RECLAMATION
Managing Water in the West

FINAL
GRAY REACH ASSESSMENT
ENTIAT RIVER, CHELAN COUNTY, Washington

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Boise, Idaho

May 2013

U.S. DEPARTMENT OF THE INTERIOR

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Acronyms and Abbreviations

BPA	Bonneville Power Administration
cfs	cubic feet per second
CMZ	Channel migration zone
ELJ	Engineered logjams
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
GIS	Geographic Information System
HCMZ	Historic channel migration zone
HEC-RAS	Hydraulic Engineering Center’s River Analysis System
LiDAR	light distance and ranging
LWM	large woody material
NOAA Fisheries	NOAA’s National Marine Fisheries Service
Reclamation	U.S. Bureau of Reclamation
RM	river mile
RPA	Reasonable and prudent alternative
Tributary Assessment	Entiat Tributary Assessment
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

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Introduction

The Bureau of Reclamation (Reclamation) and Bonneville Power Administration (BPA) contribute to the implementation of salmonid habitat improvement projects in the Upper Columbia basin to help meet commitments contained in the 2010 Supplemental Federal Columbia River Power System (FCRPS) Biological Opinion (NOAA Fisheries 2010). This Biological Opinion includes a Reasonable and Prudent Alternative (RPA), or a suite of actions, to protect salmon and steelhead listed under the Endangered Species Act (ESA) across their life cycles. Habitat improvement projects in various Columbia River tributaries are one aspect of this RPA. Reclamation provides technical assistance to states, tribes, federal agencies, and other local partners for identification, design, and construction of stream habitat improvement projects that primarily address streamflow, access, entrainment, and channel complexity limiting factors. Reclamation's contributions to habitat improvement are all meant to be within the framework of the FCRPS RPA or related commitments. The assessments described in this document provide scientific information on geomorphology and physical processes that can be used to help identify, prioritize, and implement sustainable fish habitat improvement projects and to help focus those projects on addressing key limiting factors to protect and improve survival of salmon and steelhead listed under the ESA.

Tributary and reach assessments are early steps in a process aimed at focusing habitat improvement efforts toward the most beneficial actions in the most appropriate locations (Figure 1). Several project areas may be selected based on the assessments and feedback from local project partners and stakeholders. Each project area may undergo an alternatives evaluation to conceptually identify the project that best improves habitat while addressing local stakeholder needs. The preferred conceptual alternative is typically then advanced to a 30-percent design. The final design incorporates feedback from several technical reviews provided by local and regional review teams and permitting agencies. With landowner and funding entity approval and permits in place, the final design is advanced for construction. Following construction, Reclamation and other groups monitor the physical and biological performance of the project. Performance deficiencies may be remedied through adaptive management.

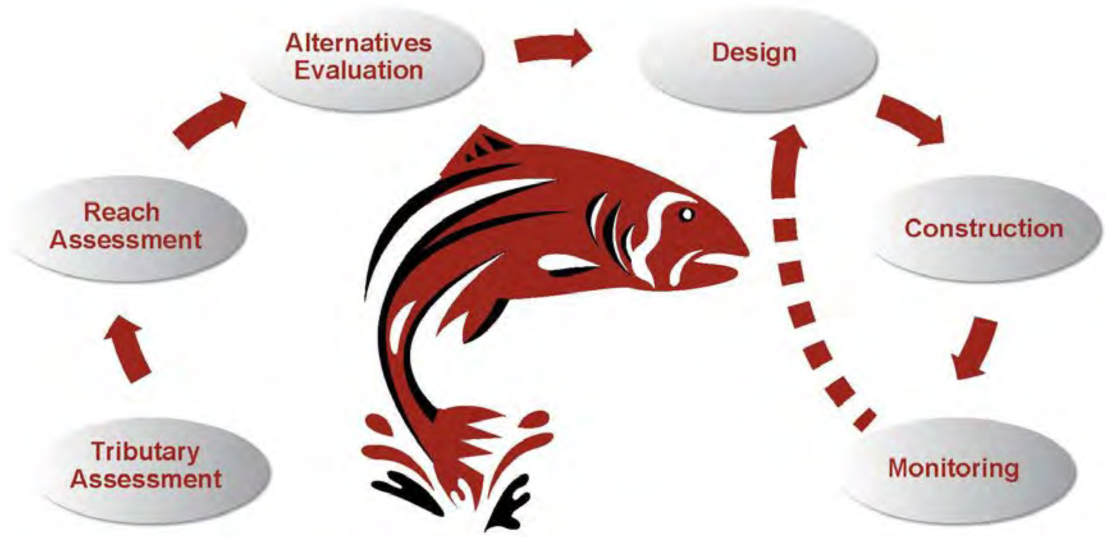

Figure 1. Flow chart illustrating typical steps in the approach to habitat improvement.

Purpose of this Reach Assessment

This Reach Assessment is a compilation report providing a range of scientific information relevant to habitat improvements for salmon and steelhead over a spatial scale fine enough to identify specific habitat improvement actions and coarse enough to support continuity between those actions. The purpose of this Reach Assessment is to assess and document reach-scale characteristics and how they have changed over time for identifying suitable habitat improvement actions that address known limiting factors within the reach. The completed Reach Assessment can be used to guide future habitat rehabilitation, ensuring that specific projects are developed and advanced in a manner suitable to the geomorphic character and trends prevalent throughout the reach. In this way, a reach-scale approach to habitat improvement can be facilitated.

In order for habitat improvements to increase fish survival on a basin scale, actions must maximize benefit at the reach scale. Habitat in the Upper Columbia River basin is relatively poor overall. In order to improve conditions across the entire basin, those few reaches where habitat improvement actions are being proposed must maximize their potential. Therefore, this Reach Assessment outlines not only geomorphic conditions and how they have changed over time it also provides a summary of geomorphically appropriate habitat actions that aim to maximize benefit potential within the reach.

Reach Assessment Philosophy

This Reach Assessment represents a reach-scale refinement of data and analyses presented in existing watershed-scale reports such as the *Entiat Tributary Assessment, Chelan County, Washington* (Tributary Assessment) (Reclamation 2009a). Information in the Reach Assessment is not intended to duplicate previous efforts, rather it is intended to provide a summary of pertinent larger-scale background information and expand upon that information at the reach scale. The Reach Assessment area was delineated from the Tributary Assessment in which the Entiat River was divided into unique valley segments and reaches based on changes in geomorphic character along the length of the channel and its floodplain. Three separate valley segments were delineated along the Entiat River based on channel gradient, geologic controls, and channel morphology. Valley Segment 2 includes roughly 5 miles of the Entiat River upstream of a prominent slope change originating at an ancient terminal glacial moraine called the Potato Moraine, named after the nearby Potato Creek tributary (Figure 2).

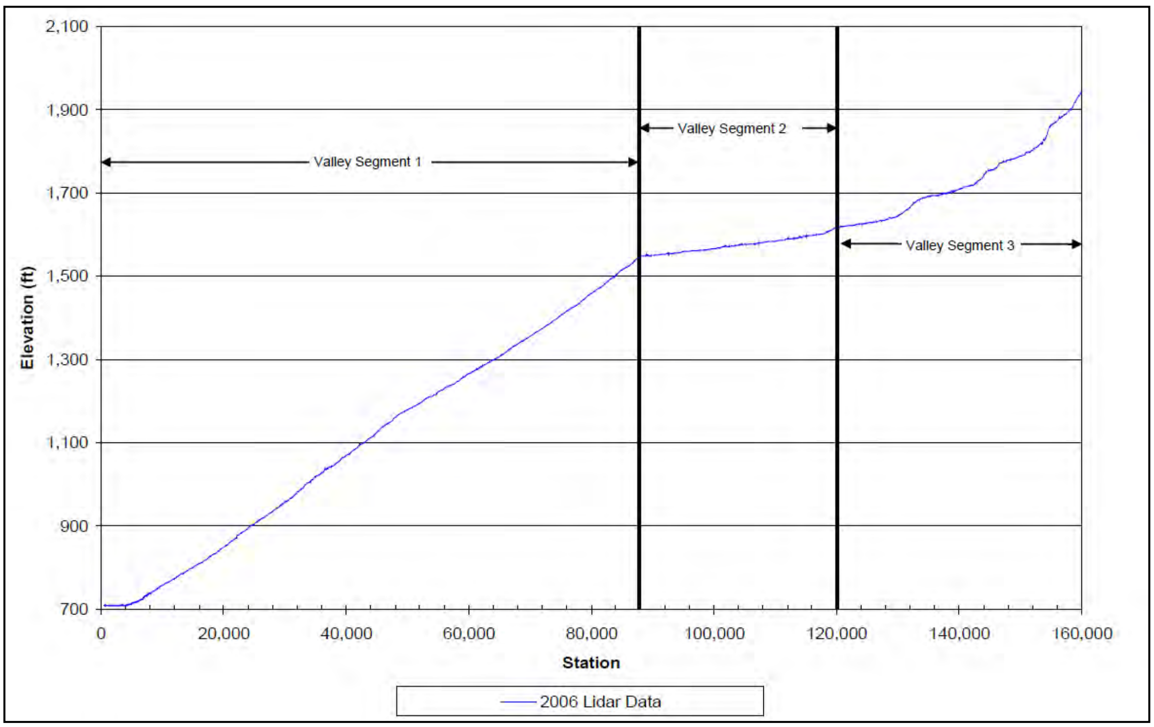

Figure 2. Longitudinal profile of Entiat River channel elevation (RM 0.1 to 27). Elevations derived from 2006 Light Detection and Ranging (LiDAR) high-resolution topography. Note the prominent slope break between Valley Segment 1 and 2 at the location of the Potato Moraine.

Within Valley Segment 2, the Tributary Assessment further delineated four separate geomorphic reaches (2A through 2D) based on fine-scale changes in slope, channel confinement, and geologic controls. This Reach Assessment focuses on Reach 2A within Valley Segment 2, referred to as the Gray assessment area after a tributary feeding the reach. The assessment area was identified in the Tributary Assessment as a high priority for reach-scale evaluation to determine potential for habitat improvement based on its unconfined channel character and existing human impacts. Additionally, the *Detailed Implementation Plan* prepared by Chelan County Conservation District identified the Middle Entiat River (RM 16.2 – 26.0) as a high priority for habitat improvement as a result of Ecosystem Diagnosis and Treatment modeling of predicted large woody material (LWM) quantities and potential habitat quality (CCCD 2006).

The Tributary Assessment generally described the Gray Reach as a sinuous, single-threaded channel with a wide, unconfined, active floodplain. The gradient of the channel is low and channel migration is low to moderate laterally and moderate to high in the downstream direction eroding into unconsolidated banks of sand and gravel alluvium. Instream channel complexity is high due in part to relatively large volumes of LWM, although less abundant than historically as a result of past channel clearing efforts. Incipient motion analysis and field observations suggest sediment is reworked on a regular basis maintaining multiple large, deep pools and tailout areas suitable for spawning. As described in the Tributary Assessment, the relatively dynamic Gray Reach has many favorable characteristics contributing to its habitat potential.

Although the entire Middle Entiat River was identified as a high priority for habitat improvement, the various strategies by which habitat improvement can be accomplished may or may not be appropriate for the Gray Reach. The Tributary Assessment addressed the potential habitat improvement implementation strategy following a hierarchical philosophy adapted from Roni et al. (2002) and Roni (2005). Following is an outline of the implementation strategy developed in the Tributary Assessment as it pertains to the assessment area:

1. Habitat Protection: A large majority of the assessment area was identified as undisturbed active floodplain, which is a high priority for protection.
2. Water Quality and Quantity: Relatively high summer water temperature and fine sediment were identified as limiting factors affecting water quality although neither are considered primary limiting factors. Water quantity was not identified as a limiting factor in the study reach.
3. Habitat Connectivity: Floodplain and side channel connection have not been identified as limiting within the study reach.

4. Channel Process: Anthropogenic impediments to channel migration were noted in three locations (RM 16.45, 17.35 and 17.65), although average channel migration rates and extents throughout the reach as a whole were also documented as "high" illustrating the limited impact resulting from the three identified impediments.
5. Instream Habitat: The Tributary Assessment identified the need for more habitat complexity throughout the entire river below RM 26 generally referring to instream structure to replace that lost by the systematic removal of LWM and other structure during the 1900s.

Reach Assessment Goals

There are two primary goals for this Reach Assessment:

1. Document historical, existing (baseline), and potential target physical conditions within the assessment area.

2. Identify potential actions to improve processes and thereby habitat, and classify each action's ability to address limiting factors.

Using this Document

This report is intended for the use of interdisciplinary scientists, engineers, and planners focusing on fish habitat improvement and rehabilitation. Conclusions from this Reach Assessment are intended to guide future project development as one tool among many others in a collaborative effort to improve habitat. The Reach Assessment provides pertinent background information regarding reach-scale geomorphic conditions and physically appropriate habitat improvement actions. As a follow-up to this report, appropriate habitat improvement actions should also be assessed and prioritized based on perceived biological benefit and landowner need/cooperation. This reach-scale assessment should not be used exclusively as the basis for site-specific habitat designs. Detailed, site-specific analyses should be conducted to identify the most appropriate suite of actions, refine conceptual plans, and develop detailed designs for implementation.

This Reach Assessment was prepared by physical scientists and engineers at Reclamation with assistance and feedback from an interdisciplinary team of local and regional scientists familiar with the Entiat River. This document was prepared following a review of available background information, significant remote analysis using a Geographic Information System (GIS), and multiple site visits during moderate- and low-flow conditions. Focus was placed on reach-scale data since larger-scaled data were already documented in the Tributary Assessment. Finer-scaled data collection will likely be necessary for each project proposed in the future.

Information documented in this report is focused around physical processes and physical changes occurring in the Entiat River. Species such as steelhead, Chinook salmon, and other key species evolved with the physical environment of the Entiat River over thousands of years, and therefore it is assumed that efforts to reestablish natural and appropriate physical conditions provide the best approach for habitat improvements intended for these species.

Background Information

The Entiat River is located on the east slope of the Cascade Mountains in north-central Washington and flows for approximately 53 miles from its headwaters to its confluence with the Columbia River at river mile (RM) 483 (Figure 3). The assessment area consists of a portion of the Entiat River from the area of the river confined by the Stormy Creek alluvial fan near Stormy Lodge at RM 17.9 downstream to the terminal glacial moraine located near Potato Creek at RM 16.1 (Figure 4).

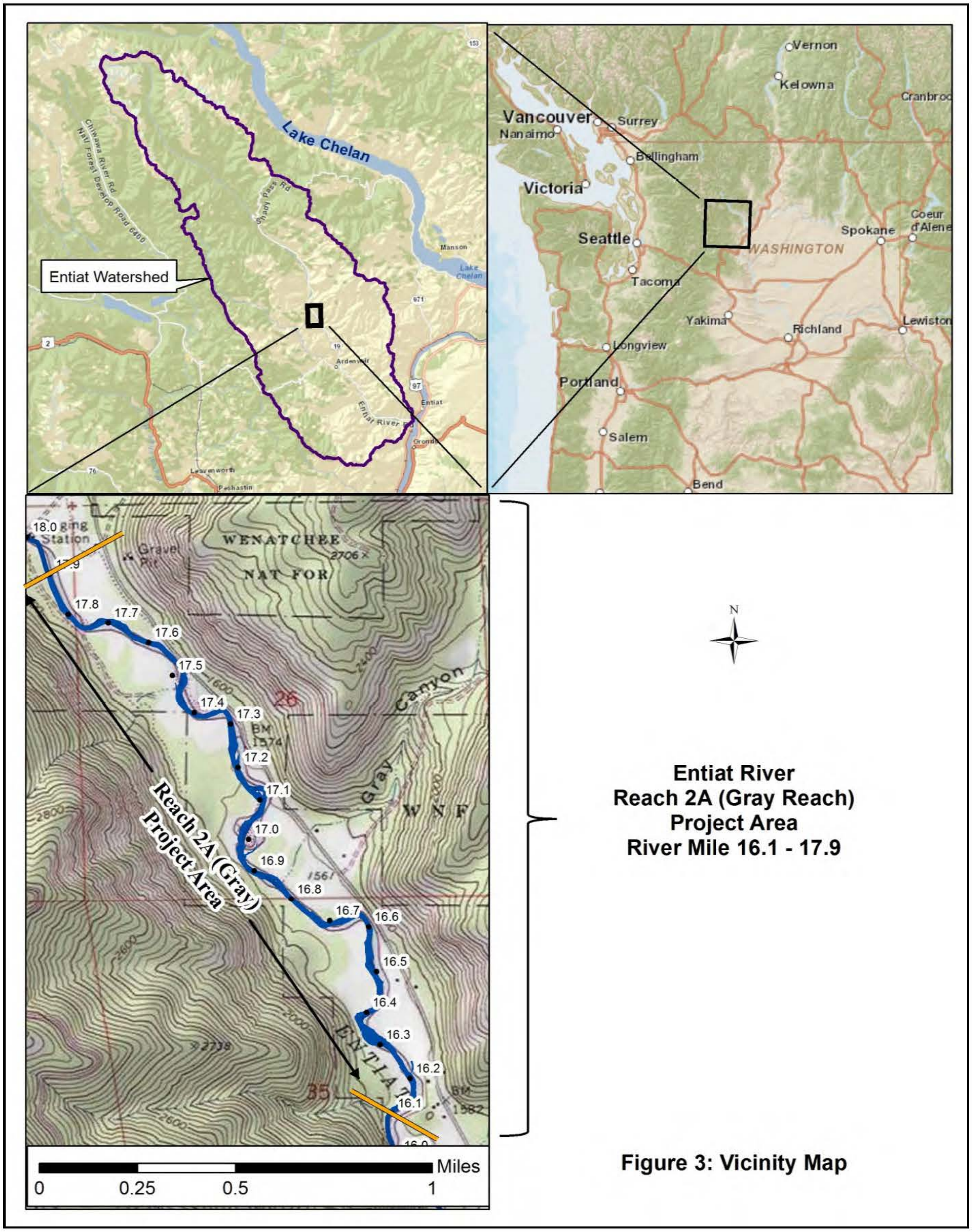

Figure 3. Entiat Gray Reach assessment area and vicinity map. The Entiat River flows into Lake Entiat which is the portion of the Columbia River impounded upstream of Rocky Reach Dam.

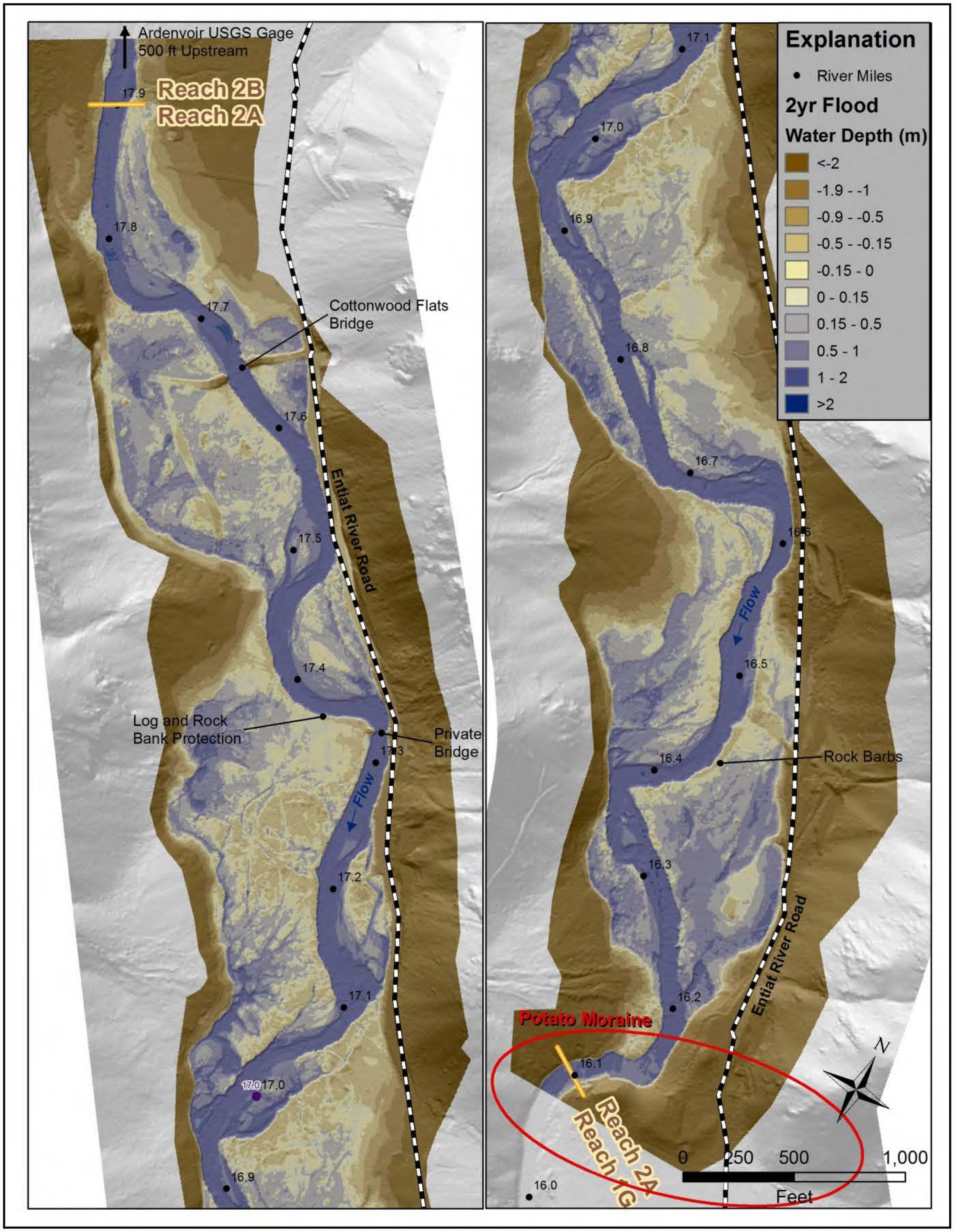

Figure 4. Topographic view, showing the reach. Topography and 2-year inundation derived from LiDAR.

Limiting Factors

Limiting factors are defined as those conditions or circumstances that limit the successful growth, reproduction, and/or survival of select species of concern. This report focuses exclusively on physical conditions for Upper Columbia River steelhead (*Oncorhynchus mykiss*) and Upper Columbia spring Chinook salmon (*O. tshawytscha*), both of which are listed under the ESA. Several existing reports have documented the limiting factors for these two species on the Entiat River. These are summarized here in the order of most limiting factor to least limiting factor based on interpreted findings from those reports as they pertain to the assessment area:

1. Lack of overwintering juvenile rearing habitat attributed to losses in floodplain connection and depleted riparian zone conditions (Andonaegui 1999; CCCD 2004; Reclamation 2009a).
2. Lack of instream structure, especially poor size and distribution of LWM (CCCD 1998; Andonaegui 1999; Reclamation 2009a).
3. Loss of well-established riparian vegetation/buffer and lack of cover (Andonaegui 1999; Reclamation 2009a).
4. Excess fine sediment has been identified as a minor limiting factor within the Entiat River as a whole (Andonaegui 1999; CCCD 2004; Reclamation 2009a). This report will show that fine sediment levels fluctuate in accordance with natural conditions and do not represent a consistent or long-term concern.
5. Fluctuating summer water temperatures above and below 303(d) listings on the Entiat River over the past several decades. Despite this, most local biologists agree that temperature is not a significant limiting factor in Reach 2A (CCCD 1998; CCCD 2004; Reclamation 2009a).

Summary of Existing Reports

The Entiat River has been the subject of many reports and analyses that suggested the river has been severely impacted by anthropogenic alterations resulting in the degradation of fish habitat. The majority of impacts identified in existing reports refer to sections of the river other than the Gray Reach (Reach 2A) described in this assessment. Additionally, the severity of the anthropogenic impacts has at times been exaggerated by not having fully taken into account the likely condition of the river before Euro-American settlement or by relying too heavily on historical accounts without independent substantiation of their descriptions. This Reach Assessment will show that while humans have impacted the Entiat River, the impact has resulted in only a minor loss of instream habitat cover and complexity in addition to lesser impacts on channel pattern, migration rates, and floodplain interaction in the Gray Reach.

Pertinent reach-scale information has been extracted from past work and used in this Reach Assessment. Specific broad-scale background information from existing reports and analyses has been summarized to help develop a better perspective regarding the reach-scale information to follow.

Regional Scale

The regional geology in which the Entiat watershed is located consists of the Northern Cascades physiographic province that is characterized by folded, metamorphosed sedimentary rocks intruded by granites forming ridges and peaks, some in excess of 8,000 feet high. Bedrock geology in the Entiat watershed consists primarily of metamorphic and intrusive igneous rock from the Swakane, Mad River, and Chelan Mountains Terrains (Reclamation 2009a). Associated with the bedrock geology are many thrust faults related to accreted terrains from the mid-Cretaceous and Eocene epochs between 40 and 100 million years ago. The majority of these faults are considered to be inactive (Lasmanis 1991) although within the past 100 years four earthquakes capable of triggering large rockfall and other mass wasting have shaken the ground within the Entiat watershed (CCCD 1998).

Climatic conditions in the region are significantly influenced by orographic uplift associated with the topographic effects of the Northern Cascade Mountains. Near the Entiat River headwaters in the high Cascades Mountains over 90 inches of precipitation per year is possible while near the confluence with the Columbia River to the east, annual precipitation averages roughly 10 inches per year (CCCD 2004). Snowfall is the dominant form of precipitation during the winter months.

Watershed Scale

The accumulation and subsequent melting of snow in the upper watershed heavily influence hydrology on the Entiat River. Most precipitation comes in the winter and spring in the form of snow resulting in a hydrologic regime dominated by late spring and early summer snowmelt. A gain/loss analysis shows that the upper half of the Gray Reach is generally gaining from groundwater at the rate of approximately 0.7 cubic feet per second (cfs) per mile while the lower half of the Gray Reach is generally losing surface flow to groundwater at the rate of 4.6 cfs/mile (CCCD 2004). Base flow within the study reach rarely falls below 65 cubic feet per second (cfs) based on daily values from the (U.S. Geological Survey) USGS gage near Ardenvoir (#12452800). Peak discharge is dominated by surface runoff, especially snowmelt events. Water quality in the Entiat River has not been identified as a limiting factor and no fish passage barriers are present in the mainstem river below the study reach although a natural waterfall blocks upstream fish passage near RM 34.

The two principal species of concern in the lower Entiat River are Upper Columbia steelhead, listed as threatened under the ESA, and Upper Columbia spring Chinook salmon, listed as endangered under the ESA. Steelhead adults tend to spawn between March and May from the mouth of the river upstream to RM 28 and in tributaries (Nelle 2005). Steelhead fry emerge from July through September and juvenile steelhead spend up to 3 years rearing in the Entiat River before migrating to the ocean, typically in April and May (USFS 2007). Spring Chinook salmon generally spawn between RM 16 and 28 (Hamstreet 2006) and the fry emerge generally between March and early May. The juvenile fish generally rear in the Entiat River until the following spring when they begin their downstream migration to the ocean (USFS 2007). Neither Entiat River populations of steelhead nor spring Chinook salmon are currently viable, and both have a high risk of extinction (CBFWA 2011).

Valley Segment Scale

- Valley is U-shaped as carved by glaciers with a gradient averaging roughly 0.4 percent.
- The valley bottom is generally broad (500 to 1,800 feet) with discrete (typically less than ½-mile long) reaches where alluvial fan debris flow deposits have prograded onto the floodplain severely restricting the valley bottom width (80 to 200 feet). The Gray Reach occupies a broad, unconfined portion of the valley segment.

Regarding the unconfined reaches within the valley segment (including the Gray Reach):

- The bed and banks are generally composed of poorly consolidated alluvial sediment consisting of gravel with cobbles and sand – alluvial channel.
- The floodplain is well connected and comprised of 2 to 7 feet of silt and sand overlying alluvial gravel and cobbles (Golder 2007; Reclamation 2009a).
- Sediment supply to the river is derived from upstream sources, episodic mass wasting processes, and local bed scour and bank erosion (Reclamation 2009a).
- Disturbance frequency is dominated by ongoing small-scale disturbance including bank erosion, annual floodplain inundation and bed scour/deposition and infrequent large-scale disturbance that is fire-related or due to seismic mass wasting. The study reach is characterized by a transport-limited sediment regime (i.e., response/deposition reach).

Historical Timeline

After Euro-American settlement of the area, recorded historical events and activities occurring in the Entiat valley have impacted river form and process. Some of the more significant historical events in the Entiat valley are summarized in Table 1. A more detailed historical timeline of the area is available in Appendix A of the Tributary Assessment (Reclamation 2009a).

Table 1. Significant historical events impacting the Gray Reach of the Entiat River.

Year or Period	Significant Historical Event
1887	First Euro-American settlers arrive in lower Entiat valley
1888 to 1917	Lumber mill holding dam formerly operated by T.J. Cannon, Cannon & Harris, and later H.H. Gray & Son at RM 0.6 blocked fish (Figure 5).
1913 to 1932	Kellogg Mill Dam at RM 3.6; 8-foot-high dam blocked fish.
1948	Flood of record is roughly 10,800 cfs as measured in lower Entiat River
1956	Rocky Reach Dam construction commenced on Columbia River
1961	Rocky Reach Reservoir filled (Lake Entiat)
1971	Last documented major removal of logjams from the river
1972	Flood measuring roughly 6,430 cfs at Ardenvoir (Figure 6).
1990s	Major fish habitat rehabilitation efforts begin

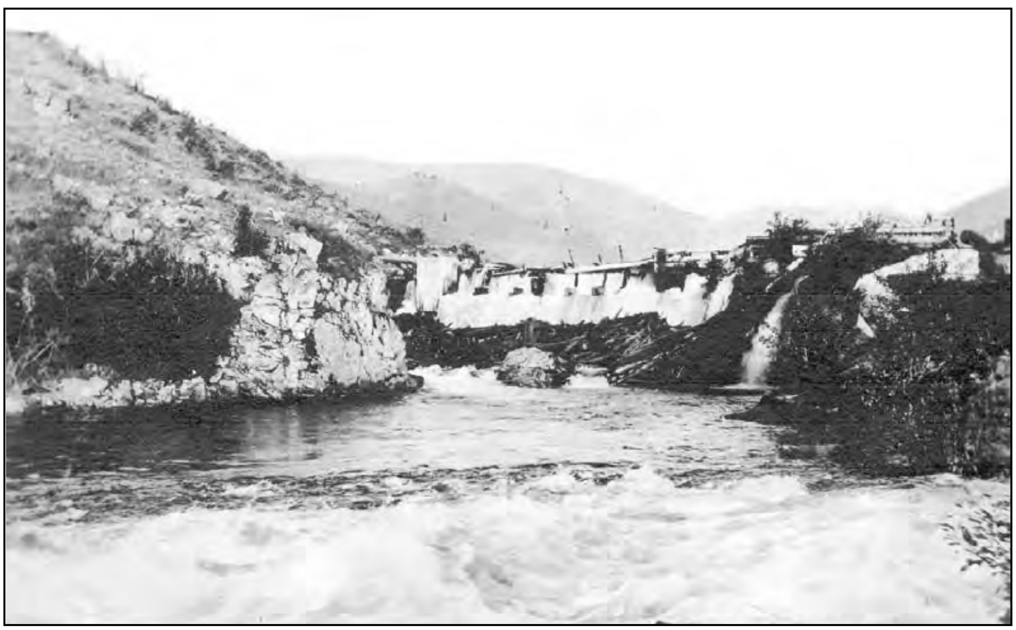

Figure 5. Formerly the T.J. Cannon, Cannon & Harris, and later the H.H. Gray & Son Mill Dam circa 1916 near RM 0.6 completely blocked upstream fish passage for decades (Reclamation 2009a).

Figure 6. A 1972 oblique aerial photo of the bridge near RM 18, immediately upstream of the Gray Reach of the Entiat River during the 1972 Flood. Courtesy of Phil Archibald (Retired USFS) via Robes Parrish (USFWS).

Historical Conditions

For this report, the historical conditions are defined as the relatively unaltered or natural conditions representative of the assessment area prior to known large-scale human influences (i.e., Euro-American settlement). Exact replication of historical conditions is often unattainable by reach-scale improvement due in part to regional or global influences such as climate change, sociopolitical constraints such as infrastructure and development pressure, plus possible irreversible threshold exceedance, or other unalterable changes that may have occurred. For these reasons, it is not the goal of habitat improvement to restore those exact conditions that existed in the past, rather to understand those natural historical conditions in which the species of concern evolved in order to inform habitat improvement. As such, the historical conditions and the physical processes that created them can be used as a guide for developing the target conditions for the reach.

Historical Form

Forms represent physical conditions on the landscape and in the river. Large-scale forms include the geometry, gradient, and composition of the valley and channel, which largely define the overall character of the channel. Smaller-scale forms include instream structures, bedforms, and channel shapes that add heterogeneity to the channel, often representing habitat for fish.

The Gray Reach of the Entiat River was historically characterized as primarily a single-threaded, sinuous channel, with a well-connected, densely vegetated floodplain. The floodplain was relatively broad and well-connected including many off-channel wetlands, alcoves, and occasional side channels. As the channel migrated through loose sand and gravel alluvium from one side of the valley to the other, it left behind channel scars and occasionally created side channels. If maintained by logjams or other large flow obstructions (boulder clusters, bedrock, well-vegetated islands, etc.), side channels may have persisted for many years, although most likely filled either partially or completely with over-bank sediment after several decades. Flow convergence along each meander bend created scour pools separated by riffles creating a well-defined pool-riffle morphology. Many large boulders and LWM added to the channel complexity, creating a diverse and dynamic channel character. Large boulders were most common where the channel was subject to colluvial inputs, such as along the valley margin, while LWM was historically somewhat more ubiquitous as discussed later in this report.

Historic channel forms are summarized in Table 2 below.

Table 2. Historical conditions and forms of the Entiat River Reach 2A (Gray).

Form	Historical Condition	Process(es) Creating/Maintaining Form
River bed and banks	River alluvium (gravel), floodplain sediment (silt/sand) hillslope colluvium and debris flow deposits (coarse rock)	Deposition of river alluvium and floodplain sediment in a low-energy, low gradient reach as a result of the Potato moraine grade control; deposition of colluvium and debris flow deposits (i.e., alluvial fans) from infrequent hillslope disturbances such as fires, severe thunderstormes and earthquakes.
Sinuosity	1.2 to 1.6	Continual alluvial deposition drove bank erosion and meander formation; large logjams and old-growth forest contributed to lateral migration and sinuosity; colluvium and debris flow deposition created areas of erosion resistance; episodic avulsions resulted from meander cut-offs which temporarily reduced sinuosity.
Channel morphology	Pool riffle	Channel migration created a sinuous channel path which along with a bed composed of erodible alluvium enabled bend scour pool formation and downstream riffle deposition; large obstructions from debris flows, rockfall and logjams influenced scour and deposition forming additionl pool-riffle combinations.
Large pools (>20m^2 and 1m deep)	9 to 12 per mile; Greater than 1:1 pool to riffle ratio	Constrictions from large instream obstructions or alluvial fan progradation forced flow convergence and scour; bend scour.
Floodplain connection	Frequent flooding	Deposition, channel migration, and unconfined valley; backwater conditions from the Potato Moraine grade control.
Off-channel habitat	Estimated average of 7 alcoves or side channels per mile representing roughly 3,000 linear feet per mile	Channel migration formed oxbows periodically connected to the mainstem; frequent floodplain inundation concentrated against the valley wall created scour and head cuts into the floodplain; beaver activity maintained long alcoves and side channels; rare perennial upstream connections maintained by scour from logjams.
LWM	5 to 10 logjams per mile; >20 pieces per mile	LWM recruited from episodic mass failures and/or from bank erosion or windfall; individual pieces deposited on bars, lodged against instream structures, or pinned against the bank; logjams required large instream structure (boulder and/or key member) for recruitment and retention of multiple pieces.
Riparian condition	Dense, mixed-age trees including old-growth and shrubs with wetlands spanning the valley bottom	Seed dispersal and a shallow local groundwater table; frequent disturbances from flooding, channel migration, debris flows, beaver, windthrow, and fire created a mosaic of age classes.

