RECLAMATION
Managing Water in the West

Lower Entiat Reach Assessment

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

January 2012

U.S. Department of the Interior

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Front photograph: Entiat River, Washington.

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List of Acronyms

AER	Alternatives Evaluation Report
cfs	cubic feet per second
ELJ	engineered logjams
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
GIS	Geographic Information System
LiDAR	Light detecting and ranging
LWD	Large woody debris
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RM	River mile
RPA	Reasonable and prudent alternative
Tributary Assessment	*Entiat Tributary Assessment*

INTRODUCTION

The Bureau of Reclamation (Reclamation) and Bonneville Power Administration contribute to the implementation of salmonid habitat improvement projects in the Upper Columbia subbasin to help meet commitments contained in the 2010 Supplemental Federal Columbia River Power System (FCRPS) Biological Opinion (NOAA Fisheries Service 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 first 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 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 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.

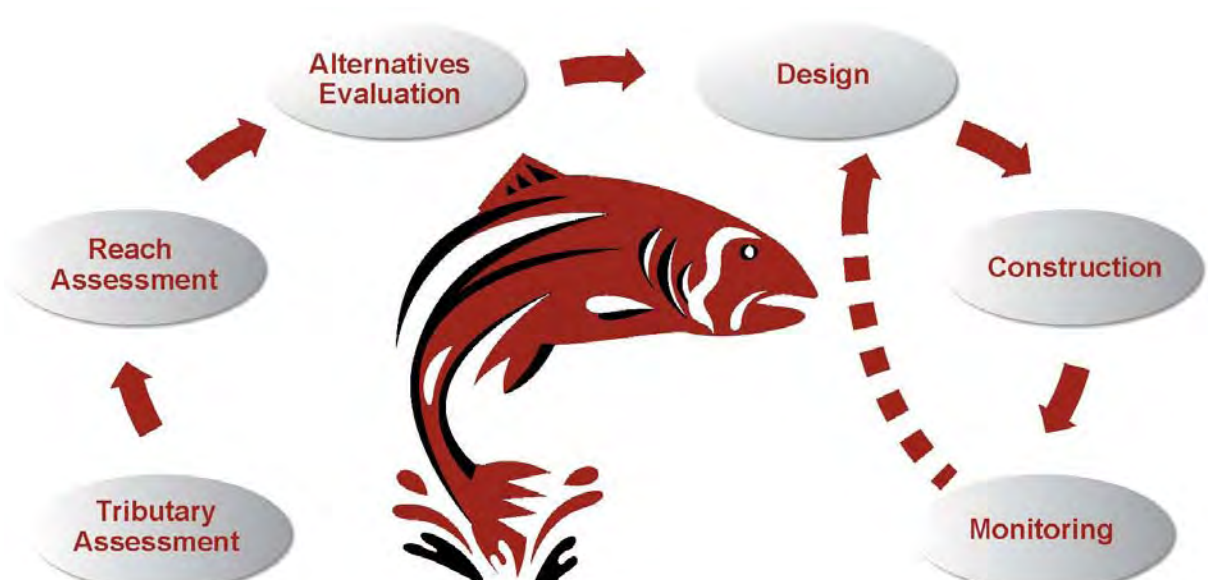

Figure 1. Flow chart illustrating steps in the approach to habitat improvement.

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 the purpose of 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.

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* (*Tributary Assessment*) (Reclamation 2009a). Information in the *Reach Asses*sment 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 broken 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 1 included the lower roughly 16.1 miles of the Entiat River downstream of a prominent slope change originating at the terminus of an ancient glacial moraine called the Potato Moraine, named after the nearby Potato Creek tributary (Figure 2).

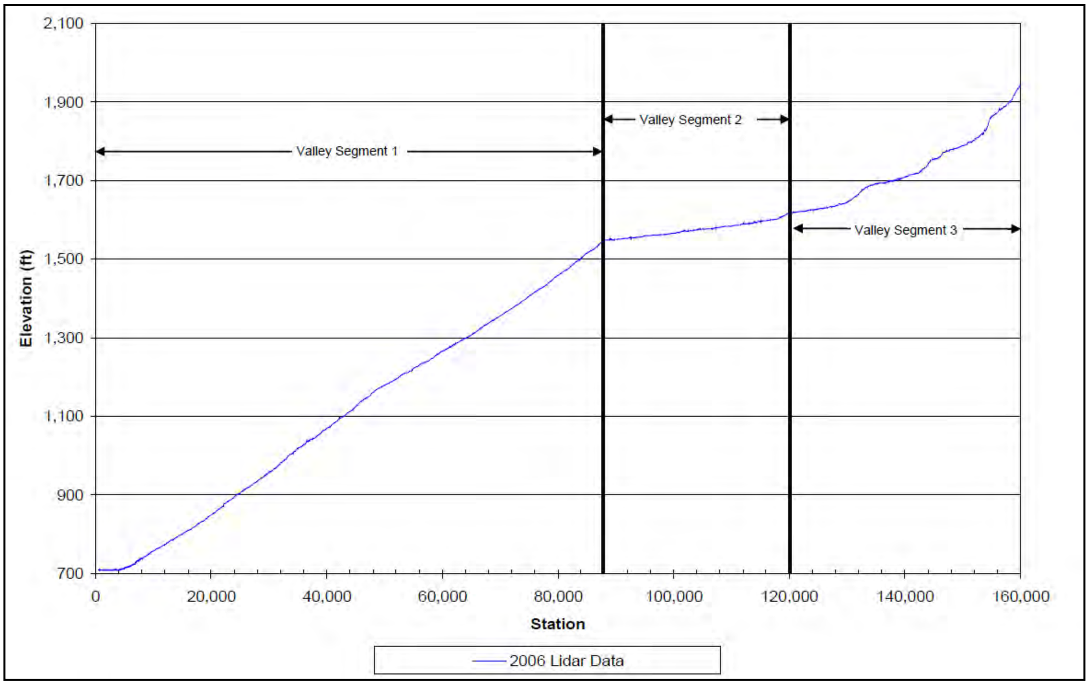

Figure 2. Longitudinal profile of Entiat River channel elevation (RM 0.1 to 27). Elevations derived from 2006 LiDAR high-resolution topography. Note the prominent slope break between Valley Segment 1 and 2 at the location of the Potato Moraine.

Within Valley Segment 1, the *Tributary Assessment* further delineated seven separate geomorphic reaches (1A through 1G) based on fine-scale changes in slope and geologic controls. This *Reach Assessment* focuses on the lower five reaches within Valley Segment 1, designated as 1A, 1B, 1C, 1D and 1E, collectively referred to as the assessment area, which was identified in the *Tributary Assessment* as a high-priority area for habitat improvement. Additionally, the Detailed Implementation Plan prepared by Chelan County Conservation District identified the lower Entiat River (RM 0.0 to 16.2) as the highest priority as a result of human impacts (CCCD 2006).

Working upstream from the mouth of the Entiat River, Reach 1A is defined by the backwater from Lake Entiat on the Columbia River. It was not prioritized as part of the *Tributary Assessment*, but, as a result of the backwater conditions, it is characterized by very low velocity flow with multiple off-channel habitat features representing high habitat potential, especially for juvenile rearing, a major limiting factor in the lower Entiat River. Reaches 1B, 1C, and 1E were all described in the *Tributary Assessment* as moderately confined, with moderate channel complexity representing the best opportunity within Valley Segment 1 for habitat improvement. Reach 1D was described in the *Tributary Assessment* as confined, with low channel complexity. Because of the many similarities between Reach 1D and the other three reaches, Reach 1D was classified as a temporary control reach for monitoring efforts through 2014. This designation may limit the amount of project work in Reach 1D through 2014 so that conditions in the control reach will remain relatively unchanged for monitoring purposes. If a high-priority project becomes available in Reach 1D prior to 2014, it may still be implemented; however, more intensive projects in this reach will likely be planned for implementation after 2014. Until then, priority will likely be given to projects in the other reaches. All of the reaches (1D, 1B, 1C, and 1E) have been included in this single *Reach Assessment* for continuity.

Although the entire lower Entiat River was identified as a priority for habitat improvement, the various strategies by which habitat improvement can be accomplished may or may not be appropriate for specific reaches. 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: None of the reaches within the assessment area were identified as a high priority for protection in the *Tributary Assessment*.

2. Water Quality and Quantity: The need for warmer/deeper water in the winter was identified in the *Tributary Assessment* for all reaches in the lower Entiat River. Water quantity was not identified as a limiting factor in the assessment area.

3. Habitat connectivity: Connection to the floodplain and off-channel habitat was identified in the *Tributary Assessment* for the lower Entiat River, although it will be shown in this report that the lack of habitat connectivity is largely a natural constraint within the assessment area.

4. Channel process: Although not identified at the tributary scale, reestablishing natural channel process is necessary in order to improve and maintain habitat over the long term. Changes and impacts to channel process will be addressed in the Existing Conditions section of this report.

5. Instream habitat: The *Tributary Assessment* identified the need for more habitat complexity in the lower Entiat River, including pools, large woody debris (LWD), and spawning gravel.

Reach Assessment Goals

There are two primary goals for this *Reach Assessment*:

1. Document past, 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 the 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. The primary use of the *Reach Assessment* should be to guide habitat improvement actions toward those options that are most geomorphically appropriate for a given reach, while providing a means to begin prioritizing a variety of actions based on potential benefit to habitat. This document should not be used exclusively as the basis for habitat design. 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 lower 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 high- 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 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 lower Entiat River. Species such as steelhead, Chinook salmon, and other key species evolved with the physical environment of the lower Entiat River over thousands of years. Efforts to reestablish natural and appropriate physical conditions represent an improvement to habitat 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 lower Entiat River from the U.S. Fish and Wildlife Service hatchery at RM 7.0 downstream to the mouth of the river at RM 0.0, including reaches 1A to 1E (Figure 4).

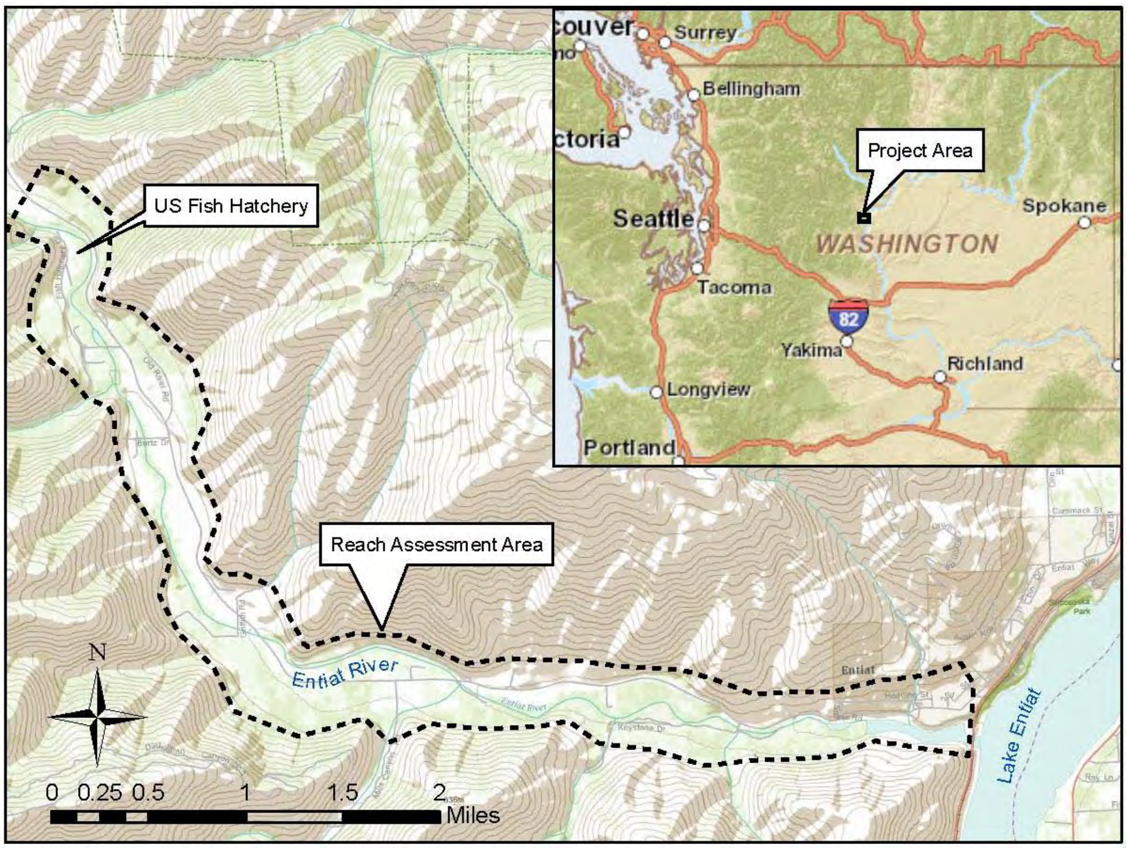

Figure 3. Lower Entiat Reach assessment area and vicinity map. The Entiat River flows into Lake Entiat which is the portion of the Columbia River impounded upstream of Rocky Reach Dam.

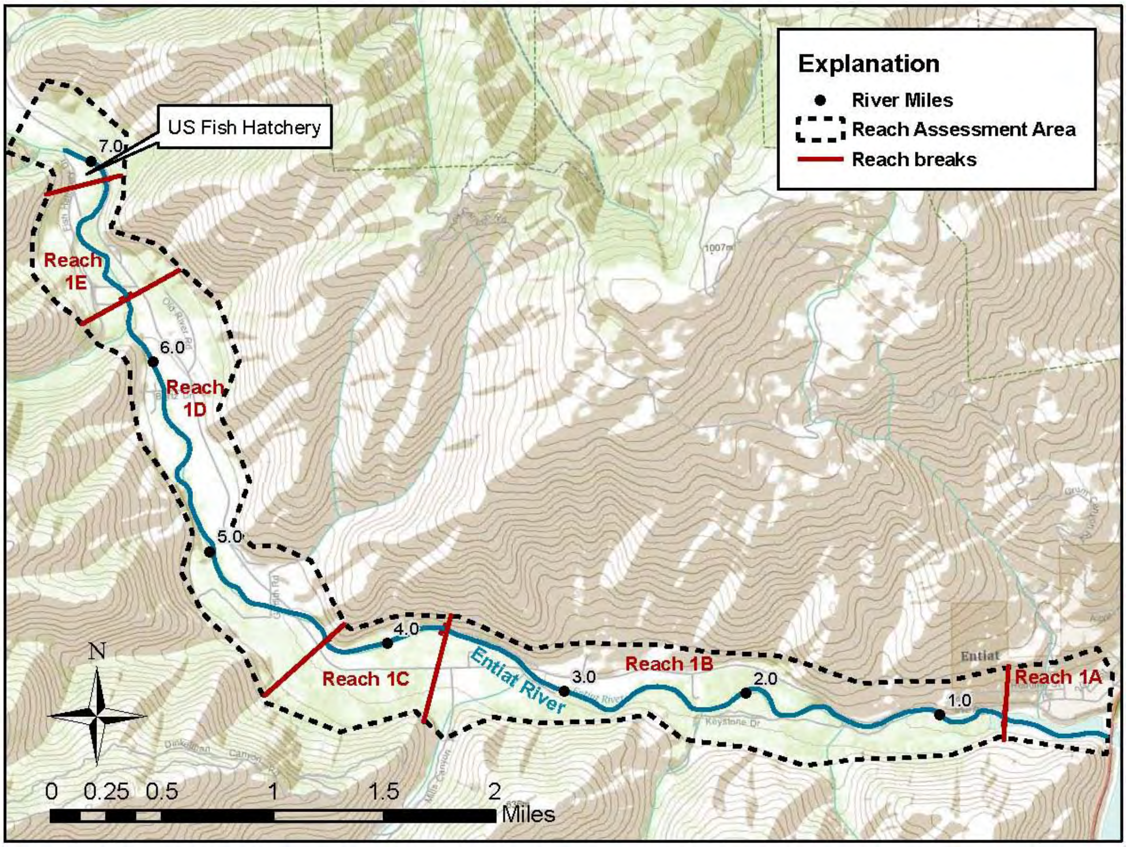

Figure 4. Topographic view, showing the reach breaks and the hatchery location by River Mile.

Limiting Factors

Limiting factors are defined as those conditions or circumstances which 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 lower Entiat River which are summarized here in the order of most limiting factor to least limiting factor based on those reports:

1. Lack of overwintering juvenile rearing habitat, especially pools with cover (Andonaegui 1999; CCCD 2004; Erickson 2004; Nelle et al. 2009; Reclamation 2009a)
2. Lack of instream complexity, especially LWD and pools (CCCD 1998; Andonaegui 1999; Reclamation 2009a)
3. Loss of well-established riparian vegetation/buffer and lack of cover (Andonaegui 1999; Reclamation 2009a)

4. Off-channel rearing for spring Chinook salmon (Reclamation 2009a)
5. Lack of adult holding habitat (Nelle et al. 2009)
6. Lack of steelhead spawning habitat (Nelle et al. 2009; Reclamation 2009a)
7. Summer and winter water temperature for spring Chinook salmon (Nelle et al. 2009)

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 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 assessment will show that while humans have impacted the lower Entiat River, the impact has largely resulted in a loss of instream habitat complexity without significant alteration to channel geometry, channel pattern, migration rates, pools, and, to a lesser degree, floodplain interaction. The majority of the existing limiting factors present on the river today were also very likely major limiting factors prior to Euro-American settlement.

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 Entiat watershed is located in the Northern Cascades physiographic province which is characterized by folded, metamorphosed sedimentary rocks intruded by granites forming ridges and peaks, some in excess of 8,000 feet high. Several of the larger peaks are glaciated. 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. These faults are considered to be inactive (Lasmanis 1991).

Climate in the Entiat basin is significantly influenced by orographic uplift associated with the 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

Hydrology on the Entiat River is heavily influenced by the accumulation and subsequent ablation of snow in the upper watershed. 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. The majority of the lower Entiat River is considered a gaining reach, especially within Reach 1D (CCCD 2004), fed by groundwater contributing to the base flow which rarely falls below 200 cubic feet per second (cfs). Peak discharge is dominated by surface runoff, especially rain-on-snow events. Water quality in the lower Entiat River has not been identified as a limiting factor and no fish passage barriers are present in the mainstem.

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. 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). An estimated average of 100 steelhead per year spawn in the lower Entiat River assessment area (Nelle 2005). Chinook salmon generally spawn between RM 16 and 28 (Hamstreet 2006) and the fry emerge generally between March and early May. The juvenile fish rear in the Entiat River until the following spring when they begin their downstream migration to the ocean (USFS 2007). Both Entiat River populations of steelhead and spring Chinook salmon are not currently viable and have a high risk of extinction (CBFWA 2011). No spring Chinook salmon redds have been observed within the Reach Assessment area (Hamstreet 2006).

Valley Segment scale

The bed and banks of the lower Entiat River are armored with coarse glacial outwash and do not significantly contribute to the supply of sediment in the river. Sediment supply to the river is derived primarily from upstream sources and episodic mass wasting processes (Reclamation 2009a). In general, the disturbance frequency in the river is considered infrequent. Of the sediment that reaches the lower Entiat valley segment, most is transported through to the mouth of the river primarily due to the steep gradient and confined valley morphology. As a result, the lower Entiat valley segment is characterized by a supply-limited sediment transport regime.

Historical Timeline

Prior to Euro-American entry to the area in the late 1800s, Native American tribes utilized the mouth of the Entiat River as a camp site. After Euro-American settlement of the area, recorded historical events and activities occurring in the lower Entiat valley impacted the river form and process. Some of the more significant historical events in the lower Entiat valley are summarized in Table 1. A more detailed historical timeline of the area is available in the Appendix A of the *Tributary Assessment* (Reclamation 2009a).

Table 1. Significant historical events impacting the lower Entiat River.

Year or Period	Significant Historical Event
1887	First Euro-American settlers arrive in lower Entiat valley
1887	First orchard irrigation ditch built – Hanan-Detwiler
1888 - 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)
1902	Entiat valley bottom cleared of timber up to RM 4.7.
1909-1950	Harris electric power plant operates on left bank at RM 1.5
1913 - 1932	Kellogg Mill Dam at RM 3.6; 8-foot-high dam blocked fish (Figure 6)
1948	Flood of record is roughly 10,800 cfs in lower Entiat River
1956	Rocky Reach Dam construction commenced
1961	Rocky Reach Reservoir filled (Lake Entiat)
1971	Last documented major removal of log jams from the river
1972	Flood measuring roughly 6,430 cfs at Ardenvoir
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 (Reclamation 2009a).

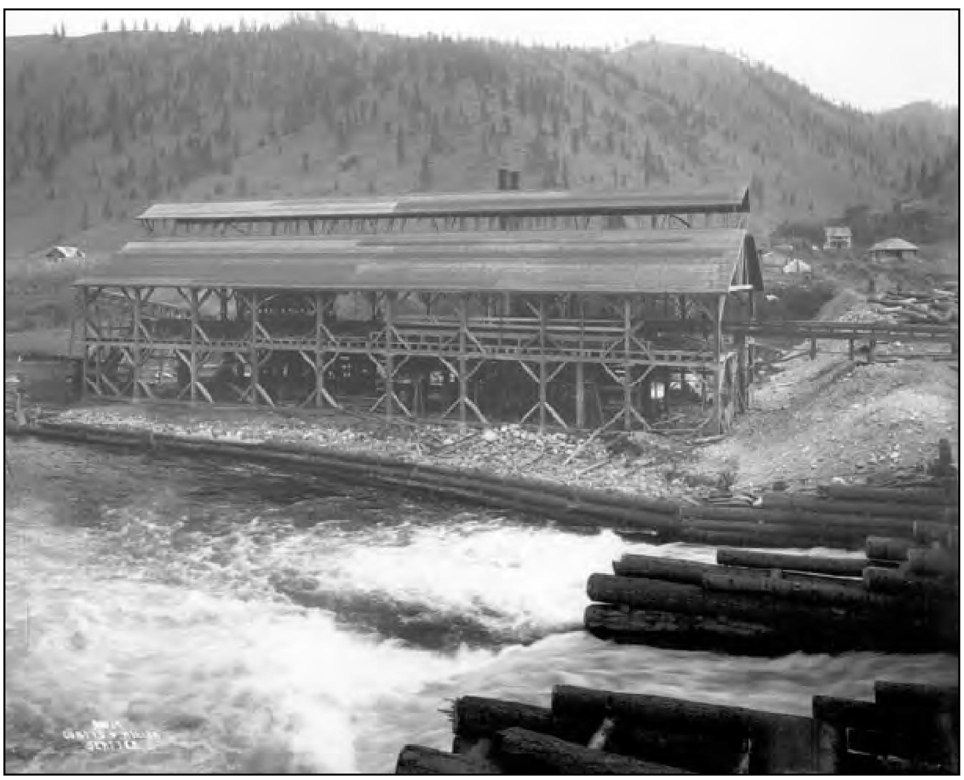

Figure 6. Kellogg Mill and dam circa 1914 near RM 3.6 (Published in Erickson 2004. Courtesy of Washington State Historical Society, Asahel Curtis Collection, #300117).

