Middle Twisp River
Reach Assessment & Restoration Strategy

SUBMITTED TO
Yakama Nation Fisheries Program

FEBRUARY 2015

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1 Introduction and Background

1.1 OVERVIEW

This assessment evaluates aquatic habitat and watershed process conditions in the Middle Twisp Reach of the Twisp River and identifies habitat restoration strategies. The Twisp River Basin is located on the eastern slope of the Cascade Mountains in Northern Washington (Figure 1). The Twisp River is a tributary to the Methow River, entering the Methow at RM 40.2. The Methow continues down the Methow valley until it joins the Columbia River at the town of Pateros, Washington. The assessment area is the mainstem Twisp River from river mile (RM) 7.8 to RM 18.1.

This reach assessment provides the technical foundation for understanding existing conditions and for identifying restoration strategies and specific restoration opportunities within the Middle Twisp Reach. Conditions are assessed from 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 system. While 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) and the Twisp Watershed Assessment (PWI 2003). 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. Restoration strategies were developed by comparing existing aquatic habitat conditions to target conditions obtained from reference areas and regional habitat thresholds.

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.

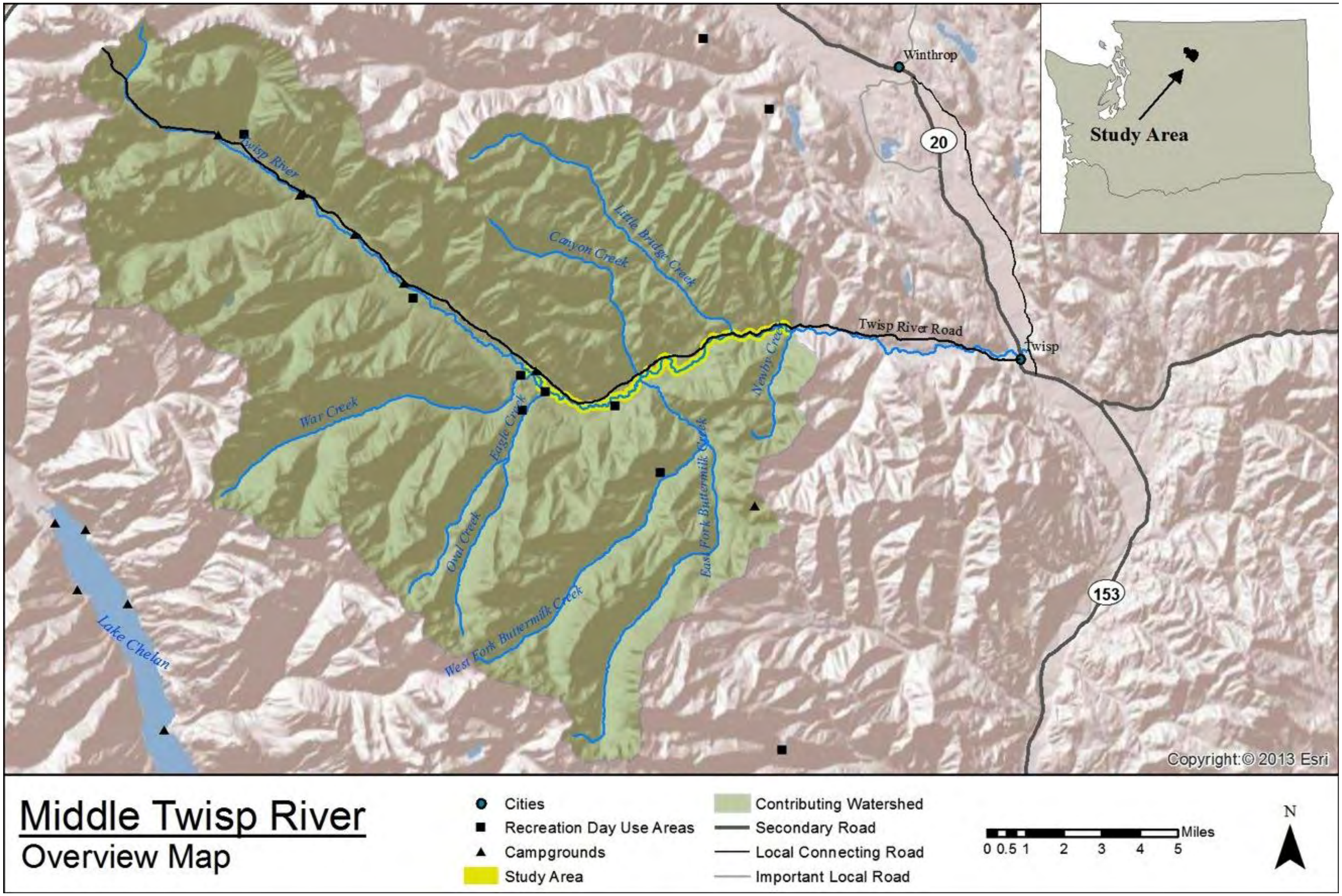

Figure 1. Middle Twisp River study area. The study area extends from RM 7.8 to RM 18.1.

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 2013).

This assessment builds off of a large body of work produced in the basin beginning in the early 1990s and proceeding throughout the 2000s. Assessment and analysis work to date has included physical assessments, biological assessments, and restoration recommendations for portions of the Twisp River. One such previous assessment includes the U.S. Bureau of Reclamation's 2008 Methow Subbasin Geomorphic Assessment, the Methow Watershed Plan (MBPU 2005), the Methow Subbasin Plan (KWA et al. 3004), PWI's Twisp Watershed Assessment, and the USFS's Twisp Watershed Assessment (1995). This assessment included the Twisp River, and overlaps with the USBR's reaches T4 (RM 7.8 to RM 9.8), T5 (RM 9.8 to RM 13.5), and T6 (RM 13.5 to RM 18.1). The Yakama Nation also completed a reach assessment on the Lower Twisp River in 2010 (Inter-Fluve 2010). This Middle Twisp Reach Assessment is the next segment upstream from the lower Twisp study area.

1.3 PURPOSE

The purpose of this assessment is to document and evaluate hydrologic processes, geomorphic processes, and aquatic habitat conditions in the Middle Twisp Reach (RM 7.8 to RM 18.1) of the Twisp River 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 physical habitat conditions and trends
- Identify strategies and actions that address critical aquatic habitat impairments limiting the productivity of local salmonid populations
- Identify strategies and actions that protect and restore the dynamic landscape processes that support sustainable riparian and salmonid habitat
- Coordinate efforts with local landowners, resource managers, and other stakeholders in order to establish collaborative efforts that contribute to the success of restoration strategies

1.4 SALMONID USE AND POPULATION STATUS

Salmonid use of the middle Twisp includes spring Chinook salmon, steelhead, bull trout, westslope cutthroat trout, rainbow trout, and brook trout. Spring Chinook salmon are listed as Endangered under the 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 Middle Twisp. Adapted from NMFS 1998 and Mullen 1992.

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

Spring Chinook salmon, steelhead, and bull trout are the most abundant species documented in the Twisp River and tributaries. A distribution map for steelhead and Chinook is presented in Figure 2. Spring Chinook spawning primarily occurs from RM 10 to RM 27. Spawning occurs in August and September. Juvenile rearing occurs year-round throughout the lower river downstream of RM 27. Steelhead trout use the entire Twisp River for spawning, in- and out-migration, and rearing. Spawning occurs March through May and juvenile rearing occurs year-round. Bull trout use the upper Twisp River from near RM 15 to RM 29 for year-round rearing, foraging, and over-wintering. Most bull trout spawning occurs between RM 22 and RM 29 in September and October (USBR 2008, App F).

The Twisp River has suitable spawning gravel throughout the mainstem and many of its tributaries, but the upper portion of the river provides higher quality spawning habitat due to less channelization, confinement, and bank hardening. Large wood in the upper Twisp River also contributes to higher quality rearing and spawning habitat, with more cool-water refugia and cover for adults and juveniles.

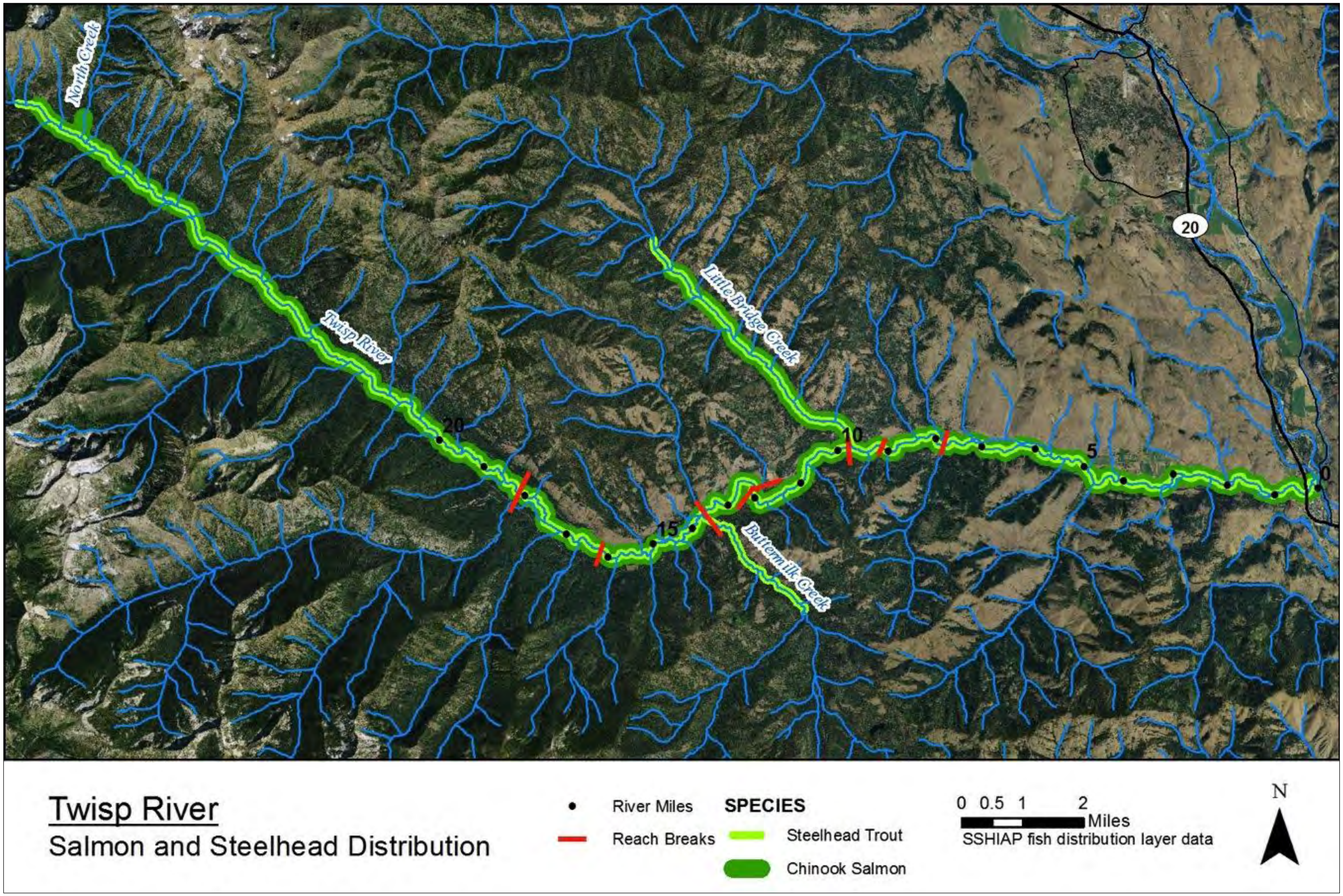

Figure 2. Chinook salmon and steelhead trout distribution throughout in the Twisp River and major tributaries.

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 Middle Twisp Reach Assessment addresses 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 needs of the listed species. Objectives that apply to areas outside the study area or that are outside the scope of this plan are not included. A list of regional objectives (applicable to all streams in the Recovery Planning area) is 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 Twisp River Basin is located in Okanagan County in North Central Washington State on the east side of the Cascade Mountains within the Columbia Cascade Ecological Province. Headwater drainages originate in the far western portion of the divide in North Cascades National park. The total catchment area is 246 square miles. The study area includes RM 7.8 to RM 18.1. The catchment area contributing to the downstream extent of the study area (7.8) includes several small drainages such as War Creek, Eagle Creek, Oval Creek, Canyon Creek, Buttermilk Creek, Little Bridge Creek, and Newby Creek.

Six distinct geomorphic reaches were delineated within the study area (Figure 3). Reach delineation was based on basin size (i.e. major tributary confluences), valley confinement, underlying geology, channel gradient, and channel type (e.g. dominant bed morphology). Reach delineation was initially conducted using remotely available data (e.g. aerial photos, LiDAR, and geology maps) and was field-verified during surveys.

2.2 GEOLOGY

This section provides a brief overview of geology; more information on the geologic setting and history of the study area is provided in Appendix D.

The Twisp River Basin is located within the eastern portion of the Northern Cascades geologic province. Within this province, the Twisp River lies within the Methow Terrane. This terrane is a combination of sandstone and shale sediments left behind by the Methow Ocean, which covered today's Methow valley region 200 to 100 million years ago. The terrane also contains traces of riverine deposited sedimentary rocks (tributaries of the Methow Ocean) as well as volcanic rocks deposited during the Cretaceous period (100 million years ago) (USGS 2004).

Fault systems in this region create topographical and hydrographic divides in the Middle Twisp River study area, and affect the position of the major structural blocks and bedrock elements in the channel. A graben-bounding fault crosses the channel at RM 9, which creates an erosion-resistant "step", or noticeable increase in grade, between RM 9 and RM 10. This location coincides with a major slope break in the long profile of the Twisp with slope being flatter upstream and steeper downstream. This is also the approximate location where glaciation extended down to during the period of last glaciation.

Current channel and valley form, including the Twisp River's U-shaped valley in the upstream portion of the study area, is most directly influenced by consecutive glaciation cycles, the last of which occurred as recently as 9,500 years ago (USBR 2008). During periods of alpine glaciation, ice streams moved from higher elevations in the basin downslope, carving out rock masses and leaving behind glacial features including U-shaped valleys, till deposits (moraines), outwash deposits (terraces), and glacial erratics.

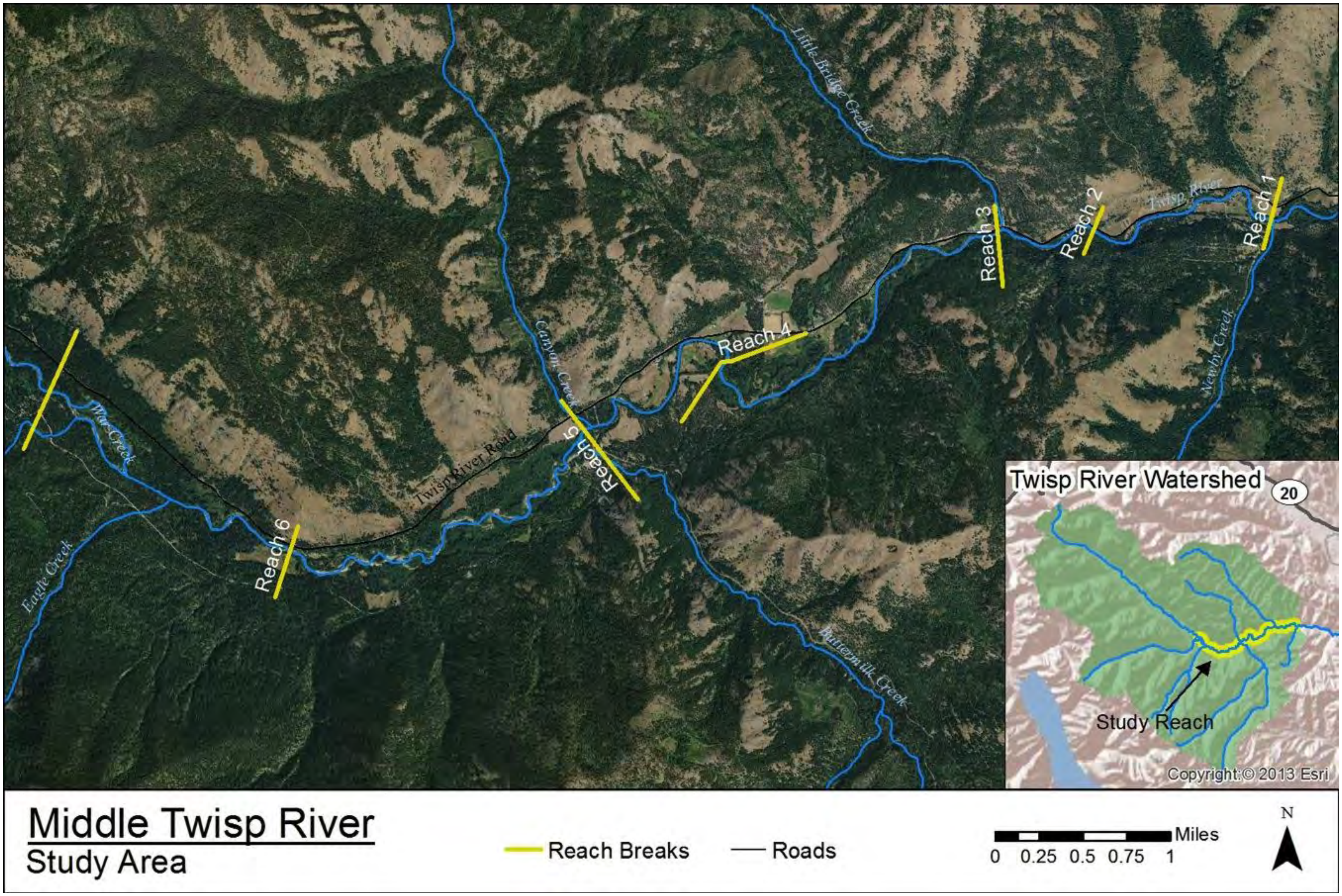

Figure 3. Geomorphic reach breaks in the Middle Twisp Study Area.

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 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 E.

Historical habitat conditions in the study area would have been influenced by the underlying geology (described previously) and the geomorphic setting. The relatively wide floodplain of the Twisp River Basin can be traced to the Pleistocene era (approximately 2.5 million –11,700 years ago), when the climate in the area was cooler, there were higher annual precipitation volumes, and glaciers dominated the landscape. High volume flooding resulted in mass-wasting deposits and alluvial fan inputs that deposited large amounts of material into the system. Following the Pleistocene was a warmer, drier climate cycle during which glaciers retreated, and the channel was no longer filled with high volumes of water to span the valley floor. Thick glacial deposits (glacial terraces) from the upstream extent of the study area to RM 10 were left behind. As the now 'underfit' Twisp River attempted to cut through its wide channel bed, lateral channel migration was limited by bedrock outcrops, mass-wasting deposits, and alluvial fan inputs from contributing drainages throughout the study reach.

Historical habitat conditions within the study area would have varied depending on the specific geomorphic conditions within each reach. In general, the confined reaches (Reaches 1 and 2) would have had high lateral and vertical stability. Due to their natural confinement, these reaches have likely changed the least compared to historical conditions, since modern human alterations such as bank armoring only have limited impacts on channel processes such as flooding and channel migration. The moderately confined reaches (Reaches 3, 4, and 6) would have had greater complexity, with more off-channel habitat, pools, log jams, and gravel deposits for spawning. Much of Reach 3, which is now considered moderately confined, would have been unconfined historically due to the absence of human confinement. The unconfined reaches (Reach 5 and historically Reach 3) would have had the most complex habitat, with extensive split flow conditions, connected off-channel wetlands, many large log jams, variable-aged riparian communities, abundant pools, and abundant spawning gravels.

As with many other Pacific Northwest river systems, large wood would have been one of the primary drivers of geomorphic form and process, and would have provided instream habitat availability and complexity. The sizes and species would have been variable, depending on the disturbance history, but likely ranged from 500-year-old trees to smaller hardwoods (USBR 2008).

Recruitment would have occurred via chronic (i.e. single tree) mortality as well as large-scale disturbances. The unconfined reaches would have recruited wood via lateral and transverse scrolling of the channel, whereas recruitment in the more confined reaches would have occurred primarily through single-tree mortality. Retention of large wood in rivers is correlated with characteristics of the wood itself and the stream size and complexity. The larger wood of the era likely would have been retained, forming large jams. In addition, the greater channel complexity would have helped in not only retaining wood, but would have promoted both geomorphic and habitat functions including creation of pools, sediment retention and sorting, creation of mid-channel vegetated islands, and providing cover and complexity for fish.

2.4 HUMAN DISTURBANCE HISTORY

This section provides an overview of human disturbance history; more information is provided in Appendix F.

Euro-American settlement began in the 1880s, sprouting three major industries that became the backbone of the economy and heavily impacted the land and water of the region: mining, agriculture and grazing, and timber harvest. Fire suppression and direct habitat alterations related to settlement have also heavily impacted the area.

The Methow Valley mining rush began in 1886 (Smith 2013). Mining likely impacted the Twisp River by altering the hydrologic and sediment regime via the removal of instream gravels, diversion of water, and deposition of mining waste in the channel and floodplain.

Agriculture and grazing were first documented in the region in 1889. By World War 1, it's estimated that over 75,000 sheep were grazing the headwaters of the Twisp River (McLean 2011). Cattle and sheep grazing resulted in localized soil compaction, bank erosion, and loss of riparian understory seedlings and shrubs. One of the most significant of the agricultural impacts, however, was water diversions, which began in the early 1900s and resulted in significant fish mortalities until the 1930s when screens were required at diversion points.

Timber harvest began in the region in the 1880s to clear land for farming and grazing (USBR 2008). It continued until the 1970s when the US Forest Service shifted logging policy to focus on salvage operations following wildfires (MVCC 2000). Overall, logging in the upland and valley floor impacted the hydrologic and sediment regime by increasing the number and scale of landslides and debris flows. In the lowlands, removal of riparian vegetation led to a loss in channel functions including streambank stability, floodplain hydraulic roughness, nutrient dynamics, moderation of stream temperature (i.e. via stream shade), and large wood recruitment.

Fire suppression, which began in 1911, has altered the fire regime and has increased the risk of moderate to high intensity burns. It has also shifted the vegetative composition from more open stands of fire-tolerant species (primarily ponderosa pine) to higher density stands of less fire-tolerant species (primarily Douglas fir). The result is fewer large trees in the riparian zone that can provide important geomorphic and habitat functions.

Human disturbances since the 1950s have resulted in significant impacts to sediment, wood, and hydrologic processes. Much of the private property has undergone vegetation clearing, floodplain grading, and residential development (Table 2). Flood mitigation practices of the mid- to late-1970s led to removal of native substrate and 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 was 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 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	3.4 mi/mi^2
Public Land	31.3%
Private Land	68.7%
Portion of Channel with Levees and Bank Armoring	27.5%
Developed and Cleared Land	18.8%

2.5 HYDROLOGY

The Twisp River drains 245 square miles of the eastern Cascades. All of the runoff generated from the Twisp River drainage basin empties into the Methow River near Twisp, Washington. Dominant hydrologic patterns are driven by precipitation in the form of snow and subsequent spring snowmelt. Peak runoff usually occurs from April to August, with the highest rates typically in June (Figure 4). Stream discharge typically returns to baseflow by September. Mean daily flow is 268 cubic feet per second and the mean annual precipitation is 43.1 inches (USGS 2013).

Precipitation amounts vary with elevation and distance from source areas. In the higher elevation areas of the basin, which top out at 8,780 feet, average annual precipitation is 65-70 inches falling mainly as snow. The downstream end of the study area is at an elevation of 1,600 ft. Tributaries in the study area include Myer Creek (RM 7.82), Coal Creek (RM 8.5), Little Bridge Creek (RM 9.78), Canyon Creek (RM 13.86), Lime Creek (RM 15.45), Scaffold Camp Creek (RM 15.86), Eagle Creek (RM 17.14), War Creek (RM 17.42), and a number of unnamed tributaries and ephemeral drainages.

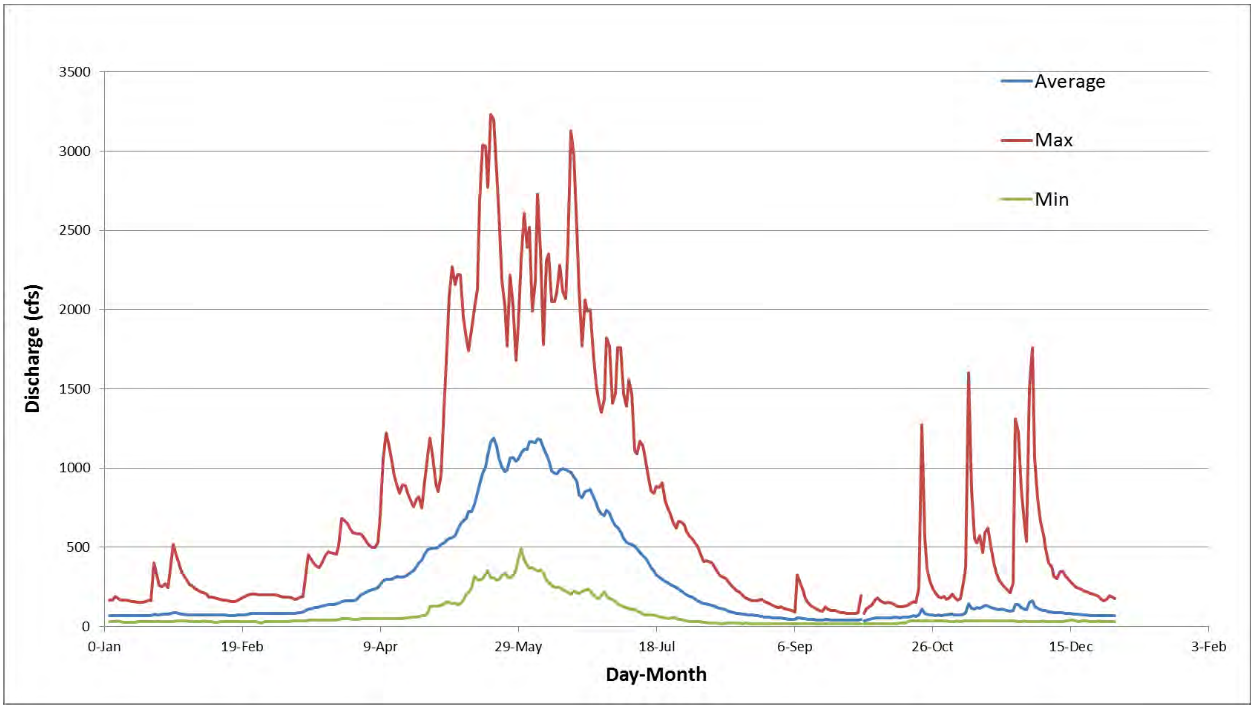

Figure 4. Average, maximum, and minimum values of average daily flows for the period between 10/1/1989 to 9/30/2013 (as measured at USGS gage number 12448998).

The timing (month) of annual peak flows from this gage is plotted in Figure 5. These data show that the flood regime is strongly influenced by spring snowmelt; out of 23 total peaks in the record, 22 of them have occurred in May and June, which is typical of rivers in the region.

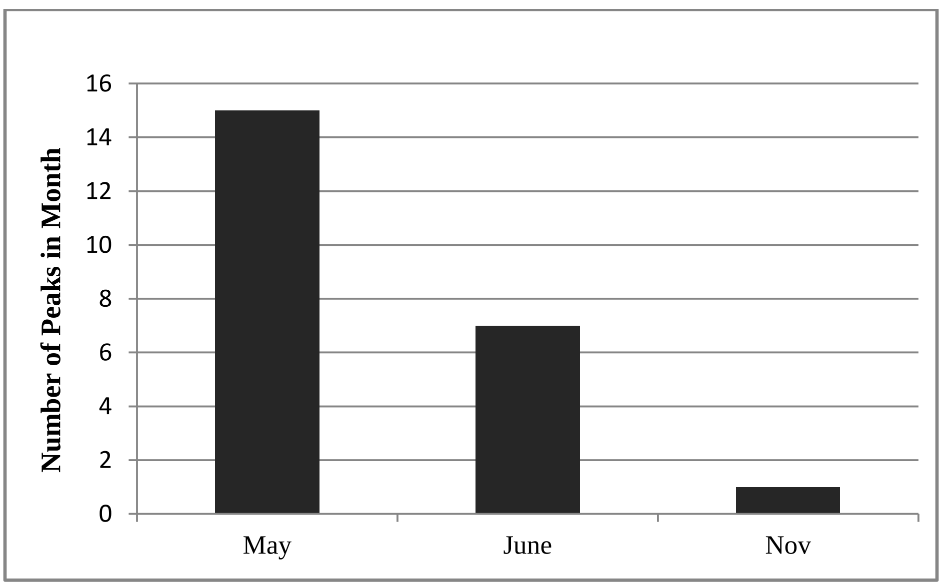

Figure 5. Month of occurrence for annual peak flow events recorded at the USGS gage on the Twisp River (as measured at USGS gage number 12448998).

There is one USGS real-time stream gage on the Twisp (USGS gage number 12448998) located at RM 1.6, with a period of record from 1989 to 2013. A list of the ten largest flood events on record is presented in Table 3. The Twisp River gage was also used to perform a flood recurrence analysis (Table 4).

Table 3. List of 10 largest measured flood peaks since 1989 (USGS gage number 12448998).

Year	Day	Discharge (ft^3/s)
2006	May 19	3230
1991	May 20	3200
1999	June 17	3130
1997	May 16	3040
2008	May 19	2930
2007	June 5	2730
1995	May 31	2610
2011	May 16	2440
1998	May 5	2270
1996	June 5	2170

Table 4. Flood Recurrence Analysis for USGS Twisp River gage (USGS gage number 12448998). Period of record from 1989 to 2013. Data retrieved on 14 November 2013.

Exceedance Probability (% Chance)	1	2	5	10	20	50
Recurrence Interval (years)	100	50	25	10	5	2
Discharge (cfs)	6,390	5,610	4,860	3,890	3,160	2,120

2.6 HYDRAULICS

2.6.1 Background

A hydraulics analysis was used to support this geomorphic assessment and subsequent restoration planning efforts. This analysis utilized available LiDAR data to run a one-dimensional hydraulic model (HEC-RAS version 4.0) for the entire study area (Reaches 1-6). 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.

2.6.2 Methods

Hydraulic Model

The hydraulic model was built using AutoCAD and 2013 aerial photographs to define the stream centerline, bank stations, overbank flowpaths and cross sections. These features were overlaid on a digital elevation model (in this case, LiDAR (Watershed Sciences 2007) from which elevations were extracted for all components of the geometric data set. Cross sections were spaced at a minimum of every 100 feet, with additional cross sections added through areas around meander bends, upstream and downstream of bridges, or where additional resolution was warranted. Once the geometric data was developed, the model was exported from AutoCAD and brought into HEC-RAS 4.0, a one-dimensional water surface profiling program. Steady-flow data was input based on flood frequency data presented in Table 5. Flows ranging from the Q2 (2-year) to the Q100 (100-year) floods were modeled (USBR 2009). Modeled flows are presented in Table 5. For the purposes of this effort, we used Manning's roughness coefficient (n) values ranging from 0.038 to 0.045 for the channel. Manning's values represent resistance to flow, and are applied both to in-channel and overbank (floodplain) areas. Values were based on field observation of median size of channel substrate and calibrated according to photographic comparisons in Barnes 1967, with reference to values provided in Acrement and Schneider (1989). Floodplain roughness varied from 0.05 to 0.08 based on overbank area conditions observed during the field survey.

Table 5. Flood frequency data used in the hydraulic model developed for the inundation analyses based on hydrologic analyses by USBR (2008). Flow change locations are listed by River Mile (RM) and closest hydraulic cross-section HEC-RAS. Discharge units at each reach are cubic feet per second.

Flood Recurrence Interval (Station)	RM 18.12 (62905.56)	RM 17.2 (57498.07)	RM 15.9 (39345.93)	RM 13.7 (39141)	RM 13.6 (38654.12)	RM 9.7 (18608.64)	RM8.4 (11566.3)	RM7.8 (8106.47)
Q2	814	936	1152	1468	1587	1803	1838	1888
Q5	1222	1404	1714	2185	2362	2683	2735	2810
Q10	1512	1737	2111	2691	2910	3306	3370	3461
Q25	1898	2181	2639	3364	3637	4132	4212	4327
Q50	2199	2527	3050	3887	4202	4774	4867	4999
Q100	2511	2886	3473	4427	4786	5438	5543	5694

There are limitations for utilizing LiDAR to model floodplain inundations. The LiDAR data available for the Twisp River is capable of producing elevation data in terrestrial environments, but cannot produce ground elevations below water (i.e. bathymetry) and the data includes 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 using HEC-GeoRAS. HEC-GeoRAS allows for visualization of floodplain inundation by overlaying HEC-RAS modeling outputs on digital terrain models. Georeferenced hydraulic modeling outputs are then displayed in ArcGIS. As described previously, there are limitations to utilizing LiDAR to model floodplain inundation and results of these analyses should not be used for detailed modeling, restoration, or infrastructure planning purposes.

Stream Power Analysis

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

$$\Omega = \gamma Q s$$

Where:

γ	=	the specific weight of water
Q	=	discharge
S	=	Energy Gradient Slope

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

Sediment Competence Analysis

Sediment competence was analyzed to provide an overview of streambed mobility. Streambed sediments will only move when the force of water acting on those sediments is greater than the force keeping those sediments in place. The force of flowing water acting on a sediment particle is the shear stress. The amount of force required to move that sediment particle is the critical shear stress. If the shear stress is greater than the critical shear stress, then the sediment 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.

To evaluate general trends in the ability of the Middle Twisp Reach to mobilize and convey sediment, excess shear ratios were calculated for the study reach. Both the Shields (1936) equation and the modified Komar (1987) equation were used for this analysis. The Komar equation is based on the concept that the larger, grade controlling particles that make up riffle crests govern bed mobility and channel form in riffle-pool streams (i.e. only once these particles become mobile does significant bed re-shaping occur).

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):

$$\tau_{C1} = \tau_{C50}^{*}(\rho_s - \rho) g D_{84}$$

And the modified version of this equation is (Komar 1987):

$$\tau_{C2} = \tau^*_{C50}(\rho_s - \rho) g D_{84}^{0.3} D_{50}^{0.7}$$

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

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

Where:

τ	=	bed shear stress	τ_c	=	critical shear stress (lb. /ft^2)
ρ	=	density of water (lb. /ft^3)	D_{84}	=	84th percentile of grain size (ft.)
g	=	gravity (ft/s)	D_{50}	=	median grain size (ft.)
R	=	hydraulic radius	s	=	slope
ρ_s	=	density of sediment (lb. /ft^3)	τ^*_{c50}	=	critical dimensionless shear stress (Shields Parameter)

Here, τ^*_{c50} was adapted from Julien (1995) and the D84 was utilized to determine the conditions required for most of the streambed to be mobilized and the potential for bed change to occur (Leopold 1992).

A total of 12 pebble counts were conducted at riffle crests to evaluate the stream substrate that is providing grade control. Pebble count data were used to evaluate sediment mobility conditions. Pebble counts were compared to hydraulic conditions of the closest hydraulic cross-section in the model, so data is only a snapshot of sediment mobility conditions, and should not be generalized to the whole reach. Due to the limited quantity of pebble counts and the fact that hydraulic parameters are based on LiDAR, data should only be utilized to understand sediment transport patterns at a conceptual level, and should not be utilized for design purposes.

2.6.3 Results

Floodplain Inundation

Inundation analysis results for the entire study area are presented below in Figure 8 and Figure 9. These maps provide a broad overview of inundation patterns at the study area scale. Higher resolution, reach-scale flood inundation maps are included in the reach-specific sections later in this document. Throughout the confined reaches (Reaches 1 and 2), flows for both the 2-year and 100-year flood events remain largely in-channel. Throughout the moderately confined and unconfined reaches (Reaches 3 – 6), water surface elevations extend beyond the main channel boundaries. In many places these flows activate side channels and inundate floodplain surfaces.

Hydraulics

Results of the 2-year and 100-year flood event hydraulic analyses are presented in Table 6 and Table 7. For both the 2-year and 100-year events, Reaches 1 and 2 had the highest stream power, average shear stress, and velocities, with Reach 2 having the maximum values for all of these parameters. These results are consistent with the higher gradient and confinement of these reaches. Stream power, shear stress, and velocity were low in Reaches 5 and 6, likely due to braided conditions and lower gradient.

Table 6. Hydraulic analysis results for the 2-year flood event.

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
Avg Velocity (ft /sec)	7.56	7.56	5.61	5.82	4.54	5.26
Shear stress (avg)	1.73	1.72	1.00	1.06	0.76	1.01
Stream Power (lb/ft/s)	12.86	13.71	6.04	6.92	3.96	5.91
Incipient Particle Size (in)	8.13	8.32	4.45	5.18	2.32	4.35

Table 7. Hydraulic analysis results for the 100-year flood event.

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
Avg Velocity (ft /sec)	10.58	10.52	8.08	8.11	6.54	7.4
Shear stress (avg)	2.78	2.74	1.68	1.72	1.33	1.65
Stream Power (lb/ft/s)	30.41	30.9	14.59	15.97	10.35	13.4
Incipient Particle Size (in)	13.01	13.26	6.87	7.31	3.68	5.95

Sediment Competence

Although these results cannot be generalized throughout the entire study area, sediment competence analyses suggests that at all but three of the analyzed flows (Reach 2 and 4 using Q100 Komar and Reach 4 using Q2 Komar), the D50 and D84 size sediment is not mobile (Figure 7).

2.6.4 Discussion

The results of the hydraulic modeling indicate that Reaches 1 and 2 have the largest shear stresses and average velocities observed within the study area. These reaches also had the largest estimated stream power during flood events and low rates of floodplain inundation. The confined nature of the channel in this area, combined with the high stream energy and large shear stresses are associated with increased sediment transport capacity, which coincides with the transport nature of Reaches 1 and 2 noted in the geomorphic assessment. Conversely, greater floodplain inundation and lower stream energy was observed in the less confined reaches (Reaches 3 – 6), which is consistent with a more depositional system. Analyzing the hydraulic analysis in combination with the geomorphic and habitat assessments shows that current channel and floodplain complexity increases in reaches with greater floodplain inundation.

Floodplain inundation modeling provided insight into the geologic processes of incision. As this section of the Twisp River has adjusted to the drier contemporary hydrologic regime, it has naturally incised, leaving behind abandoned floodplain terraces, likely formed during and following the period of last glaciation. The hydraulic inundation models of the 100-year flood helped to verify the boundaries between abandoned terraces and modern floodplain surfaces.

The modeling results also provide quantifiable evidence of the impact that human alterations have had on floodplain inundation patterns, stream energy, and incision processes. One area of significant impact is in the river-left floodplain at the upstream end of Reach 5, where there is bank armoring, multiple push-up levees, floodplain grading, and excavated borrow pits. These features have reduced floodplain inundation rates and floodplain flow patterns. They also have impacts on lateral channel dynamics. In the absence of these human impacts, the river-left floodplain in this area would be expected to be well-connected to the river during floods. Instead, the river now has limited access to this surface, which primarily occurs through backwatering from downstream gaps in the levee system or through groundwater connections.

Floodplain inundation modeling also shows the impacts that bridge constrictions have on floodplain processes and channel migration. The bridge crossings at the upstream end of Reach 6 (RM 18.1) and the upstream end of Reach 4 (RM 13.5) are the primary examples of this. 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 around the crossings. The effect of the Reach 6 bridge (RM 18.1) on floodplain inundation patterns is shown in Figure 6.