Historical Valley and Channel Form

Channel Formation

The Entiat River valley was shaped by glaciers during the Pleistocene Epoch between roughly 2.5 million and 10,000 years ago. Glaciers carved the relatively broad, U-shaped valley and deposited the terminal moraine at RM 16.1 defining the transition between valley segments one and two, and providing downstream grade control for the Gray Reach. Following the high-sediment, high-discharge Pleistocene Epoch punctuated by multiple glacial periods, the climate in the Entiat valley became relatively warmer and drier. As glaciers retreated, the remnant terminal moraine (Potato moraine) temporarily dammed the river, creating a low-energy environment upstream that filled with sediment. Over the next several thousand years the channel began to migrate back and forth on a bed of its own mostly gravel-sized alluvium. A sinuous channel developed with a highly connected floodplain and well-developed riparian zone capable of tapping into the shallow local groundwater table.

Infrequent mass wasting events associated with fire, earthquakes, and large floods resulted in the formation of alluvial fans at the mouths of the larger tributaries. Alluvial fans in the Gray Reach were generally erosion-resistant consisting of poorly sorted sediment comprised of angular cobbles, boulders and gravel embedded in a fine matrix of silt and sand. Over time, alluvial fans prograded onto the floodplain and/or encroached onto the channel which forced the Entiat River channel to migrate toward the opposite valley wall through more easily erodible floodplain alluvium (Figure 7). Within the Gray Reach, channel migration forced by alluvial fan progradation increased overall sinuosity.

Episodic rockfall consisting of large boulders (up to 25 foot diameter) from the steep valley walls added significant instream structure capable of altering channel form by influencing local bank erosion and bed scour. Rockfall was the result of ground shaking from earthquakes, frost heave, and other forms of erosion culminating in infrequent mass failure. Large volumes of rockfall and steep slope wasting (colluvium) formed erosion-resistant valley margins in several areas of the Gray Reach, while individual large boulders and boulder clusters forced flow convergence and strong scouring eddies forming localized pools in the main channel (Figure 8).

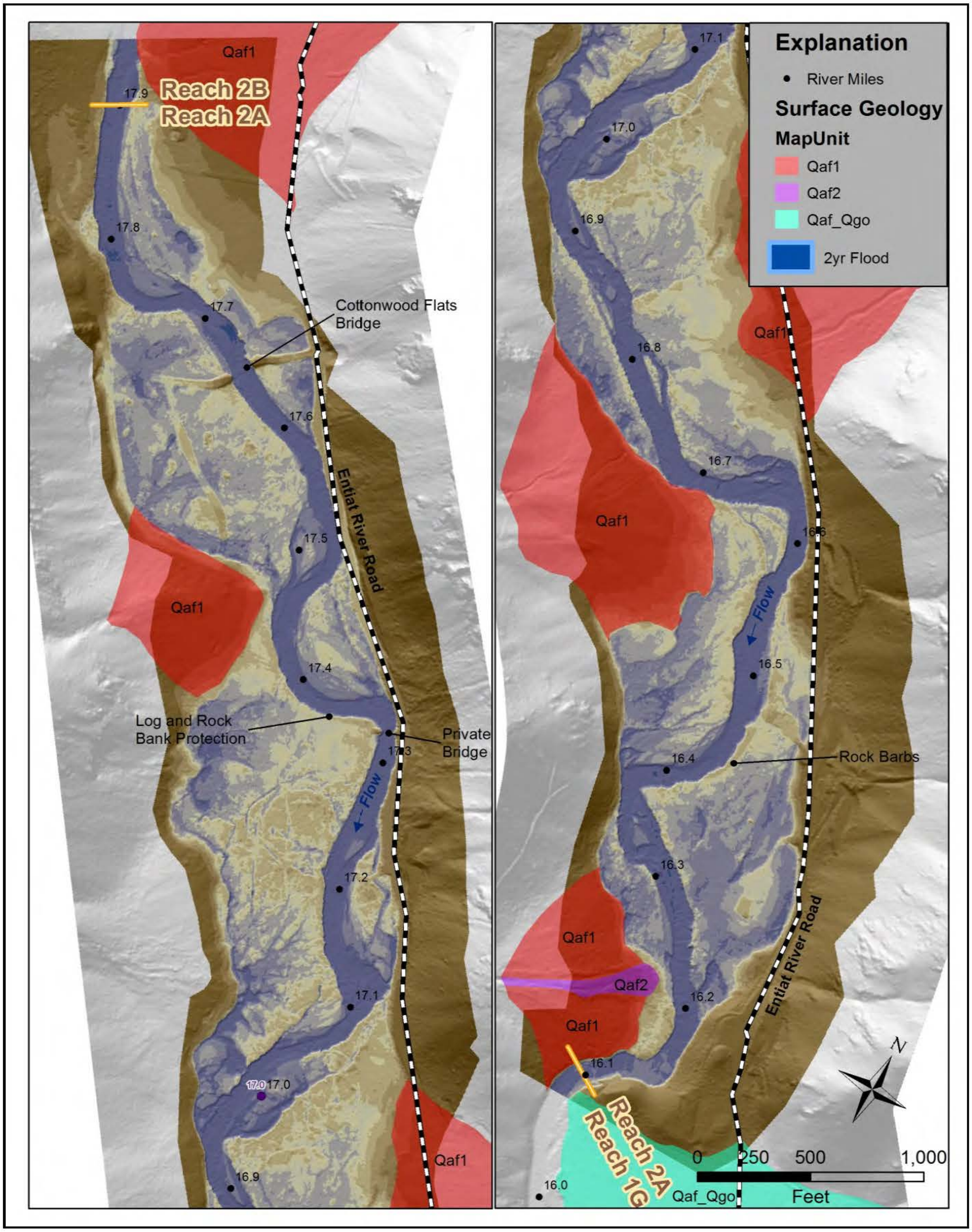

Figure 7. Erosion resistant alluvial fans (Qaf1, Qaf2) have prograded onto the floodplain forcing the Entiat River to migrate toward the opposite valley wall in these areas.

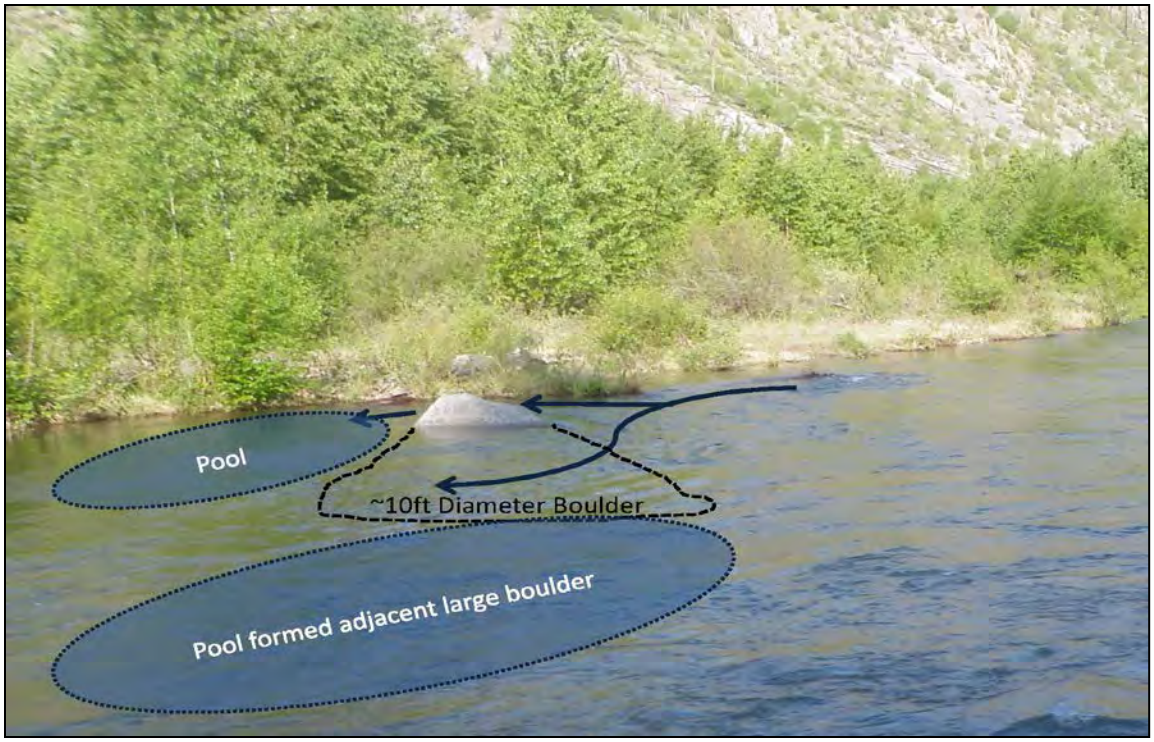

Figure 8. Rockfall from adjacent valley walls infrequently deposits large boulders in the channel creating obstructions that alter local channel hydraulics increasing diversity. The image above shows a roughly 10-foot-diameter boulder influencing hydraulics near RM 17.55.

As a result of its glacial past and more recent but infrequent debris flow and rockfall additions, a sinuous channel formed within the Gray Reach with a pool-riffle morphology and a well-connected floodplain. A balanced sediment regime of roughly equal amounts of deposition and erosion created a relatively stable yet diverse channel capable of migration without inducing incision, widening, or braiding. Channel migration reinforces a balanced sediment regime whereby erosion of the outside bank of a bend is coupled with concurrent deposition of sediment along the inside bank of the same bend. This process has resulted in the lateral movement of the Entiat River, while maintaining relatively consistent channel shape and width.

Pools and Riffles

The meandering nature of the Gray Reach created a sinuous channel enabling helical flow whereby the momentum of moving water causes it to bulge against the outside of a bend, forcing downward and downstream flow to relieve the pressure. The downward helical or corkscrew flow vectors in combination with an erodible alluvial bed resulted in localized bend scour (Figure 9). The scouring effects of helical flow break down shortly downstream of the bend where the eroded sediment is subsequently deposited forming a relatively shallow riffle. The historic Gray Reach was characterized by a series of bends with bend scour and downstream riffle deposition creating a pool-riffle morphology with roughly equal numbers of pools and riffles.

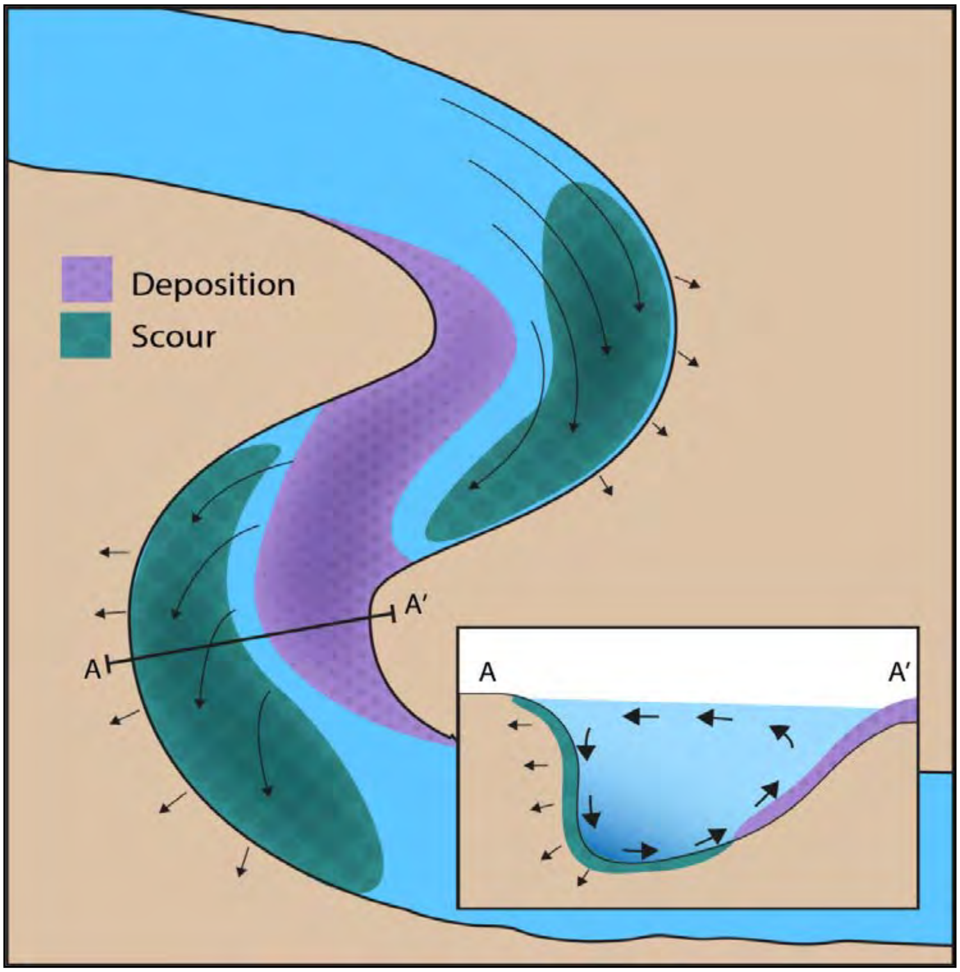

Figure 9. Simplified diagram illustrating helical flow resulting from flow passing around bends in the river. As flow enters a bend, its momentum pushes more volume toward the outside of the bend resulting in a slight bulge (increased water surface elevation) along the outside of the bend. This added pressure along the outside of the bend is relieved downward, initiating a spiral-shaped flow path around the bend. The downward flow at the outside of the bend increases scour meanwhile upward flow downstream of the bend increases deposition. The result is a pool-riffle sequence with pools generally located at the outside of each bend and riffles located between bends.

Although it is impossible to know the actual number of historic pools in the Gray Reach, it can be estimated by assuming each bend formed a pool through helical scour as described above and by estimating the maximum number of bends within the minimum meander wavelength. Measurements from historic aerial photos and ancient channel scars visible in LiDAR topography reveal an approximately 1,000-foot minimum meander wavelength. Each wavelength consisted of two bends, which combined with helical flow bend scour, resulted in a minimum of two pools per 1,000 feet. The Gray

Reach valley length is just over 9,000 feet long, resulting in a minimum of 18 total pools or 10.6 pools per mile. Given the possibility of compound pools at larger radius bends and that additional pools may have also formed between bends from scour associated with instream obstructions (boulders and logjams), it has been estimated that 15 to 20 large pools (9 to 12 pools per mile) characterized the historic Gray Reach.

Documentation in the 1930s identified roughly 6 resting pools per mile with a good distribution of both large and small pools of which about 47 percent had adequate cover (USBF 1935). Measurement criteria at the time defined resting pools as exceeding 25 square yards and 3 feet deep. In addition to pool quantity and size, the 1930s surveys reported that most pools occurring near the banks were “adequately protected by heavy bank growth and windfalls.” Surveys were completed during low flows in September of 1935, when flows were measured at 150 cfs near the mouth of the Entiat River.

Floodplain and Off-channel Character

In addition to pool-riffle channel morphology, the historic Gray Reach was further characterized by a well-connected floodplain. Floodplain connection (inundation) occurs when instream flow conveyance is exceeded and water overflows the banks. Alluvial channel formation is well balanced between erosion and deposition, trending toward a channel geometry capable of conveying bankfull flows of roughly 1 to 2 year recurrence intervals (Leopold 1994). The low-gradient valley slope, lack of measurable incision, and active channel migration created and maintained a balanced alluvial channel with a high level of floodplain connection in the Gray Reach. During exceptionally high flows, a backwater likely formed upstream of the Potato Moraine that increased water surface elevations and floodplain inundation.

Related to floodplain connection is off-channel habitat consisting of alcoves and side channels. Channel migration, avulsion, and frequent flooding created channel scars and other low-lying depressions in the floodplain. Some remained connected as alcoves, some became wetlands, and others remained connected at upstream and downstream ends forming side channels. Alcoves are off-channel, wetted areas with one (typically downstream) connection to the mainstem. Flow through the alcove during low-water periods is typically the result of hyporheic (local groundwater) conditions. Sediment transport and flushing is typically the result of high flow enabling a temporary upstream surface water connection. Most alcoves on the Gray Reach likely formed in one of two ways: 1) from multiple episodes of overbank flooding where flood water collected against the valley wall (or other topographic high) returning back into the channel as concentrated flow capable of scouring and head-cutting into the floodplain (Figure 10), or 2) channel migration and avulsion creating oxbow ponds and wetlands that were periodically connected to the main channel (Figure 11 – 1970s avulsion near RM 17).

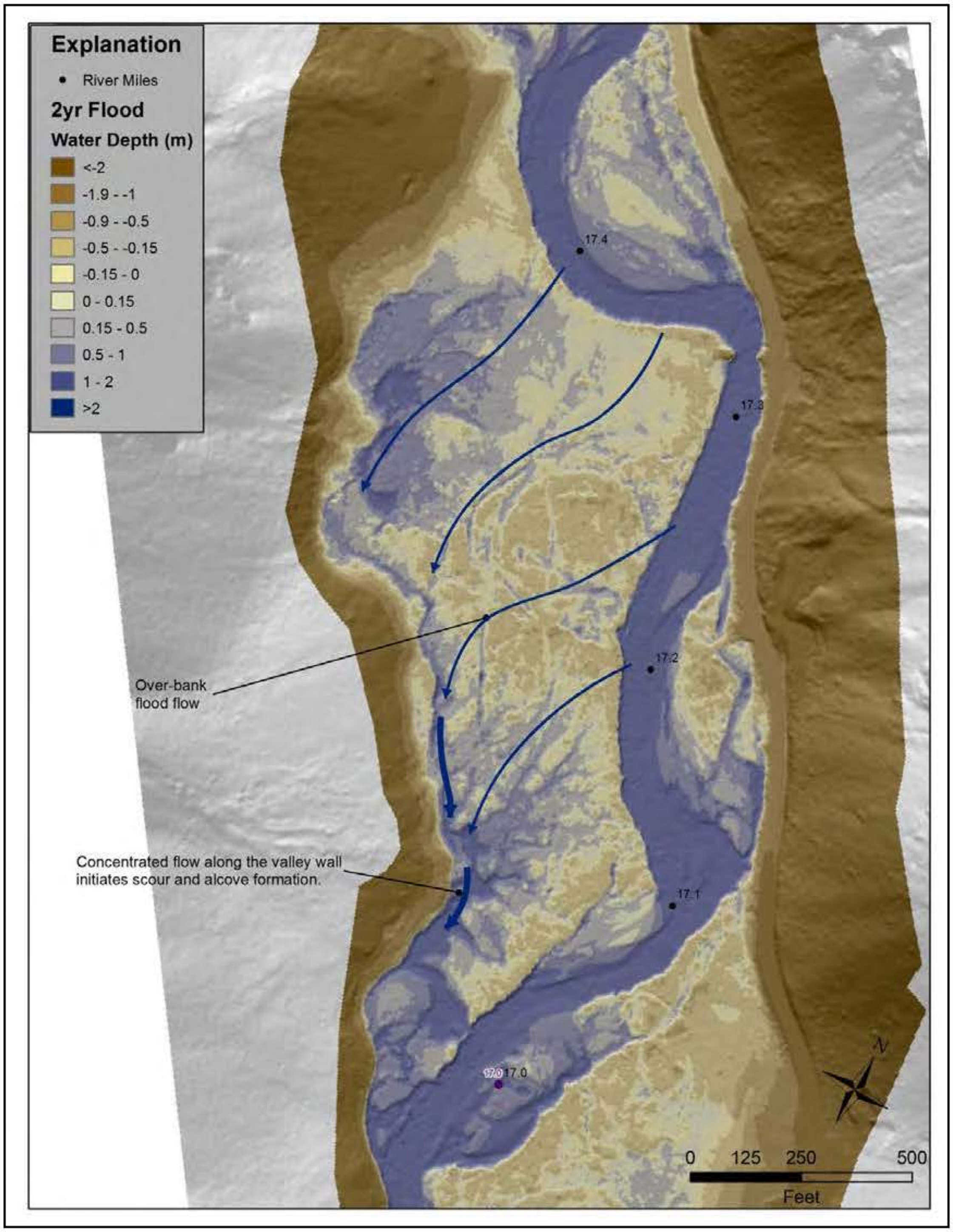

Figure 10. Alcove formation is commonly found where overbank flow is concentrated against an obstruction (like the valley wall). The concentrated flow has sufficient shear to scour an alcove channel where it flows back into the mainstem. In the area depicted by the figure, inundation mapping suggests that overbank flood flow would probably result from floods greater than the 2-year recurrence interval.

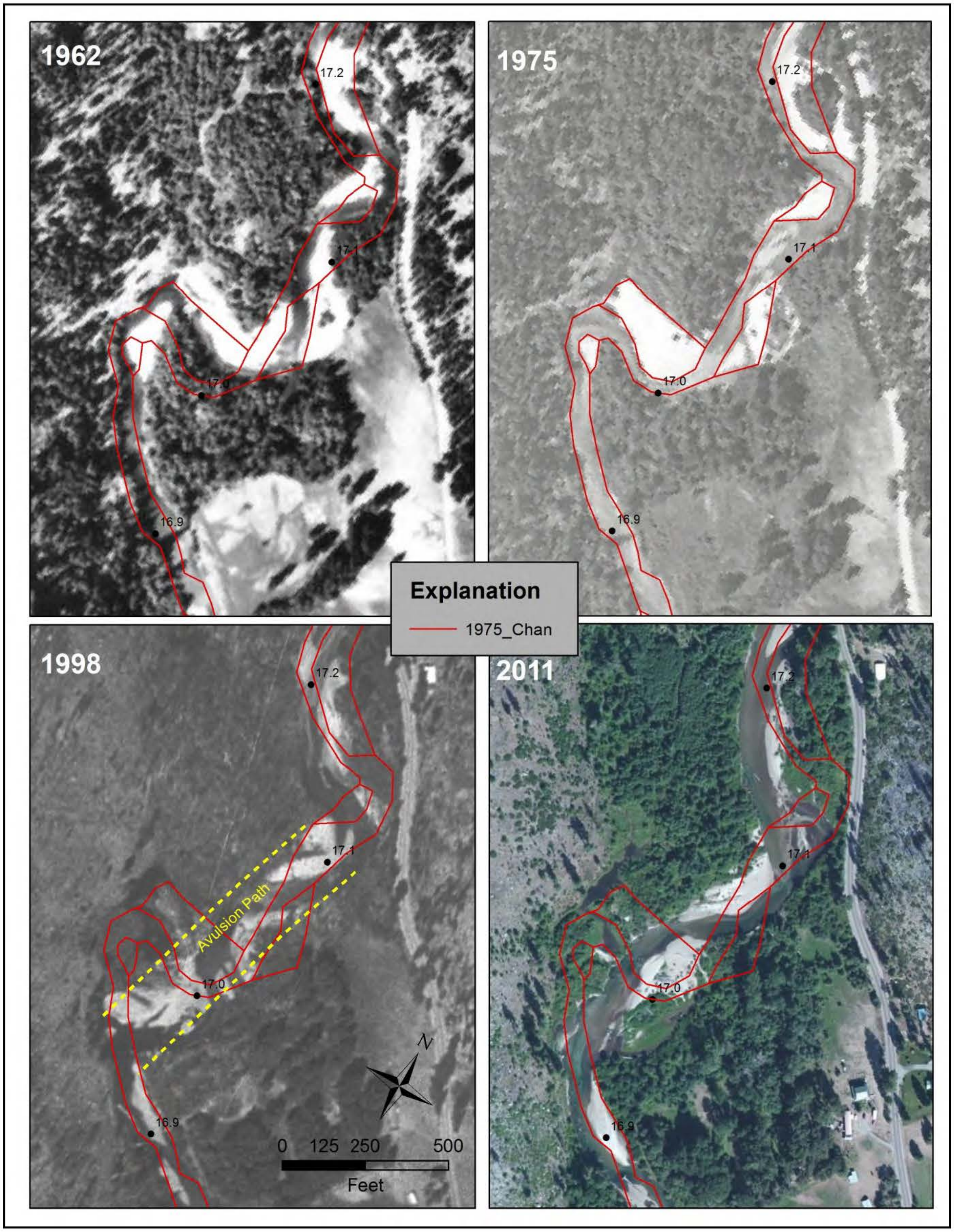

Figure 11. Time series progression from 1962 to 2011 illustrates a meander cut-off avulsion near RM 17.0. From 1962 to 1975 downstream channel migration reduced the radius of curvature until the channel cut through the bend resulting in an avulsion.

Avulsion is the abrupt movement of an active channel to a new location in the river valley. This process usually occurs in response to cumulative deposition and infilling of the active channel by sediment or debris causing the stream to rapidly erode a new channel or reoccupy a formerly abandoned channel. In the low-gradient, unconfined Gray Reach of the Entiat River, avulsions likely occurred infrequently where highly sinuous sections of channel were bypassed for a more direct path through the floodplain or across a point bar often in response to a large flood. In that case, flood flow plunging back into the mainstem likely created a nick point that propated upstream, replacing the sinuous meander with a relatively straight channel. Similarly, avulsion may also have occurred as a meander bend cutoff wherein a highly sinuous, looping bend would have been pinched off at the neck, thus abandoning the bend, and straightening the channel pattern.

Side channels formed in the same manner as alcoves, but were able to maintain an upstream surface connection by locally breaching the bank after many years of an alcove head cutting upstream or by localized scour at the site of the side channel inlet often created by a logjam or other instream obstruction. It is unlikely that perennial side channels persisted for more than a few years without a corresponding logjam or other obstruction to maintain the inlet and prevent the mainstem from migrating away from the inlet or filling it with sediment.

Historic off-channel habitat in the study reach was likely dominated by alcoves with only occasional side channels as evident from historic photos and ancient channel scars visible in detailed LiDAR topography. Most side channel inlets were blocked or never formed as the result of broad, low-profile natural levees that lined the banks of the channel (Figure 12). An explanation of natural levee formation is provided in the upcoming Historic Process, sediment transport section of this report. Perennial side channels were likely short lived (tens of years), formed by channel avulsion or rapid lateral channel migration. After several decades (or a handful of depositional events), a natural levee would have likely blocked the inlet to the side channel or the entire channel would have migrated away from the inlet or potentially avulsed through the side channel abandoning the original channel.

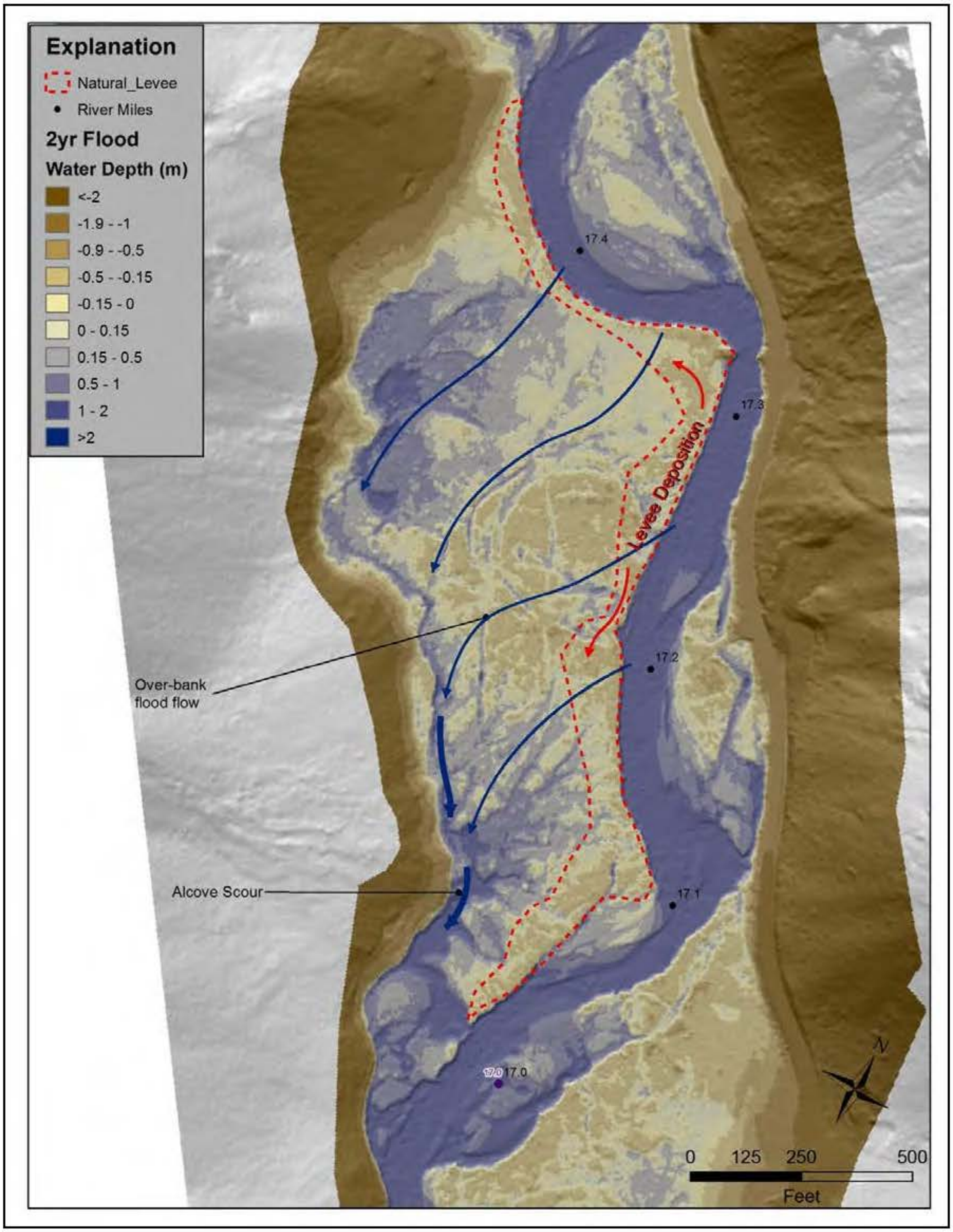

Figure 12. Broad, low-elevation natural levees are common in depositional reaches such as the Gray Reach. During floods, overbank flow carrying suspended sediment preferentially drops its sediment load near the banks when influenced by the relatively shallow, high-friction floodplain. This process is further described in the "Historical Processes" section.

Instream Obstructions

Instream obstructions can force flow to move laterally, can confine and concentrate flow, and/or can create constrictions backing up flow any of which has the potential to alter the form of a channel. Obstructions represent any object that blocks flow, but most commonly consists of large pieces of wood or rock embedded into the bed or banks of the active channel. LWM is defined in this report as any piece of wood greater than 12-inch diameter and 30-feet long interacting with stream flows. A log structure consisting of 10 or more interconnected pieces of LWM that interacts with streamflow is considered a logjam. Logjams typically consist of a key member, secondary members, and additional racked members.

- Key member – typically a very large piece of LWM providing anchoring and structural stability to the logjam. It is this piece (or these pieces) upon which all secondary and racked members are connected to maintain a persistent logjam. The key members are often embedded into the bed or bank of the channel.
- Secondary member – typically consists of LWM pinned against a key member or other structural element (boulder, live vegetation, etc.) contributing to the size and structure of the logjam and support racked material. Secondary members are generally fairly stable within the logjam (Parrish and Jenkins 2012).
- Racked member – typically smaller wood and flotsam that is pinned against the key and secondary members providing little to no structural support but enhancing cover and increasing surface area and frictional component to the logjam as a whole.

It is estimated that at any given time prior to Euro-American settlement and modern clearing of instream structure from the river, the Gray Reach of the Entiat River contained many individual pieces of LWM and multiple logjams. Based on research from undisturbed streams on the east and west side of the Cascade Mountains in the Pacific Northwest (Fox 2001) and assuming logjams formed along the outsides of bends or at the apex of split flow channels, 5 to 10 logjams and at least 20 additional pieces of LWM per mile (potentially many more) would have been expected historically compared to modern conditions. Logjams were one essential component providing localized bank stability required for the formation and longevity of perennial side channels. Logjams that develop along the outside bend may have provided “hard point” inlet control to side channels and concentrated the flows into the inlet. Without logjams providing flow concentration on the outside of bends, the inlet to a side channel would have been closed off by deposition within just a few years.

The bank stability provided by logjams further contributed to improved floodplain connection and side channel maintenance by slowing long-term rates of downstream channel migration. Hard point associated with large logjams and old growth forest reduced downstream channel migration by deflecting flow laterally and vertically. The result was a channel with many deep pools and increased potential for lateral migration. Greater lateral migration increased channel sinuosity, decreased stream gradient, and enhanced floodplain connection, and the potential for side channel formation. Without large logjams and/or old-growth forest stabilizing banks, downstream channel migration overwhelmed and eliminated most side channels before they had a chance to fully form.

In addition to wood, large boulders also obstruct flow and can rack wood enabling logjam formation. Large boulders have been delivered to the channel and floodplain over the past several thousand years through episodic rockfall associated with mass wasting near the valley margin. Although infrequent, large boulders persist on the landscape for many hundreds of years influencing local channel form over the long term.

Riparian Conditions

Riparian conditions include the vegetation type, age, and areal extent within the active floodplain (defined as the 2-year recurrence interval flood area). Although no direct evidence of pre-Euro-American settlement riparian conditions exist today, it is hypothesized that conditions were generally similar to today with the exception of more mature trees and conifers (old growth) historically. Seed dispersal from floods, wind, and other natural means of propagation following disturbance along with a shallow local groundwater table enabled establishment of a diverse riparian community across the entire valley bottom. Similar to today, prominent vegetation likely included cottonwood, willow, river birch, alder, and cedar, with Ponderosa pine and Douglas fir dominating upland areas. Wetlands occupied low-lying areas formed by channel migration or flood scour. Disturbances from flooding, channel migration, beaver, windthrow, debris flows, and fire created a mosaic of age classes.

Historical Process

In an alluvial river system, channel processes are continually working to maintain a relatively stable condition by adjusting numerous variables that are mutually interdependent: hydrology, sediment transport, channel migration, LWM recruitment, and riparian conditions, among others. As one process changes, the others respond to maintain a quasi equilibrium. The response time for adjustment depends on both the degree of change (disturbance) and the inherent condition of the river system. In an unconfined alluvial river system such as the Gray Reach of the Entiat River the response time required for natural processes to adjust to changes in form or process is relatively short. As a result, despite frequent disturbances the natural processes inherent to the system maintain a relatively stable yet diverse riverine environment.

Hydrology

Glaciers advanced and retreated multiple times within the higher elevations of the Entiat River Watershed during the last ice age resulting in a highly variable and often extreme hydrologic response that formed the Entiat River valley. In the roughly 10,000 years since the last glaciers melted, the modern climate has been marked by a relatively consistent and mild temperature and precipitation (Houghten et al. 2001) resulting in a relatively consistent hydrologic regime dominated by seasonal snowmelt.

Historically under a seasonal, snowmelt-dominated hydrologic regime, the Gray Reach of the Entiat River functioned similar to many unconfined alluvial channels by conveying modest flows within its banks but frequently spilling water onto its floodplain during high-water periods. Evidence of a historically well-connected floodplain is present in the 2 to 6 feet of silt and sand mantling many areas of the floodplain (Golder 2007; Reclamation 2009a) suggesting hundreds of years of flood deposition. The consistent climate of the past several thousand years supports a historic hydrologic regime similar to the modern regime whereby channel-forming flow is estimated to be around the 1.5- to 2-year recurrence interval flood (approximately 2,500 cfs). At this discharge bedload mobilized, bed scour and bank erosion occurred, and floodplain interaction initiated, all of which combined to help shape the historic and modern channel form of the Gray Reach.