HISTORICAL CONDITIONS

For this report, the historical conditions are defined as the unaltered or natural conditions representative of the assessment area prior to large-scale human influences (i.e., Euro-American settlement). Although it is not the goal of habitat improvement to restore those exact conditions which existed in the past, it is those natural historical conditions in which the species of concern evolved and will likely thrive in the future. 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. To reduce redundancy, conditions will be described collectively for all five reaches within the assessment area because the majority of their reach characteristics are similar. Characteristics specific to a given reach or area will be identified as such.

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. In some instances, small-scale forms greatly influence the large-scale character of the river, but that has not been the case with the lower Entiat River which has been influenced most significantly by large-scale valley and channel forms (Table 2).

Table 2. Historical conditions and forms of the Entiat River.

Form	Historical Condition	Process(es) Creating/Maintaining Form
Large Pools	Roughly 3.5 to 4.0 per mile	Bedrock, very large boulder clusters, or very large logjams would obstruct flow and create flow convergence; sharp bends against bedrock would create strong helical flow
Sinuosity	Roughly 1.1	Bedrock and glacial outwash valley controls combined with a steep gradient and erosion-resistant banks
LWD	Few logjams per mile (estimate less than 10)	LWD recruited largely from upstream and/or tributaries; other than jams forming at the heads of islands, very large key members were needed to be stable; accumulation of LWD would have been low as a result of the high transport conditions and incised channel configuration enabling entrainment of all but the largest pieces of LWD or those that were pinned to the bank
Channel geometry	Incised 1 to 20 feet	Thousands of years of sediment transport without subsequent deposition; where the channel abutted an old terrace (Qa1), the banks could be as high as 20 feet such as the right bank near RM 3.1
River bed and banks	Armored with large boulders	Thousands of years of sediment transport without subsequent deposition winnowed away most of the mobile fraction of the glacial valley fill, leaving behind a bed of very coarse boulders. The hydrologic regime that formed the existing channel was significantly higher flow and energy (post-Pleistocene) resulting in today's underfit stream.
Off-channel habitat	Estimated average of 4.3 primarily small side channels per river mile representing roughly 2,500 feet of side channel per river mile.	Side channels formed in the lower Entiat River in the few places where lateral channel migration and point bar deposition occurred. Overflow channels formed first across the alluvium on the inside of a bend, evolving into a side channel. Long side channels were rare because channel migration and low-lying floodplain area were rare. Once created, side channels were maintained by LWD at the head of the side channel metering flow into the side channel. Most side channels flowed seasonally (dry at low flow).
Floodplain connection	Limited to narrow active floodplain between terraces	Thousands of years of channel incision resulted in a narrow active floodplain; floodplain constrictions resulted in negligible backwater conditions and did not significantly influence floodplain connection
Riparian condition	Dense mature trees; riparian area was at least 100 feet wide	The lack of active channel migration enabled the development of mature to decadent vegetation throughout the majority of the riparian area.

Historical Valley and Channel Forms

The lower Entiat valley was shaped by high-volume glacial discharge during the Pleistocene Epoch between roughly 2.5 million and 10,000 years ago. Based on the size class of glacial outwash material deposited in the valley bottom, peak discharge during the Pleistocene greatly exceeded modern peak discharge. High volumes of discharge and sediment from glaciers combined to fill the lower Entiat valley with large boulders and cobbles mixed with gravel and fine sediment. Along the valley margins, accumulated debris flow deposits built alluvial fans which interbedded with the glacial outwash, especially at the mouths of non-glaciated tributary streams.

Following the high-sediment, high-discharge Pleistocene Epoch punctuated by multiple glacial periods, the climate in the Entiat valley became warmer and drier. Glaciers all but disappeared and both discharge and sediment yield decreased significantly. The Entiat River became an underfit river, defined as a relatively small stream flowing through a valley formed by and over sediment deposited from a much larger river. The lower Entiat valley segment became supply-limited (i.e., dominated by sediment transport as opposed to deposition) as a result of its new hydrologic and sediment regimes and due to the relatively steep gradient downstream of the terminal glacial moraine near Potato Creek. Since the end of the ice age, roughly 10,000 years ago, the river has been very slowly downcutting with little to no fluvial aggradation or channel migration, resulting in an incised river bordered largely by hydrologically disconnected terraces (Figure 7). Radio carbon dating of terrace surfaces shows their ages increase with height, suggesting that the river has continually incised without intervening years of aggradation (Reclamation 2009a). The lower Entiat River channel has become naturally highly confined by these coarse-grained, erosion-resistant terraces.

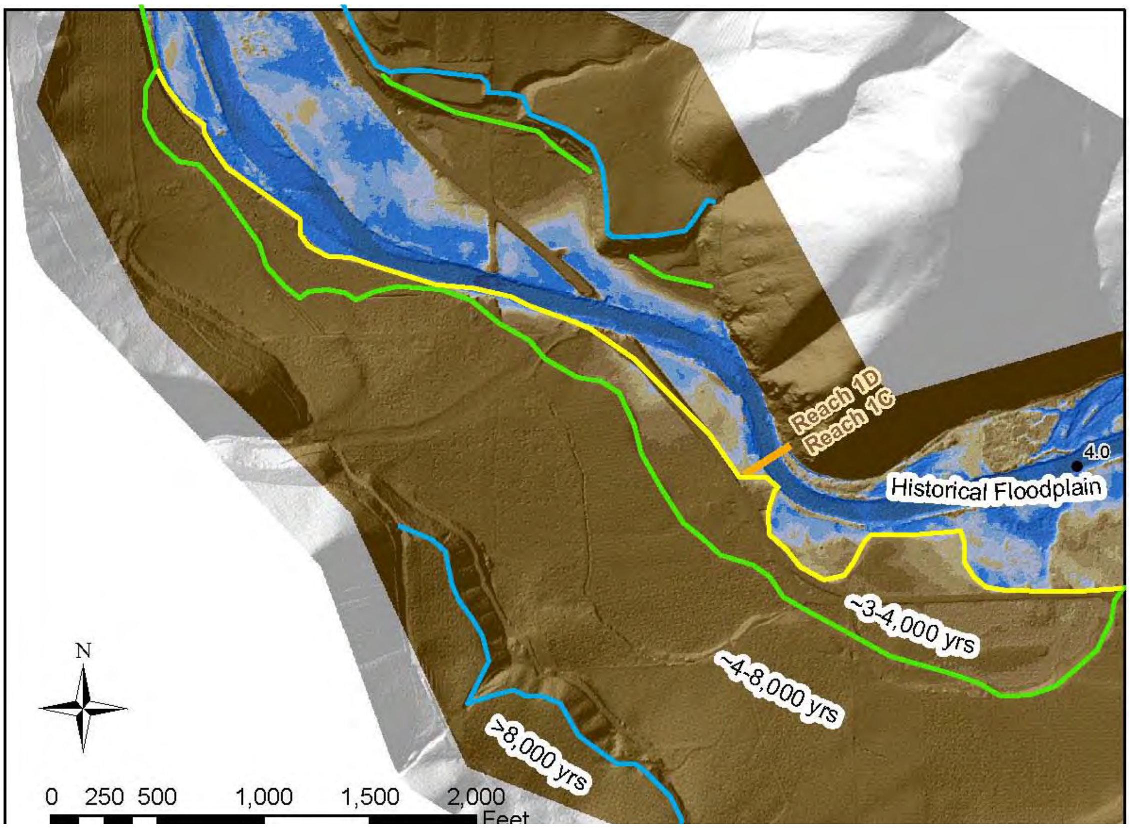

Figure 7. LiDAR view illustrating the approximate 2-year inundation area confined by progressively older terraces between RM 4 and 5 near Dinkelman Canyon. Approximate terrace ages are listed in years before present based on radio carbon dating (Reclamation 2009).

Over the past 10,000 years, sediment inputs have been dominated by episodic mass wasting, likely correlated closely with fire or other large-scale disturbances. Low frequency, high magnitude ancient debris flows continued to build alluvial fans in the valley bottom with minimal impact to the otherwise confined river. Only the largest debris flows likely influenced channel form or process, as evident by the lack of any debris flow deposits having shaped the modern river or its active floodplain in any significant way (Figure 8). No backwater deposits (fining upward sequences) have been observed upstream of confluences with tributary streams, and there has been no apparent forcing of channel pattern near tributaries with prominent ancient alluvial fans. Sediment entering the lower Entiat River from most historical and ancient debris flows was rapidly transported through the system with the exception of only the largest boulders.

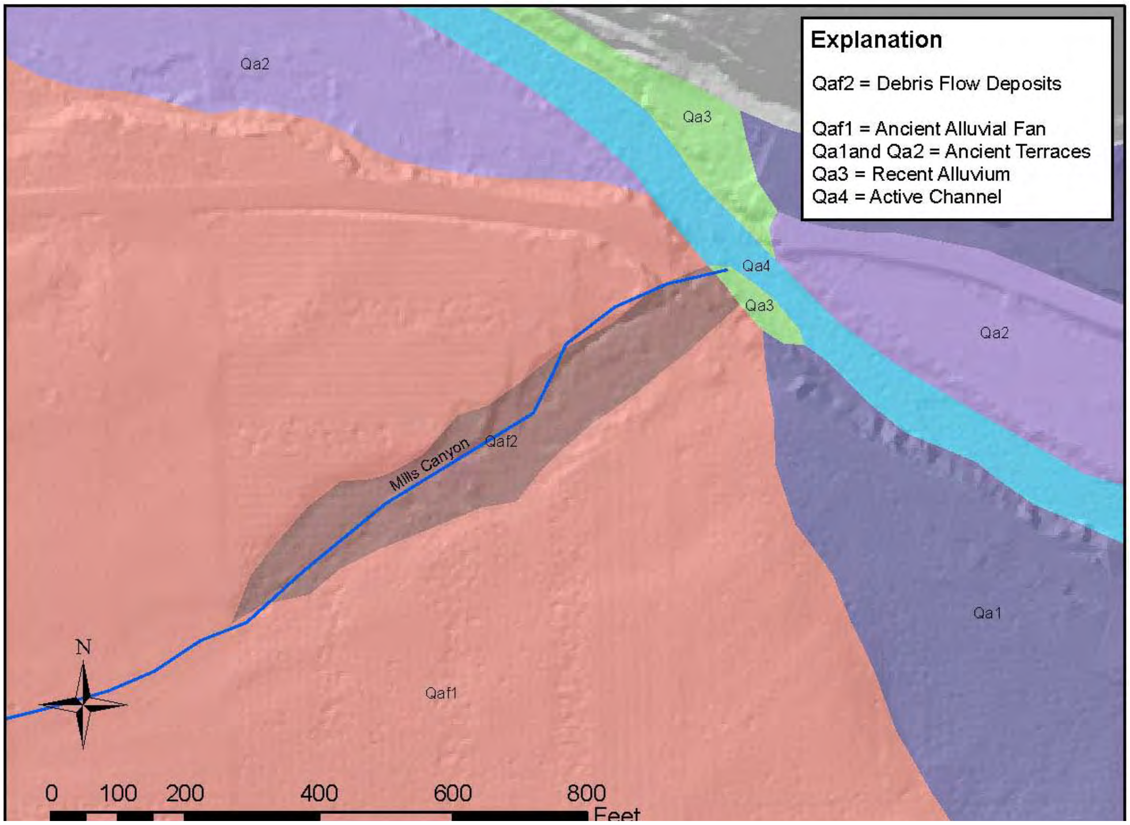

Figure 8. LiDAR hillshade view of a truncated recent debris flow deposit at Mills Canyon, illustrating the minimal effect of debris flow deposition on the overall character of the lower Entiat River.

Bank stability and infrequent bank erosion was largely a result of the banks' coarse, self-armoring composition in addition to a mature, forested riparian corridor likely consisting of mixed cottonwood, willow, dogwood, and alder transitioning to ponderosa pine and Douglas fir on the terraces (Reclamation 2009a). Historically, there were likely very few areas of interbedded fine sediment (sorted glacial outwash or overbank deposition) within the floodplain that, when exposed, would have been at higher risk of erosion. These areas of potentially erodible bank were so spatially insignificant that they would have had a negligible effect on lateral channel migration and channel pattern.

Channel pattern and sinuosity were largely a product of the valley shape and locations of exposed bedrock and coarse glacial sediment rather than fluvial processes (similar to a bedrock-confined channel). The confined lower Entiat River slowly cut its path through those areas of least resistance, resulting in a fairly straight channel pattern with bends forced by obstructions rather than formed by regular, alluvial meander action. The heavily armored banks and dense riparian vegetation further reduced rates of bank erosion and meander bend formation, reinforcing the generally straight, confined channel pattern.

The historical lower Entiat River was a classic underfit stream with a relatively straight, confined channel pattern; high-gradient, heavily armored bed; and limited floodplain and off-channel habitat areas. The majority of complexity and habitat in the lower river was provided by instream rock structures, log structures, riparian cover along channel margins, and the few locations where side channels developed.

Historical Instream Structure and Form

Instream structure and form in the historical lower Entiat River was likely provided by bedrock, large boulders, and LWD. Bedrock and large boulders would have been most prevalent near steep bedrock exposures along the valley wall. LWD would have accumulated mainly at the head of islands and to a much lesser degree along the banks. It is highly probable that large volumes of LWD would have formed very large, possibly channel-spanning logjams following fires or other significant hillslope disturbances.

A 1935 U.S. Fish Bureau survey of pools on the mainstem Entiat River recorded an average of 6.7 significant pools per mile (USFB 1935). The U.S. Fish Bureau measurement criteria defined pools as exceeding 25 square yards and 2-feet deep, but it is unclear if these criteria were applied during low flows or during conditions with higher discharge. As described in previous sections, based on the native valley-fill composed of coarse-grained (cobble and boulder) glacial outwash, it is highly likely that the lower Entiat River bed has been armored with cobbles and boulders for the past several thousand years (Reclamation 2009a). Recent efforts to create pools by building channel-spanning V-shaped weirs and large logjams have proven largely ineffective, suggesting that overcoming the threshold required to scour the armored bed requires either a large flood or substantial flow convergence. Hydraulic analysis indicates that depending on the exact location within the assessment area, mobilization of the cobble and boulder bed armor requires a roughly 10- to 45-year flood, based on existing channel geometry, or a roughly 15 to 35 percent obstruction of the channel (e.g., a logjam) with a roughly 2- to 5-year flood. It is unlikely that in 1935, the lower Entiat River contained enough large flow obstructions capable of maintaining an average of 6.7 or more large pools per mile, given the common practice at the time of clearing obstructions from the channel in order to splash logs for the timber industry. Additionally, the Old Keystone gage (12453000) did not record a flood greater than a 10-year discharge in the 2 decades preceding 1935. Based on this analysis, the lower Entiat River was likely characterized by some number of large pools less than 6.7 per mile. At all but low flows, much of the channel exceeds 2-feet depth, which would greatly exaggerate the number of large pools documented based on the U.S. Fish Bureau measurement criteria, possibly explaining the high number of large pools measured in 1935.

The most plausible means by which large pools could have been scoured from the coarse bed of the lower Entiat River and sustained for more than one season is by the presence of a large flow obstruction likely caused by bedrock, large boulders, or LWD. Interactions with bedrock and/or large boulders require the river to be near the valley wall, and the formation of large logjams is most common at the head of islands or along the outsides of sharp bends. There are currently about 30 locations in the assessment area where the river is located near the valley wall or where there are islands or sharp bends. If a large pool had been scoured at every one of these 30 locations, there would have been an average of roughly 4.3 large pools per mile. As discussed previously, it is unlikely that a large logjam capable of scouring a sizable pool would have formed at every sharp bend, island, and bedrock exposure, making roughly 3.5 to 4.0 large pools per mile a more reasonable historical estimate.

In addition to large pools, multiple small pools and pockets of hydraulic diversity included areas of slow water near fast water. Fast-water conditions likely dominated the majority of the lower Entiat River, but historically slow-water habitat existed in a few small side channels, along roughened channel margins near the banks, and in the lee of large instream structures. Side channels typically formed first as overflow channels through low-lying floodplain point bars. With very little historical channel migration, point bars and other low-lying floodplain areas would have been few in number; therefore, few large side channels likely developed under historical conditions. The side channels that did form likely evolved from short overflow channels into perennial side channels of which some eventually captured increasingly more flow, ultimately forming an island with nearly equal volumes of flow on both sides. Split flow around islands effectively doubles the length of channel margin, often with a logjam forming at the apex of the island which serves to increase the longevity of the island and split-flow conditions. There are very few locations in the lower Entiat River where historical side channel forms are present on the narrow active floodplain (Figure 9).

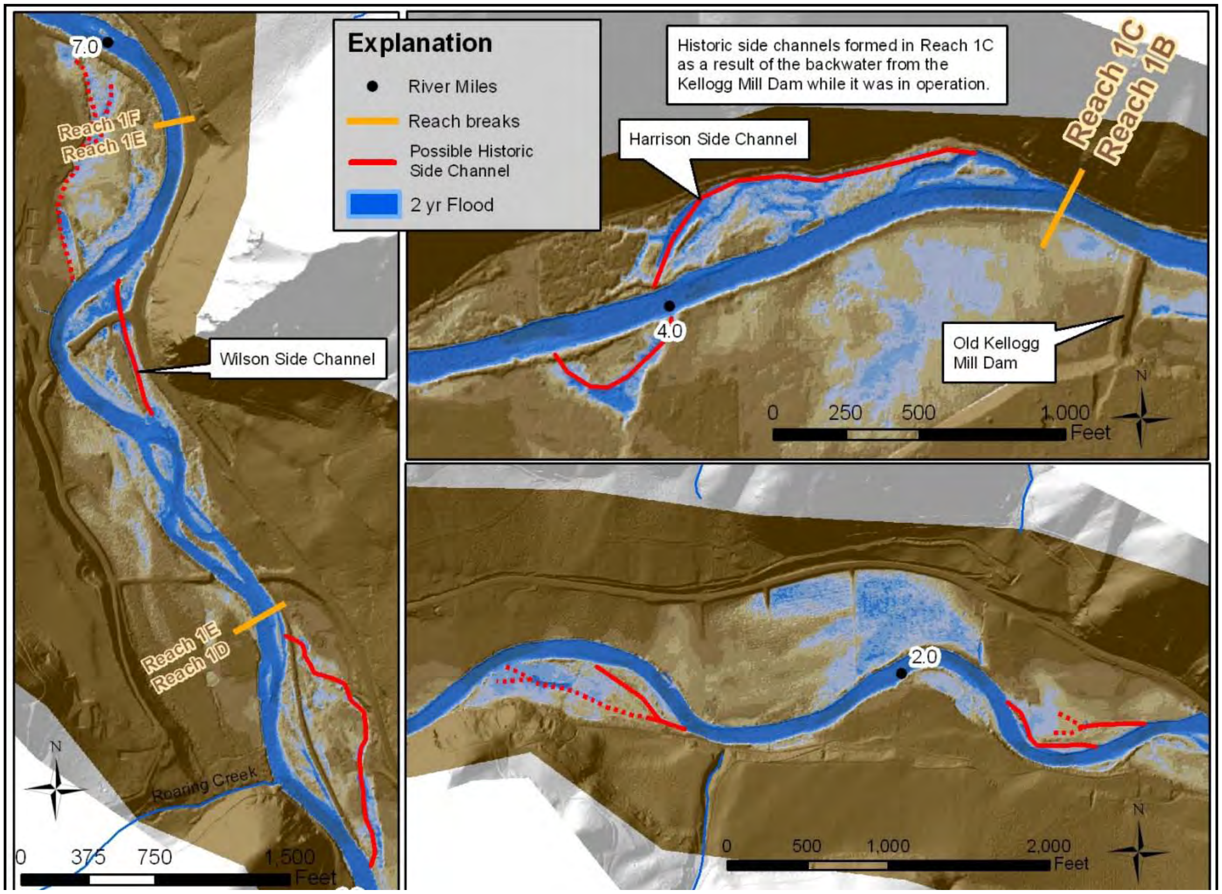

Figure 9. Possible historical high-flow (dashed line) and perennial (solid line) side channel locations within the active floodplain of the lower Entiat River that are at least partially disconnected by levees. It is unlikely that all of these side channels were perennial and/or active at the same time. Wilson side channel (RM 6.7) and Harrison Side Channel (RM 4.0) have been recently reconnected via strategic levee breaching efforts. Several additional smaller side channels likely existed historically along the inside of bends and small gravel bars as is the case under existing conditions. These smaller side channels are discussed under the Existing Conditions section of this report.

Historical Process

In an alluvial system, channel processes are continually working to maintain a relatively stable condition by adjusting numerous variables which are mutually interdependent: hydrology, sediment transport, channel migration, LWD recruitment, and riparian conditions, among others. As one process changes, the others respond to maintain a quasi equilibrium. The response time for adjustment depends both on the degree of change and the inherent condition of the river system. In an underfit river system that is as confined and as heavily armored as the lower Entiat River, the time required for natural processes to adjust to changes in form or process is generally longer than in a normal alluvial channel. This resistance to change has limited the amount of dynamic response that has occurred on the lower Entiat

River since the last ice age and has resulted in a relatively homogeneous channel, even prior to Euro-American settlement in the valley. Despite its limited diversity, the few forms that define the character of the lower Entiat River are created and maintained by channel process.

Hydrology

The lower Entiat River valley filled with coarse glacial sediment during the Pleistocene Epoch when discharge of sediment and water were both significantly greater and much more variable than modern conditions. In the roughly 10,000 years since the end of the ice age, the Holocene Epoch (modern epoch) has been marked by a relatively consistent climate (Houghten et al. 2001) and a relatively consistent hydrology.

The Lower Entiat River was historically capable of conveying large flows within its banks with minimal erosion or deposition due to its natural bed armoring, steep gradient, and generally straight, confined, and incised channel. Unlike most alluvial rivers where channel-forming flows generally fall near the 1.5- to 2-year recurrence interval, flows in excess of the 10-year recurrence interval were required in order to scour the bed, significantly interact with the floodplain, or generally induce change on the lower Entiat River.

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.

Transport competency was very high during glacial periods of the Pleistocene Epoch and the lower Entiat River was capable of episodically moving boulders in excess of 3 feet in diameter based on measurements of the grain sizes present in the deposited glacial outwash (Figure 10). Following the Pleistocene, the climate warmed/dried and the peak hydrology and the sediment competency diminished. The maximum grain sizes capable of being transported were in the cobble to small boulder size class, depending on the magnitude of discharge and degree of localized flow convergence. Grain sizes smaller than coarse gravel generally passed completely through the system to the Columbia River with the exception of lag deposits on the far descending limb of the hydrograph following each flood. Deposition and long-term maintenance of fine gravel, sand, and silt was only possible in the few off-channel and low-velocity areas along the river margins and narrow floodplain.

