – POOL FREQUENCY & QUALITY

Metric Overview

As was done in the Upper Wenatchee Watershed Assessment (Inter-Fluve 2012), the pool frequency and quality metric was adapted for the lower Wenatchee River, due to the difference in channel widths between the lower Wenatchee River and those provided in the NMFS matrix. The largest bankfull channel width provided in the NMFS matrix is 65 to 100 feet, and 4 pools per mile is the standard for this width. Lower Wenatchee River bankfull widths generally exceed the criteria: most of the study length ranged from 102 to 300 feet bankfull width. Only six channel units (totaling less than one mile) spread out among Reaches 3, 4, 6, and 8 had bankfull widths within the NMFS criteria, ranging from 66 to 93 feet bankfull width. Because of this, reaches were primarily evaluated based on the pool quality metrics provided by NMFS (1996) (e.g., depth, substrate, cover, refugia), rather than against a specific threshold number of pools.

Criteria: Adapted from NMFS (1996).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Pools	Pool Frequency and Quality	Pools have good cover and cool water and only minor reduction of pool volume by fine sediment; each reach has many large pools > 1m deep with good cover	Meets pool quality standards, but does not meet LWD standards, so unable to maintain pools over time; reaches have few deep pools (>1m) present with good fish cover	Lacking pools, pool quality is inadequate and there has been a major reduction of pool volume by fine sediment; reaches have no deep pools (> 1m) with good fish cover

Assessment Results

Pool frequency ranged from 0.5 to 3.3 pools/mile, with total pools ranging from 1 to 9 per reach. As described in the Reach Assessment, Reach 1 is effectively one large backwater pool at the confluence with the Columbia River. Reaches 10 and 8 had the next largest proportions of pool habitat, at 63% and 34%, respectively. Reaches 6 and 8 had the greatest number of deep pools with residual depths exceeding 3 feet (n=9 in both reaches). The majority of the pools throughout the lower Wenatchee River were relatively deep, with shallow residual depths (< 3 feet) comprising approximately 17 percent of total pools. All reaches were rated at risk due to not meeting LWD standards and lack of sufficient fish cover (see Section 4 of the Reach Assessment).

Table 4. Pool Characteristics by Reach

Pool Characteristics	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Residual Pool Depth (ft)										
Pools < 3	0%	100%	29%	33%	25%	10%	0%	0%	0%	0%
Pools 3-6	0%	0%	57%	67%	0%	40%	0%	11%	0%	100%
Pools 6-9	100%[1/]	0%	0%	0%	50%	10%	100%	56%	100%	0%
Pools 9-12	0%	0%	0%	0%	25%	10%	0%	33%	0%	0%
Pools >12	0%	0%	14%	0%	0%	33%	0%	0%	0%	0%
Number of pools	1	1	7	9	4	10	2	9	2	1
Pools/mile	1.3	1.2	2.2	1.6	1.7	1.8	0.5	3.3	1.1	3.3

Notes:
[1/] Reach 1 consists of one large backwater pool, with a maximum depth of 7.4 feet. No pool crest depth exists, and therefore residual pool depth is not possible to calculate.

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
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

INDICATOR: OFF-CHANNEL HABITAT

Metric Overview

Off-channel habitats, sloughs, wetlands, oxbow lakes, backwaters, floodplain channels, and blind and flow-through side-channels can provide important rearing habitat for juvenile salmonids (Roni et al. 2002). These areas can provide high-flow refugia, temperature refuge, and protection from predators, as well as productive feeding areas.

Criteria: Modified from USFWS (1998) and USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Off-Channel Habitat	Connectivity with main channel	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	Reach has some ponds, oxbows, backwaters, and other low-energy off-channel areas with cover; but availability or access is less than what would be expected in the absence of human disturbance	Reach has few or no ponds, oxbows, backwaters, or other off-channel areas relative to what would be expected in the absence of human disturbance.

Assessment Results

The lower Wenatchee River generally lacks adequate off-channel habitat. Reaches 2 and 4 through 7 are all considered **unacceptable** due to limited side-channels and other off-channel areas. In Reaches 1, 3, and 9, the abundance of off-channel habitat is considered **at risk**, with some off-channel habitat present (more in Reaches 1 and 9) but less than would be expected prior to human development. Reach 1 has relatively abundant off-channel habitat in the distributary channels on the left bank but this is still less than expected in the absence of human disturbance because the distributary channels on the right bank have been disconnected due to human alterations. Reaches 8 and 10 are rated **adequate** for this indicator because they are naturally confined and would not be expected to have off-channel habitat in the absence of human disturbance.

Table 5. Channel Type Distribution

Channel Type	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Main Channel	33%	100%	70%	85%	100%	91%	92%	100%	50%	100%
Side Channel (fast)	0%	0%	5%	11%	0%	9%	8%	0%	5%	0%
Side Channel (slow)	67%	0%	25%	4%	0%	0%	0%	0%	45%	0%

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Off-Channel Habitat	Connectivity with main channel	at risk	unacceptable	at risk	unacceptable	unacceptable	unacceptable	unacceptable	adequate[1/]	at risk	adequate[1/]

[1/] The abundance of off-channel habitat is considered adequate in Reach 8 and Reach 10 because it is similar to what would be expected in the absence of human disturbance due to being naturally confined.

5. PATHWAY: CHANNEL FORMS & PROCESSES

INDICATOR: CHANNEL DYNAMICS – FLOODPLAIN CONNECTIVITY

Metric Overview

Floodplains serve a number of significant geomorphic and ecological functions including conveyance of flood waters, sediment source and storage, supply of large wood, and development of diverse habitat for aquatic and terrestrial species (e.g., Allen 1970; Zwolinski 1992; Nanson and Croke 1992). Floodplain connectivity was evaluated based on the results from the hydraulic modeling, floodplain inundation and geomorphic mapping. For this analysis, the floodplain was divided into connected and disconnected floodplain to determine a percent disconnected. The connected floodplain was that would be inundated with over-bank flows under a 100-year flood. The disconnected floodplain 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.