In addition to snowmelt, the Entiat River basin was subject to infrequent, convective summertime thunderstorms. As stated previously, because climate conditions have not significantly changed within the past several hundred years, it is assumed that historic precipitation patterns roughly mirrored modern conditions. A cursory analysis of recent summertime high-flow gage data (USGS gage 12452800) revealed no summertime flow spikes exceeding the 1-year-flood (1,200 cfs) within the past 25 years, suggesting that convective summertime thunderstorms did not have a significant impact on main-stem hydrology. Historic accounts have shown that convective thunderstorms have historically impacted small-order tributary drainages episodically causing debris flows and sediment delivery to the mainstem.

Sediment Transport

Sediment transport can generally be separated into two categories: competency and capacity. Competency refers to the maximum grain size a stream is capable of transporting. Sediment capacity refers to the volume of sediment transported by a stream and is dependent on the channel competency and sediment supply.

Competency and capacity following the last ice age were dependent on a combination of factors including base level control (i.e., gradient) and hydrology. The terminal moraine located near Potato Creek created an elevated base level (bed control) that impounded water upstream of the moraine resulting in a low-energy environment and therefore a low competency and capacity for sediment transport. Fine-grained sediment deposited in the low-energy environment upstream of the terminal glacial moraine, and is visible in modern cut bank exposures along the channel near the downstream end of the reach. Once the valley upstream of the terminal moraine was filled with sediment, a channel and floodplain took shape. The low-gradient valley segment enabled the formation of a sinuous, alluvial channel with a well-connected floodplain.

Competency in the sinuous, alluvial channel was controlled largely by hydrology and gradient with localized variation from changes in width-to-depth ratio. Floods mobilized sediment including cobble, gravel, and fines. In the low-gradient valley segment, as discharge increased to flood stage, overbank flow initiated. Energy and flow volume were dissipated on the floodplain during large floods maintaining maximum instream competency in the cobble size range. In other words, the sediment transport competency could not increase beyond cobble grain sizes because the channel was not steep and deep enough, and energy from big floods was dissipated on the floodplain rather than focused between the banks. Areas with low width-to-depth ratios (constrictions) may have locally increased sediment transport capacity to move larger sediment and scour deep pools.

Capacity was also controlled largely by hydrology and gradient with the added component of sediment supply. Most bedload sediment was supplied from local scour (bend scour and contraction scour) and bank erosion while most suspended sediment was supplied from hillslope erosion (sheetwash) and bank erosion. Infrequent mass wasting, debris flows, and rockfall introduced a wide range of grain sizes and sediment volumes, of which most cobble and smaller sediment has been subsequently reworked by the channel. Larger boulders have not been mobilized by the channel and represent obstructions providing structure and often times bank protection throughout the reach.

Suspended sediment was primarily deposited on the floodplain or washed through the reach. As suspended sediment was transported over the banks, it was deposited creating low profile, broad natural levees lining the channel through a process called advective transport. Advective transport occurs during a flood when the water depth in the river channel is greater than the water depth on the floodplain. As sediment-laden floodwaters spill over the banks, the depth, velocity, and therefore transport capacity of these flows decreases proportionally to their distance from the river bank resulting in preferential sediment deposition in the shallow, high-friction zone directly adjacent the banks resulting in the formation of low-profile, broad, natural levees (Figure 13). Historically, the Gray Reach of the Entiat River was considered a transport limited reach with a sediment transport regime dominated by deposition. While suspended sediment was deposited on the floodplain, most bedload was deposited on bars and riffles generally after short distances of transport. The overall (suspended and bedload) sediment transport capacity depended on the duration of the transport flow. As with modern flows, in the snowmelt-dominated system, spring runoff historically lasted between 1 and 3 months on average with the majority of sediment transport occurring during that timeframe.

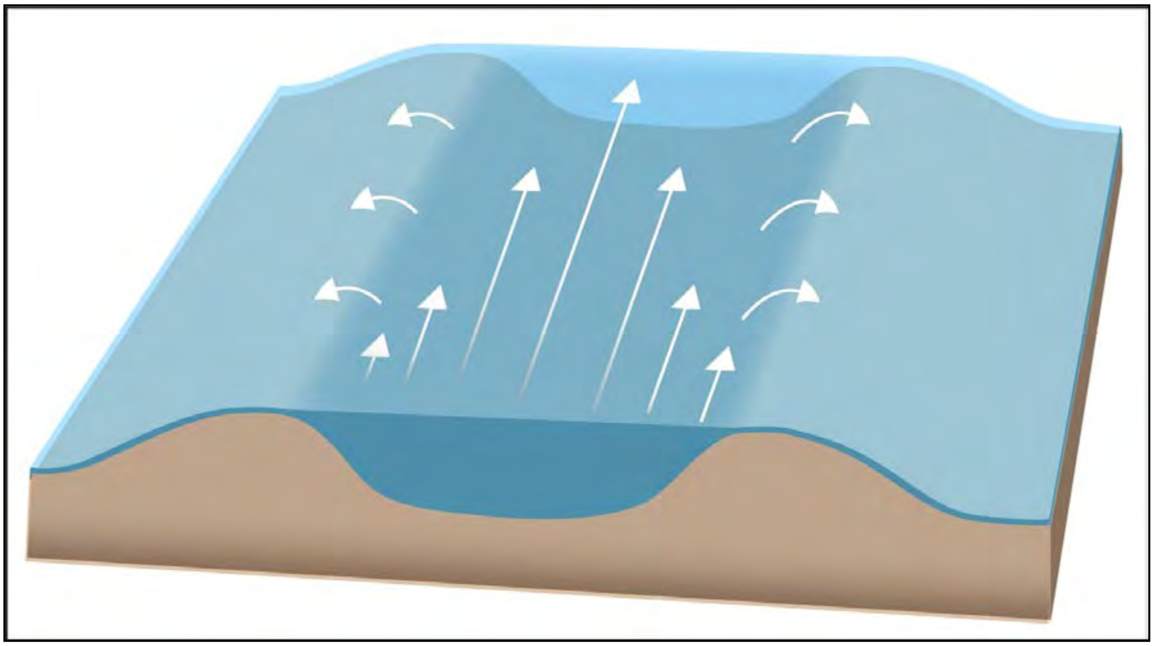

Figure 13. Advective sediment transport occurs when water depth is much greater in the channel versus the floodplain resulting in greater friction, decreased water velocity and preferential sediment deposition on the floodplain near the banks. The arrows in the illustration represent relative water velocity and direction. Deposition in this manner naturally forms broad, low-profile levees lining the main river channel as seen in portions of the Gray Reach.

Channel Migration

Historical channel migration in the Gray Reach was characterized by relatively high rates recently (within the past 75 to 100 years) but likely somewhat lower rates of migration prior to Euro-American settlement and modern timber harvesting. Recent (past 75 years) historical channel migration measurements were based on historic aerial photo comparisons representing long-term averages of small-scale changes during most years punctuated by large-scale changes during relatively few big-flood years. Migration observed within the past 75 years ranged upwards of 1 to 2 feet per year laterally and 2 to 6 feet per year in the downstream direction. Visible channel scars on the floodplain suggest the 100-plus-year historic channel was highly sinuous and characterized by channel migration and avulsion. It is hypothesized that 100-plus-year historic rates of channel migration were somewhat less (especially in the downstream direction) than recent rates of migration. Over 100 years ago, mature riparian vegetation, logjams, and relatively large quantities of LWM likely stabilized historic banks limiting downstream migration. The same structures that stabilized banks also obstructed flow (such as a large logjam) potentially causing the channel to flow around the obstruction forcing lateral migration. It is therefore plausible that lateral migration may have dominated channel processes, albeit restricted by relatively stable banks compared with those of the past 75 years as will be discussed in the Existing Conditions section of this report.

In addition to channel migration, it is highly likely that the historic channel also experienced episodic avulsions where the entire channel abruptly changed location within the valley bottom, most likely as a result of meander cut-off. This is assumed because alluvial, transport-limited reaches will tend to migrate over many sequential years of moderate flooding into a highly sinuous channel pattern. Given sufficient time and a large flood, concentrated overbank flow will tend to cut off highly sinuous meanders creating a relatively straight avulsion path. This trend has been observed in the historic aerial photo record of the last 75 years in the Gray Reach, Stormy Reach, and Preston Reach all within the relatively low-gradient “still waters” of Valley Segment 2 of the Entiat River (Figure 14).

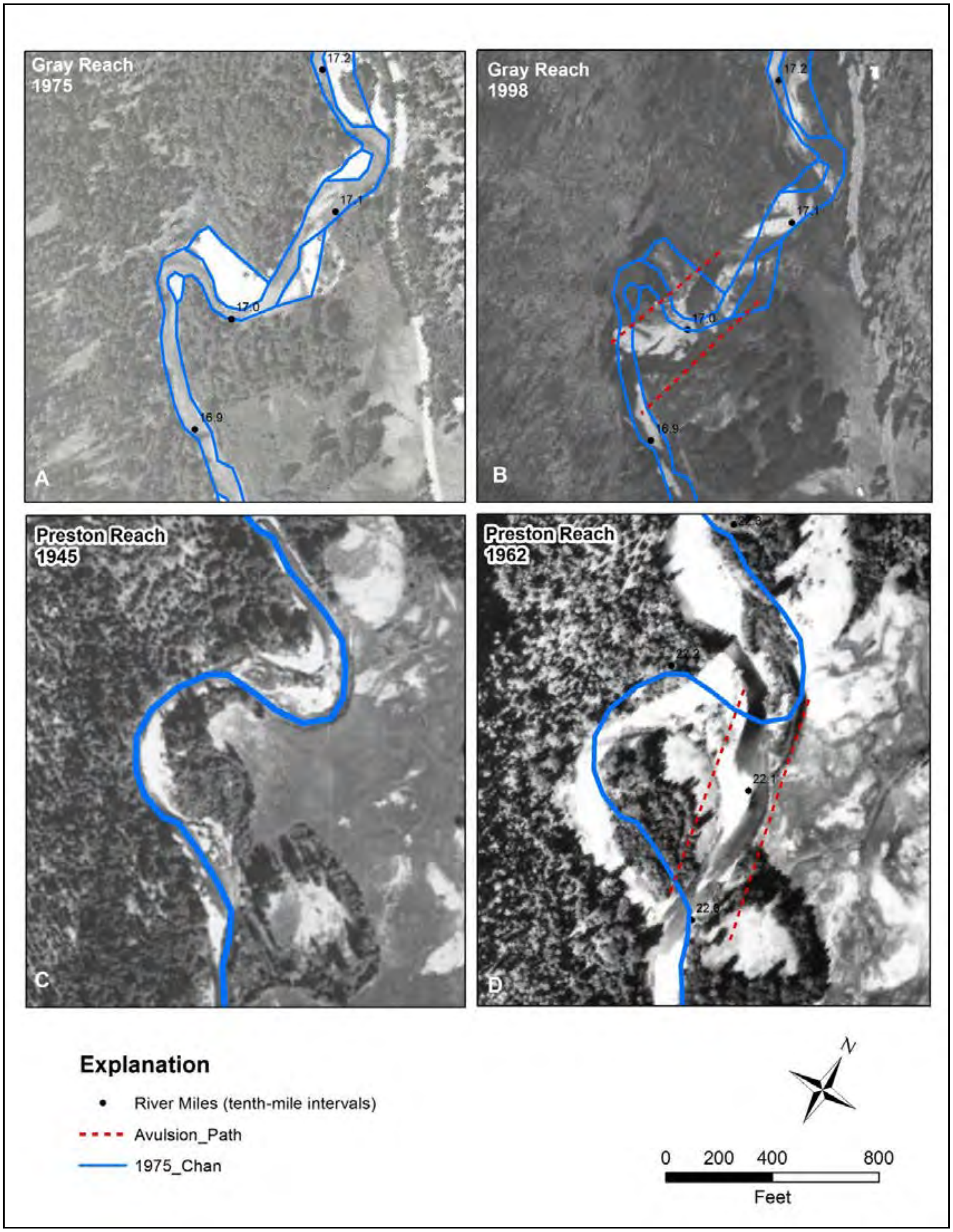

Figure 14. Meander cut-off avulsion examples from Gray Reach (photographs A and B) and from several miles upstream in the Preston Reach (photographs C and D). In both instances downstream migration reduced the bend radius ultimately resulting in a meander cut off. As the bend radius became less, flow as forced to take a longer route with increased friction around the tighter bend resulting in backwater conditions and increased overbank flow during floods. Overbank flow ultimately scoured a new, straighter path cutting off the highly sinuous meander bend.

Large-scale avulsion, cutting off more than one bend, was unlikely within the historic Gray Reach. Mature, old-growth riparian vegetation effectively protected large portions of the floodplain from channel scour beyond narrow side channels precluding large-scale avulsion. Immature forest and recently disturbed floodplain surfaces formed on newly deposited material along the inside of bends representing the most likely path for small-scale avulsion by cutting off the inside of a single bend. Logjams that may have formed on the point bars along the inside of a bend may have further influenced small-scale avulsions by splitting high flows and focusing increased volumes of floodwater across the point bar potentially initiating split flow (side channel) formation or an avulsion across the point bar.

LWM Recruitment and Retention

Under certain conditions, LWM has the potential to significantly influence channel form and process. LWM can effectively armor banks, increase hydraulic variability, deflect flow, obstruct flow, or force localized flow convergence, particularly when consolidated into logjams. However, LWM influence depends on recruitment and retention of wood.

Recruitment of LWM in the Gray Reach included upstream sources from episodic disturbances such as debris flows, avalanches and avulsions, and included local sources as a result of ongoing bank erosion and wind-throw. Retention of LWM depended both on the size of the wood and the shape of the channel. Large logs with rootwads deposited onto riffles where water depth was insufficient for the LWM to pass and subsequent deposition on the leeward side of the rootwad buried the top of the tree. Retention in this manner required large diameter trees and root wads such that the submerged portion of the log exceeded the depth of the channel at a riffle (Figure 15). LWM was also pinned against the bank by flow in certain areas. This commonly occurred at the head of islands, along the outside of bends where existing vegetation or windfall captured mobile wood as it passed by, or where flow passed onto the floodplain either at a side channel or floodway.

Figure 15. Large cedar rootwad log deposited on a riffle near RM 16.9. The end of the log has been cut off and removed. Tree diameter is approximately 3-feet where cut and nearly 5-feet at the base.

Each piece of LWM and logjam in the channel had a hydraulic effect on the river – the larger the obstruction, the bigger the effect. In the event of LWM retention and logjam formation in the middle of a riffle, the obstruction would split flow creating a hydraulic eddy and deposition in its lee, scour around its sides, and potentially create a backwater upstream. Logjams along the banks had a similar effect creating scour near the apex, an eddy downstream and a local backwater immediately upstream of the structure. Individual logs and small logjams typically do not obstruct enough of the cross-sectional area of the channel to have more than a localized hydraulic impact. Flow may be deflected around or under the log(s) potentially creating a small, localized scour pool. In general, large and small wood increased hydraulic diversity and provided cover along the banks of the Gray Reach. As discussed previously, LWM may have also increased the duration of side channel connection by reducing downstream migration and meander cutoff potential (Figure 16) or creating local scour adjacent a side channel inlet (Figure 17).

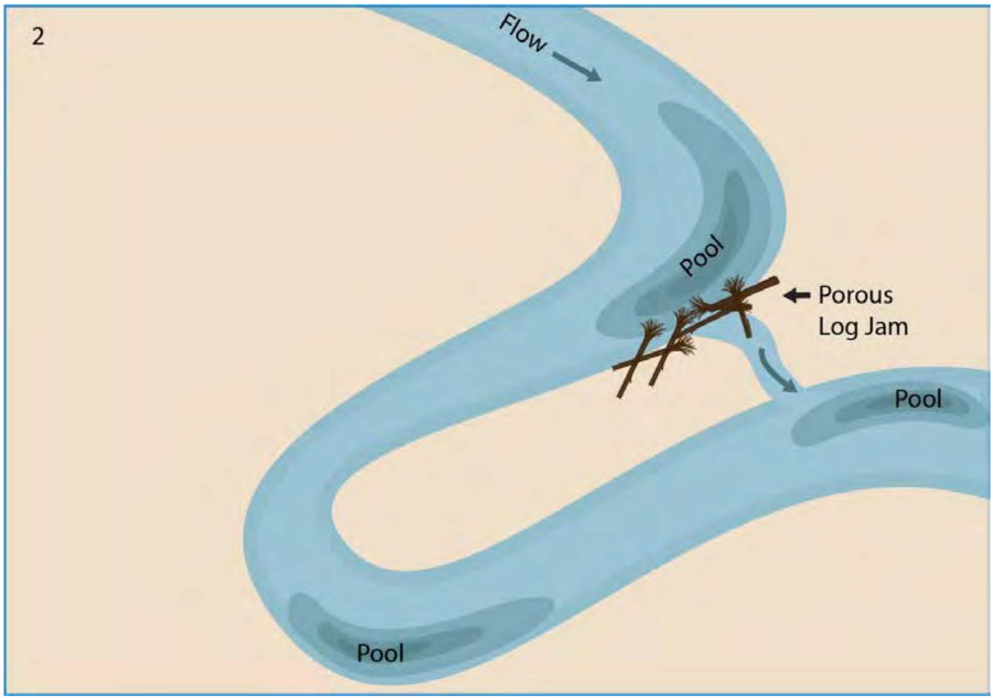

Figure 16. Diagram illustrating how a porous logjam may stabilize a bank enabling the relatively long-term persistence of a meander cut-off side channel.

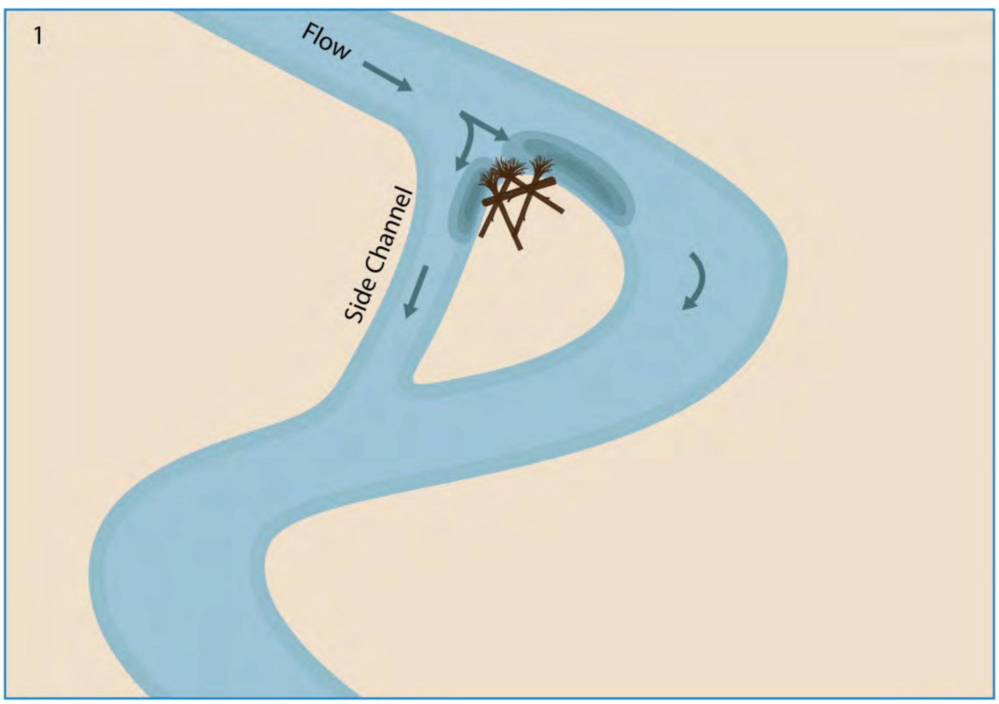

Figure 17. Diagram illustrating how a logjam on a point bar can potentially split high flow, resulting in the formation and relatively long-term maintenance of a side channel across the point bar.

Riparian Disturbance and Succession

Riparian disturbance took place frequently over a large portion of the reach historically. Flooding accompanied by silt/sand deposition occurred annually on low elevation portions of the floodplain. Deposition was primarily concentrated near the banks (see natural levee discussion). Ongoing channel migration continually eroded portions of the floodplain and created new floodplain from point bar deposition. Avulsion episodically cut through the floodplain creating new channels abandoning old channel paths or creating new side channels. Fire burned the floodplain vegetation. Debris flows deposited alluvial sediment from the valley slopes onto the floodplain and into the channel. Ice flows potentially scoured bank vegetation and/or dammed the channel temporarily increasing flood effects. Logjams may have temporarily dammed portions of the channel creating backwater conditions increasing flood effects. All of these processes resulted in the formation of a diverse, multi-species, and multi-age class riparian zone (Figure 18).

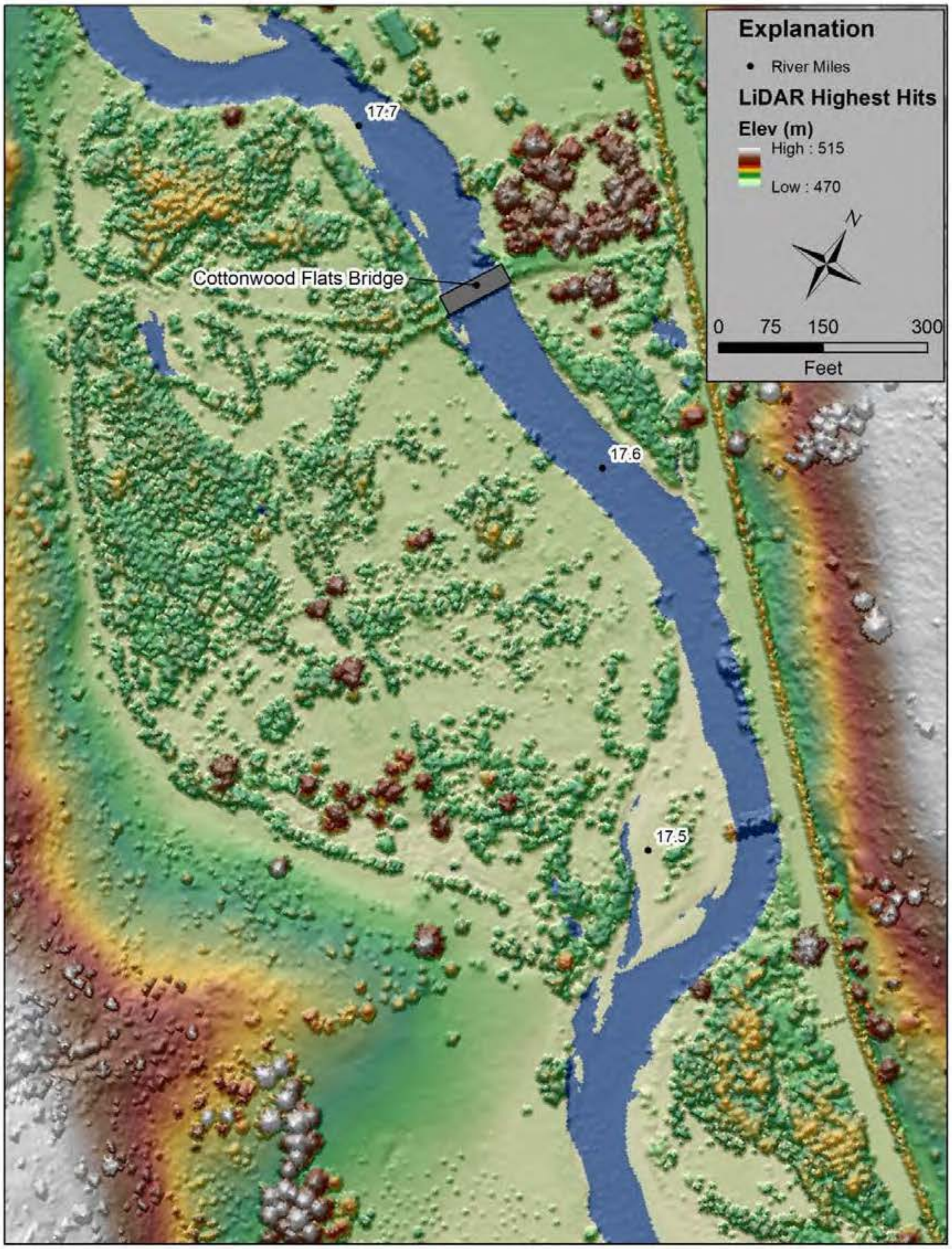

Figure 18. LiDAR imagery illustrating the highest hits returns. Grass and low vegetation is light green, shrubs and small trees are dark green to yellow, while tall matures tress are red to white. Riparian vegetation on the Gray Reach floodplain was historically diverse, including patches of old-growth forest which no longer exist. This figure illustrates the modern age structure dominated by young, low-height riparian vegetation.

Existing Conditions

Existing conditions consist of the forms and processes currently shaping the assessment area. The existing conditions along the Gray Reach of the Entiat River were assessed from data collected between 2006 and 2012. To document the extent of channel migration, data from as far back as 1945 were used to complete the assessment. Data collected to assess existing conditions included detailed LiDAR topography, aerial photos, gage data, and field observations from multiple flow levels. These data were also used to create a one-dimensional (1D) hydraulic model of the 2-year and 100-year recurrence interval floods. Results from the existing conditions hydraulic model were used to support some of the conclusions regarding channel processes and human influences present in the assessment area. In general, both the forms and processes characterizing the existing Gray Reach of the Entiat River are similar to historic forms and processes described earlier.

Existing Forms

Forms are physical conditions on the landscape and in the river. Physical conditions may also represent habitat for fish and other species that have evolved along with the landscape and channel. Changes to the channel form have the potential to impact aquatic species' habitat. The primary defining characteristic forms are described below for the assessment area. Specific information pertaining to Reach-Based Ecosystem Indicators can be found in the Appendix of this report.

Channel Dimensions

The representative bankfull channel conditions are shown in Table 3.

Table 3. Representative bankfull channel conditions.

Channel width	90 feet
Average depth	6 feet
Pool depth	12 feet
Width-to-depth ratio	15
Gradient	0.16 percent
Entrenchment ratio	6 (floodprone width divided by the bankfull width; represents the degree of floodplain confinement)

Planform

Channel planform is the pattern of the channel as seen from above, including sinuosity, meander bend shape and wavelength, and off-channel features. The average sinuosity of the Gray Reach was 1.22, calculated by dividing channel length by valley length measured from 2011 aerial photos. Also measured from 2011 aerial photos, meander bend radius of curvature averaged 217 feet for all bends, 160 feet along colluvium and alluvial fans, and 440 feet along alluvium (Figure 19). The radius of curvature was measured by matching a circle to the shape of the outside of the bend in GIS and measuring the length of the radius of the circle. Where the bend migration is impeded by the erosion-resistant valley wall, the radius of curvature is generally smaller than bends in the middle of the valley. In addition, bends along the valley wall tend to be followed by a relatively straight section for upwards of one meander wavelength. The meander wavelength, consisting of two bends (sine wave) was measured from 2011 aerial photos averaging roughly 1,100 feet with maximum amplitude of 450 feet (Figure 19).

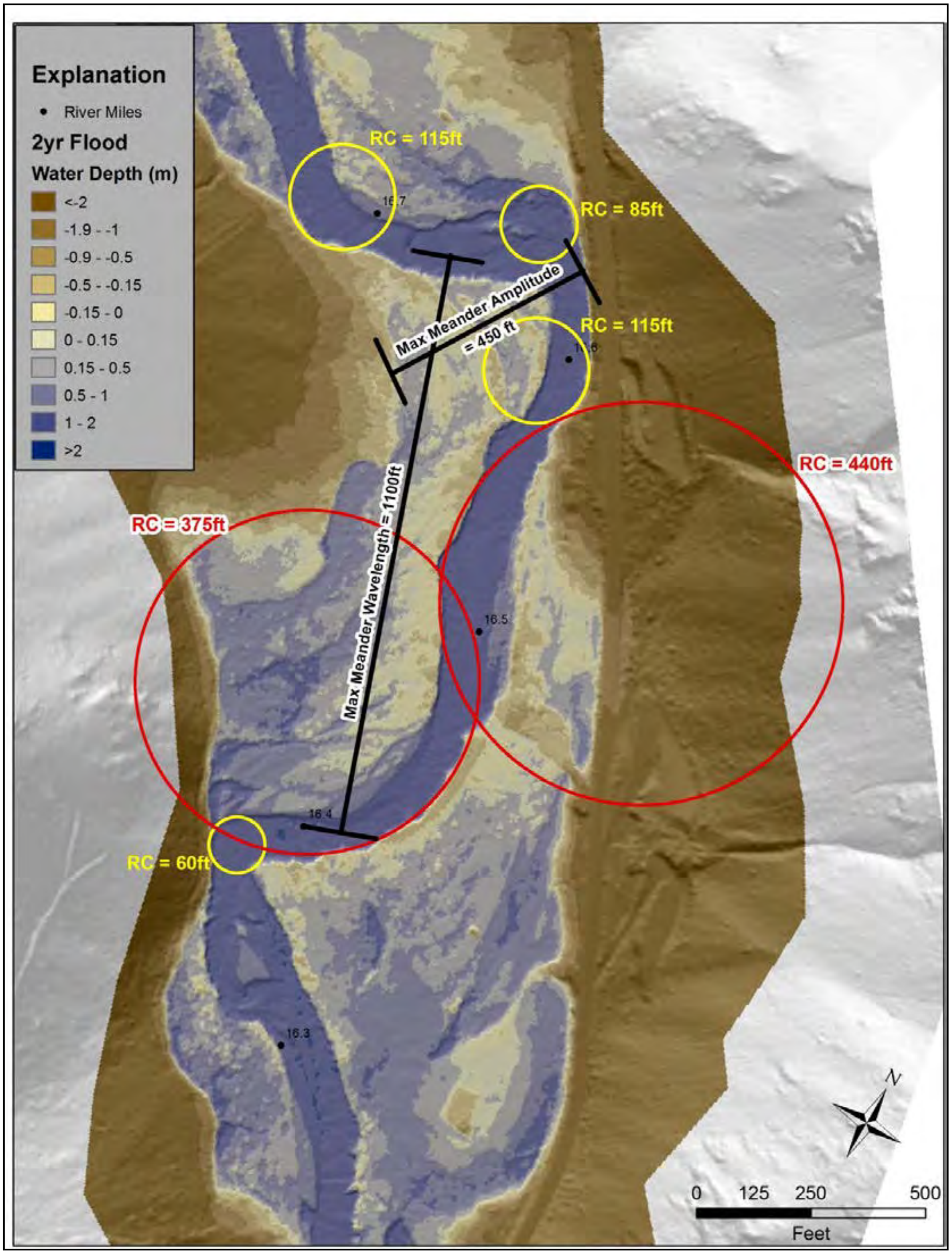

Figure 19. Meander bend radius of curvature. Meander bends formed into river alluvium have a large radius of curvature (red circles), while meander bends formed into the erosion-resistant valley wall colluvium and/or alluvial fan debris flow deposits tend to exhibit a small radius of curvature (yellow circles). The overall meander wavelength is measured from to the top of one bend to the top of the next. Meander wavelength in the Gray Reach tends not to exceed roughly 1,100 feet. Meander amplitude, measured from the base to the top of a single bend, tends not to exceed 450 feet.

Meander wavelength and amplitude have a significant impact on channel avulsion. One avulsion was captured in historic aerial photography between 1974 and 1998 near RM 16.7 (see Figure 19 above). This and other avulsions occur in the Gray Reach when the localized sinuosity exceeds approximately 1.6, meander wavelength exceeds 1,100 feet, and radius of curvature is less than 100 feet resulting in meander bend cut-off avulsion.

Channel Migration Zone

The historical channel migration zone (HCMZ) was delineated from aerial photos taken between 1945 and 2006 as part of the Tributary Assessment analyses (Reclamation 2009a). This delineation also included a number of relic channel scars interpreted as having been recently occupied by the mainstem resulting in a HCMZ that occupies nearly the entire valley bottom. This liberal interpretation of the HCMZ is accurate depending on timescale but difficult to substantiate over a defined period and therefore introduces the potential for a wide range of interpretation and potential misuse. Rather than speculating on the timing of each channel scar, this report has identified the historic channel migration zone (HCMZ) as only that area having been occupied by the active channel (mainstem and side channels) within the record of historic aerial photos (1945 to 2011). The channel migration corridor has occupied generally less than 30 percent of the valley bottom within the past 66 years with most migration occurring in those locations where the channel crosses from one side of the valley bottom to the other (Figure 20). Nearly 100 percent of the valley bottom lies within the 100-year floodplain, over half of which is within the active (2-year) floodplain, leaving open most of the valley bottom to future channel migration, avulsion, and side channel development.

Channel migration is physically limited at the valley wall by colluvium and in several locations, alluvial fans. Human-constructed riprap lines the channel banks in two locations, but is not considered a hindrance to channel migration, as these locations are directly adjacent the valley wall.

Two bank protection projects consisting of a series of rock and log barbs have disrupted migration at RM 16.4 and 17.4. The downstream site has been partially flanked by the river, and one of the flanked barbs is now collecting LWM (Figure 21). The effects of these bank protection sites are discussed in the upcoming Existing Trends portion of this report.

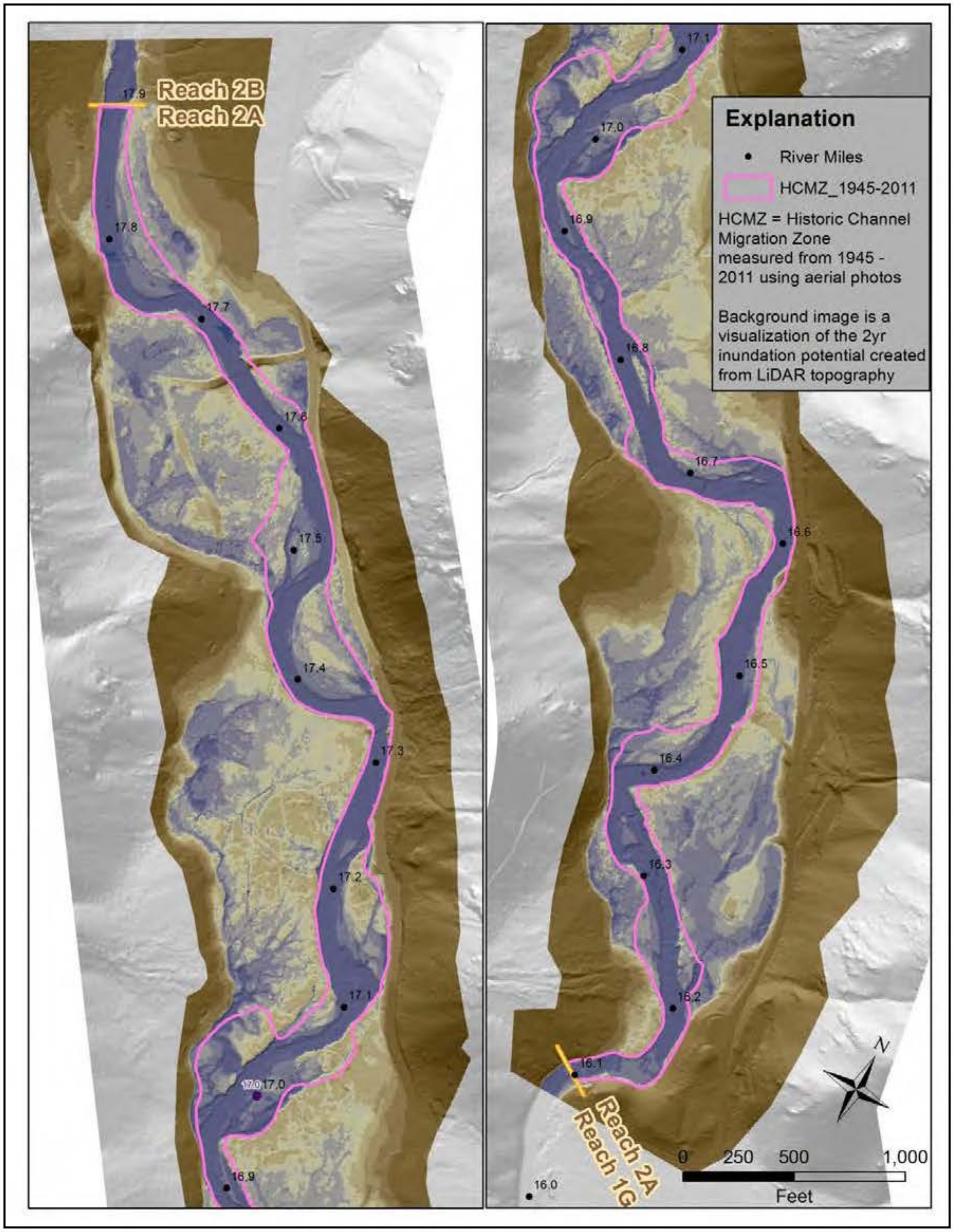

Figure 20. HCMZ measured by interpreting the active channel area from historic aerial photos between 1945 and 2011.

