UPPER WENATCHEE RIVER

STREAM CORRIDOR ASSESSMENT AND HABITAT RESTORATION STRATEGY

YAKAMA NATION FISHERIES | PO BOX 15, FORT ROAD | TOPPENISH, WA 98948

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Image credit:

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1 INTRODUCTION

1.1 Overview

This Reach Assessment evaluates aquatic habitat and watershed process conditions in the Upper Wenatchee River and identifies habitat restoration strategies. The assessment area is the mainstem Wenatchee River corridor from Lake Wenatchee to Tumwater Canyon (River Mile 35.5 to River Mile 54.5). This Reach Assessment provides the technical foundation for understanding existing conditions and for identifying restoration strategies and specific opportunities. This assessment evaluates conditions at the valley- and reach-scales and ensures that restoration actions address key factors limiting the productivity of aquatic species as well as fit within the appropriate geomorphic context of the system.

Restoration strategies were developed by comparing existing aquatic habitat conditions to target conditions obtained from reference areas and regional habitat thresholds. In areas where existing conditions were found to be deficient, restoration strategies and specific action types have been identified to restore degraded conditions.

Although restoration measures are expected to benefit numerous different aquatic and terrestrial species, there is a particular emphasis on restoration measures for recovery of Endangered Species Act (ESA) listed salmonids, including spring Chinook salmon (*Oncorhynchus tshawytscha*) and summer steelhead (*Oncorhynchus mykiss)*.

This report includes the following primary components:

- Study area characterization – Evaluation of valley- and basin-scale factors influencing aquatic habitat and stream geomorphic processes
- Reach-scale characterization – Inventory and analysis of habitat and geomorphic conditions at the reach and sub-reach scales
- Stream habitat assessment – Aquatic habitat inventory at the reach-scale
- Reach-Based Ecosystem Indicators (REI) analysis – Comparison of habitat conditions to established functional thresholds
- Restoration strategy – Includes a comparison of existing conditions to target conditions and identification of recommended reach-scale restoration measures
- Specific project opportunities – A list of specific potential project opportunities and areas that would help to accomplish the reach-scale restoration strategies.

2 BACKGROUND

This effort is being conducted as part of the Yakama Nation's Upper Columbia Habitat Restoration Program (UCHRP), which implements projects to recover habitat for ESA-listed salmon and steelhead in the Upper Columbia region. Restoration efforts by the

UCHRP work to achieve the objectives of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (Recovery Plan, UCSRB 2007) and the associated Biological Strategy (UCRRT 2008). This effort has been conducted with input and coordination from multiple entities, including the Regional Recovery Team (RTT), US Forest Service, and the Wenatchee Habitat Subcommittee.

This assessment builds off of a large body of work produced in the basin beginning in the late 1990s and proceeding throughout the 2000s. Assessment and analysis work to date has included water use reports, instream flow reports, physical assessments, biological assessments, and restoration recommendations for portions of the Wenatchee River mainstem and the majority of its tributaries. In contrast to previous assessments, this effort provides a comprehensive reach-scale analysis of the Upper Wenatchee between Lake Wenatchee and Tumwater Canyon, and identifies specific restoration strategies and actions that address identified limiting factors.

2.1 Purpose

The purpose of this assessment is to document and evaluate geomorphic processes and aquatic habitat conditions in the upper Wenatchee River and to present a comprehensive reach-based restoration strategy to address habitat limiting factors. Evaluations used in this assessment include historical characterization, geomorphic assessment, hydraulic assessment, and an aquatic habitat inventory.

Specific goals and outcomes of this assessment include:

- Provide a comprehensive inventory and assessment of geomorphic and physical habitat conditions and trends
- Identify strategies and actions that address critical aquatic habitat impairments limiting the productivity of local salmonid populations
- Identify strategies and actions that protect and restore the dynamic landscape processes that support sustainable riparian and salmonid habitat
- Coordinate efforts with local landowners, resource managers, and other stakeholders in order to establish collaborative efforts that contribute to the success of restoration strategies

2.2 Study Area

The Wenatchee River Basin is located on the east slope of the Cascade Mountains in Northern Washington (Figure 1). The Wenatchee River is a tributary to the Columbia River with a confluence at the city of Wenatchee near Columbia RM 468.4 (MWG 1995).

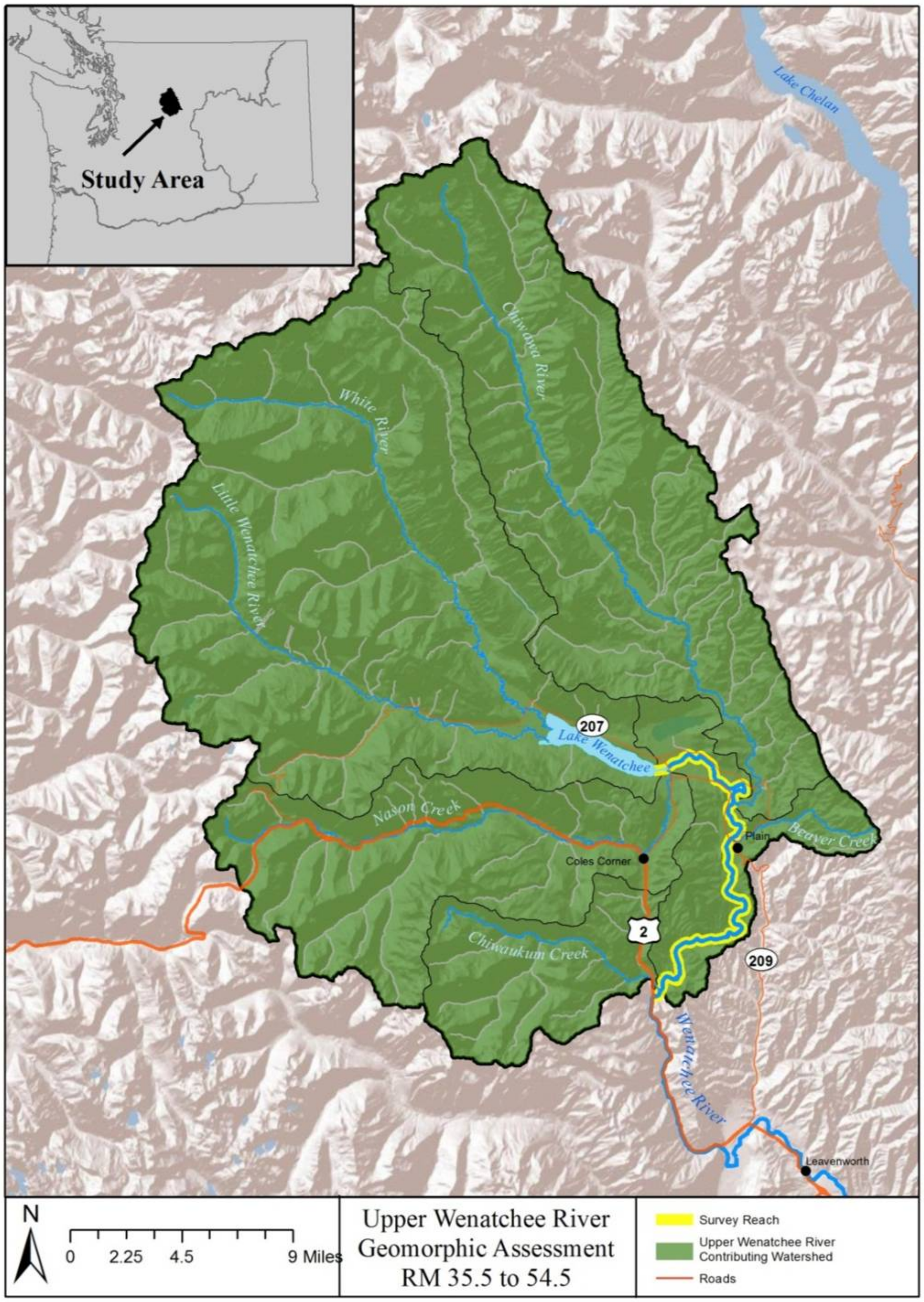

Figure 1. Upper Wenatchee River study area. The study area extends from Tumwater Canyon at RM 35.5 to Lake Wenatchee at 54.5.

2.3 Salmonid Use and Population Status

Salmonid use of the upper Wenatchee River includes spring and summer Chinook salmon, summer run steelhead, bull trout, Westslope cutthroat trout, and sockeye salmon. Spring Chinook salmon and summer steelhead are listed as Threatened under the Endangered Species Act (ESA). Human-induced changes to aquatic habitat have affected the key parameters used by federal agencies to evaluate the viability of salmonid populations; known collectively as the "viable salmonid population" (VSP) parameters: *abundance, productivity, diversity, and spatial structure* (UCSRB 2007). Failure to meet viability (i.e. VSP) criteria resulted in the listing of species under the ESA in the late 1990s. Upper Columbia River (UCR) steelhead trout and spring Chinook salmon were listed as Endangered in 1997 and 1999, respectively (UCSRB 2007). UCR steelhead were upgraded to Threatened in 2006, but were reinstated to Endangered in 2007 (UCSRB 2007). Bull trout were listed as Threatened under the ESA in 1999 (UCSRB 2007). Life-stage usage and ESA status for each species are summarized in Table 1.

Table 1. Species usage in the Upper Wenatchee River. Adapted from Pevin 2004, StreamNet 2012, and Andonaegui 2001.

Population	ESA Status	General Use	Timeframe	Distribution	Abundance	Productivity	Diversity
Spring Chinook	Endangered	Spawning & Rearing	Historic	High	Moderate-High	Moderate	High
		Rearing & Migration	Current	Moderate-High	Low-Moderate	Low-Moderate	
Steelhead	Endangered	Spawning & Rearing	Historic	High	Moderate-High	Moderate	High
		Rearing & Migration	Current	Moderate-High	Low-Moderate	Low-Moderate	
Summer Chinook	Not listed	Spawning & Rearing	Historic	High	Very High	Very High	High
		Rearing & Migration	Current	High	High	High	
Sockeye	Not listed	Migration	Historic	High	Very High	Moderate-High	High
		Spawning & Rearing	Current	High	High	Moderate-High	
Coho	Not listed – Reintroduced (domesticated Lower Columbia River stock)	Migration, Spawning & Rearing	Current				
	Extirpated	Migration, Spawning & Rearing	Historic				
Bull trout	Threatened	Migration	Historic	High	Moderate	Moderate	High
		Spawning & Rearing	Current	Moderate-High	Low-Moderate	Low-Moderate	
Westslope Cutthroat trout	Not listed	Unknown	Historic	Low-Moderate	Low	Moderate	High
			Current	Low-Moderate	Low	Low-Moderate	

2.4 Recovery Planning Context

Spring Chinook salmon, summer steelhead and bull trout are listed and protected under the Endangered Species Act (ESA) and recovery plans were completed in 2007 to prevent the extinction of Wenatchee River ESA listed fish. The Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSRB 2007) states that recovery of species viability will require reducing threats to the long-term persistence of fish populations, maintaining widely distributed and connected fish populations across diverse habitats of their native ranges, and preserving genetic diversity and life-history characteristics. The Recovery Plan calls for recovery actions within all of the “Hs” that affect salmon throughout their life history; namely Harvest, Hatchery, Hydropower, and Habitat. This upper Wenatchee River Reach Assessment addresses the Habitat component of the Recovery Plan, with a focus on the upstream 19.0 miles of the Wenatchee River corridor.

The following habitat restoration and preservation objectives were set forth in the Recovery Plan (UCSRB 2007). These objectives apply to spring Chinook, steelhead, and bull trout habitat and are consistent with the Subbasin Plan (NWPCC 2004), the Watershed Management Plan (WWPU 2006), and the Biological Strategy (UCRTT 2008). The objectives are intended to reduce threats to the habitat needs of the listed species. Objectives that apply to areas outside the study area or that are outside the scope of this plan are not included. A list of regional objectives (applicable to all streams in the Recovery Planning area) is followed by a list of specific objectives for the upper Wenatchee River basin. These objectives provided a framework and guidance for the Reach Assessment and ultimate selection of specific restoration and preservation activities conducted as part of this assessment and included in this report.

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 wood, boulders) 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

Restoration Objectives Specific to the upper Wenatchee River Basin

- Increase habitat diversity and quantity in the upper Wenatchee River by restoring riparian habitat, reconnecting side channels and the floodplain (where feasible), and adding instream habitat structures within the river.
- Provide access to naturally-forming, high quality, watered off-channel habitat and protect those areas that already exist
- Maintain (White River, Little Wenatchee River, Chiwawa River) or restore (Nason Creek, Icicle Creek, Peshastin Creek) connectivity to Wenatchee subbasin watersheds

3 ASSESSMENT AREA CONDITIONS

3.1 Setting

The Wenatchee River Basin is located in Chelan County in North Central Washington State on the east side of the Cascade Mountains within the Columbia Cascade Ecological Province. Headwater drainages upstream of Lake Wenatchee, as well as in the Nason Creek and Chiwawa River drainages, originate in the Alpine Lakes and Glacier Peak Wilderness areas. The total basin area is 1,371 square miles. The catchment area contributing to the downstream extent of the study area (RM 35.5 at Tumwater Canyon) is approximately 664 square miles and includes the watersheds of Chiwaukum Creek (50 square miles at RM 36), the Chiwawa River (199 square miles at RM 48.4), Nason Creek (106 square miles at RM 53.6), the Little Wenatchee and White Rivers above Lake Wenatchee (279 square miles), and several smaller drainages.

Eleven distinct geomorphic reaches were delineated within the study area (Figure 1). Reach delineation was based on basin size (i.e. major tributary confluences), valley confinement, underlying geology, channel gradient, and channel type (e.g. dominant bed morphology). Reach delineation was initially conducted using remotely available data (e.g. aerial photos, LiDAR, and geology maps) and was field-verified during surveys.

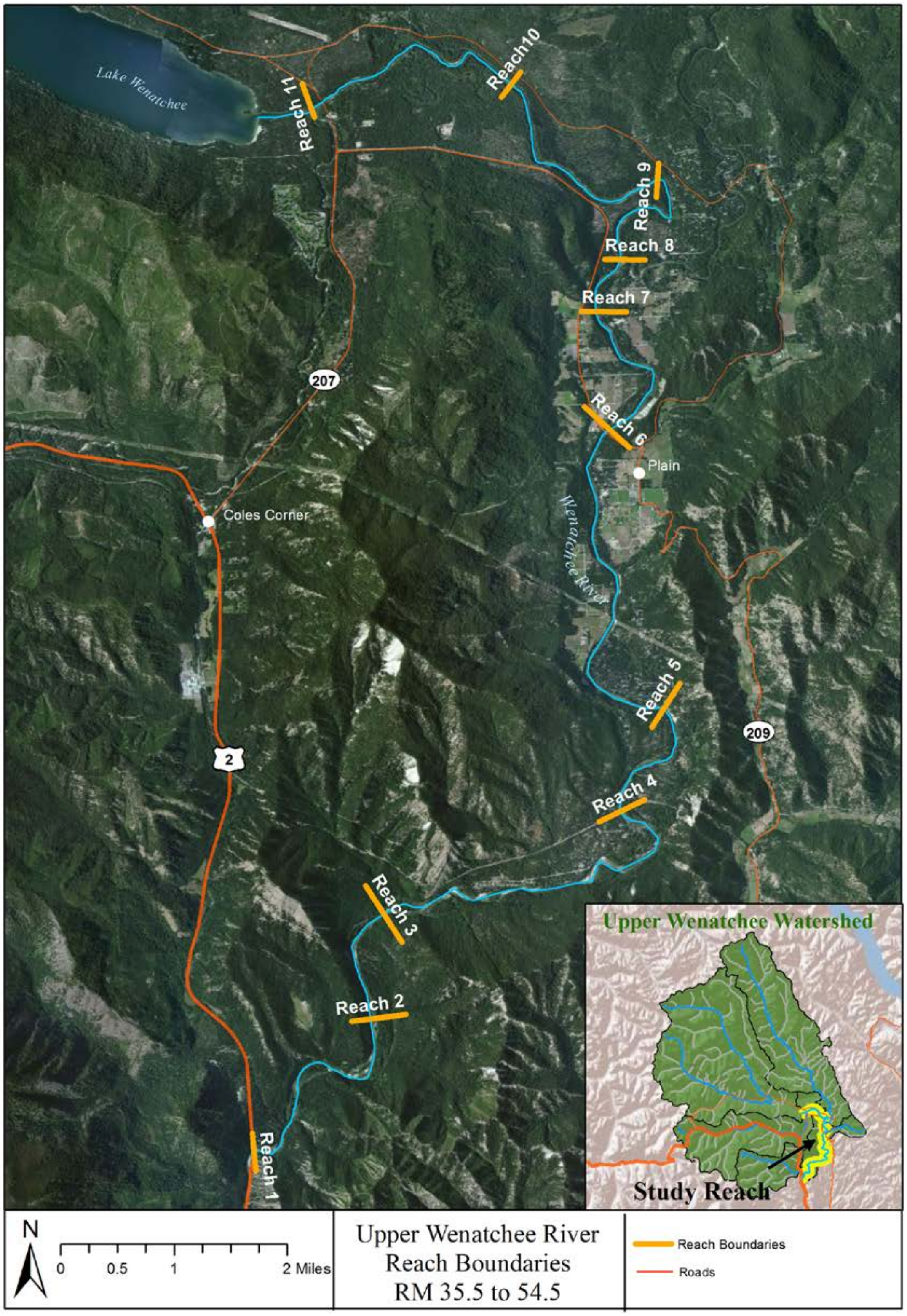

Figure 2. Geomorphic Reach boundaries for the Upper Wenatchee River Assessment.

3.2 Geology

The Wenatchee River basin is located within the Northern Cascades geologic province. This province is bounded by the Straight Creek fault system to the west, the Pasayten fault system to the east, and a less distinct structural break to the south. The Upper Wenatchee River is located within the eastern portion of the North Cascades province. Here, there are multiple northwest-southeast trending fault systems with underlying crustal fragments of differing geologic origin, known as terranes. The Upper Wenatchee River basin is primarily affected by the dynamic relationship between two of these fault systems, the Entiat and Leavenworth faults, and by the geology of their underlying terranes (Figure 3).

The Entiat fault to the east and the Leavenworth fault to the west both display normal and strike-slip movement. Movement by both these faults during the Eocene era (50 to 30 million years ago) formed a pull-apart basin known as the Chiwaukum Graben. This basin experienced high rates of deposition from the relative up-thrown structural blocks to the east and west, which formed two distinct formations within the Chiwaukum Graben. One of these formations, the Chumstick Formation, is a thick blend of deposited sandstone, conglomerate, shale, and tuff. Sandstone (of alluvial and lacustrine origin) comprises the majority this formation. This sandstone-dominated formation is a relatively easily erodible rock type and is the primary bedrock outcrop and vertical grade control encountered along the river in the study area (Gresens et al. 1978).

The Upper Wenatchee basin is also impacted by glacially (see Glacial History section below) and fluvially transported materials imported from surrounding areas. Some materials found in the bed and banks of the Upper Wenatchee originated in the highlands to the east (Mad River Terrane) and to the west (Nason-Ingalls Terrane). These rock types are primarily crystalline in nature such as gneiss, schist, and granitic rocks and form the more persistent sources of boulders in the channel (Figure 4).

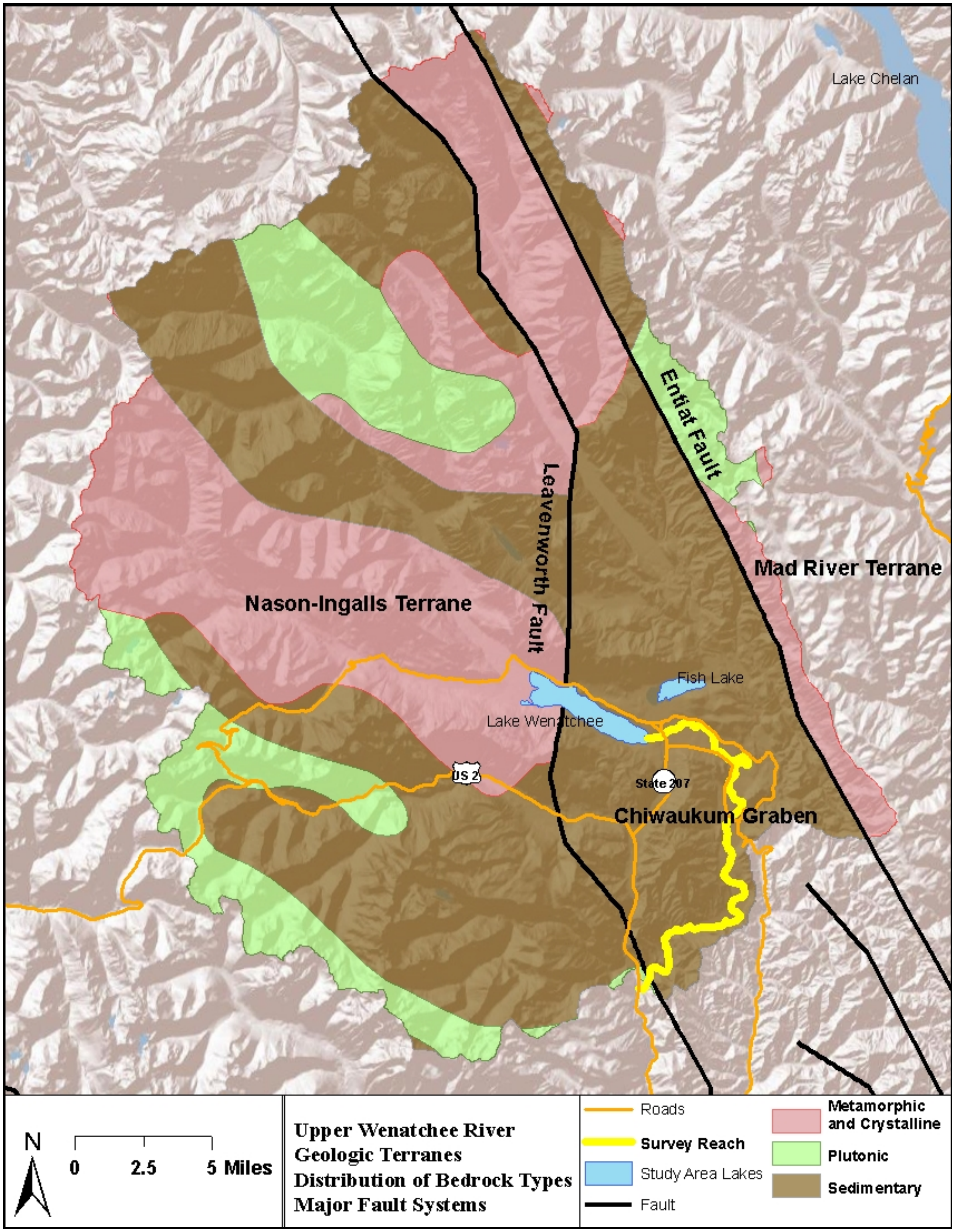

Figure 3. Geologic map of the study area showing generalizations of bedrock types, fault systems, and major geologic terranes within the contributing watershed of the study area. (Adapted from Tabor et al. 1987).

Figure 4. Boulders located in the channel and along the toe of the hillslope adjacent to the channel. This material is likely sourced from crystalline bedrock in tributary watersheds and brought into the study area as glacial deposits.

Glacial History

There are six major glacial cycles recognized in the region ranging in age from 12,500 to 165,000 thousand years before present (Porter and Swanson 2008, Table 2). During the last glaciation (late Pleistocene), masses of ice moved from higher elevations in the basin downslope, carving out rock masses and leaving behind remnant glacial erratics. Glaciation extended downstream from Lake Wenatchee through much of the study reach. Glacial deposits can be found fairly continuously along the river throughout the study area. A glacial moraine marks the upstream extent of the study area at the outflow of Lake Wenatchee. Till deposits, formed by active glacial erosion and often deposited as moraines, form the hillslopes to the north of the river from the upstream end of the study area to RM 49.3 where the Chiwawa River incises the till. Glaciation also provided substantial meltwater, which flowed downslope depositing silt, sands, and gravel. These glacial and fluvial terraces of Pleistocene age confine the channel on both sides for much of the study reach (Figure 5).

Table 2. Regional glacial cycles derived from study of deposits in the Icicle Creek drainage, and the relative ages of these respective glacial periods (adapted from Porter and Swanson 2008).

Glaciation periods that correlate with till deposits in the Icicle Creek Drainage	Approximate age of deposit
Rat Creek I and II	12,500±500 and 13,300±800
Leavenworth I and II	16,100±1100 and 19,100±3000
Mountain Home	70,900±1500
Pre-Mountain Home	93,100±2600
Peshastin	105,400±2200
Boundary Butte	At least 165,000

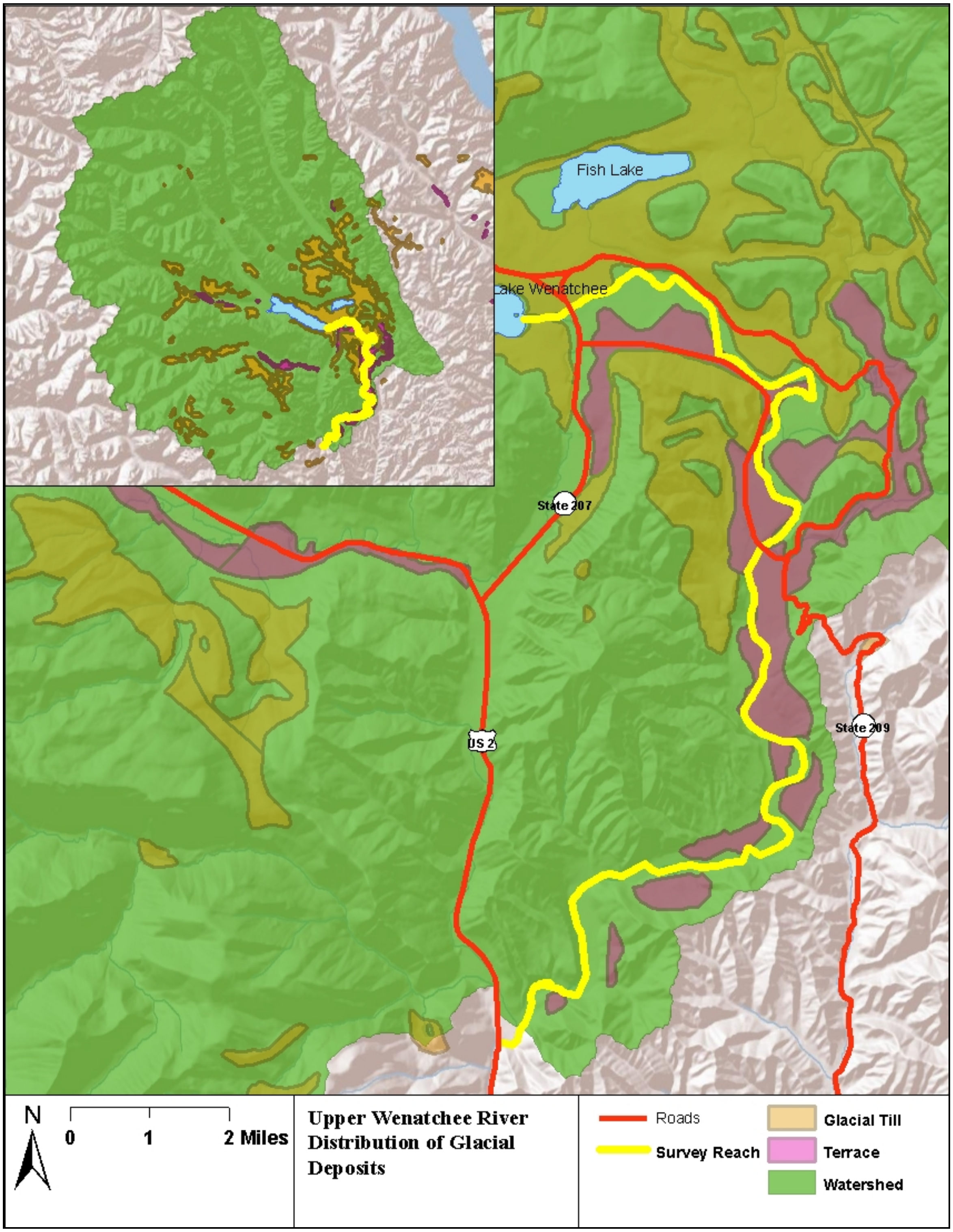

Figure 5. Topographic map depicting the distribution of mapped glacial deposits in the study area. The inset shows the wider distribution of glacial deposits in the contributing watershed (adapted from Tabor et al. 1987).

3.3 Historical Forms and Processes

3.3.1 Channel Form and Process

Although there is little direct evidence of conditions prior to Euro-American settlement (late-1800s), a couple of early surveys help to characterize historical conditions. These include the General Land Office cadastral surveys between 1899 and 1906 and a more detailed survey by the USGS in 1911. These surveys suggest that the historical channel planform geometry was similar to what is seen in modern times (Figure 6 and Figure 7), with only minor changes at naturally unconfined segments. Similar to contemporary geomorphic form and processes, alluvial reaches with relatively wide, well-connected floodplains alternated with naturally confined reaches where bedrock and glacial deposits set lateral limits on channel migration.

Within alluvial reaches (e.g. Reach 1), geomorphic processes of channel migration, channel avulsion, deposition of sediment, channel braiding, and deposition of large wood would have created complex habitat features. In contrast to the alluvial reaches, confined or partially confined reaches, such as the river through the Plain area, would not have provided the same degree of instream and off-channel habitat complexity. In many of these reaches, glacial terraces naturally confine the channel on both sides. Slow re-working at the toe of glacial terraces would have resulted in boulders, glacial lag, and boulder erratics in the channel and along the channel margin. These features would have created some hydraulic variability, scour pools, pocket water, and temporary locations for riparian vegetation establishment and accumulation of large woody material, but most of the habitat complexity would likely have been confined to the channel margins.

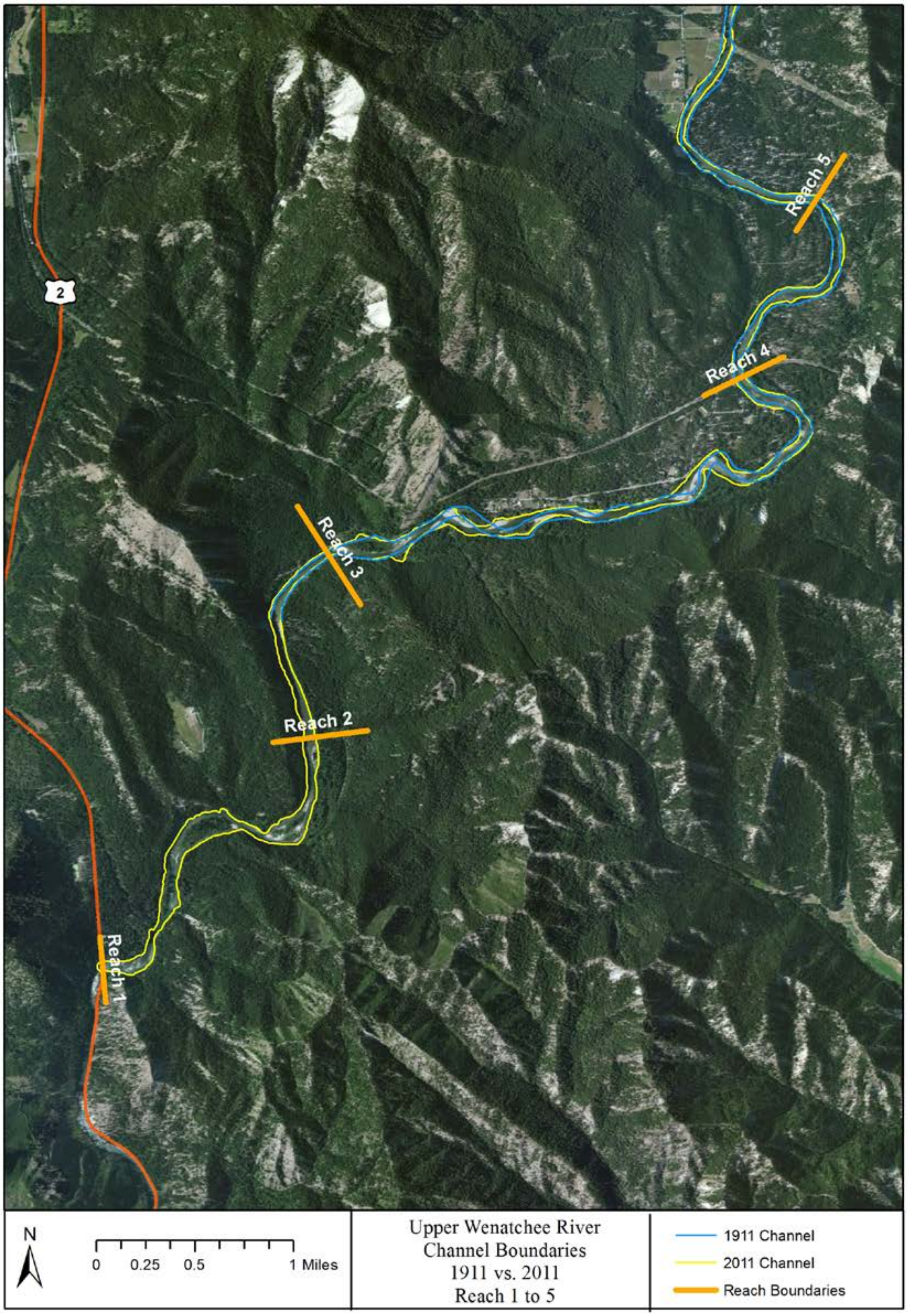

Figure 6. Channel boundary comparison between 1911 survey and 2011 aerial photo for Reaches 1-5 (1911 maps ended between reaches 2 and 3).

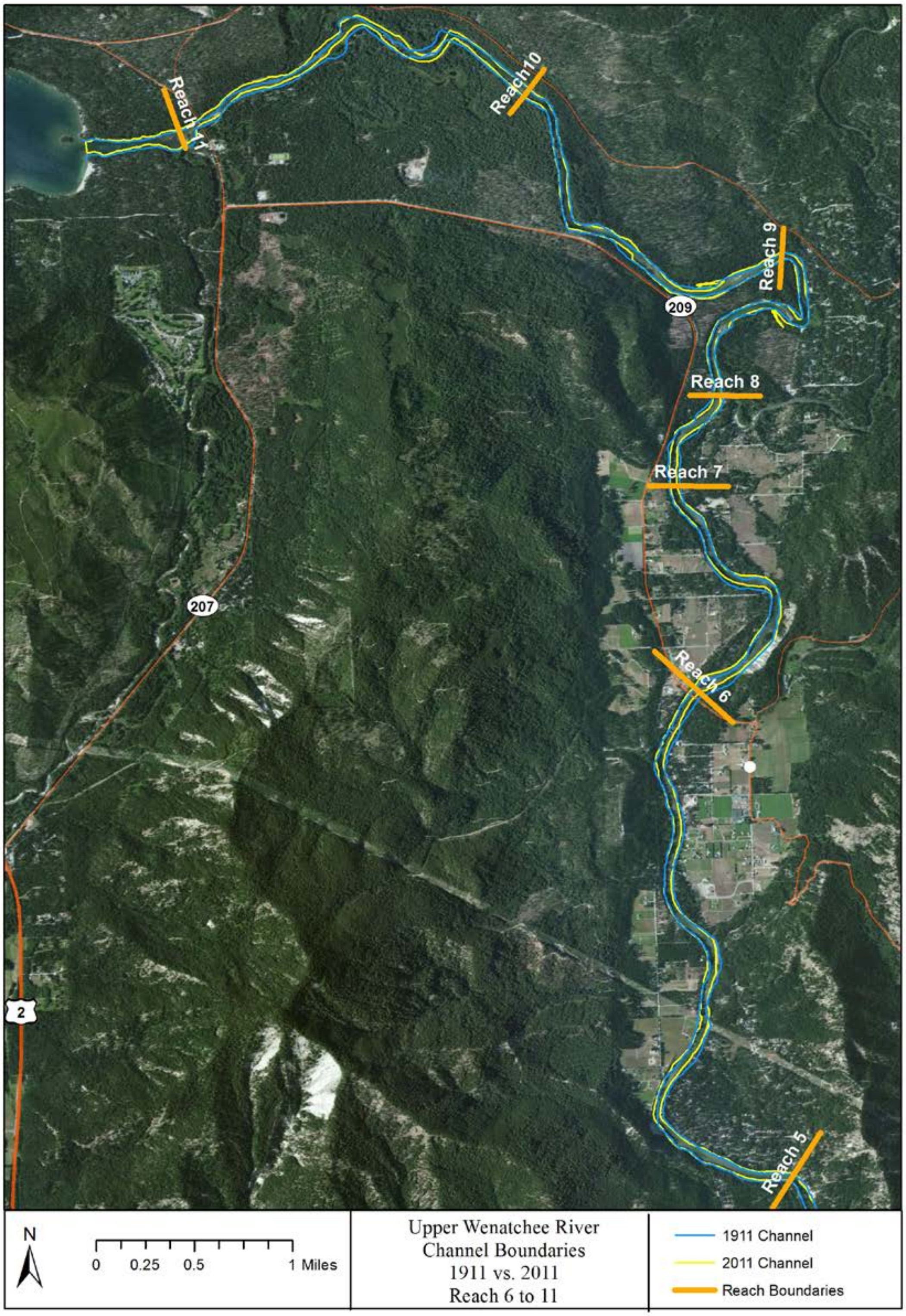

Figure 7. Channel boundary comparison between 1911 survey and 2011 aerial photo for Reaches 6-11 (1911 maps ended between reaches 2 and 3).

3.3.2 Hydrologic Regime

Similar to contemporary conditions, the natural hydrologic regime within the study area was dominated by the seasonal dynamics of a snowmelt runoff system. The flow pattern would have exhibited increasing flow through the spring with an annual peak in June and a rapid decline to baseflow conditions by late July or August. Brief high flow periods would have occurred from late October through February due to extended rain, and the largest flows would have occurred during winter months due to rain-on-snow events. As in modern times, Lake Wenatchee would have buffered hydrologic inputs from the Little Wenatchee and White Rivers. Tributary contributions downstream of the Lake are historically important as sources of non-buffered flood pulses carrying sediment and wood to the mainstem of the Wenatchee.

3.3.3 Large Wood Dynamics

Historically, large wood would have been an important driver of geomorphic form and process, and would have had a strong influence on instream habitat availability and complexity. The following section outlines large wood dynamics, including sources of instream large wood (sources), how wood is made available to the stream (recruitment), and how wood is retained within the stream where it provides habitat functions (retention).

Sources

Instream wood source areas for the Upper Wenatchee included: (1) wood additions from the river corridor (floodplain, terrace slopes, and riparian areas), and (2) wood contributed from the upper basin that has moved through Lake Wenatchee, Nason Creek, or the Chiwawa River. Wood from upstream sources has been shown to be an important component of wood loading in larger streams (McDade et al. 1990, Martin and Benda 2001), and therefore upstream areas were likely an important source of large wood for the study area. Nason Creek and the Chiwawa River would have been major contributors of upstream large wood inputs. The Little Wenatchee and the White River (Lake Wenatchee tributaries), and the margins of Lake Wenatchee itself, would also have provided wood to the study area. Given the orientation (northeast to southwest) and the four mile fetch along Lake Wenatchee, wind would likely have moved much of the large wood across the lake and down to the Wenatchee River. However, the presence of Lake Wenatchee may have reduced downstream wood loading to some degree due to the retention of wood in the lake from beaching and sinking.

Wood sourced from upstream areas and from the study reaches would have had a range of sizes depending on forest type and time since last disturbance (e.g. floods and fires). Compared to existing conditions, there would have been a greater source of large old-growth trees that would have been periodically recruited to the system. Plummer (1902) describes the forests of the “upper basin” like this:

> In the upper basin is a fine forest of old-growth red fir, red cedar, white pine, and hemlock, besides smaller growth of lovely fir. Some trees in this old growth have a diameter of 4 to 5 feet and make up a forest such as is seldom seen in eastern Washington.

In the alluvial reaches within the study area, source areas would have included much of the active floodplain, whereas in confined reaches, riparian source areas would have been closer to the channel margins. Riparian source areas historically included a valley floor heavily forested with conifers and with a dense shrub understory (Fenner 1897, Plummer 1902, US Bureau of Fisheries 1935).

Recruitment

Historically, large wood would have entered the Upper Wenatchee and upstream contributing stream channels from both chronic (i.e. single-tree mortality) and episodic disturbance-related events. Disturbance-related contributions would have included fire, floods, windstorms, avalanches, diseases, and landslides. These contributions likely provided a greater amount of wood loading than chronic contributions. Laterally-active alluvial reaches would have recruited wood via lateral and transverse scrolling of the channel, whereas recruitment in the more confined reaches would have occurred primarily through single-tree mortality. Reaches confined by high glacial terraces (see reach descriptions in Section 4) would also have recruited wood via toe erosion that initiates mass wasting events on the terrace bank. These "colluvial jams" would have been an important source of channel margin wood in confined reaches (Figure 8).

Figure 8. Example of contemporary 'colluvial jam' on Upper Wenatchee River. Historically, these types of jams would have been composed of much larger riparian trees (photo October 2011).

Retention

Retention of large wood is related to characteristics of the wood itself and also characteristics of the stream channel (Gurnell 2003). In general, the larger the wood piece (e.g. diameter and length) with respect to channel size (e.g. width and depth), the more likely it is that wood will be retained (Bilby and Ward 1989, Brauderick and Grant 2000, Bocchiola et al. 2008). In large rivers, wood is frequently retained in the channel in the form of log jams. Large, stable pieces that initiate log jam formation are often referred to as "key pieces" (WFPB 1997). Key pieces, which typically have attached rootwads, are retained in the channel first and serve as foundation pieces for capturing and racking additional wood from upstream. In the pre-disturbance Upper Wenatchee River, the greater availability of these larger key piece sized pieces, as discussed previously, would have supported a greater degree of log jam formation.

Another important factor affecting wood retention is the degree of channel complexity. A complex channel with numerous obstructions to flow such as bank protrusions, islands, gravel deposits, boulders, or other wood pieces will retain wood more readily than simplified uniform channels (Fetherston et al. 1995, Gurnell et al. 2000a, Gurnell et al. 2000b, Haga et al. 2002, Bocchiola et al. 2008). A historically more complex channel, prior to human alteration, would have provided a greater degree of in-channel wood retention compared to contemporary conditions. These wood accumulations would have promoted both geomorphic and habitat functions including creation of pools, sediment retention (trapping) and sorting, creation of multi-thread channels, and increased channel complexity and cover for fish. Jams would have formed throughout alluvial reaches in the study area, and based on jams surveyed as part of this assessment in the relatively intact Reach 1, jams may have been composed of over 200 pieces. Depending on the wood type forming the larger key pieces, these large jams could have been stable for decades.

3.3.4 River Ice

River ice on the Upper Wenatchee River (e.g. Figure 9) is a driver of geomorphic form and process. In years the Upper Wenatchee freezes over, ice impacts channel form by attaching to and then breaking off of stream banks and contributing to bed and bank scour. River ice can cause large overbank flood events due to ice-dams. As river ice begins to break-up during warming or thawing events, ice blocks move downstream and build up behind river ice or other obstructions further downstream. Areas prone to ice-damming include transitions from riffles to pools, meander bends, and mid-channel bars. Flooding has been linked to river ice on the lower Wenatchee River, Peshastin Creek, and the Entiat River. The frequency of occurrence of ice-related flooding events on the Upper Wenatchee is relatively low, but the specific extent and geomorphic impact is not well known.