Criteria: Modified from USFWS (1998).

Pathway	**General Indicators**	**Specific Indicators**	**Adequate**	**At Risk**	**Unacceptable**
Channel	Dynamics	Floodplain Connectivity	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession	Reduced linkage of wetlands, floodplains, and riparian areas to main channel; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of wetland function, riparian vegetation/succession	Severe reduction in hydrologic connectivity between off-channel wetland, floodplain, and riparian areas; wetland extent drastically reduced and riparian vegetation/succession altered significantly

Assessment Results

In Reaches 2 and 7 through 10, floodplain connectivity is considered **adequate**. However, Reaches 2, 7, 8, and 10 are also naturally confined by the topography and have limited floodplains available. Reaches 3 through 6 are considered **at risk** due to more substantial alteration to geomorphic conditions that limit connectivity. Reach 1 is rated **unacceptable** with respect to floodplain connectivity due to the right bank floodplain and distributary channels being disconnected due to human alterations.

Table 6. Percent Disconnected Floodplain

Floodplain Connectivity	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Percent Disconnected	87%	4%[1/]	43%	66%	54%	62%	9%[1/]	0%[1/]	13%	7%[1/]

[1/] Reaches 2, 7, 8, and 10 are naturally confined by topography and have limited functional floodplains.

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Channel Dynamics	Floodplain connectivity	unacceptable	adequate	at risk	at risk	at risk	at risk	adequate	adequate	adequate	adequate

INDICATOR: BANK STABILITY/CHANNEL MIGRATION

Metric Overview

Channel migration and bank erosion are natural processes that maintain river habitats by recruiting substrate, LWD, and introduction of new channel dynamics. Low gradient alluvial channels, such as much of the lower Wenatchee River, adjust laterally via bank erosion and channel avulsions (rapid shifting of channel location). Natural channel migration rates are a result of numerous physical and biological processes including hydrologic regime, underlying geology, sediment supply, streambank vegetation, and floodplain hydraulic roughness. Human actions can affect these processes, which subsequently can alter channel migration rates and erosion locations. Bank armoring, levee construction, and channelization restrict flow to generally more straightened paths as well as limiting where erosion can occur; water withdrawals and dams can alter the hydrologic regime, affecting when and how much water interacts with the channel margins; and changes in riparian vegetation such as removal of streambank vegetation and development within the floodplain can affect erosion rates and how a river interacts with the channel margins.

Criteria: From USBR (2012)

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Channel	Dynamics	Bank Stability/ Channel Migration	Channel is migrating at or near natural rates.	Limited amount of channel migration is occurring at a faster/slower rate relative to natural rates, but significant change in channel width or planform is not detectable; large woody debris is still being recruited.	Little or no channel migration is occurring because of human actions preventing reworking of the floodplain and large woody debris recruitment; or channel migration is occurring at an accelerated rate such that channel width has a least doubled, possibly resulting in a channel planform change, and sediment supply has noticeably increased from bank erosion.

Assessment Results

Overall, the lower Wenatchee River has not shifted substantially over the past 100 years. An analysis of historical data from the 1884 General Land Office (GLO) survey maps (BLM 2015) and the 1911 plan and profile surveys of the Wenatchee River conducted by the USGS (USGS 1914) indicates that only two locations in the lower Wenatchee River have shifted and/or straightened significantly compared to earlier conditions: between approximately RM 2 and 5 in Reach 3, and at approximately RM 10 in Reach 4, near Cashmere. Chelan County’s Channel

Migration Zone Study Phase II also found that the lower Wenatchee River is a relatively stable system (Jones & Stokes 2004). In isolated areas however (e.g., RM 2.2 in Reach 3), channel migration rates of as high as 15 feet per year were observed from 2007 to 2013. In addition, downcutting of the channel leading to partially incised or entrenched in many areas is considered primarily a result of post-glacial downcutting through glacial fluvial deposits (Jones & Stokes 2004). Therefore, it is possible the limited channel migration may be at or near natural rates in many areas.

However, there has been significant human alteration and armoring of streambanks that has reduced the ability of the river to migrate laterally. Bank armoring in the form of riprap, concrete walls, concrete stairways, bridge abutments, and levees were mapped as part of the geomorphic assessment. The total length of bank armoring was calculated as a percentage of reach length (Table 7). This does not include areas of channel upstream and downstream of bridges where channel migration might be affected by the bridge. Reaches with greater degrees of bank armoring were considered more impaired than those with less armoring. For this analysis, reaches with <5% armoring were assumed **adequate**, 5-10% **at risk**, and >10% **unacceptable**. Data for eroding banks are also presented in Table 7 for reference; overall, bank erosion is not a major concern in most of the lower Wenatchee River.

Table 7. Bank Characteristics by Reach

Bank Characteristics	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Armored Banks	13.6%	0.0%	13.6%	27.1%	17.8%	10.1%	5.7%	0.5%	0.6%	16.0%
Eroding Banks	0.0%	0.0%	4.3%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Channel Dynamics	Bank stability/Channel Migration	unacceptable	adequate	unacceptable	unacceptable	unacceptable	unacceptable	at risk	adequate	adequate	unacceptable

INDICATOR: VERTICAL CHANNEL STABILITY

Metric Overview

Under natural conditions, alluvial river systems tend towards a balanced state in which some erosion and deposition occurs during sediment transporting events but no net change in dimension, pattern and profile over the course of years. These systems are frequently referred to as regime channels and are in a state of dynamic equilibrium in which there is a continuous inflow and output water and sediment. Changes in the conditions including sediment supply, channel form modification, flow, or bank strength can upset the balance leading to higher rates and a trend of aggradation or incision. This can result in or disconnection from the floodplain due to incision. Channel form modification can be the result of human actions including bank armoring, removal of riparian vegetation, levee building, channel straightening, and channelization which can reduce vertical channel stability.

