Upper Methow River Reach Assessment

River Miles 61 - 80

SUBMITTED TO
Yakama Nation Fisheries

FINAL - DECEMBER 2015

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Yakama Nation Fisheries
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1 Introduction and Background

1.1 OVERVIEW

This assessment evaluates aquatic habitat and watershed process conditions in the Upper Methow River and identifies habitat restoration strategies. The Methow River Basin is located on the eastern slope of the Cascade Mountains in Northern Washington (Figure 1). The Methow River is a tributary to the Columbia River, entering the Columbia at river mile (RM) 524 near the town of Pateros, WA. The assessment area extends from Methow River RM 61 (Weeman Bridge) to RM 81 (confluence with Trout Creek).

This reach assessment provides the technical foundation for understanding existing conditions and for identifying restoration strategies for the Upper Methow River. Conditions are assessed at both the valley- and reach-scales. The aim is to identify restoration actions that address significant factors limiting the productivity of native salmonids, and to ensure that these actions fit within the appropriate geomorphic context of the river system. An emphasis is placed on understanding the underlying biological and physical processes at work and how human impacts have affected these processes and the habitat they support. Restoration measures focus on recovering, to the extent possible, these impaired processes. Although the proposed restoration measures are expected to benefit a large suite of native aquatic and terrestrial species, there is a particular emphasis on recovery of Endangered Species Act (ESA) listed salmonids, including spring Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*).

This study builds on considerable data collection and assessment work performed by others as part of past studies, including the Methow Subbasin Geomorphic Assessment (USBR 2008). This Reach Assessment updates and further refines previous data collection and assessment efforts and provides a new comprehensive habitat restoration strategy that identifies restoration targets and recommends specific actions to address habitat and stream process impairments.

This report includes the following 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 – 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 achieve the reach-scale restoration strategies.

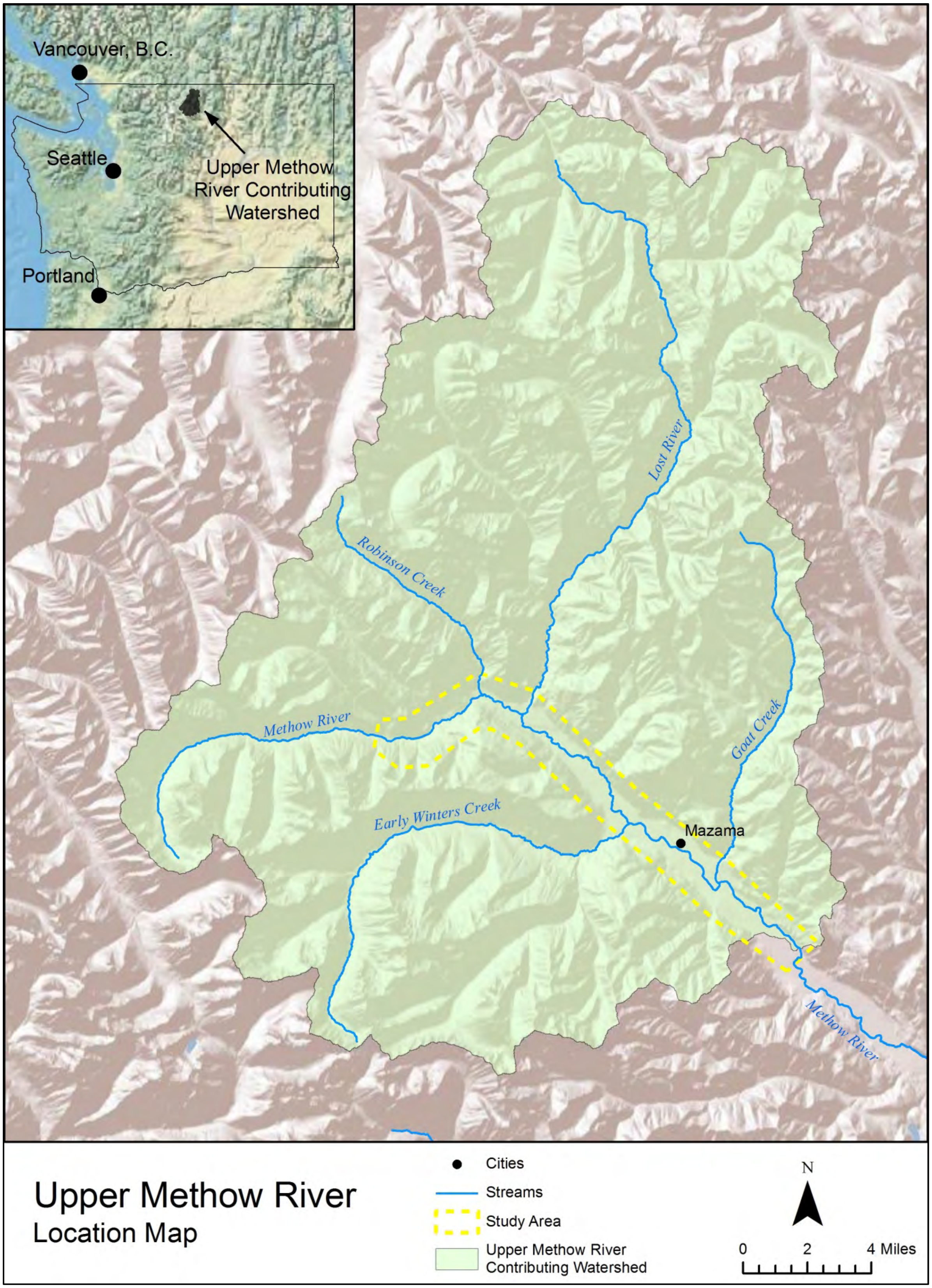

Figure 1. Upper Methow River study area. The study area extends from RM 61 (Weeman Bridge) to RM 81.

1.2 BACKGROUND

This effort is being conducted as part of the Yakama Nation's Upper Columbia Habitat Restoration Project (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 2014).

This assessment builds off of a large body of work produced in the basin primarily throughout the 1990s and 2000s. Assessment and analysis work to date has included physical assessments, biological assessments, and restoration recommendations for portions of the Methow River. The previous assessments include the US Bureau of Reclamation's 2008 Methow Subbasin Geomorphic Assessment, the Methow Watershed Plan (MBPU 2005), the Hydrogeology of the Unconsolidated Sediments, Water Quality, and Ground-Water/Surface-Water Exchanges in the Methow River Basin (USGS 2005), US Forest Service's Upper Methow River Stream Survey Report (USFS 1997) and their West Fork Methow River Stream Survey Report (USFS 2003), and the Methow Subbasin Plan (KWA et al. 2004).

1.3 PURPOSE

The purpose of this assessment is to document and evaluate hydrologic processes, geomorphic processes, and aquatic habitat conditions in the Upper Methow River (RM 61 to RM 81) and to present a comprehensive reach-based restoration strategy to address limiting factors to aquatic habitat. 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 aquatic 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

1.4 SALMONID USE AND POPULATION STATUS

1.4.1 Species Status and Distribution

Salmonid use of the Upper Methow River includes spring Chinook salmon, steelhead, bull trout, west-slope cutthroat trout, rainbow trout, and brook trout. Spring Chinook salmon are listed as Endangered under the Endangered Species Act (ESA), and steelhead and bull trout are listed as Threatened. Life-stage usage and ESA status for each species are summarized in Table 1.

Table 1. Species usage in the Upper Methow River. Adapted from NMFS 1998, Mullen 1992, and USBR 2008.

Population	ESA Status	General Use	Timeframe
Spring Chinook	Endangered	Spawning & Rearing	Historical
		Spawning & Rearing	Current
Steelhead	Threatened	Spawning & Rearing	Historical
		Spawning & Rearing	Current
Bull trout	Threatened	Foraging, Migration, Over-wintering	Historical
		Foraging, Migration, Over-wintering	Current

A distribution map for steelhead, Chinook, and bull trout is presented in Figure 2. Spring Chinook spawning within the study area occurs at the highest densities from RM 61 (start of study area; Weeman Bridge) to RM 68 (near Mazama). Survey data from 2003 to 2013 report an average of 333 spring Chinook redds and 395 steelhead redds annually in the Upper Methow River basin (above the town of Winthrop, upstream of RM 50). In the study area, specifically in 2013 (RM 61-80), the highest number of redds occurred downstream of the confluence with Lost River from RM 72-75 and upstream of the Weeman Bridge from RM 60 to 62.8. That year a total of 142 steelhead redds and 141 spring Chinook redds were counted in the study area, including Early Winters Creek, Lost River, and Suspension Creek.

The spawning activities of spring Chinook peak in late August and early September. Juvenile rearing occurs year-round throughout the study area, when and where flows allow. Steelhead trout use the Upper Methow River for spawning, in- and out-migration, and rearing. Steelhead spawning occurs March through May and juvenile rearing occurs year-round. Bull trout use the Upper Methow River for year-round foraging, migration, and over-wintering (Andoneagui 2000).

Historically, spring Chinook and steelhead utilized the mainstem of the Upper Methow River and the larger tributaries, such as Early Winters Creek and Lost River. Currently they inhabit the same distribution, although the highest densities are found in the mainstem Methow and Lost River. The numbers of spring Chinook and steelhead returning are much lower than historical estimates. In-basin and out-of-basin anthropogenic impacts have contributed to these declines. The Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSCRP) rated the Methow spring

Chinook salmon population as "at high risk of extinction within the next 100 years" if no action is taken. The UCSCRP gave steelhead trout a "Moderate to High" risk rating for extinction within the next 100 years if no action is taken.

Bull trout occupied the largest historical distribution in the basin, covering the mainstem Methow River as well as many tributaries such as Early Winters Creek, Goat Creek, Lost River, and Trout Creek. Bull trout, either fluvial, adfluvial, or resident, presently continue to have the largest range throughout the rivers and creeks of the watershed, although it is less than the historical range.

1.4.2 Proportion of Hatchery Fish

The numbers of returning spawners has been influenced by the addition of hatchery fish in the Methow and greater Columbia River basins. The effects of hatchery fish on wild fish runs is an important area of research (OCAFS 2015) but it is not addressed as part of this assessment. In the Upper Methow River (upstream of RM 50-77), the annual average number of returning spring Chinook spawners that are hatchery fish is 718 and the number of wild fish is 216, based on data from 1998-2007. In 2013, these numbers were below average with a total of 505 hatchery and 113 wild fish counted. In the study area specifically (RM 61-77) during 2013, including Lost River, Early Winters, and Suspension Creeks, a total of 195 hatchery and 63 wild spring Chinook spawners were counted (Snow etal 2014).

1.4.3 Effects of Subsurface Flow Conditions

The hydrology of the mainstem Upper Methow River between Goat Creek (RM 65) and Lost River (RM 75) can pose a risk to salmonid survival during the summer and winter (NMFS 1998, Konrad et.al 2005). In this section of the channel, seasonal low-flow conditions in late summer and autumn can result in dewatering of the channel, except for at deep pools (See section 2.6.3 for a description of the hydrology). The extent of the dewatering is dependent on the year's seasonal hydrograph which is determined by precipitation and quantity of snow pack. Very dry years have been reported to extend the zone of dewatered impacts from the Weeman Bridge (RM 61) to Robinson Creek (RM 76.5) (Andonaegui 2000). When dewatering occurs for over twelve days, eggs and embryos can become dehydrated and cause mortality. Dewatering can also result in stranding of fish in pools. The shallow and/or pooled water conditions result in increased water temperatures and reduced dissolved oxygen levels, both of which pose risks to fish survival. Studies utilizing observations made during snorkel surveys have concluded that smaller, less mature fish are less likely to migrate away from areas of the basin with declining flows. The risks associated with low or no-flow in winter months can be exacerbated by snow burial and freezing (USFS 1997, USFS 2003). During field observations in October 2014 by Inter-Fluve (IFI) staff, the mainstem channel was dry from RM 70.2 to 71.75, except in the deep pools. More information on dewatering is provided in Section 2.6.3.

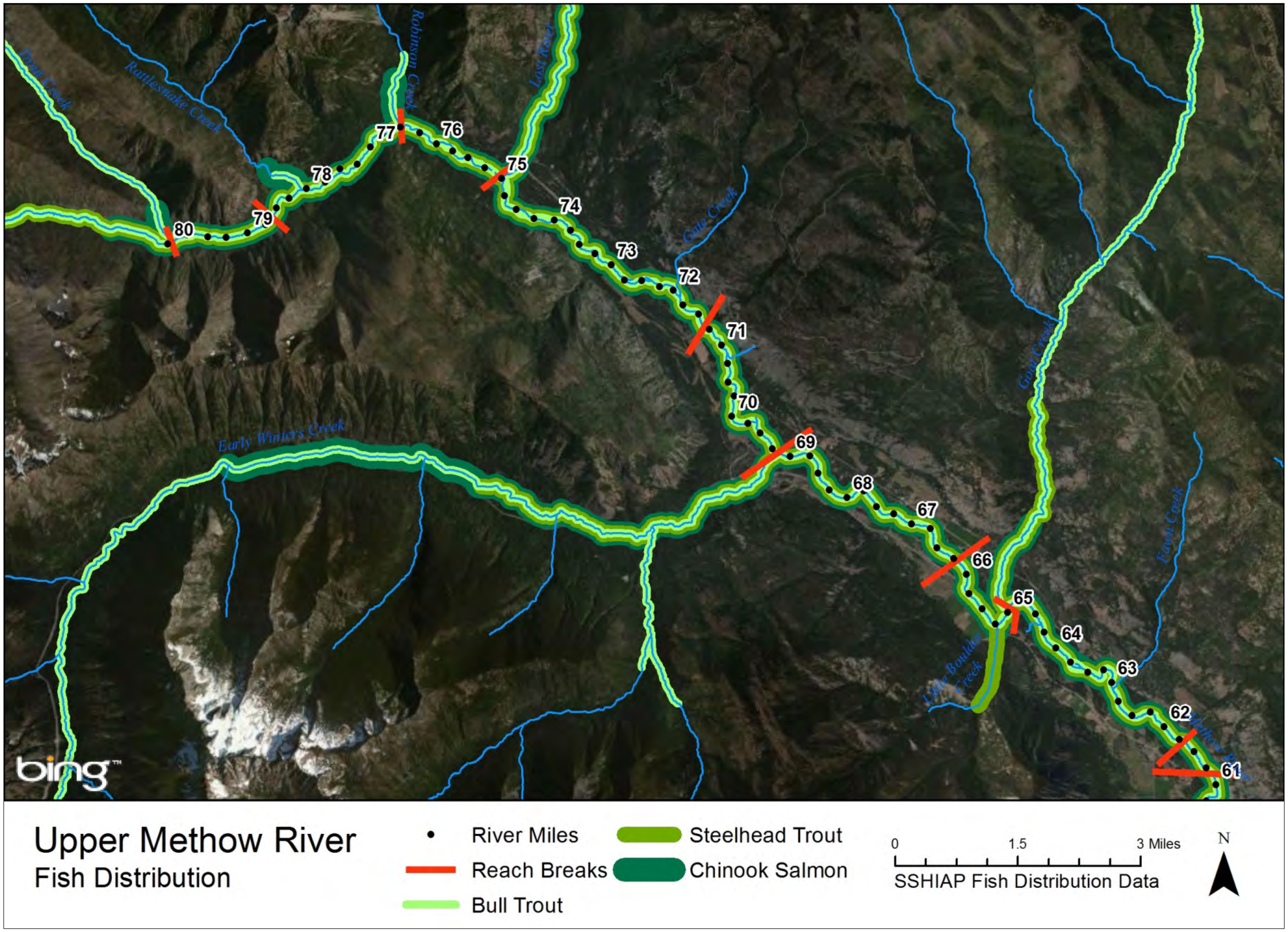

Figure 2. Chinook salmon, steelhead trout, and bull trout distribution in the Upper Methow River and major tributaries.

During survey work for this assessment in early September 2014, spring Chinook were seen spawning by IFI survey crews at the highest concentrations in the off-channel habitat commonly referred to as Suspension Creek. The confluence of Suspension Creek is located on river-right at RM 64.35. Local knowledge and WDFW employees encountered on the river confirmed this to be a common location for high densities of returning spawners. This is supported by the 2013 steelhead and spring Chinook redd counts reported by the Washington Department of Fish and Wildlife for Suspension Creek (Steelhead: 29; spring Chinook: 11). The Lost River (steelhead: 29; spring Chinook: 28) and Early Winters Creek also support high numbers of spawners. The potential risks associated with seasonal dewatering of sections of the Upper Methow mainstem emphasizes the value of wetted connected tributaries and backwater features as available summer and fall salmonid habitat.

1.5 RECOVERY PLANNING CONTEXT

Spring Chinook salmon and steelhead are listed and protected under the ESA. The Upper Columbia 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 Methow River Reach Assessment falls under the Habitat component of the Recovery Plan.

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 and are consistent with the Methow Subbasin Plan (KWA et al. 2004) and the Methow Watershed Plan (MBPU 2005). The objectives are intended to reduce threats to the habitat requirements 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 provided. 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.

1.5.1 Short-Term Objectives

- Protect existing areas where high ecological integrity and natural ecosystem processes persist
- Restore connectivity (access) throughout the historical range where feasible and practical for each listed species
- Protect and restore water quality where feasible and practical within natural constraints
- Increase habitat diversity in the short term by adding instream structures (e.g. large 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

1.5.2 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

1.5.3 Restoration Objectives Specific to the Methow Basin

- Preserve, protect, and manage instream water uses to balance flows for local uses (e.g. agriculture) and instream habitat where appropriate
- Protect and restore riparian corridors where feasible
- Remove or recondition human infrastructure that currently limits habitat connectivity and complexity (e.g. culverts, riprap) where feasible
- Increase diversity and complexity of habitat types by adding instream structures (e.g. large wood, boulders) where appropriate

2 Assessment Area Conditions

2.1 SETTING

The Methow River Basin is located in Okanagan County in north central Washington on the east side of the Cascade Mountains within the Columbia Cascade Ecological Province. The study area includes RM 61 to RM 81 of the Upper Methow River and its floodplains. The catchment area contributing to the downstream extent of the study area includes several small drainages such as Fawn Creek, Goat Creek, Little Boulder Creek, Early Winters Creek, Gate Creek, McGee Creek, Lost River, Robinson Creek, Rattlesnake Creek, and Trout Creek. The total catchment area of the study area is 426 square miles.

Nine distinct geomorphic reaches were delineated within the study area (Figure 3). Reach delineation was based on 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 reach boundaries used in past surveys. The reach boundaries were then verified in the field during survey work.

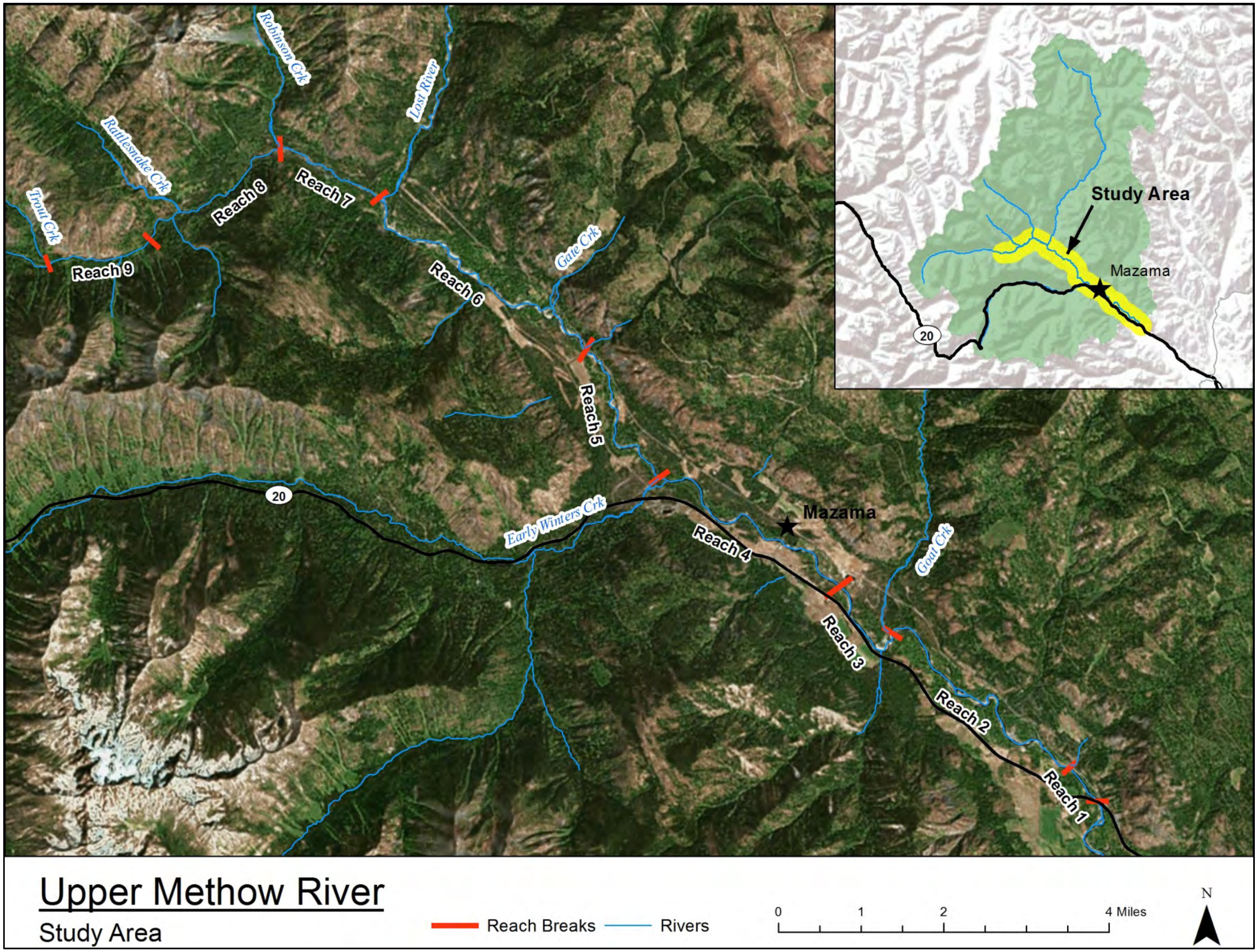

Figure 3. Geomorphic reach breaks in the Upper Methow study area.

2.2 GEOLOGY

The Upper Methow River Basin is located in the northeastern portion of the rugged North Cascades geologic province. The basin is geologically bound structurally by northwest-southeast running faults that define the eastern side of the geologic province (Schuster 2005). The faults act as hydrographic and topographic features that influence the pathway of the modern and historical Upper Methow River. The Pasayten fault zone bounds the Methow terranes on the east side and the Rose Lake and Hozameen Fault zones bound the west side (DeGraaff-Surpless et al 2003). This geologic province is a complicated mosaic of terranes that reflect about 400 million years of geologic history (Tabor and Haugerud 1999).

The surficial geologic terranes specific to the Upper Methow Basin include units of sedimentary rock of marine and riverine origin, intrusive and extrusive volcanics, metamorphic rock, and unconsolidated alluvium and colluvium (Figure 4). Sedimentary rocks form over long periods of time when the original deposits are exposed to relatively subtle geologic processes (heat, pressure, oxidation, etc.) that cement the deposits into a rock mass without drastically altering the mineralogy of the original material. The oldest surficial terranes associated with the study area are deep marine (132-110 million years) and shallow marine (110-105 million years) deposits that accumulated during the Cretaceous and Jurassic period when this area was a sea, now referred to as the Methow Ocean (Haugerud and Tabor 2009). These marine and riverine deposits have been transformed to siltstone, sandstone, argillite, and conglomerates in the Upper Methow Basin (Lasmanis 1991, USBR 2008).

Millennia of plate tectonics in this region have resulted in the construction of impressive mountain topography through processes of accretion, subduction zone volcanism, and crustal deformation. The volcanism within and near the Methow Basin included extrusive (above the surface) volcanic events of andesitic breccia and tuff (~90 million years ago), as well as intrusive (subsurface) volcanic magmatic plutons of tonalite and granodiorite (79-90 million years ago and 45-50 million years ago). Directly west of the study area, additional volcanism of the Cascade Magmatic Arc over the last 35 million years has contributed pyroclastic material (material ejected into the air from a volcano) such as ash to the Methow Basin. Most recently, these contributions have come from Glacier Peak (11,250 years ago), Mount Mazama (7,000 years ago), and Mount Saint Helens (3,400 and 35 years ago) (Beget 1984, USGS 1997).

The heat and pressure generated by mountain building (orogeny) has interestingly resulted in only minor metamorphism of the sedimentary and volcanic rocks of the Methow terranes (Haugerud and Tabor 2009). Metamorphic rocks are the result of relatively intense geologic processes (heat and/or pressure) that physically or chemically change the original mineralogy of a rock into a different material. In the Upper Methow study area portions of the volcanic materials have been metamorphosed into marble, schist, and gneiss and subsequent mineralization produced small deposits of copper and gold in a few locations of the Upper Methow Basin (Lasmanis 1991, USBR 2008).

The high-relief valleys and peaks of the Upper Methow Basin have been carved, carried away, and deposited downstream by ice and water for thousands of years – creating an impressive alpine landscape. These processes of erosion and deposition have exposed the area's complicated mosaic of bedrock and created an array of alluvial features such as terraces, fans, and floodplains composed of unconsolidated materials in the valleys. The U-shaped valley that the Upper Methow River flows through is the result of alpine and continental ice sheet glaciation most directly linked to the last glacial period (Ice Age) of the late Pleistocene and early Holocene (approximately 20,000 to 9,500 years ago). Alpine glaciers extended from the headwaters down valley as rivers of ice about 18,000 years ago, carving and deepening the upper valleys of the Methow River (Waitt 1975, Haugerud and Tabor 2009). Remnant deposits from this glacial period are found in the less disturbed upland areas. Distribution of these and other Pleistocene and Holocene deposits are included in Figure 4.

At approximately 15,000 to 14,000 years ago, lobes of the Cordilleran continental ice sheet extended into the Methow Valley (Wait and Thorson 1983, Booth et al 2003, Kovanen and Slaymaker 2004). The ice sheet overtopped mountain passes and extended down tributaries into the valley from the north at Lost River and from the west at Early Winters Creek. This coalescence of glaciers created a thick valley of ice that left only the high peaks exposed and carved a deep trough into the bedrock of the Methow terrane (Wait 1975, Riedel et al 2007). By approximately 11,000 years ago, the Cordilleran ice sheet had receded from the lower valley, leaving remnant pieces of continental ice in the upper-most valley and its tributaries. The material carved and carried by the ice becomes glacial outwash when it is transported and deposited by flowing water generated by the glacial ice melting. The outwash generated during the Cordilleran glacial recession filled the valley floor of the Methow Basin with a thick deposit of unconsolidated sediment (large boulders, cobbles, gravels, and sand). Between the Weeman Bridge and Lost River confluence, the glacial outwash deposits range from 200 to 1,000 feet deep (Konrad 2006). A re-advance of alpine glaciers at approximately 11,000 to 9,500 years ago likely combined with the remnant continental ice in the uplands to produce the necessary streamflow and sediment during their recession to create the large alluvial fans that extend out into the valley atop the glacial outwash fill (USBR 2008). Holocene alpine glacial advances described at Glacier Peak in the North Cascades (Beget 1984) at 8,400-8,300, 5,100, 3,400, and less than 1,000 years ago (Little Ice Age) suggest that additional periods of small-scale Holocene alpine glaciation was possible in the upper-most highlands of the Methow Basin.

The streamflow and sediment regime of the Methow River were greatly reduced after the glaciers retreated between nine and ten thousand years ago. In response to the modern regimes, the channel has incised into the glacial outwash deposits that had previously filled the valley floor. Today, the glacial outwash deposits form paired terraces throughout much of the study area. The Upper Methow River and its modern alluvial surfaces are inset four to forty feet below the glacial outwash terraces and alluvial fans. Talus, landslide, and debris fan deposits dress the toe of most of the steep bedrock walls that border the valley. In the confined upstream reaches above Robinson Creek, direct hillslope inputs contribute plentiful coarse-grained material to the channel and narrow floodplains.

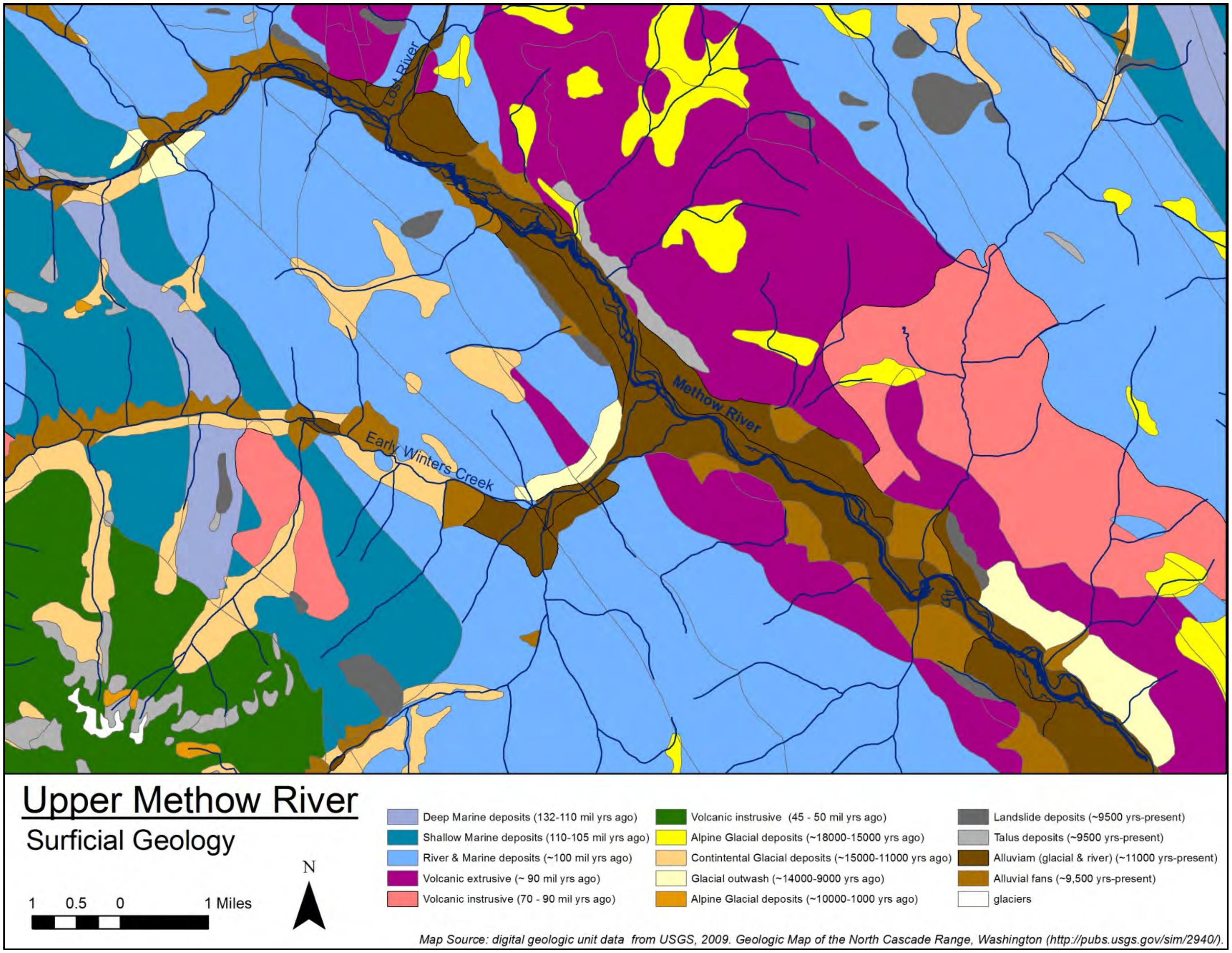

Figure 4. Surficial geology of the Upper Methow Basin study area with approximate age of origin (Waitt 1975, Burtchard 1998, Booth et al 2003, DeGraaff-Surpless et al 2003, Schuster 2005, USBR 2008, Haugerud and Tabor 2009).

2.3 HISTORICAL FORMS AND PROCESSES

Within this Reach Assessment historical conditions are considered as those that would have existed just previous to Euro-American settlement (i.e. prior to large-scale human alteration). Historical conditions represent the conditions to which native species such as salmonids were presumably best adapted, prior to the population crashes that ensued as human interventions increased on the landscape in the last two hundred years. In many cases, restoration to historical conditions will be impossible or inappropriate; however, historical conditions nevertheless provide a reference point for helping to determine how habitats and processes have changed and can help inform the identification of restoration objectives. This section provides a brief summary of historical conditions; more information is provided in Appendix D.

Although there is little direct evidence about conditions of the Upper Methow River before the early twentieth century, field observations, USGS records and related surveys, LiDAR, as well as underlying geology and glaciation cycles can provide some theories on historical channel forms of the Upper Methow River. The earliest published record of geological observation was from Russell (1900). Overall, the watershed and riparian forests were relatively undisturbed and the valley bottom was vegetated with mature forests composed of very large trees. The mature forests covered much more of the Upper Methow Valley and slopes than we see today. These forest conditions allowed the river channel to incorporate large wood into the system via floods, bank erosion, and channel avulsions. The established vegetation also metered the rate of bank erosion and created a higher degree of sinuosity in the unconfined reaches. The available aquatic habitat was likely very complex – with plentiful backwater and side-channel features, active channel migration, and avulsions.

2.4 HUMAN DISTURBANCE HISTORY

2.4.1 Land Use History

With the exception of some early explorers, fur trappers, and miners, Euro-American settlement began in the Methow Basin in the late 1890s (Appendix D). Since then, there have been several human disturbances that have impacted natural channel processes, including mining, agriculture, timber harvesting, and fire suppression.

Timber harvesting in the region has played a large part in the changes to the hydraulic and sediment regime within the Methow River. Upland timber harvest and its associated practices have likely increased the amounts of slides and debris flows that the Methow River has experienced (Appendix D). Log drives to transport harvested lumber downriver likely scoured out spawning gravels. Timber harvest along the valley floor led to the associated loss of the important channel functions this vegetation serves, including flood moderation, regulation of inundation processes, shade, moderation of stream temperature fluctuations, and providing future sources of large wood material to the channel. Past stream cleanouts have also had a significant impact on habitat. Following both the floods of 1948 and 1972, the Army Corps of Engineers removed natural large wood accumulations and channel substrate, as well as straightened portions of the channel, reducing available habitat and high flow refuge. Although large-scale snagging and riparian clearing is no longer occurring in the study area, the effects of this historical practice will continue to affect wood-loading for the foreseeable future (see Section 2.9).

2.4.2 Development Trends since 1950

The study area is currently 24% public property and 76% private property within the low geomorphic surface, with the Okanogan National Forest accounting for a majority of the public property. Much of the private property has undergone vegetation clearing, floodplain grading, and residential development. The low surface within the study area has a road density of 1.88 mi/mi^2.

Flood mitigation practices of the mid- to late-1970s led to removal of native substrate and other habitat elements such as log jams. Those practices also included the construction of levees to prevent flooding on private property, which reduces floodplain connectivity and lateral channel migration. Riprap is also used intermittently throughout the study area as a method of bank stabilization for residential properties as well as roadway embankments and bridge abutments. This armoring limits natural lateral channel migration and sediment sourcing from streambanks.

Table 2. Human alterations and modern development in the study area. The low geomorphic surface includes the contemporary floodplain and alluvial terraces.

Metric	Value in the Low Geomorphic Surface
Road Density	1.88 mi/mi^2
Public Land	24%
Private Land	76%
Portion of Channel with Levees & Bank Armoring	1%
Developed & Cleared Land	25.6%

2.5 POTENTIAL EFFECTS OF CLIMATE CHANGE

The Upper Methow River has expressed a geomorphic sensitivity to changes in discharge and sediment regimes at the close of the recent ice-age (9,500 years ago). As described previously in the Geology section, the channel has responded to the reduction in sediment and discharge regimes after the glaciers retreated by incising into the glacial outwash deposits. The channel then re-established a new floodplain and new sinuosity to equilibrate itself to the modern regimes. Since 9,000 years ago, there is evidence that subtle winter-time climate shifts have been shown to instigate periods of aggradation in the upper mainstem Columbia (between the Methow and Okanogan rivers) and lower portion of major tributaries. This research concluded that in periods of relatively warmer winters, where precipitation resulted in the buildup of snowpack and a high frequency of rain-on-snow events, increased flood frequency led to aggradation in the larger mainstem channels. Likewise, drier colder winters reduced the probability of large floods and allowed for accumulation of sediment in the upper portions of the watershed and tributaries that was then available for transport during periods of climate transitions (Chatter and Hoover 1992). It can be inferred by regional proximity that the Methow River likely experienced a higher probability of flooding and some degree of aggradation during the warmer time periods for this region during the Holocene (9,000 to 8,000; 7,000 to 6,500; 4,400 to 3,900; and 2,400 to 1,800 years before present). However, it is unclear whether this dynamic would apply to the Upper Methow study area, which is much higher in elevation than the mainstem stream segments that were evaluated.

The US Geological Survey (Voss and Mastin 2012) examined the potential impacts of predicted climate change scenarios in the Methow Basin – all of which predict increases in winter temperature. Warmer winters result in more precipitation falling as rain instead of snow. This is expected to decrease streamflow during spring and summer because of reduced snowpack, but to increase flow during fall and winter. Voss and Mastin (2012) provide a web-based tool to plot modeled flows based on climate change scenarios. Figure 5 shows the modeled data for USGS gage 12447383 (Methow River above Goat Creek near Mazama, WA), which is in the study area. These results suggest that overall snowmelt peaks will be less than existing conditions, and fall and winter peaks will be greater than existing conditions. Overall, annual peak flows would be expected to decrease in size. The effects of these potential changes on the Methow River and aquatic habitat depend on many factors such as timing of the events, sediment supply, and icing. Higher fall and winter flows could result in a greater degree of channel change, greater sediment recruitment and transport, and more frequent icing events. However, lower snowmelt peaks would result in less channel change and sediment mobilization during the spring, potentially resulting in greater channel stability. Such channel response mechanisms are important to consider with the inevitable influence that present and future climate change will have on the river.

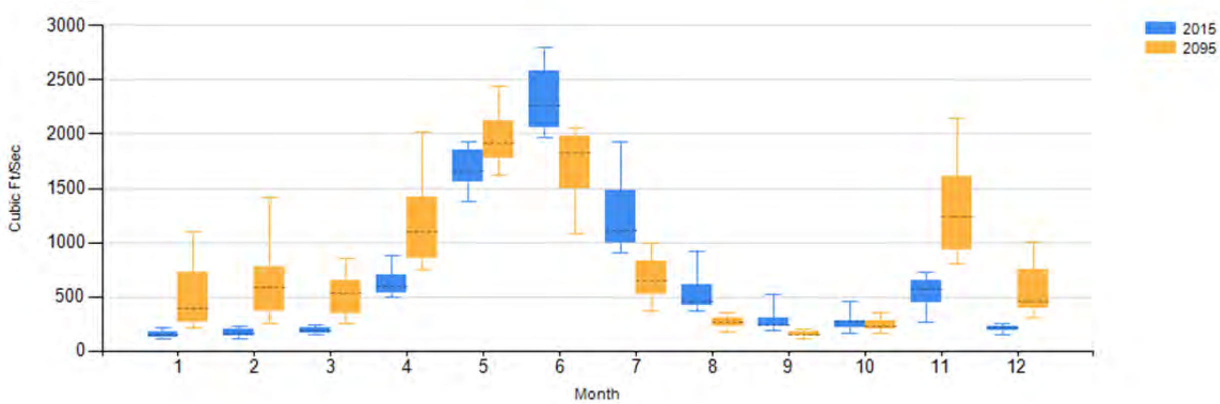

Figure 5. Boxplot of modeled average monthly flows at USGS gage 12447383 (Methow River above Goat Creek near Mazama, WA) for existing (2015) and future (2095) climate scenarios generated from Voss and Mastin (2012) web-based tool (http://wa.water.usgs.gov/projects/methow/cc.htm). Boxplots represent modeled values for all general circulation models and greenhouse gas emission scenarios. The boxes represent the semi-quartile range (25 to 75 percentile); dashed line is the median; and vertical lines extent to minimum and maximum values.

2.6 HYDROLOGY

2.6.1 Surface Water

The Methow River watershed is a sub-basin to the Columbia River in western Okanogan County, Washington. The Methow River flows from its headwaters off the eastern flanks of the Cascades (elevation 8,950 feet) for about 86 miles to its confluence with the Columbia River (elevation 775 feet), and drains approximately 1,814 square miles. The Upper Methow watershed is about 426 square miles, and has an elevation gain of approximately 1,000 feet (1,951 ft at the downstream extent of the study area to 2,950 ft at the upstream extent).

Precipitation amounts vary spatially throughout the Methow Valley. Average annual precipitation along the crest of the Cascades near the headwaters of the Methow exceeds 80 inches, but drops to only 10 inches at the confluence of the Methow and Columbia Rivers near Pateros, WA. Most of the precipitation is delivered in late autumn to early spring in the form of snow or rain (USBR 2008, Andonaegui 2000). Dominant hydrologic patterns are driven by precipitation in the form of snow and subsequent spring snowmelt. The flood regime of the Methow River is strongly influenced by spring snowmelt and precipitation regimes; river flows increase rapidly between April and June, which is typical for rivers in the region.

There is one USGS real-time stream gage on the Methow within the study area (USGS gage number 12447383) located above Goat Creek at RM 65.5 on the mainstem Methow River. This gage has a period of record for discharge from 1991 to 2015. The daily minimum, mean, and maximum for the period of record are presented in Figure 6. Peak runoff usually occurs from April to August, with the highest flows typically in June. Stream discharge is typically reduced to baseflow by September. Mean annual flow is 525 cubic feet per second, based on annual average flows from 1993-2013 (USGS 2014).

Tributaries in the study area include Fawn Creek (RM 62.85), Goat Creek (RM 65), Little Boulder Creek (RM 65.25), Early Winters Creek (RM 69.2), Goat Wall Creek (RM 71.3), Gate Creek (RM 72.9), Lost River (RM 75), Robinson Creek (RM 76.5), Rattlesnake Creek (RM78.05), Trout Creek (RM 79.9), and a number of smaller tributaries and unnamed ephemeral drainages.

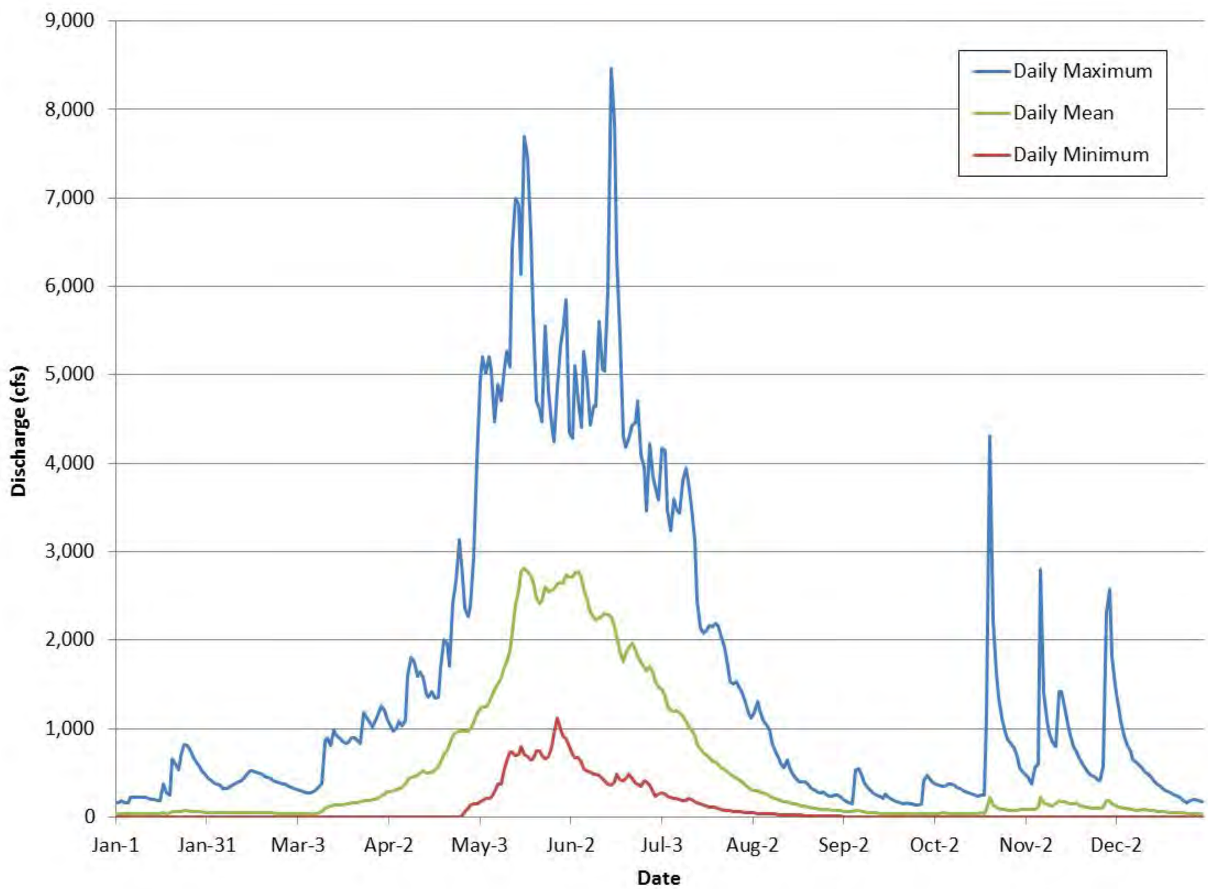

Figure 6. Mean, maximum, and minimum discharge of mean daily flows for the period 1991 to 2015 (as measured at USGS gage 12447383 - Methow River above Goat Creek near Mazama, WA).

2.6.2 Groundwater

An important component of the hydrology of the Upper Methow River is its groundwater, which is transmitted through the valley's unconfined aquifer. The aquifer is contained within the unconsolidated alluvium, glacial outwash deposits, alluvial fans, and colluvium that have filled the valley floor. These unconsolidated sediments are composed mostly of highly permeable coarse grained material (sand, gravel, cobble, boulder) that allow for active groundwater to surface water exchange and vice versa within the Methow River and its tributaries (Konrad et al 2005). Groundwater inputs contribute baseflow discharge to the mainstem channel and many of its side and off-channel features, including the groundwater-activated floodplain tributaries. The cold groundwater inputs to surface water enhance the quality of the available aquatic habitat (Andonaegui 2000). Groundwater inputs to the channel are sourced from up-valley or adjacent sections of the aquifer, as well as some lateral inflow from the terraces, alluvial fans, and tributaries (Konrad 2006a). Active hyporheic flow along the margins of the channel and through bars and bed substrate is another common groundwater/surface water exchange that occurs within the unconsolidated alluvium in the study area. Canals, used for irrigation and/or flow control, divert surface water across portions of the floodplain in the study area. On the west side of the channel, groundwater and surface flow from the alluvial fans of Early Winters Creek, Looney Creek, Little

Boulder Creek, and Lucky Jim Bluff are captured in unlined canals and re-routed. Although the flow is rerouted as surface water, it is expected that the water in the canals recharges groundwater through seepage at a rate of 1.8-3.2 thousands of acre-feet per year (Konrad et.al 2005).

The bedrock of the U-shaped Methow Valley acts as a flow boundary at the base of the basin's aquifer. The slope of the valley's bedrock controls the general down-valley flow (hydraulic gradient) of groundwater through the unconsolidated fill (Konrad 2006a). The size (width and depth) of the groundwater aquifer varies longitudinally downstream within the study area. In the narrow, higher-gradient upstream reaches above Robinson Creek (RM 76.5), direct valley wall contributions of talus and debris add a higher percentage of coarser-grained boulders and cobbles to a more shallow aquifer than the downstream reaches. Downstream from Robinson Creek, the glacial outwash deposits filled the valley with a relatively continuous surface, but the depth of the aquifer varies as the valley widens with a downstream trend. Between the confluence of Lost River (RM 75) and Goat Creek (RM 65), the slope and depth of the underlying bedrock increases. This is likely the result of a glacier from the Upper Methow, one from Lost River, and another from Early Winters Creek coalescing during the last ice-age (~15,000 years ago) and carving a deep trough in the valley floor (Kovanen and Slaymaker 2004). During the subsequent glacial retreat at approximately 10,000 years ago, the valley filled with the unconsolidated glacial outwash and alluvial fan deposits that are 500 to 1,000 feet deep in the section between Lost River and Goat Creek. Downstream from Goat Creek, the thickness of the deposits gradually decreases (Konrad et al 2005).

2.6.3 Seasonal Subsurface Flow Conditions

Seasonal variations in discharge and precipitation are reflected in the aquifer's groundwater elevation and availability. Groundwater levels reflect the seasonal hydrograph of the basin – usually decreasing from late summer or early autumn through spring and then increasing in spring and summer with snowmelt and precipitation. When groundwater levels are decreased below the elevation of the exposed channel bed, surface flow elevations are reduced or go subsurface. This seasonal variation can change the hydrologic relationship from groundwater inputs to the channel to groundwater recharge by the channel (Konrad 2006b), depending on the local characteristics of the aquifer. The impacts that seasonal dewatering of the sections of the channel has on fish survival in these river segments, such as increased water temperatures, drying of redds, and stranding, are discussed in Section 1.4.3 and Appendix A.

Subsurface flow conditions occur in the study area at low flow periods when groundwater storage is reduced and the infiltration capacity of the river bed exceeds the incoming surface water flow (Konrad 2003). This type of river reach is considered a "losing reach" because it contributes its incoming surface water to groundwater recharge. The aquifer configuration in the Upper Methow Basin that results in dewatering also produces a groundwater discharge zone from approximately Goat Creek to downstream of the Weeman Bridge (Figure 7). Here groundwater inputs usually contribute discharge to the surface water flow in the channel ("gaining reach"). However, reports indicate that in very low precipitation years, even portions of the channel between Goat Creek and the Weeman Bridge can be dry (WDW 1990).

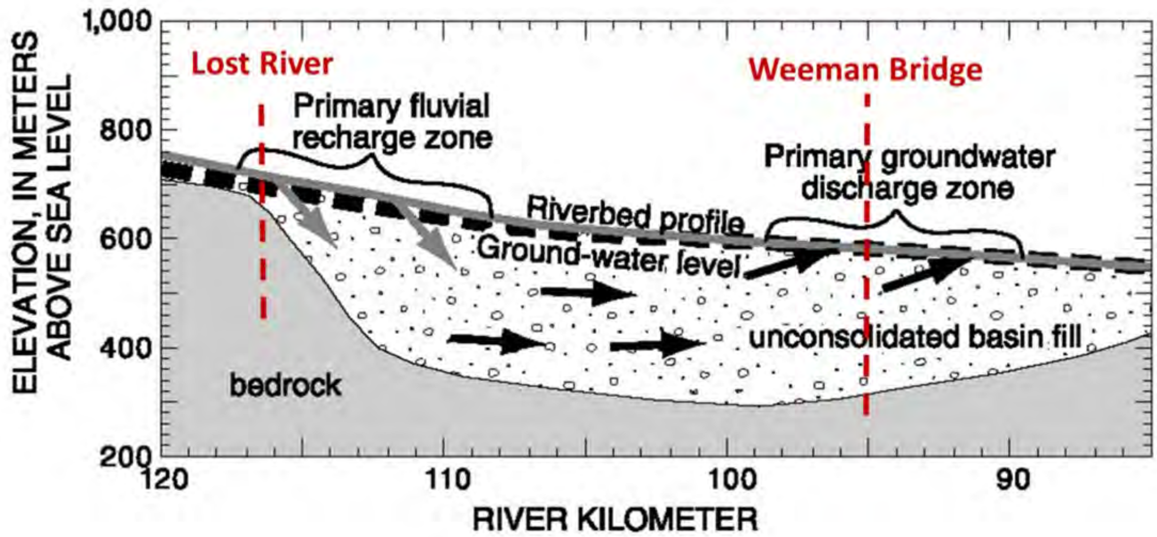

Figure 7. Section of the Upper Methow River valley showing how the configuration of the aquifer (vertical depth of the bedrock from the riverbed) influences the locations of fluvial recharge and ground-water discharge zones (derived from Figure 12, Konrad 2006a).

In the Upper Methow, river segments between the confluences of Lost River (RM 75) and Goat Creek (RM 65) often seasonally go dry with only small residual holding pools during late summer and autumn (Andonaegui 2000, Konrad 2003, WDW 1990). In this section of the river, the unconsolidated glacial outwash material is up to ~1,000 feet deep and the groundwater table usually drops below the elevation of the channel bed by late summer. The timing and extent of dewatering in the study area depends on the amount, type, and timing of precipitation that is received during the year for recharging the aquifer. A map that combines records of the extent of observed dewatering, and the location of spring Chinook redds impacted during surveys, is presented in Figure 8. Reports of dewatering or partial dewatering extend from Robinson Creek (RM 76.5) to the Weeman Bridge (RM 61) with persistent pools reported at the confluence with the Lost River, Early Winters Creek, and Goat Creek.

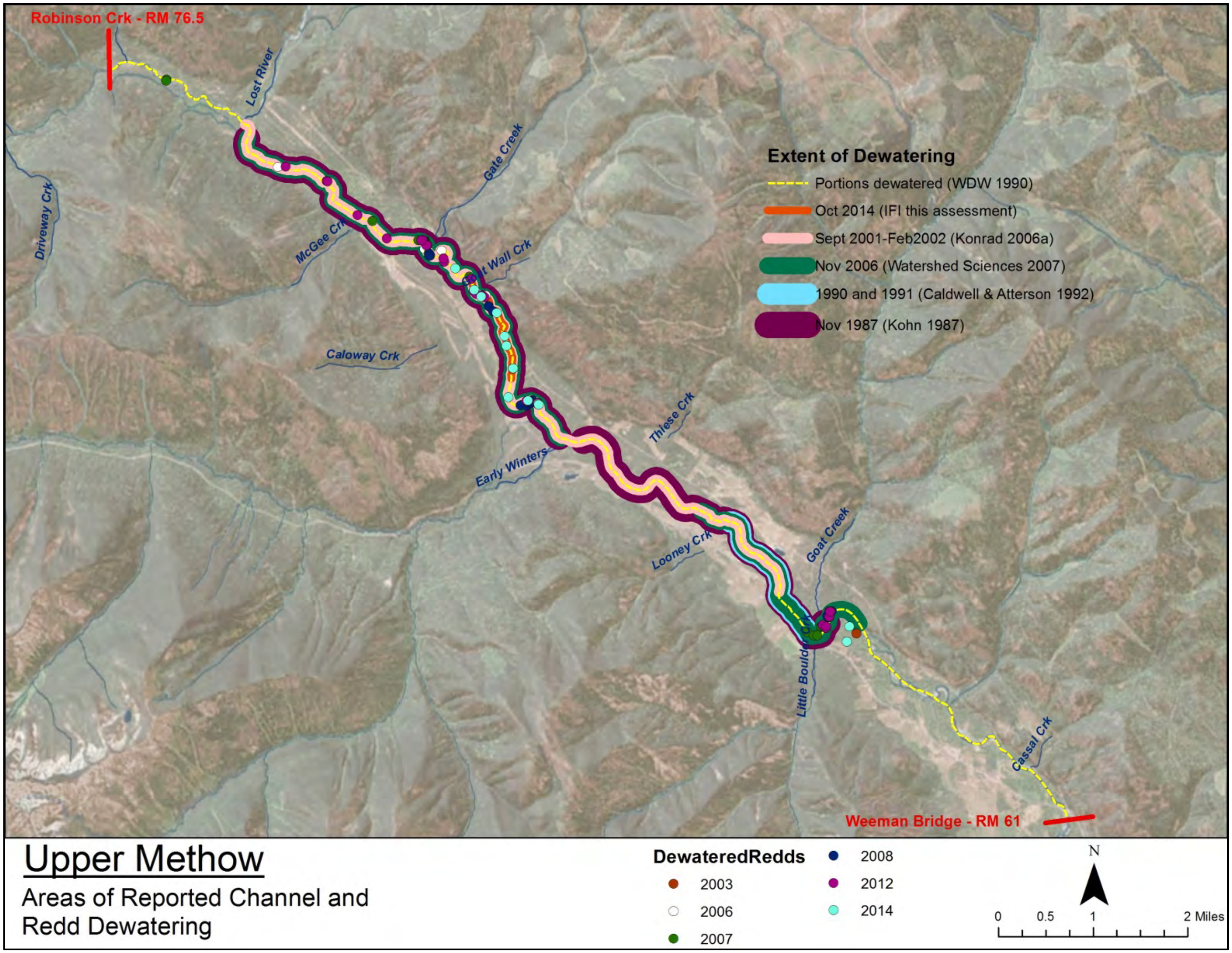

Figure 8. Extent of reported dry-season channel dewatering and observed dry redds. Dewatering includes dry channel beds and partial drying with stranding pools. Redd survey data completed by the Washington Department of Fish and Wildlife and supplied by the Yakama Nation Fisheries Department for this report.

2.7 HYDRAULICS

2.7.1 Background

The floodplain of the Upper Methow River includes many relict side-channels and surfaces with different elevations, which produce complex hydraulics and floodplain inundation patterns. While a one-dimensional model can produce relatively accurate hydraulic results, this process would require multiple iterations to break the floodplains into different channel reaches and would still lack the ability to simulate the lateral flow for proper side-channel activation and deactivation. Two-dimensional hydraulic models perform well in these situations and SRH-2D (version 2) (hereafter SRH) was therefore utilized. Using available LiDAR data, Reaches 1 to 7 and the downstream portion of Reach 8 were simulated for flood events with return periods of 2 and 100 years. 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.

2.7.2 Methods

Hydraulic Model development

The SRH hydraulic model was built in Aquaveo's Surface-water Modeling System (SMS) (version 11.2) using LiDAR data for boundary extents and elevation. The mesh was constructed with higher resolution in and near the active channels (8.5 feet triangle edge lengths), and coarser cell resolutions near the outer boundaries (25 feet triangle edge lengths) to produce a final cell count of 1,061,380. This variation in resolution ensured that river channels, bridge geometries, and grade breaks were well defined while the outer ineffective extents were limited, thus improving model efficiency.

Roughness values for the model were delineated in ArcGIS using the available aerial images and exported to SMS. One roughness value was specified throughout the main channel based on the pebble count data. The 84th percentile largest grain size was applied to Strickler's equation (Chow 1959) to obtain the estimate of 0.034. This value is consistent with the values predicted with the empirical approach described by Arcement and Schneider (1989). Other roughness values were estimated using the Arcement and Schneider (1989) method and look-up tables (Chow 1959) (Table 3).

Table 3. Manning's roughness values used in the 2D model.

Area	Manning's roughness value
Forest	0.130
Road	0.015
Floodplain vegetation	0.060
Channel	0.038
Unpaved roads	0.020

The downstream boundary condition for the model was the estimated water surface elevation calculated using Manning's equation and the total discharge. Since the model's downstream boundary was well past Reach 1, the water surface level had sufficient channel length to establish a stable and accurate level. The upstream boundary conditions and discharge estimates at river miles for the two and one-hundred year flows were calculated using the US Geological Survey National Flood-Frequency Program's contributing drainage area method for estimating flood magnitude and frequency in unregulated Washington streams (USGS 2001). This method allows for peak discharge at an ungaged location to be calculated from gaged data on the same river, if the drainage area at the ungaged location is 50-150% that of the gaged site. We used the available annual peak flow data (1991-2013) from USGS gage #12447383 located at RM 65.5 to determine the recurrence interval discharge values for the 2 and 100 year flood events and to estimate flood peak values at the ungaged locations (see Table 4). Tributary flow inputs for the 2 and 100 year flood events were extracted from the US Bureau of Reclamation estimated flow rates (USBR 2008). Upstream from the confluence with Lost River, the drainage area of the mainstem Methow River is less than 50% that at the gaged site. However, we selected to use the USGS contributing drainage area method to remain consistent with the values calculated downstream. Using these values also resulted in the 2-D model results matching observed conditions more realistically. All models were simulated with a time step of 0.5 seconds, which was consistent with the Courant condition (see Wu 2008). Each flood simulation was routed through the model for at least 6 hours to allow sufficient time for steady-state hydraulic conditions to occur.

Table 4. Peak discharge estimates at river miles within the study area for the 2 year and 100 year flood events

	RM 61	RM 62.90	RM 64.9	GAGE RM 65.5	RM 65.25	RM 67.35	RM 67.8	RM 69.25	RM 71.25	RM 72	RM 73.2	RM 75	RM 76.5	RM 78.2
2 yr flood														
Q peak (cfs)	5574	5434	4945	4902	4837	4760	4719	3666	3559	3469	3409	1168	881	822
100 yr flood														
Q peak (cfs)	14839	14468	13165	13051	12879	12674	12564	9762	9474	9236	9075	3108	2344	2187

There are limitations for utilizing LiDAR to model floodplain inundations. The 2006 LiDAR data available for the Upper Methow River is capable of producing elevation data in terrestrial environments, but cannot produce ground elevations below water (i.e. bathymetry) and the data includes frequent errors of at least up to 0.5 feet. 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.

Flood Inundation Analysis

Flood inundation was modeled by exporting the SRH-2D result from SMS into ArcGIS, which allowed for visualization of the floodplain inundation over aerial photographs. 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. Further, it is noted that the contributing flows of tributaries entering the Upper Methow River were simulated, but in most cases the inundation of the tributaries required slight modification to ensure reasonable inundated areas near the Upper Methow floodplain. Therefore, all contributing tributary inundation is specifically for maintaining accurate Upper Methow River flow rates, and not a full or accurate representation of tributary inundation. Please refer to Table 4 for river mile discharge values. The model was calibrated using the best available aerial imagery taken during a high-flow event with gaged discharge. The photos are from May 24, 2006, which captured the equivalent of a 1.8 year flow recurrence (daily average discharge of 4,000 cfs at the gaged site at RM 65.5).

Sediment Mobility Evaluation

An evaluation of sediment mobility during selected flood discharges (2 year and 100 year) was conducted at thirteen representative riffle crest sites in Reaches 1-8. Streambed sediments are transported only 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 a sediment particle of a specific size is the critical shear stress. If the shear stress is greater than the critical shear stress, then the sediment grain has the potential to 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.

During the summer of 2014, Inter-Fluve collected 13 pebble counts distributed between river miles 61 and 76 following the Wolman Pebble Count method (Woman 1954). This sparse data collection was only intended to support a reach-scale assessment, and is not considered a detailed analysis. However, combining the sediment size distributions with SRH model shear stress distribution results provides insight into the potential mobility of sediment and stream power of the modeled flood events. To evaluate general trends in the ability of the Upper Methow to mobilize and convey sediment, excess shear ratios were calculated using the Shields (1936) equation.

The shear stress applied to the bed is:

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

The critical shear stress needed to mobilize the streambed sediments is (Shields 1936):

$$\tau_{c1} = \tau_{c50*} (\rho s - \rho)_{50}$$

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

$$\tau^* = \frac{\tau}{\tau_c} = \frac{\rho R s}{\tau_{c50*} D_{50}\ (\rho_s - \rho)}$$

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_{50} = median grain size (ft)

s = slope

τ_{c50*} = critical dimensionless shear stress (Shields Parameter)

Here, τ_{c50*} was adapted from Julien (2010) and the movement of the D_{50} was assumed to represent bed mobility.

The 13 pebble counts were conducted at representative riffle crests to evaluate the stream substrate that is providing grade control. Pebble count data were used to evaluate the potential of sediment mobility during selected flood events. Since several years lapsed between the LiDAR (2006) utilized for the SRH model and the conducted pebble counts (2014), an analysis was performed to ensure that the location of each pebble count was representative to the location within the model, since in some areas channel position may have changed. This was accomplished by examining aerial photographs of 2006 and 2014; in a few cases, pebble count locations were moved a short distance (less than 100 feet) in the model to ensure the pebble counts were in appropriate locations. Further, since the SRH model produces spatial distribution of shear stress, a method was developed to provide a representative shear stress for the 13 pebble count locations. This was accomplished by averaging the shear stress values in a wide transect (cross-section) perpendicular to flow. This transect was centered at the pebble count location and bound between the river banks; and extended 25 feet upstream and 25 downstream. Finally, these averaged shear stress values for the 2-year and 100-year flood events were compared to the calculated critical shear stresses.

2.7.3 Results

Floodplain inundation

An overview of the inundation analysis results for the 2 and 100 year flood events are shown below in Figure 10 and Figure 11. These maps provide a broad overview of inundation patterns at study reaches. Higher resolution inundation maps at the reach-scale are included in the reach-specific sections later in this document. The inundation of the 2 year flood was kept in-channel only in Reach 8, whereas downstream reaches had significant side-channel activation and floodplain inundation. Similar results occurred for the 100 year flood results, with the exception of moderate side-channel activation of the confined downstream segment of Reach 8. In addition to floodplain inundation, the 2 and 100 year flood event results showed overtopping of Highway 20 in Reach 1, inundation of Highway 20 in Reach 3, and the 100 year event inundation connected to the gravel mining pit located in the river-left floodplain at river mile 66.25.

Flood inundation shown in the Lost River Community (Reach 6) is partly a function of additional flow added to the model in that region based on professional judgment to account for the flow additions in that reach according to the USBR (2008) hydrology. These inundations should therefore be interpreted with caution, particularly with respect to the modeled inundation of structures. Although there is uncertainty associated with the inundations in this area, it is clear that this community has experienced flooding issues based on field observations of numerous pushup levees and drainage canal systems throughout the floodplain in this area.

Sediment mobility

An overview of the modeled shear stress results for the 2 and 100 year flood events are shown below in Figure 12 and Figure 13. These maps provide insight into the potential sediment dynamics and stream power of these floods. As shown, shear stresses regularly range between 0.5 and 5 lb/ft^2. When the excess shear stress ratio for the selected grain size is < 1 then mobilization does not occur, but when the ratio is > 1 them mobilization is expected to occur (See Figure 9). The results of the sediment mobility evaluation suggest that bedload sediment at seven of the thirteen sampled sites becomes mobile during the modeled 2-year flood event. During the modeled 100-year flood event twelve of the thirteen sites are expected to have a mobilized bedload.

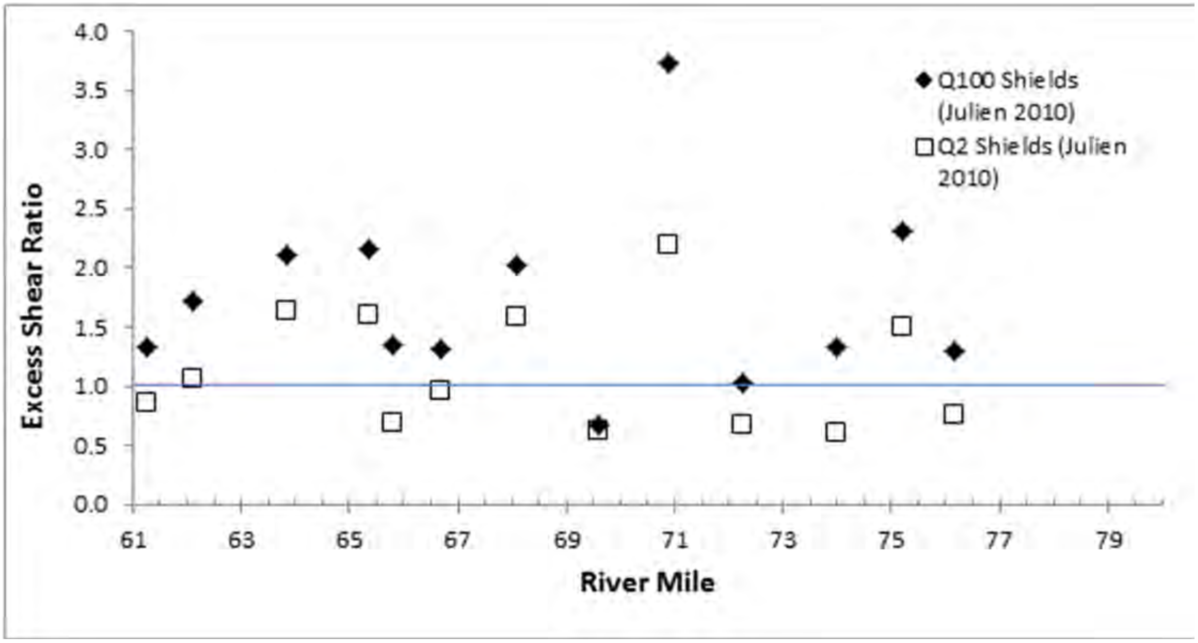

Figure 9. Sediment mobility potential at sampled sites between RM 61-76.

2.7.4 Discussion

The hydraulic analysis provides insight into flood inundation and stream energy at the time of LiDAR acquisition in 2006. The 100 year flood simulation has also helped to define the boundaries between abandoned terraces and modern floodplain surfaces. Flood simulations show that the floodplain is activated in numerous areas. Although many of the side-channels are shown as active during floods, human impacts such as levee construction, floodplain grading, and bridge crossings affect inundation patterns, floodplain connectivity, and habitat. Examples include push-up levee construction preventing floodplain inundation in Reach 2 (RMs 63.75-63.25) and Reach 8 (RM 76.75). Bridges in Reach 1 and the middle of Reach 4 (RM 67.2) have also impacted floodplain processes. These bridges and their associated approach fills interrupt floodplain flow by routing flow back into the channel at the crossing. They also limit any potential channel migration due to the bridge abutments and associated riprap. These impacts not only disrupt floodplain connectivity, but they also contribute to stream channel incision and habitat simplification in the areas near the crossings.

Although this evaluation offers only limited information with respect to sediment mobility, we can infer that the stream power generated by frequent high-flow events (2 year recurrence) is generally capable of mobilizing bedload sediment. This is consistent with the dynamic conditions observed in portions of the study area. Some of the more dynamic results (i.e. near RM 71 and 75.5) are from areas with high bedload and multi-thread channels (more transport-limited). Some of the more stable locations (i.e. RM 61.5, 69.5, and 72.3) are located in areas where the channel is influenced by confinement from either a bridge (RM 61.5) or tributary fans. These influences may be increasing stream power and therefore result in coarsening of the bed (more supply-limited). Tributary fans may also be contributing larger material to the channel at these locations. Further sediment data collection and analysis at the reach-scale is recommended as part of future restoration project design to better understand sediment transport dynamics.

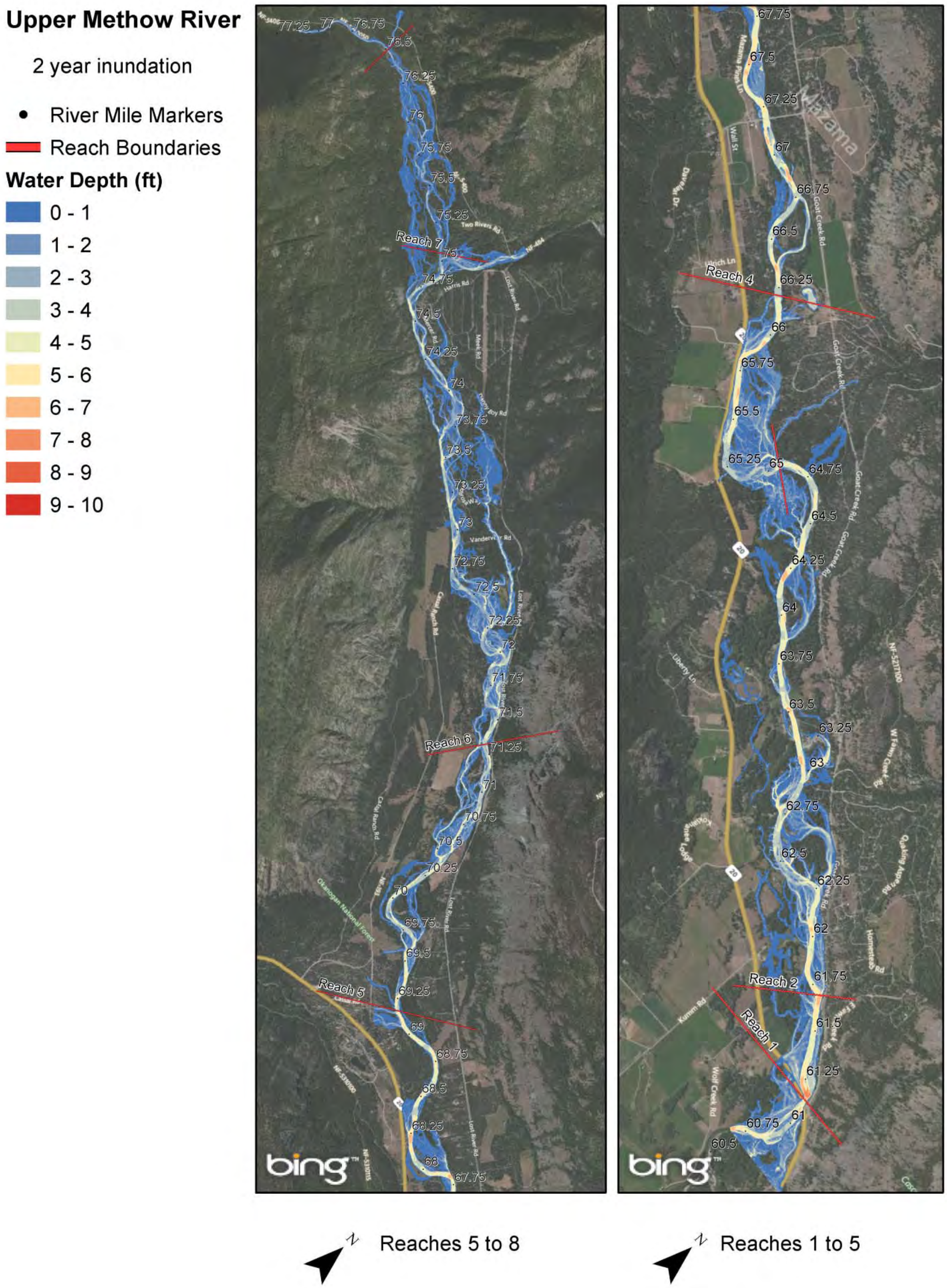

Figure 10. 2D model output for water depth for the 2YR flood. Reach scale detail is provided in the reach sections later in this report.

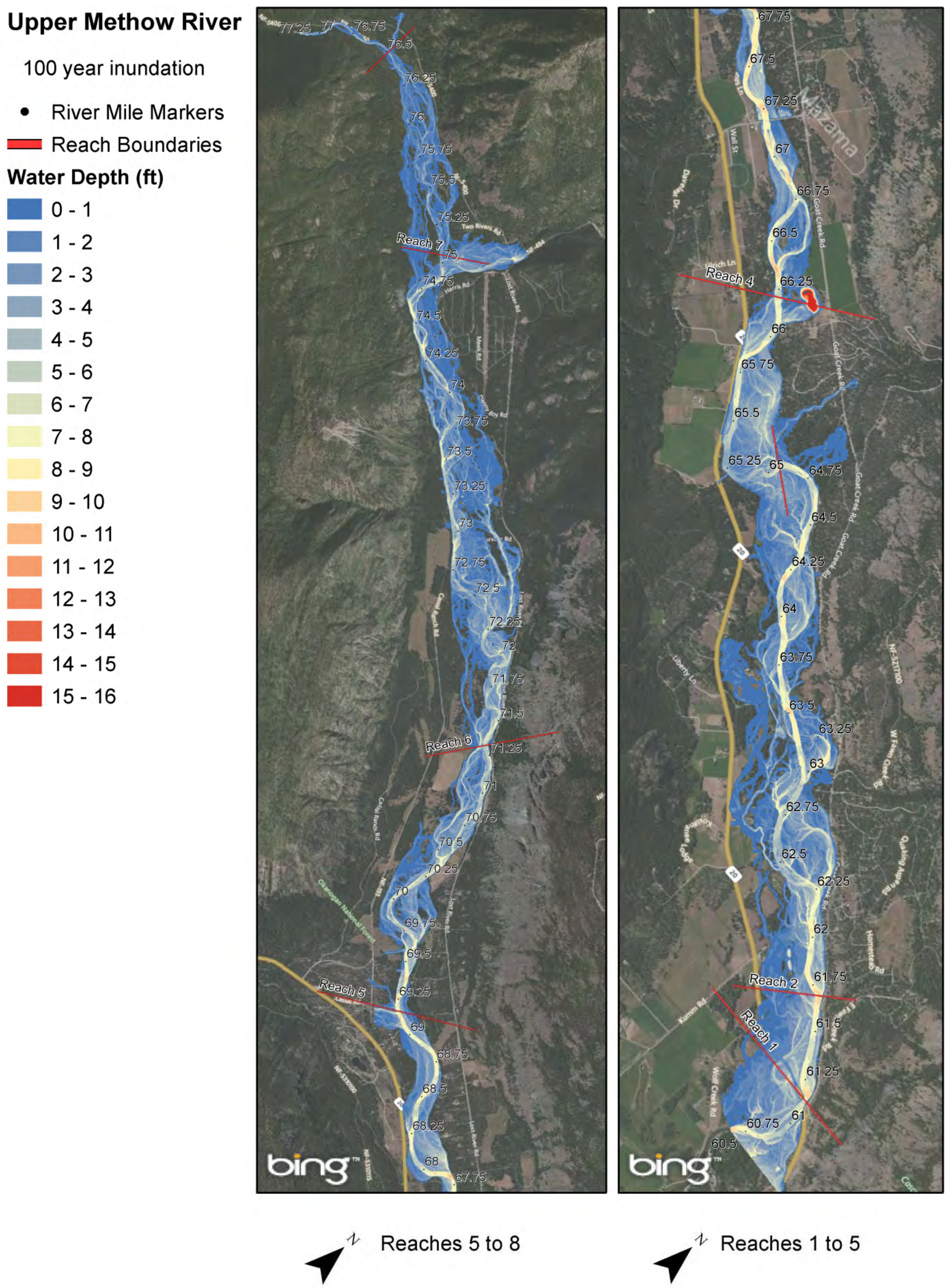

Figure 11. 2D model output for water depth for the 100YR flood. Reach scale detail is provided in the reach sections later in this report.