Figure 10. View of large boulders within the bankfull channel near RM 6.0.

Capacity during the Pleistocene Epoch was very high as a result of high volumes of water and an even greater supply of sediment which resulted in a depositional environment filling the lower Entiat River with glacial outwash sediment. Without the constant supply of sediment from glacial outwash in the years following the Pleistocene, the sediment transport capacity exceeded supply, resulting in a supply-limited system. The steep gradient and confined channel have enhanced and maintained the supply-limited conditions.

Throughout the past 10,000 years of the Holocene Epoch, the transport regime in the lower Entiat River was such that fluvial aggradation was not possible. The river has spent the past several millennia flowing on a bed composed largely of glacial outwash from the last ice age without the ability to aggrade or significantly rework its bed. Over that time, the lower Entiat River has slowly winnowed away much of the finer fraction of available bed material and formed terraces naturally disconnected from the floodplain and an active channel corridor bedded with immovable large boulders. Even large magnitude additions of sediment to the system, such as debris flows, have had essentially no lasting effect on channel form or process in the steep, transport reaches of the lower Entiat River. This sediment transport regime and the glacial history of the basin has resulted in an incised river with terraces that were formed thousands of years ago and a bed armored with large boulders.

Channel Migration

Historical channel migration on the lower Entiat River was very limited by bedrock, self-armoring banks composed largely of coarse glacial outwash, and dense bank vegetation. Rates of lateral channel migration since 1945 were measured at a maximum of 2.6 feet per year along one bank (RM 6.6) composed of late Holocene alluvium (less than 2,000 years old). Migration rates were generally immeasurable (less than 0.5 feet per year) in most other locations, including all locations where the banks are composed of older deposits (greater than 2,000 years old). Based on recent low rates of measured channel migration, the armored composition of most banks, and the general confined character of the channel, historical rates of channel migration prior to 1945 were also likely very low.

LWD Recruitment and Retention

Under certain conditions, LWD has the potential to significantly influence channel form and process. LWD can effectively armor banks, increase hydraulic variability, deflect flow, or force localized flow convergence, particularly when consolidated into logjams. For the past several thousand years, the confined river corridor and high transport competency of the lower Entiat River has limited the potential for LWD recruitment and retention. Retention likely occurred at the island apex (split flow) and to a lesser degree, outside of bends where fallen trees could rack (collect) debris. The high transport competency of the river would have served to mobilize most LWD in the middle of the channel, suggesting that island apex logjams formed at the head of existing islands. Occasionally individual pieces of LWD were recruited to the system from bank erosion, windfall, or scouring ice flows, but these events are relatively infrequent and/or spatially insignificant, so most wood likely originated from upstream and/or from debris flows in tributaries.

Where LWD accumulated, its influence on channel form or process was significantly reduced by the heavily armored bed and banks of the river. As stated earlier, very large logjams constricting flow by roughly 35 percent were required in order to force enough flow convergence to scour and maintain pools in the heavily armored bed of the lower Entiat River. The island apex jams were likely long-lived and stable because instream flows continually forced apex logjams against the head of the island. Other logjams were relatively transient without sufficient sediment deposition to anchor key members and high-competency instream flow washed accumulated debris off the banks and through the system during high discharge. Occasionally single trees or small collections of LWD pinned against bank vegetation may have been long-lived or transient depending on the structure, but they likely provided valuable cover habitat without any significant hydraulic effect.

Riparian Disturbance and Succession

Riparian disturbance occurred infrequently and over relatively small areas as a result of very low rates of channel migration and a highly confined channel with a limited floodplain area. Infrequent stand-replacing fires may have increased disturbance to the riparian area of the lower Entiat River, but the fires more commonly disturbed the surrounding hillslopes, increasing sediment and LWD recruitment potential. Riparian vegetation would have likely been mature to decadent in most locations and the roots would have helped stabilize banks and reduce the rates of channel migration.

EXISTING CONDITIONS

Existing conditions consist of the forms and processes currently shaping the assessment area. The existing conditions along the lower Entiat River were assessed from 2006 through 2011, giving a snapshot of the assessment area. 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 light detecting and ranging (LiDAR) topography, aerial photos, gauge 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 (Reclamation 2009a). Two iterations of the model were run, first excluding levees and ineffective flow areas in an effort to emulate historical conditions. For comparison, the levees and ineffective flow areas were added to the second iteration of the model to more accurately calculate existing conditions. Comparisons between the results from the historical conditions model and existing conditions model were used to support some of the conclusions regarding the effect of human influences present in the assessment area.

Existing Form of the Assessment Area

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

Channel Dimensions

Channel width and entrenchment are essentially the same throughout the photo record from 1945 to 2006. Depth is also relatively consistent throughout the entire lower Entiat River. At low flow, depth is commonly 2 feet or less across the entire channel, with poor thalweg development in most locations. At high flows, channel confinement concentrates flow in the mainstem, resulting in relatively deep, fast-moving water. This is consistent throughout the entire lower Entiat River, with the exception of Reach 1A which is significantly wider and deeper than the remainder of the assessment area because of the influence of the Lake Entiat backwater.

Planform

The lower Entiat River is a largely single-threaded planform with occasional split flows around isolated islands. The channel is relatively straight with a measured sinuosity of 1.08 (channel length divided by valley length).

Channel Migration Zone

The historical channel migration zone was delineated from aerial photos taken between 1945 and 2006 as part of the *Tributary Assessment* analyses (Reclamation 2009a). The channel migration corridor is very narrow, indicative of a confined channel with significant bank armoring (Figure 11).

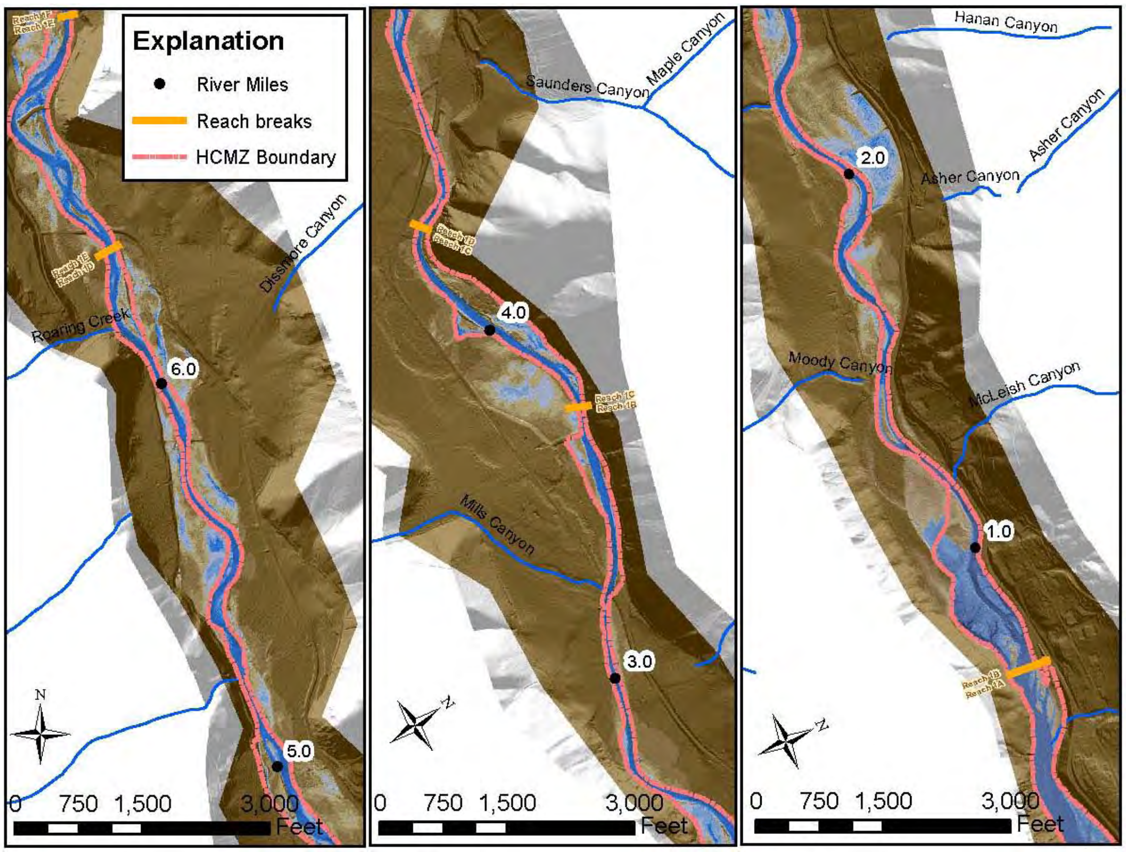

Figure 11. Channel migration zone and existing active floodplain (2-year floodplain) in the lower Entiat River. Note that both the historic channel migration zone and active floodplain are both very narrow compared with the overall valley bottom width due to confinement by terraces composed of erosion-resistant glacial outwash.

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. Downstream of the terminal glacial moraine near Potato Creek, the gradient in the Entiat River is consistently fairly steep. Within the assessment area, the gradient was measured at 1.1 percent between RM 7 to RM 3.7 where it reduces to 0.9 percent downstream to the flat backwater of the Columbia River near RM 0.6 (Figure 12).

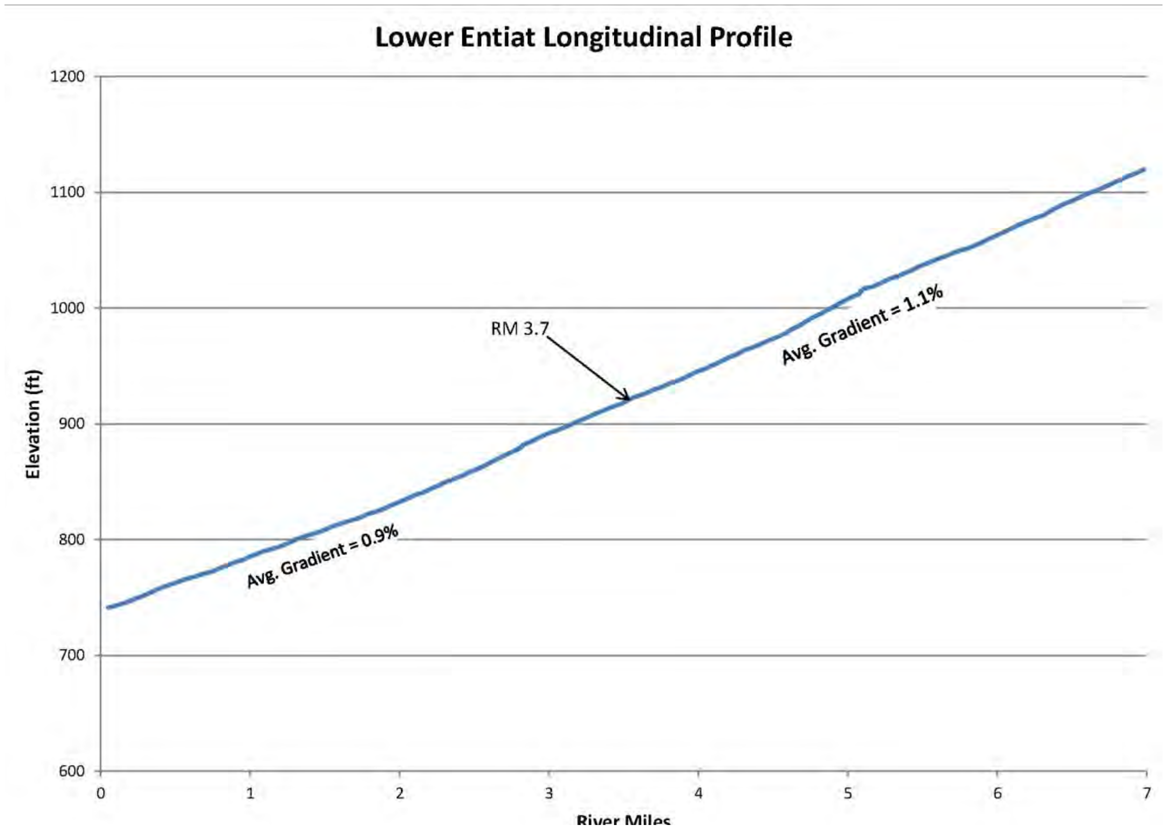

Figure 12. Longitudinal profile of the 2-year flood water surface from HEC-RAS for the lower 7 miles of the Entiat River. The average gradient decreases slightly near RM 3.7 from 1.1 percent to roughly 0.9 percent.

With the exception of Reach 1A, the bed of the lower Entiat River is composed of boulders with cobbles and coarse gravel. Bedload entering from upstream or from tributaries consists largely of sand, gravel, and small cobbles which is transported by the river on an annual basis while the bed armor is largely immobile. In most locations, the bed armor consists of grain sizes larger than small boulders, with many large boulders measuring in excess of 3 feet in diameter (Figure 13). These large boulders are remnants of glacial outwash from the last ice age. Embeddedness, defined as the packing of finer material surrounding the larger bed armor, is low to moderate in the lower Entiat River. Most fines that would serve to embed the armoring layer rarely fall out of suspension in the mainstem.

Figure 13. View of boulders in the lower Entiat riverbed near RM 1.4.

Bed form is defined as any deviation from a flat bed generated by stream flow on the bed of an alluvial channel (Bates and Jackson 1984). Since the lower Entiat River is not generally classified as an alluvial channel, there are no major bed forms defining the river bed with the exception of a few scattered pools and depositional features in Reach 1A. Nearly the entire assessment area can be classified as plane bed and generally homogeneous. Depositional bars were only observed along the insides of a few bends. Several relatively large, bar-like features were present along the insides of bends, but these are remnant, non-active bars formed by historical large-magnitude floods prior to Euro-American settlement (Figure 14). Even the largest recorded flood occurring during the spring of 1948 did not greatly affect these features.

As with historical conditions, scour and pool formation is extremely limited on the lower Entiat River. Scouring pools into such a heavily armored bed requires flows and obstructions that rarely occur naturally in the lower Entiat River, and occur even less frequently under the present conditions where LWD is so limited in the mainstem.

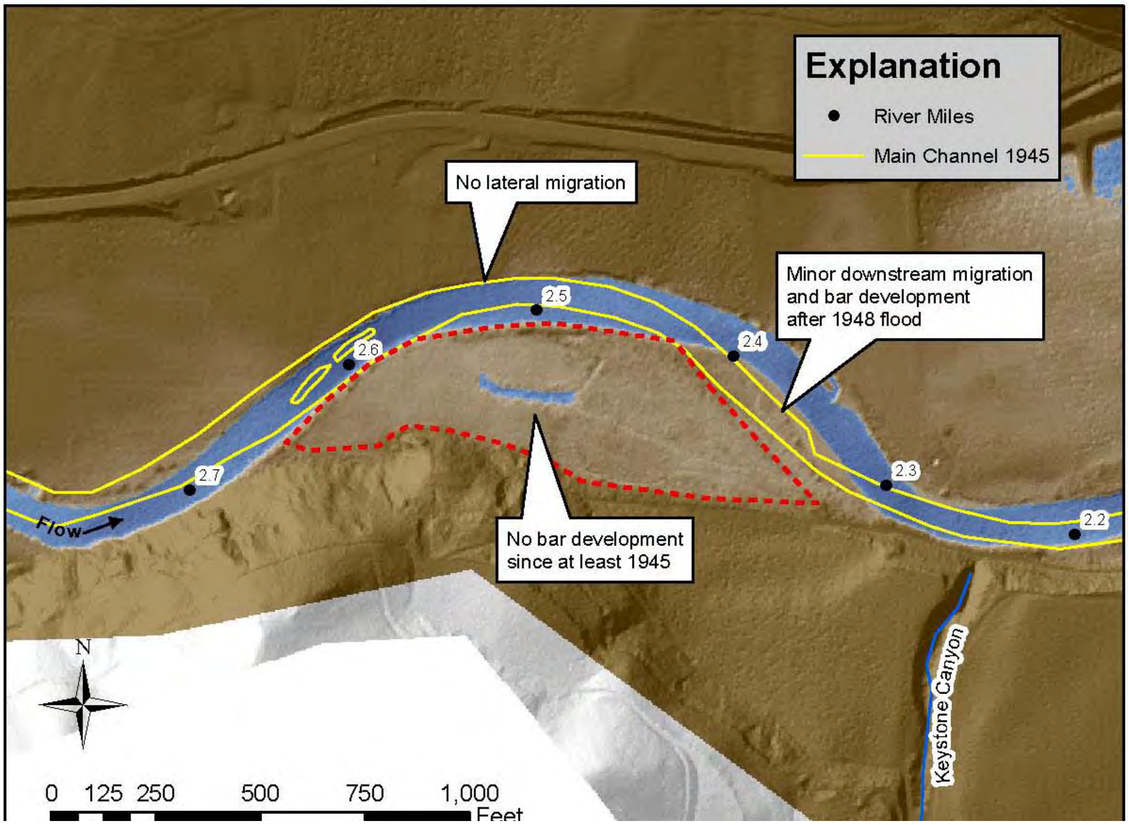

Figure 14. A large non-active bar on the inside of a bend of the lower Entiat River. Only very minor bar development on the downstream end of the bar has been observed within the 65-year photo record. This small change resulted from a single large, episodic event, as opposed to gradual change over time.

Bank Condition

Bank composition is similar to the bed composition, composed primarily of coarse-grained, erosion-resistant glacial outwash consisting largely of boulders and cobbles. Where mature riparian vegetation is present, a dense root mat binds the bank material together, increasing the erosion-resistant properties of the banks (Figure 15). During multiple field visits to the lower Entiat River at high and low flows in 2011, only one minor area of bank erosion was observed along the left bank at RM 5.0. Roughly 250 feet of the bank has receded approximately 80 feet since 1975 in this location, which is one of the few places where the bank is composed primarily of sand and gravel with limited cobbles and boulders providing armoring (Figure 16).

Figure 15. View of a bouldery bank held together with a dense root mat near RM 6.0.

Figure 16. View of the bank erosion on the left bank near RM 5.0.

Forcing Agents

Although present in the lower Entiat River, forcing agents such as channel constrictions or obstructions (e.g., LWD, bedrock, valley confinement, human features) do not significantly alter the form or process of the river. Natural bed and bank armoring exhibit far greater control of form and process than do the few constrictions and obstructions in the channel. For example, the prominent remains of the old Kellogg Mill Dam at RM 3.6 constrict flows exceeding the 25-year recurrence interval. Hydraulic modeling shows that even at the 100-year recurrence interval, negligible backwater conditions result and bed armoring prevents scour even though instream shear and velocity increase by roughly 20 percent. Channel-spanning cross vanes force flow convergence and plunging flow, yet despite this increase in scour potential, most of the existing cross vanes on the lower Entiat River have filled with coarse bedload rather than scouring pools (Figure 17 and 18). Existing LWD logjams are not of sufficient size to scour and maintain sizable pools. If scour pools form during rare events or as a result of excavation, it is likely that they subsequently fill with coarse bedload.

Figure 17. Dinkleman cross vane structure in the Entiat River at RM 4.6 four years after construction in October 2005.

Figure 18. Dinkleman cross vane structure in the Entiat River at RM 4.6 in 2011, roughly 10 years after construction and one 10-year flood. As opposed to creating a scour pool as anticipated, most of the area near the apex of the weir has filled in with coarse bedload.

The lower Entiat River is a threshold channel defined by a heavily armored bed which is only mobilized beyond a certain threshold discharge. As discharge passes beyond the threshold, the coarse bed armor becomes mobilized and is evenly distributed across the bed (live bed). When discharge falls below the threshold, the coarse bedload is no longer transported, and is deposited across the bed, often filling pools. In a threshold channel, large pools can only be maintained by flow convergence large enough to induce a local hydraulic effect sufficient to mobilize the armored bed at flows below the threshold condition. Otherwise the scour pool will fill with coarse sediment each time threshold conditions are overcome and the bed armor is mobilized. The threshold conditions may vary between sites, but they are defined by the discharge required to mobilize the bed at that location.

Off-Channel Features

There are very few off-channel features on the lower Entiat River except for a handful of side channels outlined in the Reach-Based Ecosystem Indicators table found in the Appendix. Side channels on the lower Entiat River can generally be categorized as split-flow channels where the character of the mainstem and the side channel are essentially the same, or floodplain side channels where a relatively small side channel has formed in the low-lying active floodplain, typically along the inside of a bend. The floodplain side channels are generally much smaller and have lower velocity than the split-flow channels. Several irrigation diversion channels also provide important, albeit unnatural, localized off-channel habitat.

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 delineated by hydraulic modeling. As a result of thousands of years of incision, the lower Entiat River is moderately to severely confined, with an active floodplain width no greater than three times the width of the channel, in a valley bottom that is roughly 10 times the width of the channel. In many locations, the active floodplain is not significantly wider than the bankfull channel which has been shown to convey a roughly 5-year recurrence interval flood, illustrating the extent of channel incision over the past several millennia (Figure 19; Reclamation 2009a).

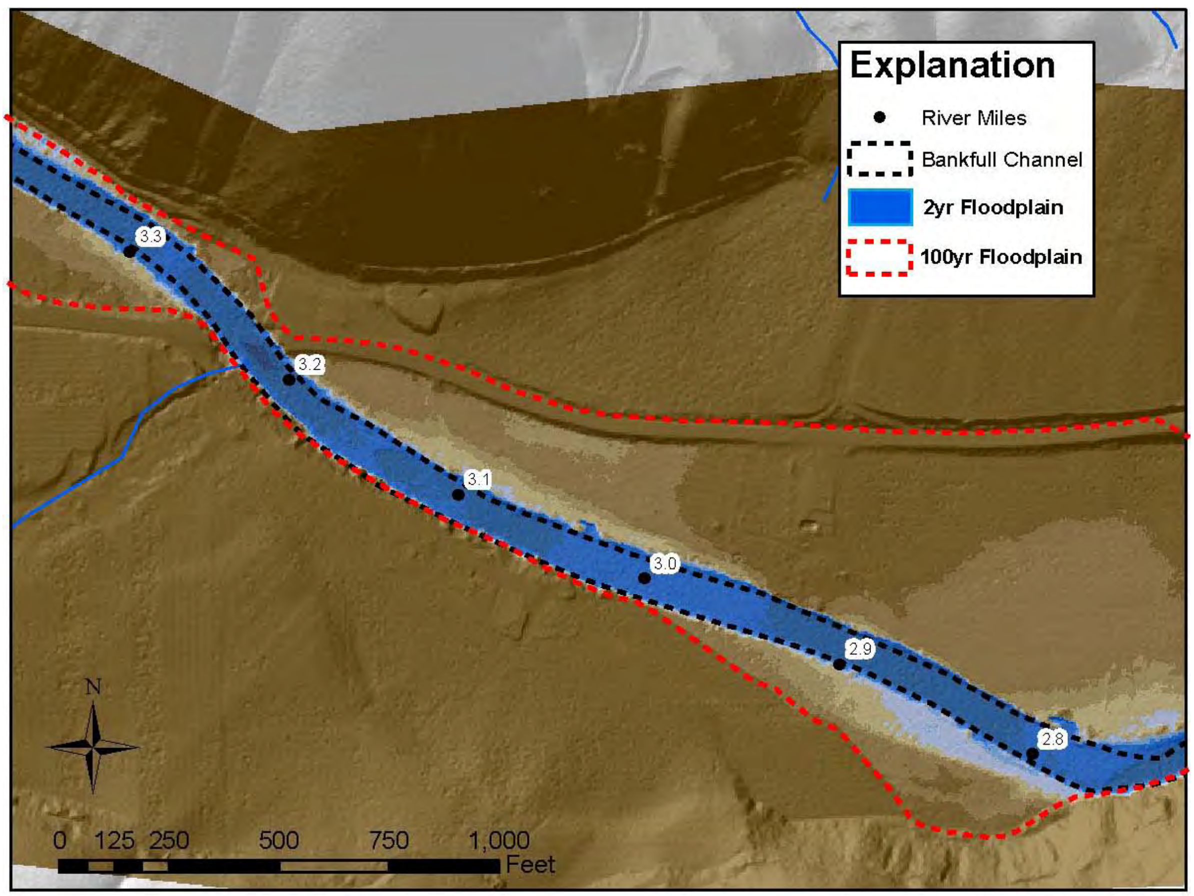

Figure 19. LiDAR view of the 2-year flood inundation area at Milne. The bankfull channel width is roughly equivalent to the active floodplain width in this location.