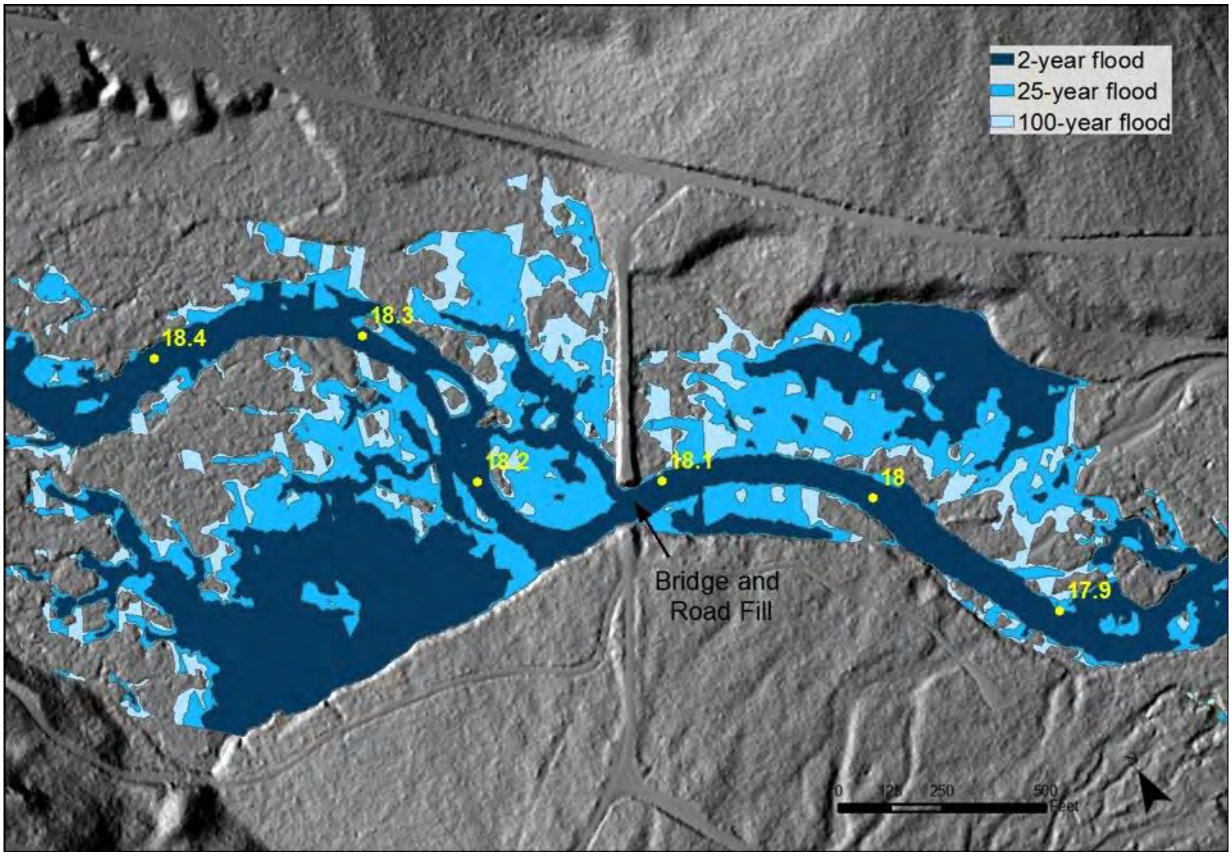

Figure 6. LiDAR hillshade map showing the effect of the Reach 6 bridge (RM 18.1) on floodplain inundation pattern.

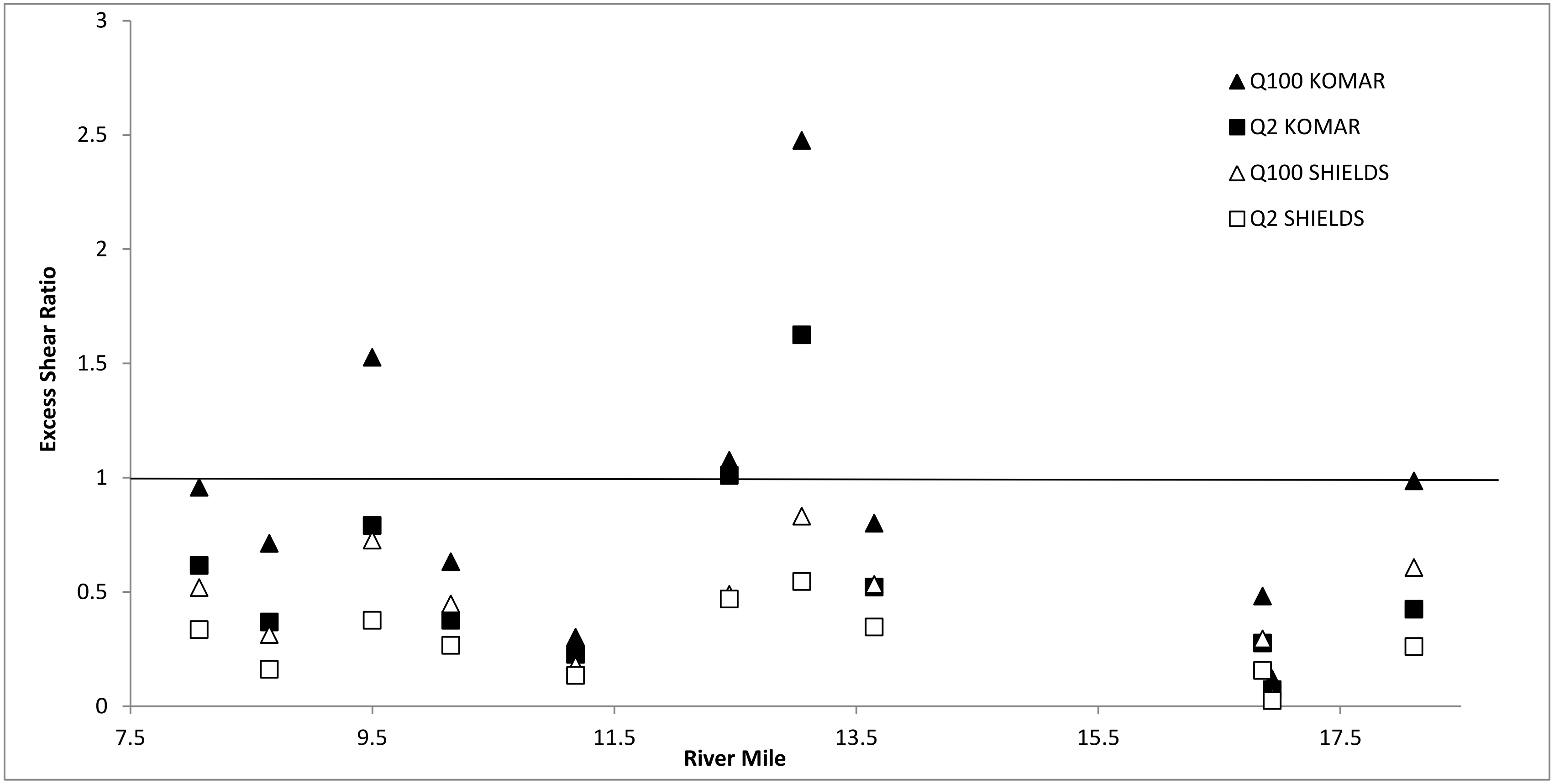

Figure 7. Excess shear ratio based on modeling and pebble count data for select locations in the study area.

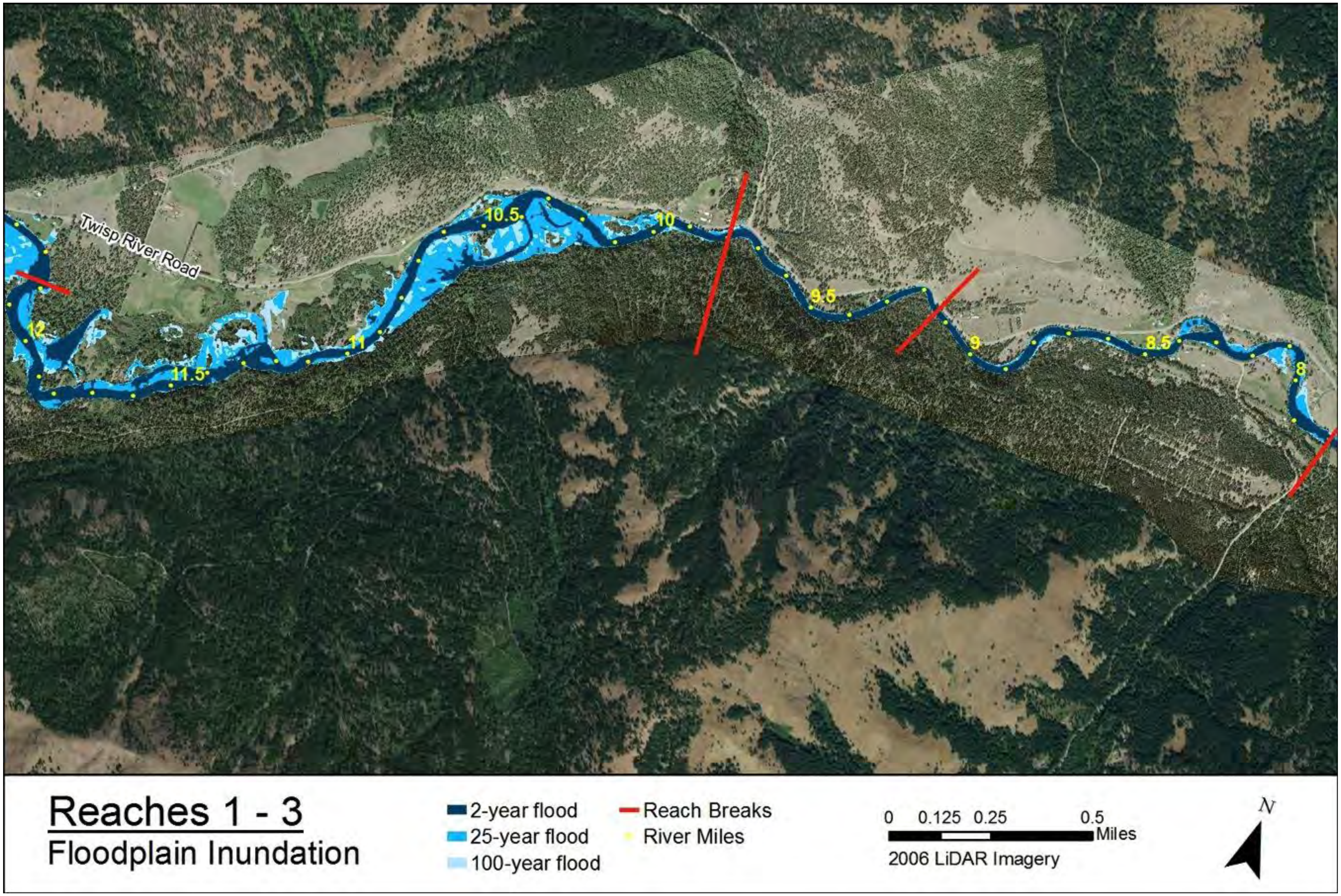

Figure 8. Reaches 1 -3 modeled floodplain inundation for the 2-, 25- and 100-year flood events.

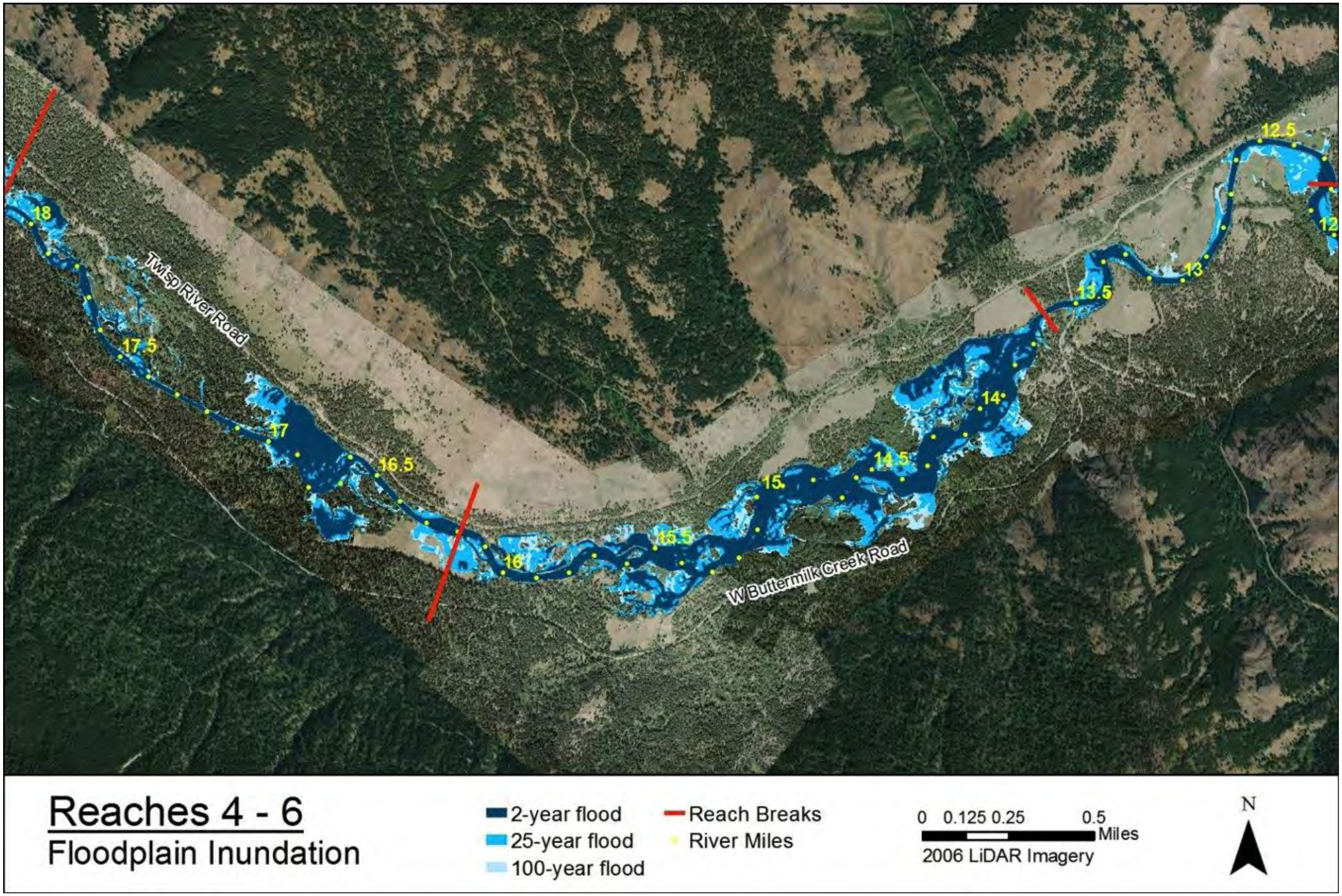

Figure 9. Reaches 4-6 modeled floodplain inundation for the 2-, 25- and 100-year flood events.

2.7 GEOMORPHOLOGY

2.7.1 Valley Morphology

The Middle Twisp River study reach meanders southeasterly with channel sinuosity ranging from 1.11 to 1.49. Valley form is principally governed by historical glaciation cycles and by a number of fault systems in the area. Glacial action within the study area left behind a classic U-shaped valley cross-section at many locations. At the widest areas, maximum valley width exceeds 4,000 feet.

As part of the Methow Subbasin Geomorphic Assessment, the USBR (2008) mapped geomorphic surfaces in the Twisp River valley. This dataset was refined for the study area based on field surveys and hydraulics analysis, which helped to identify active floodplain surfaces. The revised geomorphic surface data is provided in Figure 10, with more detail at the reach-scale provided in Section 3.

Valley morphology within the study area is dictated by bedrock type, remnants of glaciation, and hillslope processes. Upstream of RM 10, the crystalline bedrock lithology is highly erosion resistant, while downstream of RM 10 the underlying lithology is more easily erodible. Adjacent hillslopes and occasional bedrock outcrops provide lateral barriers to channel migration and vertical barriers to incision throughout the study reach. Glacial till and outwash deposits create much of the valley fill within the study area. The Twisp River has naturally incised into these deposits during the late Pleistocene and Holocene. Many terraces are believed to have been created more by decay of remnant ice blocks, rather than retreat of glacial ice sheets (i.e. these are not true moraines) (Waitt 1972). As the river has incised into these behind abandoned terraces, they serve as controls on lateral migration and provide localized sources of sediment.

Alluvial fans continue to play a significant role in determining valley- and reach- scale floodplain and river corridor morphology. Fans of various sizes and configurations have accumulated at the mouths of many of the tributaries on both sides of the valley. In some cases, such as with the large Buttermilk Creek fan, these fans have a large influence on channel position and lateral confinement. Mapping of geomorphic surfaces including alluvial fans, terrace deposits, and the modern floodplain is presented in the reach-specific sections later in this report.

2.7.2 Channel Morphology

The contemporary channel form of the Twisp River is largely influenced by underlying geology and glaciation, with some influence created by anthropogenic hydromodifications. Glaciers extended down into the study reach to RM 10, leaving behind glacial outwash, till, and in-situ terraces. As glaciers retreated and the climate began to become warmer and drier through the early Holocene, water and sediment flux was reduced and the channel incised into valley fill. This has left behind abandoned alluvial terraces, which historically were active floodplain surfaces. This process is similar to the classic channel evolution model described by Schumm et al. 1984, detailing how a channel incises due to changes in flow or sediment regime, then readjusts to a new equilibrium base elevation, and then develops new floodplains inset within the now abandoned terraces.

Today, much of the channel is predominantly confined by these alluvial terraces, glacial features (i.e. till), bedrock, and active and inactive alluvial fans. Mapping of these surfaces is included in the reach-specific sections later in this document. Confinement ranges within the study area between confined (Reaches 1 and 2), moderately confined (Reaches 3 and 4), and unconfined (Reaches 5 and 6). In the moderately confined and unconfined reaches, the channel has migrated laterally to form contemporary active floodplain surfaces.

Bed morphology was characterized as part of the Habitat Assessment (Appendix A). Bed morphology for the study area is predominantly pool-riffle in the less confined sections and plane-bed in the more confined sections. Reach slopes range from 0.57% to 1.16%. Floodprone widths are largest in the unconfined reaches, where gradient is low and the channel is more depositional, as evidenced by increased meanders, side-channels, and abundant gravel bars. Confined reaches flow through areas with narrower active floodplains where channel migration processes are naturally limited by abandoned alluvial terraces, tributary alluvial fans, and occasional bedrock outcrops. In some confined reaches, a small narrow inset floodplain is developing within the channel banks as the channel adjusts to its current equilibrium base level.

Sediment is contributed to the Middle Twisp from alluvial fan contributions, tributaries, occasional mass-wasting processes, near-channel banks, and hillslopes. These banks and hillslopes provide localized sediment from the easily erodible unconsolidated glacial till and alluvial terraces. Sediment contributions from lateral migration and vertical incision are primarily limited to the moderately confined and unconfined reaches. Channel morphologic characteristics are summarized in Figure 11 and Table 8. More detailed geomorphic descriptions for each reach can be found in the reach-specific sections later in this document.

Table 8. Summary of geomorphic and habitat conditions at the valley and channel scale among geomorphic reaches in the Middle Twisp Reach. See the Stream Habitat Assessment (Appendix A) for additional information on how these values were obtained and the methods for the habitat surveys.

	Metric	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
Channel	River Miles	7.80 – 9.14	9.14 – 9.79	9.79 – 12.22	12.22 – 13.6	13.6 – 16.19	16.19 – 18.12
	Gradient (%)	1.14	1.16	0.57	0.69	0.59	0.95
	Sinuosity	1.29	1.22	1.43	1.49	1.34	1.11
	Dominant Channel Morphology	Riffle	Riffle	Riffle	Riffle	Glide	Riffle
	Average Bankfull Width (ft)	82	91	102	80	93	72
	Confinement	Confined	Confined	Moderately Confined	Moderately Confined	Un-confined	Moderately Confined
Floodplain	Average Floodprone Width (ft)	170	117.5	320	120.8	393.1	374
% Habitat Area	Pool	12	1	14	14	23	15
	Glide	11	18	15	15	29	15
	Riffle	74	81	69	69	21	69
	Rapid	0	0	0	0	0	0
	Cascade	0	0	0	0	0	0
	Side Channel	3	0	2	2	18	1
	Braided	0	0	0	0	0	0

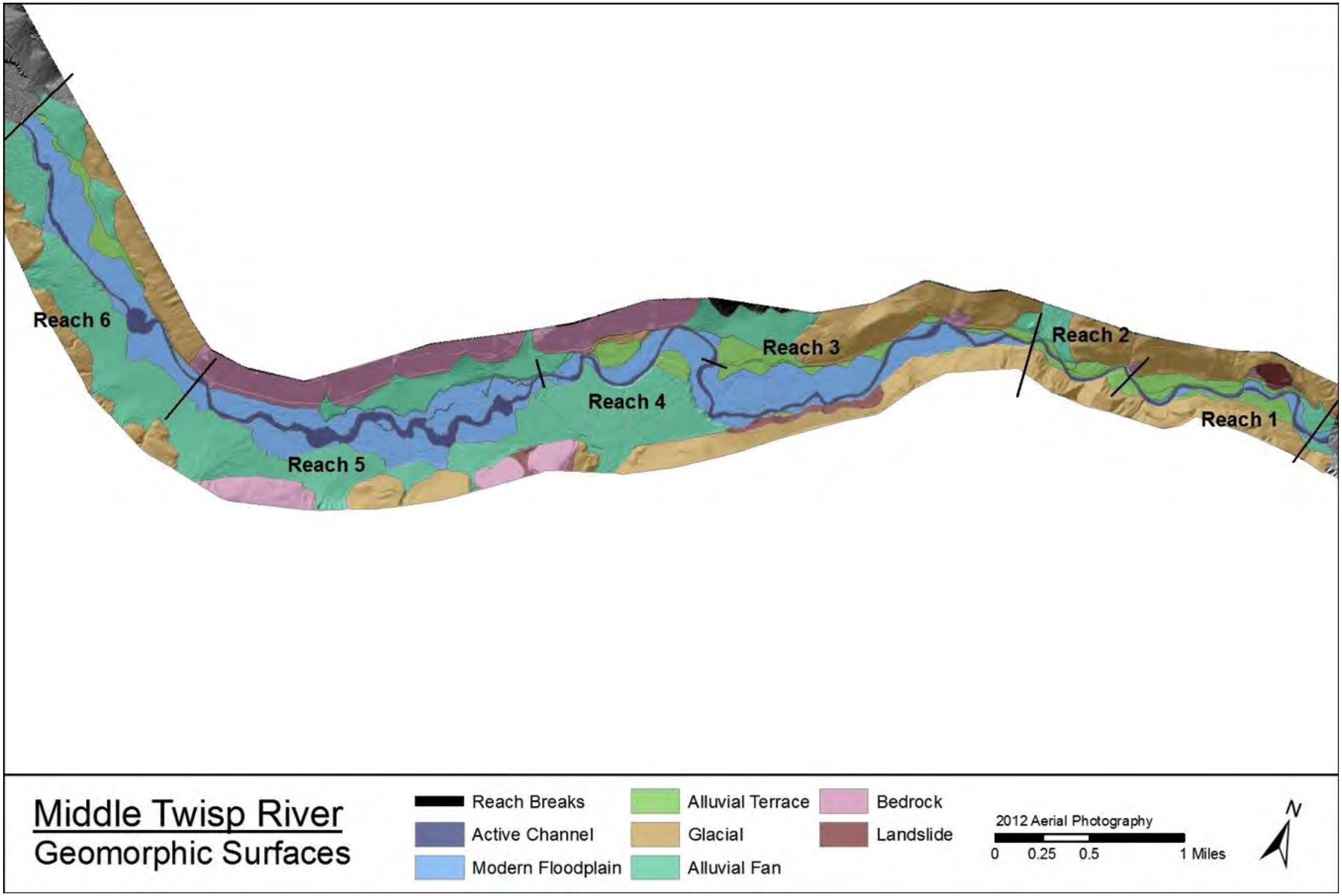

Figure 10. Geomorphic surfaces of the study area. These data are a refined version of the geomorphic surfaces data from USBR (2008), refined for the study area based on field surveys and hydraulics analysis to delineate the modern floodplain surface.

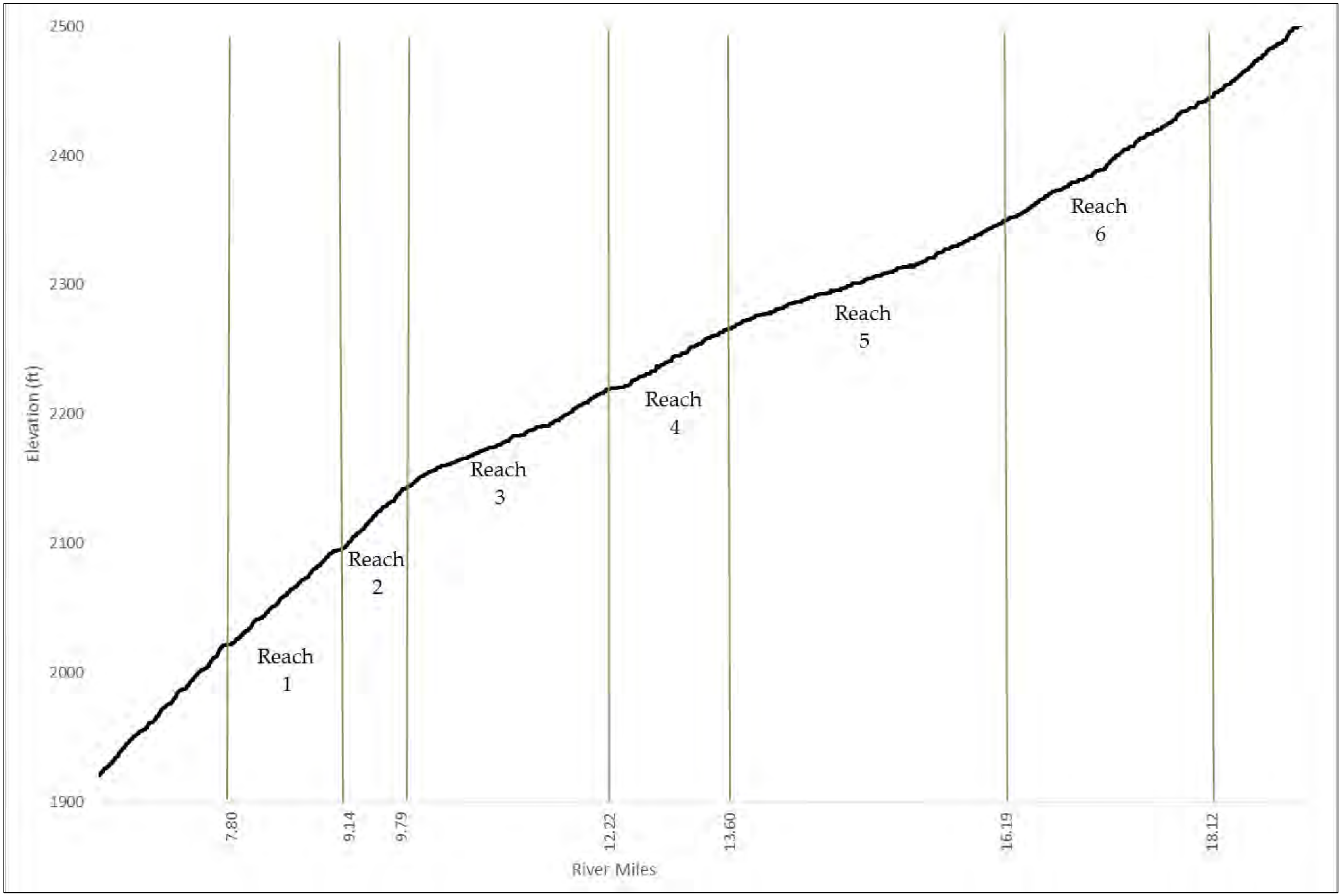

Figure 11. Longitudinal profile of the Middle Twisp Study Area. Elevation data derived from the 2006 LiDAR data.

2.7.3 Large Wood Dynamics

Existing large wood dynamics in the Middle Twisp 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.

Sources

Large wood is still sourced from riparian areas. However, the quantity and quality of contemporary large wood sources have been altered by timber harvest and fire suppression within the study area and within upstream contributing areas. Upland and riparian clearing dating to the late-1800s has and will continue to impact large wood loading for the foreseeable future. Reforested timberlands now dominate the riparian buffers and the trees are considerably smaller than what would be expected under non-harvested conditions. The 2013 habitat survey (Appendix A) classified 97% of the riparian canopy as being dominated by trees less than 21 inches diameter (diameter at breast height). It will be decades or centuries before riparian areas mature to the degree that they are able to provide a large wood recruitment source that resembles historical conditions.

Recruitment

In unconfined reaches, channel scrolling and floodplain avulsions lead to riparian and floodplain tree recruitment. This is particularly evident in the highly sinuous downstream portion of Reach 5 as well as other unconfined portions of the study area (primarily in Reaches 3, 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 and landslides during large flood events. Recruitment processes are mostly intact throughout the study area except for areas where lateral channel dynamics or bank stability have been modified through human alterations. The most common human alteration to LW recruitment in the study area is the presence of the Twisp River Road, which lies adjacent to the channel through much of Reaches 1 and 2 and within portions of the other reaches. 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. Other relatively minor areas of bank armoring associated with streamside residences also limit local recruitment.

Retention

As discussed previously, retention of wood in the channel is a function of both wood size as well as instream complexity, both of which have been affected by the legacy of human alterations. The same alterations to recruitment, described above, also affect retention. These include bank armoring that reduces margin complexity necessary for wood to get 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 may have some effect on contemporary retention processes, especially in the lower portion of the study area (downstream of Little Bridge Creek) 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 96 pieces of wood per mile (>6 inches diam; >20 ft long), on average, only 10 of these pieces were 20 inches in diameter, which means the number of key pieces necessary to initiate jam formation are lacking. 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.

2.7.4 River Ice

River ice on the Twisp is a driver of geomorphic form and process. The Twisp River often forms a frozen layer on the water's surface (surface ice), and occasionally freezes from the bottom up, which is known as anchor ice. Icing events create both localized channel impacts and larger-scale channel impacts. Localized impacts occur to the channel during a freeze event where ice attaches to and then breaks off of stream banks and contributes to bed and bank scour. Larger scale impacts occur when river ice begins to break-up during warming or thawing events. During these events blocks of ice move downstream and build up behind other blocks of river ice or other obstructions (e.g. islands). Areas prone to ice-damming include transitions from riffles to pools, meander bends, and mid-channel bars. Water then builds up behind these "dams" until enough pressure is formed to burst the dam. This has been linked to multiple flooding events, especially when winter freshets and rapid thawing events occur (e.g. Wenatchee World 2005). There is at least one recorded instance of using dynamite to remove ice jams from the Twisp River (Wenatchee World 2009). The frequency of occurrence of ice-related flooding events in the Twisp is fairly well documented, but the frequency of freezing events in the Middle Twisp is less well known. Similarly, the specific extent and geomorphic impact of ice jams, anchor ice, and frazil ice on the Middle Twisp is uncertain.

Anchor and frazil ice has been linked to adverse impacts to habitat in rivers similar to the Twisp, including fish mortalities (e.g. Brown et al. 1994, Simpkins et al. 2000). Anchor ice has been demonstrated to force juvenile and adult salmonids to abandon overwintering habitats, including pools (Brown and Mackay 1995, Jakober et al. 1998, Brown 1999). Anchor ice is more common in areas with limited riparian vegetation, as the moderating impacts of canopy cover limit the likelihood of anchor ice. Complex habitat, specifically the amount of large wood material, has been linked to increased survival of coastal populations of overwintering salmonid juveniles (Quinn and Peterson 1996). Despite these findings, the extent and types of impacts of ice to salmonid populations on the Middle Twisp is uncertain.

Figure 12. Photo of surface ice on lower Twisp River (Stamper 2013).

2.8 HABITAT CONDITIONS

Stream habitat conditions were recorded using the USFS Level 2 stream habitat inventory methods. The survey recorded information on habitat unit composition, habitat unit 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.

Pool frequency ranged from 1.5 to 13.1 pools/mile at the reach-scale and totaled approximately 15% of the total habitat in the study area. Glides were the predominant habitat type at 59% of the total study area, with riffles at 20% and side channels at 6% of total habitat area, respectively. Reach 5 had the greatest area of side-channel habitat with 15% of total habitat area in the reach.

An average of 165 pieces of wood per mile was counted in the study area (>6 inches diameter; > 20 feet long); 70% of these were "small" pieces with diameters between 6 and 12 inches. Wood frequency at the reach-scale ranged from 28 (Reach 2) to 537 (Reach 5) pieces/mile. As discussed previously, the size, availability, and quantity of wood is lower than what would have been expected historically, which has affected instream channel dynamics and habitat suitability for salmonids.

Bed substrate was predominantly cobble (55%) and gravel (34%). Suitable spawning areas were observed throughout the study area, primarily in the unconfined reaches.

Riparian areas were dominated by native riparian forest vegetation, although natural forest fire cycles and past timber harvest have reduced overall stand ages. Residential development and agricultural uses have impacted riparian conditions in many locations, particularly in Reaches 1 – 4. Results for riparian forest stand ages at the study area scale were 13% small tree (9 – 21" diameter at breast height (DBH), 13% each for sapling/pole (5 – 9" DBH), 23% for shrub seedling (1-5" DBH), and 3 % large tree (≥ 21" DBH).

2.9 WATER QUALITY

As of 2012, the Twisp River is listed as a "waters of concern" by the Department of Ecology for temperature. This determination was made based on measurements collected in 1999 at station 'Twisp River at War Creek CG' which exceeded the established criterion. Near the mouth of the Twisp the highest 7-day average daily maximum temperature recorded during the summer exceeded 16°C by about 26% in 2001 and 30% in 2005, with the threshold criterion also exceeded by over 15% at two other locations in those years. More recent measurements show that the Lower Twisp River continues to have high temperatures throughout the summer months; data from 2008 and 2009 continue to show 7-day average daily maximum temperatures with over 15% exceedance of 16°C consistently from mid-July through mid-September at the mouth of the Twisp River (USBR 2008, App I).

In 2001 and 2009, airborne thermal infrared remote sensing surveys were performed for the Twisp River. Comparisons between the longitudinal temperature profiles from the 2001 and 2009 surveys indicate that many of the same cool-water input mechanisms are still in place and act to lessen the downstream warming effect (Figure 13). There is a general warming trend over the 33 miles of the Twisp River as the water moves downstream, as can be seen in the temperature profiles. There are three notable locations of departure from this trend, two of which are located within the Middle Twisp study area (RM 10.08 and 14.48; Figure 13). Cooler water temperatures noted at RM 14.48 (Reach 5) were likely a result of hyporheic flow in the form of several small seeps and a side channel contributing cool water at this location. A second cooling trend was noted between RMs 5.51 and 10.08 during the TIR survey. The decreasing temperature in that section was likely a result of the river channel narrowing into a canyon, increasing subsurface exchange. Both locations also have tributaries entering the Twisp River, which may contribute cooler water and provide for groundwater upwelling and additional subsurface exchange.

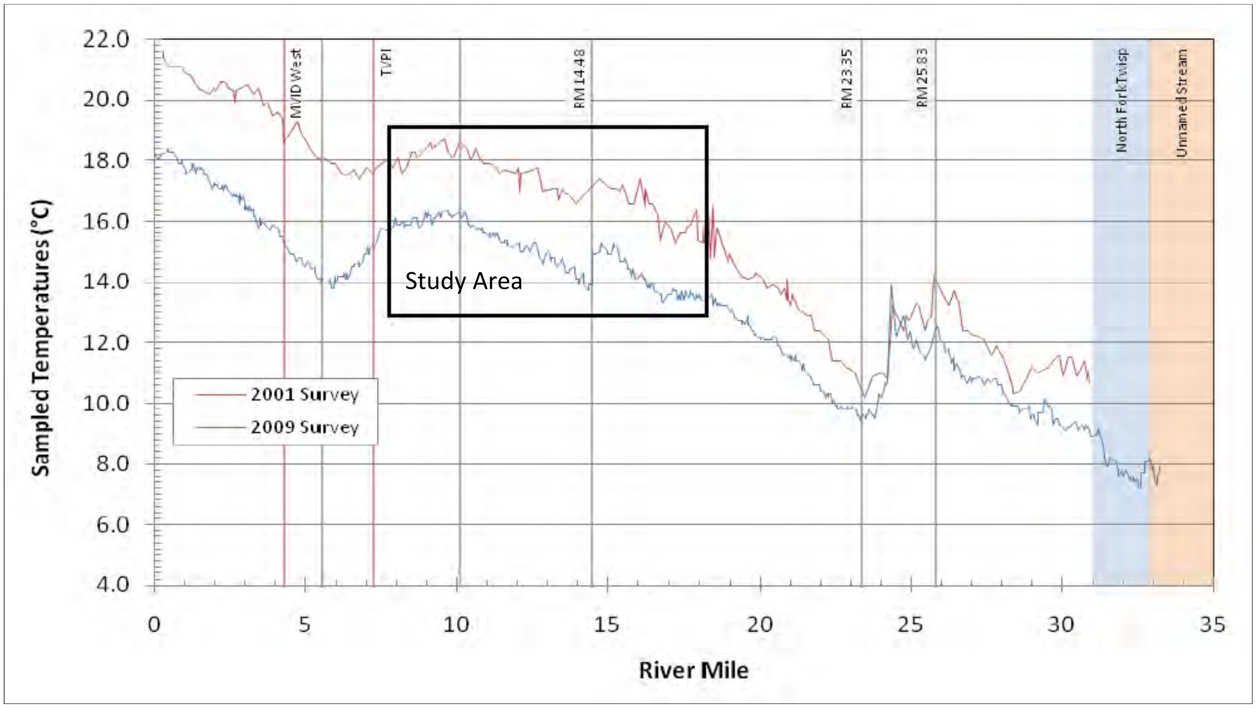

Figure 13. Longitudinal TIR temperature profiles for 2001 and 2009 for the Twisp River from Watershed Sciences, Inc.'s 2009 TIR Report. The temperature discrepancy between the two years was attributed to slightly lower water levels and higher ambient temperature during the 2001 survey compared to 2009.

Water temperature ratings for the Twisp River were developed by the USBR based on NMFS and USFWS salmonid habitat guidelines. Within the Middle Twisp River study area (from approximately RM 7.8 – 18.2), water temperature was given an "At Risk" rating for steelhead rearing and Chinook salmon migration, rearing, and spawning. The lower portion of the Twisp River had a "Not Properly Functioning" rating for steelhead, Chinook salmon, and bull trout rearing, as well as Chinook salmon spawning and migration (USBR 2008, App I). The timing of the temperature increases is also important. High water temperatures throughout the summer months, and particularly in August and September during spring Chinook spawning, may be even more detrimental to the long-term use of the Twisp River as salmon habitat (See Section 1.4 for additional fish use information). Cool water refugia during these warmer months of the year throughout the Twisp River is important for the continuance of spawning and survival of juveniles to their next life stage, as only temporary excursions through water with high temperatures can be tolerated by many salmonids.

Outside of temperature data, there is very little water quality data for the Twisp River; although it is worth noting that there is livestock grazing occurring within the watershed which may impact water quality through nutrient and sediment loading.

2.10 REACH-BASED ECOSYSTEM INDICATORS

This section presents an overview and summary of the REI results (Table 13), which are 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.

There were no fish passage barriers within the study area so each reach was therefore given a rating of adequate for this indicator. For the remainder of the indicators, some general patterns are observed. Reaches in the downstream portion of the study area (Reaches 1-2) were the most impacted reaches in the study area having the highest number of at risk and unacceptable ratings. The upstream reaches (5 and 6) were generally more functional overall with fewer at risk and only one unacceptable rating. Reaches 3 and 4 were intermediate between the upper and lower reaches. Habitat quality and riparian vegetation metrics were the most impaired. For the study area as a whole, at risk was the most common rating (33), followed by unacceptable (17), then adequate (16). Additional detail is provided in Appendix B.

Table 9. Reach-Based Ecosystem Indicator (REI) results. See Appendix B for the REI report.

General Characteristics	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
Habitat Assess-ment	Physical Barriers	Main Channel Barriers	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
Habitat Quality	Substrate	Dominant Substrate/Fine Sediment	Adequate	At Risk	Adequate	At Risk	Adequate	At Risk
	LWM	Pieces per mile at bankfull	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Adequate	Unacceptable
	Pools	Pool frequency and quality	At Risk	Unacceptable	At Risk	At Risk	Adequate	At Risk
	Off-Channel Habitat	Connect-ivity with main channel	At Risk	Unacceptable	At Risk	At Risk	Adequate	At Risk
Channel	Dynamics	Floodplain connect-ivity	At Risk	Adequate	At Risk	At Risk	At Risk	Adequate
		Bank stability/ Channel migration	At Risk	At Risk	At Risk	At Risk	At Risk	Adequate
		Vertical channel stability	At Risk	Adequate	At Risk	At Risk	At Risk	At Risk
Riparian Vegetation	Condition	Structure	Unacceptable	Unacceptable	At Risk	Unacceptable	At Risk	At Risk
		Disturb-ance (human)	Unacceptable	Unacceptable	At Risk	Unacceptable	At Risk	At Risk
		Canopy Cover	Unacceptable	Unacceptable	Unacceptable	Unacceptable	At Risk	At Risk

3 Reach-Scale Conditions

3.1 REACH 1

3.1.1 Reach Overview

Reach 1 extends from RM 7.8 (Newby Creek) to RM 9.14 for a total distance of 1.34 miles (Figure 2). The reach is a naturally confined, single thread channel with a steep gradient (Figure 14). Overall, human alterations have less of an impact on channel dynamics in this reach due to natural confinement. However, some of the most extensive riprap and levees observed in the study area occur in this reach, resulting in disconnection of the already limited floodplain. Much of the floodplain habitat that does exist has been cleared, filled, and graded. Road construction along river-left and clearing for residential and agricultural purposes has resulted in minimal wood available for future recruitment and has a significant impact on riparian vegetation. The road embankment and associated riprap have severely impacted stream bank complexity. The landownership throughout this reach is primarily private with the exception of river-right from approximately RM 8.85 to 9.05, which is Okanogan National Forest (Figure 15).

Figure 14. A representative section of Reach 1 at RM 8.