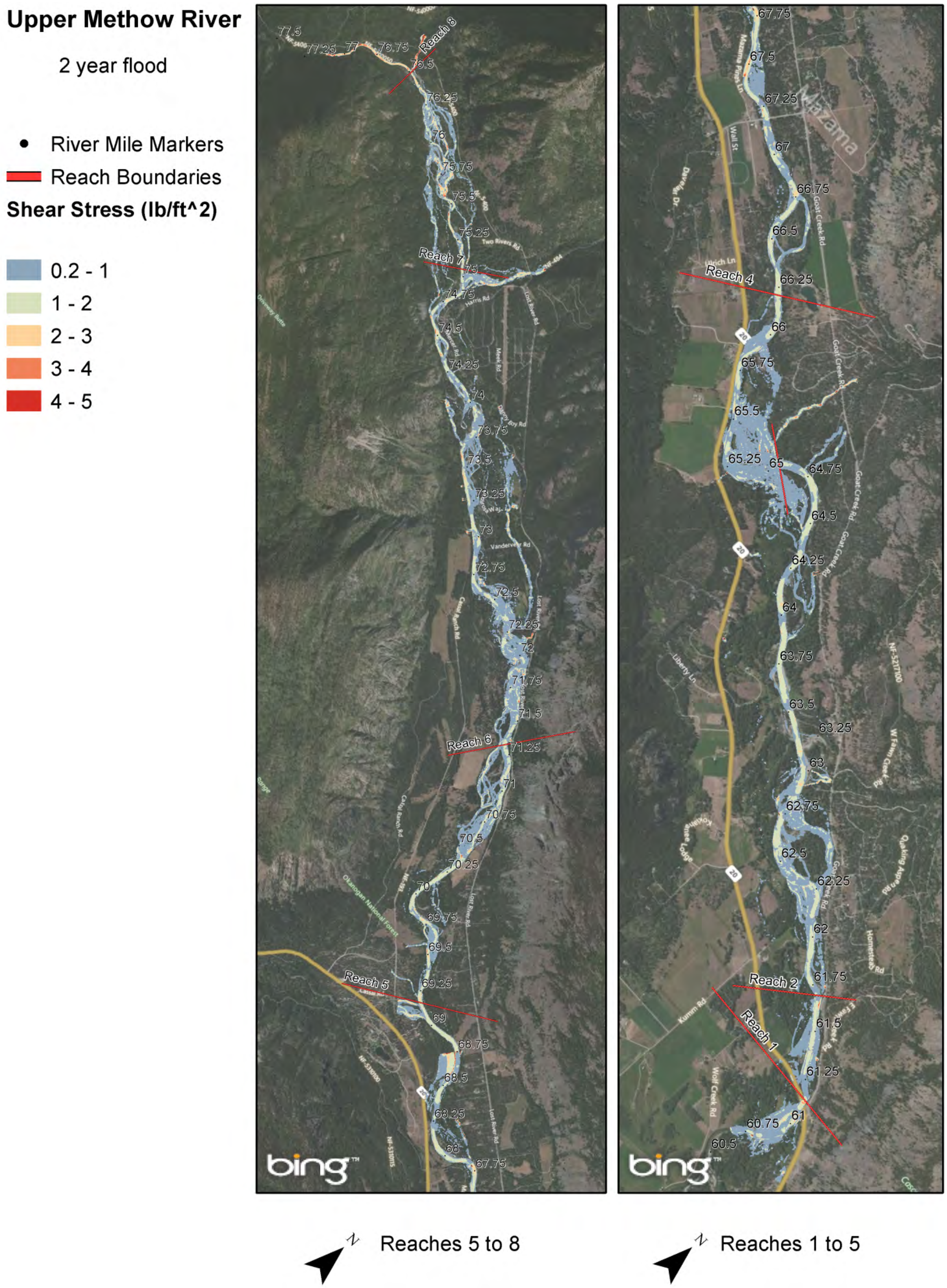

Figure 12. Output of shear stress in lb/ft^2 from the 2D model for the 2YR flood event.

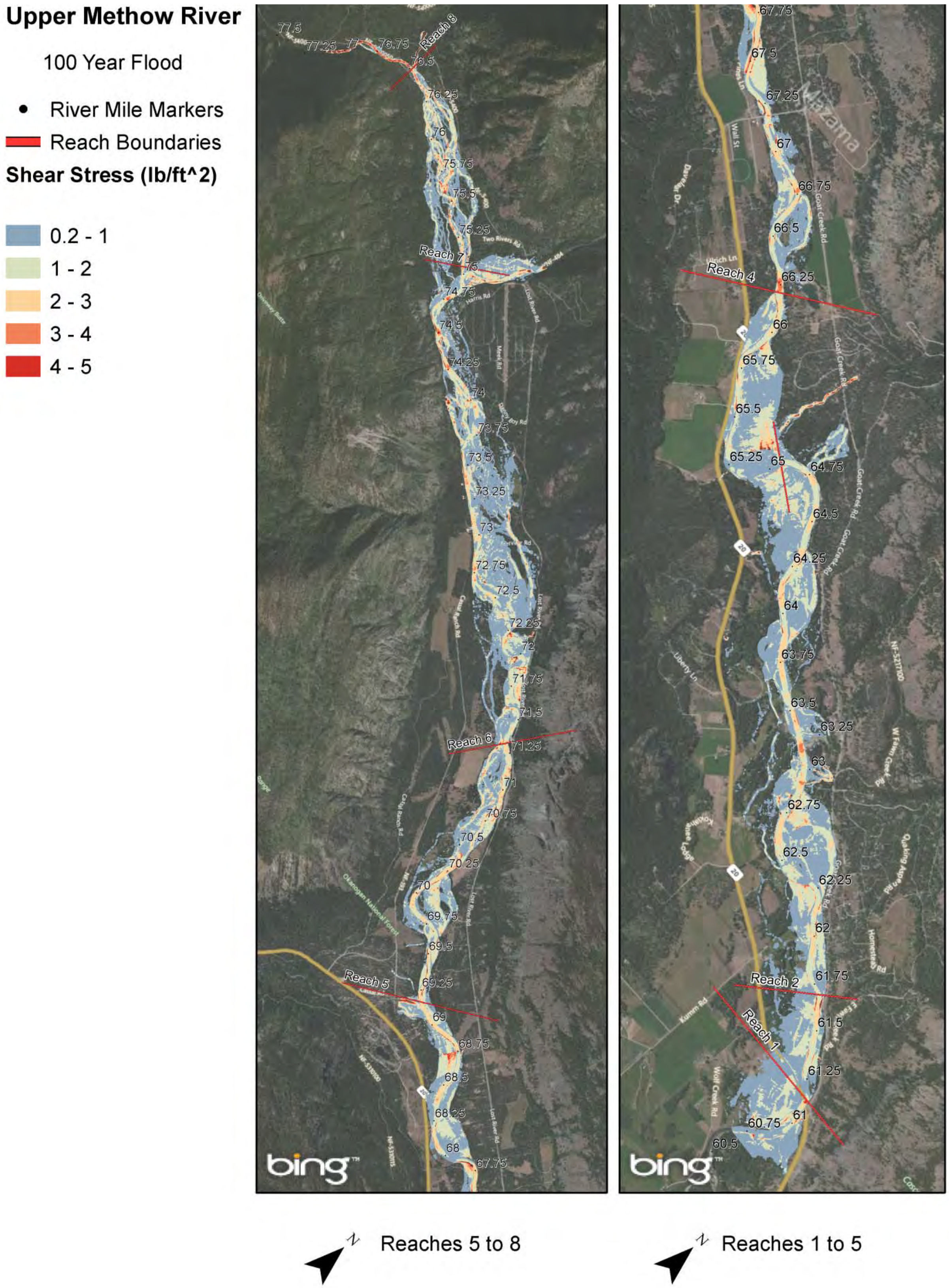

Figure 13. Output of shear stress in lb/ft² from the 2D model for the 100YR flood event.

2.8 GEOMORPHOLOGY

2.8.1 Valley Morphology

The Upper Methow River valley rests within a dramatic high-relief alpine landscape. The contemporary aspect of the valley is governed by regional fault zones that have imposed both hydrographic and topographic influences on the drainage basin for millennia. The main valley (downstream from the Lost River confluence) trends northwest to southeast, reflecting the direction of the dominant regional faults. The upper portion of the study area (from Lost River to Trout Creek) trends west to east, along what appears to be a transform fault that extends between the primary fault zones. The high, steep walls of the U-shaped valley were carved out of the area's bedrock during periods of glaciation. The most recent valley glaciation occurred between 20,000 and 9,500 year ago (late Pleistocene to early Holocene), at the end of the last ice age. Most of the headwaters and tributaries of the valley have also been formed or influenced by glacial processes, creating features such as cirques and hanging valleys in the uplands.

At the close of the last ice age, increased discharge and sediment that was generated by the melting of the glaciers filled the valley floor with a thick layer of glacial outwash deposits. Today, these deposits make an almost continuous surface that extends down-valley from Robinson Creek. On top of the glacial outwash surface are large alluvial fans, also composed of glacial-fluvial deposits. These features were created by the increased discharge and sediment generated during the retreat of the upland glaciers. The alluvial fans extend out from points where tributaries enter the valley. Glacial deposit terraces that are higher than the glacial outwash surface are present along the edges in the upper valley above Robinson Creek and as a narrow terrace on the east side of the valley below Goat Creek. These features are evidence of the sequences of glacial retreat and extension at the end of the ice age when the volume of ice in the valley was diminishing. Another result of increased discharge during glacial retreat is the v-shaped incision into the bedrock at the base of the valley in the upper-most portion of the study area above Driveway Creek and Rattlesnake Creek. Infilling of the v-notched valley floor has also occurred here via glacial-fluvial and hillslope deposits in this narrow portion of the study area. The width of the modern valley floor increases from about 0.02 miles in the upper section to 0.3 miles at Robinson Creek, to about one mile wide at the downstream end of the study area at the Weeman Bridge.

The geomorphology of the modern Upper Methow River valley is dictated by the glacial processes and features described above, superimposed on by the modern discharge and sediment regimes. Driven by reduced discharge and sediments loads, the modern channel has incised into the glacial deposits, abandoning and thus creating sets of glacial outwash terraces along the edges of the valley. The alluvial fans coming from the edges of the valley influence the channel pathways and modern floodplain dimensions. The terraces, alluvial fans, and glacially-influenced tributaries supply sediment to the modern system. Talus, landslides, and debris fan deposits are generated off of the weathered slopes and steep bedrock walls along the edge of the valley or into the channel and/or its tributaries. A map of the geomorphic surfaces of the valley including alluvial fans, terrace deposits, and the modern floodplain surfaces is presented in Figure 14. Detailed geomorphic-surface maps are provided in the reach-specific sections later in this report.

The modern channel and floodplain is referred to as the "low surface" within this report. The low surface is composed of alluvially developed geomorphic features, which are further differentiated into the following categories: Active Channel, Active Floodplain, Disconnected Floodplain, and High Floodplain. These surfaces are the product of modern sediment and climate regimes of the mid to late Holocene and as such are inset below the glacial outwash terraces and alluvial fans that border much of the valley. The low surface is likely to experience inundation during large flood events (e.g. 100 year recurrence). The area included within the low surface generally depicts the extent of modern lateral channel migration and floodplain development. However, future lateral migration is not restricted to the low surface where lateral migration may occur along glacial terraces or alluvial fan deposits. Definitions of the low surface features are provided below.

Active Channel: The bed, bars, and banks of the channel that are activated regularly by flow (1-2 years). The boundary of the active channel generally corresponds to the bankfull elevation and represents the area that is inundated by the discharge that mobilizes a majority of the available sediment and that plays the strongest role in creating the bedforms within the channel. This includes side or mid-channel bars that may be vegetated seasonally by riparian grasses, forbes, or shrubs, but that become activated frequently enough to limit permanent woody vegetation establishment.

Active Floodplain: The low-elevation floodplain surfaces adjacent to and connected to the active channel by overbank flow every 1-10 years. Regular inundation of these surfaces results in deposition of overbank deposits on the floodplain, surface scarring, and exchange of nutrients with the channel. The active floodplain surfaces are well vegetated, unless otherwise cleared, with a dense mix of forest and understory that often includes cottonwood or other riparian zone trees and shrubs.

Disconnected Floodplain: Active floodplain surfaces where magnitudes, frequencies, or patterns of floodplain inundation and/or channel migration have been altered by human modifications including roads, levees, dikes, armoring, floodplain grading, or other impacts.

High Floodplain: The modern alluvial surfaces that are higher in elevation than the active floodplains and express no evidence of current inundation (10-25 years). Modern topsoil and organic accumulations are lacking fresh overbank deposits, and floodplain scarring is less pronounced on these surfaces. In most areas, hydraulic modeling confirms that the high floodplain surfaces are likely inundated by the 100-year flood event, but inundation depths are shallow or only follow floodplain channel scar paths. Where clearing has not occurred, vegetation on these surfaces is a mixed forest and understory that often includes establishing pine seedlings (~10+ years old) and dying mature cottonwood trees – an indication of a surface that is experiencing drying, or is at risk of transitioning from a connected floodplain to a terrace. The trend towards floodplain abandonment appears to be relatively modern (within the last 100-150 years or less) and may indicate incision within the reach.

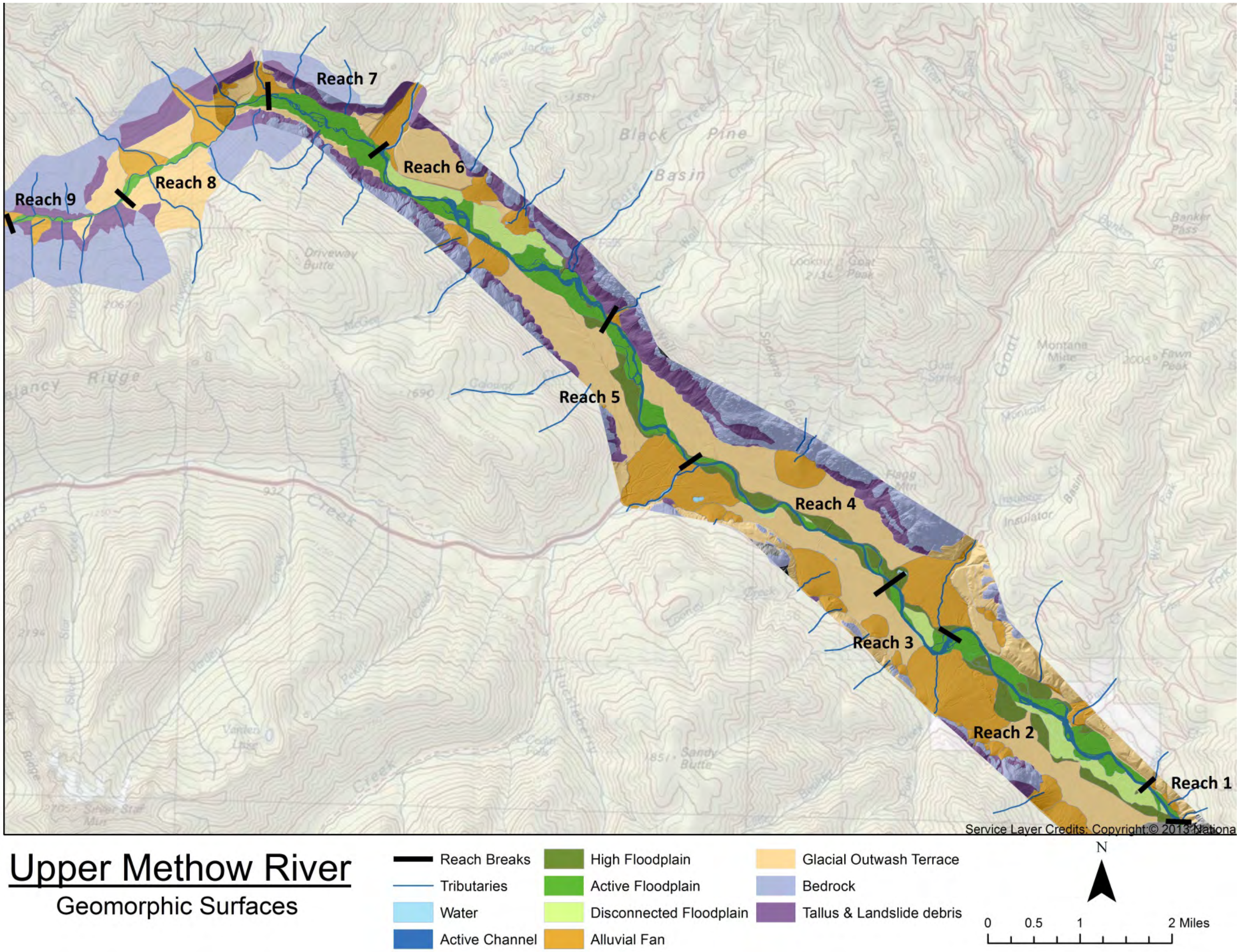

Figure 14. Geomorphic surfaces of the Upper Methow River (RM 61.15 to 80).

2.8.2 Channel Morphology

The contemporary channel form of the Upper Methow River is largely influenced by the geologic and glacial-fluvial history of the landscape described previously. Today the modern channel and its alluvial surfaces are inset below the glacial outwash terraces and alluvial fans that were deposited during the high discharge and sediment fluxes generated during glacial retreat (~10,000 years ago). As the climate became warmer and drier through the early Holocene, discharge and sediment flux was reduced. This led to the channel incising into the glacial outwash deposits, creating paired terraces from the abandoned surfaces. This is a classic channel evolution process described by Schumm et al. (1984), where incision occurs due to changes in discharge or sediment regimes, and then the channel develops a new active floodplain that is inset within the abandoned terraces. Anthropogenic modifications have imposed some additional influences on the system in the last 150 years. For example, channel incision processes in reaches one through seven have likely been influenced by modern human-imposed channel modification such as vegetation clearing and logging, log rafting, bank armoring, road and bridge building, home site development, etc. Further discussion of localized incision and the anthropogenic influences are provided in the reach-scale condition section of this report (Section 3).

A study on the potential channel migration zone of the Methow River downstream from the Lost River confluence (Golder Assoc. 2005) reveals that the estimated migration zone of the river is basically confined to the modern floodplain surfaces, with some exceptions where potential channel migration is identified along terraces or hillslope boundaries (Figure 15). Avulsion hazard areas were also identified, and were assumed to conform to the FEMA floodplain boundary.

Sediment is contributed to the channel from alluvial fans, tributaries, occasional mass-wasting processes, near-channel banks, and hillslopes. The banks of the terraces and fan toes provide localized sediment composed of glacial outwash material (sand, gravel, cobble, and sparse boulders). The modern floodplain surfaces provide and store sediment for the system that is activated through processes of overbank scour, lateral bank erosion, channel avulsion, or side-channel reactivation. Additional sediment is stored in and activated from the channel bed during high-flow events. Lateral channel migration is related to riparian condition, the density of large wood accumulations, bar development, and increased channel complexity. Lateral migration, avulsions, and side-channel activation appear to be most common in the unconfined lower-gradient reaches. More detailed geomorphic descriptions for each reach can be found in the reach-specific sections later in this document.

The study area reflects both conventional and unconventional downstream geomorphic trends. Sinuosity of the channel within the study area ranges from 1.05 in the narrow upstream section, to 1.22 in the gradually meandering unconfined mid-valley section, to almost straight (1.01) at the downstream section where anthropogenic modifications have confined the channel between bridge abutments and riprap. Stream gradient basically increases from downstream (0.30%) to upstream (2.7%). Between Reaches 6 and 7, demarcated by the confluence of Lost River, the channel gradient doubles from 0.7% to 1.5% (Figure 16).

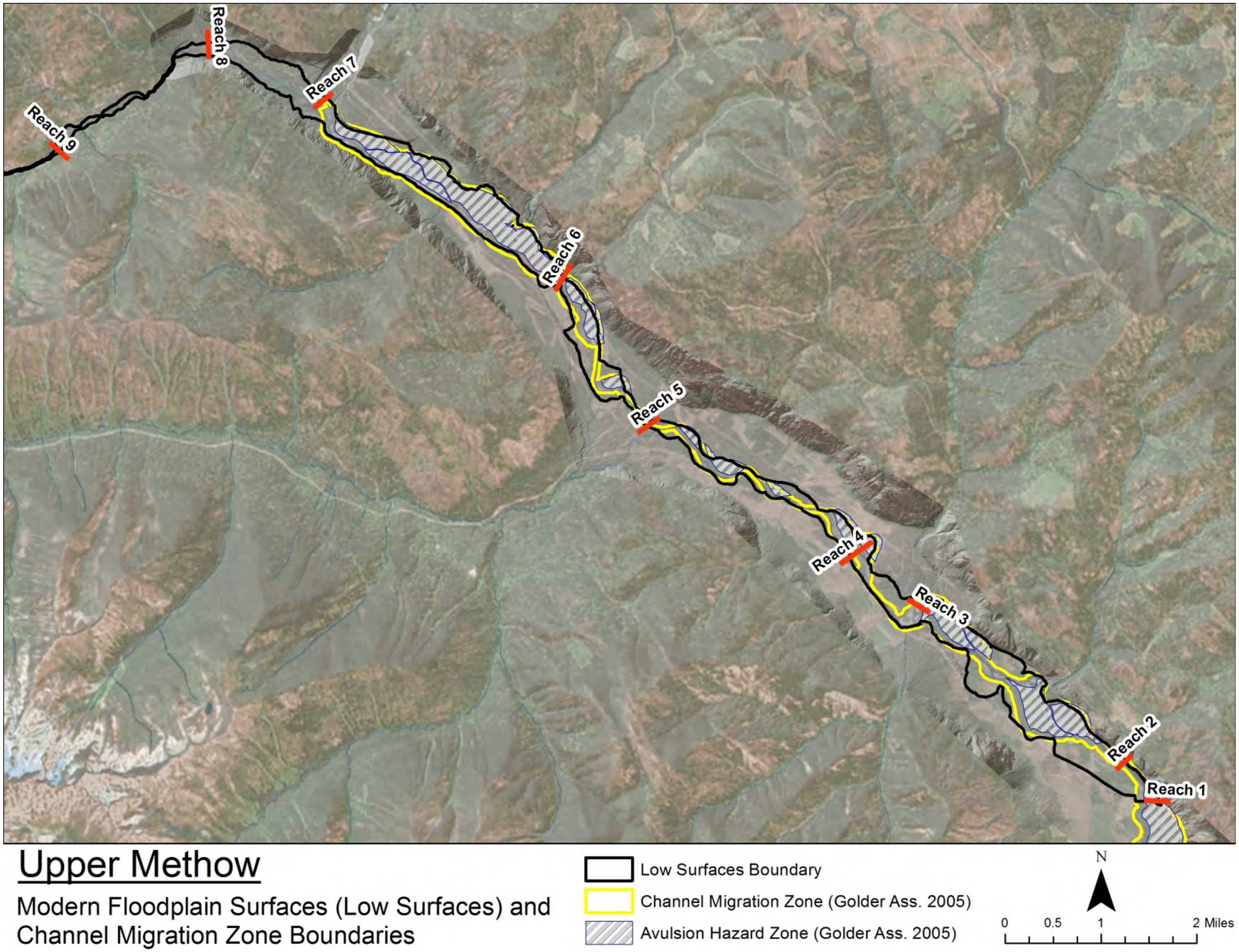

Figure 15. Lower Surfaces Boundary (mapped modern floodplain surfaces as defined in this report) within the study area and delineated channel migration and avulsion zones (Golder Ass. 2005).

The predominant bed types are extended plane-bed glides in the lower gradient reaches and riffles in the higher gradient reaches. The average floodplain widths in the study area do not increase in a downstream trend as expected. Instead, the width of the floodplain in the mid-valley reaches (3-5) decreases in comparison to the wide reaches of 2, 6, and 7. This is most notable for Reach 4 where floodplain width (365 feet) is about half of that for Reaches 5 (721 feet) and 3 (848 feet) and only a third of the width of Reaches 6 (1,394 feet) and 7 (1,345 feet). Floodplain width decreases in mid-valley because of inputs provided to the system from Early Winters Creek, located at the upstream end of Reach 4. Early Winters Creek has produced a large alluvial fan that extends across the glacial outwash terrace. The toe of the fan influences the location of the channel in the valley and the notable discharge inputs from the creek appear to locally change the hydro-geomorphic relationship to supply-limited. In supply-limited sections, a river has the capacity to transport more sediment than is delivered to it. As a result, the channel often incises vertically instead of laterally building floodplains.

Basic morphometric characteristics of each reach are listed below (Table 5) and further descriptions and explanations of the characteristics of each reach are provided in Section 3.

Table 5. Summary of geomorphic and habitat conditions at the valley and channel scale by geomorphic reach in the Upper Methow River.

	METRIC	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9
Channel and Floodplain	Length (miles)	0.55	3.1	1.3	3.1	2.1	3.7	1.5	2.2	1.3
	River Mile	61.15 - 61.70	61.70 - 64.80	64.80 - 66.10	66.10 - 69.20	69.20 - 71.30	71.30 - 75.00	75.00 - 76.50	76.50 - 78.70	78.70 - 80.00
	Stream Gradient (%)	0.30	0.5	0.4	0.5	0.6	0.7	1.5	2.2	2.7
	Channel Sinuosity	1.01	1.1	1.22	1.09	1.13	1.11	1.17	1.07	1.05
	Dominant Channel Type	Glide	Riffle	Glide	Riffle	Riffle	Riffle	Riffle	Riffle	Riffle
	Dominant Substrate	cobble	cobble	gravel	cobble	gravel	cobble	cobble	lg cobble	boulders
	Average Bankful Width (ft)	172	141	159	129	95	100	76	56	52
	Average Floodplain Width (ft)	556	1193	848	365	721	1394	1345	290	161
	Confinement*	Moderate	Unconfined	Unconfined	Moderate	Unconfined	Unconfined	Unconfined	Unconfined	Moderate
Riverine Habitat Area (%)	Pool	0	5	21	11	21	27	16	2	10
	Riffle	43	52	34	56	44	47	57	92	84
	Glide	57	24	43	30	13	15	5	1	2
	Side Channel	0	19	2	3	22	11	22	5	4

*Confinement ratio: average floodplain width/average bankful width. If $\geq$ 4 = unconfined, $\geq$2 and < 4 = moderate, < 2 = confined (Pleus & Schuett-Hames 1998)

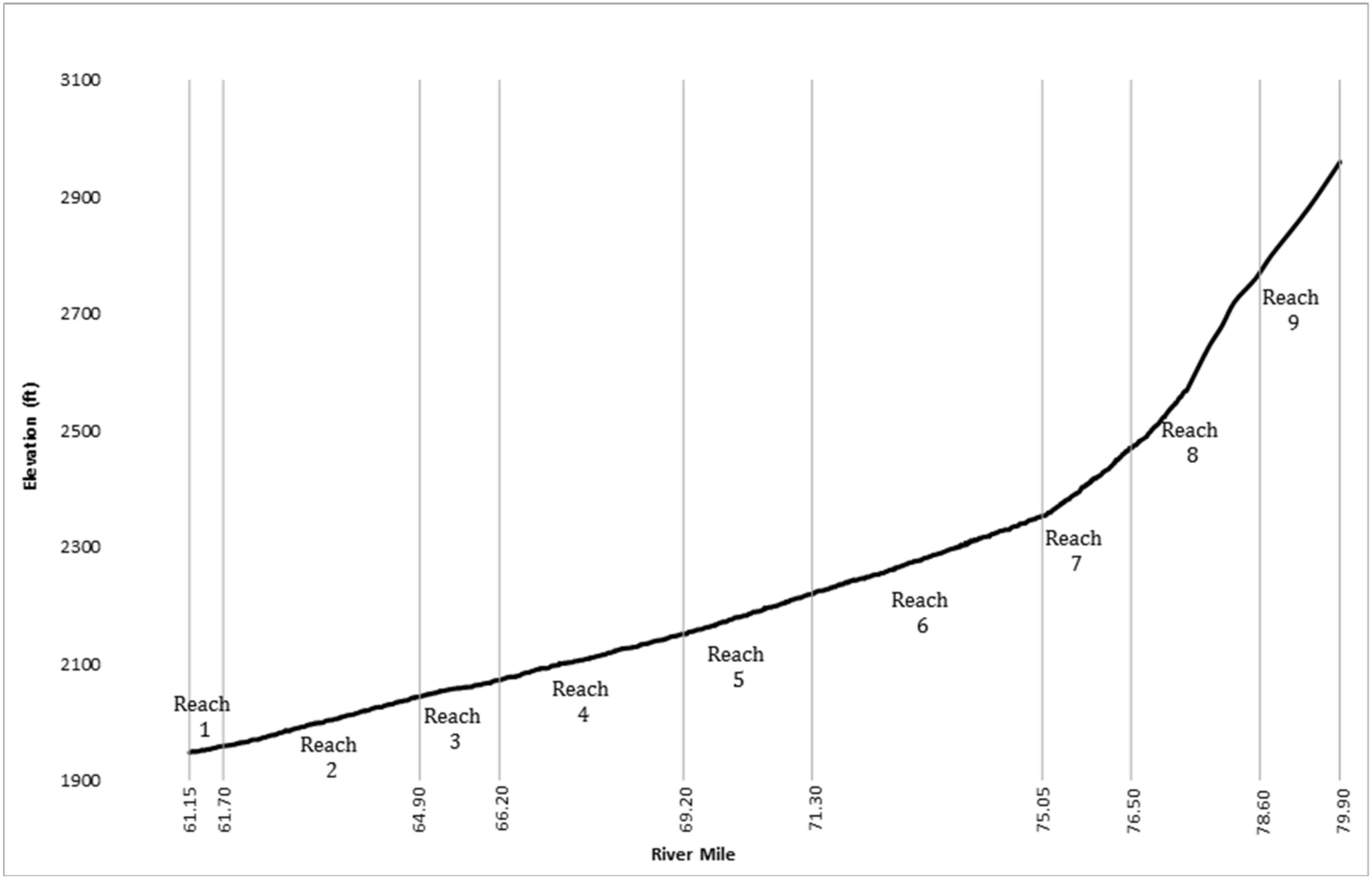

Figure 16. Longitudinal profile of the Upper Methow River study area. Elevation derived from 2006 LiDAR for Reaches 1 – 7 and USGS topographic maps for Reaches 8 and 9.

2.9 LARGE WOOD DYNAMICS

Existing large wood dynamics in the Upper Methow are a function of a legacy of river and forest management dating back to the late 1800s. 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.

2.9.1 Sources

Large old growth wood sources have been replaced largely by smaller second growth. This was reflected in the results of the 2014 Habitat Assessment (Appendix A) which identified 97% of the riparian area surveyed within 100 feet of the river as being small trees measuring 9.0 – 20.9 in. diam., or smaller. Only 3% of sampled areas were considered large (21.0 – 31.9 in. diam) as the dominant size class throughout the survey area.

One of the major sources of large wood in the Methow today is fire. The most recent large fire to impact the area, and correspondingly provide an increased source of large wood, was the Needles fire (Figure 17 and Figure 18), which burned 21,305 acres in 2003 (InciWeb 2014). While a majority of the fire was located upriver of the survey area, the final two miles of the 2014 Habitat Assessment (ending at Trout Creek) were located within the fire perimeter. The 2014 Habitat Assessment compares wood counts between the 2014 survey, a 2003 survey that occurred just before the fire, and a 1994 survey. While survey protocols have changed slightly between the three surveys, the data indicate that large wood in the Methow River has seen vast increases over the last 20 years. Small wood increased by 336%; medium wood by 550%; and large wood by 1850%.

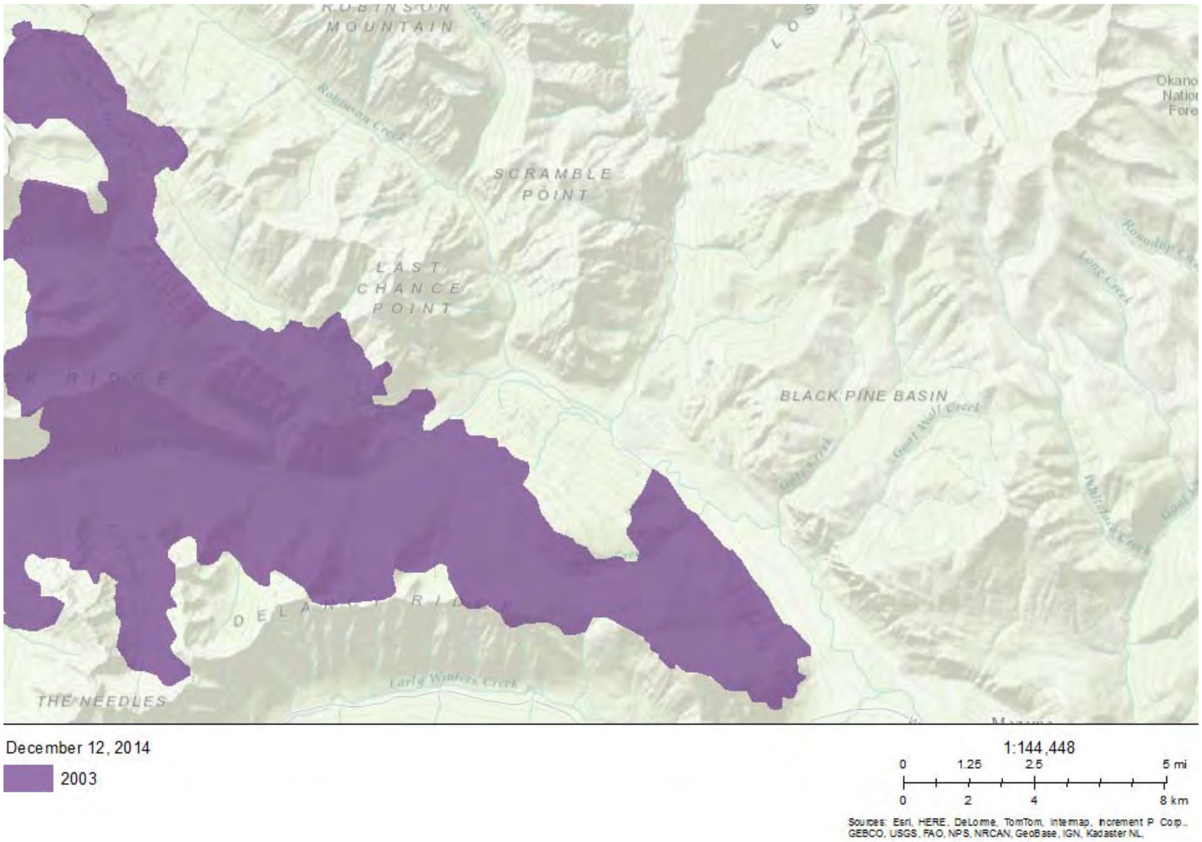

Figure 17. The Needles Fire (2003) burned 21,305 acres in 2003. Today, snags from the fire are source material for downstream logjams like the ones at RM 79.75.

Figure 18. Trees on either side of the Upper Methow River in Reach 9 were burned during the Needles Fire of 2003, leaving upright dead snags. This large log jam at RM 79.75 is believed to be the result of a snow avalanche.

2.9.2 Recruitment

In unconfined reaches, channel scrolling and floodplain avulsions lead to riparian and floodplain tree recruitment. This is particularly evident in the sinuous downstream portion of Reach 7 as well as other unconfined portions of the study area (primarily in Reaches 2, 5, and 6). This recruitment is principally driven by scour at the toe of channel banks that leads to bank failure and tree recruitment, but it also happens in avulsions (i.e. meander cutoffs). Confined areas with non-erodible banks (e.g. bedrock) only experience riparian tree recruitment through tree-fall, or from fluvial transport from upstream. Large wood is also recruited to the channel through episodic mass wasting events, particularly from debris flows, landslides during large flood events, or from snow avalanches (as occurred recently in Reach 9). Recruitment processes are mostly intact throughout the study area except for areas where lateral channel dynamics or bank stability has been modified through human alterations. The most common human alteration to LW recruitment in the study area is the presence of the roads on either side of the channel (Goat Creek Cut-off Road and Highway 20), which lie adjacent to the channel through much of the lower reaches (1- 4) and on the right bank through portions of Reaches 5-8. Bank armoring associated with the road limits not only the available riparian sources for large wood, but also the potential for wood to be recruited through natural bank erosion processes. Bridge constrictions also limit channel migration processes that reduce the potential for LW recruitment. There are other stretches of bank armoring associated with streamside residences that limit local recruitment, particularly in Reaches 1, 2, 3, 5, and 6.

2.9.3 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 in the study area. The same alterations to recruitment, described above, also affect retention. These include bank armoring that reduces margin complexity necessary for wood to become retained on margins, and confinement (e.g. bridges) that confine the channel and result in stream power that favors wood transport over deposition. These impacts only occur at specific locations and are not widespread throughout the study area.

The legacy of in-channel wood clearing and log drives, using the stream corridor as transportation for cut timber, may have some effect on contemporary retention processes, especially in the lower portion of the study area where clearing was known to occur. This clearing may have also led to the removal of large boulders, channel straightening, and simplification of channel margins, which would have reduced the potential for the channel to retain wood.

The currently available wood size also affects the ability of the channel to retain wood. The wood that is now contributed to the channel mostly represents second or third growth timber that is smaller than historical wood sizes and does not have the same ability to self-stabilize within the channel. Even though the habitat assessment (Appendix A) found an average of 125 pieces of wood per mile (>6 in. diameter; >20 ft. long), a majority (56%) of these pieces were less than 20 inches in diameter (were in the "small" size classification) and are not large enough to initiate log jam formation. The shift in riparian seral stage, and the corresponding reduction in available key pieces, has 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 tree size, retention, and the potential for jam formation.

Although today's second and third growth timber is generally smaller than historical wood sizes, Appendix A does indicate a trend towards an increased quantity of medium and large pieces since 1994 between Goat Creek and Trout Creek. The average medium/large wood (measuring more than 35 feet long and more than 12 in. diameter) has increased from 15 pieces per mile in 1994 to 58 pieces per mile in 2014.

2.10 HABITAT CONDITIONS

Stream habitat conditions were recorded using the USFS Level 2 stream habitat inventory methods. The survey recorded information on habitat unit composition and habitat characteristics including pool depth, substrate size, 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.

The Upper Methow River reaches were dominated by pool-riffle and plane-bed morphology, with some partially confined step-pool channels in Reach 8. Overall, channel bed substrate consisted primarily of cobbles (48%) and gravels (48%) with 2% boulder and 2% sand (See Habitat Assessment Appendix A). Although present in some locations, bedrock was not recorded in significant quantities to register at the reach-scale.

Riffles were the dominant habitat type, comprising 54% of the total habitat unit composition for the study area. Glides comprised 22% of the area, and pools and side-channels comprised 13% and 11% of project area, respectively. In general, glide habitat decreased and riffle habitat increased as the grade increased going upstream. Pool frequency ranged from 0 pools/mile (Reach 1) to 7.5 pools/mile (Reach 7), with an average pool frequency throughout the study area of 3.6 pools/mile. The majority of pools throughout the study area had residual depths of less than three feet (72%).

Channel widths were variable, generally becoming narrower going upstream as the river decreased in flow. Mean bankfull depths also decreased going upstream, ranging from an average bankfull depth of 3.9 feet in Reach 1 to an average of 1.6 feet in Reach 9. Floodprone widths varied substantially in the project area, ranging from 3,400 feet in Reach 1 to 70 feet in Reach 9 where the river was constrained by valley walls for parts of the reach.

Secondary channel habitat (side-channels and off-channels) accounted for approximately 11% of the habitat area throughout the study area. In total, 47 secondary channel units were observed. The average side-channel was 961 feet long (StDev 918). Reach 2 maintained not only the longest side-channel observed in the project area (4,800 feet), but also had the most overall secondary channel habitat area of all 9 reaches.

All reaches had significant human impacts, including residential development on the floodplain, channelization, roads, agriculture clearing adjacent to the river and riparian areas, levee construction, and impacts from logging. There were also fire and avalanche-related instability and disturbance. Anthropogenically caused bank erosion was minimal throughout the study area.

An average of 125 pieces of large wood per mile was counted in the project area; 56% were "small" pieces with diameters between 6 and 12 inches and lengths greater than 20 feet.

The dominant size class of riparian trees was small trees measuring 9.0 – 20.9 inches diameter (83%). Sapling/pole trees measuring 5.0 – 8.9 inches diameter were the second most dominant class (7%). The remaining 10% was distributed between large trees measuring 21 – 31.9 inches diameter (3%); shrub/seedling measuring 1 – 4.9 inches diameter (5%); and grassland/forbs (2%). The dominant riparian understory species were dogwood and cottonwood, accounting for 30% of the understory each. Additional dominant riparian understory species included snowberry/mountain maple (13%); grassland forbs (12%); willow (5%); small shrubs (5%); manzanita (3%); and cedar (2%). The overstory was dominated by cottonwood and ponderosa pine (42% and 25% respectively). Additional species observed as dominant in the overstory included dogwood (10%); cedar (10%); Douglas fir (10%); and aspen (3%).

2.11 WATER QUALITY

State water quality standards for the Upper Methow River are designated according to the Aquatic Life Use "core summer salmonid habitat", which determines the standards for various water quality parameters including temperature, dissolved oxygen, turbidity, and others (WDOE 2012). The main water quality issue in the Methow River is water temperature. The water temperature standard is 16°C from June 15 to September 15 for the 7-DADMax, which is the 7-day moving average of the daily maximum temperature. There is an additional standard for spawning and incubation protection, which is 13°C for the 7-DADMax from August 15 to July 1 (Payne 2011). Low discharge volumes and high summer air temperatures result in a warming trend as the water moves downstream. Water temperatures of 16°C or greater have been documented in the study area; however, springs and groundwater inputs along the study area contribute to some cool water pockets and locations with decreased water temperatures (USFS 2003, Watershed Sciences 2009).

Airborne thermal infrared (TIR) imagery was collected in August of 2009 for the Methow River (Watershed Sciences 2009). TIR imagery measures the thermal energy emitted from a surface and thus indicates the temperature of the surface of the water. TIR surface water temperature data were collected within the study area from the Weeman Bridge at RM 61 to RM 75 at the confluence with Lost River. It was noted that the Upper Methow River showed highly variable temperatures, with three large-scale warming and cooling cycles (Figure 19). It is assumed that the high variability in water temperature from RM 75-61 is influenced by groundwater to surface water exchanges. This is supported by the large number of seeps and springs shown in the TIR imagery near areas of surface water cooling (Figure 20). According to the TIR data, stream temperatures in August 2009 ranged from 12.4°C just below Little Boulder Creek (RM 65.17) to 19.4°C at the mouth of the Methow River. At the upstream end of the survey, Lost River (RM 75) contributed to the first cooling trend (Figure 20), but the mainstem Methow quickly warmed back up moving downstream. Near RM 70, temperatures decreased due to the input of a cool spring contributing groundwater to the channel. Again, the channel warmed up as it moved downstream until RM 64.5 near the confluence of Gate and Boulder Creek and a spring complex that adds cool water to the main channel. After each temperature decrease, the Methow quickly warmed moving downstream.

Low flow periods in the summer exaggerate water temperature variability and issues. Higher water temperatures throughout the summer months, and particularly in August and September during spring Chinook spawning, are likely detrimental to salmonid survival in the Upper Methow River (See Section 1.4 for additional fish use information). High water temperatures pose potential negative impacts to rearing salmonids, in addition to acting as a thermal barrier to migrating salmonids. Preferred temperature ranges for rearing Chinook and steelhead are 12-14°C and 10-13°C, respectively. When temperatures exceed 23-25°C, they are life threatening and will cause fish to move to other areas (Bjornn and Reiser 1991). This is of particular concern from Goat Creek (RM 65) to Lost River (RM 75) where late summer low-flows can result in large portions of the channel going dry (see Section 2.6.3). Gradual dewatering of the channel produces shallow water and pools that warm more easily. When surface water temperatures increase and flow is reduced, the potential for fish stranding, predation, and/or the desiccation of redds also increases. Low instream flows and sections that go subsurface leaving the riverbed dry during the late summer and early fall months are seasonally designated by the Washington State Department of Ecology as water quality limited (Category 4C). This underscores the importance of the availability of cool-water refugia during warm low-flow months for salmonid survival in sections of the Upper Methow River.

Other than the temperature data presented here, there is minimal water quality data for the Methow River. Adjacent land uses including residential lawns, roads, livestock grazing, dispersed camping, and gravel mining have the potential to affect water quality conditions, but the degree of impact of these actions on water quality is relatively unknown.

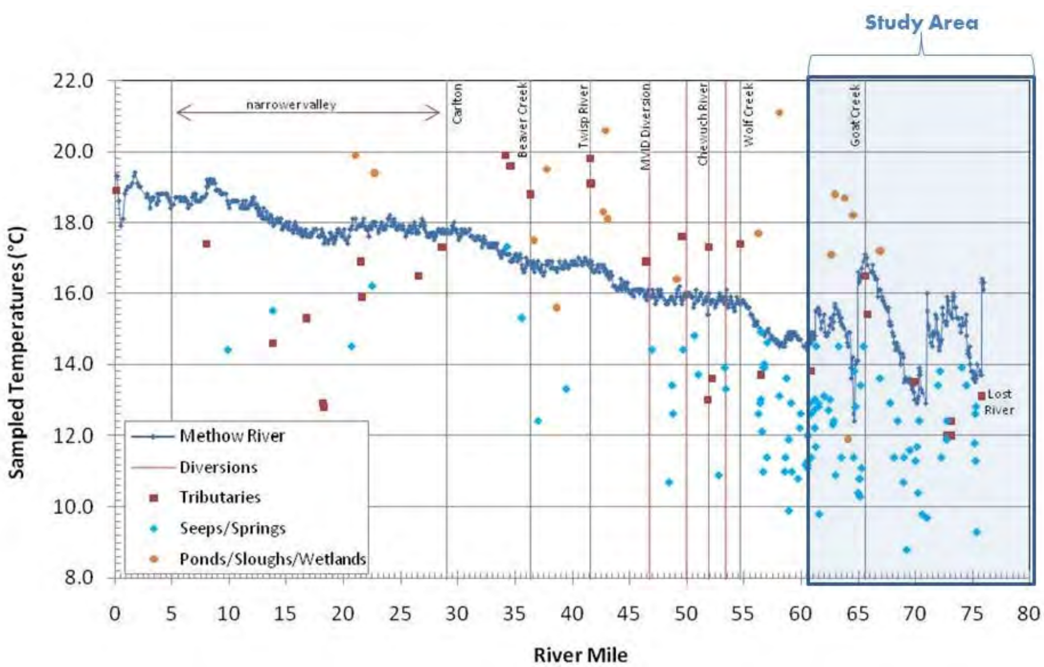

Figure 19. Surface water temperatures of the Methow River from slightly upstream of the Lost River confluence at RM 75 to its confluence with the Columbia River. Study area surface water temperatures highlighted in blue (RM61-80) indicate a high level of variability. (Derived from Figure 11 in Watershed Sciences 2009).

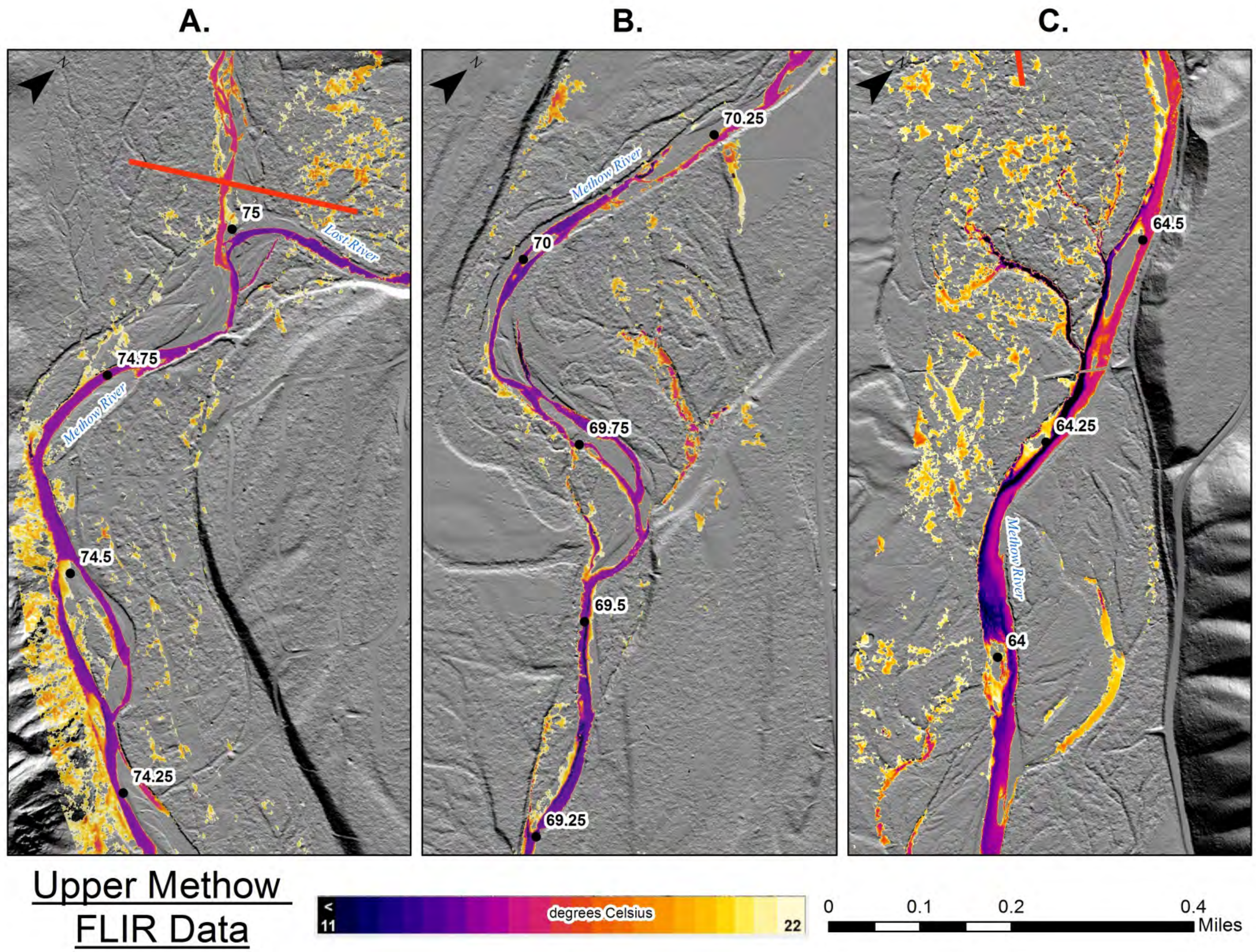

Figure 20. Surface water temperatures (FLIR) of select sections of the Upper Methow River study area. Groundwater and tributary inputs result in varied surface water temperatures.

2.12 REACH-BASED ECOSYSTEM INDICATORS

This section presents an overview and summary of the Reach-based Ecosystem Indicators (REI) analysis (Table 13), which is presented in more detail in the REI Report (Appendix B). 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 later in this document. The rating definitions, and explanations of how the ratings were made, can be found in Appendix B.

Within the study area, reaches below the confluence of Lost River (Reaches 1-6) were generally the most impacted reaches, having the highest number of **Unacceptable** ratings. Reaches 5 and 6, although having slightly fewer **Unacceptable** ratings, both had high numbers of **At Risk** ratings due to the amount of residential development along the banks of those reaches. Reach 7 had seven **At Risk** ratings, with only one **Unacceptable** rating. Reaches 8 and 9 were the least impacted, with Reach 9 receiving all **Adequate** ratings and Reach 8 having only one **At Risk** and **Unacceptable** rating each.

All reaches were given **Adequate** ratings for the Habitat Access Pathway- Main Channel Barriers indicator since there were no barriers within the main channel that completely excluded fish passage in any of the reaches. All reaches (except Reaches 8 and 9, which did not have substrate sampled) were also given an **Adequate** rating for the Dominant Substrate/Fine Sediment indicator due to gravel counts meeting appropriate percentages and minimal fine sediments in all reaches. LWM was rated **Adequate** only in Reach 9 and **At Risk** only in Reach 5; all other reaches were given **Unacceptable** ratings due to low numbers of pieces of large and medium woody debris per mile and limited (or no) jams present in the reach. The lowest three reaches were given **Unacceptable** rankings for the degree of off-channel connectivity with the main channel. Canopy cover over the main channel was **Unacceptable** in Reaches 1 – 5 due to riparian clearing from residential and agricultural development. Reaches 6 and 7, although less developed, still received **At Risk** rankings for canopy cover due to the legacy of timber harvests which has resulted in smaller, younger trees within the riparian zone. Bank Stability and Floodplain Connectivity indicators were similar, with Reaches 7, 8, and 9 receiving ratings of **Adequate** in both indicators. Reaches 3 and 5 were rated **At Risk**, and Reaches 1, 2, 4, and 6 were given **Unacceptable** ratings due to the number of human features and disturbances in those reaches.

For the study area as a whole, **Adequate** was the most common rating (38), followed by **Unacceptable** (31), then **At Risk** (30).

Table 6. Reach-Based Ecosystem Indicator (REI) results. See Appendix B for the REI report.

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9
Habitat Access	Physical Barriers	Main Channel Barriers	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
Habitat Quality	Substrate	Dominant Substrate / Fine Sediment	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	N/A	N/A
	LWM	Pieces per Mile at Bankfull	Unacceptable	Unacceptable	Unacceptable	Unacceptable	At Risk	Unacceptable	Unacceptable	Unacceptable	Adequate
	Pools	Pool Frequency and Quality; Presence of Large Pools	Unacceptable	At Risk	At Risk	At Risk	Adequate	Adequate	At Risk	At Risk	Adequate
	Off-Channel Habitat	Connectivity with Main Channel	Unacceptable	Unacceptable	Unacceptable	At Risk	Adequate	At Risk	At Risk	Adequate	Adequate
Riparian Vegetation	Condition	Structure	Unacceptable	Unacceptable	At Risk	Unacceptable	At Risk	At Risk	At Risk	At Risk	Adequate
		Disturbance (Human)	At Risk	At Risk	Unacceptable	Unacceptable	At Risk	Unacceptable	At Risk	At Risk	Adequate
		Canopy Cover	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	At Risk	At Risk	Adequate	Adequate
Channel	Dynamics	Floodplain Connectivity	Unacceptable	Unacceptable	At Risk	Unacceptable	At Risk	Unacceptable	Adequate	Adequate	Adequate
		Bank Stability / Channel Migration	Unacceptable	Unacceptable	At Risk	Unacceptable	At Risk	Unacceptable	Adequate	Adequate	Adequate
		Vertical Channel Stability	At Risk	At Risk	At Risk	At Risk	At Risk	At Risk	Adequate	Adequate	Adequate

3 Reach-Scale Conditions

The study area was divided into nine distinct geomorphic reaches to facilitate description and discussion of local channel characteristics and restoration needs (see Figure 3). Reach delineation was based on major tributary confluences, valley confinement, underlying geology, channel gradient, and channel type (e.g. dominant bed morphology). Reach boundaries utilized in previous studies of the area were also considered to help with data comparisons and change over time. Reach delineation was initially conducted using remotely available data (e.g. aerial photos, LiDAR, and geology maps). The reach boundaries were then verified in the field during survey work.

3.1 REACH 1

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.1.1 Reach Overview

Reach 1 is 0.55 miles long and extends from RM 61.15, at the Weeman Bridge, to 61.70. Land ownership throughout Reach 1 is private except for public easements at the bridge and the roads that border the reach (Figure 21). The channel is a single-thread stream limited to extended channel units of riffles and glides (Figure 22). The river in Reach 1 has a low sinuosity ratio of 1.01 and a relatively low gradient (0.4%). These and other reach metrics are provided in Table 7 and Figure 23.

The reach is semi-confined by a variety of features including riprapped channel banks, the Weeman Bridge, and a terrace hillslope with a reinforced road embankment. Hillslopes, glacial terraces, and the Goat Creek Road embankment confine the reach on river-left (east side of the channel). A narrow band of active floodplain is developing between the river and this road embankment. On river-right (west side of the channel) there is a wide, well-vegetated floodplain in the upper half of the reach, a disconnected floodplain surface in the middle of the reach, and a well vegetated high floodplain in the lower portion of the reach. The upstream end of the disconnected floodplain feature is delineated by a bank of boulder-sized riprap and a small push-up levee located in front of a private residence. A levee with riprapped banks on river-right in Reach 2 also disconnects section of the inland floodplain surface in Reach 1.

The habitat conditions in Reach 1 are discussed in Appendix A. Based on the REI analysis, 9 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). The salmon and steelhead redd distributions for the reach are mapped in Figure 21. Vegetation clearing and thinning has occurred on portions of the disconnected floodplain and away from the channel atop the alluvial terrace. Reach 1 has no log jams and only a few pieces of wood in the channel, resulting in the lowest large wood counts in the study area. A lack of large wood in the channel is likely due to past channel clearing and perhaps straightening which has resulted in minimal recent lateral channel migration. However, summer low-flows do expose alternating elongate gravel-cobble bars that indicate a gradually developing channel sinuosity. As a result, subtle westward lateral migration of the channel is occurring on river-right.

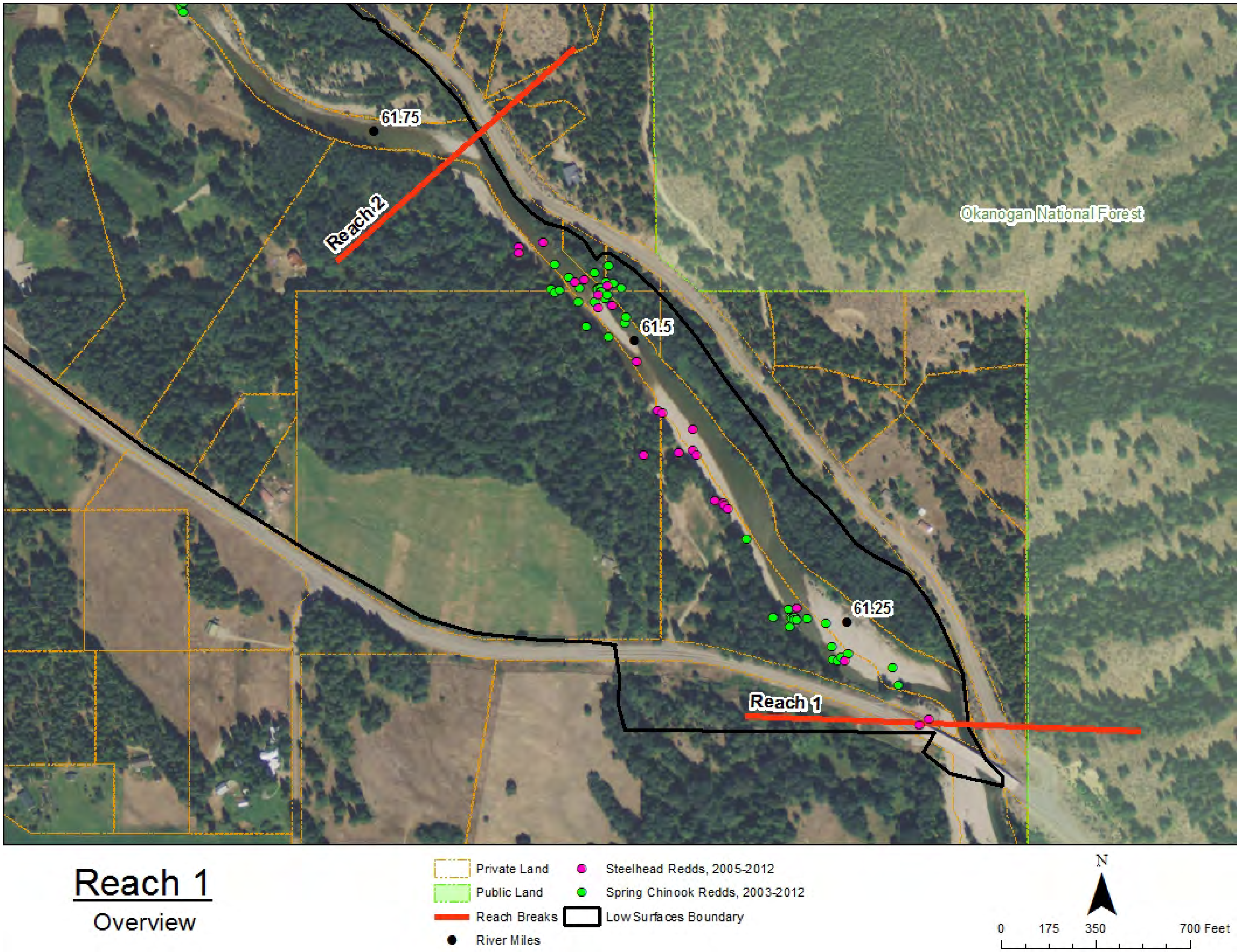

Figure 21. Reach 1 overview map with landownership and redd distribution.

Figure 22. Representative photo of Reach 1; looking upstream at RM 61.3 (9/5/2014).

Table 7. Reach 1 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	0.55
River Miles	61.15 – 61.70
Valley Gradient	0.6%
Stream Gradient	0.3%
Sinuosity	1.01
Dominant Channel Type	Extended glide-riffle
Average Bankfull Width (feet)	172
Average Floodplain Width (feet)	556
Dominant Substrate	cobble (52%); gravel (46%); sand (2%)
Bank Stability/Channel Migration	Unacceptable *(See Section2.12)*
Vertical Channel Stability	At Risk *(See Section2.12)*
Confinement Ratio	Moderate *(See Table 5)*

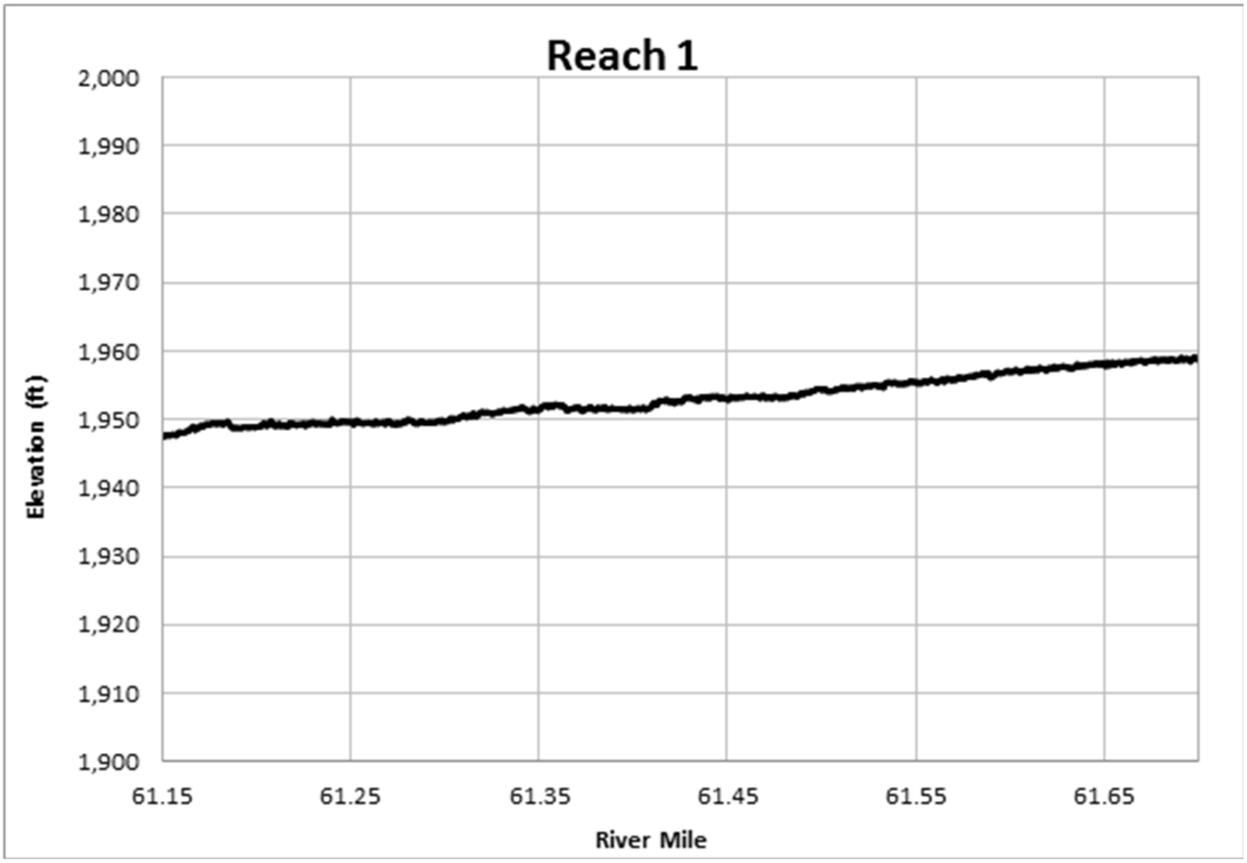

Figure 23. Longitudinal profile of the channel in Reach 1 (RM 61.15 to 61.70)

3.1.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 1 is located on the eastern edge of a wide glacial U-shaped valley, most recently carved by Quaternary glaciation. Increased discharge and sediment regimes during early Holocene periods of glacial retreat resulted in a thick layer of glacial outwash deposits filling the valley floor. Today, glacial outwash terraces border both sides of the modern alluvial surfaces in this reach. On the east side of the valley, a narrow glacial debris terrace rests on the flanks of the valley wall. This outwash terrace has elevations that get as high as one hundred feet above the modern channel. Thus, it is older than the lower, wider glacial outwash terrace on the west side of the reach. Three small alluvial fans, composed of outwash and upslope talus debris, dress the slopes of the east-side glacial terrace. The Goat Creek Road and its reinforced embankment have been constructed along the east-side terrace approximately 15 feet above the modern channel. On the west side of the valley, a large alluvial fan from a hillslope tributary spreads out across the top of the glacial outwash terrace (visible in Figure 14). The alluvial fan toe is 0.5—0.8 miles from the modern channel and its active surfaces, thus it does not directly influence the geomorphology of the modern channel. However, hydrologic inputs from the fan's tributary influence ground and surface water inputs in the area.

The channel and modern alluvial surfaces in Reach 1 are inset below the glacial outwash terraces. The modern alluvial surfaces of Reach 1 consist of a narrow active floodplain on river-left and a broad active floodplain, disconnected floodplain surfaces, and a high floodplain surface on river-right (Figure 24). All of the floodplain surfaces on river-right are fluvially scarred and the banks are topped with fines from high-flow events. The high floodplain surface at the downstream end of the reach on river-right extends up-valley from the banks of the channel between the active floodplain and the glacial outwash terrace on the western side of the reach. The disconnected floodplains were created by levees and floodplain grading. At the downstream border of the reach are high, riprapped channel banks (approximately 15+ feet) constructed of large, angular boulders (Figure 24).

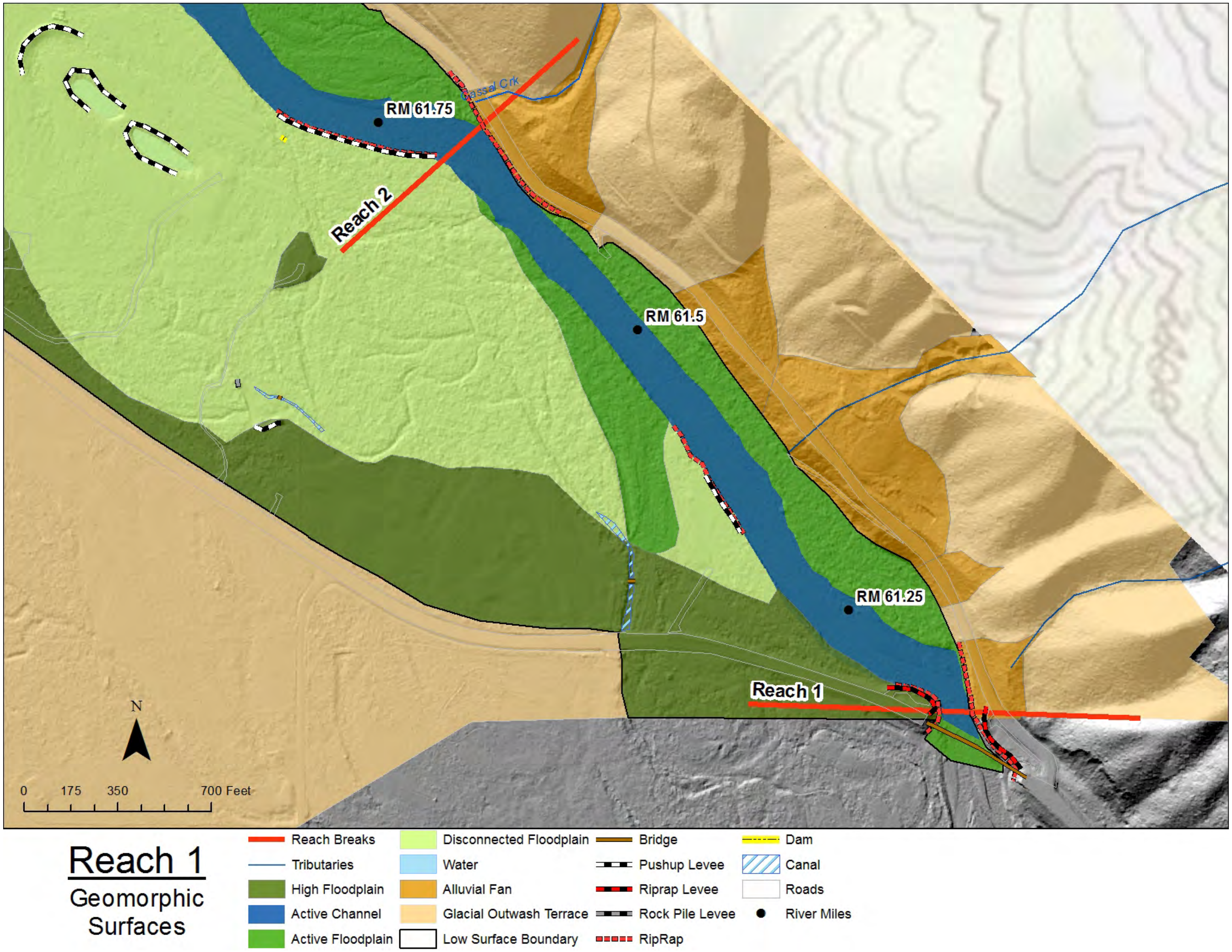

Figure 24. Geomorphic surfaces of Reach 1 overlain by selected human-built features (levees, riprap, check dams, canals, bridges, and roads).

Hydrology

Reach 1 has a seasonally fluctuating flow regime. Spring and early summer snowmelt high-flow events are expected to regularly inundate (2 year flood recurrence) the active floodplain surfaces (Figure 25). Autumn and winter low flows expose bars and banks throughout the channel with surface flows reduced to mere inches above the channel bed at riffle crests. Intense summer precipitation events and thunderstorms in the steep bedrock-dominated headwaters are capable of temporarily increasing channel discharge in Reach 1 if the precipitation event is able to recharge groundwater.

The valley floor is composed primarily of coarse-grained material that supports active hyporheic through-flow and groundwater inputs from upstream and the adjacent terraces, valley walls, and alluvial fans. Hydraulically, the channel in Reach 1 is considered a gaining reach (Konrad 2003, Konrad etal 2005). This means that incoming groundwater feeds the surface flow in the channel. However, reports of portions of the section of the channel seasonally going dry during low precipitation years exist (WDW 1990). It is expected that the channel and floodplain tributaries are actively exchanging surface flow with groundwater through hyporheic processes.

Reach 1 receives seasonal snowmelt or storm event discharge inputs from three tributaries on river-left. According to US Bureau of Reclamation surface flow estimates (2008 – Appendix J), the combined high-flow discharge inputs increase the mainstem flow by less than two percent. The tributaries are Cassal Creek at the upstream border of Reach 1 (RM 61.7) and two unnamed creeks coming off of Grizzly Mountain at RM 61.2 and RM 61.35. The large alluvial fans at the base of Lucky Jim Bluff at the west side of the valley do not directly contribute sediment or surface flow to Reach 1. Instead, irrigation canals along the edge of the fans divert surface flow for agricultural purposes. However, we suspect that the west-side fans and their tributaries do contribute groundwater inputs to the river’s overall hydraulic system, but the percentage of flow that these features contribute to the channel throughout the year in Reach 1 is unknown.

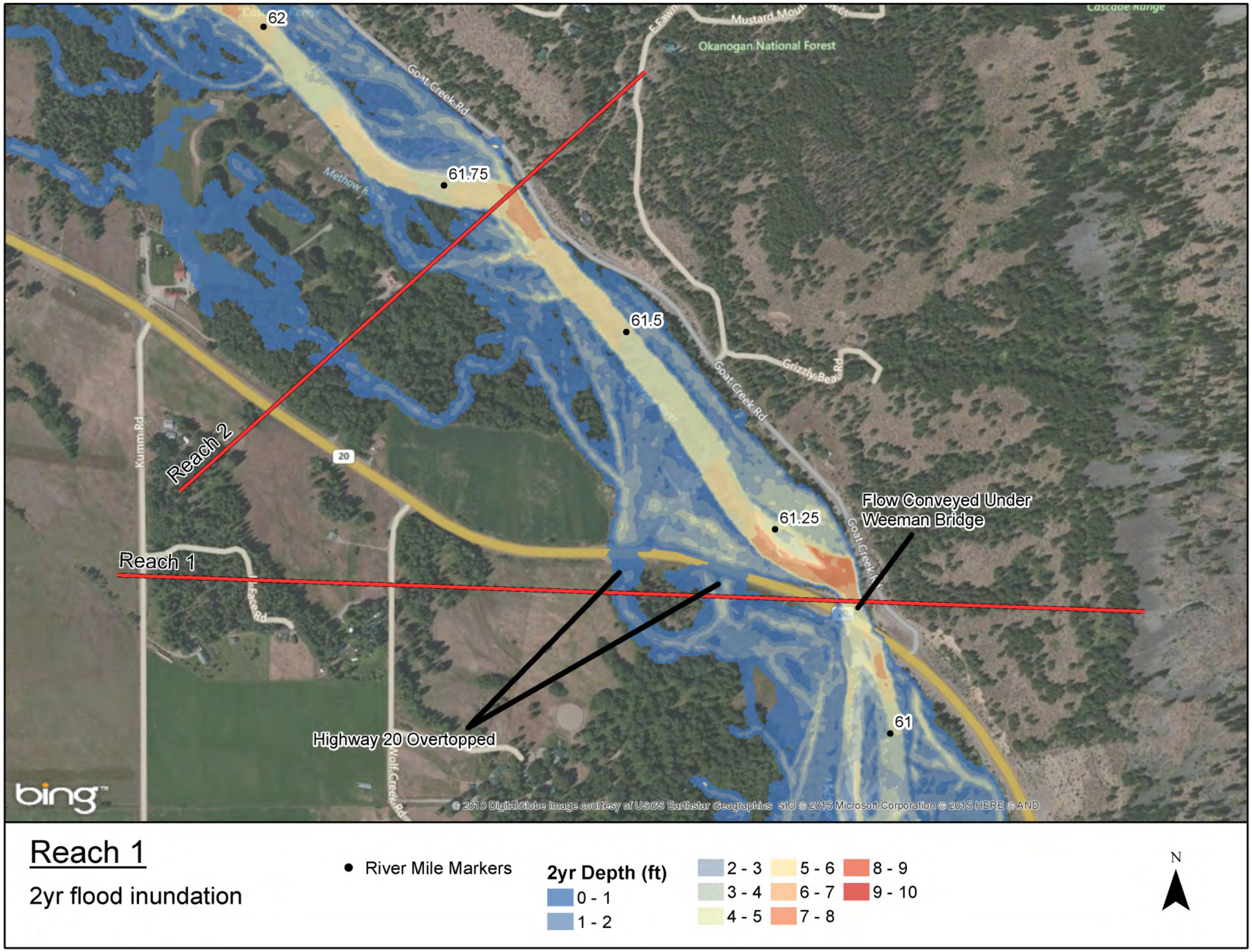

Figure 25. Floodplain inundation for 2YR flood in Reach 1 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

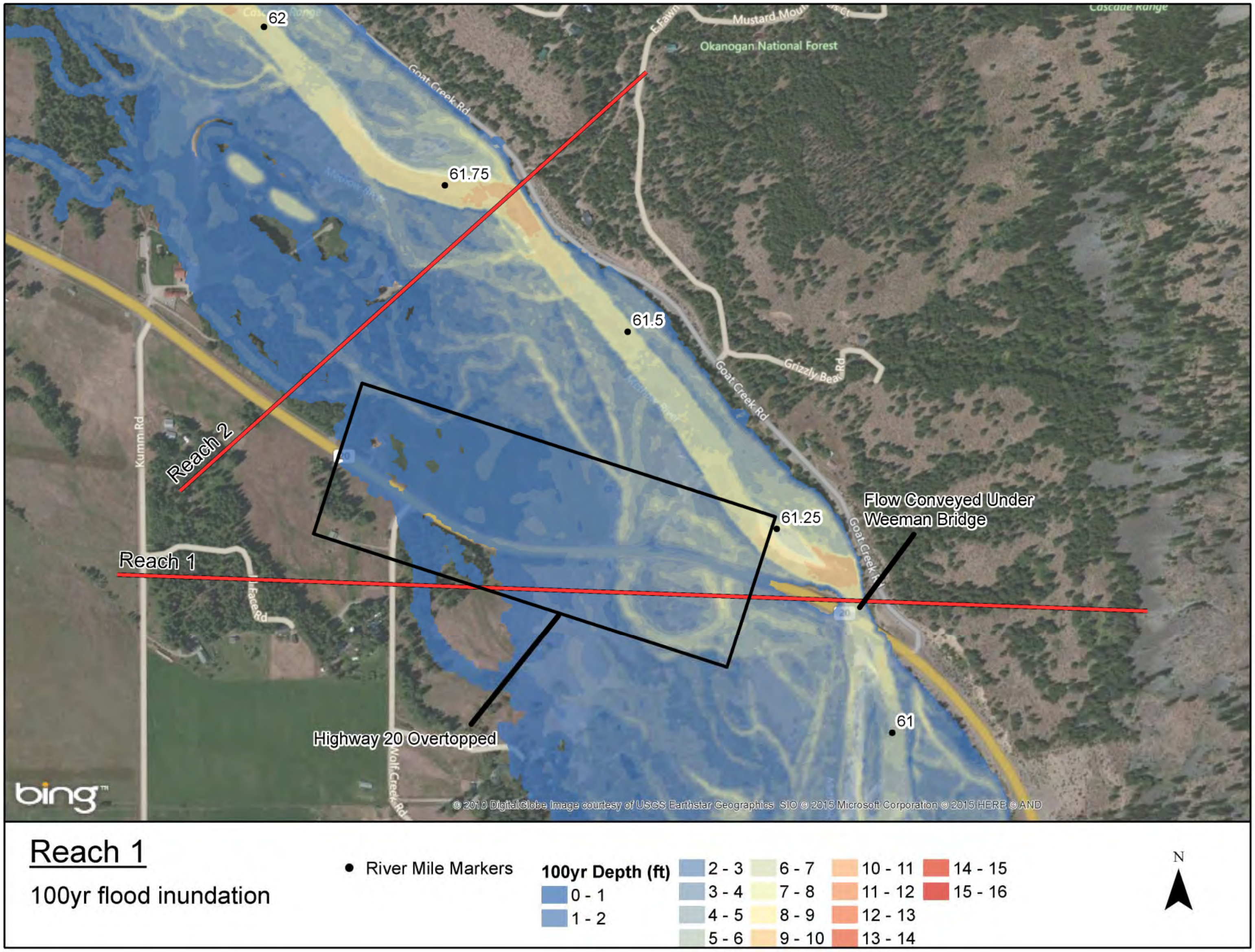

Figure 26. Floodplain inundation for 100YR flood in Reach 1 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Floodplain and Channel Migration Zone

Reach 1 is moderately stable vertically and laterally with a semi-confined channel that is relatively straight. Today the active floodplain available for migration is approximately 1,500 feet wide at the upstream end and diminishes to channel-width (115 feet) at the Weeman Bridge at the downstream end. Based on floodplain scarring, the historical migration zone at the downstream end of the reach was reduced by approximately 1,000 feet when Highway 20 and the Weeman Bridge were constructed. Today the channel remains laterally constricted and locked in place at its most downstream point between bridge abutments and high, riprapped banks. Because of its location – on the east side of the valley against glacial outwash terraces and alluvial debris toes that flank the valley walls – the channel is naturally partially confined on river-left. Bank hardening by the Goat Creek Road embankment increases the stability of the terrace banks which further confines Reach 1 on river-left. On river-right, the upper portion of Reach 1 contains an active floodplain with evidence of surface scarring and modern accumulations of over-bank deposits near the banks from RM 61.35 to 61.7. However, a leveed and riprapped bank in the downstream section of Reach 2 (RM 61.7 to 61.8) diverts much of the effective overbank flow during high waters away from the available floodplain on river-right. The other disconnected floodplain in Reach 1 is demarcated at its upstream end by boulder riprap and a low push-up levee at RM 61.35 to 61.4. However, the channel is creating a narrow, modern active floodplain surface on river-left between the channel and the road embankment from RM 61.2 to 61.65. This floodplain surface is developing as the channel gradually migrates westward into the non-riprapped banks of the floodplain on river-right. Historical imagery indicates that the only lateral migration since 1945 in this reach has occurred here and is minor (Figure 27).