Figure 9. Photo of Upper Wenatchee frozen over (1960s) (photo courtesy of Bryon Newell)

3.3.5 Habitat Conditions

The earliest descriptions of the Upper Wenatchee describe the river as “clear and pure- the lakes and larger streams in the township teem with trout of different varieties, and salmon come up the Wenatchee River in great numbers in their season” (Fenner 1897). The first known physical habitat assessment of the Upper Wenatchee describes the River as having plentiful spawning areas and adequate areas of refugia and resting. “Spawning rubble” accounted for over 40% of substrate throughout the study reach (Figure 10) (US Bureau of Fisheries 1935). The assessment notes that “good spawning areas are plentiful throughout this section.” P 19 repla

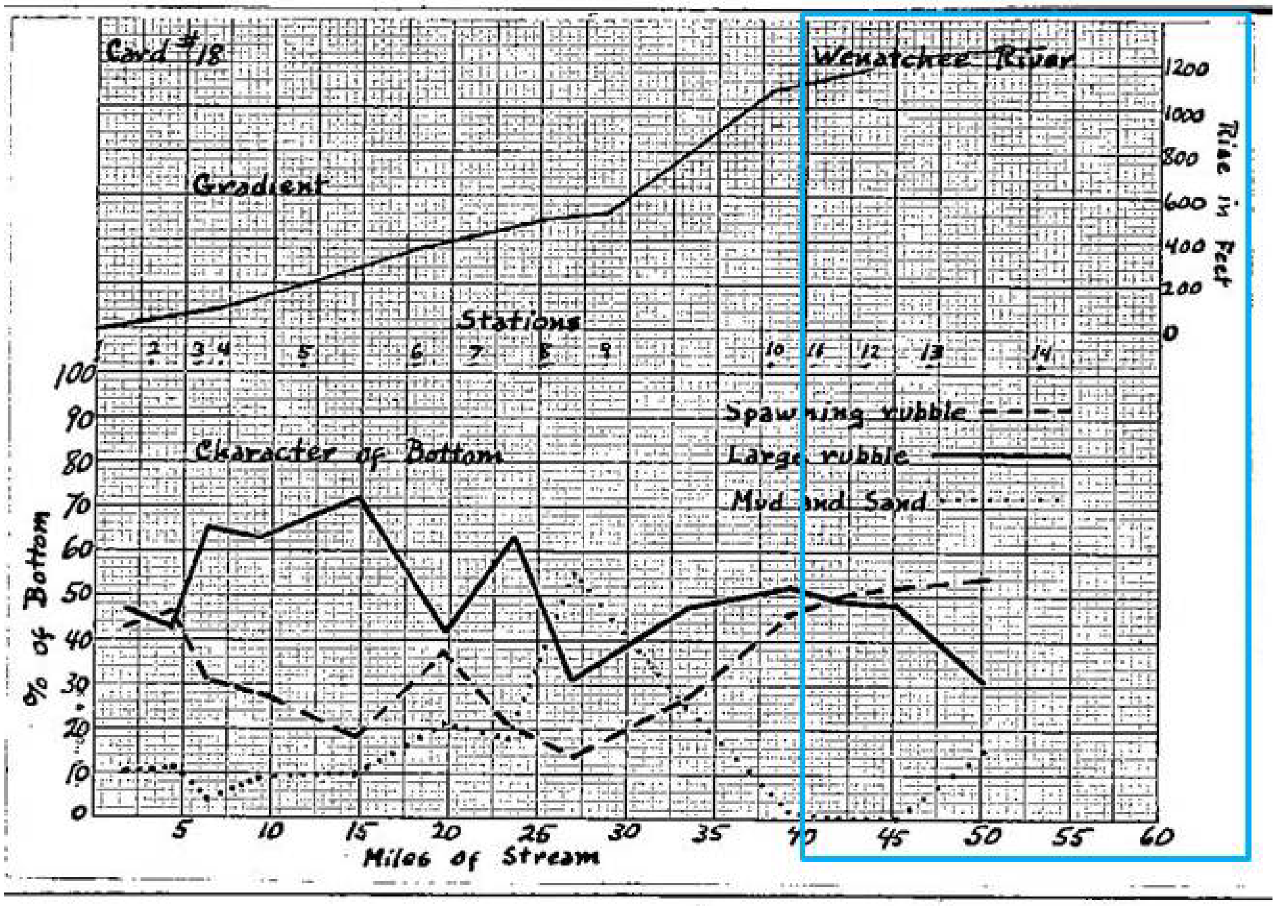

Figure 10. Physical habitat assessment results from 1935. Area enclosed in blue box is approximate study reach.

A 1950 survey documents quality habitat in the upper portion of the study reach: "the best riffles are in the upper 9 miles below the outlet of the lake" (RM 54- RM 45).

Large wood accumulations were also an important part of fish habitat. As discussed in Section 3.3.3, large wood was a major driver of geomorphic forms and processes, and their associated habitat elements throughout the Upper Wenatchee River. Historical habitat function provided by large wood included creation of pools, gravel recruitment, creation of multi-thread channels, hiding cover, and refugia during high and low flows.

3.4 Human Disturbance History

3.4.1 Early Disturbance

The first documented inhabitants of the region were members of the Wenatchi Tribe, who called the Wenatchee River the Pisquoise or the Wenatshapam River (Beckham 1995). There were three known villages in the area, Tciw'as, a fishing village (population approximately 100) at the confluence of the Wenatchee and Chiwawa Rivers, Tcitciw'aux, at Rock Creek and the Chiwawa River, and Tahkwut, at Lake Wenatchee (Roe 2002). Native American tribes hunted, gathered, and fished throughout the region. Native Americans also utilized fire to manage their berry production areas (Mullan et al. 1992).

The first Euro-American visitors to the Upper Wenatchee were fur trappers traveling through the region in the mid-1800s. With over 2,000 acres identified in the early 1900s as “beaver-dam” country (Plummer 1902), fur trapping resulted in the extirpation or large reduction in number of beavers in the basin (Andonaegui 2001). The removal of beaver from the area likely altered side-channel and floodplain dynamics by removing wetlands and bogs, altering sediment dynamics, and decreasing groundwater storage (as based on Naiman et al. 1988).

More permanent settlement began in the region by Euro-American homesteaders in 1860 (Beckham 1995). Early settlement included grazing, construction of boat ramps, small-scale logging, mining, and construction of a hotel on Lake Wenatchee in 1890.

3.4.2 Great Northern Railroad

In 1890, construction of the Great Northern Railroad promoted further settlement into the Wenatchee Basin (Beckham 1995). Completion of the railway construction in 1893 through the town of Leavenworth brought extensive economic development to the area, driven largely by timber harvest and export. The railway line was built up through Tumwater Canyon, where Highway 2 is today. As the town of Leavenworth expanded, settlement moved up the valley into the Upper Wenatchee Basin. This expansion of settlement brought increased disturbance to the region including clearing for homesteads, increased grazing, and mining. By 1908, the Great Northern Railroad built a hydroelectric plant and associated dam in Tumwater Canyon above Leavenworth to provide electricity to the railway’s Cascade Tunnel (Beckham 1995). This dam was one of the first major fish passage barriers installed on the Upper Wenatchee River. Railroad construction included construction of bridges across the Wenatchee and accelerated timber harvesting.

3.4.3 Timber Harvest and Log Drives

Small-scale timber harvest began in the Upper Wenatchee in the late 1800s. Cabins, boat ramps, early roads, and fords are visible on survey maps from 1893, indicating that by this point small-scale timber harvest was ongoing in the area. In the early 1900s, the pace and scope of the region’s timber harvest accelerated with the expansion of the railroad, improved technology, and the construction of sawmills in the area. Two known sawmills were located on the Wenatchee River, one on the current site of Lake Wenatchee State Park (Newell 2011) and a second in Leavenworth (Figure 11) (Roe 2002).

Figure 11. Power dam and mill pond in Leavenworth, WA. Early 1900s.

Riparian zones were cleared of large trees, which likely ranged up to four or five feet in diameter (Fenner 1897, Plummer 1905). Extensive timber was cleared throughout the region and selective harvest of the region’s largest timber or “high-grading” was the predominant silvicultural method until 1955 (McIntosh et al. 1994). Riparian trees were often the first to be harvested due to ease of access and transport (Figure 12, Figure 13). In 1926 alone, 80 million board feet of timber was processed at the Leavenworth Mill (Beckham 1995). Although riparian clearing is no longer occurring in the study reach, the effects of this historical practice will continue to affect wood-loading for the foreseeable future (see Section 3.5.1).

Figure 12 Historical photo (late 1920s) taken from the Old Plain Bridge looking upstream towards a logged right bank alluvial terrace (left-hand side of photo).

Figure 13. Recent photo (2011) from the Plain Bridge looking upstream. Historical logged right bank alluvial terrace is revegetated (left-hand side of photo).

Early sawmill operations included damming of the creek for log ponds and log transport via splash damming (Farnell 1979, Taylor 1999). Logs were pooled behind or placed downstream of channel-spanning dams, and typically during high spring flows, water was released from the dam to allow logs to rush downstream. Logs were driven down Nason Creek, the Chiwawa, the Chiwaukum, and the Wenatchee to the Mill in Leavenworth until 1926 (Roberts 1996, Hull 1929, BOR 1999) (Figure 14, Figure 15, and Figure 16). Leavenworth Mill operation continued until 1927, although timber harvesting continued long after this. Logs were also driven from the White River and Little Wenatchee drainages through the lake to the mill built at the current site of Lake Wenatchee State Park (Newell 2011). Impacts from these splash dams and log drives include channel simplification through the dynamiting and removal of large in-channel boulders and natural logjams and the obstruction of side channels and backwater areas. These actions would have eliminated many habitats outright and would have reduced overall habitat complexity and cover.

Figure 14. Early 1900s log drive on an unknown location of the Wenatchee River. In order to get the logs efficiently downstream, obstructions such as natural logjams and boulders would often be removed (Photo courtesy of the Wenatchee Historical Society).

Figure 15 Early 1900s log drive on an unknown location of the Wenatchee River (Photo courtesy of the Wenatchee Historical Society).

Figure 16. Early 1900s log drive on the Upper Wenatchee River (Photo courtesy of the Wenatchee Historical Society).

By the 1950s, timber harvest within the basin began to increase. The 1980s represented the heaviest timber harvest within the basin (McIntosh et al. 1994, Mullan 1992, USFS 1990). Clearcutting became the most common method of harvest. Timber harvest removed the Upper Wenatchee's native climax tree species, and combined with fire suppression, helped to shift species composition.

3.4.4 Fire Suppression

The fire regime within the Upper Wenatchee Basin is a major driver in forest ecology and influences riparian stand conditions and ultimately, instream large wood conditions. Prior to Euro-American settlement, the lower elevations of the Wenatchee Basin would have experienced frequent low intensity fires every five to ten years; and higher elevations would have experienced less frequent and higher intensity fires (often stand-replacing) every 50 to 100 years (USFS 1999, Andonaegui 2001). Decades of fire suppression beginning in the early 1900s have altered this pattern and have shifted the entire basin to a less frequent, higher intensity fire regime. Fire suppression within the basin has led to shifts in vegetative composition from more open stands of fire-tolerant species (e.g. ponderosa pine and Douglas fir) to higher density stands of less fire-tolerant species (e.g. grand fir). The historically more open stands had larger trees than the higher density stands seen today, which has served to decrease the size of riparian trees that are now available to be recruited to the river. Fire suppression has also led to a higher occurrence of noxious weeds within the area (USFS 2003).

3.4.5 Residential Development and Roadways

Human infrastructure in the form of residential development, roadways, and bridges has altered channels, riparian areas, and floodplains in portions of the study area. Residential development is most prevalent in Reaches 3-8 and Reach 10. In many areas, residential development consists of numerous small parcels that are part of organized community clubs. Most of these communities are in the Plain area and occupy significant portions of the middle reaches of the study area. Residential development is frequently associated with bank hardening, riparian clearing, and floodplain filling and grading (Figure 17). Increased road density has also accompanied increased human density in the area, and in some places has altered the drainage network and has limited the extent of floodplain inundation. Highway 207 (Lake Wenatchee Hwy), Highway 209 (Beaver Valley Road), and River Road are the primary roadways that affect the channel, riparian areas, and floodplains in the study area. Highway 209 limits floodplain function near the upstream end of the study area (right bank near RM 50.5), and has led to disconnection of areas that historically were prone to flooding (see Hydraulics discussion, Section 3.5.2). The bridge on highway 207 at the upstream end of the study area creates a hydraulic constriction at high flows, and reduces floodplain function at the confluence of Nason Creek and the Wenatchee River (see Section 3.5.2). Numerous sections of bank protection (riprap and rock spurs) are located along River Road in reaches 3-5. The Burlington Northern Railroad Bridge also creates a floodplain constriction at RM 41.9. The overall effect of these anthropogenic activities has been to reduce channel and floodplain complexity as well as the connectivity of channel and floodplain habitat.

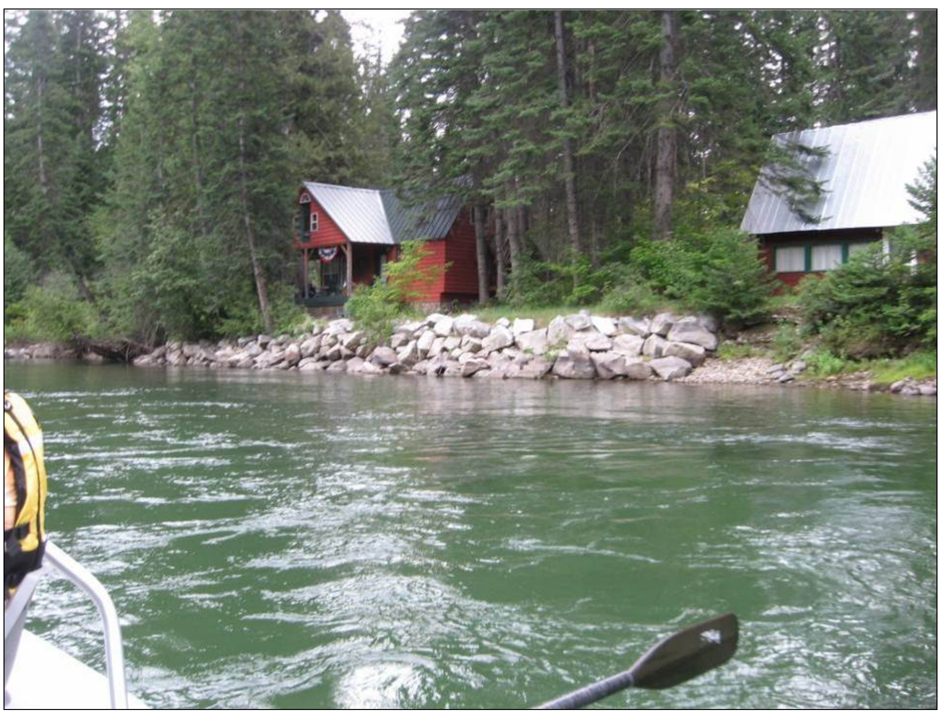

Figure 17. Residential development and bank hardening near the upstream end of the study area.

3.4.6 Habitat Alterations

The various human alterations discussed previously began to affect fish populations by the early 1900s. A 1935 habitat assessment (US Bureau of Fisheries 1935) describes declining populations of historically abundant spring Chinook and steelhead runs. By this point, habitat conditions had already been altered by construction of six irrigation diversions, dams (including the mill pond at Leavenworth and the Tumwater Dam), log drives, and railroad construction. By the late 1920s, habitat alterations had led to the extirpation of the Upper Wenatchee Coho population. The US Bureau of Fisheries (1935) reported that:

> Silvers [coho] were present in large numbers 25 years ago. It was reported that the last of the silver run was in 1926-7. In early years the silvers congregated below the mill dam at Leavenworth in such numbers that it was not uncommon to hook out six to a dozen in a few hours.

A 1950 habitat survey again documents the impacts of human alteration on the reach, particularly on changes in channel substrate. Between Plain and Tumwater Canyon, spawning substrate that was documented as plentiful in 1935 was absent by 1950: "[the] stream bed is composed mainly of large rubble and bedrock with little spawning area found" (Bryant and Parkhurst 1950). Surveyors also note that Chinook are having "considerable difficulty passing the Dryden and Tumwater Dams," despite the presence of a fish ladder documented at Tumwater in 1935. Bryant and Parkhurst (1950) go on to say "in some years the majority [of Chinook] are forced to spawn in the portion of the river below Tumwater Dam."

The impacts of historical habitat alterations continue to affect salmonid populations throughout the study reach. Although overall runs were of similar size from the 1850s to the 1980s, species composition shifted dramatically, and overall run sizes have been drastically reduced between the 1980s and today (Table 3).

Table 3. Historical run sizes of naturally produced salmonids in the Wenatchee River Basin (Mullan et al. 1992; USFS 2003; WDFW & CCPUD 2011).

Species	1850s	1986-87	2011
Chinook Salmon	41,3000	204,800	9,327
Coho Salmon	3,900	0	1,439
Sockeye Salmon	228,100	93,700	18,634
Steelhead	7,300	8,200[1]	1,299
TOTAL	280,600	306,7000	30,699

[1]*Count from 1987-1988.*

3.5 Existing Forms and Processes

3.5.1 Hydrology

The Wenatchee River is a 4th Order tributary of the Columbia River and flows generally south and east through the basin. Its flow is augmented primarily by tributary flows from the Little Wenatchee River, White River, Chiwawa River, Nason Creek, Icicle Creek, Chumstick Creek, Peshastin Creek, Mission Creek, and other smaller drainages. The approximate percentage contributions of the aforementioned tributaries to the Wenatchee River's annual flow are identified in Table 4. Approximately 73% of the Wenatchee's total annual flow can be accounted for within the study area.

Table 4. Percent contribution to Wenatchee River flow by tributary basins (adapted from Washington Department of Ecology 1983; USFS 1999).

Tributary	Percentage Contribution to Annual Flow
Little Wenatchee River	15%
White River	25%
Chiwawa River	15%
Nason Creek	18%
Icicle Creek	20%
Chumstick & Peshastin Creeks	3%
Mission Creek	1%
Other Sources	3%
Total	100%

Hydrology in the basin is driven by a combination of precipitation and snowmelt. Precipitation, in the form of snow and rain, varies with elevation and distance from the Cascade Crest. The higher, headwaters elevations of the Wenatchee Basin receive 50 to 140 inches of precipitation annually, whereas lower elevation areas receive less than 8.5 inches (WDOE 1983, Andonaegui 2001, CCG et al. 2003). These low areas are also farther east and are more affected by the rain shadow of the Cascades.

Precipitation in the form of snow, and subsequent spring snowmelt, dominates the seasonal streamflow pattern in the basin (Figure 18). Snowmelt primarily occurs during the spring and early summer, and is driven by changes in ambient air temperature, snowpack mass, and the elevational distribution of the season's snowpack (WDOE 1983). Peak runoff usually occurs from April through July, with the highest rates typically in late June. The Wenatchee typically returns to baseflows in September.

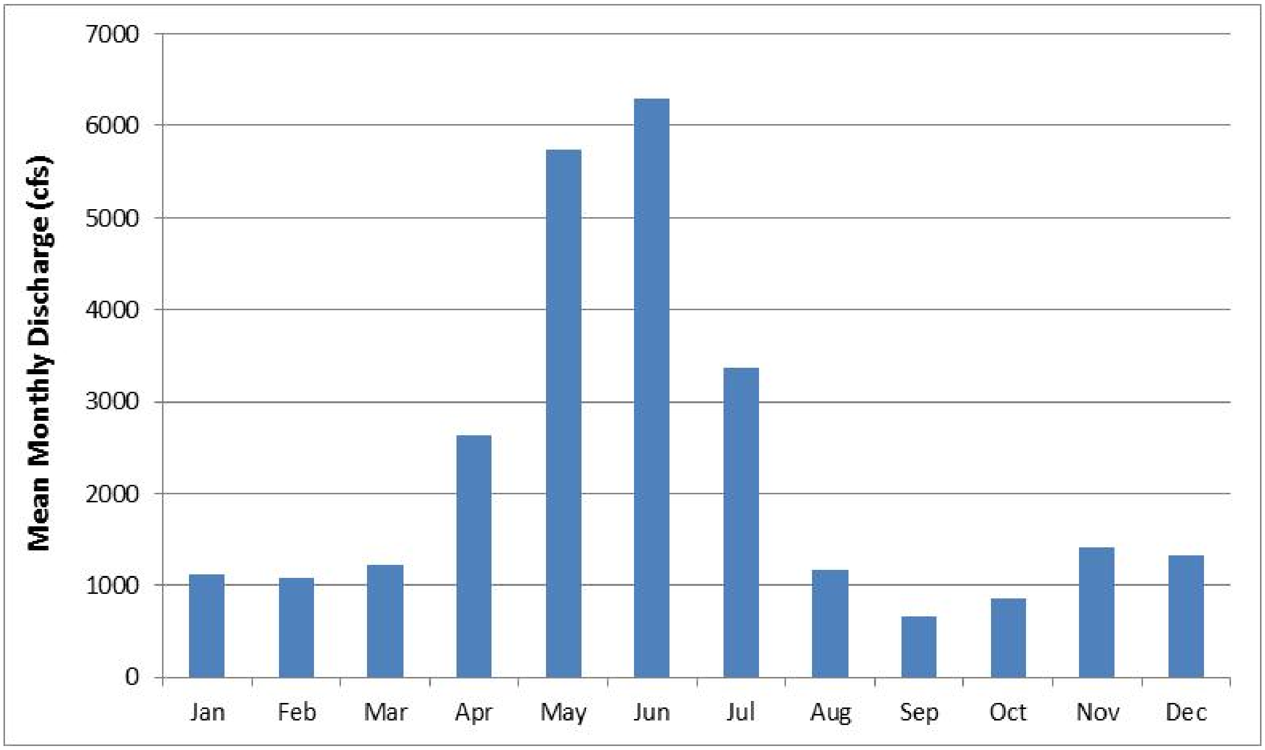

Figure 18. Mean monthly discharge for the period of record at the USGS gage at Plain, WA (Gage 12457000, 1911 to present).

The hydrology of the study area is significantly affected by Lake Wenatchee. Temporary storage in Lake Wenatchee buffers the snowmelt runoff signal from the Little Wenatchee and White River drainages, which contribute 40% of the total annual runoff to the Wenatchee River. Thus, runoff from some of the highest elevation, and highest precipitation regions of the basin are moderated by temporary storage in Lake Wenatchee. Snowmelt from the Nason Creek drainage is the first unattenuated snowmelt signal to reach the Wenatchee River.

The USGS gage at Plain, WA (Gage 12457000) has a period of record extending from 1911 to present. Flood recurrence analysis of this gage record is presented in Table 5. Annual peak flow typically occurs in late June, but the largest instantaneous peak flows on record have occurred mainly in November (Figure 19). The highest measured discharge was on November 20, 1995 and was recorded at 36,100 cubic feet per second (cfs). Large floods sometimes occur as rain-on-snow events (Figure 20).

Table 5. Flood Recurrence Analysis (Bulletin 17 B Analysis) for USGS Gage at Plain, WA (Gage 12457000). Data retrieved on 20 January 2012. Period of record extends from 1911 to 2012.

Exceedance Probability (% Chance)	0.2	1	2	5	10	20	50	80	99
Recurrence Interval (years)	**500**	**100**	**50**	**20**	**10**	**5**	**2**	**1.25**	**1.01**
Discharge (cfs)	37,285	29,045	25,799	21,728	18,764	15,827	11,683	8,870	5,824

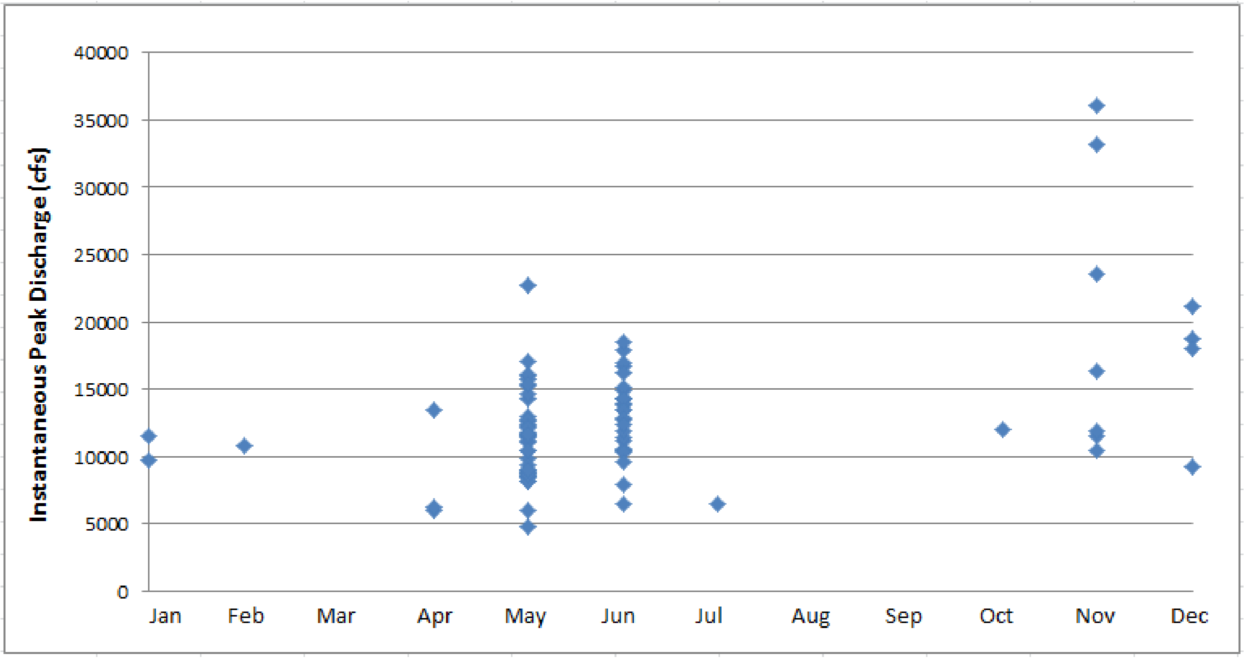

Figure 19. Instantaneous peak flow magnitudes and month of occurrence for the period of record at the USGS gage at Plain, WA on the Wenatchee River (Gage 12457000).

Figure 20. Flooding at the Headwaters Tavern near the upstream end of the study area. Photo date unknown (assumed Nov, 1990) (Photo courtesy of Bryon Newell).

Groundwater storage and release regulates base flow of the Wenatchee River during low flow periods. Alluvial aquifers are located within the channel migration zone of river valleys, and other areas where there are sizeable deposits of alluvium. The unconsolidated cobbles, sands, and gravels characteristic of alluvium provide pore space for significant groundwater storage.

Recharge of the alluvial aquifer is enhanced through channel/floodplain connectivity and off-channel features such as wetlands. Approximately 585 acres of wetlands are located within the study area from the mouth of Lake Wenatchee to Fish Lake Run. These wetlands slowly release groundwater, regulate base flows, and contribute to cooler stream temperatures (Andonaegui 2001). Other substantial sources of groundwater storage and recharge are glacial deposits that drape hillslopes and form terraces along significant portions of the valley in the study area. Direct precipitation or percolation through surface sediment recharges bedrock in the study area as well (WDOE 1983; Andonaegui 2001; Cascadia Consulting Group et al. 2003; USFS 1999). The Chumstick Formation has aquifer forming sandstone units.

3.5.2 Hydraulics

Background

A one-dimensional hydraulic model was developed to support the Upper Wenatchee Assessment. The model is used as one of several tools for analyzing flood inundation levels and for comparing stream energy patterns among reaches within the study area.

Methods

Hydraulic Model

The hydraulic model was created using the HEC GeoRAS framework to create the boundaries of the model system (stream centerline, bank stations, overbank flowpaths, and cross sections). These features were overlaid on a digital elevation model (in this case, LiDAR) from which elevations were extracted for all components of the geometric data set. Cross sections were spaced every 500 feet. This spacing was reduced to approximately every 200 feet through areas around meander bends, upstream and downstream of bridges, or where additional resolution was warranted. Once the geometric data was developed, the model was exported from ArcGIS and brought into HEC-RAS 4.1.0, a one-dimensional water surface profiling program. Steady-flow data was input based on flood frequency data at several river stations (Table 6). Flows ranging from the 2-year to 100-year floods were modeled. For the purposes of this effort, we used a Manning's n value of 0.035 for the channel and 0.08 for overbank areas based on the average channel geometry and roughness characteristics.

There are limitations for utilizing LiDAR to model floodplain inundations. The LiDAR data available for the Upper Wenatchee River is capable of producing accurate elevation data in terrestrial environments, but cannot produce ground elevations below water (i.e. bathymetry). Consequently, results of these analyses should not be used for detailed modeling, restoration, or infrastructure planning purposes. Despite this limitation, the inundation analysis is assumed to be relatively accurate for larger flood flows (i.e. 2-year return interval and above), where the topography errors would have less effect (proportionally) on the results. A sensitivity analysis was performed to see if subtracting the known discharge on the date the LiDAR was flown improved results. Flood stage elevation typically differed by less than 0.1 feet, so no discharge was subtracted for model development.

Table 6. Flood frequency data used in the hydraulic model developed for the inundation analyses based on hydrologic analyses by USBR (2008). Discharge units at each reach are cubic feet per second.

Flood Recurrence Interval	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
2	10,657	10,657	10,657	10,657	10,657	10,657	10,657	8,336	8,336	8,336	6,817
5	14,197	14,197	14,197	14,197	14,197	14,197	14,197	11,105	11,105	11,105	9,082
10	16,858	16,858	16,858	16,858	16,858	16,858	16,858	13,187	13,187	13,187	10,784
25	20,605	20,605	20,605	20,605	20,605	20,605	20,605	16,117	16,117	16,117	13,180
50	23,693	23,693	23,693	23,693	23,693	23,693	23,693	18,533	18,533	18,533	15,156
100	27,051	27,051	27,051	27,051	27,051	27,051	27,051	21,160	21,160	21,160	17,304

Flood Inundation Analysis

Flood inundation was modeled using HEC GeoRAS. HEC-GeoRAS allows for visualization of floodplain inundation by overlaying HEC-RAS modeling outputs on digital terrain models. Georeferenced hydraulic modeling outputs are then displayed in ArcGIS. As described previously, there are limitations to utilizing LiDAR to model floodplain inundation and results of these analyses should not be used for detailed modeling, restoration, or infrastructure planning purposes.

Stream Power Analysis

Stream power was analyzed as one of several variables to compare stream energy among reaches. Stream power (Ω) is a measure of the potential energy exerted per unit length of channel (Bagnold 1966) and is based on the concept that the stream is a sediment transport vehicle with varying degrees of efficiency. Stream power (Ω) represents the potential amount of 'geomorphic work' (e.g. sediment transport, scour) the stream is capable of performing:

$$\Omega = \gamma Qs$$

Where:

γ = the specific weight of water

Q = discharge

S = channel bed slope

When slope and/or discharge increase, stream power will increase (Bagnold 1966). Stream power calculations were output from the HEC-RAS model.

Sediment Competence Analysis

Sediment competence was analyzed to provide an overview of streambed mobility. Streambed sediments will only move when the force of water acting on those sediments is greater than the force keeping those sediments in place. The force of flowing water acting on a sediment particle is the shear stress. The amount of force required to move that sediment particle is the critical shear stress. If the shear stress is greater than the critical shear stress, then the sediment will be transported. Conversely, if shear stress is less than the critical shear stress, the sediment will remain stable or be deposited. A value of "excess shear stress" can be calculated as the ratio of the applied shear stress to the critical shear stress, which yields a useful term in which values greater than one represent a mobile bed condition and values less than one represents a stable bed condition.

To evaluate general trends in the ability of the Upper Wenatchee River to mobilize and convey sediment, excess shear ratios were calculated for the study reach. The Shields (1936) equation was used for this analysis. The shear stress applied to the bed is:

$$\tau = \rho g R s$$

And the critical shear stress needed to mobilize the streambed sediments is (Komar 1987):

$$\tau_C = \tau^*_{C50}(\rho_s - \rho) D_{84}^{0.3} D_{50}^{0.7}$$

The ratio of shear stress to critical shear stress is known as excess shear stress (τ^*):

$$\tau^* = \frac{\tau}{\tau_c} = \frac{\rho R s}{\tau^*_{c50}\, D_{84}\ (\rho_s - \rho)}$$

Where:

τ = bed shear stress

ρ = density of water (lb. /ft^3)

g = gravity (ft/s)

R = hydraulic radius

ρ_s = density of sediment (lb. /ft^3)

τ_c = critical shear stress (lb. /ft^2)

D_{84} = 84th percentile of grain size (ft.)

D_{50} = median grain size (ft.)

s = slope

τ^*_{c50} = critical dimensionless shear stress (Shields Parameter)

Here, τ^*_{c50} was adapted from Julien (1995) and the D_{84} was utilized to determine the conditions required for most of the streambed to be mobilized and the potential for bed change to occur (Leopold 1992). For each reach, two Wolman (1954) pebble counts were taken at riffle crests where flows allowed. A total of 16 pebble counts were conducted. Due to high flows and non-wadeable conditions experienced during the survey there are significant limitations associated with the pebble count data. In some reaches, pebble counts were done in side channels or in glides, and for some reaches, none or only one pebble count was collected. Consequently, this data should only be utilized to understand sediment transport patterns at a conceptual level, and should not be utilized for design purposes.

Results

Floodplain Inundation

Inundation analysis results are presented in the five maps located at the end of this section. Throughout the confined reaches (Reaches 4-6, Reach 9, Reach 11), flows for both the 2-year and 100-year flood events remain largely in-channel. Throughout the unconfined reaches (e.g. Reach 1, Reach 3, Reach 10), water surface elevations extend beyond the main channel boundaries. In many places these flows activate side channels and inundate floodplain surfaces.

Hydraulics

Results of the 2-year and 100-year flood event hydraulic analyses are presented in Table 7 and Table 8. For both the 2- and 100-year events, reaches 2 through 6 displayed the highest stream power, highest excess shear stress, and highest velocities, with Reach 6 having the maximum values for all of these parameters. These results are consistent with the higher gradient and confinement of these reaches (see Section 3.5.3). Stream power, excess shear, and velocity displayed a decreasing trend moving upstream from Reach 7 to Reach 11, as well as low values in Reach 1.

Table 7. Hydraulic analysis results for the 2-year flood event.

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Avg Velocity (ft /sec)	5.79	7.38	7.08	6.82	7.24	7.77	6.66	4.88	4.17	4.28	3.36
Shear stress (avg)	0.67	1.07	1.04	0.91	0.98	1.22	0.82	0.44	0.3	0.35	0.23
Stream Power (lb/ft/s)	731	1044	1181	829	833	1273	681	258	144	198	135
Incipient Particle Size (in)	3.2	5.2	5	4.4	4.7	5.9	4	2.1	1.4	1.7	1.1
Excess Shear Ratio	0.68	0.58	0.75	*	0.68	*	*	0.40	0.58	0.55	0.14

* Pebble counts not taken within these reaches due to high flows.

Table 8. Hydraulic analysis results for the 100-year flood event.

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Avg Velocity (ft /sec)	7.67	10.74	9.5	9.71	10.36	10.84	9.19	7.1	5.75	5.36	4.44
Shear stress (avg)	1.05	1.94	1.62	1.58	1.67	1.98	1.32	0.78	0.49	0.53	0.33
Stream Power (lb/ft/s)	1683	2940	2792	2215	2064	2999	1591	697	366	480	265
Incipient Particle Size (in)	5.1	9.4	7.8	7.7	8.1	9.6	6.4	3.8	2.4	2.6	1.6
Excess Shear Ratio	1.06	1.05	1.17	*	1.17	*	*	0.72	0.95	0.83	0.20

* Pebble counts not taken within these reaches due to high flows

Discussion

Overall, the hydraulic analysis confirms higher stream energy and less floodplain inundation in the confined reaches (i.e. Reach 2, 4-6, Reach 11) and greater floodplain inundation and lower stream energy in the unconfined reaches. Combining the hydraulic analysis with the geomorphic and habitat assessments shows that current channel and floodplain complexity tended to increase in reaches with the greatest potential of regular floodplain inundation (2 year flood recurrence).

Hydraulic floodplain inundation modeling provided some insight into the geologic processes of incision. The Wenatchee River has incised down through the more easily erodible Pleistocene glacial outwash terraces that border the modern floodplain surfaces. These abandoned terraces are often 10+ feet above existing floodplain surfaces, and xeric (dry) vegetation communities indicate these areas have long been abandoned. In some locations such as meander bends, terrace edges are gradual and sloping. The hydraulic inundation models of the 100 year flood helped to verify the boundaries between the abandoned and modern floodplain surfaces.

Hydraulic analysis supports the assessment that human alterations have affected floodplain inundation patterns, stream energy, and incision processes at several locations within the study area. For example, in Reach 9 (RM 50.5) Highway 209 limits floodplain inundation within the river right overbank floodplain area. In Reach 10, the Highway 207 Bridge and road fill constrict channel dimensions and have interrupted floodplain overbank flow near the Nason Creek confluence. A similar effect is observed at the Burlington Northern Railroad Bridge at the downstream end of Reach 4. Channel confinement in these areas has increased flow energy within the active channel resulting in bed scour, channel incision, and related floodplain disconnection.

More subtle anthropogenically-influenced incision processes are also highlighted by the floodplain inundation analysis. Recently abandoned surfaces that are only one to two feet above currently active floodplain surfaces are delineated by the model. These surfaces contain visible topographic evidence of scour and deposition but no evidence of modern inundation. These results support the assessment that historical splash damming, and other alterations to the floodplain such as bank hardening, homesite construction, and vegetation alterations, have accelerated incision processes in those areas. Sections of the floodplain of Reach 8 and lower Reach 9 are examples of such surfaces that were likely very active until 20-50 years ago.

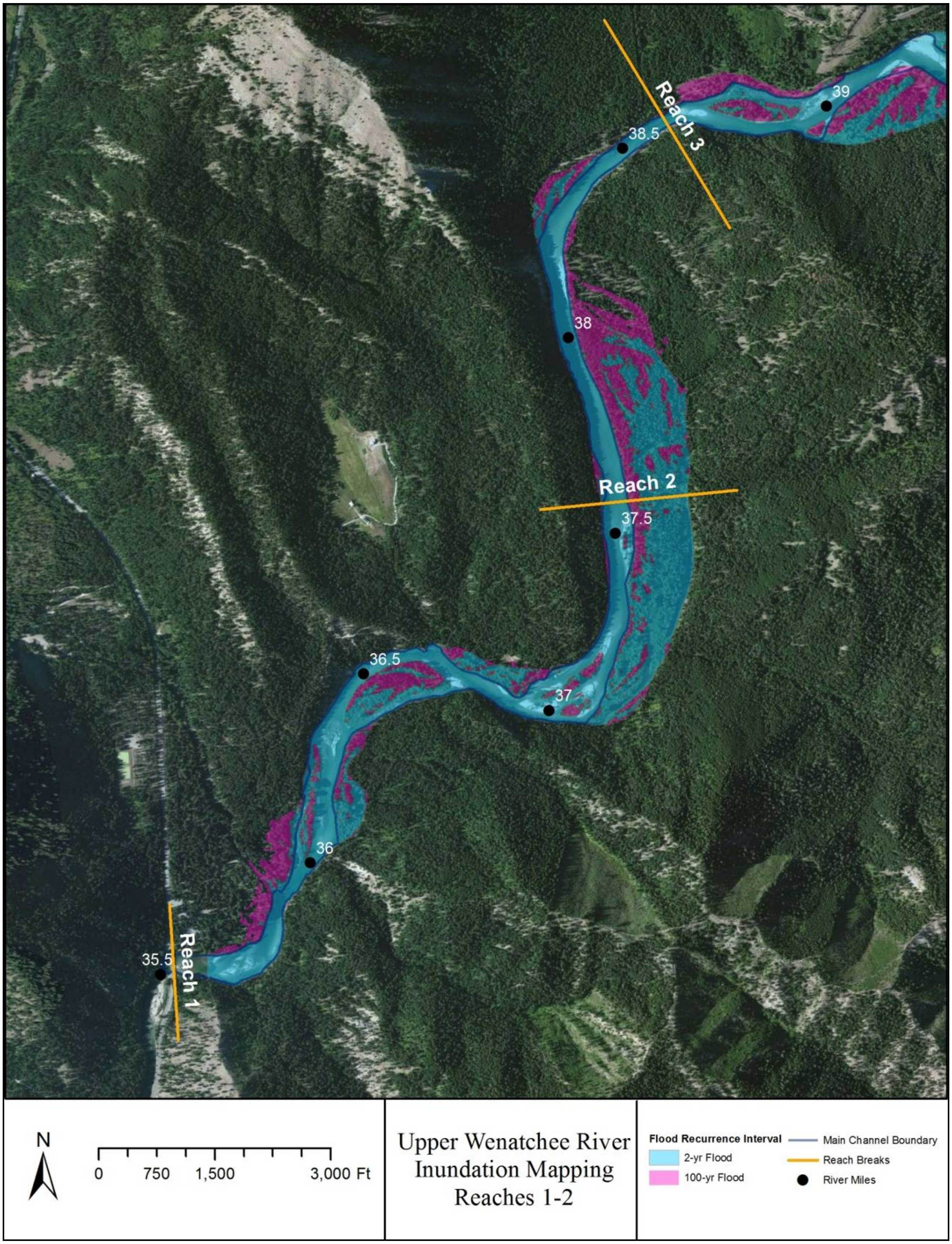

Figure 21. Reach 1 and 2 floodplain inundation potential for the 2- and 100-year flood events.

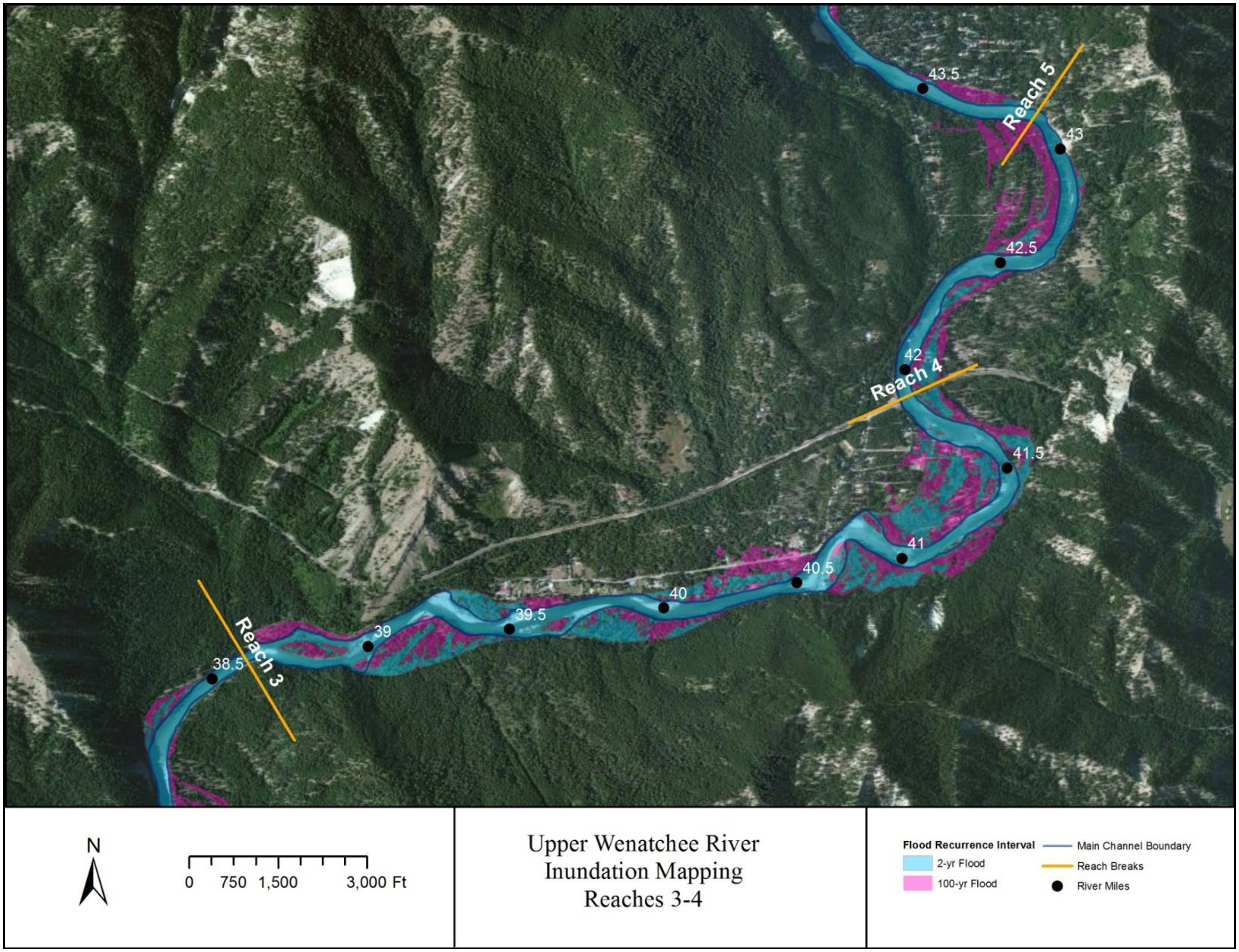

Figure 22. Reach 3 and 4 floodplain inundation potential for the 2- and 100-year flood events.