Criteria: From USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Channel	Dynamics	Vertical Channel Stability	No measurable trend of aggradation or incision and no visible change in channel planform.	Measurable trend of aggradation or incision that has the potential to but not yet caused disconnection of the floodplain or a visible change in channel planform (e.g., single thread to braided).	Enough incision that the floodplain and off-channel habitat areas have been disconnected; or, enough aggradation that a visible change in channel planform has occurred (e.g., single thread to braided).

Assessment Results

Reaches 1 is considered adequate because in the absence of changes to Rock Island Dam and reservoir, it is vertically stable. Reaches 7 through 10 are considered **adequate** because post-glacial incision has cut to bedrock grade controls limiting further incision. Reaches 2 and 6 are considered **at risk** because there is observed channel incision but it has not lead to considerable floodplain disconnection. Reaches 3 through 5 are considered **unacceptable** due to significant incision causing floodplain and off-channel habitat areas to be disconnected most flows. However, Reach 5 does have frequent exposed bedrock grade controls which may limit further incision.

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Channel Dynamics	Vertical channel stability	adequate	at risk	unacceptable	unacceptable	unacceptable	at risk	adequate	adequate	adequate	adequate

6. PATHWAY: RIPARIAN CONDITION

INDICATOR: STRUCTURE

Metric Overview

Riparian areas have many important geomorphic and ecological roles within the river system. Intact riparian corridors help maintain streambank stability, provide large wood material, water filtration processes, organic input, streamside habitat and cover, hydraulic regulation, and temperature fluctuation modification (Gregory et al. 1991). The structure of riparian areas indicates how intact the riparian system is currently. This metric is evaluated based on how well the seral stage, species composition, and complexity approximate natural conditions that would be expected in the absence of human alterations.

Criteria: From USBR (2012).

Pathway	**General Indicators**	**Specific Indicators**	**Adequate**	**At Risk**	**Unacceptable**
Riparian Vegetation	Condition	Structure	>80% species composition, seral stage, and structural complexity are consistent with potential native community.	50-80% species composition, seral stage, and structural complexity are consistent with potential native community.	<50% species composition, seral stage, and structural complexity are consistent with potential native community.

Assessment Results

Overall, riparian vegetation along the lower Wenatchee River is sparse. There are not many trees (see Indicator: Canopy Cover below), and of those present, minimal large trees only in Reaches 7, 8, and 10 (Table 8). Hardwood species are most common throughout the lower Wenatchee River, with relatively greater conifer concentrations in Reaches 7 and 8. Except for Reaches 8 and 10, all reaches are considered **unacceptable** with respect to riparian structure due to the lack of structural complexity and vegetation presence that would have occurred in the absence of human disturbance. In Reaches 8 and 10, the riparian zone is naturally limited by steep hillslopes; however, these reaches are still considered **at risk** due to reduced size class diversity.

Table 8. Channel Unit Riparian Vegetation Diameter Class Distribution

Dominant Riparian Vegetation Diameter Class (inches dbh)	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Shrub/Seeding (1.0 to 4.9)	0%	0%	4%	0%	0%	4%	0%	0%	0%	0%
Sapling/Pole (5.0 to 8.9)	100%	71%	44%	43%	18%	30%	0%	5%	0%	0%
Small Trees (9.0 to 20.9)	0%	29%	52%	57%	82%	67%	75%	52%	100%	50%
Large Trees (21 to 31.9)	0%	0%	0%	0%	0%	0%	25%	43%	0%	50%

Note: Table values represent the percentage of channel units within each reach by dominant vegetation diameter class (e.g., for Reach 2, in 71% of the surveyed channel units sapling/pole was the dominant riparian vegetation diameter class, and in 29% of channel units small trees were the dominant vegetation diameter class). Size classes were estimated for vegetation stands present, regardless of the portion of the riparian area vegetated; bare ground/developed area is not accounted for in this table.

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Riparian	Structure	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	at risk	unacceptable	at risk

INDICATOR: DISTURBANCE (HUMAN)

Metric Overview

Human disturbance changes how a river interacts with its floodplain and riparian areas. Often human disturbance in the floodplain results in reduced occurrence of mature seral stages of vegetation and riparian structure, and limits channel migration and erosion processes. This can affect riparian processes including bank stability, wood recruitment, shade, and water quality. Riparian disturbance was assessed using information from the habitat assessment (Appendix A) and an analysis of development and road densities within the 100-year floodplain. Road density was calculated based on the Chelan County Conservation District's road layer, clipped to the 100-year floodplain and divided into the Project reaches.

Criteria: From USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Riparian Vegetation	Condition	Disturbance (human)	>80% mature trees (medium-large) in the riparian buffer zone (defined as a 30 m belt along each bank) that are available for recruitment by the river via channel migration; <20% disturbance in the floodplain (e.g., agriculture, residential, roads, etc.); <2 mi/mi^2 road density in the floodplain.	50-80% mature trees (medium-large) in the riparian buffer zone (defined as a 30 m belt along each bank) that are available for recruitment by the river via channel migration; 20-50% disturbance in the floodplain (e.g., agriculture, residential, roads, etc.); 2-3 mi/mi^2 road density in the floodplain.	<50% mature trees (medium-large) in the riparian buffer zone (defined as a 30 m belt along each bank) that are available for recruitment by the river via channel migration; >50% disturbance in the floodplain (e.g., agriculture, residential, roads, etc.); >3 mi/mi^2 road density in the floodplain.

Assessment Results

As discussed above, sufficient mature trees are lacking throughout the lower Wenatchee River. Based on that aspect of the above criteria, all reaches would be considered unacceptable. Taking into account the current percent of development (land cover category) and road density (Table 9), Reaches 4 through 6 are considered **unacceptable**. The remaining reaches are rated **at risk** due to lower levels of development and road construction within the 100-year floodplain. This floodplain definition may delineate a smaller area of land than considered by other previous research of human impact on the Wenatchee River floodplain; in one case study, researchers found that as of 1949 about 55% of the Wenatchee River floodplain had been converted to agriculture, and by 2006, an overall 62% had been modified by development (of which 20% was urban) (Tomlinson et al. 2011). This context affirms that the "at risk" reaches should still be considered substantially impacted by human disturbance.