Unnatural confinement and straightening of a river often reduces vertical stability by instigating incision processes. In Reach 1, bed scour during high-energy flow periods has likely decreased the frequency of inundation of the high floodplain surface in the downstream section on river-right. Bed lowering through incision likely migrates gradually upstream in this reach. However, pulses of incoming bedload inputs from upstream (Reach 2) partially off-set bed incision enough to support the development of the floodplain surfaces mentioned above on river-left and elongate channel bars visible during low-flow.

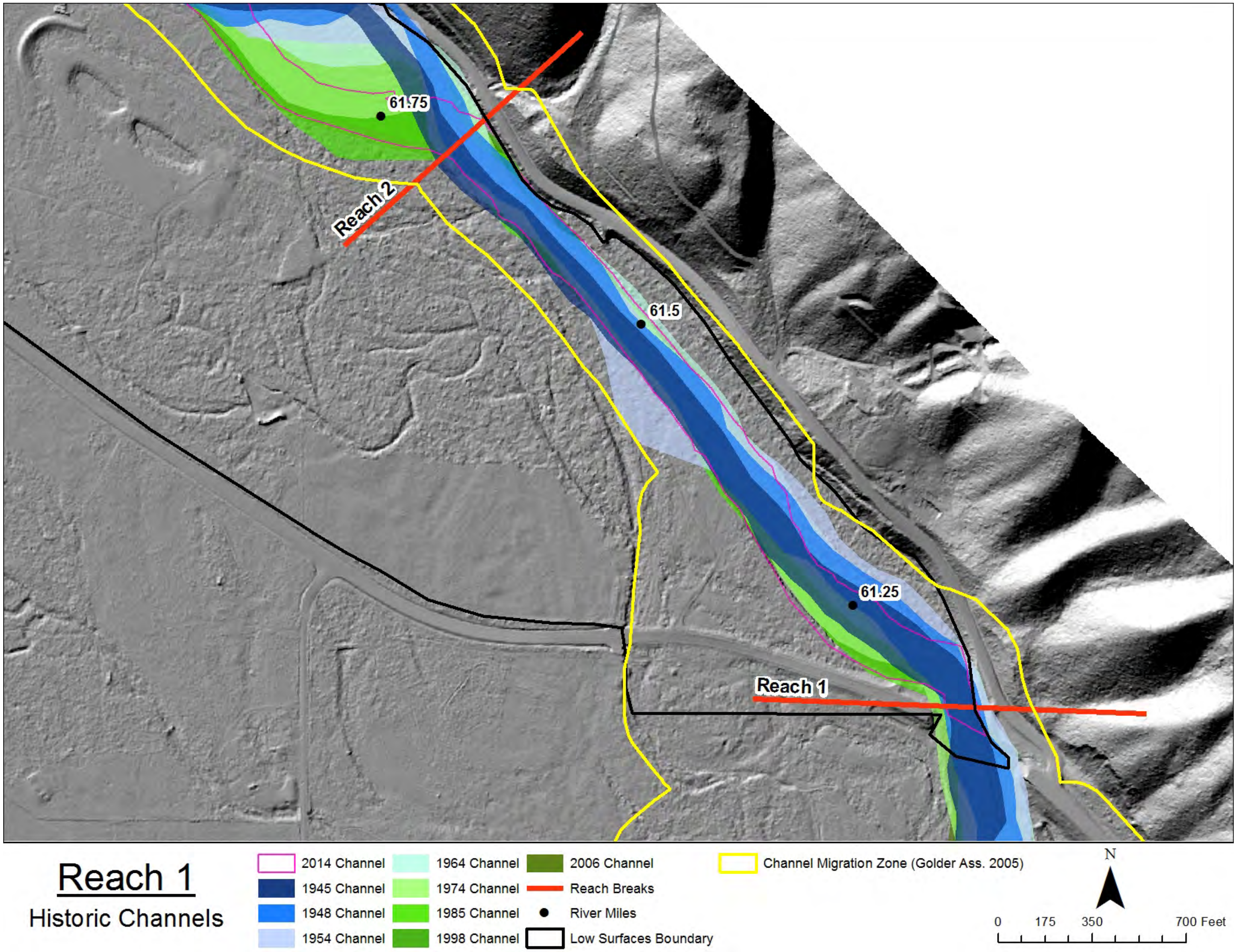

Figure 27. Historical channel locations in Reach 1.

Sediment

The substrate of Reach 1 is dominated by cobbles (52%) and gravels (46%) -- sand represents only 2%. Throughout Reach 1 the modern bedload is delivered from upstream inputs, the channel bed, and some minor bank erosion. Floodplains are composed of cobbles and gravels and topped with sand. Bedload sediment throughout the reach is well sorted (has a relatively similar diameter size range) and rounded, indicating that much of the substrate is transported fluvially during high flow events. Sands and fines accumulate on active floodplain surfaces as overbank deposits. They also are deposited at the downstream end of the channel in the backwater eddy which is located between the bar toe and road embankment on river-left at RM 61.2.

Large Wood

Reach 1 has no log jams and a low large wood count of only 4 pieces in the channel. In-channel wood distribution in the reach is presented in Figure 28 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. The marginally vegetated riprapped banks throughout the reach provide no potential for large wood recruitment. However, much of the floodplain surfaces are vegetated with maturing trees of up to 50 feet tall; the exception is at the cleared home site on river-right at RM 61.35. Recruitment from floodplain surfaces is limited by stand age and lack of lateral migration. The greatest potential for wood recruitment is along river-right where the channel is gradually migrating westward into the vegetated banks. Limited in-channel wood in Reach 1 may be the product of channel cleaning and/or historical log drives to mill sites located downstream from the Weeman Bridge. Long-term wood recruitment from upstream sources is expected to remain low due to upstream impairments to riparian zones and wood recruitment processes.

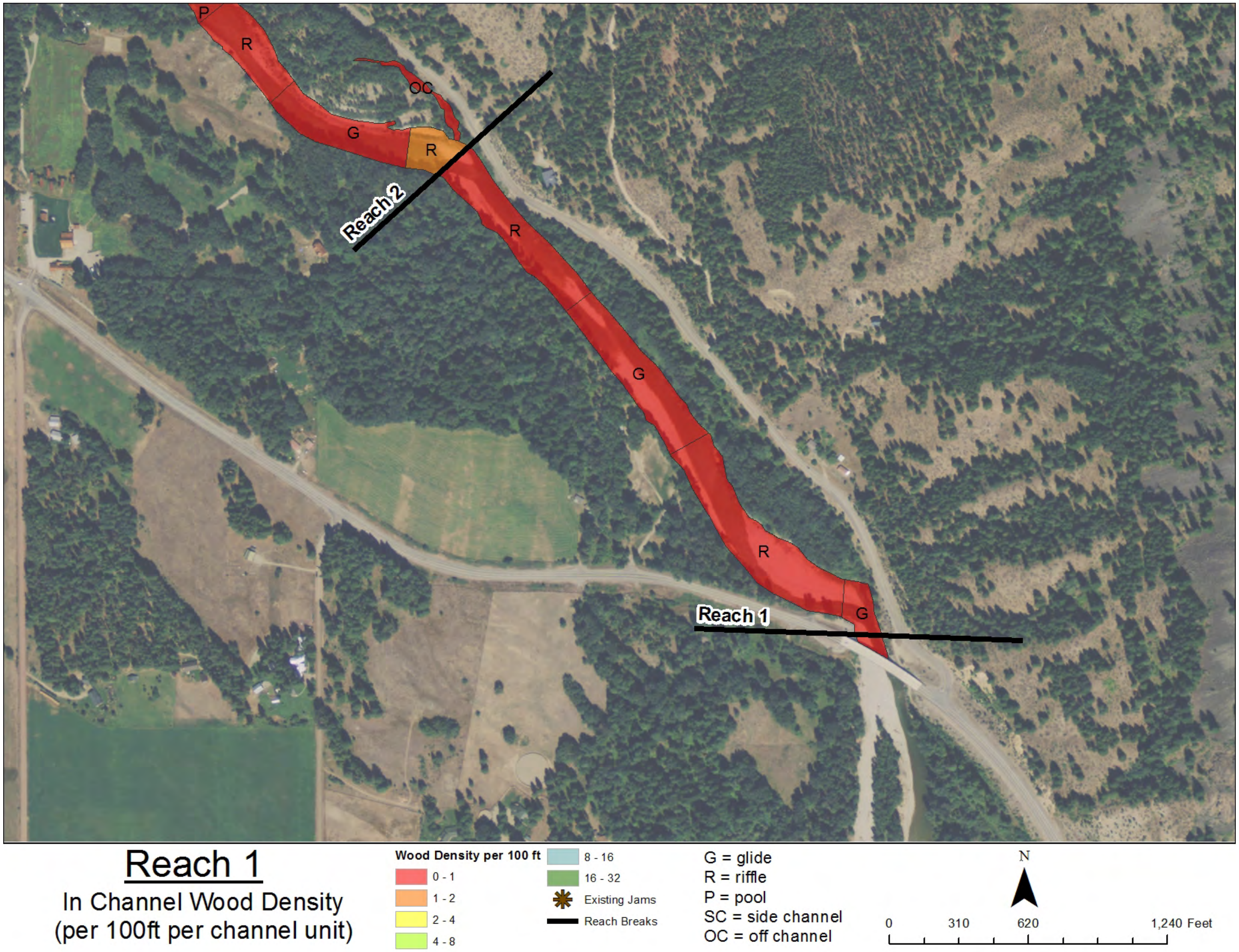

Figure 28. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 1.

Vegetation

The banks of the channel in Reach 1 are vegetated except at riprapped banks and at the cleared residential site at RM 61.35. All floodplain surfaces host maturing forests (contains trees that are 50 years or older) composed primarily of a mix of cottonwood, aspen, fir, pine, and cedar (Figure 29). These surfaces have an understory dominated by grasses and forbs. Along the banks of the channel, mature trees offer shade and nutrients where they have established. However, the width of the channel limits the percent of water surface that receives shade. The presence of sparse tree stumps and the reduced complexity in the understory vegetation suggest that the west side floodplain was thinned or logged and cleared of underbrush within the last 100 years (Figure 30). A few pine trees have established within the other vegetation on the higher alluvial terrace surfaces adjacent to the channel. Sparse patches of willow and dogwood have taken root between the angular boulders near the channel along the riprapped embankments at the road and bridge.

Figure 29. Photo of channel and varied vegetation in Reach 1 – looking upstream from RM 61.2. (9/5/2014)

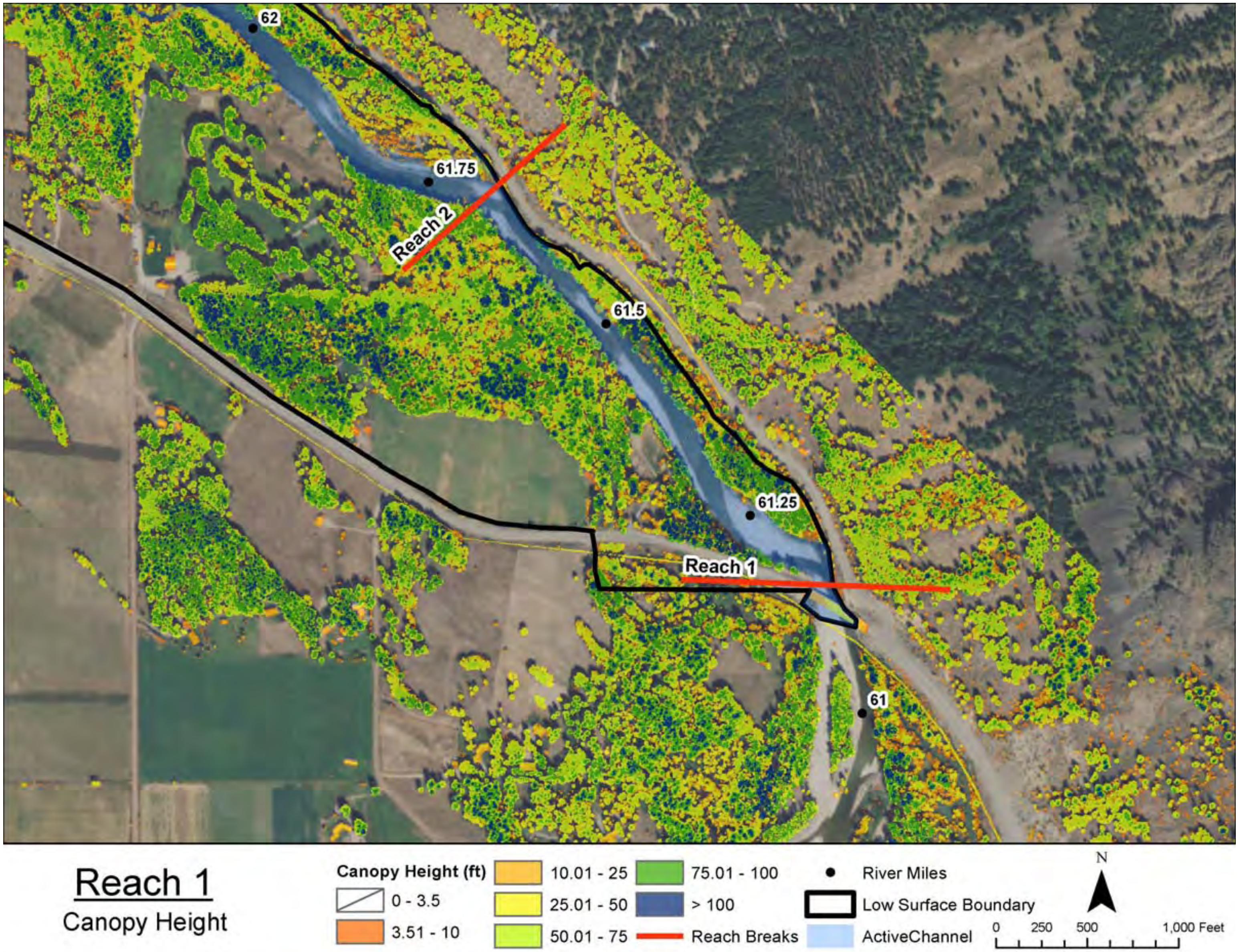

Figure 30. Vegetation canopy height for Reach 1 -- derived from LiDAR first return (highest hit) data (includes buildings and other human infrastructures).

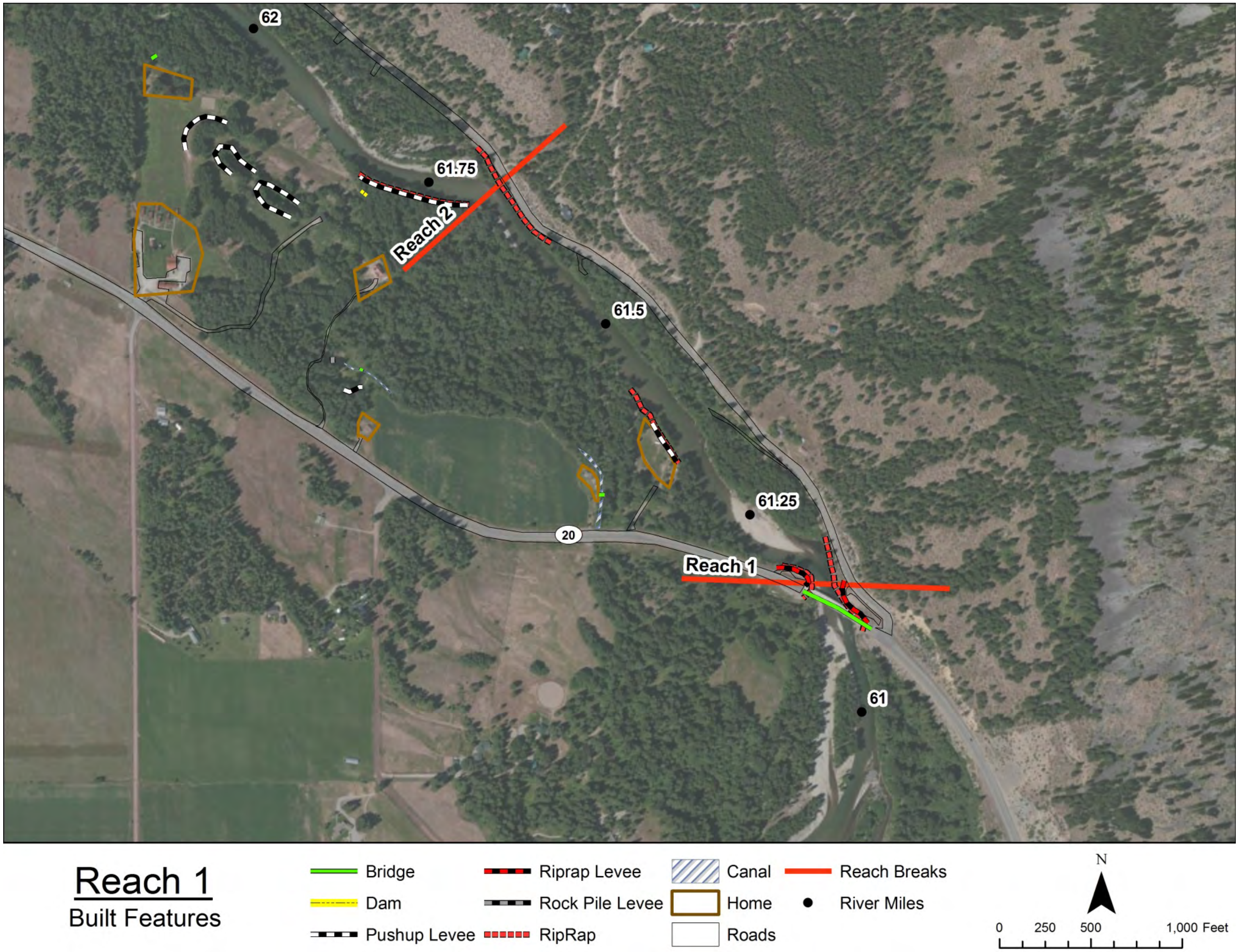

Figure 31. Primary human features in Reach 1.

3.1.3 Human Alterations

Human features are mapped in Figure 31. The primary human alterations in the reach include the following, and are described further in the subsections below.

- Changes to floodplain function and channel migration
- Loss of streambank complexity and riparian impacts
- Loss of instream habitat complexity

Changes to Floodplain Function and Channel Migration

Loss of floodplain function has occurred in the lower portion of Reach 1. The construction of Highway 20 and the Weeman Bridge crossing has resulted in unnatural constriction of the floodplain at the downstream border of the reach. Floodplain scarring and the raised road grade of Highway 20 indicate that approximately 1,000 feet of historical floodplain upstream of the bridge and approximately 2,000 feet of historical floodplain downstream of the bridge has been disconnected. This amounts to approximately 55 acres of disconnected floodplain habitat. These impacts reduce floodplain inundation, induce channel incision, and reduce the formation and long-term availability of off-channel rearing habitats that are created by channel migration processes (e.g. side-channels, alcoves, and oxbow wetlands). The right bank – immediately upstream and at the bridge crossing – has been raised. Large, angular boulder riprap that reinforces both banks was placed to restrict lateral channel migration and to protect the bridge and its abutments (Figure 32). The bridge crossing locks the channel in place along the naturally confining hillslopes on river-left. The bridge's two middle piers interact with channel flow that today results in scour on channel left and bar development on river-right.

From RM 61.35 to 61.4, the floodplain was cleared and graded for a private residence, and a subtle push-up levee and small boulder riprap were installed. Upstream from this private home site, a canal has been dug into a historical floodplain scar in order to divert surface flow off of the floodplain. All of these features combined disconnect the river from the floodplain by reducing the frequency and extent of inundation. In Reach 2 on river-right, from RM 61.7 to 61.8, large boulder riprap topped with a push-up levee holds the channel in place and diverts effective over-bank flow away from the active floodplain surface on river-right in Reach 1. This greatly reduces the capacity of the channel to laterally migrate into the floodplain, and it limits floodplain connectivity processes in the upstream portion of the reach.

Figure 32. Weeman Bridge and the associated riprapped banks at RM 61.15. (9/5/2014)

Loss of Streambank Complexity and Riparian Impacts

Stream bank complexity and riparian vegetation in Reach 1 have been reduced along riprapped banks. The high (approximately 15+ feet) riprapped banks at the Weeman Bridge and at channel-contact points along the Goat Creek Road embankment inhibit toe erosion and natural hillslope inputs, thus altering localized sediment contributions to the system. The riprap also reduces the complexity of the riparian vegetation community and notably decreases the potential for the establishment of mature stands of trees. Additionally, this reduces localized shade to the channel and removes the potential for large wood recruitment in these areas. At the private residence (RM 61.35 to 61.4), clearing and grading near the channel bank further reduces riparian vegetation communities and the benefits that they contribute to channel function.

Loss of Instream Habitat Complexity

The combination of human alterations described above has resulted in limited habitat complexity in Reach 1. Except for the forced meander in the channel at RM 62 immediately upstream from the bridge, the channel is basically straight with extended riffles and glides that have only minor bed variation. Records indicate that log drives utilized the mainstem channel here to transport cut timber to the Fender Mill located immediately downstream from the Weeman Bridge, as well as other mills downstream of the study area (Devin 1997, USBR 2008 – Appendix O). The Fender Mill was in operation until the 1930's. In-channel log transport requires clearing the channel of natural log jams and any other obstructions (large boulders, etc.). Additional clearing of large wood may have also occurred upstream of the Weeman Bridge following the large floods of 1948 and 1972, in an effort to protect bridges and other infrastructure. However, specific locations of these activities are not recorded. The expected impacts of log drives and/or "cleaning" a channel include bed scour, channel and bank simplification, and a reduction in habitat complexity (Nilsson etal. 2005, Wohl 2006, Miller 2010). Development of instream habitat complexity will be a slow process in this reach without the application of in-stream restoration, due to the riprap and levee features that minimize lateral migration and floodplain connectivity.

3.1.4 Recommended Actions

Recommended actions in Reach 1 are focused primarily on increasing mainstem channel complexity as well as mitigating for the impacts of bank armoring and the effects of the Weeman Bridge and Highway 20 road fill on floodplain connectivity and off-channel habitat. Main channel complexity can be addressed by adding log jams to mid-channel locations at the upstream end of the reach to encourage split flow conditions, and adding large wood to channel margins to enhance complexity along existing bank protection features (i.e. riprap that is currently protecting infrastructure). Channel margin jams are suggested along river-right upstream from the Weeman Bridge to reduce the need for additional bank hardening measures for bridge protection. Restoration objectives also include addressing, or at least mitigating for, the floodplain disconnection associated with the Weeman Bridge and the associated Highway 20 road fill. This may include measures to enhance flood flow through the road prism (e.g. adding culverts or bridges) and/or off-channel habitat enhancement in the river-right floodplain upstream and downstream of the crossing to create floodplain rearing habitat that does not exist due to floodplain disconnection.

Based on the available data, this reach rarely experiences subsurface flow conditions (see Section 2.6.3). There is also little opportunity within the reach for projects that would help to mitigate for the effects of subsurface conditions. For these reasons, recommended actions within the reach do not include mitigating for the effects of subsurface flow.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.2 REACH 2

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.2.1 Reach Overview

Reach 2 is 3.1 miles long and extends from RM 61.70, at its confluence with Cassal Creek, to RM 64.80, at its confluence with Goat Creek. Property in Reach 2 is owned by the Methow Salmon Recovery Foundation, the Edelweiss Maintenance Commission, the Washington Department of Fish and Wildlife, the Okanogan National Forest, and private landowners (Figure 33). The upper portion of the channel is a riffle-glide stream from RM 63 to 64.8. Channel complexity increases slightly in the downstream portion from RM 61.7 to 63, where there is increased bar development and stream type shifts to riffle-glide-pool (Figure 34 and Figure 35). The river in this reach is primarily a single-thread channel with relatively low sinuosity (1.1) and gradient (0.5%). The channel substrate is composed primarily of coarse gravels to cobbles. These and other reach metrics are provided in Table 8 and Figure 36.

The reach is semi-confined due to natural confining banks as well as human alterations along sections of the channel. The natural confining banks include glacial outwash terraces and alluvial fan toes. The modern floodplain occupies one half to one third of the valley floor, and has an average width of 1,193 feet. Floodplain scarring and deposition patterns indicate that high-flow events activate or contribute to side-channels and secondary channels in locations where human features have not altered floodplain inundation processes.

The habitat conditions in Reach 2 are discussed in Appendix A. Based on the REI analysis, 9 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). A salmon and steelhead redd distribution map for the reach is provided in Figure 33. Although sections of the floodplain and channel banks have been cleared or thinned of vegetation, over seventy-five percent of the channel banks are vegetated with maturing forests. Where they exist, these forests do provide some wood to the system and add roughness to the banks and floodplain surfaces. Natural hydrologic and geomorphic processes have been compromised due to human alterations. Riprap and levees disconnect the floodplain and off-channel features from the mainstem channel and confine lateral migration in sections of the reach. Vegetation clearing and thinning has reduced floodplain and riparian processes. Historical logging practices at the turn of the century utilized the river to transport cut logs to a mill site in the middle of the reach. This has likely influenced channel geomorphology over the last century.

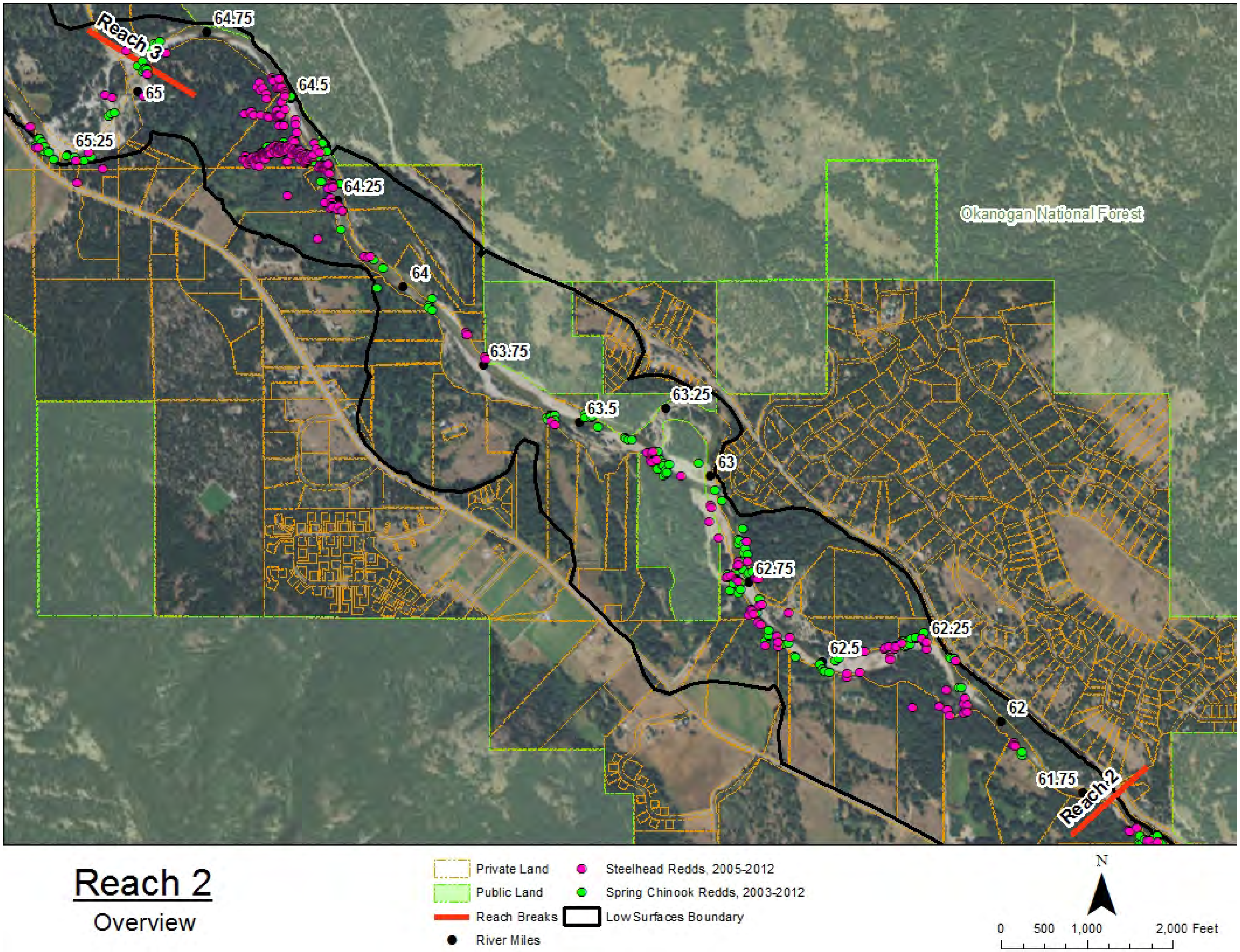

Figure 33. Reach 2 overview map with landownership and redd distribution.

Figure 34. Representative photo of upper section of Reach 2; looking downstream from RM 64.3. (8/31/2014)

Figure 35. Representative photo of lower section of Reach 2; looking downstream from RM 63.5. (9/4/2014)

Table 8. Reach 2 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	3.1
River Miles	61.70 – 64.80
Valley Gradient	0.5%
Stream Gradient	0.5%
Sinuosity	1.1
Dominant Channel Type	Riffle-glide
Average Bankfull Width (feet)	141
Average Floodplain Width (feet)	1193
Dominant Substrate	cobble (51%); gravel (49%)
Bank Stability/Channel Migration	Unacceptable *(See Section 2.12)*
Vertical Channel Stability	At Risk *(See Section 2.12)*
Confinement ratio	Unconfined *(See Table 5)*

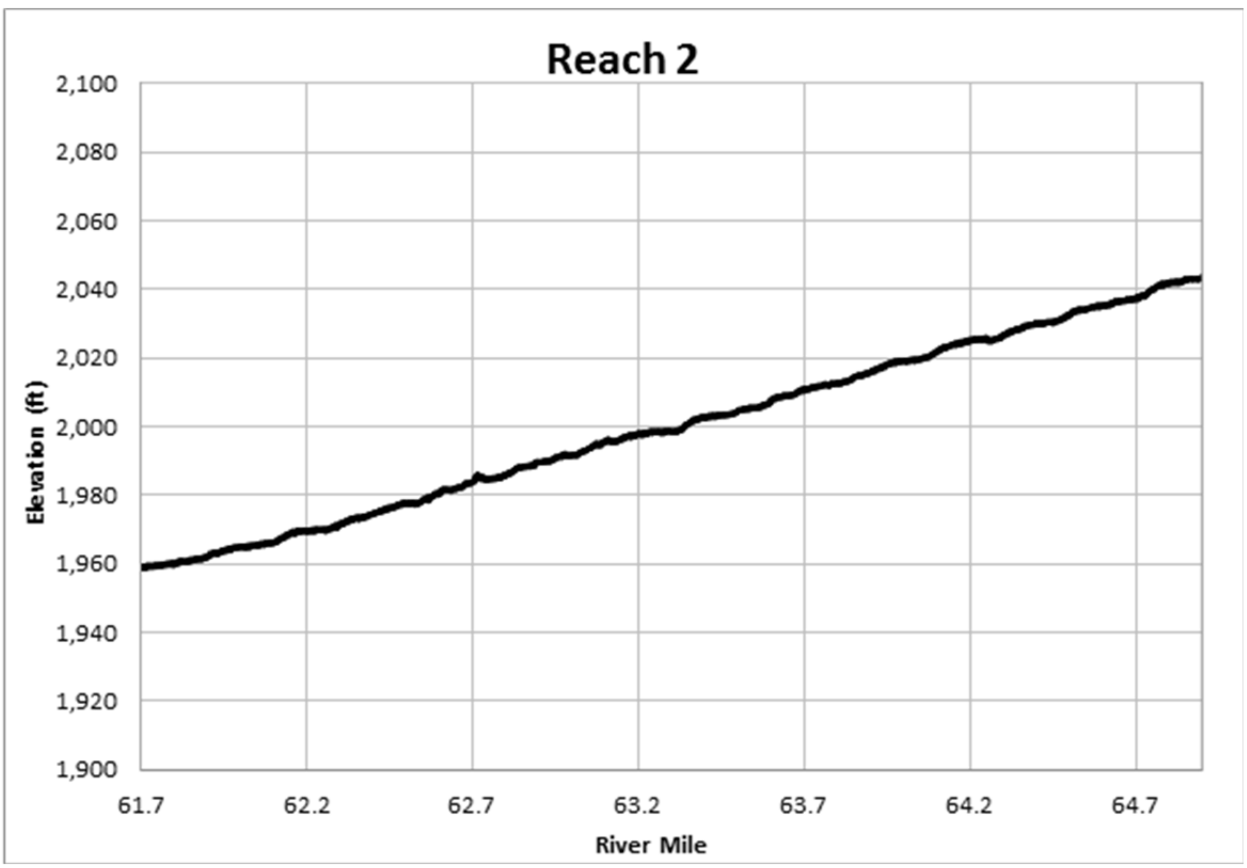

Figure 36. Longitudinal profile of the channel in Reach 2 (RM 61.15 to 61.70).

3.2.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 2 is located on the eastern side of a wide U-shaped valley most recently carved by Quaternary glaciation. Increased discharge regimes during early Holocene glacial retreat resulted in the valley floor infilling with a thick layer of glacial outwash deposits. Today, a higher and older glacial deposit terrace is located on the flanks of the hillslopes on the east-side of the valley. A wide, lower, younger glacial outwash terrace borders the west side. The modern channel and floodplain of Reach 2 are inset between and below the glacial deposit terraces. The average width of the reach is 1,193 feet and the average width of the modern active channel through the reach is 141 feet (see Figure 37).

Large alluvial fans from Little Boulder Creek and Goat Creek (both glacially-carved) influence the location of the channel at the upstream end of the reach by restricting its pathway between the toes of the two fans. These fan deposits stretch across the valley from opposite sides. Goat Creek continues to contribute sediment and discharge to the reach. The Little Boulder Creek confluence is located in Reach 3, but its fan deposits and subsurface groundwater inputs influence the upper portion of Reach 2. The alluvial fan of Fawn Creek, which is in the middle of Reach 2 on river-left (the east side of the channel), also contributes sediment and discharge to the channel. The reinforced embankment of Goat Creek Road is constructed along and into the terrace and fan deposits on the east side of the valley above the modern channel. Steep, glacially-carved bedrock walls bordering the valley create talus and additional small debris fan deposits along the edges of the valley floor; however, these deposits currently do not contribute direct inputs to the channel in Reach 2.

The channel in Reach 2 has a relatively low overall sinuosity (1.1) that changes in relation to channel complexity. From RM 61.7 to 62, and RM 63 to 64.7, the channel is less sinuous and has elongate side-channel bars. Bar size and distribution – including mid-channel bars – increases in the middle section from RM 62 to 63.8, as does sinuosity at and downstream from the Fawn Creek alluvial fan. From RM 64.7 to 64.8, channel sinuosity and complexity also increase along the toe of the Goat Creek alluvial fan. Local contributions of sediment and large wood are generated from Goat Creek and by the channel migration cut-offs that occurred on river-left at RM 62.5, RM 63.25, and RM 64 in the last twenty years.

The floodplains in Reach 2 are composed of cobbles and gravels and then topped with sands where overbank deposition has occurred. The active floodplains contain scour and fill features composed of cobbles and gravels, as well as overflow channels activated during high-flow events. Groundwater-fed tributaries and abandoned channel scars add complexity and riparian features to the floodplain. Reach 2 contains the highest number of connected side-channel and backwater features in the study area. In addition, there are two small dug ponds on river-right (at RM 61.85) that are disconnected from overbank inundation by constructed levees.

High floodplain surfaces are composed of cobbles and gravels and then topped with two or more feet of sands and developing soil. The high floodplain surfaces bordering the active surfaces of the reach are disconnected from regular inundation processes by incision, floodplain grading, and the construction of levees.

A set of large levees is located in Reach 2 on river-right from RM 63.25 to 63.7. The levees vary in elevation from three to twelve feet high. They are composed of large, angular, boulder riprap and topped with gravels and sand to accommodate a single-track road that is currently designated as a community trail. These levees run parallel to the river for approximately 650 yards. They confine the channel on river-right and disconnect floodplain and side-channels located behind them.

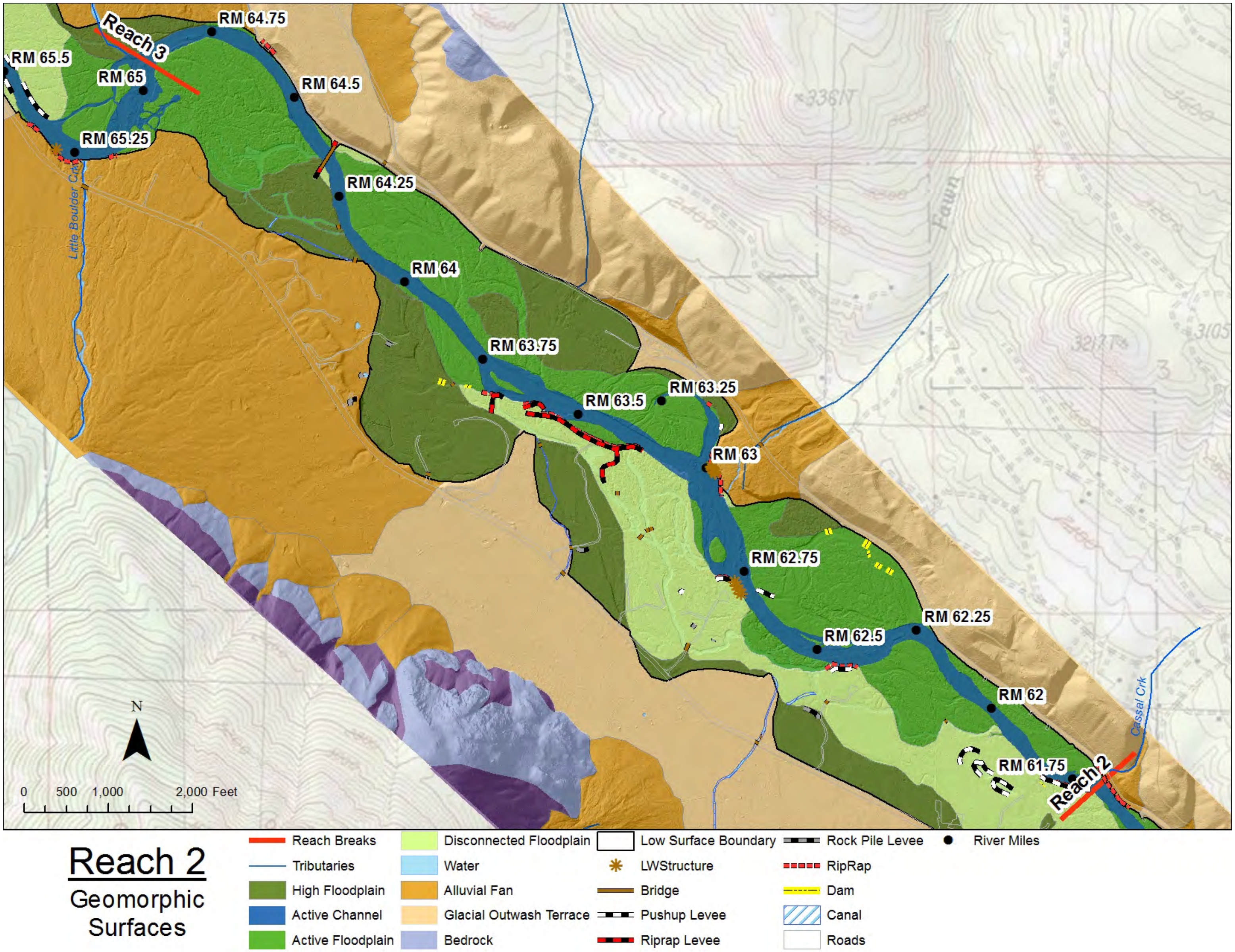

Figure 37. Geomorphic surfaces in Reach 2 with selected human-built features (levees, riprap, check dams, canals, bridges, and roads).

Hydrology

Reach 2 has a seasonally varied flow regime. Based on overbank deposits viewed in the field, spring and early summer high-flow events are expected to regularly inundate low floodplain surfaces and activate overflow channels every two to ten years (Figure 38). Late summer and autumn low flows expose bars, banks and sometimes portions of the bed throughout the reach – depending on the annual hydrograph. During the low-flow season, surface flow is often reduced to mere inches above the channel bed at riffles. Summer thunderstorms are capable of temporarily raising surface water elevations in Reach 2 if the precipitation event is significant enough to recharge the groundwater.

The valley floor is composed primarily of coarse-grained material that supports active hyporheic through-flow and groundwater inputs from upstream and the adjacent terraces, valley walls, and alluvial fans. Hydraulically, the channel in Reach 2 is considered a gaining reach (Konrad 2003, Konrad et.al 2005). This means that incoming groundwater feeds the surface flow in the channel. However, reports of portions of this section of the channel seasonally going dry in late summer and autumn during low precipitation years do exist (WDW 1990). See Section 2.6 of this report for a description of the groundwater to surface water interchange here. It is expected that the channel and floodplain tributaries are actively exchanging surface flow with groundwater through hyporheic processes.

Reach 2 receives discharge from Goat and Fawn Creeks. According to the US Bureau of Reclamation flow estimates (2008 – Appendix J), the upstream boundary of the reach receives an estimated 5% increase in surface water discharge from Goat Creek and an approximate 1% increase from Fawn Creek during high flow events. Additional subsurface contributions through the alluvial fan of Little Boulder Creek feed groundwater-activated tributaries on the floodplain in the upper portion of Reach 2. Five small, snowmelt- or precipitation-activated tributaries flow off the steep valley walls, and these contribute minor seasonal discharge. Three of these tributaries are located on river-right and have alluvial fans with irrigation canals along their fan toes. These canals divert flow for agricultural purposes and floodplain drainage. In Reach 2, the combined seasonal tributary inputs contribute an estimated 0.6% discharge to the channel during high flow events.

Groundwater-activated floodplain tributaries are important hydrologic features in Reach 2. These tributaries are fed by groundwater inputs generated upstream and from the adjacent terraces and alluvial fans. In Reach 2, these floodplain tributaries maintain off-channel riparian environments, transport sediment into the channel, and sometimes act as high-flow conduits or low points for flood-event avulsions. Many of these features are located in abandoned channel scars that have been maintained and altered by modern tributary discharge. Most of the groundwater-activated tributaries provide year-round surface water inputs and desirable off-channel aquatic habitat to the reach (Figure 40). Overflow from the mainstem causes periodic inundation and scouring, which can flush out fines and the occasional abandoned beaver dam. This appears to aid in the maintenance and complexity of these floodplain tributaries. In the groundwater fed tributaries of Reach 2 – where levees have not disconnected upstream surface-flow inputs – this sequence of fluvial processes creates salmon spawning and rearing habitat.

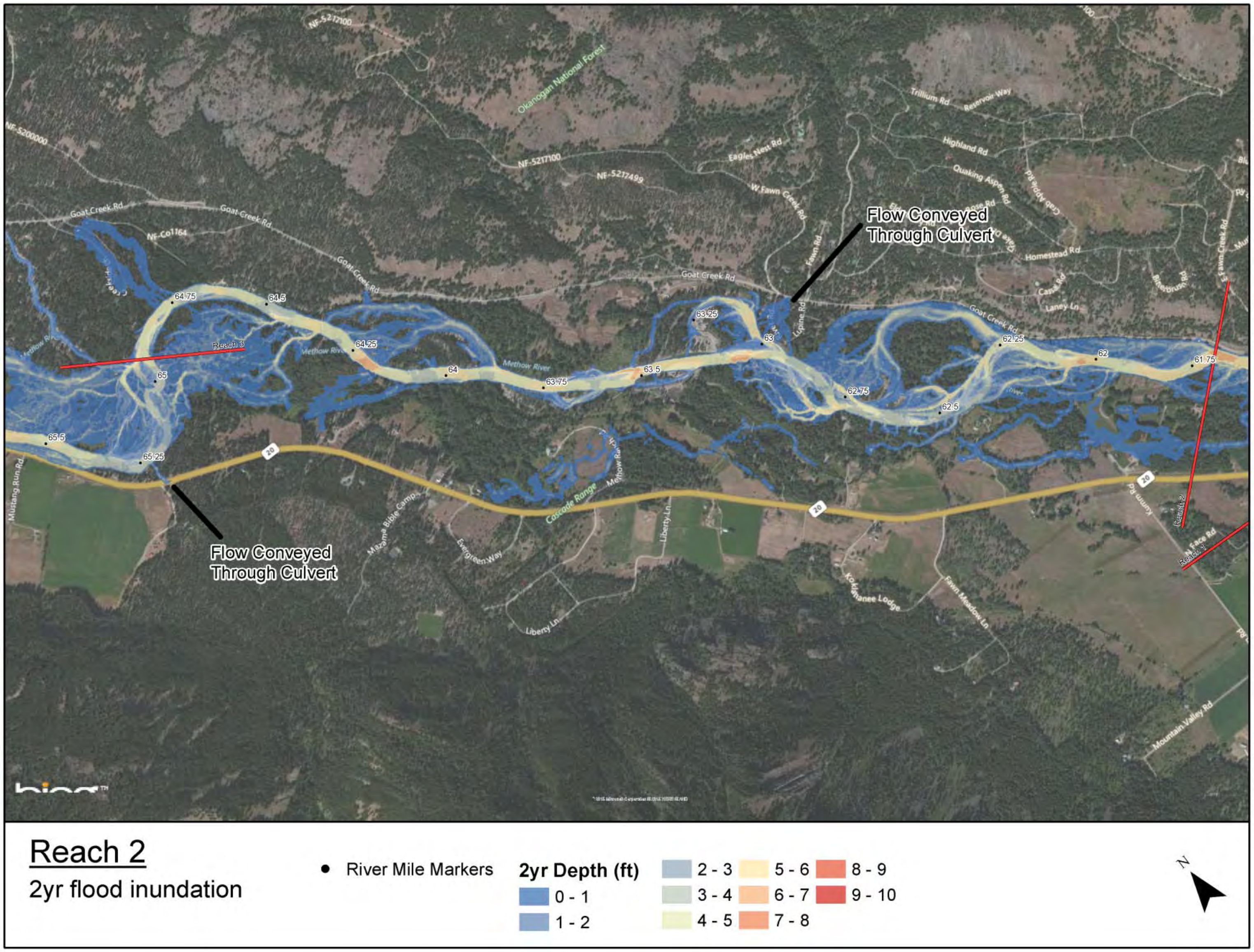

Figure 38. Floodplain inundation for 2YR flood in Reach 2 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

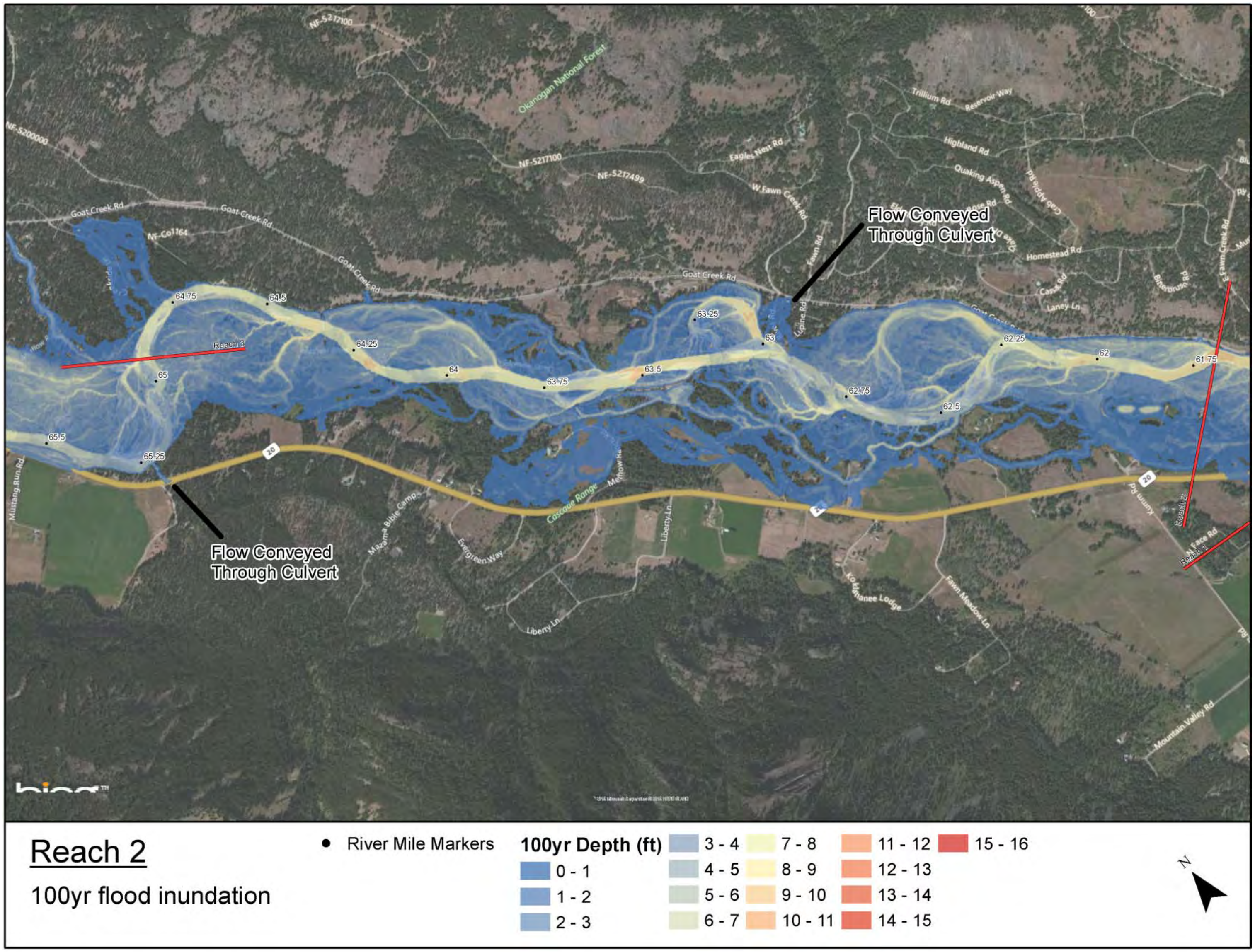

Figure 39. Floodplain inundation for 100YR flood in Reach 2 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Figure 40. Groundwater-fed tributary (Suspension Creek) on river-right floodplain at RM 64.35; inset photo of salmon spawning in this tributary. (9/3/2014)

Floodplain and Channel Migration Zone

Reach 2 is moderately stable both vertically and laterally. At the upstream end of the reach, the large alluvial fan features of Goat Creek and Little Boulder Creek influence the location and width of the reach on the eastern side of the valley floor. Riprap and levees at the downstream end maintain the location of the channel's pathway against the eastern edge of the valley and floodplain. The channel and its floodplain occupy approximately half of the valley floor with an average width of 1,193 feet. The surface of the active floodplain contains plentiful channel migration scars (scrolls and abandoned channel features) and overbank inundation features (scour and deposition). These indicate regular floodplain connectivity and channel migration patterns. However, in portions of the reach, recently constructed anthropogenic features (such as levees and riprapped banks) have disconnected sections of the floodplain and reduced the channel's capacity to migrate. Lateral migration is most restricted by riprapped banks and levees located on river-right from RM 63.25 to 63.7.

High glacial terraces and alluvial fan deposits also naturally confine lateral migration and thus influence the width of the migration zone. These features impose partial lateral confinement. The terrace banks are erodible, but the high slopes and presence of coarse boulder material are usually more difficult and slower to erode than the low-lying modern floodplain (Figure 41). Today, the mainstem channel has high cut-banks along glacial terraces on river-left from RM 62.2 to 62.25 and from RM 64.45 to 64.65. Cut-banks composed of alluvial fans contact the channel on river-right at Little Boulder Creek (RM 64.15) and on river-left at Fawn Creek (RM 62.9 to 63.1). The high bank at the Fawn Creek alluvial fan is riprapped with large, angular boulders and large constructed wood vanes; these features armor the bank and now unnaturally confine the channel here. The bank protection constructed along the Fawn Creek alluvial fan at RM 63 was constructed after a high-flow event in 2002 eroded the high bank and a private home was lost (State of Washington 2010).

Figure 41. Cut bank of glacial outwash terrace on river-left at RM 64.55. Old road grade cut into the bank with cement retaining wall for preserving community trail access. (9/3/2014)

Vertical stability of Reach 2 is considered moderate, but at risk of continued channel incision. The high floodplain surfaces in Reach 2 exist because of both natural- and human-influenced incision processes. Sections of the channel are experiencing bed incision that is likely due to the levees and riprap that constrict lateral migration. Floodplain scarring and historical channel pathways visible in aerial imagery collected between 1945 to 2012 show that three meander bends on river-left – at RM 62.5, RM 63.25, and RM 64 – have been cut off. This resulted in decreased channel length and sinuosity, which leads to an increase in channel gradient caused by bed incision (Figure 42). Additional disconnection of sections of the floodplain has occurred due to surface grading and levees. Combined, these elements will continue to simplify the channel and available habitat in Reach 2.

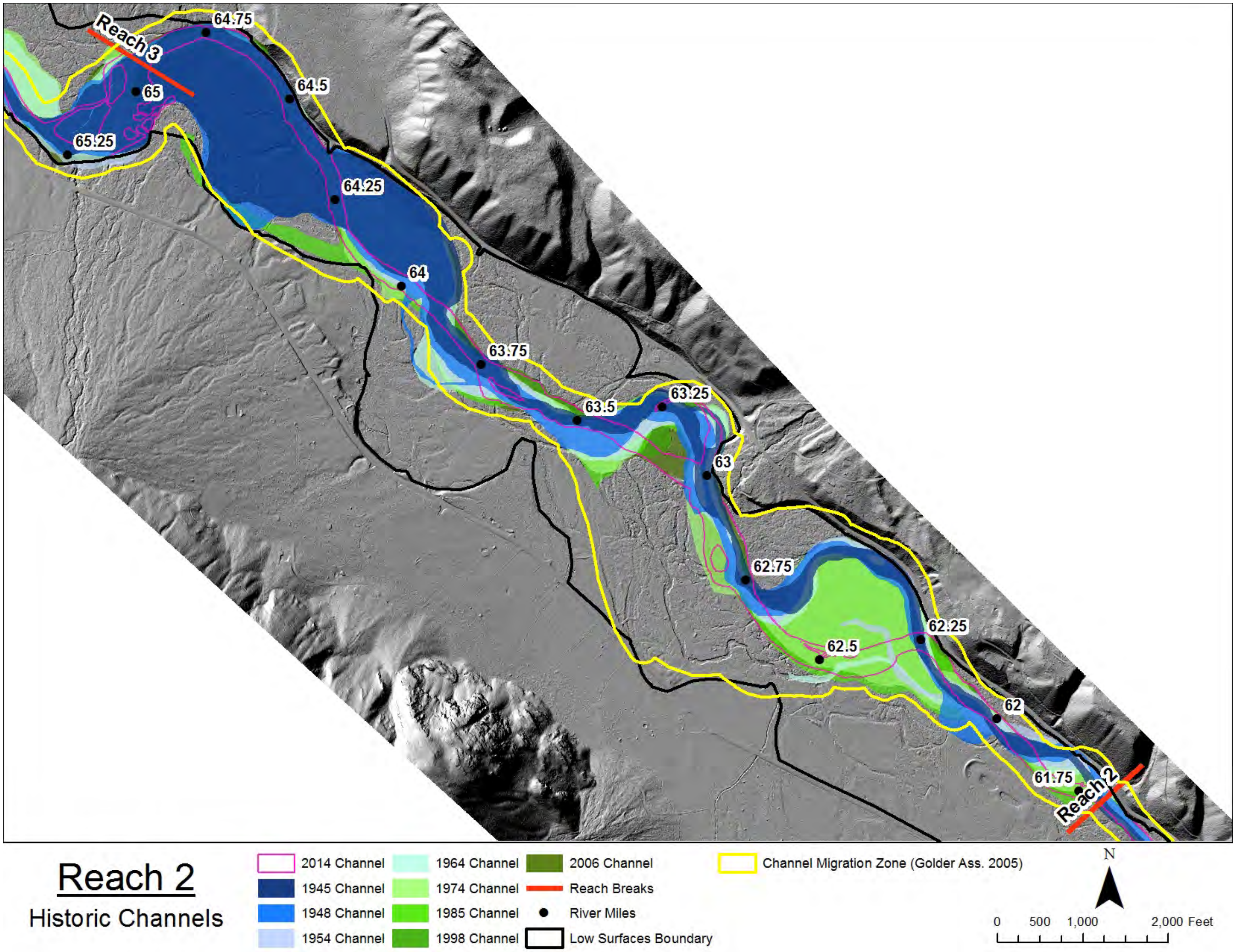

Figure 42. Historical channel locations in Reach 2.

Sediment

The substrate of Reach 2 is dominated by cobbles (48%) and gravels (48%), and has minor sand (2%) and boulders (2%). Sand is found in overbank deposits, backwater features, and eddies. Large boulders in the channel, from RM 64.5 to 64.6, are sourced directly from the steep slope of the glacial outwash terrace on river-left (see Figure 37). Groundwater tributaries that initiate on the floodplains also contribute sediment to the channel, but these inputs are usually gravels, sands and fines. The floodplains are composed of cobbles and gravels, and topped with sands. Goat Creek, Fawn Creek, and their alluvial fans all contribute additional sediment to the system. Inputs include fines and sands as well as bedload materials of small boulders, cobbles and gravels. Bedload sediment throughout the reach is fairly well sorted (has a relatively similar diameter size range) and rounded, indicating that much of the substrate is transported fluvially during high flow events.

Large Wood

Reach 2 has a relatively high in-channel large wood count. A total of 10 log jams and 398 logs (equivalent to 126 logs per mile) were counted. In-channel wood distribution in the reach is presented in Figure 43 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. The largest accumulations and jams occur where bar development is greatest – from RM 62 to 63.25 and from RM 64.8 to 64.8. The meander cut-offs that occurred in the last twenty years between RM 62.25 and RM 63.5 likely provided plentiful large wood to the reach. Today, large wood recruitment is minimal at riprapped and leveed banks or where vegetation clearing has occurred. Partial and full clearing of large trees has occurred next to the channel on private lands, near utility-pole crossings, and at foot-bridges. These occur at RM 61.85 (river-right), RM 62.65 (river-right), RM 62.75 (river-right), RM 63.6 (river-right and river-left), RM 64.35 (river-right), and RM 64.8 (river-left). The remainder of the floodplain surfaces are vegetated with both small and mature trees that provide some wood to the system (Figure 44). The width of the channel (average bankfull width is 141 feet) is too great for channel-spanning accumulations of large wood to develop in the mainstem in this reach. Instead, large jams accumulate within the active channel boundaries. The jams increase channel complexity by promoting bar development and scour pools. Where stands exist along the off-channel features, large wood contributes nutrients, shade, and complexity. The off-channel features are narrow enough that mature large wood can span the feature.

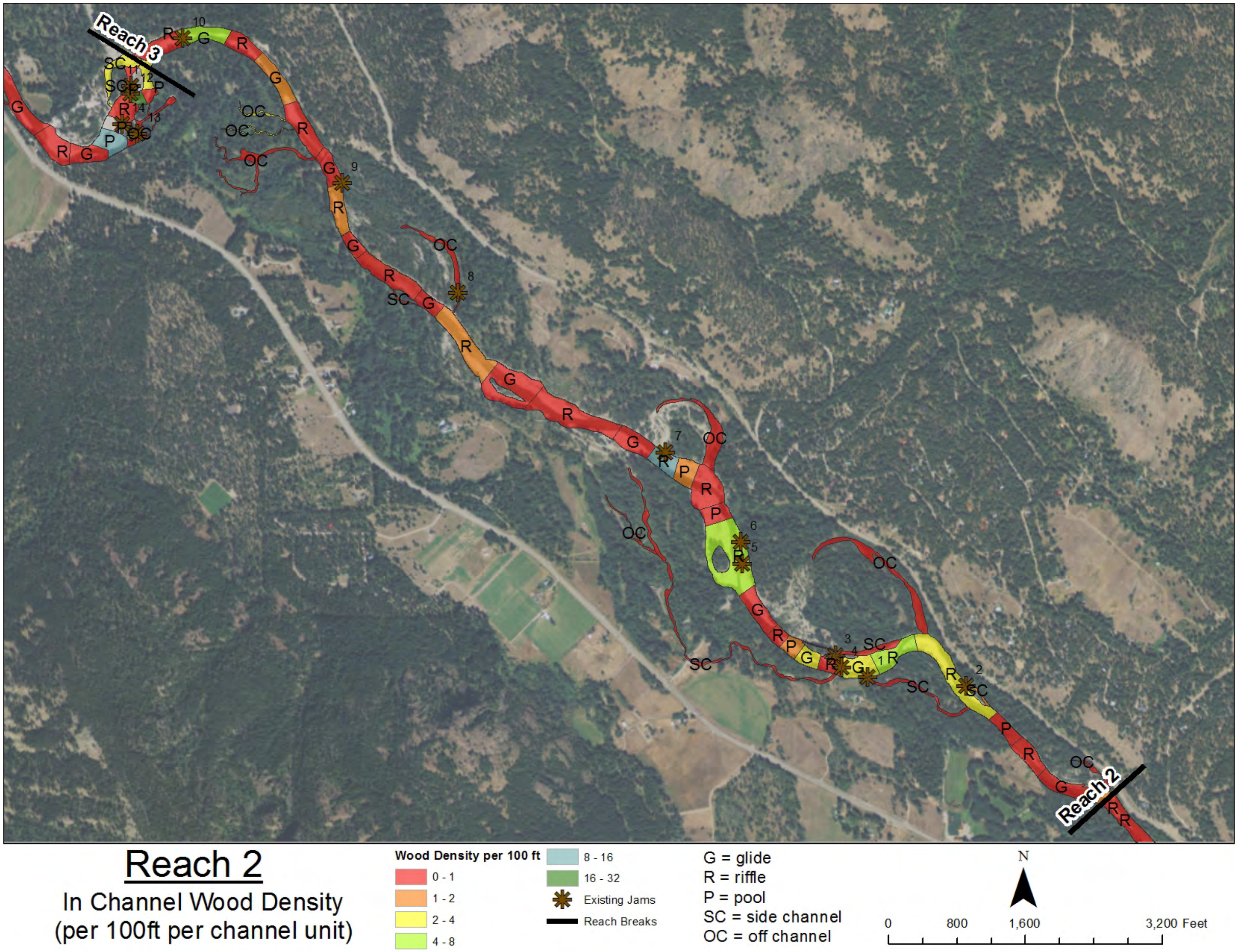

Figure 43. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 2.

Vegetation

The banks of the channel in Reach 2 are relatively well vegetated except at the cleared locations listed above and where riprap and levees exist. Sparse vegetation occurs on the steep glacial terrace slope on river-left from RM 64.4 to 64.65. The vegetated banks throughout the reach contain forests composed primarily of a mix of cottonwood, aspen, fir, pine, and cedar. Recently abandoned surfaces – such as high bars or scour and fill features – have establishing communities of cottonwood, dogwood, fir, and aspen. The age of the establishing tree stands on these features aids in identifying the history of flooding and channel pathway changes in the reach. The understory on the undeveloped floodplain surfaces is dense and includes grasses, forbs, dogwood, maple, and snowberry. The cleared or partially-cleared banks have a less complex understory dominated by grasses and forbs. Along the riprapped banks, small patches of willow and dogwood have taken root in a few of the spaces between the angular boulders near the channel. See Figure 44 for a vegetation canopy height map.

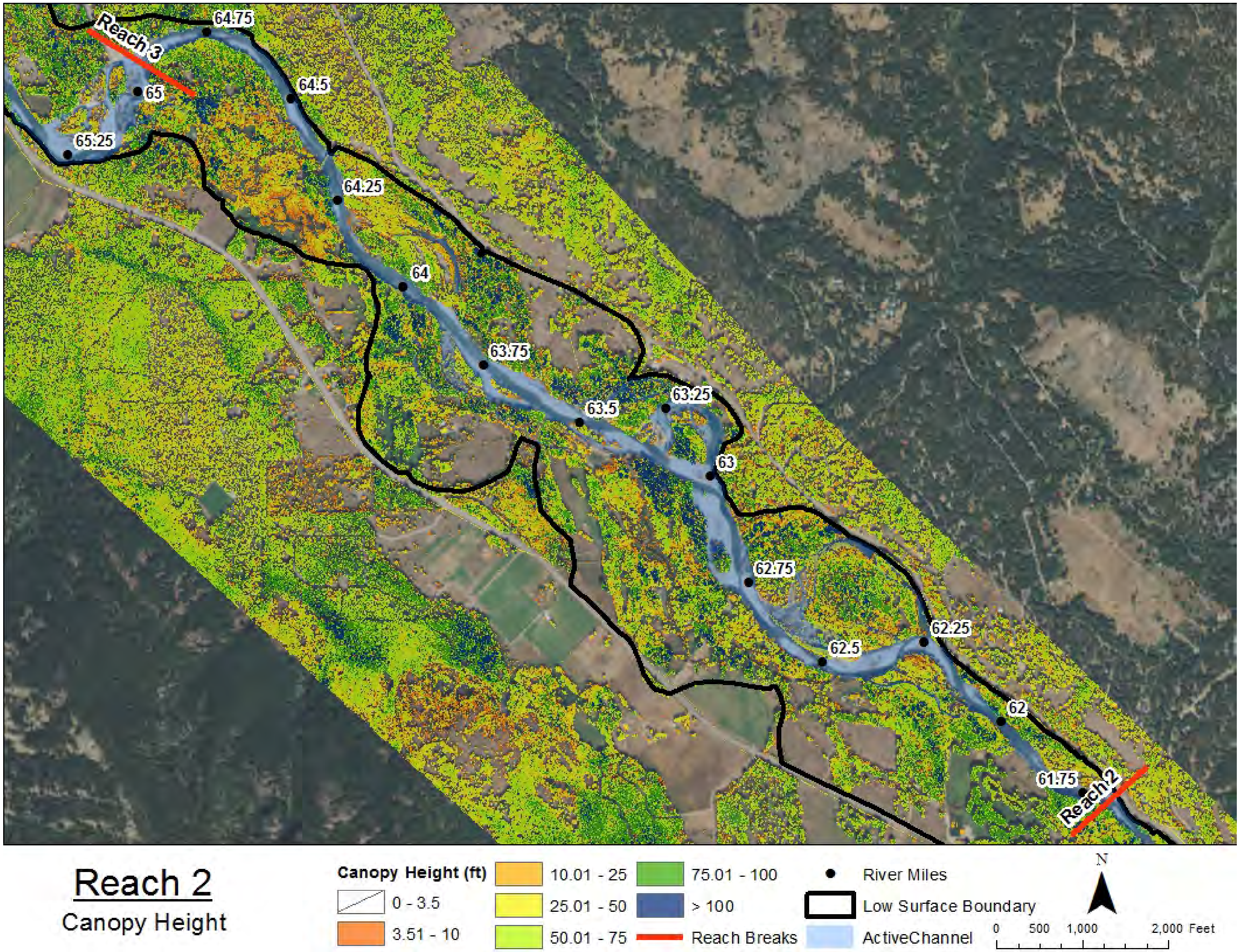

Figure 44. Vegetation canopy height for Reach 2 -- derived from LiDAR first return (highest hit) data; includes buildings and other human infrastructures.

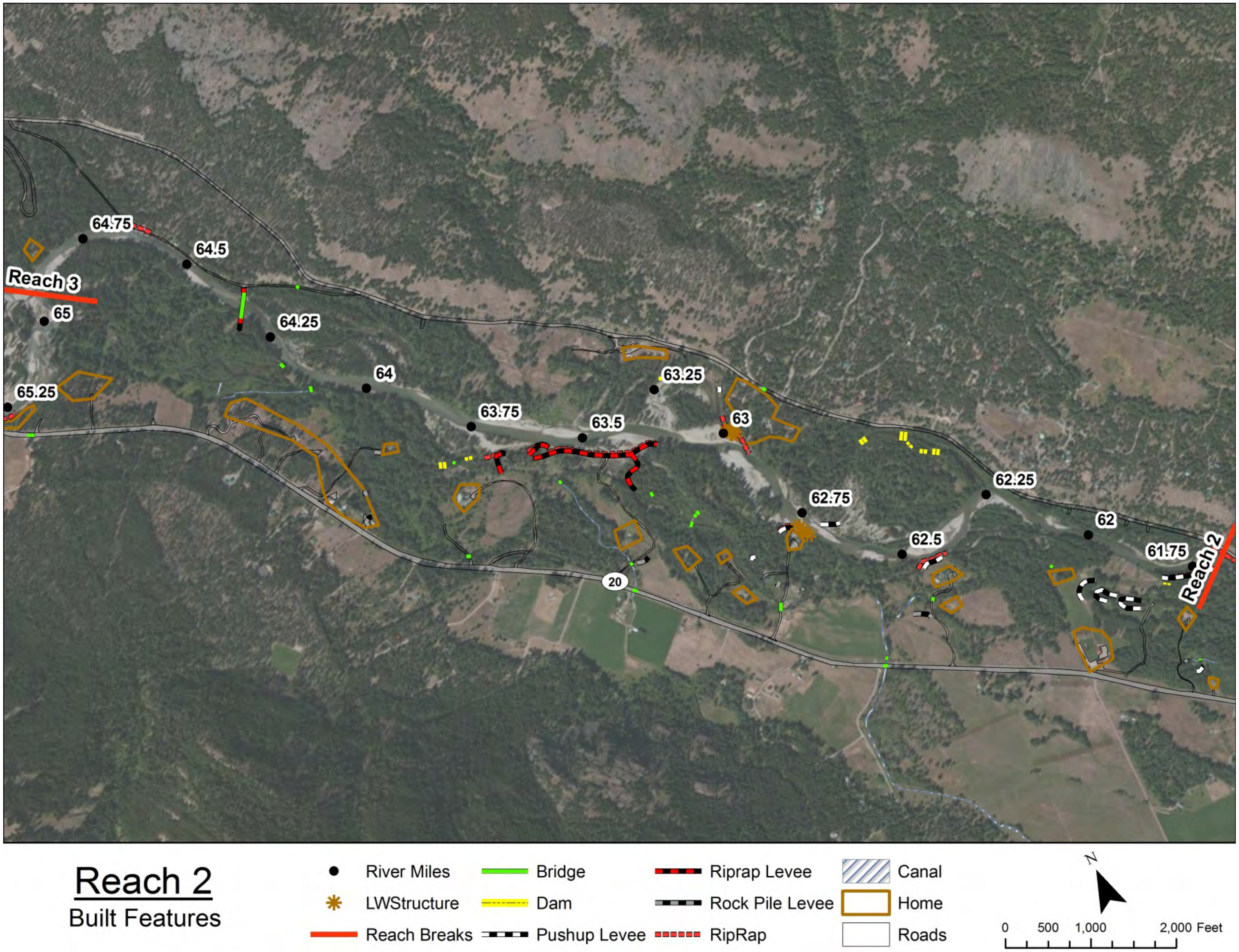

Figure 45. Primary human features in Reach 2.

3.2.3 Human Alterations

Human features are mapped in Figure 45. The primary human alterations in the reach include the following, and are described further in the subsections below.

- Changes to channel migration, floodplain function and off-channel habitat
- Changes to streambank complexity and riparian impacts
- Changes to instream habitat complexity

Changes to Channel Migration, Floodplain Function and Off-Channel Habitat

Levees and riprap have reduced the channel migration zone of Reach 2 (Figure 46). The channel width and location in the downstream portion of Reach 2 is largely locked in place. Lateral migration is limited by large-boulder riprapped banks topped with push-up levees on river-right from RM 61.7 to 61.85, RM 62.4 to 62.45, and RM 62.7 to 62.8. Riprap is used for bank protection on river-left from RM 61.7 to 61.75, RM 62.8 to 63.1, RM 63.15, and RM 64.6 to 64.65. Large wood has been attached to the riprapped banks at RM 62.7 (on river-right) and at RM 63 (on river-left).

The most severe alteration to floodplain and habitat function occurs behind the levees on river-right from RM 63.25 to 63.75. The levees are approximately eight to twelve feet high and eight to ten feet wide. The road on the top of the levee is a community trail. The levees completely block channel migration and floodplain inundation. They also block the upstream confluence points of several side-channels. This blockage keeps main channel flow from entering the side-channels, which has resulted in decreased habitat complexity and infilling with fines. The side-channels in this reach would be the longest in the study area had they not been disconnected by the levees. Today, these side-channels are currently wetted by groundwater inputs alone. Reactivation of the side-channel could be achieved by excavating notches into the levee, removing the levee entirely, or installing hydraulically-designed culverts that would allow partial through-flow from the mainstem.

Additional push-up levees composed of floodplain cobbles and soil reduce normal inundation processes on river-left from RM 62.65 to 62.7. Push-up levees built on the floodplain near dug ponds at RM 61.85 (river-right) disconnect a portion of the floodplain from normal through-flow and high-flow inundation processes. A series of check-dams in the abandoned meander scar on river-left from RM 62.25 to 65.65 reduces surface water inputs into the channel. The check-dams also limit the potential backwater habitat that this feature could provide.

Figure 46. Examples of confining features constructed of large angular riprap in Reach 2, (A) riprapped bank with cabled and anchored logs on river-right at RM 62.7; (B) section of the levee composed of riprap on river-right at RM 63.5. (9/4/2014)

Additional loss of floodplain function occurs at the suspension bridge abutments at RM 64.35 and at an armored bank at the downstream end of the reach on river-right. The suspension bridge abutments are composed of boulders, cobbles and soil (similar to push-up levees). The abutments constrict the channel between them and alter normal floodplain inundation downstream on river-right (Figure 47). At the downstream end of the reach on river-right from RM 61.7 to 61.8, a riprapped bank topped with a push-up levee also confines channel width and location. Floodplain connectivity is reduced behind and downstream from this bank and levee in Reach 2 and Reach 1. Additional floodplain levees in Reach 2 alter localized floodplain inundation processes.

Figure 47. Suspension footbridge abutment and public area on downstream side of bridge on disconnected floodplain at RM 64.35. (9/3/2014)

Changes to Streambank Complexity and Riparian Impacts

Armored banks and vegetation clearing have altered sediment and vegetation inputs to the channel in portions of Reach 2. Riprapped banks throughout the reach inhibit bank erosion and natural hillslope inputs, which in turn alter localized sediment inputs into the system. The riprap also reduces the complexity of the riparian vegetation community and notably decreases the potential for the establishment of mature tree stands. This also reduces both localized shade to the channel and large wood recruitment potential in these areas.

The loss of riparian vegetation communities and the accompanying loss of the benefits they provide have occurred on private lands, near utility poles, and at footbridge crossings. Along the main channel, these impacts are visible at RMs 61.85 (river-right), 62.65 (river-right), 62.75 (river-right), 63.6 (river-right and river-left), 64.35 (river-right), and 64.8 (river-left). Some vegetation thinning and clearing has also occurred along groundwater-fed tributaries and on floodplain surfaces near side-channels or backwater features. Loss of vegetation near these features can also increase water temperature, reduce natural bank stabilization, limit tree-fall nutrients, and reduce off-channel habitat complexity.

Changes to Instream Habitat Complexity

Instream habitat complexity has been impacted by the human alterations described previously. The armored banks and levees have contributed to reduced channel sinuosity over the past few decades. Reduced sinuosity shortens a channel, thus increasing its gradient. This promotes bed incision and reduces floodplain connectivity. According to aerial imagery, in the last ten years the channel has cut off three meanders on river-left at RM 62.5, RM 63.25, and RM 64. These avulsions recruited sediment and large wood from the floodplain into the channel. These inputs are currently maintaining local mainstem channel complexity even though sinuosity has been reduced. However, there is high potential for channel incision to continue here because of the confinement that has been imposed by the levees and armored banks. This is also true for the downstream end of Reach 2, where the channel is confined between riprapped banks. Upstream migrating bed incision from Reach 1 may also influence bed scour at the downstream end of Reach 2.

Historical gold mining in Goat Creek in the early 20th century, along with extensive logging and channel straightening, likely increased past sediment inputs and perhaps influences the character and quantity of modern sediment contributions (USBR 2008 – Appendix O). From the late 1800s to the early 1900s, records indicate that loggers utilized the mainstem channel to transport cut timber to mills downstream of Reach 2 (Devin 1997). This required clearing the channel of natural log jams and any other obstructions (large boulders, etc.). The expected impacts of log drives and/or "cleaning" a channel include bed scour, channel and bank simplification, and a reduction in habitat complexity (Nilsson etal. 2005, Wohl 2006, Miller 2010).

3.2.4 Recommended Actions

Recommended actions in Reach 2 are focused on increasing channel complexity and lateral channel dynamics as well as improving connectivity to side-channels and floodplains. Complexity and lateral dynamics can be addressed by adding large wood jams to the main channel to enhance and create bar and island development and enhance split flow dynamics. Channel margin jams are suggested to create local pool development and enhance existing features. Side channel and floodplain connectivity can be addressed by removing unnecessary riprap, push-up levees, check dams, and sediment accumulations in off-channel habitat areas. Removal or breaching of levees at RM 63.35-63.7 has the potential to reconnect the largest off-channel impairment in the study area – but further evaluation and planning is needed to address the human-based function that the levees currently serve. Reach 2 also offers good opportunity to take advantage of public-access and recreation that occurs here by adding educational signage at restoration sites. Native riparian vegetation restoration where clearing has occurred is also recommended. Restoration recommendations recognize the importance of maintaining connectivity of the mainstem channel to perennial or groundwater fed tributaries and side-channels. This has been identified as a critical component for fish survival in a system with the potential to seasonally dewater.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.3 REACH 3

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.3.1 Reach Overview

Reach 3 is 1.3 miles long and extends from RM 64.90, at the confluence with Goat Creek, to RM 66.20. Land in Reach 3, including the land owned by Foster Guest Ranch Homeowners Association, is all private (Figure 48). In the upper two-thirds of the reach, from RM 65.35 to 66.20, the channel is a straight riffle-pool-glide stream, with only two pools. Bar development is minimal here, and off-channel features are limited to a few overflow channels at the upstream end on river-right from RM 66.8 to 66.20 (Figure 49). Channel complexity improves downstream of RM 65.35, where the river becomes partially braided. In addition to increased channel sinuosity, this area has plentiful pools, bars, log jams, and connected side- and off-channel features (Figure 50). The channel substrate of Reach 3 is composed primarily of coarse gravels and cobbles. Floodplain composition is similar to the channel substrate but with sparse small boulders at the base and overbank deposits of sand. The river in this reach has a relatively low average sinuosity ratio (1.2) and gradient (0.4%). These and other reach metrics are provided in Table 9 and Figure 51.

The reach is semi-confined laterally due to a combination of natural features and human alterations. High glacial outwash terraces and the alluvial fans sourced from Goat Creek and Little Boulder Creek act as natural, partially confining features to Reach 3. The human features confining Reach 3 include levees and riprapped banks. Floodplain scarring and deposition patterns indicate that high-flow events activate or contribute to side-channel and off-channel features in locations where human features have not altered floodplain inundation processes. Atop adjacent terrace surfaces on river-right (west side of the channel), the construction of private homes and Highway 20 alter sediment and large wood inputs.

The habitat conditions in Reach 3 are discussed in Appendix A. Based on the REI analysis, 9 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). The salmon and steelhead redd distributions for the reach are mapped in Figure 48. Vegetation clearing and thinning on portions of the floodplain along river-left (east side of the channel) locally reduce bank roughness and nutrient inputs. Channel banks in the lower third of the reach are well vegetated with maturing forests. These forests provide wood to the system and add roughness to the banks and floodplain surfaces. Historical logging practices cleared large trees from the Reach. At the turn of the century, the channel was utilized to transport cut logs to mills downstream. This has likely influenced channel and floodplain processes over the last century. Natural hydrologic and geomorphic processes have been compromised where levees and riprap disconnect the channel from its floodplain and limit lateral channel migration. Off-channel human alterations such as irrigation canals, culverts, roads, a pond, home development, and tributary crossings alter sediment and discharge routing into the system.