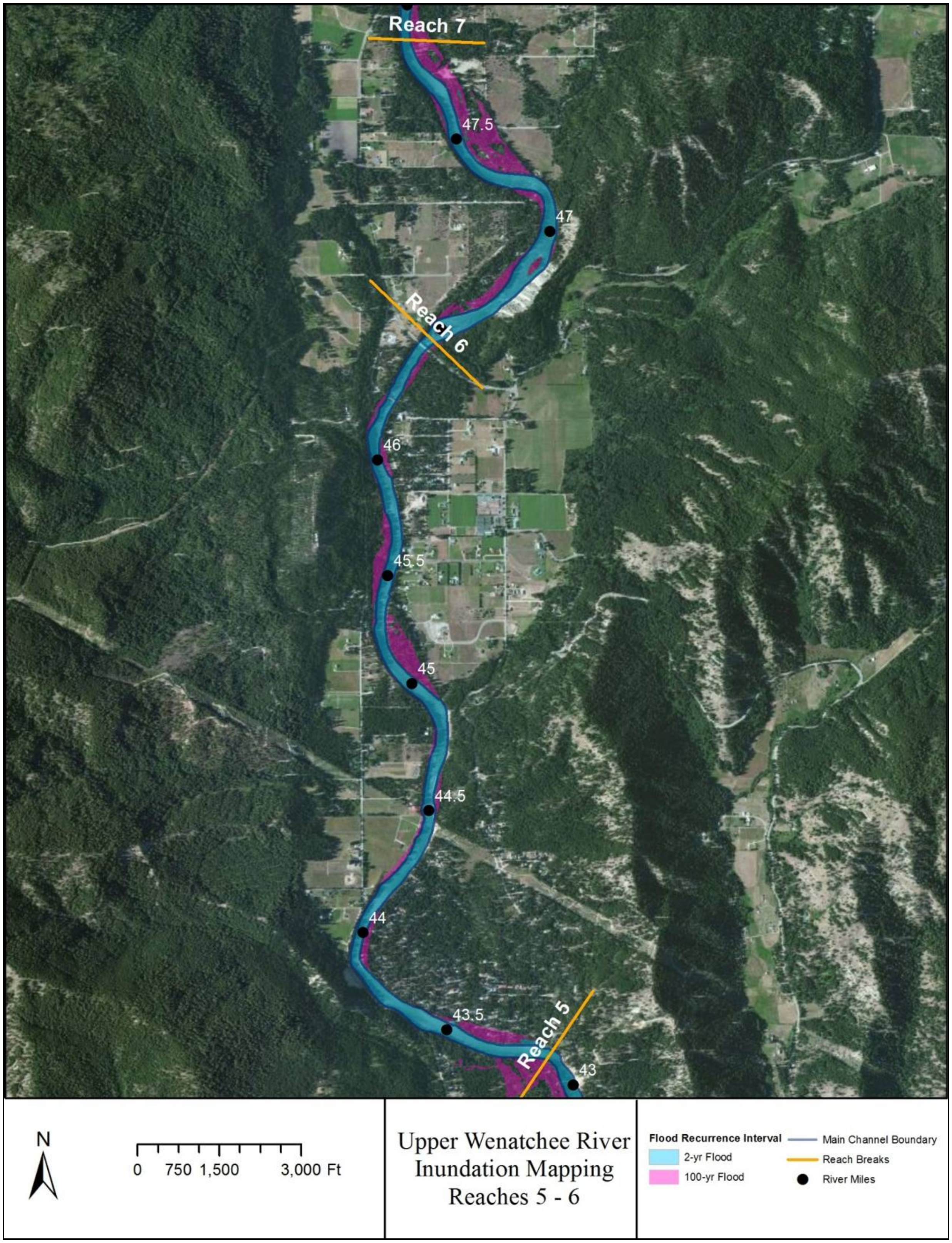

Figure 23. Reach 5 and 6 floodplain inundation potential for the 2- and 100-year flood events

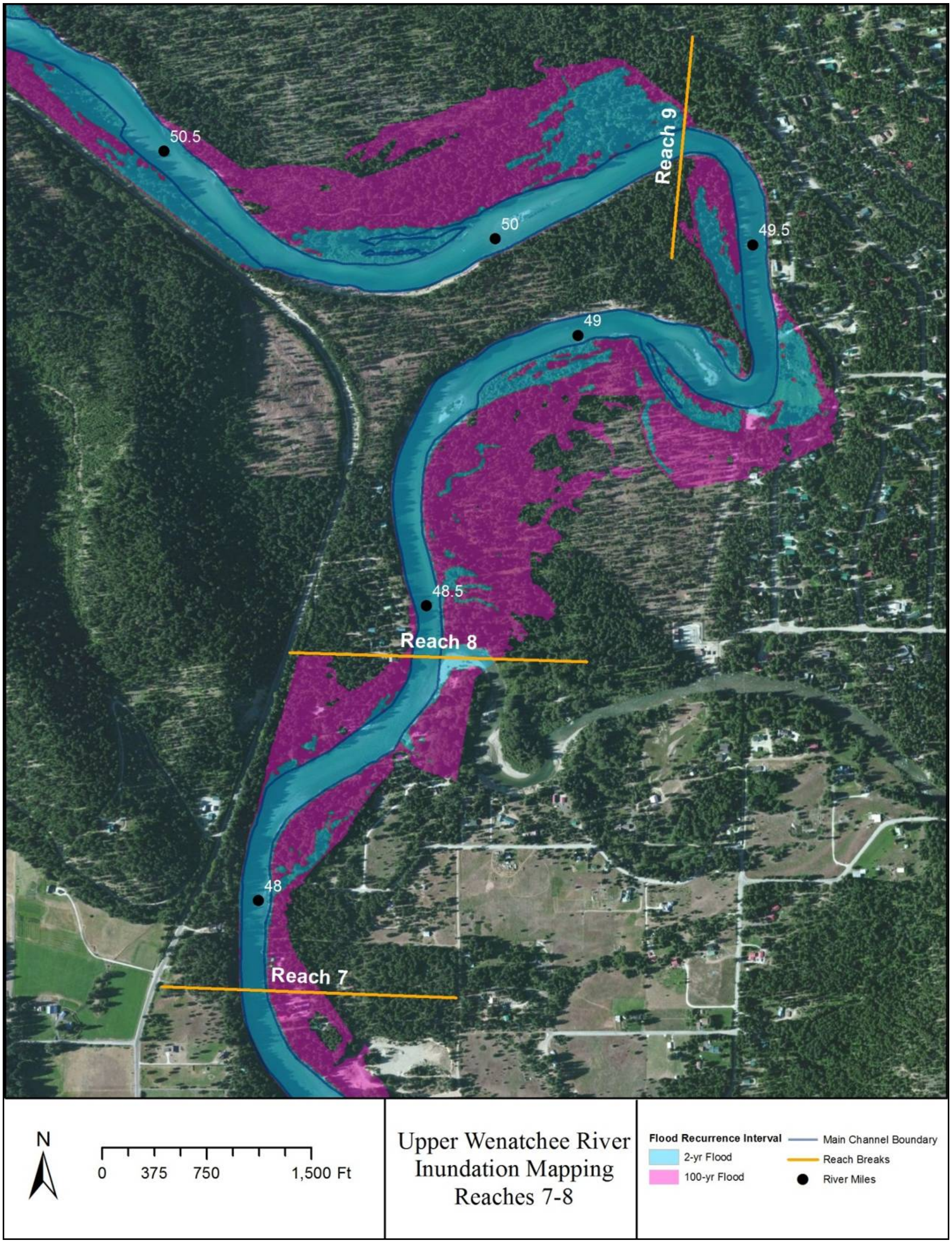

Figure 24. Reach 7 and 8 floodplain inundation mapping for the 2- and 100- year flood events

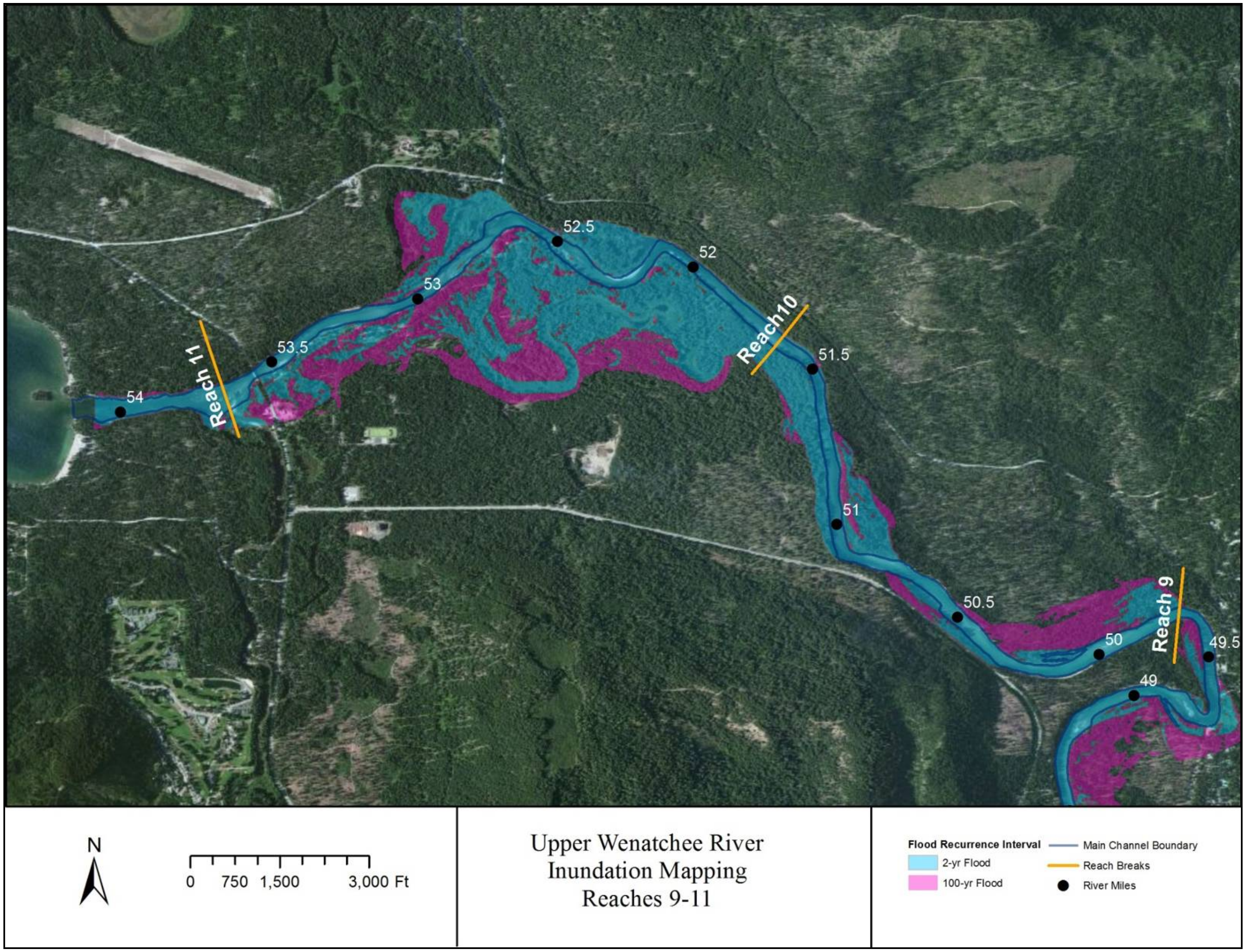

Figure 25. Reach 9, 10, and 11 floodplain inundation potential for the 2- and 100-year flood events.

3.5.3 Geomorphology

Valley Morphology

The Upper Wenatchee meanders south and eastward with channel sinuosity ranging from 1.0 to 1.62. Valley morphology within the study area is a direct result of the relationship between glacial erosion, bedrock lithology, and faulting. In terms of bedrock lithology, the Chumstick Formation that underlies the study reach and outcrops in adjacent hillslopes is relatively easily erodible in comparison to the metamorphic and plutonic rocks of adjacent terranes. Thus glaciers, and later the Wenatchee River, have been able to remove larger amounts of material and create wider valley bottoms than in tributary watersheds or directly downstream portions of the Wenatchee River that flow atop harder bedrock (i.e. Tumwater Canyon). The widest valley width in the study area is located at the upstream end between RM 53.9 and 51.0. Maximum valley width here is over 3,000 feet where Fish Lake Run flows in from the north near RM 52.9; however, the average width in this area is closer to 1,000 feet. Downstream of this point the valley narrows to under 1,000 feet at the widest with several lengths of channel with valley bottoms of only a few hundred feet. Glacial deposits, primarily terraces, create the narrow valley width that persists down to about RM 43.7 (Reach 5). Downstream of RM 43.7, the river has created a wider valley bottom through lateral channel migration at two large bends centered on RM 43 and 41.4. The valley width here increases to over 2,000 ft. Around RM 41 bedrock hillslopes constrict valley width down to under 1,500 feet at wide portions with constrictions of under 200 feet wide. The downstream end of the study reach is at the top of Tumwater Canyon where the river flows out of the sedimentary rocks of the Chiwaukum Graben and onto the crystalline rocks of the Nason-Ingalls Terrane, forming a steep, narrow canyon for several miles downstream.

Channel Morphology

Bed morphology is predominantly pool-riffle and plane-bed with channel slopes ranging from 0.1 to 0.35%. The channel frequently alternates between alluvial and confined reaches. Alluvial reaches are found in areas with wider floodprone widths, and have more channel complexity (point and mid-channel bars, large wood accumulations) and intact riparian vegetation. Confined reaches flow through areas with narrower floodprone widths, with abandoned alluvial terraces naturally limiting lateral migration. In some areas, sediment deposition at the toe of these alluvial terraces has created small, relatively mobile point bars atop which vegetation has established.

Sediment is contributed to the Upper Wenatchee from tributaries and near-channel banks and hillslopes. These banks and hillslopes provide localized sediment from the easily erodible unconsolidated glacial till, glacial terraces, and alluvial deposits along the channel margins (Figure 26). Glacial deposits provide some erosion resistance because in many locations large material has accumulated at the toe of these slopes. However, high flows are still able to easily erode above this toe support and entrain large amounts of fine grain material from banks. Bedrock outcrops found in the study reach hillslopes is chiefly from the Chumstick Formation, which exhibits downslope trending bed planes that make it more susceptible to mass wasting in weaker units (Figure 27). Sediment contributions from the Chumstick Formation would be expected to provide fine-grain material out of sandstone and shale units, and some gravels out of conglomerates. Channel morphologic characteristics are summarized in Figure 28 and Table 9. More detailed geomorphic descriptions for each reach can be found in Section 4.

Figure 26. View of unconsolidated fine grain sediment in terrace slopes along the channel in the study area.

Figure 27. Bedrock outcrop along the channel in the study area (Chumstick Formation). Note that tilting of stratigraphy has resulted in steep dip-slopes toward the channel that can result in planar failures along weak bedding planes.

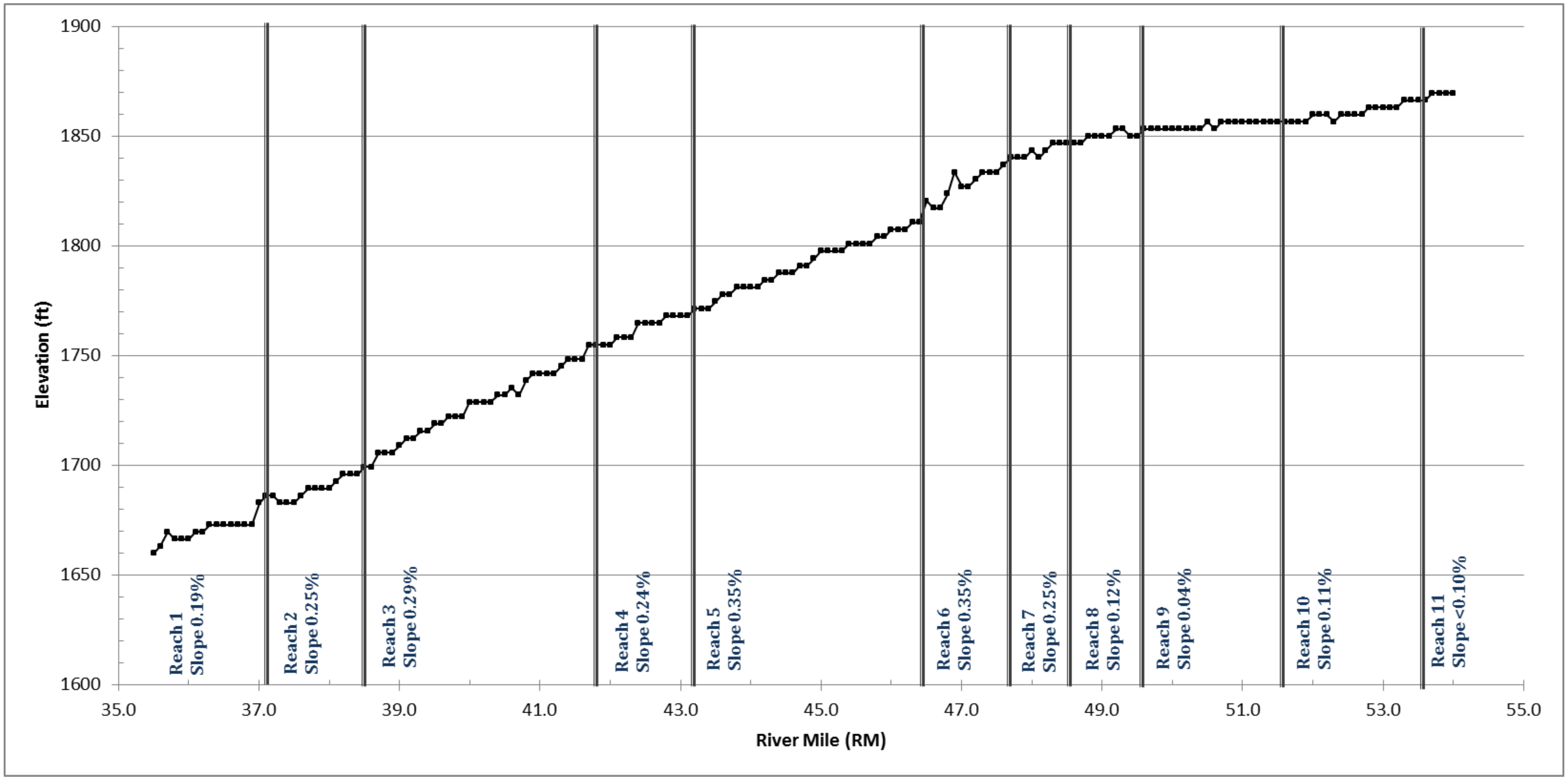

Figure 28 Longitudinal Profile of the Upper Wenatchee River study area from Lake Wenatchee to the top of Tumwater Canyon. Elevation data derived from LiDAR.

Table 9. Summary of geomorphic and habitat conditions at the valley and channel scale among geomorphic reaches in the Upper Wenatchee River.

	Metric	*Reach 1*	*Reach 2*	*Reach 3*	*Reach 4*	*Reach 5*	*Reach 6*	*Reach 7*	*Reach 8*	*Reach 9*	*Reach 10*	*Reach 11*
Channel	**River Miles**	35.5 – 37.6	37.6 – 38.6	38.6 – 41.9	41.9 – 43.1	43.1 – 46.5	46.5 – 47.9	47.9 – 48.4	48.4 – 49.7	49.7 – 51.7	51.7 – 53.7	53.7 – 54.2
	Gradient	0.19%	0.25%	0.29%	0.24%	0.25%	0.35%	0.25%	0.12%	0.04%	0.11%	<0.1 %
	Sinuosity	1.31	1.15	1.42	1.28	1.26	1.44	1.06	1.62	1.28	1.23	1.01
	Dominant Channel Morphology	Pool-riffle	Plane-bed	Pool-riffle	Pool-riffle	Riffle-glide	Riffle-glide	Riffle-glide	Pool-riffle	Plane-bed	Pool-riffle	Plane-bed
	Average Bankfull Width (ft)	325.5	312	270	276	278	NA	282	300	282	242.5	360
Floodplain	**Average Floodprone Width (ft)**	1025.5	671	1164	726	395	NA	882	605	575	786.7	590
	% Floodplain Disconnected[1]	0.0%	14.9%	56%	85.50%	81.10%	90.30%	80.70%	60.50%	0%	58.40%	0%
	% Floodplain Connected	100.0%	85.1%	44%	14.50%	23.30%	9.70%	19.30%	39.50%	100%	41.60%	100%
% Habitat Area	**Pool**	40%	13%	27%	41%	11%	0%	0%	41%	35%	57%	77%
	Riffle	10%	34%	31%	30%	56%	67%	54%	21%	14%	20%	0%
	Glide	26%	47%	23%	22%	33%	23%	46%	31%	47%	20%	18%
	Side Channel	24%	6%	19%	7%	0%	10%	0%	7%	4%	3%	5%

[1] "Disconnected" indicates that the floodprone surface's historical pattern and processes (e.g. inundation extent or frequency) have been altered due to anthropogenic actions. See Appendix B for the analysis of connected and disconnected areas.

3.5.1 Existing Large Wood Dynamics

Existing large wood dynamics in the Upper Wenatchee River are a function of a legacy of river and forest management dating back to the early years of Euro-American settlement. Historical and on-going human disturbances have impacted sources of instream large wood, the recruitment of large wood to the channel, and the ability of the channel to trap and retain wood. These processes (sources, recruitment, and retention) are discussed below with respect to contemporary large wood dynamics in the study area.

Sources

Contemporary large wood sources have been altered by timber harvest and residential development within the study area and within upstream contributing areas. Riparian clearing dating back to the late 1800s has and will continue to impact large wood loading for the foreseeable future. Reforested timberlands now dominate the riparian buffers but the trees are considerably smaller than what would be expected under non-harvested conditions (Figure 29). The 2011 habitat survey (Appendix A) classified nearly half (48%) of the riparian canopy as being dominated by trees less than 21 inches diameter (dbh). It will be decades or centuries before riparian areas mature to the degree that they are able to provide a LWD recruitment source that resembles historical conditions. Although there are relatively few areas with fully cleared riparian corridors, many riparian zones in developed areas have a cleared understory, which limits the future replacement of existing maturing trees, which is needed to provide for long-term large wood recruitment to the channel.

Figure 29. Existing riparian area in Reach 9 (taken October 2011). Large ponderosa pine at center represents an older tree that escaped the last harvest and gives some indication of what historical LWD sources may have looked like.

Recruitment

Recruitment processes have been altered within the study area as well as in upstream contributing areas. Although processes of bank erosion (e.g. meander scrolling) still recruit wood to the channel in some areas, this recruitment process has been limited in many areas due to bank armoring, channel constrictions (e.g. bridges), and human-induced incision that reduces lateral migration rates and therefore reduces the frequency of wood recruitment. Recruitment has also been reduced in upstream contributing areas, particularly in Nason Creek where much of the channel has been straightened, armored, and leveed throughout much of the lower 14 miles. Wood is currently recruited to the study area via transport from upstream sources, bank erosion (where it still occurs), single-tree mortality, and from mass wasting on the high glacial terrace banks. These mass wasting events sometimes form what we refer to as ‘colluvial jams’, which is a pile of wood debris from the landslide that remains in the channel and provides fish habitat. These were likely more common, and more stable once they reached the river, when riparian areas contained larger trees.

Retention

As discussed previously, retention of wood in the channel is a function of both wood size as well as instream complexity, both of which have been affected by the legacy of human alterations. The size of wood that is now contributed to the channel mostly represents second or third growth timber that is smaller than historical LWD and does not have the same ability to self-stabilize within the channel. Although the habitat assessment (Appendix A) found an average of 123 pieces of wood per mile, only 26% of these were greater than 20 inches in diameter, which means the number of “key pieces”, which are the very large diameter pieces that are able to initiate jam formation, would be even less. The shift in riparian seral stage and the corresponding reduction in available key pieces have reduced the ability of wood to accumulate and stay in place throughout the river. Shifts in species compositions from fire-tolerant to fire-intolerant species may have also impacted retention and jam formation. Retention has been further reduced by channel simplification and alterations to streambanks. In many channel margin areas, historical complexity would have been provided via bank irregularities, overhanging vegetation, embayments, and obstructions. These features would have provided locations for wood to become trapped and to initiate log jam formation. Bank complexity was reduced in the early 1900s as part of log drives (see Section 3.4.3) and later by riparian clearing and bank armoring.

3.5.2 Habitat Conditions

Stream habitat conditions were recorded using the USFS Level 2 stream habitat inventory methods. The survey recorded information on habitat unit composition, substrate sizes, large wood quantity, riparian conditions, and bankfull channel dimensions. The habitat assessment summary and reach reports are provided in Appendix A. A brief summary is included below.

Pool frequency ranged from 0.0 to 2.7 pools/mile at the reach-scale and totaled approximately 30% of the total habitat in the study area. Riffles and glides were nearly equally abundant at around 31%. The amount of glide habitat is higher than might be expected if large wood jams were more abundant and available to create and maintain scour pools. Side channels made up 9%

of the measured habitat units, with a total of 33 wetted side-channel units. Reach 1 had the greatest area of side-channel habitat and Reach 3 had the greatest number of side-channel units. The study area also had nine "marsh" habitat types, ranging from small backwaters to large open water ponds. Reach 10 had the greatest amount of "marsh" habitat. Some large side-channels, particularly the Natapoc side-channel complex in Reach 10, were not counted as side-channel habitat in the survey because they were not connected via surface flow. The connectivity of these side-channels has been reduced over time partially as a result of human-induced incision and confinement.

An average of 123 pieces of wood per mile was counted in the study area; 48% of these were "small" pieces with diameters between 6 and 12 inches and lengths greater than 20 feet. Wood frequency at the reach-scale ranged from 13 (Reach 7) to 294 (Reach 1) pieces/mile. As discussed previously, the size, availability, and quantity of wood is lower than what would have been expected historically, which has affected instream channel dynamics and habitat suitability for salmonids.

Bed substrate was dominated by cobbles, followed by gravels and then boulders. Sand typically made up less than 20% of the substrate and bedrock was uncommon. Suitable spawning areas were observed throughout the study area, primarily at the downstream (reaches 1-3) and upstream (reaches 8-11) ends of the study area.

Riparian areas were dominated by native riparian forest vegetation although past timber harvest has reduced overall stand ages. Residential development has impacted riparian conditions in numerous locations, particularly reaches 3-8 and 10. In many areas affected by residential development, large trees dominate the overstory but the understory has been cleared. Results for riparian forest stand ages at the study area scale were 52% large tree (≥ 21" dbh), 41% small tree (9 – 21" dbh), and 7% sapling/pole (5 – 9" dbh).

3.5.3 Reach-Based Ecosystem Indicators

This section presents an overview and summary of the REI results (Table 10), which are presented in more detail in the REI Report (Appendix C). The REI applies habitat survey data and other analysis results to a suite of REI indicators in order to develop reach-scale ratings of functionality with respect to each indicator. Functional ratings include **adequate**, **at risk**, or **unacceptable**. The REI analysis helps to summarize habitat impairments and to distill the impairments down to a consistent value that can be compared among reaches. This analysis is also used to help derive restoration targets as part of the restoration strategy presented in Section 5. The rating definitions, and explanations of how the ratings were made, can be found in Appendix C.

There were no fish passage barriers within the study area so each reach was therefore given a rating of **adequate** for this indicator. Substrate and fine sediment ratings were generally **adequate** or **at risk**, with no **unacceptable** ratings. For the remainder of the indicators, some general patterns are observed. Reaches 1 and 2, which are the least impacted reaches at the downstream end of the study area, tend to have **adequate** ratings for most, if not all, indicators. The two exceptions are LWD and pools in Reach 2. These lower reaches flow through US Forest

Service land and display some of the most complex habitat and geomorphic characteristics of the study reach.

Reach 3 transitions into more human alteration and is rated as **at risk** for most indicators. This reach is bordered by US Forest Service land on the east side but is highly developed with streamside residences on the west side. Reaches 4 through 7 are mostly **at risk** or **unacceptable** for all indicators. These reaches are heavily impacted by on-going human alterations including residential development, roadways, and floodplain alterations. Riparian and floodplain development limit off-channel habitat and channel complexity in these reaches. In reaches 8 through 11, human impacts are less except for in the upstream portion of Reach 10. These reaches are dominated by **at risk** conditions, but are also rated as **adequate** or **unacceptable** depending on the indicator.

For the study area as a whole, **at risk** was the most common rating (52), followed by **adequate** (41), and then **unacceptable** (28).

Table 10. Reach-Based Ecosystem Indicator (REI) results. See Appendix C for the REI report.

General Characteristics	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Habitat Assessment	Physical Barriers	Main Channel Barriers	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate
Habitat Quality	Substrate	Dominant Substrate/Fine Sediment	adequate	adequate	adequate	at risk	adequate	adequate	adequate	at risk	at risk	adequate	adequate
	LWD	Pieces per mile at bankfull	adequate	unacceptable	at risk	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable
	Pools	Pool frequency and quality	adequate	at risk	at risk	at risk	at risk	unacceptable	unacceptable	at risk	at risk	at risk	at risk
	Off-Channel Habitat	Connectivity with main channel	adequate	adequate	at risk	unacceptable	unacceptable	at risk	unacceptable	at risk	at risk	at risk	at risk
Channel	Dynamics	Floodplain connectivity	adequate	adequate	at risk	unacceptable	unacceptable	unacceptable	unacceptable	at risk	at risk	at risk	adequate
		Bank stability/Channel migration	adequate	adequate	unacceptable	unacceptable	unacceptable	at risk	adequate	adequate	adequate	unacceptable	adequate
		Vertical channel stability	adequate	adequate	at risk	unacceptable	at risk	at risk	at risk	at risk	unacceptable	at risk	at risk
Riparian Vegetation	Condition	Structure	adequate	adequate	at risk	at risk	at risk	at risk	at risk	at risk	at risk	at risk	at risk
		Disturbance (human)	adequate	adequate	unacceptable	at risk	unacceptable	unacceptable	at risk	at risk	at risk	at risk	at risk
		Canopy Cover	adequate	adequate	at risk	at risk	unacceptable	at risk	at risk	at risk	adequate	at risk	at risk

4 REACH-SCALE CONDITIONS

This section describes forms and processes and the effects of human alterations at the reach-scale. Additional information on instream habitat conditions, riparian conditions, and channel geometry can be found in the Habitat Assessment (Appendix A).

4.1 Reach 1

4.1.1 Reach Overview

Reach 1 is 2.1 miles long and extends from the Highway 2 Bridge (RM 35.5) upstream to RM 37.6 (Figure 30). This reach has a braided form with multiple point and mid-channel bars, partially vegetated islands, and connected backwaters. Additional sediment and surface water is contributed by Chiwaukum Creek that enters the mainstem Wenatchee River 0.4 miles from the downstream boundary of the reach. Other minor seasonal surface water sources include ephemeral hillslope drainages (ten on river left and six on river right). With an average bankfull width of 325.5 feet, the channel is relatively wide compared to most upstream reaches. Modern geomorphic forms and processes and their associated habitat elements appear relatively unaffected by direct human influence over the past 50 years. However, some evidence of historical log drives, splash damming, and riparian timber harvest exist. This reach is bordered primarily by public lands managed by the US Forest Service. The topography of the surrounding hillslopes is relatively steep and difficult to access upstream of the Chiwaukum Creek confluence. Due to the limited effects of human alterations, this reach serves as a reference for habitat restoration targets for other reaches within the study area.

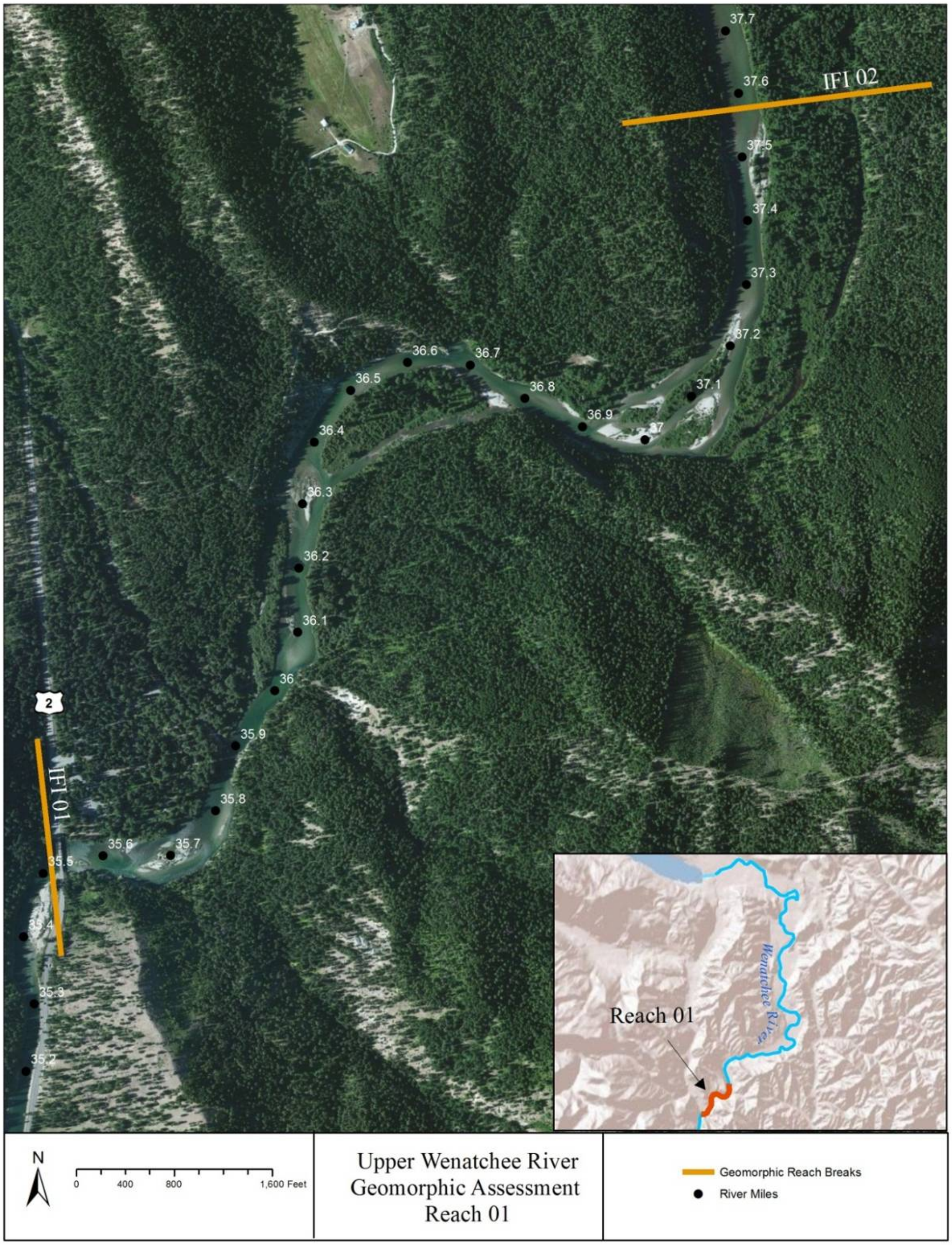

Figure 30. Overview map of Reach 1. Flow is from north to south.

4.1.2 Forms and Processes

Reach 1 is a braided reach with multiple bars and islands (Figure 31). Active depositional surfaces are present as mid-channel features and marginally along the channel's edge (e.g. RM 36.35 to RM 36.8). Both the mid- and margin-bar deposits are partially to well-vegetated and are often associated with complex secondary channels and/or backwater alcoves. Hyporheic flow through gravel and mid-channel bars occurs throughout the reach but is most prevalent in the widest segments of the valley. Channel units alternate between riffle-glide and pool-riffle. The pools throughout the reach are relatively deep (3 to >12 feet) and often channel-spanning. The riffles are complex and often transverse.

The channel and its modern floodplain are partially confined by terrace deposits and hillslopes composed of sedimentary conglomerates, ultramafic rocks, and outcrops of the Chumstick Formation. We applied the definition of partial confinement used by Brierley and Fryirs (2005), which is 10 to 90 percent of a channel's banks having contact with a valley wall. This confinement limits lateral migration and sinuosity. Although partially confined, the channel and modern floodplain of Reach 1 range in width from 0.1 to 0.25 miles – this is relatively wide compared to other reaches in the study area. The gradient of the channel in this reach is 0.19%, with a sinuosity of 1.31.

This reach is generally transport-limited, resulting in the predominance of the depositional features described above. Channel margin and mid-channel roughness features (e.g. riparian vegetation and large wood) promote gravel accumulation in these areas. The sediment supply of Reach 1 is further supplemented by the modern Chiwaukum Creek's alluvial fan. The sediment inputs from the Chiwaukum are prevalent from the downstream reach boundary to RM 36.0. The bedrock boundary of Tumwater Canyon, which is immediately downstream of this reach, serves as a hydraulic constriction and grade control for the reach as a whole.

Observed deposition and scour on floodplain surfaces indicates regular inundation by the channel. This is confirmed by the floodplain inundation hydraulics analysis presented in Section 3.5.2. Prominent floodplain scarring visible in LiDAR and aerial imagery suggests that creation and abandonment of braids and side-channels occurs somewhat regularly throughout portions of this reach. These processes have created channel and floodplain complexity.

Large wood accumulations are found on point bars and as apex jams at the upstream end of mid-channel bars and islands throughout the reach. It is well supported in the literature that bar complexes act as flow obstructions that promote the retention of wood more readily than simplified channels (Fetherston et al. 1995, Gurnell et al. 2000a, Gurnell et al. 2000b, Haga et al. 2002, Bocchiola et al. 2008). Such accumulations are predicted to promote both geomorphic and habitat function (Bisson et al. 1987) including the creation of pools, sediment retention (trapping) and sorting, creation of multi-thread channels, and increased channel complexity and cover for fish (Bjorn and Reiser 1991, Beechie and Sibley 1997, Montgomery et al. 2003, Beechie et al. 2005). Therefore, it is assumed that the presence of LWD is both a driver and a result of the complex channel-floodplain processes occurring in Reach 1.

Banks and beds are composed of gravels, sands, and cobbles with cobbles (41-44%) and gravels (32-52%) dominating. Bedrock was observed in two isolated units at RM 35.9 and RM 37.0. The riparian canopy is dense, of mid-seral stage in most locations, and provides excellent canopy cover. Dense thickets of dogwood provide significant floodplain roughness throughout the reach. Future sources of large wood material exist throughout the reach along the margins of the channel. However, larger key pieces for recruitment of other large wood are currently uncommon in the channel.

Figure 31. Representative geomorphology of Reach 1.

4.1.3 Effects of Human Alterations

Modern human alterations to this reach are limited, but there is evidence of historical timber harvest and log transport, including a mid-seral stage riparian forest, remnant log pilings (Figure 32), and sunken cut logs (presumably log drive remnants). Potential impacts from these activities are discussed in Section 3.4, but without historical data it is difficult to estimate the specific extent of human alteration. Despite past impacts, it is believed that this reach has been on a trajectory of recovery over at least the past 50 years, which has resulted in the modern habitat complexity observed today.

Modern human impacts are relatively minor and include a US Forest Service Campground (Tumwater Campground), a limited-access gravel road, and the Highway 2 Bridge. The campground is located along the right bank at the downstream end of the Chiwaukum - Wenatchee River confluence, near the downstream end of the reach. The site of the campground is atop the historical floodplain and fan deposit terraces of Chiwaukum Creek. Segments of the campground road network traverse western portions of the Chiwaukum alluvial fan(s), but do not appear to impact Chiwaukum Creek’s geomorphic function. A US Forest Service road runs along much of Reach 1’s right bank, but it is elevated above the modern floodplain surfaces. Located at the downstream boundary of the reach is the Highway 2 Bridge. Large boulder riprap armors the two cement bridge abutments and banks.

Human alterations are displayed in Figure 33, Figure 34, and Figure 35.

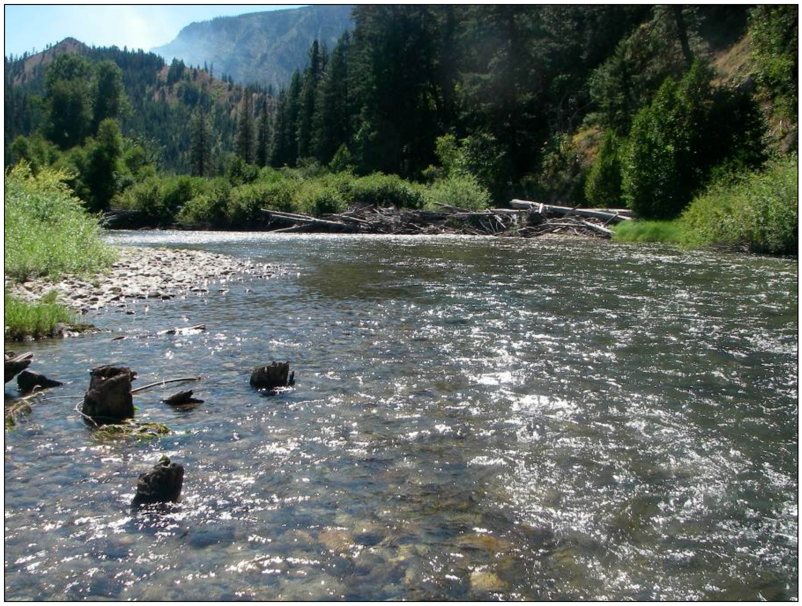

Figure 32. Remnant pilings assumed to be from historical logging practices (splash damming).

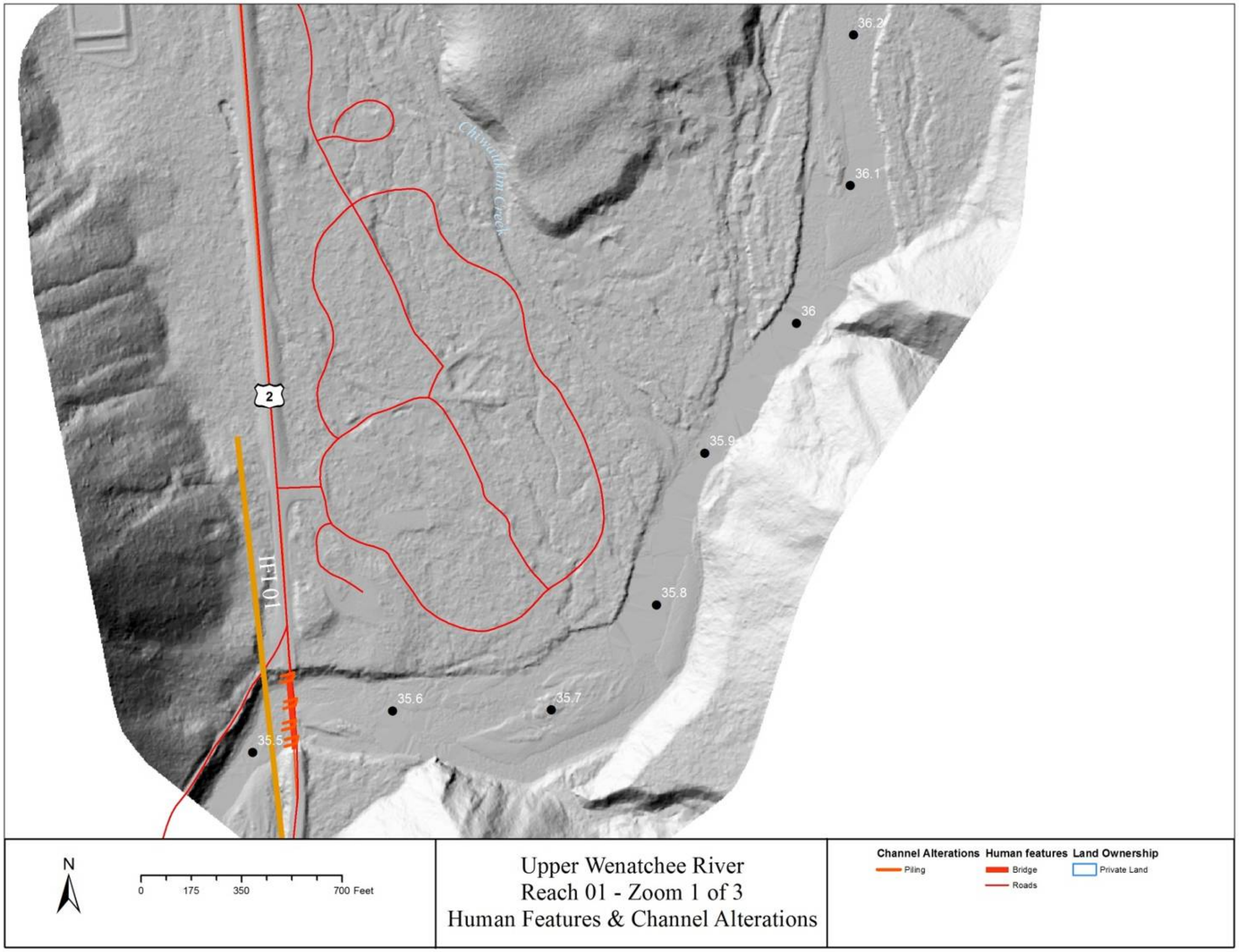

Figure 33. Human alterations in the downstream portion of Reach 1. Flow is from north to south.

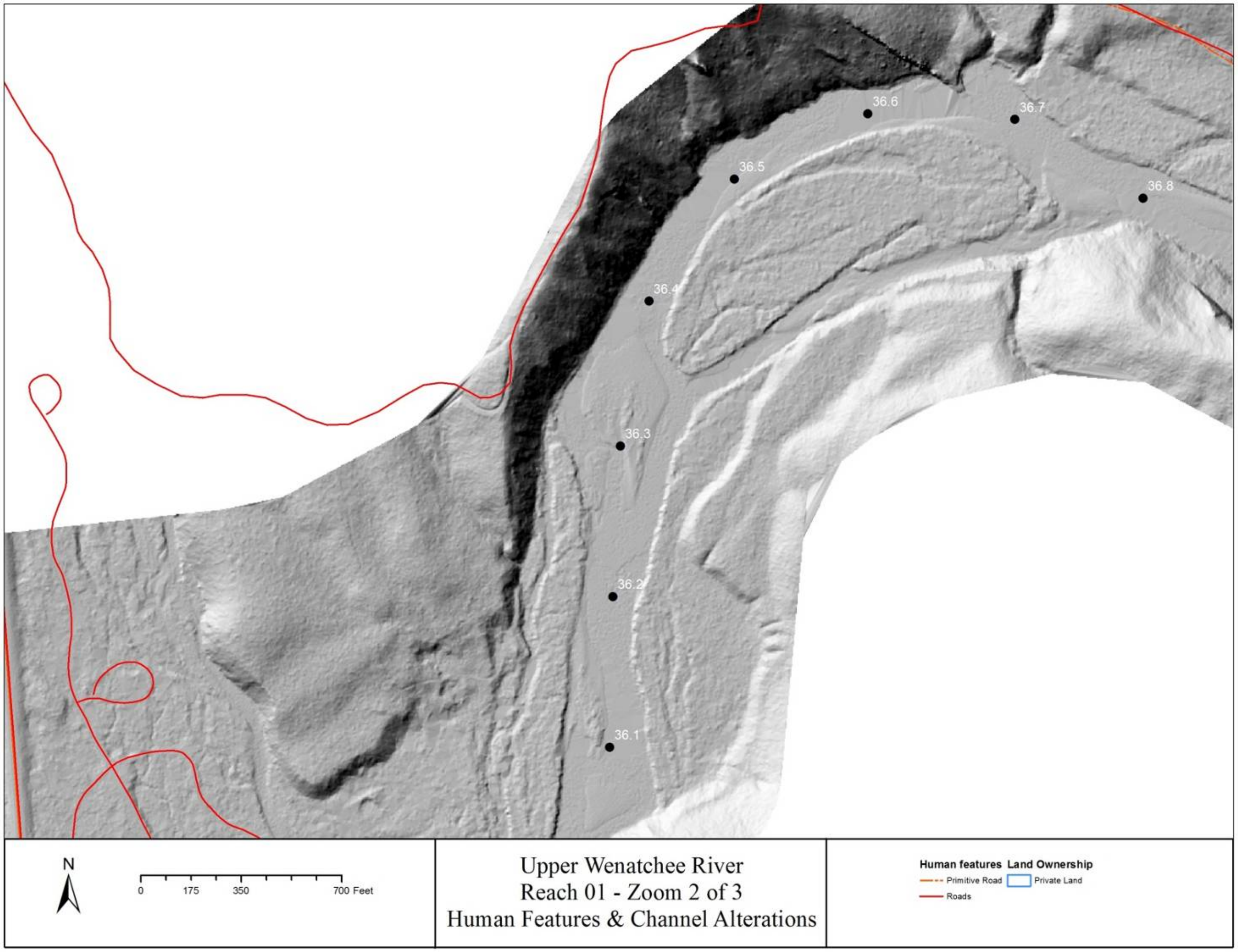

Figure 34. Human alterations in Reach 1. Flow is from north to south.