Table 9. Development and Road Density in 100-year Floodplain

Floodplain Disturbance	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Percent developed	20%	2%	32%	62%	50%	23%	13%	11%	16%	32%
Road density (mi/mi^2)	0	0.9	3.3	8.4	8.0	4.4	0.5	0.3	0.9	3.1

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Riparian	Disturbance (human)	at risk	at risk	at risk	unacceptable	unacceptable	unacceptable	at risk	at risk	at risk	at risk

INDICATOR: CANOPY COVER

Metric Overview

Riparian canopies provide shade and moderate light availability and quality to the stream and riverbed. This affects water temperature and algae growth. Water temperature is a main driver of the health, productivity, and life cycles of many aquatic organisms, including salmonids. High water temperatures during the summer and fall can often be a factor limiting habitat quality for rearing and spawning salmonids.

Criteria: Modified from USFWS (1998) and USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Riparian	Condition	Canopy Cover	Trees and shrubs within one site potential tree height distance have >80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have 50-80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have <50% canopy cover that provides thermal shading to the river.

Assessment Results

The percentage canopy cover is based on the extent of canopy closure within riparian areas (100-foot buffer approximating one site potential tree height), not the percentage of the stream that is covered. Canopy cover within 100 feet of the stream bank was estimated using the most current NLCD land cover dataset, using the forested land cover class. Canopy cover is rated unacceptable throughout all reaches. Percent canopy cover ranged from 1% in Reach 6 to 13 percent in Reach 1, all far below the “adequate” target of >80 percent.

Table 10. Canopy Cover Percentage within 100 Feet of Stream Bank

Canopy Cover	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Percent coverage	13%	6.5%	4.6%	12.7%	4.7%	1.0%	5.0%	3.2%	7.3%	1.2%

REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10
Riparian	Canopy cover	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable

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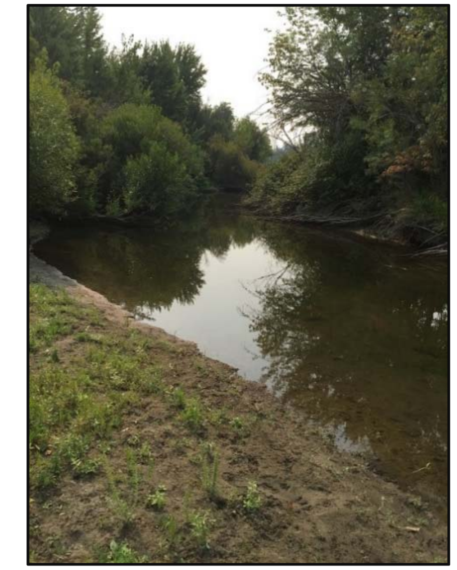
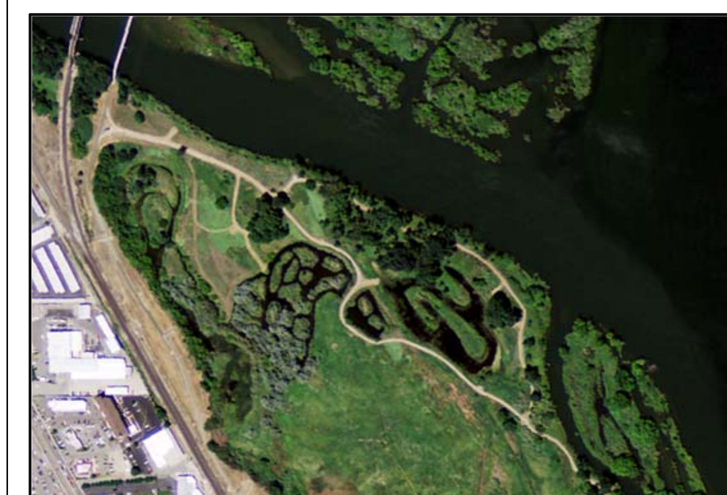
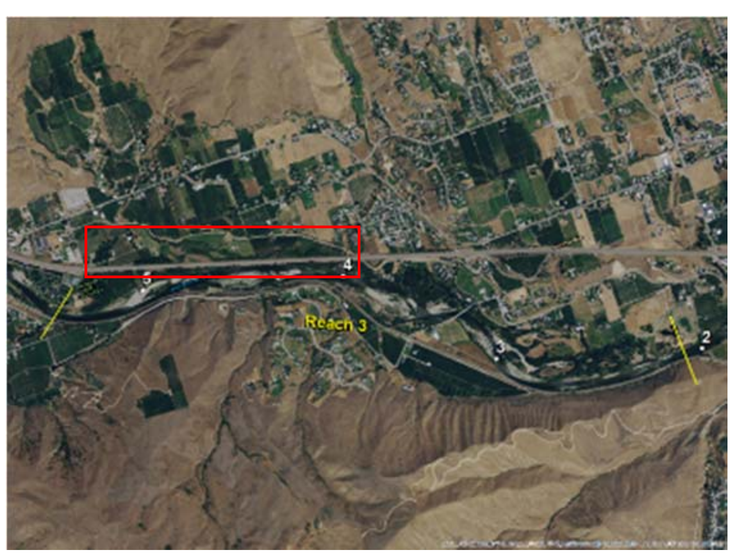
APPENDIX E