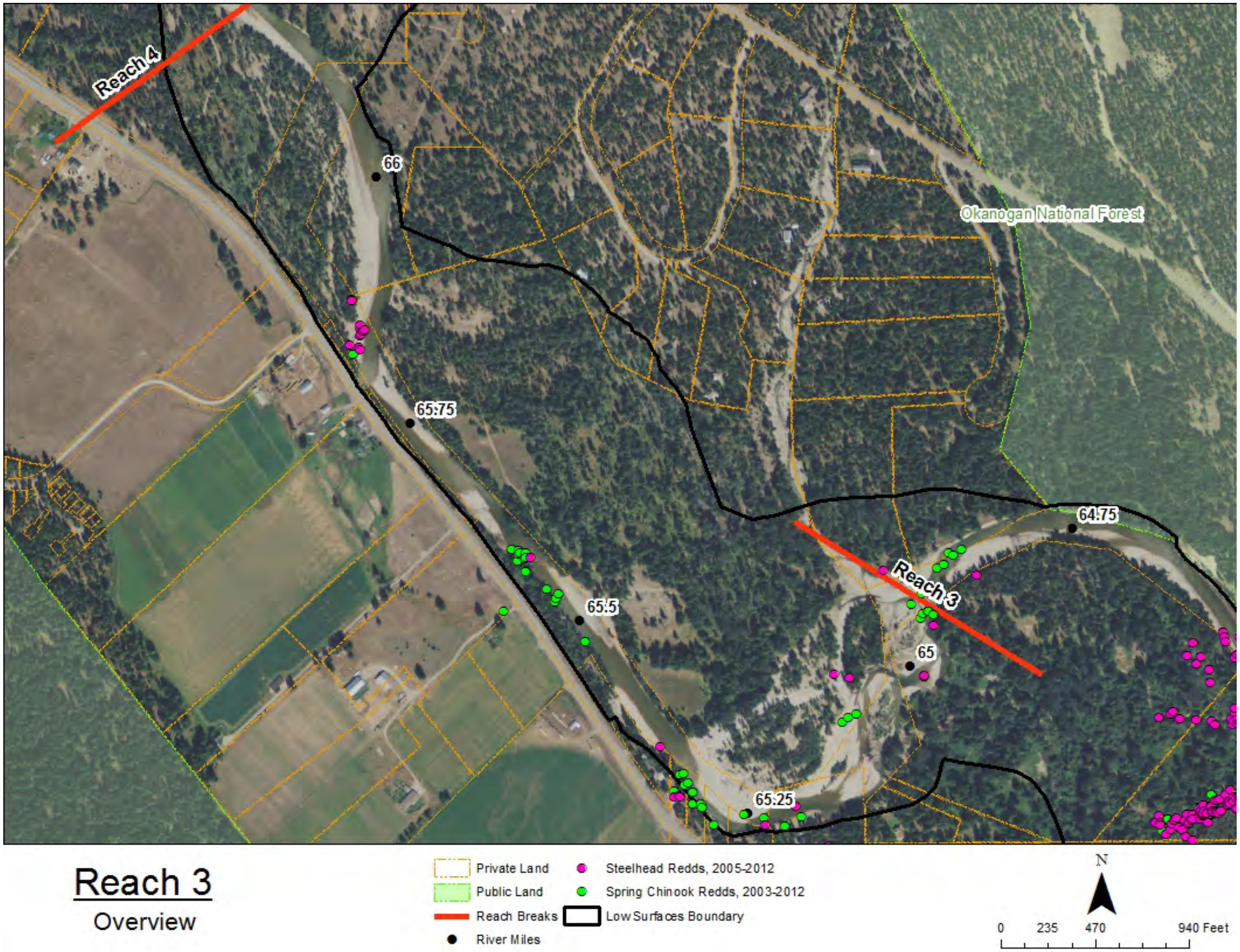

Figure 48. Reach 3 overview map with landownership and redd distribution.


Figure 49. Representative photo of upper section of Reach 3; looking downstream at RM 66.75. (9/3/2014)


Figure 50. Representative photo of lower section of Reach 3; looking downstream at RM 65.15. (9/3/2014)

Table 9. Reach 3 descriptive geomorphic metrics.

Metric	
Reach Length (miles)	1.3
River Miles	64.80 – 66.10
Valley Gradient	0.6%
Stream Gradient	0.4%
Sinuosity	1.22
Dominant Channel Type	Pool-riffle-glide
Average Bankfull Width (feet)	159
Average Floodplain Width (feet)	848
Dominant Substrate	cobble (48%); gravel (51%); boulder (1%)
Bank Stability/Channel Migration	At Risk *(See Section 2.12)*
Vertical Channel Stability	At Risk *(See Section 2.12)*
Confinement ratio	Unconfined *(See Table 5)*

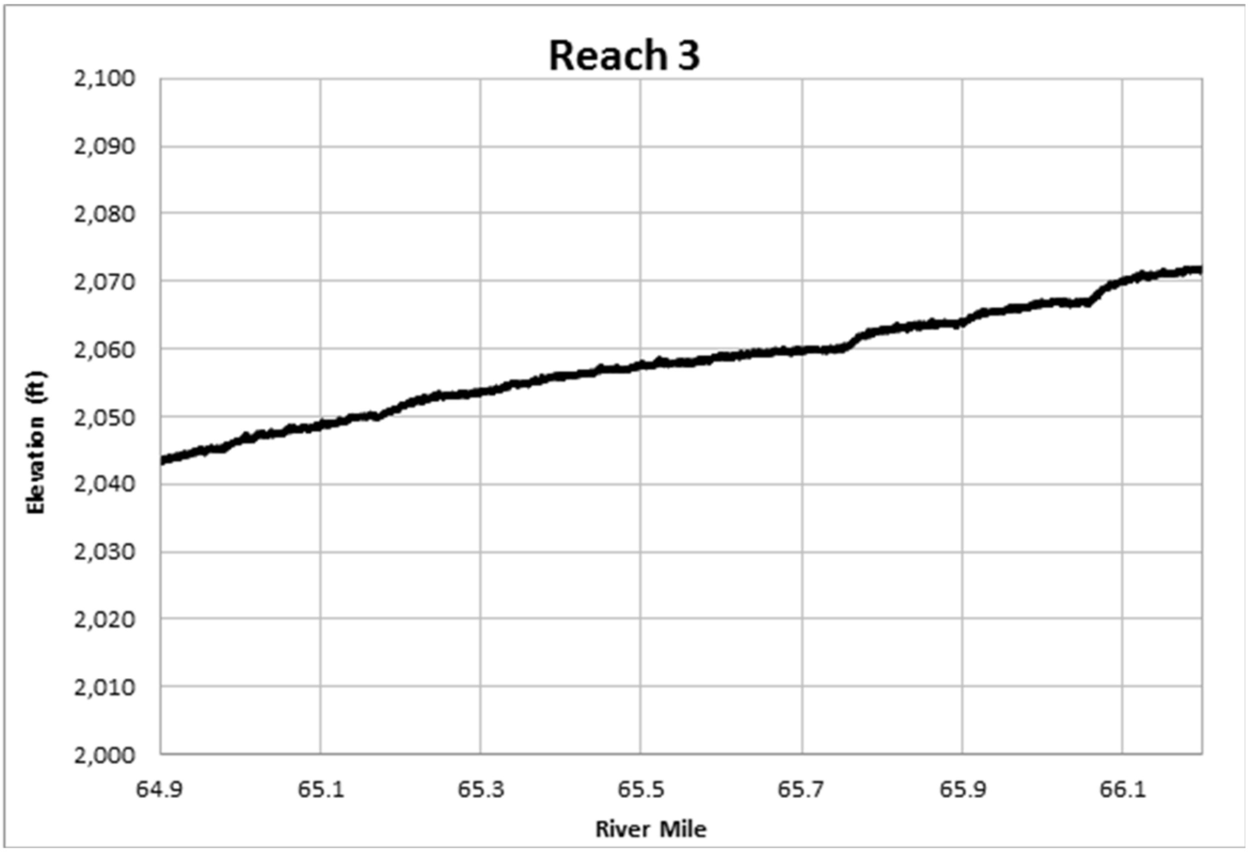

Figure 51. Longitudinal profile of the channel in Reach 3 (RM 64.80 to66.10).

3.3.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 3 is located in the center of a wide, U-shaped valley most recently carved by Quaternary glaciation. Increased discharge regimes during early Holocene glacial retreat resulted in the valley floor infilling with a thick layer of glacial outwash deposits (sand, gravel, cobbles and boulders). During glacial retreat, the tributaries also carried an increased sediment load, and this resulted in the creation of large alluvial fan deposits at the mouths of the Goat Creek and Little Boulder Creek drainages. The modern channel and floodplain of Reach 3 are inset between and below the outwash terraces and alluvial fans (Figure 52).

The channel and its modern floodplain surfaces occupy only a quarter of the valley floor. The average width of Reach 3 is 848 feet and the average bankfull width of the channel is 159 feet. Modern floodplain surfaces border the channel on river-right from RM 64.9 to 65.2, RM 65.4 to 65.6, and RM 65.8 to 66.2. The floodplain from RM 65.4 to 65.6 is a narrow strip of land between the channel and a glacial outwash terrace. This strip of floodplain has been disconnected by a levee and riprap. On river-left, the channel is bordered by floodplain surfaces from RM 64.95 to 66.85. However, levees and riprap partially disconnect the floodplain on river-left from RM 65.35 to 65.6. Along river-right, from RM 66.4 to 66.2, a glacial outwash terrace borders the river and its modern alluvial surfaces; it is six feet higher than the modern channel. Downstream from the glacial terrace on river-right, the reach borders the Little Boulder Creek alluvial fan. From RM 65.9 to 66.4, the channel is eroding the toe of the Little Boulder Creek alluvial fan. The resulting cut-bank is 10 to 12 feet higher than the modern active-channel. The Goat Creek alluvial fan borders the entire river-left side of the reach. The channel directly contacts the Goat Creek alluvial fan from RM 65.9 to 66.1. High floodplain surfaces skirt the edge of the glacial terrace in the upstream portion of the reach as well as the toe of the Goat Creek alluvial fan. The high floodplain surfaces in Reach 3 were created by the incision and channel migration of the Methow River into the glacial outwash and alluvial fan deposits.

The channel is notably influenced by the Little Boulder Creek and Goat Creek alluvial fans. The location of the channel within the valley has been determined by the extension of the fan deposits across the valley. Since glacial retreat, both creeks continue to contribute sediment and discharge to the Upper Methow River. Goat Creek's modern contributions of sediment and discharge are greater than Little Boulder Creek's. Today, Goat Creek and its modern alluvial fan are inset below historical fan deposits. The elevation of Goat Creek at its mouth (RM 64.9) is similar to the Methow River. Unlike Goat Creek, Little Boulder Creek is a hanging tributary at its confluence point (RM 65.25). This indicates that the modern discharge and stream power of Little Boulder Creek is not capable of incising into its paleo-fan deposits as quickly as the Methow River is locally incising. At the upstream border of the reach, approximately 720 feet from the channel, a pond was constructed within the Goat Creek alluvial fan. According to historical aerial imagery, the pond was dug in a meander scar that was abandoned between 1954 and 1964. The pond captures surface flow and groundwater for private irrigation and recreational purposes.

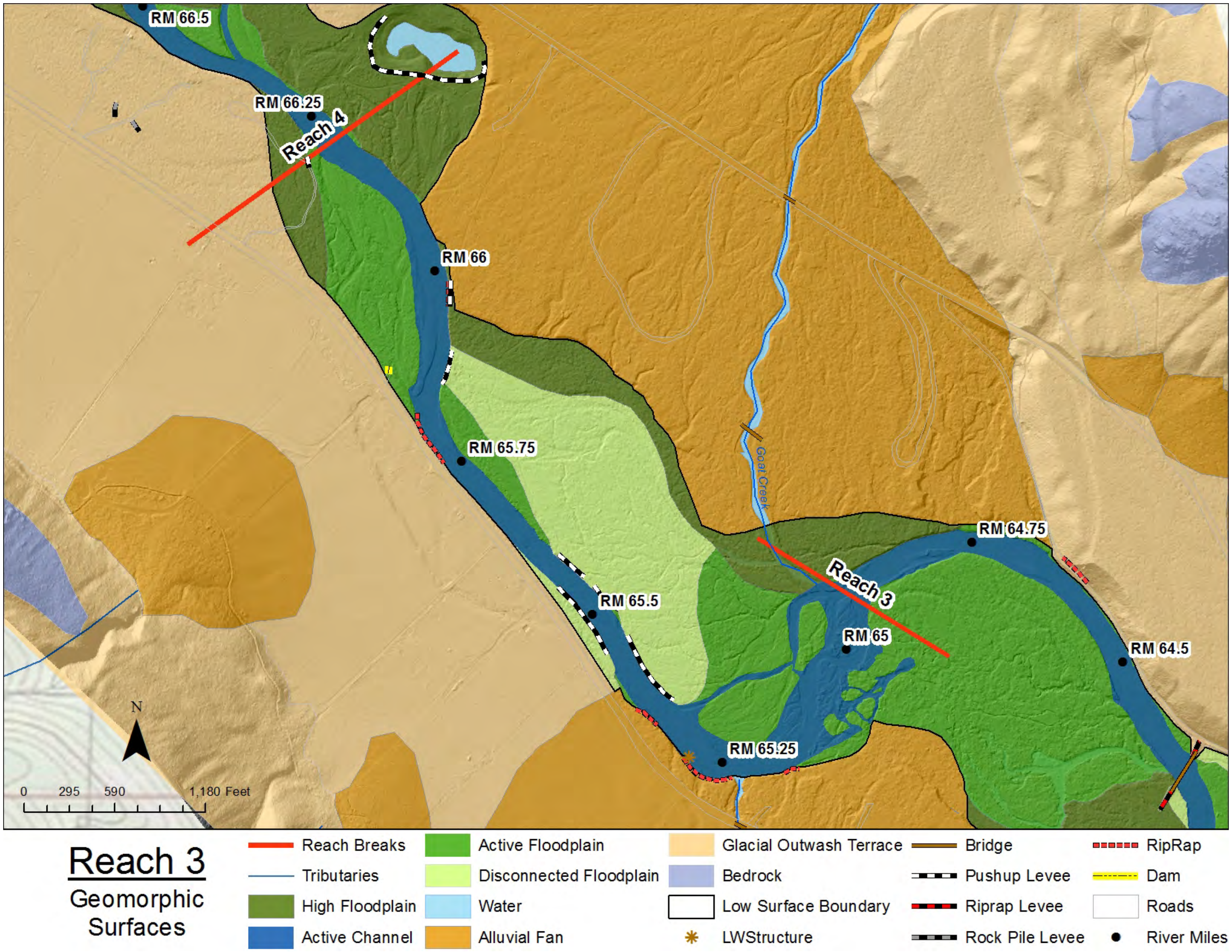

Figure 52. Geomorphic surfaces of Reach 3 with selected human-built features (levees, wood structures, riprap, check dams, bridges, and roads).

Hydrology

Reach 3 has a seasonally exaggerated flow regime with high spring and early summer snowmelt flows (Figure 54) and very low autumn and winter low flows. During low-flows, the channel can go completely subsurface or be reduced to just inches above the channel bed at riffles and glides. The extent of dewatering in this reach is dependent on the annual hydrograph. The scour pool at the meander bend (RM 65.3) is deep enough that it likely remains at least partially wetted annually during normal precipitation years. Summer thunderstorms are capable of temporarily raising surface water elevations in Reach 3 only if the storms generate enough discharge to recharge local groundwater elevations.

The valley floor and alluvial fans are composed primarily of coarse-grained material. This material supports active hyporheic through-flow and groundwater influx from upstream and from the adjacent terraces and alluvial fans. Reach 3 is the most downstream section in the study area considered to be a "losing" reach (Konrad 2003, Konrad et.al 2005). This means that the channel contributes its incoming surface flow to the subsurface groundwater reservoir. Thus, surface water in the channel of Reach 3 is only the exposed top inches-to-feet of the valley's groundwater reserve. This section of the channel can go dry in late summer and autumn (Caldwell and Atterson 1992, Andonaegui 2000, Konrad 2006a). See Section 2.6 of this report for a description of the groundwater to surface water interchange processes that occur here.

During field surveys, visible hyporheic flow was observed on the downstream end of active bar surfaces upstream of RM 65.25. Based on side-channel pool temperatures and clarity, the mainstem and multiple side-channels in the downstream section of Reach 3 are actively exchanging groundwater with surface water. The side-channels are important features in Reach 3 because they provide complex off-channel habitat that is particularly important during seasonal low- or no-flow periods.

Reach 3 receives surface flow discharge from Little Boulder Creek. According to the US Bureau of Reclamation's surface flow estimates (2008 – Appendix J), the reach receives an estimated 1.2% increase in discharge from Little Boulder Creek during high-flow events. Based on bank seepage and wetted off-channel features, the alluvial fans of Goat Creek and Little Boulder Creek contribute groundwater to the reach. However, the annual quantity and percent of that contribution are unknown.

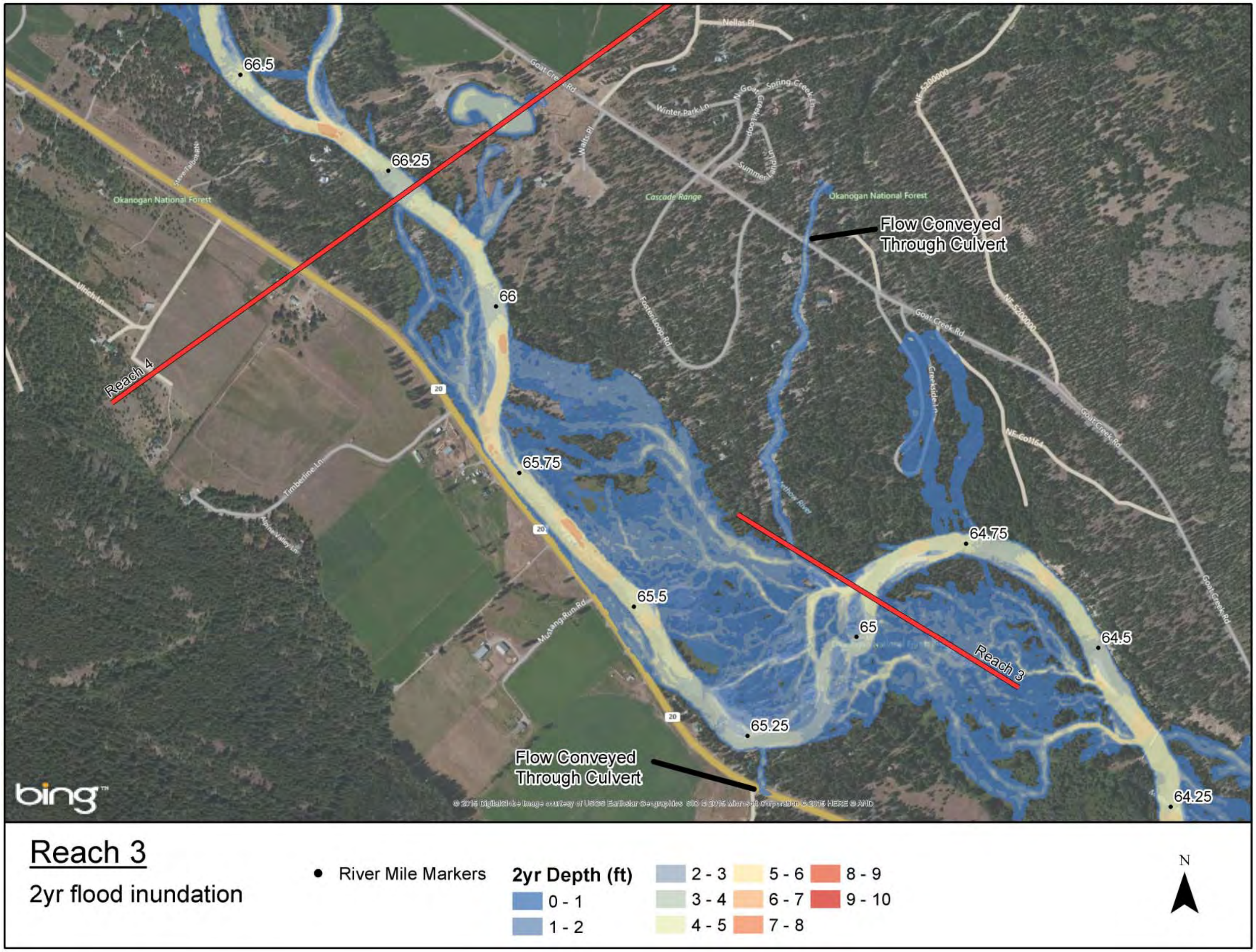

Figure 53. Floodplain inundation for 2YR flood in Reach 3 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

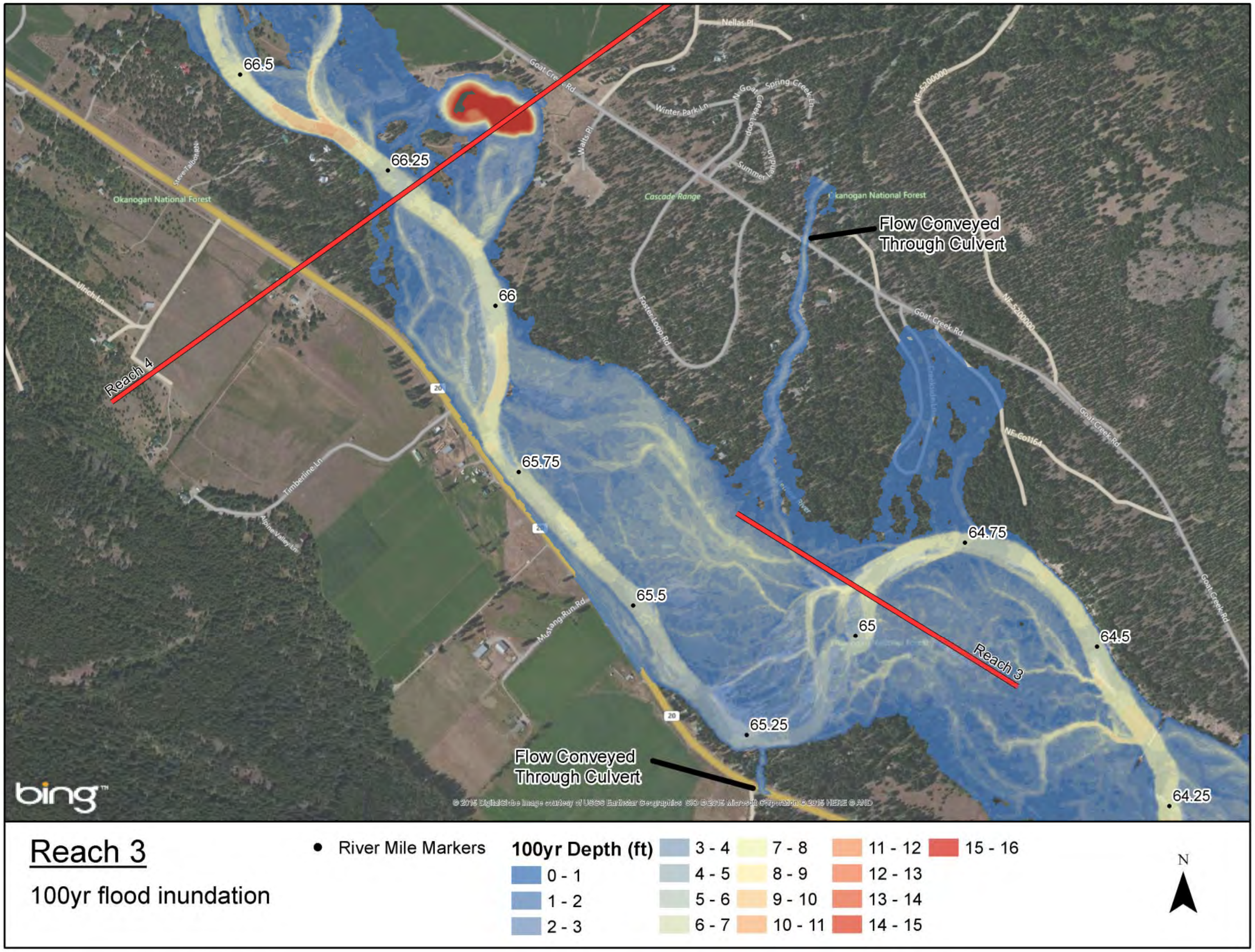

Figure 54. Floodplain inundation for 100YR flood in Reach 3 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Floodplain and Channel Migration Zone

Reach 3 is considered laterally semi-confined and vertically moderately unstable. Lateral confinement is due to a combination of natural features and human alterations. Natural, partial confinement is imposed by the high glacial outwash terrace on river-right and the alluvial fans of Goat Creek on river-left and Little Boulder Creek on river-right. From RM 65.3 to 66, levees and riprap have been constructed on sections of floodplain, terrace, and fan toes, further confining the channel. In this laterally-confined section (RM 65.3 to 66), the channel is mostly straight with only a slight meander from RM 65.85 to 66.2. The existing pools in this reach occur at the bend. The less confined section (RM 64.9 to 65.3) is between the confluences of Little Boulder Creek and Goat Creek. Here the channel is a sweeping meander with multiple side-channels and a braided channel form.

Upstream of RM 65.3, in the confined section of Reach 3, vertical stability is at risk. This is due in large part to the unnatural confinement of the channel between riprapped banks and levees. Confinement and straightening of a river often reduces vertical stability by instigating incision processes. According to historical aerial imagery, levees and riprap were constructed here after 1985. This exaggerated both pool scour and the lateral erosion of the cut-bank immediately downstream from the levees on river-right at RM 65.3. As a result, additional large-boulder riprap along the base of the high banks of the Little Boulder Creek alluvial fan was installed to reduce bank erosion and protect homes and the infrastructure of Hwy 20. Large cement slabs on the channel bed and a cement septic tank exposed in the bank at RM 65.3 are evidence of the risk of lateral bank erosion here due to upstream confinement. The lateral confinement of the channel has also led to channel-bed incision upstream of RM 65.3. Channel confinement with downstream pool scour establishes a positive feedback mechanism that is expected to result in continued incision. Downstream from RM 65.3, the channel's form changes from single-thread to partially braided with active side-channel and off-channel features. The large bars here are sourced from upstream bed scour as well as local sediment inputs from Goat Creek. Thus, the downstream section of the reach is transport limited with a locally reduced channel gradient and notably increased geomorphic complexity.

Fluvial scarring indicates that the modern floodplains in Reach 3 are inundated by high-flow events every two to ten years. However, historical aerial imagery and field observation of overbank deposition patterns indicate that the constructed levees and riprap in Reach 3 have reduced active-channel width and normal floodplain inundation. This is most evident from RM 65.35 to 66.75 along river-left, and on river-right from RM 65.4 to 65.6. As a result, the floodplains behind the levees and armored banks have been classified as disconnected. Channel migration has been limited since the construction of the levees and riprap (Figure 55).

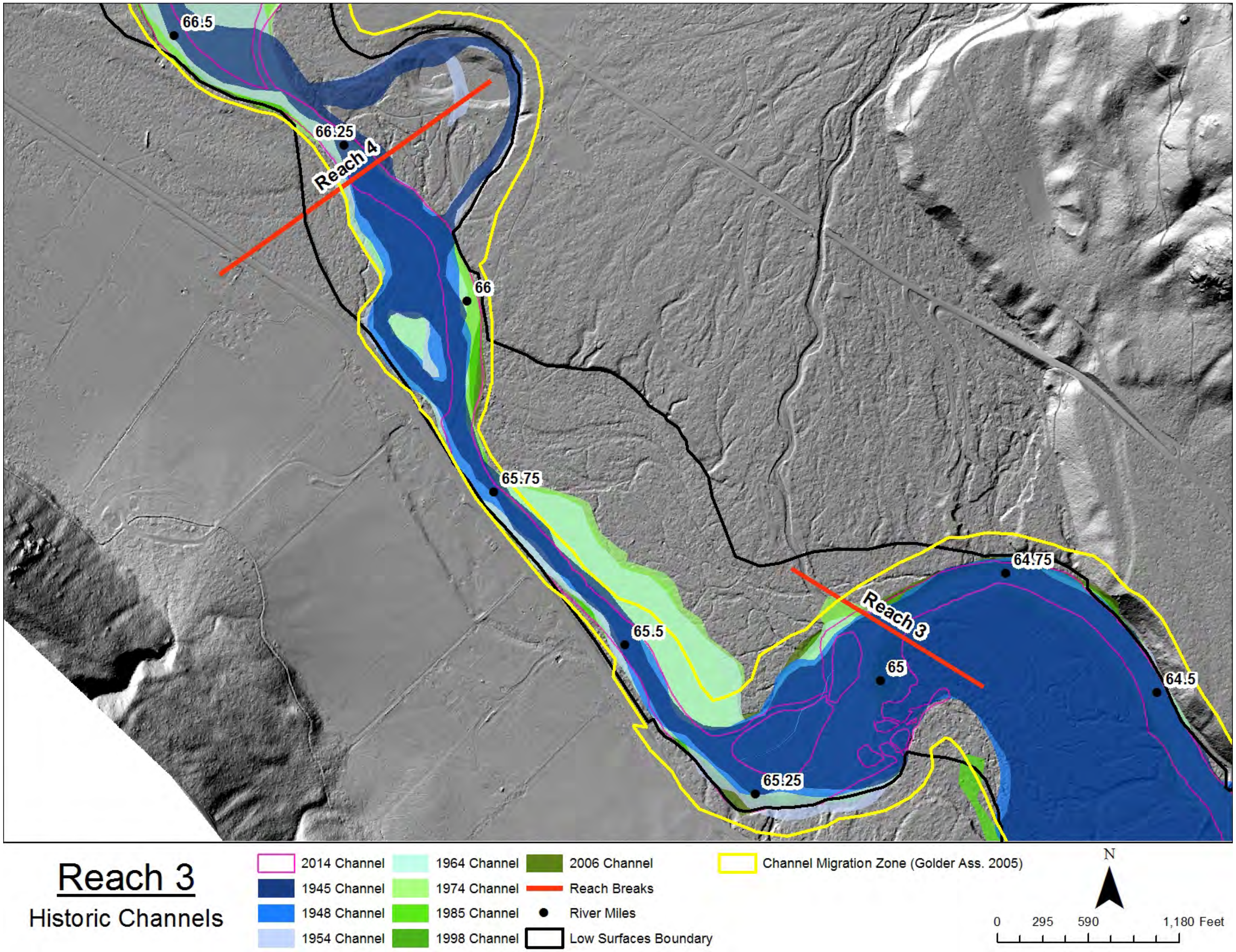

Figure 55. Historical channel locations in Reach 3.

Sediment

The substrate of Reach 3 is dominated by gravels (51%) and cobbles (48%); sparse boulders account for only 1%. The bedload is sourced from upstream inputs, the bed of the active channel, bank erosion, and contributions from Goat Creek and Little Boulder Creek. Available bank sediment is sourced from the unarmored sections of floodplains, glacial terrace, and alluvial fan toes. Floodplains are composed of cobbles and gravels and topped with sand. Some soil development is occurring on the modern alluvial surfaces. Bedload sediment throughout the reach is well sorted (has a relatively similar diameter size range) and rounded, indicating that much of the substrate is transported fluvially during high flow events. Sediment is stored in the active bars. Bar size and distribution is greatest downstream of RM 65.35. Gravels and sands accumulate on active floodplain surfaces as overbank deposits. Sand is also found in some of the side-channel pools – in the downstream section of the reach where the gradient is locally reduced.

Large Wood

Reach 3 has plentiful large wood in the channel but almost all of it is located in the unconfined section of the channel downstream of RM 65.3. In-channel wood distribution in the reach is presented in Figure 56 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. Four log jams and 190 logs were counted (the equivalent of 149 pieces per mile). Large wood accumulations in the downstream section are sourced both locally and from upstream. Potential wood recruitment from the banks of Reach 3 is limited at cleared home sites and along the large-boulder riprapped banks. From RM 65.4 to 65.8, the available forest is reduced to a vegetated-buffer that is only two to ten trees wide between the channel and the Highway 20 road prism on river-right. Recruitment from floodplain surfaces is also limited by the levees and riprap that restrict lateral migration and floodplain connectivity. Only temporary retention of large wood occurs on the narrow, longitudinal bars located in the leveed section of the reach (RM 65.3 to 66). The large wood accumulations in the downstream section of the reach maintain large pools and bars. The mainstem is too wide for channel-spanning logs to occur, but on river-right from RM 64.9 to 65.15, channel-spanning wood is plentiful in the narrow side-channels.

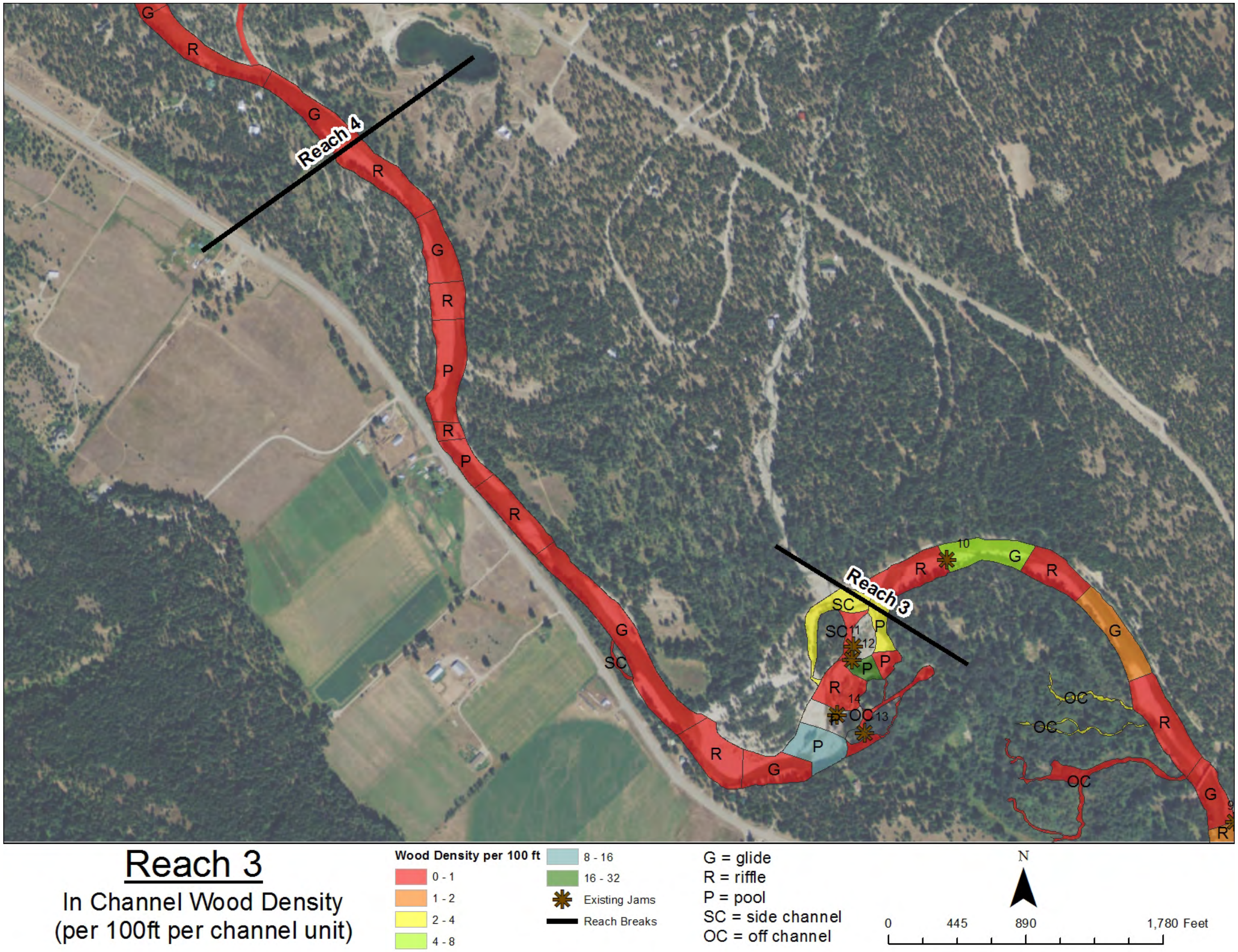

Figure 56. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 3.

Vegetation

In Reach 3, vegetation density and type is variable (Figure 57). In the downstream-most portion of the reach (RM 64.9 to 65.15), the banks and floodplain are vegetated with a dense, maturing forest consisting of trees that range from 25 to 100 years old. There is a mix of conifer and deciduous trees, such as fir and cottonwood. This forest has a low, brushy understory composed mostly of snowberry and Oregon grape. The recently active floodplain surfaces and high bars in this lower portion of the reach are vegetated with young willow, cottonwood, alder, and some sparse conifers. These trees range from five to 25 years old, and their age aids in identifying the extent of inundation and sediment mobilization that have occurred during recent flood events. Moderately dense maturing forests also exist on river-right in the upper portion of the reach from RM 65.8 to 66.2.

The terrace and alluvial fans on river-right (from RM 65.15 to 65.8) host thinned forests dominated by pine and fir, and sparse undergrowth (forbs and grasses). Exceptions to this occur along water sources where the underbrush increases in complexity and density. Recent forest thinning and clearing on the floodplain on river-left (from RM 65.2 to 66.2) have reduced floodplain vegetation complexity and roughness. On river-right, from RM 65.15 to 65.8, vegetation was removed and thinned for home sites and the construction of the Hwy 20 road prism. However, a buffer of maturing trees (two to ten deep) lines most of the channel banks throughout the reach – except near the home sites and riprapped banks on river-right from RM 65.15 to 65.35. The maturing trees offer shade and nutrients along the sections of the channel where they occur. However, the width of the channel limits the percent of water surface that can receive shade. Along the riprapped banks, sparse patches of willow and dogwood have taken root between the angular boulders.

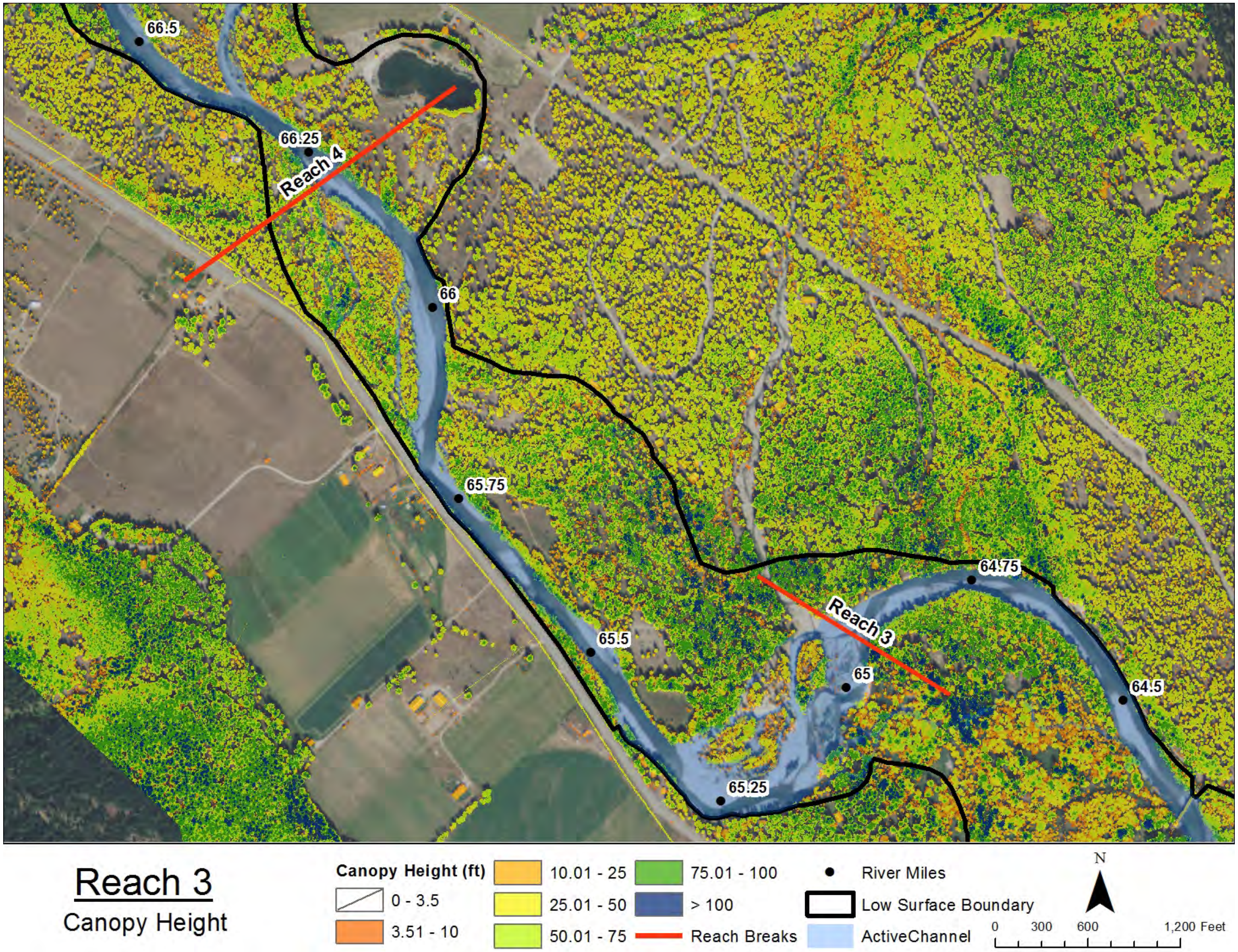

Figure 57. Vegetation canopy height for Reach 1 -- derived from LiDAR first return (highest hit) data (includes buildings and other human infrastructures).

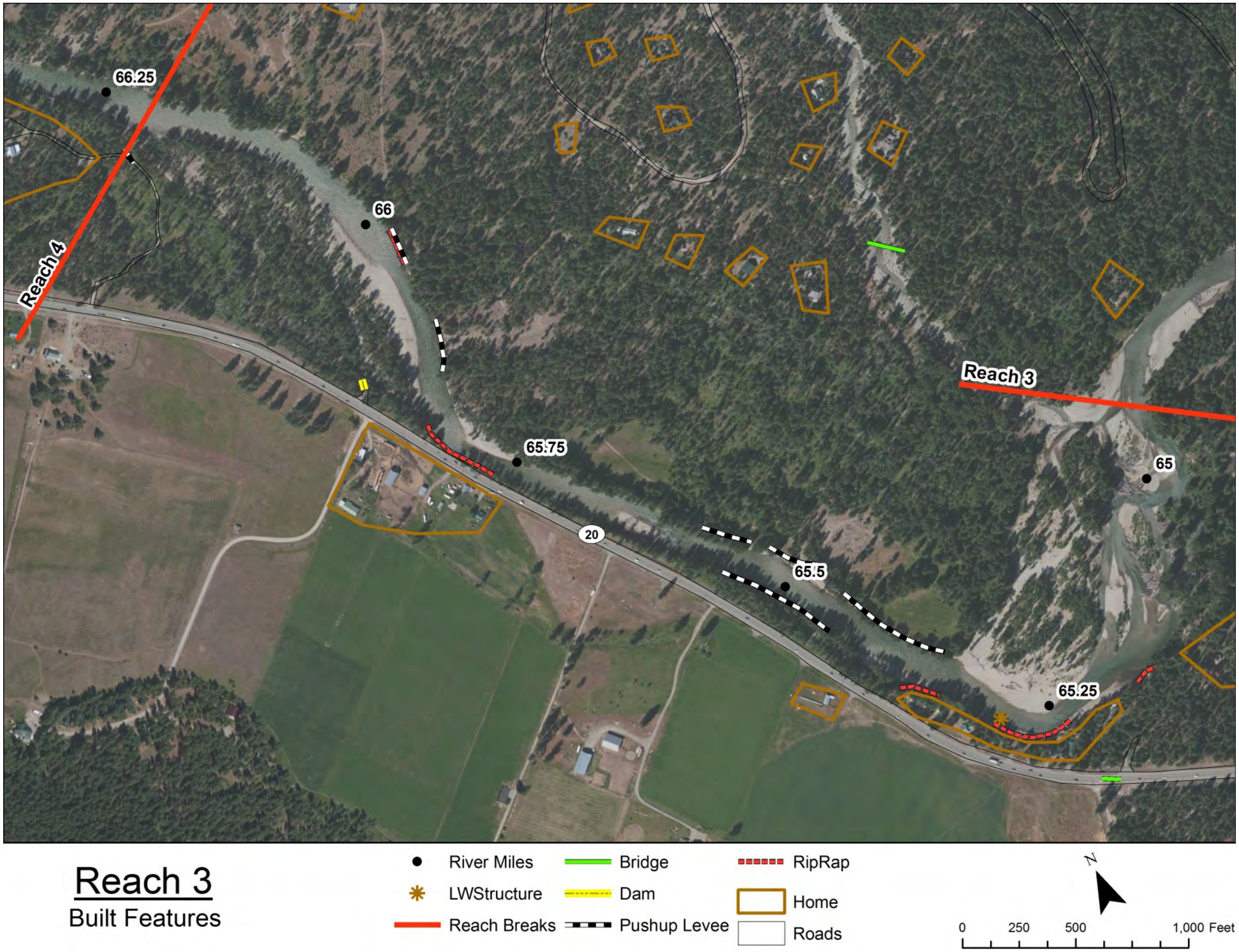

Figure 58. Primary human features in Reach 3.

3.3.3 Human Alterations

Human features are mapped in Figure 58. The primary human alterations in the reach include the following, and are described further in the subsections below.

- Changes to floodplain function and channel migration
- Changes to streambank complexity and riparian impacts
- Changes to flow inputs and sediment supply

Changes to Floodplain Function and Channel Migration

Floodplain function and channel migration have been reduced in Reach 3 as a result of constructed levees and boulder riprap. Approximately one-third of the available floodplain surfaces in Reach 3 have been disconnected from the channel by the construction of push-up levees. The levees have been built on river-right from RM 65.45 to 65.55, and on river-left from RM 65.35 to 65.55, at RM 65.85 (230 feet long), and at RM 65.9 (170 feet long). The most upstream bank protection is a boulder riprap reinforced levee at RM 65.9 on river-left. This levee aids in diverting the channel away from the alluvial fan toe and floodplain surfaces on this side of the reach. In general, the levees range from approximately two to four feet high and are composed of local boulders, cobbles, and soil (Figure 59). From RM 65.35 to 65.55, the channel is straight and basically locked in place due to the levees constructed on both sides of the channel. Here, the channel migration zone has been reduced from approximately 1,000 feet to the width of the channel (approximately 160 feet). Large boulder riprap armors the banks of the channel on river-right at RM 65.15 (100 feet long), at RM 65.35 (175 feet long), from RM 65.25 to 65.3, and from RM 65.75 to 65.8. The riprap between RM 65.15 and 65.35 is installed at the base of a high cut-bank where private homes are located. From RM 65.75 to 65.8, the riprap was installed to reduce bank erosion and protect the infrastructure of Hwy 20 (which lies approximately twenty feet behind the bank). The levees and riprap throughout Reach 3 restrict lateral channel migration and disconnect floodplain surfaces by stabilizing the banks and reducing the frequency and extent of inundation.

Figure 59. Push-up levee from land-ward side in Reach 3 on river-left at RM 65.35. (9/3/2014)

Changes to Streambank Complexity and Riparian Impacts

Streambank complexity and riparian vegetation in Reach 3 have been reduced along the riprapped banks. The riprap inhibits bank erosion, and thus alters localized sediment inputs into the system. This is particularly evident along the riprapped cut-bank on river-right from RM 65.25 to 65.3 and from RM 65.75 to 65.8 (Figure 60). The riprap also reduces the complexity of the riparian vegetation community and notably decreases the potential for the establishment of mature stands of trees along these banks. Additionally, this reduces localized shade to the channel and removes the potential for large wood recruitment in these areas. At the private residence on river-right (RM 65.15 to 65.35) and between the channel and Hwy 20 (RM 65.35 to 65.8), vegetation clearing and thinning near the channel bank further reduces the complexity of riparian vegetation and its corresponding benefits to channel function. Historical logging practices at the turn of the century cleared vegetation and utilized the river to transport cut logs to mill sites downstream (Devin 1997). This has likely reduced riparian function and channel complexity over the last century.

Most of the channel banks in Reach 3 are treed, however this vegetation buffer is only 10 to 20 feet wide in some places. Partial or complete vegetation removal on adjacent floodplain surfaces reduces bank and surface roughness and stability. On river-left, between RM 65.35 and RM 66.2 (the upstream boundary), floodplain forests have been thinned and cleared. On river-right, between RM 65.15 and 65.85, adjacent banks and surfaces have also been cleared for agricultural purposes, road construction, and home-site development. Reduced vegetation and the existence of the road and home sites alter normal surface flow routing and sediment delivery across the floodplain.

Figure 60. Riprap protected cut bank toe in Reach 3 on river-right at RM 65.30. (9/3/2014)

Changes to Flow Inputs and Sediment Supply

Roads and tributary crossings outside of the active channel and floodplain alter the natural routing of surface water inputs across the glacial outwash terraces and alluvial fans that border Reach 3. The raised road berm of Hwy 20 traverses the glacial outwash and alluvial fan terraces on the west side of the reach. Due to this road berm, natural surface water run-off from the terrace and hillslopes west of Hwy 20 are diverted through ditches, irrigation canals, and culverts. For example, Little Boulder Creek passes under Hwy 20 through a culvert. On the east side of the reach, Goat Creek passes under the Goat Creek Road at a small bridge, and then it passes under a foot bridge – both of which have abutments on the banks of the tributary. The footbridge is part of the Methow Community Trail network; these trails cross the alluvial fan and disconnected floodplain surfaces on river-left. The bridge crossings and culverts alter tributary sediment inputs by restricting the tributary's pathway across its alluvial fan. Additionally, driveways and access roads related to private residences on both sides of the reach likely alter surface water infiltration and run-off patterns.

Another constructed feature that interrupts natural surface and groundwater inputs to Reach 3 is the pond located at the upstream boundary of the reach on river-left (Figure 61). The pond was dug in a meander scar that, according to aerial imagery, was abandoned between 1954 and 1964. A levee (composed of the material removed to create the pond) is located at the edge of the feature, between the pond and the channel. It appears that one purpose of this levee is to protect the pond from potential flood inundation or channel reactivation by the mainstem Methow River. The pond is dug below the elevation of the channel bed, thus allowing it to capture area groundwater. Surface water from a spring sourced off the Goat Creek alluvial fan is also captured by the pond via a small rock-lined canal. The pond is used for private recreation and irrigation. The portion of the floodplain where the pond is located is designated as a high floodplain surface. This high floodplain surface and similar features in Reach 3 appear to be the result of local channel incision.

Historical gold mining in the early 20th century at Goat Creek, along with extensive logging in the lower portion of the tributary, likely increased past and perhaps modern sediment inputs to the reach (USBR 2008 – Appendix O).

Figure 61. Dug pond and levee (foreground) located in abandoned channel scar on river-left floodplain; upstream border of Reach 3 at RM 66.25. (8/28/2014)

3.3.4 Recommended Actions

Recommended actions in Reach 3 are focused primarily at the upstream section of the reach and include increasing channel complexity and lateral dynamics as well as improving floodplain connectivity. Complexity and lateral dynamics can be addressed by adding large wood jams to the main channel to enhance and create bar and island development. Channel margin jams are suggested for pool development and to enhance existing pool features. Floodplain connectivity can be addressed by removing unnecessary levees and bank armoring. The proximity of Highway 20 will need to be considered with these actions. Native riparian vegetation restoration where clearing has occurred is also recommended. Restoration recommendations recognize the importance of maintaining connectivity of the mainstem channel to perennial or groundwater fed tributaries and side-channels. This has been identified as a critical component for fish survival in a system with the potential to seasonally dewater. The lower portion of Reach 3 is highly complex, full of wood, and very dynamic (Figure 62). No significant work in this lower section is recommended, as it is mainly an area that should be targeted for protection, including a highly-functioning side-channel in the river-right floodplain (RM 64.4 – 65).

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

Figure 62. Dynamic, well-functioning downstream portion of Reach 3. (8/29/2014)

3.4 REACH 4

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.4.1 Reach Overview

Reach 4 is 3.1 miles long and extends from RM 66.1 to the confluence of Early Winters Creek at RM 69.2. Property within and along Reach 4 is a combination of Okanogan National Forest, private landowners, and a section of public land designated as a "common area"(Figure 63). The channel is a single-thread stream with extended riffles and glides (Figure 64). Bar development is minimal in the upper two-thirds of the reach, but large mid-channel bars with extensive wood jams exist immediately downstream of the Mazama Bridge. At these bars and log jams, channel complexity increases, including the presence of pools. The reach is considered semi-confined by glacial outwash terraces and the Early Winters Creek alluvial fan. The active floodplain has an average width of 365 feet and the channel's average bankfull width is 129 feet. The channel meanders gradually, with a sinuosity ratio of 1.09. In this Reach, the gradient of both the river and its floodplain is 0.5 percent. These and other reach metrics are provided in Table 10 and Figure 65.

The outside meander bends are predominately tall terrace cut-banks composed of glacial outwash that moderately confine the channel. The modern floodplain surfaces occupy the inside portions of the meanders. Scarring and deposition patterns indicate that overbank flood events inundate the majority of the active floodplain surface every two to ten years. This is confirmed by hydraulic modeling. The relative elevation of the floodplain surfaces to the bed of the channel and high water marks observed in the field indicate that this semi-confined reach experiences a greater fluctuation in river stage than the reaches upstream and downstream from it. The substrate of the channel is dominated by cobbles and gravels. The active floodplain, although also composed of cobbles and gravels, is topped with sand and loam. The high floodplain surfaces are similar in composition, but they are topped with developing soils.

The habitat conditions in Reach 4 are discussed in Appendix A. Based on the REI analysis, 9 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). The salmon and steelhead redd distributions for the reach are mapped in Figure 63. Along sections of the floodplain and terrace banks, home-sites have been developed and vegetation has been cleared or thinned. Most of the modern floodplain banks are vegetated with maturing forests, and this enhances the roughness of the bank and floodplain surfaces. Floodplain grading has reduced the connectivity of two small sections of the floodplain at mid-reach. Riprap-enforced abutments and a levee at the Mazama Bridge locally constrict the channel. Along a high-flow activated side-channel in the downstream portion of the reach, rock piles and cement bridge abutments restrict lateral channel migration potential. Channel-bed incision is the dominating geomorphic process in this reach – both historically and recently. The lack of large wood in the channel in the upper third of the reach is likely due to past channel clearing and minimal lateral channel migration.

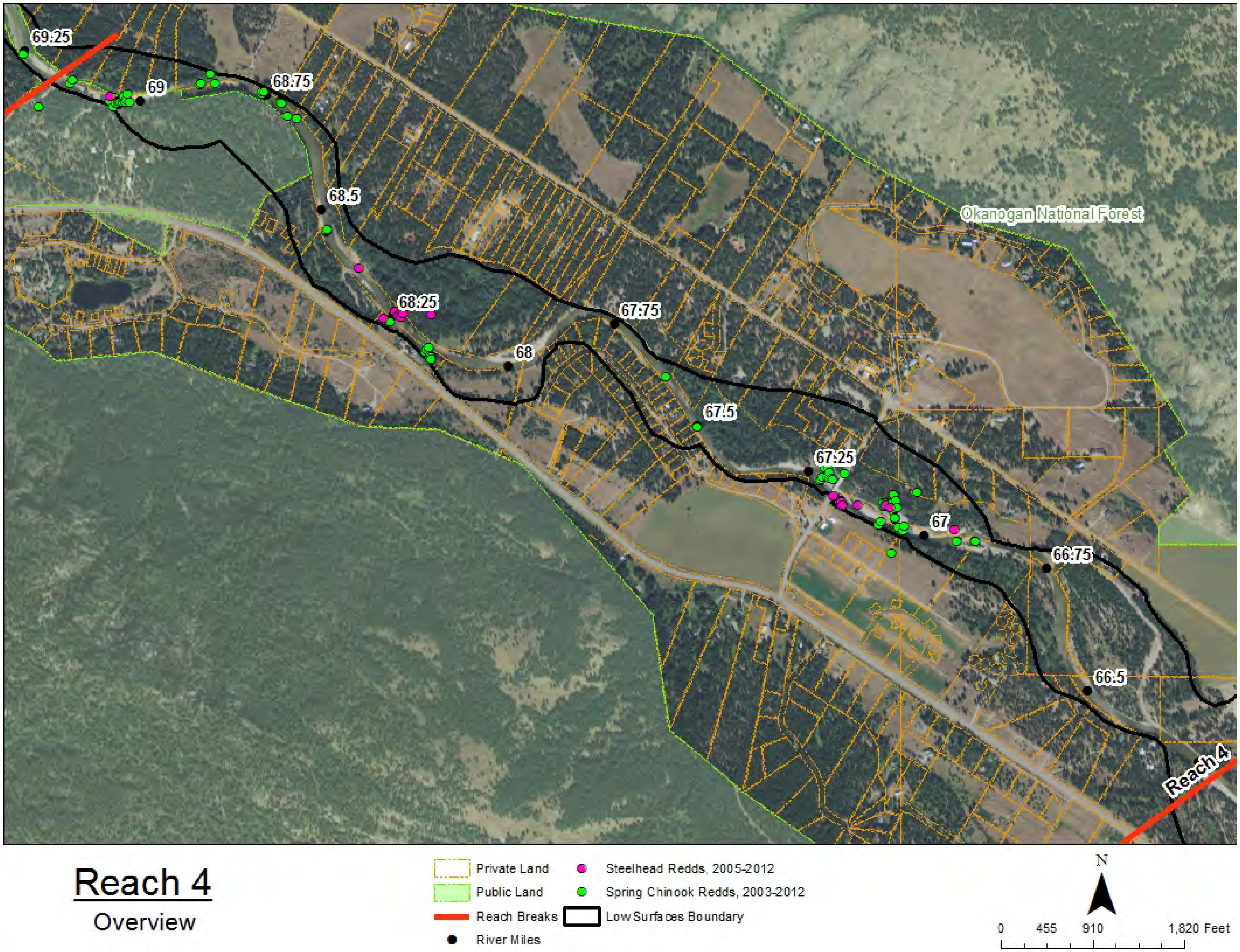

Figure 63. Reach 4 overview map with land ownership and redd distribution.

Figure 64. Representative photo of Reach 4; looking downstream at RM 68. (8/27/2014)

Table 10. Reach 4 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	3.1
River Miles	66.10 – 69.2
Valley Gradient	0.5%
Stream Gradient	0.5%
Sinuosity	1.09
Dominant Channel Type	Riffle-glide
Average Bankfull Width (feet)	129
Average Floodplain Width (feet)	365
Dominant Substrate	cobble (66%); gravel (29%); boulder (5%)
Bank Stability/Channel Migration	Unacceptable *(See Section 2.12)*
Vertical Channel Stability	At risk *(See Section 2.12)*
Confinement ratio	Moderate *(See Table 5)*

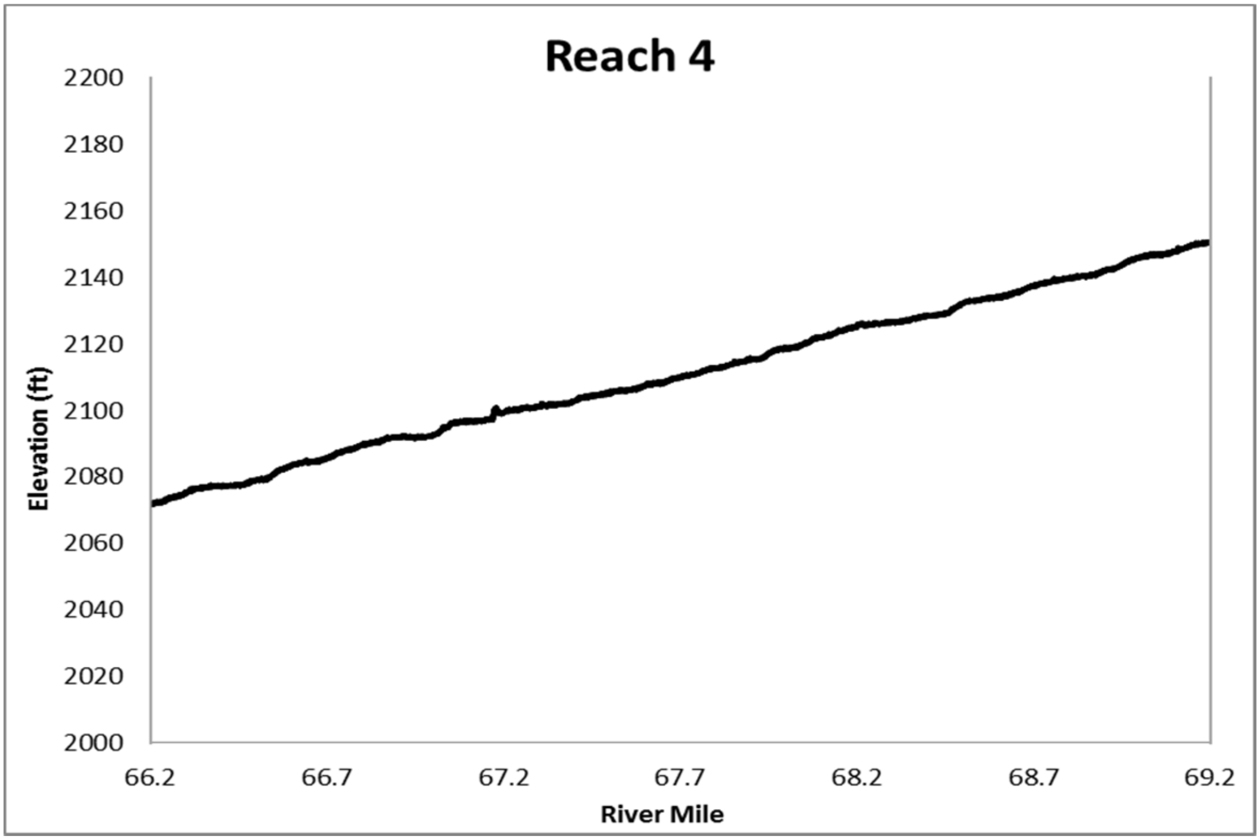

Figure 65. Longitudinal profile of the channel in Reach 4 (RM 66.10 to 69.2).

3.4.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 4 is located in a wide, glacially-carved, U-shaped valley most recently carved by Quaternary glaciation. Increased discharge and sediment regimes during early Holocene periods of glacial retreat resulted in a thick layer of glacial outwash deposits filling the valley floor. At the mouths of the tributaries that enter the valley, large alluvial fans of outwash material were also created during this time. The channel runs through the middle of the valley without contacting the steep bedrock walls. The modern channel and its relatively narrow floodplain are inset into the glacial outwash terrace and the Early Winters Creek alluvial fan. Other alluvial fans spread across the outwash terrace at Theise Creek (on the east side of the valley), at Looney Creek, and at two unnamed creeks on the west side of the valley. Although these tributaries contribute discharge to the system, none of their fan deposits extend far enough into the valley to interact with the modern channel or the floodplains of Reach 4 (Figure 66).

The active and high floodplain surfaces of Reach 4 are relatively narrow compared to those upstream and downstream. The valley floor is approximately 4,000 feet wide, yet the average active floodplain width of Reach 4 is just 365 feet. At RM 67.2, the channel is constricted between the bridge abutments of the Mazama Bridge and its associated riprapped and leveed banks. Otherwise, the channel meanders gradually between the high banks of the glacial outwash terrace and its inset floodplains. The outside meander bends often contact high terrace cut-banks composed of sands, cobbles and boulders (Figure 67). Floodplain surfaces are primarily located on the inside bends of the meanders. Where surface grading and human development has not altered surface topography of the glacial outwash terrace, subtle scarring and insets indicate that channel incision into the outwash terrace was initially gradual. Incision into the terrace was then exaggerated, most likely due to the increased discharge inputs from Early Winters Creek during glacial retreat. The increased discharge created a local hydro-geomorphic relationship where the capacity of the flow to transport sediment is greater than the available local sediment. In response to this condition, channels incise vertically instead of laterally migrating and creating floodplains with the excess sediment (Simon and Rinaldi 2006). As a result, today a relatively narrow inset floodplain exists throughout much of the reach. The active floodplain surfaces are flanked in most instances with a high floodplain surface. This indicates that incision remains a primary geomorphic process in the modern channel evolution of Reach 4.

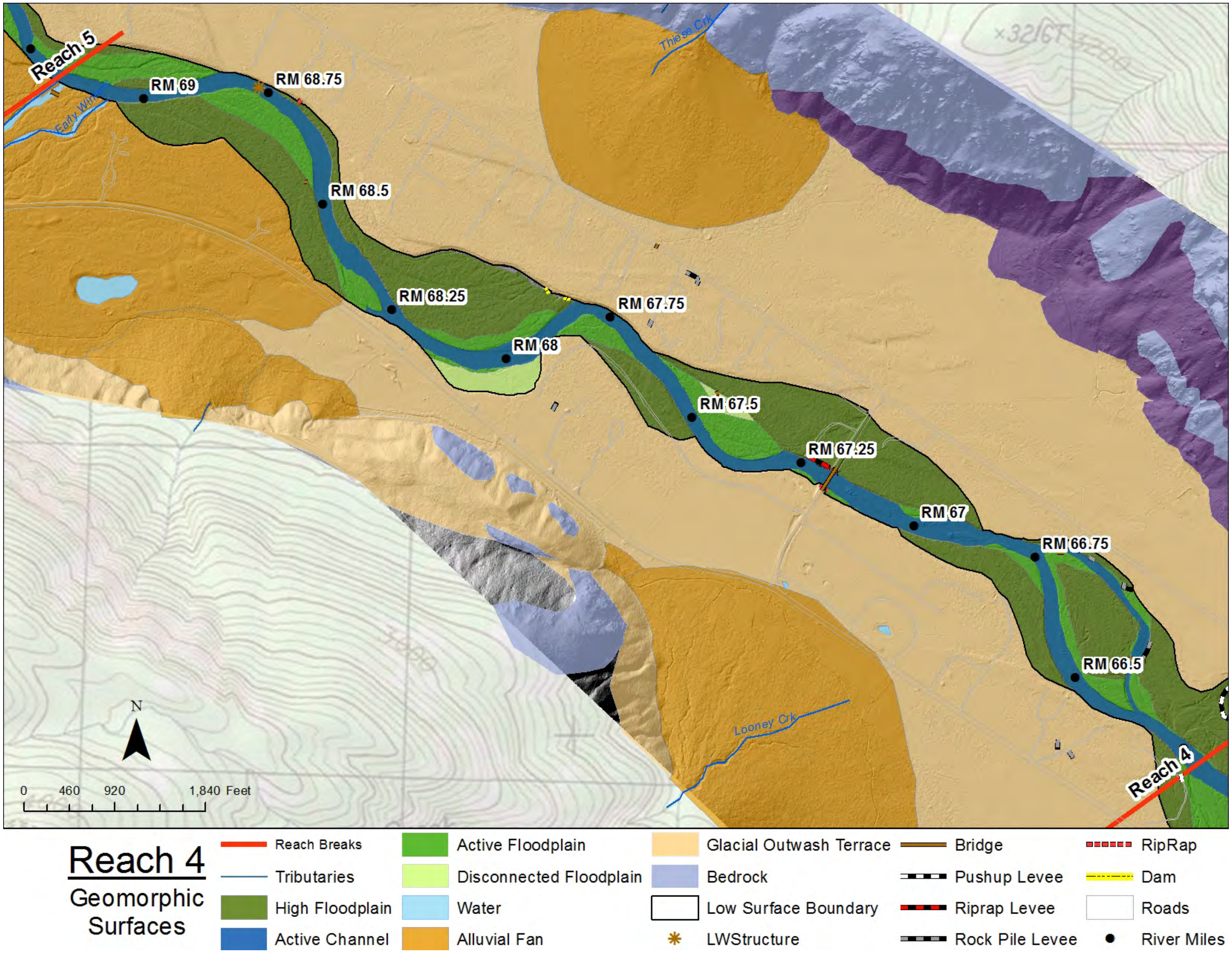

Figure 66. Geomorphic surfaces of Reach 4 with human-built features (levees, riprap, check dams, bridgess, and roads).

Figure 67. Glacial outwash terrace cut bank on river-left; looking downstream at RM 67.75. (8/27/2014)

The channel in Reach 4 is single-thread with only two overflow side-channel features and one off-channel, groundwater-fed tributary. The groundwater-fed tributary enters the channel on river-left (east side of the channel) at RM 67.8. This tributary originates from groundwater seepage at the base of the glacial terrace. It is located in an abandoned channel scar that is inset between the outwash terrace and a high floodplain surface. The tributary is a complex off-channel feature with an abandoned beaver dam, racked wood which creates small pools, and substrate of sands to gravel (Figure 68). Tree and shrub vegetation along the banks of the tributary provide shade to this off-channel feature. Decreased water temperatures were observed in the deeper pools of this tributary due to groundwater influx. In August, 2014, fingerlings were seen in the pools of this tributary during field observation. Maintaining the connectivity of this tributary to the mainstem channel is important because it provides approximately 600 yards of cool, shaded, off-channel habitat. Another groundwater-fed feature is offset from the channel by approximately 180 feet on river-left between RM 67.45 and RM 67.65. This feature also occupies an abandoned channel scar, but its surface water has been captured by a dug pond with a levee. The levee ensures that the feature remains disconnected from channel processes.

Figure 68. Ground-water fed tributary with abandoned beaver dam; looking upstream near RM 67.8. (8/27/2014)

Two side-channels that are activated during high flow locally reduce incision potential by providing additional channel area for flow transmission. A side-channel that runs from RM 66.35 to 66.75 on river-left is over 700 yards long (2,100 feet) (Figure 69). The other side-channel runs from RM 68.25 to 68.35 on river-right (west side of the channel). It is only 225 yards long (675 feet) but it offers a backwater feature during low flows that, if maintained, could provide perennial off-channel habitat. Both sode channel features have been scoured and then filled with large cobbles and gravel during high flow events.

Figure 69. High flow side-channel (dry) on river-left near RM 67.75; looking upstream. (8/27/2014).

Throughout Reach 4, the river's path gradually meanders with a sinuosity of 1.09. Fairly stable banks and minimal channel complexity confirm that this reach is relatively stable laterally. The primary channel units are extended riffles and glides with a low frequency of pools. There is a scour pool downstream from the confluence with Early Winters Creek. The series of large pools downstream from the Mazama Bridge correlate with the localized increase in channel complexity. The localized complexity is induced by accumulations of sediment and wood that create large, mid-channel bars with extensive log jams from RM 66.85 to 67.15 (Figure 70). The average bankfull width of the channel in Reach 4 is 129 feet with its widest point (approximately 230 feet) occurring in the section with the large wood jams and bars. Channel complexity increases in proximity to the large jams and bars, while lateral channel processes only slightly increase.

Figure 70. Large wood accumulations on cobble bars; looking downstream from the Mazama Bridge (RM 67.2). (8/28/2014)

The Early Winters Creek drainage, also carved by glaciers and then filled with outwash during retreat, is now inset below its historical floodplain and alluvial fan deposits. Scarring across the fan surface indicates multiple historical channel pathways upstream from the modern confluence point. Today, discharge contributions from Early Winters Creek still noticeably increase the flow in the Methow River. However, gravel-to-cobble sediment contributions from the creek do not appear to increase bar density or the presence of smaller grained sediment downstream from the confluence. Bar development at the mouth of the confluence consists of a single side-channel bar composed of large cobbles. All other sediment contributions appear to be transported downstream. Large-grained sediment contributions from high flow events in Early Winters Creek have created a subtle grade control feature in the mainstem channel that influences upstream channel elevation and localized channel gradient. The current channel bed of Early Winters Creek is composed of large cobbles and small boulders. At the confluence point, Early Winters Creek drops a few feet along the sloping toe of its alluvial fan into the Methow River. Even though this creek is incising into its fan, it is not able to incise at the rate of the mainstem channel. This continues to instigate bed incision in the lower portion of Early Winters Creek during flows with a transport capacity large enough to mobilize the available bedload. Less capable flows move laterally to dissipate stream energy across the fan toe. A secondary channel off of Early Winters Creek enters the Methow River approximately 450 feet downstream from the main confluence.

Hydrology

Reach 4 has a seasonally fluctuating flow regime. Spring snowmelt high flow events activate overflow channels. Flood events inundate available low floodplain surfaces on a regular basis (two to ten year flood recurrence) (Figure 71). Late summer, autumn, and winter low flows often leave portions of the reach dry, with isolated pools susceptible to temperature extremes (Caldwell and Atterson 1992, Andonaegui 2000, Konrad 2006a). Summer and autumn thunderstorms are capable of temporarily raising surface water elevations if discharge inputs are substantial enough to recharge groundwater elevations. The active floodplain surfaces in Reach 4 can be as much as six feet higher than the channel bed. This represents a greater fluctuation in flow stage than the wider, less confined reaches upstream and downstream.

The valley floor and alluvial fans within Reach 4 are composed primarily of coarse-grained material. This material supports active hyporheic through-flow and groundwater influx from upstream and from the adjacent terraces and alluvial fans. Despite notable discharge inputs from Early Winters Creek, Reach 4 is considered a "losing" reach (Konrad 2003, Konrad et.al 2005). This means that the channel contributes its incoming surface flow to the valley's large subsurface groundwater reservoir. Thus, surface water in the channel of Reach 4 is only the exposed top inches-to-feet of the valley's groundwater reserve. Sections of the channel in this reach can go dry in late summer and autumn, except for the pool at the confluence with Early Winters Creek (Caldwell and Atterson 1992, Andonaegui 2000, Konrad 2006a). See Section 2.6 of this report for a description of the groundwater to surface water interchange processes that occur here.

It is expected that the channel and floodplain tributaries are actively exchanging surface flow with groundwater through hyporheic processes. During field surveys in August and September 2014, hyporheic through-flow at the downstream ends of active bars was observed.

Reach 4 receives discharge inputs from Early Winters Creek, Theise Creek, Looney Creek, a few small unnamed ephemeral tributaries, and a groundwater-fed floodplain tributary. According to the US Bureau of Reclamation's surface flow estimates (2008 – Appendix J), discharge of the upper Methow River increases by 22 percent at the Early Winters Creek confluence during high flows. Early Winters Creek increases the contributing upstream drainage area of the Methow River from 276 to 358 square miles. During high flows, the other tributaries combined are estimated to increase the discharge of the river by another three percent. Neither Theise Creek nor Looney Creek have visible modern surface water input points to the Methow River. Instead, after passing under the Lost River Road through a culvert, Theise Creek's flow goes subterranean while still on its alluvial fan surface. However, the groundwater from the Theise Creek alluvial fan is a suspected groundwater source for the floodplain tributary that enters the channel on river-left at RM 67.8. Surface flow from Looney Creek and the two unnamed ephemeral tributaries on the west side of the valley are captured for agricultural purposes in canals dug at the base of their alluvial fans before reaching the Methow River.

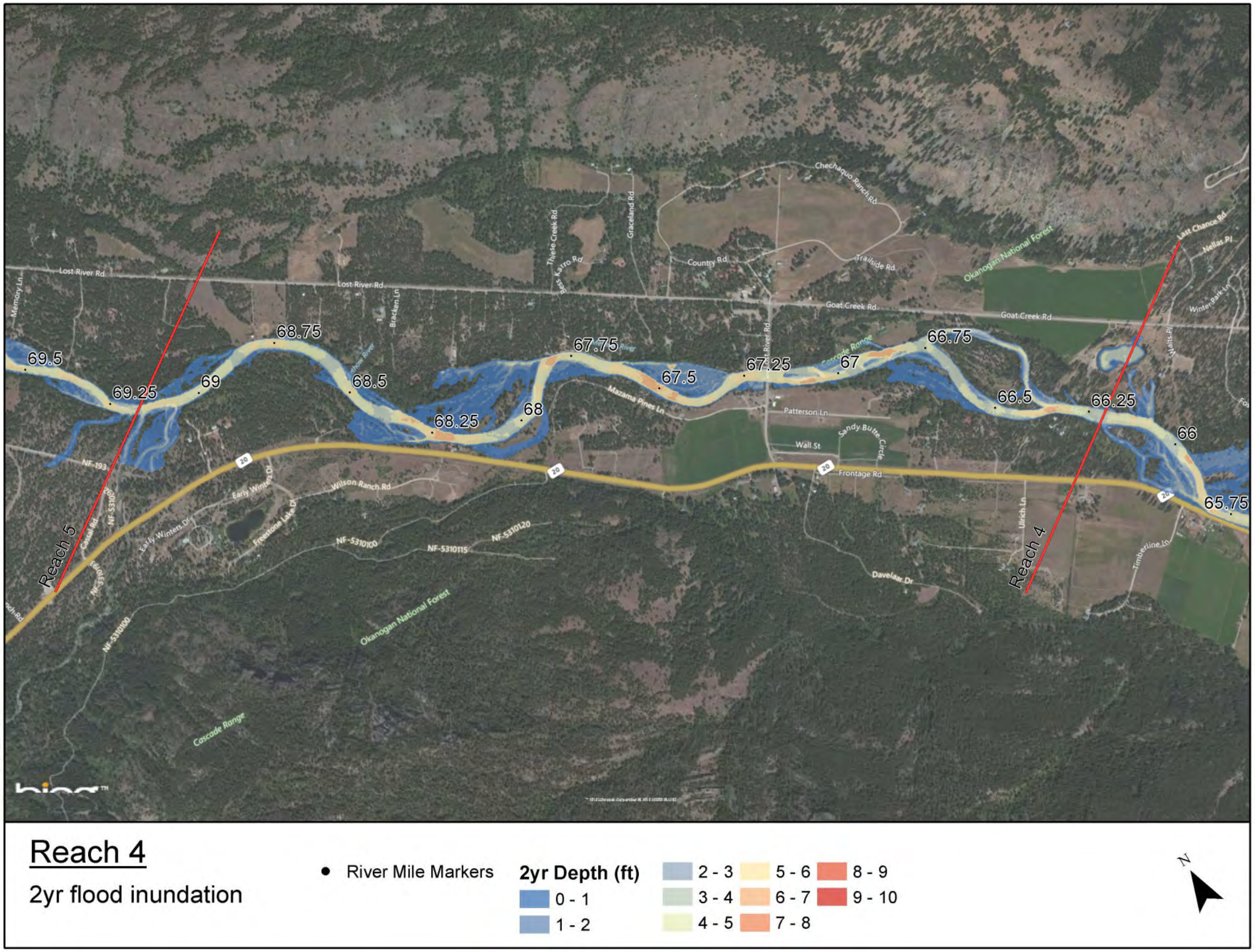

Figure 71. Floodplain inundation for 2YR flood in Reach 4 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

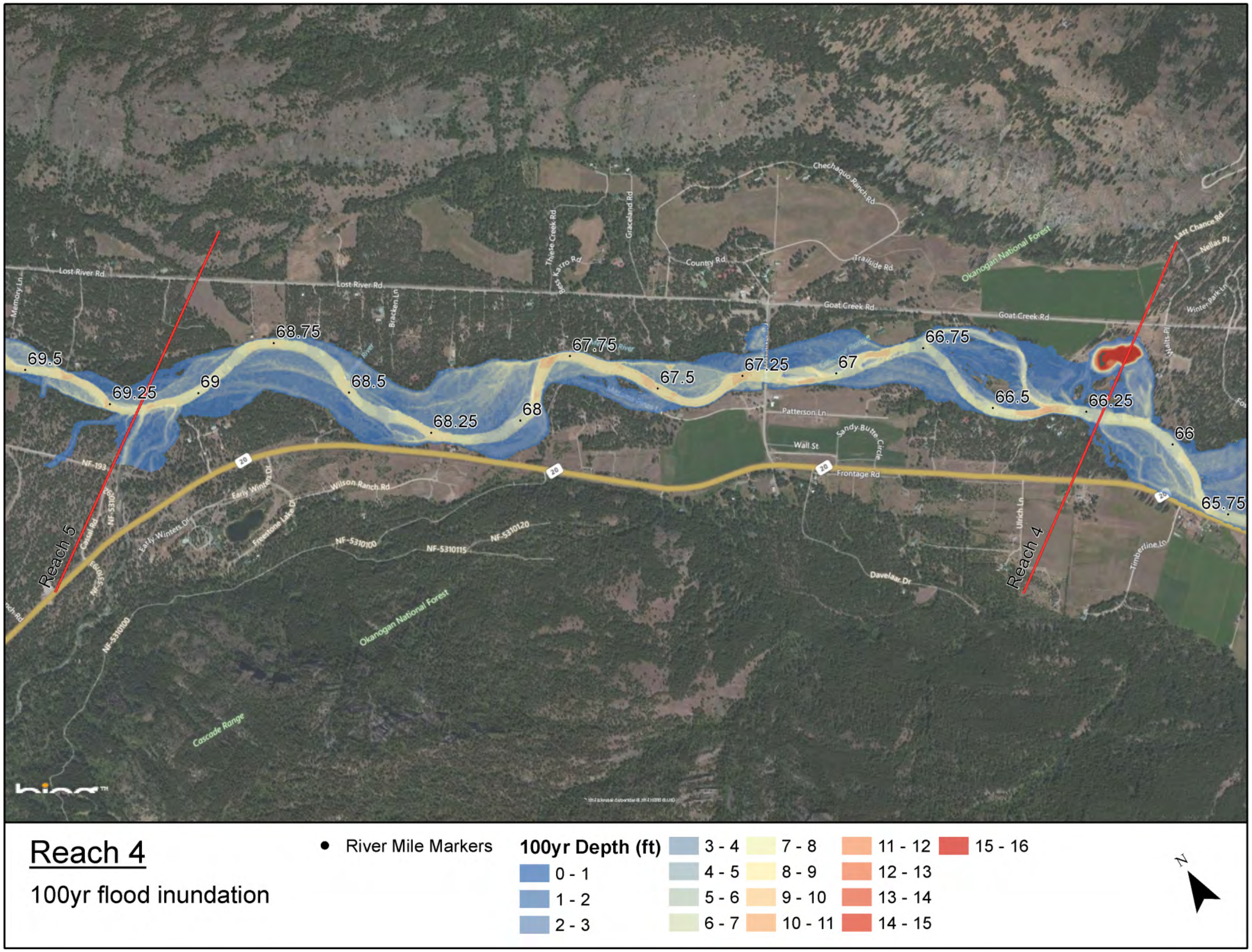

Figure 72. Floodplain inundation for 100YR flood in Reach 4 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Floodplain and Channel Migration Zone

Reach 4 is considered laterally stable and vertically active. Aerial imagery from 1945 and current times show that, except at its downstream boundary with Reach 3, the path of the channel has not changed horizontally (laterally) in the last 70 years (Figure 73). Channel banks consist of mostly boulders and large cobbles. Stable boulder and cobble banks with established moss and/or cemented sands were observed between meander bends on river-left at RM 68.2 and on river-right at RM 68.6. Evidence of minor recent lateral migration was observed on relatively short, fresh, cut banks located at RM 66.6, RM 68.45, and RM 67.1. Here, minor wood recruitment from the banks was occurring due to minor channel migration. Subtle scarring on floodplain surfaces indicates that lateral migration and avulsions did occur in Reach 4 in the past.