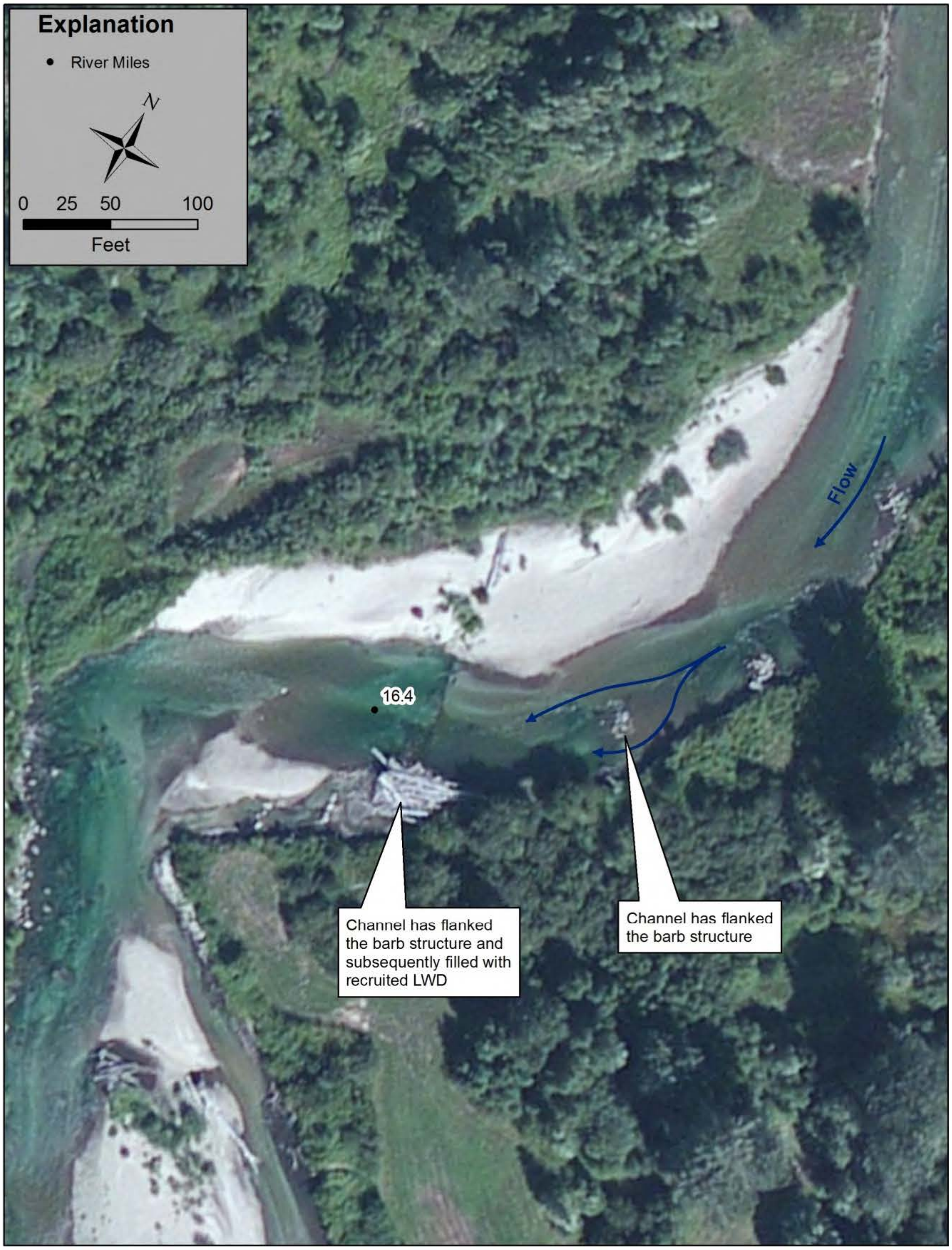

Figure 21. Rock barbs near RM 16.4. Erosion between the barbs has resulted in flanking of two of the barbs. The most downstream barb has accumulated woody material between the flanked barb and the bank.

Bed Condition

The bed of the river is described by its overall gradient and, on a finer-scale, by its grain-size distribution, armoring, and representative bed forms. For the first several miles upstream of the terminal glacial moraine near Potato Creek, the average channel gradient is consistently low compared with other reaches farther upstream and downstream in the system (0.17 percent in Gray Reach vs. 1.0 percent in lower Entiat and greater than 0.5 percent upstream of RM 23). Within the assessment area, the gradient was measured at 0.16 percent between RM 16 to RM 18.

Table 4. Average bed gradient.

RM 1 to 16	1.0 percent
RM 16 to 18 (Gray Reach)	0.16 percent
RM 18 to 23	0.2 percent
Upstream of RM 23	0.5 percent or greater

Bed composition is dominated by gravel with sand and cobble. Pebble counts were taken in 2008 and 2012 from the upstream, middle, and downstream sections of the reach, with the largest grain sizes (cobbles) observed in those locations corresponding with or immediately downstream from the highest velocity sections of the river (Table 5). The surface of the bed was minimally armored with coarse material, while substantially more sand was present several inches below the surface. Very little silt or clay sediment was observed during any of the pebble counts, although pebble counts themselves do not account for fine sediment, other than by visual inspection.

Table 5. Grain Size Analysis collected from multiple pebble counts (see the Appendix for more details). Grain sizes are dominated by gravel with increased cobble percentages found immediately downstream of scour pools associated with constrictions. Sand and other fines were not differentiated.

Substrate (mm)	Percent (Representative Channel Section)	Percent (Downstream of Constriction)	Percent (Average)
Sand and Fines (0.06-2.0)	29.09 percent	14.06 percent	24.79 percent
Fine Gravel (2-8)	5.18 percent	8.70 percent	6.19 percent
Medium Gravel (8-16)	11.22 percent	9.64 percent	10.77 percent
Coarse Gravel (16-64)	46.31 percent	52.76 percent	48.16 percent
Cobble (64-256)	8.20 percent	14.85 percent	10.10 percent
Boulder (256-4096)	0.00 percent	0.00 percent	0.00 percent
Total	100.00 percent	100.00 percent	100.00 percent

USFS sediment analysis using a McNeil core sampler identified the bed material from spawning areas to be composed of nearly 20 percent fines (less than 1 millimeter [mm]). High levels of fine sediment were attributed to fire-related sediment inputs and low flows reducing transport capacity (CCCD 2004). The USFS report (summarized in CCCD 2004) suggests that during low-flow years, fine sediment accumulated due to a lack of flushing flows, but there is a very poor correlation between flow volume and fine sediment accumulation.

Although elevated levels of fine sediment accumulation were documented, spawning and egg incubation are not identified as limiting factors for this reach, and it is not shown that increased fines has resulted in increased mortality. This may be a result of reporting fines as less than 1 mm, which includes a large fraction of sand. Silt and clay are less than 0.065 mm.

During 2012 field reconnaissance, fine sediment (primarily sand) was observed in slack-water areas and beneath the surficial bed layer where expected. Fine sediment was not observed on the surface in the many spawning riffles observed in the study reach, and dozens of Chinook were observed spawning in early October 2012. No bed material sampled was embedded as a result of fine sediment filling interstitial space. In the 2006 management plan (CCCD 2006), fines are defined as less than 1 mm (which includes medium and fine sand), easily accounting for the high volumes documented in that report if samples were taken below the surface sediment layer. Subsurface sand itself is non-cohesive and easily excavated by salmonids while building redds and is not likely transported and deposited within the reach during Chinook spawning and incubation periods, as instream velocity is generally not sufficiently high during those low-flow periods in most years. In late winter and early spring, instream flow and velocity increase sufficiently to mobilize not only sand, but many gravel- and cobble-sized particles during steelhead spawning. Sand deposition during high flows occurs on the floodplain and in backwater eddies, not in the spawning riffles potentially housing eggs or alevins. Sand deposition in eddies only occurs as high flows begin to wane on the decreasing limb of the hydrograph, typically in late June through July and August after egg incubation and juvenile emergence. In addition, it has been shown on other rivers that mortality associated with fine sediment accumulation can be a result of decreased permeability and substrate embeddedness (Chapman 1988) likely attributed to silt and clay not sand. Due to other potential factors that could affect egg to fry survival, it is difficult to determine if the reported 18.96 percent fines (primarily sand) reduces egg to fry survival within the Gray Reach or any other reach of the Entiat River beyond normal background conditions.

Bedform is defined as any deviation from a flat bed generated by streamflow on the bed of an alluvial channel (Bates and Jackson 1984). Bedforms observed in the Gray Reach included many series of riffles and pools with secondary ripples observed in backwater eddies where sand has been deposited.

As with historical conditions, scour pools are common at nearly all bends, through channel constrictions and around nearly all channel obstructions (LWM and boulders). Deposition forming bars and riffles occurs immediately downstream of each large scour pool, resulting in a predominantly pool-riffle bedform.

Depositional bars were observed along the insides of most bends; relatively few mid-channel bars formed behind obstructions (LWM) or downstream of low-radius bends with significant bend scour pools (deposition of sediment scoured from the bend).

Bank Condition

The majority of the Gray Reach is characterized by banks composed of alluvial gravel with sand and cobble (similar to the bed) overlain by 2 to 7 feet of floodplain silts and sands (Figure 22). In several locations adjacent alluvial fans, the banks are composed of debris flow deposits generally consisting of coarse angular boulders mixed with cobbles and gravel in a sandy silt matrix (Figure 23). Similarly, where the channel has migrated to the edge of the valley, the bank nearest the valley wall is often composed of colluvium consisting of angular boulders (Figure 24). Alluvial fan and colluvial deposits are both highly erosion resistant.

Figure 22. Bank erosion near RM 17.45 illustrating roughly 3 feet of floodplain silt/sand overlying gravel and cobble.

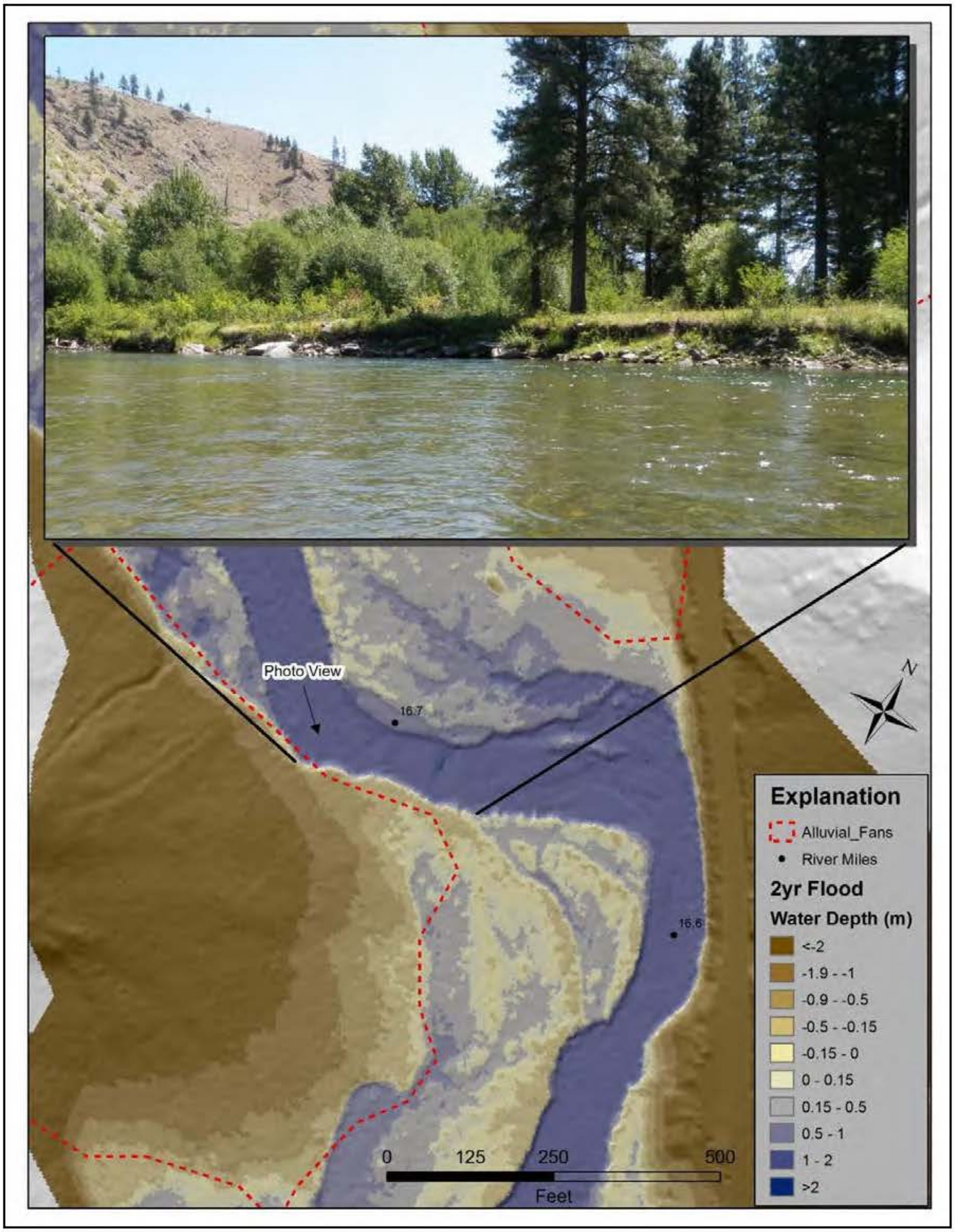

Figure 23. Erosion-resistant alluvial fan exposure composed of coarse angular boulders with sand and gravel near RM 16.7.

Figure 24. Large angular boulders comprise the majority of colluvium deposited along the valley wall. This photo was taken near RM 17.6 where the channel flows adjacent the valley wall for several hundred feet.

Forcing Agents

Forcing agents are channel forms and/or structures that constrict or otherwise obstruct the channel influencing local physical conditions and channel geometry. Channel constrictions and obstructions within the Gray Reach generally consist of LWM, colluvium, valley confinement, and human-constructed features such as bridges and bank revetments. Channel constrictions include two bridges, two natural valley wall constrictions and the narrow corridor through the ancient glacial Potato Moraine (Figure 25). Each constriction narrows the effective width of the channel and/or floodplain forcing high flows through a relatively narrow opening increasing shear stress and velocity by approximately 90 percent during a 100-year flood according to HEC-RAS modeling of the reach (Figure 26). Although significant, increased shear and velocity from bridge constrictions is roughly equivalent to natural shear and velocity increases resulting from confinement against the valley wall or Potato Moraine suggesting that while the human-constructed features may be unnatural, their instream hydraulic impact is within the natural range of variability for this reach.

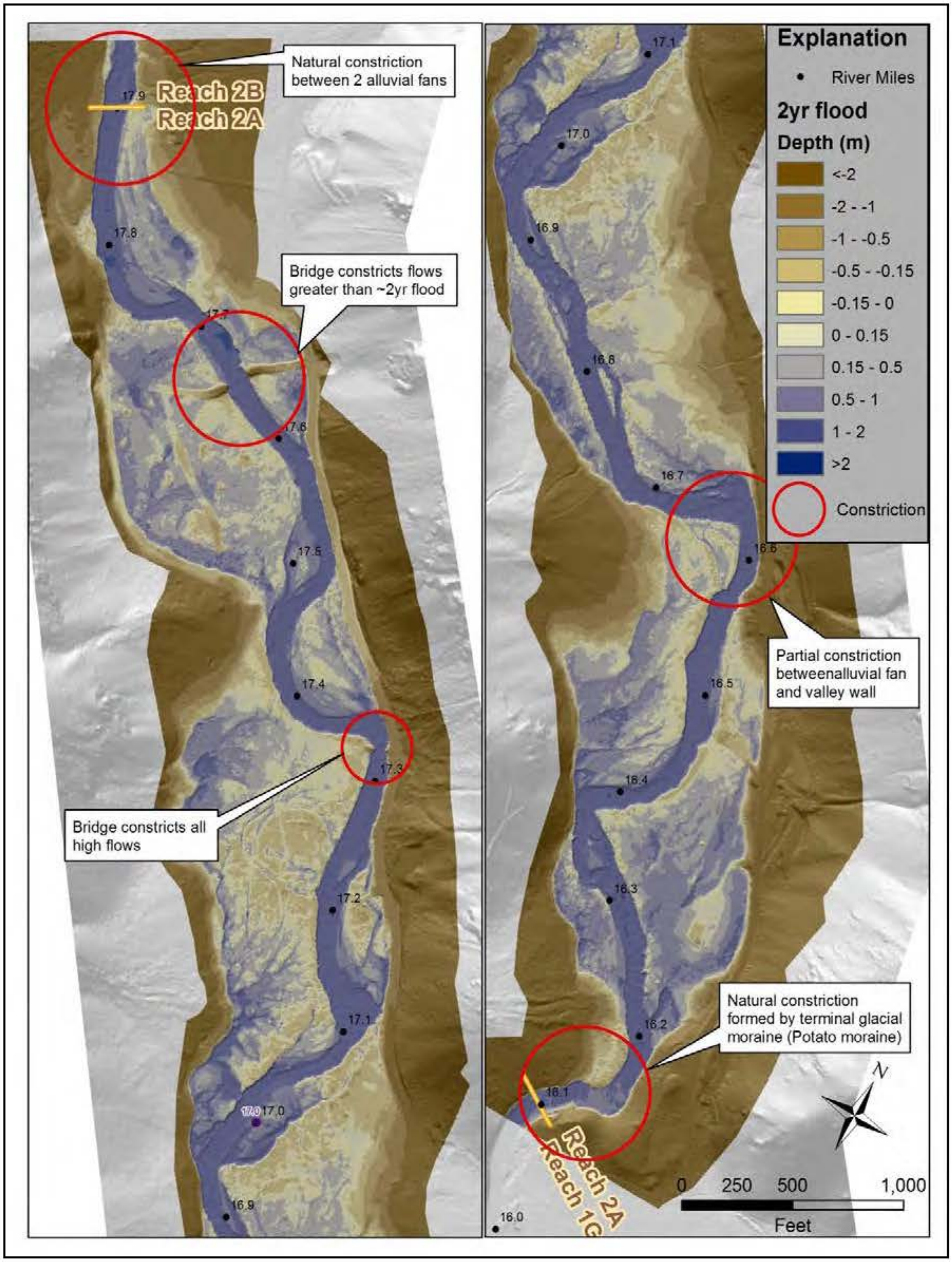

Figure 25. Natural and anthropogenic floodplain and channel constrictions.

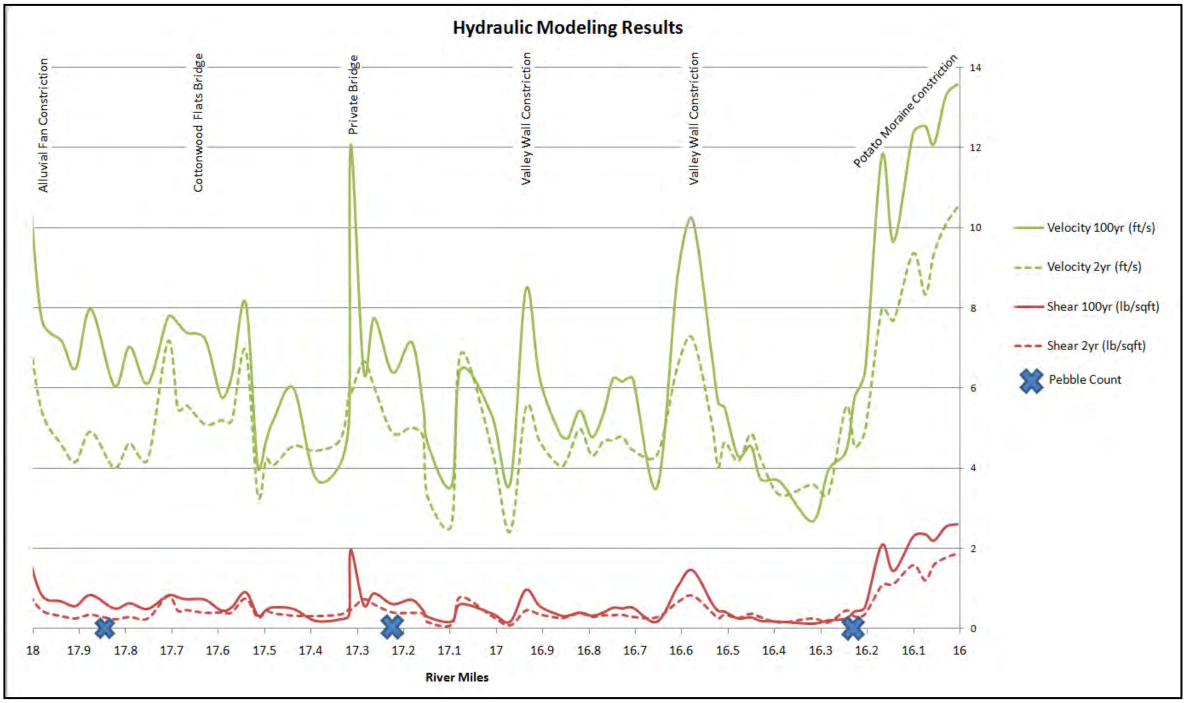

Figure 26. Hydraulic modeling results (HEC-RAS) show increased velocity and shear during 2-year and 100-year floods at valley constrictions.

Similar to constrictions, obstructions may also impact channel form. LWM and other obstructions such as large boulders force split flow around or plunging flow over the obstruction resulting in localized scour pool formation and deposition in the lee of the structure. Colluvium along the valley wall resists bank erosion and lateral migration, often dissipating energy vertically resulting in pool formation. Human-constructed features in the Gray Reach (other than bridge constructions discussed above) include log and rock barbs (RM 16.45 and 17.4) which function similarly to colluvium along the bank resisting channel migration and creating vertical scour. In addition, a human-constructed levee accompanies the log and rock barbs at RM 16.45 focusing a larger percentage of flood flow within the banks locally increasing instream velocity and scour. Natural levees of similar size to the existing human-constructed levee are also present within the reach; therefore, it is unclear what effect (if any) the human-constructed levee has had on channel form or process within the study reach (Figure 27). It is likely that this human-constructed levee has had a negligible impact.

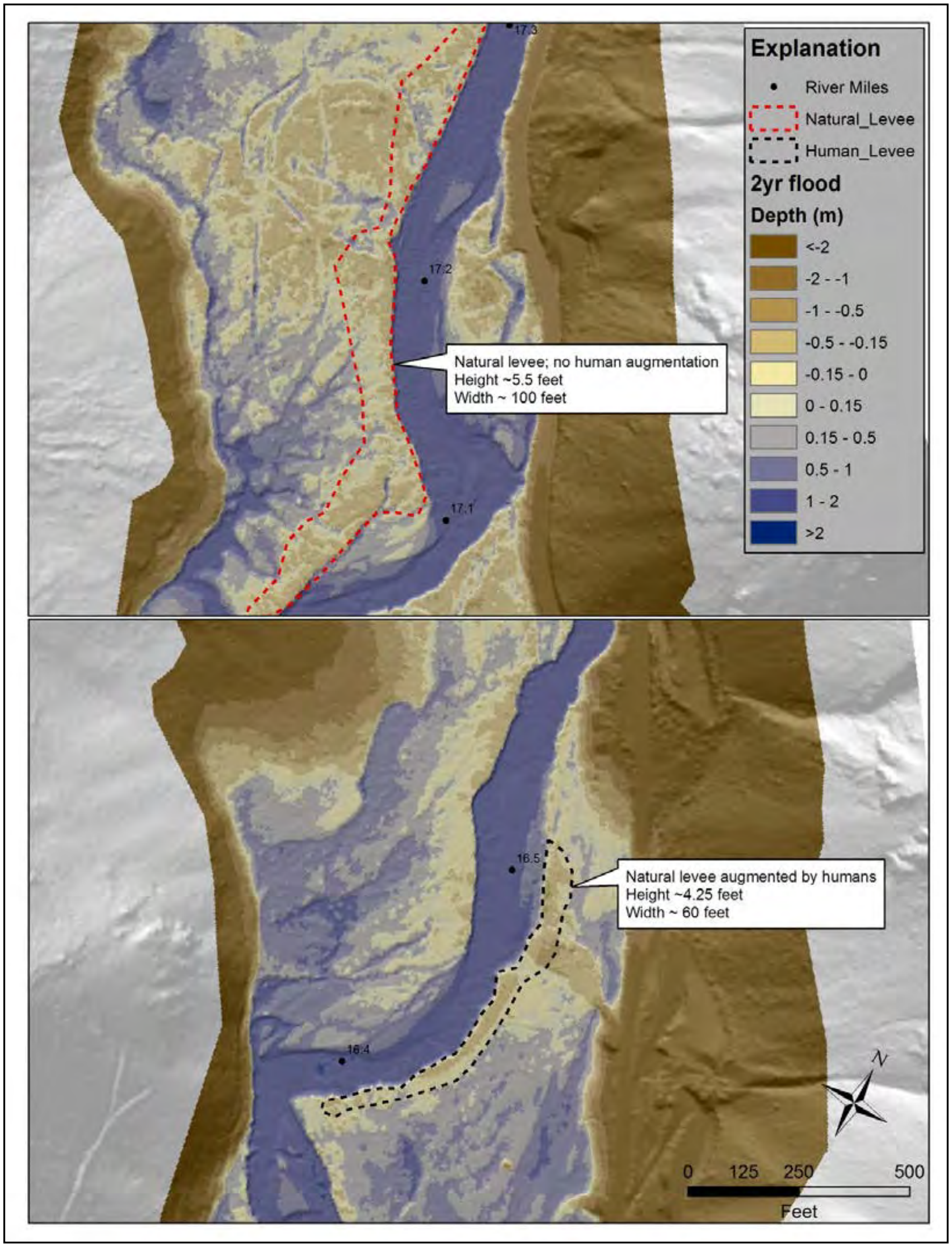

Figure 27. Representative natural levee shown in the upper panel versus a natural levee augmented by humans in the lower panel. The degree of augmentation in the levee between RM 16.4 and 16.5 is unclear, but rock barbs have been constructed along this bank, and it is likely that excavation spoils associated with the bank protection were deposited on the bank augmenting the existing natural levee (which remains smaller than the representative natural levee illustrated in the upper panel suggesting negligible impact).

It should be noted that the orientation and shape of bank protection structures (natural or human-built) would potentially influence channel process very differently. Longitudinal bank armoring (i.e., oriented roughly parallel to the valley axis), especially that which is hydraulically smooth, has a tendency to direct flow downstream, enhancing downstream channel momentum, carrying unnaturally high energy downstream. Lateral bank armoring (i.e., oriented roughly perpendicular to the valley axis), especially that which is hydraulically rough, has generally the opposite effect. The lateral structure is an obstruction to down-valley flow, which tends to force energy right or left, enhancing lateral channel migration. While instream velocity and shear may increase locally at the structure, the overall impact to the stream is a reduction in down-valley momentum and increased hydraulic variability.

Off-channel Features

There are many off-channel features within the Gray Reach. Seasonally activated high-flow side channels are abundant on the inside of many bends in the reach where high-flow cuts across point bars. No perennial side channels were observed during 2012 field reconnaissance, although one seasonally activated side channel was identified using LiDAR and hydraulic modeling (left bank at RM 16.8) (Figure 28). This side channel was observed during low-flow in October 2012 with residual pools containing water but no surface connection to the main-stem channel. The RM 16.8 seasonal side channel was formed by an abandoned meander of the main-stem as evident in 1945 historical photos. As the channel migrated from left to right after 1945, the side channel remained in the old channel scar along the left bank and has slowly been filling with sediment.

Much more prolific than side channels are alcoves, which maintain only a downstream connection to the mainstem. Alcoves form by channel migration, avulsion, or continual flood flow concentrated along the valley wall as discussed previously. Given the tendency for the Gray Reach to form low-profile natural levees and fill historic oxbow channels with sediment, most relic channels evolve into alcoves or cut-off completely from the main-stem forming open water ponds and wetlands.

Floodplain and Riparian Conditions

The active floodplain is defined in this assessment as that area of the valley bottom inundated with surface flow during a 2-year recurrence interval flood as estimated by hydraulic modeling (Figure 29). No evidence suggests that existing floodplain and riparian conditions differ considerably from historic conditions with the exception of those areas that have been disturbed for rural residential development (9.6 acres or 15 percent of the 2-year floodplain). This disturbance includes the clearing of riparian vegetation and the selective removal of mature (old-growth) timber.

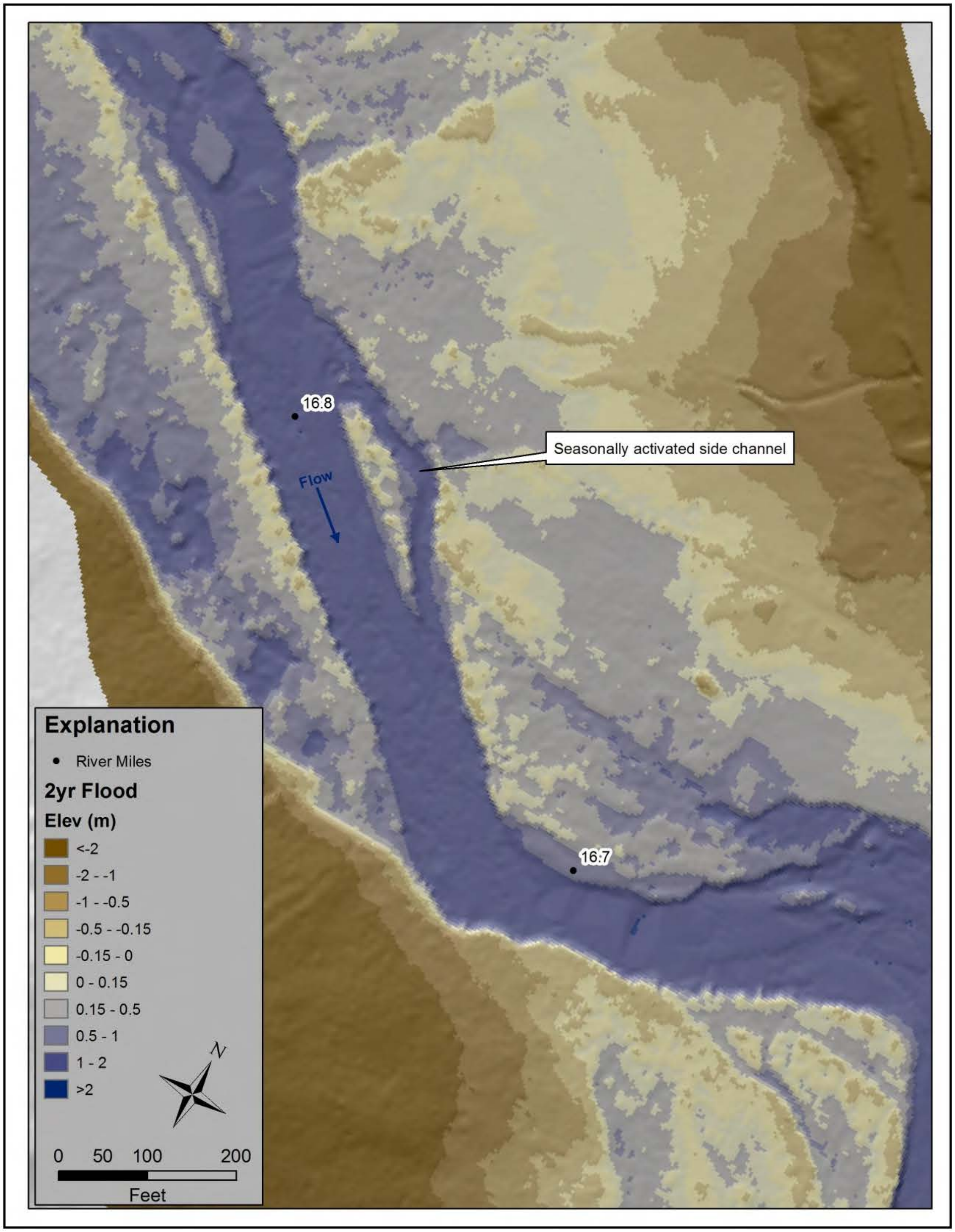

Figure 28. LiDAR 2-year inundation map illustrating location of seasonal side channel near RM 16.8. During field reconnaissance (August 1, 2012, 1:00pm) the side channel was disconnected and discharge measured at the Ardenvoir gage (USGS 12452800) was roughly 400 cfs. It is estimated that the side channel becomes connected between 500 and 600 cfs.