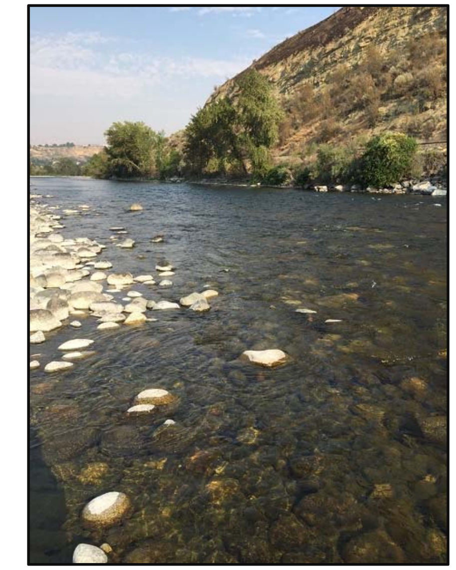
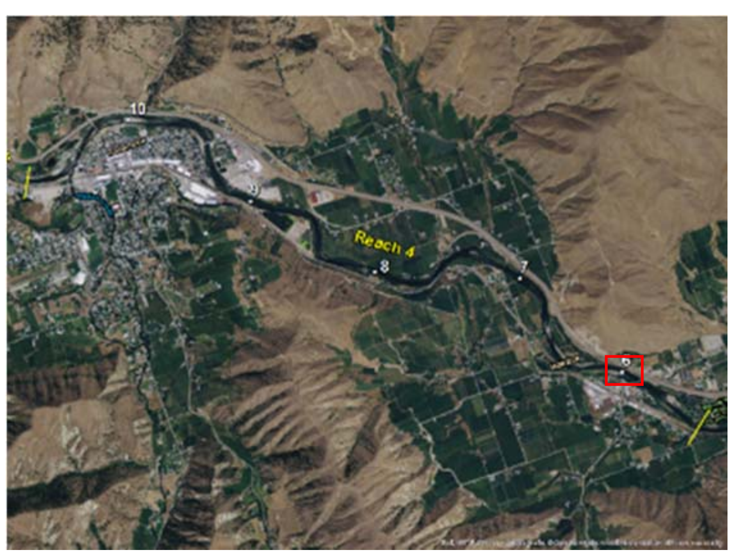
Potential Project Opportunities

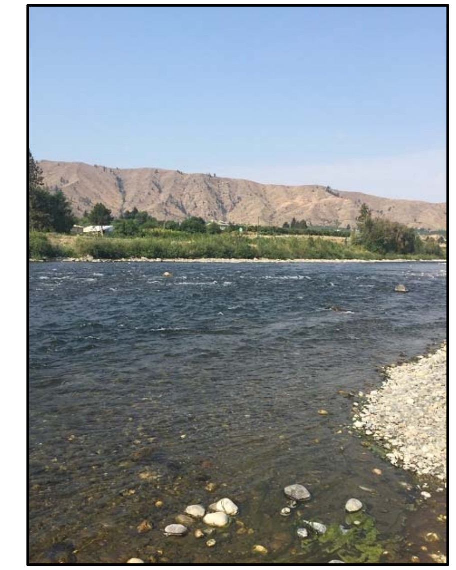
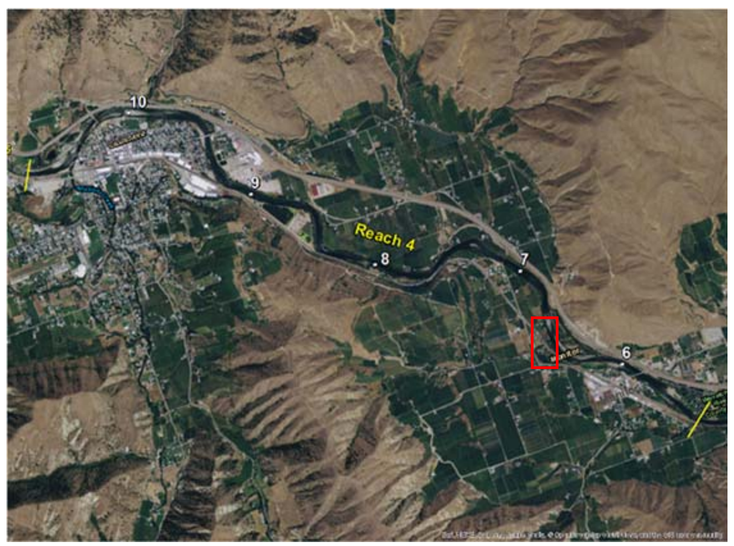
Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 1		RM 0.8 Left Bank	Install Habitat Structures	1 – Land Protection 20 – LWD Placements	Existing distributary channels lack complex instream habitat and cover. Install large wood habitat structures in distributary channels to create habitat complexity and cover; protect property to maintain existing connectivity. Access to channels for large wood placement may be problematic.	28	
		RM 0.8 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 14 – Beaver Re-introduction 16 – Bank Shaping and Stabilization 17 – Remove Bank Armoring 18 – Bank Bioengineering 20 – LWD Placement 24 – Floodplain Restoration 25 – Floodplain Benching 28 – Secondary Channel 31 – Alcove	Existing distributary channels are disconnected from mainstem, floodplain is perched. Evidence of past restoration efforts, but did not reconnect to mainstem. Reconnection of historic distributary channels and disconnected floodplain, with added large wood structures will provide added instream habitat. Modification of existing trails and install water crossing structure.	11	
Reach 2		RM 1.9 Left Bank	Floodplain Habitat Reconnection	1 – Protection 12 – Riparian Buffering 20 – LWD Placements 31 - Alcove	There is a small existing alcove located on the outside bend, providing limited habitat. Floodplain upstream can be graded to increase the size of the existing backwater alcove. Install large wood habitat structures to create habitat complexity and cover; plant native vegetation.	23	