The historical trend of incision in Reach 4 is marked by sequences of subtle meander scars on the glacial outwash terrace and the Early Winters Creek alluvial fan. These meander scars gradually stair-step into the outwash terrace that filled the valley floor during glacial retreat. The gradual stair-step style of the scars indicates an initial and relatively gradual trend of incision into the outwash deposits. The modern inset channel and floodplain are the result of a subsequent exaggerated period of incision that perhaps was induced by increased discharge from Early Winters Creek during glacial retreat. Modern incision trends are creating the high floodplain surfaces in Reach 4. On the high floodplain surfaces, the vegetation is transitioning towards a drier pine-dominated forest with a less dense understory of grasses and forbs than what is found on the lower, more active floodplain surfaces. This further reveals that modern vertical incision processes are occurring in Reach 4. The trend of incision was likely exaggerated in the last century by logging and the transport of timbers downstream. Without additional research, the rate of modern incision throughout the reach will remain unknown. However, the relative elevation of the high floodplain surfaces suggests that the incision rate is more exaggerated in the downstream portion of the reach.

The channel and its floodplain traverse the middle of the valley between and below the glacial outwash terraces. At no point does the channel contact the valley wall or bedrock in Reach 4. The outwash terrace banks are approximately eight to twelve feet above the modern channel. Though erodible, the terrace banks partially confine the current pathway of the channel throughout the reach. The relative elevation of the active floodplain surfaces over the channel bed is greater in Reach 4 than in other reaches in the study area. Here, active floodplain surfaces range from three to six feet above the channel. The relative elevation of floodplain surfaces increase in the downstream portion of the reach where the width of the channel narrows. This confirms that flow stage varies more dramatically in Reach 4 than in the less confined reaches upstream and downstream.

Evidence of relatively modern lateral channel processes exists at the downstream-most section of Reach 4. At the downstream reach boundary on river-left there is an abandoned channel scar. The feature now resides on a high floodplain surface and has since been dug out to create a pond with a levee. According to aerial imagery, this old channel pathway was abandoned between 1954 and 1964 – only 55 years ago. As a result, the local sinuosity of the channel was reduced, increasing local incision processes and the development of a high floodplain surface on river-left.

Small units of disconnected floodplain surfaces have been created by floodplain grading and clearing along river-right (from RM 67.9 to 68.15) and behind an active floodplain surface on river-left (from RM 67.4 to 67.55).

Sediment

Based on field observations and two representative gravel counts, the substrate of Reach 4 is dominated by cobbles (53%). The percent of gravel-sized material is lower (39%) and boulder-sized material is higher (4%) than in the reaches upstream and downstream from it. Sand is a minor component (5%) in the channel and is found in developing soils on floodplains, as topping on high bars, and as still water deposits in backwater features. Gravel is found as topping on high bars or in off-channel features. The floodplains have large cobbles and boulders at their bases and a top layer of gravel and sands. Where channel contact points occur, glacial outwash terrace banks offer local sources for sand-to-boulder-sized material. Early Winters Creek and its alluvial fan have contributed a notable amount of sediment to the upper portion of Reach 4. Early Winters Creek has deposited large cobbles and boulders across the Methow River at its modern confluence point. The deposit imposes a subtle grade control on the Methow River that influences upstream channel elevation.

The groundwater-fed floodplain tributary on river-left at RM 68 is sand-to-gravel bedded. Bedload throughout the reach is moderately sorted (within similar diameter size range) and rounded, indicating that much of the substrate is transported fluvially during high flow events.

Although high flow inputs from Early Winters Creek notably increase downstream discharge of the river, sediment inputs from the creek do not result in a higher density of bars, nor does it appear to alter grain-size distribution downstream from its confluence point. The increased discharge provided by Early Winters Creek appears to increase the transport capacity of the channel such that the upper portion of the reach is sediment-limited. This higher discharge, and thus higher sediment transport capacity, could also help to explain the shift in channel form from the upper reaches, which are more aggradational, to this reach, which is less aggradational. At the downstream end of the reach, once the converging fans of Goat Creek and Little Boulder Creek come in, the regime shifts back to aggradational.

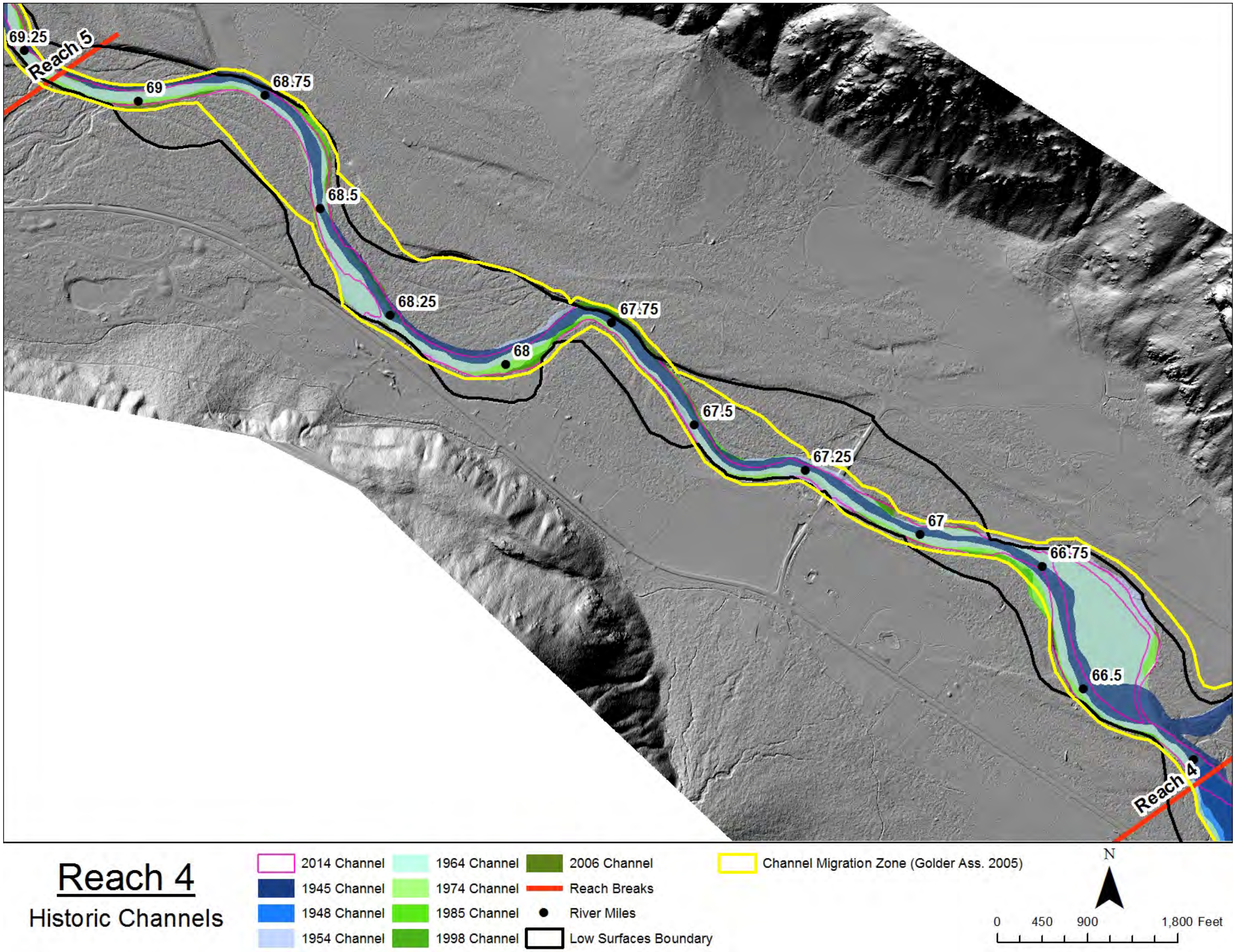

Figure 73. Historical channel locations in Reach 4.

Large Wood

Reach 4 has a moderate in-channel large wood count of 362 logs (56.7 logs per mile) but only three log jams. In-channel wood distribution in the reach is presented in Figure 74 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. Almost all the large wood pieces are part of the three large log jams located between RM 66.85 and RM 67.15, just downstream of the Mazama Bridge (Figure 75). These jams are geomorphically effective at creating local channel complexity and habitat complexity in an otherwise simplified reach. At these three log jams, large active bars are maintained and there are deep scour pools. It is assumed that at least part of this wood was sourced from Reach 5 and transported to this location since lateral erosion processes (and thus tree recruitment) in the upper third of Reach 4 are minimal. Besides these large log jams, the other in-channel wood counted in the reach is a handful of single pieces on river-left at RM 68.45. Here, a bar is now developing and very slight lateral migration towards river-right has recently occurred. A horizontal ballast log acting as a weir has been placed and secured to large boulders in the channel bed at RM 68.75. This log is serving as a subtle grade control for sediment accumulations on the upstream side (which includes some gravels) and a shallow plunge pool (approximately 2.5 feet deep) on the downstream side. Due to the slight increased bed elevation on the upstream side, the channel has widened locally such that effective flow now passes around the ends of the placed log.

Large wood recruitment potential exists in Reach 4 due to vegetated floodplain surfaces adjacent to the channel. However, wood retention is limited to the section of the channel immediately downstream from the Mazama Bridge. Approximately 70 percent of the floodplain banks in the reach are vegetated with maturing trees – stands with trees 50 years old and older. However, recruitment of the large wood is limited by the lack of lateral mobility, as well as reduced beaver populations and vegetation clearing. Minimal large wood retention occurs between the Mazama Bridge at RM 67.2 and the upstream boundary of the reach at RM 69.2. All notable large wood retention occurs between RM 66.3 and 67.15 in conjunction with the accumulations of gravels and cobbles that create large bars. Simplification of the channel above the bridge and the accumulation of material below the bridge may be the result of historical log drives to a mill site near Mazama at approximately RM 67.2.

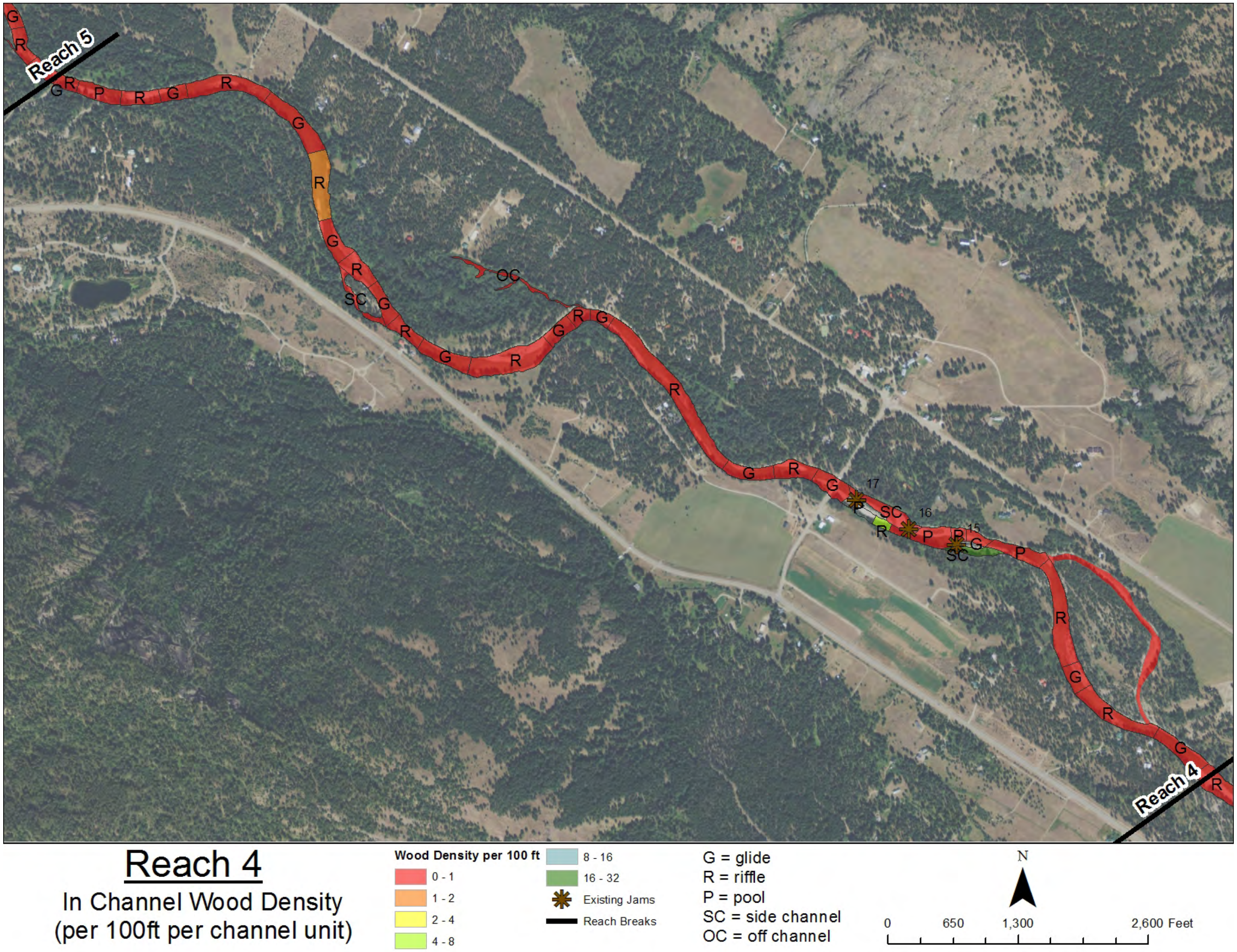

Figure 74. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 4.

Figure 75. Large wood jam at apex of a cobble bar (RM 67.15). (8/28/2014)

Vegetation

Anthropogenic influences and the relative elevation of floodplain surfaces compared to the channel bed create varied vegetation densities and types in Reach 4 (Figure 76). For example, the high glacial outwash terraces next to the channel have been extensively cleared and graded for agriculture and/or home-site development. As a result, the vegetation composition on almost all of the terrace banks has been greatly reduced to pastures, grasses and lawns with only small areas of sparse pine trees. The Early Winters alluvial fan has also been thinned and cleared for road, campground, and home development. However, the edge of the fan along river-right between RM 69.1 and 69.2 has a vegetated buffer that is composed of a maturing forest of mixed conifers (trees 50 years old and older).

Where modern vegetation removal has not occurred, the floodplain surfaces are vegetated with a maturing forest. About 70 percent of the floodplain surfaces are at least partially vegetated with forests older than fifty years old. Modern vegetation clearing has occurred on the active floodplain surfaces primarily at trails and access points. On uncleared floodplains, forests are composed of a mix of conifers and deciduous trees that include cedar, fir, cottonwood, and aspen. These forests have a dense understory that includes grasses, forbs, dogwood, maple, devil's club, equisetum, snowberry, willow, and box-elder. Less dense vegetation is found on low floodplain surfaces on river-left between RM 67.85 and 68.2 and on river-right between RM 68.25 and 68.35 and RM 66.7 and 66.8. In these less-densely vegetated areas, floodwaters appear to have partially scoured soil and vegetation in the last ten to twenty years. Here, the vegetation is either larger trees that survived the flood-scour or young establishing vegetation. The medium-to-high floodplain surfaces (three to six feet above the channel bed) have maturing forests of 50-plus years old where clearing has not occurred. The higher floodplain surfaces have maturing mixed forests that also include young (5- to 25-year-old) pine trees and a slightly less dense understory. The presence of young pine trees on the high floodplain surfaces indicates a relatively modern decrease in floodplain connectivity on these surfaces – likely the result of incision. The uncleared high floodplain surfaces that flank the active floodplains are vegetated with a mix of maturing conifers that include pine trees. The understory on the high floodplain surfaces has more grasses and forbs and is less variable and less dense than the understory on the active floodplain surfaces.

Where clearing or thinning has occurred, the complexity of the understory and the density of the maturing trees have been reduced. Two floodplain surfaces have been classified as disconnected from the channel due to vegetation clearing and surface grading. The disconnected floodplain surfaces are located on river-right between RM 67.9 and 68.15 and on river-left between RM 67.45 and 67.55. The small disconnected floodplain unit on river-left is set off of the channel approximately 180 feet behind a vegetated floodplain. This area is partially cleared with a dug pond and levee for private recreational use. Modern partial vegetation clearing has occurred on the active and high floodplains in Reach 4 on river-right from RM 66.35 to 66.7, RM 67.45 to 67.7, RM 68.3 to 68.75, and RM 68.9 to 69.1, and on river-left from RM 66.2 to 66.35, RM 66.85 to 67.3, and RM 67.4 to 67.65. Along the riprapped banks at the Mazama Bridge, sparse communities of willow and dogwood cling to the spaces between the angular boulders. The main channel in Reach 4 is wider than the average tree height, thus shading is partial and limited to only 20 to 70 percent of the channel depending on the time of day.

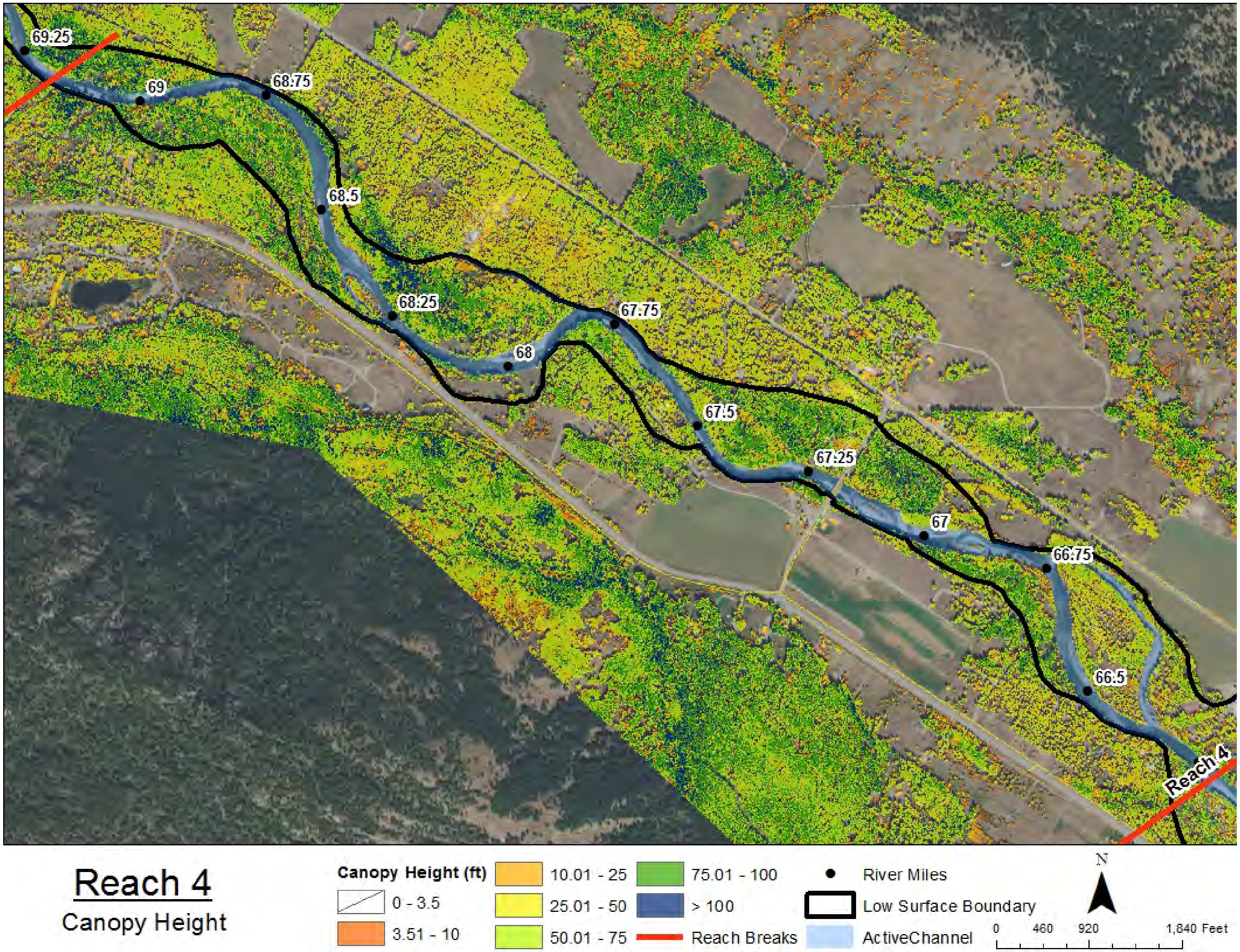

Figure 76. Vegetation canopy height for Reach 4 -- derived from LiDAR first return (highest hit) data (includes buildings and other human infrastructures).

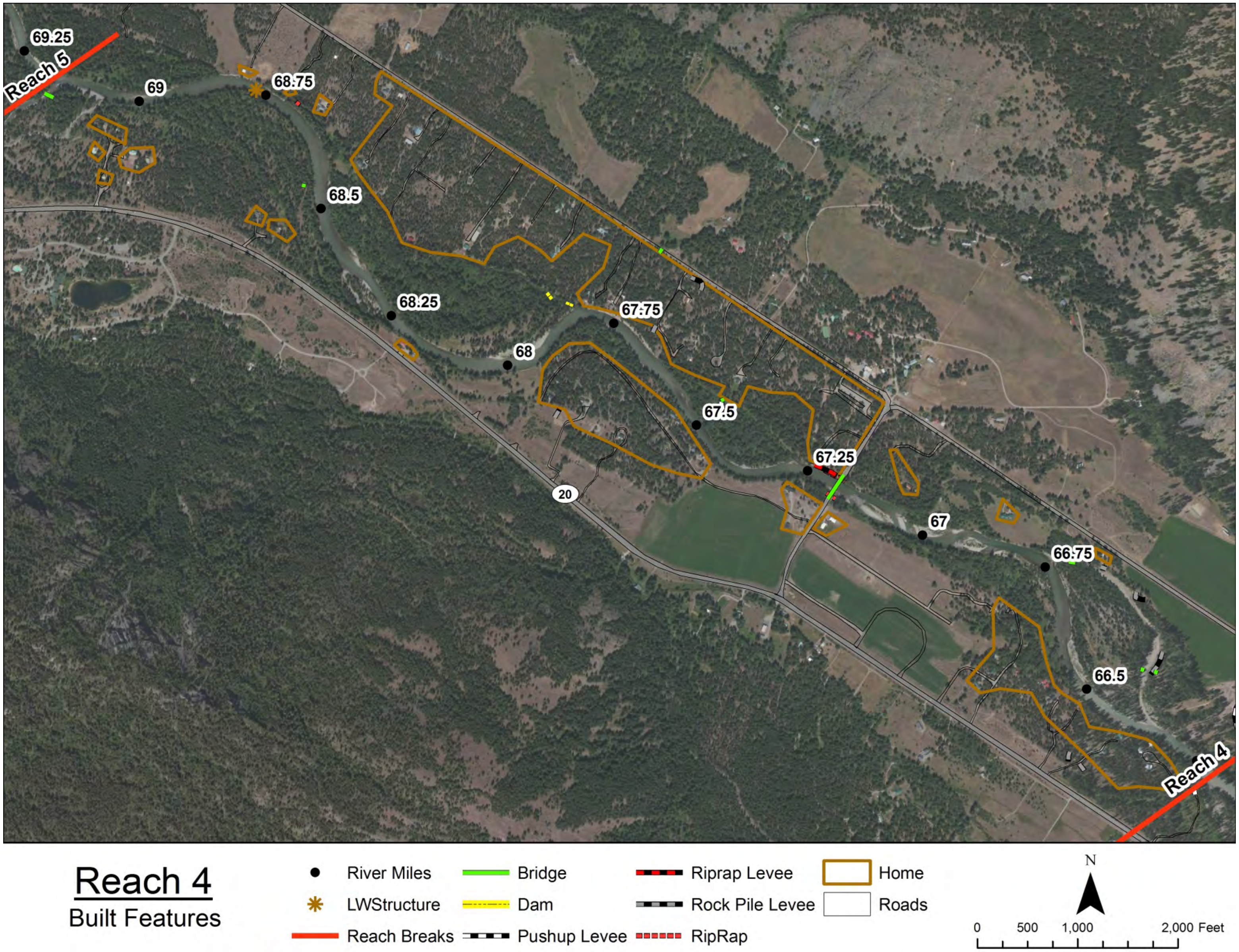

Figure 77. Primary human features in Reach 4.

3.4.3 Human Alterations

Human features are mapped in Figure 77. The primary human alterations in the reach include the following, and are described further in the subsections below.

- Changes to floodplain function and off-channel habitat
- Changes to streambank complexity and riparian impacts
- Changes to channel migration and sediment supply
- Changes to instream habitat and channel complexity

Changes to Floodplain Function and Off-Channel Habitat

Floodplain function and off-channel habitat have been altered in sections of Reach 4 due to floodplain grading and vegetation removal. Surface grading and vegetation clearing have disconnected sections of the modern floodplain on river-right between RM 67.9 and 68.15 and on river-left between RM 67.45 and 67.55. Reduced vegetation and grading alters normal surface flow routing and sediment delivery across the floodplain surfaces. The grading on river-left at RM 67.45 includes a dug pond with a levee. This relatively small pond captures surface flow from a groundwater-fed floodplain tributary before it connects to the mainstem channel. This eliminates the potential cold-water, off-channel habitat that this tributary could provide to the reach. Similarly, a dug pond and levee constructed on the river-left floodplain at the downstream boundary of the reach captures groundwater as well as surface water from an incoming tributary for private irrigation and recreational use. Both of the ponds were dug into abandoned channel scars that, if reconnected to the mainstem channel, could potentially provide perennially available off-channel habitat.

Changes to Streambank Complexity and Riparian Impacts

Streambank complexity and riparian vegetation in Reach 4 have been reduced where channel banks have been cleared of vegetation and/or armored with riprap. Vegetation clearing and thinning reduces bank and surface roughness and stability. It also decreases the hydro-ecological benefits that established riparian vegetation provides: shade, large wood, nutrients, and the regulation of sediment inputs. Almost all of the glacial outwash terrace banks and surfaces have been cleared for agricultural and home site development in Reach 4 – decreasing vegetation input potential. Although approximately 70 percent of the floodplain banks are at least partially vegetated, vegetation clearing and thinning has reduced modern riparian function on river-right from RM 66.35 to 66.7, RM 67.45 to 67.7, RM 68.3 to 68.75, and RM 68.9 to 69.1 and on river-left from RM 66.2 to 66.35, RM 66.85 to 67.3, and RM 67.4 to 67.65.

The large boulder riprap at the Mazama Bridge (RM 67.2) inhibits bank-toe erosion and natural bank and hillslope processes, thus altering localized sediment inputs to the system. The riprap also reduces the complexity of the riparian vegetation and notably decreases the potential for the establishment of mature tree stands. Additionally, this reduces localized shade to the channel and removes the potential for large wood recruitment in this area. The riprap armors both channel banks at the bridge and extends approximately 250 feet upstream from the bridge on river-left.

Changes to Channel Migration and Sediment Supply

Bridge crossings impact natural geomorphic processes of the Methow River in Reach 4 and its primary tributary, Early Winters Creek. The Mazama Bridge and its associated abutments and riprapped banks constrict the channel's width and limit lateral channel processes by locking the pathway of the channel in place at RM 67.2 (Figure 78). Early Winters Creek has two bridge crossings that influence its lateral processes across the top of its alluvial fan. The Highway 20 Bridge and a Methow Valley Community Trail footbridge cross the creek near each other approximately 550 yards upstream from the confluence. The bridges and their associated abutments and riprapped banks locally lock the pathway of the creek in place. This can promote incision and influence downstream sediment delivery to the Methow River. However, below these bridges, the creek is laterally active, creating a secondary channel that traverses the fan to the mainstem channel. An old river crossing located 280 yards upstream from the confluence was removed over twenty years ago – likely by flood waters. When in use, this crossing likely restricted the pathway of the creek as well as sediment delivery to the mainstem.

Figure 78. Mazama Bridge and riprapped bank on river-left (RM 67.2). (8/28/2014)

New but small cement bridge abutments and rock pile levees constructed on the banks of the side-channel on river-left between RM 66.35 and 66.75 impose potential restrictions on lateral migration. uring high flows, activation of the side-channel creates an island feature that is otherwise connected to the Methow Valley Community Trail network. Bridge abutments appear to be part of two new footbridges that will allow island access when the side-channel is wetted. A set of cement bridge abutments is located 200 feet from the upstream confluence and another set is located 550 feet from the downstream confluence. The abutments are built on the existing banks and thus restrict lateral channel processes (migration or widening). The rock piles are the result of surface grading on the adjacent alluvial surfaces.

Changes to Instream Habitat and Channel Complexity

Channel geomorphology throughout much of Reach 4 is simplified, except in the short section between RM 67.85 and 68.15 where large wood and sediment accumulations locally increase channel complexity. Otherwise, the channel is laterally stable, comprised of extended riffles and glides, lacking in large wood accumulations, and is experiencing a modern trend of bed incision. From the late 1800s to the early 1900s, records indicate that loggers utilized the mainstem channel to transport cut timber to mills located near the town of Mazama (RM 67.25) and to other mills downstream (Devin 1997). This required clearing the channel of natural log jams and any other obstructions (large boulders, etc.). Following the large floods of 1948 and 1972, in an effort to protect bridges and other infrastructures, it is likely that the US Bureau of Reclamation did additional clearing of large wood above RM 67.25 -- specific locations of these activities are not all recorded (USBR 2008 – Appendix O). The expected impacts of log drives and/or “cleaning” a channel include bed scour, channel and bank simplification, and a reduction in habitat complexity (Nilsson etal. 2005, Wohl 2006, Miller 2010). These practices likely amplified modern incision throughout much of the reach and removed the gravels and fines from the channel bed.

3.4.4 Recommended Actions

Recommended actions in Reach 4 are focused on increasing channel complexity and lateral dynamics as well as improving side-channel and floodplain connectivity. Complexity and lateral dynamics can be addressed by adding large wood jams to the main channel to create bars and islands, and adding large wood jams to channel margins to enhance cover to existing features and promote localized wood recruitment. Channel margin jams are suggested to initiate pool development and to enhance complexity in existing pools. A meander bend jam on river-left at RM 68.75 could shift flow energy from the cut bank (with a dwelling) towards the floodplain on the opposite side. Log jams could also be used to capture fluvially-transported wood from upstream reaches. The large jams downstream of the Mazama Bridge indicate that fluvial wood is available if stable jams can be constructed to capture and retain it.

Side channel connectivity can be addressed by removing unnecessary push-up levees and installing apex jams at the upstream end to encourage split flow. The pond/gravel pit on river-left at the boundary between Reaches 4 and 3 has the potential for reconnection to the mainstem (Figure 61). Native riparian vegetation restoration where clearing has occurred is also recommended.

Restoration recommendations recognize the importance of maintaining connectivity of the mainstem channel to perennial or groundwater-fed tributaries and side-channels. This has been identified as a critical component for fish survival in a system with the potential to seasonally dewater. Improving fish access to groundwater-fed areas, including the ponds in the river-left floodplain near RMs 67.5 and 66.25 could provide important low water refuge. Lower Early Winters Creek and the mainstem area just downstream of the confluence remain wetted even during very dry periods. Improving access to lower Early Winters Creek, and improving habitat conditions around the confluence area, could also help to provide low water refuge.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.5 REACH 5

Refer to Section 2.2 and** 2.8 **for geologic and geomorphic context of the study area and explanation of terminology.

3.5.1 Reach Overview

Reach 5 is 2.1 miles long and extends from RM 69.20, at its confluence with Early Winters Creek, to RM 71.30, at its confluence with Goat Wall Creek. Except for the upstream-most 900 yards on river-left at the Goat Wall Creek alluvial fan (which is within the Okanogan National Forest), property in Reach 5 is privately owned (Figure 79).

The channel is laterally active with a moderate sinuosity of 1.13 and an average stream gradient of 0.6%. The channel is primarily a single-thread stream with braided sections occurring where sediment accumulations create relatively large mid-channel and transverse bars at low flow. The dominant channel type in the upper half of the reach is riffle-pool and the dominant channel type in the lower half is riffle-glide. The substrate of the channel is dominated by cobbles and gravels. The modern floodplain is also composed of cobbles but topped with gravels and sands. Reach metrics are provided in Table 11 and Figure 81.

The reach is semi-confined at its downstream end from RM 69.1 to 69.55 between the Early Winters Creek alluvial fan terrace on river-right (west side of the channel) and a glacial outwash terrace on river-left (the east side of the channel). The remaining upstream portion of the reach is unconfined. The modern floodplain has an average width of 721 feet and the channel's average bankfull width is 95 feet. However, active floodplain width varies from as narrow as 85 feet at RM 70.3 to approximately 1,800 feet at RM 69.85. Active side-channel and off-channel features increase system complexity from RM 69.25 to 69.8 and from RM 70.4 to RM 70.9. Floodplain scarring and deposition patterns indicate that high-flow events activate additional side- and off-channel features.

The habitat conditions in Reach 5 are discussed in Appendix A. Based on the REI analysis, 7 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). The salmon and steelhead redd distributions for the reach are mapped in Figure 79. Surface grading and vegetation clearing and thinning have occurred on most of the glacial outwash terrace surfaces adjacent to the reach, as well as on sections of the inset high floodplain surfaces. The floodplain surfaces are well vegetated with maturing forest (trees of 50 years or older). These forests provide wood to the system and enhance the roughness of bank and floodplain surfaces. Floodplain levees and riprap-armored banks impose local restriction on lateral migration and natural sediment input processes.

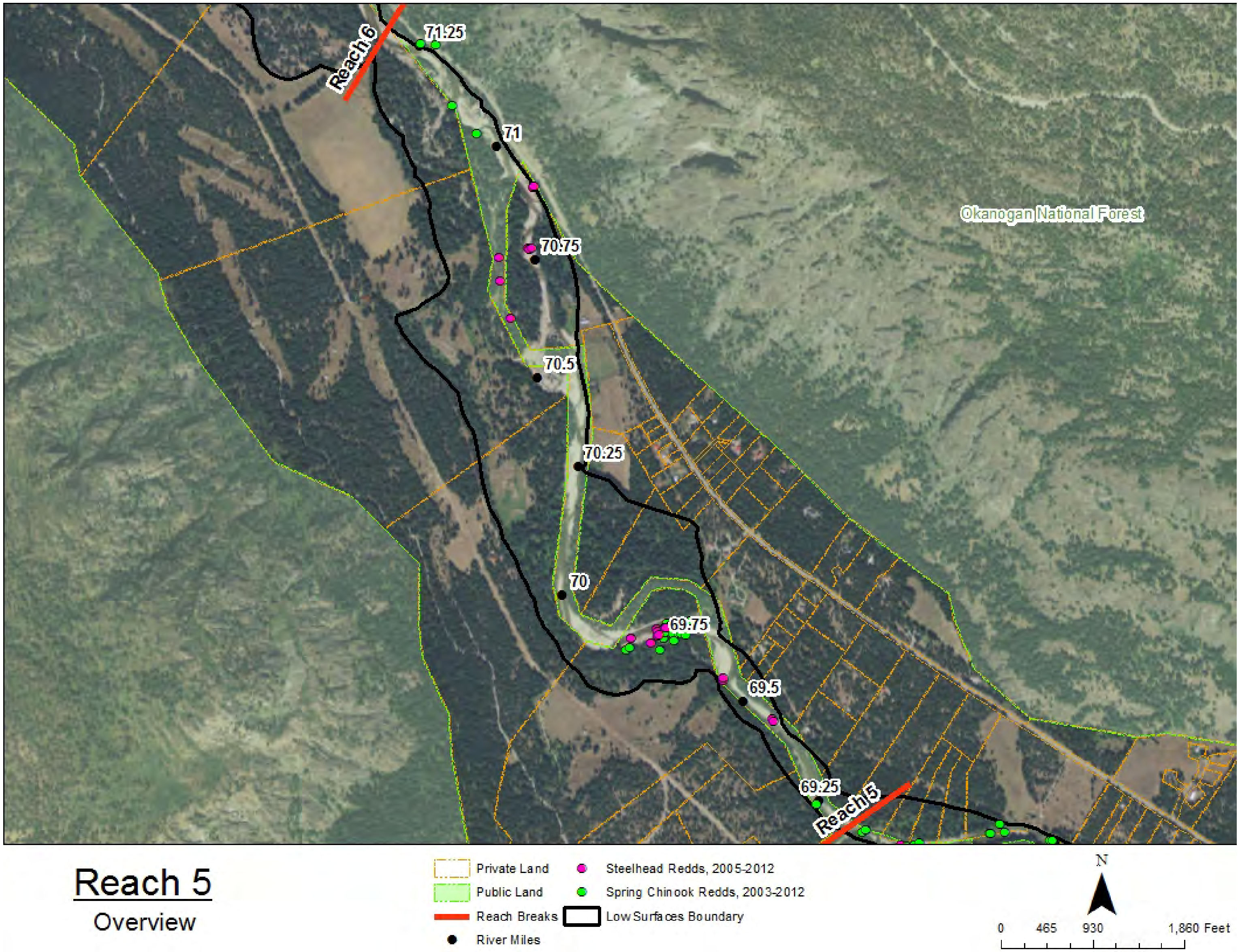

Figure 79. Reach 5 overview map with landownership and redd distribution.

Figure 80. Representative photo of Reach 5; looking upstream at RM 71. (8/26/2014)

Table 11. Reach 5 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	2.1
River Miles	69.20 – 71.30
Valley Gradient	0.7%
Stream Gradient	0.6%
Sinuosity	1.13
Dominant Channel Type	Pool-riffle-glide
Average Bankfull Width (feet)	95
Average Floodplain Width (feet)	721
Dominant Substrate	Gravel 61%; cobble 33%; sand 5%; boulder 1%
Bank Stability/Channel Migration	At Risk *(See Section 2.12)*
Vertical Channel Stability	At Risk *(See Section 2.12)*
Confinement ratio	Unconfined *(See Table 5)*

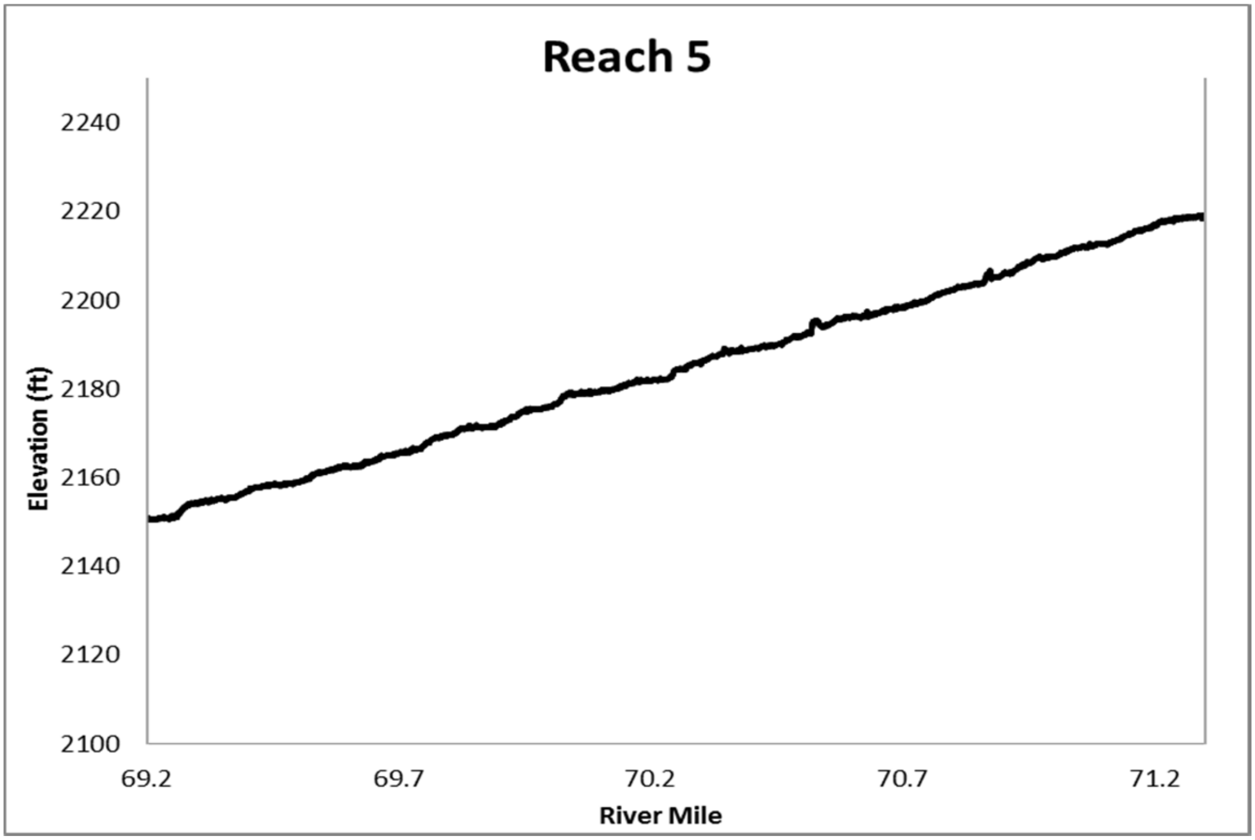

Figure 81. Longitudinal profile of the channel in Reach 5 (RM 69.20 to 71.30).

3.5.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 5 is located in a wide, U-shaped valley most recently carved by Quaternary glaciation. Increased discharge and sediment regimes during early Holocene periods of glacial retreat resulted in a thick layer of glacial outwash deposits (coarse sand to boulder-sized alluvium) filling the valley floor. A large alluvial fan also composed of outwash material was created during this time at the mouth of Early Winters Creek. The channel, its active floodplain, and the high floodplain surface are inset below the glacial outwash terraces and the Early Winters Creek alluvial fan. The glacial outwash deposits form terraces on the west side of the valley in the upper half of Reach 5 (RM 69.75 to 71.3) and on the east side in the lower half of the reach (RM 69.2 to 70.85). Goat Wall Creek has a steep alluvial fan that also borders the channel in the upstream portion of the reach, but its toe is also inset below the outwash terrace (Figure 82).

Compared to the rest of the reach, the channel is less sinuous from RM 69.2 to 69.6 where it is confined within the high banks of an outwash terrace on river-left and the Early Winters Creek alluvial fan on river-right. Sinuosity is also reduced in the upstream section between RM 70.85 and 71.2 where the channel currently skirts the toe of the valley wall on river-left. Large side- and mid-channel bars composed of cobble and gravel are abundant upstream of RM 69.6 in the less confined portion of the reach. From RM 69.3 to 71.3, the large mid-channel cobble bars exposed at low-flow give the channel a braided form. Large boulders in the channel at RM 69.65 create a subtle knickpoint, with a change in bed elevation of approximately two feet.

Alluvial surfaces of Reach 5 consist of two high floodplain surfaces and a relatively wide active floodplain. The active floodplain surfaces range in height over the channel bed from three to five feet. The surfaces of the floodplains are fluvially scarred and the banks are topped with fines and debris deposited by recent high-flow events. The high floodplain surfaces are six or more feet higher than the channel. Where surface grading has not occurred, some subtle fluvial scarring is visible on the high floodplain surfaces. A narrow high floodplain surface flanks the floodplain on river-left between RM 69.2 and 69.4. The other high floodplain surface is relatively large and borders the active floodplain and the channel. Cut-banks on this surface contact the river or side-channels for approximately 175 feet near RM 69.65 and between RM 69.9 and 70.15, and between RM 70.45 and 70.55. From RM 71.2 to the upstream boundary at RM 71.3, the river-left side of the channel contacts the steep alluvial fan of Goat Wall Creek. Downstream from RM 69.75, the reach is bordered on river-right by the high cut-bank of the Early Winters Creek alluvial fan.

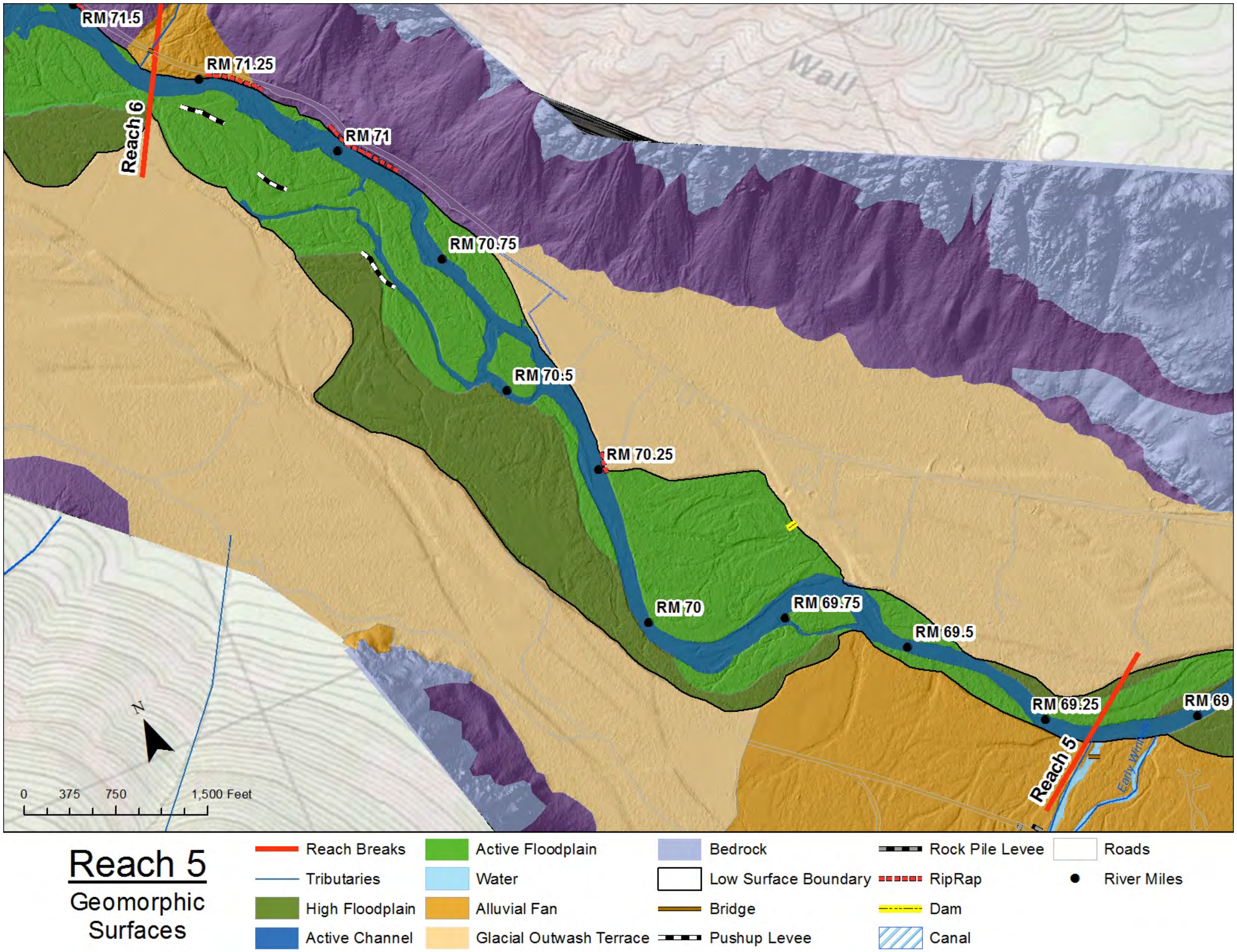

Figure 82. Geomorphic surfaces of Reach 5 with select human built features (bridges, levees, riprap, check dams, canals, and roads)

Figure 83. Pool with large boulders at RM 71.2. (8/26/2014)

The wide valley of Reach 5 is bordered by steep bedrock walls. These valley walls contribute talus and alluvial debris fan deposits to the valley floor and the channel. In the upper portion of the reach, direct talus and rock-fall inputs to the channel have occurred on river-left between RM 71.85 and 71.2. At this location, massive rock-fall boulders in the channel contribute to pool development and maintenance (Figure 83). However, modern rock-fall inputs are reduced here by the steep, fifteen-to-thirty-foot-high riprapped embankment of the Lost River Road. At RM 71, on river-left, the channel contacts a bedrock wall for a length of approximately 60 feet.

Extended side- and off-channel features add complexity to the geomorphology and hydrology of Reach 5. These features occupy abandoned channel scars located on active floodplain surfaces; and where connectivity with the channel is maintained, they provide important off-channel aquatic habitat. Groundwater inputs contribute cold surface water to these features. The most extensive off-channel feature is a groundwater-fed tributary located in a meander scar that is approximately 1,200 feet long (Figure 84). This feature enters the channel on river-right via a side-channel connector that runs between RM 70.6 and 70.4. The other two side-channel and two off-channel features are located between RM 69.25 and 69.8. This includes a groundwater activated tributary that enters the channel on river-right at RM 69.25. This tributary (off-channel feature) captures groundwater seepage from the cut bank of the Early Winters Creek alluvial fan.

Figure 84. Groundwater-fed tributary near RM 70.4; at downstream end looking upstream. (8/26/2014)

A variety of features in Reach 5 indicate that during high flow events, there is notable sediment transport as well as floodplain connectivity with the channel. Aerial photos from 1945, 1974, 1998, 2006, and the present, confirm that historically the channel migrated laterally within its modern floodplain via side-channel occupation, meander extension, and avulsion. Near both of the side-channels described above, there are scour and fill features composed of cobbles and gravels. These features occur where a flood event has filled in a side-channel or overflow channel with bedload material. Based on observed overbank deposits, floodplain scour, and hydraulic modeling, numerous floodplain channels are activated during flood events every two-to-ten years.

Hydrology

Reach 5 has a seasonally fluctuating flow regime. Spring snowmelt events regularly activate overflow channels and flood events inundate low floodplain surfaces on a regular basis (2 year flood recurrence) (Figure 86). Late summer, autumn, and winter low flows often leave most of the channel dry, with isolated pools susceptible to temperature extremes. During field observations in October 2014, the channel was dry from RM 70.2 to 71.75, except in isolated deep pools. Summer and autumn thunderstorms are capable of temporarily raising surface water elevations if discharge inputs are substantial enough to recharge groundwater elevations.

The valley floor and alluvial fans within Reach 5 are composed primarily of coarse-grained material. This material supports active hyporheic through-flow and groundwater influx from upstream and from the adjacent floodplains, terraces, and alluvial fans. Hyporheic flow at the downstream ends of active bars was observed in August and September 2014 during field surveys. However, Reach 5 is considered a "losing" reach hydrologically (Konrad et al 2005). This means that the channel contributes its incoming surface flow to the valley's large subsurface groundwater reservoir. Sections of the channel become dry when the incoming surface water flow is less than the quantity of water the channel is contributing to the groundwater reservoir. Sections of the channel in this reach often go dry in late summer and autumn, except for deep pools (Caldwell and Atterson 1992, Andonaegui 2000, Konrad 2006a). See Section 2.6 of this report for a description of the groundwater to surface water interchange processes that occur here.

Reach 5 receives surface water inputs from Goat Wall Creek, Caloway Creek, and a few ephemeral tributaries generated from the hillslopes. According to US Bureau of Reclamation surface flow estimates (2008 – Appendix J), discharge of the upper Methow River increases by one percent at the Goat Wall Creek confluence (river-left at RM 71.3) during high flows. Combined, Caloway Creek and the few other ephemeral tributaries that enter the valley on the west side of the reach are estimated to increase flows by an additional one percent during high flow periods.

It is important to note that most of the off-channel features in Reach 5 likely become active side-channels during flood or high-flow events. When disconnected from the channel during low flow periods, these features are wetted by groundwater. The groundwater appears to be generated from both hyporheic inputs from upstream and from the adjacent floodplains, terraces, and alluvial fans. Groundwater seepage was observed (August 2014) from the toe of the Early Winters Creek alluvial fan into the off-channel feature and the mainstem channel. This off-channel feature traverses the edge of the floodplain along the toe of the fan and eventually delivers the collected groundwater to the mainstem as surface flow at RM 69.25.

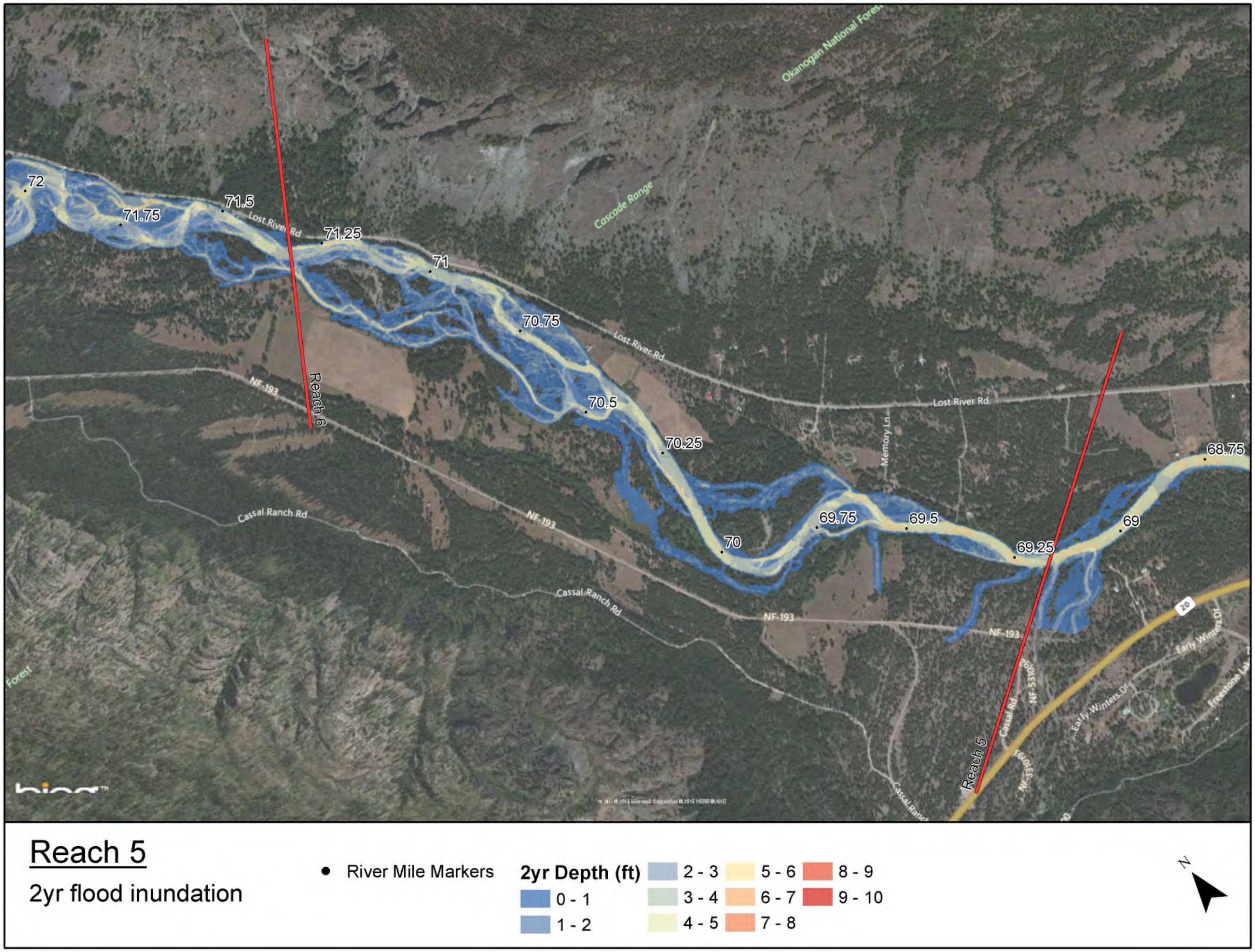

Figure 85. Floodplain inundation for 2YR flood in Reach 5 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

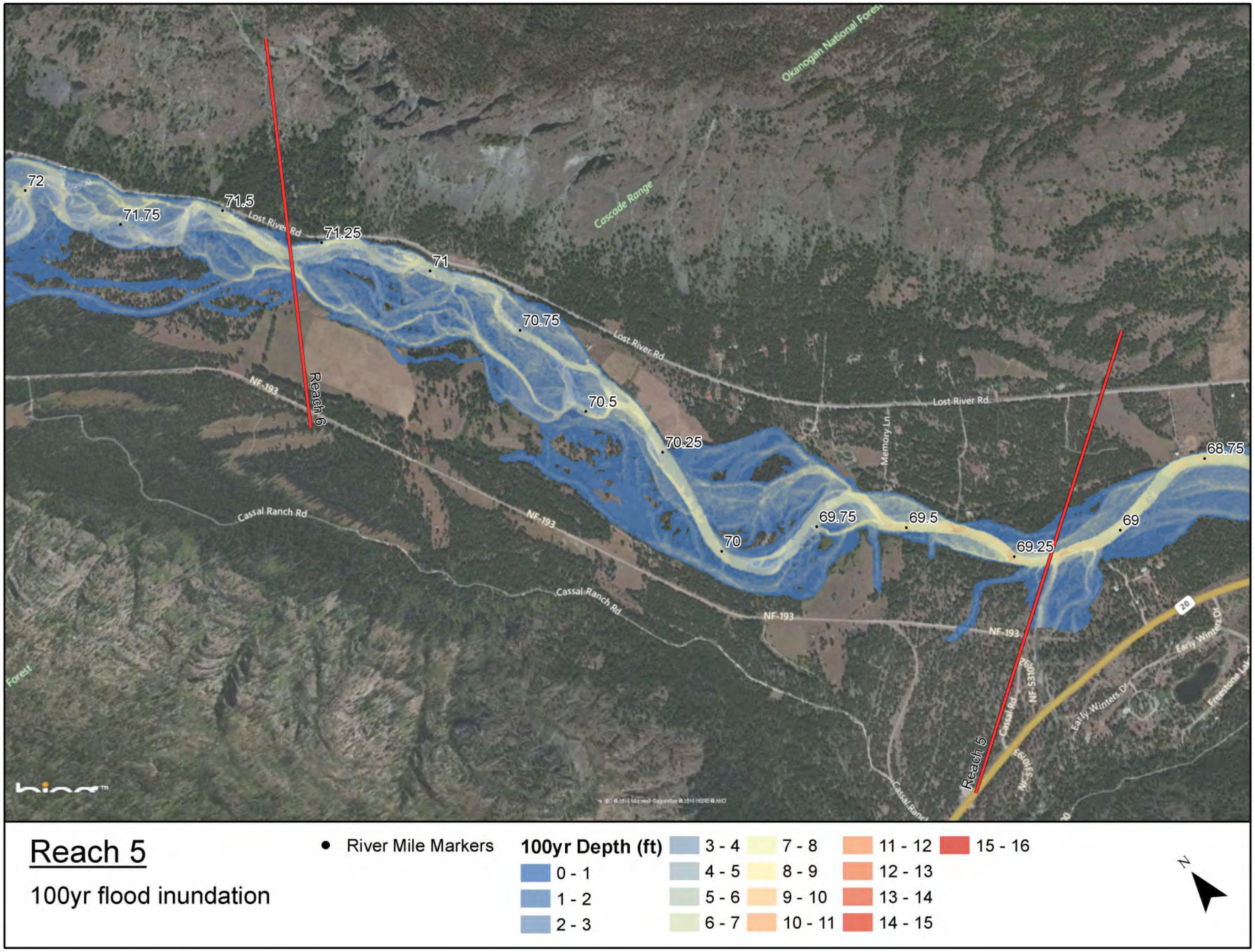

Figure 86. Floodplain inundation for 100YR flood in Reach 5 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Floodplain and Channel Migration Zone

Reach 5 is relatively active laterally (Figure 87). It is vertically stable in the upper third of the reach but potentially vertically unstable in the lower third of the reach. In the lower part of the reach, downstream from RM 69.6, the channel is naturally partially confined between a high glacial outwash terrace on river-left (approximately 7-12 feet above the channel) and the high cut toe of the Early Winters Creek alluvial fan (approximately 6-8 feet above the channel). In this section of the reach, the inset modern surfaces and channel are only 250 to 400 feet wide. Aerial photos from 1945 and 1974 show some lateral channel processes that were likely instigated by the large 1948 flood of record (Figure 87). More current aerial imagery indicates that since that time, lateral channel processes have been minimal in this confined section of the reach. A subtle knickpoint (approximately 2-3 feet high) at RM 69.65 is created by boulders that appear to be placed in the channel. The boulders are acting as a local grade and head-cut control on what could be minor upstream migrating bed incision. Reduced-but-not-eliminated floodplain connectivity occurs in the lower confined portion of the reach. Bar size and distribution is notably reduced to narrow, elongate lateral cobble bars in this section. The side- and off-channel features fed by groundwater are currently maintaining the hydrologic and geomorphic complexity in this section.

Upstream from RM 69.6 to the reach border at RM 71.3, the channel is considered mostly unconfined. Minor partial confinement occurs where the channel contacts bedrock, slope talus debris, and the Goat Wall Creek alluvial fan toe along the valley's edge between RM 70.75 and 71.3 on river-left. Confinement here is considered minimal due to the width of the active available floodplain at this location on river-right (up to 900 feet). However, remnant sections of push-up levees located on river-right at RM 70.75 (400 feet), RM 71 (250 feet), and RM 71.25 (350 feet) provide evidence of an attempt at channel confinement in the past. The levees are located on what is now active floodplain, but according to aerial imagery was the channel bank in 1945. The levee has been breached and historical aerial imagery confirms channel migration behind all of the levees except the one located at the edge of the high floodplain surface at RM 70.75. This levee appears to have successfully diverted active channel flows from the bank of the high floodplain surface behind it. Partial confinement also occurs from RM 70.25 to 70.4 where the channel and its floodplain are constricted between a graded and cleared glacial terrace on river-left and a graded and thinned high floodplain surface on river-right. At the base of this outwash terrace bank (river-left at RM 70.3) is a naturally cemented cobble-sand shelf that is hardened and stable – further hardening this bank (Figure 88). This section of the reach has a constricted width of approximately 250 feet. The remainder of the reach is unconfined and laterally active.

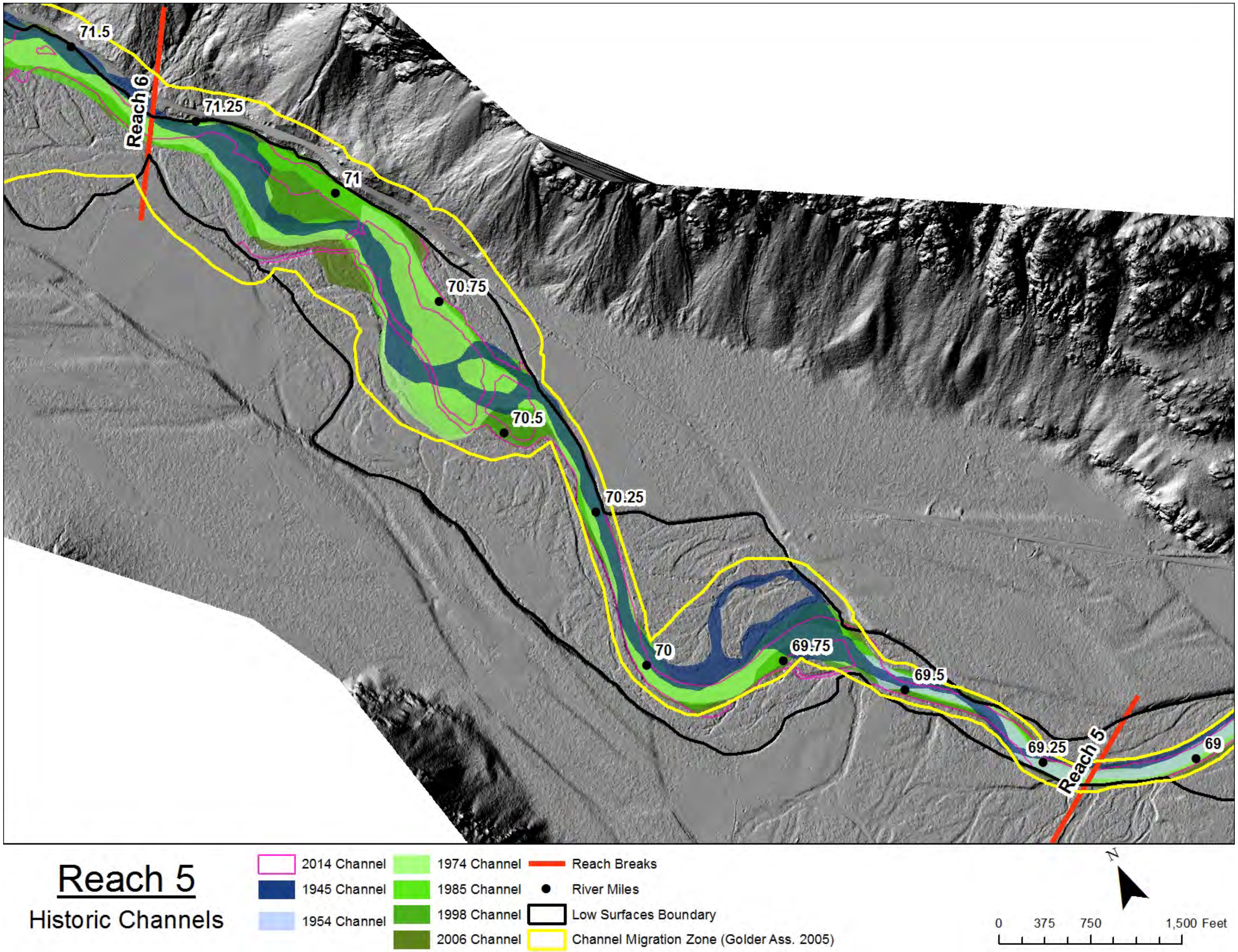

Figure 87. Historical channel locations for Reach 5.

Figure 88. Cobble-sand shelf -- hardened through plucking and armoring (RM 70.3). (8/26/2014)

Aerial photos from 1945, 1974, 1998, 2006, and 2011 confirm that modern lateral migration through side-channel occupation, meander extension, and avulsion has occurred in the past seventy years in Reach 5 upstream from RM 69.6. Active lateral processes generate large wood inputs to the channel through bank erosion and channel migration. Fluvial scaring and observed overbank deposits indicate that floodplain surfaces throughout reach 5 were recently inundated during high flow events – likely the 2006 and 2008 high flows. A variety of features in Reach 5 indicate that during high flow events, there is notable sediment transport as well as floodplain connectivity with the channel. In addition to active side- and off-channel features located in abandoned channel scars, there are scour and fill features on the floodplain from RM 69.6 – 70 and RM 70.4 – 71.3. During high flow events, these features experience bed scouring at peak flow and bed infilling during receding flow. Plentiful large active cobble bars indicate abundant sediment availability and transport throughout the reach. From RM 69.3 to 71.3, cobble bars exposed at low flow give the channel an active braided form.

Sediment

Based on field observations and two representative gravel count surveys, the substrate of Reach 5 is dominated by gravels (67%) and cobbles (29%) with minor sand (3%) and negligible boulders. Sand is found as overbank deposits on floodplains, as topping on high bars, and as still-water deposits in backwater features or at eddy points. Massive boulders (5 feet diameter or more) in the channel from RM 70.8 to 71.2 were locally sourced as rock-fall talus from the bordering valley wall on river-left. Floodplain surfaces are composed of cobbles and gravel with a thick topping of coarse sands and fines. The base of these surfaces contain large cobbles and small boulders. A developing soil horizon rich in loam and organic material tops the high floodplain surfaces. The high cut-banks of the glacial outwash terraces supply coarse sands, gravels, cobbles, and boulders. Goat Wall Creek and its alluvial fan contribute a mix of coarse sands to cobble-sized material at the upstream border of the reach. Sediment inputs from Goat Wall Creek may have been altered during periods of gold placer mining in the early 1900s (USBR 2008). Incoming sediment from upstream provides additional sand-to-cobble sized substrate during high flow. The side-channels and groundwater-fed tributaries (off-channel features) that traverse the floodplains contribute gravels, sands, and fines to the channel. Bedload throughout the reach is well sorted (has a similar diameter size range) and rounded, except for minor contributions to the channel from the bedrock and talus slopes on river-left between RM 70.85 and 71.25. These sediment contributions are generally larger in size and more angular.

Large Wood

Reach 5 has a high in-channel wood count of 321 pieces (155.6 logs per mile) and nine log jams. In-channel wood distribution in the reach is presented in Figure 89 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. The greatest abundance of in-channel wood occurs between RM 70.5 and 71.25 where large cobble bars are plentiful and a few of the massive rock-fall boulders act as racking agents for wood. Throughout the remainder of the reach, in-channel wood accumulations occur in conjunction with mid- and side-channel bars. Off-channel wood accumulations also occur on low floodplain surfaces. Single-piece and channel-spanning log jams occur in the side- and off-channel features. The width of the main channel is too great for channel-spanning accumulations to develop. Instead, wood accumulates on, across, and between the large cobble-gravel bars.

Large wood retention and recruitment is fairly good in Reach 5 with the exception of the riprapped and/or cleared banks. Even in the downstream section of the reach where the channel is confined and less complex, wood retention on the active bar surfaces appears only slightly reduced compared to the more complex middle section of the reach. Retention of wood is high in the upper section of the reach where channel complexity is greatest. Most of the wood in Reach 5 appears to be recruited from local banks or from immediately upstream of the reach boundary. The well-vegetated floodplain and alluvial surfaces adjacent to the channel offer high recruitment potential. Past and current lateral channel migrations resulted in local wood inputs to the channel. In August 2014, fresh wood inputs were observed from eroding banks (Figure 90).

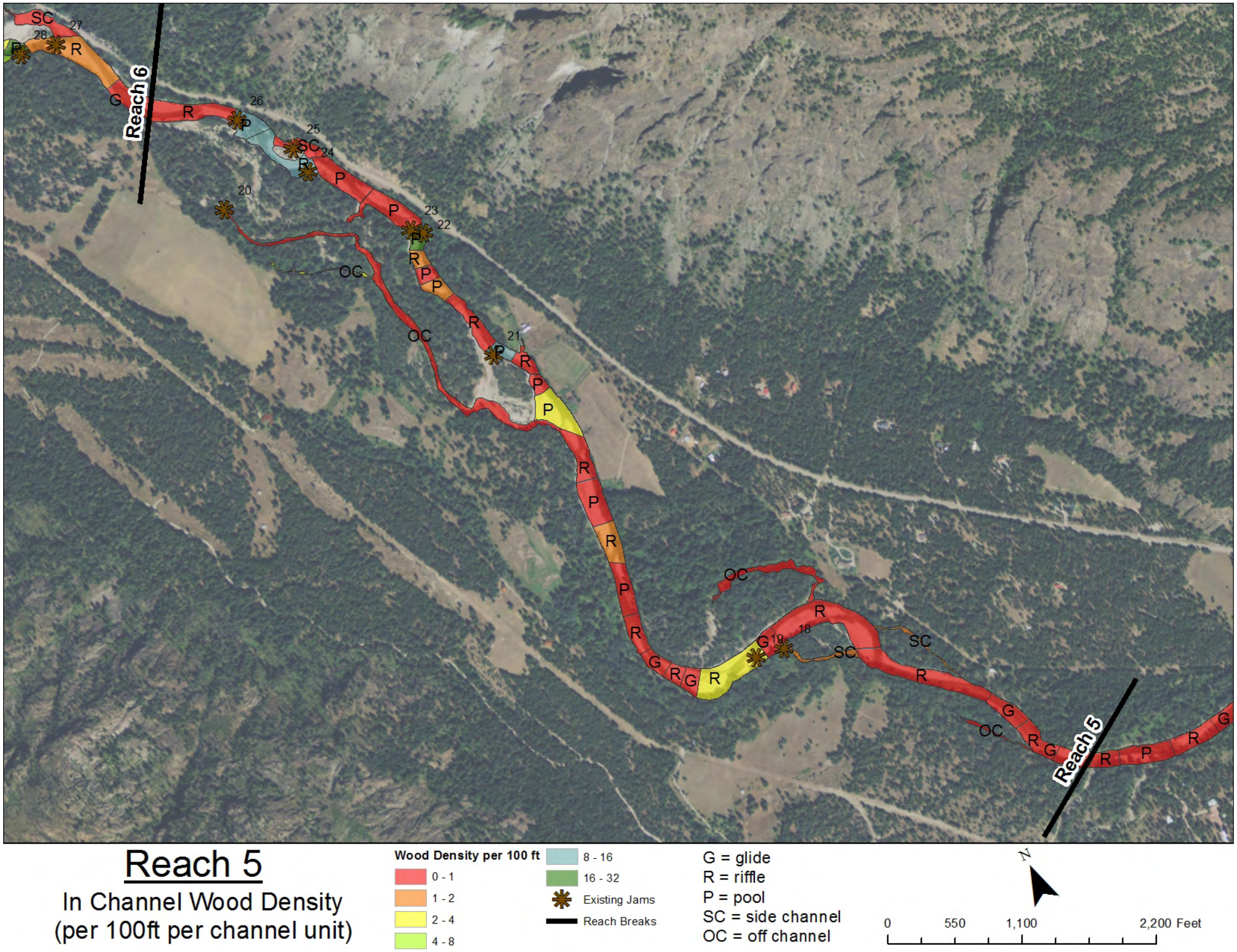

Figure 89. In-channel large wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 5.

Figure 90. A) Active large wood recruitment through bank erosion (RM 70.7); B) Large wood accumulations on bars. (8/27/2014)

Where vegetation has been removed or the banks have been armored, recruitment potential of large wood is reduced or eliminated. Vegetation has been cleared or thinned for home-site development and/or agricultural purposes along every section where the channel contacts outwash terrace banks (river-left RM 70.25 – 70.55, RM 69.6 – 69.65, and RM 69.4 for 200 feet). Vegetation thinning and clearing has also occurred on river-right adjacent to the channel on the high floodplain surface from RM 69.9 to 70.1 and adjacent to a side-channel from RM 70.45 to 70.85. Large boulder riprap placed on the banks reduces or eliminates wood recruitment on river-left at RM 70.25 (for 180 feet) and from RM 70.9 – 71.1 and RM 71.15 – 71.25. The cobble/soil push-up levee located on the banks of the high floodplain surface on river-right (RM 70.75 to 70.85) reduces recruitment behind and downstream from it.

Vegetation

Anthropogenic influences result in varied vegetation densities in Reach 5 (Figure 91). For example, most of the high glacial outwash terraces have been cleared or thinned, and frequently graded, for agriculture and/or home-site development. As a result, the vegetation composition on the altered terrace banks has been reduced to pastures and lawns, sometimes with sections of sparse pine trees. The most extreme example of vegetation clearing and surface grading is on the outwash terrace on river-left between RM 70.25 and 70.55. The Early Winters alluvial fan has also been thinned and cleared for road, campground, and home development. However, the edge of the fan along river-right between RM 69.2 and 69.55 has a wide vegetated buffer that is composed of maturing forest (trees 50 years old and over) with mixed conifers. The Goat Wall Creek alluvial fan hosts a maturing forest of mixed conifers along the channel on river-left between RM 71.25 and 71.3 that is 50 to 125 feet wide. The remainder of the fan toe edge is dissected from RM 71.15 to 71.25 by the Lost River Road. The road cut is riprapped and tree density is greatly reduced there.