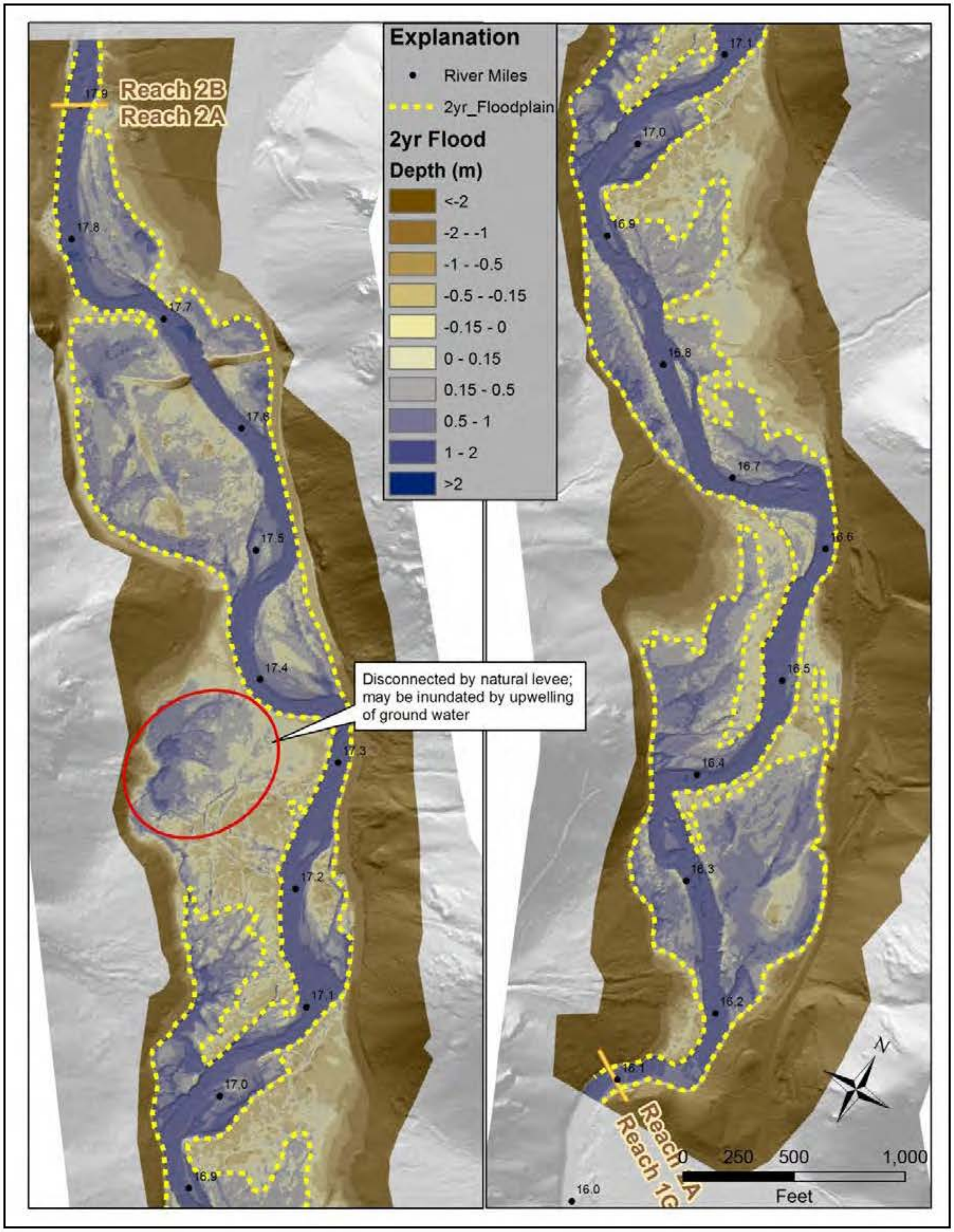

Figure 29. Approximate 2-year floodplain outlined in yellow as estimated using LiDAR topography and HEC-RAS hydraulic modeling.

The area occupied by the active floodplain represents approximately three times the area occupied by the active channel, and roughly half the total valley bottom area. The floodplain surface is comprised of 2 to 7 feet of silt and sand overlying alluvial gravel and cobbles (Golder 2007; Reclamation 2009a). Approximately 15 percent of the 2-year floodplain area is considered disturbed (bare earth, road, cleared land, buildings, or garden) (Table 6). Riparian vegetation is dense and of mixed-age, although dominated by young trees including cottonwood, alder, river birch, dogwood, and willow. Areas dominated by mature trees represent approximately 16 percent of the active floodplain, small trees and shrubs 68 percent, grass 12 percent and no vegetation 4 percent (Table 7). All measurements were made using 2006 aerial photography and LiDAR. Small trees were identified as those less than 20 feet tall based on highest-hit LiDAR data.

Table 6. Acres and percent of total active (2 year) floodplain disturbed versus undisturbed based on 2006 aerial photos.

Disturbance – Entire 2 year floodplain		
Disturbed	9.6	14.63 percent
Undisturbed	56.1	85.37 percent

Table 7. Acres and percent of total active (2-year) floodplain occupied by different age classes of riparian vegetation.

Riparian Conditions – 2 year floodplain		
Mature trees	10.3	15.71 percent
Small trees/shrubs	45.0	68.54 percent
Grass or pasture	7.9	12.09 percent
No vegetation	2.4	3.66 percent

Existing Physical Processes

The forms characterizing the Gray Reach of the Entiat River are created and maintained by physical processes that can generally be grouped into categories, including hydrology; sediment transport; channel migration; LWM recruitment and retention; and riparian disturbance and succession. Additional specific information regarding physical processes can be found in the table of Reach-Based Ecosystem Indicators in the Appendix.

Hydrology

As with historic conditions, existing hydrologic inputs in the Entiat River basin are dominated by surface runoff, and peak runoff is dominated by snowmelt, with the largest floods occurring after rain-on-snow events (Figures 30 and 31). The topography of the Entiat River basin is steep and likely yields relatively short lag times between precipitation and runoff. This is particularly important with regard to summer thunderstorms that can increase mainstem flow, although typically increasing flow by less than a few hundred cfs (inferred from USGS gage 12452990 and 12452800). While surface runoff makes up the majority of flow in the Entiat River at any given time, the Gray Reach gains flow from groundwater in the upper half of the reach (approximately 0.7 cfs per mile) and loses flow to groundwater in the lower half of the reach (-4.6 cfs per mile) (CCCD 2004). Irrigation withdrawals upstream of and within the Gray Reach are few, and are not considered to significantly affect the hydrologic regime at any time of year. Marking the downstream end of the Gray Reach is a surface water diversion (McKenzie Ditch) with a 4 cfs water right, accounting for generally less than 2 percent of the summer low-flow in the reach. Flood frequency recurrence intervals for the Gray Reach are summarized in Table 8 below.

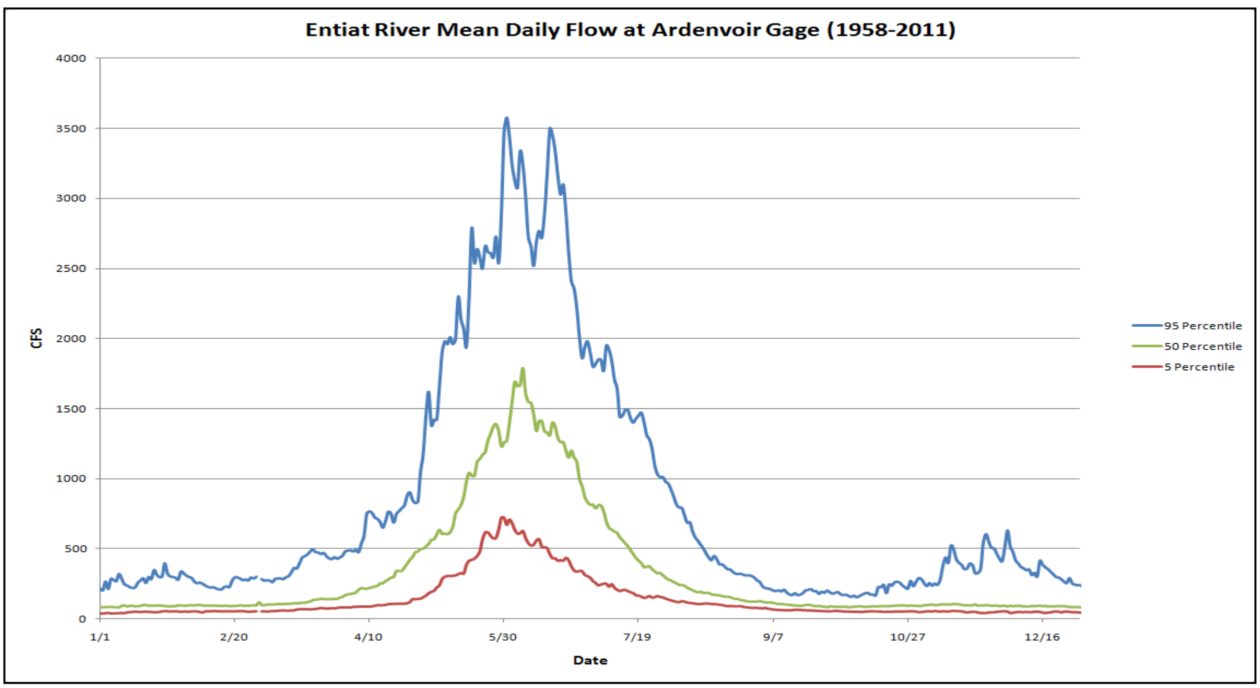

Figure 30. Entiat River Mean Daily Flow at Ardenvoir Gage (1958-2011). Blue represents the 95th percentile (wet), green is the 50th percentile (average) while red is the 5th percentile (dry).

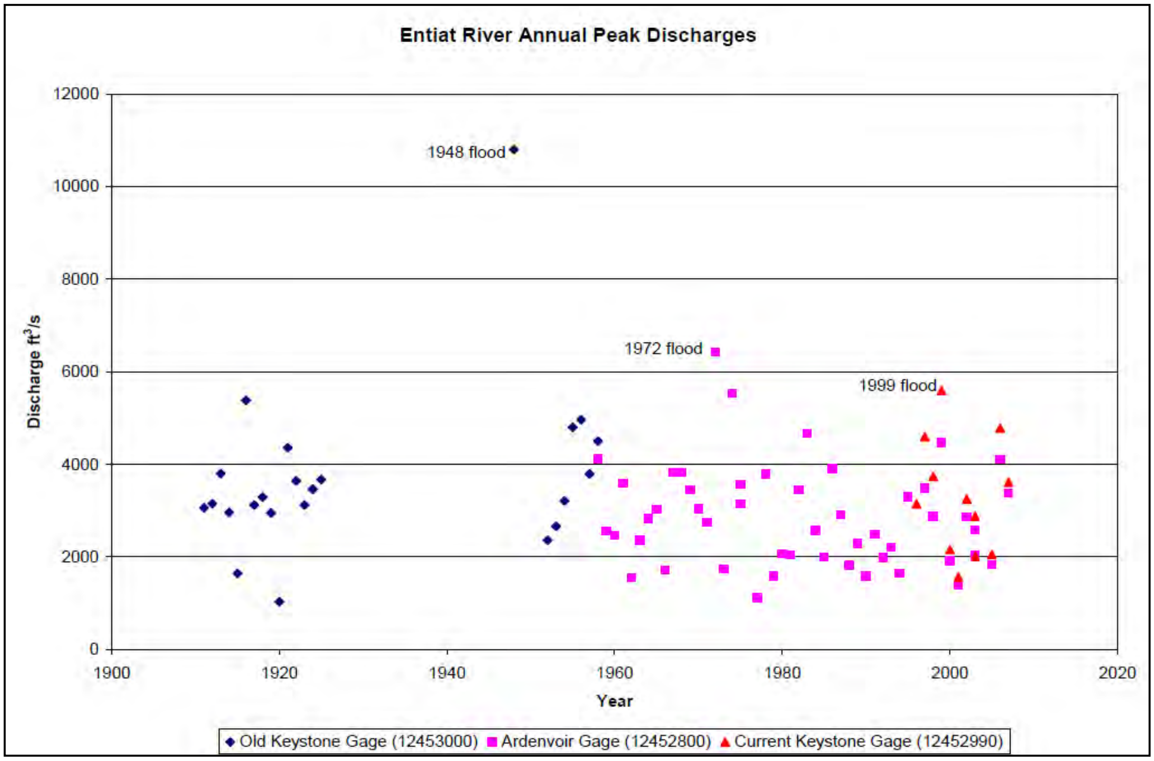

Figure 31. Entiat River Annual Peak Discharge as measured from three different gages. The Ardenvoir gage is located approximately 500 feet upstream of the Gray Reach.

Table 8. Flood frequency recurrence intervals for the Ardenvoir Gage located approximately 500 feet upstream of the Gray Reach (Reclamation 2009a).

Location	Drainage Area (sq miles)	2-yr flood (cfs)	10-yr flood (cfs)	50-yr flood (cfs)	100-yr flood (cfs)
Ardenvoir Gage	203	2,510	4,320	5,730	6,330

Effective flow is defined as that discharge that transports the largest cumulative volume of sediment over the long term. In other words, while a single large flood may move a very large volume of sediment, many smaller floods may cumulatively move substantially more sediment. Channel form (planform, width, depth, and cross-section shape) is largely dictated by these “effective flows.” While the effective discharge has not been measured in the Gray Reach of the Entiat River, it is likely around the 1.5 to 2 year flood, which is the most common effective discharge for alluvial streams similar to the Gray Reach (Leopold 1994). Channel forming flows induce erosion, deposition, and generally result in sediment entrainment, scour and bank erosion. Hydraulic models predict incipient motion of bedload around the 2-year recurrence interval, depending on the specific location, supporting the effective flow estimate.

Sediment Transport

The Gray Reach of the Entiat River is considered a transport-limited reach with a pool-riffle morphology, which has not changed since historical times. Transport-limited reaches are dominated by deposition, active channel migration, avulsion, and a well-connected floodplain, which are all accurate descriptions of the Gray Reach. Sediment sources remain consistent with historic sources including bank erosion, remobilization of the bed, episodic debris flows, and hillslope sheet erosion. It is likely that modern hillslope erosion has increased somewhat as a result of road density, but no data exist to support this hypothesis. Recent instream measurements of fine sediment suggest hillslope erosion is more directly related to fire disturbance than roads (interpreted from CCCD 2004).

Scour at each bend and around obstructions with subsequent deposition immediately downstream results in a pool-riffle bed morphology. Channel unit mapping of pools, riffles, runs, and glides identified approximately 48 percent of the channel area as pool habitat and 30 percent as riffle, supporting the classification of pool-riffle morphology. The pattern of pool-riffle sequences is associated with the channel's sinuosity, which in turn is related to channel migration as discussed below.

When sediment deposition occurs preferentially on or very near a stream's banks, vertical accretion of the banks occurs creating a natural, topographic separation between the channel and the floodplain. This topographic break is called a levee. Natural levee formation occurs as a result of diffuse transport and/or advective transport of sediment from the mainstem to the floodplain. As discussed previously, advective transport is likely the dominant mechanism for levee deposition in the Gray Reach defined as deposition resulting from shallow water and increased friction along the banks. Natural levees are frequently associated with low-gradient stream corridors subject to frequent overbank floods like the Gray Reach of the Entiat River. LiDAR topography of the Gray Reach floodplain reveals broad natural levees separating the mainstem from the floodplain creating low-elevation floodplain basins along the valley margin. These floodplain basins collect water and overflow into the mainstem often with sufficient velocity and shear stress to scour a downstream surface connection resulting in the formation of an alcove (see Figures 10 and 12 above). Conversely, side channel inlets tend to fill with sediment over the span of a few decades as a result of levee deposition (e.g., seasonal side channel at RM 16.8).

Channel Migration

Meander bend channel migration involves erosion of the outside bank of a bend coupled with concurrent deposition of sediment along the inside bank of the same bend. This process results in the lateral movement of the channel, while maintaining consistent channel shape and width. The area of the most pronounced migration usually occurs where the flow converges against the outer bank near the downstream end of a bend, resulting in simultaneous lateral and downstream migration of the bend. Where laterally migrating meander bends impinge on erosion resistant material such as bedrock or colluvium along the valley wall, lateral movement ceases and downstream migration of the bend often begins or accelerates.

In the Gray Reach, migration appears to follow a pattern whereby the river migrates laterally at an average rate of 1 to 2 feet per year (based on historic aerial photo interpretation) until it impinges against the valley wall, then flows relatively straight along the valley wall for roughly 1,000 to 1,500 feet, before crossing the valley impinging upon the opposite valley wall and repeating the cycle. Downstream migration dominates when the channel flows along the valley wall (or other longitudinal obstruction), while lateral and downstream migration both occur in locations where the river crosses the valley. It is in these locations where the river is passing through the middle of the valley that avulsions (meander cut-offs) tend to occur. Avulsions appear to be the result of several years of migration resulting in progressively tighter radius bends (less than 100-foot radius of curvature) which are ultimately cut off during a flood (i.e., RM 17 after 1975). Meander cut-offs likely follow many progressive years of lateral migration increasing sinuosity until culminating during a flood, but not necessarily a large flood.

Channel migration appears most common and has the highest rates when banks are composed of loose sand- to cobble-sized alluvium (Table 9). Coarse bouldery colluvium armors the banks along the valley wall, significantly limiting migration laterally into the valley wall. Also, potentially limiting migration is cohesive clayey silt observed at the toe of the bank in the lower reach (downstream of RM 17.0). The cohesive sediment improves bank stability and likely reduces rates of channel migration in this area. Clayey silt is the depositional facies associated with ponding likely attributed to ancient backwater conditions from the Potato Moraine following glaciation thousands of years ago.

Current conditions, with no large logjams or old-growth timber stabilizing banks, have resulted in a downstream-dominated migration pattern. There may have been a period of adjustment from historically lateral-dominated migration to currently downstream-dominated migration when overall sinuosity reduced within the reach, but any transition has long since stabilized. Rather than downstream migration overtaking bends resulting in a progressively straighter reach, sinuosity remains relatively constant. This is evident in measurements of channel migration and sinuosity, which have changed minimally over the historic photo record. As each bend propagates downstream via channel migration, the overall channel pattern and sinuosity is translocated downstream as well. This process can be compared to a conveyer belt moving successive bends downstream until encountered by an obstruction (the Potato Moraine) which halts the process.

Table 9. Major channel migration areas measured between 1945 and 2006 in the Gray Reach of the Entiat River. N/A refers to no net lateral migration either resulting from no measurable bank recession or migration back and forth with no net movement. In summary: Qa2 = Late Holocene alluvium not older than 2,000 years old. Qa3 = Recent alluvium.

RM	Bank	Lateral Rate (feet/year)	Downstream Rate (feet/year)	Bank Material
17.8	Right	1.93	3.11	Qa2, Qa3
17.45	Right	1.34	6.77	Qa2
17.1	Left	N/A	4.09	Qa3
17.0	Right	N/A	1.93	Qa3
16.63	Left	N/A	1.89	Qa3
16.37	Right	N/A	0.49	Qa3

LWM Recruitment and Retention

Instream structures and obstructions have the ability to force channel response. Most Pacific Northwest streams and fish habitat evolved with significant inputs of LWM that contributes to the amount of instream structure and channel response present in a given reach. The Gray Reach of the Entiat River is no different; however, similar to other Pacific Northwest streams, the availability of LWM in the river has declined over the past century. Timber harvests and riparian clearing for development have removed upland and riparian trees, especially large-diameter key members (Figure 32). Larger trees are heavy, float low in the water, and take much more stream power to move than smaller logs and, consequently, are more likely to be retained by a river as key members capable of racking smaller logs.

Figure 32. Photo of timber stockpiled at the Kellogg Mill near RM 3.4 in 1914. Note the large size of the timber and the general lack of standing trees both in the valley bottom and on the hillslopes (published in Erickson 2004).

LWM recruitment in the Gray Reach depends on delivery from upstream sources, debris flows, avalanches, episodic windfall, and recruitment from bank erosion (channel migration and avulsion). Recruitment processes are similar to historic conditions, but without large key members available due to timber harvest practices, the potential for logjam formation and logjam size are both reduced. Periodic river clearing has also reduced the potential number of LWM pieces (Reclamation 2009a).

LWM retention was observed to be most common in depositional zones (point bars), pinned against vegetation along the outside of banks, and at the head of islands (Figure 33). Many individual logs were observed during 2012 fieldwork, and only one existing logjam was counted. The existing logjam had racked against the most downstream rock and log barb installed as bank protection on the left bank near RM 16.4. Several logs (less than 10) were also observed at the head of a mid-channel bar near RM 16.35, but the logs appeared transitory, only pinned against young vegetation without any key members.

A large logjam was observed in the 2006 aerial photo along the right bank at RM 16.32, but did not persist through 2011. Throughout the photo record, no logjam was observed to persist over 10 years, which is attributed to the lack of large key members available to the reach and periodic clearing efforts as described earlier.

Figure 33. Photos of existing LWM in the Gray Reach.

A) Photo looking downstream at natural logjam formed against a mature, overhanging river birch tree on river left near RM 16.2

B) Photo looking upstream at a natural single large cottonwood log with additional woody material in a large alcove (abandoned main-stem following 1970s avulsion) on river left near RM 17.

C) Photo looking upstream at a single large cedar deposited in 2006 (based on historical aerial photo review) on a riffle mid-channel near RM 16.9. The top of the tree was cut off in between July 2010 and August 2011 based on aerial photo review.

D) Photo looking upstream at two single rootwad logs buried into the bank. It is hypothesized that these logs were deposited in the channel many years ago, buried by sediment as the channel migrated away, then subsequently exhumed when the channel avulsed in the 1970s – Right bank, near RM 17.

E) Photo looking at the right bank, flow is from right to left, constructed log and rock barbs that have racked additional woody material along the right bank near RM 17.37.

Riparian Disturbance and Succession

Riparian vegetation influences other processes largely based on the type, density, and age of vegetation within the riparian corridor. In general, where mature, high-density bank vegetation persists, channel migration is typically less or redirected, LWM recruitment is typically greater, and shade is improved when compared to young, sparsely vegetated riparian areas.

Succession is dependent on disturbance that is common in the Gray Reach resulting from floodplain scour, deposition, fire, human clearing, channel migration, and avulsion. Frequent disturbance across a large portion of the floodplain results in a diverse species mix and age mosaic. Although diverse, there are relatively few areas within the floodplain dominated by large mature trees suggesting the reach has been subject to large-scale disturbance within the past 100 years including fire and logging.

Changes from Historical Conditions

Overall, the physical condition of the Gray Reach of the Entiat River has changed at the hand of human influence, but most notably with regards to riparian vegetation, LWM, and migration rates (Table 10). The general channel form, sediment transport regime, and hydrologic regime have likely not significantly changed. The most significant change to channel character resulted from the loss of instream structure and cover primarily associated with less available key (large) pieces of LWM, generally younger/smaller age class of available wood in the riparian area, and occasional mechanical clearing of LWM from the channel. These changes have also affected migration rates as discussed previously resulting in increased rates of downstream migration and potentially lower rates of lateral migration.

Other human-caused changes include two bank protection projects further altering the natural rate of channel migration near RM 16.45 and 17.4, two bridges both of which have elevated approaches that constrict flood flows, and a levee that has negligible impact as discussed previously.

Table 10. Relative comparison of historical conditions and the existing conditions.

Form	Historical Condition	Existing Condition	Processes Impaired Resulting in the Change	Degree of Impairment Based on Limiting Factors (high, medium, low)
River bed and banks	River alluvium (gravel), floodplain sediment (silt/sand) hillslope colluvium and debris flow deposits (coarse rock)	River alluvium (gravel), hillsope colluvium, debris flow deposits, log, and rock bank armor	Channel migration impaired by two log and rock bank protection projects (RM 16.45 and 17.4)	Low; channel migration altered locally but continues on a reach-scale; Similar to debris flow deposit.
Sinuosity	1.2 to 1.6	1.25	Lateral migration has declined due to lack of logjams and old-growth forest	Medium; very long natural recovery period
Channel Morphology	Pool riffle	Pool riffle	N/A	N/A
Large Pools (>20m^2 and 1m deep)	9 to 12 per mile; Greater than 1:1 pool to riffle ratio	9.4 per mile; Greater than 1:1 pool to riffle ratio	Local pool scour impaired by lack of instream structure	Low; few large pools associated with instream structure; most formed by bend scour
Floodplain connection	Frequent flooding	Frequent flooding	N/A	N/A
Off-channel habitat	Estimated average of 7 alcoves or side channels per mile representing roughly 3000 linear feet per mile	5.5 per mile representing approximately 2000 linear feet per mile	Channel migration imparied altering natural alcove formation, but may increase avulsion and side channel formation potential; No logjams to maintain side channel inlets	Low; process and form are different than natural/historic but result in nearly equal off-channel habitat potential
LWM	5 to 10 logjams per mile; >20 pieces per mile	0.5 logjams per mile; 16.5 Pieces per mile	LWM Recruitment is impaired by lack of large key members	Medium; very few logjams form as a result of few key members capable of racking LWM
Riparian condition	Dense, mixed-age trees and shrubs including old-growth and wetlands; spanning the valley bottom	Dense, mostly young trees and shrubs with wetlands; approximately 10 acres disturbed	LWM Recruitment is impaired because few large mature trees are present within the riparian corridor	Medium; but trending toward recovery

Logging

Logging for timber harvests and related activities have resulted in less LWM available for recruitment, increased runoff potential, and potentially increased fine sediment production (Reclamation 2009a). The lack of LWM recruitment is the most significant change affecting the limiting factors in the assessment area as a result of logging. Although assumed to be significant, this change is impossible to quantify. Transporting harvested timber down the river to lumber mills also impacted the river by scouring the bed, mobilizing above average amounts of bedload sediment, and removing many instream structures.

Removal of LWM

The actual number of historical logjams per mile is unknown, but estimated at 5 to 10 logjams per mile as discussed previously. It was well documented that logs for the timber industry were splashed down the Entiat River, likely through the project reach, in order to be delivered to various lumber mills farther downstream. The practice of splashing timber concluded in the middle of the 20th century. Since that time, logjams have periodically been cleared for flood protection, but since the mid 1970s LWM have generally been allowed to accumulate in the Entiat River (Reclamation 2009a). Over the past few decades, aerial photo review has shown only one logjam in the Gray Reach (2006) suggesting that although logs are not as frequently removed from the system, large key members capable of racking sufficient material to form a jam are not being recruited to the reach. The 2006 logjam at RM 16.32 persisted for less than 2 years. It is unclear if it was dismantled by a flood or by human intervention. A single large cottonwood root wad is present in the same area, and shows signs of attempted human removal (chainsaw cuts and treetop removed).

Bank Protection

Two rock and log barb bank protection sites were observed at RM 16.45 and 17.4. Both sites significantly limit natural channel migration. Despite this, they have not created an unnatural condition (forms are similar to those where the channel encounters an erosion-resistant debris flow deposits from an alluvial fan). The difference is this is a human introduced “hard point” and may be considered unnatural, despite not significantly altering the channel form or creating “unnatural” conditions.

The site at RM 17.4 is rough, stable, and has resulted in a complex bank with deep pools, but has also essentially eliminated downstream channel migration at this site, where prior to implementation migration averaged roughly 10 feet per year primarily in the downstream direction (from 1945 to 1998). The riparian vegetation had been cleared along this bank sometime prior to 1945, which likely increased migration rates (especially downstream) and subsequent bank protection measures. Since the project was completed in 1998, minimal riparian vegetation has recovered with the majority of the site remaining poorly vegetated (mostly grass and small trees and shrubs).

The downstream site at RM 16.45 consists of five rock and log barbs creating a rough bank along a low levee. It is unclear if the levee is natural or human-made, but is roughly the same height and geometry of natural levees in the area, and therefore is not considered an “unnatural” human impact. The barbs, however, limit channel migration which prior to implementation averaged roughly 3.7 feet per year mostly in the downstream direction. Similar to the upstream site, the riparian vegetation in this area had been cleared prior to 1945 likely increasing the rate of bank recession and downstream channel migration. Despite the barbs, recent bank erosion between barbs has caused the fourth of five structures to be flanked by the river. It is now positioned nearly in the middle of the channel where it is racking wood and creating a logjam similar to what may occur if a large boulder or boulder cluster had fallen into the river from the valley wall. The remaining barbs are stabilizing a previously unstable bank enabling the establishment of riparian vegetation. Currently, the riparian vegetation consists primarily of dense 10+year old age class shrubs. Barbs have succeeded in stabilizing the bank while vegetation becomes established, and structures are beginning to fail enabling the re-establishment of more “natural” rates of channel migration and avulsion potential.

Both of the log and rock barb bank protection projects described above impact channel processes similar to banks composed of debris flow deposits, which are common in the reach, or similar to banks composed of old growth timber, which were historically common. The structures create a hard bank along the outside of a bend enhancing bend scour and pool formation, while limiting natural downstream channel migration. Especially at the upstream site (RM 17.4), maintaining the existing bend location with barbs obstructs downstream flow, forcing the channel directly into the left bank along the armored valley wall. Hydraulic modeling predicts a backwater condition to occur during large floods as a result of this channel pattern, which may add to the amount of overbank flow in the vicinity of the barbs and increase the potential for avulsion.

Two areas of riprap bank armoring were also observed along the Entiat River Road (RM 17.3 and 17.55) directly adjacent colluvium along the valley wall, and therefore, not considered a significant impact to natural channel migration. The riprap is generally rough, incorporating barbs, which helps reduce the velocity along the bank similar to a natural colluvial surface.

Roads and Development

Hard surfaces and compacted soil associated with roads and development can lead to increased runoff potential and greater volumes of sediment production. Increased runoff and increased sediment production have not been identified as limiting factors for the Entiat River, although increased fine sediment observed in sediment samples taken from the riverbed has been identified as a possible concern. Logging and clearing of the riparian areas is the most significant impact associated with roads and development in the Entiat River basin that likely contributes to increased runoff and fine sediment production.

Roads and associated bridges constrict the channel and floodplain in two areas (Figure 25). Similar to the bank protection sites addressed above, these features alter rates of natural channel migration and create scour due to flow convergence under the bridges, but these types of forms are not uncommon within this reach associated with large rockfall and debris flow deposits. The difference is that these are human introduced forms and may be considered unnatural despite creating “natural” conditions.

For example, the approach fill associated with the Cottonwood Flats Bridge located at RM 17.65 alters the flow path and channel migration character of the channel, but does not prevent migration. As the channel continues to erode the left bank, it will be forced into a more sinuous, lower radius of curvature flow path in order to continue passing beneath the bridge thereby reducing the local gradient and increasing bend friction. Because the bridge abutment prevents bank erosion and subsequent migration in the downstream direction, bank erosion and migration will continue laterally, potentially impacting a nearby house. During periods of flood flow, the increasing backwater condition will likely raise flood surface elevations upstream of the bridge, also potentially impacting the nearby house and increasing the avulsion potential on the right bank. The bridge abutments and approach fill have not precluded channel migration, but have altered its natural pattern forcing only lateral migration as opposed to a combination of both lateral and downstream migration at the site of the bridge. The backwater formed by the bridge may actually increase the frequency and duration of floodplain inundation and may also increase the potential for a partial or full channel avulsion.

Removal of Riparian Vegetation

The removal of riparian vegetation for rural development (clearing) has impacted approximately 15 percent of the floodplain in the Gray Reach assessment area. It is estimated that the majority of the 2-year floodplain (approximately 65 acres) would have been populated with riparian vegetation prior to Euro-American settlement in the area, but as measured from 2011 aerial photos, only 57 acres are vegetated, mostly with young or immature trees and shrubs. This estimate does not include upland areas encompassed by alluvial fans or other lands inundated beyond the estimated 2-year flood event. Many large/mature trees have been historically removed from the riparian area, although current low levels of logging and clearing suggest riparian vegetation is trending toward recovery in most locations. The removal of mature riparian vegetation (and instream structure such as logjams) has likely increased the rates of downstream channel migration by reducing bank stability.

Beaver

Removal of beaver has impacted riparian communities and recruitment of LWM, most notably along channel margins and within the many wetlands, alcoves, and side channel areas in the Gray Reach. Beaver activity would have increased the rate of LWM recruitment and likely improved the longevity and connection of alcoves and side channels by excavating surface water paths to the mainstem (Figure 34). Current observations of a well-established side channel on the right floodplain in the Preston Reach (RM 21.5) show that beaver dams regulate flow through the side channel increasing its longevity by reducing the potential for complete channel capture avulsion. Beaver activity in the riparian and off-channel areas may also affect nutrient cycling, deposition of fine sediment, off-channel water velocity, and vegetative succession. It is unlikely that beaver activity has had a profound effect on mainstem channel processes other than the recruitment of woody material.

Figure 34. Low flow connection excavated in silt and sand by beavers between the mainstem channel and a beaver pond located in an alcove near RM 17.0.

Fire

Changes in the fire regime to more frequent severe fires have not resulted in recorded or observed increases in sediment delivery in the Entiat River. High-intensity storm events following severe wildfires can significantly increase sediment production temporarily, but monitoring efforts have shown that sediment recovery is relatively rapid (CCCD 2004). For example, the overall trend in fine sediment sampled in the Entiat River has remained relatively constant since 1993, which includes the period of time immediately following the extensive Tyee Fire in 1994. Although water temperature data is unavailable from historic times, more frequent severe fires within the riparian area may affect water temperature by reducing shade and thermal mass associated with the riparian vegetation, but neither temperature nor fine sediment have been identified as a limiting factor in the Gray Reach.

Existing Trends

Overall, the Gray Reach appears to be largely trending toward improved habitat conditions, with the exception of a few locations where riparian clearing persists. Most remaining human impacts are associated with riparian conditions and LWM, both of which require many decades before significant improvements will be noticed. Immediate action will provide a stopgap ensuring the long-term success of currently threatened and endangered species in the Entiat River.

Anticipated changes to future physical habitat if no action is taken to deviate from existing trends include: 1) increased overall age and minor increased area of riparian vegetation, 2) ongoing channel migration, 3) potential off-channel habitat formation, 4) potential LWM and logjam recruitment, and 5) effects from global climate change.

Riparian Vegetation

Riparian vegetation will continue to age where it has not been cleared, and recent (as well as ongoing) planting efforts continue to improve the riparian condition of the reach (i.e., RM 16.5 and RM 17.4). Modern logging and clearing practices are strictly controlled within the riparian area, and historic clearing and splashing of timber is not anticipated to return. Yet, there is no reason to believe existing clearings will be planted with native vegetation without support and pressure applied by local habitat improvement agencies and groups. All planting efforts should consider temporary bank protection to ensure establishment of mature vegetation. Recent plantings near RM 16.5 are not likely to persist as they become undermined by the river where the bank is otherwise barren and unstable (Figure 35).

Figure 35. Bank erosion observed on the right bank near RM 16.5. The bank is composed of 3 to 4 feet of silt and sand over gravel and cobble. Recent riparian plantings can be observed on the floodplain surface, but the plantings are threatened by the erosion without any substantial structure to stabilize the bank.

Channel Migration

Easily erodible banks and a low gradient, depositional environment will continue to promote channel migration long into the future. By measuring historic rates (1945 through 2011) and locations of channel migration, mapping bank conditions and surface geology, and measuring meander traits including wavelength and amplitude, future channel migration characteristics can be estimated. Generally, the Gray Reach is expected to continue migrating as it has done in the past with greatest rates in the downstream direction, limited to no migration into erosion-resistant materials, and meander cut-off avulsions occurring when the localized sinuosity exceeds approximately 1.6, meander wavelength is generally less than 600 feet, and radius of curvature is less than approximately 100 feet.

Lateral and downstream migration rates calculated by comparing bank locations between successive historic aerial photos were used to estimate potential channel migration zones (CMZ) for 25, 50, and 100 years of continual migration. These preliminary delineations were truncated in areas where erosion-resistant bank materials limited migration potential (many locations) and expanded where new bar formation and/or poor riparian vegetation may enhance migration (RM 16.5 and RM 17.2). Human constraints on migration were also factored into the delineation, and CMZ estimates were made assuming long-term maintenance of human-constructed features and without human-constructed features. Figures 36 to 38 illustrate the future predicted CMZ.