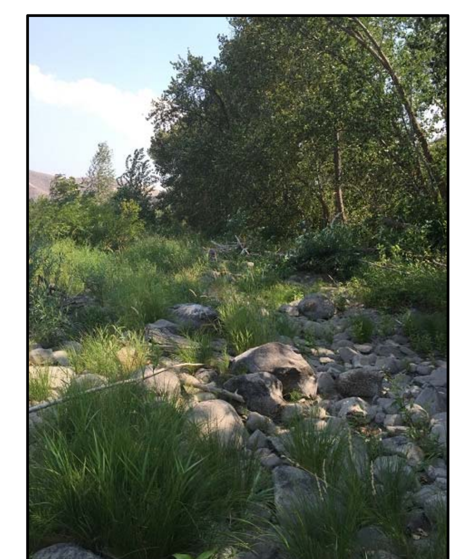
Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 2		RM 2.0 Left Bank	Tributary Restoration	1 – Protection 12 – Riparian Buffer Strip 15 – Riparian Fencing 20 – LWD Placement 24 – Floodplain Restoration 34 – Pool Construction 35 – Riffle Construction 37 – Channel reconstruction	Existing irrigation ditch (Highline Ditch return) currently functions as a cold water return source. Confluence is connected at summer low flows, so channel is perennially accessible. Realignment of this channel, with construction of pools and large wood structures will significantly increase rearing capacity along with shading via native vegetation planting.	9	
Reach 3		RM 2.2 to 3.0 Left Bank	Floodplain Habitat Reconnection	1 – Protection 12 – Riparian Buffer 18 – Bank Bioengineering 20 – LWD Placements 24 – Floodplain Restoration 26 – Thermal Refugia 27 – Perennial Side Channel 28 – Secondary Channel 32 – Hyporheic Off-Channel 36 – Meander Re-connect	Existing side channels with existing cover and decent instream habitat are cut off from main channel. Evidence of past restoration efforts at downstream end of floodplain. Excavation of inlet and ELJ to control inlet flows. Reconnecting side channels and installing large wood structures will increase available rearing habitat. Purchase for future protection.	1	
		RM 3.0 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placements 24 – Floodplain Restoration 31 – Alcove	Proposed backwater alcove area is currently accessed at the 2-yr flood event. Would require minimal excavation to activate perennially. Would require excavation or large wood placement upstream to encourage perennial flows to utilize the low floodplain topography. Plant native vegetation.	19	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 3		RM 3.3 Right Bank	Enhance Existing Bank Protection	18 – Bank Bioengineering 20 – LWD placement	Existing groins provide bank stability, but only minimal habitat benefit to river. Additions of large wood and ELJ would create local habitat complexity and cover. Large wood additions provide opportunity to create local scour pools.	30	
		RM 3.8 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placement 24 – Floodplain Restoration 27 – Perennial Side Channel 28 – Secondary Channel 31 – Alcove	Downstream section of existing side channel has very good habitat complexity and cover, while upstream section is lacking. No defined inlet to side channel, will require large amount of excavation to initiate side channel, ELJ to control inlet flows and large wood for habitat complexity and cover. Plant native vegetation. Upstream section is in close proximity to railroad.	14	
		RM 4.0 Left Bank (CMZ 6)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 20 – LWD Placements 25 – Floodplain Excavation 27 – Perennial Side Channel	Existing side channel has decent habitat and cover, but is not accessed perennially. Large sediment loads are deposited at inlet of side channel. Excavate to initiate side channel with realignment of inlet could improve function of side channel sediment flushing flows and increase temporal use.	24	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 3		RM 4.5 Left Bank	Enhance Existing Bank Protection	18 – Bank Bioengineering 19 – Boulder Placements 20 – LWD Placements	Existing groins provide some bank protection but minimal habitat benefit to river. Additions of large wood would create local habitat complexity and cover. Large wood additions provide opportunity to create local scour pools.	31	
		RM 4.8 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placements 24 – Floodplain Restoration 28 – Secondary Channel 31 – Alcove	Existing backwater alcove is functioning properly. Expand this alcove to provide increased backwater and low floodplain habitat. Alcove is fed by hyporheic flows, no need to excavate inlet to channel. Install large wood habitat structures to create habitat complexity and cover; plant native vegetation	16	
		RM 4.0 to 5.2 Left Bank	Floodplain Habitat Reconnection	1 – Land Protection 6 – Road Grading 12 – Riparian Buffer 20 – LWD Placement 23 – Relocate Floodplain Infrastructure 24 – Floodplain Restoration 27 – Perennial Side Channel 28 – Secondary Channel 32 – Hyporheic Off-Channel 36 – Meander Re-connect 39 – Barrier removal	Large portion of floodplain cut off by U.S. Highway 2. Reconnection of this section would greatly increase habitat availability. Evaluate several alternatives for reconnection or groundwater infiltration projects. Bridges or realignment of the highway may be considered.	2	