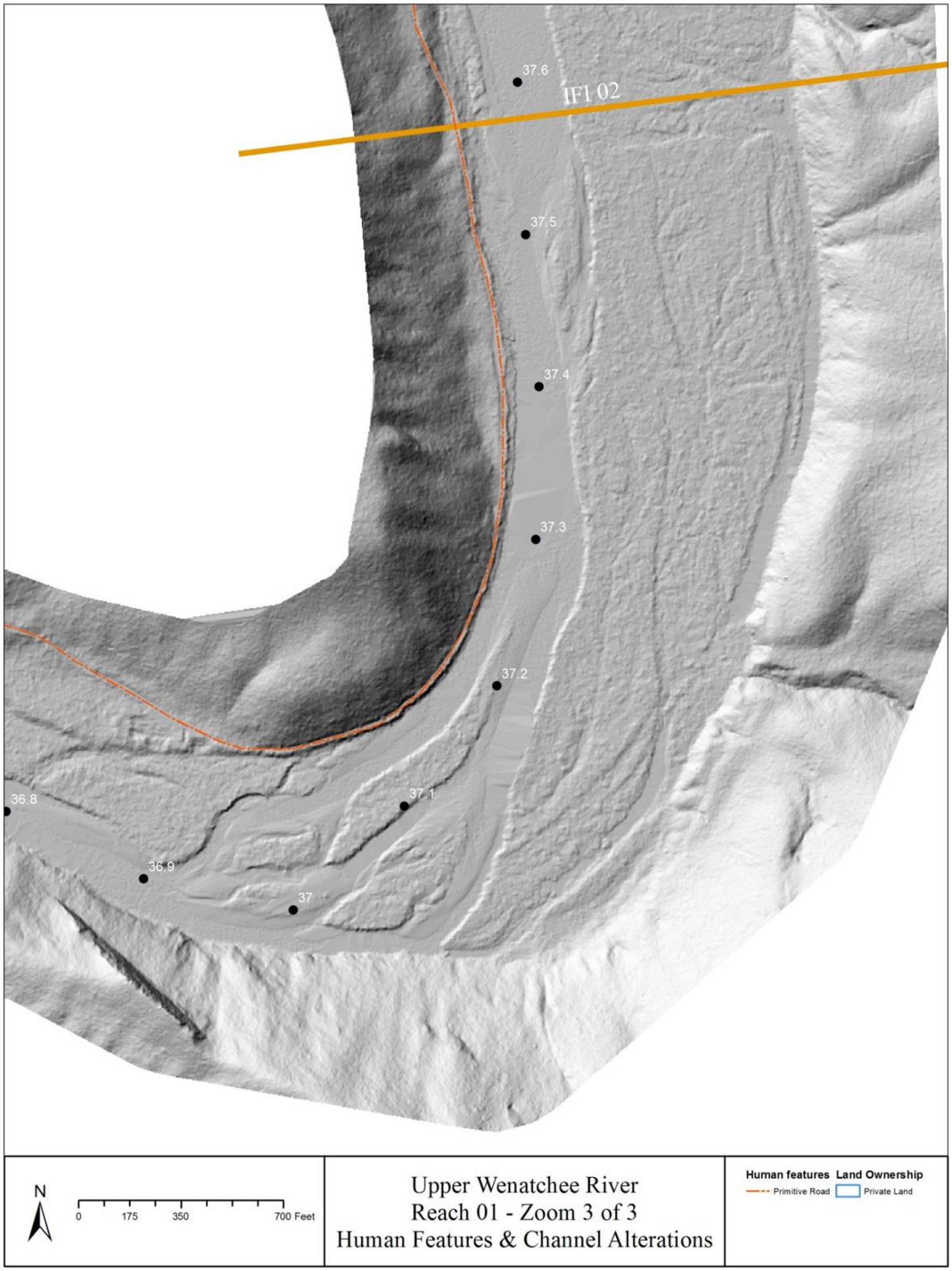

Figure 35. Human alterations in the upstream portion Reach 1. Flow is from north to south.

4.2 Reach 2

4.2.1 Reach Overview

Reach 2 is one mile long and extends from RM 37.6 to RM 38.6 (Figure 36). The reach has a confined slight meandering form with some longitudinal bar development at the channel margin and one mid-channel bar and a point bar that are located at the downstream end of the single meander bend. The channel is notably less wide than Reaches 1and 3. The channel and its floodplain surfaces are confined by hillslopes of the Chumstick Formation on river-right and river-left. Minor seasonal surface water sources include ephemeral hillslope drainages (four on river left and nine on river right). Similar to Reach 1, the geomorphic forms and processes, and their associated habitat elements, seem relatively unaffected by direct human influence for the past 50 years. However, evidence of historical riparian timber harvest exists. The reach is bordered primarily by forested public lands managed by the US Forest Service. Surrounding hillslopes are relatively steep with ground-access limited to an unmaintained USFS road on river-right.

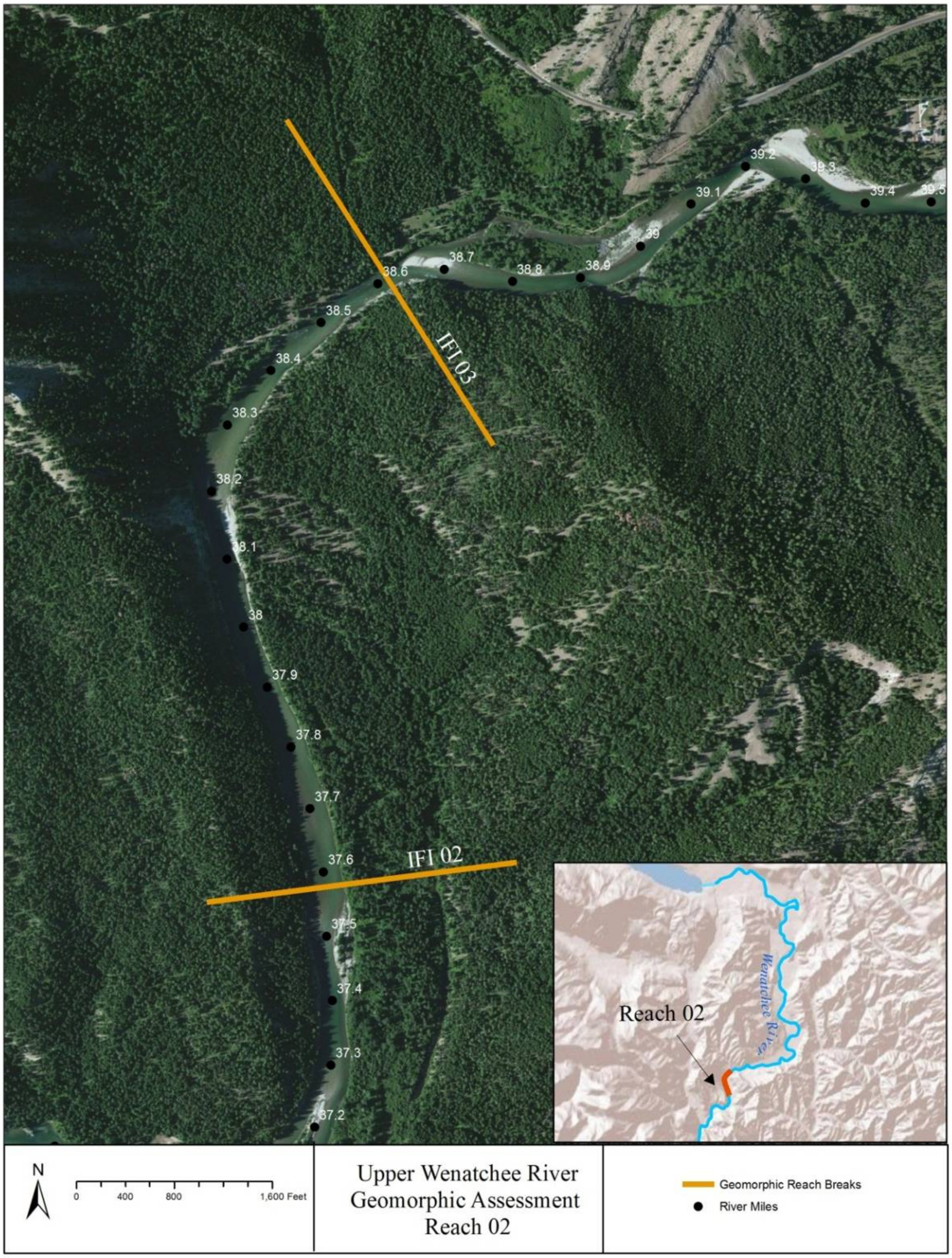

Figure 36. Overview map of Reach 2. Flow is from north to south.

4.2.2 Forms and Processes

Reach 2 slightly meanders with a channel sinuosity of only 1.15. The channel is relatively flat, homogenous, and plane-bed. The gradient of the channel in Reach 2 is 0.25%. Bed substrate ranges from sands to boulders but is dominated by cobbles (See Habitat Assessment – Appendix A). The channel and its modern floodplain surfaces are partially confined by hillslopes composed of the Chumstick Formation along river-right from RM 37.6 to RM 38.2 and river-left from RM 38.4 to RM 38.6. A small (9.24 acres) abandoned historical alluvial floodplain surface further confines the channel along river-left from RM 38.1 to 38.15.

Although more narrow and with a higher gradient than Reaches 1and 3, this reach maintains modern floodplain surfaces but only minor active bar surfaces (see Figures 4 and 5 in Appendix B). A single mid-channel bar and a point bar are present at the downstream end of the only meander bend (RM 38.2). The largest floodplain surface at RM 37.6 to RM 38.1 is on river-left and connects to a similar surface downstream in Reach 1. Average combined width of the channel and its modern floodplain surfaces here is 671 feet.

Figure 37. Representative plane-bed morphology of Reach 2.

Reach 2 is marginally transport dominant. This classification is based on increased bed-material grain sizes and slope compared to Reach 1 and 3, minimal active bar surfaces, simplified bed topography, reduced width, and in-channel sediment supplied downstream to Reach 1.

Along the landward side of the main floodplain unit (river-left, RM 37.6 to RM 38.1), there are wetted channel scars that connect to similar features downstream in Reach 1. These wetted areas are sourced by both hillslope runoff and hyporheic flow. In Reach 2, the wetted abandoned channels are silting in and discontinuous in the upstream portion. The floodplain scaring suggests that the lower portion of this reach was recently more complex than present. It is stipulated that large wood jam(s) likely influenced more dynamic channel-floodplain connectivity here.

This reach has experienced incision resulting in the abandoned historical floodplain surface on river-left. Parallel topographic steps extend from the abandoned floodplain surface in a downstream transverse pattern onto the modern floodplain. Age of established tree cover on the transverse scrolls decreases with relative elevation of the step surfaces. This suggests that channel straightening and simplification occurred in tandem with incision. Hydraulic modeling of floodplain inundation (Section 3.5.2) confirms the transverse incision pattern and it highlights the subtle natural levee developing along river-left as a result of high-flow deposition of the simplified channel. The hydraulic modeling also indicates that much of the wide, wetted and scarred floodplain behind the natural levee is inundated at flows equivalent to or less than the two year flood event. Further analysis of tree stand age would establish rate of incision through the reach and may provide more insight to historical conditions.

Exposed bedrock is located at RM 37.9 and RM 38.6. The presence of bedrock imposes a vertical control on channel processes. At these locations, the river has reached an elevation at which incision rates are limited. This has possibly allowed Reach 2 to maintain connectivity with much of its floodplain.

Large wood accumulations are minor but present. Some accumulations are found at the margin of the channel. Large wood is also present where bar development is occurring.

Riparian vegetation in Reach 2 is well-developed relative to other portions of the study area. Vegetation is primarily of mid-seral stage. This provides for well-functioning canopy cover along the banks, future sources of large wood material, and hydrologic and hydraulic regulation.

4.2.3 Effects of Human Alterations

Modern human alterations throughout this reach are limited in the past 50 years. However, evidence of historical timber harvest and log transport exists throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4.3. Notable in this reach is the past harvest of mature riparian trees, which has reduced the available large wood sources to the stream and floodplain. It is likely that the incision andchannel simplification of this reach was accelerated by past log drives and splash dams (primarily through channel scouring and/or removal of large wood jams). However, without historical data it is difficult to estimate the specific extent of human alterations to this reach.

Existing human alterations include a primitive road that abuts the channel on river-right from RM 38.5 to RM 38.6. There is some fill associated with the road but impacts to the channel are minimal as it does not appear to affect channel migration rates or impact floodplain inundation.

Human alternations and development are illustrated in Figure 38 and Figure 39.

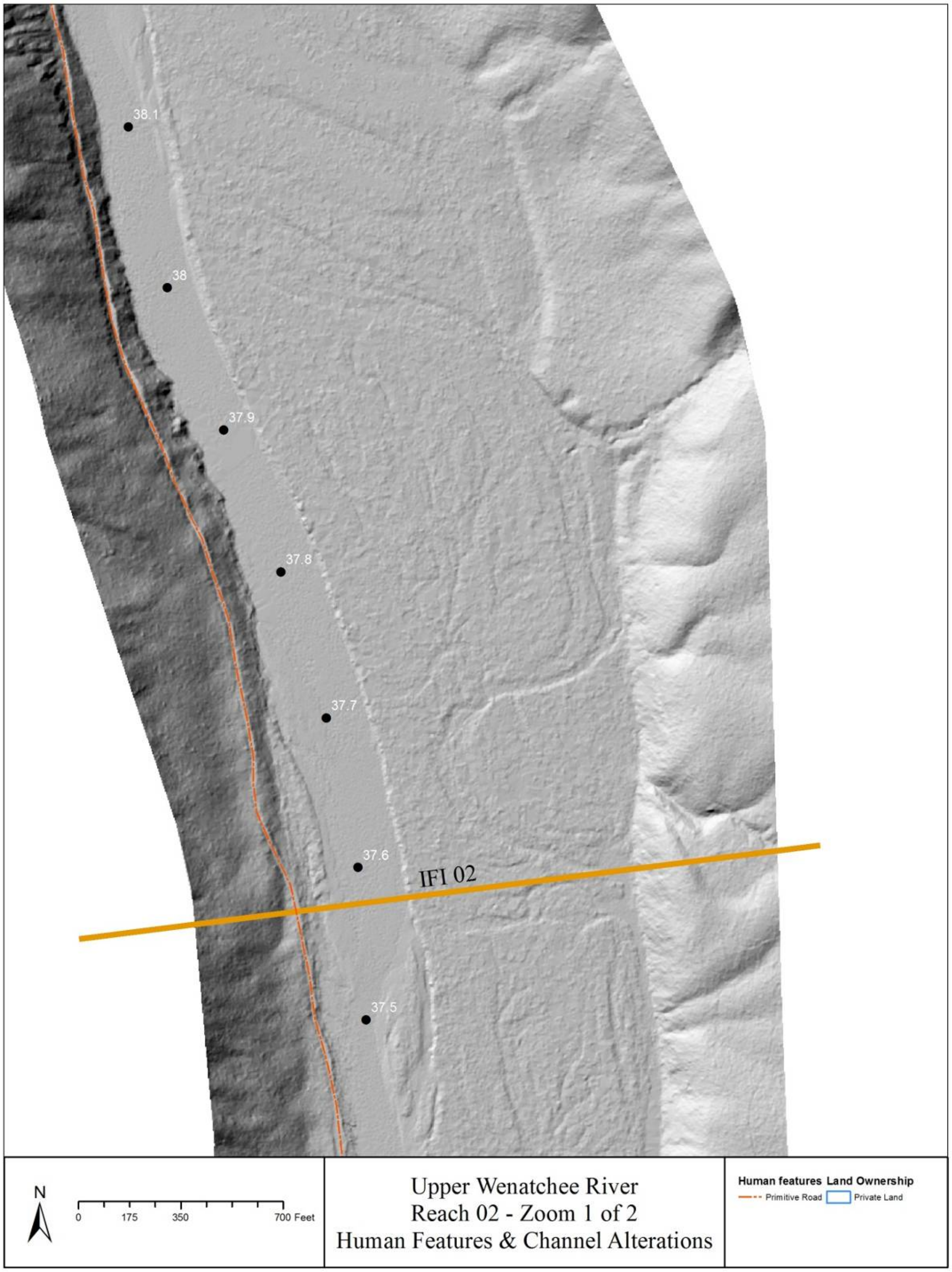

Figure 38. Human alterations in the downstream portion of Reach 2. Flow is from north to south.

Figure 39. Human alterations in the upstream portion of Reach 2. Flow is from north to south.

4.3 Reach 3

4.3.1 Reach Overview

Reach 3 is 3.3 miles long and extends from RM 38.6 upstream to the Burlington Northern Railroad Bridge at RM 41.9 (Figure 40). This is a complex reach with prevalent point and mid-channel bars and a few small vegetated islands. Floodplain surfaces contain numerous connected high flow channels and backwater features. Fourteen ephemeral drainages on the left bank and twelve on the right bank contribute seasonal surface water inputs to the system. Deadhorse Creek enters on river-right at RM 38.62 and is substantial enough that it continues to contribute small quantities of surface flow during the dry summer months. Impacts on geomorphic forms and processes from anthropogenic development begin to increase in Reach 3 relative to Reaches 1 and 2. Private homesite and infrastructure development on the floodplain as well as bank hardening through the installation of riprap and retaining walls exists throughout much of the reach on the river-right floodplains and banks. Despite this development, limited incision or confinement is occurring in the channel. As a result, access to off channel habitat is available through much of the reach.

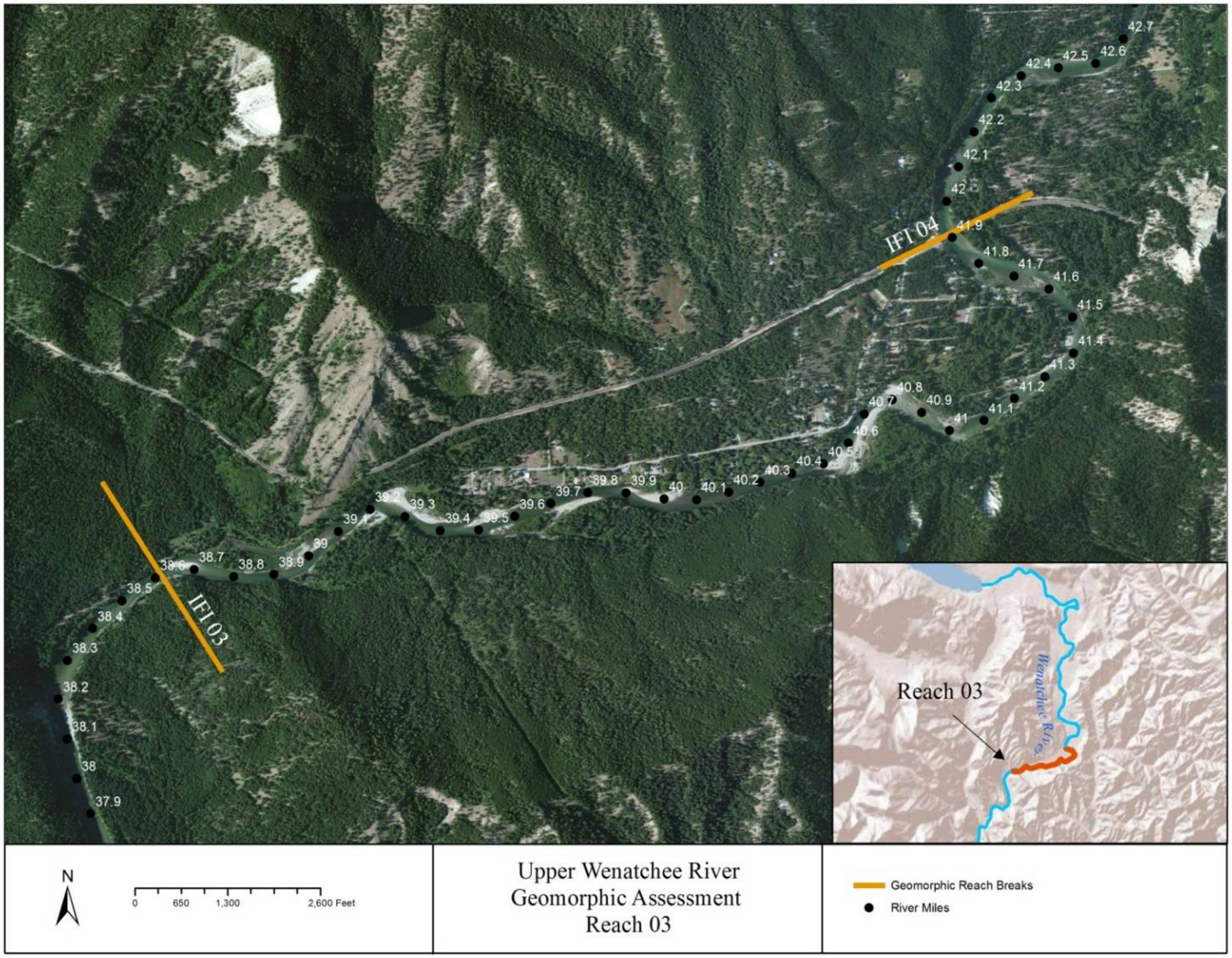

Figure 40. Overview map of Reach 3. Flow is from northeast to southwest.

4.3.2 Forms and Processes

Reach 3 is a meandering channel with plentiful active bar surfaces and relatively low floodplain surfaces that have gradually sloping banks. Large mid-channel bars are prominent in the upper half of the reach and the presence of vegetated islands shifts the lower half of the reach into a partially braided form. The bed morphology is primarily pool-riffle, with periodic occurrences of riffle-glide sequences (Figure 41 and Figure 42). There are extensive transverse riffles in the lower portion of the reach. Bedrock exposures of the Chumstick Formation are visible within the channel between RM 40.8 and RM 41, which control and steepen the channel gradient. Hyporheic flow through gravels and mid-channel bars occurs throughout the reach.

Figure 41. Representative of upstream portion of Reach 3 (July 25, 2011). Taken at RM 41.9 on right bank facing downstream.

Figure 42. Representative of downstream portion of Reach 3 (July 26, 2011). Photo taken at RM 38.61 from right bank facing upstream.

The channel and its modern floodplain are partially confined by the Chumstick Formation and glacial deposit terraces. The channel is further confined by development and periodic bank hardening of the floodplain on river-right. The channel and modern floodplain of Reach 3 range in width from 0.1 to 0.37 miles - widening in a downstream pattern. Topographic features on the anthropologically-impacted floodplains suggests that the active floodplain was wider historically (pre-development). Over-bank deposits and visible scarring/scour indicate that the modern floodplain surfaces along the left bank are active (i.e. regularly inundated) especially between RM 40.6 and RM 41. This is confirmed by the floodplain inundation hydraulics analysis presented in Section 3.5.2. The gradient of the channel in this moderately complex reach is 0.29%, with a sinuosity of 1.42.

Although Reach 3 exhibits the steepest gradient of the entire study area, it is generally transport-limited, resulting in the predominance of active depositional features. Most of the bars lack mature or well-developed vegetation indicating frequent inundation (scour and deposition), temporary sediment storage, and frequent remobilization of bedload. Throughout the reach, high flow events activate secondary channels and scour floodplain surfaces (especially along river-left). Where banks are not hardened by riprap, this appears to be a laterally active reach.

Substrate, bars, and islands are composed of sands to large cobbles and sparse boulders with cobbles (37%) and gravel (28%) dominating. The riparian canopy increases in density and maturity in a downstream pattern. The lower portion is of mid-seral stage in most locations along river-left and provides good canopy cover. The mature riparian and floodplain vegetation provides hydraulic roughness during overbank flows - important for floodplain development and stabilization. Vegetation is altered in the residentially developed areas. Where banks have been hardened with riprap, the riparian bank vegetation has been removed.

Large wood accumulations are found on bars and as apex jams at the upstream end of some mid-channel bars. Two notably large bar apex log jams are located at RM 39 and at RM 41.8 (Figure 43). These massive apex jams add localized complexity to the system. Historically, depositional areas throughout this reach likely accumulated large amounts of wood during flood events, creating geomorphic and habitat complexity.

Figure 43. Locations of large wood accumulation in Reach 3.

4.3.3 Effects of Human Alterations

Throughout the reach, the right bank has been highly modified by anthropogenic development. At the upstream end of Reach 3 (RM 41.9) the railroad bridge abutments and associated riprap create a localized artificial channel constriction. This constriction limits lateral channel migration and creates a localized increase in channel velocities, which has created scour pools.

Bank hardening (e.g. riprap, concrete walls) and boulder spurs associated with the development of homesites are present in Reach 3 along the right bank (RM 39.55 to RM 41.81). Extensive riprap (Figure 44) and cement wall construction are located at RM 40.9 to RM 41.8. This bank hardening has disconnected a significant portion of floodplain and restricts channel migration. Site assessment and LiDAR elevation data indicate that this area would be active if bank hardening and walls did not prevent (or limit) floodplain inundation. Despite extensive bank alteration, field observations indicate that flooding continues to be a challenge to homeowners.

Residential development along river-right further reduces floodplain connectivity. Floodplain dissection from road construction to homesites is common and often includes fill or grading of surfaces. A primitive gravel road extends along river-right from RM 38.6 to RM 39.45 that turns into a paved primary road (River Road) from RM.45 to RM 41.9. Vegetation removal and alteration is also common in association with homesite development in Reach 3.

Figure 44. Riprap on river-right (RM 42.8).

Historical timber harvest and log transport occurred throughout the study area (see Section 3.4.3). The historical harvest of mature riparian trees has reduced large wood sources available to the stream and floodplain.

At the downstream boundary of the reach (RM 38.62), a perched culvert disconnects the Deadhorse Creek tributary from the mainstem (Figure 45). The culvert (5ft x 3ft) is perched approximately 2 feet above a connector pool to the Wenatchee River. On the date of the survey, juvenile salmonids were observed in the scour pool that is created at the downstream end of the culvert. Although this perched culvert disconnects potential habitat in Deadhorse Creek, the estimated loss of in-channel habitat is only 190 feet due to a natural salmonid barrier created by a gradient increase at the valley wall.

Human alterations are mapped in Figure 46, Figure 47, Figure 48, and Figure 49.

Figure 45. Perched culvert in Deadhorse Creek (RM 38.6). Surface water connection was present on day of survey (July 26, 2011).

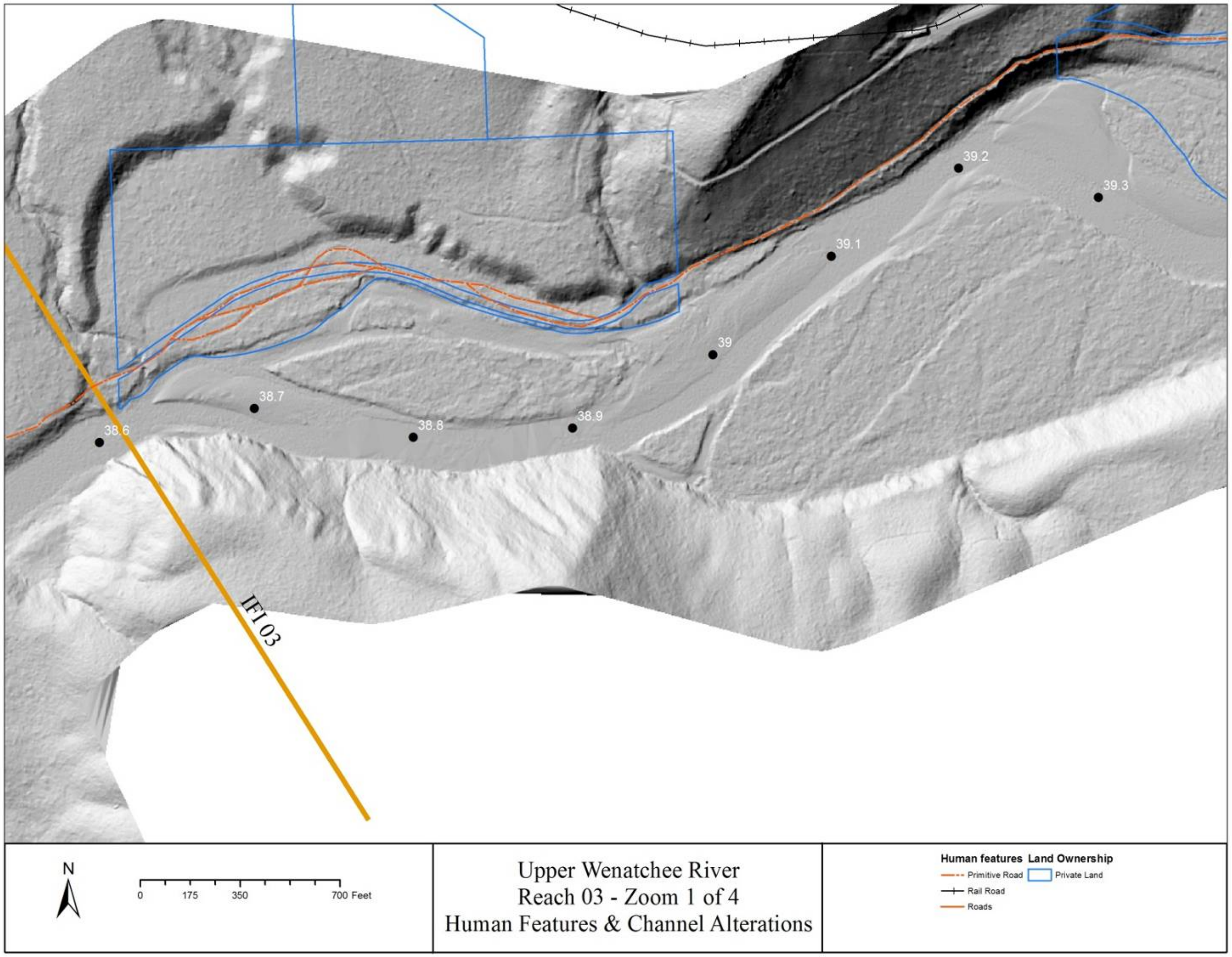

Figure 46. Human alterations in the downstream portion of Reach 3. Flow is from east to west.

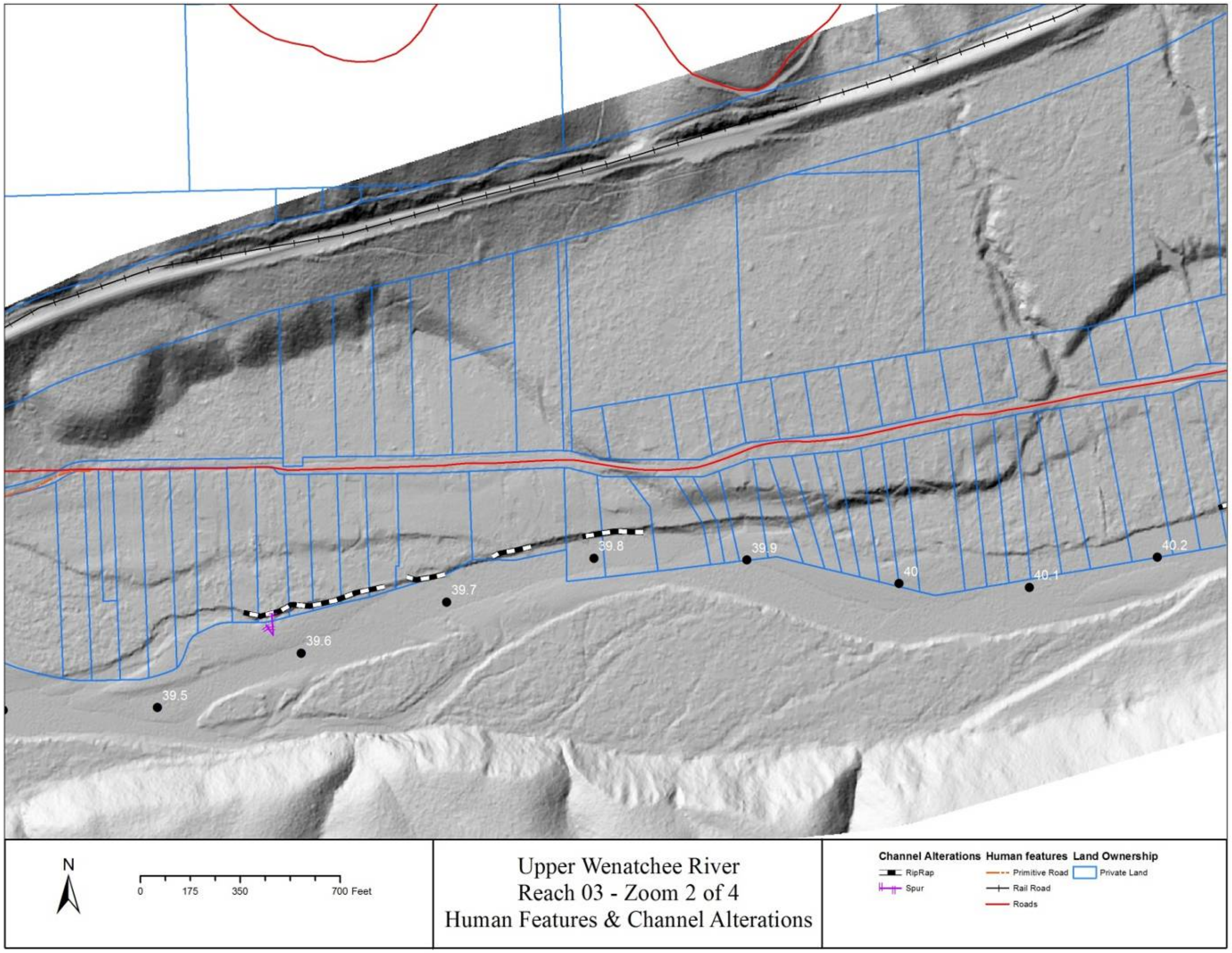

Figure 47. Human alterations in Reach 3. Flow is from east to west.

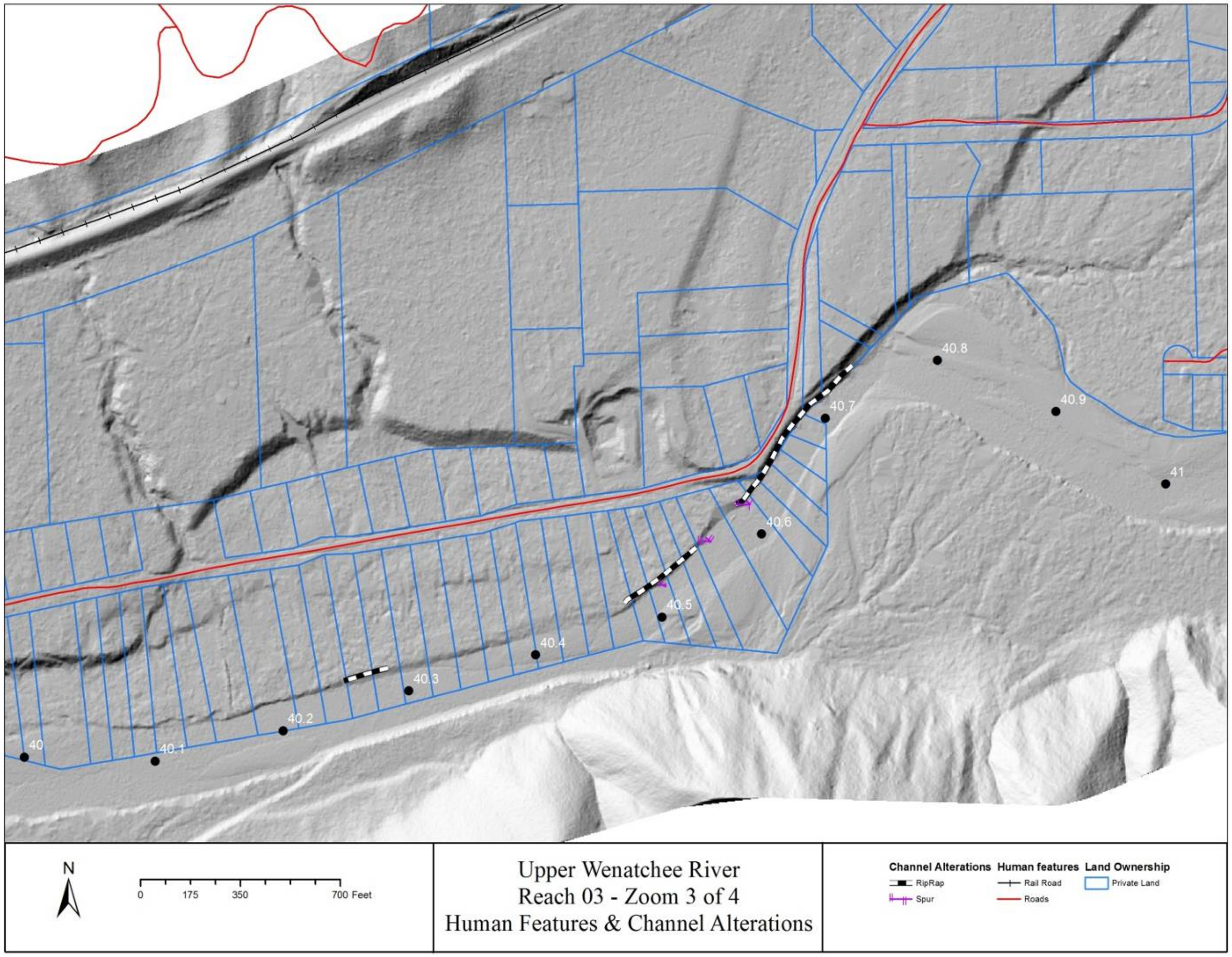

Figure 48. Human alterations Reach 3. Flow is from east to west.

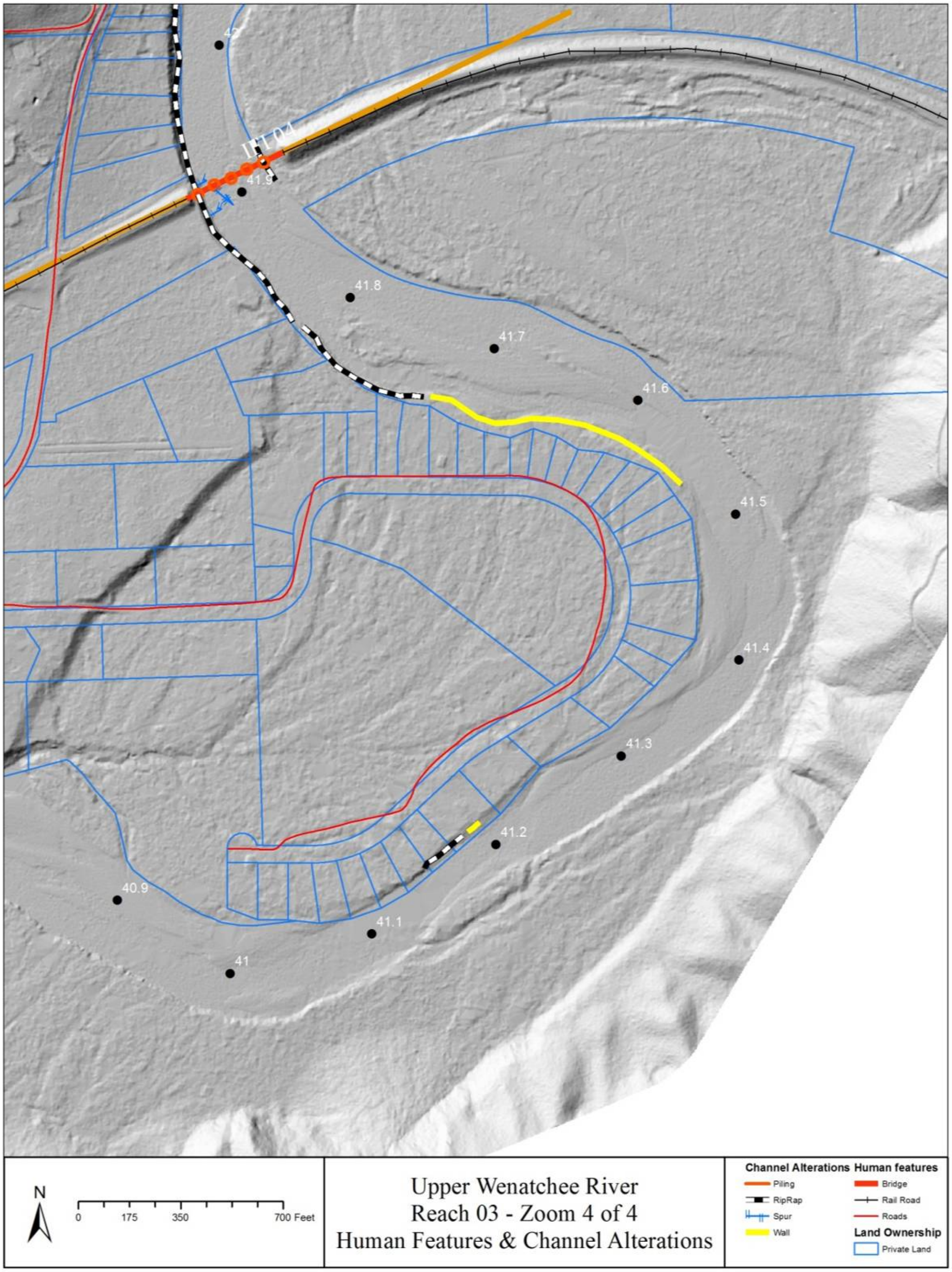

Figure 49. Human alterations in the upstream portion of Reach 3. Flow is from north to south.

4.4 Reach 4

4.4.1 Reach Overview

Reach 4 is 1.2 miles long and extends from the Burlington Northern Railroad (RM 41.9) upstream to RM 43.1 (Figure 50). This is a confined meandering reach with minimal mid-channel and point bar development. Mid-channel bars are present in conjunction with pockets of connected floodplain surfaces and side channel habitat. Minor seasonal surface water input sources include ephemeral hillslope drainages (three on river-left and four on river-right). Two additional ephemeral drainages are leveed by the railroad and redirected to enter the Wenatchee at RM 41.9 on river-right. Residential development influences floodplain inundation.

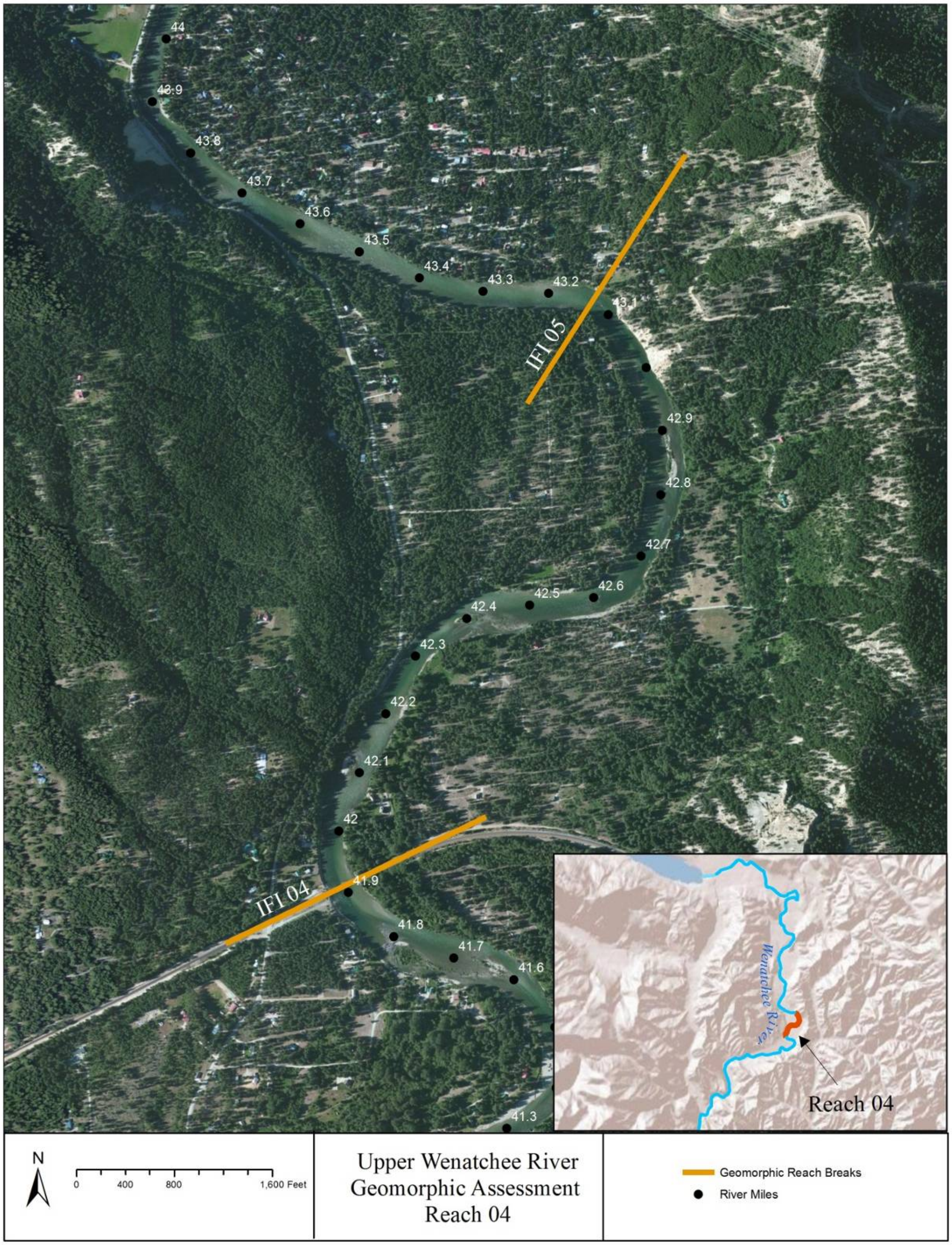

Figure 50. Overview map of Reach 4. Flow is from north to south.