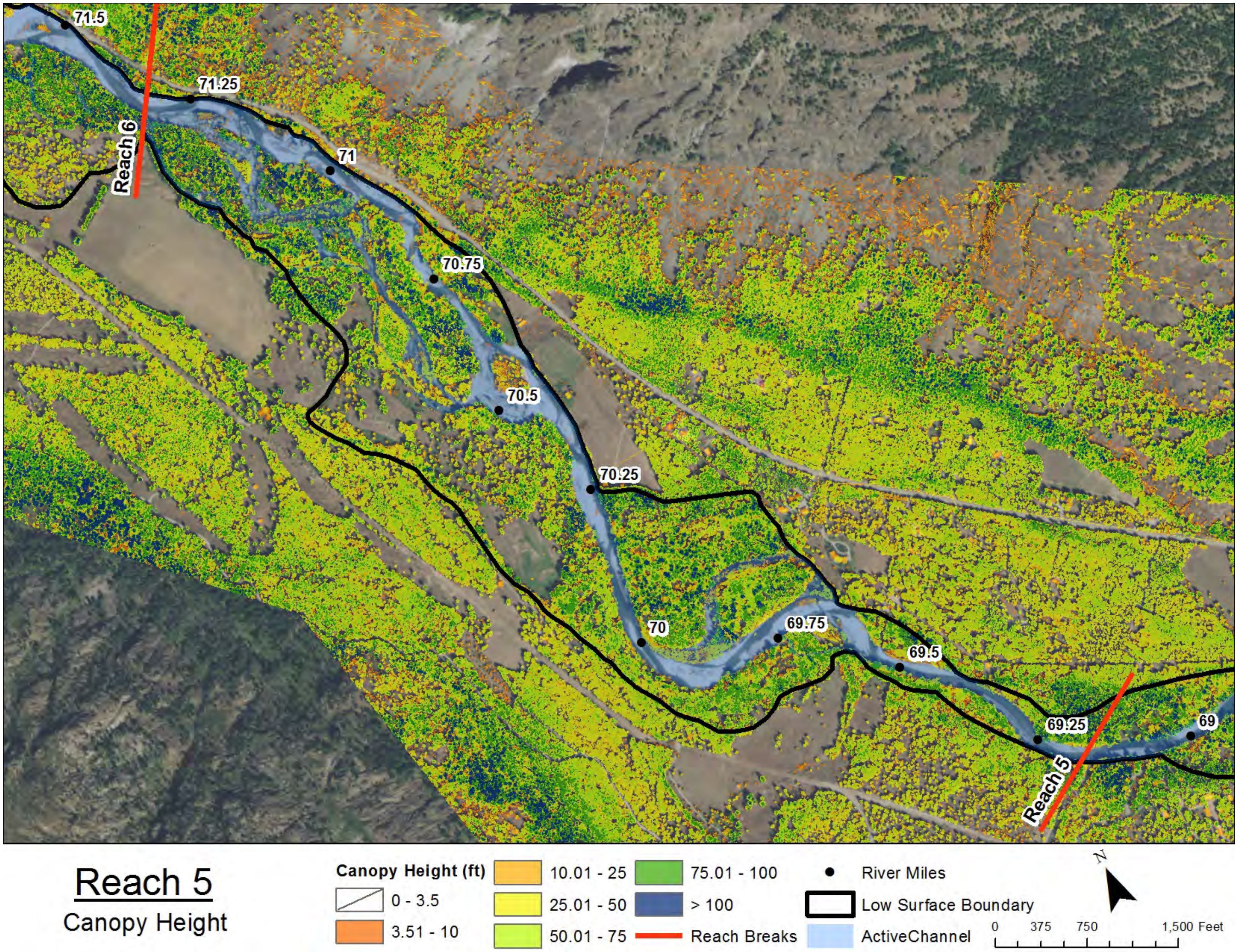

Figure 91. Vegetation canopy height for Reach 5 -- derived from LiDAR first return (highest hit) data (includes buildings and other human infrastructures)

The floodplains of Reach 5 are vegetated with maturing forests (50-plus years old) composed of mixed deciduous and conifer trees with a thick, well-developed understory. Historic logging reduced stand density to some degree on most of the inset surfaces. Noticeable vegetation clearing, thinning, and surface grading have occurred on sections of the high floodplain surface on river-right between RM 70.15 and 70.8 and RM 69.75 and 69.85. Where these actions have occurred, the tree density is reduced and the understory has been simplified such that it is dominated by grasses and forbs. All of the floodplain surfaces in Reach 5 are well vegetated with maturing forests and a healthy understory – although stand density may be slightly reduced due to past historical logging. The low active floodplain surfaces (such as high bar tops) contain establishing vegetation that includes willow, cottonwood, and alder (0-15 year age range). The age of the establishing tree stands on these features aids in identifying the history of flooding (scour and fill) and channel migration in the reach. The higher floodplain surfaces are vegetated with a maturing mosaic forest that includes both conifers and deciduous trees such as cedar, fir, cottonwood, and alder; trees in these areas range from 25 to 100 years old. The understory on the floodplain surfaces is dense and includes grasses, forbs, dogwood, maple, devil's club, equisetum, and snowberry.

The vegetation on surfaces adjacent to the channel increases bank and floodplain roughness and stability throughout the reach. Along the sections of riprapped banks and road fill on river-left at RM 70.25 (for 170 feet), between RM 70.9 and 71.1, and RM 71.15 and 71.25, either no vegetation exists or very sparse communities of willow and dogwood cling to the spaces between the angular boulders near the channel. Here, only a few trees are located atop the 15 to 30 foot high embankments. The side-channels receive shade and organic material where established floodplain vegetation exists. The main channel in Reach 5 is wider than the average tree height, thus shading occurs primarily along the banks.

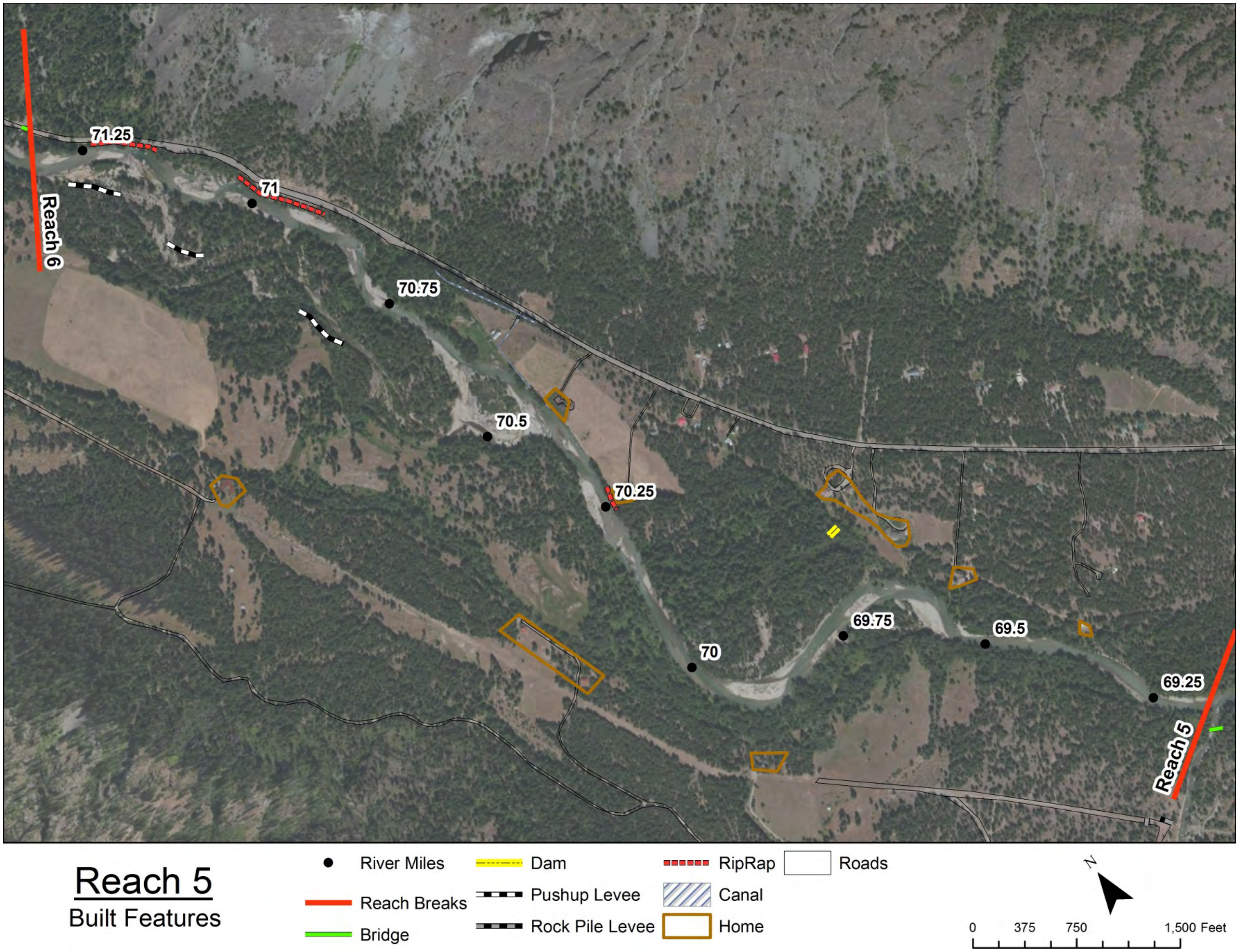

Figure 92. Primary human features in Reach 5.

3.5.3 Human Alterations

Human features are mapped in Figure 92. The primary human alterations in the reach include the following, and are described further in the subsections below.

- Changes to floodplain function
- Changes to streambank complexity and riparian impacts

Changes to Floodplain Function

Historical vegetation removal, grading, and levee construction have had some impact on modern floodplain function. The floodplains are currently vegetated with maturing forests that include trees 50 to 100 years in age. However, historical logging from the early 1900s (evidenced by stumps and cut wood) has resulted in a minor reduction in stand density and tree height across the modern floodplain surfaces. The initial impacts of logging on floodplain function would have been greater than the residual impacts that we see today. Initial impacts would have included a reduction of bank and surface roughness, increased avulsion rates and instability, and limited large wood recruitment potential.

The push-up levee at the edge of the high floodplain surface on river-right at RM 70.75 disconnects floodplain processes. This levee is approximately 400 feet long and diverts channel flow away from the banks of this surface. It is likely that this levee is partially responsible for the disconnection of this surface from the channel. Remnant sections of another push-up levee are located on the floodplain on river-right between RM 71 and 71.25. This levee has been breached by flood waters leaving only an upstream section that is approximately 350 feet long and three feet tall and a downstream section approximately 250 feet long, four feet tall, and 15 feet wide. The downstream section of this levee has a flat road prism on top (Figure 93). It appears this levee was originally built along the 1945 channel boundary, which would have affected floodplain connectivity until the levees were finally breached and eroded. Although the levees have been breached, their presence continues to influence flood inundation patterns and possibly the location of the main channel and side-channels.

Figure 93. Section of the breached push-up levee on the floodplain near RM 71.1. (8/26/2014)

Changes to Streambank Complexity and Riparian Impacts

Stream bank complexity and riparian vegetation in Reach 5 have been reduced along a levee and at riprapped banks. Construction of the Lost River Road (on river-left between RM 70.75 and 71.3) resulted in banks that are reinforced with large angular boulders. This inhibits toe erosion and natural bank and hillslope inputs from the slope talus and alluvial fan deposits, thus altering localized sediment inputs to the reach. The riprap also reduces the complexity of the potential riparian vegetation and limits the establishment of mature tree stands. These impacts reduce shade and large wood recruitment potential. Similarly, a boulder-riprapped bank at the toe of the high outwash terraces on river-left at RM 70.25 (175 feet long) reduces streambank complexity by altering natural sediment inputs and vegetation establishment. At this site, the riprap-reinforced bank also limits local lateral channel migration where it protects a private residence near the edge of the terrace surface.

Additional loss of riparian vegetation and the benefits it provides has occurred to some degree on most of the surfaces adjacent to the channel in Reach 5. Partial or complete vegetation removal along outwash terrace banks near the channel and/or its side- and off-channel features are visible on river-left between RM 69.35 and 69.75, and RM 70.25 and 70.55, and on river-right between RM 70.9 and 71.3. Sections of the high floodplain surface on river-left between RM 70 and 70.8 have also been cleared or thinned. Loss of vegetation near these features can increase local water temperatures, reduce natural bank stabilization, limit tree-fall nutrients, and reduce off-channel habitat complexity. The banks of the floodplain are well-vegetated with maturing forests, but evidence of historical logging here (a few stumps and cut wood) has resulted in a minor reduction of stand density and potential tree height. There is no modern clearing or homesite development occurring on the floodplains and thus these surfaces are naturally recovering. As a result, the active and high floodplain surfaces do provide both small and large wood to the channel through lateral channel processes. However, the loss of beaver populations in this reach has likely reduced riparian wood inputs to the mainstem as well as to the side-channels and tributaries.

3.5.4 Recommended Actions

Recommended actions in Reach 5 are focused on improving the habitat and connectivity of the existing side-channel network, enhancing floodplain function, increasing channel complexity, and restoring riparian function. Side-channel network enhancement can be addressed by removing push-up levees, placing apex jams to encourage split flows, adding large wood, and creating pools. Improving floodplain function can occur through removal of push-up levees and passive recovery of mature floodplain forests. Restoring riparian function can occur through native riparian vegetation planting where clearing has occurred. Channel complexity can be addressed with log jams and debris capture jams designed to collect and retain wood that is fluvially-transported into the reach.

Restoration recommendations recognize the importance of maintaining connectivity of the mainstem channel to perennial or groundwater-fed tributaries and side-channels. This has been identified as a critical component for fish survival in a system with the potential to seasonally dewater.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.6 REACH 6

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.6.1 Reach Overview

Reach 6 is 3.75 miles long and extends from RM 71.3, at its confluence with Goat Wall Creek, to RM 75, at its confluence with Lost River. Property ownership in Reach 6 is Washington Department of Fish & Wildlife, Okanogan National Forest, and private landowners (Figure 94). This is the longest reach in the study area. The reach has both semi-confined and unconfined sections. Confining features include glacial outwash terraces, alluvial fans, talus-draped hillslopes, levees, and riprap-armored banks. The channel is single-thread with a riffle-pool-glide form and a moderate sinuosity of 1.11 (Figure 95). The substrate of the channel is dominated by cobbles and gravels. The modern floodplain is also composed of cobbles and gravels, but topped with plentiful sands. The natural floodplain has an average width of 1,394 feet. In the middle portion of the reach, the maximum width of the floodplain was approximately 2,400 feet prior to human confinement of the channel. Floodplain width diminishes to approximately 275 feet at the downstream border, where it is naturally confined between alluvial debris fan deposits and a terrace. These and other reach metrics are provided in Table 12 and Figure 96.

Floodplain scarring and deposition patterns indicate that high-flow events activate side- and off-channel features where human alterations have not modified floodplain inundation processes. Historically, the channel was laterally active and had multiple side-channels. Modern migration rates and the number of off-channel features have been reduced over the last few decades by the installation of riprap and levees. However, combined sediment inputs from upstream, Lost River, and local cut-banks supply sufficient bedload to maintain active bars. Even in the artificially confined sections of the reach, the channel contains large bars composed of cobble and gravel; these add complexity and sinuosity at low flows. Side channels and groundwater-fed tributaries on the floodplain contribute habitat complexity to the reach where connectivity has not been blocked by levees or canals. On the floodplain adjacent to the channel, flood events create scour and fill features that are composed of bedload material. These features indicate active bedload transport during high-flow events.

The habitat conditions in Reach 6 are discussed in Appendix A. Based on the REI analysis, 8 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). The salmon and steelhead redd distributions for the reach are mapped in Figure 94. Although some of the floodplain and channel banks have been cleared or thinned of vegetation, most of the channel banks are vegetated with maturing forests. These forests provide large wood to the system and enhance the roughness of bank and floodplain surfaces. Where armored banks and home-site development obstruct channel and floodplain connectivity, natural geomorphic processes are compromised. The community of Lost River is located in the upper portion of the reach on the terrace and floodplain surfaces on the northeast side of the channel (river-left).

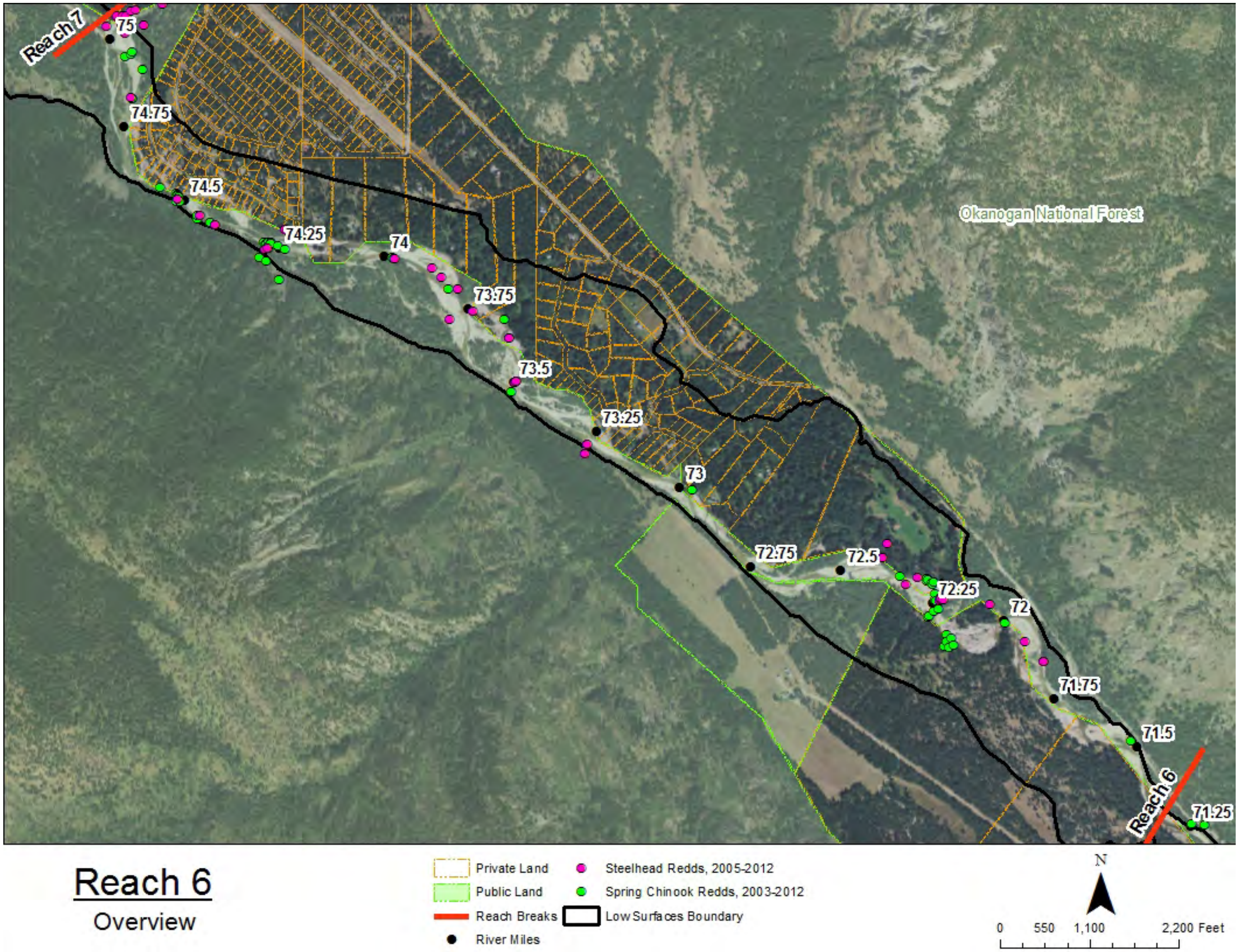

Figure 94. Reach 6 overview map with landownship and redd distribution.

Figure 95. Representative photo of Reach 6; looking downstream at RM 74.25. (8/14/2014)

Table 12. Reach 6 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	3.7
River Miles	71.30 – 75
Valley Gradient	0.8%
Stream Gradient	0.7%
Sinuosity	1.11
Dominant Channel Type	Pool-riffle-glide
Average Bankfull Width (feet)	100
Average Floodplain Width (feet)	1394
Dominant Substrate	cobble 51%; gravel 45%; boulder 2%; gravel 2%
Bank Stability/Channel Migration	Unacceptable *(See Section 2.12)*
Vertical Channel Stability	At Risk *(See Section 2.12)*
Confinement ratio	Unconfined *(See Table 5)*

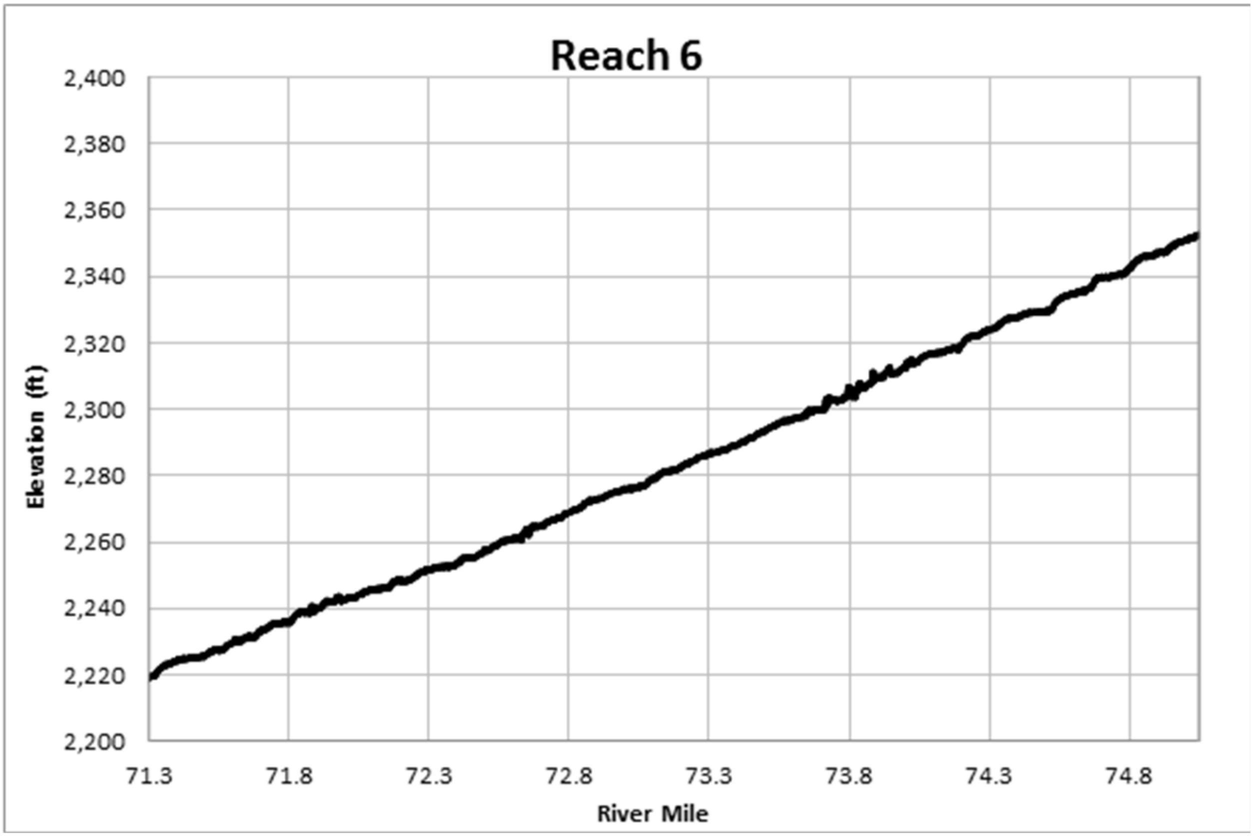

Figure 96. Longitudinal profile of the channel in Reach 6 (RM 71.30 to 75).

3.6.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 6 is located in a wide, glacially-carved, U-shaped valley. Increased discharge and sediment regimes during early Holocene periods of glacial retreat resulted in a thick layer of glacial outwash deposits filling the valley floor (Figure 97). The modern channel and floodplain in Reach 6 are inset into the outwash deposits that today form terraces along the edges of the valley. In the upper portion of the reach, glacial outwash terraces are located along river-left (the northeast side of the valley). In the lower portion, they are located along river-right (the southwest side of the valley). The Lost River drainage, also carved by glaciers, is now inset below its historical floodplain and alluvial fan deposits. Lost River's notable contribution of sediment and discharge to the Methow River influences geomorphic features and processes downstream. Discharge contributions from Lost River more than double the flow in the Methow River and the abundant sediment contributions influence bar development in the upper portion of the reach.

Reach 6 is located in a valley bordered by steep bedrock walls. These valley walls contribute talus and alluvial debris fan deposits to the valley floor and the channel. In the upper portion of the reach, direct talus and rock-fall inputs to the channel occur from RM 74.15 to 74.7 on river-right. In the lower portion of the reach, they occur on river-left from RM 71.4 to 72.1. However, modern rock-fall inputs in this lower section are reduced by the riprapped embankment of the Lost River Road. At mid-reach between RM 72.85 and 73.85, alluvial debris fan deposits stretch from both sides of the valley walls across the glacial terraces. The steep, high, cut-bank of McGee Creek's historical alluvial fan currently borders the channel on river-right (from RM 72.85 to 73.4). McGee Creek continues to contribute sediment and discharge to the modern channel.

The channel in Reach 6 varies from relatively straight to meandering with a moderate average sinuosity of 1.11. The channel is less sinuous from RM 72.85 to 73.5 and from RM 74 to 74.7 where it is confined by hillslopes and terraces on river-right, and then riprap, levees, and cleared banks on river-left. Primary classification of the channel is riffle-pool, but glide units are present in the more confined and less complex areas of the channel. Reach 6 does contain a relatively high number of pools (6.3 per mile) compared to the average of the study area (3.6 per mile). Large side- and mid-channel bars composed of cobble and gravel are abundant throughout the reach. Bar size and distribution increases in unconfined channel sections. Island features and mid-channel bars split the channel into active side-channels that redistribute flow, thus increasing the overall complexity of both channel and floodplain features. Based on observed overbank deposits and scour, multiple side- and off-channel features as well as many high-flow and abandoned channel scars are activated during flood events approximately every two years.

A variety of features in Reach 6 indicate that during high flow events, there is notable sediment transport as well as floodplain connectivity with the channel. Aerial photos from 1945, 1974, and 1985 confirm that historically, the channel migrated laterally within its modern floodplain via side-channel occupation, meander extension, and avulsion. Near the channel, there are scour and fill features composed of cobbles and gravels (Figure 98). These features occur where a flood event has filled in a side-channel or overflow channel with bedload material – sometimes to an elevation approximately equal to that of the floodplain surface. Groundwater-fed side-channels and abandoned channel scars add complexity to the geomorphology and hydrology of the reach. The side-channels and groundwater-fed tributaries also provide important off-channel aquatic habitat.

Small high floodplain surfaces in the most downstream portion of the reach on river-right have remnant scroll bar features and developing soil. These alluvial surfaces are the result of channel bed incision, which is likely being amplified by the modern artificial confinement of the channel at RM 71.3 (the downstream border of Reach 6). There is a unique cut-bank feature located at RM 72.2 on river-left where the active channel is eroding into alluvial deposits comprised primarily of fines (silts, sands, and clays). The stratigraphy in the cut-bank reveals a complex layering that includes former locations of a tributary channel, evidenced by gravel lenses and surface depressions (Figure 99).

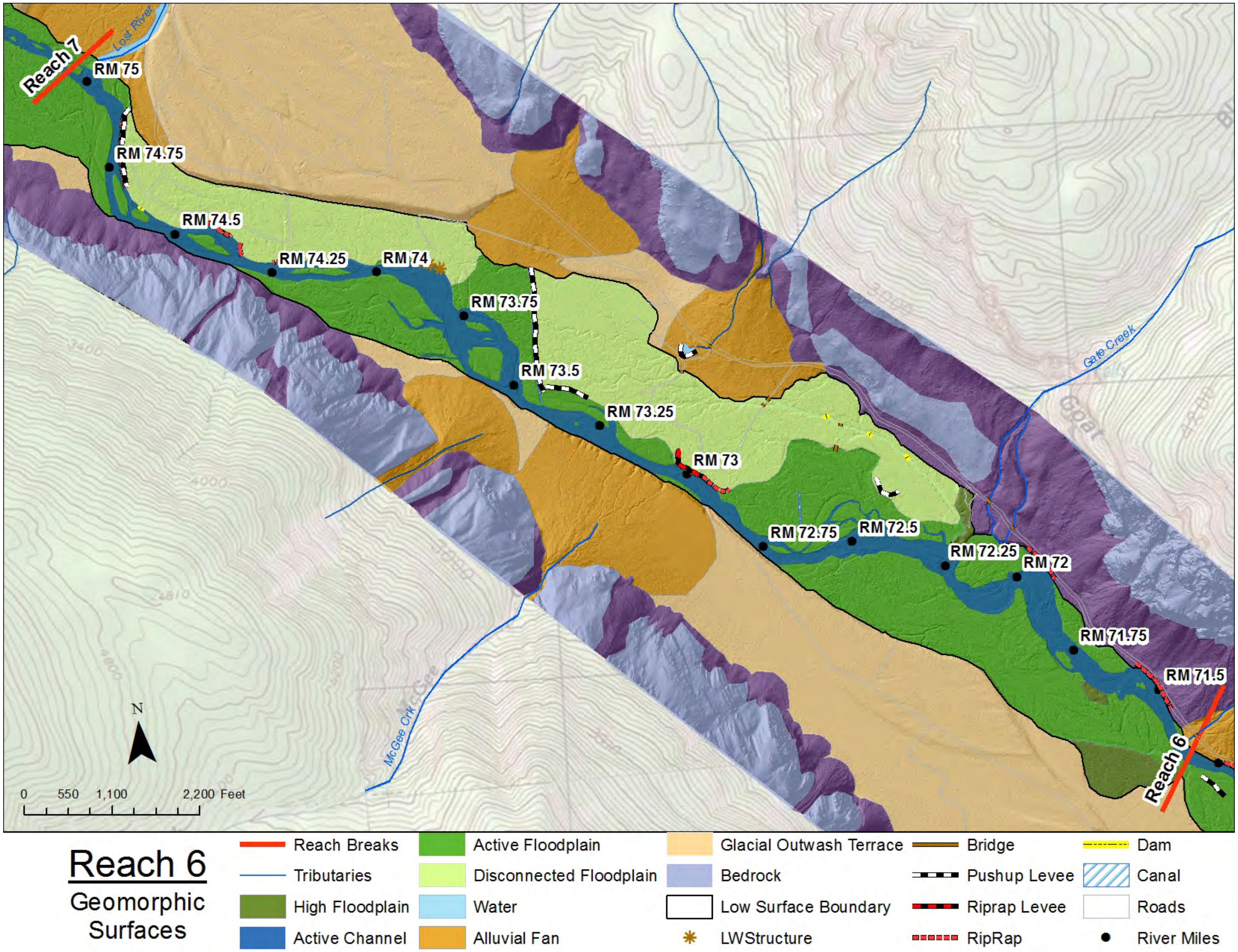

Figure 97. Geomorphic surfaces of Reach 6 with selected human-built features (log structures, levees, riprap, check dams, canals, bridges, and roads).

Figure 98. Cobble-gravel filled side-channel near RM 72.5.

Figure 99. Cut-bank located at RM 72.2 on river-left -- composed of alluvium (silts, sands, and clays with gravel lenses), with a paleo-channel notch. (8/15/2014)

Hydrology

Reach 6 has a seasonally fluctuating flow regime. Spring snowmelt events activate overflow channels. Flood events inundate available low floodplain surfaces on a regular basis (2 year flood recurrence) (Figure 100). Late summer, autumn, and winter low flows often leave most of the reach dry, with isolated pools susceptible to temperature extremes (see discussion in Section 2.6.3). Summer and autumn thunderstorms are capable of temporarily raising surface water elevations if discharge inputs are substantial enough to recharge groundwater elevations.

The valley floor is composed primarily of coarse-grained material that supports hyporheic flow and groundwater influx from upstream and the adjacent terraces, valley walls, and alluvial fans. Hyporheic through-flow at the downstream ends of active bars was observed during field surveys in August and September 2014. Despite notable discharge from Lost River, Reach 6 is considered a "losing" reach (Konrad etal 2005). This means that the channel contributes its incoming surface flow to the valley's large subsurface groundwater reservoir that is up to 1,000 feet deep in this area (Konrad 2006b). During low flow periods, sections of the channel become dry when the incoming surface water flow is less than the quantity of water the channel is contributing to the reservoir to recharge groundwater. See Section 2.6 of this report for a description of the groundwater to surface water interchange processes that occur here.

Reach 6 receives surface water inputs from Lost River, McGee Creek, Gate Creek, and a handful of seasonal or ephemeral hillslope tributaries. According to US Bureau of Reclamation surface flow estimates (2008 – Appendix J), discharge of the Methow River increases by 66% at the Lost River confluence during high flows. The Lost River increases the contributing upstream drainage area from 85 square miles to 256 square miles. Thus, the Lost River watershed is an important hydrologic and geomorphic agent in the upper Methow Basin. During high flows, McGee Creek, on river-right at RM 73, increases discharge by less than 1%, and Gate Creek, on river-left at RM 72.3, increases discharge by approximately 1.3%.

An important hydrologic feature in Reach 6 is the side-channel that traverses the floodplain on river-left from RM 73.8 to 72.3. The feature is now disconnected from the mainstem at the upstream end by a constructed canal that crosses its path. The canal blocks surface flow from entering the side-channel, and instead diverts it off the floodplain. Today, downstream from the canal, this side-channel still has surface flow but it is fed by groundwater inputs alone. The groundwater is generated upstream and from the adjacent terraces and alluvial fans. Where the side-channel borders the toe of a large alluvial fan, notable upslope groundwater inputs lower the temperature of its surface water. This side-channel traverses the edge of the floodplain along the north side of the valley and eventually delivers the collected groundwater to the mainstem as surface flow at RM 72.3. Three large beaver dams and a few log jams create pools that impose natural grade control on the stream and facilitate the local accumulation of fines and nutrients (Figure 102).

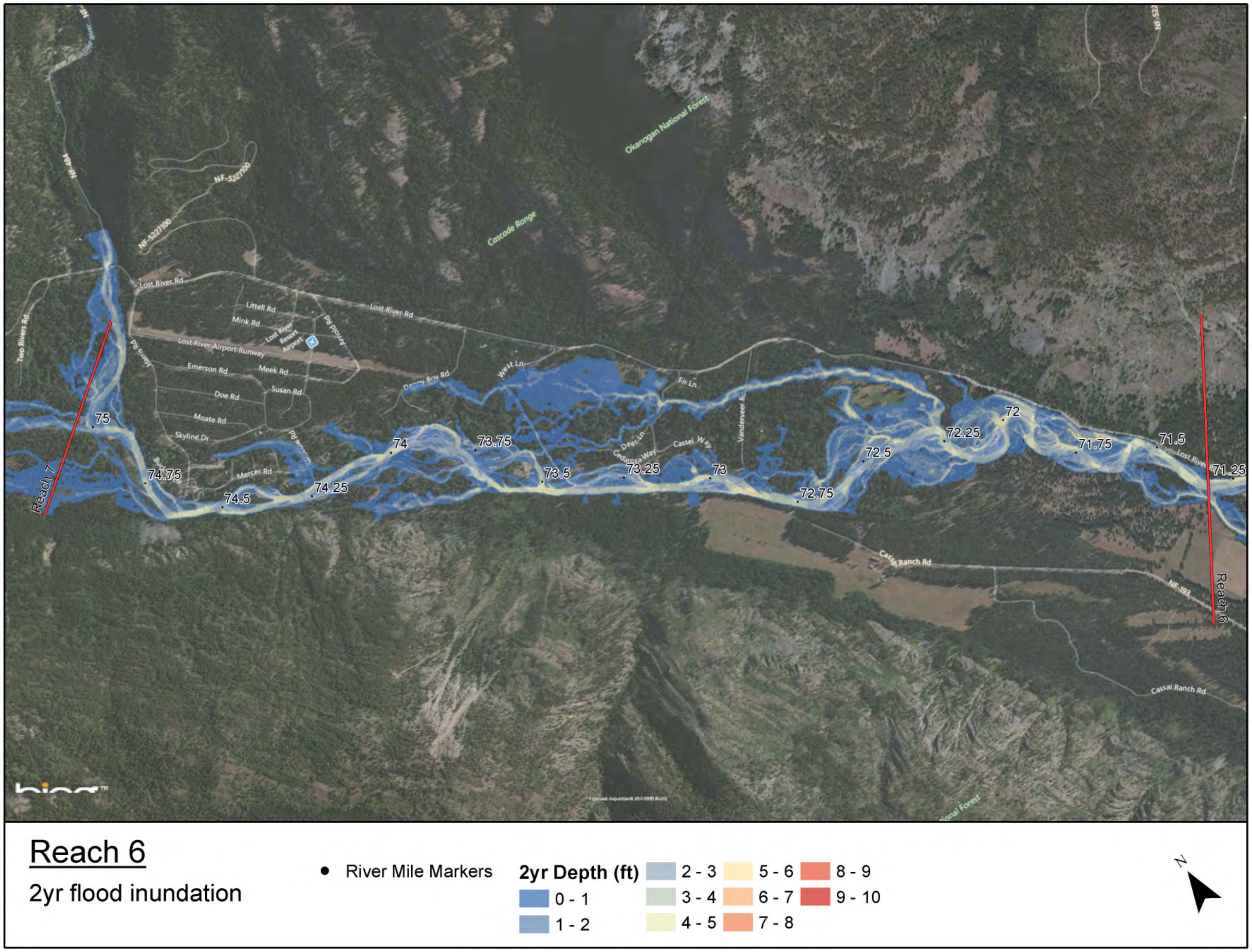

Figure 100. Floodplain inundation for 2YR flood in Reach 6 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

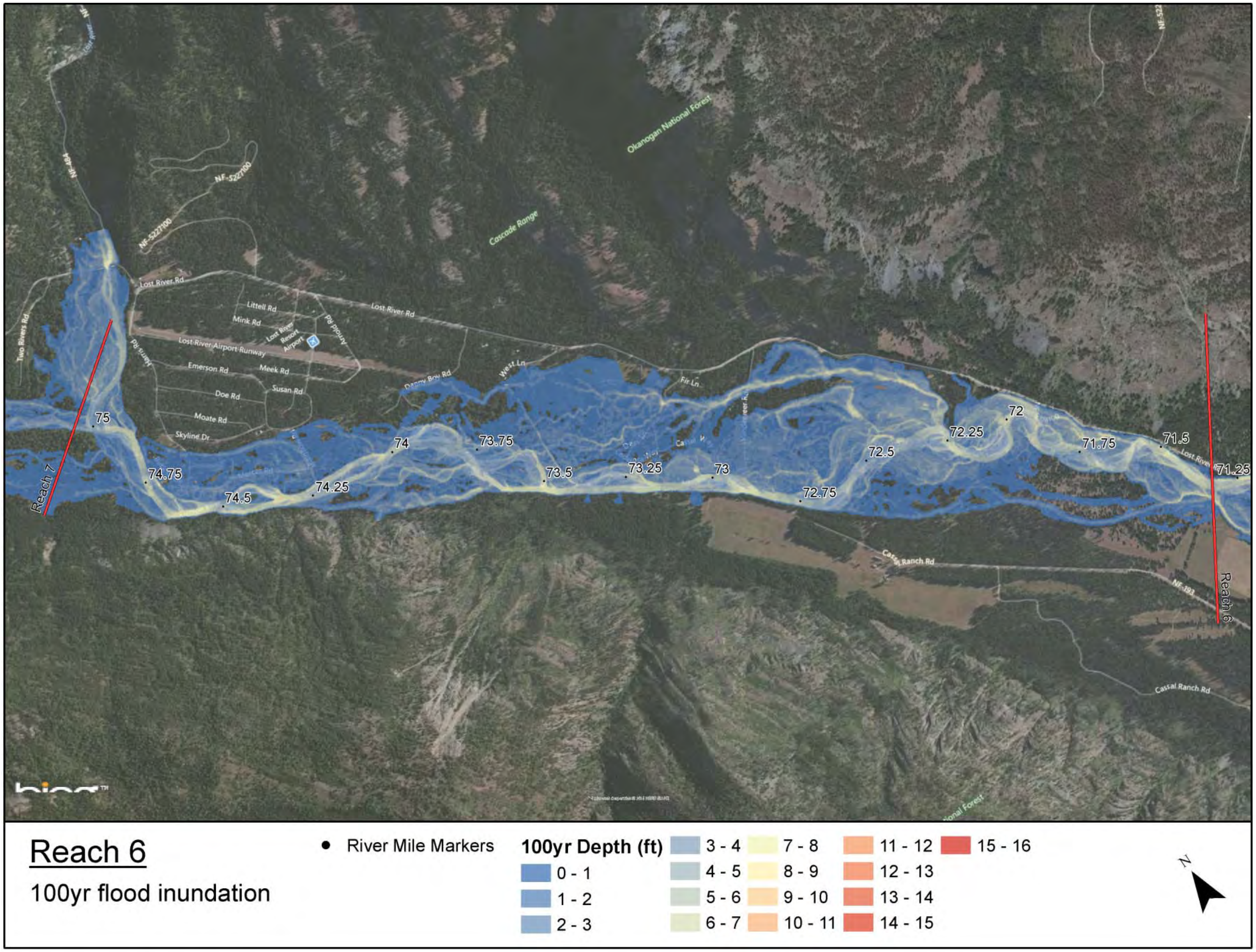

Figure 101. Floodplain inundation for 100YR flood in Reach 6 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Figure 102. Ground-water wetted side-channel, disconnected from mainstem at upstream end by canal. Located on river-left between RM 73.8 and 72.3. (8/24/2014).

Floodplain and Channel Migration Zone

Reach 6 is naturally active laterally and vertically. Natural partial confinement of the reach occurs where it contacts valley walls and terrace banks. Aerial photos from 1945 to 1985 confirm modern lateral migration through meander extension and avulsion (Figure 103). However, in sections of the reach, modern lateral processes have been restricted by riprap and levees constructed along the channel banks. For example, the historical migration zone on river-left from RM 72.85 to 73.5 was reduced by 700 to 1,000 feet, and from RM 74 to 74.85 by 650 to 900 feet. At these sites, the channel is also confined on river-right by valley walls or banks cut into alluvial fan and glacial terrace slopes that are 10 to 15 feet higher than the active channel. Artificial confinement of a river often reduces vertical stability by instigating incision processes. However, bed incision is partially offset here by plentiful sediment inputs sourced from the Lost River and the terrace slopes. These sediments support bar and island development in the upper half of the reach.

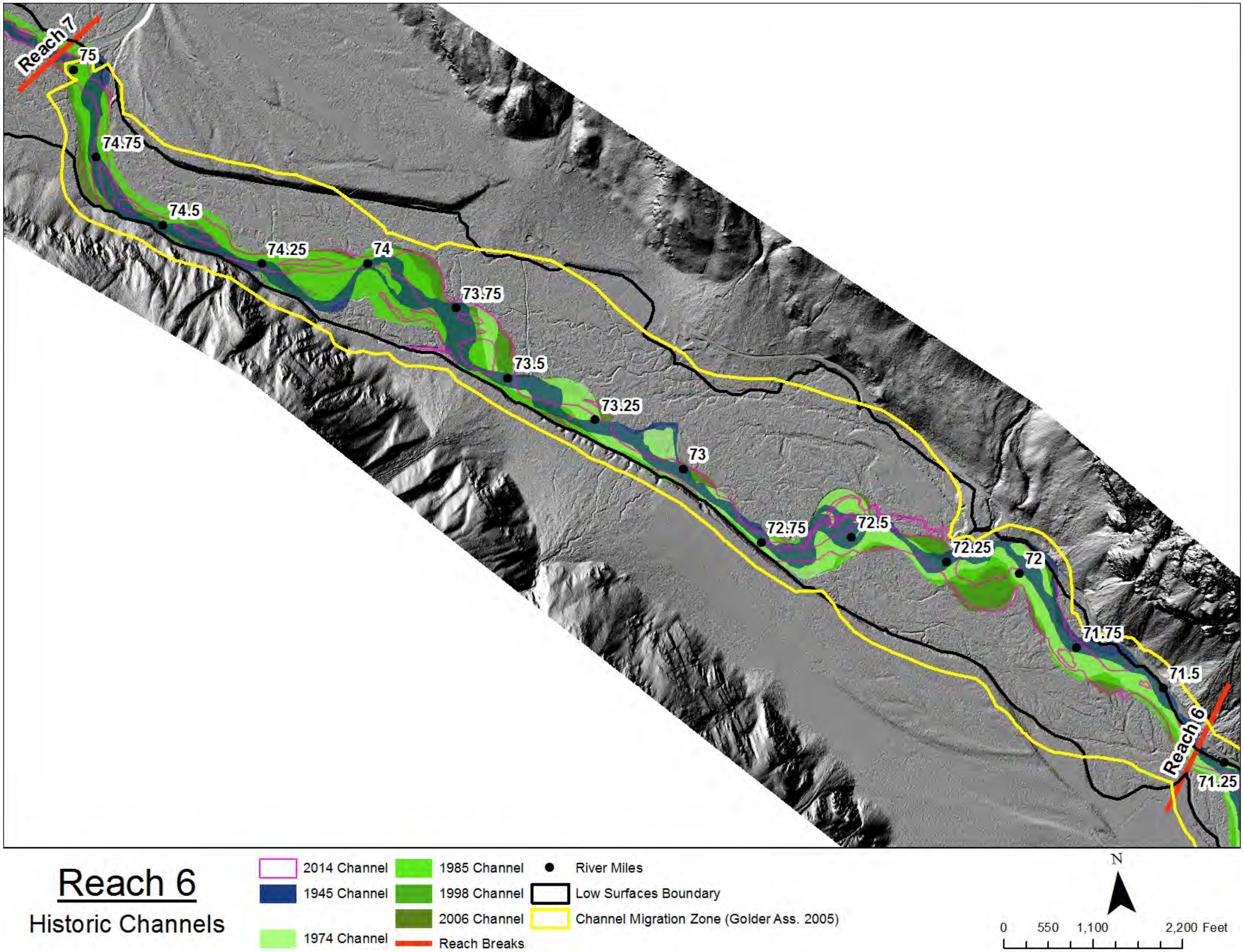

Figure 103. Historical channel locations for Reach 6.

The location of the channel and its active floodplain shifts from one side of the valley to the other. As a result, it is naturally confined on river-right in the upstream section and on river-left in the downstream sections by valley walls and high (10 to 15 foot) cut-banks along glacial outwash terraces and alluvial fans. At the downstream border, the channel migration zone is naturally reduced to only 275 feet between the Goat Wall Creek alluvial fan on river-left and glacial and alluvial terraces on river-right. As expected, where migration zones are reduced, incision has occurred. At the downstream end of Reach 6, an alluvial terrace and ascending scroll bars on the high floodplain surface on river-right (west side of the reach) confirm a history of gradual incision. The elevation of active floodplain surfaces varies; going from approximately two feet (low), four feet (medium), and six feet (high) above the channel bed. Overbank deposits observed in the field indicate that all elevations of floodplains were recently inundated during high-flow events – likely the 2006 and 2008 flood events. This is confirmed by hydraulic modeling (Figure 100 and Figure 101). The variance and mixed distribution of floodplain elevations indicate historically active vertical and lateral migration patterns in the reach. Where human features have not altered floodplain inundation processes, high-flow events activate side and off-channel features on river-left from RM 72 to 72.7, and on river-right from RM 71.35 to 72.7 and RM 73.65 to 74.25.

Sediment

The substrate of Reach 6 is dominated by cobbles (51%) and gravels (45%) with minor sand (2%) and boulders (2%). Sand is found as overbank deposits on floodplains, as topping on high bars, and as still-water deposits in backwater features or at eddy points. Large boulders in the channel on river-right from RM 74.35 to 74.65 were locally sourced from talus on the bordering valley wall. Boulders, cobbles, and coarse sand are supplied from the high cut-banks of glacial terrace and alluvial fan deposits on river-right from RM 72.7 to 73.6. A unique cut-bank on river-left at RM 72.25 is currently being eroded by the channel. This bank is composed of clay and sand with lenses of gravel and a submerged base of cobbles and small boulders. The deepest meander bend scour pool in the reach is at the base of this cut-bank. The side-channels that traverse the floodplains also contribute sediment to the channel and these inputs are usually gravels, sands, and fines. The floodplains are composed of cobbles and gravels and are topped with sands. Lost River and its alluvial fan contribute a large amount of cobbles and gravels to the bedload of Reach 6. Bedload sediment throughout the reach is well sorted (has a relatively similar diameter size range) and rounded, indicating that much of the substrate is transported fluvially during high flow events

Large Wood

Reach 6 has a moderate in-channel large wood count of 388 logs (48 logs per mile) and 10 log jams. In-channel wood distribution in the reach is presented in Figure 104 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. The most geomorphically effective wood accumulations occur where channel and floodplain complexity is greatest – from RM 71.5 to 72 and from RM 73.5 to 73.75. Large wood recruitment is minimal at riprapped and leveed banks or where vegetation clearing has occurred. Partial and full clearing of large trees has occurred on private lands along channel banks on river-left from RM 72.85 to 73.25 and from RM 73.8 to 74.85.

On river-right, from RM 72.25 to 73.1, clearing of vegetation for agriculture has occurred on the top of the terrace and alluvial fan, but the high cut-bank remains treed. Clearing along the banks has occurred on river-right from RM 71.65 to 71.85, and also on active floodplain surfaces that are set back from both sides of the channel from RM 72.25 to 72.5. The remainder of the floodplain, terrace, and hillslope surfaces are well vegetated with both small and mature trees. These trees provide wood to the main channel and side-channels. Channel-spanning log jams occur in the smaller side-channels, but the width of the main channel is generally too great for channel-spanning accumulations to develop given the size of currently available large wood pieces. Instead, wood accumulates on the cobble-gravel bars. Where large jams occur, they create channel complexity by promoting bar development and scour pools. In Reach 6, large and small wood recruitment, especially of cottonwood, is enhanced by the active presence of beavers (Figure 103). Wood contributions by beavers play an important role in side-channel pool development and grade control.

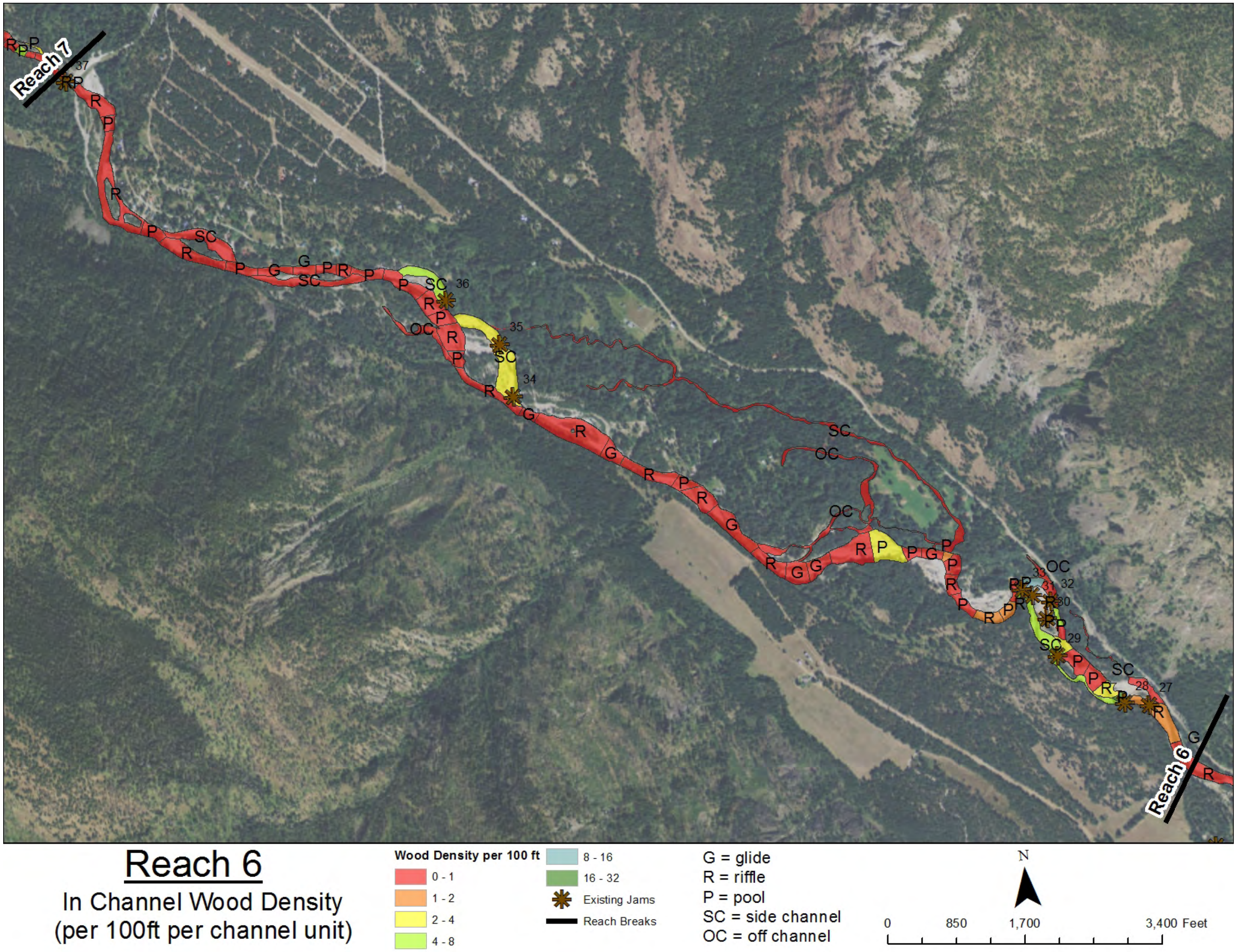

Figure 104. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 6.

Figure 105. Beaver chew on a large cotton adjacent to the mainstem in Reach 6. (8/15/2014)

Vegetation

The banks of the channel in Reach 6 are well vegetated except at the cleared locations listed above and where riprap and levees have been constructed (Figure 106). A sparse distribution of trees and shrubs exist on the high cut-banks of the glacial terrace and alluvial fan deposits on river-right from RM 72.7 to 73.6, but density and age is reduced due to the instability of the slopes. The other vegetated floodplain banks throughout the reach contain forests composed of a mix of cottonwood, aspen, fir, pine, and cedar. Stands of massive cedar and aspen occur in well-vegetated sections of the floodplain on river-left between RM 73.2 and 73.5. Recently abandoned low surfaces, such as high bars or scour and fill features, have establishing communities of cottonwood, dogwood, fir, and aspen. The understory on the undeveloped floodplain surfaces is dense and includes grasses, forbs, dogwood, maple, devil’s club, equisetum, and snowberry. Vegetation increases surface roughness and stability in these areas. The cleared or partially-cleared banks have a less complex understory dominated by grasses and forbs. Along the riprapped banks, either no vegetation exists, or very sparse communities of willow and dogwood cling to the spaces between the angular boulders near the channel. The side-channels receive shade and organic material from floodplain vegetation. The main channel in Reach 6 is wider than the average tree height, thus shading occurs primarily along the banks on river-right (southwest side).

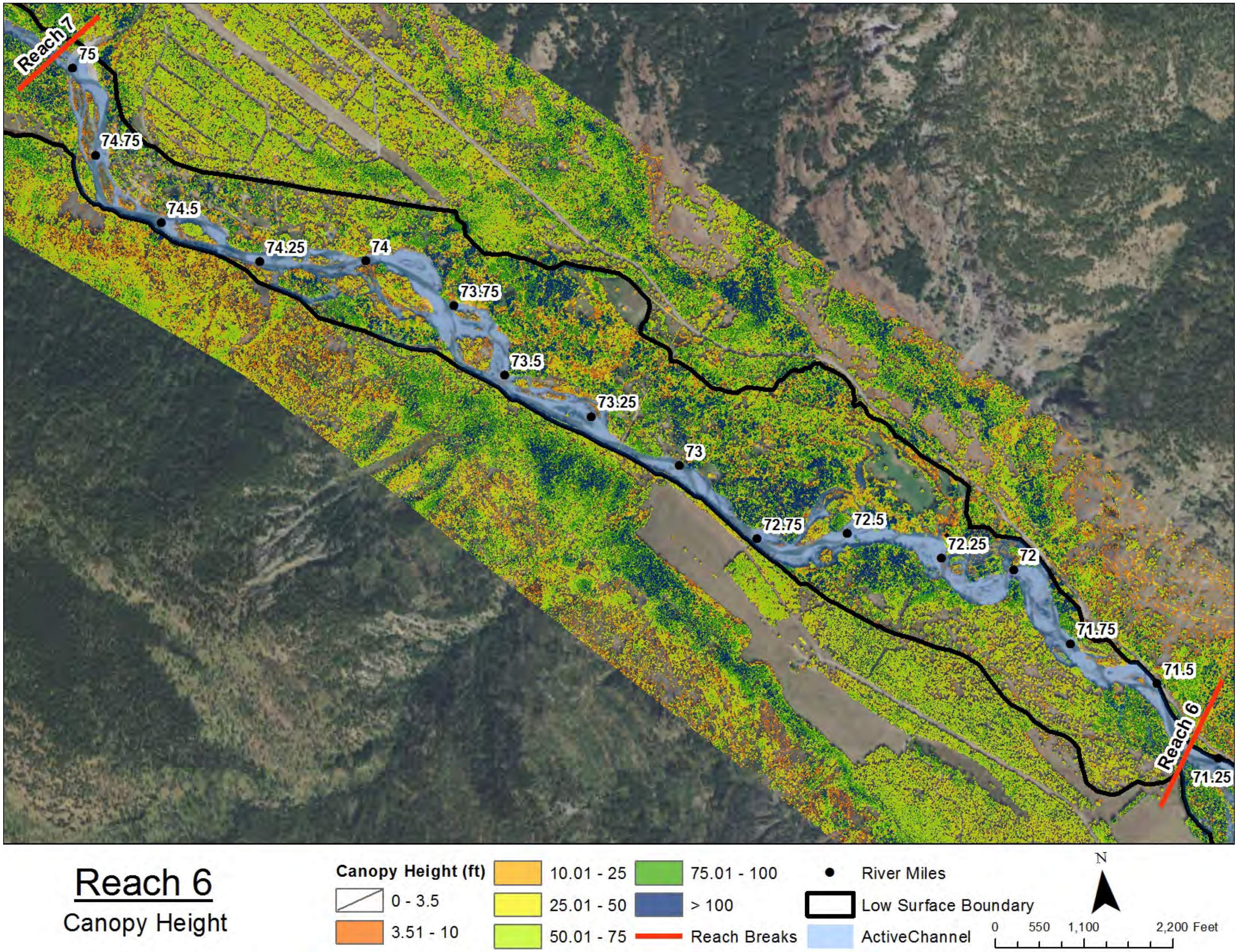

Figure 106. Vegetation canopy height for Reach 6 -- derived from LiDAR first return (highest hit) data (includes buildings and other human infrastructures).

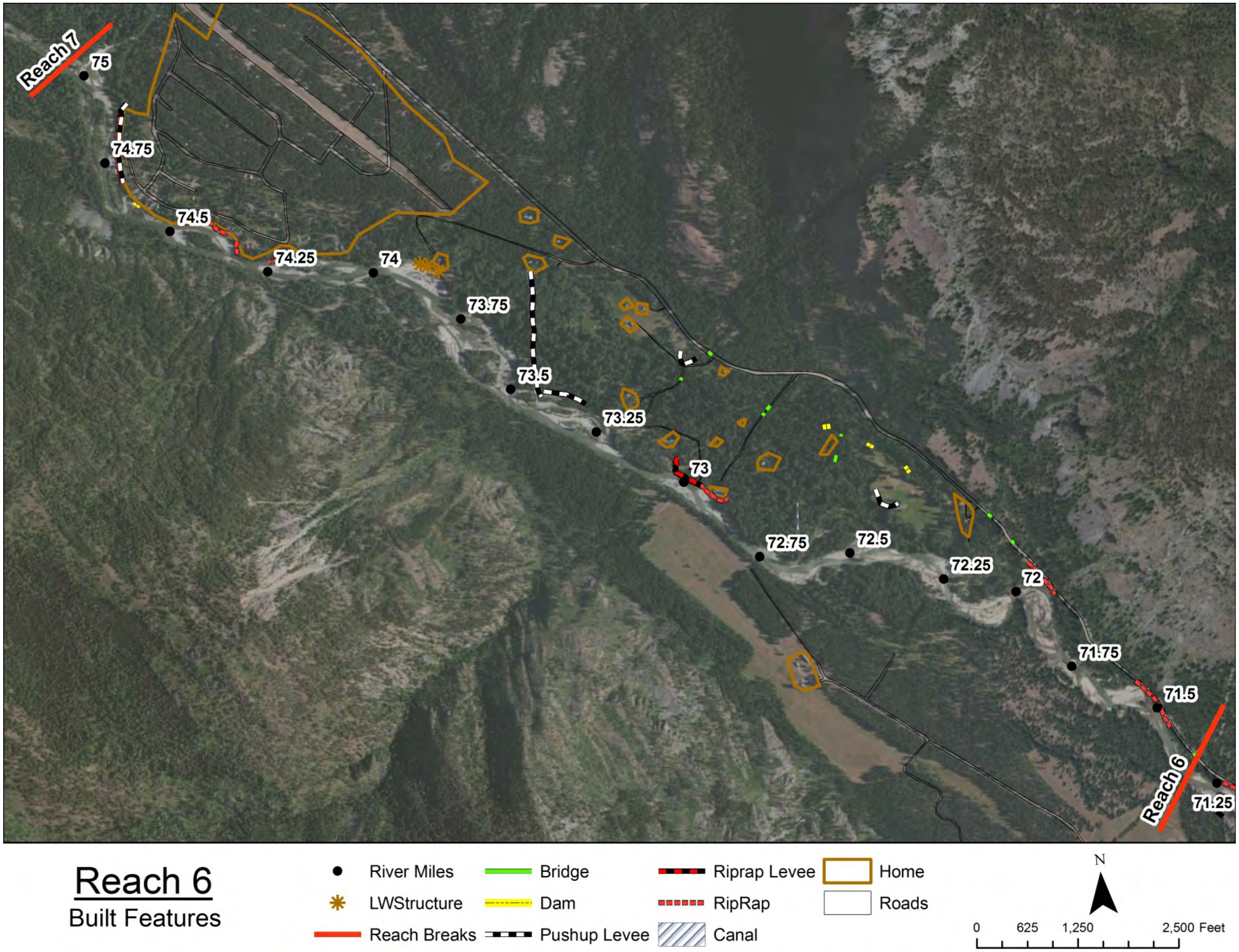

Figure 107. Primary human features in Reach 6.

3.6.3 Human Alterations

Human features are mapped in Figure 107. The primary human alterations in the reach include the following, and are described further in the subsections below.

- Changes to floodplain function and channel migration
- Loss of streambank complexity and riparian impacts
- Loss of instream habitat complexity

Changes to Floodplain Function and Channel Migration

Loss of floodplain function has occurred in Reach 6 on river-left from RM 72.25 to 74.85. These losses represent over half of the floodplain surfaces in the reach. The losses differ in severity, but all have occurred as a result of a variety of human-induced activities. The most severe floodplain losses are associated with the development of the Lost River Community. Road construction, vegetation clearing, and the surface grading and filling that comes with home construction have altered riparian and floodplain processes severely from RM 73.8 to 74.85 and moderately from RM 72.25 to 73.8. Installation of riprap and levees (push up and riprap) along sections of the bank restrict lateral channel migration and floodplain connectivity by stabilizing the banks and reducing the frequency and extent of inundation. This occurs on river-left at the following: from RM 72.9 to 73.1, from RM 73.3 to 73.45, at RM 73.85 and 74.25, from RM 74.35 to 74.45, and from RM 74.65 to 74.85. A push-up levee on river-left at RM 72.45 is constructed of material graded from the pasture. This levee reduces local inundation rates from mainstem and side-channel overbank flows.

The feature that disconnects the largest amount of floodplain from the channel is a 1,600-foot-long canal constructed across the floodplain on river-left at RM 73.45 (Figure 108). The canal captures surface flow and diverts it off of the floodplain and back to the mainstem channel. It was built to reduce flooding of the private property downstream. This feature also disconnects a prominent side-channel from upstream surface water inputs. The canal was made of material dug from the floodplain; this same material was used to construct a levee along the canal's east side in an effort to further reinforce the canal's purpose.

The channel migration zone of Reach 6 has been notably reduced. The riprapped banks and levees mentioned above stabilize the banks and constrict natural lateral migration. The historical migration zone on river-left from RM 72.85 to 73.5 was reduced by 700 to 1,000 feet. Now the active width of the channel here is approximately 250 feet. Here, the channel is basically locked in place between the riprap on river-left and the naturally confining high cut-bank of the McGee Creek alluvial fan on river-right. From RM 74 to 74.85, the historical channel migration zone was reduced by 650 to 900 feet. At RM 74.4, the channel is confined to a width of only 400 feet between riprap and the valley wall.

Figure 108. Constructed canal that drains surface water from the floodplain and disconnects a side-channel. Photo taken at the downstream end looking up-canal near RM 73.45. (8/14/2014)

Loss of Streambank Complexity and Riparian Impacts

Streambank complexity and riparian vegetation in Reach 6 have been reduced along riprapped banks. The large boulder riprap in front of the Lost River Community and at channel-contact points along the Lost River Road embankment (RM 71.45 to 71.55 and RM 71.9 to 72.1) inhibit toe erosion and natural bank and hillslope inputs, thus altering localized sediment inputs to the system. The riprap also reduces the complexity of the riparian vegetation and notably decreases the potential for the establishment of mature tree stands. These impacts reduce localized shade to the channel and remove the potential for large wood recruitment in these areas.

Additional loss of riparian vegetation and the benefits it provides has occurred on private lands. Partial or complete vegetation removal along the banks of the main channel is visible on river-left from RM 72.85 to 73.25, RM 73.8 to 74.8, and RM 71.6 to 72.15. The surface of the glacial terrace has been cleared and graded for agricultural use near the channel on river-right from RM 72.75 to 73.1, but the slope of the terrace is fully treed. Some vegetation thinning and clearing has also occurred in patches on floodplain surfaces near side-and off-channel features. Loss of vegetation near these features can also increase water temperature, reduce natural bank stabilization, limit tree-fall nutrients, and reduce off-channel habitat complexity.

Loss of Instream Habitat Complexity

Records indicate that log drives utilized the mainstem channel in Reach 6 to transport cut timber to historical log mills that operated in the early 1900s. The known mills were located near RM 73

(Green Mill), RM 72 at Gate Creek, and RM 71 at Goat Wall Creek (Goat Wall Mill) (Devin 1997, USBR 2008 – Appendix O). In-channel log transport requires clearing the channel of natural log jams and any other obstructions (large boulders, etc.). Additional clearing of large wood likely occurred following the large floods of 1948 and 1972, in conjunction with floodplain and bank protection features (riprap, levees, canals). However, specific locations of these activities are not recorded. The expected impacts of log drives and/or "cleaning" a channel include bed scour, channel and bank simplification, and a reduction in habitat complexity (Nilsson etal. 2005, Wohl 2006, Miller 2010).

3.6.4 Recommended Actions

Recommended actions in Reach 6 are focused on improving floodplain and side-channel function and connectivity as well as increasing channel complexity. Floodplain function and connectivity can be improved by removing/modifying unnecessary riprap and levees, placing meander jams along the bank to improve margin habitat, and removing or selectively breaching the floodplain drainage canal (RM 73.5). Enhanced alcove and side-channel connectivity can be addressed by removing unnecessary riprap and push-up levees, and placing apex jams with select excavation to enhance through-flow. The design and extent of these actions will need to consider the impacts to infrastructure and private property in the Lost River Community. Channel complexity can be increased by placing large wood jams that capture wood, build islands, enhance lateral migration, and deflect flow away from the Lost River Road and Community. Planting native riparian vegetation where clearing has occurred is also recommended.

Restoration recommendations recognize the importance of maintaining connectivity of the mainstem channel to perennial or groundwater fed tributaries and side-channels. This has been identified as a critical component for fish survival in a system with the potential to seasonally dewater.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.7 REACH 7

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.7.1 Reach Overview

Reach 7 is 1.5 miles long and extends from the Lost River Confluence at RM 75.05 to the Robinson Creek confluence at RM 76.5. Except for one private residence on the Lost River alluvial fan terrace at RM 75.2, Reach 7 lies entirely within the Okanogan National Forest (Figure 109). The river is a complex riffle-pool-glide stream with channel bed material dominated by gravels and cobbles and some small boulders (Figure 110). The reach is geomorphically active. It receives pulses of sediment sourced from upstream and local channel beds and banks. The channel in Reach 7 contains complex multi-threaded sections and vegetated islands. At low-flow stages, large side- and mid-channel bars of cobble and gravel are exposed. The floodplains are composed of the same material as the channel substrate but with more boulders at the base and accumulations of sands and fines on top. The modern floodplain surfaces have an average width of 1,345 feet. The channel is moderately sinuous (1.17) and is unconfined. The channel has an average bankfull width of 76 feet and a gradient of 1.5%. These and other reach metrics are provided in Table 13 and Figure 111.

The valley is bordered by narrow bands of glacial outwash terraces and bedrock hillslopes overlain with talus debris. Lost River and Robinson Creek both have active alluvial fans that contribute discharge and sediment to the reach. The floodplain and banks are vegetated with maturing or mature forests and a mixed understory. The vegetated floodplains supply plentiful large wood to the system and add roughness to most of the banks. Burn scars on the older trees indicate historical forest fires.

The habitat conditions in Reach 7 are discussed in Appendix A. Based on the REI analysis, 6 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). The salmon and steelhead redd distributions for the reach are mapped in Figure 109. Partial clearing and a sparse web of single-track dirt roads – used for river access and camping – exist along the majority of river-left (north side of the channel). A recreational trail runs along the edge of the valley on river-right (south side of the channel); it was created from a decommissioned road. Healthy, natural, hydrologic and geomorphic processes are occurring in this reach.

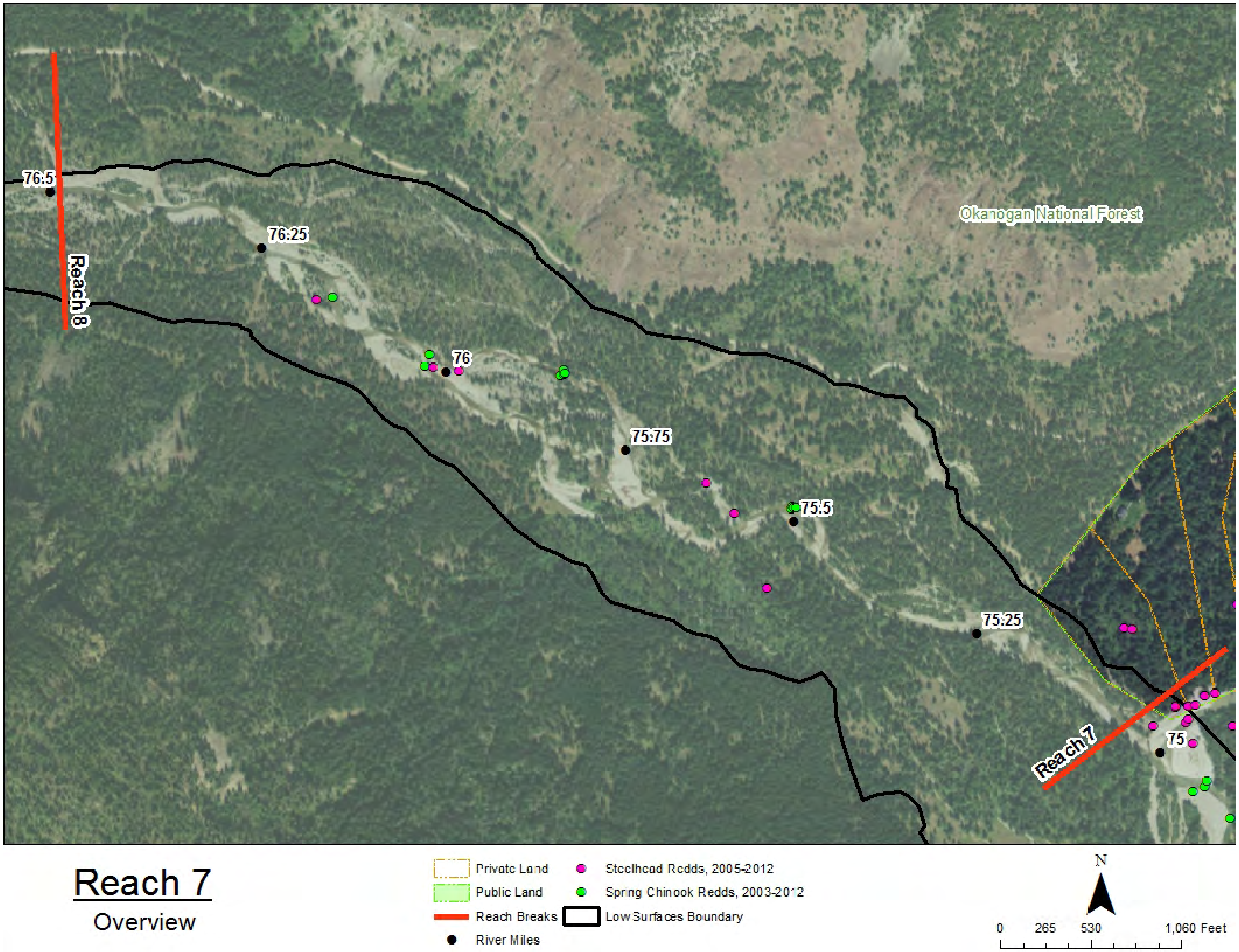

Figure 109. Reach 7 overview map with landownership and redd distribution.

Figure 110. Representative photo of Reach 17 looking upstream at RM 76.15. (8/15/2014)

Table 13. Reach 7 descriptive geomorphic metrics.

Metric	
Reach Length (miles)	1.5
River Miles	75 – 76.5
Valley Gradient	1.8%
Stream Gradient	1.5%
Sinuosity	1.17
Dominant Channel Type	Riffle-pool
Average Bankfull Width (feet)	76
Average Floodplain Width (feet)	1345
Dominant Substrate	cobble 51%; gravel 42%; boulder 5%; sand 2%
Bank Stability/Channel Migration	Adequate *(See Section 2.12)*
Vertical Channel Stability	Adequate *(See Section 2.12)*
Confinement ratio	Unconfined *(See Table 5)*

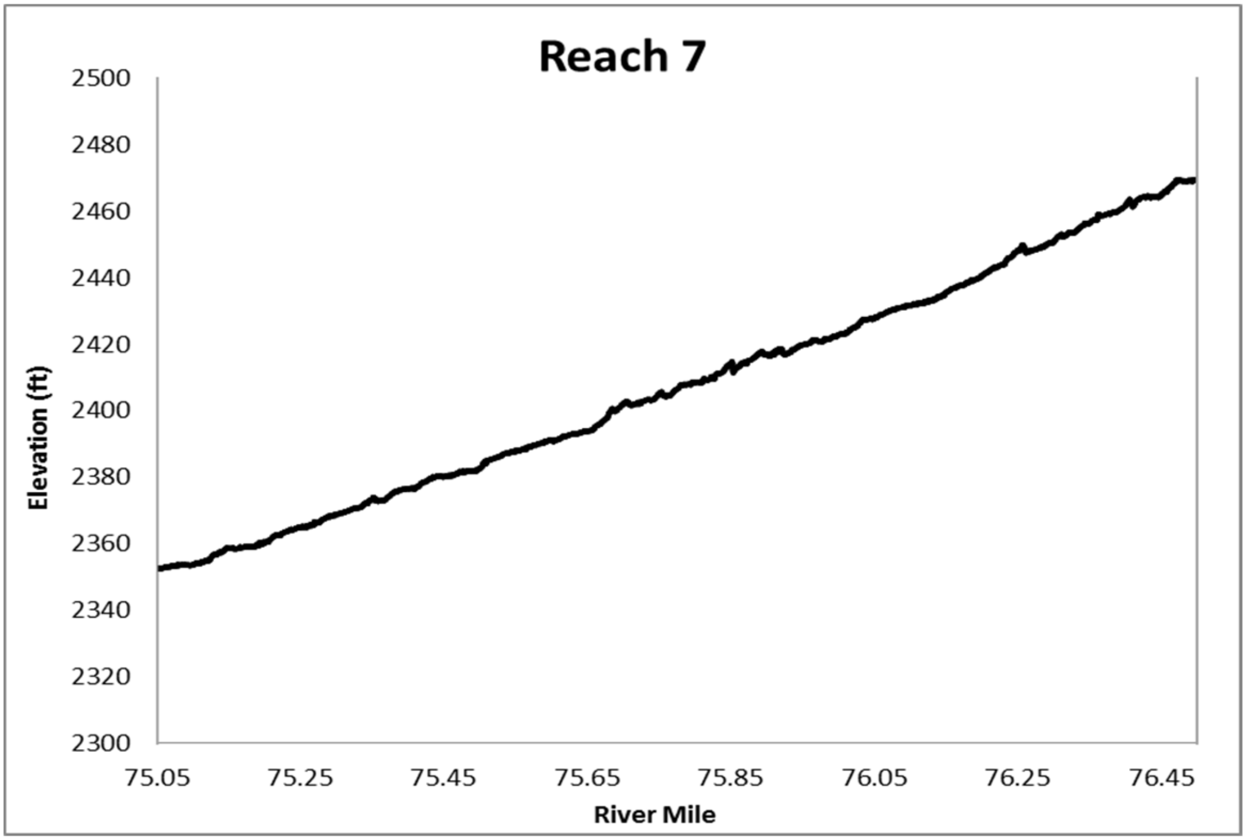

Figure 111. Longitudinal profile of the channel in Reach 8 (RM 75 to 76.5).

3.7.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 7 is located within a wide U-shaped valley most recently carved by Quaternary glaciation. Increased discharge regimes during early Holocene glacial retreat resulted in the valley floor infilling with a thick layer of glacial outwash deposits. The modern channel and floodplain in Reach 7 are inset into the surface of the glacial outwash deposits that today form terraces along the edges of the valley. Like the Methow Valley, both the Robinson Creek and Lost River drainages were carved by glaciers. Both contribute outwash material to Reach 7, and today, their modern alluvial fans are inset below their historical fan deposits. The valley in Reach 7 is wider and less confined than the upstream reaches of the study area. Sediment is transported into Reach 7 from the upstream, higher gradient Reach 8. Pulses of mobilized sediment periodically render Reach 7 transport limited. The valley is bordered by steep bedrock hillslopes that contribute talus and small debris fan deposits to the edges of the valley floor. However, these deposits do not contribute direct inputs to the channel. A map of the geomorphic surfaces is provided as Figure 112.

The modern active floodplain surfaces in Reach 7 range in elevations and inundation rates. The outside edge of the floodplain is relatively higher than the floodplain surfaces near the channel. Modern fluvial scarring patterns indicate infrequent inundation at the outside edges of the floodplain. However, regular groundwater and/or seasonal snowmelt-activated tributaries divert surface flow across the outer floodplain surfaces to the main channel. Near the channel, the active floodplain surfaces vary in elevation [1-2 feet (low); 2-4 feet (medium); 4-5 (high)] relative to the channel bed in a manner that is sometimes incongruent with the age and type of established vegetation. For example, near RM 75.7 on river-left, there are surfaces with tall mature trees at the water's edge with fresh sand-to-cobble deposits around the base of the trees. Infilling of a recently abandoned channel at RM 75.5 on river-right resulted in a bare cobble surface that is flush with the adjacent floodplain surface. This surface is approximately five feet above the bed of the channel. The forested, mid-channel islands in Reach 7 also have varied elevations and stages of established vegetation. These features indicate that the channel experiences fluxes of mobilized sediment during high flow events. The sediment is delivered from upstream as well as scoured from the channel bed and banks of Reach 7. The activated sediment is then transported through the channel in pulses. This results in sequences of aggradation and degradation that can change the relative elevation of the channel bed to the existing floodplain surfaces.