There are many alluvial (formed by water) and fluvial (formed by streams) landscape features visible in high-definition LiDAR topographic imagery. The differences between those features distinguish what has been formed by and continues to be shaped by the modern river and what features are ancient, having been formed thousands of years ago (Figure 20).

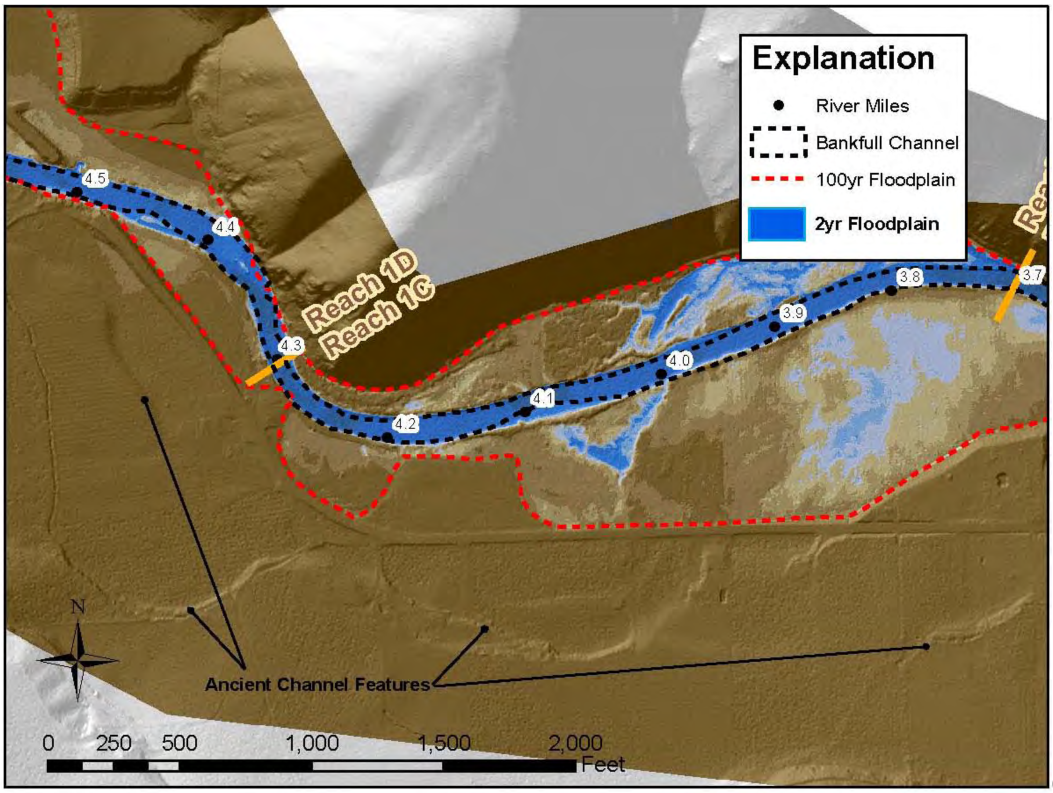

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Figure 20. LiDAR view of ancient channel features located on terraces well above the floodplain between RM 4 and 5.

Existing Reach-Specific Forms

Reach 1E

The overall channel character is relatively complex, given the steep gradient and degree of entrenchment. Scattered LWD and a nearly continuous strip of riparian vegetation provide cover and bank stability in this reach which is characterized by multiple, perennial split-flow side channels. Riprap along the right bank extending beneath the bridge near RM 6.6 may have accelerated bank erosion downstream at RM 6.5 resulting in the formation of an island at this location (Figure 21).

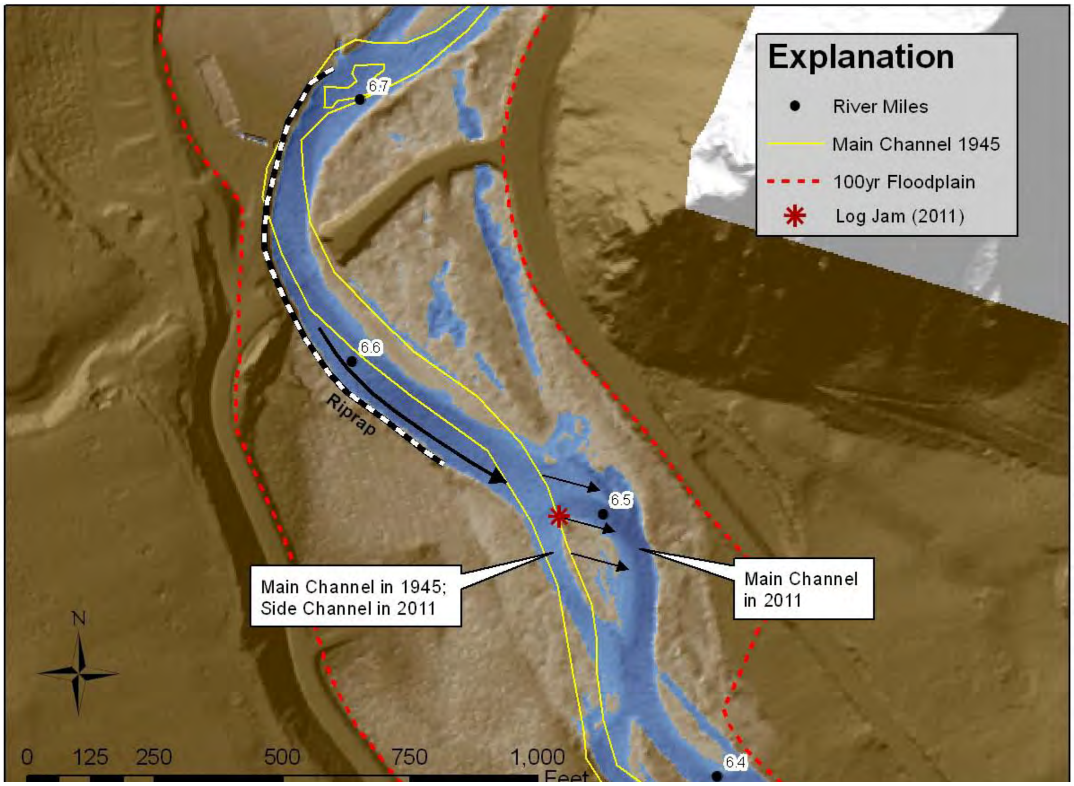

Figure 21. LiDAR view showing a location near RM 6.5 where the placement of riprap has created a hydraulically smooth bank resulting in accelerated rates of bank erosion and the formation of an island immediately downstream. Note the change in channel position between 1945 in yellow versus the 2006 LiDAR map.

Reach 1D

The character of this reach is defined by the presence of several small floodplain side channels generally along the inside of channel bends. Some of the side channels convey perennial flow and others convey seasonal flow. Depending on its form, LWD accumulation partially blocks some side channels, potentially cutting them off over time, or LWD diverts additional flow into other side channels, expanding their capacity. Aside from the apex of islands, few other locations have accumulated LWD. The existing riparian buffer is very narrow, and the potential for large trees falling into the river and providing habitat and cover is low due to armored banks and the lack of many large trees.

Steep bedrock slopes supply large angular boulders to the reach where the channel abuts the valley wall. Boulder clusters increase instream roughness and local complexity, sorting bed material and providing velocity breaks in an otherwise steep, high-velocity reach. It is likely that large boulders and boulder clusters were removed from the reach in the early 1900s to accommodate log drives. The current number of large boulders and boulder clusters is probably less than what existed naturally.

Reach 1D is a temporary control reach with limited project implementation planned for 2014 and larger-scale implementation planned for 2020.

Reach 1C

Reach 1C is the only reach in the lower Entiat River with clearly visible historical channel meanders that have been cut off; however, these meanders existed as a result of the Kellogg Mill Dam. It is unclear to what extent the 1948 flood restraightened the channel in this reach and what was straightened by human manipulation, but it was likely a combination of the two. There are significant off-channel habitat features well within the active floodplain that have the potential to provide off-channel habitat, particularly for juvenile fish.

The gradient in Reach 1C has also been impacted by the Kellogg Mill Dam, indicated by a convex profile where the gradient in the upper half of the reach is 0.90 percent which increases to 1.2 percent in the lower half of the reach. This form likely signifies a minor slow-moving head cut. The thalweg is well defined in the relatively flat upper half of the reach and is poorly defined in the relatively steep lower half of the reach. The pattern exhibited by the thalweg represents the likely future reestablishment of channel sinuosity within this reach, which has a wavelength roughly equivalent to, but out of phase with, that of the 1940s channel (Figure 22). Although a relatively straight channel is expected given the steep gradient and naturally armored bed and banks, some sinuosity is expected to develop within this straightened reach.

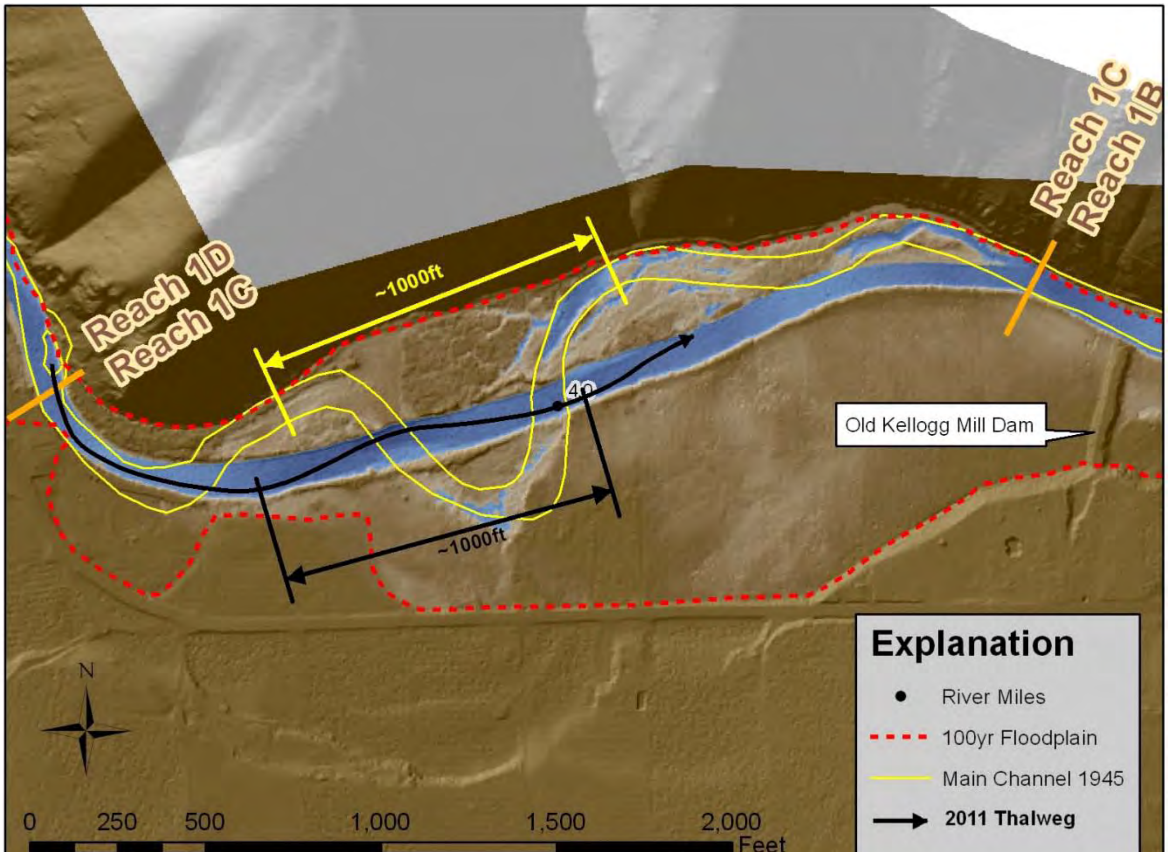

Figure 22. LiDAR view showing the existing thalweg wavelength and post Euro-American settlement meander wavelength caused by the old Kellogg Mill Dam in Reach 1C. Even without the dam, a small amount of sinuosity with similar wavelength is expected to develop here.

Reach 1B

The upper half of Reach 1B is generally straight and highly confined by terraces composed largely of coarse-grained glacial outwash and contains little to no LWD. The lower half of Reach 1B is relatively sinuous, with small areas where the floodplain is accessible to floods exceeding a roughly 2-year recurrence interval. Several push-up levees restrict flood access to larger areas of the floodplain. Where the floodplain is constricted either by terraces or the valley wall, bed grain sizes are generally larger and channel sinuosity is less.

The lower end of the reach is influenced by backwater effects from the Columbia River. A large backwater alcove is located on the right floodplain in the lowermost 1,500 feet of the reach. The alcove receives surface flow during floods exceeding the roughly 2-year recurrence interval and is otherwise fed by hyporheic flow.

Reach 1A

Reach 1A is defined by the backwater effect from Lake Entiat on the Columbia River. The extent of the backwater varies depending on the level of the water backed up behind Rocky Reach Dam. As a result of the backwater, the grain sizes, velocity, shear, and overall stream power all decrease throughout the length of the reach. Reach 1A is the only depositional reach in the entire lower Entiat valley segment as a result of the heightened base level caused by the unique backwater conditions in this reach.

EXISTING PHYSICAL PROCESSES

The forms characterizing the lower Entiat River are created and maintained by physical processes which can generally be grouped into categories, including hydrology; sediment transport; channel migration; LWD 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

In the Entiat River basin, the hydrologic inputs are dominated by surface runoff, and peak runoff is dominated by snowmelt, with the largest floods occurring after rain-on-snow events. 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 which can increase mainstem flow, although typically increasing flow by less than a few hundred cfs (inferred from USGS gauge 12452990).

Regarding groundwater, the lower Entiat River is considered a gaining reach. Groundwater inputs make up roughly 8 percent of the base flow in the lower 7 miles of the river, with the remainder derived from surface and groundwater inputs upstream (calculated from data presented in CCCD 2004). The largest fraction of groundwater input to the lower Entiat River is between RM 4.5 and 5.5, averaging roughly 30.51 cfs per mile. The remainder of the lower Entiat assessment area actually loses surface water to the local groundwater table (CCCD 2004).

Bankfull flow is often commonly assumed to be equivalent to the 1.5- to 2-year recurrence interval, but in many sections of the lower Entiat River, the bankfull capacity of the channel (as calculated using HEC-RAS hydraulic models) is higher than the 5-year recurrence interval flood (Reclamation 2009a). The confined character of the river focuses high volumes of flow within the banks rather than dissipating flow and energy across a broad floodplain. The 2-year and 100-year inundation areas are both narrow and confined between ancient terraces (Figure 23). A full breakdown of the calculated discharges at various recurrence intervals can be found in the Reach-Based Ecosystem Indicators tables (Appendix).

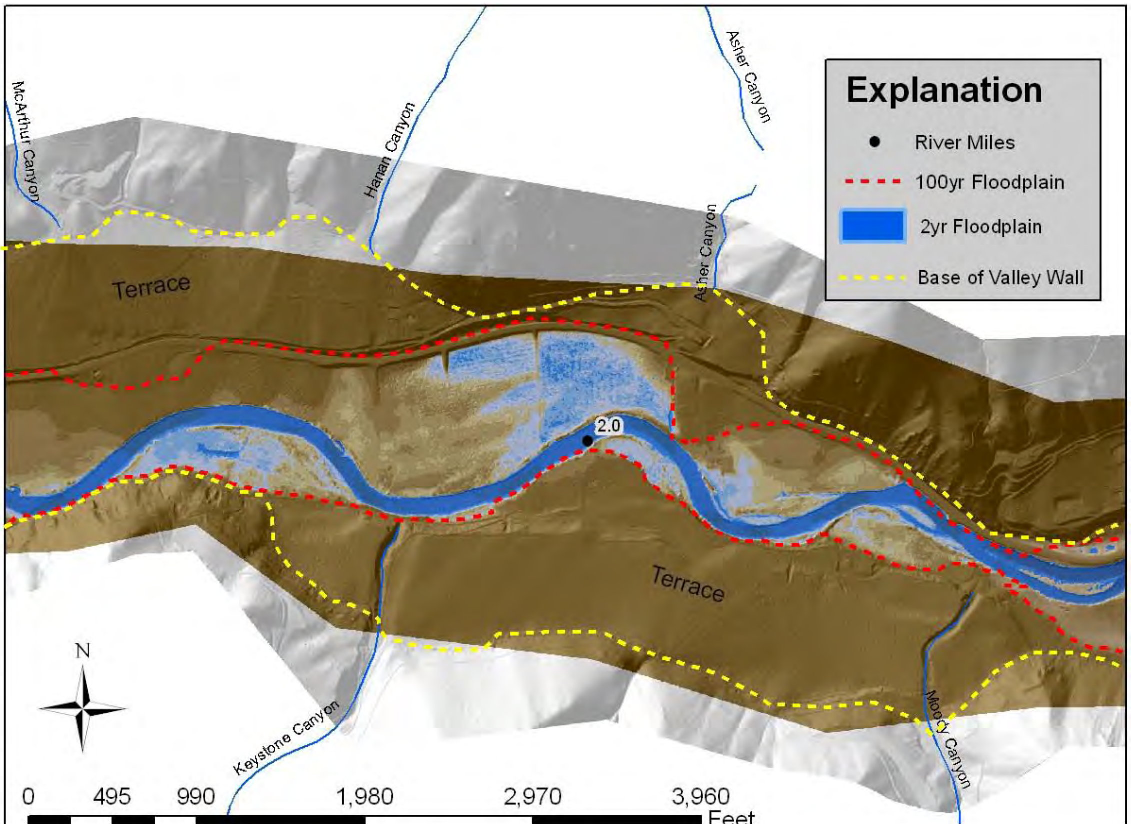

Figure 23. LiDAR view illustrating the level of channel confinement by comparing differences between the valley bottom, 100-year floodplain and the 2-year inundation area.

Irrigation withdrawals artificially reduce summer low flows, but low-flow passage has not been identified as a limiting factor in the lower Entiat River. Summer water temperatures increased by excessively shallow water, reduced riparian vegetation, and warm water irrigation returns have been identified as a minor limiting factor.

During low flows in the winter months, anchor ice sometimes forms in the lower Entiat River which has the potential to disturb the bed of the river, including spawning gravels. Anchor ice forms when the air temperature is well below freezing and the water temperatures quickly drop to the freezing point. Turbulent heat exchange prevents ice formation at the water surface, but the relatively calm water occupying the interstitial space between grains of cobbles and boulders on the river bed enables tiny platelets of ice called frazil ice to coagulate and attach, creating a progressively larger ice surface which grows into blocks of anchor ice (Hammar and Shen 1995). Anchor ice can become large enough that the combination of shear and buoyancy can dislodge the ice from the bed, often disturbing the bed in the process. Anchor ice is less frequently formed in deeper, less turbulent, and/or warmer water. Although it has not been historically documented, all of the conditions for anchor ice formation existed historically and anchor ice has likely affected the lower Entiat River for thousands of years.

In addition to anchor ice, surface ice also forms on the lower Entiat River in areas of low water velocity, particularly along the banks. Surface ice accumulation can become significant which can create ice dams when broken apart during high-flows.

Sediment Transport

The sediment transport regime has changed very little on the lower Entiat River during historical times. Sediment supply is still largely derived from upstream sources and punctuated by episodic inputs following large fires or other disturbances in the basin. Recent reports have shown that more intense fires and the network of dirt and gravel roads in the Entiat River basin have increased the amount of runoff carrying fine (silt and sand) sediment to the river (Reclamation 2009a), but observations of the few depositional bars show very few fines. In an average year, most fine sediment likely gets flushed through the system during high flows and is deposited on the expanding delta at the mouth of the river or in the few slow-water, off-channel areas in the floodplain, such as Harrison Side Channel near RM 4.0. The substantial amount of sediment observed in these locations suggests that the sediment load entering and passing through the lower Entiat River is significant, but there are no bedload or washload sampling data providing quantitative estimates. A relatively small amount of fine sediment deposition may occur in the mainstem of the lower Entiat on the extreme declining limb of the hydrograph or as a result of sediment inputs during low water (e.g., summer rainfall on logging roads) when discharge is not sufficient to mobilize fine sediment. U.S. Forest Service monitoring efforts have shown a weak correlation between low precipitation and the accumulation of fine sediment due to the lack of flushing flows (CCCD 2004). Local debris flows also contribute to the sediment load in the system, but do not appear to significantly influence deposition in the lower Entiat River, force flow convergence, or restrict the channel. With the exception of the largest grain sizes, the majority of sediment that enters the channel from a debris flow is transported through the system during annual high flows. Bank erosion within the assessment area has been shown to be low, representing a negligible source of sediment.

The existing lower Entiat River has a high transport competency and capacity compared to the volume and size of sediment entering the stream, thereby creating a supply-limited condition dominated by sediment transport. Under these conditions, alluvial deposition is infrequent and incision is common. During most high flows, fine sediment is winnowed away, leaving behind an armored layer of course grain sizes. Several pebble counts taken from the channel bed reveal an average median grain diameter (D_{50}) of 154mm (cobble) and an average 84^{th} percentile grain diameter (D_{84}) of 343mm (boulder) (Figure 24). The very coarse bed armor derived from glacial outwash sediment has limited the amount of natural incision that has occurred, but the channel has incised as much as 20 feet in some areas over thousands of years. Several areas of riprap bank armoring and levees have served to further confine the channel, increasing both transport capacity and competency, but not to the point where the channel is able to consistently mobilize its armored bed. Nevertheless, the incised and armored channel more closely resembles a bedrock-controlled channel than an alluvial system.