4.4.2 Forms and Processes

Reach 4 is a meandering reach with minor mid-channel and point bar development (Figure 51). Sinuosity of the channel is 1.28. Mid-channel bars were located at RM 42.1, RM 42.4 and RM 42.9, which correspond with widening of the channel and a reduction in channel gradient. Bed morphology is pool-riffle throughout the reach. Areas of increased gradient occur where in-channel bedrock composed of the Chumstick formation is present. The presence of bedrock serves as a vertical grade control and limits localized potential incision. Hyporheic flow is evident at the downstream end of point bars, most notably at RM 42.4.

The channel and the modern floodplain are confined by terraced glacial deposits and exposures of the Chumstick formation. The channel is further confined by anthropogenic development and bank hardening on the low floodplain surfaces. The width of the channel and its modern floodplain ranges from 500 to 800 feet, widening in a downstream direction. The gradient of Reach 4 is 0.24%. The gradient locally increases in relation to the in-channel bedrock exposures.

The modern floodplain surfaces in this reach have gradually sloping banks that alternate with steep terrace or Chumstick confining bank walls. Where terrace banks are being undercut they appear to supply a significant sediment source to the reach. Substrate of the channel ranges from sands to cobbles, with cobble (43%) and large gravel (29%) as the dominant size classes. Some minor boulder inputs from the banks occur where the channel abuts the Chumstick formation. Floodplain and bar composition throughout the reach is primarily gravel and cobble. The bars are partially vegetated with willow indicating some degree of in-channel sediment storage.

Large wood accumulations occur in correlation with bar development in Reach 4. At the time of the survey (summer 2011), a significant apex jam was present on the point bar located at RM 43.05. Riparian vegetation is primarily large trees.

Figure 51. Representative geomorphology of Reach 4.

4.4.3 Effects of Human Alterations

Anthropogenic landscape alterations are prevalent throughout Reach 4. At the downstream-most boundary of the reach the Burlington Northern Railroad laterally confines the channel. Both the left and right bank bridge abutments currently act as hydraulic constrictions during over-bank flows (Figure 52). Riprap has also been installed up and downstream of the railroad bridge further immobilizing the channel and impairing the growth of riparian vegetation (Figure 53).

Figure 52. Burlington Northern Railroad Bridge Pilings

Figure 53. Right bank armoring

Homesite development has occurred along both banks and atop floodplain surfaces throughout Reach 4. A majority of the development is located on terrace surfaces and therefore does not directly impact channel geomorphology. Development on the low floodplain surfaces include removal or alteration of riparian vegetation, grading of floodplain surfaces for homesites, and some infrastructure (access roads and utilities). As a result, limited channel-floodplain interactions occur here and thermal shading has been reduced. Small riprap walls at RM 42.2, RM 42.35, and RM 42.9 likely have minimal impact on the stream. A portion of a side-channel appears to have been filled on the left bank near RM 42.3.

Historical timber harvest and log transport exists throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4.3. Removal of timber along floodplain surfaces has also occurred.

Inundation mapping conducted as part of the hydraulics analysis shows that considerable floodplain constriction is created by the Burlington Northern Railroad Bridge crossing at the downstream end of Reach 4, which has likely caused base lowering that has progressed upstream. This is supported by inundation extents within the meander bends in Reach 4 that show limited inundation only at the largest flood events (e.g. 50 to 100-yr events) despite scroll scars evident from LiDAR that indicate these surfaces were laid down in relatively recent history and would therefore be expected to have greater floodplain connectivity.

Locations of human alterations are displayed in Figure 54 and Figure 55.

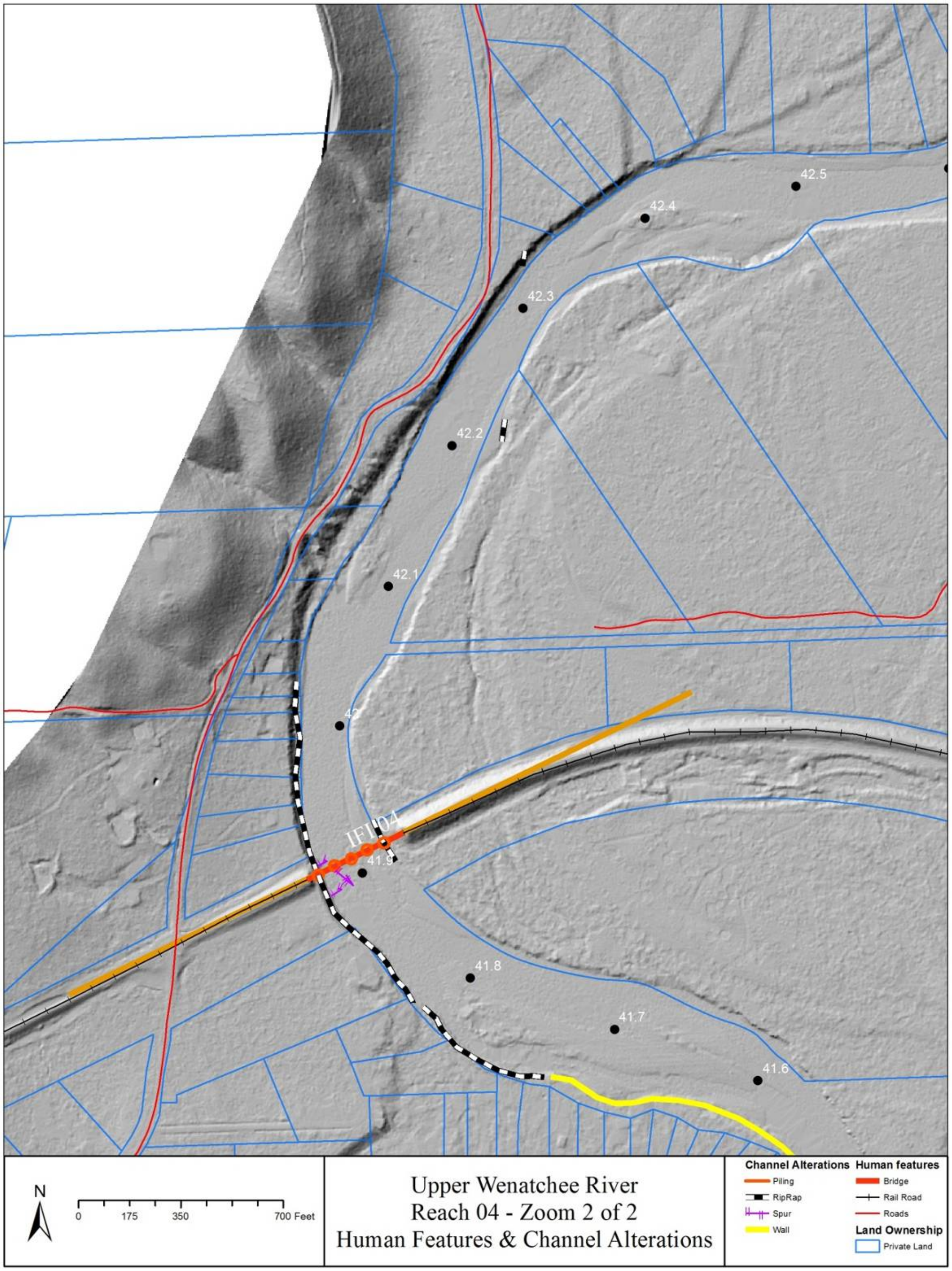

Figure 54. Human alterations in the downstream portion of Reach 4. Flow is from north to south.

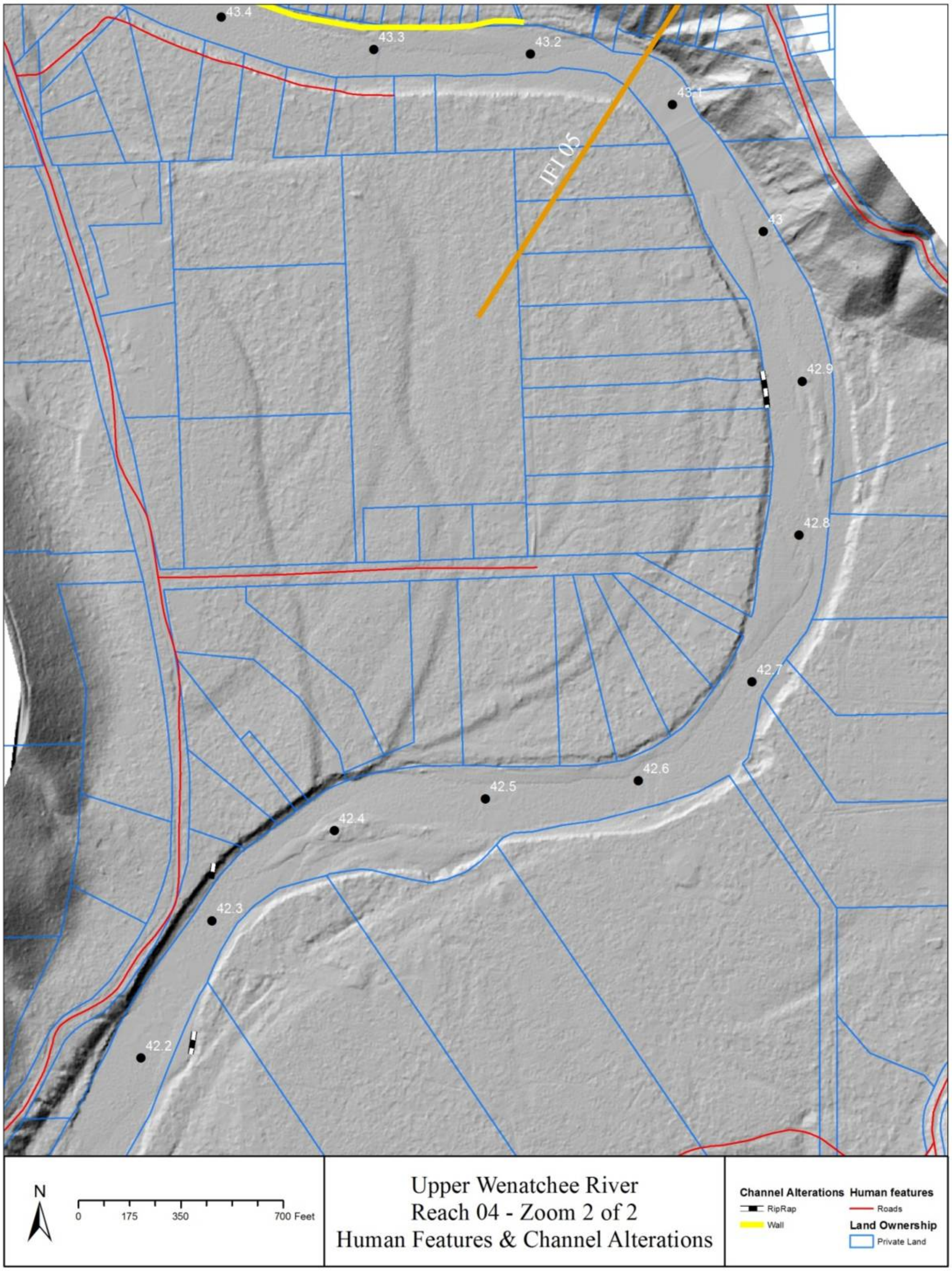

Figure 55. Human alterations in the upstream portion of Reach 4. Flow is from north to south.

4.5 Reach 5

4.5.1 Reach Overview

Reach 5 is 3.4 miles long and extends from RM 43.1 to the confluence of Beaver Creek at RM 46.5 (Figure 56). The reach is meandering and naturally confined within steep terrace banks and high walls of exposed Chumstick Formation. There are small narrow modern floodplain units and minimal bar development. Reach 5 receives surface water and sediment inputs from Beaver Creek (1-2 cfs throughout the year), which enters from river-left at RM 46.5. A second left bank tributary (waterfall) enters at RM 44.7 and provides additional but minimal surface water inputs. Residential development in Reach 5 increases substantially compared to the downstream reaches.

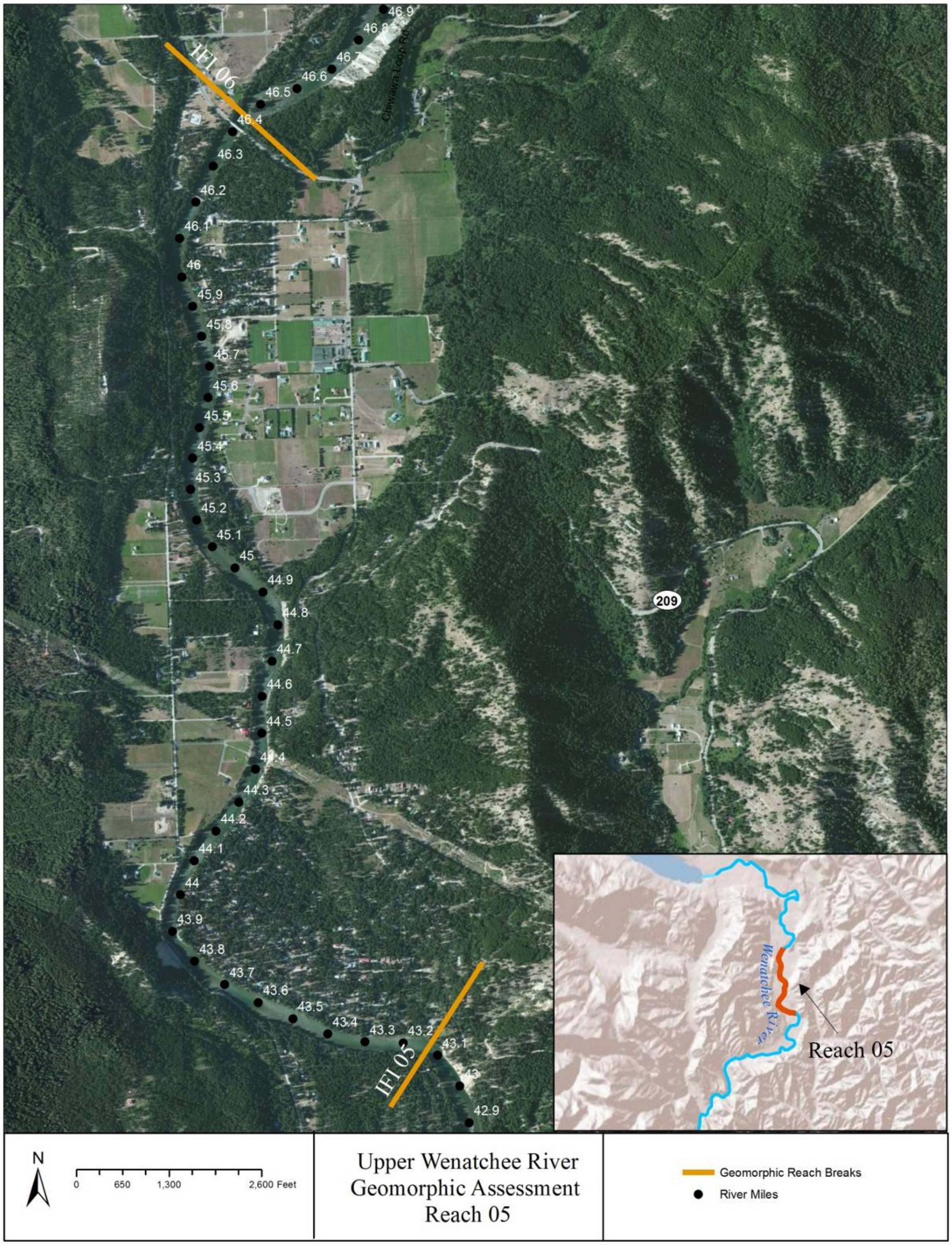

Figure 56. Overview map of Reach 5. Flow is from north to south.

4.5.2 Forms and Processes

Reach 5 is a slightly meandering reach with minimal bar and floodplain development (Figure 57). Overall sinuosity is 1.26 and it is more exaggerated in the downstream portion of the reach. The bed morphology is primarily riffle-glide with periodic shifts to pool-riffle sequences. The pools are channel-spanning and greater than eight feet deep. The riffles offer localized increases in velocity.

Figure 57. Representative geomorphology of Reach 5.

The channel and its modern floodplain are naturally confined within terraces of glacial outwash (Figure 58) and exposures of the Chumstick Formation. The glacial outwash terraces are a result of glacial meltwater mobilizing, transporting, and depositing materials in the Wenatchee valley during and after the last glacial period. Since deposition, the channel has incised into and reworked the glacial outwash deposits (NPCC 2004, Tabor et al. 1987). The channel is further confined by development and bank hardening of the marginal floodplain surfaces. Confinement limits lateral migration and exaggerates changes in flood stage relative to discharge. As a result the river is a transport dominant reach with minimal available off-channel habitat or large wood retention. The gradient of Reach 5 is 0.25%.

The banks of the low modern floodplain surfaces are sloping and composed of sands with cobbles at the base. They are vegetated with a well-established mix of riparian trees and shrubs. This provides canopy cover along the banks and future sources of large wood material. Bank slumping and mass wasting of the terraces in the upper portion of this reach has influenced the development of a few small narrow floodplain surfaces. The channel substrate ranges from sand to boulders, but cobbles are the dominant size class (41%) through the reach.

Figure 58. Terraced banks (alluvium terrace deposits). Terrace surface was approximately 8' above water surface elevation (August 2011).

4.5.3 Effects of Human Alterations

Anthropogenic landscape alterations are present throughout Reach 5. At the upstream-most end of the reach the Old Plain Bridge (RM 46.21) and the Beaver Valley Rd Bridge (RM 46.4) both have sets of cement pilings and associated large boulder riprap that influence flow patterns that create local scour pools. An additional set of pilings (RM 46.39) from a decommissioned bridge also remain in the channel. Because of natural confinement, it is unlikely that these pilings present a significant impediment to overbank flow.

Bank hardening (e.g. riprap, concrete walls) associated with homesite and road development and maintenance exists in Reach 5. Large granite boulder riprap lines a steep terrace bank at RM 43.6 to 44.1 where River Road runs parallel to the channel. Along the banks on river-left at RM 43.2 to 44.1 a series of riprap and cement walls periodically armor the bank.

Residential homesite development and its related infrastructure are located next to the channel on both the high terrace surface and many of the low floodplain surfaces. The development on the terraces does not have direct impact on the channel but secondary impacts such as vegetation alteration and bank stability are of concern. Development on the low floodplain surfaces include removal or alteration of riparian vegetation, grading of floodplain surfaces for homesites, and some infrastructure (access roads and utilities). As a result, minimal channel-floodplain interactions occur here and thermal shading has been reduced.

Historical timber harvest and log transport occurred throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4, which also includes a comparison of historical and current photos of this reach.

Locations of human alterations are displayed in Figure 59, Figure 60, Figure 61, and Figure 62.

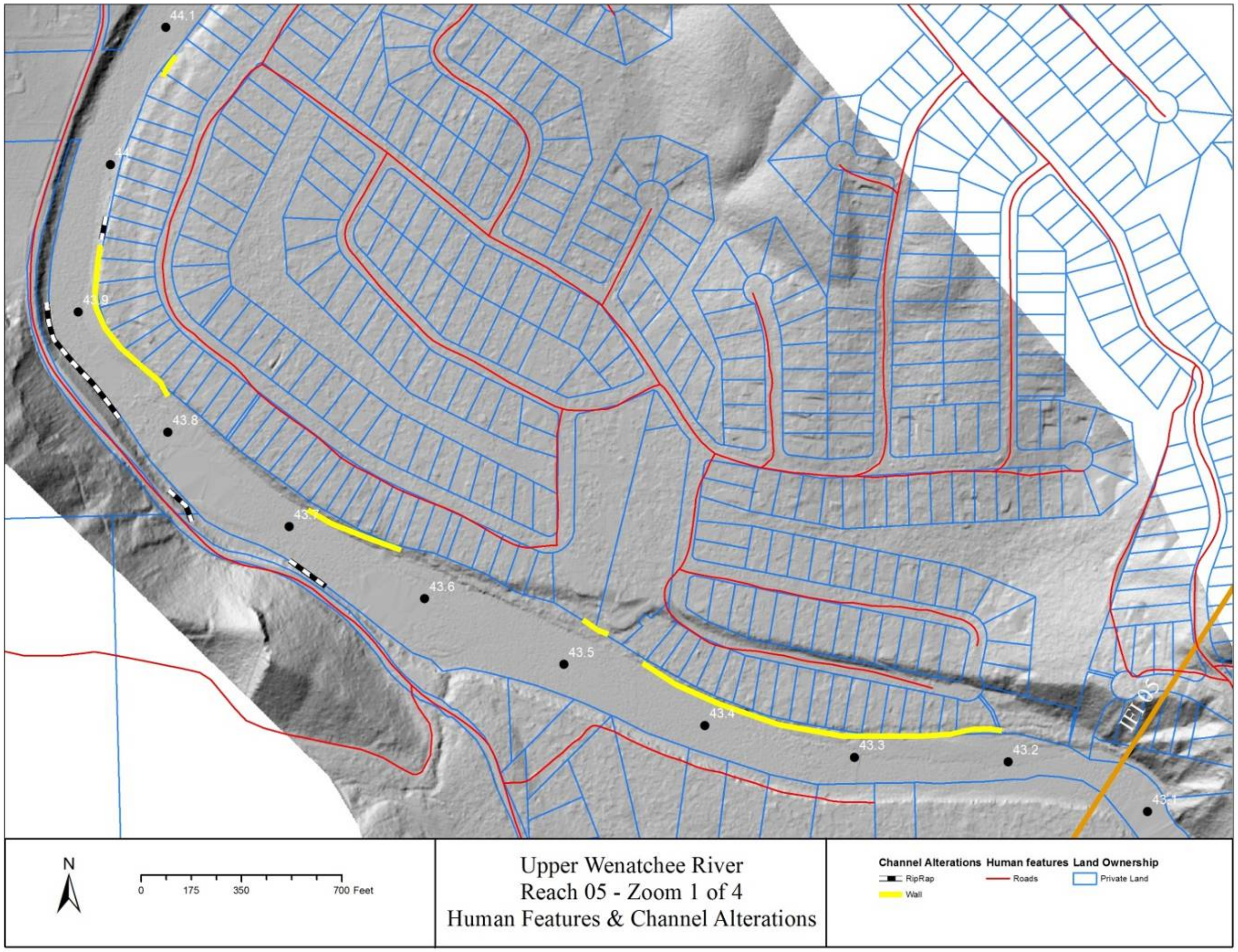

Figure 59. Human alterations in the downstream portion of Reach 5. Flow is from northwest to southeast.

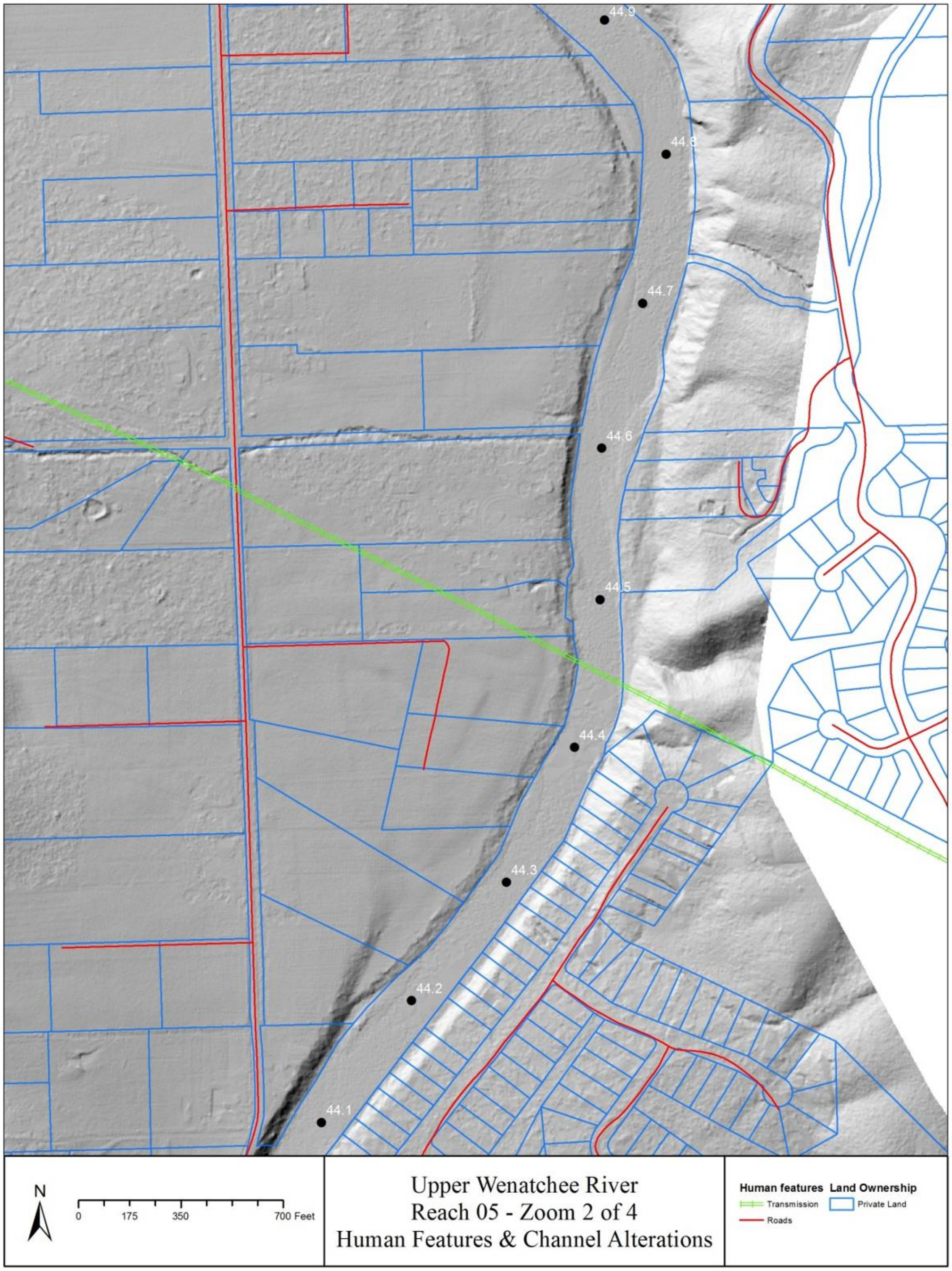

Figure 60. Human alterations in Reach 5. Flow is from north to south.

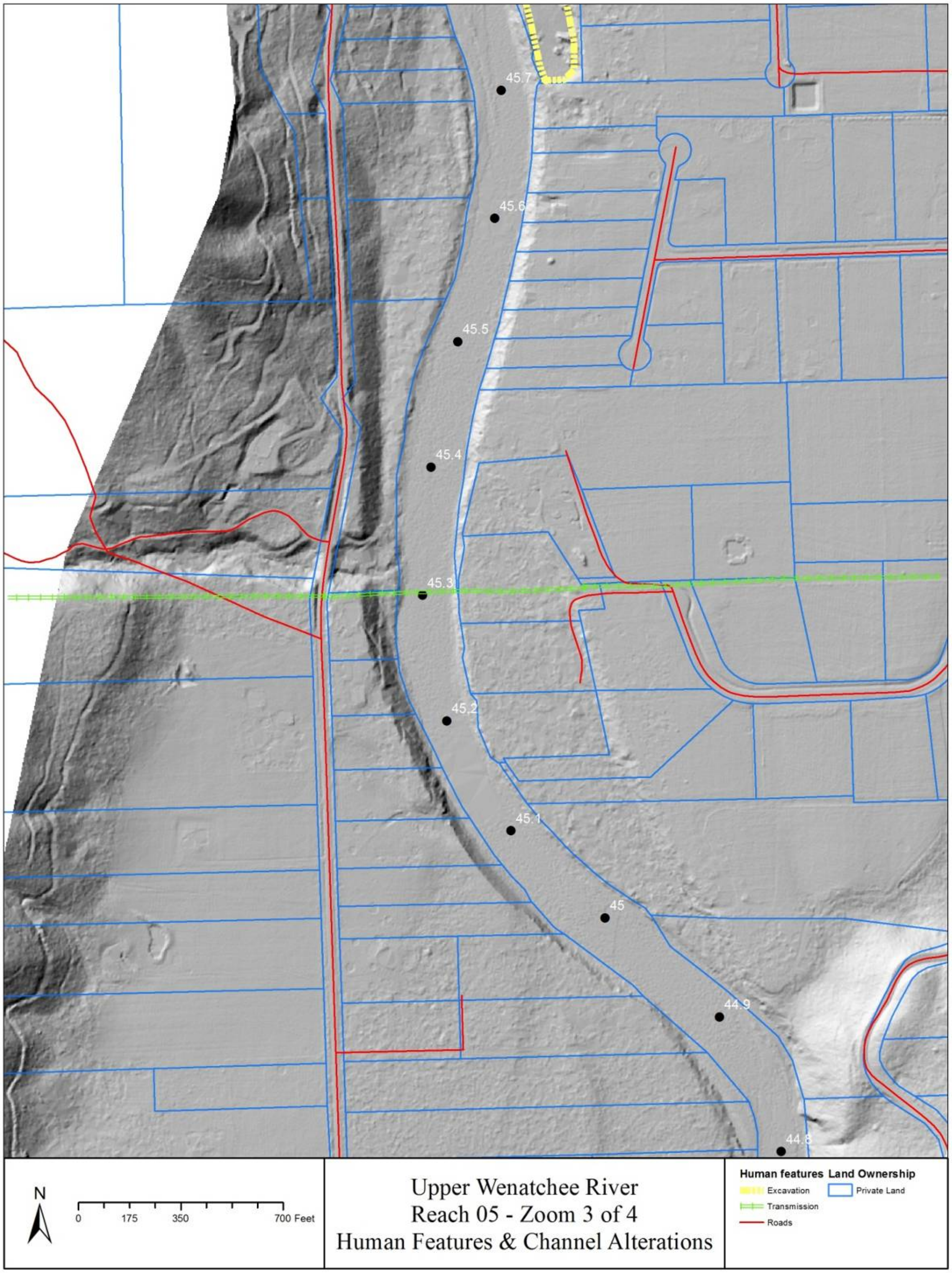

Figure 61. Human alterations in Reach 5. Flow is from north to south.

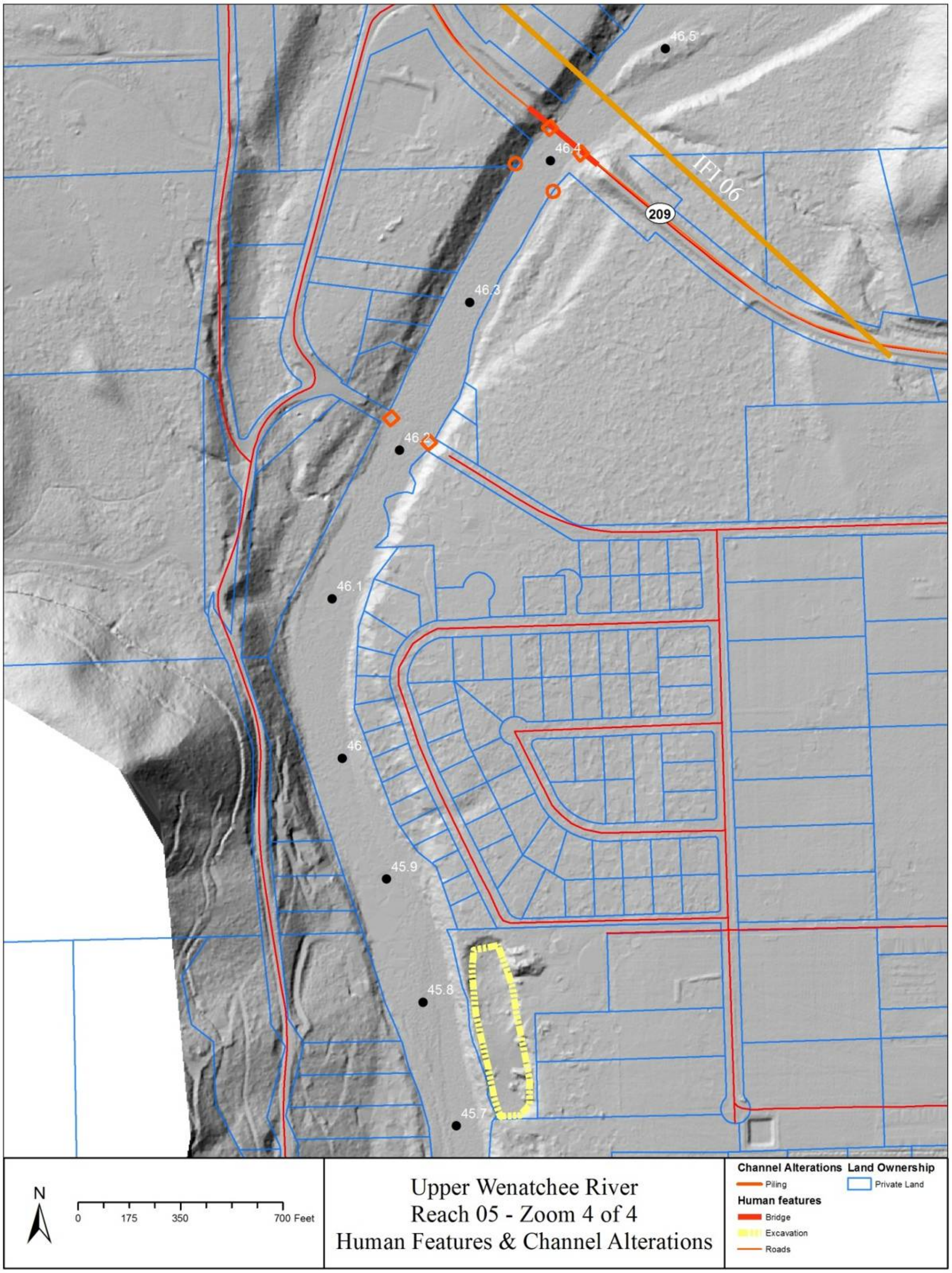

Figure 62. Human alterations in Reach 5. Flow is from north to south.

4.6 Reach 6

4.6.1 Reach Overview

Reach 6 is 1.4 miles long and extends from the confluence of Beaver Creek (RM 46.5) to RM 47.9 (Figure 63). This reach is partially confined and has only minor bar deposition. Large vegetated islands exist in the downstream portion of the reach where an exposure of the Chumstick Formation confines the channel on river-left. One unnamed tributary at RM 47.1 contributes negligible surface water inputs. Residential development has further confined this reach and likely accelerated its rate of channel incision by reducing the frequency and extent of floodplain inundation. Due to the prevalence of development on the floodplain, combined with natural channel confinement, there are limited restoration opportunities within the reach.

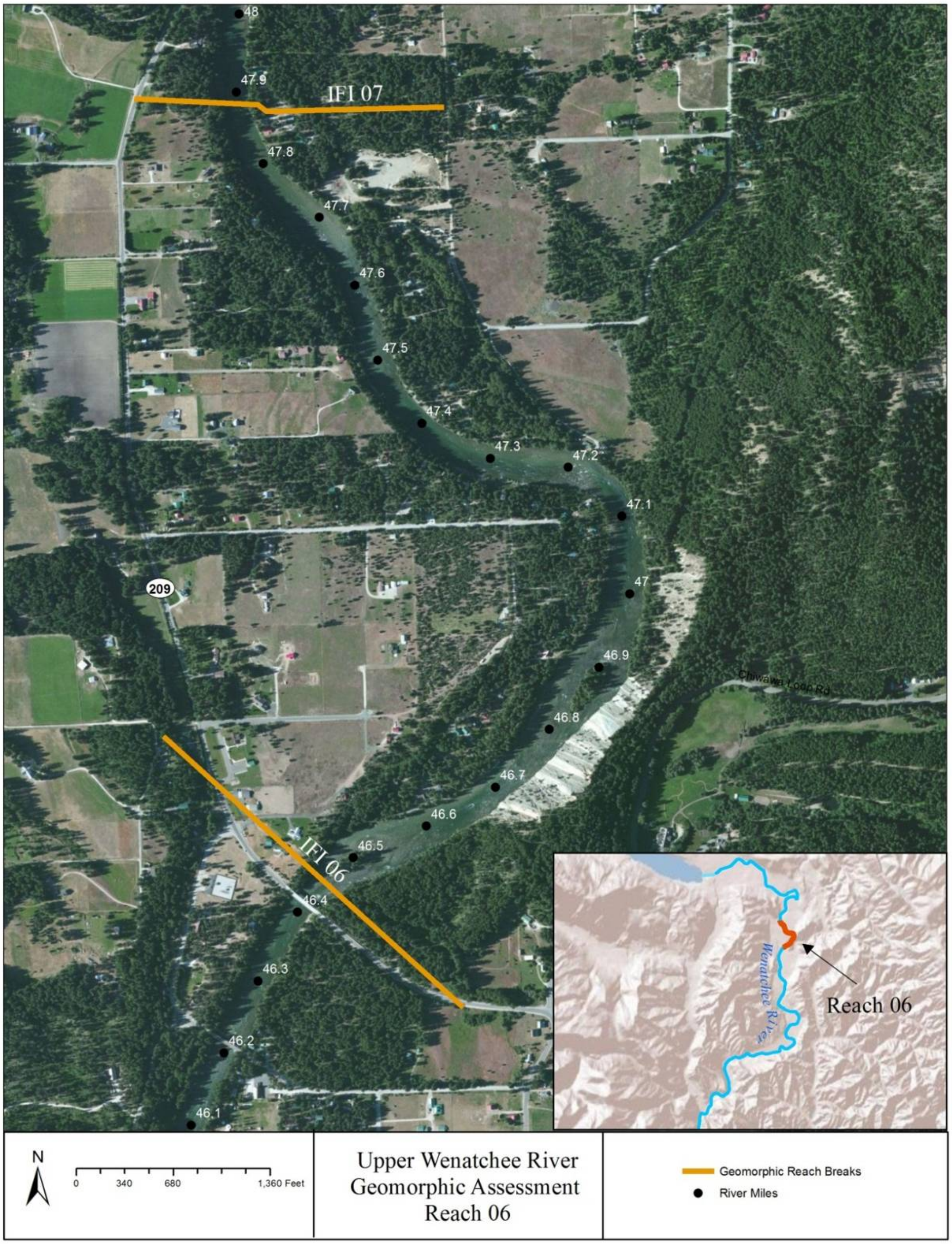

Figure 63. Overview of map of Reach 6. Flow is from north to south.

4.6.2 Forms and Processes

Reach 6 contains a meandering channel with a sinuosity of 1.44 and only minor bar development. Two large vegetated islands in the downstream section of the reach locally widen the channel and add complexity. The bed morphology is primarily riffle-glide with extended units of each. The glides are relatively short and narrower than the alternating riffle units in the straighter downstream portion. Substrate throughout the reach ranges from coarse sands to boulders with cobbles (45%) and boulders (30%) composing most of the bed material. Boulders are prominent in the riffles where gradient increases. In the downstream portion boulders are locally sourced from the adjacent Chumstick Formation.

The channel and its modern floodplain are partially confined by a steep wall of the Chumstick Formation on river-left (RM 47.1 to RM 49.7) and terraces of glacial outwash deposits on river-right (RM 47.4 to RM 47.9). See Figure 64 and Figure 65 for images of the confining terraces. Lateral left meander amplitude is controlled by the exposed Chumstick Formation. The vertical grade is likely controlled by bedrock of the Chumstick Formation at points throughout this reach, but high water velocities made this difficult to verify. The channel is further confined by development and bank hardening on modern floodplain surfaces. Reach 6 has the highest gradient within the study area with a gradient of 0.35%, creating higher flow velocities. Gradient is greatest in the downstream portion of the reach.

Despite the increase in slope and velocity in the downstream portion of the reach, there are two vegetated islands. These mid-channel areas of sediment storage briefly shift channel form to braided and offer access to lower-velocity side channels. According to the hydraulic analysis in Section 3.5.2, neither the floodplain nor the islands in Reach 6 are inundated during flow events equivalent to or less than the two year flood. Large bar apex logjams were located at the upstream end of each island at RM 46.54 and RM 46.92. The large wood, boulders, and islands offer refuge from high flow velocities and some minor margin complexity in the downstream portion of the reach.

The islands and floodplains are vegetated with mature trees and shrubs of mid-seral stage. Where development and bank hardening has occurred, the vegetation is altered. The island banks are sloping and composed of large cobbles topped with coarse sands. The banks of other floodplain surfaces are gradually sloping and composed of gravels to sands.

Figure 64. Chumstick Formation along river-left from RM 46.7 to RM 47.1

Figure 65. Terraced deposits forming right bank at upstream end of reach (August 2011).

4.6.3 Effects of Human Alterations

Throughout Reach 6 the floodplain has been modified by anthropogenic development. Eighty-one percent of the modern floodplain has been affected by bank armoring, levees, residential development, and riparian modifications in Reach 6 (see Appendix B). Residential homesite development and its related infrastructure are located next to the channel on both the high terrace surface and many of the low floodplain surfaces (Figure 66). Homesite development on the floodplain surfaces also includes floodplain dissection by roads and utilities installation, removal or alteration of riparian vegetation, fill or grading, and minor localized bank hardening (riprap constructed of tires).

On the river-left floodplain surface at RM 47.7 there is a 3.52 acre gravel excavation pit (Figure 67). Adjacent to the pit a push-up levee has been constructed along river-left to protect the excavation pit. The levee extends up and downstream of the pit in front of residential homes and alters the frequency and extent of floodplain inundation.

Figure 66. Homesites along the right bank across from the exposed Chumstick Formation (photo taken at RM 47.1, facing upstream).

Figure 67. Gravel excavation pit (highlighted in yellow) along left bank in upstream portion of Reach 6.

Historical timber harvest and log transport occurred throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4.3. The Habitat Assessment (Appendix A) includes a comparison of historical and current photos of this reach. Removal of timber along floodplain surfaces has also occurred.

Locations of human alterations are displayed in Figure 68 and Figure 69.

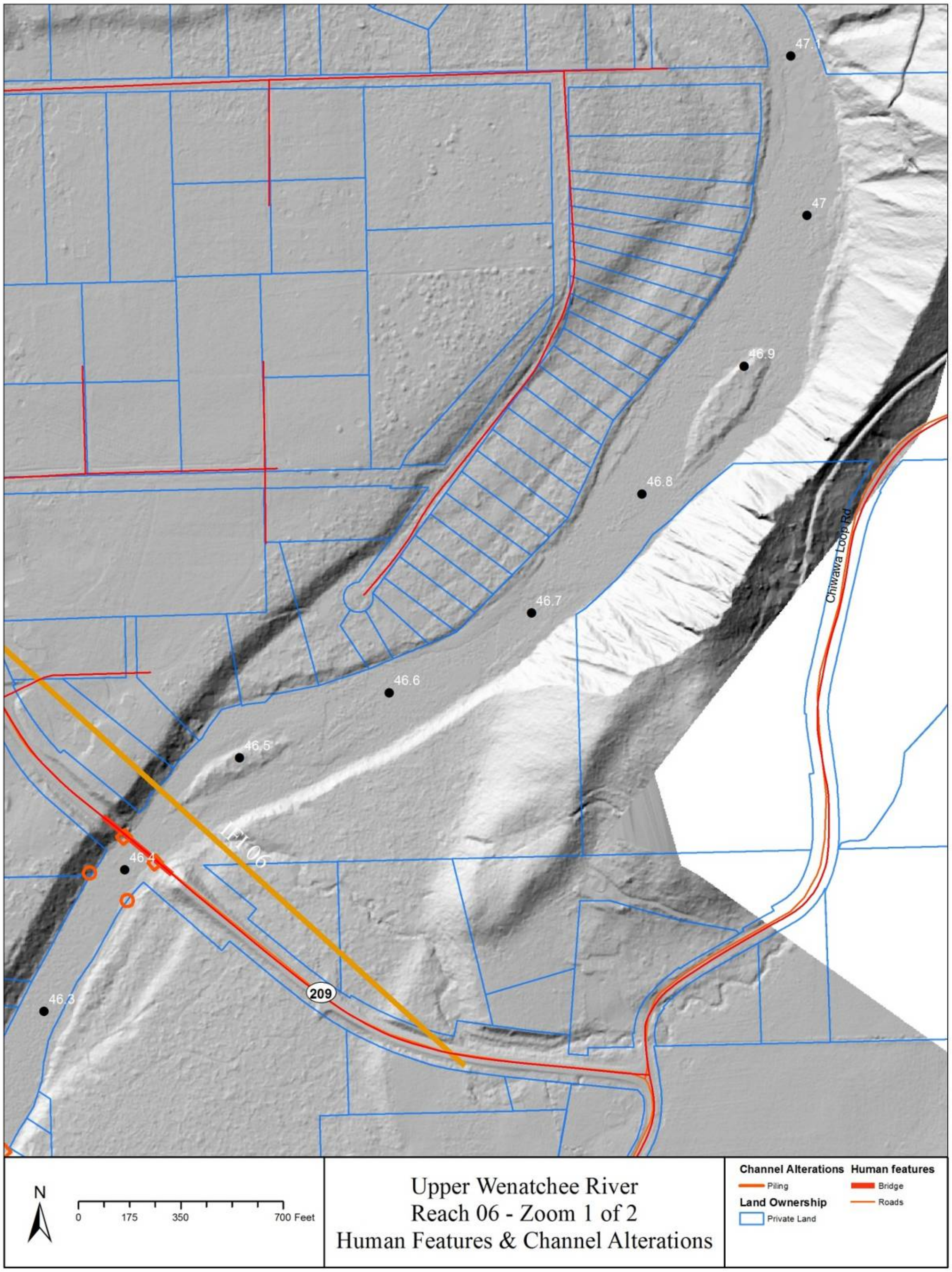

Figure 68. Human alterations in the downstream portion of Reach 6. Flow is from northeast to southwest.