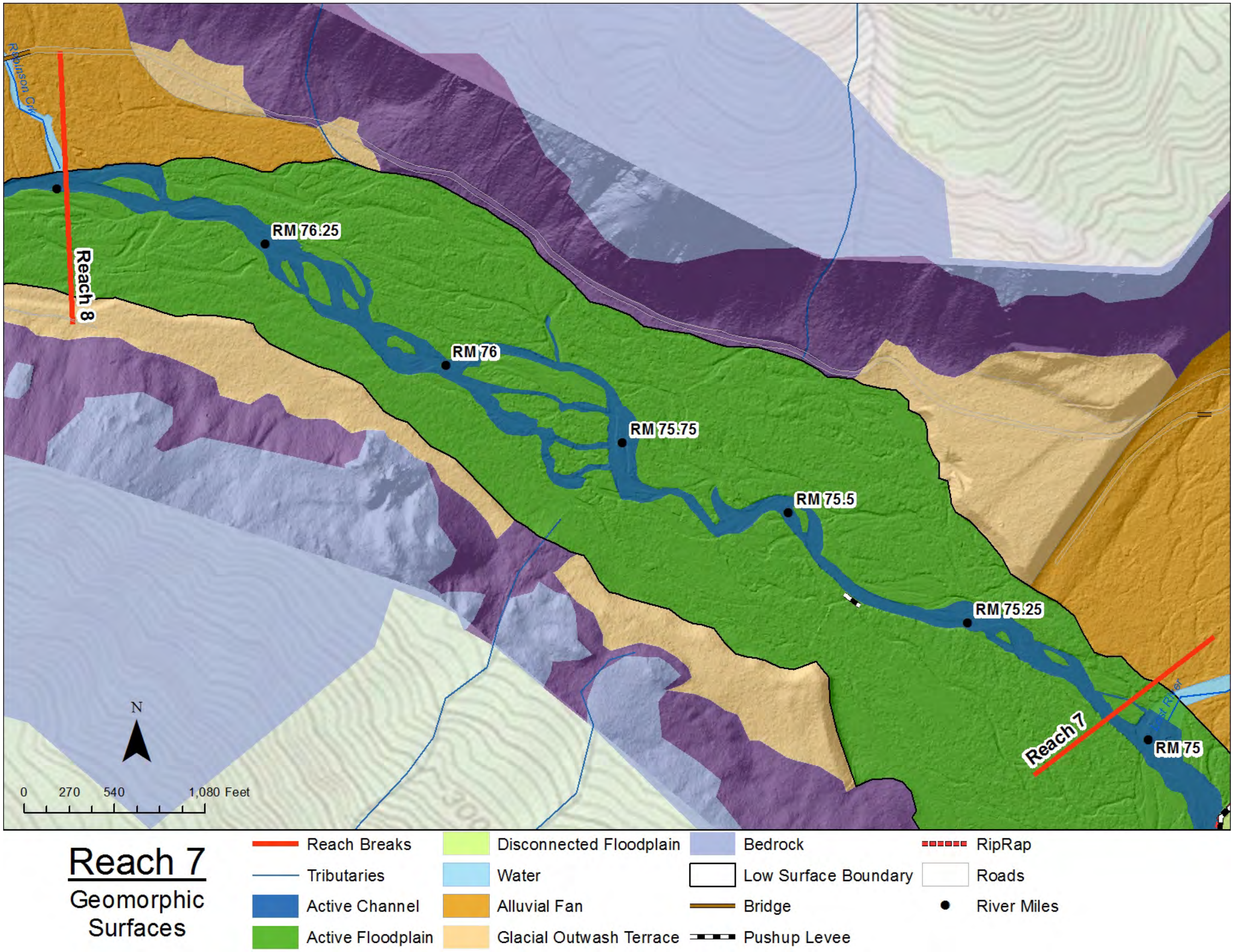

Figure 112. Geomorphic surfaces of Reach 7 with selected human built features (levees, riprap, bridges, and roads).

Hydrology

Reach 7 has a seasonally fluctuating flow regime. Based on field observations, late spring and early summer snowmelt events activate side-channels and inundate the low and medium elevation floodplain surfaces every two to ten years (Figure 113). Autumn low flows expose bars and banks throughout the reach. There are reports of portions of the channel going dry seasonally during low precipitation years (WDW 1990), but this does not appear to be the norm. When this occurs, the channel is contributing its surface flow to the large subsurface groundwater reservoir located downstream from Reach 7 (Konrad 2006b). Otherwise, this reach is considered a "gaining" reach -- incoming groundwater and surface water feeds the surface flow in the channel. See Section 2.6 of this report for a description of the groundwater to surface water interchange processes that occur at the downstream end of Reach 7.

The upstream watershed is dominated by bedrock peaks and valley walls; these features have low surface-water retention. For this reason, large summer thunderstorms are capable of temporarily raising surface water elevations in reach 7. The valley floor is composed primarily of coarse-grained material that supports active hyporheic flow. As a result, within the active floodplain of Reach 7, the channel and its side-channels are actively exchanging surface flow with groundwater through hyporheic processes. There are also groundwater inputs from upstream and from adjacent terraces, valley walls, and alluvial fans. The bedrock floor of the glacially-carved valley confines groundwater; and that groundwater flows below and through the glacial outwash deposits that infilled the valley thousands of years ago.

Reach 7 receives discharge from Robinson Creek and ephemeral tributaries. According to the US Bureau of Reclamation's surface flow estimates (2008 – Appendix J), the upstream boundary of the reach receives an estimated 24% increase in discharge from Robinson Creek during high flow events. It is assumed that Robinson Creek and Lost River contribute subsurface groundwater but the quantity or percent of that contribution annually is currently unknown. Four small ephemeral tributaries contribute the equivalent of approximately 2% of the discharge in the reach. Activated by seasonal snowmelt or precipitation, their minor seasonal discharge runs off of the steep walls to the valley floor. Two of these ephemeral tributaries are located on river-right and two are on river-left. It is assumed that most of the ephemeral tributary inputs contribute to the groundwater system near the edge of the valley. Several tributaries that initiate on the modern floodplains are activated and fed by groundwater generated from upstream, as well as groundwater from the adjacent terraces and hillslope. In Reach 7, these floodplain tributaries maintain off-channel riparian environments, transport sediment into the channel, and sometimes provide low points on the floodplain for high flow or flood event avulsions.

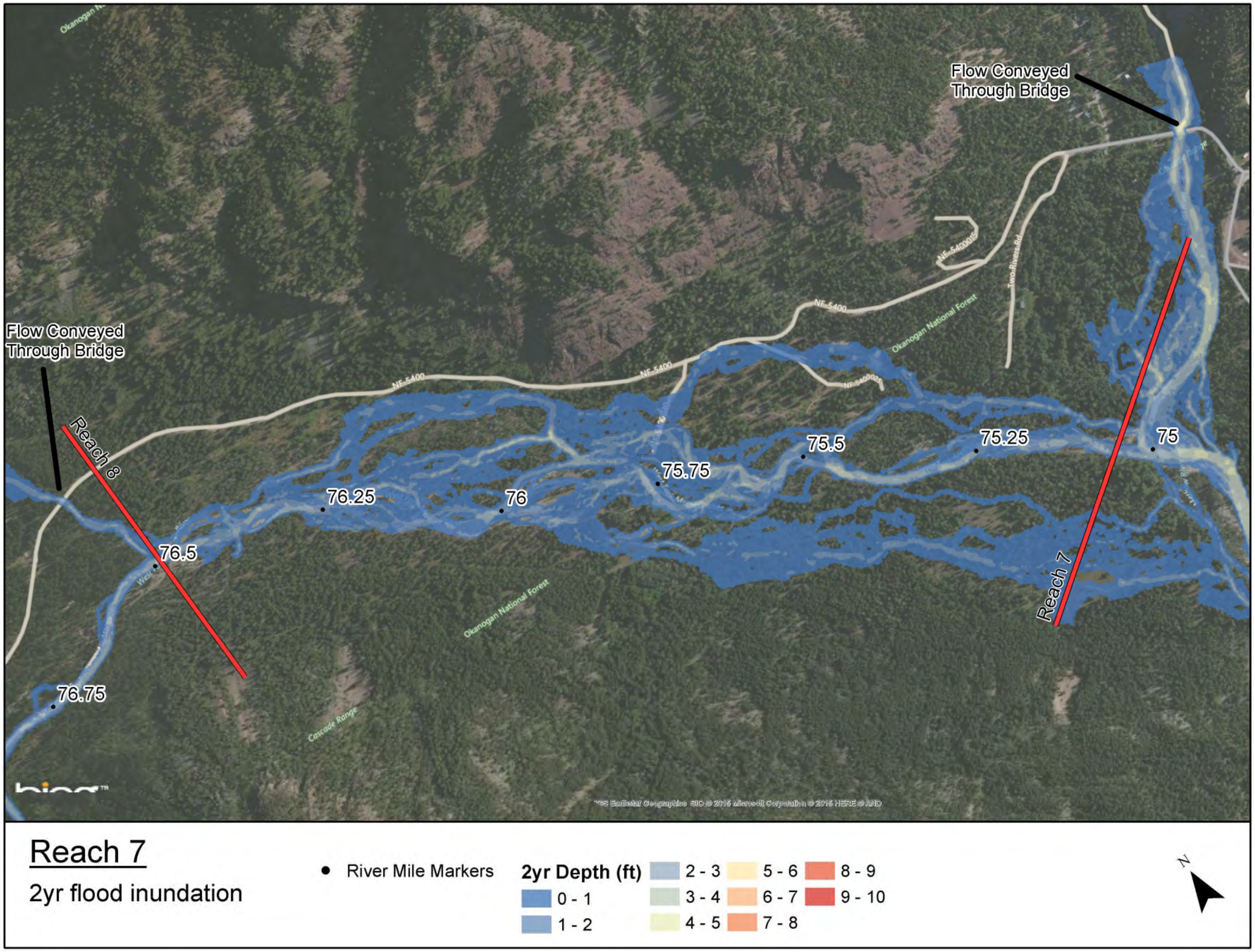

Figure 113. Floodplain inundation for 2YR flood in Reach 7 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

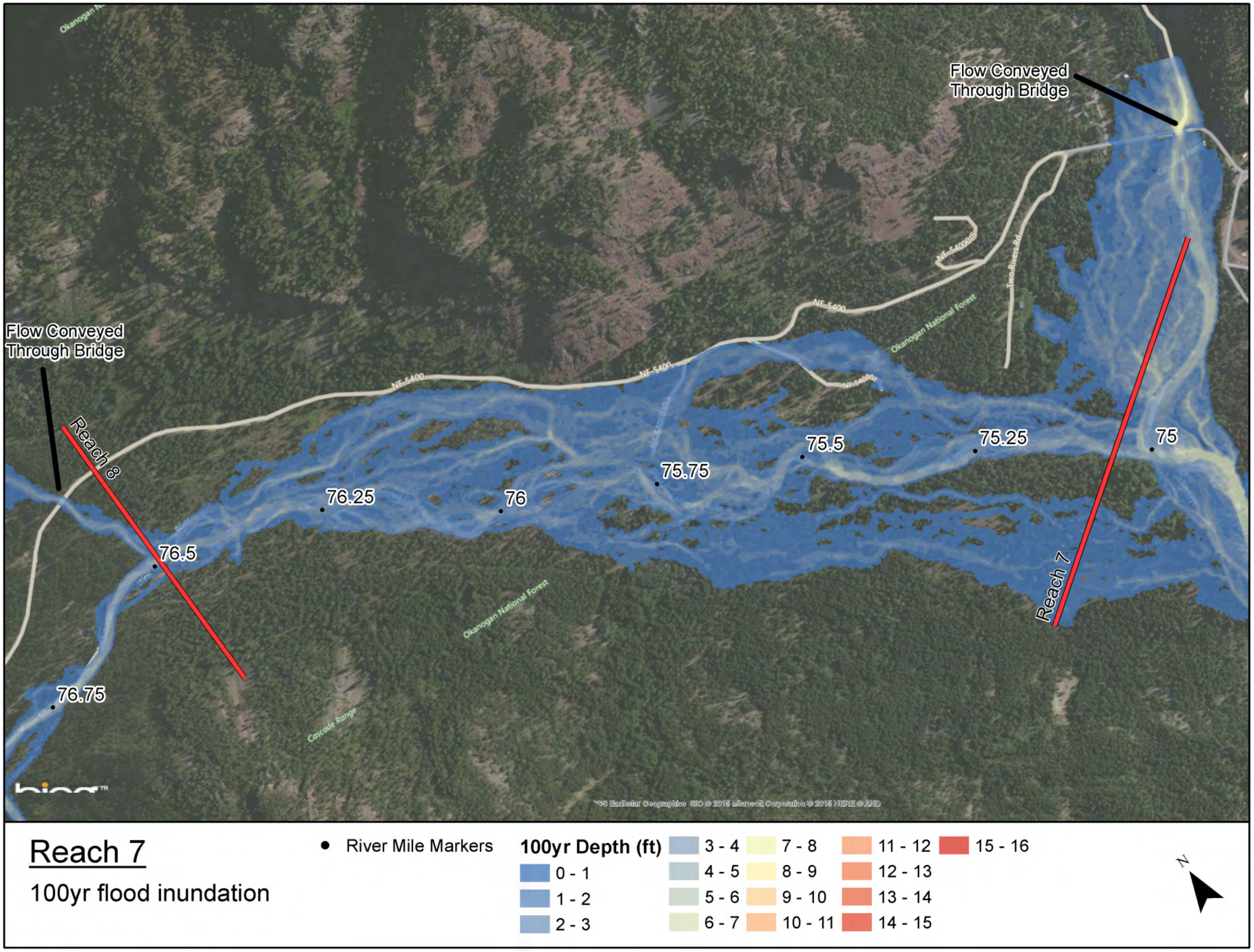

Figure 114. Floodplain inundation for 100YR flood in Reach 7 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Floodplain and Channel Migration Zone

The channel in Reach 7 is well-connected to its modern floodplain. Overbank deposits (sand, gravel, wood, and organic debris) indicate regular inundation of the floodplain surfaces along the channel. The potential channel migration zone throughout the reach is laterally unconfined within a floodplain that occupies most of the valley floor. The width of the floodplain increases from 740 feet at the upstream end to 1,500 feet at the downstream end. The channel currently flows through the central portion of the floodplain without contacting the terraces and hillslopes that border the valley. The banks throughout the reach are composed of small boulders and cobbles. In most locations, the banks are reinforced with established vegetation. Thus, during normal or low flows, the banks are relatively resistant to bank failure and erosion. A single push-up levee, at RM 75.4 on river-right, is the only confining human-built feature on the floodplain. Composed of local floodplain material, and approximately 130-feet long and three-feet high, this levee is located on a cut-bank that is currently being eroded by the channel. The levee currently limits surface flow connectivity to a 2,400 foot long side-channel through the river-right floodplain.

The river is vertically and laterally active during high flow events. Channel migration processes in Reach 7 include multichannel and side-channel avulsions, as well as high flow activated channels (Figure 115). The channel is periodically vertically mobile due to abundant bedload inputs, large wood accumulations, and a sufficient amount of stream power during high flow events. Sediment inputs in this reach are sourced from upstream (Reach 8), Robinson Creek and its fan, and from the local channel bed and floodplain. The abundance of sediment in Reach 7 maintains large side- and mid-channel bars throughout much of the reach. Bedload sediment fluxes likely occur in pulses that result in sequences of bed aggradation and degradation. These sequences migrate upstream and downstream as a result of normal channel bed evolution in this sediment-rich reach.

In Reach 7, the floodplain features are inundated at different rates due to the range in surface elevations relative to the channel bed [low (1-2 feet), medium (2-4 feet) and high (4-5 feet)]. Through processes of bed erosion or deposition, the rate of inundation for a particular floodplain surface can change if the channel bed elevation changes. Accumulations of sediment and/or large log jams that force changes in the river’s hydraulics at a site can instigate lateral migration, channel avulsions, or the creation of multiple channels. High flow events can result in scour and/or fill of channel beds. A good example of this can be seen at the recently filled and abandoned channel on the south side of the channel at RM 75.75 (Figure 116).

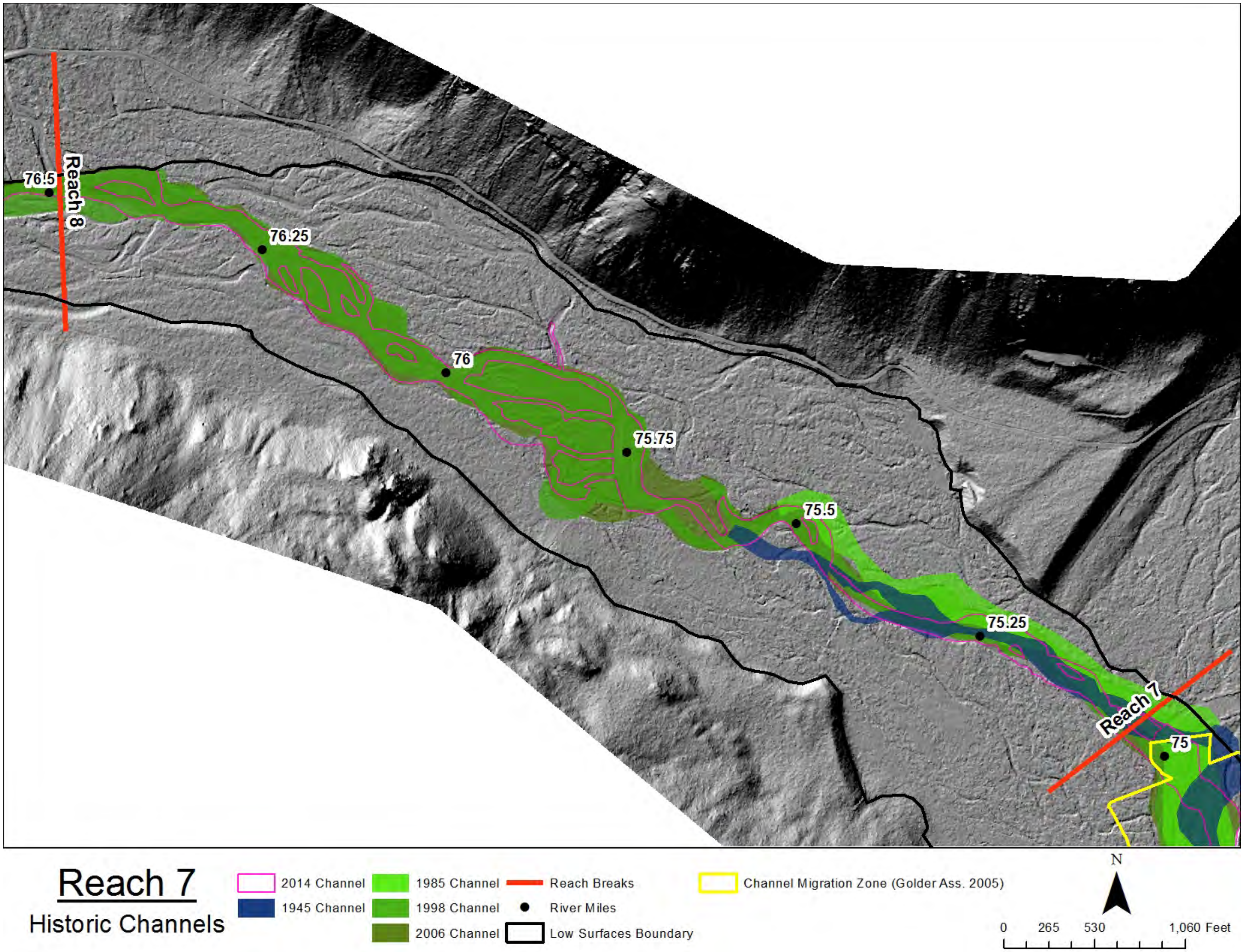

Figure 115. Historical channel locations for Reach 7.

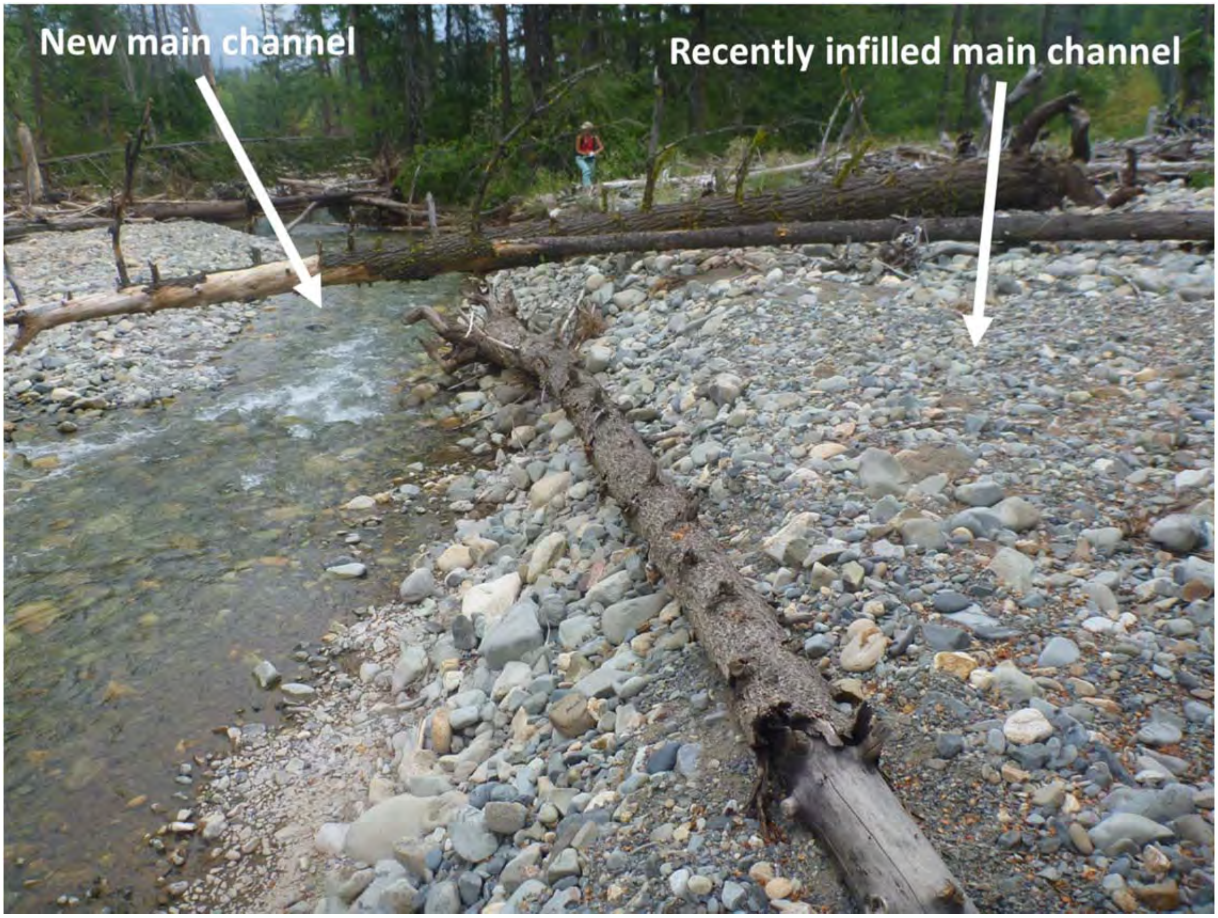

Figure 116. Change in channel location through infilling (instigated by wood accumulations during high flow) and avulsion at RM 75.75.

Sediment

The substrate of Reach 7 is dominated by cobbles (51%) and large gravels (42%) with some small boulders (5%). Sand (2%) is rare within the active channel, except at backwater locations or eddy points (such as near large wood accumulations). The floodplain is composed of materials similar to those seen in the channel bed, but the floodplain has more boulders at its base, as well as accumulations of small gravels, coarse sands, and fines on its surface from overbank deposition. Although this reach regularly mobilizes sediment, it is considered slightly transport limited relative to the quantity of sediment it has available. The excess sediment is stored in the large channel bars and floodplains. Reach 7 receives a notable amount of sediment from the confined transport reach upstream (Reach 8). Robinson Creek and its alluvial fan (modern and historical) also contribute additional gravels, cobbles, and boulders to the upstream section of Reach 7. The channel from RM 76.4 to 76.5 is cutting into the higher, coarser, historical alluvial fan of Robinson Creek. These sediment sources give the channel here a higher percentage of boulder-sized substrate than found downstream.

Large Wood

Reach 7 has abundant large wood in the channel. Six log jams and 221 pieces of wood were counted (the equivalent of 139 pieces per mile). In-channel wood distribution in the reach is presented in Figure 117 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. Much of the wood (88%) is small or medium sized (<12 inches diameter) and is therefore very transient. There is a lack of the large pieces necessary to self-stabilize in the channel and to serve as the key pieces for log jam formation. The log jam frequency of 3.8 jams per mile is much less than would be expected under natural conditions. Many of the banks and floodplain surfaces are vegetated with mature conifers and deciduous trees with high recruitment potential. Other surfaces have younger stands of typically less than 50 years, which may represent vegetation colonization of bar features created during the 1948 flood. Bank erosion, surface inundation, and channel avulsions all recruit large wood. Once recruited, it is then retained in the channel on the large bars and adjacent, low floodplain features. Channel-spanning logs do occur in Reach 7, especially in the multi-threaded sections where channel widths are reduced. A fresh avulsion path cutting through a vegetated island at RM 75.8 has created a large log jam that includes channel-spanning and racked large wood. Large wood and debris accumulations are common on floodplain surfaces near the active channel. They are also common in ephemeral tributaries and high flow or groundwater-activated channels on the floodplain. Large wood jams and accumulations further increase the geomorphic complexity of the reach by enhancing bar development and maintaining scour pools and off- and side-channel features.

Vegetation

The channel banks and floodplains of Reach 7 are well vegetated (Figure 118). There are maturing forests with trees 50 years or older along the banks and islands that provide shade to the channels and increase bank stability. Mature trees and the dense understory increase floodplain roughness and surface stability. This supports overbank deposition and promotes soil development on floodplain surfaces. The overstory is composed of a mixed forest that includes fir, pine, cedar, aspen, maple, and cottonwood. The understory is a mosaic of shrubs and forbs that includes snowberry, Oregon grape, dogwood, rosehip, elderberry, and thimbleberry (Figure 119). From RM 75.3 to 76.4 along river-left, and at RM 75.7 on river-right, vegetation density is reduced on the floodplains where clearing has occurred to accommodate river access and camping.

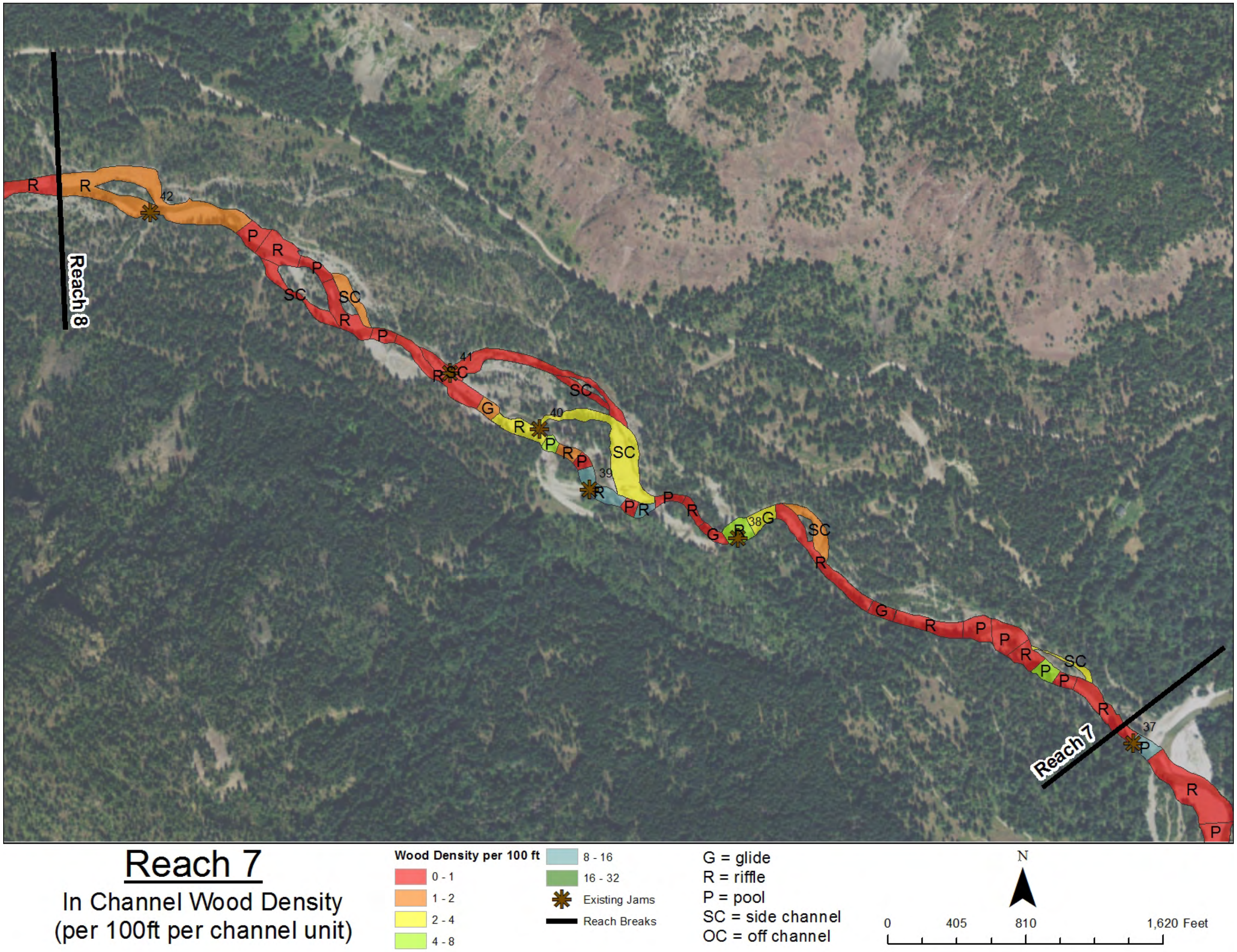

Figure 117. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 7.

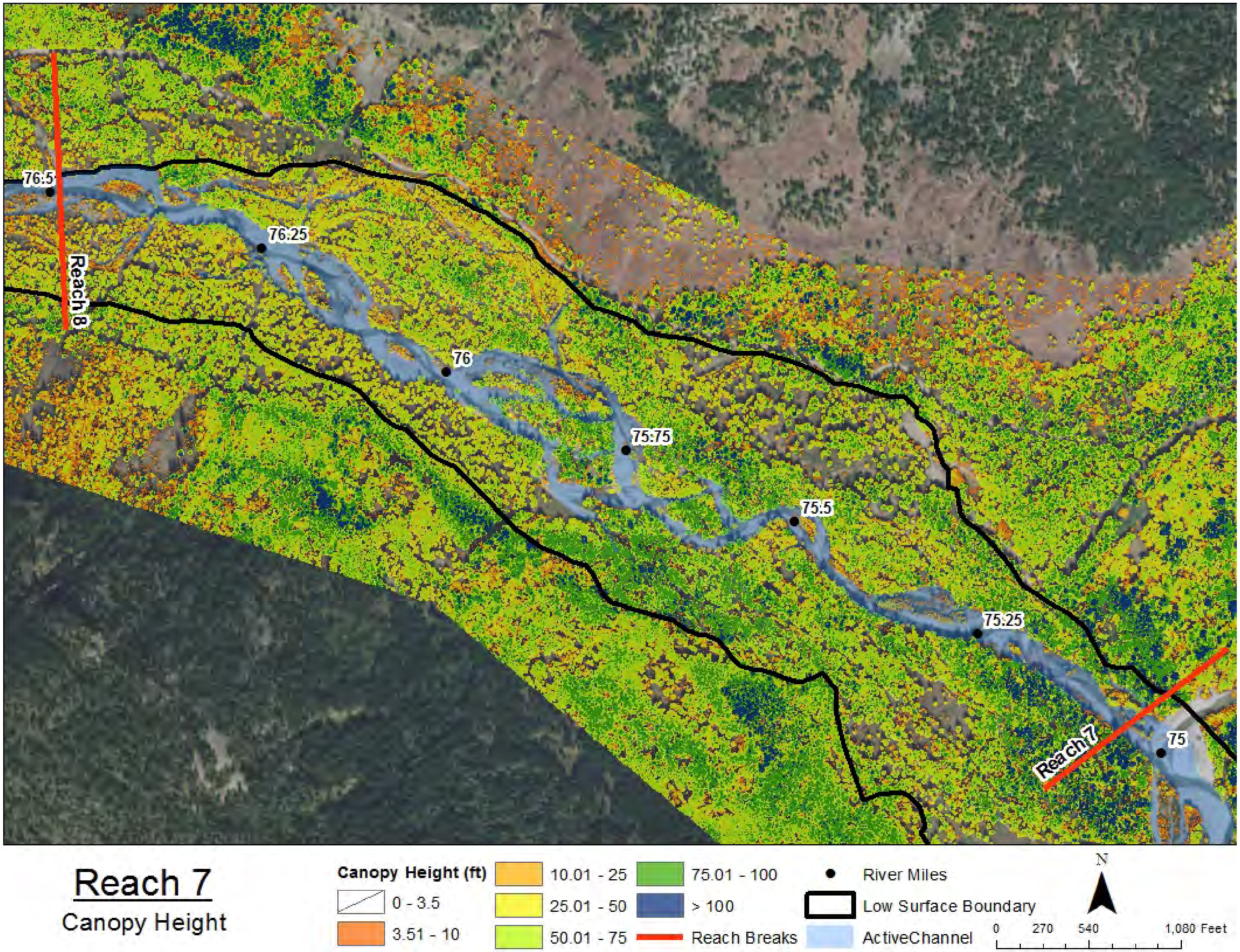

Figure 118. Vegetation canopy height for Reach 7 -- derived from LiDAR first return (highest hit) data (includes buildings and other human infrastructures).

Figure 119. Example of mixed vegetation along a side-channel at RM 75.8. (10/15/2015)

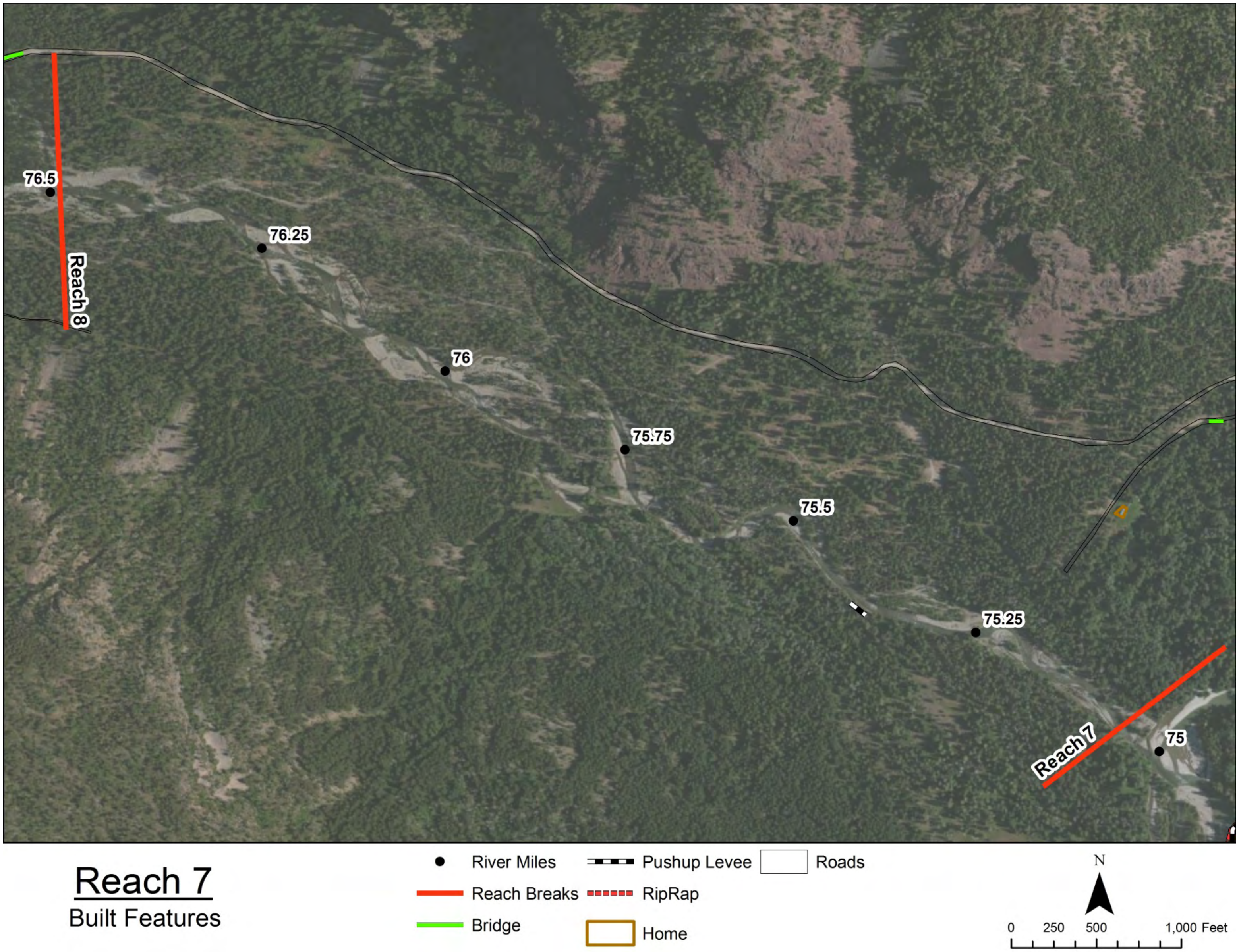

Figure 120. Primary human features in Reach 7.

3.7.3 Human Alterations

Human features are mapped in Figure 120. The primary human alteration in the reach includes the following, which is described further in the subsection below.

- Changes to channel and floodplain function

Changes to Channel and Floodplain Function

One push-up levee, approximately 130 feet long by three feet tall, and constructed from local cobbles and soil, is located on river-right at RM 75.4. The intention of this feature appears to be to reduce the connectivity between the mainstem channel and a small but prominent floodplain side-channel. It is assumed that this effort was made to keep the mainstem from avulsing into and through the floodplain during a high flow event.

A double track, dirt, Forest Service Road (FS 5400) borders the floodplain on the north side of the reach. On river-left, from RM 75.3 to 76.4, a sparse web of single track dirt roads provides access to the river and floodplain. Forest Service Road 5400 crosses Robinson Creek and Lost River over bridges at the edge of the valley above the active floodplain. The bridge crossings have the potential to alter tributary sediment inputs and to restrict shifts in tributary pathways across their alluvial fans. Along the south side of the valley, a decommissioned road has been converted to a recreational trail. This trail travels through a few open meadows on the floodplain, including one that borders the channel at RM 75.7. Historical human alterations to the river-right floodplain in Reach 7 are indicated by the trail and meadows described above, as well as by the presence of a small dilapidated structure. However, the ungraded condition of the meadows and the lack of stumps suggest that no recent vegetation removal has occurred there.

Partial vegetation clearing, single-track dirt road construction, and historical gravel extraction has slightly impaired natural floodplain function. Within Okanogan National Forest lands, vegetation thinning and dirt roads accommodate river access, camping, and hunting on river-left from RM 75.3 to 76.4. The roads and reduced vegetation cover alter normal surface flow routing and sediment delivery across the floodplain. However, the vegetation clearing on river-left in Reach 7 only slightly impacts forest density and composition along the banks of the channel. Historical gravel pit extraction is demarcated on old topographic maps near the channel along river-left at RM 75.3. Channel migration and bar development has removed evidence of the pit, but a dirt road still accesses the channel in this area.

3.7.4 Recommended Actions

Recommended actions in Reach 7 are focused on restoring channel complexity and increasing side-channel and floodplain connectivity. Channel complexity is best addressed by placing apex and debris capture log jams to establish more islands and enhance lateral and split flow conditions. Debris capture jams are likely to be effective at capturing much of the smaller wood anticipated to enter the reach from upstream due to recent wildfire, debris flow, and snow avalanche contributions. Side-channel and floodplain connectivity can be addressed by removing the push-up levee, constructing apex jams, and targeted excavation. Channel margin improvements can be made with large wood complexes along unvegetated banks. Native riparian vegetation planting in the few areas where clearing has occurred is also recommended.

Restoration recommendations recognize the importance of maintaining connectivity of the mainstem channel to perennial or groundwater-fed tributaries and side-channels. This has been identified as a critical component for fish survival in a system with the potential to seasonally dewater.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.8 REACH 8

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.8.1 Reach Overview

Reach 8 is 2.2 miles long and extends from the Robinson Creek confluence (at RM 76.50) to RM 78.60. All of Reach 8 is within the Okanogan National Forest (Figure 121). The channel and its narrow floodplain are confined between hillslopes, glacial outwash terraces, and alluvial fans. The channel in Reach 8 has a relatively high gradient (2.2%) and a moderate sinuosity of 1.07. The active floodplain has an average width of 290 feet; however, it narrows to channel width in the confined section from RM 78.85 to77.35 and then widens to 760 feet at the confluence with Robinson Creek. The average active channel width in Reach 8 is 56 feet. These and other reach metrics are provided in Table 14 and Figure 123.

The channel in Reach 8 is a single-thread, riffle-pool stream with extended riffles and short pools (Figure 122). Many of the pools are maintained with boulder steps. There are three side-channels from RM 76.6 to 76.9, where aggradation is occurring due to local sediment inputs and large wood accumulation. The channel bed and active floodplains are composed of materials ranging in size from gravels to boulders, but large cobbles dominate the substrate. Hillslope inputs include weathered bedrock debris, glacial lag, and glacial terraces (rounded sand to boulders). Alluvial fan inputs from river-left (north side of the channel) also contribute sand- to boulder-sized material to the channel. Coarse sand and gravels are efficiently transported through the channel except where they are temporarily stored on floodplains or in localized deposition zones such as bar tops or eddies. The reach is vegetated with maturing forests except where forest fires recently burned most of the vegetation. The forest fire in 2003 left standing snags from RM 77.9 to 78.6; this section now has an establishing understory of shrubs and saplings. The remaining snags are now a plentiful source of large wood to the channel. This wood is influencing and will continue to influence geomorphic processes in Reach 8, and downstream reaches, for a decade or more.

The habitat conditions in Reach 8 are discussed in Appendix A. Based on the REI analysis, only 4 of 11 habitat indices are rated as either unacceptable or at risk (see Table 6). Human alterations to Reach 8 are minimal and limited to a dirt road, trails, and three campgrounds that are mostly located above the active floodplain. Construction of push-up levees and the partial clearing of vegetation at Ballard Campground (RM 76.75) have the potential to locally impede natural channel processes. Otherwise, healthy, natural, hydrologic and geomorphic processes are occurring in this reach.

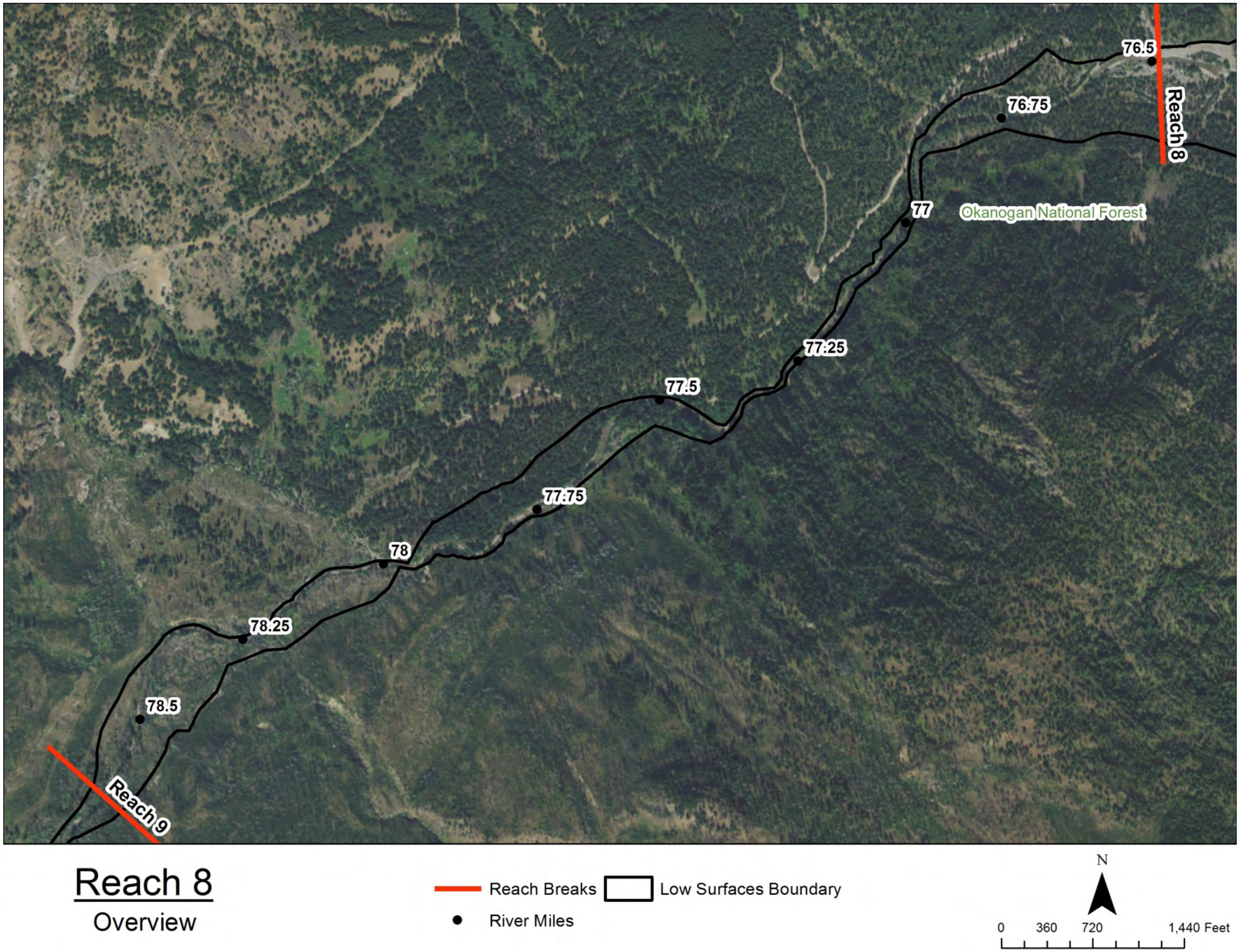

Figure 121. Reach 8 overview map.

Figure 122. Representative photo of Reach 8; looking downstream at RM 78.25. (10/15/2014

Table 14. Reach 8 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	2.2
River Miles	76.5 – 78.7
Valley Gradient	2.6%
Stream Gradient	2.2%
Sinuosity	1.07
Dominant Channel Type	Cascading riffle-pool
Average Bankfull Width (feet)	56
Average Floodplain Width (feet)	290
Dominant Substrate	large cobble & boulder; sparse sand and gravel
Bank Stability/Channel Migration	Adequate *(See Section 2.12)*
Vertical Channel Stability	Adequate *(See Section 2.12)*
Confinement ratio	Unconfined *(See Table 5)*

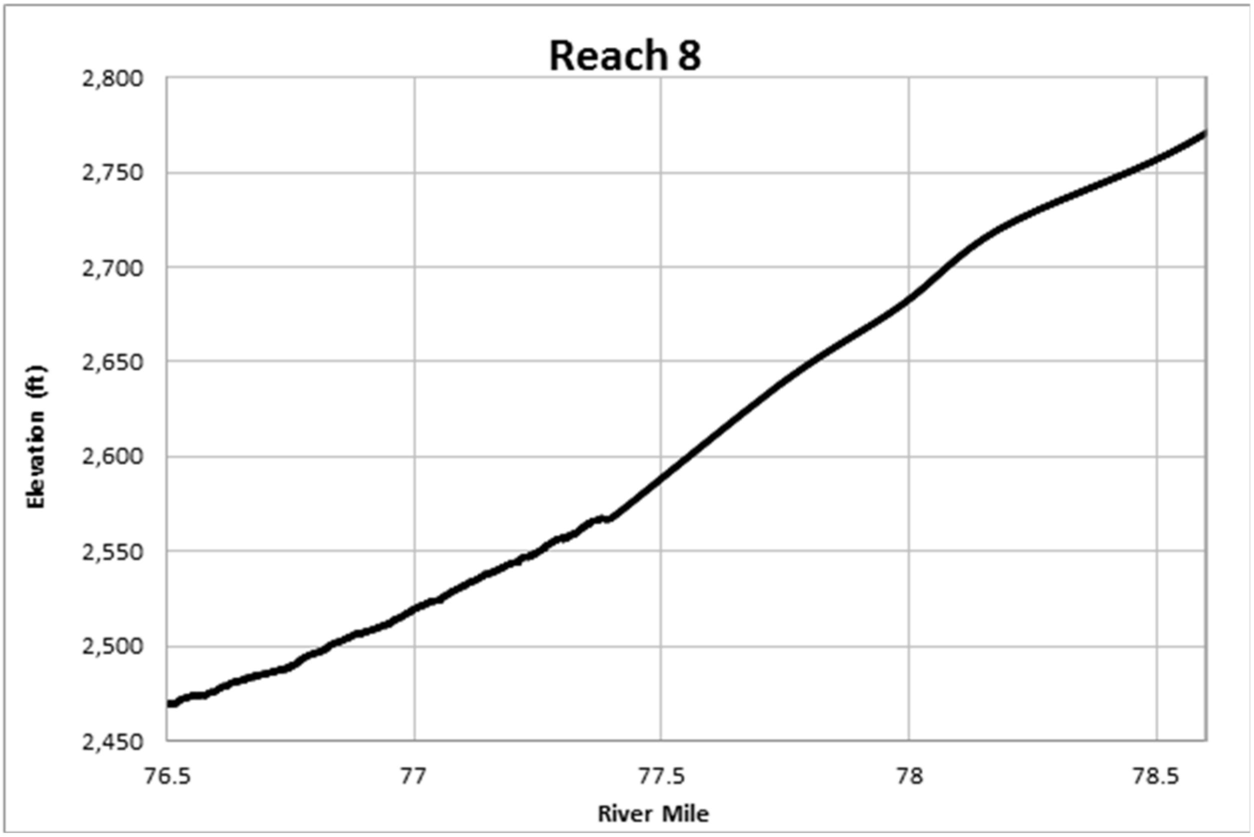

Figure 123. Longitudinal profile of the channel in Reach 8 (RM 76.5 to 78.7).

3.8.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 8 is located within a U-shaped valley that was most recently carved by Quaternary glaciation. Increased discharge regimes during early Holocene glacial retreat deposited thick layers of glacial outwash across the valley floor. The valley walls are less confining in Reach 8 than upstream in Reach 9. In Reach 8, there are remnants of a paired set of glacial outwash terraces that form tall hillslopes on the edges of the valley. A lower set of outwash terraces is located from RM 77 to 78, indicating at least one sequence of incision and/or glacial extension, followed by more valley infilling during glacial retreat. Subsequent high discharge and sediment loads from glacially-carved tributaries on river-left have created wide boulder-to-cobble alluvial fans across the glacial outwash terraces. These same tributaries continue to deposit material across their alluvial fans and to the channel, but with a reduced hydrologic regime. A map of the geomorphic surfaces is provided as Figure 124.

In response to the modern sediment and discharge regimes, the channel in Reach 8 has incised into the terrace and fan deposits, creating a narrow, inset, active floodplain. Modern vertical incision rates are limited in this reach by the size of the underlying substrate and incoming sediment supplies. Where the channel contacts the terrace hillslope, inputs are a mix of sand- to boulder-sized rounded sediment. An example of such inputs is visible on river-right at RM 77.9, where a recent landslide occurred from a terrace slope that overlies bedrock. The landslide contributed glacial outwash material and large wood directly into the channel. These inputs have temporarily increased local and downstream channel complexity. Weathered bedrock and talus slopes also contribute direct hillslope inputs where they contact the channel on river-right, from RM 77.15 to 77.4.

Hydrology

Reach 8 has a seasonally fluctuating flow regime. Late spring and early summer snowmelt events activate side-channels and often inundate the narrow, low floodplain surfaces. Fresh accumulations of coarse sand and gravels on the lower floodplain surfaces suggest regular inundation rates of every two to 10 years. Hydraulic modeling performed on the lower third of the reach, where surface elevation LiDAR was available, confirms side-channel activation by high flow events in the more confined downstream section of the reach (Figure 125 and Figure 126). It is only during high flow events that the channel is capable of mobilizing its over-sized bedload of cobbles and boulders. Autumn low flows expose banks and large instream boulders. Summer thunderstorms are capable of temporarily raising surface-water elevations in Reach 8 because the bedrock-dominated valley walls and upstream drainage areas have low surface-water retention capacity.

The valley floor is composed primarily of coarse-grained material that supports active hyporheic flow and groundwater influx from upstream and the adjacent terrace slopes and alluvial fans. The mainstem channel and side-channels within the active floodplain of Reach 8 are actively exchanging surface flow with groundwater through hyporheic processes. At pools, temperatures collected during the survey were markedly lower, suggesting groundwater influx.

Surface water contributions in Reach 8 include four ephemeral tributaries and two perennial tributaries. These deliver discharge from steep hillslopes and adjacent glacially-carved hanging valleys. One of the unnamed ephemeral creeks enters the reach on river-left. This tributary flows over a well-developed fan that splits the flow of the tributary such that it has two input points (RM 77.2 and RM 76.85) to the reach. Hydrologic inputs from the ephemeral tributaries are dependent on local snowpack and summer thunderstorms. The main ephemeral contributions occur at river miles 76.55, 76.8, 76.85, 77.2, and 77.35. According to the US Bureau of Reclamation’s surface-flow estimates (2008 – Appendix J), the combined ephemeral tributaries contribute an estimated 4% of the discharge within the reach during high flows. The perennial Driveway Creek enters the valley on river-right at RM 78.25 with no-to-little modern alluvial fan, and contributes approximately 3% of the surface flow. The other perennial tributary, Rattlesnake Creek (RM 78.1), contributes approximately 10% of the discharge in the reach and enters the valley on river-left over a well-developed alluvial fan. The fans are composed of coarse material that acts as a conduit for subsurface groundwater contributions. However, the quantity of groundwater that the tributaries contribute to Reach 8 is unknown.

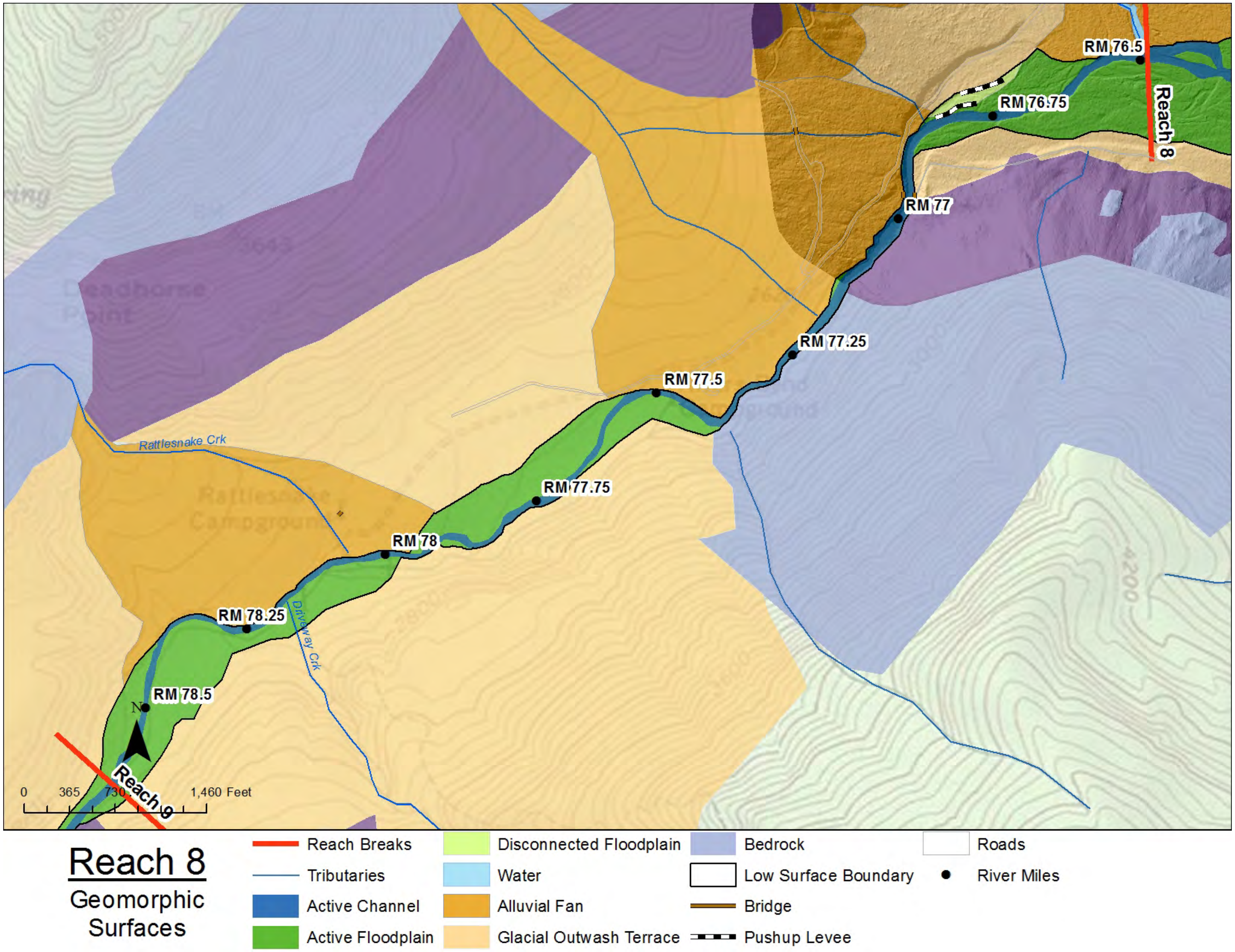

Figure 124. Geomorphic surfaces of Reach 8 with human-built features (bridges, levees, and roads).

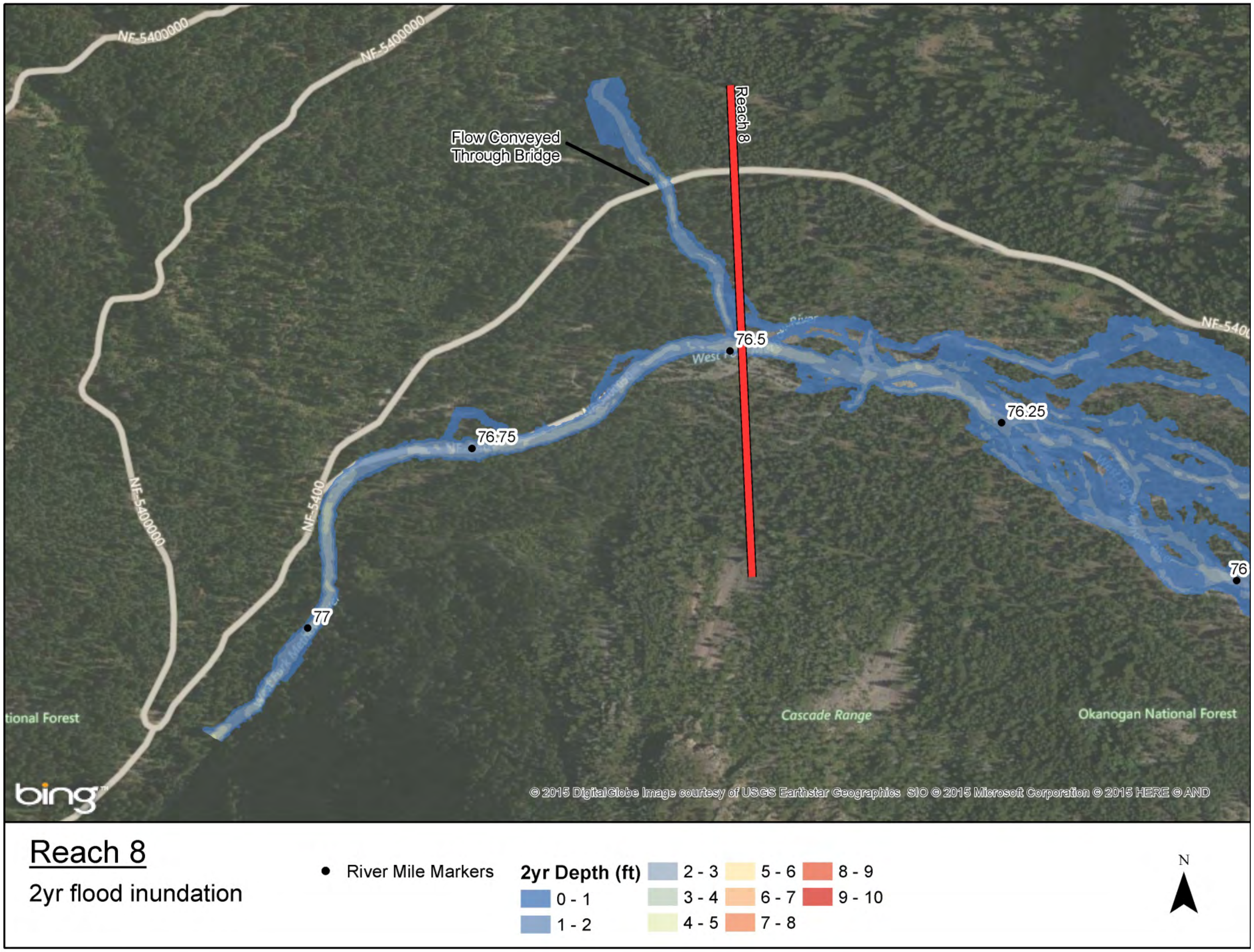

Figure 125. Floodplain inundation for 2YR flood in Reach 8 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

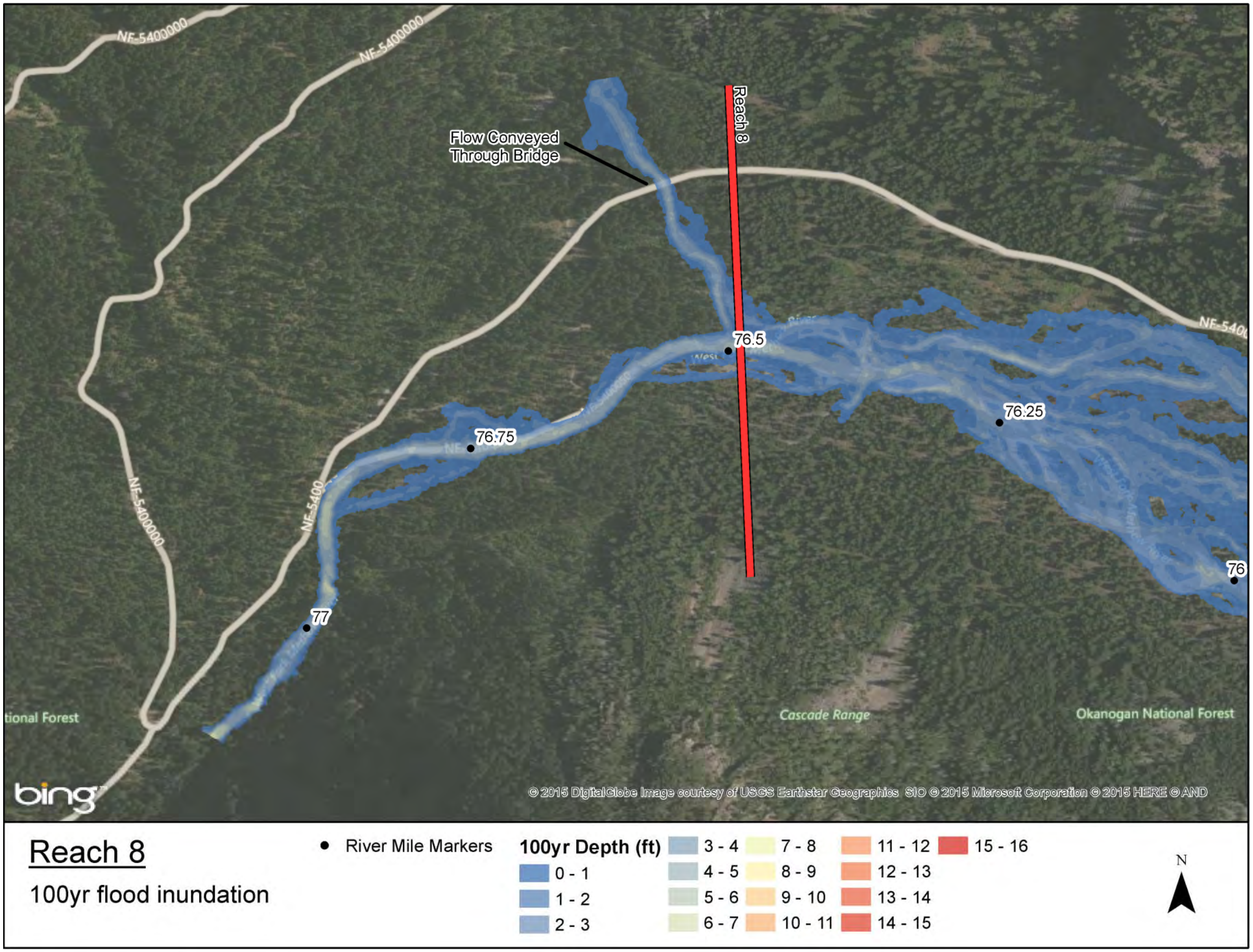

Figure 126. Floodplain inundation for 100YR flood in Reach 8 – developed using a 2D hydraulic model (SRH-2D) built with 2006 LiDAR elevation data.

Floodplain and Channel Migration Zone

The floodplain and channel migration zone of Reach 8 alternates between confined and moderately confined. Lateral movement is restricted by glacial outwash terraces, alluvial fan toes, and adjacent bedrock walls. The inset, active, floodplain width ranges from 36 feet to 760 feet with an average overall width of 290 feet. The migration zone and active floodplain surfaces are the most narrow and straight from RM 76.85 to 77, where the channel is confined by bedrock and talus on river-right and the steep toe of a fan on river-left. Minimal change of mainstem channel location has occurred in the last fifteen years according to aerial imagery (Figure 127). Vertical stability is maintained in Reach 8 by plentiful incoming sediment from upstream and the adjacent slopes. Vertical incision here is also limited by the relative size of the substrate to the modern discharge regime. Currently, the modern channel is mostly connected to the inset floodplain surfaces of the narrow valley. Fresh accumulations of coarse sand and gravels on the lower floodplain surfaces suggest regular inundation rates of every two to 10 years. The presence of small side-channels from RM 76.6 to 76.9 indicates that this section of Reach 8 has aggraded in response to sediment inputs. Most recent sediment and large wood inputs to this section are from a landslide off of a glacial terrace slope at RM 76.9, on river-right.

Sediment

The substrate of this reach is dominated by large cobbles. However, bedload size in Reach 8 ranges from gravels to large boulders, with very sparse accumulations of sand. The extended riffle beds are composed of cobbles and boulders. Direct hillslope inputs to this reach include material from weathered bedrock, glacial outwash terraces, and alluvial fans. The sediment load is primarily locally sourced, but clasts are rounded to sub-angular due to the variety of hillslope sources. Where large boulders are present, they add hydraulic roughness to the bed and banks. The step-pool channel units are defined by relatively stable boulder steps. Gravel-sized bedload is present in pockets and as bars in depositional zones in the channel near large wood accumulations, at eddies, or as bar features in seasonally-occupied, high flow secondary channels. Coarse sands are present as overbank deposits on low-lying vegetated floodplain surfaces and as a top layer on some of the bar features, especially immediately downstream from landslides or colluvium. All other fine-grained sediment is fluvially transported through this reach. Gravel counts were not conducted in Reach 8 because of large bedload size relative to channel geometry, and the lack of LiDAR for hydraulic modeling.

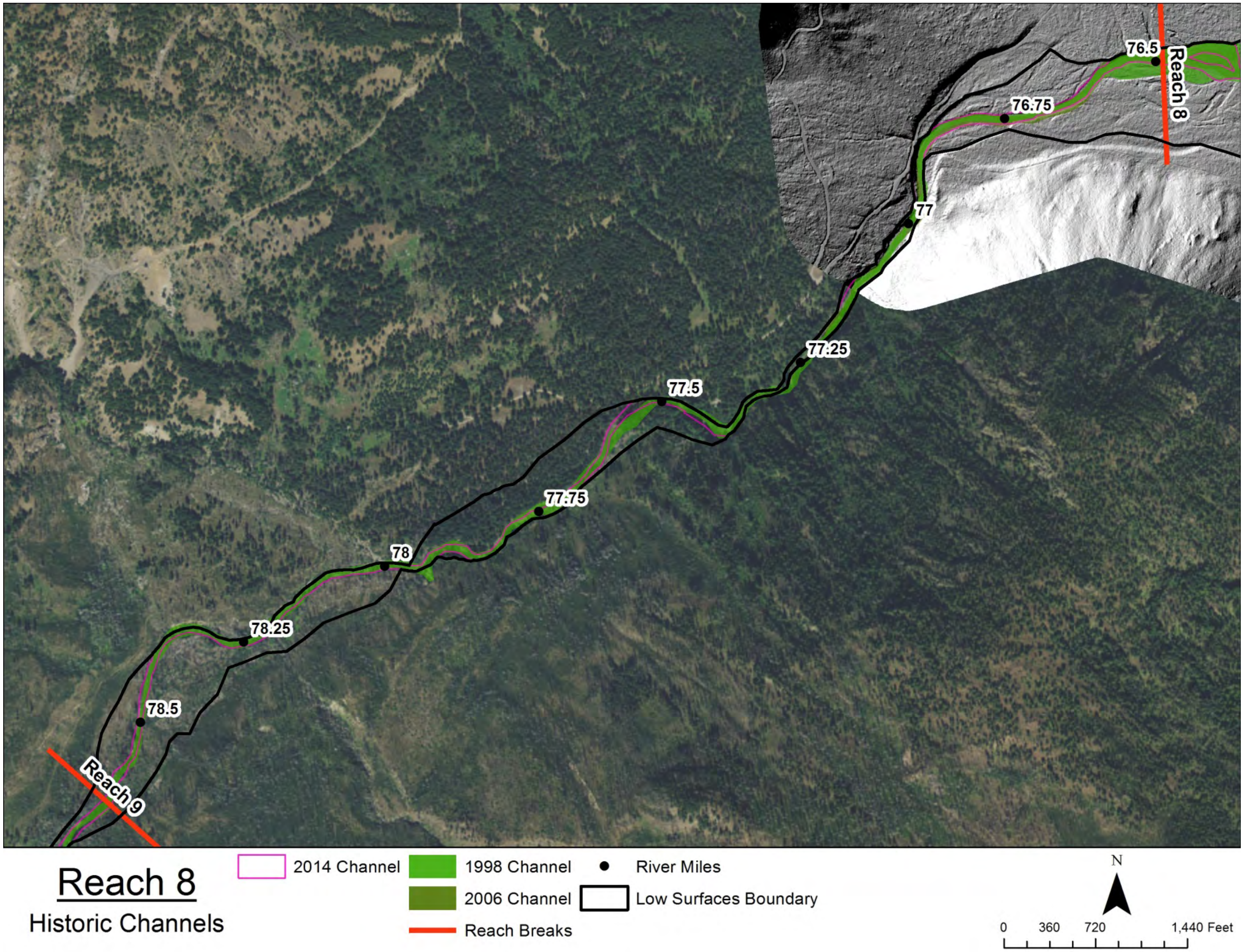

Figure 127. Historical channel locations for Reach 8.

Large Wood

Reach 8 has a moderate amount of large wood in the channel. Four log jams and 275 logs were counted; the equivalent of 123 logs per mile. In-channel wood distribution in the reach is presented in Figure 129 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. The valley floor and adjacent terraces and fan slopes throughout this reach are well vegetated with mature conifers. These mature trees offer high recruitment potential for wood. The upper 0.7 miles of Reach 8 recently burned in the Needles forest fire (2003), leaving burnt standing snags near the channel. These snags currently increase the likelihood of local wood inputs to the upper section of the reach. Channel width allows for channel-spanning logs to occur in Reach 8 even though the extended riffle sections have a steep enough gradient to transport large wood downstream. Channel complexity and floodplain connectivity is increased where in-channel large wood retention has occurred in the form of log jams.

Vegetation

The channel banks and floodplains of Reach 8 are well vegetated. Low vegetation density on the confining slopes is due to slope steepness and rocky composition, patchy historical thinning, and forest fires (Figure 130). Vegetation density is also reduced at bedrock contact points. The overstory of vegetation on the valley floor is composed of a mature forest of fir and cedar. These trees reach heights of more than 50 feet, except in the upstream section which was recently impacted by the Needles forest fire in 2003. The mature conifer forest supplies ample shade to the channel and floodplain. The understory along the banks is a mixed composition of vegetation that includes dogwood, maple, ninebark, and sparse cottonwood (Figure 128). The density of the understory increases where conifers are young, and where the overstory has been removed by forest fires and/or landslides. The lack of stumps on floodplain surfaces indicates that no major logging activities occurred in the upper two-thirds of the reach in the last 100 years.

Figure 128. Varied bank vegetation in Reach 8 - burned snags, dense understory, mature conifers; looking upstream at RM 77.5. (9/5/2104)

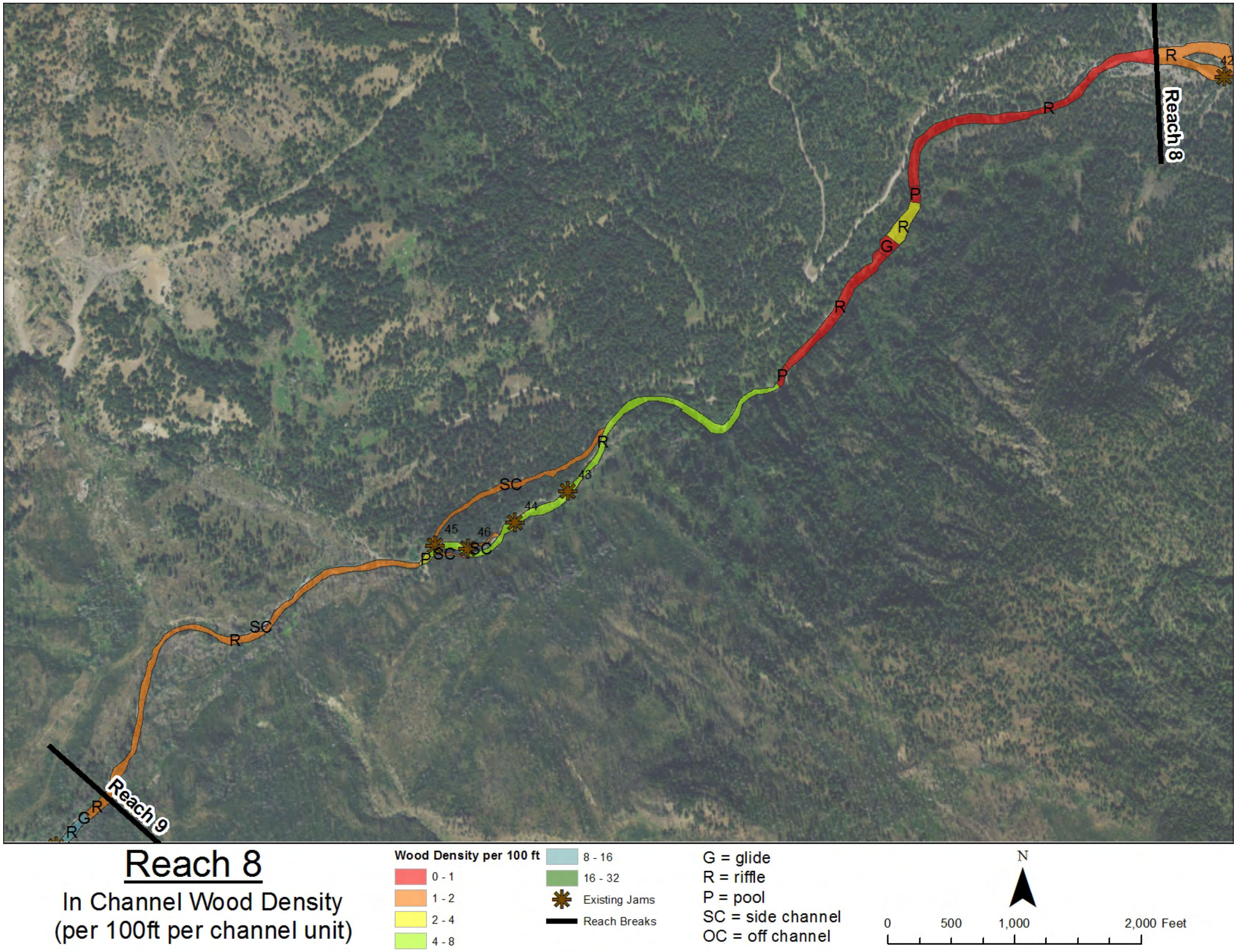

Figure 129. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel unitsin Reach 8.

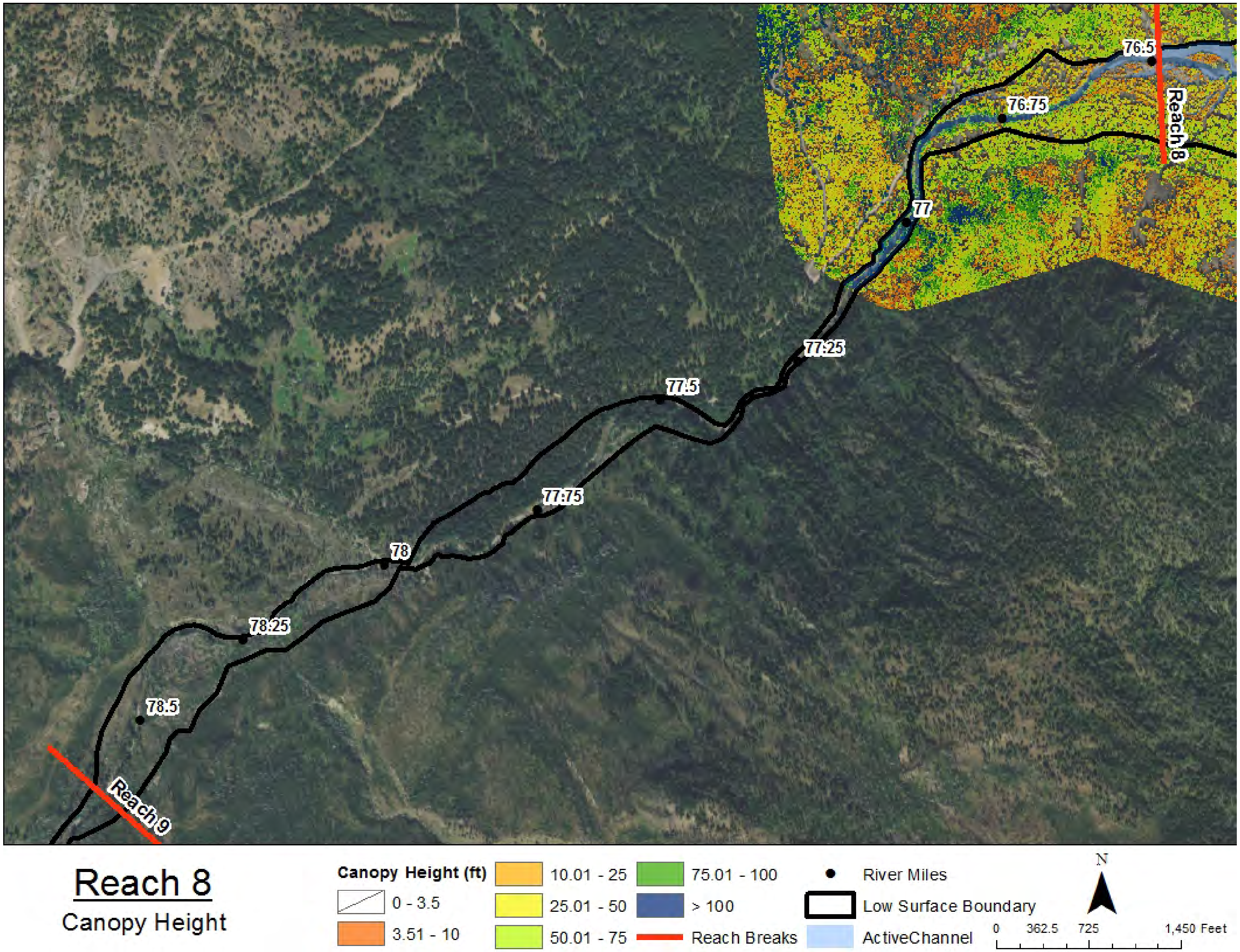

Figure 130. Vegetation canopy height for Reach 8 -- derived from LiDAR first return (highest hit) data. Available only for the lower portion of the reach from RM 76.5 to 77.15.