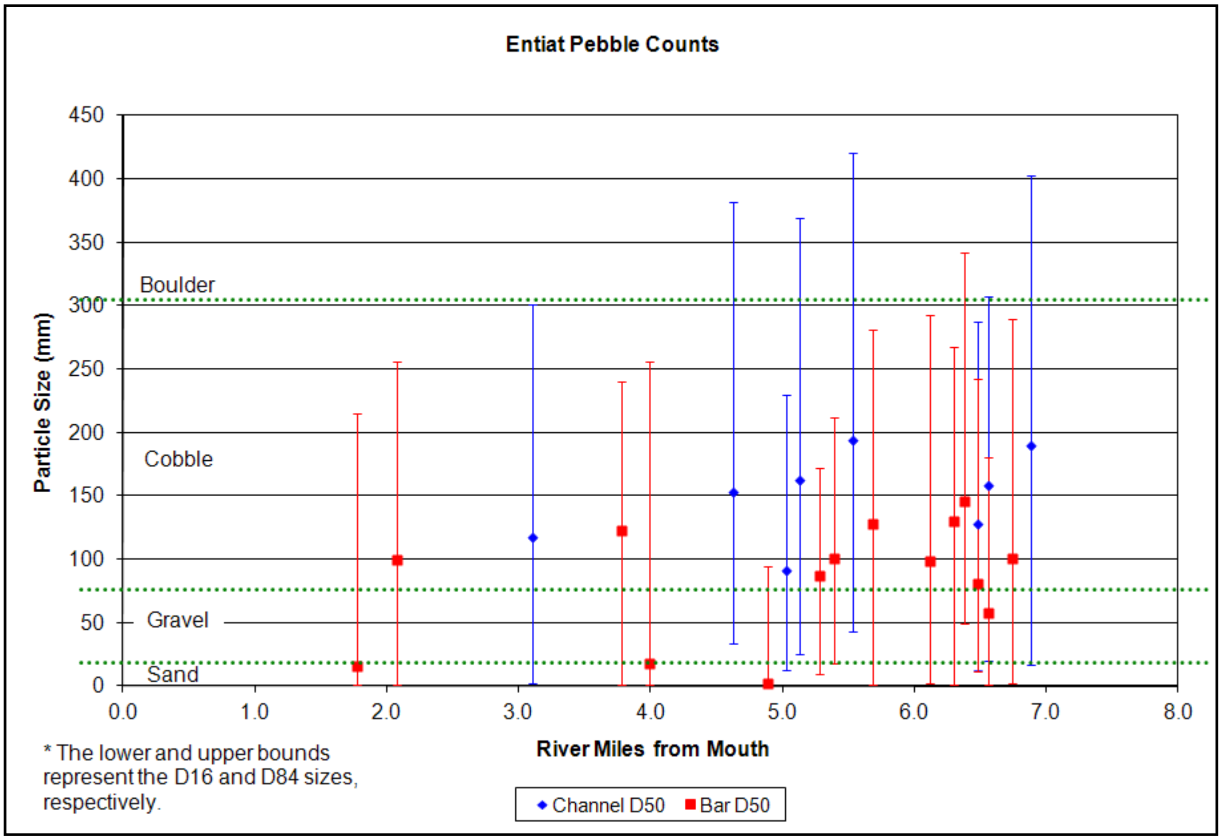

Figure 24. Pebble count data illustrating the large grain sizes comprising the surface material on the channel bed and bars of the lower Entiat River. Average channel bed D50 (median grain size) is 154mm (cobble) while average channel D84 (84th percentile grain size) is 343mm (boulder). Dotted green lines separate grain sizes between sand, gravel, cobble and boulders. The data was collected by Reclamation in 2005 as part of the Tributary Assessment effort.

As discussed previously, the lower Entiat River is a threshold channel defined by coarse bed armor requiring a roughly 10- to 45-year flood to be mobilized depending on local channel geometry. It is during these infrequent threshold events that large-scale channel-forming processes occur, and clear-water scour conditions change to live-bed. Under live-bed scour, the entire bed is mobile, not just point locations near obstructions. Also, scour pools that form reflect equilibrium between sediment entering from upstream and sediment removed locally. Under live-bed conditions, many scour pools previously formed often fill with coarse bedload during the recessional stage of a flood when the threshold is reestablished. Large instream channel obstructions, sharp channel bends and combinations thereof represent channel forms which often influence local hydraulics sufficiently to maintain large, deep scour pools in the event thresholds are surpassed and the bed armor is mobilized. Hydraulic modeling suggests that in a representative reach of the lower Entiat River, an instream structure must obstruct nearly 30 percent of the channel at bankfull in order to maintain a large, deep scour pool due to coarse bed armor. The relationship between bend geometry, helical flow, and scour requires multi-dimensional hydraulic modeling in order to estimate scour potential. Projects with the aim of producing large, deep, long-term scour pools should consider detailed hydraulic modeling at the local scale to estimate scour potential.

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, lateral movement ceases and downstream migration of the bend begins.

Natural bank armoring from glacial outwash sediment and riparian vegetation have severely limited the amount of channel migration in the lower Entiat River and very few locations of measurable migration were observed during the field surveys (Table 3). Measured channel migration was most apparent in the aerial photo record between 1945 and 1962 which encompasses the 1948 flood. Very little channel migration was observed in photos after 1962, suggesting the process of channel migration requires very large magnitude floods in the lower Entiat River.

Table 3. Channel migration measured between 1945 and 2006 in the lower Entiat River. Channel migration was negligible in areas not identified in the table for the period of record. Lateral migration was measured perpendicular to the longitudinal valley axis while downstream migration was measured parallel to the longitudinal valley axis. A complete description of the surficial geology composing the bank material can be found in Appendix C of the *Tributary Assessment (*Reclamation 2009a). In summary: Qaf1 = Older Holocene alluvial fan deposit at least 3,000 years old. Qa2 = Late Holocene alluvium not older than 2,000 years old. Qa3 = Recent alluvium.

Reach	RM	Bank	Type	Length (feet)	Rate (feet/year)	Bank Material
1E	6.6	Left	Lateral	150	2.5	Qa3
1D	6.2	Right	Lateral	110	1.8	Qaf1
1D	5.6	Left	Lateral	65	1.1	Qa2
1D	5.4	Right	Lateral	140	2.3	Qa2
1D	5.0	Left	Lateral	95	1.6	Qa2
1B	2.5	Left	Downstream	170	2.8	Qa2
1B	1.7	Left	Lateral	125	2.0	Qa2
Significant widening in Reach 1A resulting from backwater condition						

LWD 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 LWD which contributes to the amount of instream structure and channel response present in a given reach. The lower Entiat River is no different; however, similar to other Pacific Northwest streams, the availability of LWD 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 25). 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 25. 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).

LWD recruitment in the lower Entiat River has been largely dependent on upstream sources and episodic wind fall, because recruitment from bank erosion and channel migration is limited in the lower Entiat River. Recruitment is also limited partially because of the few large key members entering the river in the low-gradient reaches upstream of the Potato Moraine, most are unlikely to be mobilized and transported to downstream reaches. Also, unlike historic times, very few trees of the caliber to constitute a key member can be found growing near the modern mainstem river. Consequently, the potential for recruiting and retaining large key members in the assessment area is very low.

There are generally low numbers of LWD in the assessment area compared with transport-limited response reaches such as the Preston and Stormy reaches upstream of the Potato Moraine. The high transport competency, heavily armored bed, and confined channel in the lower Entiat River severely limit the potential retention of LWD and reduce the potential effects LWD can impart on the river. LWD retention was observed to be most common at the head of islands in the form of small logjams (Figure 26). A total of 16 existing logjams were counted during field work in 2011, excluding LWD accumulations in Reach 1A (see Appendix for the LWD count). Of those, 11 were natural logjams and 5 were constructed. Of the 11 natural logjams, all but one formed at the head of an island. Scattered LWD was also observed along the banks in locations where they were hung up on living riparian vegetation. Single logs and small logjams may be transient or long-lived depending on their composition and whether or not they are held in place by stable bank vegetation or boulders. These log structures provide valuable cover habitat and local velocity breaks despite imparting little influence on mainstem hydraulics.

Figure 26. View of an existing naturally occurring logjam at the head of an island located near RM 6.4.

Riparian Disturbance and Succession

Riparian vegetation influences other processes largely based on the type, density, and age of vegetation within the riparian corridor. The riparian overstory is dominated by mature to decadent cottonwood trees with a willow, dogwood, and alder dominated understory. Very few conifers were observed within the riparian area. The existing riparian corridor is narrow, typically less than 25 feet wide and very rarely over 100 feet wide, but mostly continuous offering some amount of shade, nutrients and bank stabilization to the river throughout most of the assessment area. The roots of mature cottonwood trees were observed growing between and holding together boulders and cobbles along the banks of the river, increasing the erosion resistance of those banks. Of the few individual pieces of LWD observed, most were large fallen cottonwood trees, likely blown over by the wind or some means other than undermining from bank erosion.

Riparian species are not generally present on terraces elevated more than about 10 feet above the ordinary high water mark, although it is difficult to determine if this is a result of clearing or a lack of accessible groundwater. Other than the narrow strip of relatively undisturbed riparian vegetation along the riverbanks, the majority of the active floodplain capable of sustaining a riparian area has been cleared for orchards, roads, and other development. Human disturbance tends to be absolute; regeneration and succession are typically excluded by human disturbance because the riparian area is converted to and maintained as something other than riparian vegetation.

The natural disturbance frequency within the riparian area is very low, mainly as a result of the extremely low occurrence of bank erosion and channel migration. Although common in the uplands farther upstream, fire has not burned the riparian area within the assessment area in recent history.

Changes from Historical Conditions

Overall, the physical condition of the lower Entiat River has changed very little when comparing likely historical characteristics (prior to Euro-American settlement) to modern characteristics (Table 4). The general channel planform, profile, width-to-depth ratio, entrenchment, and grain sizes have likely not significantly changed, with few notable exceptions. The most significant changes to channel character have resulted from the loss of structure and complexity in-stream and along the banks.

Table 4. 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)
Large Pools	Roughly 3.5 to 4.0 per mile	0.5 per mile	Lack of large instream structures and LWD recruitment potential	High
Sinuosity	Roughly 1.1	Roughly 1.1	Unchanged	--
LWD	Few logjams/mile (estimate less than 10)	2.3 logjams per mile; 132 individual pieces per mile	Logging and clearing have reduced the amount of available wood for recruitment; lack of instream structure reduces retention potential	High
Channel geometry	Incised 1 to 20 feet	incised 1 to 20 feet	Unchanged	--
River bed and banks	Armored with large boulders	Armored with large boulders and riprap	Change is strictly related to form; process impairment is negligible	Low
Off-channel habitat	Approximately 4.3 side channels per mile averaging roughly 2,500 feet of side channels per river mile	3.7 side channels per mile averaging 2,063 feet of side channels per river mile	Channel migration and flooding impaired by levees and lack of significant instream structure	Low
Floodplain connection	Limited to narrow active floodplain between terraces	Limited to narrow active floodplain and further reduced by levees	Levees have cut-off approximately 20% of the active (2-year) floodplain	Medium
Riparian condition	Dense mature trees; riparian area was at least 100 feet wide	Partially mature trees; riparian area is generally 25 feet wide	Change is strictly related to form; result of clearing for development	Medium to High

Dams

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 (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)

Splash dams impounded water, sediment, and logs which were released episodically in large volumes to facilitate log drives. Obstacles such as large boulders and natural LWD jams were systematically removed (typically with dynamite) to reduce the risk of a jam-up during the drive. Channels without a history of splash dams have been shown to have tens to hundreds of times more naturally occurring LWD and more/deeper pools when compared with similar channels with a history of splash dams (Wohl 2004; Miller 2010). The splash dams and associated log drives on the lower Entiat River resulted in the removal of instream structure, perpetuating and increasing an already predominantly homogeneous bed.

Historically Reach 1C was likely single-threaded and relatively straight, similar to other reaches within the lower Entiat River valley segment. A lumber mill dam (Kellogg Mill dam) approximately 8 feet high blocked flow for decades in the early 20th century at the downstream end of the reach. This roughly 8-foot increase in the base level significantly reduced the local gradient, resulting in deposition and increased channel sinuosity as is seen in aerial photos from the 1940s. Following removal of the dam, the reach was straightened and the banks were protected for flood control which increased the channel gradient. The convex shape of the existing profile through Reach 1C suggests the channel has not yet completely adjusted to the dam removal, as the steeper lower section continues to headcut into the flatter upper section. Even without human straightening, the channel would have likely adjusted to the dam removal by straightening to its historical relatively low sinuosity and headcutting through the sediment deposited upstream of the old dam.

Flood Control

Following the 1948 flood, portions of the lower Entiat River channel were deepened and straightened in an effort to increase conveyance, thereby reducing flood potential (Erickson 2004). Historic channel straightening is only apparent in Reach 1C (RM 3.6 to 4.2) where measured sinuosity decreased from 1.24 in 1945 to 1.03 in 1962, representing a 17 percent decrease (Figure 27). The channel was mechanically straightened following the 1948 flood (Reclamation 2009), but it is unclear how much of the channel straightening may have actually resulted from the flood itself or how much straightening would have occurred naturally if given time to adjust to the dam removal. The highly sinuous reach as measured in 1945 was not natural; rather, it was the result of decades of sediment deposition in the backwater of the Kellogg Mill Dam that was located at RM 3.6. The Kellogg Mill Dam was destroyed in 1932 (Reclamation 2009), and a very large flood, such as the 1948 flood, could have resulted in an avulsion through the reach, naturally straightening the overly sinuous channel. Based on the gradient, the presence of erosion-resistant glacial outwash throughout the valley bottom and measured sinuosity immediately upstream and downstream, a more appropriate "natural" sinuosity for the reach would be roughly 1.1 (as opposed to 1.24). Using this as a baseline, the decrease in sinuosity between RM 3 and 4 would only be about 6 percent, not 17 percent as previously documented. Although it is possible that other sections of the lower Entiat River have been straightened to accommodate orchards or other human uses, there is no topographic or geomorphic evidence suggesting that additional significant channel straightening occurred downstream of RM 7.0.

Also following the 1948 flood, levees and riprap totaling 2 miles in length were installed within the lower Entiat River (Erickson 2004). Today there are a total of approximately 3.4 miles of riprap and levees within the 14 miles of riverbank (right bank plus left bank) along the lower Entiat River, with approximately 15.4 percent of banks containing levees and approximately 8.4 percent protected by riprap. Of the levees, 75 percent are constructed of native bed/bank material (push-up levee) without armoring, many of which are discontinuous. Of the riprap, 52 percent is adjacent bedrock and 21 percent is located beneath bridges. Based on estimates from LiDAR mapping and hydraulic modeling, small push-up levees currently block roughly 20 percent of the 2-year floodplain area from floodwater access. As discussed previously in this report, the addition of levees and riprap has increased local instream shear and velocity, but not to the point of inducing bed scour or significant bank erosion. The volume of water and the rate at which water is moving in the overbank area (with or without levees) is insignificant compared with the volume and rate of water within the bankfull channel.

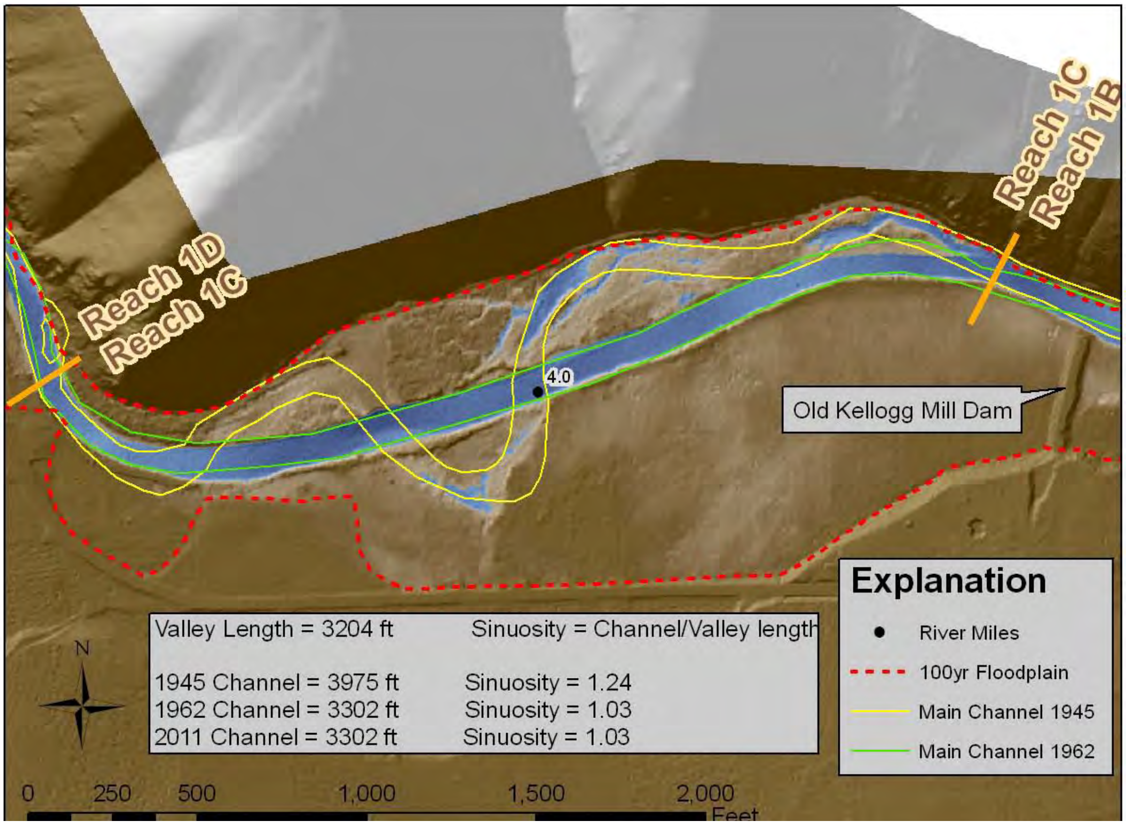

Figure 27. LiDAR view of the sinuosity changes over time in Reach 1C.

Logging

Logging for timber harvests and related activities have resulted in less LWD available for recruitment, increased runoff potential, and increased fine sediment production (Reclamation 2009a). The lack of LWD 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 LWD

The number of historical logjams per mile is unknown, but the confined river corridor and high transport competency of the lower Entiat River has limited recruitment and retention of LWD for thousands of years. It was well documented that most natural logjams were removed from the lower Entiat River by dynamite or other mechanical means in order to clear the path for splashed timber passing downstream to the lumber mills (Reclamation 2009a;

CCCD 2004; Erickson 2004). 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 generally LWD has been allowed to accumulate in the lower Entiat River (Reclamation 2009a). Over the past few decades, a total of 16 logjams (2.3 per mile) have formed in the lower Entiat River, 5 of which were constructed as part of various habitat improvement projects.

Of the 16 existing logjams in the lower Entiat River, most are located at the head of islands. Assuming a scattering of natural logjams would have formed on the banks as well as the islands, it is likely that historically there were more logjams than are present today, but not dozens more. The conditions did not exist historically to recruit vast numbers of logjams as in other transport-limited rivers. Historical logjams may have been significantly larger than existing logjams, given the lack of large diameter key members today. Historically, there were also likely more individual LWD structures associated with wind-fallen trees that were large enough to remain stable in the river for more than one or two high flow seasons.

Loss of Large Pools

The number of large pools reportedly decreased by 91 percent, from 6.7 to 0.5 large pools per mile, between the 1935 U.S. Bureau of Fish counts of resting pools and the modern counts of Class I pools (Andonaegui 1999). In the U.S. Fish Bureau pool count, resting pools were defined as pools greater than 25 square yards and 2 feet deep; the Class 1 pool counts were defined as pools greater than 3 feet deep and 20 square yards (CCCD 1998; Andonaegui 1999). The depth requirement between these two measurements is significantly different, favoring greater numbers of pools under the 1935 definition. It is difficult to make a direct comparison of the number of pools without the same measurement methods and without knowing the specific methodology for taking the measurements (e.g., what were the river flows at the time of measurement; were the pool depth measurements taken from the water surface, bankfull surface, or as a comparison of maximum depth to average depth).

As a result of these unknowns, the documented 91 percent decrease in pools may not be completely accurate. The reduction in pools is likely closer to a maximum of 52 to 60 percent derived from an estimate of 3.5 to 4.0 pools per mile historically as previously discussed. The reduction in large pool quantity is likely a consequence of the removal of instream structure such as log jams and large boulder clusters. Without large instream structures capable of forcing significant flow convergence, the armored bed cannot be scoured and large pools cannot be formed or maintained.

Agriculture and Irrigation

As many as 19 irrigation diversions and several associated passage barriers once existed on the Entiat River (Erickson 2004). Stream surveys between 1934 and 1937 indicated no Upper Columbia Chinook salmon and very few Upper Columbia steelhead were returning to the Entiat River, largely as a result of passage barriers associated with irrigation dams as well as logging and hydroelectric dams (Erickson 2004). All known passage barriers associated with irrigation have now been addressed on the lower Entiat River, but the effect of past barriers has impacted the system.

Irrigation withdrawals also reduce instream flows, particularly during summer low-flow periods. Several irrigation diversions remain in the lower Entiat River. Summer low flows and elevated temperatures have not been identified as major limiting factors for this area; however, the lower portion of Reach 1B has been listed for elevated water temperatures by the Washington State Department of Ecology (WDEQ 2011). Fish screens have been installed on all of the lower Entiat River irrigation diversions to prevent entrainment.

Over roughly the past decade, several irrigation diversions have been screened to prevent fish entrainment or otherwise improved or consolidated to provide greater instream flow on the Entiat River. For example, improvements at the Knapp-Wham diversion and irrigation piping allowed for the decommissioning of the Hanan-Detwiler diversion near RM 5.1 conserving approximately 2 cfs of surface water in the mainstem of the lower Entiat River. Additionally, several farm water efficiency improvements throughout the river basin have replaced impact sprinkler heads with more efficient nozzles, conserving instream flow which has yet to be quantified.

Roads and Development

Hard surfaces associated with roads and development can lead to increased runoff potential and increased sediment production. Increased runoff and increased sediment production have not been identified as limiting factors for the lower Entiat River, although increased fine sediment production has been identified as a limiting factor in reaches farther upstream. The high sediment transport capacity of the lower Entiat River buffers the assessment area from impacts associated with increased sediment production. Logging and clearing of the riparian areas is the most significant impact associated with roads and development in the lower Entiat River.