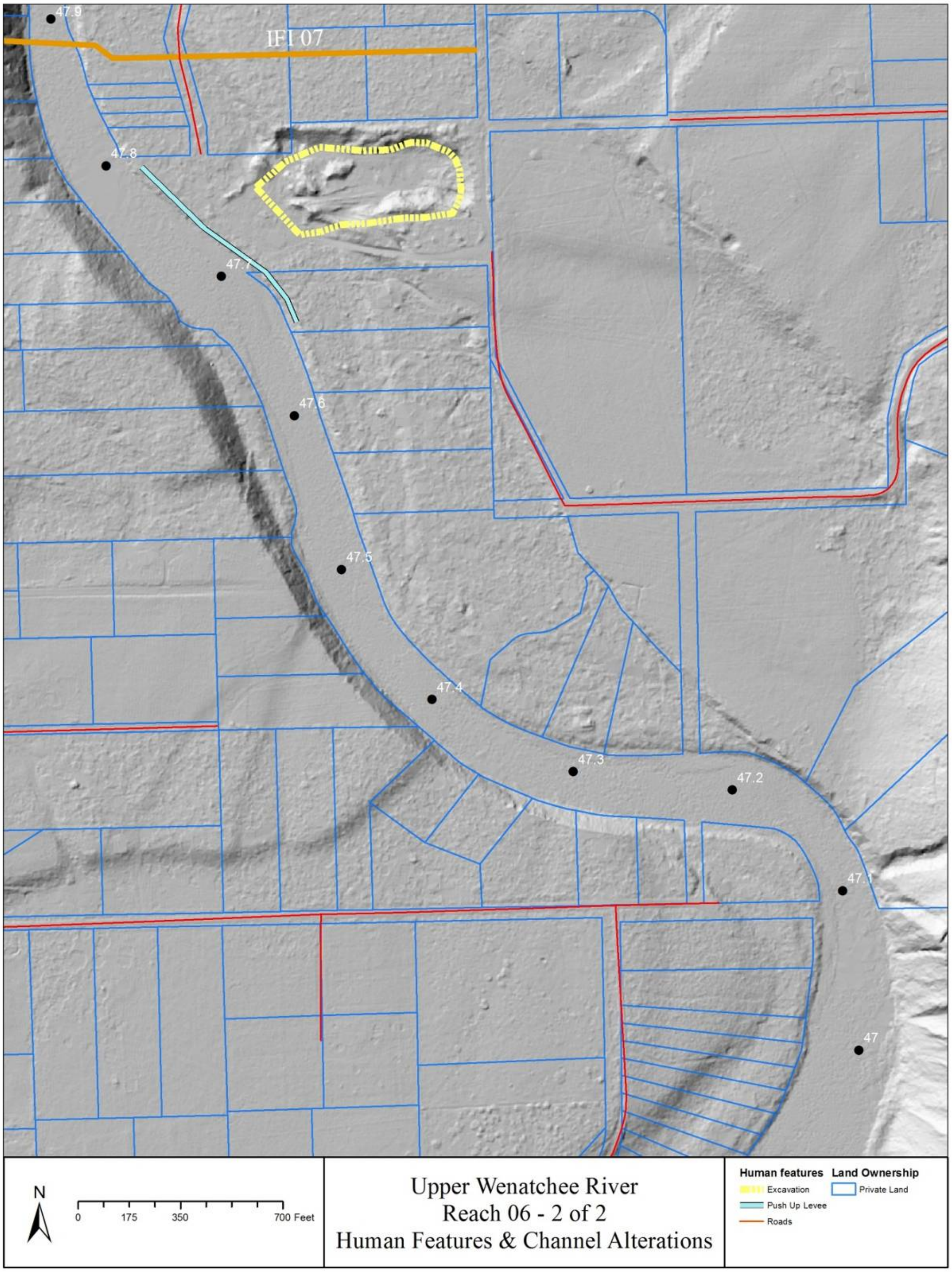

Figure 69. Human alterations in the upstream portion of Reach 6. Flow is from north to south.

4.7 Reach 7

4.7.1 Reach Overview

Reach 7 is 0.5 miles in length and extends from RM 47.9 upstream to the confluence of the Chiwawa River at RM 48.4 (Figure 70). The slightly meandering channel and its modern floodplain are confined by terraces of glacial outwash. Point bar development is present with minor large wood accumulations occurring along the margins of the channel. Surface water discharge and sediment inputs from the Chiwawa River influence channel form and processes in Reach 7. In places, residential development has impacted channel processes by altering or removing riparian canopy and influencing connectivity of floodplain surfaces. The natural and development-induced confinement presents few restoration opportunities.

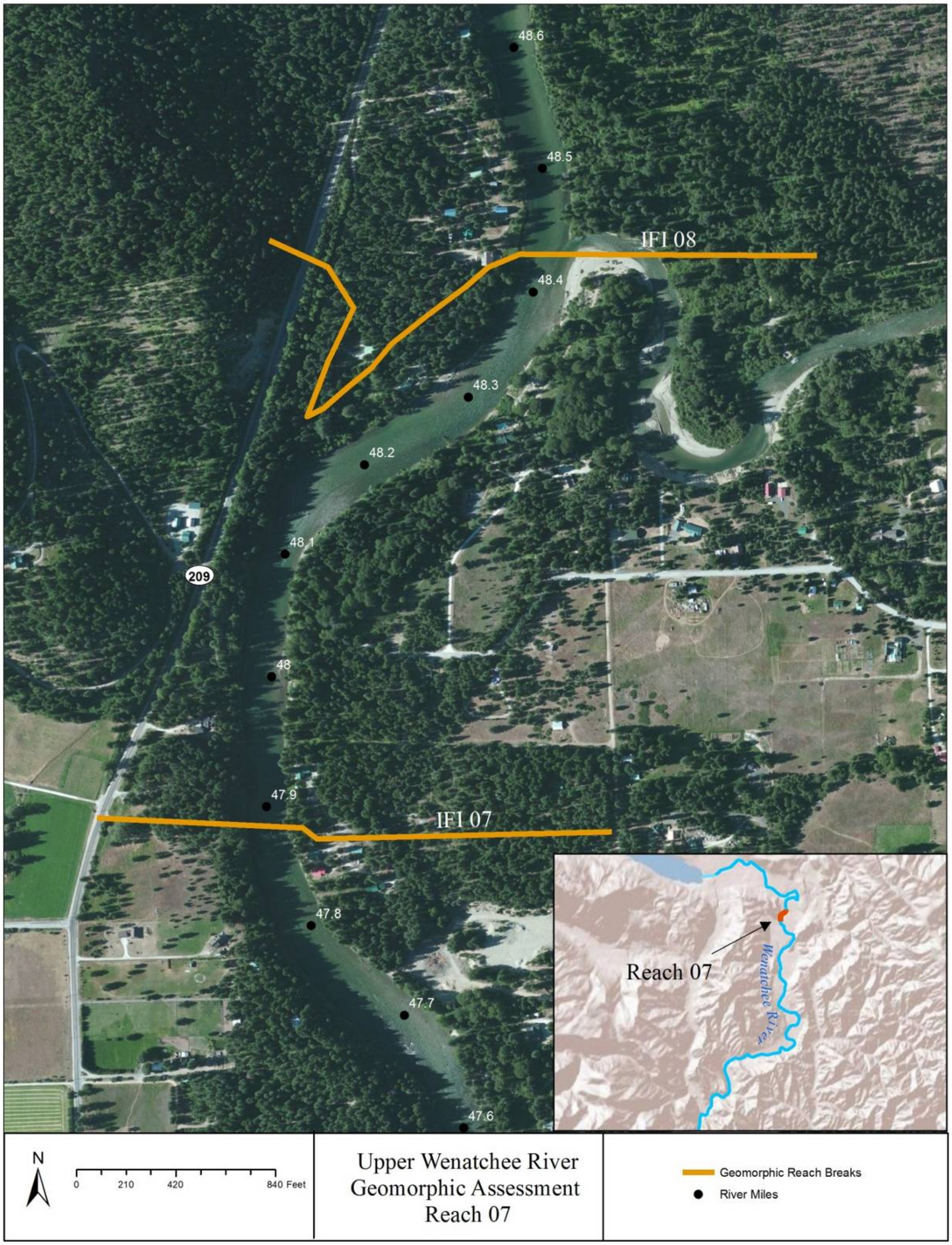

Figure 70. Overview map of Reach 7. Flow is from north to south.

4.7.2 Forms and Processes

Reach 7 contains a slightly meandering channel with minor point bar development but some lateral channel margin deposits. The point bars (RM 48 and RM 48.15) have slowly vegetating bar-tail deposits on the downstream ends. Bed morphology is riffle-glide (Figure 71) with the exception of a pool located downstream of the convergence of the Chiwawa River.

Figure 71. Riffle-glide facing downstream standing on Chiwawa River's alluvial fan.

Channel morphology and hydraulics are influenced in Reach 7 by an increase in discharge and sediment sourced from the Chiwawa River and its alluvial fan (Figure 72). Relative to upstream, the channel widens slightly and velocity increases. The increased flow allows the channel to effectively transport the increased bed-load inputs. Hyporheic flow exchange is evident within the alluvial fan deposits at the confluence of the Chiwawa and Wenatchee Rivers. Substrate ranges from sands to boulders with boulders (35%) and cobbles (33%) dominating. Sands to cobbles are prominent at the Chiwawa River confluence (Figure 73).

Figure 72. Alluvial fan deposits from Chiwawa River.

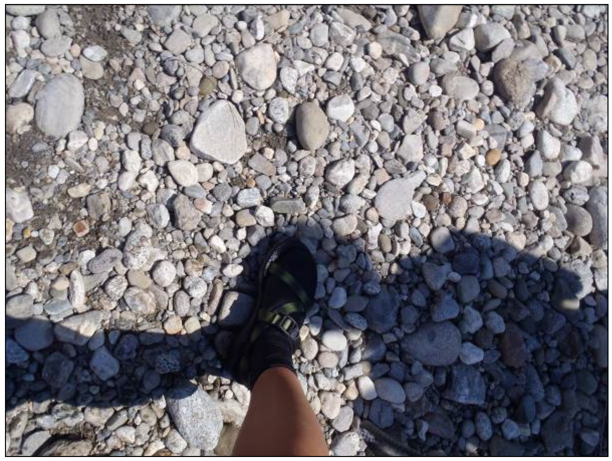

Figure 73. Sand to cobble on alluvial fan of Chiwawa River.

The channel and its modern floodplain are partially confined by terraces of glacial outwash deposits. The channel abuts the high terrace bank on river-right from RM 47.9 to RM 48.14. The modern floodplain surfaces are low with sloping banks and alternate between human-altered and functioning. Hydraulic modeling of floodplain inundation reveals that most of the modern floodplain surfaces in Reach 7 are not inundated with flow events equivalent to or less than the two year flood (Section 3.5.2). This suggests that incision is occurring in this reach even with the additional sediment inputs from the Chiwawa River and its alluvial fan. The relatively short length of the reach and terrace confinement result in a sinuosity of 1.06. The gradient of Reach 7 is 0.25%. Slope is greatest in the downstream portion of the reach where the channel is confined by the terrace. Here transport capacity of wood and sediment also increases, as evidenced by modern scour at the base of riparian vegetation throughout the reach (Figure 74).

Only minor large wood accumulations occur along the margins of the channel. Floodplain surfaces are vegetated with mature trees and shrubs except where vegetation has been altered or removed at homesites.

Figure 74. Scour at base of mature ponderosa pine in riparian area.

4.7.3 Effects of Human Alterations

Human alterations affecting the channel are primarily restricted to the left bank. These alterations include home development and riparian vegetation removal and/or alteration. Where homesite development has occurred much of the floodplain has been altered by fill or grading. The riparian canopy has been completely cleared at many homesites, and at other sites, understory shrubs and saplings have been cleared and only select large trees remain. Where canopies have been completely cleared, lateral channel scour is undercutting banks and they are slumping into the channel (Figure 75 and Figure 76).

Figure 75. Clearing of riparian vegetation resulting in bank slumping.

Figure 76. Left bank slumping due to lack of riparian vegetation.

The modern floodplain and its banks alternate between human altered and functioning (Figure 77 and Figure 78). In the lower portion of the reach fewer impacts to riparian vegetation have occurred in conjunction with homesite development. However, the relative seral stage of these canopies is young compared to intact riparian canopies. Only small-scale riprap was observed at two sites and presents minimal influence on the channel or floodplain inundation.

Figure 77. Homesite where small willows and dogwood has been allowed to establish.

Figure 78. Intact riparian canopy.

Historical timber harvest and log transport occurred throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4.3. Removal of timber along floodplain surfaces has also occurred.

Locations of human alterations within Reach 7 are located in Figure 79.

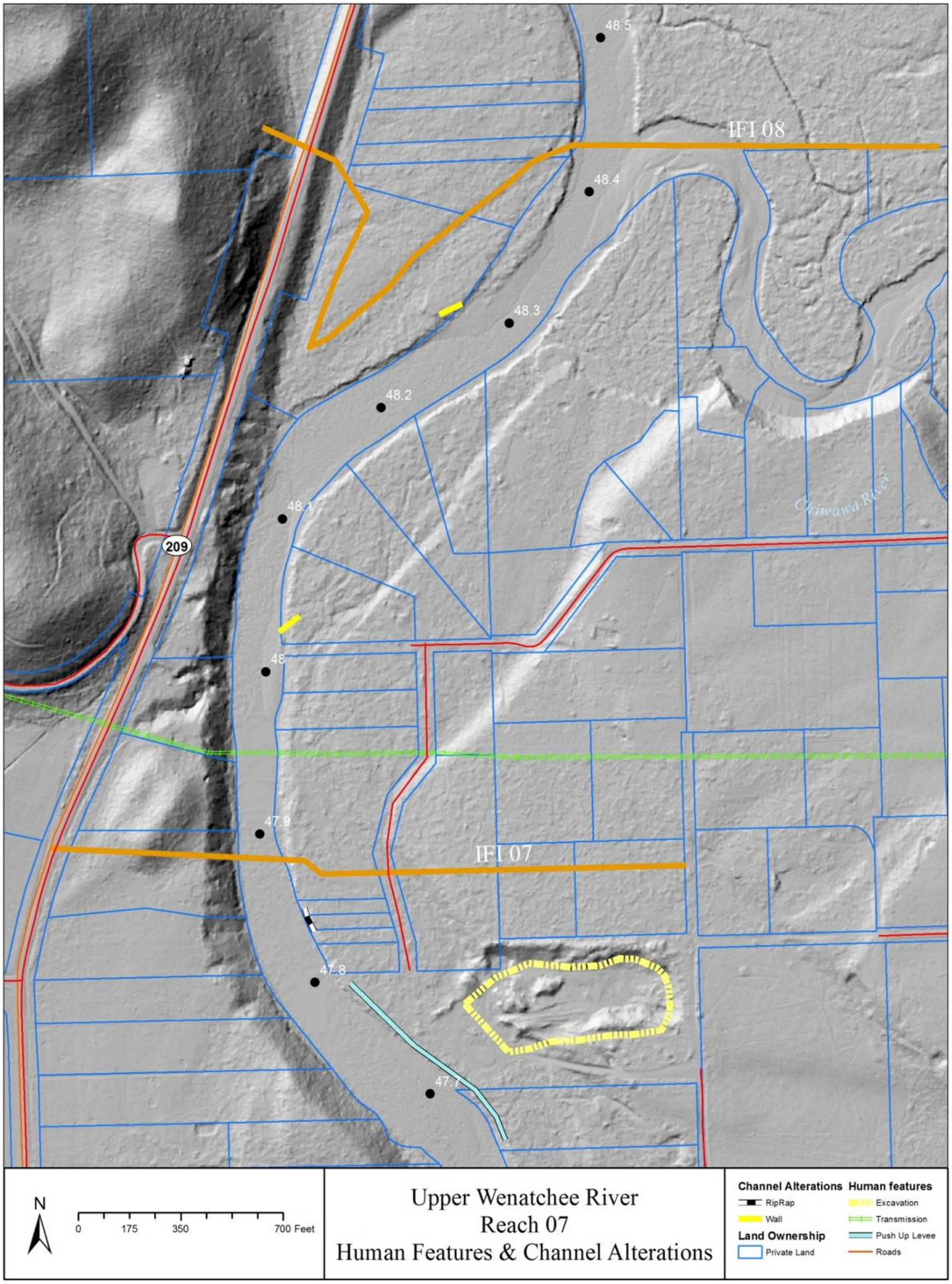

Figure 79. Human alterations in Reach 7. Flow is from north to south.

4.8 Reach 8

4.8.1 Reach Overview

Reach 8 is 1.3 miles long and extends from the confluence of the Chiwawa River (RM 48.4) to RM 49.7 (Figure 80). The channel is meandering with point bar development and two mid-channel bar features. Channel bank confinement from terraces of glacial drift and outwash deposits alternates with modern floodplain banks. A few small ephemeral streams sourced off the terraces and hillslopes contribute minor seasonal discharge inputs into the Wenatchee River. This reach offers both connected and disconnected backwater habitat within the modern floodplain surfaces. Geomorphic forms and processes are relatively unaffected by human disturbance on the floodplain and terrace surfaces that are managed by the US Forest Service. On private and state lands, anthropogenic development, including bank hardening, has disconnected portions of the modern floodplain.

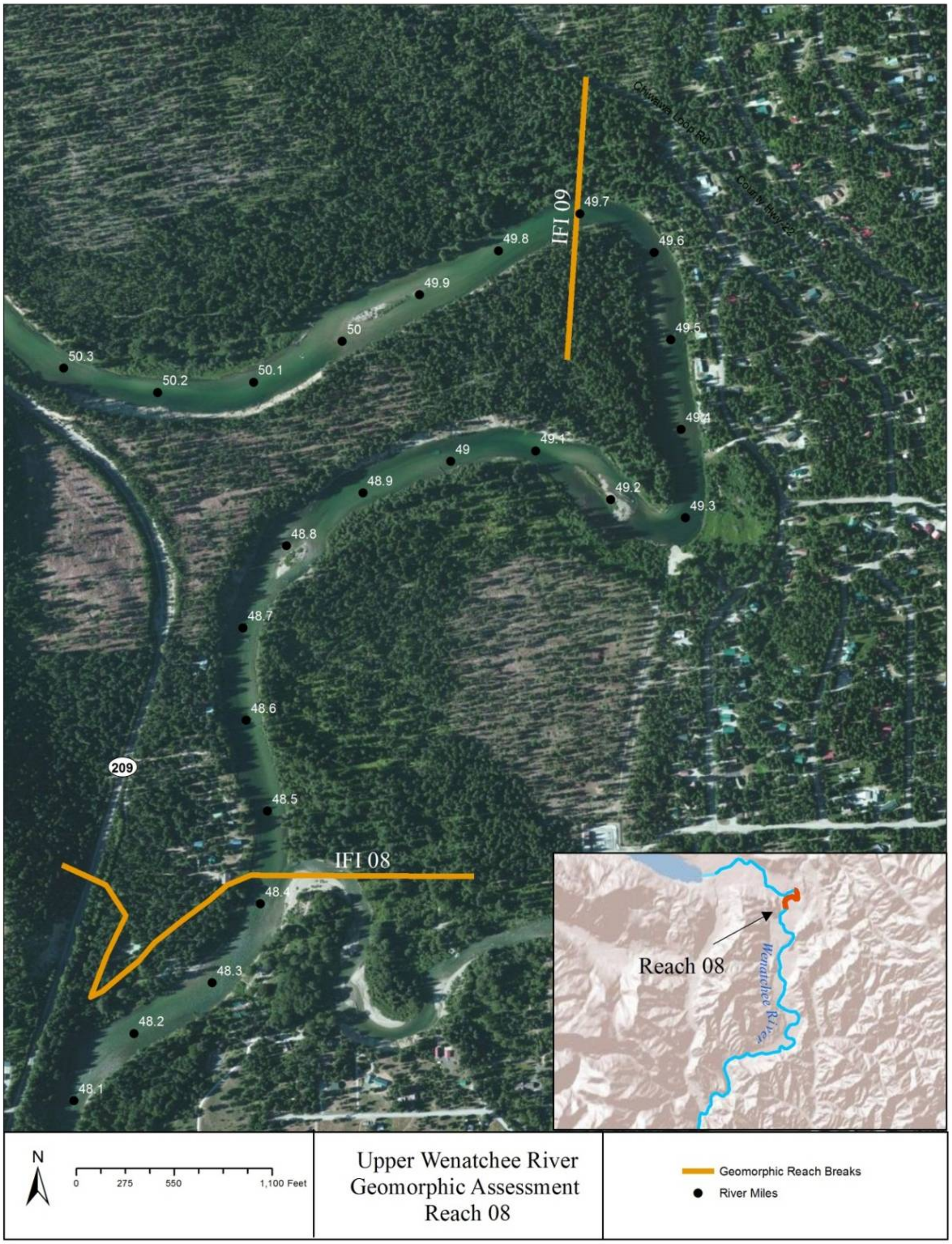

Figure 80. Overview map of Reach 8. Flow is from north to south.

4.8.2 Forms and Processes

Reach 8 is a meandering reach with a channel sinuosity of 1.62. Bar development is occurring as narrow elongate point bars associated with meanders and two established mid-channel bars located within riffles at RM 48.4 and RM 49.2. Bed morphology is mostly pool-riffle with interspersed glide units. A large channel-spanning pool is located at the meander at the upstream-most portion of the reach. The pools are relatively long and deepest at meander bends (RM 49.3 and RM 49.1). Substrate ranges from sands to boulders but is dominated by cobbles (39%) and gravel (30%).

This reach is partially-confined by terraces of glacial drift and outwash. Ninety percent of the right bank is confined by glacial terraces and river-left abuts terrace banks at RM 49.45 to RM 49.7. The channel is further confined in the downstream portion of river-right by the disconnection of the modern floodplain from anthropogenic development. The low modern floodplain surfaces alternate with terraces to form the channel banks. Overall gradient of the reach is 0.12%.

In the upstream portion of the reach incision (translating into Reach 9) is resulting in minor floodplain disconnection. Multiple elevations of abandoned floodplain surfaces exist along the left bank indicating a long-term process of incision. A disconnected floodplain wetland on river-left at RM 49.3 is evidence of more modern incision. The upstream-most modern floodplain surface on river-right has sandy soils but inundation is historical or only very infrequent Hydraulic modeling of floodplain inundation (Section 3.5.2) confirms these findings. Low elevation floodplain surfaces with sloping banks are present further downstream where modern incision processes are minimal. These lower surfaces house narrow backwater habitats that connect to the main channel at the downstream end. These backwaters exchange both surface and hyporheic flow with the mainstem Wenatchee (Figure 81).

Floodplain surfaces are well-vegetated with a mix of conifers and shrubs. Riparian and modern floodplain vegetation has been removed or altered in areas of development. Large wood is lacking in the system with only minor accumulations occurring along the margins. Tree mortality atop the high terrace banks offers key pieces of wood to the system that could promote large wood accumulations.

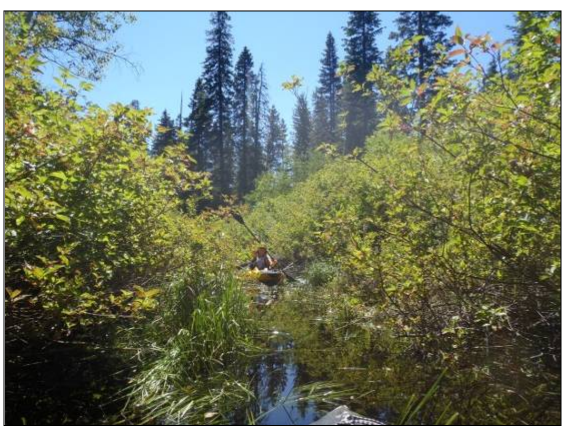

Figure 81. Off-channel habitat at RM 49.2 (river-left) looking downstream (left photo), and looking upstream (right photo).

4.8.3 Effects of Human Alterations

Floodplain connection is limited by geologic factors, incision, and anthropogenic development. The hydraulic analysis and modeling of floodplain inundation indicates that floodplain connectivity is reduced below its potential in Reach 8 (Section 3.5.2). Without historical data it is not possible to determine how much human alterations have affected natural rates of incision and channel evolution in Reach 8. However, it is clear that anthropogenic development has directly disconnected portions of the floodplain from the channel. Beginning at RM 48.7, fill and construction of Beaver Valley Road (Highway 209) has disconnected pockets of the floodplain behind it on river-right. Where homesite development has occurred the floodplain is dissected by roads, vegetation has been altered or removed, and many surfaces have been filled or graded.

Bank hardening at RM 49.3 further impairs floodplain inundation and lateral migration. A cement and steel retaining wall protrudes slightly into the channel protecting the bank from all channel processes (Figure 82). The wall is part of the Washington Department of Fish and Wildlife's Chiwawa Ponds fish hatchery facility. This facility also includes fill and small buildings. Just upstream from the fish hatchery facility the floodplain surface has been graded and much of the native vegetation has been removed (now dominated with mowed grass) to facilitate community recreational activities. This area contains a disconnected wetland complex. According to the hydraulic modeling, the fish pond facility and its structures directly limit inundation on this low surface. The nearby disconnected wetland complex does get inundation with flows equivalent or less than a two year flood event.

Figure 82. WDFW Chiwawa Ponds Fish Hatchery intake structure.

Without historical data it is difficult to determine if the lack of large wood in the system is a result of localized riparian clearing or historical logging practices that cleared and scoured the channel for log transport. Other potential impacts of historical logging practices are discussed in detail in Section 3.4.3.

Human alterations are mapped in Figure 83 and Figure 84.

Figure 83. Human alterations in the downstream portion of Reach 8. Flow is from north to south.

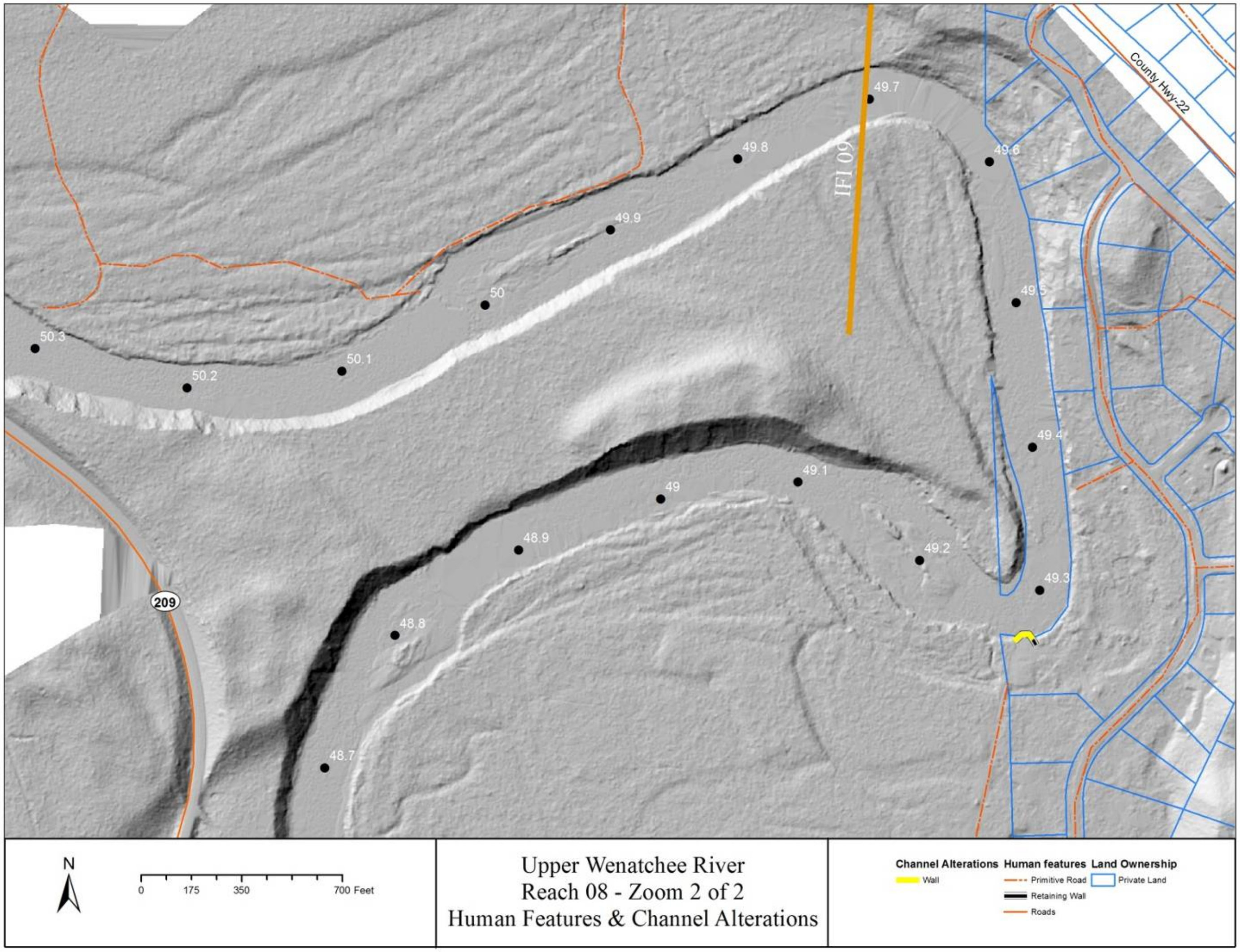

Figure 84. Human alterations in the upstream portion of Reach 8. Flow is from northwest to the south.

4.9 Reach 9

4.9.1 Reach Overview

Reach 9 extends 1.92 miles from RM 49.73 to RM 51.65 (Figure 85). This channel slightly meanders through a partially confined alluvial valley. High quality connected backwater habitats and disconnected wetlands are located within the low elevation floodplain surfaces. The banks alternate between modern floodplain surfaces and high steep terraced banks of glacial drift and outwash. Incision is notably reducing floodplain connectivity in the downstream portion of the reach. A few small ephemeral streams sourced off the terraces and hillslopes contribute minor seasonal discharge inputs into the Wenatchee River. There is evidence of past riparian timber harvest. This reach is bordered primarily by public lands managed by the US Forest Service. The high steep terrace walls make access challenging on river-right in the downstream portion of the reach.

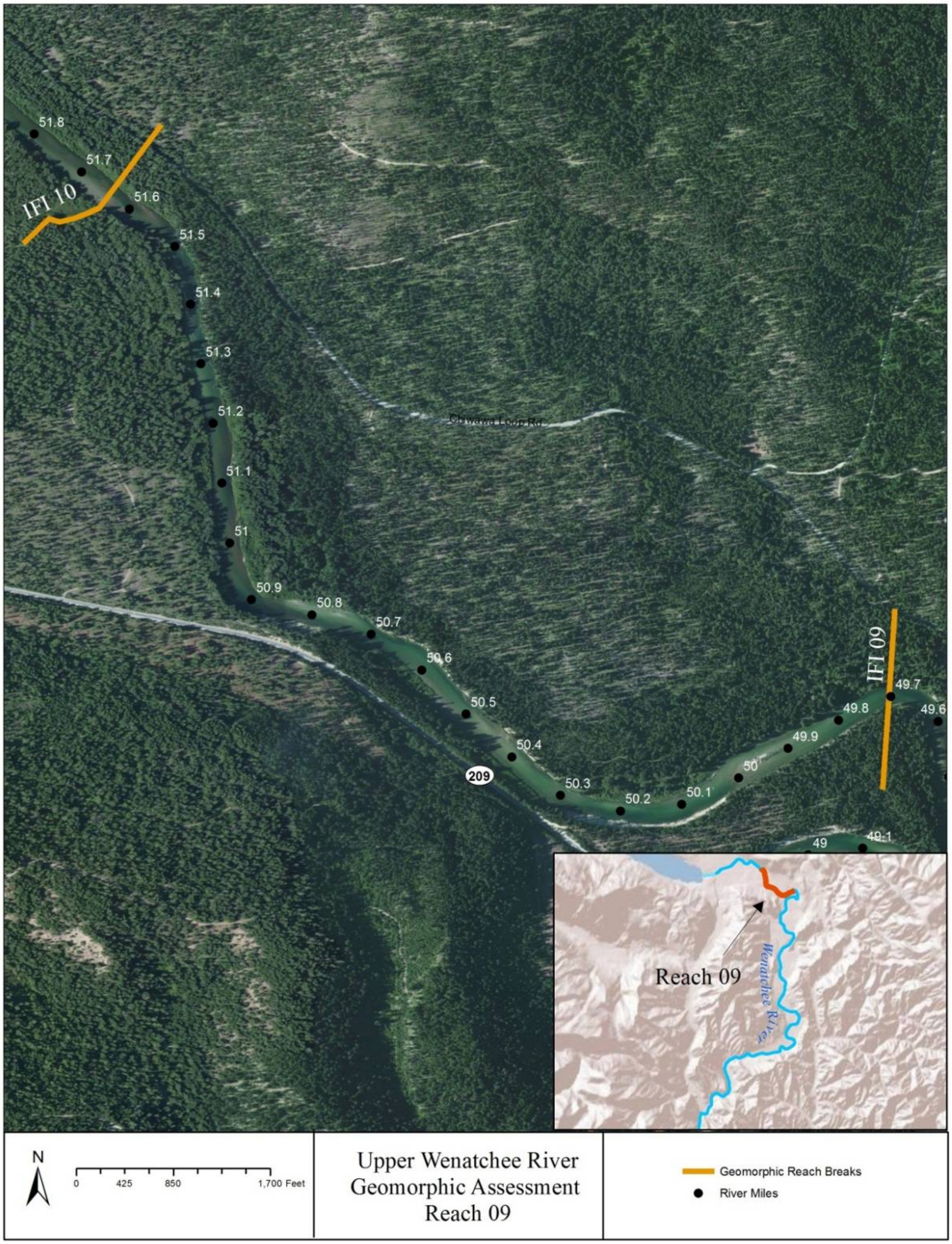

Figure 85. Overview map of Reach 9. Flow is from northwest to southeast.

4.9.2 Forms and Processes

Reach 9 contains a slightly meandering channel with a sinuosity of 1.28. Channel morphology is largely homogeneous plane-bed with riffle-glide characteristics. The riffle-like characteristics include an increase in channel width and gradient, and a slight decrease in depth, and at RM 49.98, the development of mid-channel bar complexes that are associated with a bar apex logjam. At the downstream-most portion of the reach, the glide deepens as the channel approaches the meander bend to meet the deep channel-spanning pool of Reach 8. Substrate ranges from sands to sparse boulders, but gravels (47%) and sands (26%) dominate the composition of the channel bed as well as the modern floodplain surfaces.

The channel and its modern floodplain are partially confined by terraces of glacial drift and outwash. The steep terrace banks supply sediment to the system at cut-bank exposures. Minor periodic large-wood inputs are supplied by the forested terrace surfaces that create wood accumulations at the base of the terrace slope (Figure 86). Alternating terrace banks have naturally limited the channel's lateral migration throughout the reach.

Figure 86. Example of a channel margin large wood accumulation from steep terrace banks.

The modern floodplain surfaces contain backwater and wetted off-channel habitat. The backwater habitats are connected to the channel at the downstream outlets of partially abandoned secondary or overflow channel scars. Wetland habitats occupy similar features but surface water connectivity with the main channel has been eliminated by incision and/or outlet infilling in the downstream portion of the reach. This pattern of connectivity is visible in the inundation analysis presented in Section 3.5.2. The wetland habitats and backwater in the upper portion of the reach are regularly inundated and their surrounding floodplain surfaces are almost fully inundated with flows equivalent to a two-year flood event. The backwaters exchange both surface and hyporheic flow with the channel.

The gradient of Reach 9 is 0.04%, less than half that of Reach 8 and 10. However, the minimal complexity and relative straight form of the channel through Reach 9 gives the flow a stream power that is more than half of its neighboring reaches (Section 3.5.2). Incision is resulting in the disconnection of modern floodplain surfaces in the downstream portion of the reach. Evidence of relatively modern incision includes recently abandoned or very rarely inundated floodplain surfaces, a hanging tributary junction at RM 49.8 on river-left, and surface topography of elevated point bar scrolls at RM 50.2 that are now sequentially vegetated with maturing forest.

If incision continues in Reach 9, it has the potential to lead to reduced channel complexity, increased channel slope and flow energy, reduced flood peak attenuation, and increased peak magnitude for a given event. A lack of bedrock in Reach 9 means that incision processes have the potential to migrate upstream and start reducing inundation rates in Reach 10.

The floodplain and terraces bordering the channel are well vegetated with maturing mixed forests. This provides for well-functioning canopy cover throughout the reach. Despite the vegetated banks, Reach 9 is lacking in large wood. Some accumulations are found at the margin of the channel and at one apex jam on the mid-channel bar complex located at RM 49.98.

4.9.3 Effects of Human Alterations

Minor anthropogenic alterations currently exist within Reach 9. There are no private land-holdings but established transportation routes directly influence two of the floodplain units. Fill used in the construction of Beaver Valley Road (Hwy 209) isolates floodplain surfaces from channel processes on river-right between RM 50.3 and 50.75. A set of primitive dirt roads and trails cross the downstream river-left floodplain unit between RM 49.7 and 50.5, but these appear to impose little to no impact on river processes.

Evidence of historical timber harvest and log transport exists throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4.3. Notable in Reach 9 is the historical harvest of mature trees, lack of channel complexity and form, and creosote soaked logs buried in the banks and bed of the channel. These clues suggest bed scour and channel simplification as a result of harvest practices. Without historical data it is difficult to know how much incision processes have been accelerated by historical timber harvest practices compared to natural downcutting through the glacial drift and outwash deposits. Regardless, simplification and resultant incision of the channel’s bed has led to variability in floodplain connectivity within Reach 9. The pattern of incision and disconnection in the downstream portion of the reach is visible in the inundation analysis presented in Section 3.5.2. These processes are also influencing floodplain connectivity in the upstream-most portion of Reach 8.

Human alterations are mapped in Figure 87, Figure 88, and Figure 89.

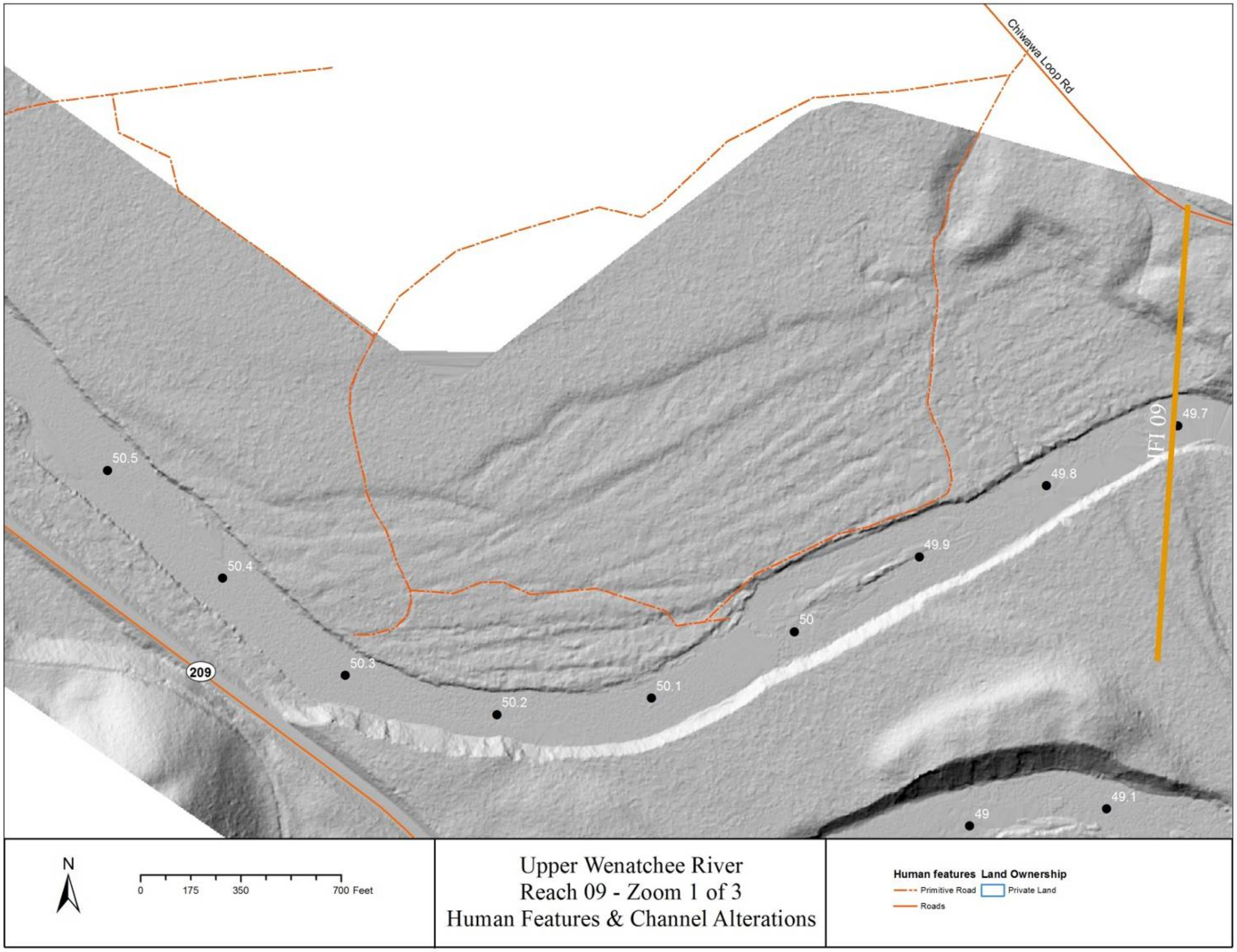

Figure 87. Human alterations in the downstream portion of Reach 9. Flow is from west to east.

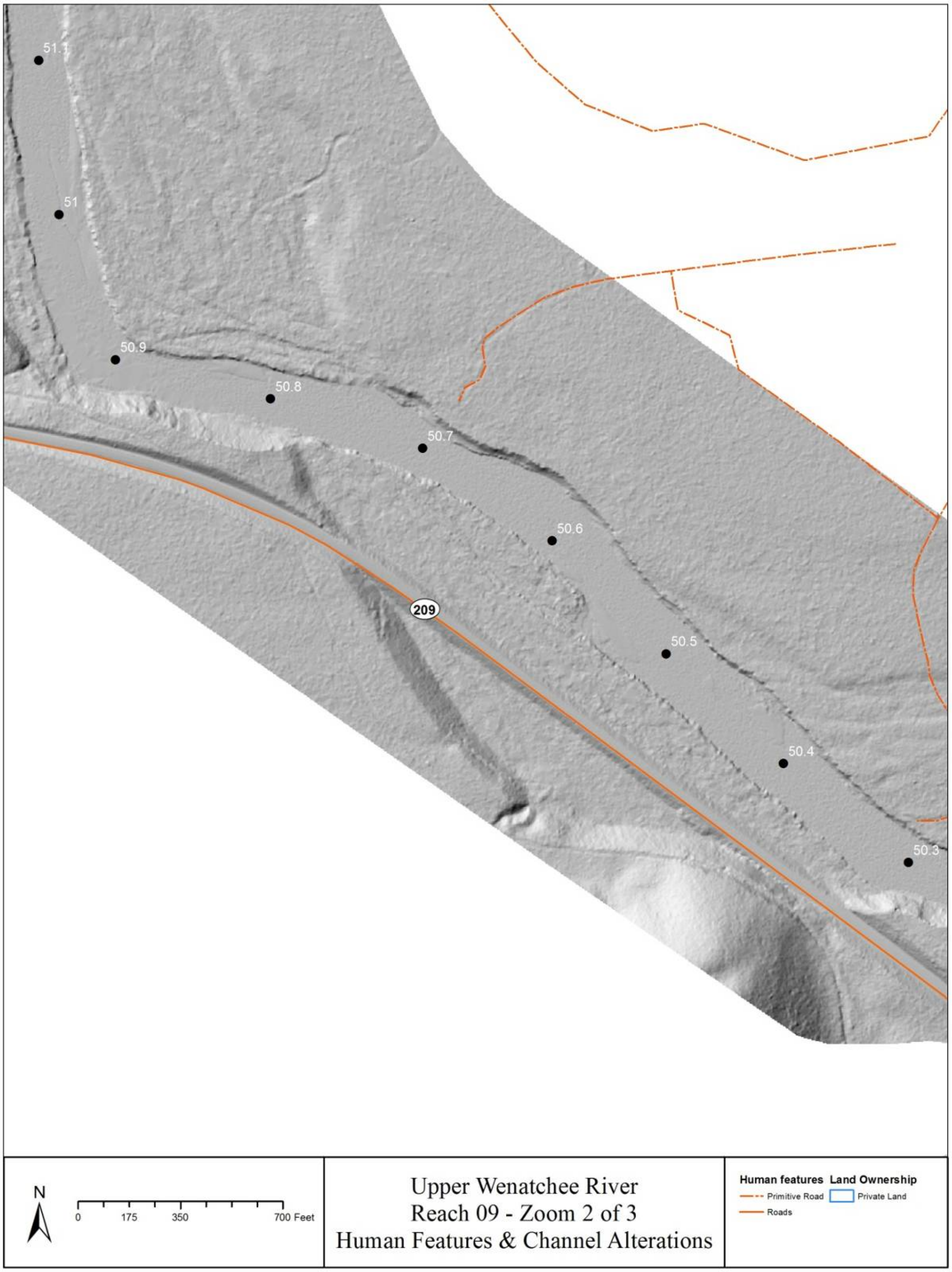

Figure 88. Human alterations in the Reach 9. Flow is from northwest to southeast.