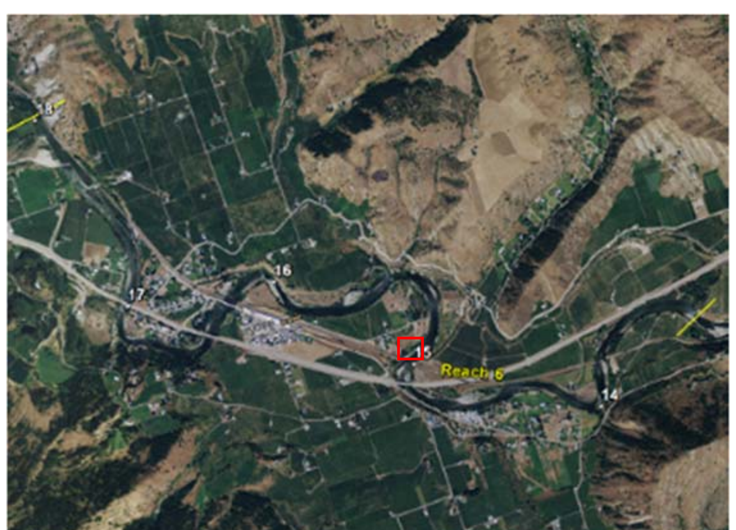
Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 3		RM 5.0 to 5.3 Right Bank	Enhance Existing Bank Protection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placement 24 – Floodplain Restoration 26 – Thermal Refugia 27 – Perennial Side Channel 32 – Hyporheic Off-Channel (groundwater)	Existing groins provide some bank protection but minimal habitat benefit to river. Additions of large wood would create local habitat complexity and cover. ELJ additions provide opportunity to create local scour pools.	37	
Reach 3		RM 5.2 Left Bank	Floodplain Habitat Reconnection	18 – Bank Bioengineering 19 – Boulder Placement	Existing side channel has good habitat complexity and cover but is cut off from main channel flows. High flood events may access channel, but existing habitat is not being used perennially. Excavation of an inlet for base flows to the side channel would increase surface flows and habitat complexity.	13	
Reach 4		RM 6.0 Left Bank	Enhance Existing Bank Protection	18 – Bank Bioengineering 19 – Boulder Placement	Existing groins provide some bank protection but minimal habitat benefit to river. Additions of large wood would create local habitat complexity and cover. Large wood additions provide opportunity to create local scour pools.	38	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 4		RM 6.2 Mid-channel	Install Habitat Structures	19 – Boulder Placement	This section of river is lacking instream habitat complexity. Addition of mid-channel boulder clusters would create local scour pools and increase the instream habitat complexity in areas where hydraulics characteristics are suitable.	33	
Reach 4		RM 6.5 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placement 24 – Floodplain Restoration 31 – Alcove 32 – Hyporheic Off-channel (groundwater)	Floodplain and off-channel habitat is currently cut off from the main river by the railroad. Low topography in the vicinity can be converted to groundwater galleries, or larger project to create backwater alcove. Evaluate potential for directing groundwater to off-channel areas. Purchase floodplain properties.	18	
Reach 4		RM 6.5 Left Bank (Pioneer Side Channel)	Install Habitat Structures (Modify Existing Restoration Site)	1 – Land Protection 12 – Riparian Buffer 20 –LWD Placement 27 – Perennial Side Channel 34 – Pool Construction 35 – Riffle Construction	Existing side channel functions hydraulically but lacks complex habitat and cover. Possible alternate project is to reshape channel and create complex pool habitat that are not currently present in side channel.	7	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 4		RM 6.9 Mid-channel	Install Habitat Structures	19 – Boulder Placements	This section of river is lacking instream habitat complexity. Addition of mid-channel boulder clusters would create local scour pools and increase the instream habitat complexity in areas where hydraulics characteristics are suitable.	34	
		RM 7.9 Mid-channel	Install Habitat Structures	19 – Boulder Placements	This section of river is lacking instream habitat complexity. Addition of mid-channel boulder clusters would create local scour pools and increase the instream habitat complexity in areas where hydraulics characteristics are suitable.	35	
		RM 8.1 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placement 23 – Relocate Floodplain Infrastructure 24 – Floodplain Restoration	Historic side channel has been altered by man-made construction. Purchase property in floodplain. Reconnection would require some excavation to remove fill and structures, and to recreate full extent of side channel. Existing side channel would provide added habitat and cover. Install ELJ for inlet flows and large wood to create habitat complexity and cover; plant native vegetation.	26	