Roads and associated bridges constrict the channel and floodplain in several areas (Figure 28). Artificial constriction has a negligible effect on water surface elevation across all flows, but can increase the local channel velocity and shear roughly 20 percent when measured in HEC-RAS by comparing geometries with and without the constriction. Despite the local increase in channel velocity and shear, road and bridge constrictions have not caused incision or localized pool scour which indicates that their impacts are negligible due to the armored nature of the bed and banks.

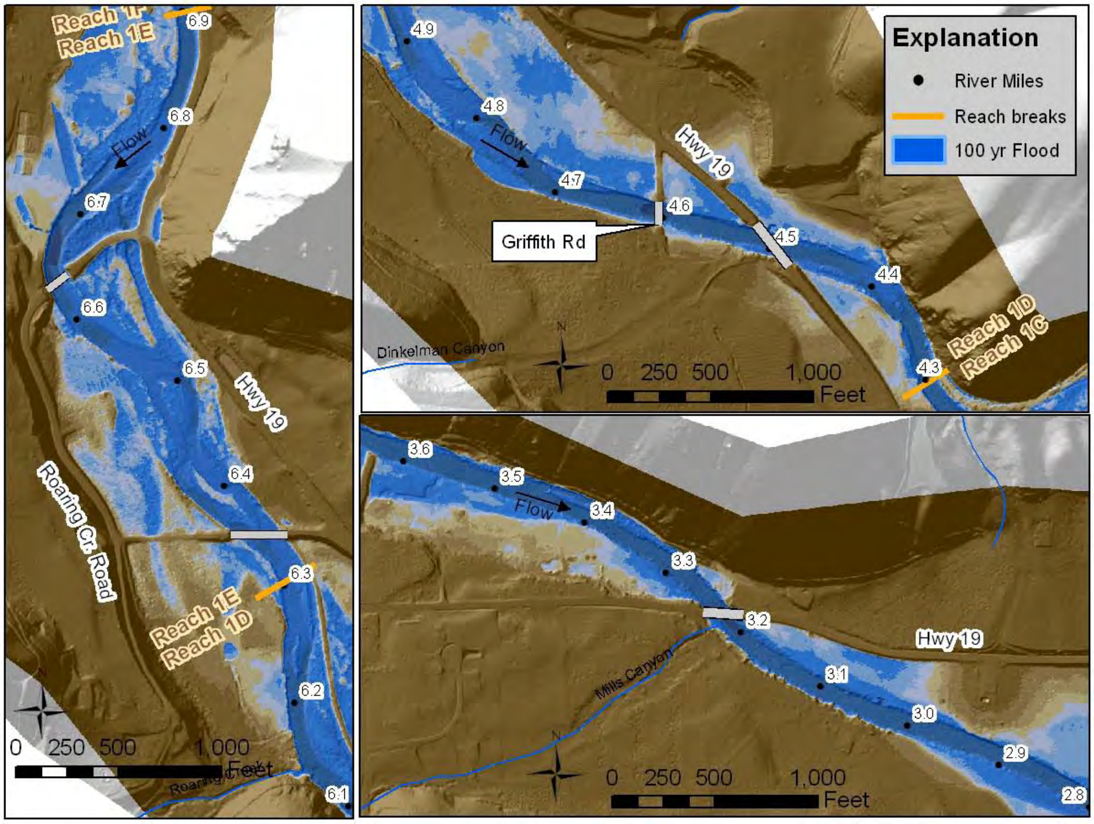

Figure 28. LiDAR view showing road/bridge constrictions and the estimated 100-year flood inundation area.

Removal of Riparian Vegetation

The removal of riparian vegetation for agricultural expansion is ubiquitous across the entire lower Entiat valley. It is estimated that the majority of the 2-year floodplain (approximately 170 acres) would have been populated with riparian vegetation prior to Euro-American settlement in the area. Surveys and photos from the 1930s show the entire lower Entiat River valley completely void of trees (Erickson 2004). Since 1945, the small amount of riparian vegetation has generally remained constant or has decreased, with the exception of Reach 1A where riparian vegetation nearly doubled as a result of bar and floodplain development associated with deposition in the backwater from Rocky Reach Dam on the Columbia River (Erickson 2004 and analysis from this *Reach Assessment*). Based on GIS measurements from 2006 aerial photography, there are roughly 106 acres of riparian vegetation, representing a 38 percent net reduction, 24 percent of which has been lost since 1945. This estimate does not include upland areas encompassed by terraces or other lands inundated beyond the estimated 2-year flood event. Most large cottonwoods (greater than 30 inches in diameter at breast height) have been removed since cottonwood can harbor pests that damage crops (Erickson 2004).

Beaver

Removal of beaver has impacted riparian communities and recruitment of LWD, most notably along channel margins and within the few existing side channels in the lower Entiat River. Beaver activity would have increased the rate of LWD recruitment and likely improved the longevity of small side channels by restricting flow into the side channels. Without a structure regulating flow into the side channel, the tendency is for the channel to become abandoned or convey more and more flow, eventually evolving into a larger channel with essentially the same character as the mainstem. Current observations show that many of the small low-velocity side channels today are partially maintained by LWD, which beaver activity would have improved. 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 debris.

Fire

Changes in the fire regime to more frequent severe fires have not resulted in recorded or observed increases in sediment delivery in the lower Entiat River. High-intensity storm events following severe wildfires can significantly increase sediment production, but the high sediment transport capacity of the lower Entiat River generally buffers the assessment area from impacts associated with increased sediment (CCCD 2004). For example, the overall trend in fine sediment sampled in the lower 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.

Existing Trends

Without the potential for significant alluvial deposition, channel migration, or LWD recruitment, it is unlikely that the lower Entiat River will naturally develop into a dynamic, habitat-rich environment even after several centuries of evolution. However, small-scale changes are likely to occur over shorter periods of time.

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 riparian vegetation to provide shade, less water in the river, less snowmelt in the summer, and warmer temperatures, the potential to increase water temperatures on the lower Entiat River is high. Summer water temperatures and low-flow passage barriers may become more significant limiting factors in the future. On the other hand, 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 lower Entiat River. Some of the only observable dynamic changes to have occurred on the lower Entiat River were the result of large floods. Greater peak flow suggests the potential for more extreme floods, which, although potentially damaging to human infrastructure, health, and safety, may actually induce change and increase channel complexity on the lower Entiat River.

It is likely that warmer/drier summers with less snowpack will equate to more fires and fewer trees, especially in the lower elevations of the basin. With fewer trees, the potential for LWD recruitment will continue to decline along with shade and cover.

Overall, the sum of positive and negative habitat trends appears to be weighted toward the negative side of the scale. Without action, the future looks less promising than the present for habitat in the lower Entiat River.

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, targeted conditions can be identified which will provide fish with the physical habitat necessary to overcome identified biological limiting factors.

Table 5 outlines the physical conditions generally preferred by steelhead and spring Chinook salmon during several different life stages as compiled by the U.S. Forest Service in Entiat, Washington. Spawning and egg incubation habitat for spring Chinook salmon have been omitted from the tables for this report, because spring Chinook salmon did not historically nor do they currently spawn in the lower Entiat River.

Table 5. 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 m);[a] 0.78 feet (less than 24 cm)[b]	N/A
Velocity	2.3 feet/second (0.71 m/second)[a] 1.31 to 2.98 feet/second (40 to 91 cm/sec)[b]	N/A
Gravel size	1.28 inches (32.5 mm)[a] 0.24 to 4.0 inches (0.6 to 10.2 cm)[b]	N/A
Water temperature	Between 39°F (4°C)[b] and 55°F (13°C)[r]	N/A
Other	Prefer protective cover	N/A
Egg incubation to emergence habitat		
Fine sediment (particles less than 1 mm)	Less than 20% fine sediment results in increased embryonic survival[c]	N/A
Water temperature	5.0° C to 11.0° C[d]	N/A
Dissolved oxygen	At least 50% survival of embryos achieved at 5 mg/L to 9 mg/L[e]	N/A
Juvenile rearing habitat		
Groundwater	Groundwater provides cooler temperatures during the summer and warmer temperatures during the winter, resulting in increased juvenile survival.[c]	

<table>
<tr><th>Perferred Habitat</th><th>Steelhead</th><th>Spring Chinook Salmon</th></tr>
<tr><td>Velocity</td><td colspan="2">Less than 1.0 feet/second for holding; proximity of low-velocity water for holding to relatively high velocity water for feeding[p, q]
Refugia from extreme high flows and extreme high velocity[q]</td></tr>
<tr><td>Large woody debris</td><td colspan="2">Large woody debris increases the complexity of stream habitats by creating areas with different depths, velocities, substrate types, and amounts of cover[c,p]

more than 20 pieces/mile
more than 12-inch diameter, more than 35 feet long;[k,n]
and adequate sources of woody debris recruitment in riparian areas</td></tr>
<tr><td>Pools</td><td colspan="2">As pool density (m^2/km) increases, smolt production increases (i.e., 2,000 [m^2/km] pool area resulted in approximately 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 more than 3 m in wetted width at base flow, pools more than 1 m deep (holding pools) with good cover and cool water and a minor reduction of pool volume by fine sediment[l]</td></tr>
<tr><td>Temperature</td><td colspan="2">10.0° C to 14° C[g]</td></tr>
<tr><td>Substrate Character and Embeddedness</td><td colspan="2">Substrate is gravel or cobble with clear interstitial spaces;
reach embeddedness less than 20%[i,j,ln]</td></tr>
<tr><td>Overhead Cover</td><td colspan="2">Juveniles exhibit preference for habitats with overhead cover[o]</td></tr>
<tr><th colspan="3">Adult holding habitat</th></tr>
<tr><td>Pool Quality</td><td>Depth 1.0 to 1.4 m[h];
Deep habitats of intermediate size (200 to 1,200 m^2)[h];
Adults use pools with cover associated with flow (average is 9.3 cm/second). Cover associated with flows less than 3 cm/s are avoided[h];
Low streambed substrate embeddedness (less than 35%)[h].</td><td>Where streams are more than 3m 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]</td></tr>
<tr><td>Pool Frequency</td><td>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</td><td>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</td></tr>
</table>

Perferred Habitat	Steelhead	Spring Chinook Salmon
Large Woody Debris	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	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	less than or equal to 10[k, m]	
Streambank Condition	More than 80% of any stream reach has at least 90% stability[l,m]	

[a]Zimmerman and Reeves 2000.
[b]Nelle and Moberg 2008.
[c]Quinn 2005
[d]Murray and McPhail 1988.
[e]Coble 1961.
[f]Sharma and Hilborn 2001
[g]Bjorn and Reiser 1991.
[h]Nakamoto 1994.
[i]USFWS 1995
[j]NOAA Fisheries Service 1995.
[k]USFS 1994
[l]WDNR. 1993
[m]Overton et al. 1995
[n]USFS et al. 2004
[o]Fausch 1993.
[p]Liepitz 1994
[q]Bouwes et al. 2010
[r]Archibald 2012

Although it is helpful to understand the physical conditions preferred by the species of concern, not all of those conditions are appropriate for the lower Entiat River given its natural character and modern constraints. Table 6 summarizes the constraints that will likely influence the habitat improvement process.

Table 6. Summary of constraints impacting habitat improvement on the lower Entiat River.

Constraint	Description
Floodplain development	Buildings, roads, bridges, and irrigation components among other human infrastructure have encroached onto the floodplain and in some cases restrict the potential for floodplain and channel rehabilitation due to the risk of damaging valuable infrastructure. Land acquisitions and easements for areas with high habitat potential could be considered to reduce the effect of this constraint over time.
Floodplain clearing	Large portions of the valley bottom and active floodplain have been converted from native vegetation to agriculture, orchards, grazing pasture, and manicured gardens. 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.
Irrigation	Irrigation withdrawals reduce the volume of available water during the irrigation season and, in some instances, return warm water to the channel. Removal of all irrigation practices is unrealistic in the short term, since irrigation is vital to the local economy.
Human safety and liability	Although logjams and other instream structures are a natural component of rivers, many people view instream structures as unsafe. It is unlikely that the very large, potentially channel-spanning logjams that are necessary to create habitat diversity and habitat on the lower Entiat River will be 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.

Many of the limiting factors affecting fish growth and survival on the lower Entiat River are a result of lack of sufficient slow-water and off-channel habitat which do not readily form in this type of system characterized by high velocity, sediment transport and incision. Although improvements can be made to reduce anthropogenic impacts to limiting factors for steelhead and salmon, many of the existing limiting factors are mainly the result of natural conditions and have likely been limiting in the lower Entiat River for thousands of years.

Instream Structure

The greatest anthropogenic impacts on river process and fish habitat in the lower Entiat River are related to clearing the channel of instream structures and clearing a large proportion of the riparian area which reduces the potential for recruiting new instream structures. Clearing riparian vegetation also has the secondary effect of reducing cover and shade, both of which contribute to limiting factors for the assessment area. Target conditions include greater numbers of instream structure, including LWD and boulders, as well as the establishment of mature riparian vegetation. Greater numbers of large logjams in particular will increase the potential for pool development, with a target condition of roughly 3.5 to 4 large pools per mile. LWD and other instream structures will be most effective where they can interact with other structures, including bedrock, in order to amplify their cumulative effect. More instream structures will also create habitat diversity, instream velocity breaks, and cover, all of which will address limiting factors. The LWD component of the instream structures should be maintained by the natural succession of riparian vegetation in a broad, relatively undisturbed riparian corridor. Ideally, the target riparian corridor width would roughly equal that of the floodplain. Taking constraints into account, an appropriate target would be 100 feet wide or greater. The selection of a 100-foot riparian buffer is based on tree height, the potential for LWD recruitment and shade, and the very low rates of channel migration in the lower Entiat River. Beyond 100 feet from the bank, shade and LWD recruitment potential are very low. Without active migration, the buffer area will not likely need to be expanded to account for significant bank recession. Creation of these conditions through natural succession will take hundreds of years to achieve.

Sinuosity

The channel form has been altered by humans directly through mechanical means, including channel straightening. Target conditions for sinuosity are essentially identical to the existing conditions, with a sinuosity near 1.1, with the exception of Reach 1C near RM 4.0 where channel straightening has occurred. Based on the existing thalweg location, meander bends are developing in the otherwise straight reach with a wavelength roughly equivalent to historical conditions. The only difference between past sinuosity and target sinuosity in Reach 1C will be the amplitude of the bends that ultimately form there. The bend amplitude in the 1940s averaged 300 feet, which was enhanced by the backwater conditions from the Kellogg Mill dam. In the absence of the Kellogg Mill dam, the amplitude of future bends is unlikely to equal that of the impounded 1940s channel. An appropriate amplitude for the existing channel gradient is between 150 to 200 feet, which provides a consistent gradient rather than the convex profile that exists through the reach today.

Bed and Banks

Target conditions for the bed and banks do not differ from the existing and past conditions with the exception of removing riprap where possible. Both the bed and banks are naturally armored with boulders derived from glacial outwash and as a result, significant channel migration is not expected in most locations with or without riprap. The greatest benefits will be associated with the removal of existing riprap from those few areas where channel migration is expected over time (Figure 29). For example, in Reach 1C, channel migration is expected to follow the pattern of the existing thalweg development, with expansion into the left bank where the thalweg abuts the left bank and expansion into the right bank where the thalweg abuts the right bank. In Reach 1C, removal of riprap will allow the channel to continue adjusting to the straightening that occurred after removal of the Kellogg Mill dam.

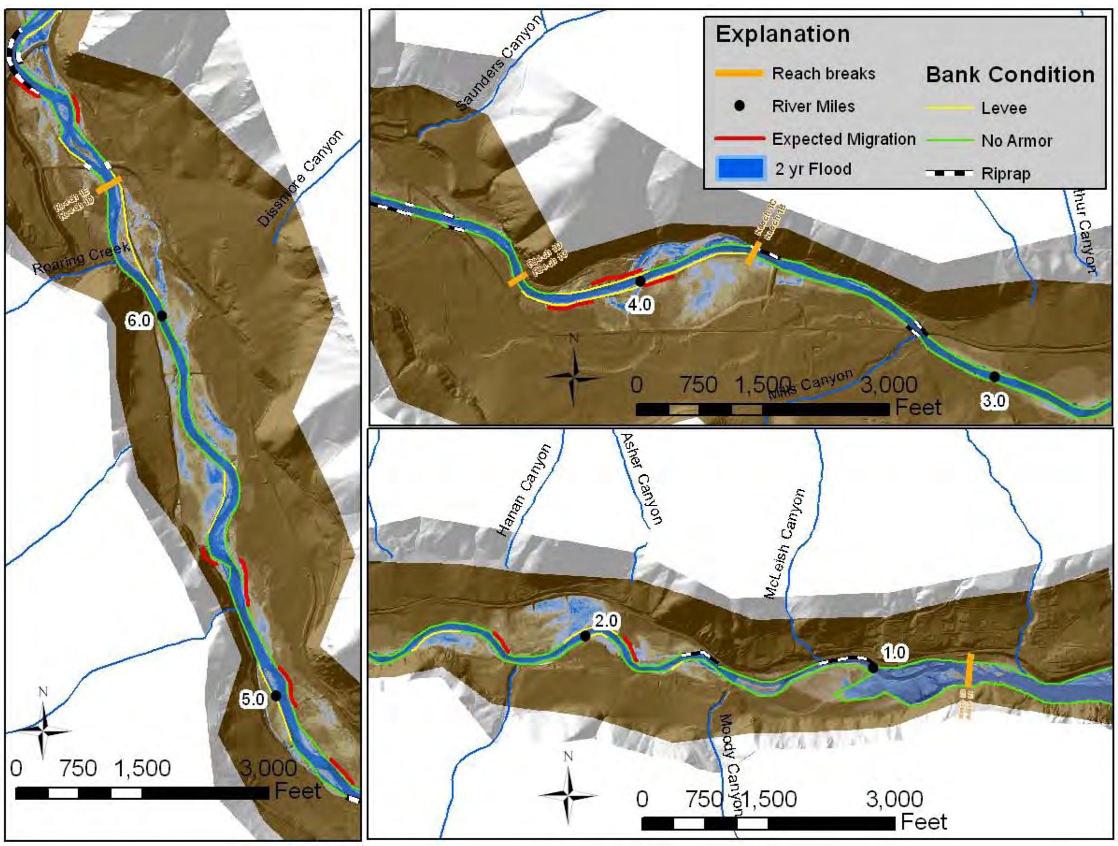

Figure 29. LiDAR view of locations where channel migration (albeit slight) is most likely to occur over time based on measured trends in historic channel migration, bank composition, and observed thalweg development. Bank erosion and the potential for migration may occur elsewhere, but those banks highlighted in red show the greatest potential for migration. The red lines do not represent a prediction of the lateral extent of migration, only where along the bank migration is most likely. Predictions assume no bank protection. The amount of migration is unknown, but based on channel migration rates in other areas of the lower Entiat, it can be assumed that both lateral and downstream migration rates would not likely exceed an average rate of 3 feet per year, with the greatest amount of migration expected within the first few years following removal of bank protection.

Floodplain Connection

Floodplain connection has been impacted by levees constructed to protect property and infrastructure. The majority of these structures have had little effect on the channel due to the naturally armored, confined, and incised conditions in the lower Entiat River, but there are several locations where levees cut off an otherwise accessible floodplain. Levee and riprap removal will help achieve the target conditions. Levees and riprap may need to be maintained in areas where required to protect infrastructure that cannot be relocated or abandoned. In some instances, it may be possible to partially achieve floodplain connection even with the constraints, by passing a regulated amount of water through a levee using a culvert, irrigation gate, or some other metering device. Although the target conditions include full reconnection of available floodplain, partial reconnection is beneficial and may be considered as a viable alternative when the constraints dictate. For habitat occupied by anadromous fish with a life cycle of generally less than 10 years, the floodplain areas with the potential for frequent inundation will provide more benefit than the floodplain areas inundated only by large, infrequent floods (Figure 30).

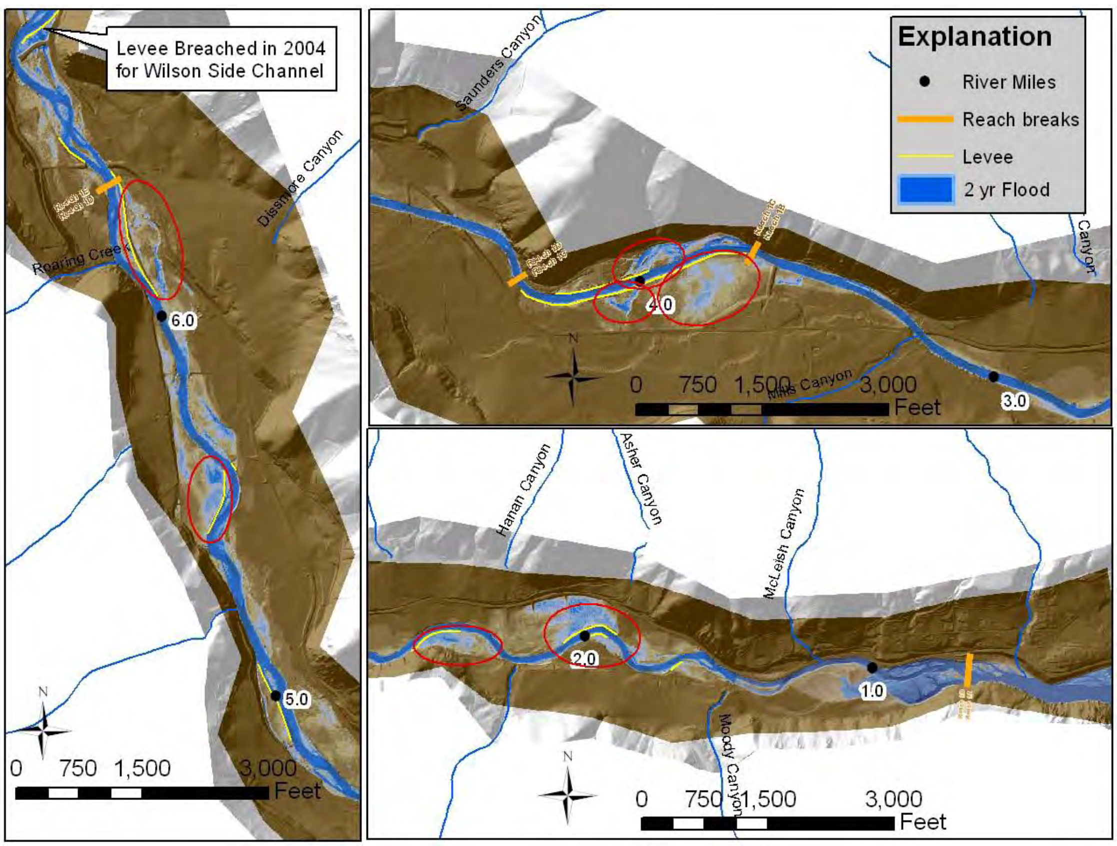

Figure 30. LiDAR view showing the 2-year floodplain highlighting areas cut off behind levees.