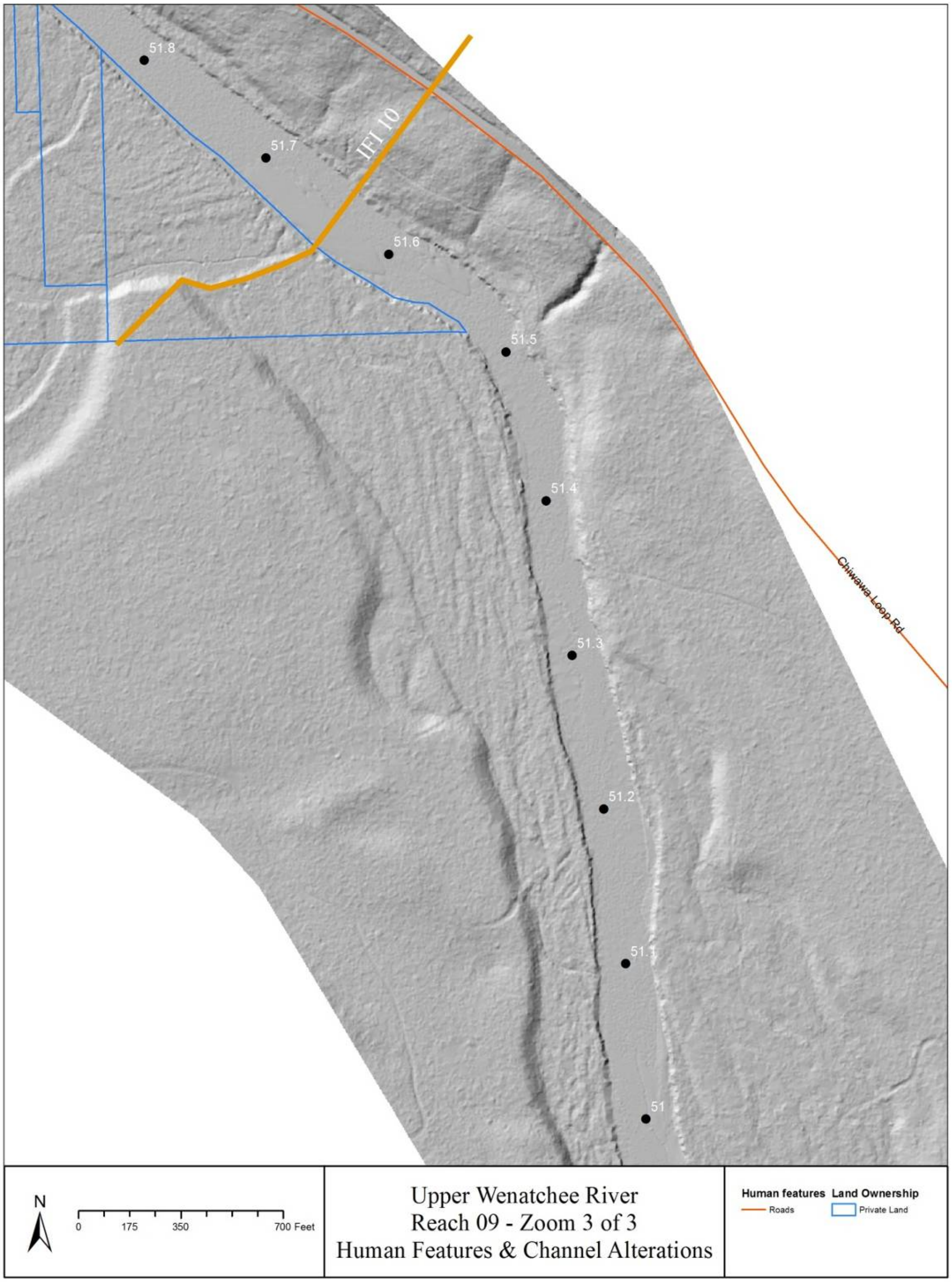

Figure 89. Human alterations in the upstream portion of Reach 9. Flow is from north to south.

4.10 Reach 10

4.10.1 Reach Overview

Reach 10 is 2.02 miles long and extends from RM 51.65 upstream to the confluence with Nason Creek at RM 53.67 (Figure 90). The channel meanders through a wide alluvial reach that is partially confined by terraces of glacial drift and outwash. Floodplains contain large complex backwaters and off-channel aquatic habitat located in abandoned channels and scroll scars. Surface water discharge and sediment inputs from Nason Creek influence channel form and processes in Reach 10. Fish Lake Run Creek is a small tributary that enters the mainstem via the backwater complex at RM 52.1. Other small ephemeral streams sourced from the hillslopes contribute additional seasonal surface water inputs. Anthropogenic impacts associated with homesite development dominate processes on the right bank. Additional impacts from bridge/road construction and historical logging practices are also evident. Most of the river-left floodplain is US Forest Service land.

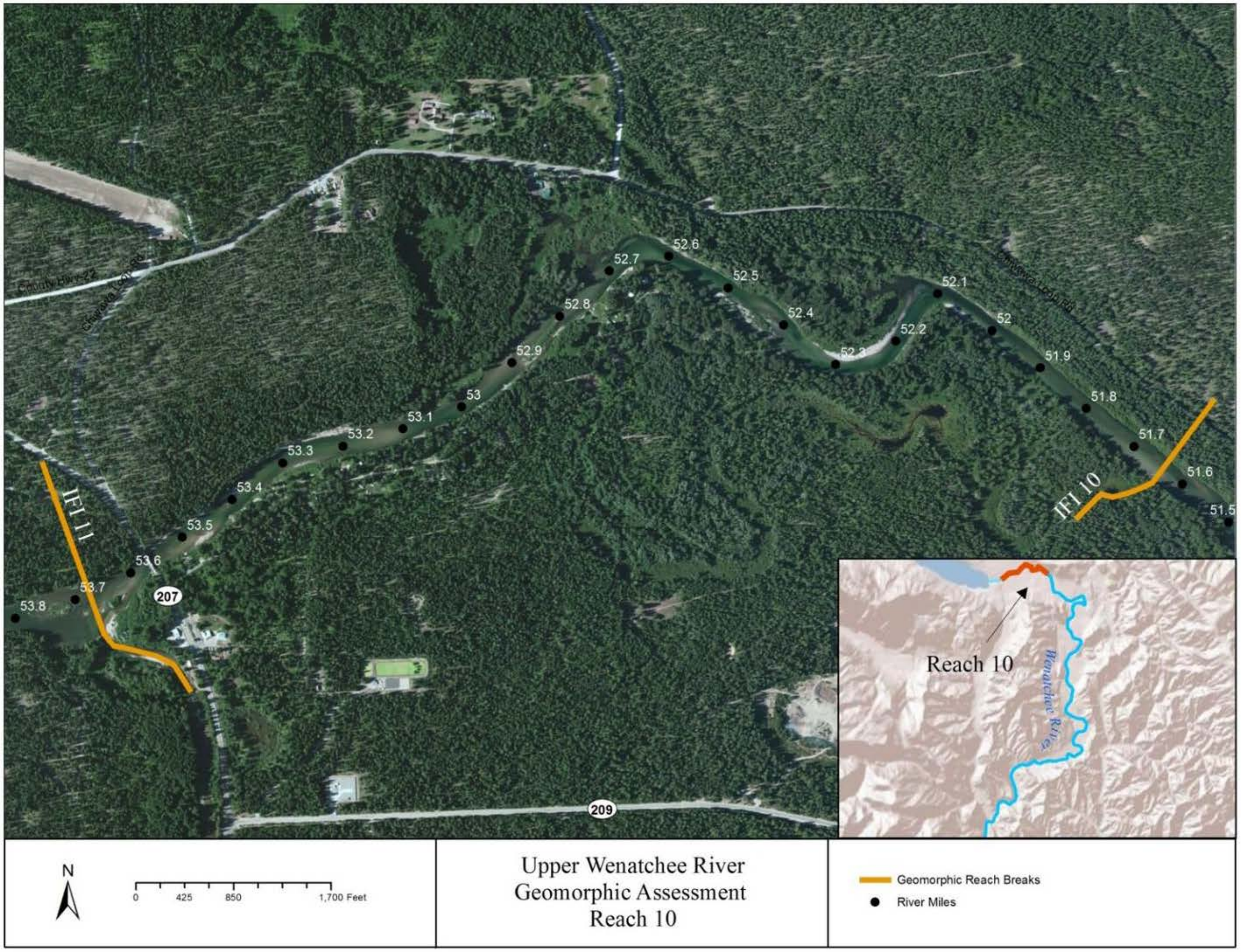

Figure 90. Overview map of Reach 10. Flow is from west to east.

4.10.2 Forms and Processes

Reach 10 contains a slightly meandering channel with long straight sections in the up and downstream portions. The channel's sinuosity is 1.23 with a gradient of 0.11%. Bed morphology is a mix of subtle pool-riffle and plane-bed glide units. Near the confluence with Nason Creek and where the channel is more sinuous, complexity of bed morphology is greater. Point and mid-channel bar development occurs in the upper half of the reach prior to channel simplification in the downstream portion. Substrate ranges from sands to sparse boulders with cobbles (49%) and gravel (36%) dominating the composition of the channel bed.

The channel and its modern floodplain occupy a partially-confined alluvial valley with an average width of 786 feet. Terraces of glacial drift and outwash confine the channel on river-left at RM 53.05 to RM 53.7 and at RM 52.6 (Figure 91). Homesite development and bank hardening on river-right at RM 52.6 to RM 53.57 further confine lateral channel migration in the upper portion of the reach (Brae Burn Rd area). Historical survey maps and channel migration scars visible in high resolution LiDAR imagery indicate that this reach was more sinuous and actively mobile in recent history.

Figure 91. Representative geomorphology of Reach 10 with river-left terrace confinement and low-elevation river-right floodplain surfaces.

Depositional patterns, photo imagery, and floodplain topography suggest that the majority of alluvial floodplain materials in Reach 10 originated as fan deposits from Nason Creek. Inputs from Nason Creek had a greater influence on the geomorphic processes of Reach 10 prior to road and bridge construction that now confines the location of the confluence. Based on bar and island development at the modern confluence, Nason Creek still provides substantial bedload that influences channel processes at its mouth (Figure 92).

Figure 92. Point bar development as part of the alluvial fan deposits at the mouth of Nason Creek.

The modern floodplains are composed of sands to cobbles with bank steepness increasing relative to increasing sand/loam content. Floodplain bank elevations range slightly in Reach 10 but all are capable of being inundated during flood flows. Hydraulic modeling presented in Section 3.5.2 confirms that a large portion of the modern floodplain surfaces are capable of being inundated during flow events equivalent to a two year flood.

The floodplains in Reach 10 contain extensive off-channel wetlands and large connected backwater complexes. Both features are located in abandoned channel scars or scrolls and offer highly functioning habitat. The extensive wetland features are located within the downstream half of the river-right floodplain (Figure 93). These features are disconnected from each other and the mainstem channel, except during flood events. The extensive backwaters located within the two small floodplain surfaces on river-left offer very good connected aquatic refugia. Emergent vegetation and large wood accumulations at these features offer highly functioning habitat.

The floodplain and terraces bordering the channel in Reach 10 are well vegetated with maturing mixed forests, except where residential development is occurring. This provides for well-functioning canopy cover throughout large portions of the reach. There are sufficient forested surfaces adjacent to the channel yet Reach 10 appears to be lacking in large wood material accumulations that could add habitat and geomorphic complexity to the reach. Sparse minor wood accumulations are found at the margins of the channel and at bar locations.

Figure 93. Wetland located within historical channel scar on right bank from RM 51.7 to RM 52.9 (photo taken facing upstream).

4.10.3 Effects of Human Alterations

A large portion of the right bank has been modified by anthropogenic development. At the upstream end of Reach 10 (RM 53.57) fill for the construction of Hwy 207 isolates downstream floodplain surfaces from historical geomorphic processes associated with both the Wenatchee River and Nason Creek. Additionally, the Hwy 207 bridge abutments and associated riprap create a localized artificial channel constriction. This constriction limits lateral channel migration and creates a localized increase in channel velocities which has created scour pools. Here the Wenatchee River is held in place against the confining terrace slopes on river-left.

In general, the construction of Hwy 207 impedes the natural migration rates and patterns of what was once a dynamic channel confluence of Nason Creek and the Wenatchee River. This historically active area is evidenced by 1887 survey maps (Figure 94), surface topography, and channel scars visible in LiDAR imagery. Modern flood history (1990) and the hydraulic floodplain inundation model (Section 3.5.2) confirm the potential for dynamic flood hydraulics to occur at the confluence of Nason Creek and the Wenatchee. It appears that the confinement of the channel at the Hwy 207 Bridge further backs up floodwaters at the confluence. As a result, serious flooding of the small community of Lake Wenatchee along Hwy 207 can occur as flood stages breach the road and its fill.

Residential homesite development further disconnects the upper 1.5 miles of the river-right floodplain. Homesite development here also includes floodplain dissection by roads and utilities installation, removal or alteration of riparian vegetation, fill or grading of surfaces, and installation of localized bank hardening or protection such as riprap and retaining walls, as well as small boat docks and rock spurs for diverting flow. The off-channel wetland features described above extend across the river-right floodplain behind the homesite development.

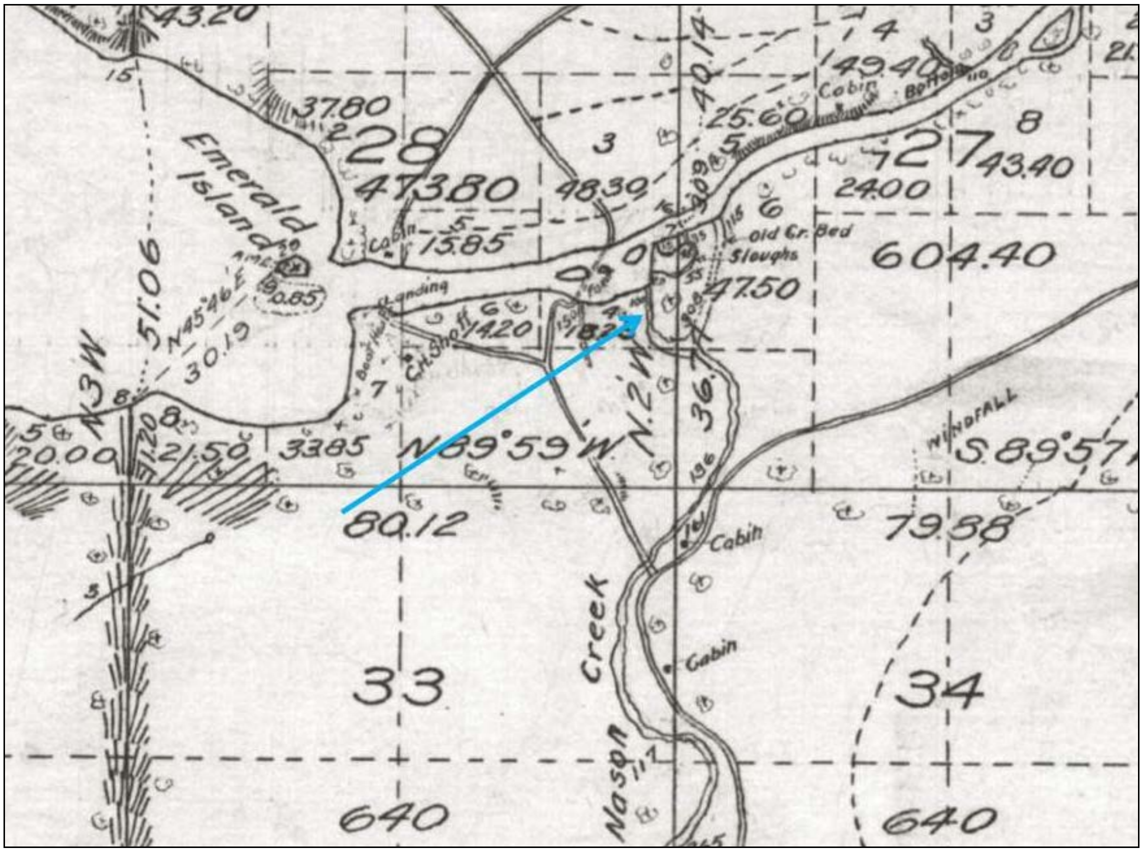

Figure 94. 1887 survey map of confluence of Wenatchee River and Nason Creek. Delineated "Old Cr. Bed" highlights Nason Creek's formerly highly active alluvial fan.

Evidence of historical timber harvest and log transport exists throughout the study area. Potential impacts of these practices are discussed in detail in Section 3.4.3. It is inferred that splash damming at the historical mill site located upstream in Reach 11, and related downstream scour, resulted in channel simplification in Reach 10. The hydraulic inundation model presented in Section 3.5.2 shows that river-right floodplain connectivity is limited in areas of homesite development and bridge construction. Incomplete inundation at the two year flood discharge stage of some low-elevation modern floodplain surfaces in Reach 10 raises the concern of some degree of human-accelerated incision processes in the upstream portion of the reach where anthropogenic influences are most prevalent. However, without historical data it is difficult to determine the extent that the effects of these practices have had on the channel. The oldest survey maps of record from the area (1883 and 1893) depict human development (cabins, boat ramps, etc.) on the floodplain (see Figure 94). In these maps the mainstem channel is already located against the river-left terrace banks indicating that form and location of the channel was already established by that time.

Human alterations are mapped in Figure 95, Figure 96, and Figure 97.

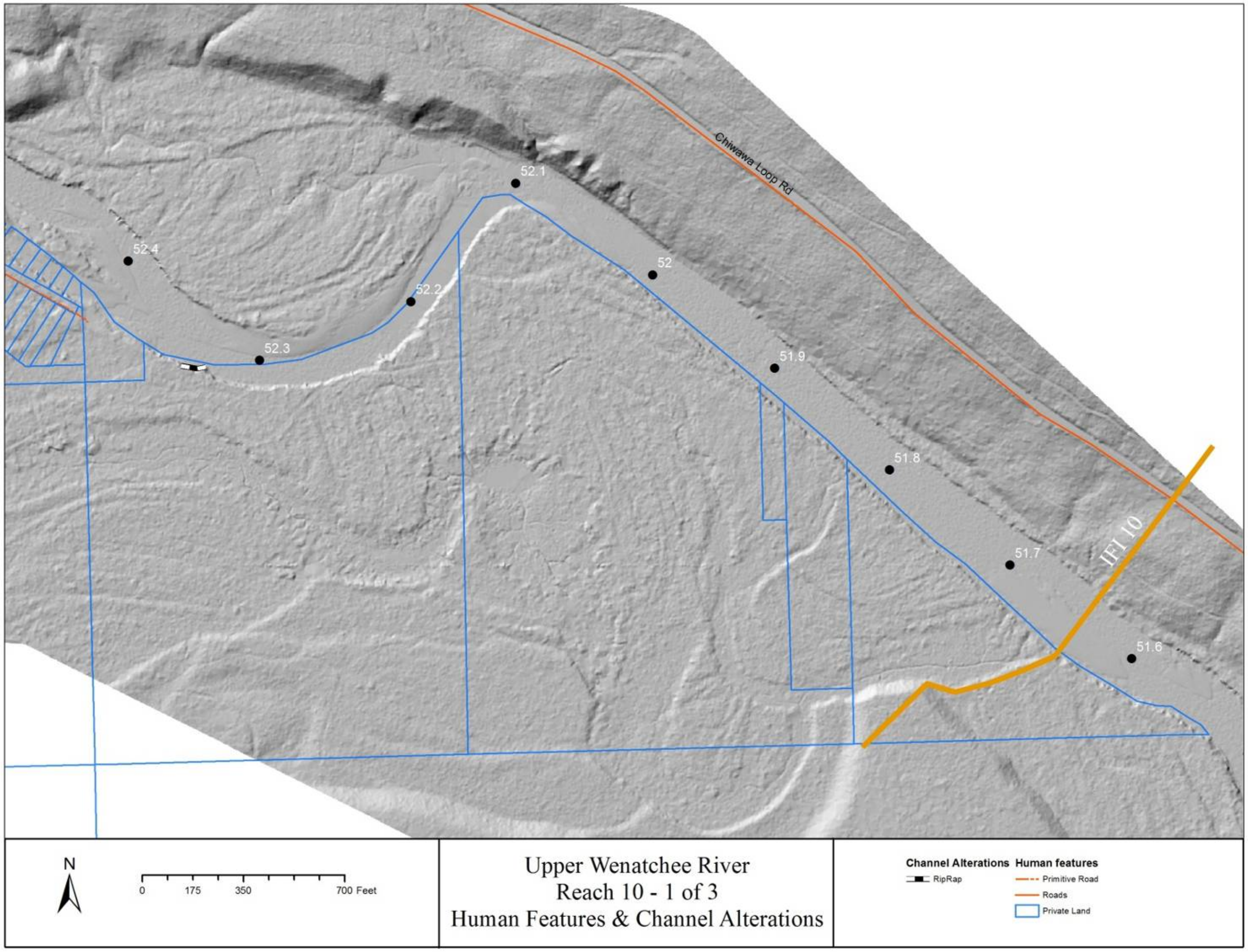

Figure 95. Human alterations in the downstream portion of Reach 10. Flow is from northwest to southeast.

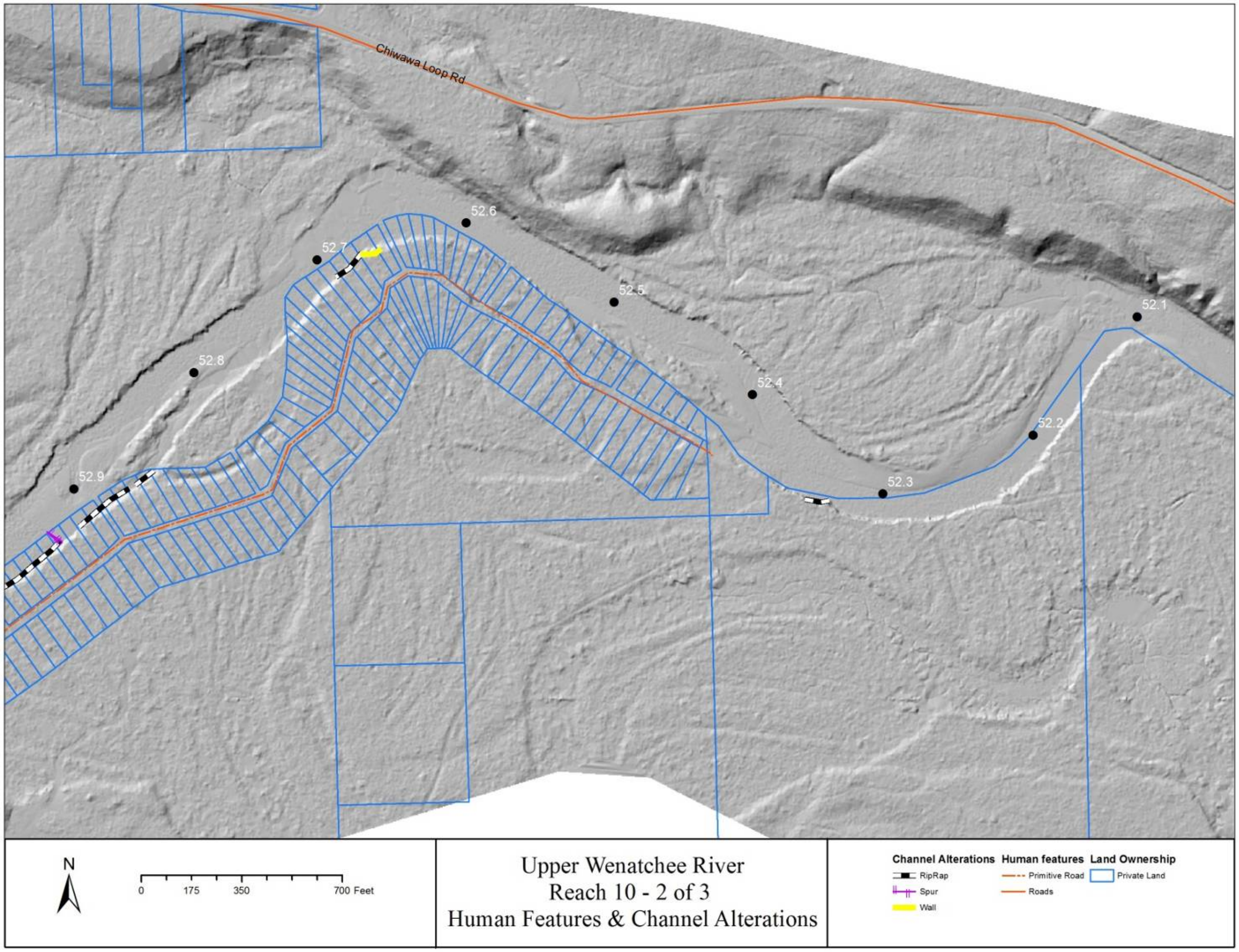

Figure 96. Human alterations in Reach 10. Flow is from west to east.

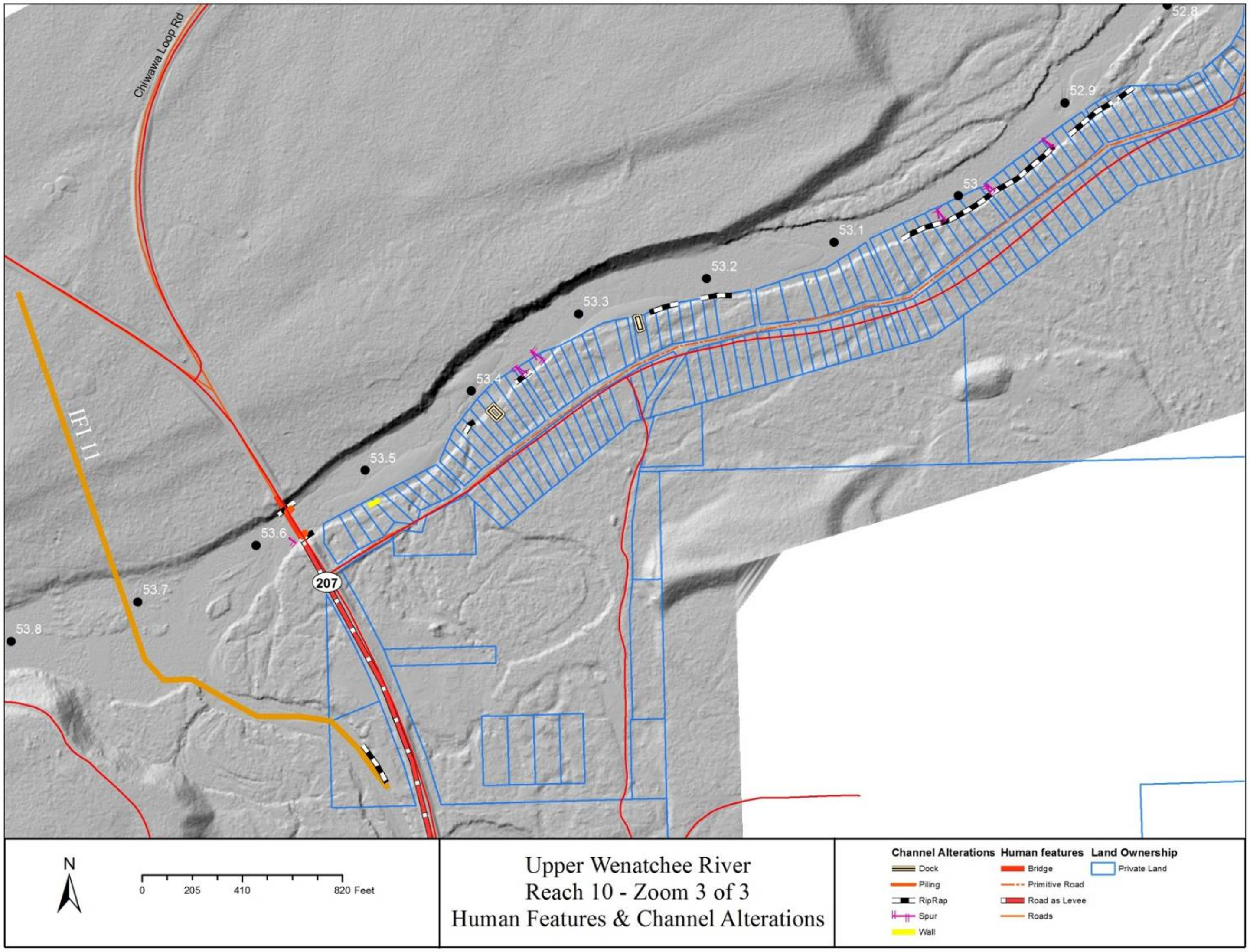

Figure 97. Human alterations in the upstream portion of Reach 10. Flow is from west to east.

4.11 Reach 11

4.11.1 Reach Overview

Reach 11 is 0.5 miles long and begins at the confluence of Nason Creek and extends upstream to the outlet of Lake Wenatchee at RM 54.15 (Figure 98). This is the upstream-most reach of the mainstem Wenatchee River and it is defined by a mix of lacustrine and riverine geomorphology between the Lake and the Upper Wenatchee River. Lake Wenatchee acts a hydrologic moderator that supplies base-flow discharge to Reach 11 during low flow late-summer months. It is assumed that groundwater inputs to the channel through the surrounding glacial deposits are also occurring. The channel is straight and confined until it widens at the confluence with Nason Creek. The geomorphic processes of the downstream portion of Reach 11 are influenced by discharge and sediment inputs from Nason Creek. The upper half of the reach is managed by Washington State Parks and Recreation and the lower half is managed by the US Forest Service. Historically, the upstream most 2,000 feet of the channel were used as a log holding pond for a mill located where Lake Wenatchee State Park is today (Hink 2008, HEC 2009).

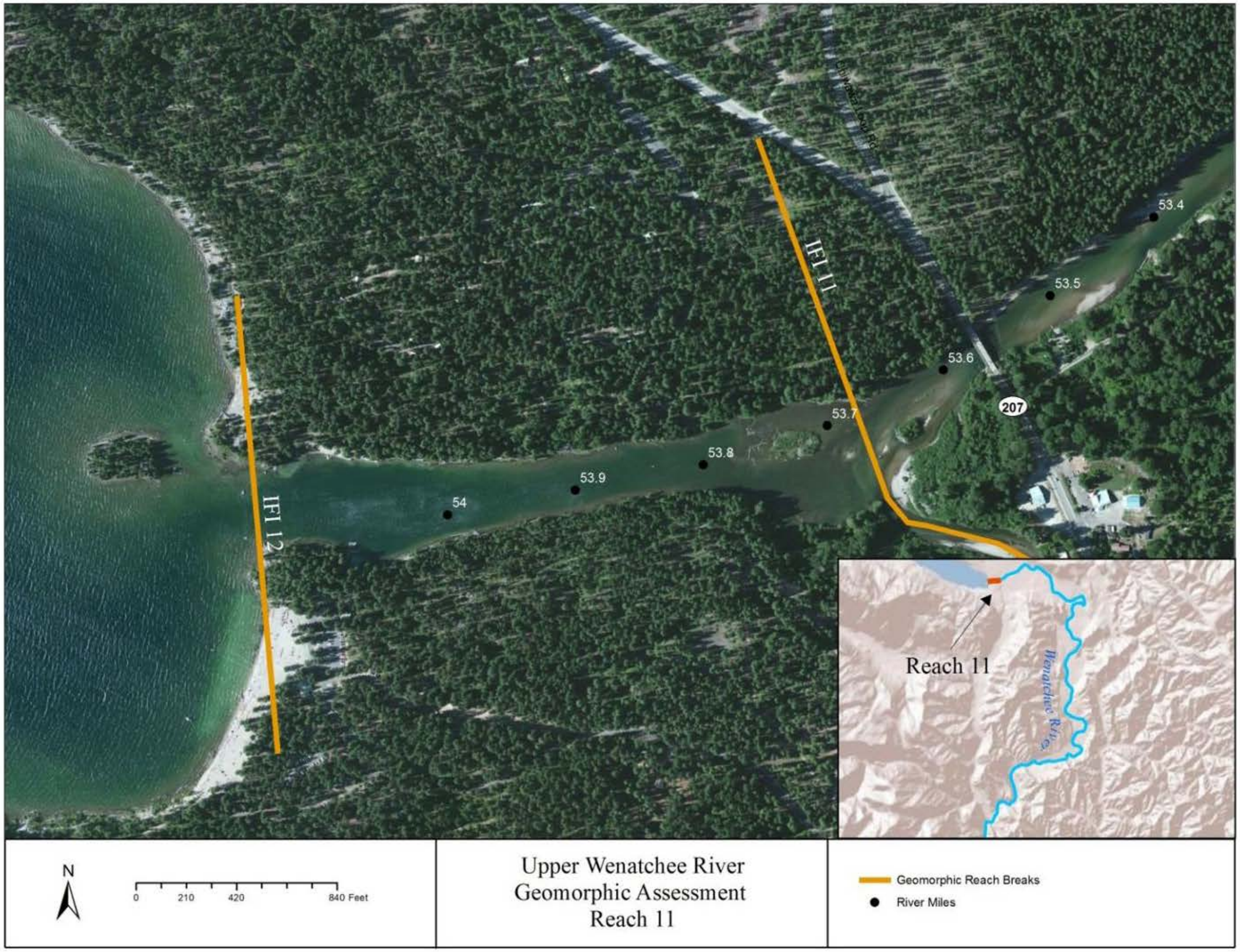

Figure 98. Overview map of Reach 11. Flow is from West to East.

4.11.2 Forms and Processes

Reach 11contains an almost perfectly straight channel with a sinuosity of 1.01. The upper 0.5 miles of the reach is entirely confined by glacial terrace deposits that the Wenatchee River has incised through. The channel is planebed with a subtle pool-glide morphology and very limited complexity (Figure 99). At the lower 0.1 miles of the reach channel form and processes are influenced by sediment and discharge inputs from Nason Creek. Here the channel widens and mid-channel island and bar development is occurring behind large glacially deposited boulders and accumulating large wood. Channel substrate throughout the reach ranges from sands to large boulders, with cobbles as the dominant grain size (60%). The overall gradient of the channel in Reach 11 is <0.10%.

Figure 99. Representative geomorphology of Reach 11, facing downstream (July 20, 2011).

Where the channel has incised through the glacial deposits in the upper 0.5 miles of the reach, there are no existing floodplain surfaces. The lower portion of the reach widens near the confluence of Nason Creek but remains confined by a glacial deposit terrace on river-left. On river-right at the confluence with Nason Creek, there are low-elevation floodplain surfaces that experience regular inundation. Small backwaters that occupy channel scars on these floodplains connect to lower Nason Creek.

The floodplain and terraces bordering the channel are well vegetated with maturing mixed forests and riparian plants. This provides good canopy cover along the margins of the channel. Despite the vegetated banks, Reach 11 is lacking in large wood. The steep banks of the confining glacial terraces are currently supplying only minor large wood inputs. However, wood accumulations are part of the developing mid-channel bar/island complex in the lower portion of the reach and are found as driftwood deposits along the margins of the upper portion of the reach.

4.11.3 Effects of Human Alterations

Modern anthropogenic alterations have only minor direct impacts on Reach 11 but the effects of past transportation routes and timber harvest practices continue to influence channel processes. The upper section of Reach 11 is currently managed by Washington State Parks and Recreation. This land contains campgrounds with recreational beaches, boat docks and launches, and minor road and trail development. The lower 0.1 miles of channel and the Nason Creek confluence area are managed by the US Forest Service. A low-impact walking trail bisects the floodplain at the confluence of Nason Creek.

Abandoned cement bridge pilings are located at RM 53.85 along both channel banks. The pilings create minor localized scour pools at their base. The bridge no longer exists but the remnant pilings are associated with access roads on both the right and left banks atop the glacial deposit terraces.

Historical timber harvest and log transport practices have altered the channel in Reach 11. Impacts include excavation in the uppermost 2,000 feet of the reach to create a log-holding pond for a mill located where Lake Wenatchee State Park is today (Hink 2008, HEC 2009). It is presumed that large boulders and remnant glacial erratics in the channel were dynamited and cleared to create space for this log-holding pond. Dredging and scour associated with downstream log transport likely further reduced channel complexity throughout the reach. Due to minimal sediment inputs from the lake, the upper section of Reach 11 remains altered by these historical land-use practices.

The construction of Hwy 207 and its bridge-crossing only 0.1 miles downstream from the Reach 11 boundary influences channel location and mobility. These structures and their associated fill and bank riprap currently restrict natural channel migration patterns of both Nason Creek and the Wenatchee River.

Human alterations in Reach 11 are mapped in Figure 100.

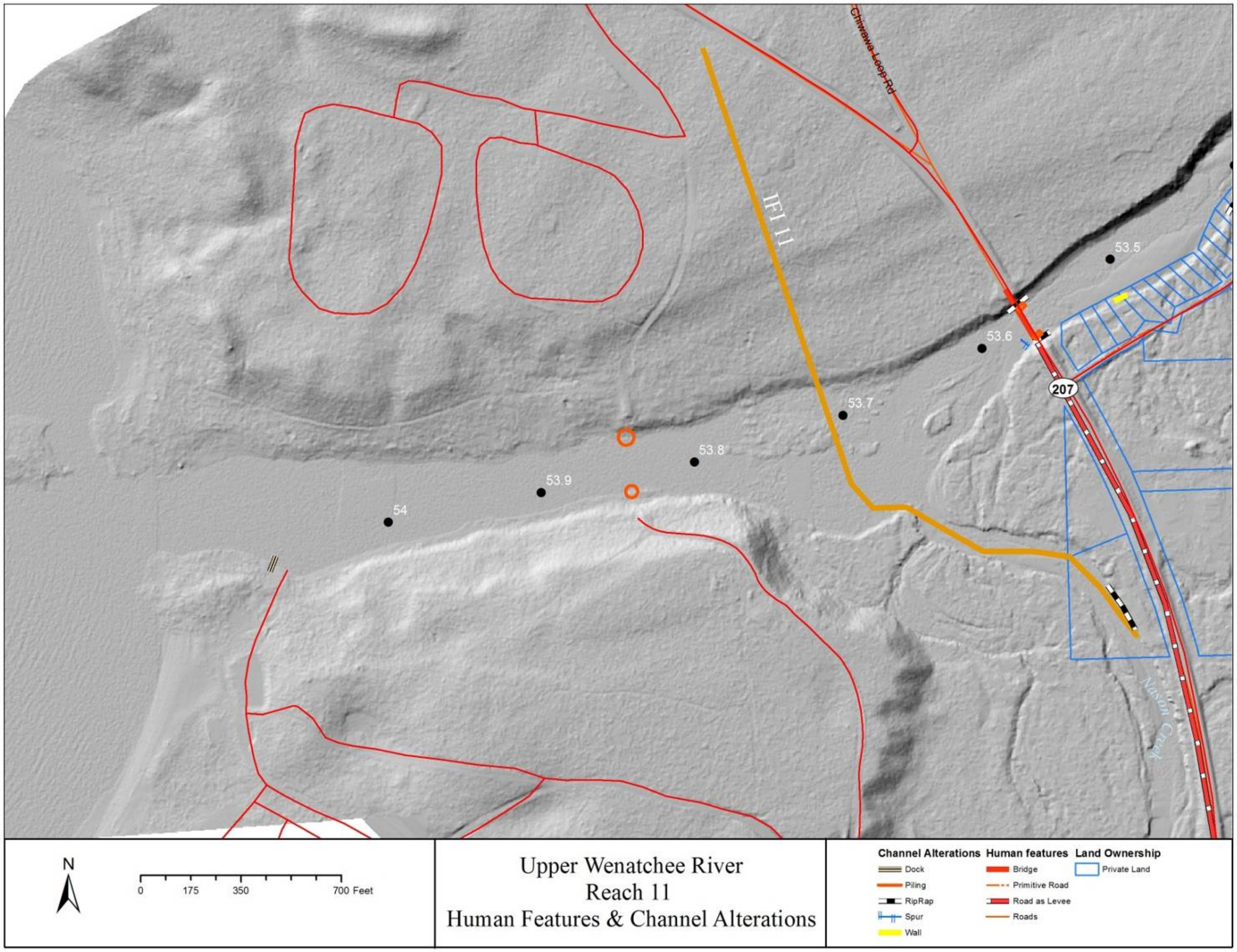

Figure 100 Human alterations in Reach 11. Flow is from west to east.

5 RESTORATION STRATEGY

5.1 Introduction

Development of the restoration strategy was guided by the habitat objectives set forth in the Upper Columbia Recovery Plan (UCSRB 2007) and by field and analytical work conducted as part of this Reach Assessment. Specifically, strategies were developed based on: 1) previous studies, 2) new analyses and field surveys conducted as part of this reach assessment, 3) a comparison of existing and target habitat conditions, and 4) current site conditions and human uses. The restoration strategy is presented in Section 5.4 and includes narrative descriptions and strategy tables that outline the restoration strategy for each reach.

The restoration strategy includes ‘action types’ as well as specific potential project opportunities. Five general action types were developed for use in this assessment and are applied as appropriate to individual reaches. Action types are developed at a broader scale than projects, and may be achieved through the use of numerous project types. For example, the action type “off-channel habitat enhancement” might be achieved via numerous project types ranging from re-connecting habitat blocked by a levee to excavating new off-channels in the floodplain.

For most reaches, at least 4 of the 5 action types are recommended, which indicates that much of the study area suffers from similar types of habitat impairments. The specific project opportunities, on the other hand, are more site specific and have unique characteristics depending on the particular habitat conditions, land uses, and geomorphic context of the site. Despite the additional specificity for projects, more analysis will still be necessary before projects are implemented; this may include topographic survey, hydraulic modeling, engineering analysis, and alternatives evaluation.

Specific potential project opportunities are linked to their respective action type(s) in the tables in Section 5.4 and are described in greater detail in Appendix D. The projects listed in Appendix D represent an initial step in identifying projects that fit the action types for each reach. Because of potential feasibility constraints (e.g. landowner cooperation), numerous potential projects have been identified, with the assumption that only a fraction of the potential opportunities will be taken to implementation. Additional information related to the approach to project identification is included in Appendix D.

5.2 Existing and Target Habitat Conditions

One of the primary tools for identifying action types and projects is a comparison of existing and target habitat conditions. This highlights habitat deficiencies and helps to develop restoration strategies. For each reach, existing and target habitat conditions are presented for a suite of habitat and geomorphic categories (Section 5.4 tables). Existing conditions were developed based directly on analyses and surveys performed as part of this Reach Assessment. Existing conditions information draws heavily from the habitat survey data (Appendix A) and also from the hydraulics and geomorphology assessments (Section 3.5.2 and 0).

Target conditions were developed using the REI targets as well as reference site conditions and inference from regional studies. See Section 3.5.3 and Appendix C for more information on the

REI analysis. The REI analysis is based on previous REI analyses conducted as part of previous Reach Assessments conducted by the USBR in other Upper Columbia tributaries. Due to unique conditions in the Upper Wenatchee River, a couple of notable variations were made to the REI and the corresponding restoration targets. These variations apply to the LWD metric and the pools metric, and are discussed below.

For the large wood and log jam category, the targets are: 1) greater than 80 wood pieces per mile (>12 inches diameter; >35 feet long, which constitutes the 'medium' and 'large' sizes from the habitat survey) and 2) greater than 4 log jams per mile (minimum 10 qualifying pieces). We chose to use the western cascades 80 pc/mi target from NMFS (1996) as opposed to the eastern cascades 20 pc/mi target for the following reasons. First, based on measurements of wood in unmanaged streams in eastern Washington, Fox and Bolton (2007) determined that the NMFS (1996) standard is low for larger eastern Washington streams (5m-50m bankfull width), which had greater than 40 pc/mi on average. Because the bankfull widths on the upper Wenatchee are even larger than the streams included in the Fox and Bolton study (i.e. average of 90m), historical wood numbers would be expected to be even greater, primarily due to large log jams that are assumed to have been present in this reach historically (see Section 3.3.3). Second, Reach 1, which serves as a reference reach due to its relatively undisturbed condition, has 142 pc/mi currently; and there is no reason to believe that wood numbers here would be higher now than under historical conditions. Lastly, the upper Wenatchee study area as a whole averaged 64 pc/mi under existing conditions; consequently, achieving >80/pieces per mile is believed to be an appropriate and attainable restoration goal.

The log jam target of 4 log jams/mi was obtained with reference to existing conditions in Reach 1 (3.8 jams/mi). It is believed that historically, wood pieces within the study area would have mainly been associated with log jams. Fox (2003) reported that in unmanaged streams in Washington, for channels >50-100m bankfull width, over 80% of the wood pieces occurred in groups of 10 or more.

The pool frequency and quality metric was also adapted for the Upper Wenatchee River. 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. Because Upper Wenatchee bankfull widths far exceed the criteria (ranging from 270 feet to 360 feet), reaches were primarily evaluated based on the pool quality metrics provided by NMFS (1996) (e.g. depth, substrate, cover, refugia), rather than number of pools.

5.3 Restoration Strategy Descriptions

The Restoration Strategy includes five general action types. These are described in the sections below. There is not a specific action type identified to address water quality and quantity. Although these are not believed to be significant limiting factors in the study area, they will nevertheless be partially addressed through improvements to riparian conditions and habitat connectivity (i.e. increased floodplain storage). The potential impact of water withdrawals is being addressed through other efforts (e.g. WRIA planning) and is beyond the scope of this study.