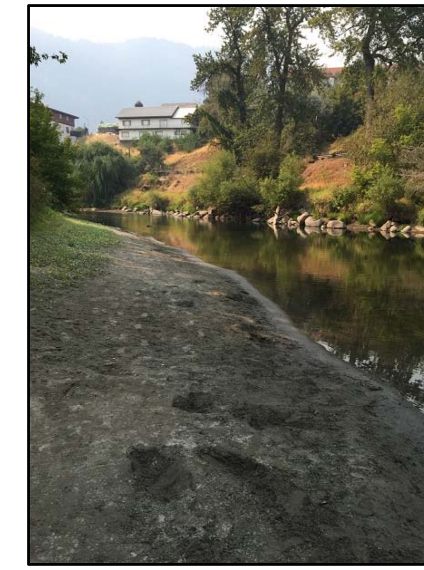
Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 4		RM 8.6 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 3 – Mitigate Point Source Impacts 12 – Riparian Buffer 20 – LWD Placement 23 – Relocate Floodplain Infrastructure 24 – Floodplain Restoration 27 – Perennial Side Channel 28 – Secondary Channel 31 – Alcove 37 – Channel Reconstruction	Creating a large floodplain by relocating the treatment facility would provide much needed habitat complexity in a section of river that lacks both habitat and cover. Creation of the floodplain would require large amounts of excavation, large wood structures. Conduct soil and site remediation. Reconstruct floodplain habitats.	10	
		RM 9.0 Mid-channel	Install Habitat Structures	19 – Boulder Placements	This section of river is lacking instream habitat complexity. Addition of mid-channel boulder clusters would create local scour pools and increase the instream habitat complexity in areas where hydraulics characteristics are suitable.	36	
		RM 9.2 to 10.7 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 3 – Mitigate Point Source Impacts 12 – Riparian Buffer 20 – LWD Placement 22 – Levee Modification 23 – Relocate Floodplain Infrastructure 24 – Floodplain Restoration 27 – Perennial Side Channel 28 – Secondary Channel 31 – Alcove 37 – Channel Reconstruction	Modification of the existing levee would give access to historic floodplain to reestablish historic meander pattern. This opportunity has many potential constraints and would require levee modifications, including the potential for a setback levee, and the relocation of homes and businesses.	4	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 5		RM 12.0 Left Bank	Floodplain Habitat Reconnection	1 – Land Protection 20 – LWD Placement 22 – Levee Modification 24 – Floodplain Restoration 27 – Perennial Side Channel 28 – Secondary Channel 32 – Hyporheic Off-channel (groundwater)	Existing side channel has good habitat and cover, but is cut off from base flows. Lots of existing large wood in side channel. Excavate to initiate side channel for perennial flows, add large wood structures to enhance existing habitat. Would require excavation and removal of large log jam at inlet of side channel.	25	
Reach 6		RM 13.3 Left Bank (CMZ 11)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 20 – LWD Placement 21 – Weir for Grade Control 27 – Perennial Side Channel 31 – Alcove	Existing side channel functions but lacks complex habitat and cover. Possible alternate project is to reshape channel and create complex pool habitat that are not currently present in side channel. Install ELJ and grade control structure to control inlet flows.	22	
		RM 13.8 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 20 – LWD Placement 23 – Relocate Floodplain Infrastructure 24 – Floodplain Restoration 27 – Perennial Side Channel 28 – Secondary Channel 31 – Alcove 37 – Channel Reconstruction	Floodplain is dissected by railroad. Complete reconnection would require construction of bridges for BNSF Railway. Large excavation to reconnect floodplain and off-channel habitats at lower flood events. Purchase floodplain properties.	3	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 6		RM 14.4 Right Bank	Enhance Existing Bank Protection	20 – LWD Placements	Existing groins provide some bank protection but minimal habitat benefit to river. Additions of large wood would create local habitat complexity and cover. ELJ and large wood additions provide opportunity to create local scour pools.	32	
		RM 14.6 Left Bank (CMZ 12 and 13)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 20 – LWD Placement 21 – Grade Control Weirs 27 – Perennial Side Channel 30 – Wetland 31 – Alcove	Existing side channel has good habitat complexity and cover but is cut off from main channel flows. High flood events may access channel, but existing habitat is not being used perennially. Excavation of an inlet for base flows to the side channel would increase habitat complexity and provide sediment flushing flows. Increase hydraulic connectivity of CMZ 12 and 13.	17	
		RM 15.0 Right Bank	Floodplain Habitat Reconnection	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placement 26 – Thermal Refugia 27 – Perennial Side Channel 31 – Alcove 32 – Hyporheic Off-Channel (groundwater)	Utilizing existing groundwater spring location to create perennial backwater alcove would provide cold water recharge and rearing habitat. Install large wood structures to protect inlet of alcove and to create habitat complexity and cover. Plant native vegetation.	20	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 6		RM 15.3 Right Bank (Dryden Fish Enhancement Project)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 14 – Beaver Re-introduction 18 – Bank Bioengineering 20 – LWD Placement 22 – Levee Modification 24 – Floodplain Restoration 28 – Secondary Channel 38 – Structural Passage	Existing pond upstream of confluence has good habitat and cover, but fish access is restricted by a levee and beaver dam. Partial removal of levee would provide perennial access to past restoration efforts.	15	
		RM 18.0 Right Bank	Tributary Restoration	1 – Land Protection 7 – Road Decomissioning 12 – Riparian Buffer 20 – LWD Placement 24 – Floodplain Restoration 34 – Pool Construction 35 – Riffle Construction 37 – Channel Reconstruction	Historic channel is dissected in two locations by access road. Reacquisition of historic channel would require relocation of access road. Large wood structures would increase habitat complexity and cover in historic channel. Plant native vegetation.	6	
Reach 7		RM 18.4 Left Bank	Install Habitat Structures	1 – Land Protection 20 – LWD Placement	Existing side channels function properly, but lack complex habitat and cover. Installing large wood structures would increase habitat complexity and cover. Would require large wood structures, as side channel takes a large portion of storm flows.	29	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
		RM 20.5 Left Bank	Remove Instream Structures	23 – Relocate Floodplain Infrastructure	Left bank structure removal to enhance aesthetics of river in this area and increase un-interrupted flood capacity.	39	
Reach 9		RM 24.4 Right Bank (CMZ 19A – Boat Launch)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 20 – LWD Placement 24 – Floodplain Restoration 28 – Secondary Channel 31 – Alcove	Existing backwater alcove lacks complex habitat and cover. Install large wood structures to increase habitat and cover. Excavate outlet of channel to provide perennial access. Opportunity to excavate an inlet to alcove.	12	
Reach 9		RM 24.5 Right Bank (CMZ 19)	Install Habitat Structures	1 – Land Protection 20 – LWD Placement	Existing side channels function properly, but lack complex habitat and cover. Installing large wood structures would increase habitat complexity and cover. Would require large wood structures, as side channel takes a large portion of storm flows. Infrastructure downstream should be considered when designing large wood structures. Plant native vegetation.	21	

Geomorphic Reach	Project Opportunity Location	Name	Action Type	Potential Restoration Actions	Description and Rationale	Rank	Photo/Imagery
Reach 9		RM 24.5 Left Bank (Blackbird Island)	Install Habitat Structures	1 – Land Protection 20 – LWD Placement	There is evidence of large wood under streambed creating grade controls. Lack of complex instream habitat in side channel. Existing scour at bridges. Install large wood structures that consider recreational boater safety and to create scour pools, instream habitat and cover. Restore and protect existing bridge abutments. Opportunity to reshape channel to create complex habitat.	27	
		RM 24.7 Left Bank (ICTU Blackbird Island)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 20 – LWD Placement 23 – Relocate Floodplain Infrastructure 24 – Floodplain Restoration 27 – Perennial Side Channel 39 – Barrier Removal	Outlet to channel is blocked by apparent beaver activity. Excavate to widen the existing outlet channel to preserve the woody debris and cover while providing perennial fish access to channel. Evaluate alternates to excavate an upstream inlet to create surface flow connectivity.	8	
Reach 9		RM 25.0 to 25.6 Right Bank (CMZ 20)	Floodplain Habitat Reconnection (Modify Existing Restoration Site)	1 – Land Protection 12 – Riparian Buffer 20 – LWD Placement 27 – Perennial Side Channel 28 – Secondary Channel 32 – Hyporheic Off-Channel (groundwater)	Existing side channels have good habitat and cover, but entire channel is clogged with fine sediment. Excavate inlet of side channels to provide perennial flows in side channels, install large wood structures to increase habitat complexity and cover, and create local scour pools. Opportunity to redirect Icicle Creek into side channels.	5	

APPENDIX F

Project Opportunities Geodatabase

(provided on DVD)

This appendix is provided separately.

APPENDIX G

Project Opportunities Prioritization Matrix

(provided on DVD)

This appendix is provided separately.