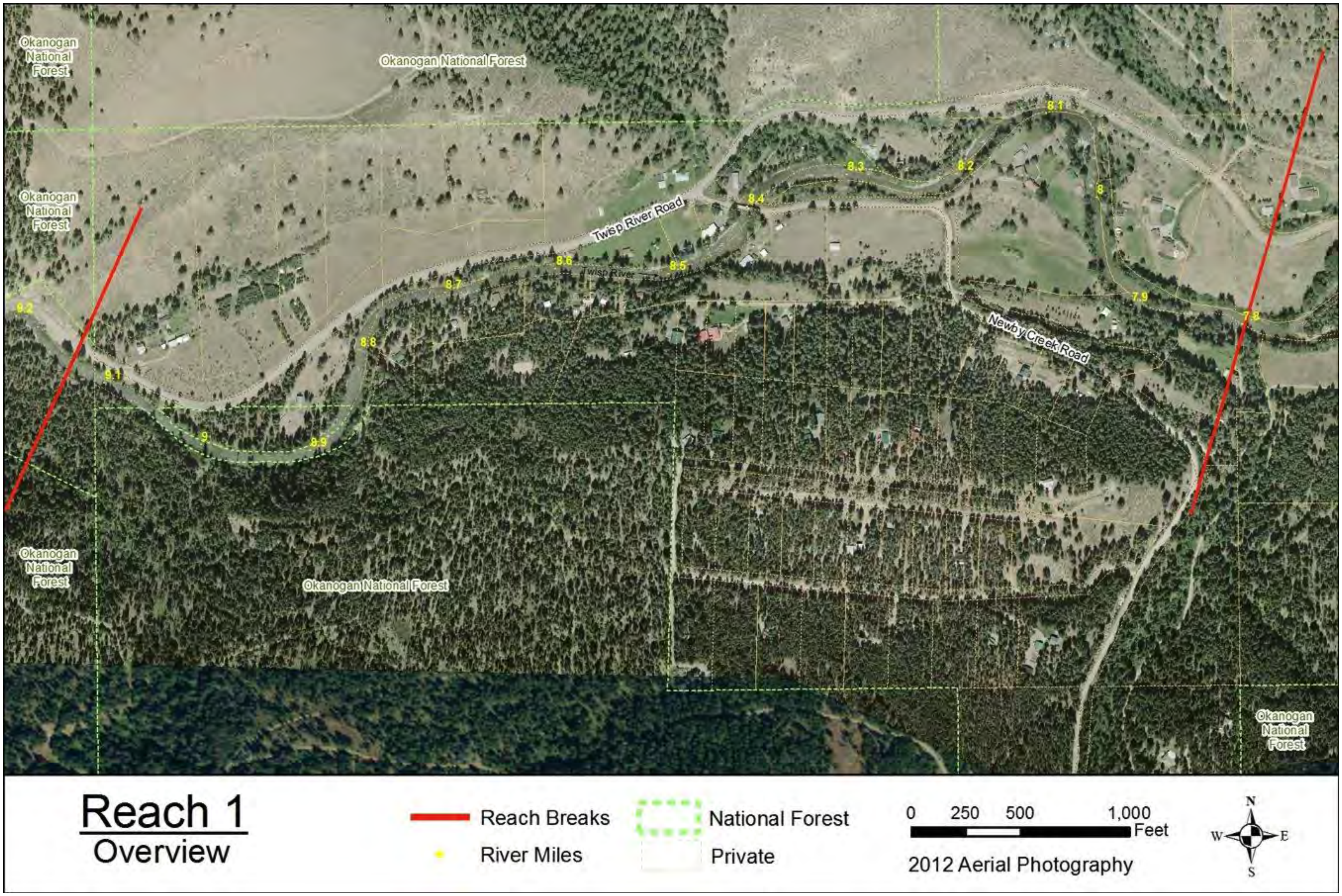

Figure 15. Overview map of Reach 1 showing land ownership.

Table 10: Summary of Reach 1 characteristics.

Metric	Value
Reach Length	1.34 miles
River miles	7.8 to 9.14
Valley gradient	1.38%
Stream gradient	1.14%
Sinuosity	1.29
Dominant Channel Type	Plane-bed
Avg bankfull width	81.7 ft
Avg floodplain width	170 ft
Dominant substrate	Cobble

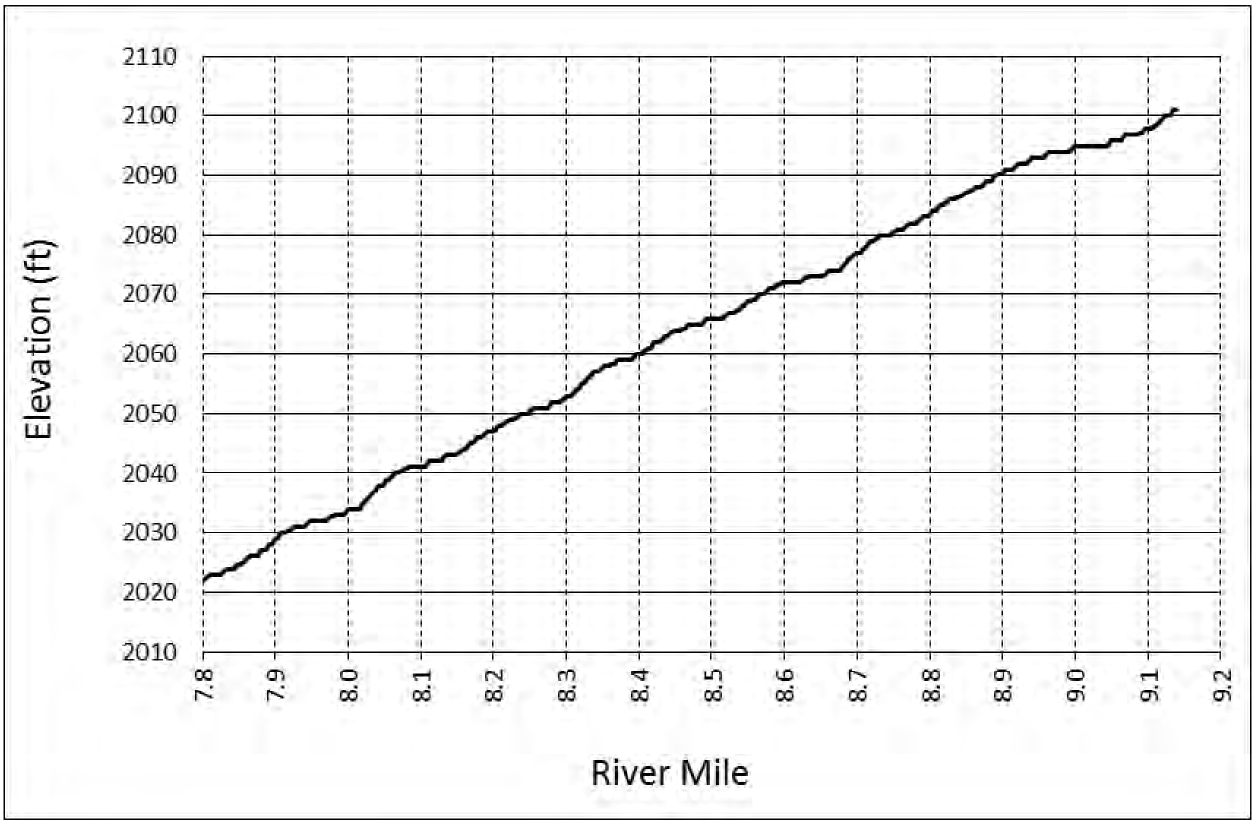

Figure 16. Longitudinal profile of Reach 1. Elevation data is derived from the 2006 LiDAR data and so represents water surface at the time of the LiDAR flight.

3.1.2 River Morphology and Geomorphic Processes

Geology and Landforms

Abandoned glacial and alluvial terraces provide lateral constraints to the river throughout Reach 1, accounting for the reduced floodplain width and single thread nature of the channel. These lateral constraints on the channel, in combination with the steep gradient and low channel sinuosity, result in a boulder-step riffle planform interspersed with long glides. Comparison to a previous habitat survey in 2001 (PWI report, Appendix A) shows that the quantity of pools meeting depth criteria has decreased from 5.2/mile to 2.5/mile, indicating an increase in fast water units within this reach over the past 12 years.

Hydrology

A small tributary enters the channel along river-left at RM 8.4 and provides less than 2% of the total channel flow to the river at this location. The tributary is not a large sediment source to the river. There are few hyporheic flow inputs due to the confinement. There may be hillslope groundwater sources in some areas but the extent of them is unknown.

Floodplain and Channel Migration Zone

The reach has high vertical stability and is naturally laterally constricted by glacial terraces on both sides of the channel with a modern alluvial terrace on the intermediate surface on the river-left. The confinement limits lateral migration and sinuosity and the large substrate observed on the streambed (see Sediment section below) provides vertical stability for the channel. The single thread nature of the channel and lack of lateral migration is apparent when comparing the channel boundaries observed over the historical record (Figure 19).

With the exception of a couple of discrete locations, a majority of the flood events are contained within the channel, including the 100-year event (Figure 18). The lack of floodplain inundation and single thread nature of the channel results in minimal habitat availability, especially in comparison with the braided channels downstream of this reach. Extensive amounts of riprap and numerous levees were constructed within this reach and much of the limited floodplain habitat that does exist has been cleared, filled and graded. The highest amount of human alterations in the study area occurred within this reach, but due to the natural channel confinement, these alterations have less of an impact on channel dynamics and habitat.

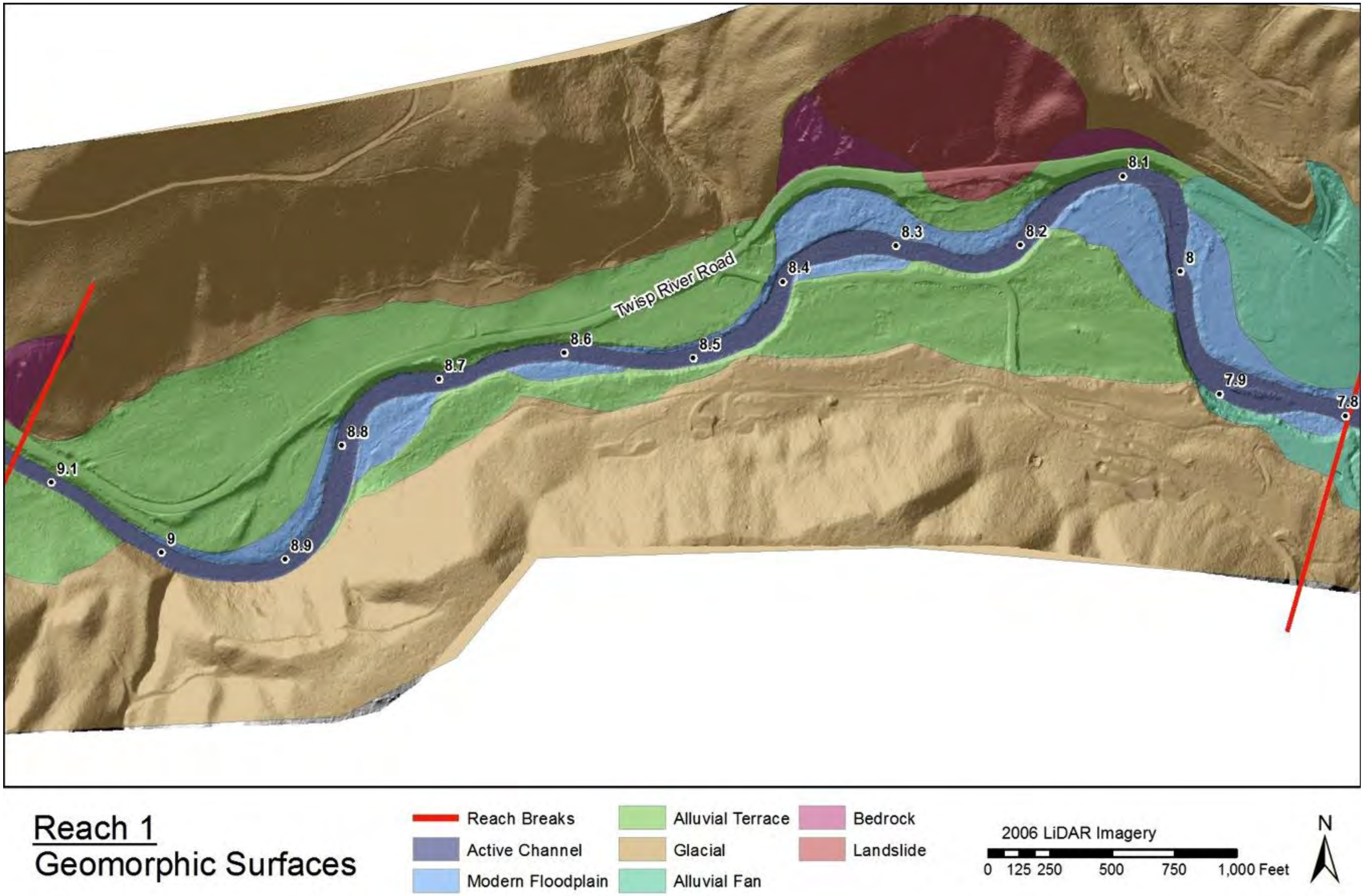

Figure 17. Geomorphic surfaces for Reach 1.

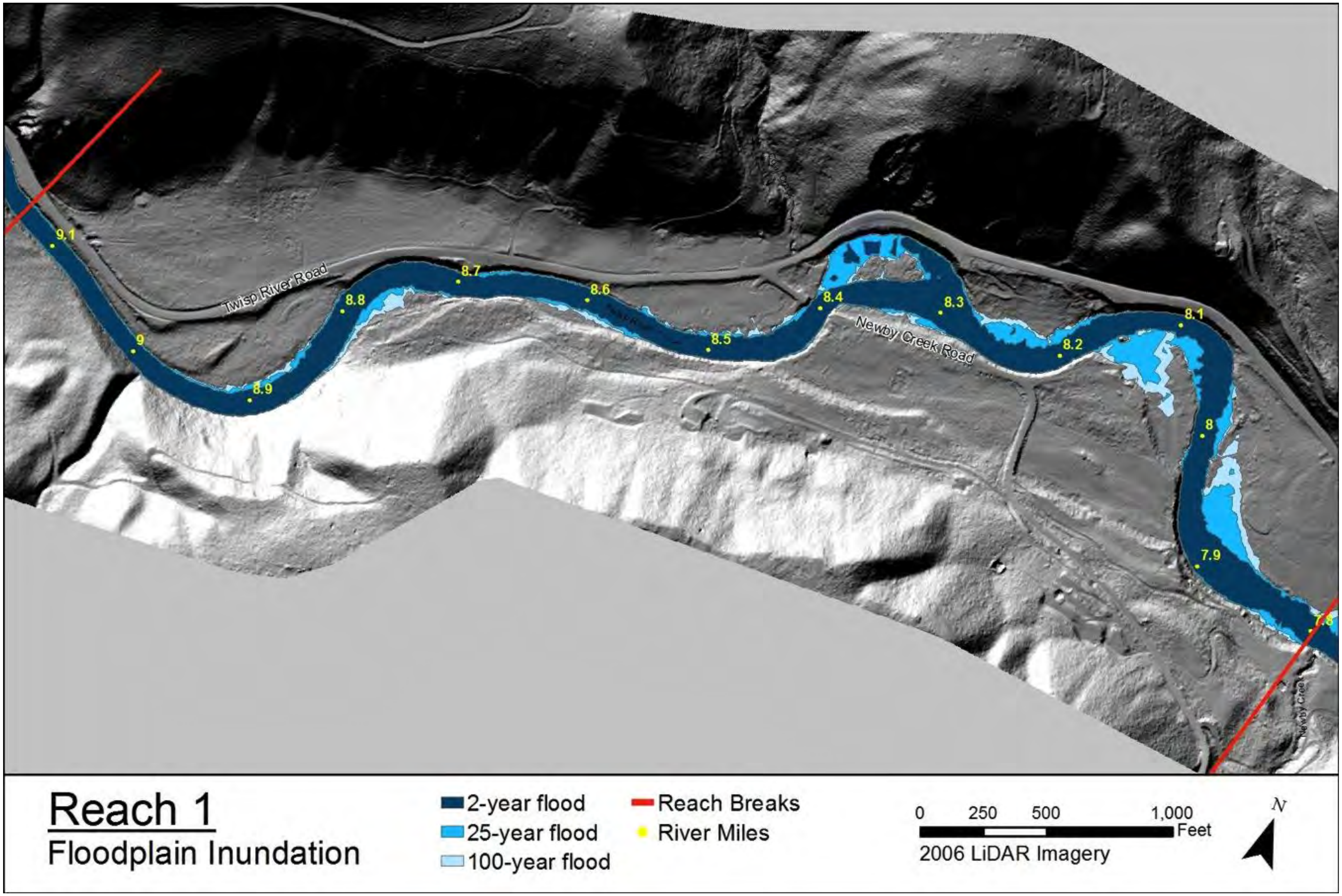

Figure 18: Floodplain inundation mapping for Reach 1

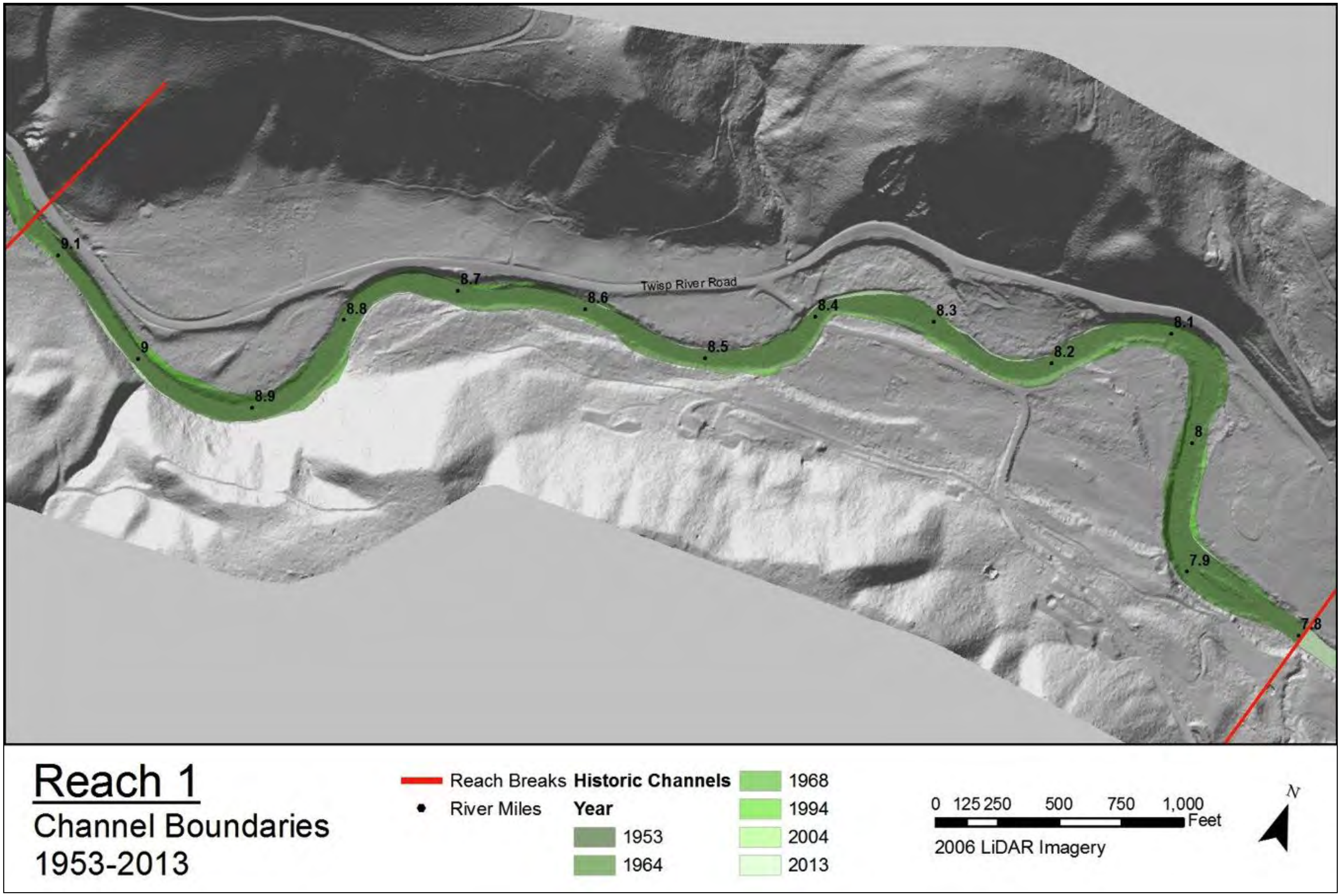

Figure 19. Historical Channel Boundaries for Reach 1.

Sediment

This reach has abundant boulders and large cobble (61% cobble), the majority of which have likely been sourced from hillslopes and glacial lag. The gradient of the reach and lack of accumulation of fine sediment on the majority of the channel bed suggest that most fine sediment is transported through this reach, with the exception of in-channel gravel deposition in some of the glides. Sediment sourcing from the terraces has taken place, resulting in the presence of large boulders within the channel. The colluvial boulders act as large hydraulic roughness and provide the extent of geomorphic and habitat complexity in Reach 1. The boulders create localized scour pools throughout the reach, which in turn provides holding habitat for fish.

Vegetation

The upstream portion of Reach 1 has a high density of riparian vegetation along the south side of the channel with significant reduction of vegetation along the north side of the channel and the downstream portion of the south side of the channel. The majority of the riparian clearing was prevalent on the south side of the river for the first half of the reach, and on the north side of the river for the second half of the reach. Based on the habitat survey, Reach 1 had a variable riparian corridor with a majority of the reach composed of grassland/ forbes (75%) and small trees (25%). Species composition was variable with most of the understory identified as hawthorne, dogwood, and willow; the overstory was largely composed of cottonwood, Douglas fir, and ponderosa pine. The first return LiDAR image indicates that in areas where clearing did not take place, a majority of the overstory was between 25 and 100 feet tall. The channel banks were primarily composed of old growth conifers on the terraces that provide shade to the channel as well as act as a potential source for large wood recruitment to the channel (Figure 20).

Figure 20 Potential for large wood recruitment along river-right terrace at RM 8.5. There are several mature conifers with exposed root masses on the edge of the terrace.

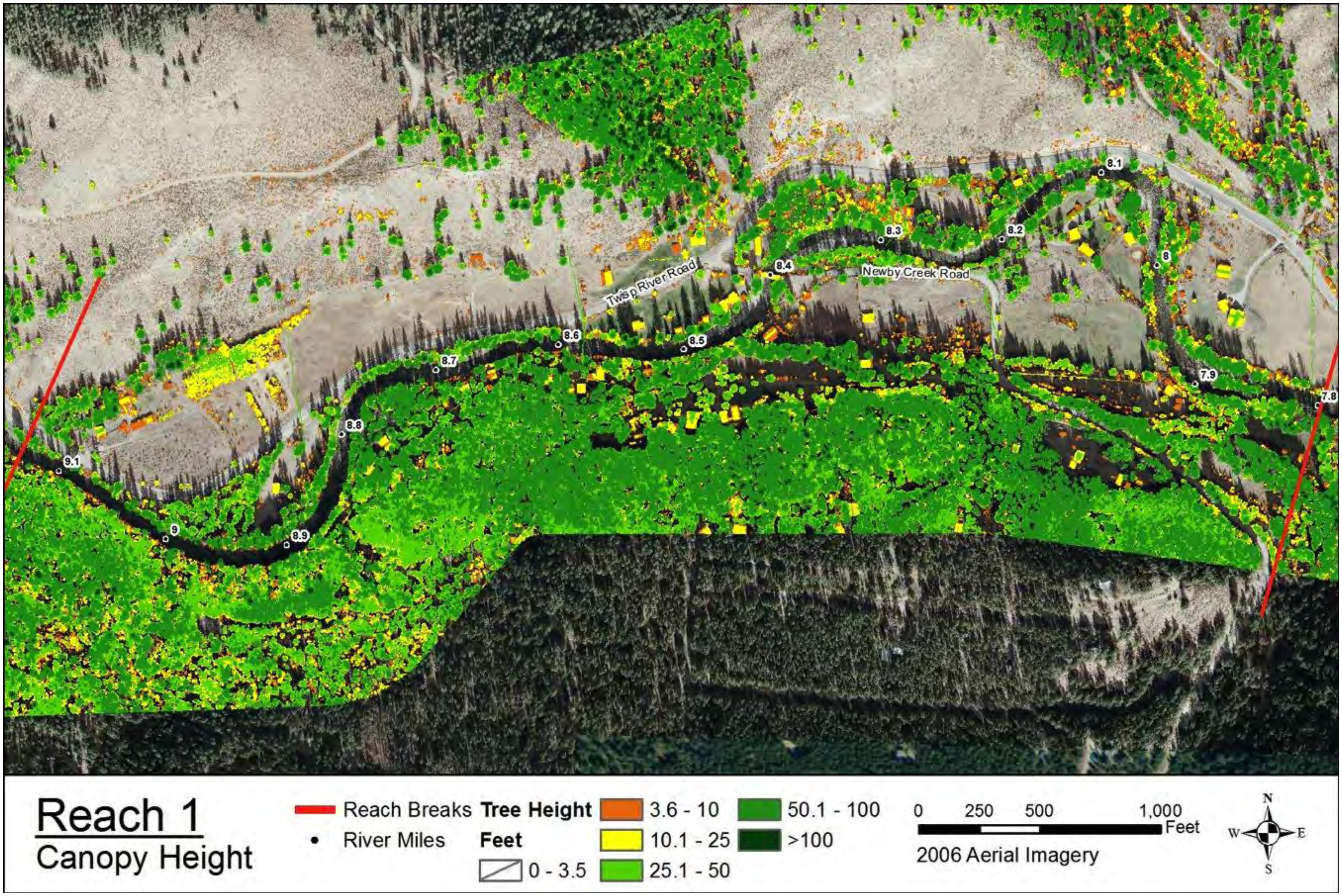

Figure 21. LiDAR first return (highest hit) data for Reach 1. These data show vegetation canopy heights. Buildings and other human infrastructure are also included in this data.

3.1.3 Human Alterations

Significant amounts of human alterations have occurred within Reach 1, with some of the most extensive riprap and levees of the study area (Figure 22). Much of the limited floodplain habitat that exists has been cleared, filled, and graded for residential and agricultural purposes. The construction of Twisp River Road and the associated road embankments and riprap have severely limited stream bank complexity. The riparian impacts are significant and result in minimal wood available for recruitment in the future.

Loss of Already-Limited Floodplain Function

Human alterations to the floodplain have impacted geomorphic processes throughout Reach 1. The majority of channel and floodplain alterations are associated with residential clearing and development (Figure 22). Along the right bank, the riparian corridor has been cleared, the floodplain has been graded and a pushup levee was constructed. These alterations have removed hydraulic roughness, with the potential for accelerated bank erosion as well as disconnecting the active floodplain from the channel.

The roadway construction, embankment creation, and riprap installation that has occurred in Reach 1 impedes stream bank complexity but does not seem to greatly impact natural channel migration, as the channel is naturally confined. Lateral channel dynamics have been impacted by the bridge and its associated abutments at RM 8.4 (Figure 23). The bridge does not have piers in the channel and appears to be appropriately sized, but the riprap along both sides of the channel, up and downstream of the structure, is acting as a lateral constriction to the channel upstream of the bridge. Riprap was also installed to protect the property banks in locations where residential clearing and grading occurred (Figure 22). The use of riprap along those banks, as well as the pushup levee along river-right (RM 8.8), disconnects the river from the floodplain by reducing the frequency and extent of floodplain inundation.

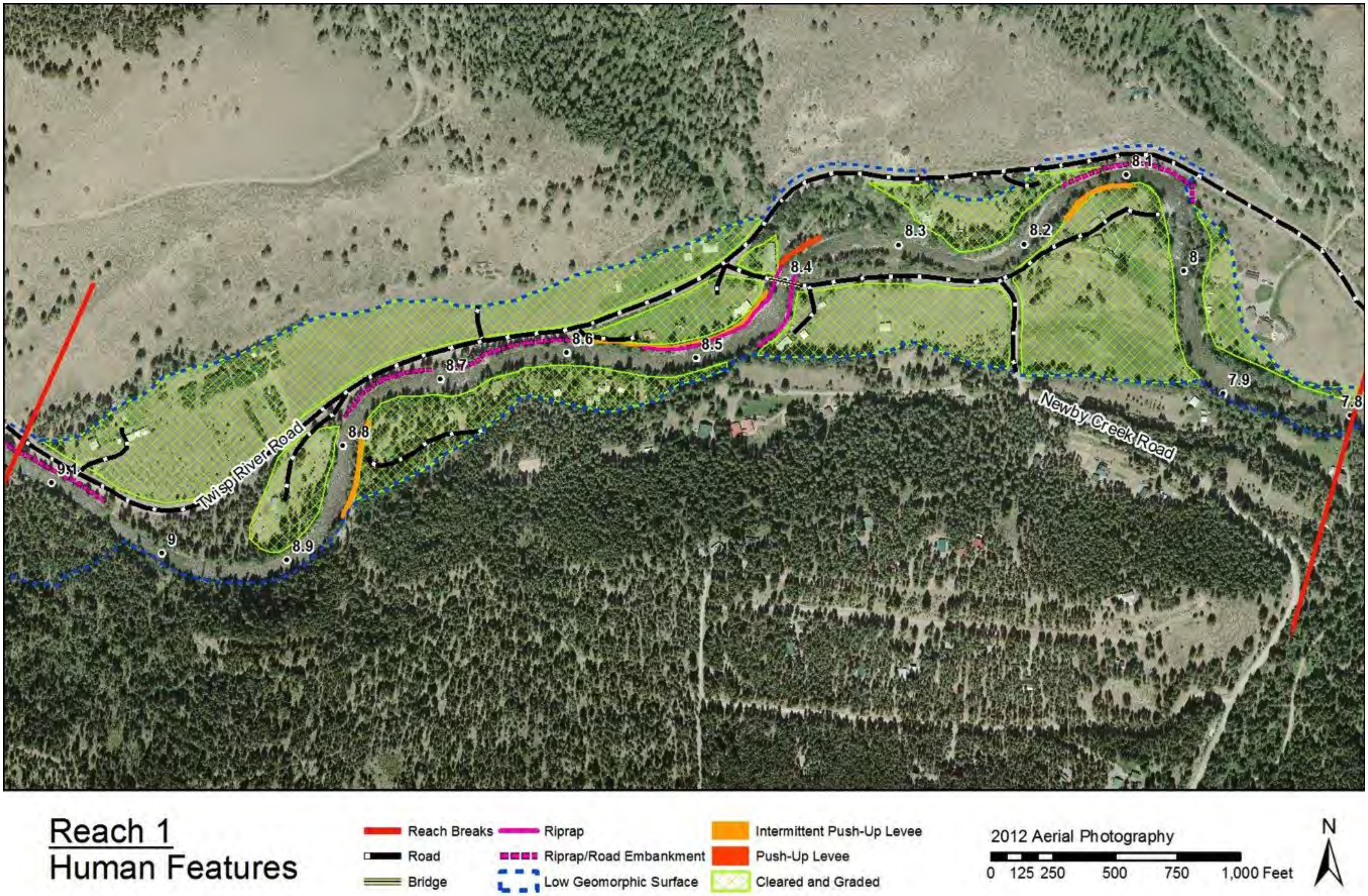

Figure 22. Human features in Reach 1 that are within the low surface.

Figure 23 Looking upstream at the bridge at RM 8.4.

Significant Riparian Impacts

Riparian vegetation has been greatly impaired due to human alterations throughout this portion of the study area, with almost the entire north side of the channel exhibiting loss of vegetation due to clearing and grading for residential and agricultural purposes, as well as the construction of the roadway and its associated embankments (Figure 22). The loss of large wood that has occurred reduces the amount of shade provided to the channel, as well as limits the potential for large wood recruitment in the future. The amount of clearing that has occurred is significant and has a large impact on the presence of large wood counted within the channel throughout this reach.

Loss of Streambank Complexity

While the construction of Twisp River Road did not impact lateral channel migration due to natural confinement, it did severely limit streambank complexity. The roadway forms the channel margins throughout the reach along the north side of the channel. The installation of riprap inhibits toe erosion and the potential for localized scour that can act as a source of sediment to the system and aid in the recruitment of large wood to the channel. Currently, there is very little bank complexity in the form of undercut banks, overhanging vegetation, alcoves, and wood cover.

3.2 REACH 2

3.2.1 Reach Overview

Reach 2 corresponds to the upstream portion of Reach T4 from the Methow Subbasin Geomorphic Assessment (USBR 2008). This reach extends from RM 9.14 to RM 9.79 (the confluence of Little Bridge Creek) for a total distance of 0.65 miles. A representative photo is shown in Figure 24 and an overview map is included as Figure 25. This steep-gradient, riffle-dominated, single thread channel is naturally confined by glacial terraces and alluvial fan deposits. The natural confinement of this reach has resulted in minimal changes to the location of the channel over the historical photo record (dating back to 1953). It also lessens the amount of off-channel and side habitat available as well as the impact that human alterations have on channel dynamics in this location. There are significant impacts to the riparian zone as a result of the road on river-left and clearing for residential and agricultural uses. The human alterations to the riparian zone on river-left reduce hydraulic roughness across that surface as well as large wood available for recruitment into the river in the future. The construction of the road embankments and installation of riprap along the toe has also impacted the complexity of the stream bank. The landownership directly abutting the channel is primarily private, with the exception of river-right from approximately RM 9.43 to 9.6 which is the Okanogan National Forest (Figure 25).

Figure 24. A representative photo of Reach 2 taken at RM 9.4.

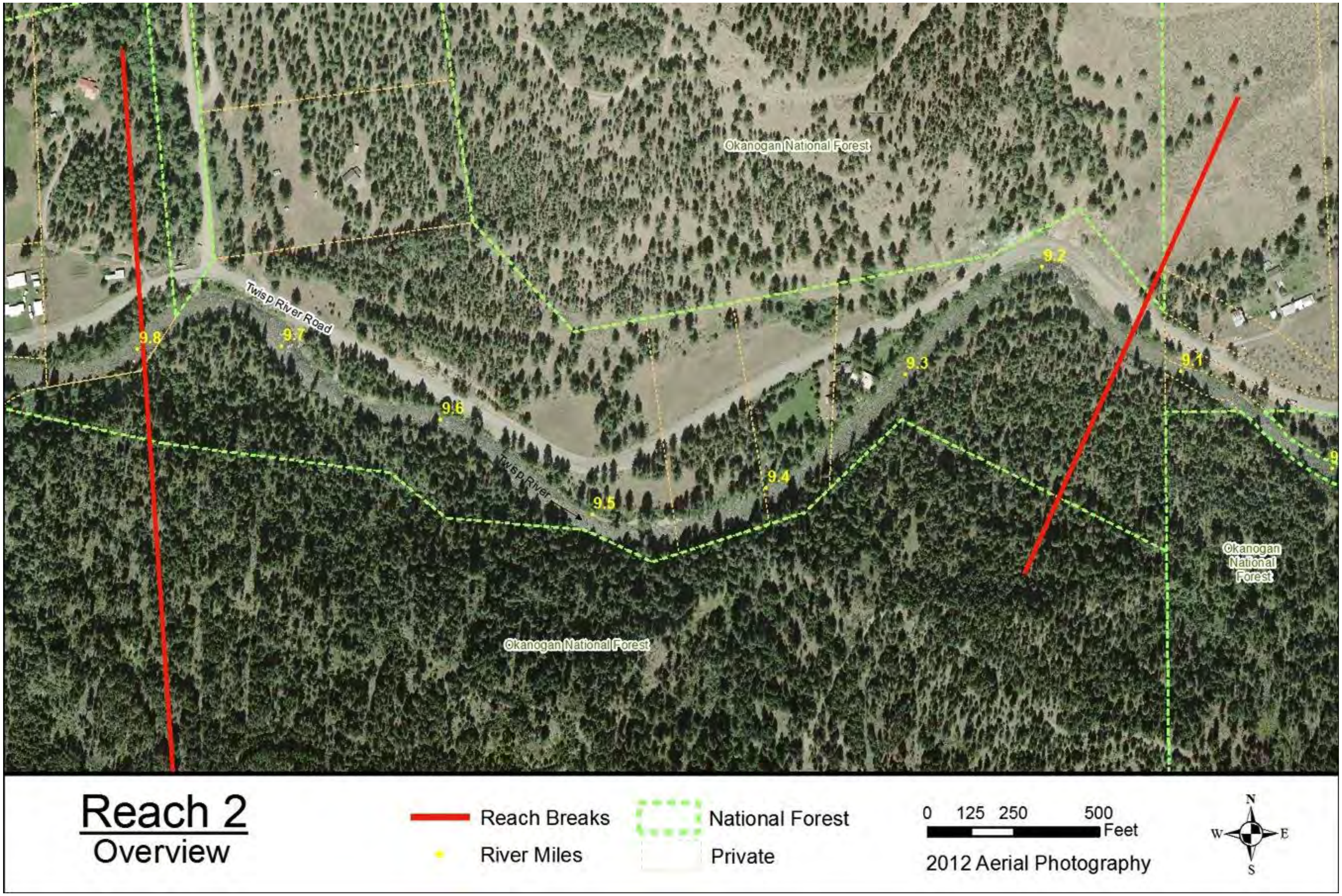

Figure 25. Overview map of Reach 2 showing land ownership.

Table 11. Table 1: Key descriptive and geomorphic metrics for Reach 2.

Metric	Value
Reach Length	0.65 miles
River miles	9.14 to 9.79
Valley gradient	1.26%
Stream gradient	1.16%
Sinuosity	1.22
Dominant Channel Type	Plane-bed
Avg bankfull width	91 ft
Avg floodplain width	118 ft
Dominant substrate	cobble

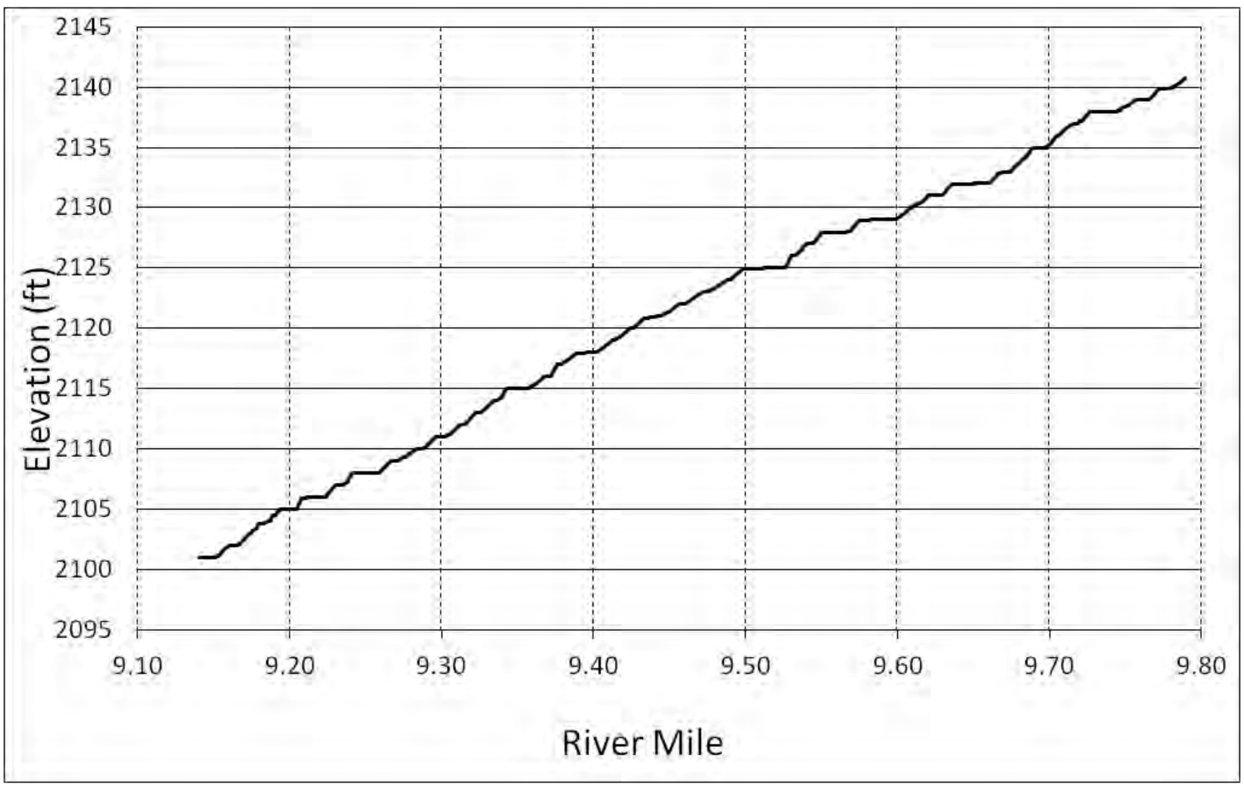

Figure 26. Longitudinal profile of Reach 2. Elevation data is derived from the 2006 LiDAR data and so represents water surface at the time of the LiDAR flight.