5.3.1 Protect and maintain

Protection projects involve preservation of high quality habitat. Preventing further degradation of other areas is generally not identified as a 'protect and maintain' action because it is considered inherent in all potential actions. In many cases, adequate protection may already be in place through existing laws and regulations. The adequacy and enforcement of these regulations needs to be considered when planning for protection activities.

Examples:

- Direct purchase (fee acquisition) of an area of functioning habitat and physical processes, or of an area at risk of further degradation through development
- Obtaining a conservation easement from a landowner in order to eliminate agricultural or residential development uses within a riparian buffer zone

5.3.2 Riparian restoration

Riparian restoration projects are located in areas where native riparian vegetation communities have been significantly impacted by anthropogenic activities such that riparian functions and connections with the stream are compromised. Restoration actions are focused on restoring native riparian vegetation communities in order to reestablish natural stream stability, stream shading, nutrient exchange, and large wood recruitment. Even though it is not always explicitly stated, riparian restoration is a recommended component of most restoration projects, particularly within the disturbance limits of the project.

Examples:

- Replanting a riparian buffer area with native forest vegetation
- Eliminating invasive plant species that are preventing the reestablishment of a native riparian forest community

5.3.3 Habitat reconnection via infrastructure modification

This strategy includes removal/modification of bank armoring, levees, roadways, or fill. Habitat reconnection projects are located in areas where floodplain and channel migration processes have been disconnected due to anthropogenic activities. These are areas that have the potential for an increase in habitat quality and a reestablishment of dynamic processes through their reconnection. Restoration actions are focused on reclaiming a component of the system that has been lost, therefore regaining habitat and process that was previously a functional part of the river system.

Habitat reconnection projects may also include the reestablishment of fish passage where it has been blocked. For the Upper Wenatchee, there are no passage barriers on the mainstem but there are off-channel habitats where fish access has been affected by fill or by legacy incision of the mainstem.

Examples:

- Removal or selective breaching of a levee or road embankment to enhance floodplain connectivity

- Removal of rip-rap and replacement with LW in order to eliminate bank hardening and channelization that restricts channel migration, simplifies the channel, and compromises instream aquatic habitat quality and quantity

5.3.4 Placement of structural habitat elements

This strategy includes placement of habitat structures such as large wood, log jams, or boulders in order to achieve numerous habitat and geomorphic objectives. These types of projects can span a broad range of structure versus function-based approaches. For instance, a single log placement might be used in an existing pool to simply provide salmonid hiding cover, which would be chiefly a form-based approach. In contrast, a large constructed log jam might be used as a more function-based element that is intended to create split-flow conditions, create a bar/island complex, and to create and maintain scour pools. Structural elements are placed in areas where they would naturally accumulate and would be maintained by the existing stream hydrology and geomorphology.

Examples:

- Installation of a bar apex log jam to create and maintain a multi-thread channel system with mid-channel bars/islands and split-flow conditions, thus maximizing margin habitat and complexity
- Installation of a meander-bend log jam to maintain pool scour and to increase velocity refuge and cover for juvenile salmonids
- Installation of individual pieces of large wood in an existing off-channel area to increase hiding cover from aquatic, terrestrial, and avian predators

5.3.5 Off-channel habitat enhancement

Off-channel habitat enhancement projects are located in areas (e.g. floodplains) where there is the potential to increase the quantity and quality of off-channel habitat. Off-channel projects may include the activation of existing floodplain habitat areas that have been disconnected via channel incision or floodplain alterations. In other cases, off-channel areas can be created via excavation and construction of floodplain features such as backwaters, groundwater-fed channels, and flow-through side channels.

Examples:

- Construction of off-channel features such as alcoves, backwaters, or flow-through side channels that are connected to the main channel
- Construction of a groundwater-fed channel to provide cool summer and warm winter temperatures for rearing salmonids

5.4 Reach-Scale Strategies

5.4.1 Reach 1

Reach 1 has been relatively unaffected by direct human alterations for at least the past 50 years. Previous impacts included log drives and riparian timber harvest but the reach has been on a trajectory of recovery since these historical impacts. Except for at the downstream end (Highway 2 crossing), the reach has limited access and is almost entirely within US Forest Service ownership. Because of the relatively intact and functional geomorphic processes and aquatic habitat, this reach is used as a reference reach to help develop target conditions for the remainder of the study area.

The primary restoration strategy for Reach 1 is to protect and maintain. This designation is given due to the particularly high quality habitat, not because there are any imminent threats to this reach. The one potential project opportunity in this reach is to add large key pieces of wood that would be available to initiate log jam formation and enhance lateral channel dynamics, pool scour, cover, and complexity. The very large key pieces needed to form log jams are much less abundant than historical conditions and it is believed that re-introducing key pieces would create a positive habitat response by collecting additional wood, sorting sediment, and providing direct habitat benefits. Access is difficult so key pieces would likely have to be flown in and placed by helicopter. In some areas, decommissioned access roads may be able to be utilized.

Reach 1 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	55% large tree 45% small tree or smaller No human disturbance	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Protect and maintain** Allow existing forest to mature.	No specific actions identified. Land is completely within USFS ownership and is assumed to be protected from riparian clearing.
Floodplain Connectivity	Floodplain width / BFW = 3.2. No human disturbance in the floodplain	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Protect and maintain**	No actions identified
Bank condition / Channel migration	Channel migration is operating at or near natural rates. No bank armoring	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Protect and maintain**	No actions identified
Vertical channel stability	No significant human-induced aggradation or incision.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Protect and maintain**	No actions identified
Pools	Pools per mile = 2.7 40% pool habitat 100% of pools >1 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Protect and maintain**	No actions identified

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and log jams	142 pieces / mi 3.8 jams /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Protect and maintain** **Placement of structural habitat elements including large wood, log jams, or boulders** Potential key piece supplementation: add large key pieces of wood that would be available to initiate log jam formation. The very large key pieces needed to form log jams are much less abundant than historical conditions.	Key piece supplementation at natural log jam formation locations (e.g. bar apexes, off-channel areas, meander bends).
Off-Channel Habitat	24% side-channel habitat. Multiple abandoned oxbows and floodplain wetlands are currently connected to the channel.	Reach has ponds, oxbows, backwaters, side-channels, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Protect and maintain**	No actions identified

5.4.2 Reach 2

Similar to Reach 1, this reach has been relatively unaffected by direct human alterations for at least the past 50 years. Previous impacts included log drives and riparian timber harvest but the reach has been on a trajectory of recovery since these historical impacts. Reach 1 is higher gradient, lower sinuosity, and has less habitat complexity than adjacent reaches. Previous log drives and decreased wood quantities likely contribute to simplification.

The primary restoration strategy for Reach 2 is to protect and maintain. This designation is given due to the existing degree of limited human impact, not because there are any imminent threats to this reach. As with Reach 1, the one potential project opportunity in this reach is to add large key pieces of wood that would be available to initiate log jam formation and enhance lateral channel dynamics, pool scour, cover, and complexity. The very large key pieces needed to form log jams are much less abundant than historical conditions and it is believed that re-introducing key pieces would create a positive habitat response by collecting additional wood, sorting sediment, and providing direct habitat benefits. Access is difficult but not as challenging as in Reach 1. There is a primitive road (now closed) along the river-right bank that could be utilized or key pieces could be flown in and placed by helicopter.

Reach 2 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	56% large tree 44% small tree or smaller. No human disturbance	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Protect and maintain** Allow existing forest to mature.	No specific actions identified. Land is completely within USFS ownership and is assumed to be protected from riparian clearing.
Floodplain Connectivity	Floodplain width / BFW = 2.2. No human disturbance in the floodplain	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Protect and maintain**	No actions identified
Bank condition / Channel migration	Channel migration is operating at or near natural rates. No bank armoring	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Protect and maintain**	No actions identified
Vertical channel stability	No significant human-induced aggradation or incision.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Protect and maintain**	No actions identified

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Pools	Pools per mile = 0.9 13% pool habitat 100% of the pools are between 1 and 2 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Protect and maintain** Key piece supplementation described for large wood could help enhance pool habitat.	Key piece supplementation described for large wood could help enhance pool habitat.
Large wood and log jams	26 pieces / mi 1.0 jams /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Protect and maintain** **Placement of structural habitat elements including large wood, log jams, or boulders** Potential key piece supplementation: add large key pieces of wood that would be available to initiate log jam formation. The very large key pieces needed to form log jams are much less abundant than historical conditions.	Key piece supplementation at natural log jam formation locations (e.g. bar apexes, off-channel areas, meander bends).
Off-Channel Habitat	6% side-channel habitat. Natural confinement limits off-channel development. Off-channels exist where they would have historically.	Reach has ponds, oxbows, backwaters, side-channels, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Protect and maintain**	No actions identified.

5.4.3 Reach 3

The restoration strategy for Reach 3 includes two primary approaches: 1) addressing human alterations to riparian areas and floodplains (primarily along river-right), and 2) enhancing existing habitat that has moderate-to-high function (primarily along river-left). Opportunities for addressing human alterations include riparian restoration, removing or modifying bank armoring, and removing or modifying floodplain encroachments. These efforts would help to accomplish the floodplain and bank condition targets. This work is primarily associated with addressing alterations at a few large riverside communities including the High Valley Community and the Meacham Road area. Due to the degree of existing human presence, this will be challenging in many locations.

Opportunities for enhancing existing habitat include creating off-channel habitats and adding wood pieces and log jams for pools, cover, and complexity. These efforts would help to achieve the log jam and pool frequency targets. Much of this work could occur along river-left except at the downstream end of the reach where there are good opportunities for projects along both banks. The river-right bank is primarily privately-owned and the river-left bank is primarily National Forest land. Accessing the river-left bank will be challenging except for at the upstream end where there may be the potential for access off of Camp 12 Road.

Reach 3 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	40% large tree 60% small tree or smaller >20% human disturbance Human disturbance is located within much of the riparian zone, mostly along the right bank. Disturbance includes roadway, houses, and bank armoring.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Riparian restoration** Work with landowners to plant cleared riparian and floodplain areas. Look for opportunities to set back roadways and other human infrastructure out of riparian areas.	Multiple locations, primarily along the river-right bank, have been identified for riparian planting. These include residential areas associated with the Meacham Road area, the Meacham Flats area, the High Valley community, and the Wenatchee Pines community. In addition, projects that address other attributes should all include riparian restoration as a component of restoration work. <u>Specific Project Opportunities:</u> Meacham Road Project (RM 41.7R), High Valley US Riparian & Margin Habitat Enhancement (RM 40.6R), High Valley DS Riparian & Margin Habitat Enhancement (RM 39.7R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Floodplain Connectivity	Floodplain width / BFW = 4.3 Nearly half of the floodplain has been disconnected due to residential development and roadways. Impacts include filling, grading, walls, and clearing.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Where possible, set back roadways, remove retaining walls, remove fill, and remove/modify other human infrastructure affecting floodplain processes.	Work with landowners to address floodplain development at the Meacham Road area, the Meacham Flats area, the High Valley community, and the Wenatchee Pines community. Investigate the potential to set-back or modify River Road where it abuts the channel near RM 40.7. Removal of bank armoring and installation of log jams (described for other attributes) will allow more natural rates of overbank flows. <u>Specific Project Opportunities:</u> See projects under bank condition/channel migration below.
Bank condition / Channel migration	28% of the streambanks in this reach are affected by bank armoring	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	Multiple locations along river-right have been identified for removing or modifying bank armoring, which includes rip-rap, spur dikes, and concrete walls. These include areas along the Meacham Road area, Meacham Flats, the High Valley community, and along River Road. <u>Specific Project Opportunities:</u> Meacham Road Project (RM 41.7R), High Valley US Riparian & Margin Habitat Enhancement (RM 40.6R), High Valley DS Riparian & Margin Habitat Enhancement (RM 39.7R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	There was likely minor past incision related to historical log drives and bank armoring.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Apex jams to trap sediment and build grade.	Projects incorporating bar apex log jams listed below under LWD would be expected to trap sediments, help control grade, and raise the channel bed over time.
Pools	Pools per mile = 1.9 27% pool habitat 100% of the pools are >1 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to form pools. **Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removing bank armoring to enhance pool quality.	Several locations have been identified for enhancing margin habitat (e.g. removing bank armoring), and placing large wood and log jams. Margin enhancement will improve pool quality and cover. Placement of wood (described below) will develop and maintain local scour pools. Specific Project Opportunities: See large wood and bank condition enhancement projects.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and log jams	133 pieces / mi 1.2 jam /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Riparian projects to improve long-term LW recruitment. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and pool scour, as well as mainstem bar apex jams to enhance lateral channel dynamics. Several other projects described for other metrics also include wood placements. <u>Specific Project Opportunities:</u> RM 41.3 Meander Bend Jams RM 41 Jams (bar apex) RM 40.4 Meander Bend Jams RM 40 Meander Bend Jams RM 39.4 Meander Bend Jams Zimmerman Off-Channel and Mainstem Enhancement (RM 39.3)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	19% side-channel habitat. Existing side and off-channel habitat is relatively well-connected but lacks adequate cover and complexity. Human alterations affect off-channel function in a few locations.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Off-channel habitat enhancement** Excavation to increase off-channel habitat area. **Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removal of armoring that limits side-channel function or connectivity. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of wood for cover and to enhance connectivity of off-channel areas.	There are opportunities to enhance existing side-channels and to create new ones. Specific Project Opportunities: Meacham Road Project (RM 41.7) Wenatchee Pines Off-Channel Enhancement (RM 41.5) RM 41.1 Side Channel Enhancement Meacham Flats Off-Channel Enhancement RM 40.5 Alcove Enhancement RM 39.6 Off-Channel Enhancement Zimmerman Off-Channel and Mainstem Enhancement (RM 39.3) Tunnel Alcove Enhancement (RM 39) Deadhorse Island Side-Channel Enhancement (RM 38.9)

5.4.4 Reach 4

Lack of off-channel habitat, lack of large wood and log jams, and lack of pools are the primary deficiencies to be targeted for restoration in Reach 4. Residential development throughout this reach has affected floodplain processes via fill and structural encroachments on the floodplain; but opportunities for floodplain restoration are limited due to the heavy human presence and the numerous individual private parcels. The Primitive Park Side-Channel project, which would reconnect a side-channel via removal of floodplain fill, would be a great project if landowner collaboration could be achieved. There are a few opportunities to place bar apex log jams to directly enhance habitat as well as to increase lateral channel dynamics associated with wood.

Reach 4 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	78% large tree 22% small tree >20% human disturbance Isolated but consistent riparian disturbance along the reach, mostly associated with homes and River Road.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Riparian restoration** Work with landowners to plant cleared riparian and floodplain areas. Look for opportunities to set back roadways and other human infrastructure out of riparian areas.	The riparian disturbance is primarily associated with residential development. Specific riparian-only projects have not been identified as they are isolated and associated with individual residences off of Mule Tail Flats Road (west side) and Primitive Park Road (east side). Look for opportunities to work with willing landowners to conduct riparian restoration. <u>Specific Project Opportunities:</u> Railroad Bridge Channel Margin Enhancement (RM 41.9) Other projects for this reach include some degree of riparian restoration opportunity
Floodplain Connectivity	Floodplain width / BFW = 2.6 Over half of the floodplain is considered disconnected due to residential development and roadways. Impacts primarily include filling, grading, and clearing. There are no levees or other significant individual floodplain disconnections.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Where possible, set back roadways, remove fill, and remove/modify other human infrastructure affecting floodplain processes.	Work with landowners to address floodplain development at residences off of Mule Tail Flats Road (west side) and Primitive Park Road (east side). Floodplain projects associated with residential development will require working with individual landowners to address residential development impacts (e.g. fill, grading, clearing). <u>Specific Project Opportunities:</u> Investigate the potential to set-back or modify River Road where it abuts the channel near RM 42.2.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	<8% of the streambanks in this reach are affected by bank armoring	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	There are isolated areas of bank armoring (rip-rap, stairways) associated with residences. The largest bank armoring is associated with the railroad bridge crossing at the downstream end of the reach (RM41.9). <u>Specific Project Opportunities:</u> Railroad Bridge Channel Margin Enhancement (RM 41.9)
Vertical channel stability	There is past incision related to bank armoring and confinement (railroad bridge). Floodplains within the broad meander bends are not inundated at the same frequency as historical conditions.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Apex jams to trap sediment and build grade.	Projects incorporating bar apex log jams listed below under LWD would be expected to trap sediments, help control grade, and raise the channel bed over time.
Pools	Pools per mile = 2.2 41% pool habitat 67% of the pools are >1 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to form pools. **Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removing bank armoring to enhance pool quality.	The railroad bridge project would enhance pool habitat along the channel margin. Placement of wood (described below) will develop and maintain local scour pools. <u>Specific Project Opportunities:</u> See large wood and bank condition enhancement projects.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and log jams	35 pieces / mi 0.8 jam /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Riparian projects to improve long-term recruitment. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and pool scour, as well as mainstem bar apex jams to enhance lateral channel dynamics. Several other projects described for other metrics also include wood placements. Along the toe of the high glacial terraces, "colluvial" jams can be created that mimic natural jams formed by mass wasting events off the terrace slope. Specific Project Opportunities: Mule Tail Flats Log Jams (RM 42.9) Primitive Park Apex Jams (RM 42.4) Railroad Bridge Apex Jams (RM 42.1) Railroad Bridge Channel Margin Enhancement (RM 41.9)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	7% side-channel habitat. At a couple of sites, side-channel habitat is disconnected due to human disturbance (residential-related). In general, natural confinement tends to limits off-channel development in this reach.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removal of fill to reconnect side-channel habitat. **Off-channel habitat enhancement** Potential for excavation, in addition to fill removal, to create a flow-through side-channel (Primitive Park Side-Channel Enhancement) **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of wood in off-channel areas for cover and to enhance connectivity.	There are opportunities to reconnect and enhance existing side-channels and to create new habitat. <u>Specific Project Opportunities:</u> Primitive Park Alcove Enhancement (RM 42.7) Primitive Park Side-Channel Enhancement (RM 42.3)

5.4.5 Reach 5

Reach 5 has high natural confinement but has been further confined by human development in riparian and floodplain areas. These impacts have also degraded streambanks and riparian forests and have simplified channel margin habitat. There are numerous private parcels including small riverside parcels that are a part of the Ponderosa Community Club and the Alpine Community Club. Restoration efforts will need to address habitat deficiencies to achieve the targets for riparian tree size, floodplain connectivity, bank condition, pools, large wood / log jams, and off-channel habitat. Restoration opportunities primarily include addressing riparian and channel margin impairments associated with residential development. This includes riparian planting as well as removing or modifying bank armoring. There are also a few opportunities for meander-bend and bar apex log jam placements.

Reach 5 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	61% large tree 39% small tree or smaller Significant clearing in some areas. Clearing is related to residential development, agriculture, and the powerline crossing near RM 44.4. Houses and other structures are located within 100-ft of streams in many areas.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Riparian restoration** Work with landowners to plant cleared riparian areas. Look for opportunities to set back human infrastructure out of riparian areas.	Multiple locations have been identified for riparian planting. These include residential areas associated with the Ponderosa Estates development, the River Road area on river-right, and the powerline corridor and nearby rural residential areas. In addition, projects that address other attributes should all include riparian restoration as a component of restoration work. Opportunities to work collaboratively with landowners to revegetate riparian corridors should be pursued where feasible. <u>Specific Project Opportunities:</u> Ponderosa Estates Riparian and Channel Margin Enhancement (RM 43.5R) Powerline Riparian and Margin Habitat Enhancement (RM 44.3) River Road Channel Margin Enhancement (RM 43.7R) 45-Mile Margin Jams and Riparian Enhancement (RM 45.1R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Floodplain Connectivity	Floodplain width / BFW = 1.42 The channel corridor is largely confined by natural terraces. The majority of the historically available floodplain is developed and affected by human alteration. The Beaver Valley Road Bridge bisects a portion of the left-bank floodplain.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Protect and maintain** Allow no further alteration of floodplains or loss of floodplain connectivity.	Specific opportunities to promote floodplain connectivity were not observed due to a high degree of natural confinement. Preventing further degradation should be prioritized. Projects listed under Bank condition/Channel migration will partially address floodplain functions. Removing the floodplain fill on the eastern approach to the Beaver Valley Road Bridge should be considered when the bridge is replaced, but it is probably not a significant enough impairment to warrant removing in the near-term.
Bank condition / Channel migration	At the downstream portion of the reach, banks are impacted by armoring associated with residential development and River Road. This includes riprap, retaining walls, and concrete stairways. Less than 5% of the total bank length is armored. Channel migration is largely naturally limited by high terraces.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	Opportunities to address channel migration and bank condition are associated with residential bank armoring and River Road. <u>Specific Project Opportunities:</u> River Road Channel Margin Enhancement (RM 43.7R) Ponderosa Estates Riparian and Channel Margin Enhancement (RM 43.5R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	There is past incision likely related to historical log drives and possibly related to existing bank armoring.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Apex jams to trap sediment and build grade	Projects incorporating bar apex log jams listed below under LWD would be expected to trap sediments, help control grade, and raise the channel bed over time.
Pools	Pools per mile = 1.0 11% pool habitat 100% of the pools are >1 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to create and enhance pools. **Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removing or modifying bank armoring to enhance pool quality.	The margin habitat enhancement projects, bank condition enhancement projects, and large wood projects will create scour pools and enhance cover within pools. <u>Specific Project Opportunities:</u> See large wood and bank condition enhancement projects.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and log jams	32 pieces / mi No log jams.	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Riparian projects to improve long-term recruitment. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and pool scour, as well as mainstem bar apex jams to enhance lateral channel dynamics. <u>Specific Project Opportunities</u> Gravel Pit Colluvial Jams (RM 45.8L) 45-Mile Margin Jams and Riparian Enhancement (RM 45.1R) Camp 12 Apex Jam Powerline Riparian and Margin Habitat Enhancement (RM 44.3) River Road Channel Margin Enhancement (RM 43.7R) Riata Bend Enhancement (RM 43.2L)
Off-Channel Habitat	0% side-channel habitat. Existing and future potential off-channel habitat is limited by natural confinement and past incision related to log drives and bank armoring.	Reach has ponds, oxbows, backwaters, side-channels, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Off-channel habitat enhancement** Excavation of off-channel habitat where altered river processes reduce the likelihood of future off-channel habitat creation.	A few areas with low floodplain terraces may have opportunities for excavation of off-channel habitats. Most of these areas are dominated by residential development and so opportunities are limited. <u>Specific Project Opportunities</u> Riata Bend Enhancement (RM 43.2L)

5.4.6 Reach 6

This reach has high natural confinement and a steep plane-bed channel, which has limited the degree of habitat impairments and reduces the need and opportunities for restoration. Riparian degradation and a lack of log jams are the primary habitat deficiencies. There may be some opportunities to work with riverside landowners to re-plant riparian areas, but they primarily just need time to mature. The Schugart Flat Levee Removal and Riparian Enhancement project is the only specific project that was identified. This project would remove a low push-up levee and restore riparian conditions at a Chelan County gravel pit and adjacent private parcels.

Reach 6 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	12% large tree 88% small tree or smaller The riparian corridor has been affected by past clearing associated with residential and municipal uses and is in early seral stages. There are not many large cleared areas compared to Reach 5 downstream.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Protect and maintain** Allow the existing young forest to mature. **Riparian restoration** Work with landowners to revegetate riparian corridors where feasible.	Work with landowners to replant native riparian species and to prevent additional clearing. <u>Specific Project Opportunities</u> Schugart Flat Levee Removal and Riparian Enhancement (RM 47.6L)
Floodplain Connectivity	Development, grading, and a levee within the floodplain has disconnected floodplain surfaces. Natural confinement by high terraces limits floodplain availability throughout much of the reach.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove levees, fill, and infrastructure affecting floodplain connectivity.	Address the levee and grading at the Chelan County gravel pit (Schugart Flat). Where feasible, work with owners of private streamside residences to remove floodplain infrastructure and fill. <u>Specific Project Opportunities</u> Schugart Flat Levee Removal and Riparian Enhancement (RM 47.6L)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	Roads, residential development, fill, bank armoring, and one levee affect channel migration. Banks are affected by residential uses (yards).	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	Where feasible, work with owners of private streamside residences to remove infrastructure that affects bank conditions and channel migration. <u>Specific Project Opportunities</u> Schugart Flat Levee Removal and Riparian Enhancement (RM 47.6L)
Vertical channel stability	There is likely minor past incision related to historical log drives.	No measurable trend of human-induced aggradation or incision. [adapted from REI]	No strategies identified	No actions identified
Pools	Pools per mile = 0.0 0% pool habitat	This is a steep reach that consists naturally of riffle and glide habitat types. Pocket pools currently exist within these habitat types. [Channel typing]	No strategies identified	No actions identified
Large wood and log jams	67 pieces / mi 0.7 jams/mi Most of the wood is located in 2 apex log jams.	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Allow for long-term maturation of existing forested riparian areas that are in early seral stages.	No actions identified

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	10% side-channel habitat. Natural confinement limits off-channel development.	Reach has ponds, oxbows, backwaters, side-channels, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	No strategies identified	No actions identified

5.4.7 Reach 7

Reach 7 has similar confinement as Reach 6 and also has limited restoration need or opportunity. The primary habitat deficiencies are pool habitat, large wood, and bank condition. The primary restoration opportunity is riparian and channel margin work associated with a degraded riparian buffer and eroding streambank along river-left near the upstream end of the reach.

Reach 7 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	100% large tree 0% small tree or smaller >20% human disturbance Human disturbance is located within much of the riparian zone. Disturbance includes houses and bank armoring.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Riparian restoration** Work with landowners to plant cleared riparian areas. Look for opportunities to set back infrastructure out of riparian areas.	The riparian disturbance is primarily associated with residential development. Look for opportunities to work with willing landowners to conduct riparian restoration. <u>Specific Project Opportunities:</u> Riparian and Streambank Restoration (RM 48.3L)
Floodplain Connectivity	Floodplain width / BFW = 3.12 There has been some impairment of floodplain function through residential development, fill, and bank armoring.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove fill and infrastructure affecting floodplain connectivity.	Work with landowners to address floodplain development where feasible.
Bank condition / Channel migration	80% of the channel margins are affected by human development and alteration.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring. Address residential development impacts to streambanks.	There are retaining walls at RM 48.02R and RM 48.29L. These walls are currently protecting residential development, so removal may be unlikely. Work with landowners where feasible to remove bank armoring and prevent further bank armoring.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	There is likely minor past incision related to historical log drives.	No measurable trend of human-induced aggradation or incision [adapted from REI]	No strategies identified	No actions identified
Pools	Pools per mile = 0.0 0% pool habitat	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to create and enhance pools.	Work with landowners to place pool-forming structures and to enhance pool cover along channel margins. <u>Specific Project Opportunities:</u> Riparian and Streambank Restoration (RM 48.3L)
Large wood and log jams	13 pieces / mi No log jams	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Riparian projects to improve long-term recruitment. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Work with landowners on wood placement along channel margins to enhance localized pool scour and habitat complexity. <u>Specific Project Opportunities:</u> Riparian and Streambank Restoration (RM 48.3L)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	0% side-channel habitat. Creation of future side-channel habitat is limited by human development in floodplain areas.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removal of floodplain alterations to improve processes of off-channel habitat creation. **Off-channel habitat enhancement** Excavation of off-channel habitat where altered river processes reduce the likelihood of future off-channel habitat creation.	A few areas with low floodplain terraces may have opportunities for excavation of off-channel habitats. Most of these areas are dominated by residential development and so opportunities are limited. No specific action identified.

5.4.8 Reach 8

Reach 8 has relatively high natural confinement from glacial terraces. The floodplain areas that do exist have been impacted by residential development and the hatchery intake near RM 49.3. Most of the land is National Forest except for private residential lands at the upstream end on river-left (Chiwawa River Pines Community) and the downstream end on river-right. Habitat impairments include degraded riparian areas, lack of large wood and log jams, disconnected off-channel habitat, and floodplain/CMZ disconnections due to bank armoring. Addressing bank armoring associated with the hatchery intake could help long-term channel migration processes and off-channel development in this area. There are opportunities to place wood and log jams for both instream cover and to increase lateral channel dynamics (e.g. split flow conditions). The Cottonwood Lane Off-Channel Enhancement project area presents a good opportunity to create new off-channel habitat and is likely an area where fill was historically placed in potential off-channel habitat. This would be a great opportunity for riparian restoration even if off-channel creation work at this site is not feasible. There may be other opportunities to work with individual private landowners to conduct riparian restoration. There are also a few opportunities to enhance the connectivity of existing off-channel areas.

Reach 8 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	37% large tree 63% small tree >20% human disturbance There is riparian disturbance throughout the reach, primarily along the left bank at the upstream end and right bank at the downstream end.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Riparian restoration** Work with landowners to plant cleared riparian areas and to allow for the maturation of existing early seral stage forests. Look for opportunities to set back human infrastructure out of riparian areas.	The riparian disturbance is primarily associated with residential development. Specific riparian-only projects have not been identified as they are isolated and associated with individual residences. Riparian restoration should accompany all projects listed for this reach.
Floodplain Connectivity	Floodplain width / BFW = 2.02 Over 60% of the floodplain is considered disconnected due to residential development and roadways. Impacts primarily include filling, grading, and clearing. There are no levees or other significant individual floodplain disconnections.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Where possible, Remove fill and infrastructure affecting floodplain connectivity. **Protect and maintain** Allow no further alteration of floodplains or loss of floodplain connectivity.	Work with landowners to address floodplain development where feasible. Work with WDFW on addressing the floodplain impacts of the hatchery diversion.
Bank condition / Channel migration	There are only two areas with bank armoring in the reach. One associated with a residence and one associated with the hatchery intake near RM 49.3.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	The most notable bank armoring is associated with the WDFW Chiwawa Ponds Hatchery. Work with WDFW to enhance this channel margin area. Work with landowners to prevent the use of riprap and other bank armoring techniques.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	There is likely minor past incision related to human uses including historical log drives and bank armoring.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Apex jams to trap sediment and build grade	Projects incorporating bar apex log jams listed below under LWD would be expected to trap sediments, help control grade, and raise the channel bed over time.
Pools	Pools per mile = 1.8 41% pool habitat 100% of the pools are >1 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to create and enhance pools. **Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removing bank armoring to enhance pool quality.	Work with landowners to place pool-forming structures and to enhance pool cover along channel margins. <u>Specific Project Opportunities:</u> See large wood enhancement projects
Large wood and log jams	57 pieces / mi 0.8 jam /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Riparian projects to improve long-term recruitment. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and pool scour, as well as mainstem bar apex jams to enhance lateral channel dynamics. <u>Specific Project Opportunities</u> Cottonwood Lane Habitat Complexity (RM 49.5) Intake Island Log Jams (RM 49.2) Chiwawa Fan Island Jams (RM 48.8) Chiwawa Jct Jams (RM 48.6L)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	7% side-channel habitat. In general, natural confinement tends to limit off-channel development in this reach.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removal of floodplain alterations to improve processes of off-channel habitat creation. **Off-channel habitat enhancement** Excavation of off-channel habitat where altered river processes reduce the likelihood of future off-channel habitat creation.	There are a couple of opportunities to enhance existing off-channels and to create new ones. Specific Project Opportunities: Cottonwood Lane Off-Channel Habitat (RM 49.3L) Intake Island Off-Channel Habitat (RM 49.1L) Chiwawa Fan Island Off-Channel Habitat (RM 48.85L)

5.4.9 Reach 9

Reach 9 has habitat impairments related to floodplain disconnection (Beaver Valley Road fill), riparian stand ages, log jam frequency, and pool frequency. Although this reach has experienced natural incision into Pleistocene glacial terraces, anthropogenic-related incision and upstream confinement (in Reach 10) has likely resulted in channel simplification and disconnection of off-channel habitats. The reach is entirely bordered by National Forest land and there are several opportunities for habitat restoration. Although Beaver Valley Road cuts off a portion of the river-right floodplain near RM 50.5, the small amount of disconnection and the cost of road relocation would likely not justify a project here. Pool frequency, jam frequency, and off-channel impairments can be addressed through various types of log jam placements. Jams can be used in this reach to create mid-channel islands and to induce split-flow conditions. Jams and selected excavation could also be used to increase off-channel complexity (e.g. Mosquito Alley Off-Channel and Complexity Enhancement Project). This reach is currently dominated by glide habitat; log jams could also be used to increase the quantity of pool and riffle habitat, which are lacking in this reach. Riparian areas are only moderately impaired and primarily need time for stand ages to increase.

Reach 9 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	62% large tree 38% small tree Densely vegetated riparian canopy and intact understory. Riparian areas are affected by dispersed camping areas along the river-left bank in some areas.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Protect and maintain** Allow the existing young forest to mature.	Riparian restoration should accompany all projects listed for this reach.
Floodplain Connectivity	Floodplain width / BFW = 2.04 A portion of the floodplain is disconnected by Beaver Valley Road along the right bank near RM 50.5. Portions of the floodplain show signs of past incision, potentially related to historical log drives.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Protect and maintain** Allow no further alteration of floodplains or loss of floodplain connectivity. **Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Address existing floodplain impairments through removal or relocation of human infrastructure.	Consider set-back of Beaver Valley Road where it cuts off a portion of the floodplain near RM 50.5.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	There is no bank armoring in Reach 9. This reach has the highest percentage of actively eroding banks within the study reach at 22%. Much of this erosion appears natural but may be partially related to past incision and the presence of early seral riparian vegetation.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Protect and maintain** Allow maturation of riparian vegetation to bring erosion/migration rates closer to natural rates. **Placement of structural habitat elements including large wood, log jams, or boulders** Provide channel margin structure that will reduce rapid erosion and help to bring erosion rates closer to natural rates.	There is the opportunity to enhance margin complexity via wood placements. These projects will also serve to reduce rapid erosion by deflecting stream energy from streambanks. Projects should be configured to not reduce natural bank migration rates. <u>Specific Project Opportunities:</u> Mosquito Alley Channel Complexity (RM 51.2) Mosquito Bend Off-Channel and Complexity Enhancement (RM 50.9R) Beaver Valley Rd Off-Channel and Complexity Enhancement (RM 50.5)
Vertical channel stability	There is past incision related to confinement by glacial terraces along both banks. This reach, more than others, appears to have undergone somewhat accelerated incision processes that may result from building of Beaver Valley Road, upland timber harvest, and/or log drives. Active incision appears to have stabilized in the existing condition.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Apex jams to trap sediment and build grade.	Projects incorporating bar apex log jams listed below under LWD would be expected to trap sediments, help control grade, and raise the channel bed over time.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Pools	Pools per mile = 1.4 35% pool habitat 100% of the pools are >1 m deep	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to create and enhance pools.	Placement of large wood could enhance pools by providing cover for habitat, and can create localized scour to develop and maintain pools. <u>Specific Project Opportunities:</u> See large wood and bank condition enhancement projects.
Large wood and log jams	75 pieces / mi 0.5 jam /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and pool scour, as well as mainstem bar apex jams to enhance lateral channel dynamics. Along the toe of the high glacial terraces, "colluvial" jams can be created that mimic natural jams formed by mass wasting events off the terrace slope. <u>Specific Project Opportunities</u> Mosquito Alley Channel Complexity (RM 51.2) Mosquito Bend Off-Channel and Complexity Enhancement (RM 50.9R) Beaver Valley Rd Off-Channel and Complexity Enhancement (RM 50.5) Fifty-Mile Log Jams (RM 50)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	4% side-channel habitat. There are existing alcoves and off-channel wetlands, many of which are only inundated at high flows.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Off-channel habitat enhancement** Excavation of off-channel habitat where altered river processes reduce the likelihood of future off-channel habitat creation. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of wood for cover and to enhance connectivity.	There are a couple of opportunities to enhance existing off-channels and to create new ones where they have been disconnected by incision processes. A few of the existing low surfaces that have off-channel wetland habitat that is inundated only during high flows provide the opportunity for near-margin bar apex jams that would build islands and divert flow into off-channel areas. Specific Project Opportunities: Mosquito Alley Channel Complexity (RM 51.2) Mosquito Bend Off-Channel and Complexity Enhancement (RM 50.9R) Beaver Valley Rd Off-Channel and Complexity Enhancement (RM 50.5) Fifty-Mile Side Channel (RM 50.2L)

5.4.10 Reach 10

Reach 10 is a complex section of the Wenatchee River with conditions ranging from nearly pristine backwater habitat to dense residential areas within riparian areas. This results in a range of restoration opportunities within the reach. Habitat impairments include moderate riparian impairment (mostly associated with streamside residences), impaired channel migration and floodplain inundation (i.e. fill and armoring associated with Braeburn Road developments and floodplain disconnection associated with the Lake Wenatchee Hwy Bridge), log jam frequency, and off-channel habitat. Impaired off-channel habitat includes lack of cover in existing backwater areas and impaired connectivity of the large Natapoc off-channel area in the river-right floodplain.

There are a variety of restoration opportunities depending on the type of impairments and land uses. Addressing riparian degradation and bank armoring along Braeburn Road residences will require cooperative partnerships with willing landowners to enhance riparian vegetation and channel margin complexity. Large-scale changes to channel migration or floodplain processes associated with these developments are not anticipated. In several locations, adding log jams could be used to enhance lateral channel dynamics as well as to increase channel margin complexity and pool habitat. The two large existing backwater habitat areas (Chiwawa Jct and Fish Lake Run backwaters) could be enhanced by adding cover and complexity via large wood placements. The Natapoc project is one of the best potential opportunities for enhancing floodplain and off-channel connectivity in the entire study area. This off-channel complex is connected to the mainstem via surface flows during high water periods but connectivity at lower flows is believed to be affected by anthropogenic-related channel incision and residential developments along Braeburn Road. These impacts also reduce the potential for long-term creation and maintenance of off-channel habitats in this area via floodplain flows, channel migration, and avulsion processes.

Reach 10 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	75% large tree 19% small tree 6% sapling/pole Dominated by large trees, and wetland vegetation in connected off-channel areas. There is cleared vegetation and human infrastructure within the riparian zone at the upstream end of the reach on the right bank associated with residential development along Brae Burn Road.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Riparian restoration** Work with landowners to re-plant cleared areas and to move infrastructure out of riparian areas.	Work with landowners along Brae Burn Road to enhance riparian conditions. Riparian restoration should accompany all projects listed for this reach. Specific Project Opportunities: Brae Burn Streambank Enhancement (RM 53.5R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Floodplain Connectivity	Floodplain width / BFW = 3.25 Much of the floodplain along this reach lies within the Nason Creek fan and is disconnected via Highway 207 and residential developments along Brae Burn Road.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Where possible, set back roadways, remove fill, and remove/modify other human infrastructure affecting floodplain processes. **Off-channel habitat enhancement** Reconnect existing off-channel habitats where connectivity has been impacted by development or incision.	Work with landowners on a long-term approach to restore floodplain connectivity affected by the Brae Burn Road developments. Enhance connections to off-channel habitats where connectivity has been impacted by development or incision, such as the large Natapoc off-channel. See the Off-Channel section for specific projects.
Bank condition / Channel migration	Over 700 feet of the right bank at the upstream end of the reach is armored (Brae Burn Road area). 18% of the banks within the reach are actively eroding, some of which is related to residential development, some which is related to past incision, and some which may be natural.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	Remove bank armoring and set back development and roadways where feasible. <u>Specific Project Opportunities:</u> Brae Burn Streambank Enhancement (RM 53.5R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	There is past incision related to confinement by glacial terraces. Accelerated incision may be related to bank armoring, artificial confinement, roads, and historical log drives. Active incision appears to have stabilized in the existing condition.	No measurable trend of human-induced aggradation or incision [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove bank armoring where possible to promote more natural rates of channel aggradation and incision. **Placement of structural habitat elements including large wood, log jams, or boulders** Apex jams to trap sediment and build grade	Where possible, address artificial confinement at the upper end of the reach within the Nason Creek fan area. Specific Project Opportunities: Brae Burn Streambank Enhancement (RM 53.5R) Projects incorporating bar apex log jams listed below under LWD would be expected to trap sediments, help control grade, and raise the channel bed over time.
Pools	Pools per mile = 2.3 57% pool habitat	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to create and enhance pools.	Placement of large wood could enhance pools by providing cover for habitat, and can create localized scour to develop and maintain pools. Specific Project Opportunities: See large wood and bank condition enhancement projects.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and log jams	101 pieces / mi 1.5 jams /mi	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Riparian restoration** Riparian projects to improve long-term recruitment. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and pool scour, as well as mainstem bar apex jams to enhance lateral channel dynamics. Along the toe of the high glacial terraces, "colluvial" jams can be created that mimic natural jams formed by mass wasting events off the terrace slope. Specific Project Opportunities Lower Nason Jams (RM 53.65R) Midway Jams (RM 53.1L) Pirate Island and Pirate Island II (RM 52.8 and 52.45) Natapoc Margin Jams (RM 52.3R) Mile 52 Colluvial Jams (RM 52L) Natapoc Outlet Apex Jams (RM 51.7)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	3% side-channel habitat. The reach has two large backwater complexes that provide excellent refuge, but flowing side channels were uncommon within the reach. There are existing off-channel wetland (i.e. Natapoc), but most of these are only inundated at high flows.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Removal of floodplain alterations to improve processes of off-channel habitat creation. **Off-channel habitat enhancement** Excavation of off-channel habitat where altered river processes reduce the likelihood of future off-channel habitat creation. **Placement of structural habitat elements including large wood, log jams, or boulders** Placement of wood for cover and to enhance connectivity.	There are several opportunities to enhance existing off-channels and to create new ones where they have been disconnected by incision processes. The large Natapoc Project on river right near the downstream end of the reach offers a good opportunity to enhance connectivity of a large off-channel complex. <u>Specific Project Opportunities:</u> Nason Confluence Downstream (RM 53.6R) Alcove and Side-Channel Enhancement (RM 53.4L) Midway Backwater Enhancement (RM 53L) Chiwawa Jct Backwater (RM 52.7L) Natapoc Project (RM 52R) Fish Lake Run Backwater (RM 52.1L)

5.4.11 Reach 11

This short reach has limited habitat impairments and corresponding limited opportunities for restoration. The primary habitat impairments are a lack of log jams and impaired off-channel habitat. Off-channel impairments are associated with a lack of cover in an existing alcove and general loss of off-channel habitat in the Nason Creek delta area. The First Island Project presents a good opportunity for construction of a bar apex log jam; this jam would be expected to capture more wood from upstream and would enhance pool scour and split-flow conditions at this location. There is an existing off-channel area upstream of the confluence of Nason Creek that is only connected at high flows. This area could be excavated to enhance off-channel rearing at a greater range of flows. This project would help mitigate for the alteration that the Hwy 207 road fill and bridge have on long-term creation and maintenance of floodplain habitats within the Nason Creek fan area. Landownership is mostly State Park and National Forest and access conditions are good.

Reach 11 Restoration Strategy

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	100% large tree The overstory is dominated by large conifers but some clearing has occurred associated with the State Park at the upstream end.	At least a 100 ft riparian buffer with: > 80% mature trees. < 20% riparian disturbance (human) [REI]	**Protect and maintain**	Riparian restoration should accompany all projects listed for this reach.
Floodplain Connectivity	Floodplain width / BFW = 1.64 The floodplain is well-connected.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	**Protect and maintain**	No actions identified
Bank condition / Channel migration	The reach is migrating at or near natural rates. There are remnant concrete pilings near RM 53.85 but these are believed to have a minimal effect on channel processes and may be providing habitat in the form of localized scour pools and cover.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	**Habitat reconnection via removal/modification of bank armoring, levees, roadways, or fill** Remove or modify bank armoring.	Remove bridge pillars Specific Project Opportunities Bridge Pillar Removal (RM 53.85)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	There has been local scour and incision related to the Hwy 207 Bridge at the downstream end of the reach but no significant measurable incision in the reach as a whole.	No measurable trend of human-induced aggradation or incision [adapted from REI]	No strategies identified	No actions identified
Pools	Pools per mile = 2.0 77% pool habitat	~3-4 pools/mi. 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 fish cover. [Reach 1 and REI]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of structure to create and enhance pools.	Placement of large wood could enhance pools by providing cover for habitat, and can create localized scour to develop and maintain pools. <u>Specific Project Opportunities:</u> See large wood projects
Large wood and log jams	242 pieces / mi 0 jams /mi Most of the wood is scattered along channel margins at the upstream end of the reach (windblown lake wood) or is sunken wood believed to be from historical log drives.	> 80 pieces/mi (>12 diam; > 35 ft long) [Reach 1 and inferred from Fox 2003] > 4 log jams/mi [based on conditions in Reach 1 and inferred from Fox 2003]	**Placement of structural habitat elements including large wood, log jams, or boulders** Placement of large wood and log jams where large wood would naturally accumulate and would provide the greatest habitat benefit.	Large wood additions include individual pieces or jams along margins to enhance margin habitat and provide localized cover. <u>Specific Project Opportunities</u> First Island (RM 53.75) Nason Confluence Upstream (RM 53.7R)

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	5% side-channel habitat. There is one mainstem side-channel. There is one alcove along the right bank.	Reach has ponds, oxbows, backwaters, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	**Protect and maintain** Protect and maintain Nason Creek confluence area. **Off-channel habitat enhancement** Enlarge and enhance connectivity of off-channel area at mouth of Nason.	There is a good opportunity at the upstream end of the Nason Creek confluence to enhance and enlarge existing off-channel habitat. <u>Specific Project Opportunities:</u> Nason Confluence Upstream (RM 53.7R)

6 NEXT STEPS

This restoration strategy does not take the next step of prioritizing potential project opportunities, which is beyond the scope of this Assessment. However, prior to project implementation, projects should be prioritized in order to select and move forward with the projects that have the greatest potential benefits. As part of the YN's UCHRP, the YN uses an internal process for prioritization that considers numerous factors including: 1) biological and habitat benefits, 2) the degree to which projects address root causes of problems, 3) costs, and 4) feasibility and risk constraints. Other project sponsors are encouraged to apply similar criteria to project prioritization to ensure that the most beneficial projects are moved forward to implementation.

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