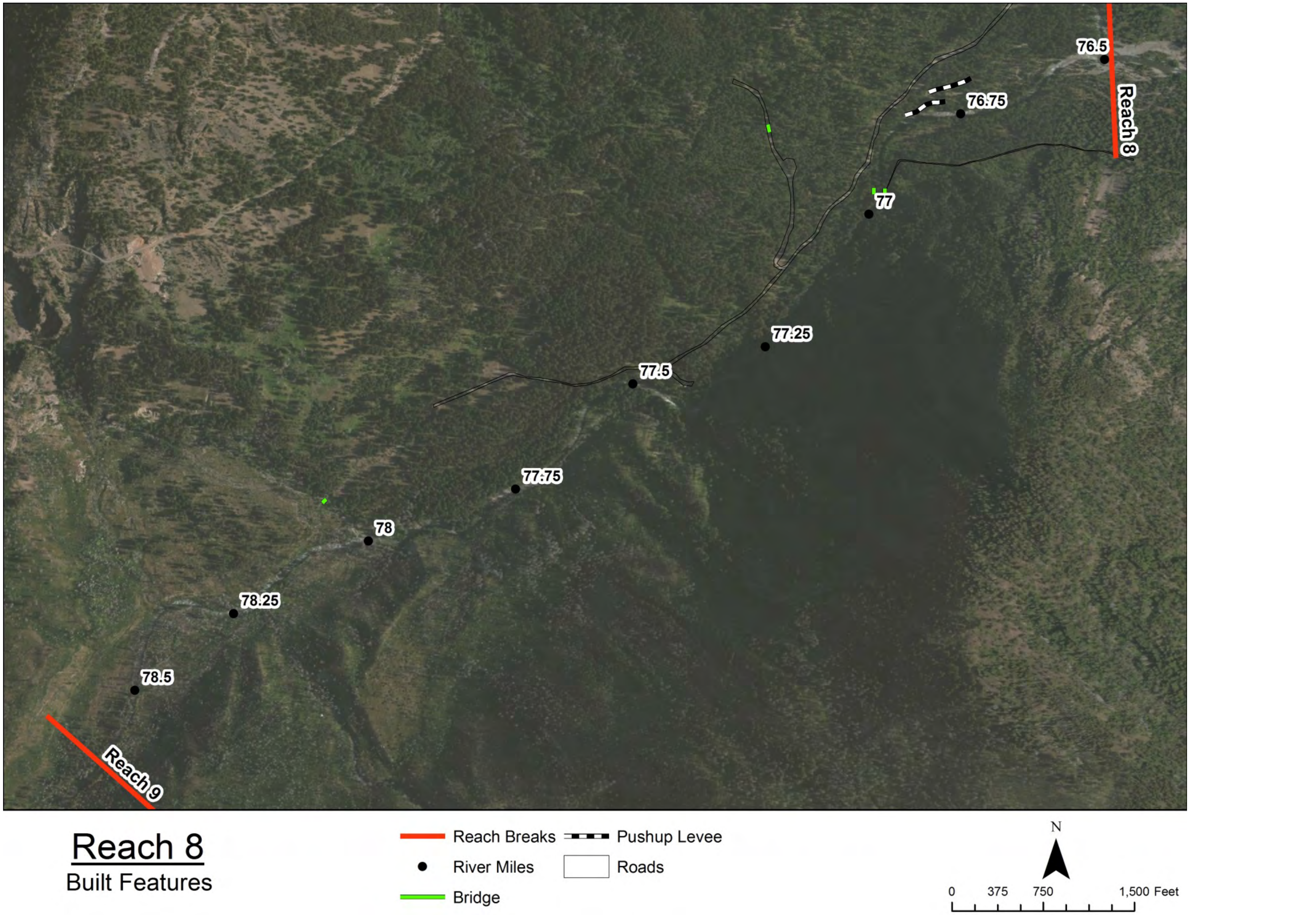

Figure 131. Primary human features in Reach 8.

3.8.3 Human Alterations

Reach 8 has experienced only minor anthropogenic alterations to modern channel processes. Human features are mapped in Figure 131. The primary human alteration in the reach includes the following, which is described further in the subsection below.

- Changes to channel and floodplain function

Changes to Channel and Floodplain Function

A set of push-up levees was constructed at the upstream end of Ballard Campground on river-left from RM 76.75 to 76.8. They were made from local cobbles, boulders, and soil. The intention of these features appears to be to restrict the channel from flooding or laterally migrating into the campground and trails. The campground and trails are located on the active floodplain adjacent to the channel and slightly downstream from the levees. The levees slightly constrict natural lateral channel processes here and reduce the active floodplain and channel migration zone by approximately 100 feet.

A few other human-built features interact relatively inconsequentially with natural channel processes in Reach 8. A double track, dirt Forest Service road (FS 5400) runs along the terrace and fan surfaces on river-left above the active floodplain and channel. A few single track dirt roads branch off of this road allowing access to Ballard, River Bend, and Rattlesnake Campgrounds. Forest Service road 5400 has four tributary crossings (fords, small bridges, or culverts). These features have the potential to alter tributary sediment inputs and to restrict shifts in tributary pathways across their alluvial fans. Rattlesnake Campground is also the trailhead (Trail No. 480) for a one- to three-foot-wide path that runs across the terrace and alluvial fan slopes on river-left. The trail is higher in elevation than the channel and its active floodplain features. A decommissioned road has been converted to a recreational trail on the other side of the river. Located on top of the glacial terrace on river-right, and in the downstream portion of the reach, this road/trail intersects the channel where the channel is completely confined between hillslopes at RM 76.95. Cement bridge abutments remain at this historical crossing, but the alterations they currently pose to channel processes is inconsequential. The river-right abutment was constructed on an existing bedrock wall, only slightly altering natural bank roughness. The river-left abutment is approximately 15 feet above and 20 feet inland from the channel bank on a terrace surface.

3.8.4 Recommended Actions

Recommended actions in Reach 8 are focused on reactivating side-channels and floodplain surfaces. However, existing mostly undisturbed conditions and access challenges limit restoration opportunities in Reach 8. Side-channel and floodplain reactivation can be addressed by removing the push-up levee and bank armoring near Ballard Campground.

See Section 4 of this report for the restoration strategy and specific project recommendations for the reach.

3.9 REACH 9

Refer to Section 2.2 and 2.8 for geologic and geomorphic context of the study area and explanation of terminology.

3.9.1 Reach Overview

Reach 9 is 1.3 miles long and extends from RM 78.7 to the confluence with Trout Creek at RM 80. The Trout Creek confluence is the upstream boundary of the study area. The channel in Reach 9 is a relatively straight, single-thread, cascading stream with extended riffles and boulder steps (Figure 133). The channel and its narrow floodplain are confined between adjacent hillslopes with an average floodplain width of 161 feet and an average bankfull width of 52 feet. Valley width is greatest at approximately 350 feet at the upstream end at the Trout Creek alluvial fan and narrowest at approximately 55 feet near RM 79. The reach has a relatively high gradient compared to the rest of the study area (2.7%). These and other reach metrics are provided in Table 15 and Figure 23.

The channel geomorphology is driven by seasonal spring snowmelt discharge, hillslope contributions, and large wood inputs. The valley floor of the reach is well vegetated with mature forests, but a forest fire in 2003 left only snags standing from RM 79.6 to the upstream boundary of the reach. Locally-sourced boulders and large cobbles dominate both channel bed and bank material. During normal flow conditions, gravel- to sand-sized material is transported downstream, while the boulder substrate remains relatively stable.

The habitat conditions in Reach 9 are discussed in Appendix A. Based on the REI analysis, none of the 11 habitat indices are rated as either unacceptable or at risk (see Table 6). Natural, healthy, hydrologic and geomorphic processes are occurring in this reach. There are minimal-to-no modern human alterations influencing channel processes. All of Reach 9 is contained within the Okanogan National Forest.

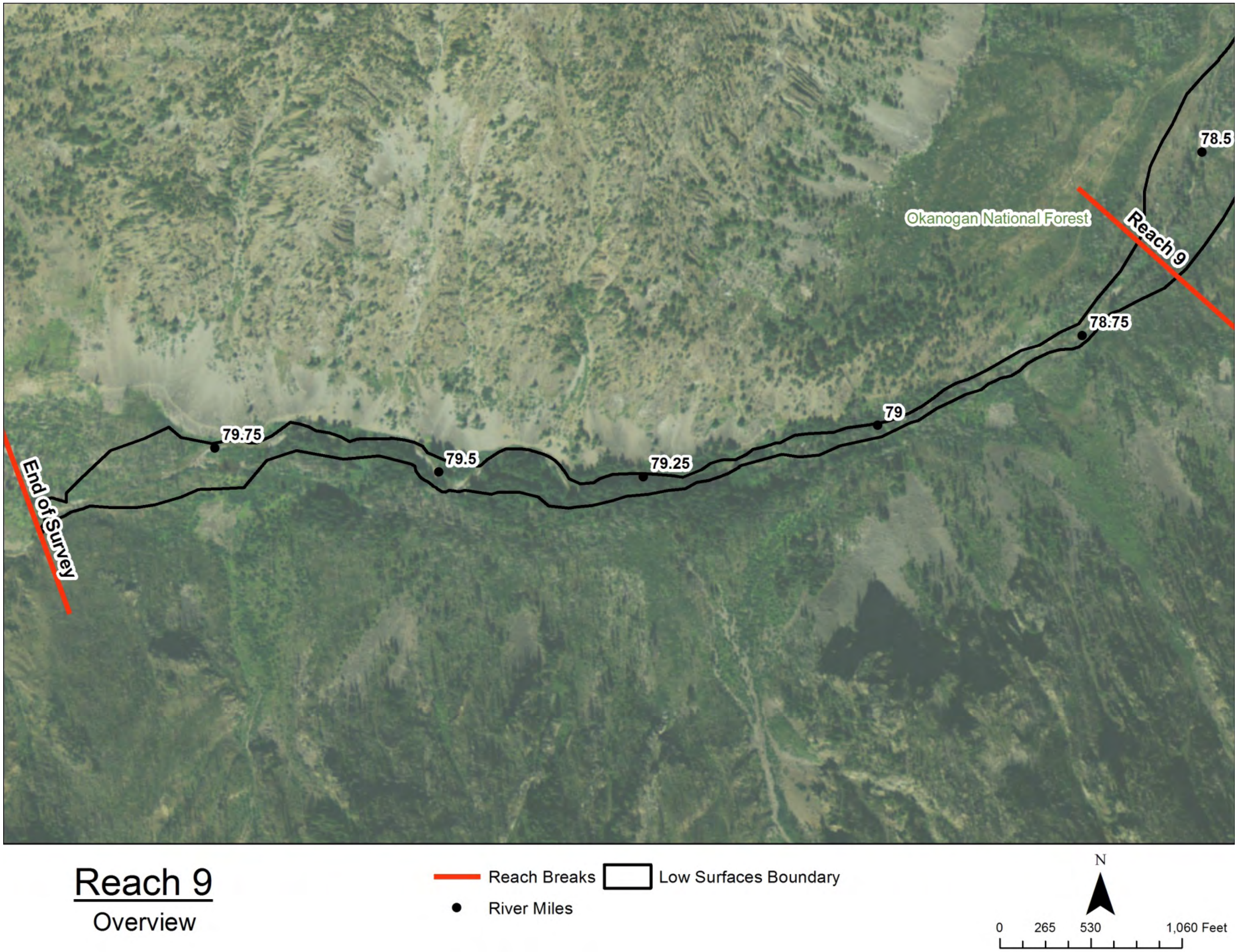

Figure 132. Reach 9 overview map.

Figure 133. Representative photo of Reach 9; looking downstream at RM 79.30. (9/2/2014)

Table 15. Reach 9 descriptive geomorphic metrics.

Metric	Value
Reach Length (miles)	1.3
River Miles	78.7 – 80
Valley Gradient	2.5%
Stream Gradient	2.7%
Sinuosity	1.05
Dominant Channel Type	Cascading riffle
Average Bankfull Width (feet)	52
Average Floodplain Width (feet)	161
Dominant Substrate	boulder & large cobble; sparse sand and gravel
Bank Stability/Channel Migration	Adequate *(See Section 2.12)*
Vertical Channel Stability	Adequate *(See Section 2.12)*
Confinement ratio	Moderate *(See Table 5)*

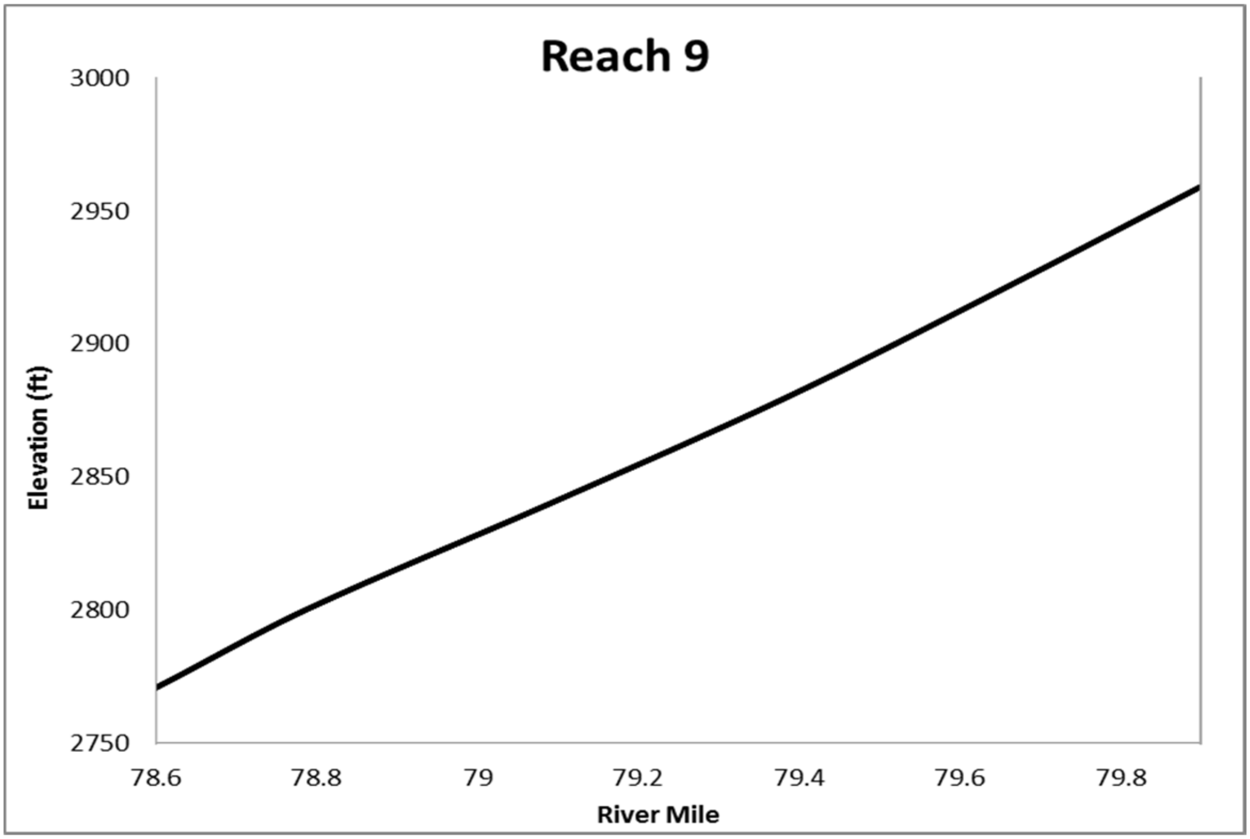

Figure 134. Longitudinal profile of the channel in Reach 19 (RM 78.7 to 80).

3.9.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 9 is confined within a narrow U-shaped valley carved by Quaternary glaciation. Increased discharge regimes during early Holocene glacial retreat further incised the floor of the valley in Reach 9. This has resulted in a subtle V-shape at the valley's base, which is most notable from RM 79 to 79.75. Once the glaciers retreated and the discharge regime was reduced, the floor of the valley has been infilling with coarse-grained sediment. These sediment inputs are sourced from local hillslopes, debris fans, and outwash coming from upstream. Today, the floodplain and the substrate in the channel are dominated by large cobbles and boulders. The steep walls and peaks of the adjacent hillslopes contain other glacial features, such as the cirque-carved headlands of Hungry Creek and an unnamed creek slightly upstream. Outwash generated from these hanging valleys creates the fan deposits located from RM 79.1 to 79.2 and from RM 79.5 to 79.6; both of these sections are on river-right (Figure 135).

The valley walls that confine Reach 9 are composed of weathered ancient bedrock of varied geologic compositions – metamorphic, sedimentary, and plutonic. Through seasonal freeze/thaw cycles and snowmelt-driven fluvial processes (including avalanches), the steep bedrock walls produce rock fall and landslides that accumulate as talus along the foot of the slopes and onto the narrow floodplains. The loose composition and active nature of the talus fans on river-left (north) slopes render these areas mostly unvegetated – except at fan toe accumulations near the channel and floodplain. The outwash fans coming off the river-right (south) slopes are more vegetated because they are less steep, more matrix-supported, and have a more seasonally-consistent water supply.

The valley in Reach 9 is narrow enough for outwash fans and landslides to create toe run-out deposits of rock and debris that often extend across the valley. In response to such inputs, and depending on their quantity and character, the channel may be forced to shift location from one side of its narrow floodplain to the other. Some very large boulder rock-fall inputs from the valley walls (four to ten feet in diameter) also influence channel position, bank stability, and roughness. A good example of this occurs at RM 79.4.

The floodplain surfaces of Reach 9 are irregular and vary in elevation due to the formative processes described previously. Floodplain surfaces are narrow and discontinuous throughout the reach because the position of the channel oscillates between the confining walls. Coarse sand and gravels deposited from overbank flows have accumulated on top of most of the floodplain surfaces. These deposits host developing soils that support mature forests.

In May 2014, an avalanche deposited hillslope debris and a massive quantity of downed large wood onto the floodplain from RM 79.6 to 79.7. Generated by unstable mountaintop snow accumulation, the avalanche entered the valley, toppling trees and distributing debris onto the valley floor. This event contained enough mass and force to distribute snapped trees on the opposite side of the valley where the avalanche ran up the foot of the slope. Today, large wood debris from this event buries the valley floor and toe slopes for approximately 500 feet (Figure 136). Avalanche-generated fines that had been deposited directly into the channel were subsequently flushed out by late spring high flows of 2014. However, Reach 9 and downstream areas will likely be influenced by this source of large wood and debris for decades.

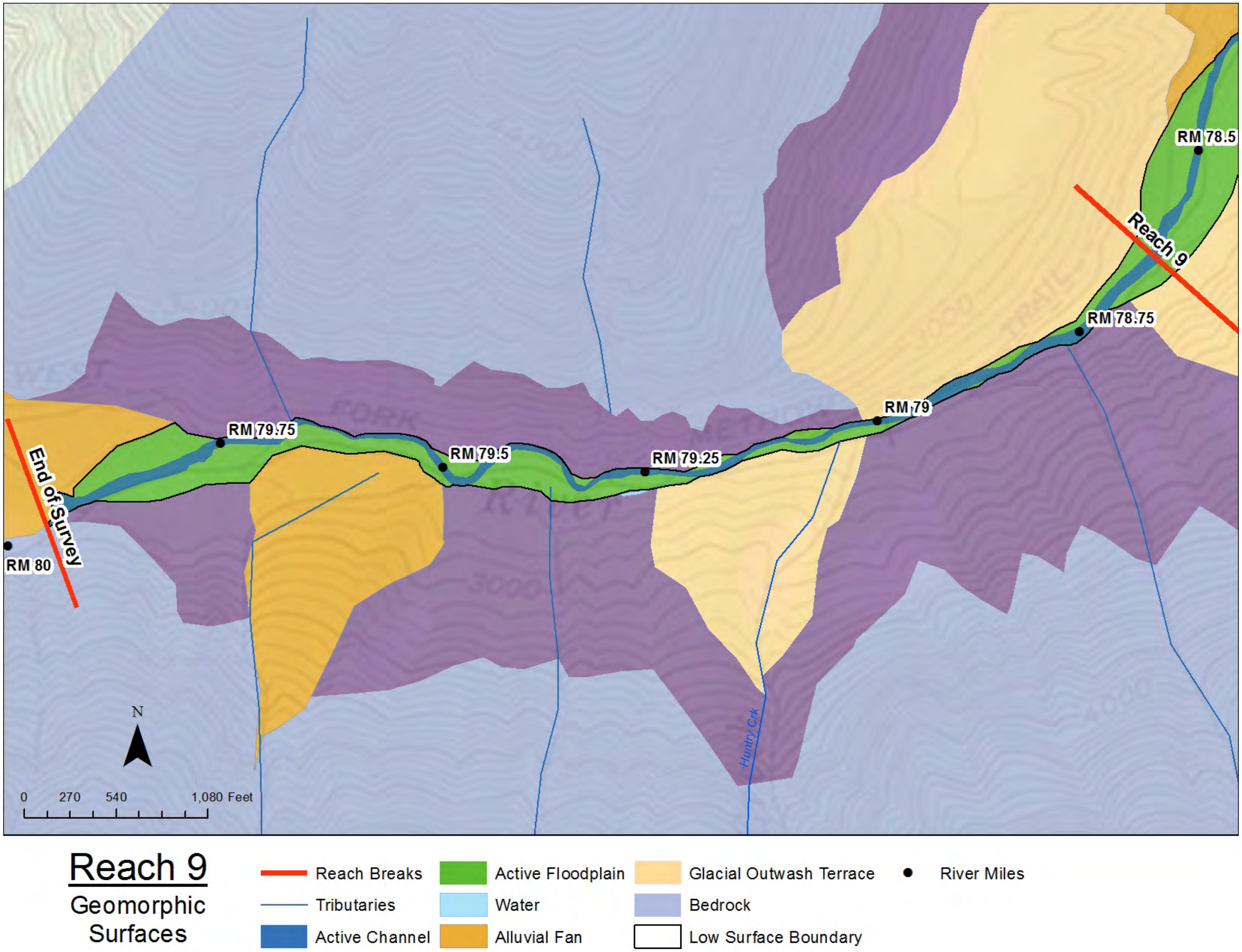

Figure 135. Geomorphic surfaces of Reach 9.

Figure 136. Downed trees and debris from May 2014 avalanche; looking upstream at RM 79.6. (10/15/2014)

Hydrology

Reach 9 has a seasonally dynamic flow regime. Late spring and early summer snowmelt flood events activate side-channels and potentially inundate narrow, low floodplain surfaces. Even though the reach has a relatively high gradient, it is only during high flow events that the channel is likely capable of mobilizing its over-sized bedload. The reach remains wetted throughout the year, but low flows in summer and autumn expose bank tops and large instream boulders. Summer thunderstorms are capable of temporarily raising surface-water elevations in Reach 9 because the bedrock-dominated walls and upstream drainage areas have low surface-water retention capacity. Based on the pattern of vegetation establishment observed in this reach, it is rare that a single thunderstorm is capable of generating enough flow to inundate floodplain surfaces.

The valley floor is composed primarily of coarse-grained material, and this material supports active hyporheic flow and groundwater influx from upstream and the adjacent hillslopes. The mainstem channel and side-channels within the active floodplain of Reach 9 are actively exchanging surface flow with groundwater through hyporheic processes. Groundwater seepage from the toe of a debris fan was also observed in the bank of a side-channel on river-right near RM 79.35.

Surface water contributions to the Methow River in Reach 9 include Trout Creek and a handful of ephemeral snowmelt- or precipitation-activated tributaries. The tributaries deliver discharge from the steep hillslopes and adjacent glacially-carved hanging valleys. According to the US Bureau of Reclamation's surface-flow estimates (2008 – Appendix J), discharge increases by 30% at the confluence of Trout Creek. The ephemeral snowmelt- or precipitation-activated tributaries contribute a total of approximately 6% of the surface water discharge during high flows. Hydrologic inputs from the tributaries are dependent on local snowpack and summer thunderstorms. Two tributaries feed outwash (alluvial/debris) fans at Hungry Creek (RM 79.1 to 79.2), and an unnamed creek (RM 79.5 to 79.6) on river-right. Surface flow from these tributaries is minimal during the summer months; even so, dense communities of dogwood, vine maple, and aspen on the fans indicate that subsurface flow occurs through the porous matrix of debris that the fans are composed of. The scale of influence or percentage of groundwater flow contributed by the tributaries is unknown.

Floodplain and Channel Migration Zone

The floodplains and channel migration zone of Reach 9 are narrow and confined laterally between the bedrock valley walls and their hillslope debris fans. Vertical stability is maintained by both the relatively large size of the channel's substrate and regular hillslope inputs. Episodic events of aggradation caused by hillslope inputs (landslides, outwash, avalanches, etc.) can force localized channel responses that include changes in channel location and elevation. Minimal change of mainstem channel location has occurred in the last fifteen years according to the aerial imagery (Figure 137). The hillslope inputs that extend across the valley floor force processes of incision when the channel is required to re-establish a pathway. However, substrate size here has a limiting effect on incision rates and depths. Currently, the modern channel remains actively connected to the low-to-medium elevation (a half foot to three feet) floodplain surfaces of the narrow valley. Fresh accumulations of coarse sand and gravels on the majority of the floodplain surfaces suggest regular (two- to ten-year) inundation. The presence of small side-channels along the edge of the valley walls and low active floodplain surfaces from RM 79.3 to 79.55 indicate that this section of Reach 9 is responding to a period of bed aggradation caused by a localized abundance of sediment.

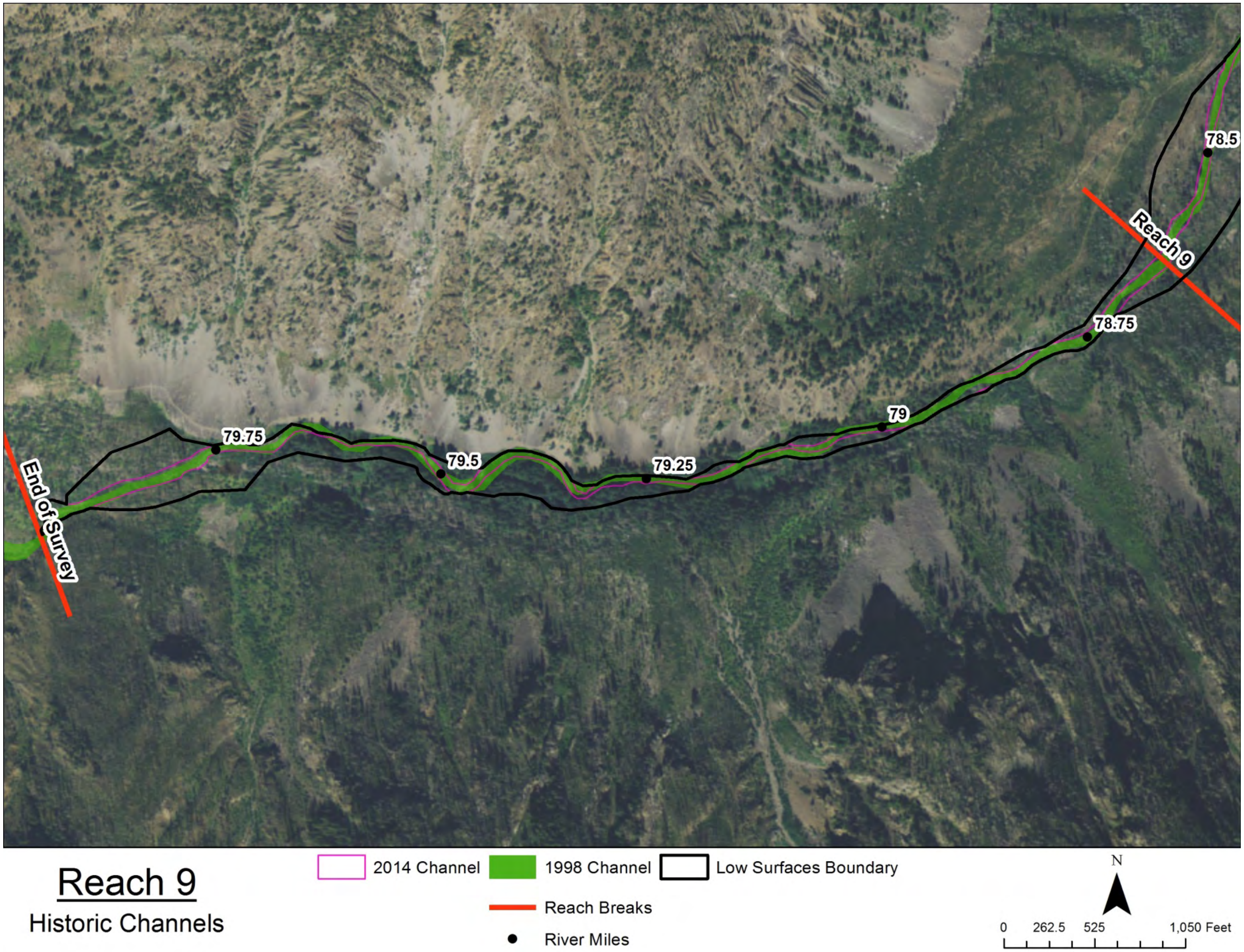

Figure 137. Historical channel locations for Reach 9.

Sediment

The substrate of Reach 9 is dominated by boulders and large cobbles. The sediment is primarily sourced directly from the steep, adjacent, confining hillslopes. These adjacent slopes are composed of weathered bedrock and talus fans. The Trout Creek confluence and its alluvial fan contribute additional sediment to the upstream portion of the reach, and these inputs include cobbles and boulders. Downstream from the confluence, most of the bedload is locally sourced and thus is angular to sub-angular. The rock-fall boulders add hydraulic roughness and stability to the channel bed and banks. Some small, gravel-sized bedload is present at a few transient, depositional zones in the channel near large wood accumulations or at eddies. Sands are present as overbank deposits on the few, very narrow floodplain surfaces. Otherwise, all fine-grained material is fluvially transported through this dynamic, cascading reach. Gravel counts were not conducted in Reach 9 because of the large bedload size relative to channel geometry, and the lack of LiDAR for hydraulic modeling.

Large Wood

Reach 9 has the highest wood count in the study area. Seven log jams and 467 logs were counted; an equivalent of 116 logs per mile. In-channel wood distribution in the reach is presented in Figure 138 as a density, or the number of wood pieces per 100 feet within each delineated channel unit type. The valley floor and channel banks of this reach are well vegetated and mature conifers offer high recruitment potential for large wood throughout the reach. The upper 0.3 miles of the reach was burned in the Needles forest fire in 2003, and standing snags left by that fire currently increase the likelihood of large wood inputs to the upper section of the reach. From RM 79.6 to 79.7, the 2014 avalanche described earlier supplied a massive quantity of downed trees directly to the valley floor and across the channel. There are channel spanning logs throughout this reach because channel width is smaller than mature tree height (at least 50 feet) (Figure 139). In Reach 9, channel complexity and floodplain connectivity is increased where log jams occur.

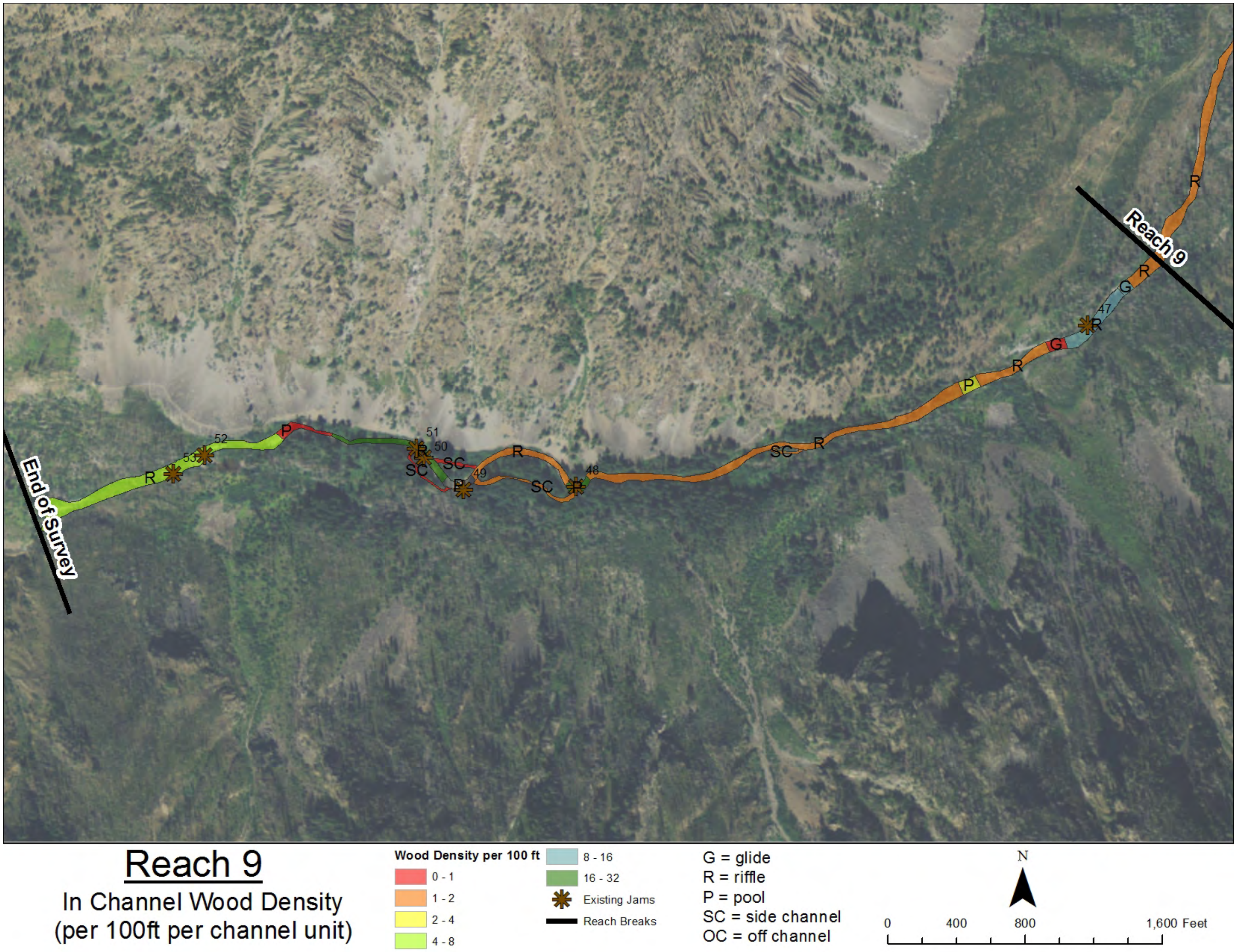

Figure 138. In-channel wood distribution (qualifying wood pieces per 100 ft channel length) within delineated channel units in Reach 9.

Figure 139. A) Channel-spanning logs and dense floodplain vegetation in Reach 9; looking downstream at RM 79.2, B) Large wood accumulation and cobble accumulations at RM 79.1. (09/02/2014)

Vegetation

The channel banks and floodplain of Reach 9 are mostly well vegetated. The overstory of vegetation is composed of a mature forest of fir and cedar. This forest reaches heights of more than 50 feet except in the upstream section, which was impacted by the forest fire. The mature conifer forest supplies ample shade to the channel, side-channels, and floodplain. The understory is mixed in composition, and includes dogwood, maple, ninebark, and sparse cottonwood. The density of the understory increases along some of the banks, at talus fan toes, and at other locations where conifers are young or have been removed by modern landscape process (i.e. forest fires, avalanches, relatively-modern hillslope deposits). Thus, in Reach 9, the composition and maturity of the vegetation indicates the modern stability of floodplain surfaces.

3.9.3 Human Alterations

Reach 9 has no-to-minimal modern anthropogenic alterations. The lack of stumps on floodplain surfaces indicates that no major logging activities have occurred here in the last 100 years. An established foot trail (Trail No. 480) runs along the base of the hillslope on river-left; it varies from one- to three-feet wide. Higher in elevation than the channel and its active floodplain features, it imposes no-to-minimal impact on channel processes. At the avalanche debris slide described above, the trail has been destroyed.

3.9.4 Recommended Actions

No specific restoration or preservation actions are recommended for this reach. The reach lies entirely within the Okanogan National Forest so is assumed to already receive sufficient protection from future human alteration.

See Section 4 of this report for the restoration strategy and specific recommendations for the reach.

4 Restoration Strategy

4.1 INTRODUCTION

The restoration strategy provides the linkage between the technical analyses performed in the Reach Assessment and the identification and prioritization of specific restoration actions. The key goals and guiding principles of the restoration strategy include the following:

1) Provide an explicit and direct linkage between assessment findings and project identification/prioritization.
2) Acknowledge and incorporate the interactions between fish use, aquatic habitat, geomorphology, hydrology, hydraulics, and riparian ecological processes.
3) Identify the recovery "gap", which is the difference between existing conditions and target conditions. Use this gap to identify and prioritize projects.
4) Consider the trajectory of the system if no actions are taken and the recovery potential given land use, social, and economic constraints.
5) Emphasize the recovery of root causes (i.e. habitat-forming processes) of impairments. Rely on projects that enhance or create habitats as secondary measures where full recovery is not possible or where the timeline for full recovery may be too long for species recovery.

Included in the strategy is a snapshot summary of the Reach Assessment findings, followed by reach-scale restoration objectives, recommended action types, specific restoration project opportunities, and project prioritization/ranking. Appendix C is an integral piece of the restoration strategy and includes detailed project information, project maps, and results of the project prioritization.

4.2 RESTORATION STRATEGY FRAMEWORK

An overview of the restoration strategy for the entire study area is presented in Section 4.3. Following this, in Section 0, are the individual reach-scale restoration strategies. The information included in the reach-scale strategies is described in the subsections below.

4.2.1 Summaries of Reach Assessment Findings

For each reach, the summary of reach assessment findings distills the large amount of information contained in the Reach Assessment into a snapshot summary for each reach. It includes a designation of good, moderate, or high for overall ecological function. The rationale for the designation is provided in the table. The summary also includes a description of the trajectory of the system if no action is taken. This is based primarily on the geomorphic analysis including current trends and the effects of land use. A rating of high, medium, or low is also provided for the recovery potential of the reach. This designation is based on the likelihood of being able to effectively address degraded processes and habitat based on the realities of current and anticipated land use, infrastructure, and ownership.

4.2.2 Restoration Objectives

Restoration objectives were developed for multiple ecological attributes, including habitat, geomorphic, and riparian attributes. These objectives are presented as restoration targets. They are made to be as quantifiable as possible at this stage of analysis. These target conditions are compared to existing conditions from the Reach Assessment. This highlights habitat deficiencies and the "gap" that needs to be filled to recover habitat.

Target conditions were developed using the REI targets as well as reference to site conditions and inference from regional studies. The REI analysis is based on previous REI analyses conducted as part of previous Reach Assessments conducted by the USBR and YN in other Upper Columbia tributaries, with some modifications. See Section 2.12 and Appendix B for more information on the REI analysis.

4.2.3 Restoration Action Types

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 elements. For example, the action type "off-channel habitat enhancement" might be achieved via numerous project elements ranging from re-connecting habitat blocked by a levee to excavating new off-channels in the floodplain. 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.

The various action types and project elements may be considered either as Restoration, Enhancement, or Creation. We consider true restoration actions to be those that address root causes of impairments and that aim to return the system close to its naturally functioning state. This is often not achievable due to past changes to the underlying processes or due to process impairments that are unlikely to change due to infrastructure. An example true restoration project would be a project that fully removes a levee to restore natural floodplain inundation patterns. Enhancement measures are those that improve or rehabilitate habitat to the extent possible given existing impaired processes. Placement of large wood to provide cover and complexity is an example of enhancement. Creation projects are those that create new habitat that is currently lacking or that will not be created on its own in a reasonable timeframe given existing process impairments. Excavating a backwater alcove into the floodplain is an example of a creation project.

The five general action types are described in the sections below.

Protection

Protection projects involve preservation of existing habitat that may be at risk of degradation. Protection of other areas is generally not identified as a 'protect and maintain' action because it is considered inherent in all potential actions. Protection projects are identified in areas where existing or potential land ownership or land use suggests that further degradation could occur. Areas identified for protection may have existing high quality and functioning habitat or may contain impaired habitat in need of restoration. In many cases, adequate protection may already be in place through existing laws, policy, or management plans. The adequacy and enforcement of these regulations needs to be considered when planning for protection activities.

Examples:

- Direct purchase (fee acquisition) 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

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

Habitat Reconnection via Infrastructure Modification

This strategy includes removal/modification of bank armoring, levees, roadways, bridges, or fill. Habitat reconnection projects are located in areas where floodplain and channel migration processes have been disconnected due to anthropogenic activities. These types of projects are frequently applied to address issues associated with floodplain connectivity (i.e., alterations to flood inundation rates or patterns), bank stability/channel migration, vertical channel stability, and off-channel habitat availability. These project types are applied to areas that have the potential for an increase in habitat quality and a reestablishment of dynamic processes through their reconnection. In some cases, these actions are focused on restoring a component of the system that has been lost, therefore regaining habitat and process that was previously a functional part of the river system. In cases where full restoration is not possible, such as when a levee can only be partially removed or breached, these actions may only provide enhancement of conditions.

Habitat reconnection projects may also include the reestablishment of fish passage where it has been blocked by human infrastructure or management. For the upper Methow River, there are no passage barriers on the mainstem but there are side- and off-channel habitats where fish access has been affected by levees, fill, and roadways.

Examples:

- Removal or selective breaching of a levee or road embankment to enhance floodplain connectivity and/or to restore fish access to off-channel habitats
- Removal of riprap 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

Placement of Structural Habitat Elements

This strategy includes placement of habitat structures such as large wood, logjams, 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 logjam 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. These projects are generally considered enhancement measures, as they do not fully restore the root cause of the problem (e.g. growth and recruitment of key pieces).

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

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. These actions generally include the enhancement or creation of habitat, rather than the full restoration of root causes of the lack of off-channel habitat.

Examples:

- Construction or enhancement 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

4.2.4 Projects and Prioritization

Projects were identified through field surveys and analysis performed in the Reach Assessment. Project elements were identified that are believed to best achieve target conditions and to address key factors limiting salmonid populations. These projects represent an initial first step in this process; it is expected that projects will be modified as appropriate once project-specific surveys, analysis, and stakeholder coordination are performed as part of design. Project opportunities are linked to their respective action type(s) in the reach tables in Section 0 and are described in greater detail in Appendix C.

Project prioritization was performed to rank the projects into three priority tiers. Prioritization occurred by subjecting the projects to a set of scoring criteria. These criteria are based on several factors, including how well projects address the “gap” between existing and target conditions, fish use/potential use of the area, and whether or not projects address root causes of impairments. Projects are also given a cost score and feasibility designations in order to provide other relevant information used in project selection and planning.

4.3 RESTORATION STRATEGY OVERVIEW

An overview of the restoration strategy at the study area scale is presented in Table 16 and in map form in Figure 140 and Figure 141. The detailed reach-scale strategies are included in Section 4.4.

Table 16. Overview of restoration strategy.

Reach	Ecological Function	Trajectory	Recovery Potential	Projects & Priority
Reach 1	Poor	Same or decline	Low-to-Moderate	Weeman (Tier 1)
Reach 2	Poor	Same or decline	High	Weeman (Tier 1) Fawn Creek (Tier 1) Trail Bridge (Tier 1)
Reach 3	Poor	Same or decline	High	Goat Creek (Tier 1)
Reach 4	Poor	Same or decline	Moderate-to-High	Lower Mazama (Tier 2) Upper Mazama (Tier 2)
Reach 5	Poor-to-Moderate	Same or improve	High	A-Wall (Tier 2) Goat Wall (Tier 2)
Reach 6	Poor-to-Moderate	Same	Moderate-to-High	Gate Creek (Tier 3) Cedarosa (Tier 1) Lost River (Tier 2)
Reach 7	Moderate-to-High	Same or improve	High	Two Rivers (Tier 3) Robinson (Tier 3)
Reach 8	Moderate-to-High	Improve	High	Ballard (Tier 3)
Reach 9	High	Improve	High	No projects identified

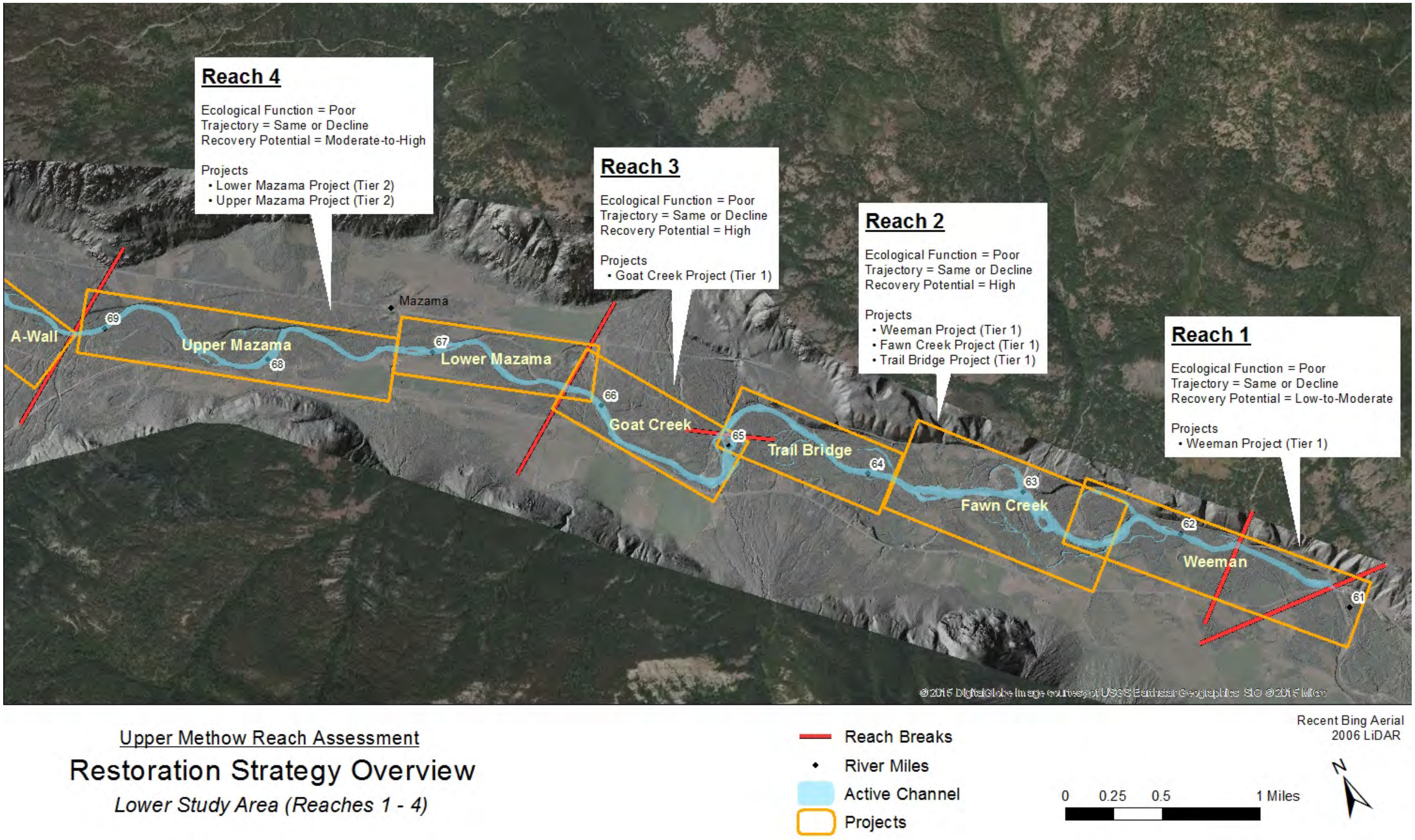

Figure 140. Overview of the Restoration Strategy for the downstream portion of the study area.

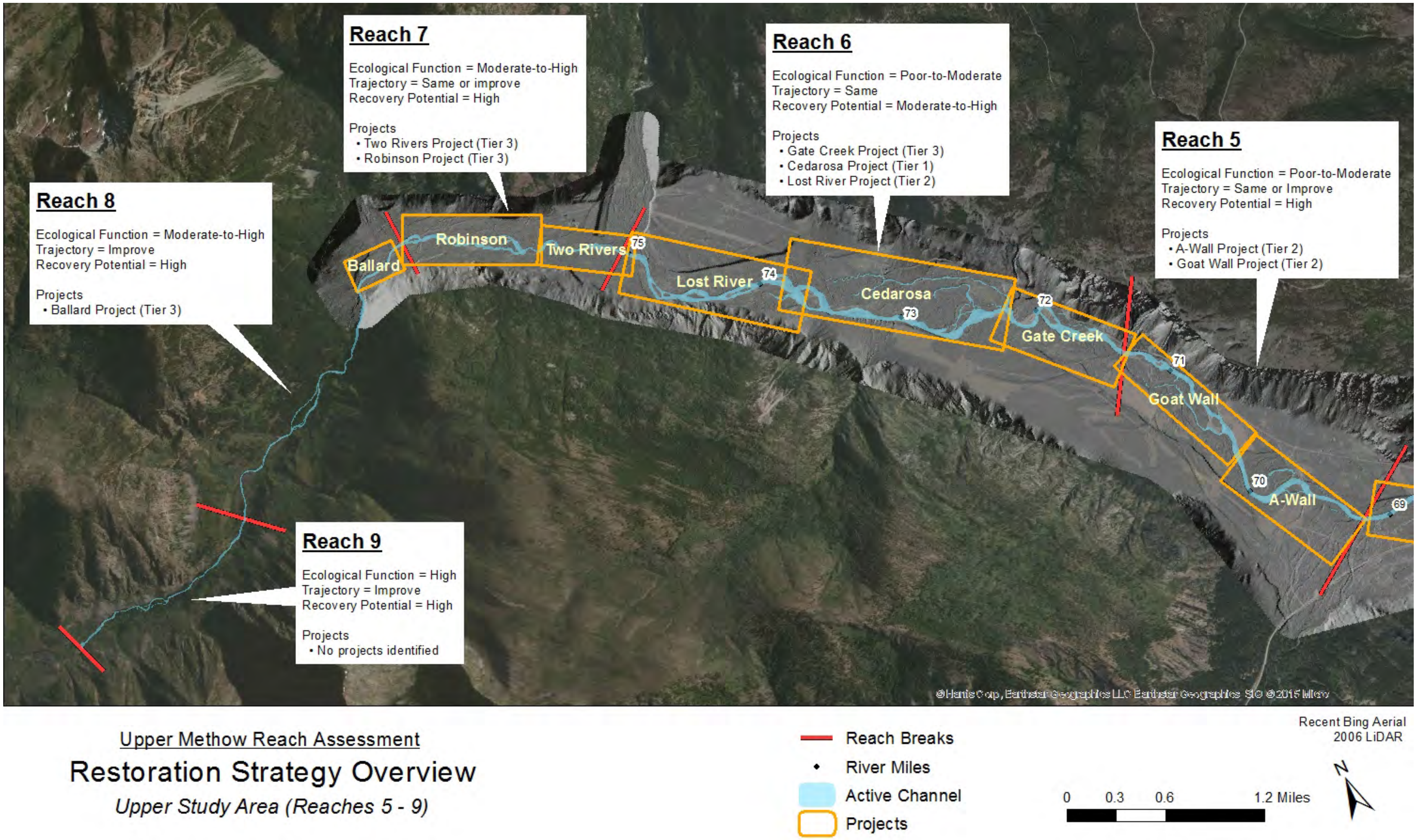

Figure 141. Overview of the Restoration Strategy for the upstream portion of the study area.

4.4 REACH-SCALE STRATEGIES

4.4.1 Reach 1 Restoration Strategy

Overall ecological function	**Poor**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 9 of 11 REI metrics are at risk or unacceptable. Significant impairments of channel and floodplain function due to Weeman Bridge, Highway 20 fill, bank armoring, and riparian clearing.
Trajectory if no action taken	**Same or decline**
	Continued degradation due to persistent anthropogenic impacts to floodplain, channel migration, riparian, and large wood processes. Some passive recovery of riparian function due to maturing vegetation.
Recovery potential	**Low-to-moderate**
	Highway 20 fill, Weeman Bridge, and other areas of bank armoring that protects infrastructure are unlikely to be modified; or modification will be challenging and require long time horizon for planning and significant expense.
Restoration objectives	**Target conditions in Table 17**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 17 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall primarily in the Enhancement and Creation categories since full restoration will be challenged by existing infrastructure and ownership.
Projects & Prioritization	**Weeman Project (Tier 1)**
	The downstream portion of the Weeman Project encompasses Reach 1. The project area also extends downstream of the study area as it relates to enhancing conditions associated with the Highway 20 crossing. Receives Tier 1 rank due to high fish use, high impairment, and moderate recovery potential. This reach is typically perennially wetted and is expected to have high year-round fish use.

Table 17. Reach 1 Restoration Objectives, Action Types, and Projects.

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Project
Riparian condition	<50% species composition, seral stage, and structural complexity are consistent with potential native community. 100% small tree 15% canopy cover Human disturbance is located within approximately 3% of the floodplain and 6% of the 100-foot riparian buffer zone. Disturbance includes a home site with riprap and pushup levee at RM 61.35, and a riprap wall along river-left at the upstream portion of the reach associated with Goat Creek Cutoff Road.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian Restoration	Weeman Project
Floodplain Connectivity	This reach is naturally laterally constricted by terrace and alluvial fan deposits on river-left. Some riprap and levees are present in this reach, minimally impacting floodplain connectivity. The Weeman Bridge significantly affects floodplain connectivity at the downstream end of the reach. 1.07 mi/mi² of road 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. <2mi/mi² road density in the floodplain [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Weeman Project

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Project
Bank condition / Channel migration	Minimal lengths of the streambanks in the reach are affected by bank armoring, mostly riprap along the road embankment or used to protect residential property. The Weeman Bridge restricts channel migration at the downstream end of the reach.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Weeman Project
Vertical channel stability	Subtle channel bed incision and reduced floodplain connectivity is present in this reach due to channel confinement by riprap, bridge abutments, and levees. High floodplain surface development at the downstream section of the reach due to incision.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Weeman Project
Pools	There are no pools in the reach. Pools per mile = 0 0% pool habitat 0 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Element	Weeman Project
Large wood and logjams	2.5 M-L pieces / mi 0 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Weeman Project

Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Project
Off-Channel Habitat	0% side-channel habitat. There were no side-channels observed in this reach. Though channel confinement naturally limits the extent of side-channel habitat, the potential for off-channel habitat is somewhat more constrained by the effects of the roadway, residential development, and the Weeman Bridge on lateral channel migration and floodplain connectivity. A lack of logjams also limits potential 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]	Off-Channel Habitat Enhancement	Weeman Project

4.4.2 Reach 2 Restoration Strategy

Overall ecological function	**Poor**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 9 of 11 REI metrics are at risk or unacceptable. Significant impairments of channel and floodplain function due to the levee system, trail bridge, bank armoring, riparian clearing, and development.
Trajectory if no action taken	**Same or decline**
	Continued degradation due to persistent anthropogenic impacts to floodplain, channel migration, riparian, and large wood processes. Some passive recovery of riparian function due to maturing vegetation. Channel incision expected to continue due to artificial confinement.
Recovery potential	**High**
	The primary impact is the levee/trail system, which is assumed to be challenging but not impossible to address given social and property constraints. The potential habitat and geomorphic function is high.
Restoration objectives	**Target conditions in Table 18**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 18 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall primarily in the Restoration and Enhancement categories assuming large-scale levee removal/modification can occur. Some actions will fall into the Enhancement category given existing infrastructure and ownership.
Projects & Prioritization	**Weeman Project (Tier 1)** **Fawn Creek Project (Tier 1)** **Trail Bridge Project (Tier 1)**
	Reach 2 has high restoration potential. Some of the greatest potential is associated with the levee complex on river-right midway through the reach (Fawn Creek Project). There are also other side-channel reconnection projects and opportunities to enhance in-channel complexity and lateral channel dynamics. Only the upstream portion of the Weeman Project is within Reach 2. Projects rank high due to high fish use, projects that address root causes, and a high potential for recovery. This reach is typically perennially wetted and is expected to have high year-round fish use.

Table 18. Reach 2 Restoration Objectives, Action Types, and Projects.

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	<50% species composition, seral stage, and structural complexity are consistent with potential native community. 100% small tree 20% canopy cover Human disturbance is located within approximately 26% of the floodplain. 9.6% of the 100-ft riparian buffer has been cleared. Disturbance includes roads and home sites with some riprap and cleared lawns. A large levee with riprap is present along the channel boundary and into the riparian zone between RM 63.25 and 63.75.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian Restoration	Trail Bridge Project Fawn Creek Project Weeman Project
Floodplain Connectivity	Natural connectivity is reduced by high road density in the floodplain, residential and agricultural features, and the long river-right levee system. 2.75 mi/mi² of road 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] <2mi/mi² road density in the floodplain	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements Off-Channel Habitat Enhancement	Trail Bridge Project Fawn Creek Project Weeman Project

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	Between RM 62.5 and RM 63.25 the channel is naturally active and has recently avulsed resulting in the main channel straightening and a side-channel/oxbow remaining in the historic main channel. Additionally, RM 63.8 upstream to the end of the reach is naturally active and migrates frequently. The residential and agricultural features along the banks of the channel have restricted substantial natural migration activity, particularly on the river-right floodplain where high-value habitat is cut off from the main channel by a levee.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Fawn Creek Project Weeman Project
Vertical channel stability	This reach has reduced channel sinuosity with a high potential for incision and reduced floodplain connectivity due to channel confinement by riprap and levees.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Trail Bridge Project Fawn Creek Project Weeman Project
Pools	Pools have minimal cover and there are only 3 large pools (> 3 ft deep) in the reach. Pools per mile = 1.25 5% pool habitat 3 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Trail Bridge Project Fawn Creek Project Weeman Project

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and logjams	64.3 M-L pieces / mi 2.9 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Trail Bridge Project Fawn Creek Project Weeman Project
Off-Channel Habitat	19% side-channel habitat. Man-made barriers such as levees are blocking portions of floodplain and reducing off-channel habitat connectivity.	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]	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement	Trail Bridge Project Fawn Creek Project Weeman Project

4.4.3 Reach 3 Restoration Strategy

Overall ecological function	**Poor**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 9 of 11 REI metrics are at risk or unacceptable. Significant impairments of channel function due to push-up levees, the proximity of Hwy 20, bank armoring, and riparian clearing.
Trajectory if no action taken	**Same or decline**
	Continued degradation due to persistent anthropogenic impacts to floodplain, channel migration, riparian, and large wood processes. Continued incision from levees and riprap in the upper 2/3 of the reach. Continued lack of LW recruitment due to bank armoring. Some passive recovery of riparian function due to maturing vegetation.
Recovery potential	**High**
	Many of the push-up levees and some of the bank armoring do not appear to be protecting infrastructure and could potentially be removed or modified. Riparian work will have high long-term benefits. Roadway impacts are likely to remain.
Restoration objectives	**Target conditions in Table 19**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 19 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration** **Protection**
	Actions fall primarily in the Restoration and Enhancement categories assuming levee and bank armoring removal can occur. Protection is recommended for the downstream portion of the reach, the river-left floodplain, and the downstream river-right floodplain.
Projects & Prioritization	**Goat Creek Project (Tier 1)**
	There is moderate-to-high restoration opportunity in this reach, including some opportunities to remove levees and bank armoring and to increase in-channel structure and complexity. The Goat Creek Project is a high ranking project due to high fish use, relatively high impairment (upstream 2/3 or reach), and high potential for recovery.

Table 19. Reach 3 Restoration Objectives, Action Types, and Projects.

Reach 3 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	<50% species composition, seral stage, and structural complexity are consistent with potential native community. 75% small tree 25% grass/forb 20% canopy cover Human disturbance is located within approximately 45% of the floodplain. 4.5% of the 100 ft riparian buffer has been cleared. Disturbance includes Highway 20 road embankment at RM 65.75, homes with riprap throughout the reach, and push-up levees along the channel corridor, primarily at RM 65.5.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian Restoration	Goat Creek Project
Floodplain Connectivity	The road adjacent to the channel on river-right for a majority of the reach restricts any potential floodplain activity. Levees and riprap have been used throughout the reach to prevent floodplain activation into agricultural and residential areas, particularly on river-left. 2.56 mi/mi^2 of road 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] <2mi/mi^2 road density in the floodplain	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement Placement of Structural Habitat Elements	Goat Creek Project

Reach 3 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	The road adjacent to the channel on river-right for a majority of the reach restricts any potential migration activity. Levees and riprap have been used throughout the reach to prevent channel migration into agricultural and residential areas, particularly on river-left where historical channel migration activity occurred.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements Protection (downstream end of reach)	Goat Creek Project
Vertical channel stability	There is channel bed incision and reduced floodplain connectivity in this reach due to channel confinement by levees and riprap. There is a high potential for continued incision processes in this reach.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Goat Creek Project
Pools	All pools in this reach have a residual depth greater than 3 feet, and most have good cover. Pools per mile = 5.5 21% pool habitat 7 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Goat Creek Project
Large wood and logjams	76.3 M-L pieces / mi 3.1 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements Protection (downstream end of reach)	Goat Creek Project

Reach 3 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	2% side-channel habitat. Four side-channels were present in this reach, though only one had slow-moving water. Man-made levees are blocking portions of floodplain and reducing connectivity of potential off-channel habitat.	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 Protection (downstream end of reach)	Goat Creek Project

4.4.4 Reach 4 Restoration Strategy

Overall ecological function	**Poor**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 9 of 11 REI metrics are at risk or unacceptable. Significant impairments of channel function due to Mazama Bridge, levees, bank armoring, and riparian clearing.
Trajectory if no action taken	**Same or decline**
	Continued degradation due to persistent anthropogenic impacts to floodplain, channel migration, and large wood processes. Continued incision is expected, partly due to human actions (e.g. past log drives that removed wood) and bank armoring/bridge. Some passive recovery of riparian function due to maturing vegetation.
Recovery potential	**Moderate-to-High**
	The Mazama Bridge, riparian impacts from local residences, and floodplain grading are likely to persist. Some push-up levees and cleared riparian areas could be addressed.
Restoration objectives	**Target conditions in Table 20**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 20 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall primarily in the Enhancement category since full restoration will be challenged by existing infrastructure and ownership.
Projects & Prioritization	**Lower Mazama Project (Tier 2)** **Upper Mazama Project (Tier 2)**
	The restoration potential is high but is somewhat constrained by private infrastructure and roads (and bridge) around the town of Mazama. Two projects are identified. The boundary between the two projects is the Mazama Bridge. They rank as Tier 2 due to moderate fish use, moderate-to-high existing impairment, and moderate potential for full recovery. This reach typically runs dry in late summer and may have limited year-round fish use.

Table 20. Reach 4 Restoration Objectives, Action Types, and Projects.

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	<50% species composition, seral stage, and structural complexity are consistent with potential native community. 100% small tree 10% canopy cover Human disturbance is located within approximately 24% of the floodplain. 14.5% of the 100 ft riparian buffer has been cleared. Disturbance within the low geomorphic surfaces is relatively minimal due to the naturally moderately confined channel in this reach. However, there are substantial roads and home sites with associated cleared areas and lawns throughout the reach on both river-right and river-left, often very close or adjacent to the channel and which may influence condition of the riparian zone and channel.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian restoration	Upper Mazama Project Lower Mazama Project

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Floodplain Connectivity	The bridge and associated bank armoring at RM 67.2 near Mazama somewhat reduces local connectivity with the floodplain, but otherwise few human features are present that affect the floodplain connectivity to the channel. The channel is naturally moderately confined in this reach. 0.33 mi/mi² of road 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] <2mi/mi² road density in the floodplain	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements Off-Channel Habitat Enhancement	Upper Mazama Project Lower Mazama Project
Bank condition / Channel migration	There is bank armoring associated with the bridge at RM 67.2 near Mazama, but otherwise little human features are present. Though agricultural and residential uses are present along the banks in this reach, the channel is naturally moderately confined in this reach, therefore little bank migration has occurred	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Upper Mazama Project Lower Mazama Project
Vertical channel stability	Subtle channel bed incision resulting in reduced active floodplain connectivity, and alluvial terrace development.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Upper Mazama Project Lower Mazama Project
Pools	Pools have inadequate cover and there are few large pools (> 3 ft deep) in the reach. Pools per mile = 1.7 11% pool habitat 5 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Upper Mazama Project Lower Mazama Project

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and logjams	23.2 M-L pieces / mi 0.7 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Upper Mazama Project Lower Mazama Project
Off-Channel Habitat	3% side-channel habitat. Four side-channels with little woody debris were identified. Minimal LWD within the side-channels limits off-channel habitat complexity.	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]	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement	Upper Mazama Project Lower Mazama Project

4.4.5 Reach 5 Restoration Strategy

Overall ecological function	**Poor-to-Moderate**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 7 of 11 REI metrics are at risk or unacceptable. Impairments of channel and riparian function due to Lost River Road, residential development, riparian clearing, and push-up levees in the floodplain.
Trajectory if no action taken	**Same or slight improvement**
	Impacts to floodplain and off-channel connectivity are relatively minor. Complexity and structure expected to improve as riparian and floodplain vegetation matures.
Recovery potential	**High**
	Push-up levees affecting floodplain and off-channel connectivity are relatively minor and it is assumed they can be removed. Riparian impacts can possibly be addressed through establishment of buffers and replanting. Channel margin impacts along Lost River Road are expected to persist but their location along the valley wall limits their overall impact.
Restoration objectives	**Target conditions in Table 21**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 21 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall primarily in the Restoration and Enhancement categories assuming push-up levee removal and riparian enhancement can occur. Enhancement along existing riprap banks will improve margin complexity
Projects & Prioritization	**A-Wall Project (Tier 2)** **Goat Wall Project (Tier 2)**
	Reach 5 has moderate-to-high restoration opportunity. The projects include a combination of side-channel reconnection, side-channel enhancement, channel margin complexity, and in-channel wood structures designed primarily to capture in-coming wood expected from upstream reaches. These projects rank as Tier 2 due to moderate fish use and relatively high functioning habitat under existing conditions. This reach typically runs dry in late summer and may have limited year-round fish use.

Table 21. Reach 5 Restoration Objectives, Action Types, and Projects.

Reach 5 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	<50% species composition, seral stage, and structural complexity are consistent with potential native community. 67% small tree 33% sapling/pole 20% canopy cover Human disturbance is located within approximately 33% of the floodplain. 3.5% of the 100 ft riparian buffer has been cleared. Disturbance includes roads and cleared home sites with associated riprap and levees.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian restoration	Goat Wall Project A-Wall Project
Floodplain Connectivity	There are several riprap or levee features in this reach, though they do not disconnect the floodplain very substantially. They occur near the upstream end of the reach primarily. Road embankments along the river channel and secondary channels also disconnect the floodplain from the channel on river-left. Due to these features, the channel is disconnected along portions of this reach. 3.86 mi/mi^2 of road 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 <2mi/mi^2 road density in the floodplain [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements Off-Channel Habitat Enhancement	Goat Wall Project A-Wall Project

Reach 5 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	There are a few instances of riprap or levees protecting houses and private property in this reach. These occur near the upstream end of the reach, between RM 70.75-71.25 primarily. Road embankments along the river channel and secondary channels also limit migration near RM 70 on river-right and near RMs 71 and 71.25 on river-left. Due to these human features, the channel is migrating below natural rates for this reach.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Goat Wall Project A-Wall Project
Vertical channel stability	Subtle channel bed incision resulting in reduced active floodplain connectivity, and alluvial terrace development.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Goat Wall Project A-Wall Project
Pools	Pools have relatively good cover and there are many large pools (> 3 ft deep) in the reach. Pools per mile = 5.3 21% pool habitat 9 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Goat Wall Project A-Wall Project
Large wood and logjams	54 M-L pieces / mi 3.86 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Goat Wall Project A-Wall Project

Reach 5 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	20% side-channel habitat. A majority of the secondary channel habitat is hyporheic flow off-channel habitat located between RM 70.4 – 71.2, and had an average temperature approximately 2°C cooler than the main channel with decent canopy cover. Artificial levees are blocking portions of the floodplain at the upstream end of this reach. The channel in this reach is a naturally unconfined channel, therefore would expect to have greater amounts off-channel habitat.	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]	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement	Goat Wall Project A-Wall Project

4.4.6 Reach 6 Restoration Strategy

Overall ecological function	**Poor-to-Moderate**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 8 of 11 REI metrics are at risk or unacceptable. Impairments of channel and floodplain function are related to bank armoring, levees, diversion of floodplain flow (i.e. canals), and residential clearing/development.
Trajectory if no action taken	**Same**
	Continued degradation due to persistent anthropogenic impacts to floodplain, channel migration, and large wood processes. Some passive recovery of riparian function due to maturing vegetation.
Recovery potential	**Moderate-to-High**
	Recovery potential varies throughout the reach. In the upstream half of the reach, full recovery will be challenging given the infrastructure protecting the Lost River Community and the Cedarosa Community. Recovery potential is high in the downstream portion of the reach.
Restoration objectives	**Target conditions in Table 22**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 22 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall primarily in the Enhancement category since full restoration will be challenged by existing infrastructure and ownership. There are some Restoration and Creation elements also included.
Projects & Prioritization	**Gate Creek Project (Tier 3)** **Cedarosa Project (Tier 1)** **Lost River Project (Tier 2)**
	Reach 6 has moderate-to-high restoration potential. Gate Creek is Tier 3 due to moderate fish use and relatively well-functioning habitat. Cedarosa is Tier 1 due to high relative impairment but high recovery potential. Lost River is Tier 2 due to moderate fish use, high impairment, but moderate recovery potential. This reach is typically dry in late summer/fall and may have limited year-round fish use.

Table 22. Reach 6 Restoration Objectives, Action Types, and Projects.

Reach 6 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	50-80% species composition, seral stage, and structural complexity are consistent with potential native community. 11% large tree 78% small tree 11% sapling/pole 30% canopy cover Human disturbance is located within approximately 27% of the floodplain. 8.2% of the 100 ft riparian buffer has been cleared. Disturbance is particularly located in the upstream portion of this reach between RM 72.5 – RM 75 in the Lost River community, and includes roads and cleared home sites, often with associated riprap and levees.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian Restoration	Lost River Project Cedarosa Project
Floodplain Connectivity	There is significant riprap and levees along the channel in this reach. Additionally, a large number of roads are present in the floodplain that restrict floodplain activation throughout the reach, primarily on river-left. Due to the high density of human features, the channel is substantially cut off from the floodplain 4.02 mi/mi^2 of road 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 $<2 mi/mi^2$ road density in the floodplain [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements Off-Channel Habitat Enhancement	Lost River Project Cedarosa Project Gate Creek Project

Reach 6 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	There are a number of instances of riprap or levees protecting houses and private property in this reach. Additionally, roads built in the floodplain contribute to restricted migration of the channel throughout the reach, primarily on river-left. Due to these human features, the channel is migrating significantly below natural rates for this reach.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Lost River Project Cedarosa Project Gate Creek Project
Vertical channel stability	Reduced channel sinuosity with some potential for incision and reduced floodplain connectivity due to channel confinement by riprap, and levees.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements	Lost River Project Cedarosa Project Gate Creek Project
Pools	Pools have relatively little cover, but there are many large pools (> 3 ft deep) in the reach. Pools per mile = 6.3 26% pool habitat (highest of all 9 reaches) 14 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Lost River Project Cedarosa Project Gate Creek Project
Large wood and logjams	48.3 M-L pieces / mi 2.8 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Lost River Project Cedarosa Project Gate Creek Project

Reach 6 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	11% side-channel habitat. Eight side-channels, several over 1,000 ft with cool-water inputs from groundwater or tributaries, are present in this reach.	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]	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement	Lost River Project Cedarosa Project Gate Creek Project

4.4.7 Reach 7 Restoration Strategy

Overall ecological function	**Moderate-to-High**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 6 of 11 REI metrics are at risk or unacceptable. Mostly at risk conditions except for Large Wood, which is unacceptable.
Trajectory if no action taken	**Same or improve**
	Some floodplain clearing for recreation expected to continue. Some continuing impacts from roadways in valley, primarily on tributary connectivity. Passive recovery of riparian function expected due to maturing vegetation.
Recovery potential	**High**
	Few significant human features impairing fundamental processes. Public land expected to offer continued protection.
Restoration objectives	**Target conditions in Table 23**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 23 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall primarily in the Restoration and Enhancement categories.
Projects & Prioritization	**Two Rivers Project (Tier 3)** **Robinson Project (Tier 3)**
	Reach 7 has moderate restoration potential, mostly related to restoring the large in-channel structure that is lacking in the reach, and also increasing side-channel and floodplain connectivity in a few locations, including one side-channel obstructed by a push-up levee. The projects are Tier 3 due to existing relatively high functioning habitat and moderate fish use.

Table 23. Reach 7 Restoration Objectives, Action Types, and Projects.

Reach 7 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	50-80% species composition, seral stage, and structural complexity are consistent with potential native community. 40% small tree 20% sapling/pole 40% shrub/seedling 25% canopy cover Human disturbance is located within approximately 18.4% of the floodplain. 8.8% of the 100 ft riparian buffer has been cleared. Disturbance is located on river-left of this reach, and includes roads and cleared areas.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian Restoration	Robinson Project Two Rivers Project
Floodplain Connectivity	This reach is has few instances of human features in the floodplain that could restrict connectivity with the channel. 0.95 mi/mi^2 of road 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 $<2 mi/mi^2$ road density in the floodplain [adapted from REI]	Habitat Reconnection via Infrastructure Modification Placement of Structural Habitat Elements Off-Channel Habitat Enhancement	Robinson Project Two Rivers Project
Bank condition / Channel migration	This reach is moderately unconfined, and there are few instances of human features in the floodplain that could restrict channel migration activity.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Placement of Structural Habitat Elements	Robinson Project Two Rivers Project

Reach 7 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Vertical channel stability	No measurable trend of aggradation or incision and no visible change in channel planform.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Placement of Structural Habitat Elements	
Pools	Pools have relatively little cover, but there are several deep pools (> 3 ft deep) in the reach. Pools per mile = 7.5 16% pool habitat 7 pools > 3 ft deep	~4 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Robinson Project Two Rivers Project
Large wood and logjams	48.3 M-L pieces / mi 2.8 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Robinson Project Two Rivers Project
Off-Channel Habitat	11% side-channel habitat. Seven predominantly fast-moving side-channels are present in this reach.	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]	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement	Robinson Project Two Rivers Project

4.4.8 Reach 8 Restoration Strategy

Overall ecological function	**Moderate-to-High**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 4 of 11 REI metrics are at risk or unacceptable. Mostly at risk conditions except for Large Wood, which is unacceptable.
Trajectory if no action taken	**Improve**
	Some floodplain clearing and road impacts at downstream end. Passive recovery of riparian function expected due to maturing vegetation.
Recovery potential	**High**
	Few significant human features impairing fundamental processes. Public land expected to offer continued protection.
Restoration objectives	**Target conditions in Table 24**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 24 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Habitat reconnection via infrastructure modification** **Placement of structural habitat elements** **Off-channel habitat enhancement** **Riparian restoration**
	Actions fall in the Restoration and Enhancement categories.
Projects & Prioritization	**Ballard Project (Tier 3)**
	Reach 8 has relatively little restoration potential due to the existing mostly undisturbed condition and challenging access to the upper portion of the reach. There is one project identified, the Ballard Campground Project. It is Tier 3 due to existing relatively high functioning habitat and moderate fish use.

Table 24. Reach 8 Restoration Objectives, Action Types, and Projects.

Reach 8 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	50-80% species composition, seral stage, and structural complexity are consistent with potential native community. 100% small tree 90% canopy cover Human disturbance is located within approximately 4.1% of the floodplain. 1.9% of the 100 ft riparian buffer has been cleared. Disturbance is located in the downstream portion of this reach and includes roads and cleared areas associated with the campgrounds.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	Riparian Restoration	Ballard Project
Floodplain Connectivity	This reach is naturally laterally constricted by terraces and hillslopes on both sides of the channel and has little natural floodplain throughout the entire reach. 1.32 mi/mi^2 of road 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 <2mi/mi^2 road density in the floodplain [adapted from REI]	Habitat Reconnection via Infrastructure Modification	Ballard Project

Reach 8 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	This reach is naturally laterally constricted by terraces and hillslopes on both sides of the channel throughout the entire reach. Historic channel location has not moved considerably, therefore the rate of channel migration has not changed substantially.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Habitat Reconnection via Infrastructure Modification	Ballard Project
Vertical channel stability	No measurable trend of aggradation or incision and no visible change in channel planform.	No measurable trend of human-induced aggradation or incision [adapted from REI]	None Identified	None Identified
Pools	Pool frequency is low and pools have minimal cover. Only two large pools (>3 ft deep) are present in this reach. Pools per mile = 1.4 2% pool habitat 2 pools > 3 ft deep	~9 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	Placement of Structural Habitat Elements	Ballard Project
Large wood and logjams	57.5 M-L pieces / mi 1.8 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	Placement of Structural Habitat Elements	Ballard Project

Reach 8 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	5% side-channel habitat. Four side-channels were present in this reach. Though only one was classified as fast-moving, it was the longest side-channel at 1,740 feet, with all other slow-moving side-channels totaling only 550 feet.	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]	Habitat Reconnection via Infrastructure Modification Off-Channel Habitat Enhancement	Ballard Project

4.4.9 Reach 9 Restoration Strategy

Overall ecological function	**High**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. All REI metrics rated as adequate. Habitat quality is generally high.
Trajectory if no action taken	**Improve**
	Passive recovery of riparian and floodplain function expected due to maturing vegetation.
Recovery potential	**High**
	No significant human features impairing fundamental processes. Public land expected to offer continued protection.
Restoration objectives	**Target conditions in Table 25**
	Reach 9 has very little restoration potential due to the existing mostly undisturbed condition and challenging access. No projects were identified. Existing and target conditions are provided in Table 25 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**No projects identified**
	Public land expected to offer continued protection.
Projects & Prioritization	**No projects identified**
	Public land expected to offer continued protection.

Table 25. Reach 9 Restoration Objectives, Action Types, and Projects.

Reach 9 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Riparian condition	50-80% species composition, seral stage, and structural complexity are consistent with potential native community. 100% small tree (due to recent fire and landslides) 60% canopy cover There is no human disturbance within the floodplain or 100-ft riparian buffer in Reach 9.	At least a 100 ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy closure in the riparian zone. [REI]	None Identified	None Identified
Floodplain Connectivity	This reach is naturally laterally constricted by terraces and hillslopes on both sides of the channel and has little natural floodplain throughout the entire reach. There are no human features that further restrict connectivity besides an old bridge abutment. 0 mi/mi^2 of road 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 $<2 mi/mi^2$ road density in the floodplain [adapted from REI]	None Identified	None Identified

Reach 9 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Bank condition / Channel migration	This reach is naturally laterally constricted by terraces and hillslopes on both sides of the channel throughout the entire reach. Historic channel location has not moved significantly.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	None Identified	None Identified
Vertical channel stability	No measurable trend of aggradation or incision and no visible change in channel planform.	No measurable trend of human-induced aggradation or incision [adapted from REI]	None Identified	None Identified
Pools	Pool frequency is low and pools have minimal cover. Reaches have no large pools (>3 ft deep) with good fish cover. Pools per mile = 3 10% pool habitat 3 pools > 3 ft deep	~9 pools/mi. Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Many large pools >3 ft deep with good fish cover. [REI]	None Identified	None Identified
Large wood and logjams	110.2 M-L pieces / mi 4.5 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox and Bolton 2007] ≥ 4 logjams/mi [based on conditions in Reaches 5 and 9]	None Identified	None Identified

Reach 9 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Off-Channel Habitat	4% side-channel habitat. Only four side-channels, half of which are fast-moving, are present in this reach.	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]	None Identified	None Identified

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