3.2.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 2 is laterally constrained primarily by alluvial fan deposits generated from Little Bridge Creek along the north side of the valley and also by glacial terraces that form a steep bank along the south side (Figure 27). There is evidence of erosion along the toe of the alluvial fan in the downstream portion of the reach, but the intermediate surface has since been abandoned due to channel incision. The channel has generally maintained its current location throughout the period of record (through 1953). These geomorphic units lining the channel provide great lateral control through the reach, resulting in a single-thread morphology through this steep (1.16% gradient; Figure 26), riffle dominated (81%) reach. The lack of lateral migration is also evidenced in the low calculated sinuosity and low channel complexity in comparison with surrounding reaches.

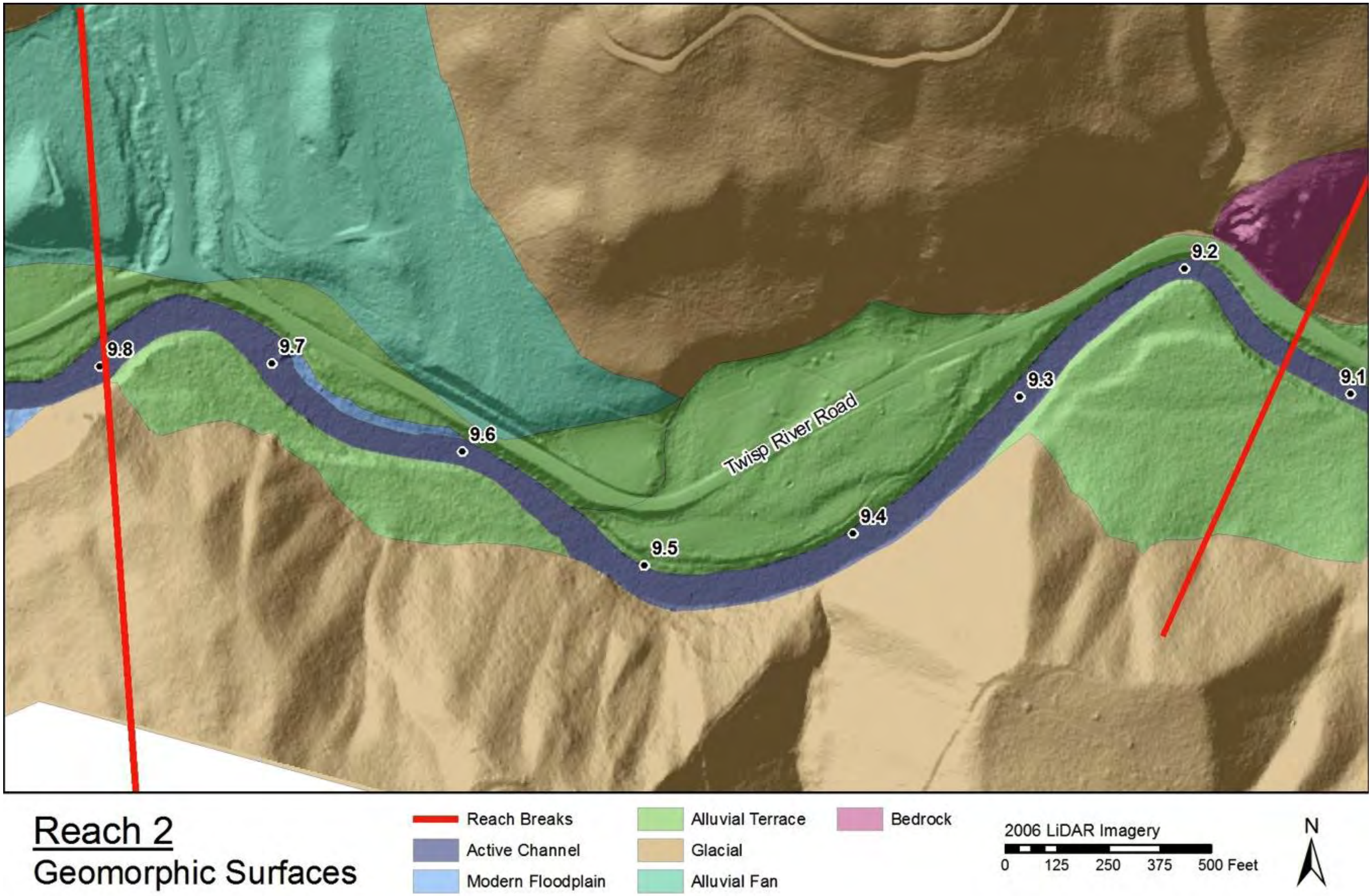

Figure 27. Geomorphic surfaces map showing the natural confinement found on both sides of Reach 2.

Hydrology

Little Bridge Creek enters the main channel along the north side of the channel, in the upstream portion of this reach. It is connected to the mainstem of the Twisp River through a large bottomless arch culvert that runs under Twisp River Road. This tributary contributes about 10% of the flow to the Twisp River at this location. Little Bridge Creek is a naturally laterally and vertically confined boulder-step-pool system with a boulder-cobble bed. The aggradation observed within the culvert at the mouth of the tributary provides evidence that Little Bridge Creek is contributing sediment to the main channel (Figure 28).

Figure 28 Looking upstream at Little Bridge Creek

Floodplain and Channel Migration Zone

There is minimal floodplain availability due to the naturally confined valley morphology of this reach. Lateral stability has limited the formation of side channels and lateral scour pools throughout this reach. Channel changes were mapped from aerial photos dating back to 1953 (Figure 30) and show the stability of this reach. All of the flood events that were modeled as part of the hydraulics analysis (up to the 100-year event) were confined within the extents of the main channel (Figure 29).

The LiDAR provides evidence that channel incision has previously taken place resulting in the abandoning of intermediate surfaces in the downstream portion of the reach. The road embankment and associated riprap provide some floodplain and channel migration zone impacts and are discussed further in the Human Alterations section.

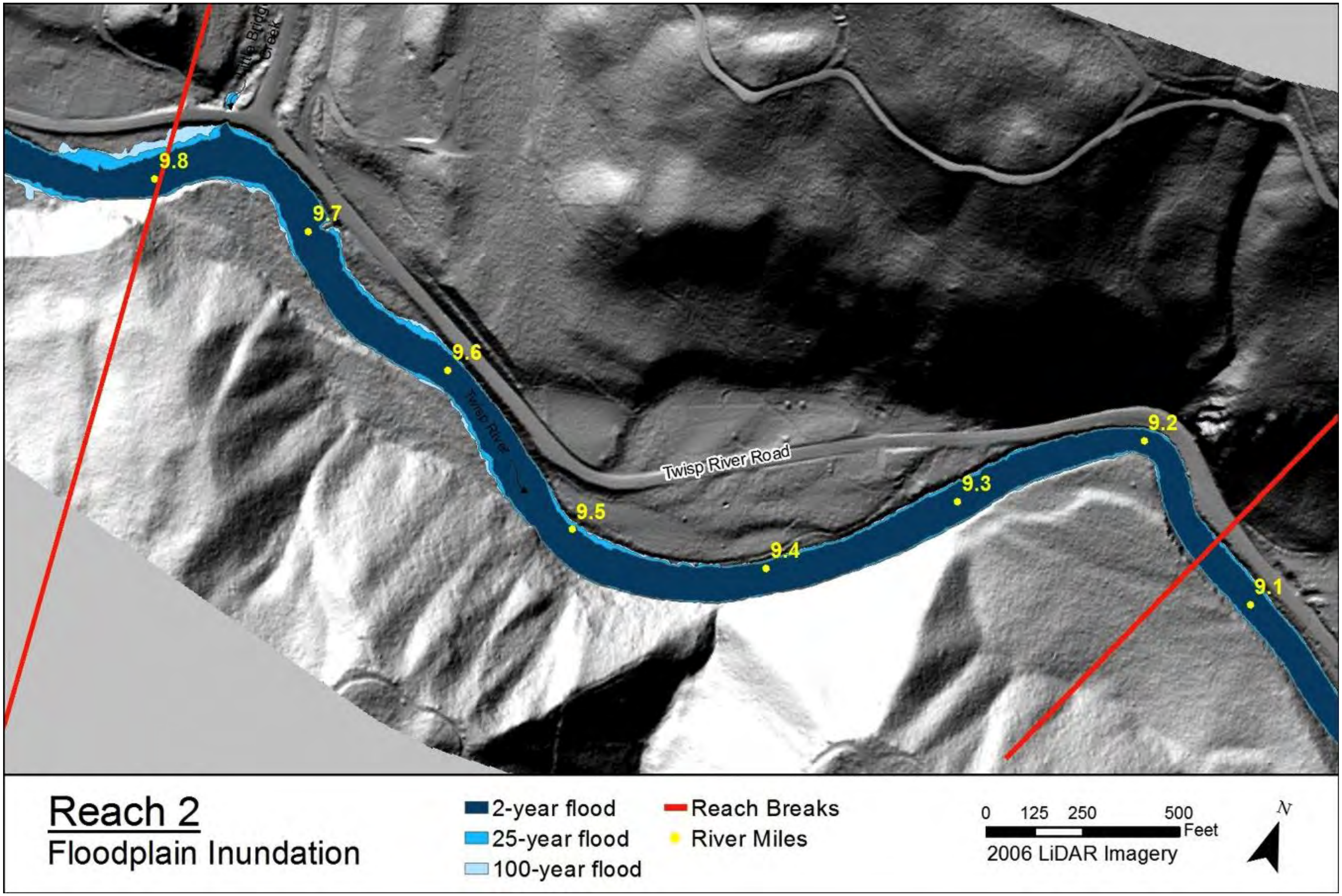

Figure 29. Floodplain inundation for selected years.

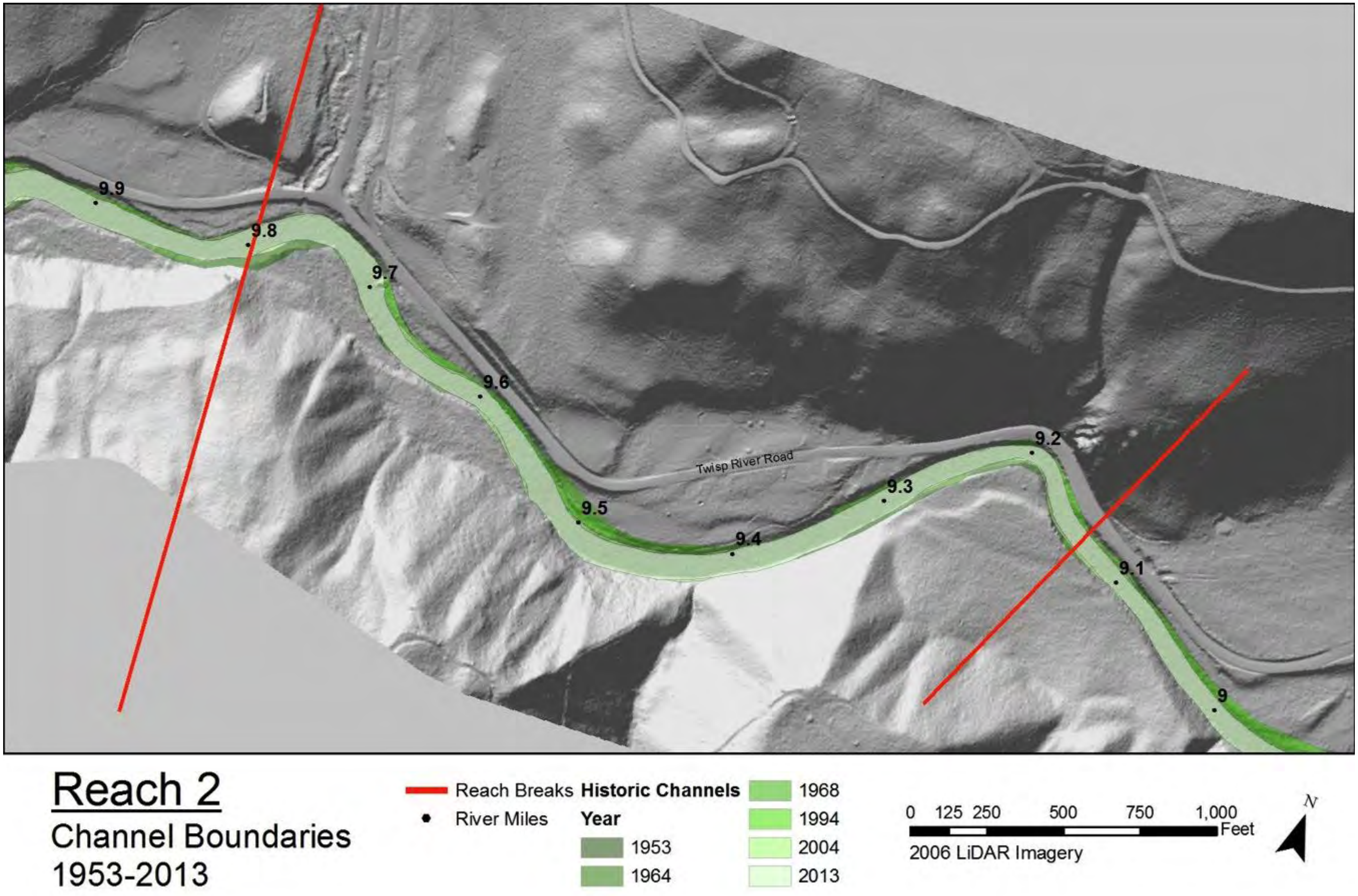

Figure 30. Historical channel boundaries for Reach 2.

Sediment

Due to the steep, single thread nature of this channel, it is predominately a transport reach for sediment that enters the system. The channel substrate is primarily cobble (45%) with the presence of gravels and boulders that have likely been sourced from local alluvial fan deposits. The large bed material limits vertical incision as well as provides a limited amount of instream habitat complexity. Boulders provide hydraulic complexity that create localized pocket water throughout the channel for salmonid resting and holding.

There are several sediment sources to this reach including contributions from Little Bridge Creek, bank erosion from the road embankment, and older alluvial fan deposits that the river has eroded into. At the upstream end of the reach, Little Bridge Creek contributes sediment during floods as evidenced by the sediment accumulation at the mouth of the tributary (Figure 31). The Twisp River Road embankment along the north side of the channel is unvegetated and provides fine sediment and limited amounts of gravel to the channel throughout this reach (Figure 32).

Figure 31 Sediment accumulation in the bottomless culvert at the confluence of the Little Bridge Creek tributary and the Twisp River.

Figure 32 The roadway on river-left acts as a source for fine sediment, sand, and gravel entering the channel.

Large Wood

Reach 2 had the lowest wood counts of the entire study area (18 total pieces total) and did not have any log jams. A fallen conifer was noted in this reach at RM 9.7 (Figure 33) and resulted in an area of localized cobble accumulation, but the overall lack of wood in the reach, swift current, and large substrate are indicative of a transport reach that lacks instream habitat. The steep, heavily vegetated banks, primarily along the south side of the river, are potential sources of additional large wood recruitment to the system.

Figure 33 large wood recruitment at RM 9.7.

Vegetation

The riparian vegetation in Reach 2 is severely impacted by human alterations on the north side of the channel, whereas the south side is relatively untouched. There were large areas of clearing, primarily along the north side of the channel, as well as about 75 feet of unstable banks at RM 9.65. In portions of the reach where the riparian corridor is undisturbed, the overstory species was exclusively Douglas fir (100%) and the understory was 50% unknown softwoods and 50% alder. The riparian vegetation within Reach 2 was dominated by small trees as shown in the first return LiDAR data (less than 50 feet; Figure 34), which do not provide much potential for large wood recruitment or shade to the channel along the north side of the channel due to the nearby roadway. Riparian vegetation on the south side of the channel provided good shade throughout the reach.

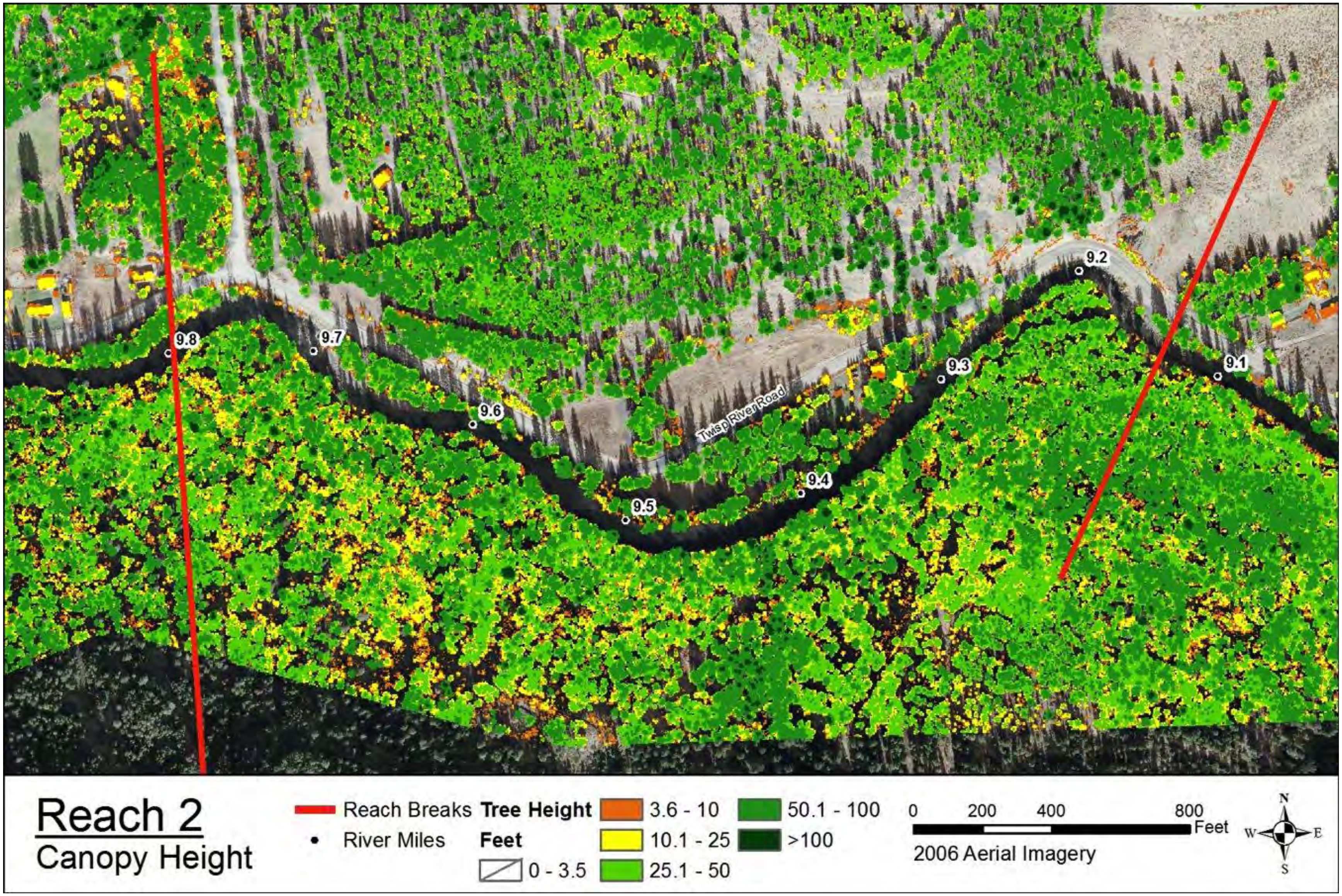

Figure 34. LiDAR first return (highest hit) data for Reach 2. These data show vegetation canopy heights. Buildings and other human infrastructure are also included in this data.

3.2.3 Human Alterations

Overall, human impacts have less impact on channel dynamics in this reach since the channel is naturally confined. However, there are significant human alterations that limit the amount of large wood and reduce streambank complexity (Figure 35).

Loss of Streambank Complexity

Twisp River Road forms the channel margin along river-left for a majority of this reach. The associated road embankments and riprap have severely impacted streambank complexity. The roadway was constructed in the modern alluvial terrace and the alluvial fan and does not appear to be limiting lateral channel migration; however, it is acting as a source of fine sediment, sand, and gravel to the channel. The fine sediment entering the system as a result of the embankment can accumulate in-between flood flows and have the potential to reduce spawning habitat availability.

Large angular riprap has been installed along the base of the road embankment along river-left (Figure 36). The riprap likely does not have a significant impact on channel migration due to the confined nature of the reach, but it does have some effect on gravel and large wood recruitment processes along the channel margins. There is a large bottomless culvert at the confluence of Little Bridge Creek and the Twisp River (approximately RM 9.75) along river-left (Figure 31). Sediment deposition within the culvert has occurred, which is a result of the change in profile of Little Bridge Creek as it meets the Twisp.

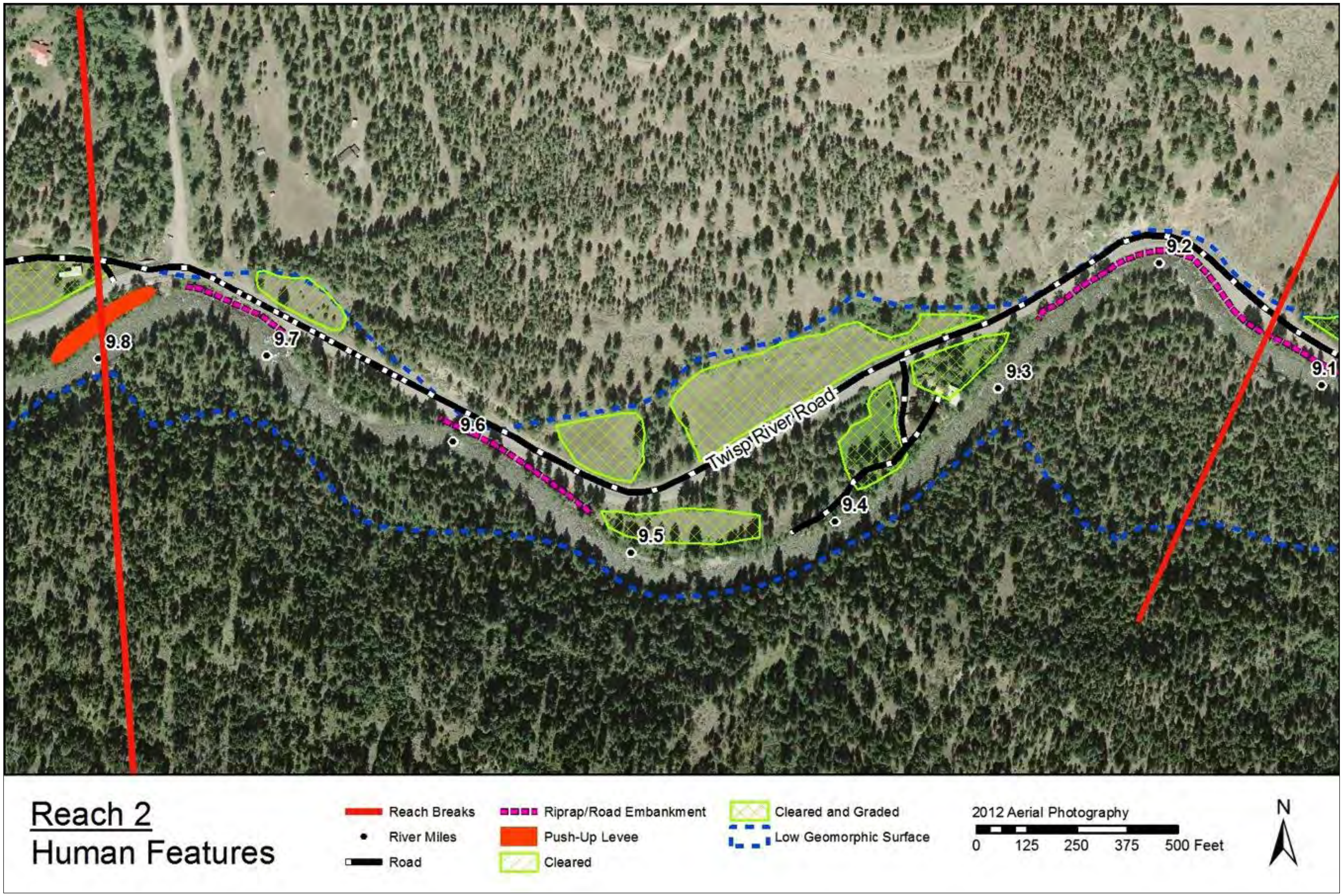

Figure 35. Human features in Reach 2.

Figure 36 The road embankment at RM 9.15 looking upstream.

Significant Riparian Impairment

There are significant impacts to riparian vegetation as a result of River Road along the north side of the channel. Clearing for residential and agricultural uses also impairs riparian function throughout the reach.

Figure 34 shows that a majority of the vegetation is less than 50 feet tall, with patches of trees up to 100 feet tall. There are several areas along the north side of the channel where the riparian corridor is very narrow and clearing has occurred up to the channel's edge. There are some fallen conifers in this reach, but wood recruitment is much lower than would be expected under undisturbed conditions. Past removal of riparian vegetation impacts biological and physical processes. The lack of a dense vegetative canopy reduces the amount of shade provided to the stream, increasing summer water temperatures and decreasing winter water temperatures. The removal of vegetation from the system has reduced the amount of wood available for future recruitment.

3.3 REACH 3

3.3.1 Reach Overview

Reach 3 corresponds to the downstream portion of USBR Reach T5 and extends from River Mile 9.79 (Little Bridge Creek confluence) to 12.22 for a total length of 2.43 miles. The gradient is lower than the downstream reaches and the road no longer directly abuts the channel. This reach is riffle dominated and the surface is primarily cobble. The sinuosity and complexity of the channel increases compared to Reaches 1 and 2, with increased floodplain inundation. However, there has been a reduction in floodplain connectivity (inundation frequency) and lateral channel dynamics since historical conditions, which is likely the result of past floodplain filling, grading, and development in the downstream half of the reach along river-left. These impacts may have contributed to channel incision and disconnection of the channel upstream, where the broad left-bank oxbow is now abandoned. This area, located at RM 11.3 – 11.87, may provide great opportunities to reconnect expansive off-channel salmonid rearing habitat. The ownership in this reach is predominately private, with RM 11.5 to 11.8 within the Okanogan National Forest on both sides of the river (Figure 38).

Figure 37. A representative photo of Reach 3 at RM 11.8.

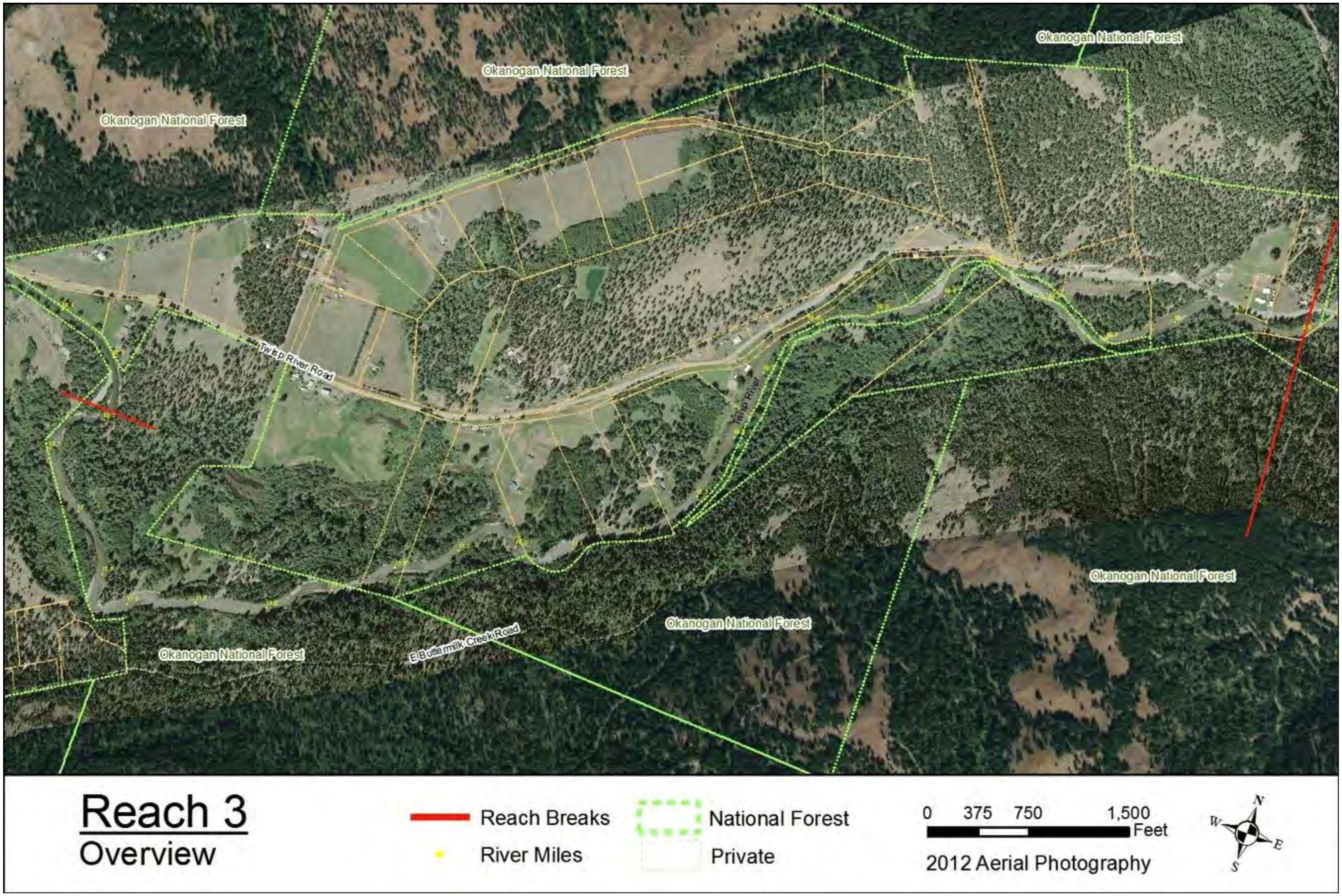

Figure 38. An overview of Reach 3 with landownership.

Table 12. Key descriptive and geomorphic metrics for Reach 3.

Metric	Value
Reach Length	2.43 Miles
River Miles	9.79 – 12.22
Valley Gradient	0.85%
Stream Gradient	0.57%
Sinuosity	1.43
Dominant Channel Type	Pool-Riffle
Avg Bankful Width	102.2 ft
Average Floodplain Width	>300 ft
Dominant Substrate	Cobble

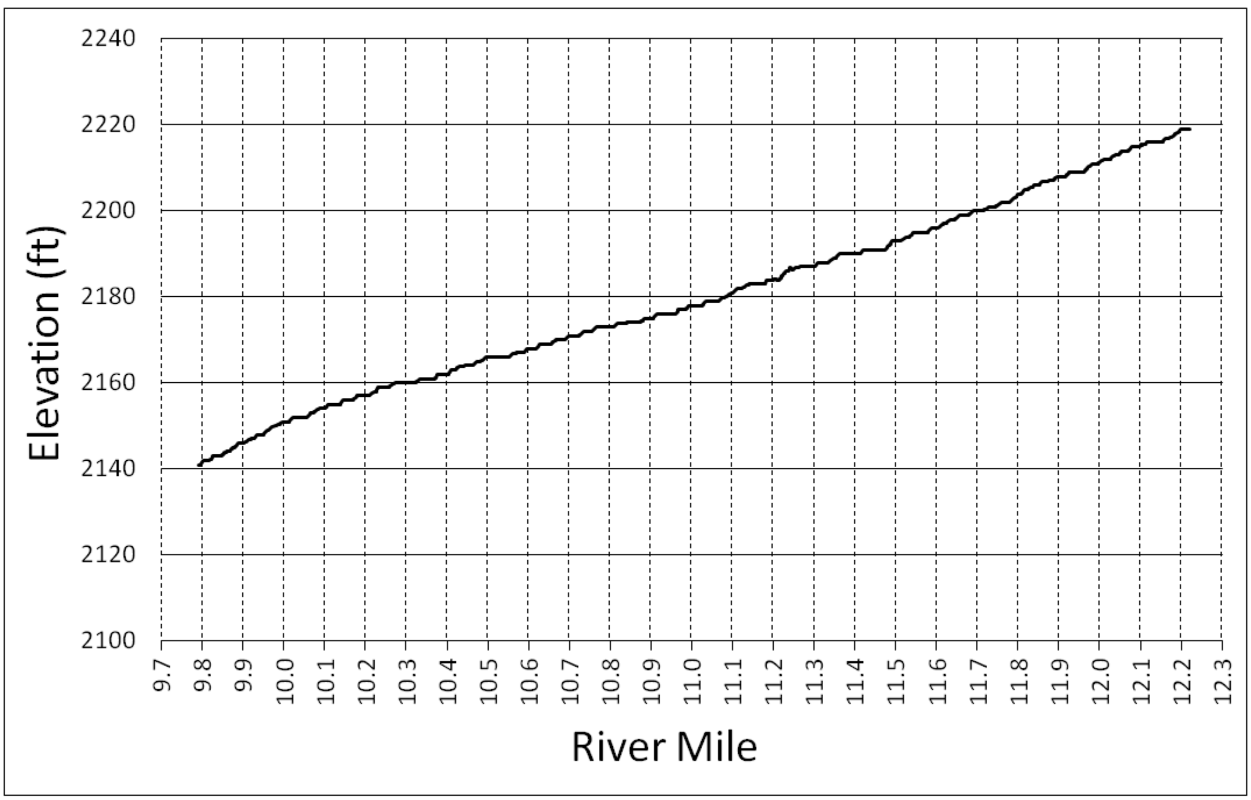

Figure 39. Longitudinal profile of Reach 3. Elevation data is derived from the 2006 LiDAR data and so represents water surface at the time of the LiDAR flight.

3.3.2 River Morphology and Geomorphic Processes

Geology and Landforms

This reach has a much wider and more well-connected floodplain than the downstream reaches. It is bounded on both sides primarily by glacial till deposits. The channel has eroded into this material, resulting in landslide deposits along valley-left in the upstream half of the reach. Channel gradient is 0.57%, compared to the much steeper 1.16% in Reach 2. The channel remains dominated by fast-water reaches (69% riffles), but there is greater lateral dynamics and higher quality habitat. There are three side channels within the reach, which account for 2% of the habitat unit area.

Hydrology

There are no significant tributary inputs in this reach. There is subsurface flow contributed from the modern alluvial floodplain along the left-bank that was observed during field surveys (near RM 11.47). Hyporheic flow is assumed to occur throughout the reach in low gradient alluvial sections with higher sinuosity and the presence of gravel bars.

Floodplain and Channel Migration Zone

The floodplain in Reach 3 is several hundred feet wide and is inundated semi-regularly (Figure 40). Channel sinuosity, complexity, and floodplain inundation are higher than in downstream reaches. In the upstream half of the reach, the river is against the south valley wall and there is a broad floodplain on the north side that is comprised of an extensive network of remnant oxbows that represent former channel locations. The channel migration zone in this location, at least historically, was very large. This surface has likely seen a reduction in floodplain inundation (and migration) due to channel incision caused by downstream floodplain development and channel constriction. This is described in more detail in the Human Alterations section. In the downstream half of the reach, the river runs primarily along the north side of the valley and there is a distinctive abandoned oxbow in the river-right floodplain near RM 10.5. This surface remains relatively well-connected to flood flows.

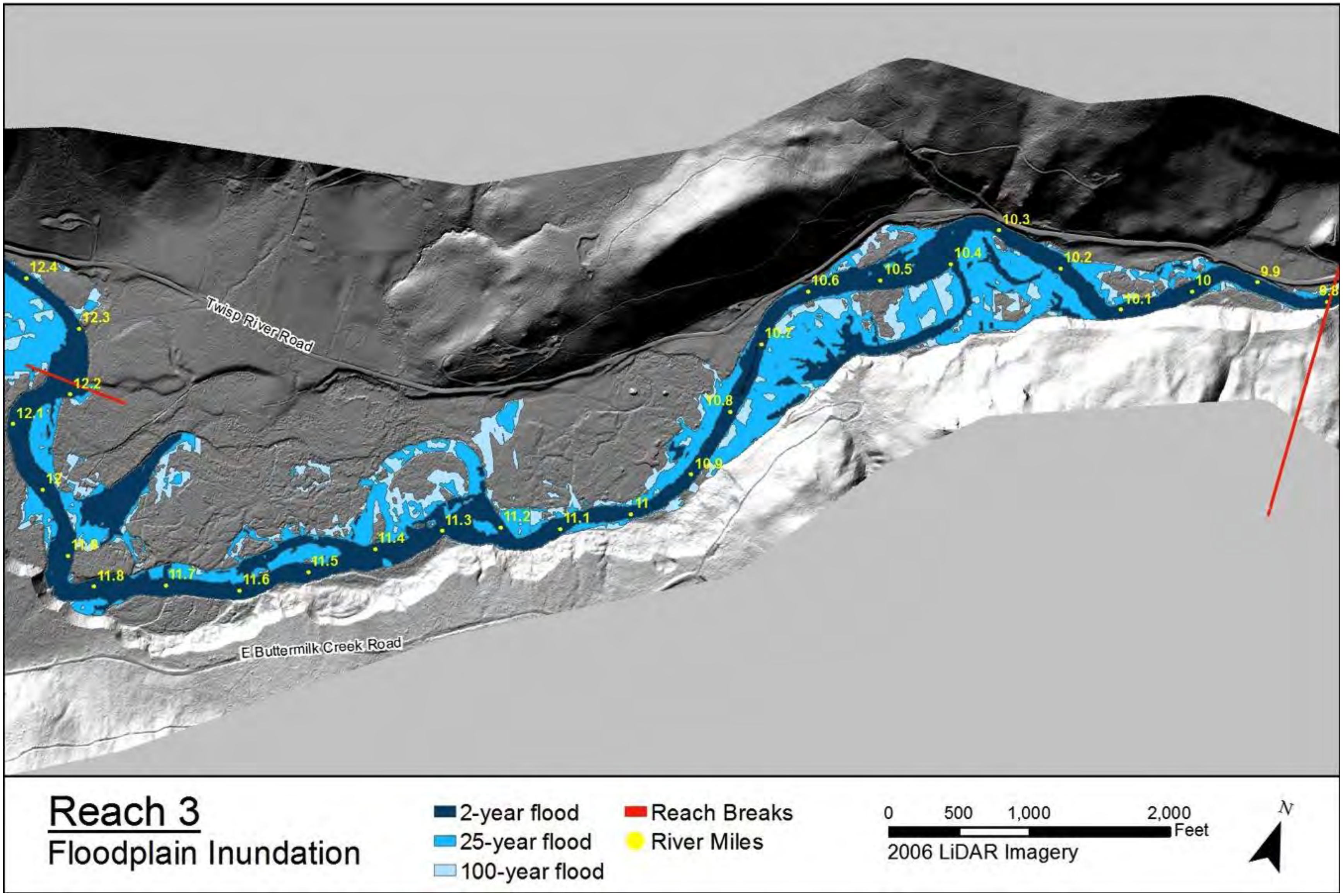

Figure 40 Extents of floodplain inundation for selected flood recurrence intervals in Reach 3. Flood inundations developed using HEC-GeoRAS based on the LiDAR surface.