Related to floodplain connection is the establishment of viable off-channel habitat. Several side channels currently exist on the lower Entiat River, many of which are supported with LWD in the form of logjams at the inlet of the side channel. For split-flow side channels around islands, logjams often protect the island from excessive erosion while providing structure and cover for fish. On smaller, floodplain side channels, logjams often partially block the inlet(s), reducing high-flow volumes through the side channel and preventing avulsion or higher volumes of split flow. Target conditions on the lower Entiat River include more LWD located at the inlet of existing side channels to improve their longevity and habitat diversity. Side channel evolution on the lower Entiat River begins with overflow across a point bar; therefore, targeted side channel development should occur on point bars, especially where channel migration is expected (Figure 31).

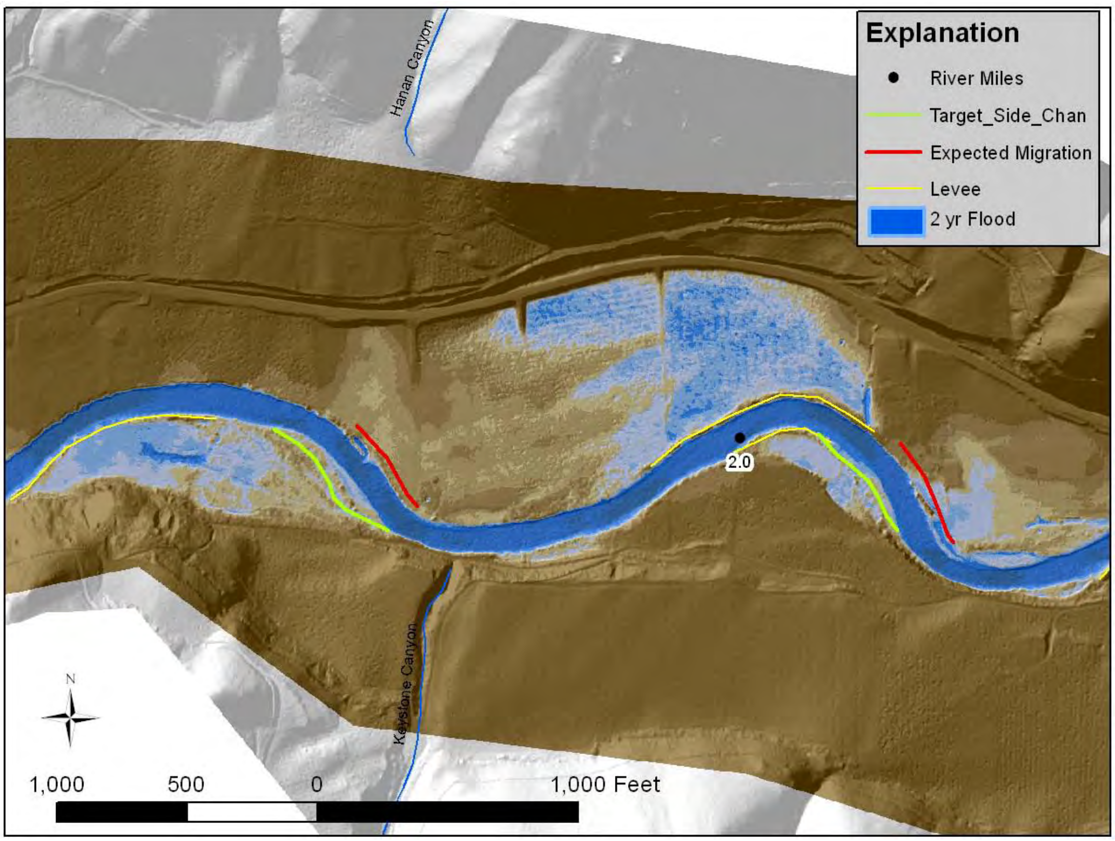

Figure 31. Targeted point bar locations for future side channel development opposite banks where channel migration is likely. Bank erosion and the potential for migration may occur elsewhere, but those banks highlighted in red show the greatest potential for migration. The red lines do not represent a prediction of the lateral extent of migration, only where along the bank migration is most likely. Note that targeted side channels follow existing high-flow pathways along the inside of the bend and do not bisect the point bar.

Summary

Target conditions are similar to past conditions with the exception of accommodating major constraints where necessary. Despite many human modifications to the river, the natural resistance to change in the lower Entiat River has resulted in very few significant alterations of its form or process. Table 7 is a summary of the few differences between past, existing, and target conditions, including natural processes necessary to maintain target conditions and the limiting factors addressed.

Table 7. Summary of the 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
Large Pools	Roughly 3.5 to 4.0 per mile	0.5 per mile	3.5 to 4.0 per mile	Recruitment of large instream structures to force flow convergence	Juvenile habitat; instream complexity; adult holding; water temperatures
Sinuosity	Roughly 1.1	Roughly 1.1	Roughly 1.1	N/A	N/A
LWD	Few logjams/mile (estimate less than 10)	2.3 logjams per mile; 132 individual pieces per mile	5 to 10 logjams per mile; as many individual pieces providing cover along the banks as possible	LWD recruitment and retention	Juvenile habitat; instream complexity; cover; adult holding; steelhead spawning
Channel geometry	Incised 1 to 20 feet	Incised 1 to 20 feet	Incised 1 to 20 feet	N/A	N/A
River bed and banks	Armored with large boulders	Armored with large boulders and riprap	Armored with large boulders	Remove riprap where possible	Instream complexity; off-channel rearing
Off-channel habitat	Few side channels	Fewer side channels	Few side channels, but more than existing	Channel migration where possible; recruitment and retention of LWD	Juvenile habitat; riparian vegetation and cover; off-channel rearing
Floodplain connection	Limited to narrow active floodplain between terraces	Limited to narrow active floodplain and further reduced by levees	Limited to narrow active floodplain between terraces and reduced only by levees protecting vital infrastructure	Remove and/or selectively breach levees	Riparian vegetation and cover; off-channel rearing

Form	Historical Condition	Existing Condition	Target Condition	Process(es) Needed to Achieve Target Condition	Limiting Factor(s) Addressed
Riparian condition	Dense mature trees; riparian area at least 100 feet wide	Partially mature trees; riparian area generally 25 feet wide	Dense mature trees; riparian area at least 100 feet wide	N/A	Instream complexity; riparian vegetation and cover; off-channel rearing; water temperatures

POTENTIAL HABITAT ACTIONS

The lower Entiat River has not been a dynamic system since the last ice age, and it will not become a dynamic system without major changes to the entire watershed. Reach-based habitat improvement actions should not be expected to create a dynamic, thriving, juvenile rearing nursery or any other major change to the existing character of the lower Entiat River. Habitat improvement efforts should be aimed at improving and enhancing those forms and processes that currently exist, rather than attempting to create wholly new conditions that may not be appropriate or sustainable. The lower Entiat River requires more areas with deep pools, slow water, and cover, preferably within the same vicinity, to make the greatest improvement to limiting factors affecting salmonids.

The implementation strategy as summarized in the *Tributary Assessment* utilizes a hierarchical approach to habitat improvement adapted from Roni et al. (2002) and Roni (2005) including the following categories: 1) Habitat Protection, 2) Water Quality and Quantity, 3) Habitat Connectivity, 4) Channel Process, and 5) Instream Habitat. Although the implementation strategy groups habitat improvement actions according to specific categories, most actions complement each other and overlap between categories. Following is a summary of each category of the implementation strategy including those habitat improvement actions appropriate to that category.

Habitat Protection

The most viable and sustainable habitat protection actions in the lower Entiat River will focus on existing off-channel habitat, instream structures, and riparian vegetation (Figure 32). Existing off-channel habitat includes several small floodplain side channels, particularly within Reach 1D, and relatively large amounts of low-velocity, off-channel habitat in Reach 1A associated with backwater conditions. Instream structure protection includes logjams at the head of islands, banks with accumulated LWD and existing habitat improvement projects. Riparian vegetation protection includes those areas with dense vegetation located within the 2-year floodplain or within 100 feet of the existing banks. Any of these areas represents valuable existing habitat that should benefit from protection; however, since the channel is not dynamic, habitat protection and a reliance on natural process evolution alone will not change habitat conditions on the lower Entiat River for hundreds of years.

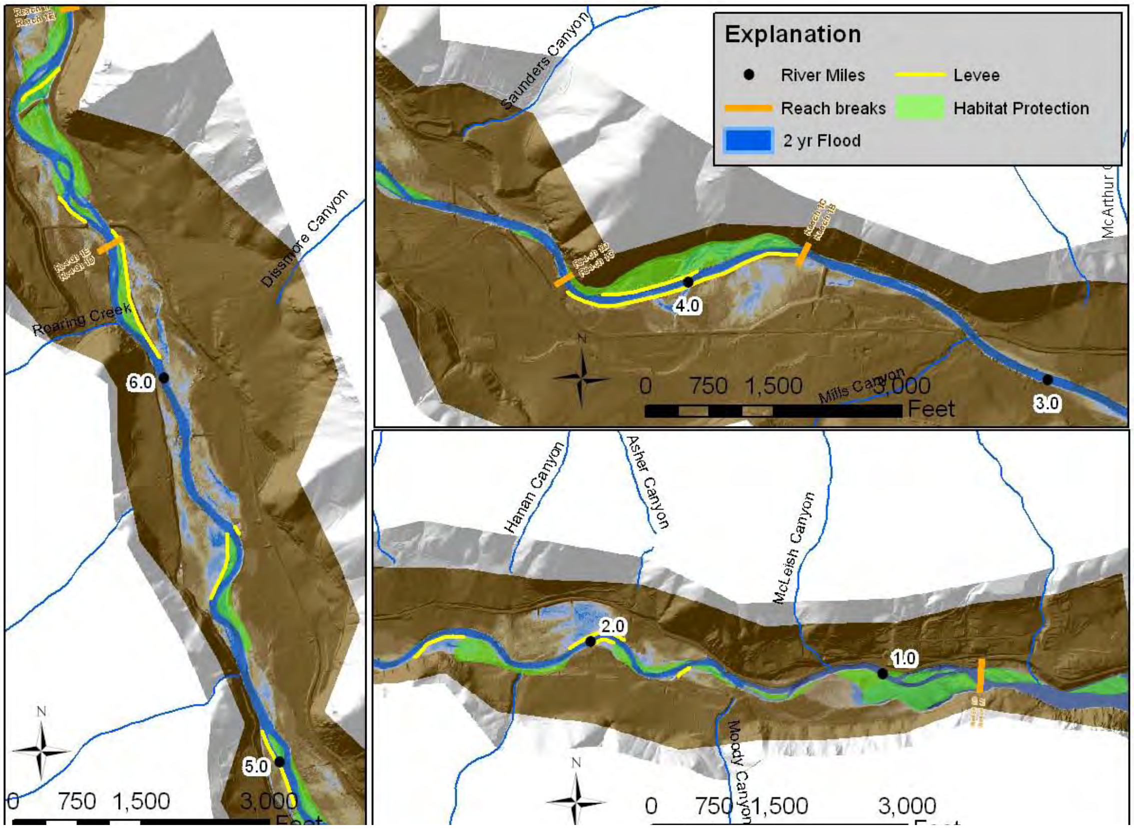

Figure 32. LiDAR view of potential habitat protection areas denoted based on floodplain accessibility and presence riparian vegetation. Instream habitat improvements are still appropriate within these areas.

Water Quality and Quantity

Existing and ongoing improvements and modernization of irrigation diversions and withdrawals will continue to address the issue of water quantity on the lower Entiat River. Additionally, improving riparian vegetation will increase shade and help reduce instream temperatures while increasing natural instream nutrients and buffering potential pollutants from agricultural operations. Increased floodplain connection will increase hyporheic flow, potentially changing water temperatures both in the summer (cooler) and winter (warmer). More instream structures have the potential to increase deep-water pools that provide relatively warm-water refuge for rearing juveniles during the cold winter months.

Habitat Connectivity

For this report, habitat connectivity refers only to the removal of human-constructed barriers to existing habitat. The following proposed actions have the potential to improve habitat connectivity within the lower Entiat River.

Levee Removal and Breaching

The most appropriate action to improve habitat connectivity includes removing levees to reconnect the narrow active floodplain on the inside of bends where side channels or alcoves can form (Figure 33). Removing a levee on the inside of a bend could possibly enable the river to access previously disconnected floodplain habitat and also could potentially scour a side channel over time. The time necessary to scour a side channel depends on the frequency of large floods and the extent of bed armoring at the particular site; consequently, the natural development of a side channel after levee removal may take many years. As an alternative, excavating a side channel or alcove can speed up the process considerably by emulating those conditions which likely would have been created by river scour naturally. If a low-velocity side channel or alcove is excavated without the potential for periodic flushing flows, it will likely fill with sand and gravel. The river transports large quantities of sand and gravel which could potentially cause sediment problems after the development of side channels and alcoves. To improve flow connection and stability/longevity, placement of LWD should be planned and included at the side channel split-flow location.

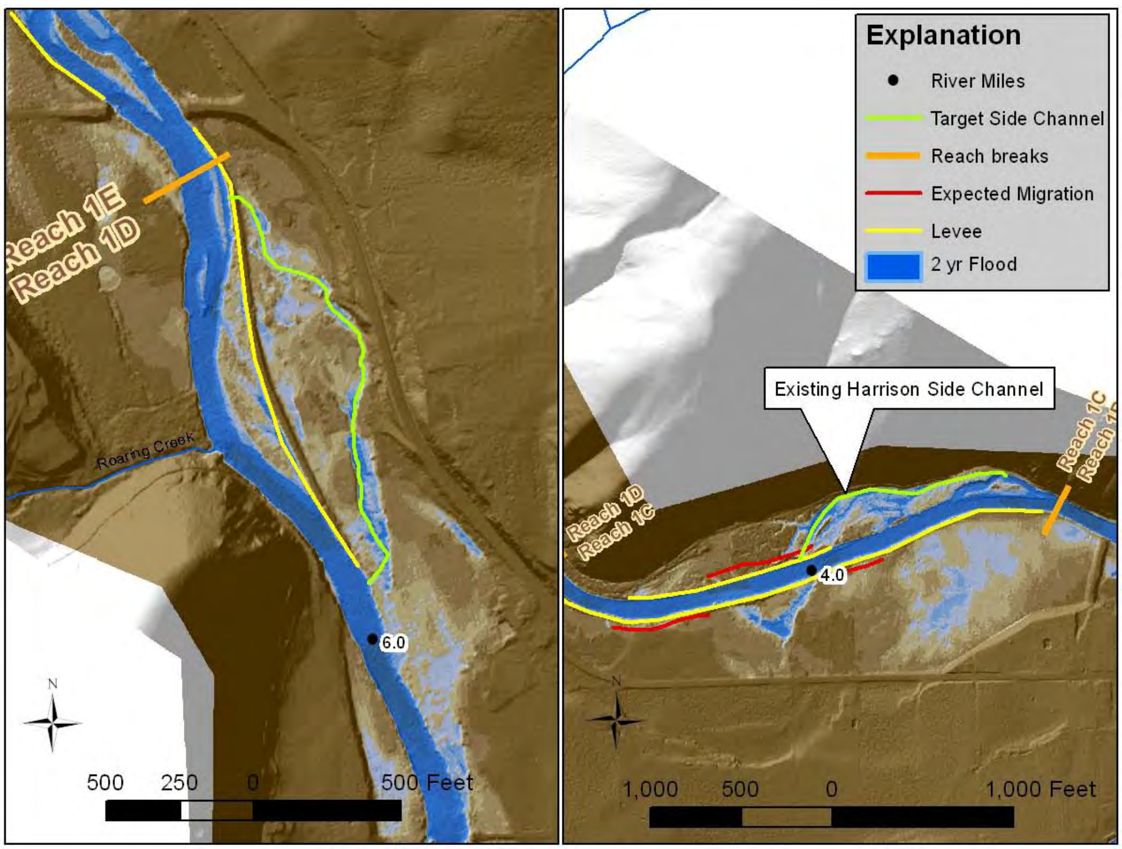

Figure 33. Potential levee removal locations for side channel development. Those banks highlighted in red show the greatest potential for migration if bank armoring were removed. The red lines do not represent a prediction of the lateral extent of migration, only where along the bank migration is most likely.

In addition to LWD at the inlet of a side channel, the invert elevation of the inlet and the number of inlets will need to be evaluated to address sediment issues. Many of the naturally developed floodplain side channels in the lower Entiat River do not have a single, well-defined inlet; rather, they have two or more inlet channels with an invert elevation located just below the bankfull elevation. These small inlets converge several tens of feet back from the bank to form a deeper, single side channel at an elevation somewhat lower than that of the low-flow water surface (Figure 34). During high flows, the multiple inlets serve to dissipate flow energy before converging in the side channel, which reduces the risk of excessive scour and avulsion. During low flows, there often is not an upstream surface connection, but hyporheic flow refreshes the side channel and maintains the surface connection at the outlet.

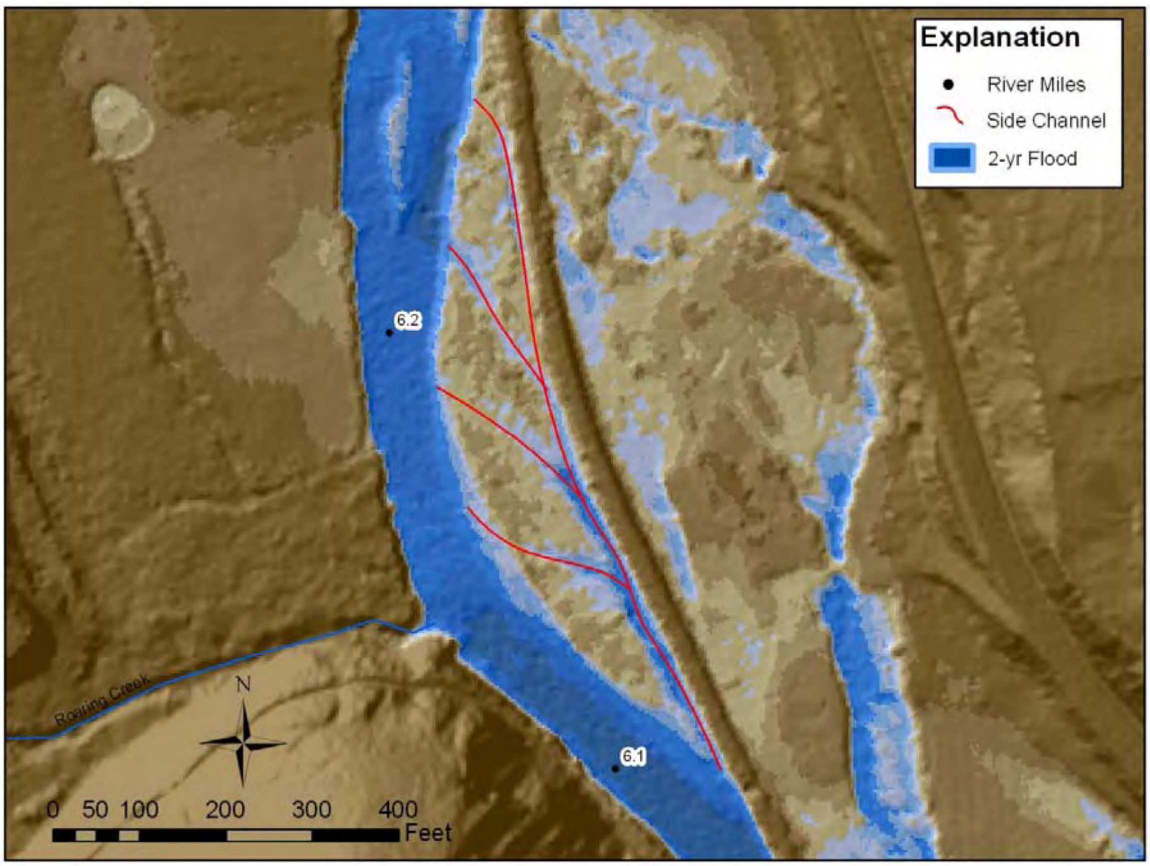

Figure 34. LiDAR image illustrating a side channel with multiple inlets. The main trunk of the side channel is equal to or lower than the elevation of the main channel while the multiple inlets are higher, receiving flow only during high water. As a result, the inlets are disconnected at low flow, and the side channel functions as an alcove. During high water, flushing flows enter through the multiple inlets, inhibiting deposition of fine sediment from potentially filling the side channel.

Side channels in areas other than the inside of a bend do not commonly form and are not maintained as well in straight sections or along the outside of a bend. Much of the risk associated with side-channel function and flooding can be controlled with a culvert or some other flow regulating device passing water through a levee rather than removing the entire levee. In areas where levee removal is not feasible due to constraints, culvert-fed or regulated side channels represent a viable option with minimal risks to property and infrastructure behind the levee. Completed in 2004 by the Washington Department of Fish and Wildlife, the Wilson Side Channel on the left bank near RM 6.7 is one example where low flow has been successfully passed through a levee into a side channel using a culvert. This type of side-channel connection would also potentially work well behind a large existing levee located on the left bank between RM 6.0 and RM 6.3 (Figure 35). Although these types of habitat improvements do not completely restore natural processes in the river, they do not work against or diminish the natural process and are considered a net benefit to habitat in the short term and long term.