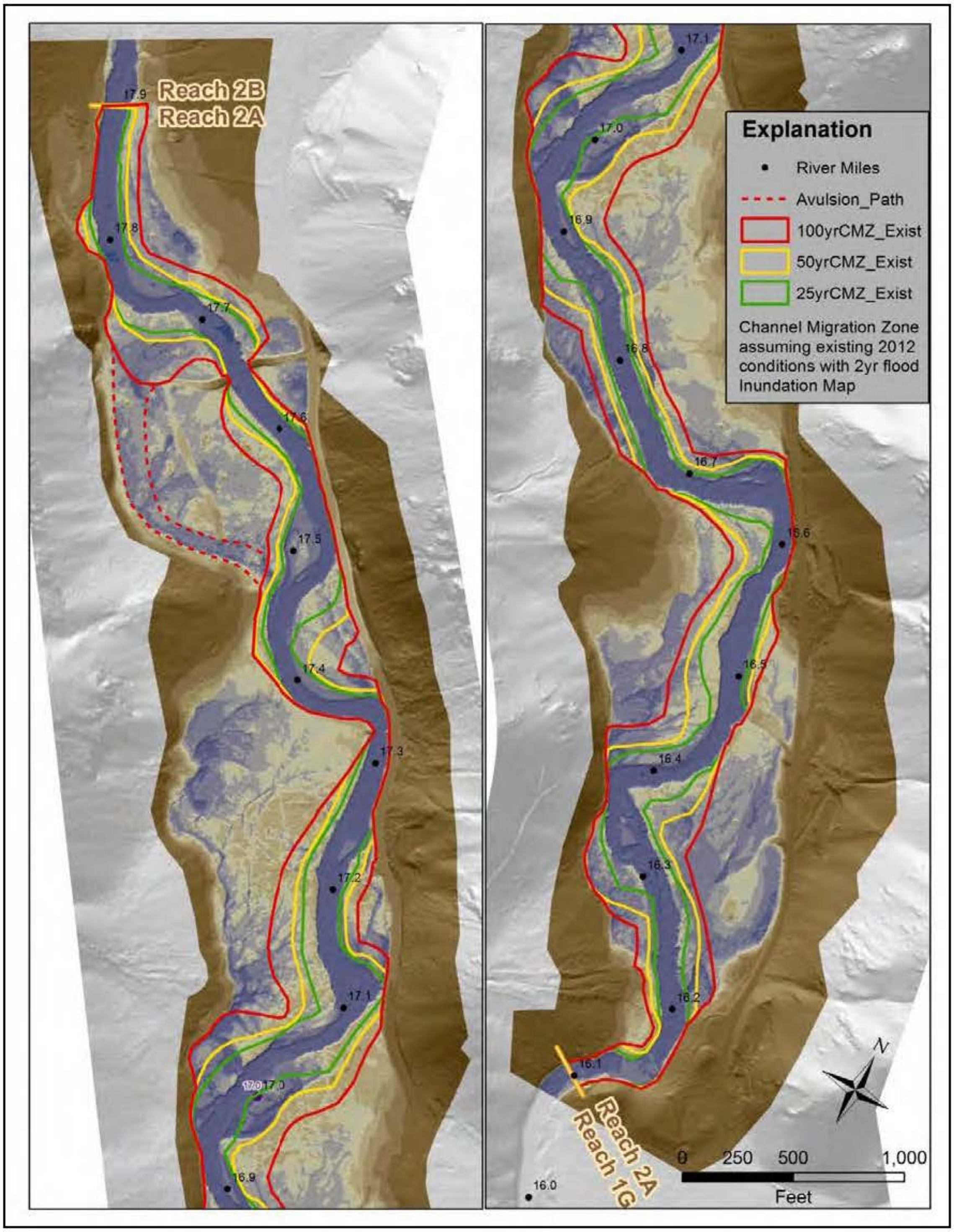

Figure 36. Estimated future CMZ calculated from historic lateral and downstream migration rates. The CMZ illustrated in the figure assumes existing human-constructed bank protection and natural erosion-resistant banks will prevent future erosion in these areas.

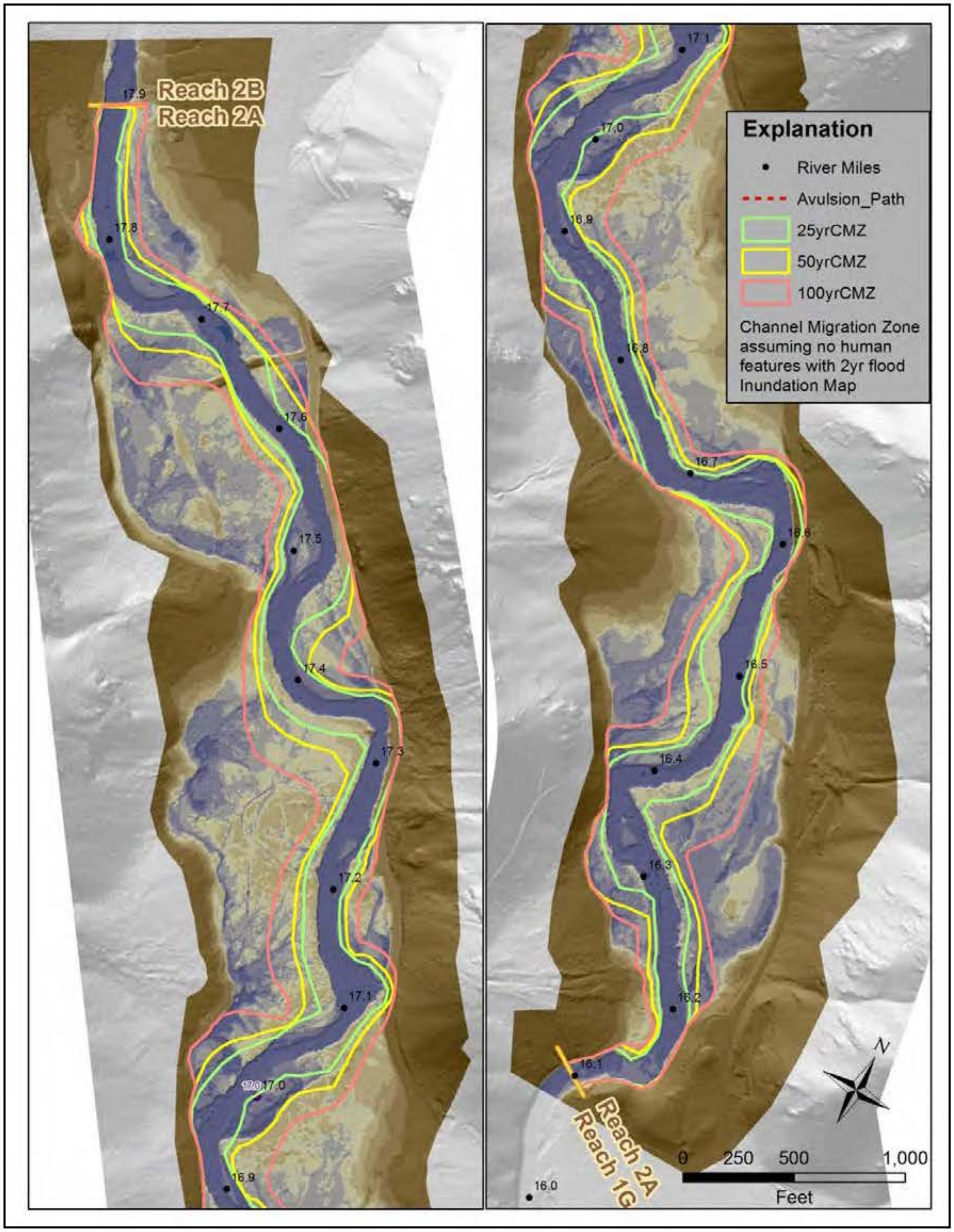

Figure 37. Estimated future CMZ calculated from historic lateral and downstream migration rates. The CMZ illustrated in the figure assumes no human-constructed bank protection.

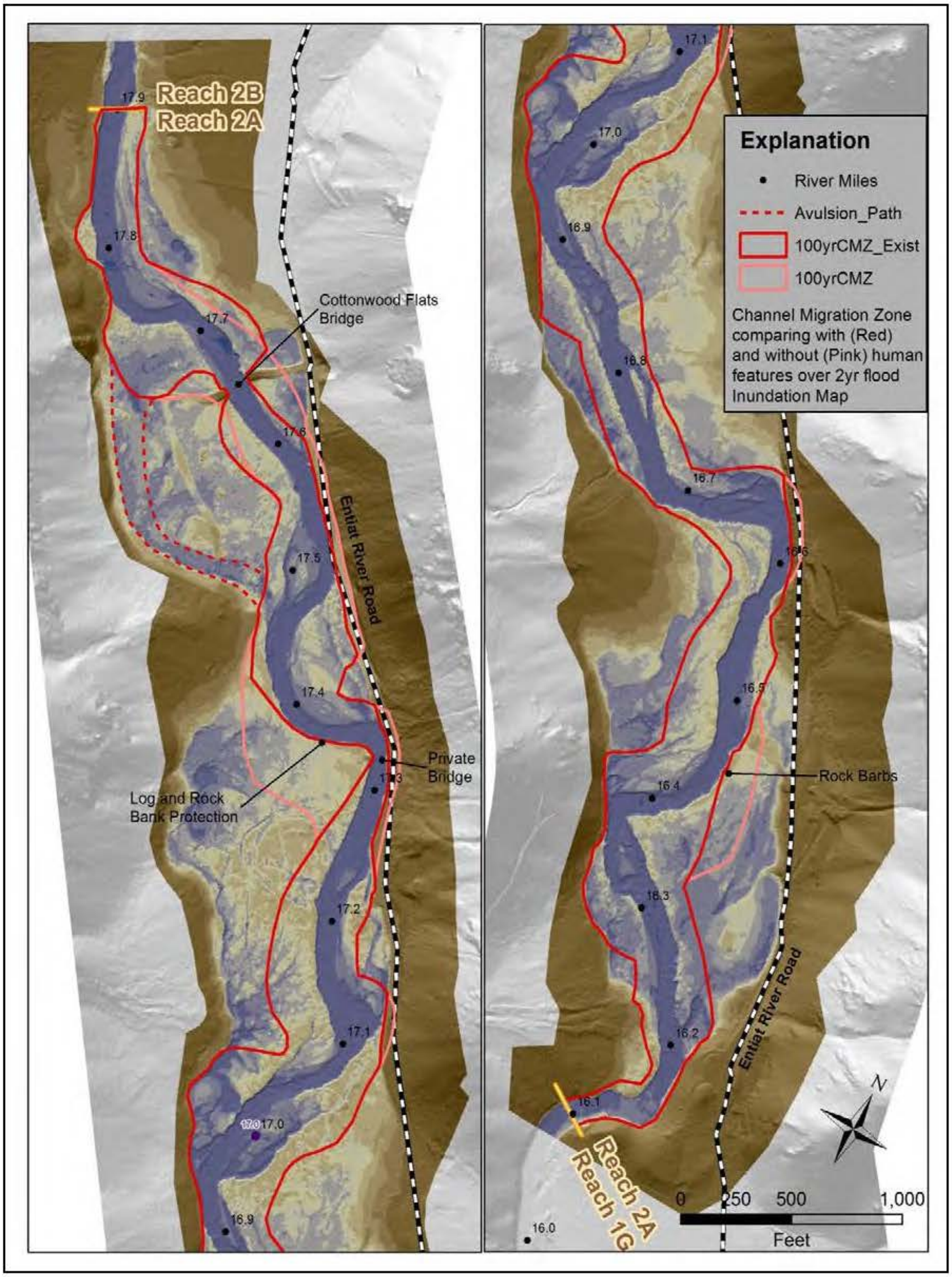

Figure 38. Estimated 100-year CMZ showing predicted human-related erosion barriers (Red) compared with no human-related erosion barriers (Pink).

Off-channel Habitat Formation

The Gray Reach has shown through channel migration and avulsion the ability to create new off-channel habitat features such as alcoves and side channels. Future off-channel formation is anticipated to occur at roughly the same rate as historically, although existing human features may increase the likelihood of avulsions forming side channels. Historically, avulsions in the Gray Reach were of the relatively small, meander-cutoff variety, leaving behind one or two oxbow channels connected for only a relatively short period of time as a perennial side channel. Typically, the inlet to these features filled with sediment as natural levees formed near the banks converting the side channels to alcoves with only a downstream connection after several years. Persistent side-channels occurred historically in locations with stable banks and mature riparian vegetation as discussed previously in the Historic Instream Obstructions section. Where a hardened bank restricts downstream channel migration and forces flow against the opposite bank composed of erosion-resistant materials (e.g., RM 17.4) or forces increased lateral migration (e.g., RM 17.65), the floodwater stage upstream of the structure tends to increase due to backwater conditions. Greater floodwater elevations increase over-bank flow and the potential for avulsion and/or side-channel formation to relieve the increased pressure on the bank. Additional off-channel habitat in the form of alcoves is likely to be created following existing processes described earlier in this report (Figure 39).

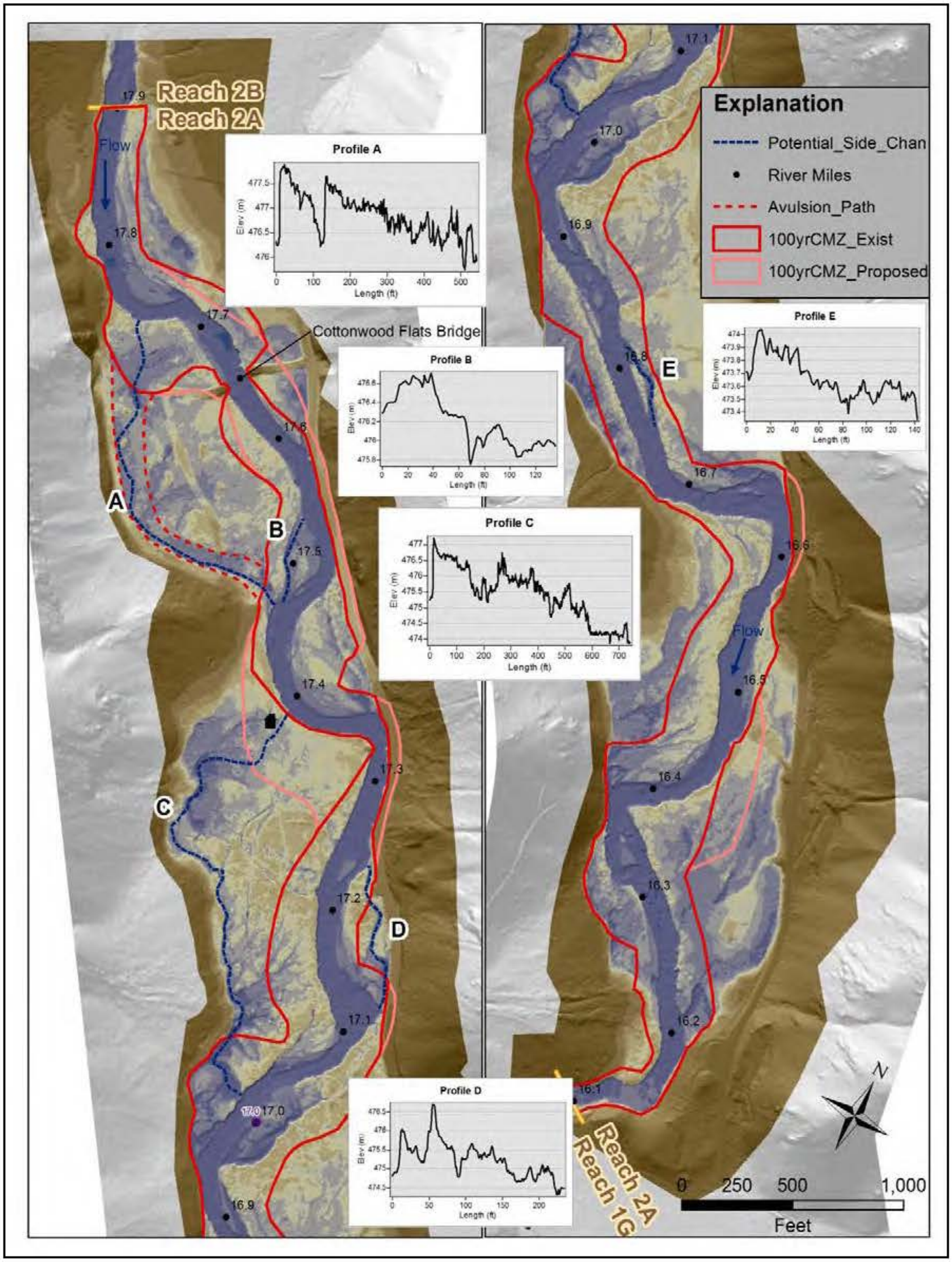

Figure 39. Side channels in the Gray Reach of the Entiat River are of two types:

1) Short, relatively straight, short-lived (+/- 25 yrs) flow split around a logjam or other obstacle.

2) Long, sinuous, long-lived (+/- 100 yrs) flow passing through a breach in the River's natural levees, concentrating against the valley wall, and forming a relatively narrow/deep channel

Potential side channels B, D, and E represent the type discussed in option 1 above. Formation and maintenance of these channels requires a logjam or similar obstruction on the downstream side of the channel's inlet in order to split flow, scour the inlet, and create/maintain the side channel. Over time, the mainstem is likely to migrate into or away from the side channel, altering hydraulics, and sediment deposition to the point where the side channel is absorbed by the mainstem or filled with sediment. As a result, this type of side channel has an anticipated life of +/-25 years depending on the migration rate in that area.

Potential side channels A and C represent the type discussed in option 2 above. Formation and maintenance of these types of channels historically required relatively stable main-stem banks near the inlet coupled with backwater conditions during high flows. Bank stability was historically provided by patches of old-growth forest and associated logjams. Backwater conditions were historically (and currently) provided by sharp bends, channel constrictions, and/or obstructions (e.g., logjams). The backwater condition resulted in more frequent overbank flows, which ultimately scoured an opening through the natural levee. Stable banks allowed this overbank flow to persist in the same location for many years. Given enough time, repeat floods scoured and maintained a complete side channel. Beaver dams would temporarily impound the side channel, which would ultimately bypass the beaver dam to either side, enhancing side-channel sinuosity. This is exemplified in an existing side channel in the Preston Reach on the right bank near RM 21.6.

The potential side channels identified may also provide habitat without a perennial surface water connection given sufficient flow capable of maintaining a series of connected pools and an alcove at the downstream end. Recent historical trends (past 100 years) suggest the Gray Reach of the Entiat River is dominated by downstream migration, which may decrease the feasibility of creating a perennial upstream surface water connection in some proposed side channels.

Profiles were estimated using LiDAR, which commonly over-estimates surface elevations in thick brush and grass as are present in each potential side channel identified. Actual surface elevations may be several feet lower in the side channel profiles representing less "cut" if excavated as part of a habitat project.

LWM Recruitment

The future recruitment of LWM depends on the availability of large wood and its ability to be retained within the reach. Improved riparian conditions with older trees will improve the size of recruited woody material in the future (several decades from now), and with increased size comes improved retention as large logs are less easily transported by the river. Additionally, increased side channel formation, if it occurs, creates split flow enhancing LWM capture and retention at the apex of the flow split. It is anticipated that LWM recruitment will continue along the existing trend of slowly increasing the total number of individual logs for several decades at which time sufficiently large size and volume of available logs will begin to more consistently form persistent logjams in addition to individual log structures.

Global Climate Change

Global climate models predict increased summer temperatures, warmer winter temperatures, earlier spring runoff, greater maximum peak discharge, less low-elevation snowpack, lower summer flows, and warmer water temperatures for the inland mountain region of the Pacific Northwest (Reclamation 2011; Rieman and Isaak 2010; Houghton et al. 2001). Potentially lower summer flows and increased summer water temperatures present the most significant negative impacts to target fish species that may result from climate change. With less potential water in the river, less snowmelt in the summer, and warmer temperatures, the potential to increase water temperatures on the Entiat River is high. Summer water temperatures may become a more significant limiting factor in the future. Conversely, warmer winter temperatures will lead to higher water temperatures and greater volumes of winter flow which may improve overwintering habitat characteristics, assuming adults are able to successfully migrate and spawn.

The potential negative impacts resulting from earlier runoff and greater peak flow are less significant with regard to physical habitat in the Entiat River as a whole. Many dynamic changes occur as a result of large floods or debris flows associated with runoff. Greater peak flow suggests the potential for more extreme floods, which, although potentially damaging to human infrastructure, health, and safety, may actually further induce change and increase channel complexity on the Entiat River.

It is likely that warmer/drier summers may increase fires or other timber mortality in the basin. With fewer trees, the potential for LWM recruitment may decline along with shade and cover over the long term (hundreds of years).

Target Conditions

Target conditions represent the most appropriate physical characteristics for a given reach, which should guide future habitat improvement projects. The difference between target conditions and historical conditions is that target conditions take into consideration existing conditions, constraints, and future trends. Critical to the development of target conditions is an understanding of the linkage between the physical characteristics of the channel and the biologic needs of the species of concern. By better understanding this relationship, target conditions can be identified which will provide fish with the physical habitat necessary to overcome identified biological limiting factors.

Table 11 outlines the physical conditions generally preferred by steelhead and spring Chinook salmon during several different life stages as compiled by the USFS in Entiat, Washington.

Table 11. Preferred habitat characteristics for steelhead and spring Chinook salmon at various life stages.

Perferred Habitat	Steelhead	Spring Chinook Salmon
Spawning Habitat		
Depth	1.8 feet (0.54 meters)[a]; 0.78 feet (<24 cm)[b]	Minimum water depth limit= 1 foot (30 cm)[p]
Velocity	2.3 feet/second (0.71 meters/second)[a] 1.31 to 2.98 feet/second (40 to 91 cm/sec)[b]	Optimal range=0.30 to 0.9 meters/second[p]
Gravel size	1.28 inches (32.5 mm)[a] 0.24 to 4.0 inches (0.6 to 10.2 cm)[b]	Optimal substrate mixture=6 percent fines, 59 percent to 86 percent gravel (~15 cm in diameter), and 8 percent to 35 percent cobble >15cm[p] Optimum spawning gravel size:21 percent for 0.3 to 1.25 cm; 41 percent for 1.25 to 6 cm; 24 percent for 6 to 10 cm; and 14 percent for 6 to 15 cm[p] Mean spawning gravel size of 4.2 cm[p]
Water temperature	39.2°F; 4.0°C [b]	Ranges between 4.4 to 18.0°C; >12.8°C increases mortality to spawning females[p]
Other	Prefer protective cover	Prefer spawning in tailouts/glides
Egg incubation to emergence habitat		
Fine sediment (particles less than 1 mm)	< 20 percent fine sediment results in increased embryonic survival[c]	< 20 percent fine sediment results in increased embryonic survival[c]

Perferred Habitat	Steelhead	Spring Chinook Salmon
Water temperature	5.0° C to 11.0° C [d]	41-52°F; 5-11°C [d]= Highest rate for successful fertilization to emergence[d]
Dissolved oxygen	≥50 percent survival of embryos achieved at 5 mg/L to 9 mg/L [e]	≥8 mg/l at temperatures ≥7°C but ≤10°C and ≥12 mg/l at temperatures >10°C[p]
Juvenile rearing habitat		
Groundwater	Groundwater provides cooler temperatures during the summer and warmer temperatures during the winter resulting in increased juvenile survival.[c]	
Velocity	Less than 1.0 feet/second for holding; proximity of low-velocity water for holding to relatively high velocity water for feeding[q, r] Refugia from extreme high flows and extreme high velocity[r]	
Large woody material	LWM increases the complexity of stream habitats by creating areas with different depths, velocities, substrate types, and amounts of cover. [c] >20 pieces/ mile >12-inch diameter >35 feet length[k,n]; and adequate sources of woody material recruitment in riparian areas	
Pools	As pool density (m^2/km) increases, smolt production increases (i.e., 2,000 (m^2/km) pool area resulted in ≈1,000 smolts/km and 3,000 pool area (m^2/km) resulted in between 2,000 and 3,000 smolts/km).[f] Where streams are >3 m in wetted width at base flow, pools >1 m deep (holding pools) with good cover and cool water and a minor reduction of pool volume by fine sediment[l] Pool to riffle ratio 1:1[p]	
Temperature	10.0° C to 14° C [g]	
Substrate Character and Embeddedness	Substrate is gravel or cobble with clears interstitial spaces reach embeddedness <20 percent[i, j,ln]	
Overhead Cover	Juveniles exhibit preference for habitats with overhead cover[o]	
Adult holding habitat		
Pool Quality	Depth 1.0-1.4 meters[h]; Deep habitats of intermediate size (200-1,200 m^2) [h]; Adults use pools with cover associated with flow (avg=9.3 cm/second). Cover associated with flows < 3 cm/s are avoided [h]; Low streambed substrate embeddedness (<35 percent) [h].	Where streams are more than 3 m in wetted width at base flow, pools more than 1 m deep (holding pools) with good cover and cool water, minor reduction of pool volume by fine sediment[n]

Perferred Habitat	Steelhead	Spring Chinook Salmon
Pool Frequency	channel width — # pools/mile[k,n] 5 feet — 184 10 feet — 96 15 feet — 70 20 feet — 56 25 feet — 47 50 feet — 26 75 feet — 23 100 feet — 18	channel width — # pools/mile[k,n] 5 feet — 184 10 feet — 96 15 feet — 70 20 feet — 56 25 feet — 47 50 feet — 26 75 feet — 23 100 feet — 18
Large Woody Debris	>20 pieces/ mile >12-inch diameter >35 foot length[i,n;] and adequate sources of woody debris recruitment in riparian areas	More than 20 pieces/mile More than 12-inch diameter, more than 35 feet long;[i, n] and adequate sources of woody debris recruitment in riparian areas
Temperature	10.0° C to 14° C [g]	10.0° C to 14° C [g]
Channel Condition and Dynamics		
Average Wetted Width/Maximum Depth Ratio in scour pools in a reach	≤10[k, m]	
Streambank Condition	>80 percent of any stream reach has ≥90 percent stability,l,[m]	

a Zimmerman and Reeves 2000
b Nelle, R.D. and J. Moberg 2008
c Quinn 2005
d Murray and McPhail 1988
e Coble 1961
d Sharma and Hilborn 2001
f Bjorn and Reiser 1991
h Nakamoto 1994
i USFWS 1995
j NOAA Fisheries 1995
k USFS 1994
l WDNR. 1993
m Overton et al. 1995
n USFS et al. 2004
o Fausch 1993.
p Raleigh, Miller, and Nelson 1986
q Liepitz 1994
r Bouwes et al. 2010

Although it is helpful to understand the physical conditions preferred by the species of concern, not all of those conditions are appropriate for the Gray Reach of the Entiat River given its natural character and modern constraints.

Table 12 summarizes the constraints that will likely influence the habitat improvement process.

Table 12. Summary of constraints impacting habitat improvement on the lower Entiat River.

Constraint	Description
Floodplain development	Buildings, roads, bridges, and other human infrastructure have encroached onto the floodplain and in some cases restrict the potential for channel migration, floodplain connection, and riparian succession.
Floodplain clearing	Portions of the valley bottom and active floodplain have been converted from native vegetation to rural development including houses, driveways, lawn, etc. It is unlikely that all of this land can be reclaimed for native vegetation and floodplain connection, but buffer areas could be collaboratively developed especially in areas of high habitat potential.
Human safety and liability	Although logjams and other instream structures are a natural component of rivers, many people view instream structures as unsafe. Very large, potentially channel-spanning logjams may not be considered socially acceptable in the near term future due to human safety and liability concerns.
Climate change	The Entiat River is likely to experience larger peak floods, lower summer flows, and warmer summer water temperatures in the future as a result of climate change. Habitat actions should consider conditions that are likely to occur in the future to target conditions that will buffer endangered species from the changing conditions enabling them more time to adapt and evolve.
Funding, politics, and time	Habitat rehabilitation is a collaborative process that requires cooperation, time, and money. Without sufficient amounts of all three, habitat improvement is constrained.

Bed and Banks

Target conditions for the bed and banks do not differ from the existing and past conditions with the exception of increased roughness along smooth banks lacking structure, and improved riparian conditions to support bank stability in those locations where human structures have been installed. Mature riparian vegetation will allow for the eventual removal or failure of existing or future bank stabilization structures.

Fine sediment (including sand-sized sediment and smaller) is currently not considered a limiting factor nor is it impacting physical conditions. Target conditions should be flexible to account for natural variations in fine sediment loading associated with periods of increased disturbance such as fire. Maintaining an active CMZ and improving riparian conditions will enable the channel to recover from episodic pulses of fine sediment through dynamic change and increased diversity, as opposed to confined transport reaches, which do not deposit fine sediment and therefore are relatively static and less diverse.

Fine sediment should be monitored to ensure long-term summer and fall accumulation is not increasing as the result of surface runoff from convective precipitation over disturbed areas such as roads and clearings.

Sinuosity

Target sinuosity is unchanged from existing or past conditions. It is anticipated that future migration will maintain a sinuous channel form similar to historic conditions with minimal change to sinuosity, meander wavelength, meander amplitude and bend radius of curvature. Bank protection and bridge structures have influenced and will continue to influence channel migration by impeding downstream migration. Despite these influences, the resultant form is similar to natural channel forms within the reach where the channel impinges against naturally erosion-resistant bank material. Additionally, although channel form is altered, the resultant condition may not have a negative impact on limiting factors. In fact, the altered form may be favorable if, for example, the result is a seasonal side channel as discussed in the previous section on Existing Trends.

Channel Morphology and Pools

A sinuous channel in an alluvial system will support the long-term maintenance and formation of pools via bend scour. Instream structure (especially logjams) will also support the formation of pools by forcing local flow convergence. Channel sinuosity is expected to remain unchanged, but targets for instream structure will increase (as discussed below), providing increased potential for the formation of large pools. Currently, the Gray Reach is dominated by large pools (nearly 50 percent of the total instream area). Target conditions should not significantly increase or decrease the total area occupied by large pools, but increased structure should break those areas up into series of more complex and slightly smaller (but still considered “large”) pools, including pools in locations other than the outside of bends.

Floodplain Connection

Floodplain connection has not changed significantly from historic to existing conditions, and target conditions remain essentially the same. The only potential target would be to address concerns similar to channel migration with regards to existing human obstructions altering the location and possibly timing of floodplain connection.

Off-channel Habitat

As discussed previously in the Historical Conditions section, perennial side channels likely required logjams and/or old-growth forest in order to persist. If existing or future bank stabilization and bridge structures are anticipated to persist for many decades, perennial side channels may once again become both feasible and geomorphically appropriate. Currently, and for the past 100+ years, relatively high rates of downstream channel migration have precluded the formation and persistence of perennial side channels. Potential habitat improvement projects in the Gray Reach can therefore either target existing trends of relatively rapid downstream channel migration and a tendency toward alcove formation, or target the formation and persistence of side channels with logjam-type bank stabilization and/or flood enhancement features. Allowing for both options is feasible and appropriate and may result in the greatest amount of habitat diversity, but one may interfere with the other if not planned appropriately. It is hypothesized that over the next several hundred years either or both options will result in a channel with large logjams and perennial side channels assuming the continuation of existing trends.

Instream Structure and LWM

Many of the limiting factors affecting fish growth and survival on the Entiat River are not significantly realized in the Gray Reach, but perhaps the largest human-related impact to physical form and process has been the clearing of instream structures from the river and logging portions of the riparian area reducing the potential recruitment of new instream structures. Target conditions include greater numbers of larger instream structure (LWM), as well as the establishment of mature riparian vegetation to ensure long-term recruitment of future LWM.

LWM and other instream structures will be most effective where they can interact with other structures and features, including bedrock, side channels, and alcoves in order to amplify their cumulative effect. Logjams and log barbs may be used to stabilize banks to facilitate the establishment of mature riparian vegetation also potentially allowing for the evolution and persistence of diverse side channel features. Additionally, more instream structure will create habitat diversity, instream velocity breaks, and cover, all of which will address limiting factors. The LWM component of the instream structures should be maintained by the natural succession of riparian vegetation in a broad riparian corridor.

Riparian Conditions

Target riparian conditions include a mosaic of species and ages, similar to the existing condition, but with substantially more mature timber. The target riparian corridor width should roughly equal that of the floodplain, but considering constraints, an appropriate target would be at least 100 feet from each bank or to the valley wall, whichever is less. The 100-foot-wide riparian buffer is based on tree height and the potential for LWM recruitment and shade. Beyond 100 feet from the bank, shade, LWM recruitment, and nutrient exchange are relatively low unless the channel migrates into that area. For these reasons, the target riparian corridor should be expanded beyond 100 feet in select areas to account for predicted channel migration. Without planting and bank stabilization efforts, creation of these conditions through natural succession will take hundreds of years. Maintaining mature riparian areas where they exist and improving future riparian areas will improve bank stability, promote future LWM recruitment and retention, and provide shade and cover along the banks of the channel, alcoves and side channels. Mature riparian conditions may also improve side-channel longevity by limiting side channel geometry (width and depth) thereby preventing stream capture avulsion.

Summary

Target conditions in the Gray Reach are similar to existing conditions with the exception of increased instream structure, increased riparian vegetation (especially mature vegetation), and the potential for improved side-channel creation and alcove enhancement. Essential for successful development of these target conditions is increased LWM recruitment and retention. Logjams and log structures create scour pools with cover, support side channel and alcove formation and persistence, and create hard-points in the valley bottom protecting and enabling the establishment of pockets of old-growth riparian vegetation. Table 13 summarizes the few differences between past, existing, and target conditions, including natural processes necessary to maintain target conditions and the limiting factors addressed.

Table 13. Summary of historical, existing, and target conditions of the lower Entiat River.

Form	Historical Condition	Existing Condition	Target Condition	Process(es) Needed to Achieve Target Condition	Limiting Factor(s) Addressed
River bed and banks	River alluvium (gravel), hillslope colluvium and debris flow deposits (coarse rock)	River alluvium (gravel), hillslope colluvium, debris flow deposits, log and rock bank armor	River alluvium (gravel), hillslope colluvium, debris flow deposits, possible log and rock bank protection	LWM recruitment and retention to stabilize banks	Instream structure
Sinuosity	1.2 to 1.6	1.25	1.2 to 1.6	LWM recruitment and retention; riparian succession	Instream structure and off-channel rearing
Channel Morphology	Pool riffle	Pool riffle	Pool riffle	N/A	N/A
Large Pools ($>20m^2$ and 1m deep)	9 to 12 per mile; Greater than 1:1 pool to riffle ratio	9.4 per mile; Greater than 1:1 pool to riffle ratio	9 to 12 per mile	Increased localized scour from LWM	Instream structure
Floodplain connection	Frequent flooding	Frequent flooding	Frequent flooding	N/A	N/A
Off-channel habitat	Estimated average of 7 alcoves or side channels per mile representing roughly 3000 linear feet per mile	5.5 alcoves or side channels per mile representing approximately 2,000 linear feet per mile	7 alcoves or side channels per mile; 3,000 linear feet per mile	LWM recruitment and retention used to initiate and maintain side channels and improve alcove connections	Off-channel rearing
LWM	5 to 10 logjams per mile; >20 pieces per mile	0.5 logjams per mile; 16.5 pieces per mile	5 to 10 logjams per mile; >20 pieces per mile	LWM recruitment and retention	Instream structure and off-channel rearing
Riparian condition	Dense, mixed-age trees and shrubs with old growth and wetlands spanning the valley bottom	Dense, mostly young trees and shrubs with wetlands; approximately 10 acres disturbed	Dense, mixed age trees and shrubs with wetlands; <10 acres disturbed	Riparian succession	Well-established riparian buffer; summer temp.

Potential Habitat Actions

Despite historic removal of instream structure and the introduction of bank protection, bridges, and riparian clearing, the Gray Reach of the Entiat River physically functions similarly to historic conditions. While little or no long-term change in reach-scale channel process or general form can be measured or deduced comparing past and existing data, local forms and process have been affected by human actions in a handful of locations. Those impacts have generally resulted in conditions not unlike natural conditions elsewhere in the reach. Reach-scale physical forms and processes are therefore considered to be functioning within the realm of what is believed to be geomorphically appropriate for a response reach of this type. Those human-related activities that have impacted local physical conditions are trending toward improvement, but many decades are anticipated before the improvement has any impact (i.e., recruitment of large trees for LWM and more mature riparian vegetation), and some areas may not recover if residential clearings are maintained in existing locations.

Habitat actions may be implemented in order to move the current trend more rapidly and decidedly in the direction of the targeted conditions. Habitat actions are completed following a hierarchical philosophy that includes the protection of existing quality habitat followed by improvements to water quality/quantity, habitat connection, channel process, and instream habitat. Many geomorphically appropriate habitat improvement actions are identified in the following sections. These actions do not necessarily represent all possible and/or appropriate actions for this reach.