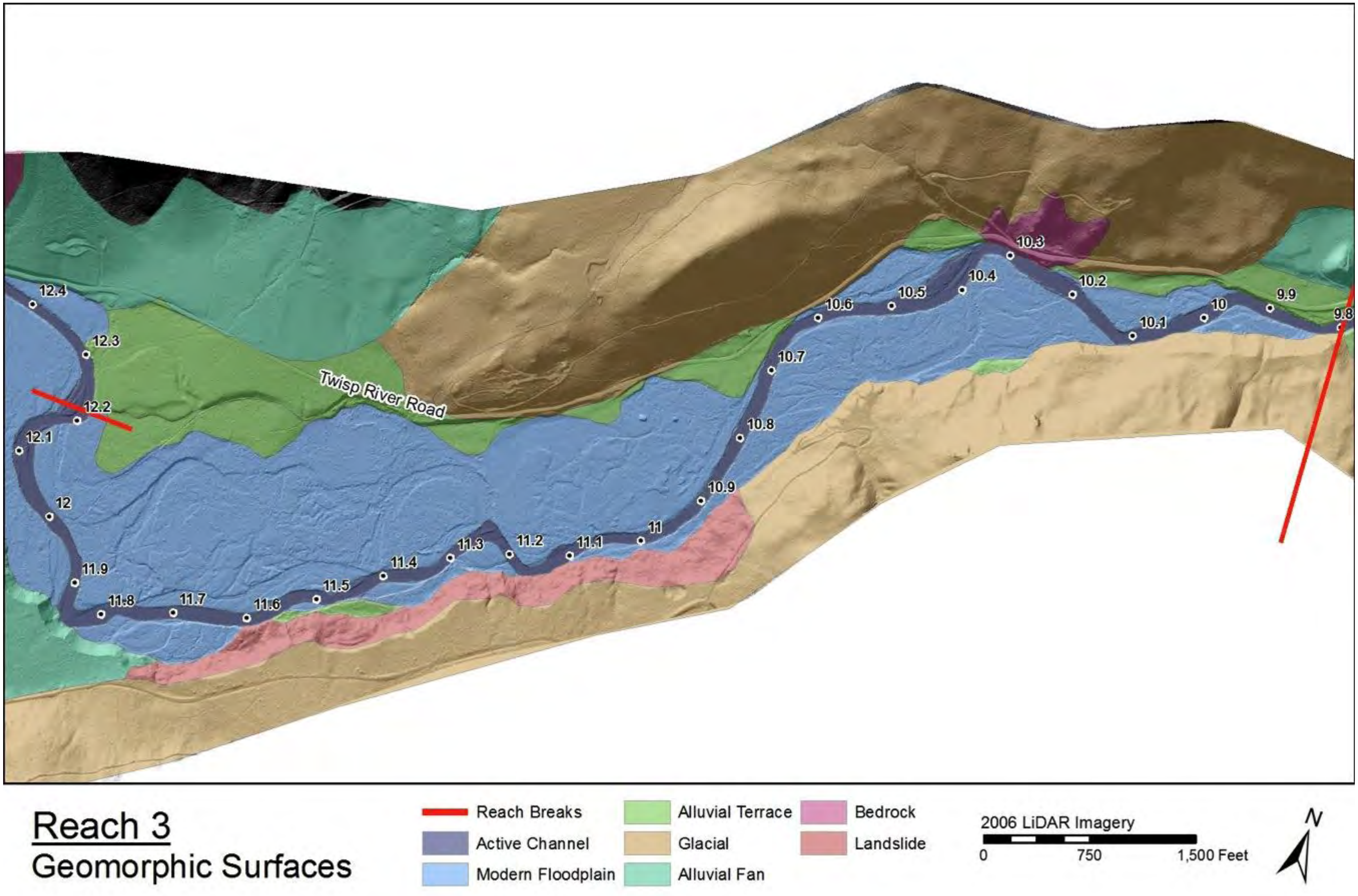

Figure 41. Geomorphic surfaces for Reach 3.

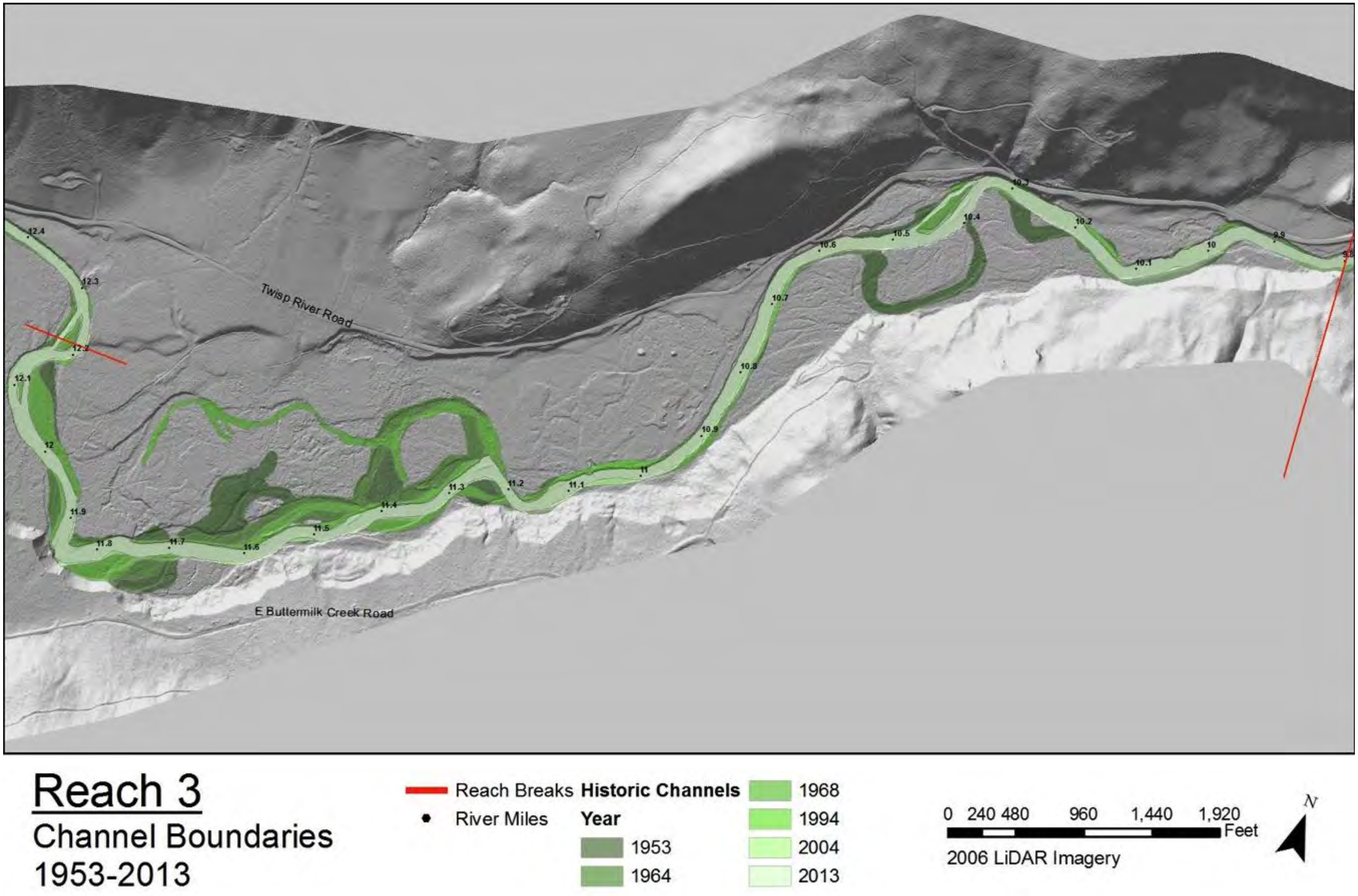

Figure 42. Historical channel boundaries for Reach 3.

Sediment

Reach 3 is primarily a response reach, although human alterations have likely increased transport conditions. The quantity of boulders present in Reach 3 is less than the downstream sections, but the channel substrate remains primarily cobble (69%; Habitat assessment, Appendix A). Material is sourced from bank erosion into contemporary floodplain surfaces (Figure 43) but also from erosion into tributary fan and glacial deposits on valley-right in the upstream half of the reach. Unconsolidated cobble and gravel are entering the system in this reach, providing a good source for spawning gravel recruitment downstream.

The presence of gravel cobble bars and apex log jams, which result in sediment deposition, indicate that this reach is acting primarily as a response reach (Figure 44). Several bars were observed throughout this reach; some were a result of large wood and boulders creating deposition zones, whereas others were well-established point bars. The size of the material that is accumulating on the exposed mid-channel bars is finer than what was observed in the downstream reaches.

Figure 43. The high eroding banks with natural alluvium protecting the toe of the bank at RM 11.77 are acting as a source of fine sediment to the system.

Figure 44. Gravel/cobble bar at RM 9.96 looking upstream, just out of the photo is a large boulder at the upstream side of the bar.

Large Wood

Large wood in Reach 3 averaged 54 pieces/mile, almost half of the study area average (96 pieces/mile). Historically, this reach would have been expected to have a high frequency of large wood and log jams throughout. Active recruitment of large wood to the channel was noted, primarily along river-left, but due to the channel's pattern of lateral migration and the high density of large conifers along the banks, the quantity of wood observed in the channel is lower than expected given the conditions. Two apex log jams were noted within the reach (Habitat Assessment, Appendix A). Higher wood frequencies would have existed historically as a result of recruitment by bank erosion and avulsions, which have been reduced. Riparian clearing along river-left has further reduced large wood recruitment potential. An increase in large stable log jams would help to improve lateral and vertical channel dynamics.

Vegetation

Reach 3 had a highly variable riparian corridor. Grassland/forbs, and small trees accounted for 29% of the reach; large trees, sapling/pole, and shrub/seedling each accounted for 14% of the riparian corridor (Habitat Assessment, Appendix A). The image created from the LiDAR first return data

(Figure 45) shows that the vegetation canopy heights were dominated by trees ranging from 10 to 50 feet tall, with a few patches of vegetation over 100 feet tall. The overstory was primarily composed of cottonwoods and Douglas fir, but also contained ponderosa pine. The understory was dominated by alder with some dogwood noted in the Habitat Assessment report (Appendix A).

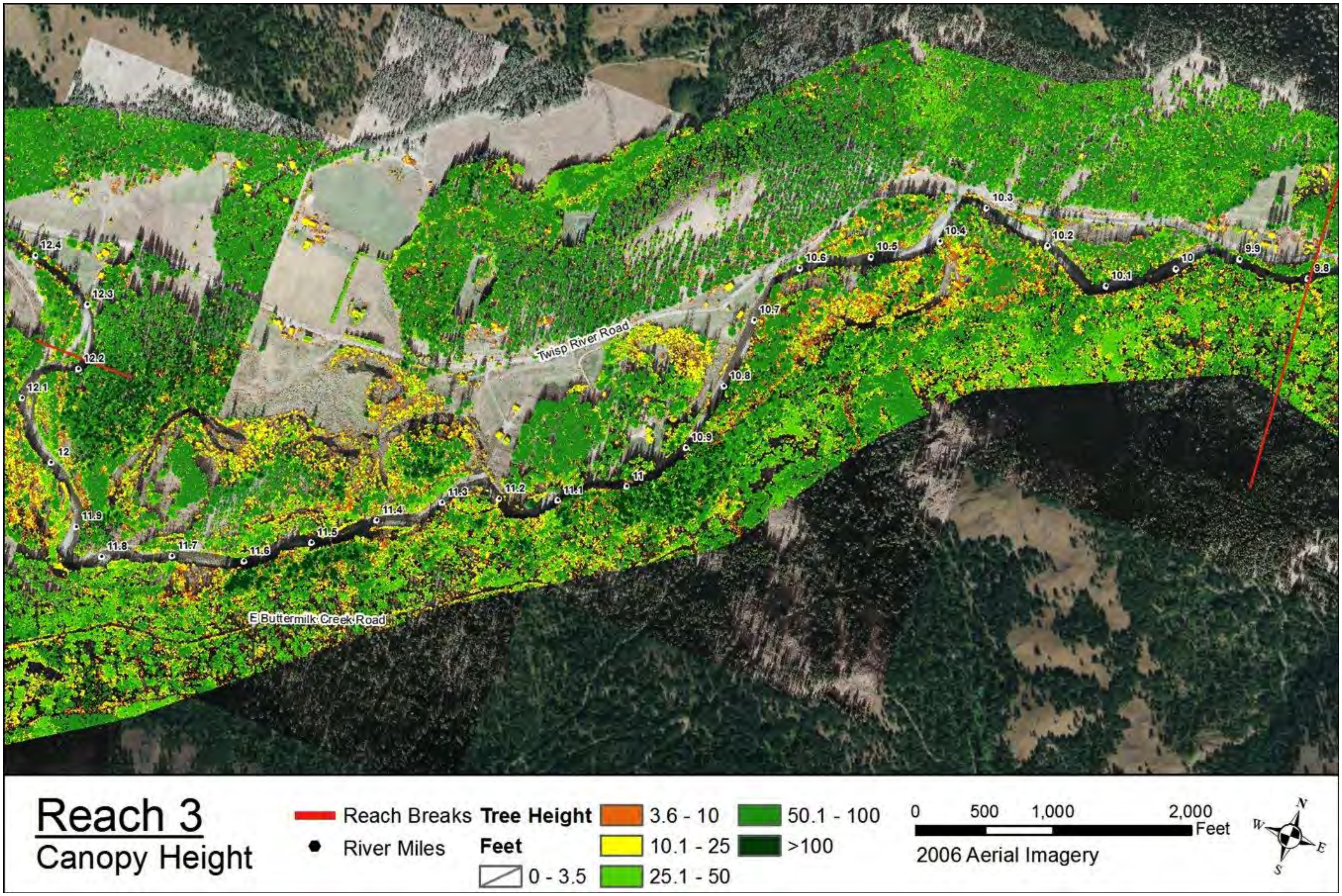

Figure 45. LiDAR first return (highest hit) data for Reach 3. These data show vegetation canopy heights. Buildings and other human infrastructure are also included in this data.

3.3.3 Human Alterations

Floodplain Filling, Grading, and Channel Constriction

Floodplain filling, grading, and channel constriction have occurred in the river-left floodplain in the middle portion of the reach between RM 10.8 and ll.3. This surface has been filled and graded to support residential and agricultural uses. Along the left-bank at RM 11.2, there is bank armoring and a levee that constrain the channel. It is likely that these practices have resulted in channel downcutting that continued upstream. The localized as well as upstream channel incision has reduced floodplain inundation and has decreased lateral channel dynamics. The loss of large wood and log jams has likely contributed to these impacts. The effects of these practices extends at least up to the upstream end of the reach near RM 12. Aerial photos pre-1960 and topographic evidence suggest that historically, this area was characterized by a more sinuous channel planform, multi-thread channel segments, and well-connected floodplains. Large abandoned oxbows in the river-left floodplain at RM 11.3 and 11.8 are evidence of this. This reach historically would have functioned more like Reach 5 given the width of the low surface, valley gradient, and lack of lateral controls on the channel. It currently has much less complex habitat.

Loss of Instream Habitat Complexity

Historically, this reach would have been expected to have a high frequency of large wood and log jams. Jams would have been recruited by bank erosion and avulsions, which have been reduced. Riparian clearing has further reduced recruitment potential. Large stable log jams would help to increase lateral and vertical channel dynamics.

Riparian Impairment

There are several areas where there has been significant riparian and floodplain clearing. Most of these are located along the river-left bank between RM 10.6 and 11.3, which is also where the greatest floodplain impairment has occurred as described above. Additional areas include on the river-left near RM 11.7-11.8 and on river-right near 10.5-10.6. The road embankment on river-left at RM 10.3 also impairs riparian function and channel margin habitat (Figure 46). Riparian alterations in Reach 3 have reduced floodplain hydraulic roughness and have reduced the availability of large wood for recruitment.

Figure 46. RM 10.27 river left, the road embankment and large angular riprap installed at the bank toe.

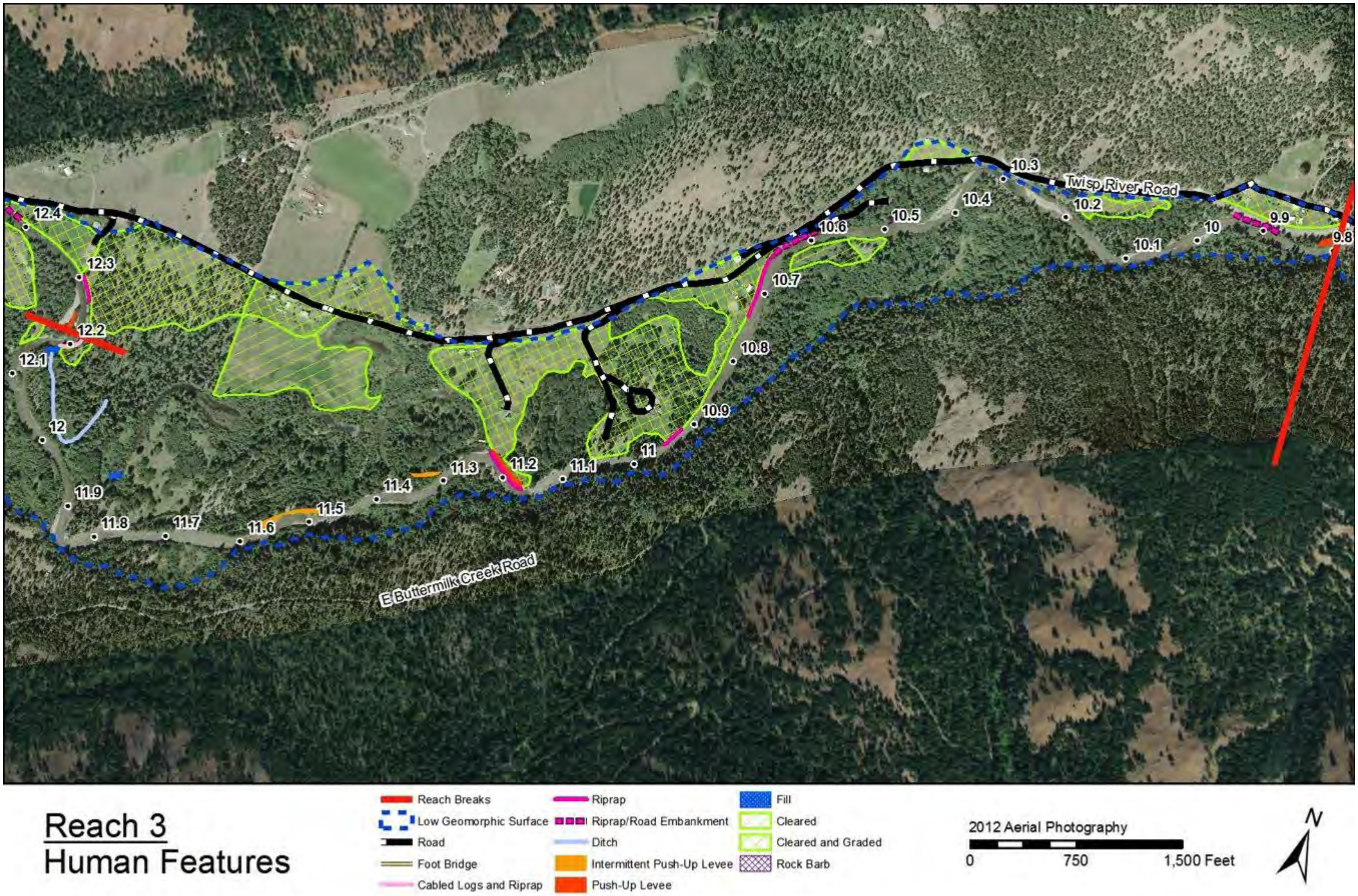

Figure 47 Human features in Reach 3.

3.4 REACH 4

3.4.1 Reach Overview

Reach 4 extends from RM 12.22 to 13.60 (the confluence with Buttermilk Creek) for a total distance of 1.38 miles. A representative photo is provided in Figure 48 and an overview map is included as Figure 49. The reach is semi-confined by glacial terraces, hillslope contacts, and tributary fans and has a moderately steep gradient (1.21%). It is the most sinuous reach in the study area but this is not a result of extensive meander development or high planform diversity. The high sinuosity (1.49) is due to a long arcing bend through much of the reach, which is governed primarily by the influence of the Buttermilk Creek alluvial fan encroaching into the Twisp River valley from the south. There has been relatively little change in channel location over the historical photo record (back to 1953) due largely to natural confinement; however, clearing and grading associated with agricultural uses may be a contributing factor. Despite the overall lack of planform diversity, there are 3 short sections of split flow around small stable islands, and some alcove development in a few locations. Off-channel and side-channel habitat is otherwise very limited. The channel units are dominated by riffle habitat (69%), which reflects the moderately high gradient and lateral controls on the channel. Landownership is predominately private, with the exception of RM 12.4 to 12.5 on river-left and RM 13.4 to 13.5 on river-right, which are National Forest. Agricultural uses, primarily pastures for livestock grazing, dominate portions of the floodplain and riparian areas.

Figure 48. A representative section of Reach 4 at RM 12.8.

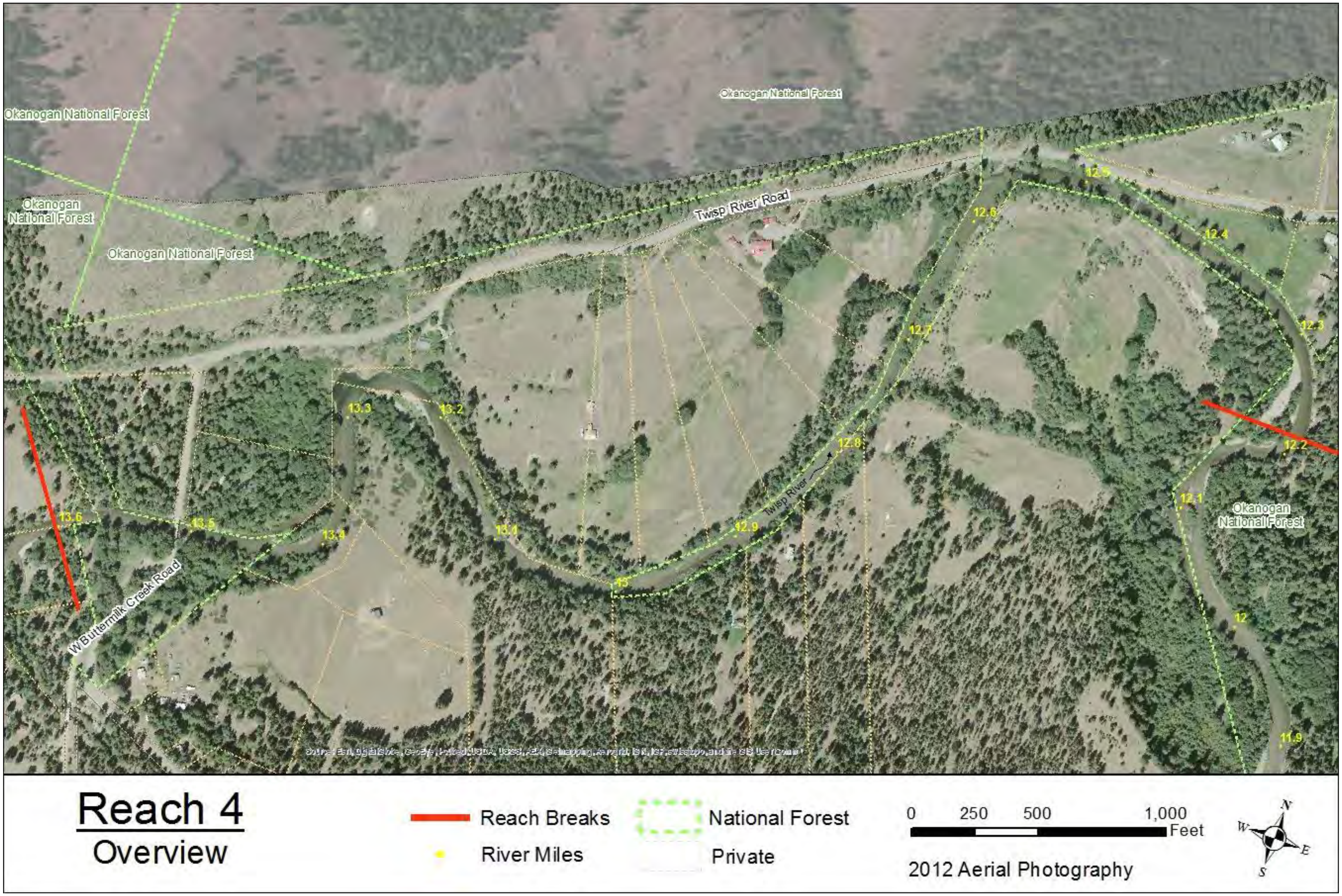

Figure 49. Overview map of Reach 4 showing landownership.

Table 13. Key descriptive and geomorphic metrics for Reach 4.

Metric	Value
Reach Length	1.38 miles
River miles	12.22 to 13.60
Valley gradient	0.72%
Stream gradient	1.21%
Sinuosity	1.49
Dominant channel type	Plane-bed
Avg bankfull width	79.5 ft
Avg floodprone width	120.75 ft
Dominant substrate	Cobble

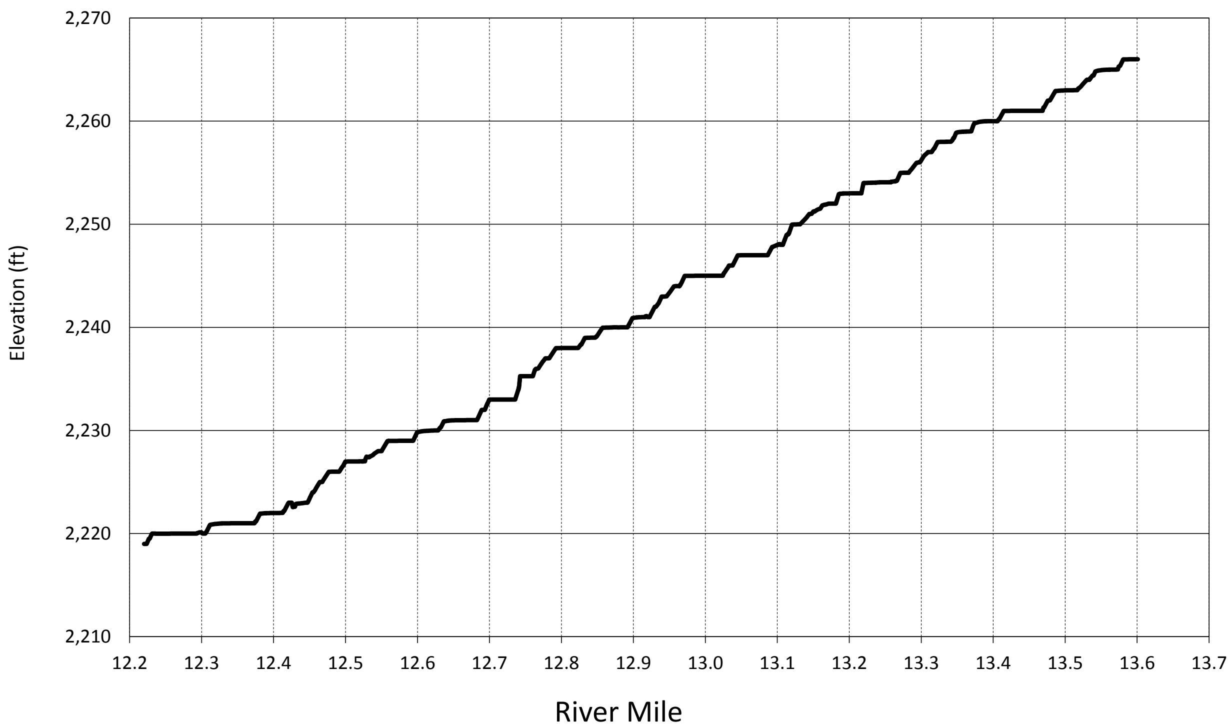

Figure 50. Longitudinal profile of Reach 4. Elevation data is derived from the 2006 LiDAR data and so represents water surface at the time of the LiDAR flight.

3.4.2 River Morphology and Geomorphic Processes

Geology and Landforms

Alluvial fan deposits provide the primary lateral controls on the channel. Hillslope contacts and glacial terraces are also present along the reach (Figure 52). The large Buttermilk Creek alluvial fan occupies much of the southern side of the valley in this reach and creates the long arcing northern bend in the river. The fan deposits have been eroded to various degrees as the channel has widened following past incision. At the downstream end of the reach, there is a series of intermediate terraces that appear to have formed following erosion into the Buttermilk Creek fan (Figure 51). These surfaces are likely comprised of glacial outwash material that formed during and immediately following the last glaciation period. The smaller modern channel has incised into these surfaces and has created a new lower floodplain surface, abandoning these higher terraces.

The influence of the Buttermilk Creek alluvial fan has resulted in the semi-confined nature of this reach, with the modern extent of active floodplain largely controlled by its presence. Erosion into this material via channel scrolling has created the modern floodplain surface. More recent contributions of alluvial material from Buttermilk and Canyon Creeks have a large influence on these erosion processes. The influx of material fuels the cycle of bedload deposition, lateral erosion, subsequent downriver deposition, etc.

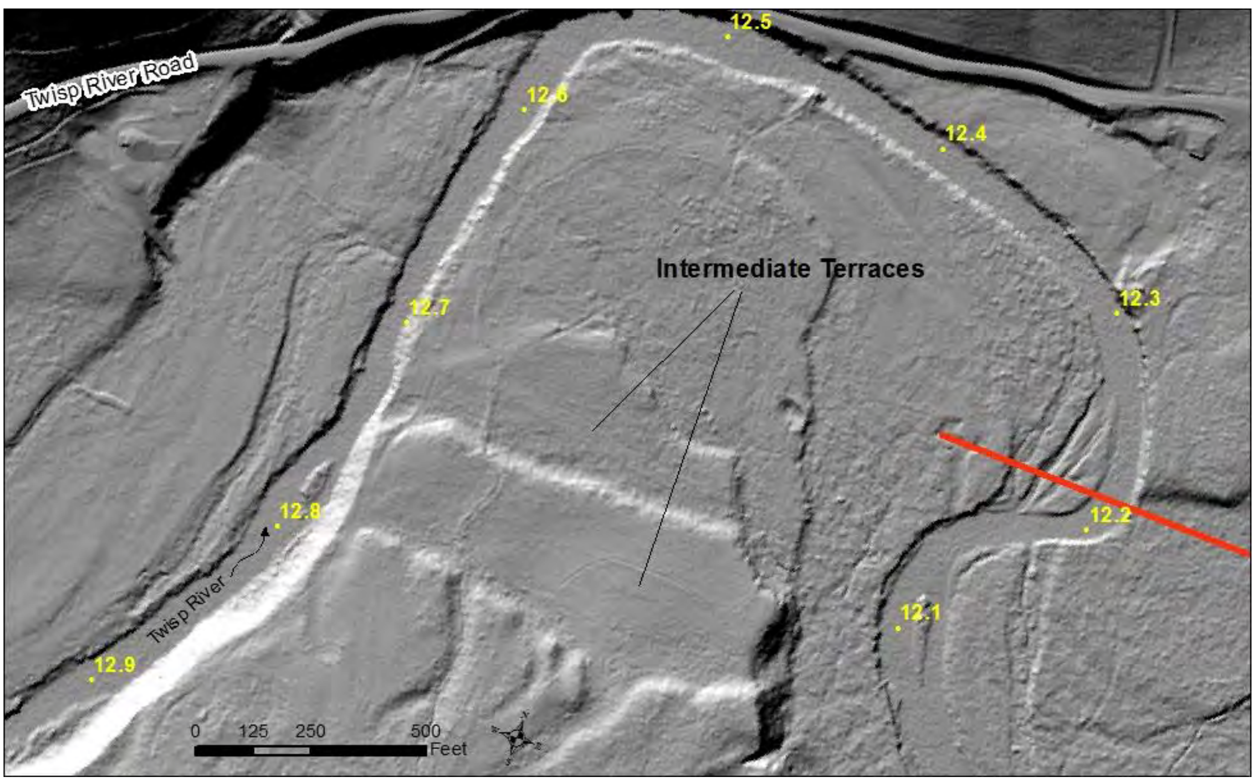

Figure 51. Location of glacial outwash terrace deposits formed during or immediately following the period of last glaciation.

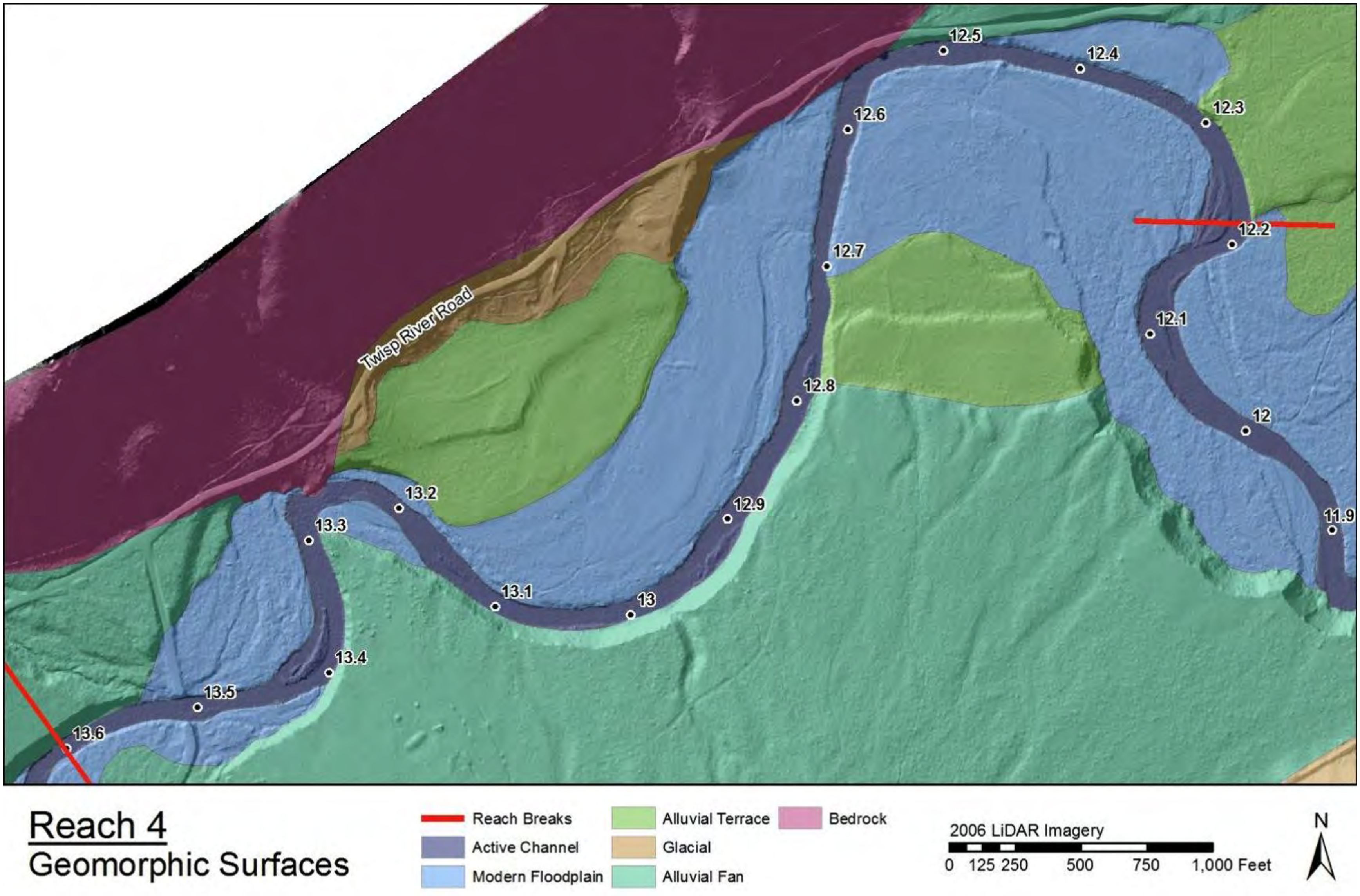

Figure 52. Geomorphic surfaces in Reach 4.

Hydrology

There are two tributaries that enter the reach at the upstream end: Buttermilk Creek and Canyon Creek. Buttermilk Creek, which enters from the south, is a significant contributor of flow. Buttermilk Creek adds approximately 20% of the flow to the Twisp River at this location. The contemporary Buttermilk Creek channel is located along the upstream edge of the fan. It has been in this location at least since the period of the earliest aerial photo records (1953). Canyon Creek is smaller, but is steep and contributes large material to the Twisp River channel (Figure 53).

Figure 53. Mouth of Canyon Creek showing large cobble and boulder material contributed to the mainstem Twisp.

Floodplain and Channel Migration Zone

Although this is the most sinuous reach in the study area, it has only moderate floodplain availability due to the semi-confined nature of the channel. The floodplain inundation map from HEC-RAS modeling using the LiDAR-derived surface is provided in Figure 54. Alluvial fan deposits naturally limit lateral channel migration and floodplain formation through this reach, resulting in relatively high lateral stability. LiDAR provides evidence that the channel has experienced multiple historical incision episodes based on sequences of abandoned terraces on the distal end of the Buttermilk Creek alluvial fan as well as on the north side of the valley near RM 13.1 – 13.2. There is also more recent evidence of incision on the terrace on river-left in the middle of the reach where alluvial processes (scour) are visible on the now abandoned terrace (see Figure 52).

There is greater floodplain connectivity and evidence of more recent active channel migration at the upstream and downstream ends of the reach. The floodplain is relatively well-connected at the upstream end where the river has re-worked bedload material contributed from Buttermilk and Canyon Creeks. The floodplain is also relatively well-connected at the downstream end (river-right) where the channel has scrolled to the north and has left a low floodplain surface to the south.

Channel changes since the earliest available aerial photos were mapped and are presented in Figure 54. This analysis shows that the channel has been mostly stable since 1953. There are no aerial photos that pre-date the flood of record in 1948, when channel adjustments would likely have occurred.

The Buttermilk Creek Road Bridge at the upstream end of the reach, and the private bridge at RM 12.46, provide some floodplain and CMZ impacts. These are discussed in greater detail in the Human Alterations section below.

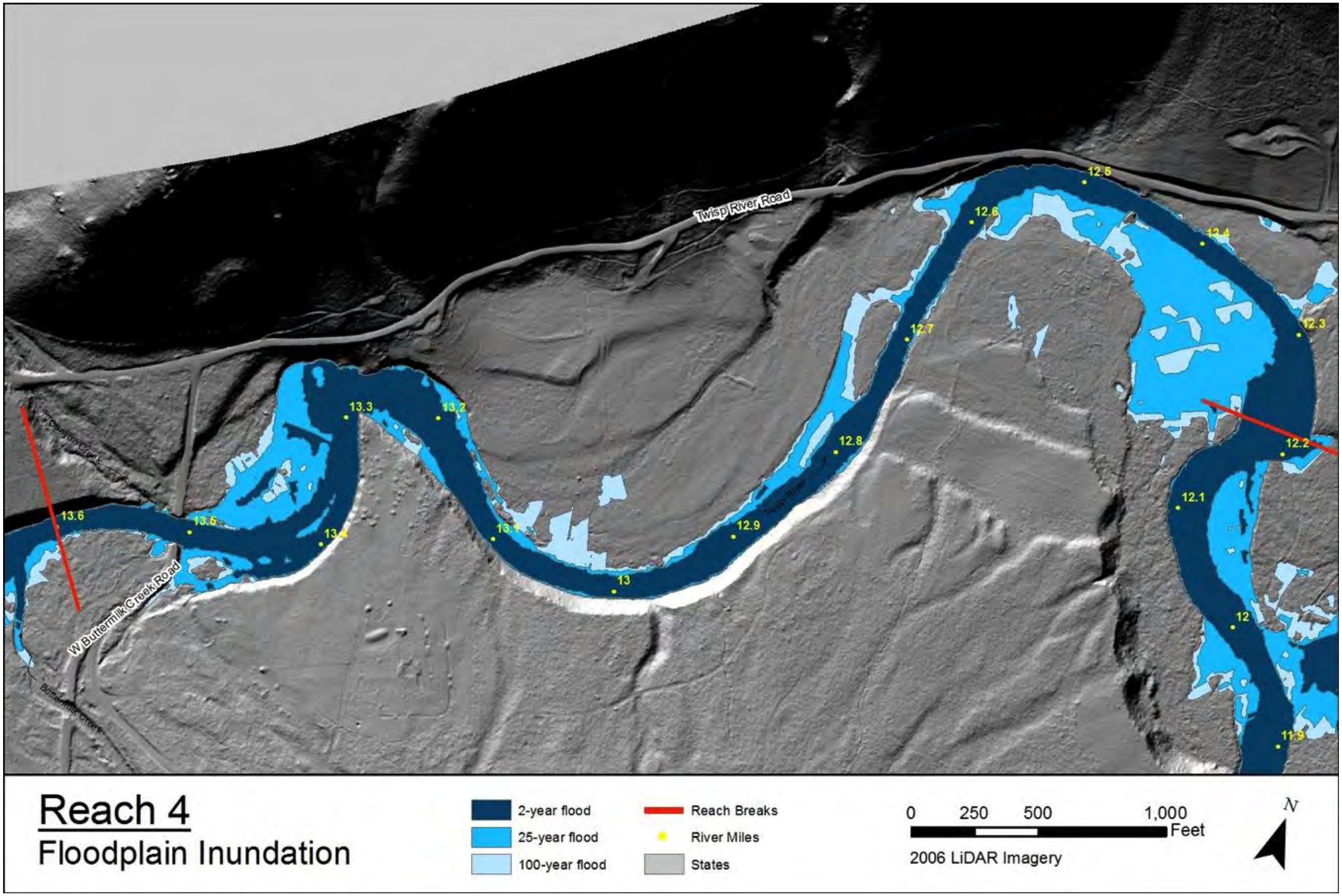

Figure 54. Extents of floodplain inundation for selected flood recurrence intervals in Reach 4. Flood inundations developed using HEC-GeoRAS based on the LiDAR surface.

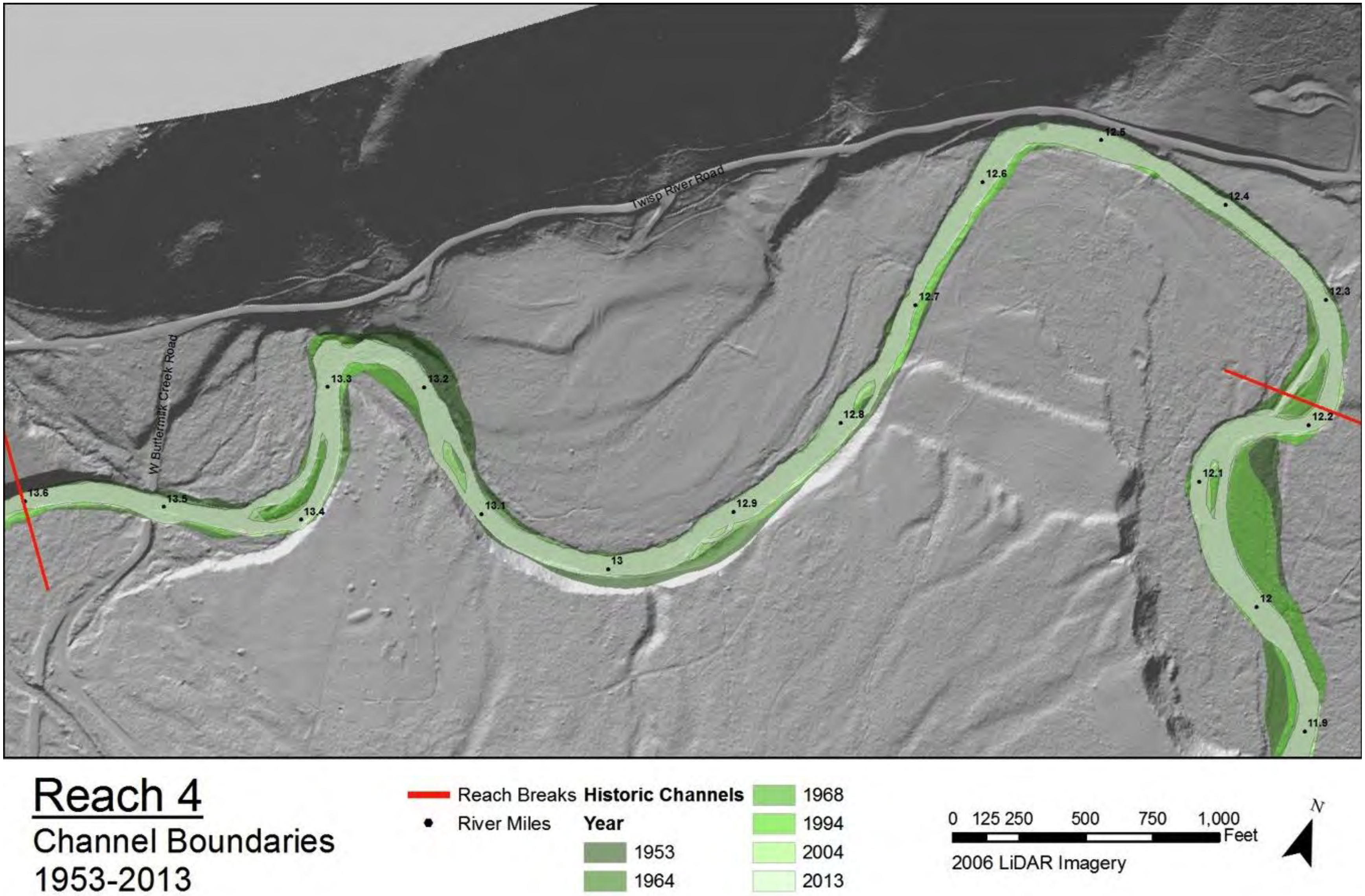

Figure 55. Historical Channel Boundaries

Sediment

The reach is primarily transport dominated, with occasional areas of deposition ('response'), which are mostly located in the upstream and downstream portions of the reach where the river has developed a wider active channel migration zone and gradient is less. Plane-bed riffle and glide channel units prevail, with only occasional pools. Bed substrate is dominated by cobbles (56%), with gravels subdominant (31%). There are few gravel bars (Figure 56). There are not many fines, although fine sediment accumulation was observed on the channel bed at the downstream end of the reach where the gradient lessens.

There are several sediment sources in this reach including older fan deposits that the river has eroded into, more recent tributary inputs, and bank erosion from modern alluvial surfaces. Topographic evidence indicates that the channel has been eroding towards the river-right into the large Buttermilk Creek alluvial fan; however, the channel has been relatively stable over the last 60 years (available air photo record). Contemporary active erosion into more recent alluvial surfaces occurs in various locations. Near RM 12.9, there is active erosion along the river-left bank, resulting in gravel recruitment to the channel. Another sediment source occurs just downstream of RM 13 where large alluvial fan material output from the abandoned alluvial fan channel has resulted in a large accumulation of boulders approximately 12 to 15 feet above the water surface elevation. The cobble and boulder bar located just downstream is also likely sourced from this channel.

Buttermilk Creek and Canyon Creek enter the reach at the upstream end and contribute sediment during floods. The 1953 aerial photo shows evidence of a recent debris flow in Buttermilk Creek, which likely contributed a significant amount of sediment, including bedload, to the Twisp River (Figure 57). It is possible the debris flow occurred during the 1948 regional flood event.

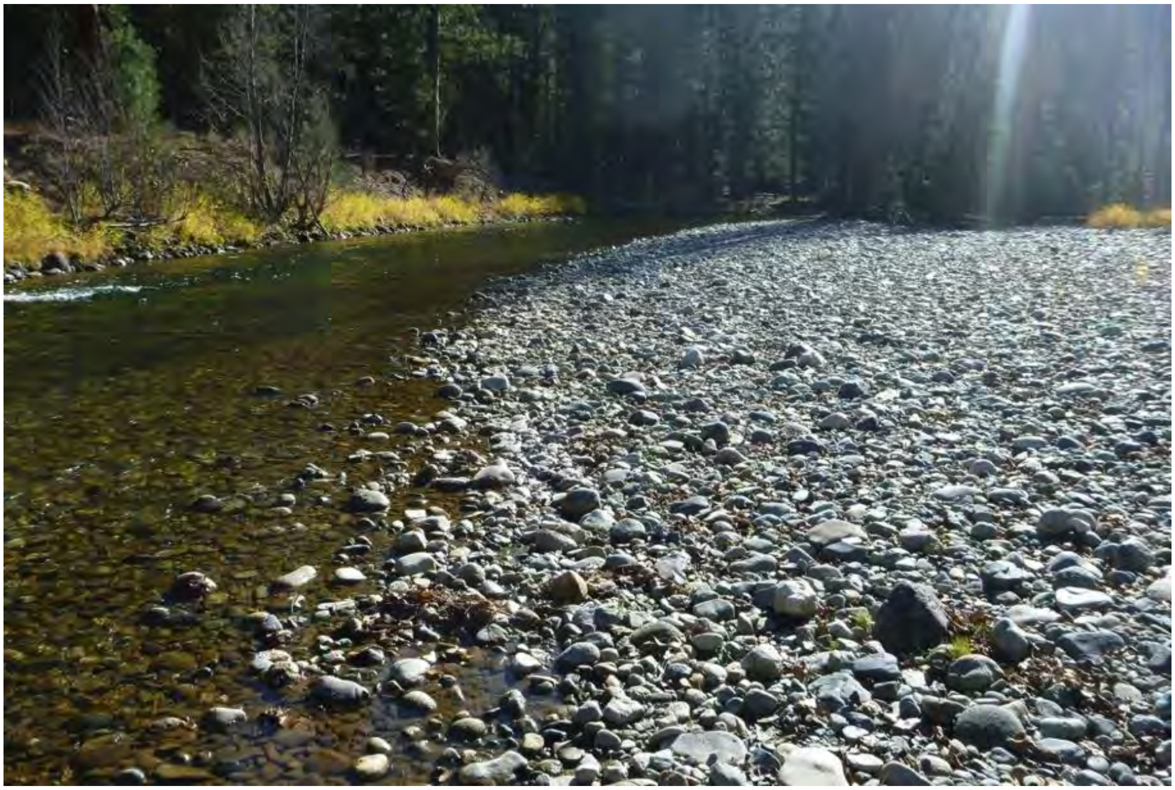

Figure 56. One of the few cobble bars in Reach 4. This one is located on river-right near RM 12.3.

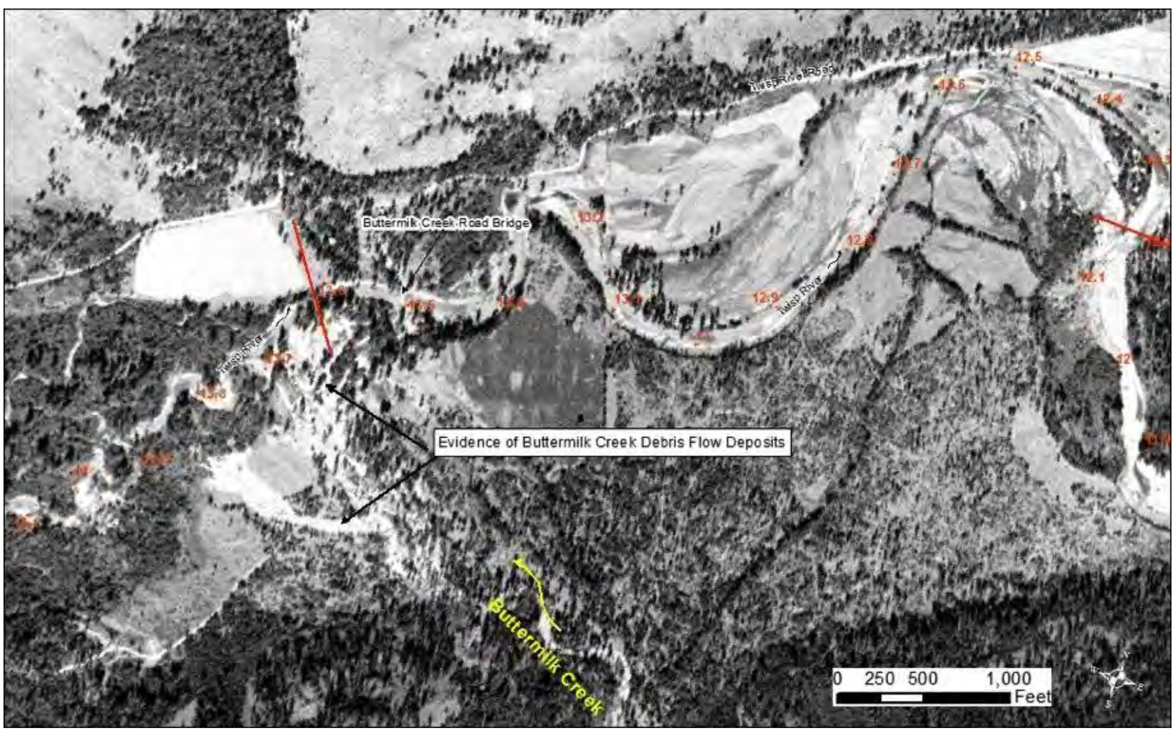

Figure 57. 1953 aerial photo of Reach 4 and downstream portion of Reach 5 showing evidence of Buttermilk Creek debris flow deposits. The red lines are the reach breaks.

Large Wood

Reach 4 had the lowest frequency of medium and large wood in the study area (9.4 medium and large pieces per mile), but had relatively abundant small wood and 2 bar apex log jams. The jams were comprised primarily of small material. The existing in-channel complexity that does exist in this reach is largely a result of the islands and log jams that are driving split flow. The islands that were observed in this reach had established alders providing stability and protection from erosion. The islands also act as a strainer for wood being transported downstream.

Figure 58. Bar apex log jam near RM 12.8 in Reach 4. This is one of only two log jams in the reach. Both jams were comprised primarily of the 'small' size class of large wood.

Vegetation

Vegetation conditions in Reach 4 consist of a variable width riparian buffer comprised of both conifers (primarily Douglas fir) and deciduous species (primarily cottonwood and alder). Canopy heights are depicted in Figure 59, which demonstrates the relatively young and sparse riparian and floodplain vegetation conditions. Of the 5 measured habitat units in the habitat survey, dominant overstory vegetation was 'small tree' for 3 of them, 'grass/forb' for 1, and 'no vegetation' for 1.

Riparian and floodplain vegetation in Reach 4 play a lesser role in channel form and dynamics compared to the more alluvial reaches (i.e. Reaches 3, 5, and 6) in the study area where there is a greater degree of floodplain connectivity and riparian trees are more readily recruited to the channel. Recruitment of riparian trees does still occur in Reach 4, but it is primarily from natural tree mortality, with only a few areas where there is active recruitment from bank erosion. Riparian vegetation does, however, play an important role in providing bank integrity and stream shade.

Under historical conditions, vegetation would have played a larger role in channel form and process in the reach. This would have been the result of large trees that could be recruited to the channel as stable "key pieces" of LW. The resulting log jams would then create additional lateral dynamics, with more recruitment of LW, and the cycle would continue. There also would have been large shade-producing conifers that would have helped control water temperatures.

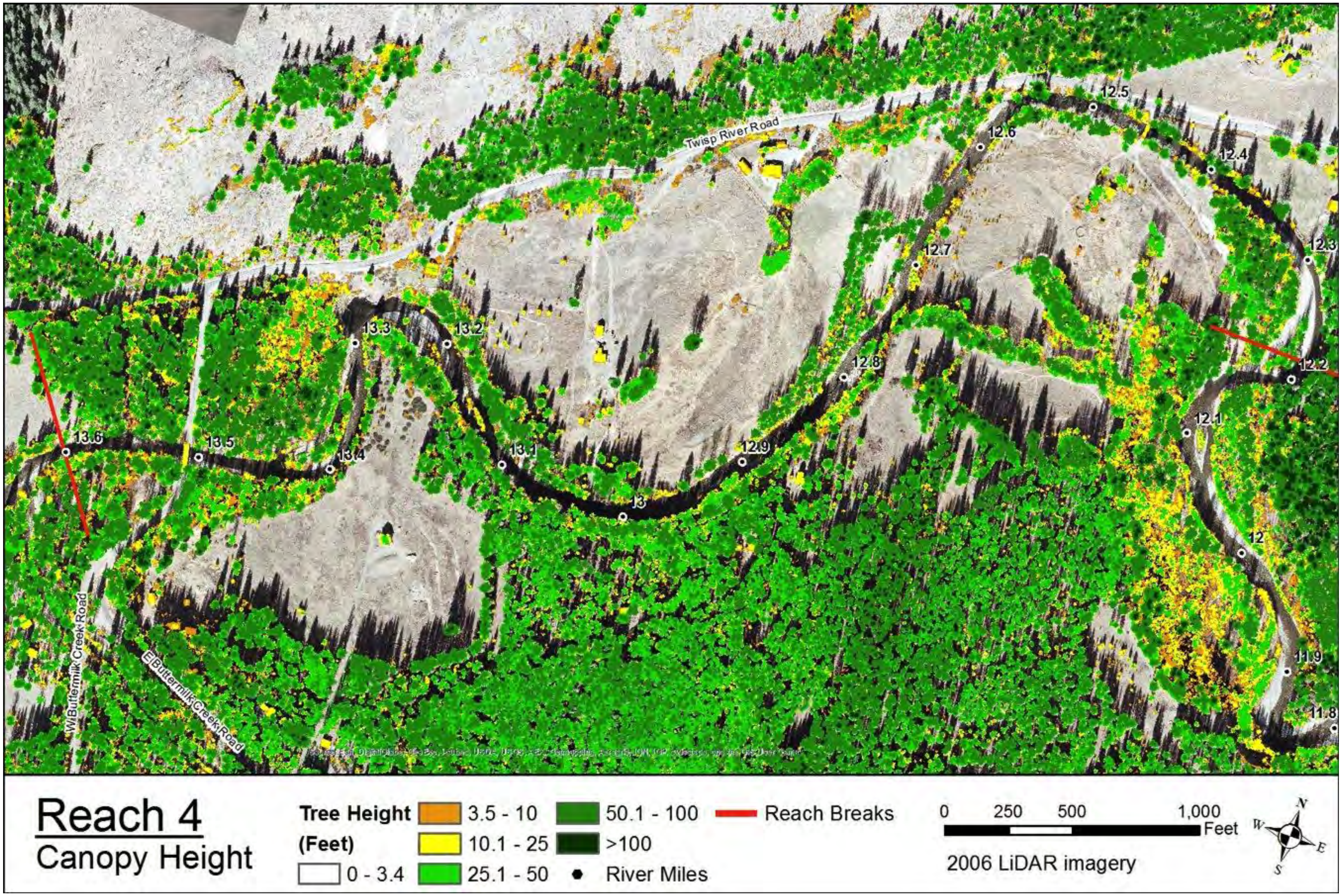

Figure 59. LiDAR first return (highest hit) data for Reach 4. These data show vegetation canopy heights. Buildings and other human infrastructure are also included in this data but there are only a few occurrences in the reach.

3.4.3 Human Alterations

The already limited amount of floodplain inundation and channel migration potential has been altered by bridges, levees, floodplain grading, and bank armoring. There are two bridges in this reach contributing to floodplain discontinuity and inhibiting lateral migration. Much of the floodplain has been cleared and graded for agricultural, residential, and recreational uses. Push-up levees, oftentimes intermittent, are located along much of this reach, with impacts on floodplain inundation rates. Cleared riparian areas dominate much of the reach with impacts to channel stability, shade, and large wood recruitment. Large wood and log jam numbers are significantly reduced from what would be expected under historical conditions. A map of human features in the reach is provided in Figure 62.

Bridges

One of the primary human alterations to Reach 4 are the two bridges that cross the Twisp River. The downstream bridge (RM 12.46) has associated riprap upstream and downstream along both banks that affects floodplain inundation along river-right (Figure 60). The effect is less on river-left due to the proximity of the hillslope. The bridge appears to be low and narrow and is acting as a channel constriction under high flows. Gullying was noted on the left bank along the roadway around RM 12.55, with the potential for fine sediments entering the system. There are multiple large trees leaning over the channel in this area that are potential sources of large woody debris and could enhance in-channel habitat and provide cover for fish.

There is a second bridge at RM 13.5 (Figure 61). The bridge and associated riprap disconnect natural fluvial processes; the road prism disconnects floodplain continuity and the riprap prevents channel migration. The right bank has large gravel deposits extending from the center bridge pillar to the bank abutment. This deposit is composed of material similar to the channel bed materials, indicating the potential for mobilization during high flow events. There is fill associated with the roadway on the north and south approaches to the bridge. These block floodplain continuity in the river-left and river-right floodplains. The hydraulic modeling results indicate that this human alteration has resulted in floodplain discontinuity, particularly on river-right, as a result of road embankment construction.

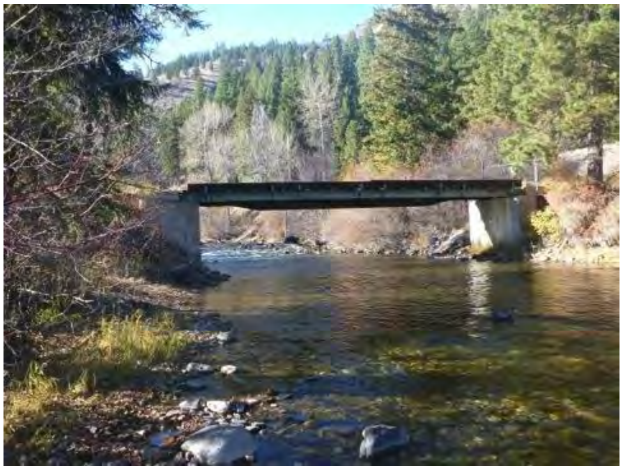

Figure 60. A small single lane bridge with abutments on the channel margin at RM 12.46.

Figure 61. Bridge at RM 13.5 looking upstream.

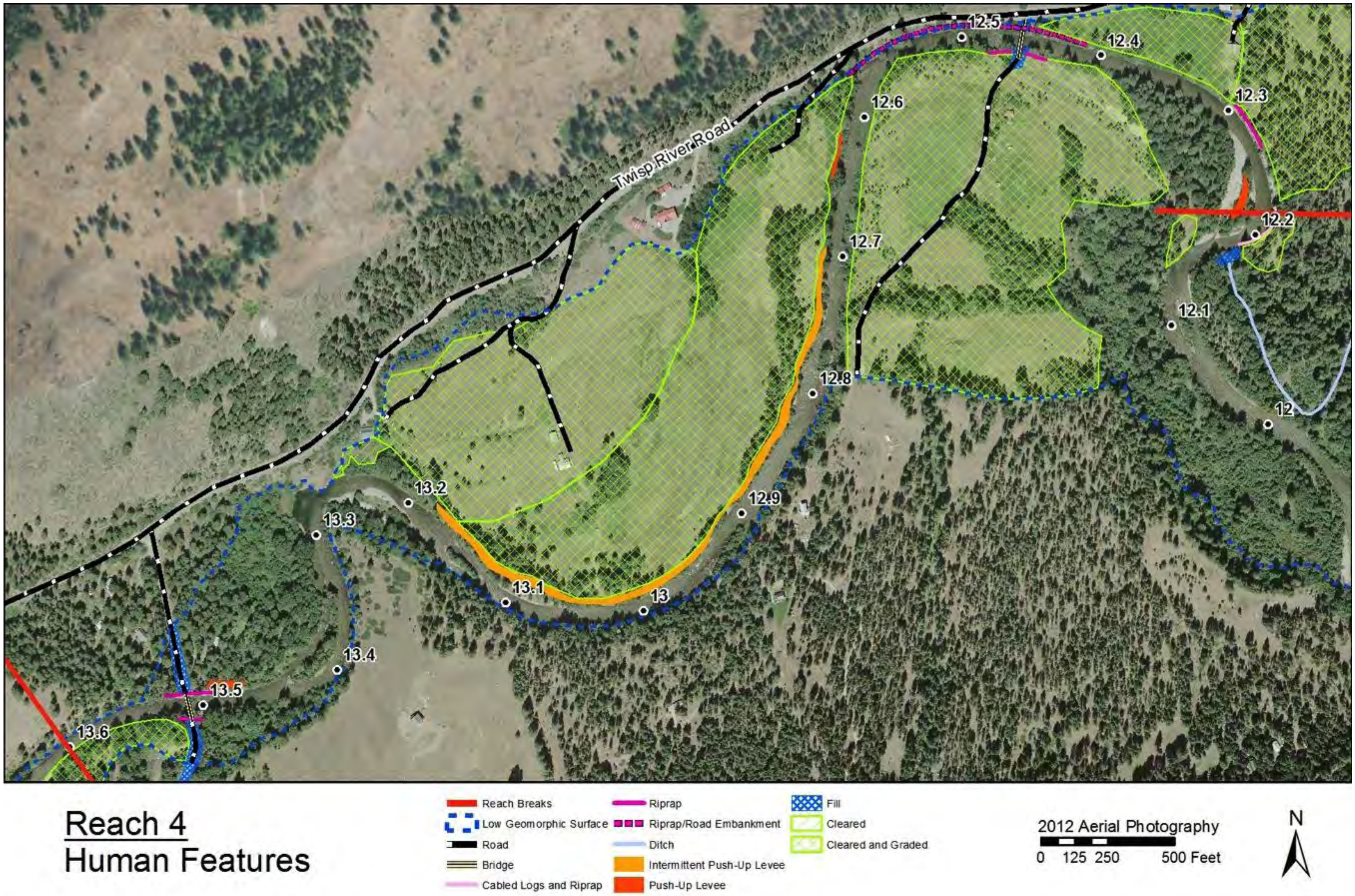

Figure 62. Human features in Reach 4.

Floodplain Grading, Levees, and Bridges

Much of the floodplain has been cleared and graded for agricultural, residential, and recreational uses. Push-up levees, oftentimes intermittent, are located along much of the reach, with impacts on floodplain inundation rates. Clearing and grading has taken place along river-left from RM 12.3 to 13.15 in the modern alluvial terrace as well as the 100-year floodplain. Bank erosion was noted at several locations throughout the reach (e.g. right bank at RM 12.6) likely a result of riparian vegetation clearing to the water's edge. There is a push-up levee on river-left at RM 12.81 with fallen alders on it that was potentially constructed to prevent flow into the high flow channel on the left-bank. There is also a push up levee along the right-bank on the interior of the channel bend at RM 12.24, but it does not appear to be disconnecting hydraulic connectivity of the annually active high flow channel on the interior of the levee. Two bridges, and their associated approach fills, contribute to floodplain disconnection and inhibit lateral migration.

Loss of Instream Habitat Complexity

Due to the transport dominated character of the reach and general lack of planform complexity, large wood would not be expected to play as large of a role in Reach 4 compared to Reaches 3 or 5. However, large wood jams would nevertheless have been expected to form under historical conditions when wood loading and wood sizes were greater. These contributions would likely have increased complexity and dynamics (e.g. split flow, channel migration) in the reach compared to historical conditions. The lack of wood in recent decades may help explain the relatively static location of the channel over the past 60 years.

Significant Riparian Impairment

Riparian and floodplain vegetation conditions in Reach 4 have been heavily impacted by human uses including the Twisp River Road, agricultural clearing, and clearing associated with rural residences. The canopy height figure (Figure 59) shows the degree of impact on riparian vegetation in the reach. This figure demonstrates that the riparian buffer is rarely greater than 100 feet wide and that riparian vegetation is mostly comprised of trees less than 100 feet tall. There are several areas with little to no riparian corridor where there is clearing up to or very near the channel.

Impaired riparian conditions have affected several biological and physical processes in the reach. The potential for LW loading has been reduced, and is likely at least partially responsible for the low LW and log jam numbers. Some of the bank erosion occurring in the reach, particularly around RM 12.9 appears to be related to lack of riparian vegetation needed to provide bank integrity. Lack of riparian canopy also affects water temperature in this reach. Beyond the riparian areas, floodplain areas are also heavily cleared, particularly on the river-left in the middle section of the reach and within the river-right floodplain at the downstream end of the reach. These reductions in floodplain vegetation can have negative impacts on floodplain refuge habitat, rates of channel migration/avulsion, off-channel habitat development, and LW recruitment during avulsion or channel migration events.

Figure 63. View of river-left bank near RM 12.65 showing evidence of active clearing of riparian and floodplain vegetation.

3.5 REACH 5

3.5.1 Reach Overview

Reach 5 corresponds to the downstream portion of T6a from the USBR Methow Subbasin Geomorphic Assessment and extends 2.59 miles from RM 13.6 (confluence of Buttermilk Creek) to RM 16.19. Reach 5 is a dynamic, lower gradient braided reach (Figure 64). This portion of the study area provides analog conditions as much of the reach has a dynamic, multi-thread channel, with active lateral channel dynamics, abundant off-channel habitats, and high large wood and log jam numbers. There is a large levee/pond complex in the upstream portion of the reach along river-left, reducing available habitat and limiting lateral migration to the north in this area. This reach exhibits rapid channel repositioning via bank erosion and avulsions. Significant channel changes occur on the order of every 10 to 15 years. This degree of change, although good for creation of new habitats, may be greater than under historical conditions when larger riparian trees, larger downed trees in the channel and floodplain, and large stable log jams would have created a greater degree of stability. The more active contemporary channel could potentially be a redd scour and sedimentation issue.

Landownership in Reach 5 is primarily private, with the exception of a small portion of the active floodplain on both sides of the channel from approximately RM 14 to 14.2 and along river-right from RM 15.1 to 15.3 and 14.2 to 14.4, which is National Forest land (Figure 65).

Figure 64. A representative section of Reach 5 at RM 14.1.

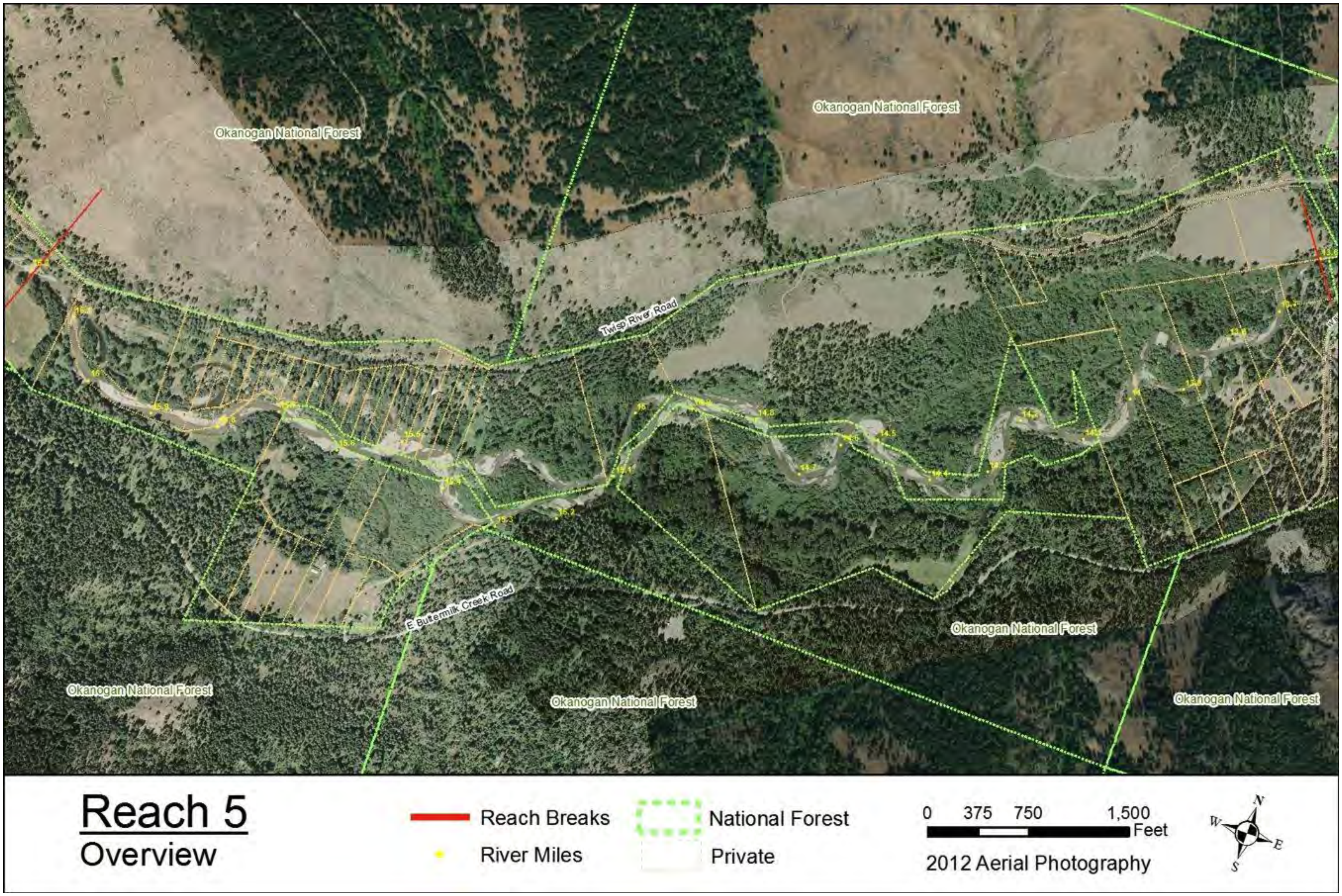

Figure 65. Overview map of Reach 5 showing landownership.

Table 14. Key descriptive and geomorphic metrics for Reach 5.

Metric	Value
Reach Length	2.59 miles
River miles	13.6 to 16.19
Valley gradient	0.84%
Stream gradient	0.59%
Sinuosity	1.34
Dominant Channel Type	Pool-riffle
Avg bankfull width	92.6 ft
Avg floodplain width	393 ft
Dominant substrate	Gravel/cobble

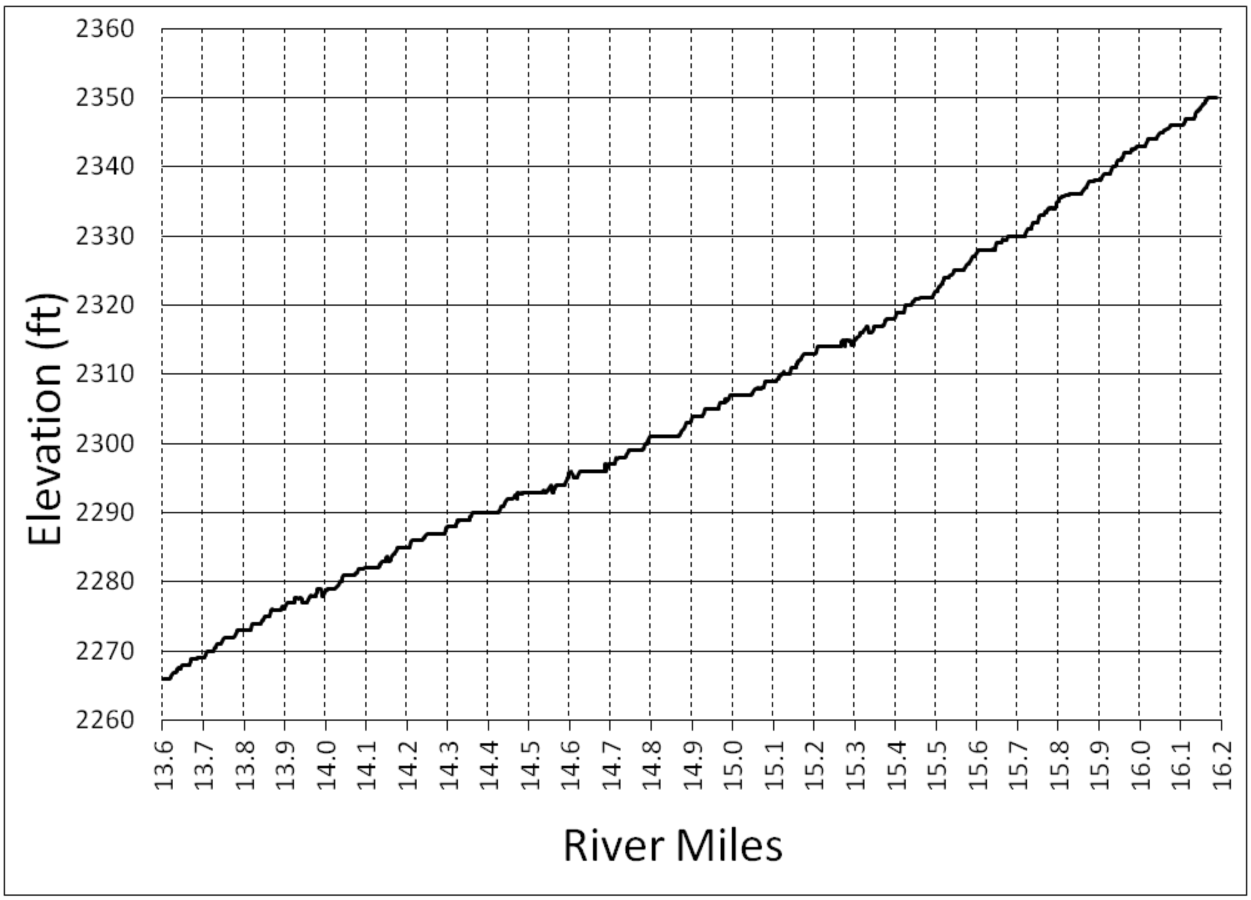

Figure 66. Longitudinal profile of Reach 5. Elevation data is derived from the 2006 LiDAR data and so represents water surface at the time of the LiDAR flight.

3.5.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 5 has a complex, multi-thread channel, with active lateral channel dynamics and abundant off-channel habitats. The mainstem has a relatively even makeup of glides, riffles and pools (Appendix A). The dynamic braided system is largely due to the channel's low gradient (0.59%; Figure 66) and lack of confinement along the channel margins, with alluvial fans primarily forming the margins along the north and south valley walls.

Hydrology

There are two primary tributaries that enter this reach. At the upstream end, Scaffold Camp Creek enters from river-right. The Scaffold Creek alluvial fan has a large effect on channel morphology in this area. At the downstream end of the reach, Buttermilk Creek enters from river-right. Buttermilk Creek contributes approximately 20% of the flow to the Twisp River. Other drainages include Lime Creek and numerous smaller unnamed tributaries.

Floodplain and Channel Migration Zone

The floodplain in Reach 5 was the widest and most active within the study area (Figure 72). Based on results from the hydraulics analysis, nearly the entire valley floor is inundated at the 100-year flood and many of the off-channel habitat features are active at more frequent flows (Figure 71). The braided nature of the channel results in frequent active high-flow channels and point and mid-channel bars that are active during regular high flow events (e.g. Q1 to Q5; Figure 71). This portion of the study reach had extensive side channel networks with dense vegetative cover in some locations, providing excellent habitat. This portion of the study area provides a good analog for the active nature and frequent floodplain inundation that would be expected to be found in Reaches 3 and 6 in the absence of human alterations.

The dynamic nature of the channel in this reach has resulted in channel migration as recently as 2012, with an avulsion and channel abandonment that took place at RM 14.5 (Figure 68). The previous channel is primarily exposed gravel deposits with high flow channels throughout the area. Based on the historical aerial photo record, the channel has actively migrated throughout the low surface over the past several decades (Figure 72). As discussed below under the Large Wood section, the rate of channel adjustment may be greater now due to a reduction in sizes for both instream wood and riparian trees. This may have a detrimental effect on habitat conditions through redd scour.

Reach 5 has the largest amount of side channels within the study area, with the 19 measured side channels accounting for 18% of the habitat area in the reach (Habitat Assessment, Appendix A). The largest side channel was 4,956-feet long with significant amounts of wood accumulation that provides a tremendous amount of rearing habitat as well as spawning potential (Figure 69). The side-channels and backwater alcoves throughout the floodplain provide high flow refugia (Figure 70).

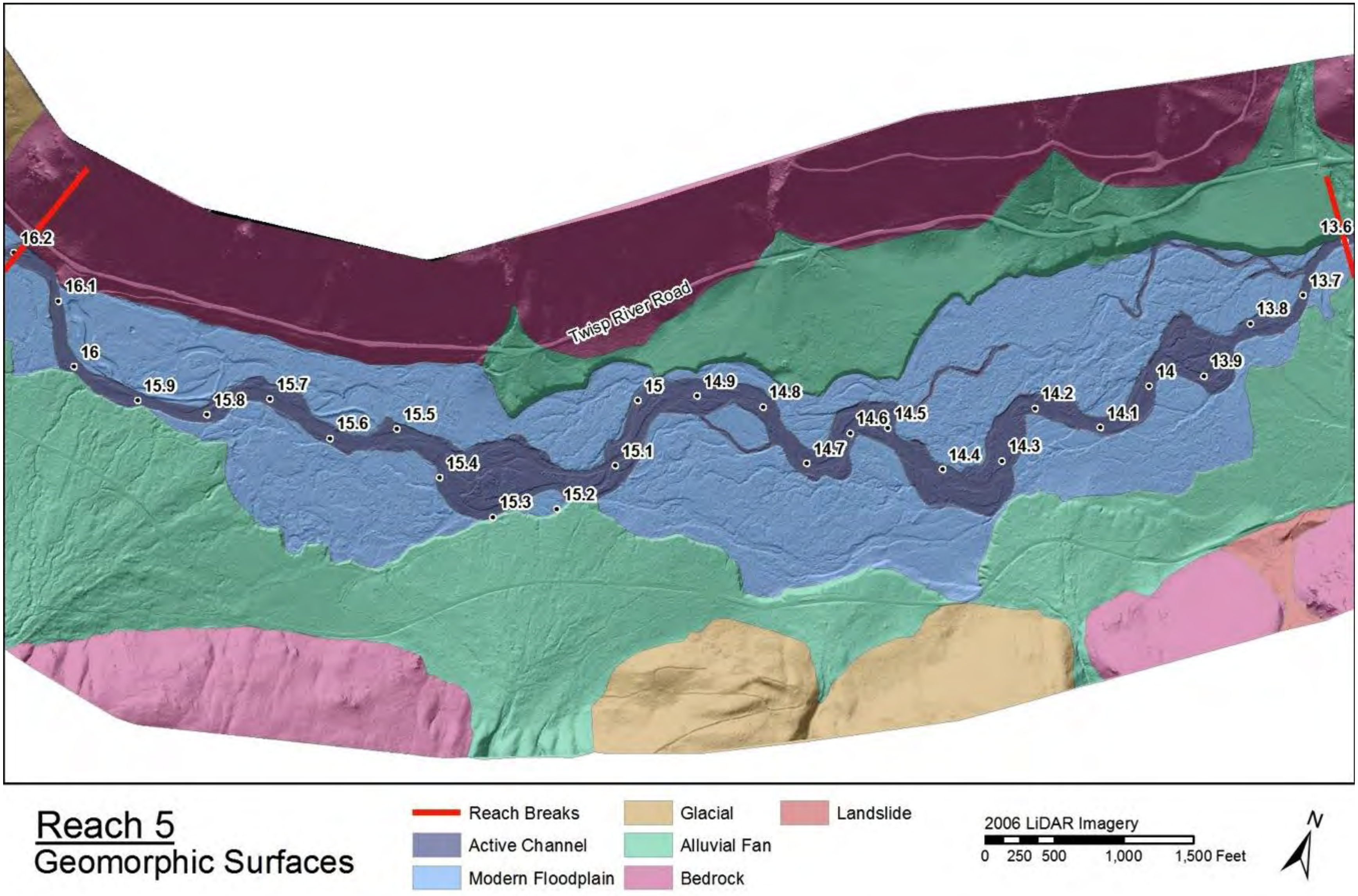

Figure 67. Geomorphic surfaces in Reach 5.