Habitat Protection

Protecting existing habitat is the first priority in the Gray Reach. The majority of the reach and its surrounding floodplain consists of high-quality physical habitat and will continue to improve over time as riparian vegetation matures. Old-growth riparian vegetation is completely absent from the Gray Reach, and it is the old-growth vegetation that contributes to the stabilization of banks and the recruitment of key-member logs capable of racking wood to form logjams. Those areas, which should be targeted for habitat protection, include undisturbed or recovering areas within the 100-year floodplain, especially those within the projected CMZ (Figure 40). Any proposed instream or riparian habitat improvement project area should also be considered for habitat protection.

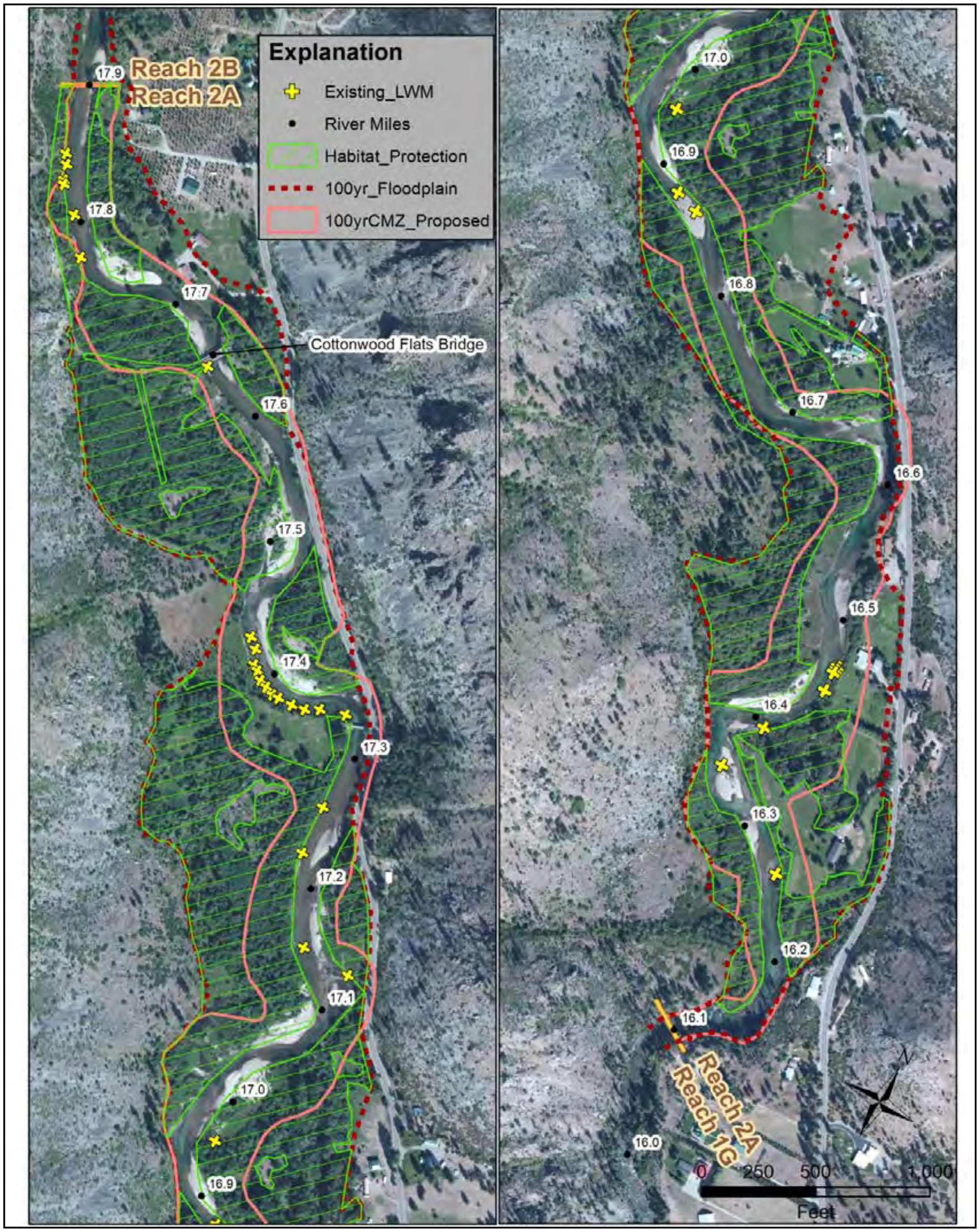

Figure 40. Potential habitat protection areas.

Water Quality and Quantity

Water quality and quantity have not been explicitly identified as major limiting factors in the Gray Reach. Nevertheless, increasing riparian zone width and age class will buffer fine sediment inputs from surface runoff and increase shade respectively. Less fine sediment and greater shade will further improve water quality.

Habitat Connectivity

Habitat connectivity refers to the removal or modification of human-caused barriers to existing habitat. In the Gray Reach, there are two habitat connectivity issues associated with human activities. The first is a small driveway, which blocks fish access and flow through a small seasonal side channel on the left bank near RM 17.2. Potential habitat improvement actions may include removing the driveway or adding a culvert or bridge and possibly enhancing the side channel to improve the upstream and downstream connections. Additional habitat improvements including channel excavation and/or LWM installation may further enhance the side channel potentially increasing the duration of its effective use.

The second human-caused issue related to habitat connectivity is the lack of instream LWM, especially logjams, enabling the formation and persistence of alcoves and side channels. Historic conditions suggest that connection to alcoves and side channels may have been significantly enhanced by the increased presence of LWM. The surface water connection to existing seasonal side channels and alcoves can potentially be improved and/or prolonged through the short-term strategic placement of logjams and long-term improvement of LWM recruitment/retention.

Logjams at the head of riffles, particularly on the point bar of sharp bends, will facilitate flow splits, promoting high-flow floodplain activation and possible side channel or alcove formation and maintenance. Logjams positioned at the outlet of alcoves and side channels may also improve the downstream surface-water connection with these off-channel habitat features (Figure 41). Several alcoves and flood channels outlet into the Gray Reach in areas controlled by backwater conditions at high flow. The backwater conditions result in deposition of sand and fine gravel in the outlet channels at high flow. Strategically placed logjams can improve scour characteristics by forcing flow convergence or plunge flow during relatively low discharge when the backwater condition is no longer in place, thereby clearing the outlet of deposited sediment and improving access. While scour at these locations may improve downstream connection, it is difficult to predict, and improper structure type and/or location may actually increase deposition and cut-off the connection. The most risk-free action to improve off-channel access via downstream connection is to force more flow into the side channel or alcove from upstream ensuring adequate flushing flow capable of moving the anticipated sediment load.

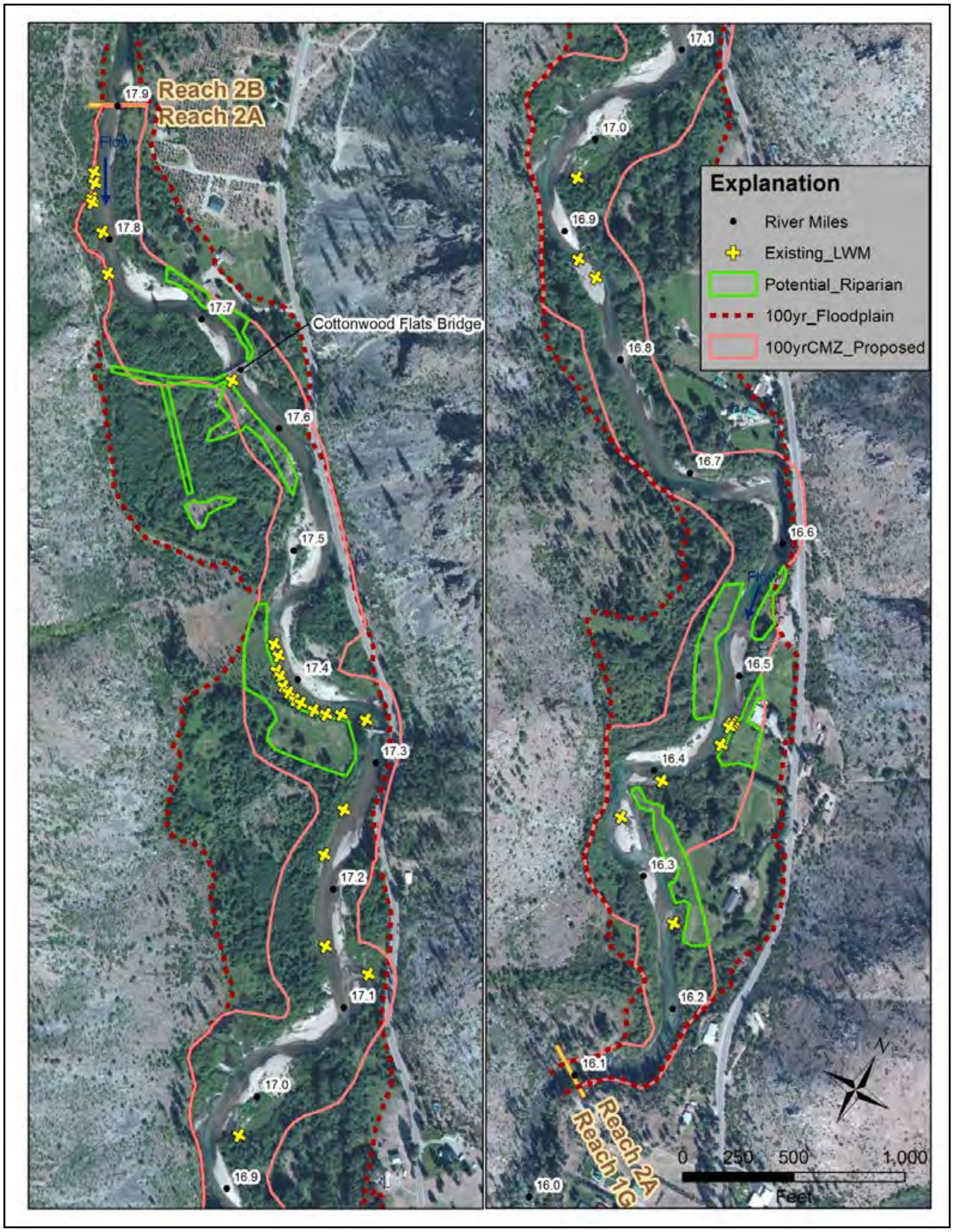

Figure 41. A 2011 aerial photo with outlines illustrating potential riparian improvement project locations and existing LWM features in reference to the approximate 100-year floodplain and estimated 100-year CMZ (assuming no human barriers to migration).

Channel Process

Channel processes are those actions that work to create and maintain channel forms and habitat. Because most processes are interdependent, improving one process alone may not result in the desired effect to the channel form and habitat. For projects that improve channel process, the linkages between processes and how those linkages are driven by factors inside and outside of the project area and the reach must be considered. Actions that are grouped together to potentially improve channel process will provide the most long-term habitat benefit. All actions considered should include an analysis of channel process to ensure the activity will work with the natural processes of the reach.

Poor recruitment and retention of LWM, especially logjams, is the single greatest human-related impact in the Gray Reach. With very few large trees available along the banks, local LWM recruitment potential is relatively low. Some large wood is transported down the river from upstream sources, but these occurrences are infrequent. The assessment area would benefit in the short term by the direct placement of LWM and in the long term by the establishment and maintenance of a broad, mature riparian zone from which LWM could be recruited in the future.

LWM structures include engineered logjams (ELJ) and individual logs. ELJs are constructed from multiple overlapping logs that act as a single large structure. For stability, the individual component logs of an ELJ are often tethered together or overlapping in such a way that the individual components act together as a single structure. ELJs can be constructed in the middle of a channel or along the bank and are intended to be long-lived features, capable of withstanding large floods (Figure 42).

There are several different types of LWM structures that can be used to influence channel processes in the Gray Reach.

- Apex jams – used to split flow, promote side channel/island formation, and possibly increase local stage to induce upstream side channel activation or avulsion. Apex jams are most appropriate at the head of islands or other split flow locations.
- Barb jams – temporarily stabilize an unnaturally unstable bank or to redirect flow to increase migration where appropriate; increase bank friction creating scour and habitat complexity; reduce instream velocity potentially increasing floodplain connection and side-channel activation; gravel sorting. Barb jams are most appropriately located along the bank on the outside of a bend as an individual structure or series of coordinated structures.
- Individual logs – provide cover; localized scour and gravel sorting. Individual logs are appropriate along any bank and emulate natural wind-fall or undermining due to bank erosion.

Figure 42. A 2011 aerial photo illustrating locations for potential LWM habitat improvement (logjams and individual cover logs). The intended purpose of each individually labeled logjam is described in the table below. Individual cover logs may be constructed from 1, 2 or 3 logs (typically) with the intent to provide cover and micro-scale velocity breaks, but typically do not significantly affect project-scale hydraulics. Cover log structures are show in locations where cover was observed to be lacking during 2012 field reconnaissance, but cover log structures are appropriate nearly anywhere a tree has the potential to fall into or deposit in the main channel or off-channel areas.

LWM #	Purpose of LWM
1 a, b, c	Stabilize bank; potentially split high flow into side channel
2 a, b	Split high flow
3 a, b	Define alcove outlet; create pool
4	Split flow; build mid-channel bar/island
5	Split flow into side channel
6	Split high flow; potentially form flood channel across bar
7	Split flow; build mid-channel bar/island
8	Split high flow and/or force flow right; build bar
9 a, b, c	Stabilize excessive bank erosion
10 a,b	Split high flow; potentially form a flood channel across the floodplain

A second geomorphic process, which has been altered by human influence, is channel migration. Road fill at the Cottonwood Flats Bridge (RM 17.65) restricts downstream migration by forcing flow to pass through a fixed opening. Similarly, two bank stabilization projects (RM 16.45 and 17.4) restrict downstream migration along the outside of meander bends. By altering the channel process of downstream channel migration, each of these sites has resulted in the potential for increased lateral channel migration and overbank flow due to potential backwater conditions. Two separate habitat improvement actions are potentially appropriate for these sites.

The first action includes removal of the migration barriers. This action assumes that the past 100+ years of downstream-dominated channel migration in the Stillwater reaches of the Entiat River (including the Gray Reach) is the dominant and most beneficial process with regards to generating fish habitat and maintaining a healthy ecosystem, or that the diversity of habitat resulting from downstream migration will provide the greatest habitat benefit to the reach as a whole. Encouraging downstream migration will promote new floodplain development, small and medium woody material recruitment (very little large wood currently available on the floodplain), and alcove formation where abandoned oxbow channels maintain a downstream connection to the mainstem.

The second action includes maintaining the migration barrier(s), thereby promoting lateral migration, vertical scour and overbank flow, providing potentially diverse (possibly more or less favorable) biological benefits.

Both actions are geomorphically appropriate for this reach but result in the creation of different forms. Actions increasing overbank flow in particular have the potential to improve side-channel formation and longevity. It is hypothesized in this report that prior to Euro-American settlement and logging in the Entiat Valley, a patchwork mosaic of mature old-growth timber persisted in the valley bottom of the Gray Reach. Each patch of old growth increased bank stability and the potential for logjam formation. The result was a relatively erosion-resistant area of the floodplain, which obstructed downstream migration, increased overbank flow, and possibly allowed for the formation of perennial or seasonal side channels. Stabilizing banks with ELJs and/or log barbs is an appropriate means by which this process can be emulated using habitat improvement actions in place of old-growth forest and natural logjams improving the potential for side channel and other off-channel habitat (Figure 43).

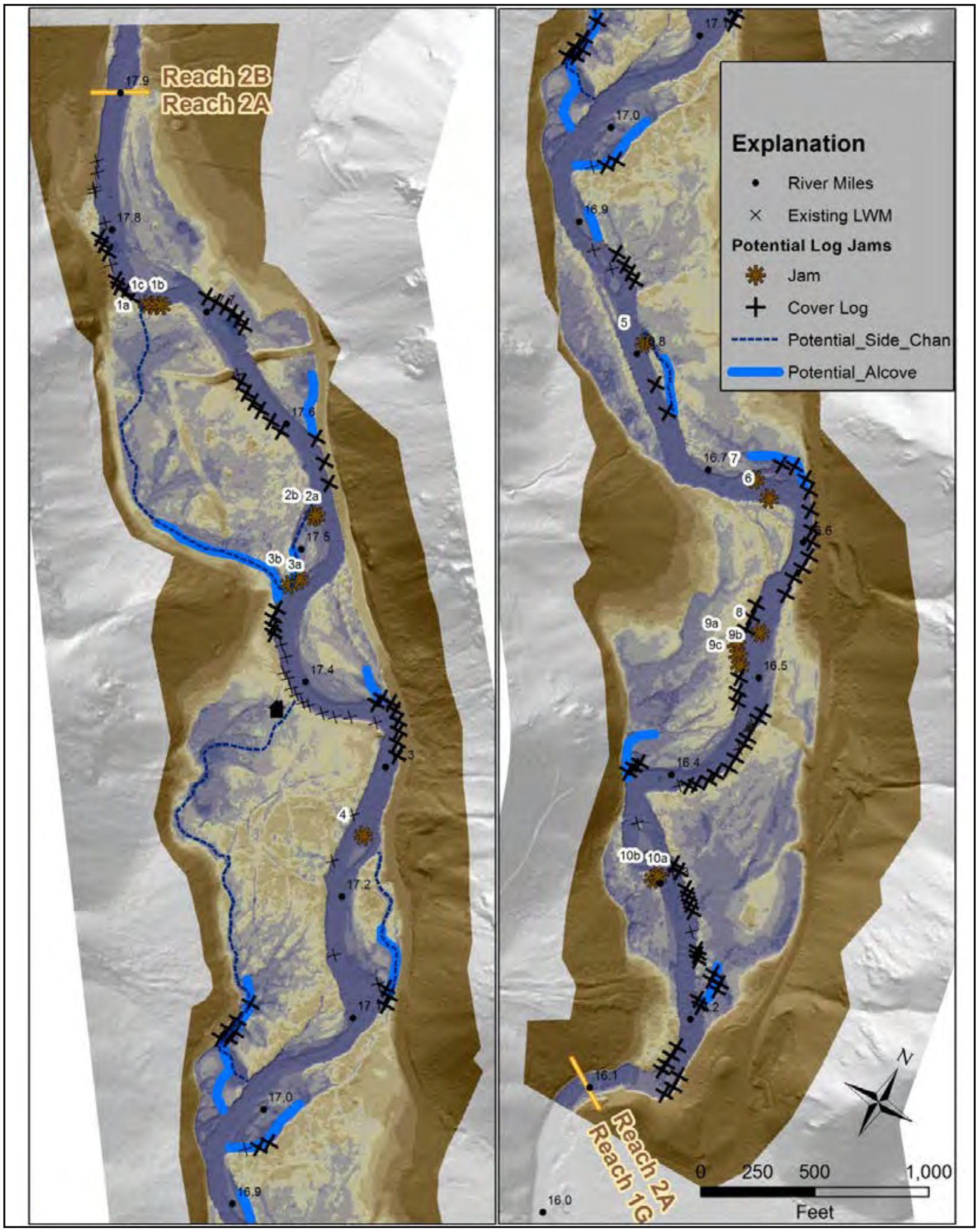

Figure 43. Areas of side channel and alcove improvement potential. Logjams may be required to stabilize banks and promote sufficient off-channel flow to maintain side channels and alcoves over the long term emulating old-growth forest bank conditions.

Riprap and road fill along the valley wall has a negligible effect on channel process, although increasing the roughness of these features is an action that may more closely emulate natural conditions, reduce local instream velocity, and create more diverse habitat in these areas.

Finally, actions pertaining to the protection and establishment of mature riparian vegetation and development of a broad riparian zone will facilitate long-term bank stability, provide overhead cover and shade to the reach, and in the long term will provide a source for LWM to the reach. Revegetation efforts, best management practices, and establishment of a broad riparian buffer within the accessible floodplain will provide the most direct benefit to improving riparian processes in the Gray Reach. An appropriate riparian buffer occupies the predicted CMZ or is 100 feet wide as measured from each bank, whichever is larger. In many locations, existing rates of downstream migration currently exceed the time period required to grow riparian vegetation large enough to function as a "key member" in a logjam or to effectively stabilize eroding banks. Therefore, it may be necessary to temporarily stabilize banks with engineered logjams or similar bioengineering-type structures to ensure riparian vegetation can become established and mature in the future.

Instream Habitat

Anthropogenic impacts to the Gray Reach have affected instream habitat as well. While the river is trending toward recovery, the lack of large trees available to the river for LWM will require many decades to recover fully. Smaller logs and boulder clusters currently provide structure, cover, and diversity, but larger logjams are rare and once formed tend to be short lived, lacking large key members. For example, a large logjam visible in 2011 aerial photos on the right bank near RM 16.9 was washed out after only one year. As discussed previously, LWM placement can improve channel process and acts as a stopgap until natural recovery can take over in several decades. Small-scale LWM structures (cover logs) are appropriate nearly anywhere a tree has the potential to fall into or be deposited on the channel or off channel areas. Cover logs generally provide micro-scale habitat and velocity breaks with minimal project-scale hydraulic effects.

Boulders and/or boulder clusters are also appropriate instream structures common throughout the Gray Reach. Boulder clusters represent instream channel obstructions providing localized scour, cover, and added complexity. Large boulder clusters may rack wood and/or produce hydraulic effects enabling split flow. Boulder clusters are appropriate anywhere within the Gray Reach as boulders have the potential to be delivered via rockfall or debris flows throughout the reach. Boulder clusters should be sited in locations where instream habitat complexity is not feasible or practical using LWM or in addition to LWM.

Finally, large rockfall and/or debris flows provided the greatest historical channel changes and complexity within the Gray Reach by blocking flow, inducing avulsions, creating side channels, capturing large volumes of LWM, forcing channel migration, and generally increasing diversity. Debris flow occurrences are rare and may be accompanied by collateral damage. Nevertheless, opportunities may be available to use multiple boulder and LWM structures to induce large-scale changes similar to debris flows in order to force channel change and promote habitat complexity. For example, boulder clusters and strategic LWM placement can be used near RM 17.7 to stabilize the left bank and create a flow constriction similar to that of a debris flow. The effect in this location would promote overbank flow and side channel development on the right bank meanwhile providing bank protection for the residential structures on the left bank.

Summary

The Gray Reach of the Entiat River has changed very little from historic conditions and is generally considered to function appropriately considering the reach type and valley characteristics. Human activities have nevertheless impacted the reach. At the reach-scale, the lack of mature old-growth timber and clearing of structure (i.e., LWM) from the channel has reduced overall channel complexity and may have impacted the channel's ability to create stable side channels. It is unclear how long ancient side channels remained active before filling in with sediment or otherwise being cut off from the mainstem. With more mature riparian vegetation (old-growth forest) and several large logjams influencing flow, it is very likely that side channels formed and persisted for years if not decades. Under the conditions of the past 100+ years (without old growth and large logjams), downstream channel migration has dominated channel process and effectively prevented side channels from persisting for the long term. The mainstem channel tends to migrate away from either the inlet or the outlet of the side channel after only a handful of years.

Although relatively unaffected by human influence, infrequent large-scale debris flows have also affected channel form and process historically forming alluvial fans on the valley bottom. The erosion-resistant fans create channel constrictions and force rapid channel migration, avulsion, and other complex responses resulting in diverse habitat.

At the local scale, human removal of LWM and other structure from the channel has reduced the amount of instream cover and local pool scour and hydraulic complexity. Diverse but immature riparian vegetation resulting from historic logging and land clearing practices has reduced the local LWM recruitment potential and provides limited overhead cover and shade to the reach. Also road fill, bridge abutments, and bank protection have altered the local rate of downstream channel migration.

Each of the human-related impacts to the Gray Reach can be addressed by habitat improvement actions. Most importantly, because so much of the Gray Reach is in reasonably good physical condition, any action proposed must first be evaluated to ensure the short-term disturbance associated with project implementation will not cause more harm than the long-term result of the completed project will create good. Secondly, stakeholders and project partners need to collectively decide if individual project goals should emulate an old-growth dominated valley bottom with side channels and relatively low rates of downstream migration, or if this scenario is infeasible or less beneficial than promoting existing trends of downstream channel migration, alcove formation, and increasing habitat along the banks provided by LWM and riparian cover. Both options appear to be geomorphically appropriate at the reach scale, but are considered mutually exclusive within the same project area. Finally, it is clear that the modern channel lacks instream structure and cover, particularly along the banks where it can be utilized by juvenile fish. The addition of small LWM structures, individual cover logs, and boulder clusters is a relatively simple habitat improvement action that is appropriate throughout the entire length of the Gray Reach.

Pertinent target conditions and potential habitat improvement actions have been summarized in Table 8.

Table 14. Summary of habitat improvement actions and their potential benefits to limiting factors.

Form	Target Condition	Habitat Improvement Action	Potential benefit to limiting factors (high, medium, low)
River bed and banks	River alluvium (gravel), hillslope colluvium, debris flow deposits, possible log and rock bank protection	Engineered logjams; log barbs, rock and log barbs	High to Medium
Sinuosity	1.2 to 1.4	N/A	N/A
Channel Morphology	Pool riffle	N/A	N/A
Large Pools (>20m^2 and 1m deep)	9 to 12 per mile	Engineered logjams, LWM and boulder clusters	Low
Floodplain connection	Frequent flooding	N/A	N/A
Off-channel habitat	7 alcoves or side channels per mile; 3,000 linear feet per mile	Logjams, log and rock barbs, enhance existing channels via excavation	High

Form	Target Condition	Habitat Improvement Action	Potential benefit to limiting factors (high, medium, low)
LWM	5 to 10 logjams per mile; 20 pieces per mile	Logjams, individual LWM structures for hydraulic diversity and cover	High (if many structures)
Riparian condition	Dense, mixed age trees and shrubs with wetlands; < 10 acres disturbed	Plant riparian vegetation; fencing; bank stabilization	Low (short term) High (long term)

Next Steps

This reach assessment is intended to be used as one tool among many to help guide river process rehabilitation and habitat improvement in the Gray Reach of the Entiat River. The actions outlined in this report represent appropriate actions for the river, but are not an exhaustive assessment of all possible actions that can be used to achieve habitat benefits.

- Step 1 – Identify physically appropriate actions (this assessment).
- Step 2 – Identify from those actions that are physically appropriate, which provide the greatest biological benefit (RTT and local partner review).
- Step 3 – Identify from those actions that are physically appropriate and of significant biological benefit which are socially acceptable and of benefit to individual landowners (sponsor support and project development).

The potential habitat actions outlined in this report can be grouped in any number of ways or places to form projects. In some instances, only one course of action may be appropriate, whereby project development is relatively simple. In other instances, multiple groupings may be appropriate requiring prioritization based on collaboration amongst project stakeholders. In either case, evaluating the proposed action(s) based on the findings of this assessment and the goals and objectives of the project stakeholders will ensure the most appropriate suite of actions is developed. Throughout the entire project development, design, and implementation process, this Reach Assessment can be used as a reference to verify whether or not project components are appropriate for the geomorphic character and trends prevalent in the Gray Reach of the Entiat River. Completed projects can be evaluated to determine the extent to which they helped achieve the identified target conditions. Shortcomings can be addressed through adaptive management of the project and in future project designs.

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Glossary

Term	Definition
ablation	Removal of material; in the case of snow, removal by either melting or vaporization.
action	Proposed protection and/or rehabilitation strategy to improve selected physical and ecological processes that may be limiting the productivity, abundance, spatial structure or diversity of the focal species. Examples include removing or modifying passage barriers to reconnect isolated habitat (i.e. tributaries), planting appropriate vegetation to reestablish or improve the riparian corridor along a stream that reconnects channel-floodplain processes, placement of large wood to improve habitat complexity, cover and increase biomass that reconnects isolated habitat units.
advective sediment transport	Transport of sediment onto the floodplain where deposition occurs adjacent the banks as a result of much lower water depths and much greater friction on the floodplain compared with in the active channel. Broad-crested levees often form along the banks of a river as a result of advective sediment transport.
alluvial fan	An outspread, gently sloping mass of alluvium deposited by a stream, esp. in an arid or semiarid region where a stream issues from a narrow canyon onto a plain or valley floor. Viewed from above, it has the shape of an open fan, the apex being at the valley mouth.
alluvium	A general term for detrital deposits made by streams on river beds, floodplains, and alluvial fans; esp. a deposit of silt or silty caly laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas and lakes.
anthropogenic	Caused by human activities.
bankfull	The volume of water in the river at which the physical banks of the channel are overtopped. For an incised river, bankfull may be a much greater recurrence interval flood than a non-incised river.
bedrock	The solid rock that underlies gravel, soil or other superficial material and is generally resistant to fluvial erosion over a span of several decades, but may erode over longer time periods.
channel-forming flow	Sometimes referred to as the effective flow, it is the flow that transports the largest cumulative volume of sediment over the long-term.
channel morphology	The physical dimension, shape, form, pattern, profile and structure of a stream channel.
channel planform	The two-dimensional longitundinal pattern of a river channel as viewed on the ground surface, aerial photograph or map.
control	A natural or human feature that restrains a streams ability to move laterally and/or vertically.
degradation	Transition from a higher to lower level or quality. A general lowering of the earth's surface by erosion or transportation in running waters. Also refers to the quality (or loss) of functional elements within an ecosystem.

Term	Definition
diversity	Genetic and phenotypic (life history traits, behavior, and morphology) variation within a population. Also refers to the relative abundance and connectivity of different types of physical conditions or habitat.
ecosystem	An ecologic system, composed of organisms and their environment. It is the result of interaction between biological, geochemical and geophysical systems.
floodplain	that portion of a river valley, adjacent to the channel, which is built of sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stages.
fluvial	Produced by the action of a river or stream. Also used to refer to something relating to or inhabiting a river or stream. Fish that migrate between rivers and streams are labeled “fluvial”.
fluvial process	A process related to the movement of flowing water that shape the surface of the earth through the erosion, transport, and deposition of sediment, soil particles, and organic debris.
geomorphic reach	An area containing the active channel and its floodplain bounded by vertical and/or lateral geologic controls, such as alluvial fans or bedrock outcrops, and frequently separated from other reaches by abrupt changes in channel slope and valley confinement. Within a geomorphic reach, similar fluvial processes govern channel planform and geometry resulting from streamflow and sediment transport.
geomorphology	The science that treats the general configuraion of the earth’s surface; specif. the study of the classification, description, nature, origin and development of landforms and their relationships to underlying structures, and the history of geologic changes as as recorded by these surface changes.
GIS	Geographical information system. An organized collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.
limiting factor	Any factor in the environment that limits a population from achieving complete viability with respect to any Viable Salmonid Population (VSP) parameter.
ordinary high water	The average high-water surface at any given point on a river generally defined by the presence of persistent terrestrial vegetation.
reach-based ecosystem indicators (REI)	Qualitative and/or quantifiable physical and/or biological indicators that are referenced to watershed characteristics and reach characteristics.
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
riparian area	An area adjacent to a stream, wetland, or other body of water that is transitional between terrestrial and aquatic ecosystems. Riparian areas usually have distinctive soils and vegetation community/composition resulting from interaction with the water body and adjacent soils.
riprap	Materials (typically large angular rocks) that are placed along a river bank to prevent or slow erosion.

Term	Definition
river mile (RM)	Miles measured in the upstream direction beginning from the mouth of a river or its confluence with the next downstream river.
side channel	A distinct channel with its own defined banks that is not part of the main channel, but appears to convey water perennially or seasonally/ephemerally. May also be referred to as a secondary channel.
spawning and rearing habitat	Stream reaches and the associated watershed areas that provide all habitat components necessary for adult spawning and juvenile rearing for a local salmonid population. Spawning and rearing habitat generally supports multiple year classes of juveniles of resident and migratory fish, and may also support subadults and adults from local populations.
subbasin	A subbasin represents the drainage area upslope of any point along a channel network (Montgomery and Bolton 2003). Downstream boundaries of subbasins are typically defined in this assessment at the location of a confluence between a tributary and mainstem channel. An example would be the Middle Fork John Day River subbasin.
subreach	Distinct areas comprised of the floodplain and off-channel and active-channel areas. They are delineated by lateral and vertical controls with respect to position and elevation based on the presence/absence of inner or outer riparian zones.
terrace	A relatively stable, planar surface formed when the river abandons its floodplain. It often parallels the river channel, but is high enough above the channel that it rarely, if ever, is covered by over-bank river water and sediment. The deposits underlying the terrace surface are primarily alluvial, either channel or overbank deposits, or both. Because a terrace represents a former floodplain, it may be used to interpret the history of the river.
tributary	A stream feeding, joining, or flowing into a larger stream or lake.
valley segment	An area of river within a watershed sometimes referred to as a subwatershed that is comprised of smaller geomorphic reaches. Within a valley segment, multiple floodplain types exist and may range between wide, highly complex floodplains with frequently accessed side channels to narrow and minimally complex floodplains with no side channels. Typical scales of a valley segment are on the order of a few to tens of miles in longitudinal length.
watershed	The area of land from which rainfall and/or snow melt drains into a stream or other water body. Watersheds are also sometimes referred to as drainage basins. Ridges of higher ground form the boundaries between watersheds. At these boundaries, rain falling on one side flows toward the low point of one watershed, while rain falling on the other side of the boundary flows toward the low point of a different watershed.

APPENDIX A

GRAY REACH, ENTIAT RIVER, REACH-BASED ECOSYSTEM INDICATORS (REI)

Appendix A

Reach-based Ecosystem Indicators (REI) Version 1.1

The Gray Reach assessment area includes RM 16.1 to RM 17.9. Rating of each indicator was completed based on data available from readily available sources and unpublished monitoring data provided by the Integrated Status and Trend Monitoring Program (ISEMP) (Burgoon 2012). The ranges of criteria presented here are not absolute and should be adjusted as more data become available.

GENERAL CHARACTERISTICS: REGIONAL SETTING

Ecoregion	**Bailey Classification**	Domain - Human Temperate Domain	Province – Cascade Mixed Forest-Coniferous Forest-Alpine Meadow Province	Section – Eastern Cascades Section
	Omernik Classification	Chelan Tephra Hills	N/A	N/A
	Physiography	Division – Pacific Mountain System	Province – Cascade-Sierra Mountains	Section – Northern Cascade Mountains
	Geology	Geologic District 218	Lithology – Calc-Alkaline Intrusive	N/A

GENERAL CHARACTERISTICS: DRAINAGE BASIN

Geomorphic Features	Basin Area	Basin Relief	Drainage Density	Hydrologic Unit Code	Stream Order	Land Ownership
	268,000 acres	700 feet - 9,249 feet	----	170200100104	4	84% public

GENERAL CHARACTERISTICS: VALLEY SEGMENT

Valley Characteristics	Valley Bottom Type	Valley Bottom Width	Valley Bottom Gradient	Valley Confinement	Channel Patterns
	Alluvial	900-300 feet	0.0018 foot/foot	Unconfined	Sinuous

GENERAL CHARACTERISTICS: CHANNEL SEGMENT

Channel Characteristics	Valley Type	Elevation	Dominant Channel Type	Bed form Type	Channel Gradient	Sinuosity
	Unconfined	1563 feet – 1548 feet	Rosgen C4	Riffle - Pool	0.0016 foot/foot	1.25

GENERAL CHARACTERISTICS: WATERSHED CONDITION

GENERAL INDICATORS: EFFECTIVE DRAINAGE NETWORK AND WATERSHED ROAD DENSITY

Criteria: The following criteria were developed by USFWS (1998).

General Characteristics	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Effective Drainage Network and Watershed Road Density	Increase in Drainage Network/ Road Density	Zero or minimum increases in active channel length correlated with human-caused disturbance and Road density less than 1 miles/miles^2	Low to moderate increase in active channel length correlated with human-caused disturbances and Road density 1 to 2.4 miles/miles^2	Greater than moderate increase in active channel length correlated with human- caused disturbances and Road density more than 2.4 miles/miles^2

Data:

Area	Square Miles	Road Density*
Entiat watershed	693	2.5 mi/mi^2

* Assuming all roads are "open"

Narrative:

Based on the available data for the entire watershed, road density in the Entiat River watershed is considered minimally beyond the threshold for unacceptable condition, but it is assumed that road density is less in the upper watershed affecting the Gray Reach therefore likely reducing the road density to an **At Risk** condition for this reach. A high road density may increase surface runoff and input of fine sediments to the river. Roads have also enabled clearing of timber and development of the floodplain to the detriment of habitat in the river.

GENERAL INDICATORS: DISTURBANCE REGIME

Criteria: The following criteria were modified from USFWS (1998).

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

Data: Fires, years, and acreage from the Tributary Assessment (Reclamation 2009: Appendix A and USFS 2007).

Year	Name	Area (acres)	Recovery (years)	Estimated Seral Stage (assuming total burn)	Percentage of Drainage Basin
1910	Signal/Tyee Peak	2,560	~100	Large tree condition	< 1%
1925	Mad River, Spectacle Butte, Borealis Ridge, Three Creeks, Lake Creek, Brennagan Creek, Gray Canyon, and Mud Creek	2,900	~85	Large tree condition	1%
1961	Tenas George Fire	3,750	~45	Small tree condition	1%
1962	Forest Mountain	520	~45	Small tree condition	< 1%
1966	Hornet Creek #143	1,210	~45	Small tree condition	< 1%
1970	Entiat/Slide Ridge, and Gold Ridge	65,300	~40	Small tree condition	24%
1976	Crum Canyon	9,000	~35	Small tree condition	3%
1988	Dinkelman Canyon	53,000	~20	Sapling/pole condition	20%
1994	Tyee	140,196	~15	Shrub/seedling –	52%

Year	Name	Area (acres)	Recovery (years)	Estimated Seral Stage (assuming total burn)	Percentage of Drainage Basin
				sapling/pole condition	
2001	Tommy Creek	640	~10	Shrub/seedling condition	< 1%
2006	Tinpan	9,247	<5	Grass/forb condition	3%

Data: No existing or historic dams have been identified in the Gray Reach, but several dams have influenced the Entiat River. Several dams were built on the Entiat River during the late 1800s and early 1900s for the purpose of splashing timber and generating hydroelectric power. Three prominent channel-spanning dams were built on the river, all of which completely blocked fish passage (Erickson 2004):

1. Mill dam, operated by T.J. Cannon, Cannon & Harris, and G.H. Gray & Son (RM 0.6) – 13 feet high; destroyed in the 1948 flood
2. Mill dam, operated by Kellogg Mill (RM 3.6) – 8 feet high; partially removed in 1932
3. Power diversion dam supplied water to the Entiat Power Plant maintained by Puget Sound Power and Light (RM 3.4) – 3 feet high; removed prior to 1945 (the exact date is unknown)

Narrative:
Fires are a natural component of the Entiat watershed disturbance regime, but with recent fire suppression, wildfires tend to burn more severely than in the past. Dams once completely blocked fish passage to the Entiat River which has a legacy effect on the system as anadromous fish populations recover. Currently there are no dams or other fish passage barriers located within the mainstem of the Entiat River up to Entiat Falls (a natural passage barrier) near RM 26. The river continues to adjust from the legacy of historic dams, and the resiliency of habitat to recover from additional disturbance is limited by this legacy. For these reasons, the disturbance regime in the lower Entiat River is **At Risk**.

GENERAL CHARACTERISTICS: FLOW/HYDROLOGY

GENERAL INDICATORS: STREAMFLOW

Criteria: The following criteria were developed by USFWS (1998).

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

Interpretation: Statistical Flood Recurrence Intervals and Discharge

Recurrence interval (years)	Discharge (cubic feet per second)
2	2510
10	4320
50	5730
100	6330

Narrative:

The magnitude, timing, duration and frequency of peak flows within the Gray Reach have not been significantly altered by human actions. Peak flow continues to be dominated by spring snowmelt, and baseflow influenced primarily by the amount and timing of late season snowpack. Several dams that once impounded water on the Entiat River have been removed. Irrigation withdrawals reduce the low-flow discharge volume in the Entiat River, but fish passage as a result of extreme low flows has not been identified as a limiting factor for this area. For these reason, streamflow in the Gray Reach of the Entiat River is considered **Adequate**.

Global climate change has the potential to change the streamflow characteristics of the Entiat River in the future, which is discussed in the body of the *Gray Reach Assessment: Entiat River* report.

GENERAL CHARACTERISTICS: WATER QUALITY

GENERAL INDICATOR: TEMPERATURE

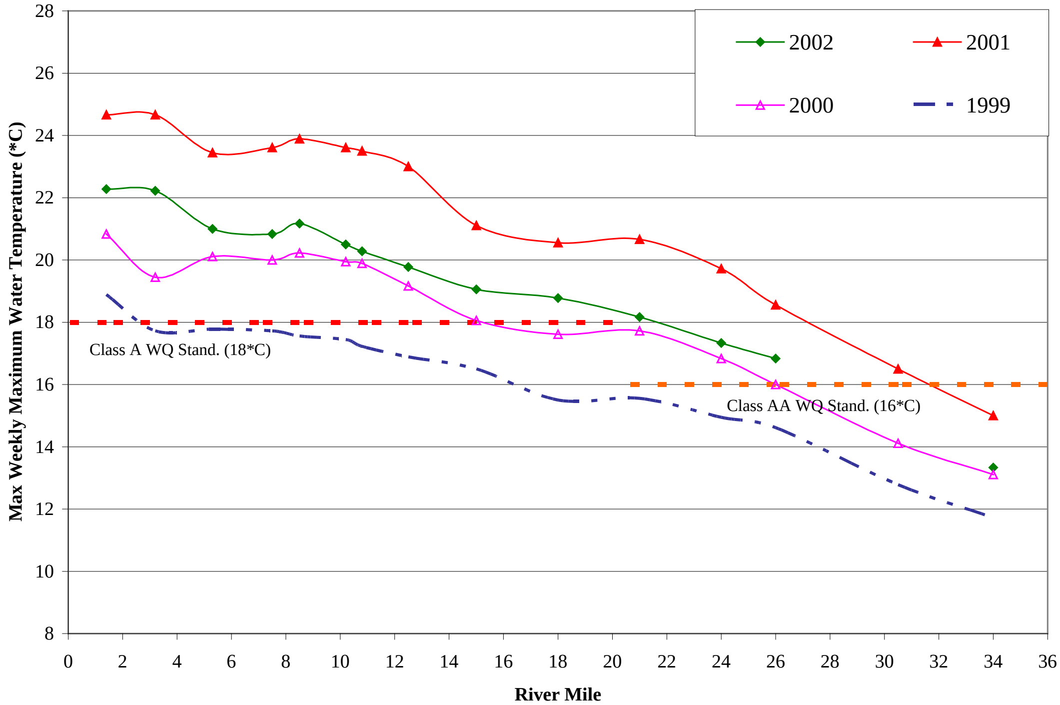
Criteria: The following criteria were developed by Hillman and Giorgi (2002), USFWS (1998).

General Characteristics	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Water Quality	Temperature	MWMT[a]/ MDMT[b]/ 7-DADMax[c]	Bull Trout: Incubation: 2-5°C Rearing: 4-10°C Spawning: 1-9°C Salmon and Steelhead: Spawning: June-Sept 15°C Sept-May 12°C Rearing: 15°C Migration: 15°C Adult holding: 15°C or 7-DADMax performance standards (WDOE): Salmon spawning 13°C Core summer salmonid habitat 16°C Salmonid spawning, rearing and migration 17.5°C Salmonid rearing and migration only 17.5°C	MWMT in reach during the following life history stages: Incubation: <2°C or >6°C Rearing: <4°C or >13-15°C Spawning: <4°C or >10°C Temperatures in areas used by adults during the local spawning migration sometimes exceed 15°C or 7-DADMax performance standards exceeded by ≤15%	MWMT in reach during the following life history stages: Incubation: <1°C or >6°C Rearing: >15°C Spawning: <4°C or >10°C Temperatures in areas used by adults during the local spawning migration regularly exceed 15°C or 7-DADMax performance standards exceeded by >15%

[a] MWMT = Maximum Weekly Maximum Temperature
[b] MDMT = Maximum Daily Maximum Temperature
[c] 7-DADMax = Seven Day Average Daily Maximum

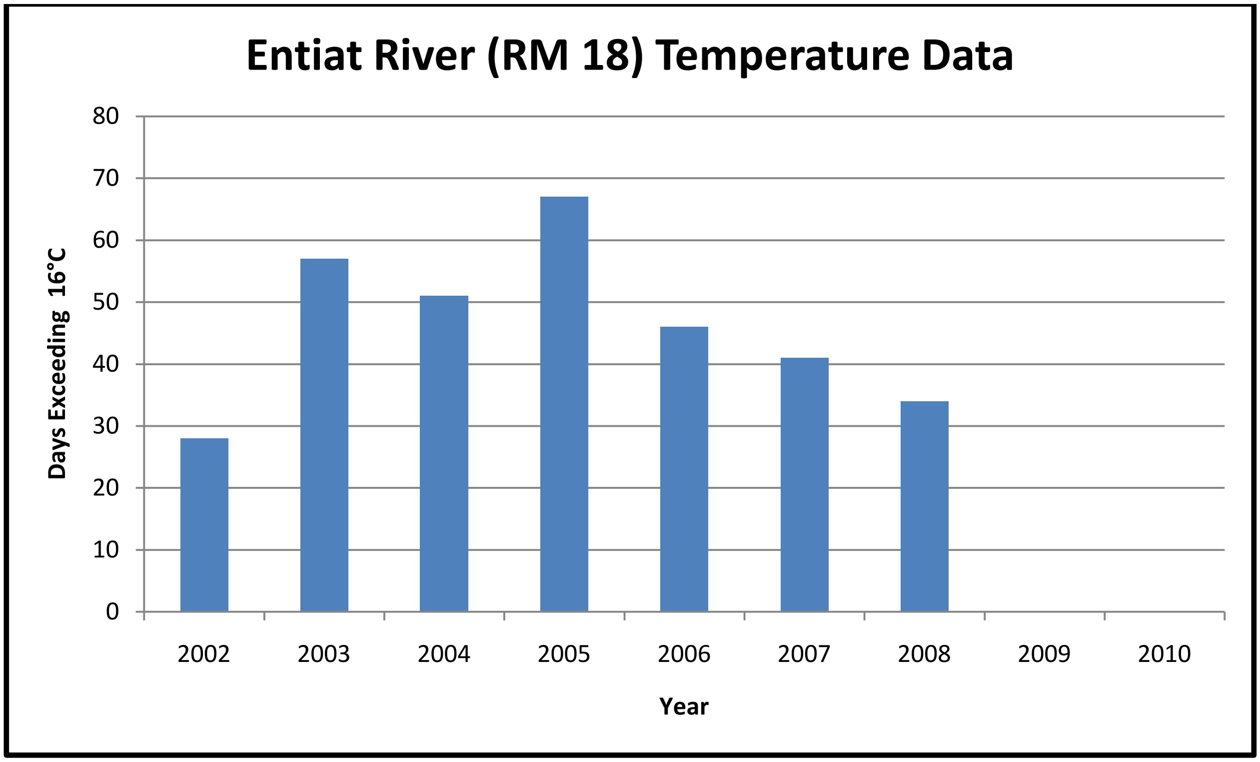
Data Source 1: Washington State Department of Ecology, 2003. Assessment of Water Temperatures of the Entiat River.

Graph 1: USFS Measured Max Weekly Maximum Temperatures (°C) for the Entiat River (Gray Reach is roughly between RM 16 and 18)



Data Source 2: Unpublished USFS Monitoring – Catherine Willard, Personal Communication

Graph 2: USFS Measured Days where the maximum instream temperature exceeded 16°C per year for the Entiat River (RM 18).



Narrative:

Weekly water temperatures for river miles 16-18 are shown to be above the Class A Water Quality Standard of 18 C for 2001 and 2002. See graph 1. Class A and Class AA standards are legacy terms from past reports written prior to revisions of Washington's water quality standards. Current standards for the Gray Reach include the designated use of Core Summer Salmonid Habitat, the temperature criterion for which is 7-DADMax – not to exceed 16°C. The current water quality standard has therefore been exceed 3 or 4 years reported, although water temperature has not been identified as a primary limiting factor in the Gray Reach of the Entiat River. Unpublished monitoring data received from the U.S. Forest Service (Willard 2013) include water temperature monitoring from 2002 through 2010 from RM 18. For this 9-year record, there has been an average of 36 days per year in which the Core Summer Salmonid Habitat maximum temperature has exceeded 16°C. Within the 9-year record, two years (2003 and 2005) exceed the 7-DADMax performance standards for Core Summer Salmonid Habitat.

Data Source 3: 2003 Stream Temperature Monitoring Report

Chart 1: Stream Temperature Monitoring Report

Table 1. Water Temperature Data Summary for the Entiat and Mad Rivers and Lake Chelan Tributaries (2003)

Location	Monitoring Period	# of Days Monitored	# Days exceeding 64.4°F	# Days Average 7-Day Max of 58°F was exceeded
Entiat River Locations				
RM 1.4, Keystone	1/1-12/31	365	60	N/A
RM 3.2, Fire Station	4/16-10/29	197	58	N/A
RM 5.8, Knapp Wham Bridge	5/18-10/29	165	61	N/A
RM 7.1, USFWS Hatchery				N/A
RM 8.5, Rinstead Canyon	5/18-10/30	166	55	N/A
RM 10.2, Cooper's Store	5/17-10/29	166	42	N/A
RM 10.8, Near Milepost 10	6/21-10/29	131	51	N/A
RM 12.5, below Medsker Canyon	Broken Cable	0		N/A
RM 15.0, Near Roundy Cr.	5/18-10/30	166	25	N/A
RM 18, near Stormy Cr. Gage	1/1-12/31	365	31	N/A
Total		**1721**	**383**	N/A

Narrative:

Table lists number of days where temperature exceeded 64.4 degrees F (last two lines list relevant data). RM 16-21 is referred to as a moderating zone. Temperature would be expected to increase here due to still water, however is moderated likely due to “a ground aquifer created by glacial till.” Overall Conclusions state that the Entiat River “has its own unique thermal regime” and recommendations are to repeat monitoring of locations in table 1 to asses effects of water temperature on Chinook salmon egg incubation. Given unconfirmed temperature moderation from groundwater in conjunction with moderate exceedance of temperature standards and anticipated increased warming resulting from predicted global climate change, temperature is considered to be At Risk within the Stormy Reach.

GENERAL INDICATORS: TURBIDITY

Criteria: The performance standard for this indicator is from Hillman and Giorgi (2002) and Washington State Department of Ecology.

General Characteristics	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Water Quality	Sediment/Turbidity	Turbidity	Performance Standard: Acute <70 NTU Chronic <50 NTU For streams that naturally exceed these standards: Turbidity should not exceed natural baseline levels at the 95% CL. <15% exceedance or Turbidity shall not exceed: 5 NTU over background when the background is 50 NTU or less; or a 10 percent increase in turbidity when the background turbidity is more than 50 NTU (WDOE – 173-201A-200)	15-50% exceedance.	>50% exceedance.

Data Source: Water Quality Index Scores by Constituent (1994 to 2010) - collected at Water Quality Monitoring Station 46A070 - Entiat River near Entiat, Washington, Lat. 47° 66′ 32″ Long. 120° 25′ 06″, Waterbody ID: WA-46-1010, River Mile 1.5, Washington State, Department of Ecology. http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=&tab=wqi&scrolly=387&wria=46&sta=46A070&docextension=.xls&docextension=.xls

Data Source: Washington State, Department of Ecology, Water Quality Index Scores by Constituent historical records from 1994 to 2010 show that the water quality index for turbidity was rated as “moderate” 4 out of 17 times (24 percent) and rated as “good” 13 out of 17 times (76 percent).

Summary: Data were collected at RM 1.5; no available data for Gray Reach. The Washington State, Department of Ecology historical records for Water Quality Index Scores by Constituent shows that the WQI for turbidity has been rated “good” for the last 10 consecutive years suggesting that the lower Entiat River reach is likely **Adequate** with regard to turbidity.

GENERAL INDICATORS: CHEMICAL CONTAMINATION/NUTRIENTS

Criteria:

General Characteristics	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Water Quality	Chemical Contamination/ Nutrients	Metals/ Pollutants, pH, DO, Nitrogen, Phosphorous	Low levels of chemical contamination from land use sources, no excessive nutrients, no CWA 303d designated reaches or Washington State Department of Ecology standards – 173-201A-200	Moderate levels of chemical contamination from land use sources, some excess nutrients, one CWA 303d designated reach.	High levels of chemical contamination from land use sources, high levels of excess nutrients, more than one CWA 303d designated reach.

Data Source: Water Quality Index Scores by Constituent (1994 to 2010) - collected at Water Quality Monitoring Station 46A070 - Entiat River near Entiat, Washington, Lat. 47° 66′ 32″ Long. 120° 25′ 06″, Waterbody ID: WA-46-1010, River Mile 1.5, Washington State, Department of Ecology. **http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=&tab=wqi&scrolly=387&wria=46&sta=46A070&docextension=.xls&docextension=.xls**

Data Source: Washington State, Department of Ecology, Water Quality Index Scores by Constituent historical records from 1994 to 2010 show that the water quality index for suspended solids was rated as “moderate” 8 out of 17 times (47 percent) and rated as “good” 9 out of 17 times (53 percent). The water quality index for pH was rated as “moderate” 11 out of 17 times (65 percent) and rated as “good” 6 out of 17 times (35 percent). The water quality index for total phosphorus was rated as “moderate” 2 out of 17 times (12 percent) and rated as “good” 15 out of 17 times (88 percent).

Summary: Data were collected at RM 1.5; no available data for Gray Reach. Washington State, Department of Ecology historical records for Water Quality Index Scores by Constituent suggests that the lower Entiat River reach may be **At Risk** in regard to suspended solids and pH.

GENERAL CHARACTERISTICS: HABITAT ACCESS

GENERAL INDICATOR: PHYSICAL BARRIERS

Criteria: The following criteria have been modified from USFWS (1998).

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

Narrative:

No mainstem barriers are present on the Entiat River below the Gray Reach; therefore, this indicator is considered to be **Adequate**.

GENERAL CHARACTERISTICS: HABITAT QUALITY

GENERAL INDICATOR: SUBSTRATE

Criteria: Performance standards for these criteria are from Hillman and Giorgi (2002).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Substrate	Dominant Substrate/ Fine Sediment	Gravels or small cobbles make-up >50% of the bed materials in spawning areas. Reach embeddedness in rearing areas <20%. <12% fines (<0.85mm) in spawning gravel or ≤12% surface fines of ≤6mm	Gravels or small cobbles make-up 30-50% of the bed materials in spawning areas. Reach embeddedness in rearing areas 20-30%. 12-17% fines (<0.85mm) in spawning gravel or 12-20% surface fines of ≤6mm	Gravels or small cobbles make-up <30% of the bed materials in spawning areas. Reach embeddedness in rearing areas >30%. >17% fines (<0.85mm) in spawning gravel or >20% surface fines of ≤6mm

Data: From ISEMP 2011 (unpublished). Provided by the ISEMP, Reclamation's Technical Service Center (TSC), and Reclamation Pacific Northwest (PN) Region. Downstream of constriction percentage refers to the average of pebble count statistics recorded below known channel constrictions in 2011 (ISEMP) and 2012 (Reclamation PN Region). Representative substrate samples were averaged from pebble counts taken at representative locations by ISEMP and Reclamation (TSC and PN Region) collected between 2008 and 2012.

Substrate (mm)	% (Representative Channel Section)	% (Downstream of Constriction)	% (Average)
Sands and Fines (.06-2.0)	29.09%	14.06%	24.79%
Fine Gravel (2-8)	5.18%	8.70%	6.19%
Medium Gravel (8-16)	11.22%	9.64%	10.77%
Coarse Gravel (16-64)	46.31%	52.76%	48.16%
Cobble (64-256)	8.20%	14.85%	10.10%
Boulder (256-4096)	0.00%	0.00%	0.00%
Total	100.00%	100.00%	100.00%

Data: ISEMP 2011 provided by James White. ISEMP data collection included the use of a McNeil Core Sampler, which enables fine sediment (sand-size and less) evaluation. For this reason, only ISEMP data were used to estimate representative overall grain size distribution.

Pebble Count Data:	Diameter (mm)
D15 (mm)	9.35
D35 (mm)	24.50
D50 (mm)	29.94
D84 (mm)	56.41
D95 (mm)	78.14
Dominant Substrate:	Coarse Gravel
Embeddedness:	Low to Moderate
Fine Sediment:	<12 %

Data: USFS 2012 Fine Sediment Monitoring: Entiat River and Mad River Annual Report prepared by Catherine Willard (March 2013).

Data collected from pool tail-outs and glides: Entiat RM 16 to 17.75: Average Percent Fines = 12.47% (Max 16.63%; Min 9.99%).

Interpretation:

River Miles:	**16.1 – 17.9**
Habitat Reach:	**Gray**
Dominant Substrate	Adequate
Embeddedness	Adequate
Fine Sediment	Adequate

Narrative:
Data suggest coarse sediment scoured at a constriction is generally deposited immediately downstream resulting in somewhat larger grain sizes in these locations. Representative sampling via pebble count and McNeil core samplers yielded similar results for grain sizes greater than 2mm all suggesting overall **Adequate** conditions within the entire reach assessment area.

GENERAL INDICATOR: LARGE WOODY MATERIAL (FREQUENCY)

Criteria: The following criteria were developed by USFWS (1998).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Large Woody Material (LWM)	Pieces Per Mile at Bankfull	>20 pieces/mile >12" diameter >35 ft length; and adequate sources of woody material available for both long- and short-term recruitment	Currently levels are being maintained at minimum levels desired for "adequate," but potential sources for long-term woody material recruitment is lacking to maintain these minimum values	Current levels are not at those desired values for "adequate", and potential sources of woody material for short- and/or long-term recruitment are lacking

Data: Individual log counts provided by ISEMP (2012).

Data Collection Year:	2010	2011
Large wood per mile (in-channel only):	21.5	11
Small (>20 feet long, 4-6 inches diameter)	25	3
Medium (> 20 feet long, 6-12 inches diameter)	28	3
Large (> 20 feet long, >12 inches diameter)	15	19
Total individual large and medium logs	43	22
Logjams (10 or more logs per jam)	1	0

Interpretation:

River Miles:	RM 16.1 – 18.9
Habitat Reach:	**Reach 2A**
Large Wood Per Mile	At Risk

Narrative:

Old growth vegetation capable of replenishing the missing stock of large key members has been largely removed from the watershed and will not recover for hundreds of years. Despite reasonable number of smaller woody debris, the low quantity of large key members capable of racking sufficient wood to form a logjam capable of influencing channel hydraulics has resulted in a condition that is considered **At Risk**.

GENERAL INDICATOR: POOLS (FREQUENCY)

Criteria: The following criteria were developed by USFWS (1998).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Pools	Pool Frequency and Quality Large Pools (in adult holding, juvenile rearing, and over-wintering reaches where streams are >3 m in wetted width at base flow)	Pool frequency: Channel width No. pools/mile 0-5 feet 39 5-10 feet 60 10-15 feet 48 15-20 feet 39 20-30 feet 23 30-35 feet 18 35-40 feet 10 40-65 feet 9 65-100 feet 4 Pools have good cover and cool water and only minor reduction of pool volume by fine sediment. Each reach has many large pools >1 m deep with good fish cover.	Pool frequency is similar to values in "functioning adequately", but pools have inadequate cover/temperature, and/or there has been a moderate reduction of pool volume by fine sediment. Reaches have few large pools (>1 m) present with good fish cover.	Pool frequency is considerably lower than values for "functioning adequately", also cover/temperature is inadequate, and there has been a major reduction of pool volume by fine sediment. Reaches have no deep pools (>1 m) with good fish cover.

Data: Survey info from ISEMP provided by James White; data represents all pools large, medium, and small. Data regarding large pools estimated from 2012 field surveys conducted for the purpose of this *Reach Assessment*. For the purpose of this report, large pools are defined as exceeding 20 square yards in area and 3 feet in depth at low flow (roughly 200 cfs).

River Miles:	**RM 16.1-17.9**
Average of all pools per mile	9.4
Average Riffles per mile	7.8
Ratio of Pools to Riffles:	1.2

Narrative:

Pools documented in 1930s at roughly 6 resting pools per mile (between Reaches 8 and 9 which includes 2A), with a good distribution of both large and small pools of which about 47% had adequate cover. Most pools occurring near the banks were "adequately protected by heavy bank growth and windfalls." (USBF 1935). Historic pools estimates are documented at 9-12 pools per mile in the body of the Gray Reach Assessment, suggesting that the removal of logjams and other in-stream structure had impacted pool habitat by 1935. The 2012 field observations revealed primarily very large pools associated with bend scour (averaging 2,766 yd^2 per pool). As discussed in the body of the Reach Assessment, greater numbers of channel obstructions and structure (LWM, logjams, etc) likely increased pool frequency but may have reduced their overall size. 2012 measurements revealed 9.4 large pools per mile and over 50% of the channel area designated as "pool habitat" all of which suggest the Gray Reach is in **Adequate Condition**.

GENERAL INDICATOR: OFF-CHANNEL HABITAT

Criteria: The following criteria have been modified from USFWS (1998).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Off-channel Habitat	Connectivity with Main Channel	Reach has many ponds, oxbows, backwaters, and other off-channel areas with cover, and side channels are low energy areas. No manmade barriers present along the mainstem that prevent access to off-channel areas.	Reach has some ponds, oxbows, backwaters, and other off-channel areas with cover, and side channels are generally high energy areas. Manmade barriers present that prevent access to off-channel habitat at some flows that are biologically significant.	Reach has few or no ponds, oxbows, backwaters, and other off-channel areas. Man-made barriers present that prevent access to off-channel habitat at multiple or all flows.

Data: Side Channels documented during field work for this assessment in 2011.

Side Channel Type	Flow Duration	Bank	Length (feet)	Location (RM)	Reach	Connection	Notes
Split flow	seasonal	R	395	17.5	2A	connected	Split flow across a point bar during high flow only. No LWM at apex of split.
Split flow	perennial	L	230	17.22	2A	connected	Split flow around a depositional mid-channel bar associated with a riffle. No structural control.
floodplain	flood	L	710	17.2	2A	disconnected	High flow floodplain channel disconnected by a private road prism.
Split flow	seasonal	R	230	16.87	2A	connected	Split flow around large single cottonwood log deposited on a riffle. Low flow passes to the left of the log, while high flow splits.
floodplain	seasonal	L	365	16.8	2A	connected	Side channel is seasonally connected; occupies historic main-stem channel.
Split flow	perennial	L	300	16.33	2A	connected	Split flow around a mid-channel bar beginning to accumulate LWM; primary channel is to the right.
floodplain	perennial	Both	variable	N/A	2A	connected	Several alcove channels are connected perennially, but only receive flushing flow during floods.

Narrative:

The reach assessment area is dominated by alcoves with a handful of seasonal and perennial side channels. As discussed in the body of the Reach Assessment, alcoves tend to dominate the off-channel habitat of the Gray Reach as a result of significant downstream channel migration. It is hypothesized that prior to clearing of old growth timber, the Gray Reach floodplain contained patches of old growth timber and the channel likely accumulate large logjams anchored by old-growth key members recruited by local bank erosion. Old growth timber along the banks coupled with large logjams likely stabilized banks resulting in historic (over 200 years ago) downstream migration rates significantly less than those observed in recent history. With less downstream migration and relatively stable banks, it is conceivable that side channels may have dominated off-channel habitat (as opposed to alcoves) in the distant past.

The Gray Reach is unconfined and generally very well connected with the floodplain. Large areas of off-channel habitat are available in the form of alcoves, ponds and several side channels (as outlined above) providing **Adequate** off-channel habitat conditions although potentially different than those prior to Euro-American settlement.

GENERAL INDICATOR: DYNAMICS – Floodplain Connectivity

Criteria: The following criteria have been modified from USFWS (1998).

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

Data: Disconnected subreach analysis by Reclamation (within the active 2-year floodplain).

River Miles:	Total
Levee Total (length)	0 feet
Push-up Levee (length)	0 feet
Disconnected Area	0 acres

Narrative:

The Gray Reach of the Entiat River is characterized by natural levees as much as 4-feet higher than the surrounding floodplain. No human levees or similar features were observed during field reconnaissance that would alter the natural character of the floodplain connection in this reach. One natural levee may have been augmented by human activities, but the levee is significantly smaller than other natural levees within the reach, and is not considered detrimental to natural floodplain connection. Therefore, the floodplain connectivity indicator is considered **Adequate.**

GENERAL INDICATOR: DYNAMICS – Bank Stability and Channel Migration

Criteria: The criteria for bank stability/channel migration were agreed upon by the assessment team as a relative condition of the specific indicator.

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

Data: Channel Migration between 1945 and 2011—Gray Reach Entiat River

RM	Bank	Lateral Rate (feet/year)	Downstream Rate (feet/year)	Bank Material
17.8	Right	1.93	3.11	Qa2, Qa3
17.45	Right	1.34	6.77	Qa2
17.1	Left	N/A	4.09	Qa3
17.0	Right	N/A	1.93	Qa3
16.63	Left	N/A	1.89	Qa3
16.37	Right	N/A	0.49	Qa3

Data: Human features analysis by Reclamation.

Human Features	Linear feet
Levee/Push-up Levee	0
Bank Protection (along valley wall; negligible impact)	970
Bank Protection (in middle of floodplain)	990

Narrative: Migration appears to follow a pattern whereby the river impinges against the valley wall, then flows relatively straight for roughly 1,000 - 1,500 ft, then crosses the valley impinging upon the opposite valley wall repeating the cycle. Downstream migration dominates when the channel flows along the valley wall, while lateral and downstream migration both occur in locations where the river crosses the valley. It is in these locations where the river is passing through the middle of the valley that avulsions (meander cut-offs) tend to occur. Avulsions do not appear to be related to large floods, rather to progressively tighter radius bends ultimately getting cut off (less than 100ft radius of curvature) (i.e.,: RM 17 after 1975). Meander cut-offs likely occur during floods, but not necessarily large floods.

Migration was measured by comparing historic aerial photos (1945-2011). Measurements were made in those areas where maximum change was observed. Average downstream and lateral rates were calculated and applied to the entire reach over a 25-year, 50-year, and 100-year period to estimate potential future channel migration. Each potential channel migration area was further modified based on bank materials (i.e.,: channel migration considered negligible in erosion-resistant debris flow deposits, against the valley wall, or against human bank protection). Channel migration areas were exaggerated to incorporate a factor of safety in areas where recent, new bar development was observed (RM 16.5).

As discussed in the body of the Reach Assessment, it is hypothesized that prior to clearing of old growth timber, the Gray Reach floodplain contained patches of old growth timber and the channel likely accumulate large logjams anchored by old-growth key members recruited by local bank erosion. Old growth timber along the banks coupled with large logjams likely stabilized banks resulting in historic (over 200 years ago) downstream migration rates significantly less than those observed in recent history.

Although channel migration rates have most likely increased as a result of human activities (clearing of old-growth forest), channel migration is generally unimpeded and rates are recovering along with riparian vegetation along a slow but steady pace. For these reasons, bank stability, and channel migration are considered **Adequate** although improved bank protection would further reduce the overall human impact within the reach.

GENERAL INDICATOR: DYNAMICS – Vertical Channel Stability

Criteria: The criteria for bank stability/channel migration were agreed upon by the assessment team as a relative condition of the specific indicator.

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

Data: GIS analysis and field notes.

River Miles:	RM 16.1 – 17.9
Average Mean Daily Flow (USGS gage 12452800 near Ardenvoir)	375 cubic feet per second
Representative Bankfull Width	90 feet
Representative Bankfull Width/Depth Ratio	15
Representative Active Floodplain Width is the 2-year inundation area	500 feet
Entrenchment Ratio (Floodprone width / bankfull width)	5.5
Rosgen Channel Type	C4

Narrative: The Gray Reach has shown no indication or trend toward reach-scale aggradation or incision. The channel dynamics are well balanced between erosion and deposition representative of a graded alluvial system. Human disturbance has not significantly increased or changed the reach-scale rate or amount of incision in the Gray Reach with the exception of local scour pool formation associated with bridges and bank protection. Based on this assessment, vertical channel stability is **Adequate**.

GENERAL CHARACTERISTICS: RIPARIAN VEGETATION

GENERAL INDICATOR: CONDITION – Structure

Criteria: The criteria for riparian vegetation structure were agreed upon by the assessment team as a “relative” indication to the functionality of the specific indicator.

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

Data: Seral stage analysis for 30-meter buffer zone by Reclamation from 2011 aerial photos and LiDAR interpretation.

Riparian Buffer (30-meter width):	Acres	Percentage
Grass or Pasture	1.81	7.99%
Small Trees and Shrubs	0.19	0.84%
Mature Trees	2.44	10.79%
No Vegetation	18.16	80.38%

Narrative:

Undisturbed riparian areas are assumed to consist of a species composition that is natural and appropriate for the Gray Reach of the Entiat River. It is hypothesized that much of the historic (>200 years old) floodplain consisted of patchwork old growth forest. No old growth forest remains today, and very little mature forest was measured (10.79% of the 2yr floodplain area). Although only 5.7% of the 10m buffer area is considered disturbed, the lack of mature riparian vegetation structure suggests the condition is **Unacceptable**.

GENERAL INDICATOR: CONDITION – Disturbance

Criteria: The criteria for riparian vegetation disturbance were agreed upon by the assessment team as a “relative” indication to the functionality of the specific indicator.

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

Data: Derived from vegetation density visible in 2011 aerial photography in locations within the 2-year floodplain as defined from hydraulic modeling developed primarily from 2006 LiDAR topography.

Disturbance within 30m buffer from bank	Acres	Percentage
Undisturbed area	20.55	90.93%
Disturbed area (bare earth, lawn, buildings, roads, etc)	2.05	9.07%

Narrative:

Undisturbed riparian areas are assumed to consist of a species composition that is natural and appropriate for the Gray Reach of the Entiat River. It is hypothesized that much of the historic (>200 years old) floodplain consisted of patchwork old growth forest. No old growth forest remains today, and very little mature forest was measured (10.79% of the 2yr floodplain area). Although only 9.07% of the 30m buffer area is considered disturbed (meaning bare ground, grass lawn, or infrastructure) the lack of mature riparian vegetation structure suggests a poor condition is largely the result of unacceptable structure (classified above) and therefore disturbance alone is considered to be **At Risk** (poor structure, but not bare earth).

GENERAL INDICATOR: CONDITION – Canopy Cover

Criteria: The criteria for riparian vegetation canopy cover were agreed upon by the assessment team as a “relative” indication to the functionality of the specific indicator.

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

Data: ISEMP monitoring data provided by James White included within the 10m buffer area.

Cover Range	Percentage
0-25% Cover:	27.27%
26-50% Cover:	11.36%
51-75% Cover:	13.64%
76-100% Cover:	47.73%

Data: Seral stage analysis for 10 meter buffer zone by Reclamation.

Seral Stage (10-meter width):	Acres	Percentage
Grass or Pasture	0.29	4.41%
Small Trees and Shrubs	5.91	89.33%
Mature Trees	0.38	5.77%
No Vegetation	0.03	0.49%

Narrative:

Greater than 70 percent of riparian buffer zone (10 meter width along both banks) is in the “Small Trees and Shrubs” condition. The 10-meter buffer zone is used as a surrogate to evaluate the condition of canopy cover. Furthermore, cover measurements indicate that the area of 50 percent cover or better represents better than an average of about 60 percent of the 10-meter buffer area. Based on the seral stage of vegetation within the 10-meter buffer (poor) and riparian cover measurements (adequate), the canopy cover condition is **At Risk**.

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