Figure 68. Channel avulsion occurred at RM 14.5 and a large gravel deposit remains on river-left in the previous main channel with evidence of high flow scour

Figure 69. A representative photo from the 4,956 foot long side channel.

Figure 70. River right at RM 14.4 there is a beaver dam creating a backwater alcove.

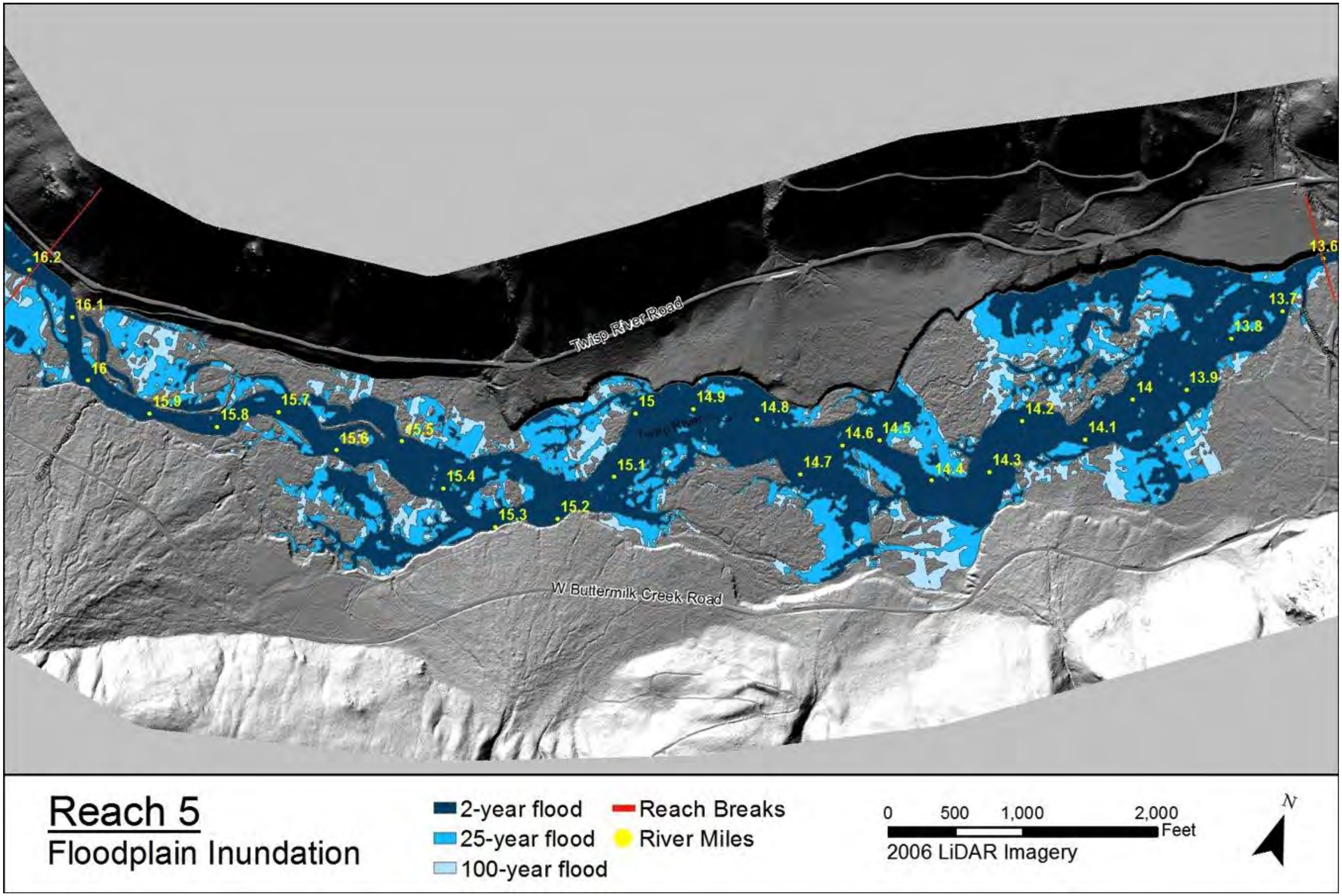

Figure 71. Extents of floodplain inundation for selected flood recurrence intervals in Reach 4. Flood inundations developed using HEC-GeoRAS based on the LiDAR surface.

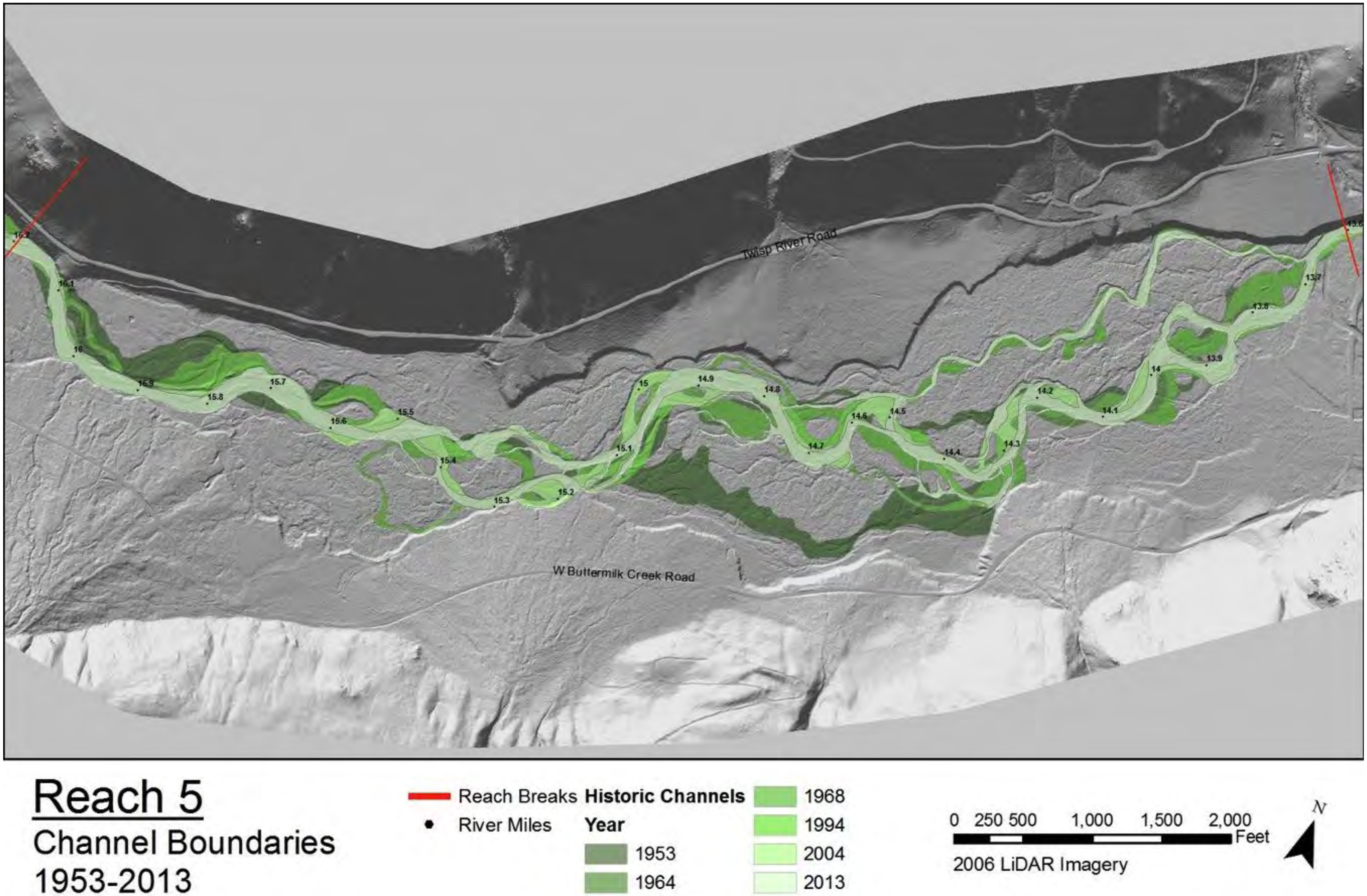

Figure 72. Historical channel boundaries for Reach 5.

Sediment

The sediment measured on the channel bed in this reach was equal parts gravel and cobble, and is the finest observed in the study area. The finer composition of the bed surface is likely a result of the low gradient depositional channel type. Bars observed in this reach were primarily gravel and sand, and lacked established vegetation on these surfaces, indicating that they are scoured and filled regularly.

This reach is very much a response reach and may be on a trend of aggradation based on the frequent bar deposition and frequent planform adjustment. Material is sourced almost exclusively from erosion of the modern floodplain surface, with only a few areas where the channel currently abuts terrace deposits (primarily alluvial fan in origin). Thus, the bed sediments lack the coarse input from colluvial sources relative to other reaches.

Large Wood

Reach 5 had high quantities of large wood and log jams when compared to the remainder of the study area. This reach had 537 pieces of wood, for 207 pieces per mile. A significant portion of the wood (27%, or 145 pieces) were found in the over 15,000 feet of side channel habitat (Appendix A). Although this reach had a significant amount of total wood, only a fraction of the pieces (34 pieces) were considered “large” pieces (>20 inches diameter; >35 feet long). There was also a lot of smaller wood that was smaller than the minimum length required for a qualifying piece, and therefore was not counted. A total of ten log jams were observed in Reach 5, comprising 155 pieces of wood (Appendix A). Significant quantities of cut wood were found near RM 15.4 that appeared to have been cut just upstream. Large wood was observed to typically accumulate at bar apexes and along low-angle gravel bars (Figure 73 and Figure 74). Wood is an important catalyst for rapid channel repositioning via bank erosion and avulsions. The frequency of channel adjustment may actually be greater now compared to historical conditions due to the relatively small size of the wood that is in the channel and that is available to be recruited. Historically, large wood would serve as key pieces that would form large jams that would persist for many years or even decades. In the current condition, there are smaller jams that are more transient and allow for more frequent channel adjustment. This poses a potential risk to salmonids via increased potential for redd scour or burial.

Figure 73. Large amounts of LWD have accumulated throughout this reach especially in the areas highlighted in red boxes.

Figure 74. Rm 13.85 wood deposition on the gravel bars throughout the channel.

Vegetation

The riparian corridor is relatively young with 43% shrub/seedling; 29% sapling/pole; 21% small trees; and 7% having no vegetation. The lack of mature vegetation is likely due to the dynamic nature of the channel that results in a re-setting of the vegetation trajectory relatively frequently (Figure 75). There are patches of large cottonwoods, and some large conifers, that are evident in the floodplain, but the channel is not currently eroding into these areas.

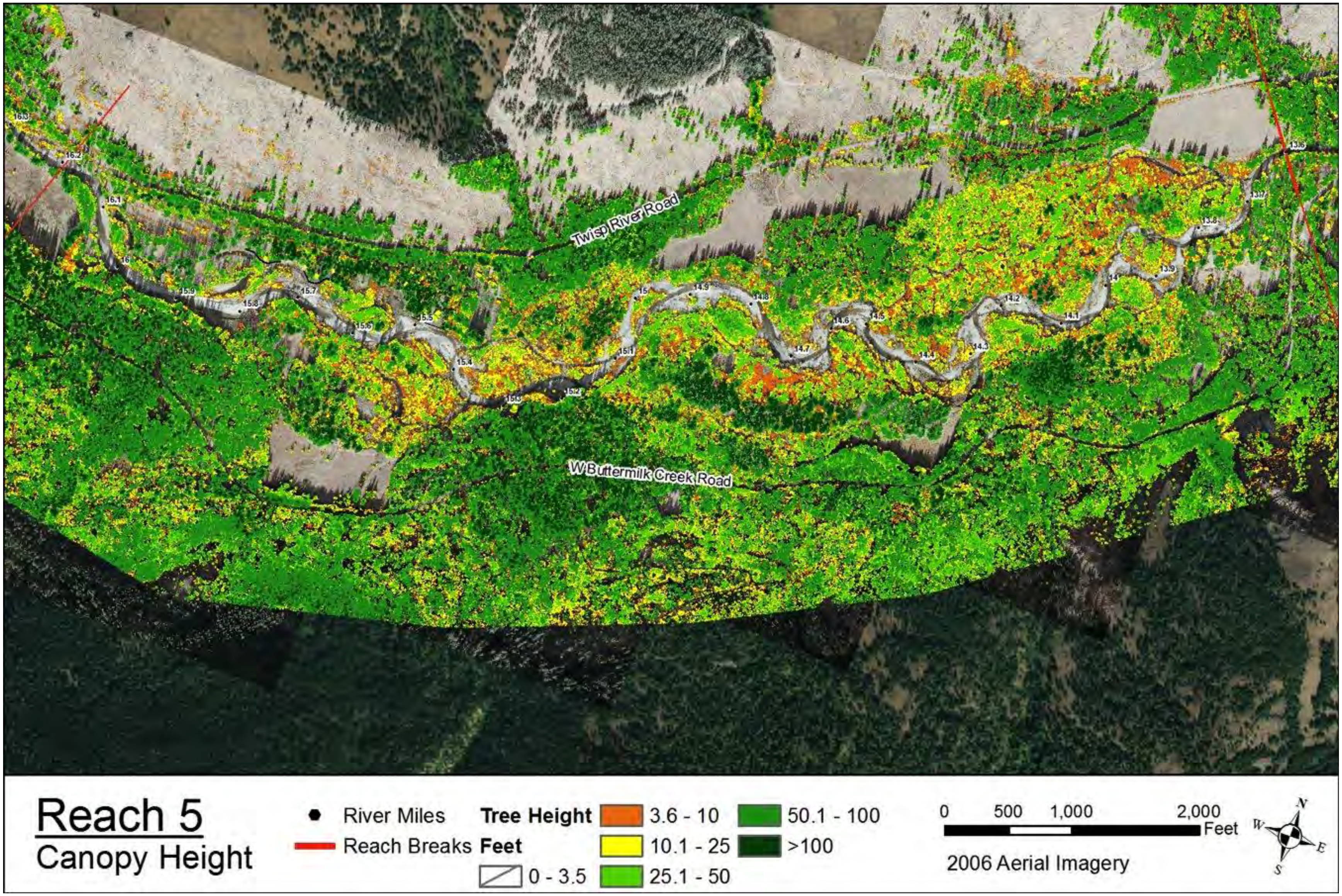

Figure 75. LiDAR first return (highest hit) data for Reach 5. These data show vegetation canopy heights. Buildings and other human infrastructure are also included in this data but there are only a few occurrences in the reach.

3.5.3 Human Alterations

Much of the reach length is largely unaffected by contemporary human hydromodifications. However, at the upstream and downstream ends of the reach there are some significant impairments. The greatest impairments occur at the upstream end of the reach in the river-left floodplain, where there is a levee and excavated pond complex that degrades floodplain function and off-channel connectivity. At the downstream end of the reach, on river-right, there are several areas of bank armoring that impair channel migration and riparian function. Past riparian timber harvest, combined with the probable past removal of large wood from the channel, has reduced riparian and in-channel structure, which has likely contributed to the extremely dynamic condition of this reach.

Figure 76. RM 13.8 riprap with large posts and a constructed footbridge constructed along river right opening to a gravel clearing.

Figure 77. RM 13.85 Significant riprap has been placed along river right of this this residential clearing with recreational elements up to the bank's edge.

Floodplain Fill, Grading, Levees, and Bank Armoring

There are two main areas where floodplain filling, grading, levees, and bank armoring have occurred: 1) downstream end on river-right from RM 13.6 to 13.9, and 2) upstream end on river-left from RM 15.45 to 16.1.

At the downstream end, clearing and grading have occurred within the 100-year floodplain related to recreational and residential uses (Figure 76 and Figure 77). There are also several areas of riprap along the channel banks and the construction of a small footbridge (RM 13.8). There is also a gabion wall that lines the lower end of Buttermilk Creek, near the confluence.

At the upstream end, there is a levee and excavated pond complex that impairs floodplain function, channel migration, and off-channel connectivity in this area. The levee complex limits lateral channel migration, reduces floodplain inundation, and disconnects the open water ponds and floodplain features from the mainstem Twisp River (Figure 79 and Figure 80). There is a gabion wall at the inlet to this levee complex (RM 16.1; Figure 78). A culvert provides an inflow to the pond complex under annual high flows with an outflow location at the levee breach at RM 15.91. The gabion walls prevent lateral channel migration. The culvert allows high flows to enter the pond complex, but does not allow for fish to access the area, except for at very high flows. The near channel pond at RM 15.8 has no low flow connectivity to the main channel, but is connected under high flows. The pond is approximately 4 feet deep and has fine sediment accumulation and submerged vegetation; tthere was no evidence of fish present in the pond complex. Just downstream of the primary levee and pond complex, there are a few areas were bank armoring (primarily riprap) is protecting houses within the floodplain and channel migration zone.

Figure 78. Gabion wall and culvert located at the upstream end of the large pond complex along river left at RM 16.1.

Figure 79. Pushup levee at RM 15.9 along river-left with established conifers

Figure 80. The near channel pond at RM 15.75 has no low flow connectivity to the main channel

Riparian Impairment

Riparian clearing has occurred primarily in the areas described above at the upstream and downstream ends of the reach. Clearing of riparian vegetation has reduced shading, the potential for large wood input, and bank stability.

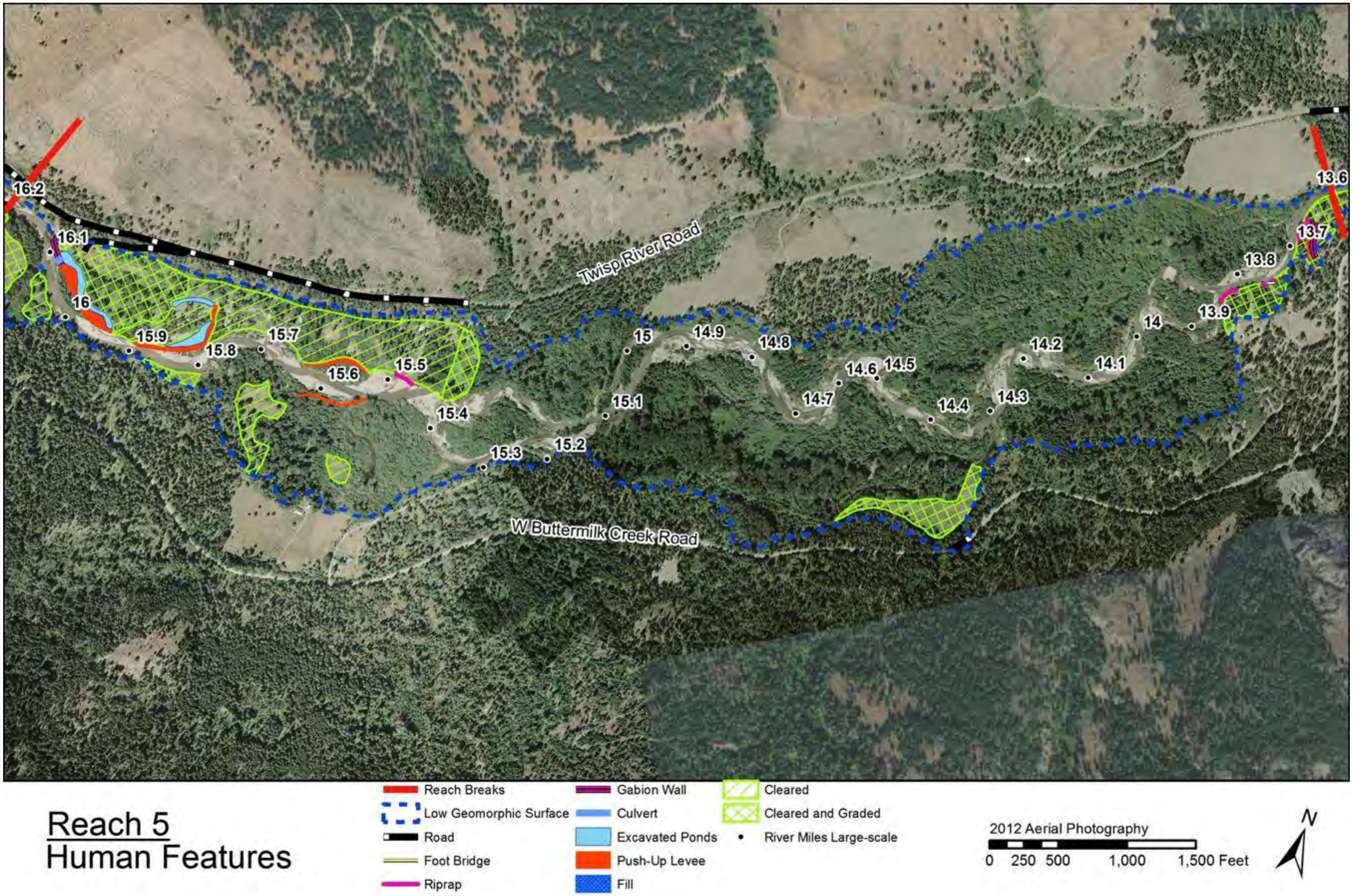

Figure 81. Human features in Reach 5.

3.6 REACH 6

3.6.1 Reach Overview

Reach 6 corresponds to Reach T6b from the Methow Subbasin Geomorphic Assessment (USBR 2008). Reach 6 is 1.93 miles long and extends from RM 16.19 to 18.12 (the upstream extent of this study; Figure 82). This reach is mostly unconfined but has a relatively steep gradient. There are different processes occurring throughout the reach; the upstream portion is fan dominated, the middle portion is naturally confined, and the lower portion of the reach is unconfined and dynamic. The fan dominated upper reach has overflow channels in the river-left floodplain. It is possible that there has been moderate disconnection of the floodplain in this portion of the reach due to the upstream bridge and floodplain fill effects. The bridge constricts the channel and the approach fills interrupt floodplain flows. The confined middle portion of the channel is a transport reach with some fallen conifers providing recruitment. The dynamic lower area has seen a recent avulsion (estimated following the 2012 floods) and is in an early successional channel state. In general, beneficial dynamic processes are occurring in this reach. This reach is predominately within the Okanogan National Forest with the exception of the downstream portion of the reach (Figure 83).

Figure 82. A representative section of Reach 6 at RM 17.6.

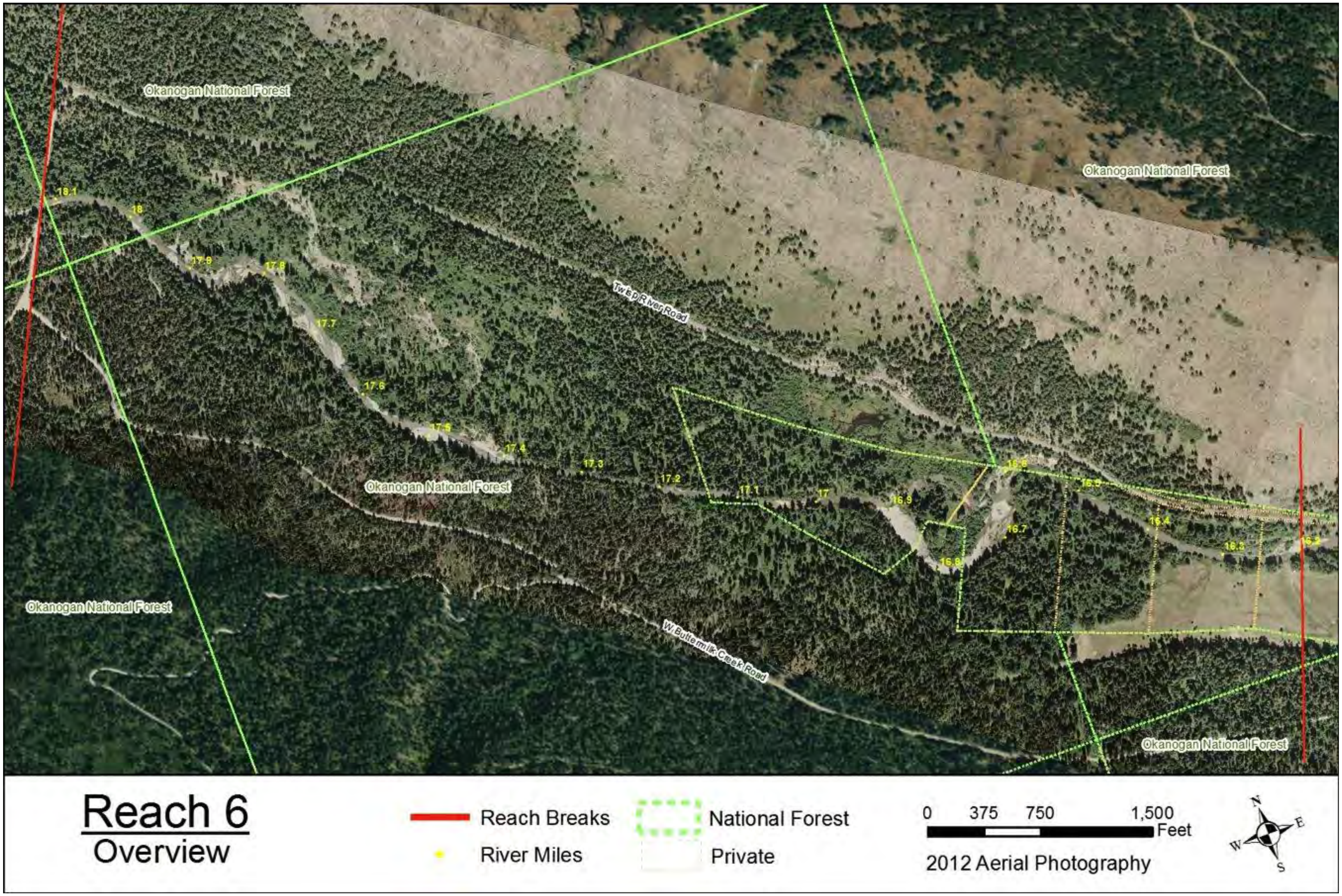

Figure 83: Overview map of Reach 6 showing landownership.

Table 15. Key descriptive and geomorphic metrics for Reach 6.

Metric	Value
Reach Length	1.93 miles
River Miles	16.19 to 18.12
Valley Gradient	1.08%
Stream Gradient	0.95%
Sinuosity	1.11
Dominant Channel Type	Pool-riffle
Avg Bankfull Width	72 ft
Avg floodplain Width	260 ft
Dominant Substrate	Cobble/ gravel

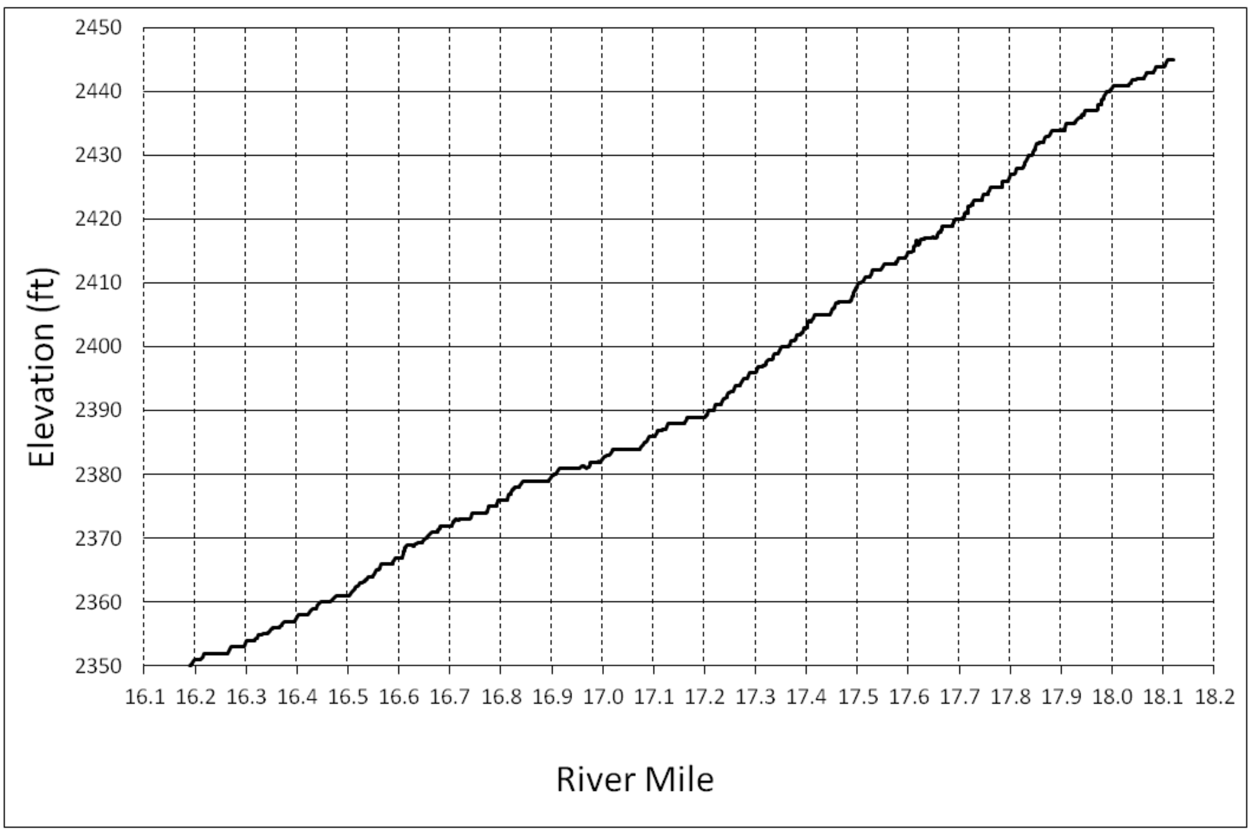

Figure 84. Longitudinal profile of Reach 6. Elevation data is derived from the 2006 LiDAR data and so represents water surface at the time of the LiDAR flight.

3.6.2 River Morphology and Geomorphic Processes

Geology and Landforms

Reach 6 is bounded on the river-right (south side of the study area) by the War Creek and Eagle Creek alluvial fans. Glacial, tributary fan, and alluvial terrace deposits form the north side of the valley. On river-left at the upstream end of the reach there is a broad floodplain that was occupied by the river as recently as the late 1980s. Reach 6 is high gradient in the middle, low gradient in the lower portion, and moderate gradient in the upper portion. Overall gradient is 0.95%. The reach has relatively low sinuosity (1.11). The channel units observed within this reach are primarily fast water units (69% riffles).

Hydrology

Two tributaries enter the mainstem in Reach 6, one of which was active under low flows and the other was ephemeral. The active tributary enters the mainstem along river-right at RM 17.11 (Eagle Creek). The steep, cobble-gravel channel had a step-pool planform and accounts for 15% of the flows observed in the mainstem directly downstream of this location. The second tributary was a large well-defined ephemeral tributary upstream on river-left at RM 17.22. It is primarily dry at low flows with some groundwater noted in the topographical depressions near the mouth. It appears to receive infrequent scouring flows and is composed of large cobble and small boulders with multiple pieces of large wood across the channel. War Creek enters the reach at the upstream end on river-right.

Floodplain and Channel Migration Zone

The channel is currently located adjacent to the alluvial fans on river right, with a large floodplain on river left for a majority of the reach. The river left floodplain pinches out with very little active floodplain development at the transition between Reach 5 and 6 (RM 16.2) where there are visible bedrock outcrops on the left bank channel margin. The maximum floodplain width is approximately 500 meters, making it one of the largest floodplains in the study area (Figure 87). Regular (i.e. Q1, Q2) floodplain inundation and scouring have created complex geomorphic features throughout the reach. Side-channels and backwater alcoves created through scour and fill alluviation provide high flow refugia throughout the reach (Figure 86).

Based on the results of the hydraulic analysis, portions of the entire valley floor are inundated during the 100-year flood and many of the off-channel habitat features are active at more frequent flows (i.e. Q2; Figure 87). In the upstream portion of the reach, the former mainstem once occupied what is currently the river-left floodplain (Figure 88). This channel is currently a high flow channel and is approximately 4 feet above the current elevation of the channel bed. There is evidence of scouring flows on this surface.

There is a wetland complex along valley-left at RM 16.6, which are old channel scars and were 3 to 4 feet deep at the time of the survey (Figure 86). The water surface elevation is controlled by beaver dams and natural earth berms. The outflow location does not appear to have low flow surface connectivity and there is an existing groundwater-fed outflow that is stopped approximately 80 feet from the mainstem by debris and floodplain deposits. This area is likely inaccessible to fish and lacks cover, but appears to be a properly functioning wetland.

There was a mainstem avulsion caused by a large log jam and upstream sediment accumulation, which forced a levee breach at RM 16.8. The new channel is now located to the north of the old channel. The new channel is still actively responding to this event, with new channel erosion resulting in large gravel bars and wood recruitment along the new meander. This area remains very dynamic and unstable.

The historical channel boundaries, shown in Figure 88, illustrate the dynamic nature of the channel and the previous channel avulsions that have taken place.

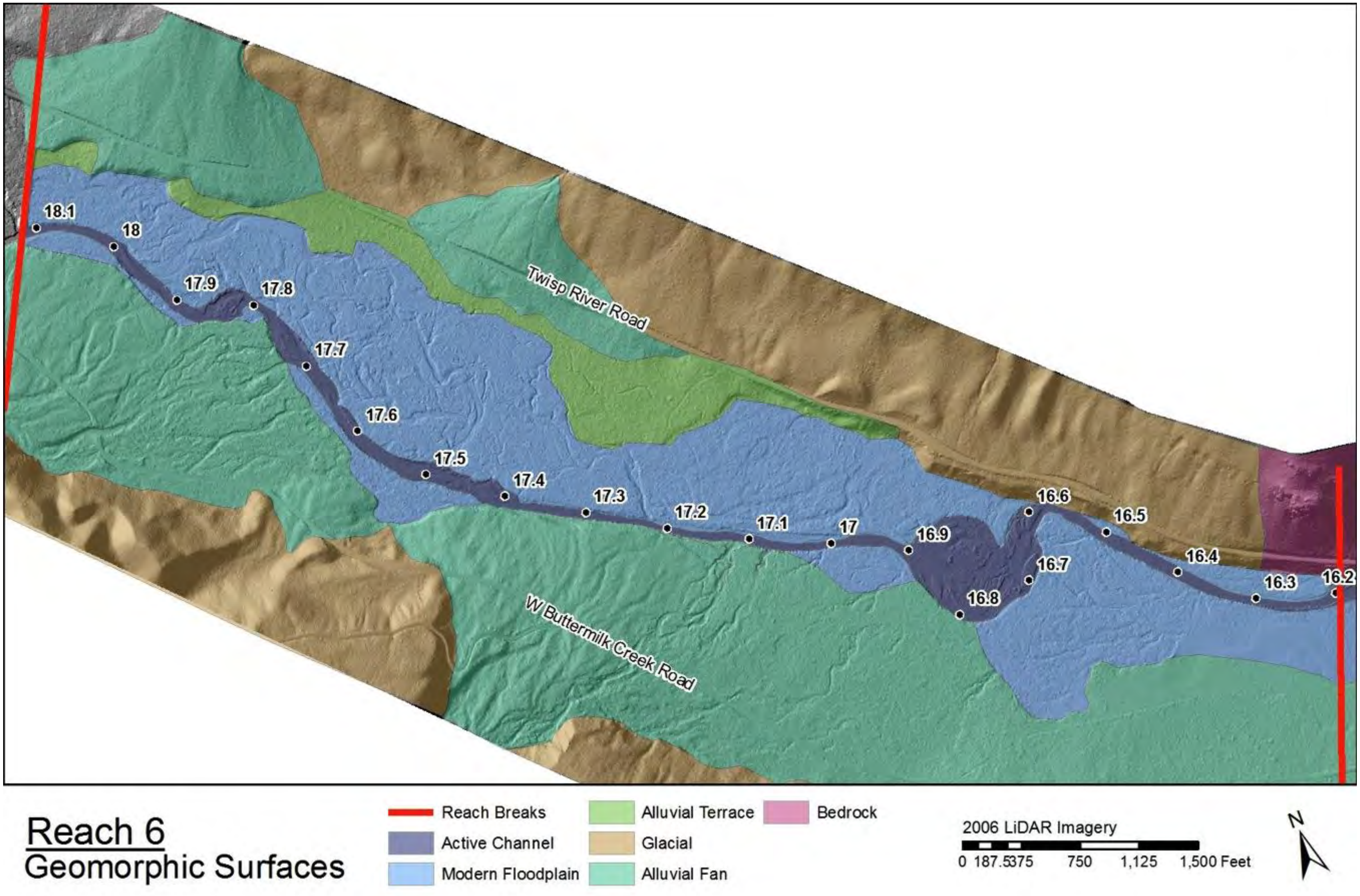

Figure 85. Geomorphic surfaces for Reach 6.

Figure 86. Wetland complex along river-left at RM 16.6.

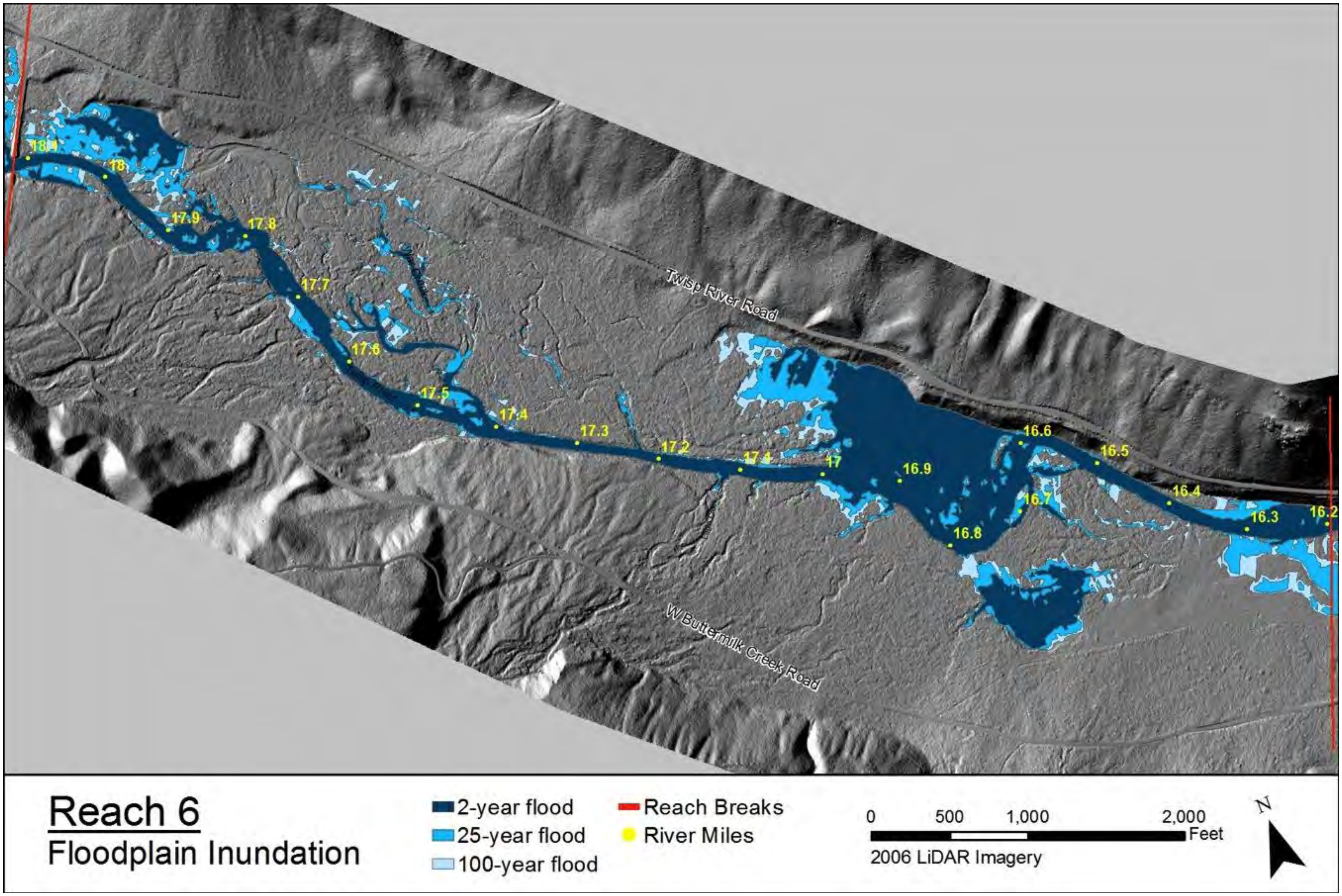

Figure 87. Floodplain inundation mapping for Reach 6.

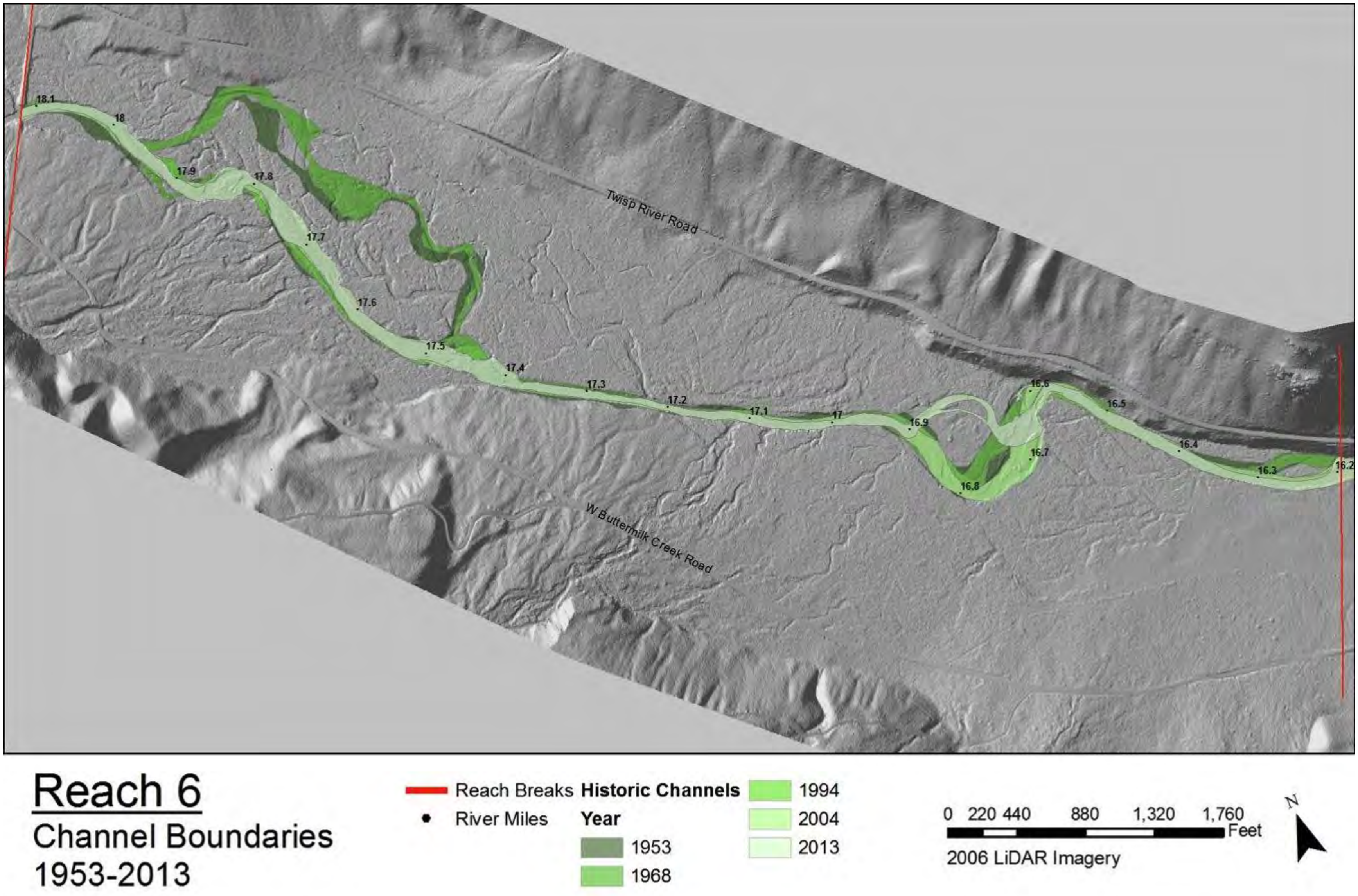

Figure 88. Historical channel boundaries for Reach 6.

Sediment

Bed substrate is dominated by cobble (55%), with gravel subdominant at 38%. Sources of sediment include War Creek and Eagle Creek, which periodically contribute debris flow deposits. Much of the material is derived from the modern floodplain surfaces along river-left, which are regularly eroded into through natural channel adjustment processes. During debris flows from river-right, these surfaces are rapidly eroded due to the influx of larger debris flow deposits from valley-right. Another source of sediment is the erosion into glacial deposits along river-left near RM 16.5. This erosion recruits large boulders that add complexity to in-stream habitat. The mid-channel bars are primarily composed of gravel and sand with little established vegetation on the exposed surfaces, indicating frequent scour (Figure 89).

Figure 89. Looking upstream at RM 16.6, the highly dynamic nature of this portion of the reach is evidenced by the exposed gravels and high flow channels.

Large Wood

Reach 6 had significantly more large wood than most of the other reaches, with the second highest count of large wood in the study area (169 pieces distributed at 88 pieces/mile) and the second highest log jam count (three log jams totaling 30 logs; Habitat Assessment, Appendix A). Although mature conifers along river-right offer a high potential for woody debris recruitment to the channel, the amount of wood is estimated to be much lower than what would be expected historically given the depositional nature and geomorphic complexity of this reach. Large wood would have played a major role, especially in the upstream and downstream ends of the reach in the less confined areas. The wood would have likely accumulated at the apexes of islands, throughout side channels, and on the outside of meander bends. The difference between the observed, present-day conditions and the historical conditions is likely due to the removal of large wood that took place during the 1970s. The amount of wood available for recruitment in the immediate future is also lower than historical conditions. This is a result of floodplain and riparian forests that are in early or mid-successional stages.

Figure 90. RM 17.25 looking upstream. Channel spanning woody debris and highly vegetated banks that have the potential for future recruitment.

Vegetation

The riparian corridor consists of relatively young vegetation, with 63% small trees; 25% shrub/seedling; and 12% of the measured units being dominated by no vegetation. The canopy height map (Figure 91) shows the pattern of riparian and floodplain vegetation. There is a lack of vegetation at the upstream end on river-left, possibly related both to high flow scouring flows as well as clearing associated with the nearby campground. At the downstream end on river-right, there is a cleared pasture where riparian and floodplain vegetation is highly degraded. In other areas, such as in the middle portion of the reach, there are stands of trees in excess of 100 feet tall.

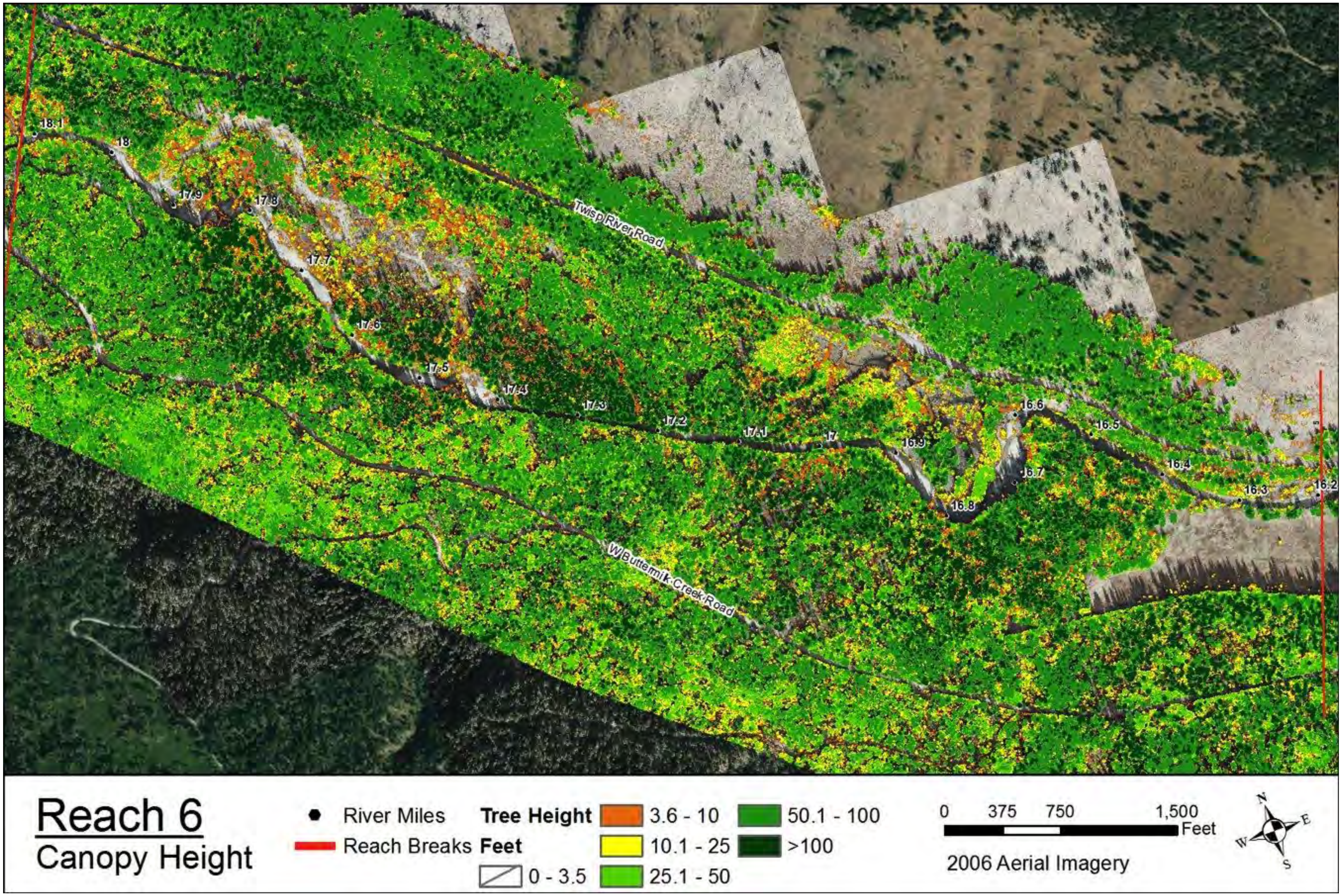

Figure 91. LiDAR first return (highest hit) data for Reach 6. These data show vegetation canopy heights. Buildings and other human infrastructure are also included in this data but there are only a few occurrences in this reach.

3.6.3 Human Alterations

Bridge Constriction at Upstream End

The bridge at the upstream end of the reach affects floodplain function and channel migration (Figure 92). The primary impact on floodplain function is the fill associated with the north approach, which bisects the floodplain. There is a single undersized culvert under the road fill, but the upstream intake was unidentifiable and did not appear to be conveying flows effectively. High flows are currently routed along the upstream edge of the fill back into the channel at the bridge. The bridge also restricts channel migration and prevents natural planform adjustment. In addition to altering flow and channel migration patterns, the bridge and associated roadway is acting as a fine sediment input along river-right, with evidence of scouring flows in this location.

Figure 92. Channel spanning bridge at RM 18.12, the upstream extent of this geomorphic study.

Floodplain Grading and Riparian Clearing

The primary area of impact from floodplain grading and clearing is at the downstream end of the reach on river-right where the land has been cleared and graded for agricultural uses. This area has a very narrow, or non-existent, riparian buffer. The bank is actively eroding and channel margin complexity is low.

In the upstream portion of the reach in the river-left floodplain (from approximately RM 17.8 to 18), there has been clearing and grading for a gravel roadway (Figure 94). There is riprap along the toe to prevent erosion. This does not have a significant impact on channel or floodplain processes as it is located at the outside edge of the 100-year floodplain. Near RM 16.8, there is the remnant of a push-up levee. The push-up levee was breached during the channel avulsion at this location.

Figure 93. The push-up levee on river left at RM 16.8 is composed of cobbles and sands.

Figure 94. Gravel road and clearing and grading along river left corresponding to RM 17.8 to 18.0

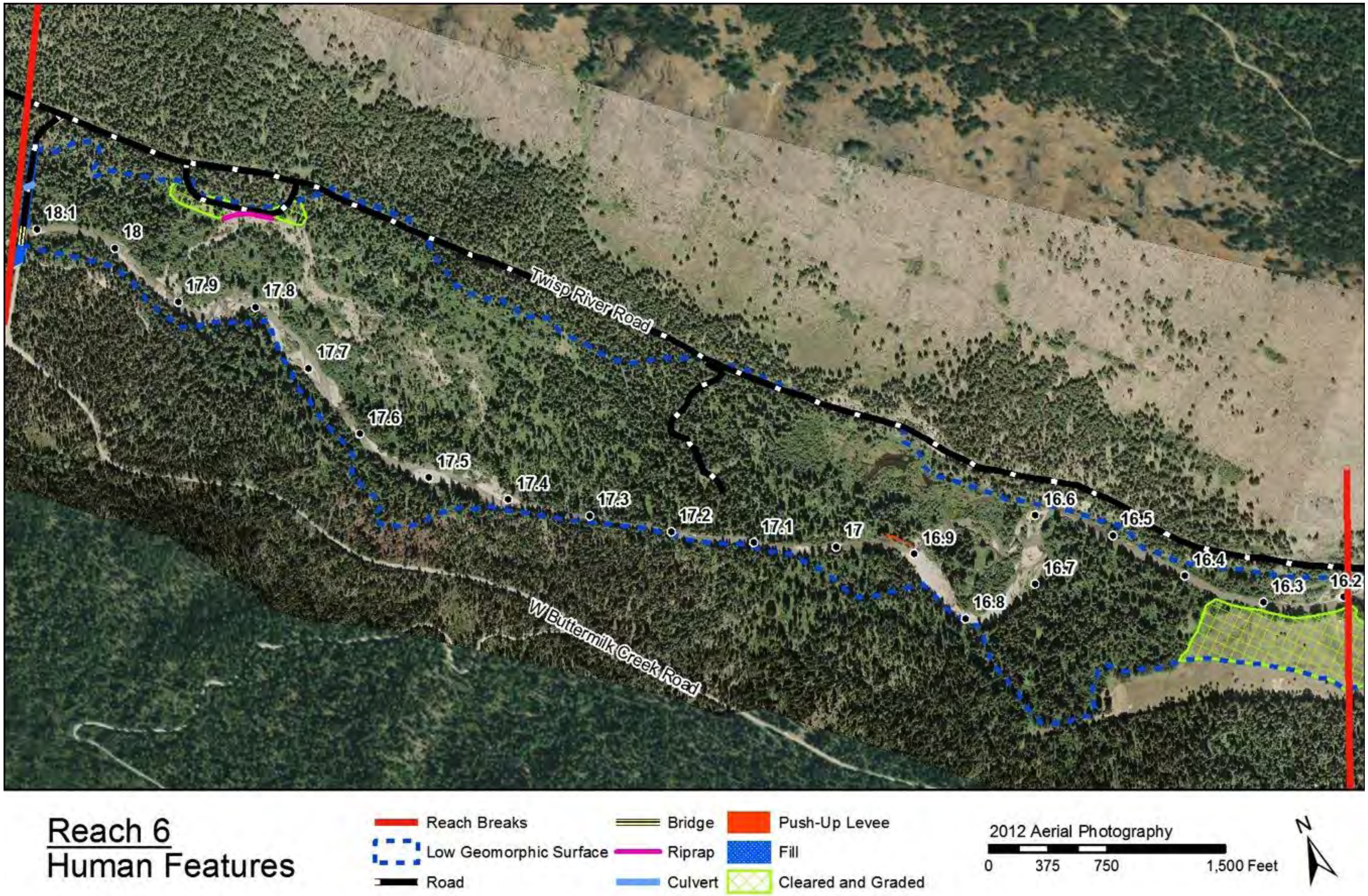

Figure 95. Human features in Reach 6

4 Restoration Strategy

4.1 INTRODUCTION

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

The restoration strategy includes 'action types' as well as specific potential project opportunities. Five general action types were developed for use in this assessment and are applied as appropriate to individual reaches. Action types are developed at a broader scale than projects, and may be achieved through the use of numerous project types. For example, the action type "off-channel habitat enhancement" might be achieved via numerous project types ranging from re-connecting habitat blocked by a levee to excavating new off-channels in the floodplain. The specific project opportunities, on the other hand, are more site specific and have unique characteristics depending on the particular habitat conditions, land uses, and geomorphic context of the site. Despite the additional specificity for projects, more analysis will still be necessary before projects are implemented; this may include topographic survey, hydraulic modeling, engineering analysis, and alternatives evaluation.

Project opportunities are linked to their respective action type(s) in the tables in Section 0 and are described in greater detail in Appendix C. The projects listed in Appendix C represent an initial step in identifying projects that fit the action types for each reach.

4.2 EXISTING AND TARGET HABITAT CONDITIONS

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

Target conditions were developed using the REI targets as well as reference to site conditions and inference from regional studies. See Appendix B for more information on the REI analysis. The REI analysis is based on previous REI analyses conducted as part of previous Reach Assessments conducted by the USBR and YN in other Upper Columbia tributaries. Modifications have been made to the large wood REI targets; these are discussed in the REI appendix (Appendix B).

4.3 RESTORATION ACTION TYPES

The Restoration Strategy includes five general action types. These are described in the sections below.

4.3.1 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

4.3.2 Riparian Restoration

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

Examples:

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

4.3.3 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. Restoration actions are focused on reclaiming a component of the system that has been lost, therefore regaining habitat and process that was previously a functional part of the river system.

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

Examples:

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

4.3.4 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.

Examples:

- Installation of a bar apex logjam 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 logjam 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

4.3.5 Off-Channel Habitat Enhancement

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

Examples:

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

4.4 RESTORATION STRATEGY OVERVIEW

The restoration strategy for the study area includes a variety of approaches depending on existing limiting factors, the potential for biological and physical habitat improvements, and site-specific opportunities observed during field surveys. These strategies, and the technical basis for them, are presented in detail at the reach-scale in Section 0. Table 16 provides a snapshot of the restoration strategy at the study area scale. This table includes just the key summary points regarding existing conditions and restoration opportunities. This same information is repeated in map form in Appendix C.

Table 16. Overview of restoration strategy at the study area scale.

Reach	Overview of conditions	Overview of restoration strategy
Reach 1	Natural confinement Loss of the already limited floodplain function Significant riparian impacts Loss of streambank complexity	Limited Restoration Potential Newby to Bridge Project – Riparian restoration, limited off-channel enhancement, large wood to enhance streambank complexity
Reach 2	Natural confinement Loss of streambank complexity Significant riparian impacts	Limited Restoration Potential Newby to Bridge Project – Riparian restoration, large wood to enhance streambank complexity
Reach 3	Moderately confined to unconfined channel with good potential habitat Floodplain filling, grading, and channel constriction Reduced lateral channel dynamics via armoring Loss of instream habitat complexity Riparian impairment	High restoration potential Newby Narrows Project – enhance instream complexity, enhance off-channel rearing areas and connectivity, riparian restoration Horseshoe Side-Channel Project – remove bank armoring and levees to restore channel migration. Address incision impacts through enhancing connections with off-channels, enhance instream complexity, riparian restoration.
Reach 4	Natural moderate confinement Floodplain grading, levees, and bridges Loss of instream habitat complexity Significant riparian impairment	Moderate restoration potential Buttermilk Fan Project – levee removal, bank armoring modification, off-channel enhancement, instream complexity, riparian enhancement
Reach 5	Generally high quality conditions in downstream portion Floodplain Fill, Grading, Levees, and Bank Armoring in upstream portion Riparian impairment	High restoration and preservation potential Buttermilk Bends Project – Preservation plus whole tree placement for key pieces Scaffold Camp Project – levee removal, bank armoring removal, floodplain re-grading, off-channel enhancement, riparian enhancement
Reach 6	Natural moderate confinement Dynamic areas at upstream and downstream ends of reach Bridge constriction and associated floodplain impacts Floodplain grading Riparian clearing	Moderate restoration potential Scaffold Camp Project – only a small portion of this project is within this reach. Includes off-channel enhancement, streambank complexity, riparian planting. Eagle Project – whole tree placement, potential for enhancing connectivity to floodplain wetlands War Project – address impacts related to upstream bridge, instream complexity, potential off-channel enhancement.

REACH-SCALE STRATEGIES

4.4.1 Reach 1

There is limited restoration potential in Reach 1 due to natural confinement and the high degree of human infrastructure adjacent to the channel. Only one project, the “Newby to Bridge” project, is located within this reach; it also includes Reach 2. The main restoration focus is riparian restoration, including re-establishing the native riparian vegetation community in numerous locations throughout the reach. This will be challenging, as many of these locations are cleared areas maintained for rural residential or small-scale agricultural uses. In addition to riparian restoration, there is one location where there is an opportunity for creation and enhancement of off-channel habitat. This area is located along the river-left bank near RM 8.3. There may also be areas throughout the reach where channel margin habitat could be enhanced via the placement of large wood along the channel boundaries. However, these projects would likely be opportunistic (i.e. where there are willing landowners), small-scale, and isolated; and so may not provide sufficient habitat benefits given the cost and planning efforts required for implementation.

Reach 1 Restoration Strategy

Table 17. Reach 1 Restoration Strategy Table.

Reach 1 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. 25% small tree 75% grassland 0% medium-large trees 30% canopy cover Human disturbance is located within approximately 70% of the riparian zone. 43.1% of the 100 ft riparian buffer has been cleared. Disturbance includes a road and associated riprap at RM 8.1, clearing and grading on both sides of the channel for houses and lawns, and a push-up levee along river-right at the downstream portion of the reach.	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	Newby to Bridge Project
Floodplain Connectivity	Reach is naturally confined throughout most of its length. Where floodplains exist, there is reduced connectivity of the	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions,	Off-channel habitat enhancement	Newby to Bridge Project

Reach 1 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	floodplain to the main channel. Roadways and push-up levees have a moderate impact on floodplain inundation rates in a few locations. 3.45 mi/mi^2 of road in the floodplain.	riparian vegetation and succession. Minimal human disturbance of the floodplain <2mi/mi^2 road density in the floodplain [adapted from REI]		
Bank condition / Channel migration	Many of the streambanks in the reach are affected by bank armoring, mostly riprap along the road embankment or used to protect residential property. However, the reach is naturally laterally constricted by terraces and hillslopes on both sides of the channel throughout much of the reach.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Placement of structural habitat elements	Newby to Bridge Project
Vertical channel stability	Floodplain alterations and channelization have likely resulted in some degree of vertical incision. Incision is likely limited by coarse substrate, including lag from glacial and tributary fan sources.	No measurable trend of human-induced aggradation or incision [adapted from REI]	No actions identified	
Pools	Pools have inadequate cover and there are few large pools (> 3 ft deep) in the reach. Pools per mile = 3.7 12% pool habitat	~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	Placement of structural habitat elements	Newby to Bridge Project

Reach 1 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	1 pool > 3 ft deep	cover. [REI]		
Large wood and logjams	12 M-L pieces / mi 0 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox 2001] ≥ 3 logjams/mi [based on conditions in Reach 5]	Placement of structural habitat elements	Newby to Bridge Project
Off-Channel Habitat	2% side-channel habitat. The only side channel observed in this reach is a fast moving 348' channel located at the beginning of the reach with little cover offered. The natural extent of potential off-channel habitat is constrained by the effects of the roadway and residential development on lateral channel migration and floodplain connectivity, which are necessary for long-term creation and maintenance of adequate off-channel habitat. A lack of logjams also limits off-channel development.	Reach has ponds, oxbows, backwaters, side-channels, and other off-channel areas with cover that are consistent with natural conditions. No manmade barriers are present that prevent access to off-channel areas. [adapted from REI]	Off-channel habitat enhancement	Newby to Bridge Project

4.4.2 Reach 2

The restoration strategy in Reach 2 is similar to Reach 1; however, Reach 2 has even greater natural confinement and very limited opportunity for meaningful restoration. The only project identified for Reach 2 is the "Newby to Bridge" project, which also encompasses Reach 1. Riparian restoration is the primary strategy, but this will be challenging due to private rural residential uses. The Twisp River Road also has a significant impact on riparian vegetation along much of the river-left side of the reach. Addressing riparian impairments associated with the roadway will also be challenging. As with Reach 1, there may be some limited opportunity for enhancing channel margin habitat using large wood placements, but these projects would be isolated, opportunistic, and may provide questionable fish benefits given the level of coordination that could be required.

Reach 2 Restoration Strategy

Table 18. Reach 2 Restoration Strategy Table.

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 40% canopy cover Human disturbance is located within approximately 60% of the riparian zone. 11.6% of the 100 ft riparian buffer has been cleared. Disturbance includes roads and associated riprap, lawns, and houses.	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	Newby to Bridge Project
Floodplain Connectivity	The channel is naturally confined by glacial terraces and alluvial fan deposits. The modeled flows (2-100 year event) were confined to the main channel and no floodplain or side channels were observed in this reach, which is additionally constrained by the road and residential alterations.	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	No actions identified	

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	0 mi/mi^2 of road in the floodplain.			
Bank condition / Channel migration	Much of the river-left channel margin is affected by road embankments comprised of fill and riprap. There are also houses with access roads along the river and vegetation impacts up to the top of bank.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	Placement of structural habitat elements	Newby to Bridge Project
Vertical channel stability	Channel substrate is primarily cobble/gravel/boulder. There is no clear evidence of channel incision. The large material may be helping to limit channel incision. Natural confinement limits the impacts of bank armoring on vertical stability.	No measurable trend of human-induced aggradation or incision [adapted from REI]	No actions identified	
Pools	Pools have inadequate cover and there are few large pools (> 3 ft deep) in the reach. Pools per mile = 1.54 1% 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 elements	Newby to Bridge Project
Large wood and logjams	11 M-L pieces / mi 0 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox 2001] ≥ 3 logjams/mi [based on conditions in Reach 5]	Placement of structural habitat elements	Newby to Bridge Project
Off-Channel	0% side-channel habitat.	Reach has ponds, oxbows, backwaters, side-channels,	No actions identified	

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat	The naturally confined valley morphology limits the formation of side channels and other off-channel habitat. Much of the habitat complexity in this reach is created by large boulders and cobbles.	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]		

4.4.3 Reach 3

Reach 3 has some of the best restoration potential in the study area. This is due to a combination of factors, including the natural geomorphic character, the degree of human impacts (and resulting limiting factors), and site specific opportunities. In contrast to the downstream reaches (Reaches 1 and 2), Reach 3 is less confined, meandering, and dynamic, with the potential to provide high quality in-channel and off-channel spawning and rearing habitat. However, human influence has had significant impact on the reach in some areas, including bank armoring, levees, riparian clearing, and channel simplification. These impacts have reduced habitat quantity and quality, and in some cases, limit the ability of the system to effectively create and maintain high quality habitat into the future. Impaired processes and habitat, however, are generally recoverable due to land use patterns and site specific opportunities. There are two projects that were identified in Reach 3, the "Newby Narrows" project and the "Horseshoe Side-Channel" project. The Newby Narrows project is located near the downstream end of the reach. The primary element of the Newby Narrows project would create and enhance off-channel rearing habitat within a disconnected floodplain channel scar network on river-right. There is also opportunity to enhance off-channel habitat on river-left and to enhance mainstem habitat complexity through large wood and log jam placements. The other project in Reach 3 is the Horseshoe Side-Channel project, which is located at the upstream end of the reach. This project offers one of the best potential restoration opportunities in the study area. It has also been investigated previously as a potential project area by the US Bureau of Reclamation (USBR 2006), and the project opportunities discussed in this Reach Assessment build off of those prior investigations and concepts. The site consists of an extensive floodplain wetland and abandoned oxbow complex on river-left. The main channel in this area has experienced incision due to downstream channel confinement and floodplain fill. These impacts have reduced the hydrologic and fish passage connectivity between the main channel and floodplain. There are numerous opportunities within this project area to enhance connectivity to existing floodplain wetlands, increase the quantity of off-channel areas, promote channel migration, increase floodplain inundation rates, and increase mainstem channel complexity.

Reach 3 Restoration Strategy

Table 19. Reach 3 Restoration Strategy Table.

Reach 3 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. 29% small tree 29% grassland/forb 14% shrub/seedling 14% sapling/pole 14% medium-large trees 50% canopy cover Human disturbance is located within approximately 50% of the riparian zone. 12.9% of the 100 ft riparian buffer has been cleared. Disturbance includes roads and associated riprap, lawns, and houses.	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	Newby Narrows Project Horseshoe Side-Channel Project
Floodplain Connectivity	Reduced floodplain connectivity due to roads, bank armoring, and push-up levees. There has also been fill and grading in the floodplain, particularly in the upstream portion of the reach.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI]	Habitat reconnection via infrastructure modification Off-channel habitat enhancement Placement of structural habitat elements	Newby Narrows Project Horseshoe Side-Channel Project

Reach 3 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	1.80 mi/mi^2 of road in the floodplain	<2mi/mi^2 road density in the floodplain		
Bank condition / Channel migration	Portions of the reach are affected by bank armoring, which impairs streambank complexity and reduces natural rates of channel migration. Push-up levees and riprap are present intermittently along river-left. Clearing and grading for residential and recreational uses has taken place in the active floodplain.	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	Newby Narrows Project Horseshoe Side-Channel Project
Vertical channel stability	There are signs of vertical instability based on abandoned floodplain surfaces. Channelization and floodplain filling and grading appear to have caused incision in several locations, especially in the Horseshoe Side-Channel project area. Limited presence of gravel bars, even in very unconfined portions of the channel, suggest a general trend of incision.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat reconnection via infrastructure modification Placement of structural habitat elements	Newby Narrows Project Horseshoe Side-Channel Project
Pools	Pools have inadequate cover and there are few large pools (> 3 ft deep) in the reach. Pools per mile = 4.5 14% pool habitat	~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.	Placement of structural habitat elements	Newby Narrows Project Horseshoe Side-Channel Project

Reach 3 Attribute	**Existing Condition (from assessment)**	**Target Condition [source]**	**Action Type**	**Potential Projects**
	3 pools > 3 ft deep	[REI]		
Large wood and logjams	18 M-L pieces / mi 0.82 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox 2001] ≥ 3 logjams/mi [based on conditions in Reach 5]	Placement of structural habitat elements	Newby Narrows Project Horseshoe Side-Channel Project
Off-Channel Habitat	2% side-channel habitat. Three side channels with minimal amounts of woody debris. There is extensive off-channel wetland habitat in the Horseshoe Side-Channel Project area but most of it is not connected to the mainstem except at very high flows.	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	Newby Narrows Project Horseshoe Side-Channel Project

4.4.4 Reach 4

Reach 4 has moderate restoration potential. Most of the reach is moderately confined by tributary fans and these constraints limit the future habitat potential to some degree. Channels are more naturally plane-bed and simplified, so their ability to provide abundant salmonid spawning and rearing habitats are naturally limited. There are, however, areas where human impacts have resulted in habitat and process impairments and where meaningful restoration work could nevertheless improve conditions. These areas tend to be spread out across the entire reach and span multiple property owners and impairment types. Restoration therefore risks being somewhat piecemeal and opportunistic. The reach is entirely encompassed by the "Buttermilk Fan" project, which also extends upstream into the downstream portion of Reach 5. This project includes multiple potential elements, including removing push-up levees, removing/modifying bank armoring, creating/enhancing off-channel habitat, riparian restoration, and instream complexity using large wood. One of the primary elements of this project is addressing floodplain disconnection caused by the long push-up levee in the middle of the reach along river-left. Although intermittent, this levee, and other impacts, have likely contributed to stream channel incision that has further affected floodplain connectivity and the ability of the channel to freely migrate and create off-channel habitats over time. Removing the levee, performing selective off-channel excavation, riparian restoration, and targeted log jam placement could help to reconnect the floodplain and off-channel habitats. Overall, infrastructure (e.g. bridges) and land-use constraints (e.g. agricultural uses) will affect what can reasonably be accomplished in this reach.

Reach 4 Restoration Strategy

Table 20. Reach 4 Restoration Strategy Table.

Reach 4 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. 60% small tree 20% grassland/forb 20% no vegetation 20% canopy cover Human disturbance is located within approximately 80% of the riparian zone. 54.1% of the 100 ft riparian buffer has been cleared. Disturbance includes roads and associated riprap, lawns, and houses.	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	Buttermilk Fan Project
Floodplain Connectivity	Floodplain connectivity is reduced by the two bridge crossings and associated fill on the approaches. There are also intermittent push-up levees and moderate amounts of past floodplain filling and grading. 2.88 mi/mi^2 of road in the	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	Buttermilk Fan Project

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	floodplain			
Bank condition / Channel migration	There is bank armoring associated with the two bridges but otherwise not extensive armoring. Floodplain grading and push-up levees have some impact on channel migration, as does the approach road fills at the two bridge crossings.	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	Buttermilk Fan Project
Vertical channel stability	The two bridge crossings create constrictions that have likely resulted in channel incision. Push-up levees and floodplain fill and grading have likely contributed to downcutting. Flood scars on the now-abandoned surface on river-left (mid-reach) suggests channel incision.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Habitat reconnection via infrastructure modification	Buttermilk Fan Project
Pools	Pools have inadequate cover and there are few large pools (> 3 ft deep) in the reach. Pools per mile = 4.3 14% pool habitat 2 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	Buttermilk Fan Project
Large wood and logjams	9 M-L pieces / mi 1.45 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox 2001] ≥ 3 logjams/mi [based on conditions in Reach 5]	Placement of structural habitat elements	Buttermilk Fan Project
Off-Channel	2% side-channel habitat.	Reach has ponds, oxbows,	Off-channel habitat	Buttermilk Fan Project

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat	Four side channels with little woody debris were identified. Log jams within two of the side channels and one small off-channel wetland also contribute to off-channel habitat complexity.	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]	enhancement Habitat reconnection via infrastructure modification	

4.4.5 Reach 5

The restoration strategy for Reach 5 has two primary components depending on location. These two components are represented by the upstream "Scaffold Camp" project and the downstream "Buttermilk Bends" project. The Buttermilk Bends project encompasses most of the reach. This project area is the most intact (i.e. least human impact) of the entire study area and the strategy here is primarily focused on preservation as opposed to restoration. However, there may be some limited restoration work that could provide some important benefits and would support the existing intact processes. In this segment, the floodplain and channel migration zone is wide, unconfined, and actively migrating. There is wood recruitment and regular planform adjustment, which creates new habitats on a 1-2 year basis. Although this active dynamism is beneficial, and reflects a lack of artificial constraints on the channel, there may be concerns with dramatic planform adjustments that occur on a very frequent timescale, more frequent than would be expected prior to removal of the historical large structure provided by large wood jams (with large key pieces) and riparian forests with large trees. Remnant large cottonwood stands, and some large conifer stands, give evidence of past conditions. As a result of the lack of large structure in the contemporary channel and floodplain, lateral (planform) and vertical (profile) adjustments occur regularly and may pose risks to salmonids in the form of redd scour. The potential treatment approach that has therefore been identified is the placement of large whole trees in the channel at numerous locations. To limit disturbance to existing vegetation, these trees would ideally be placed by helicopter or by machines via carefully placed access points. Whole trees would provide the large structure that is missing from this area and would serve as key pieces to create and maintain naturally-formed log jams over time.

In contrast to the Buttermilk Bends project, the Scaffold Camp project, which is located near the upstream end of the reach, has significant human-related impairments that provide some of the greatest restoration opportunity in the study area. The primary impairments are related to a levee and floodplain pond complex on river-left. These features restrict lateral channel migration, affect floodplain inundation rates and patterns, and affect riparian and floodplain forest succession. The origin of these features is unknown, but they do not appear to be protecting any significant built infrastructure and aerial photo analysis suggests that must of this floodplain area could be reconnected. The specifics of the approach will require further investigation, but the general strategy would include removal of levees, removal of bank armoring, re-grading of ponds to create off-channel and side-channel habitat, large wood placement, and the restoration of riparian and floodplain forest vegetation. This project also extends upstream into Reach 6, where there is additional opportunity to enhance off-channel connectivity, instream complexity, and riparian conditions.

Reach 5 Restoration Strategy

Table 21. Reach 5 Restoration Strategy Table.

Reach 5 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. 21% small tree 43% shrub/seedling 29% sapling/pole 7% no vegetation 70% canopy cover Human disturbance is located within approximately 30% of the riparian zone. 6.4% of the 100 ft riparian buffer has been cleared. Disturbance includes roads and associated riprap, lawns, and houses.	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	Scaffold Camp Project
Floodplain Connectivity	Floodplain connectivity is high in the downstream half of the reach but is affected by levees, fill, and excavated ponds on river-left in the upstream half. These features reduce the extent, frequency, and patterns of floodplain inundation.	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] $<2 mi/mi^2$ road density in the	Habitat reconnection via infrastructure modification Off-channel habitat enhancement Placement of structural habitat elements	Scaffold Camp Project

Reach 5 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	1.33 mi/mi^2 of road in the floodplain	floodplain		
Bank condition / Channel migration	There are a few areas of riprap protecting houses and private property. These occur at the upstream end on river-left and at the downstream end on river-right. Bank migration is impaired at these locations. Much of the remainder of the reach is migrating near (or slightly above) natural rates.	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	Scaffold Camp Project
Vertical channel stability	Due to its low gradient and wide floodprone width, this reach provides relatively high sediment storage capacity. It is highly dynamic, likely more than historical conditions due to loss of large trees in riparian areas and in log jams.	No measurable trend of human-induced aggradation or incision [adapted from REI]	Placement of structural habitat elements	Scaffold Camp Project Buttermilk Bends Project
Pools	Pools have good cover with only a minor reduction in pool volume from fine sediment and there are many large pools (> 3 ft deep) in the reach. Pools per mile = 13.2 23% pool habitat 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 Habitat reconnection via infrastructure modification	Scaffold Camp Project Buttermilk Bends Project

Reach 5 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Large wood and logjams	54 M-L pieces / mi 3.86 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox 2001] ≥ 3 logjams/mi [based on conditions in Reach 5]	Placement of structural habitat elements	Scaffold Camp Project Buttermilk Bends Project
Off-Channel Habitat	18% side-channel habitat. Nineteen side channels were identified, one almost a mile long and with moderate amounts of LWM that met the standards. Four off-channel wetlands were also identified, comprising roughly 12,000 square feet and including numerous beaver dams and log jams.	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	Scaffold Camp Project

4.4.6 Reach 6

Reach 6 has moderate restoration potential that is focused in two primary locations. These include the upstream "War" project and the downstream "Eagle" project. The Eagle project area is a highly dynamic area where a recent stream channel avulsion has altered the planform pattern for approximately 1,000 feet. Due to the recent avulsion, this area is in an early successional geomorphic and riparian vegetation condition and adjustments will be expected to continue to occur in response to the avulsion. Under historical conditions, this type of channel change would be expected to recruit large trees that would serve as key pieces and form large stable jams. However, under current conditions, the large wood recruited during the avulsion is smaller and less stable, and therefore more mobile over time. The treatment strategy here is to place large whole trees at select locations that will provide the large structure that is missing and to serve as key pieces. There may also be the potential for enhancing connectivity to the existing floodplain wetland complex along the river-left valley wall toe.

The other restoration area in Reach 6 is the War project, which is located at the upstream end of the reach adjacent to the War Creek fan on valley-right. This project has multiple elements, including addressing floodplain disconnection caused by the upstream bridge (and associated approach fills), increasing instream channel complexity using large wood, and enhancing connectivity to the river-left floodplain area. This area, however, is dynamic, and there is evidence of scour across the left bank floodplain that may provide some uncertainty with the potential effectiveness of off-channel work in this area. These conditions warrant further investigation.

Reach 6 Restoration Strategy

Table 22. Reach 6 Restoration Strategy Table.

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. 63% small tree 25% shrub/seedling 12% no vegetation 50% canopy cover Human disturbance is located within approximately 40% of the riparian zone. 4.2% of the 100 ft riparian buffer has been cleared. Disturbance includes roads and associated riprap, lawns, and houses.	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	War Project Eagle Project
Floodplain Connectivity	The bridge and approach fills at the upstream end impair floodplain inundation rates and patterns. On river-right at the downstream end, floodplain grading has impaired floodplain inundation patterns. Floodplains are relatively well-connected throughout the remainder of the reach.	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession. Minimal human disturbance of the floodplain [adapted from REI] $<2 mi/mi^2$ road density in the floodplain	Habitat reconnection via infrastructure modification Off-channel habitat enhancement Placement of structural habitat elements	War Project Eagle Project

Reach 6 Attribute	**Existing Condition (from assessment)**	**Target Condition [source]**	**Action Type**	**Potential Projects**
	0.62 mi/mi^2 of road in the floodplain			
Bank condition / Channel migration	The bridge at the upstream end of the reach has some impact on bank migration, but overall, there are minimal impacts on bank stability and channel migration processes.	Channel is migrating at or near natural rates. Minimal bank armoring or human-induced erosion. [adapted from REI]	No actions identified	
Vertical channel stability	There is vertical instability at the upstream bridge crossing, which creates a constriction that has resulted in channel incision. The remainder of the reach is near the natural range of vertical stability.	No measurable trend of human-induced aggradation or incision [adapted from REI]	No actions identified	
Pools	Pools either have inadequate cover or there are few large pools (> 3 ft deep) in the reach. Pools per mile = 7.7 15% pool habitat 2 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	War Project Eagle Project
Large wood and logjams	35.8 M-L pieces / mi 1.55 jams /mi	> 42.5 pieces/mi (>12 diam; > 35 ft long) [from Fox 2001] ≥ 3 logjams/mi [based on conditions in Reach 5]	Placement of structural habitat elements	War Project Eagle Project
Off-Channel Habitat	1% side-channel habitat. Two slow-moving side-	Reach has ponds, oxbows, backwaters, side-channels, and	Off-channel habitat enhancement	War Project Eagle Project

Reach 6 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
	channels with minimal LWM were identified in this reach.	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]		

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