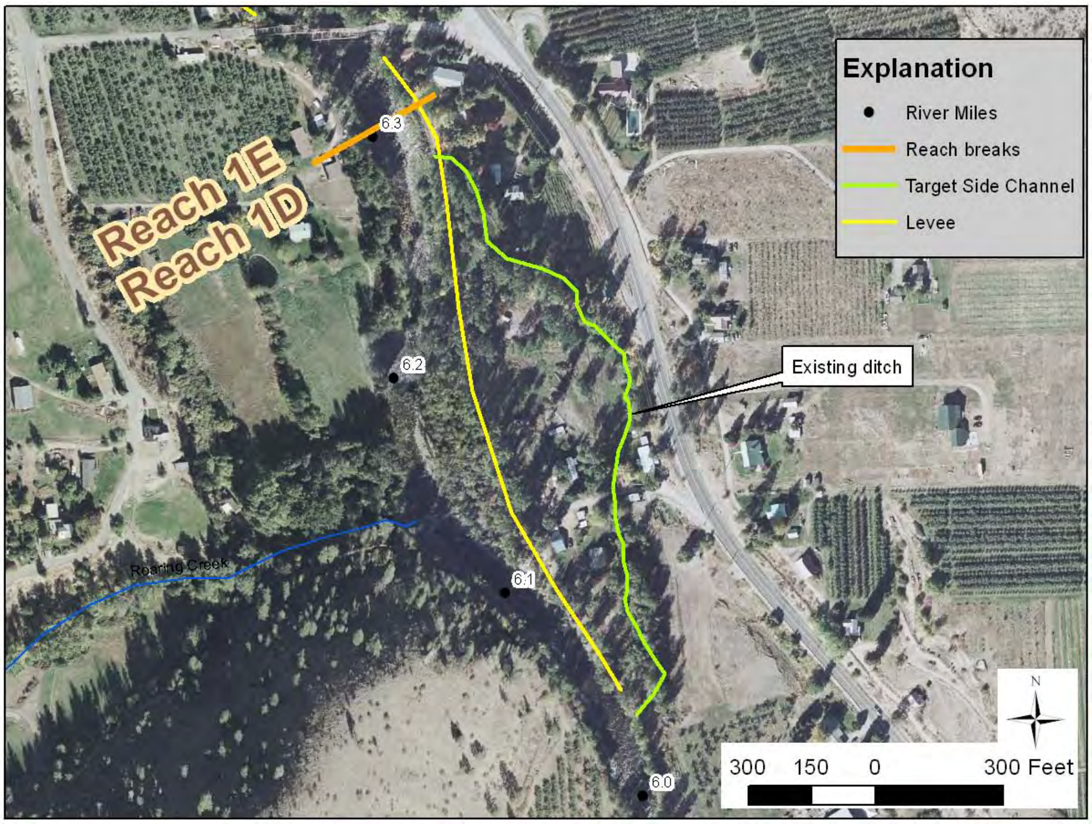

Figure 35. Potential culvert-regulated side channel area behind levee.

In addition to side channels and alcoves, removing levees for the sake of improved floodplain connection also provides a habitat benefit. The decision to remove levees for habitat benefits should be based on the potential for improved frequency of inundation and the actual habitat derived from that improvement. A floodplain with mature riparian vegetation that is inundated annually will provide considerably more habitat benefit to salmonids than will a barren floodplain that is only occasionally inundated during extreme flood events. Given the condition of the lower Entiat River, the removal of a levee will not necessarily result in improved channel migration and/or instream habitat. These potential secondary benefits will need to be verified with further analysis at a project-specific scale. Side channel excavation is not appropriate within floodplain areas that are inundated less frequently than a roughly 5-year recurrence interval flood, or if both banks of the side-channel would exceed 5 feet in height. These are not natural conditions and should not be emulated.

Channel Process

Channel processes are those actions that work to create and maintain channel forms and habitat. For this report, processes have been grouped into major categories: hydrology, sediment transport, channel migration, LWD recruitment, and riparian disturbance and succession. 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 on the lower Entiat River.

Levee Removal and Breaching

Reconnecting habitat through the removal or breaching of levees as discussed previously will help to improve riparian disturbance and succession processes by increasing floodplain connection. Floodplain scour and deposition disturbances provide exposed soil for cottonwood establishment; increased inundation that improves seed propagation and soil moisture; improved nutrient cycling; and other biologic benefits.

Riprap Removal

Riprap has a very minor impact on channel form and process in the lower Entiat River. Natural bed and bank armoring and thousands of years of incision have confined the channel, preventing significant migration. Despite limited migration potential, there are several locations where the addition of riprap has cut off bank erosion processes in areas where channel migration would have otherwise occurred (Figure 36). Removal of riprap in these locations may allow channel migration processes to reestablish. In general, it is best to remove riprap and allow channel migration on the outside of bends to encourage bar building and floodplain development on the inside of the bend. Riprap removal along a straight stretch of river or the inside of a bend may not provide any immediate or long-term habitat benefit or improve channel process.

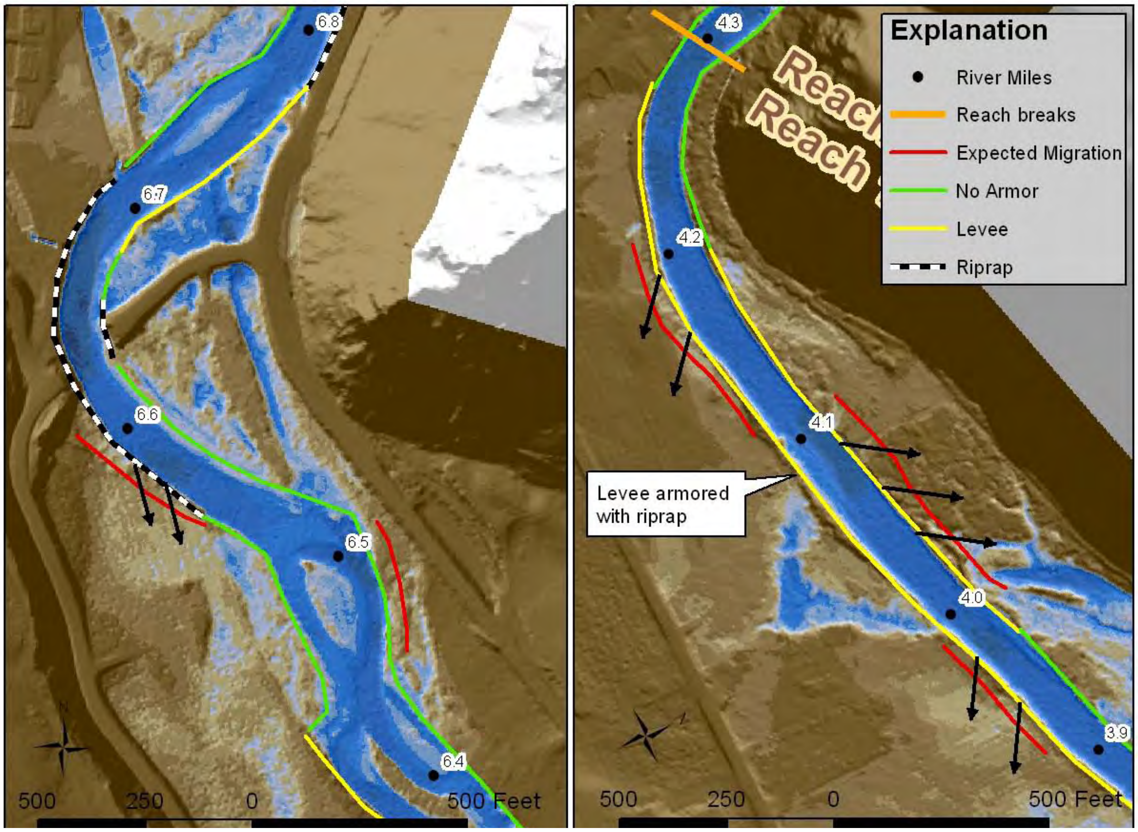

Figure 36. LiDAR view showing areas along the lower Entiat River where riprap has prevented channel migration. Arrows indicate the probable direction of migration if bank protection was removed, and red lines indicate the banks which would mostly likely be influenced by migration. The red lines do not represent a prediction of the lateral extent of migration, only where along the bank migration is most likely. The extent of migration has not been predicted, but based on channel migration rates in other areas of the lower Entiat, it can be assumed that both lateral and downstream migration rates would not likely exceed an average rate of 3 feet per year, with the greatest amount of migration expected within the first few years following removal of bank protection.

Road Fill Removal

Similar to levees, road fill potentially blocks floodplain access, particularly where the approaches to bridges constrict the floodplain. Based on results from hydraulic modeling, the impact of road fill to the river form and process is negligible. In fact, increasing flow convergence through constrictions has the potential to improve habitat conditions on the lower Entiat River by creating a low-velocity backwater condition upstream of the constriction and increasing flow velocity at the constriction that may create a large scour pool, both of which are desirable conditions in the river. Removal of existing road fill will not likely improve favorable channel processes and should not be targeted as a priority for habitat improvement.

Riparian Planting and Buffer Establishment

Better floodplain connection and riprap removal will improve riparian conditions only if riparian species are present and established. Revegetation efforts, livestock fencing, and establishment of a broad riparian buffer within the accessible floodplain will provide the most direct benefit to improving riparian processes in the lower Entiat River. A riparian buffer that is a minimum of 100 feet wide will ensure adequate shade, cover, and LWD recruitment to the river.

Placement of LWD Structures

With very few large trees available along the banks and limited channel migration, local LWD recruitment potential in the lower Entiat River is very low. Some large wood is transported down the river from upstream sources, but there are relatively few places for that wood to be retained. The assessment area would benefit in the short-term by the direct placement of LWD and in the long-term by the establishment and maintenance of a broad, mature riparian zone from which LWD could be recruited in the future.

LWD 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 and the entire structure is commonly backfilled with rock and/or soil ballast. 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.

There are several different types of LWD structures that can be used to influence channel processes in the lower Entiat River. Generally, mid-channel logjams can be effectively utilized to split flow and enhance island features which can reduce the width-to-depth ratio of the channel and increase the length of habitat along the channel margins (Figure 37). Logjams located on the bank can serve to deflect flow from the bank or simply provide hydraulic variability and cover along the bank. Instream structures can be used to force flow into bedrock or other obstructions to enhance scour, potentially generating pools and velocity breaks needed by juvenile and adult salmonids (Figure 38). In order for a logjam or other channel obstruction to affect sediment transport processes enough to scour large pools, the structure would need to be large and/or located along the outside of a bend. Individual logs or small multi-log structures have very little hydraulic influence on the mainstem channel but can provide valuable cover and local velocity breaks. Detailed hydraulic modeling of the specific project site will be necessary to determine the design, appropriate size, and placement of a given structure or suite of structures.

Figure 37. Constructed mid-channel ELJ located on the Green River, Washington (courtesy Anchor QEA).

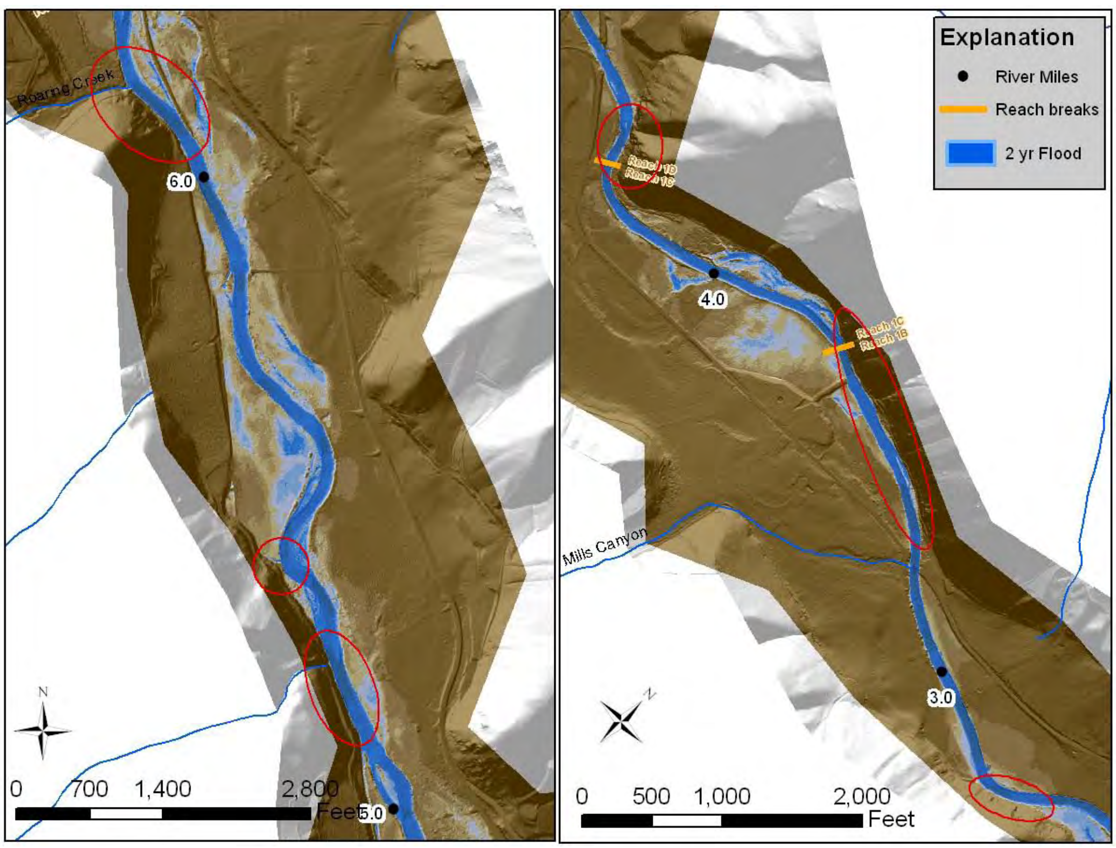

Figure 38. LiDAR view showing areas along the lower Entiat River where flow could be directed against a bedrock bank for improved scour potential and habitat formation.

Placement of Large Boulder Clusters

Large boulder clusters do very little to affect channel process in the lower Entiat River because much of the bed and banks of the river are already composed of large boulders derived from glacial outwash. Similar to LWD, boulder clusters can be used to enhance hydraulic variability and provide cover for fish, but short of constructing a channel-spanning structure, boulder clusters are unlikely to significantly influence process on the lower Entiat River (Figure 39). They are more appropriate for providing instream habitat.

Figure 39. Constructed boulder cluster in the lower Entiat River near RM 1.4.

Instream Habitat

Anthropogenic impacts to the lower Entiat River have affected instream habitat more than any other category previously outlined. The river currently lacks the ability to readily create new habitat through natural processes alone. As a result of the incised river system, the majority of habitat that historically existed on the lower Entiat River was instream habitat; therefore, re-establishing instream habitat is vitally important to salmon and steelhead. Appropriate actions to create instream habitat include placement of LWD structures, placement of large boulder clusters, and to a lesser degree, the installation of channel-spanning rock weirs.

Placement of LWD Structures

In the lower Entiat River, mid-channel ELJs are only appropriate at the apex of existing or emergent islands where they tend to form naturally. In addition to improving processes, mid-channel ELJs interact with a wide range of flows, providing hydraulic variability and much needed cover for a variety of fish species and life stages. Using mid-channel ELJs to obstruct flow in order to raise the stage of the river upstream of the structure is not appropriate in the lower Entiat River. With the steep gradient and confined river, a mid-channel obstruction large enough to back up flow is likely to induce bank erosion and/or bed scour sufficient to reestablish the original hydraulic radius within a few years after the obstruction is installed.

Bank ELJs are large structures located along the bank to provide hydraulic variability and cover (Figure 40). Logjams naturally accumulate and are most appropriate in those areas where high flows first overtop the banks. Floating logs and debris will accumulate in the shallow waters of these overflow areas where the moving water is forcing the logs against the bank rather than pushing the logs farther downstream. For this reason, bank ELJs are most appropriate at or adjacent to the inlets of overflow channels and floodplain side channels. In some instances, a large tree or other obstruction protruding from the bank may begin to rack additional wood and form a logjam. This type of logjam was historically less common in the lower Entiat River, but would have occasionally formed along the outside of a bend or near bedrock.

Figure 40. Bank engineered logjam in the Stillaguamish River, Washington (courtesy Anchor QEA).

Streambank barbs are relatively low-profile structures protruding from the bank that are intended to be overtopped during annual high flows (Figure 41). Barbs accelerate water around their apex and are commonly used to scour pools, or a string of barbs spaced appropriately can be used to redirect the thalweg away from the bank. The angle of a barb can also be adjusted to modestly direct flows because water will overtop the barb perpendicular to the barb's longitudinal axis. It is unlikely that rock or log barbs alone can create and maintain large pools in the heavily armored lower Entiat River, but log barbs were observed developing local scour pockets more readily than rock barbs. Barbs of any type are extremely effective at creating slow-water eddies along the banks which, combined with cover, provide valuable juvenile refuge during high flows or rearing habitat at lower flows. Like other log and rock structures, barb design requires project-specific hydraulic modeling to ensure the most appropriate size and positioning.

Figure 41. LWD Barb in the Entiat River near RM 3.0.

Single log structures in the lower Entiat River do not obstruct flow enough to significantly alter process or form, but by themselves, single log structures can provide local hydraulic complexity and cover. Depending on its location, orientation, and size, a single log structure can be constructed to rack additional available LWD, potentially developing into a logjam. Individual logs can be placed with rootwads facing the channel and interacting with flow, or with the bole of the tree complete with branches extending into the channel. Larger rootwads or more branches provide a greater volume of cover and hydraulic refuge for juvenile fish. Single logs can be buried into the bank, anchored to the bank, or pinned between existing vegetation for stabilization. When pinned between existing vegetation, the log can potentially pivot up and down with changing water surface levels. Individual log structures are appropriate anywhere a large, mature tree could potentially fall into the river, particularly within Reach 1A where an individual tree may not require substantial anchoring.

Placement of Large Boulder Clusters

Boulder clusters, while not greatly influencing channel process on the lower Entiat River, can increase bed roughness, increase hydraulic variability, create local scour pockets, and provide cover for fish. Boulders can be arranged with gaps between them to force flow convergence or overlapped to force flow divergence. In either case, the added roughness in the channel may influence local bank conditions which should be verified with a hydraulic model prior to construction. The potential for influencing bank conditions may be beneficial, particularly if flow can be forced against a bedrock or similarly erosion-resistant bank to induce scour and pool formation. Because the natural bed armor in the lower Entiat River consists of boulders almost 3 feet in diameter, individual rocks in individual boulder clusters should be at least 3 feet in diameter, preferably even larger.

Cross Vane Rock Weirs

Cross vane weirs are essentially two barbs built on opposite banks that connect in midstream, creating a channel-spanning structure. The shape of the cross vane weir can be used to force flow convergence of flow divergence because flow passes over the weir perpendicular to its longitudinal axis. For this reason a V-shaped weir can be positioned with the point of the “V” pointing upstream to force flow convergence between the two arms of the weir (Figure 42). Likewise, if the “V” is pointing downstream, flow will diverge as it overtops the weir. The slope, angle, and alignment of the arms forming the weir determine the extent which flows will plunge over the weir converging or diverging. Rock weirs commonly fail due to excessive scour beneath one or both arms of the weir undermining the structure, or by excessive deposition altering the structure’s performance (Reclamation 2009b). Rock weir design determined by project-specific hydraulic modeling will ensure the most appropriate rock arrangement, weir slope, angle, and positioning.

Figure 42. V-shaped weir on the Entiat River near RM 3.1.

Rock weirs cease to function when they are flanked by large volumes of flow. For this reason, weirs are most appropriately constructed in areas where bank erosion is minimal, typically in straight, entrenched sections of the river. Although rock weirs have been effectively utilized on the lower Entiat River, their failure rate is relatively high when compared with alternative structures capable of producing similar results. Weirs are static structures in which movement of any one rock forming the weir can cause the entire structure to fail or function improperly. Log structures and boulder clusters are more natural, less prone to failure, and equally capable of creating the same conditions as a channel-spanning weir.

Summary

Several habitat improvement actions fit within one or more categories of the implementation strategy for the lower Entiat. In addition to the hierarchy provided by the implementation strategy, the potential benefit to limiting factors provided by each action will also determine its priority. Table 8 provides a summary of those individual actions considered most appropriate for preserving, initiating, and/or creating the identified target conditions in the lower Entiat River.

Table 8. Summary of habitat improvement actions and their potential benefits to limiting factors.

Form	Target Condition	Habitat Improvement Action	Potential benefit to limiting factors (high, med, low)
Large Pools	3.5 to 4.0 per mile	Placement of LWD	High
Sinuosity	Roughly 1.1	Removal of riprap	Low
LWD	5 to 10 logjams per mile; as many individual pieces providing cover along the banks as possible	Placement of LWD; riparian planting; fence and maintain a riparian buffer	High
Channel geometry	Incised 1 to 20 feet	N/A	N/A
River bed and banks	Generally armored with boulders	Remove riprap	Low
Off-channel habitat	Few side channels, but more than existing	Placement of LWD; removal of levees; excavate side channels	High
Floodplain connection	Limited to narrow active floodplain between terraces and reduced only by levees protecting vital infrastructure	Remove levees; breach levees with culverts	Medium/Low
Riparian Condition	Dense mature riparian corridor at least 100 feet wide	Riparian planting; fence and maintain a riparian buffer	Medium

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 lower 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. 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 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 lower 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.
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.

TERM	DEFINITION
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.
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.

TERM	DEFINITION
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.
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.

TERM	DEFINITION
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

Reach-Based Ecosystem Indicators

Appendix - Table of Reach-Based Ecosystem Indicators

Side Channel Type	Flow Duration	Bank	Length (feet)	Location (River Mile)	Reach	Connection	Notes
split flow	seasonal	R	260	6.7	1E	connected	Island populated by pioneering vegetation only
floodplain	perennial	L	780	6.6	1E	connected	Wilson Side Channel; human-made; regulated by culverts
split flow	perennial	R	320	6.5	1E	connected	Logjam at apex of island
floodplain	seasonal	L	260	6.4	1E	connected	Primarily an overflow/flood channel with minor LWD at inlet
split flow	perennial	R	630	6.4	1E	connected	Logjam at apex of island; side channel is cutting off
floodplain	perennial	L	280	6.3	1D	connected	Logs are beginning to accumulate on island; grass vegetation only
floodplain	N/A	L	1600	6.3	1D	disconnected	Cut off by levee
split flow	perennial	L	200	6.3	1D	connected	No LWD at head of island; island is slowly unraveling
floodplain	seasonal	L	650	5.6	1D	connected	Only accessed during large floods (greater than 2-year event)
floodplain	perennial	R	430	5.5	1D	connected	No surface connection at low flows, only hyporehic
floodplain	perennial	R	300	5.3	1D	connected	No surface connection at low flows, only hyporehic; LWD at inlet
floodplain	N/A	R	1600	5.2	1D	disconnected	Inlet blocked at Hanan-Detwiler diversion; human-made.
split flow	perennial	R	420	5.1	1D	connected	LWD at head of island

Side Channel Type	Flow Duration	Bank	Length (feet)	Location (River Mile)	Reach	Connection	Notes
floodplain	seasonal	L	400	4.8	1D	connected	Very small; only active during floods exceeding 2-year recurrence interval.
floodplain	perennial	R	475	4.7	1D	connected	LWD metering flow at inlet; best side channel in the lower Entiat
floodplain	seasonal	R	200	4.4	1D	connected	LWD partially blocking flow at inlet
split flow	perennial	R	150	4.3	1D	connected	Nearly equal split flow around a small island with LWD at apex of island.
floodplain	N/A	R	630	4	1C	disconnected	Historical channel formed by backwater from Kellogg Mill; disconnected by levee
floodplain	perennial	L	1300	3.9	1C	connected	Harrison side channel; inlet filling with sediment; human-made
floodplain	perennial	L	350	3.7	1C	connected	Located at and maintained by diversion
floodplain	seasonal	L	390	1.6	1B	connected	Accumulating LWD at inlet
split flow	perennial	L	1100	1.5	1B	connected	Part of "below the bridge" project; side channel slowly filling with sediment
Many split-flow and floodplain side channels below RM 1.0 resulting from Columbia River backwater; connected							

Appendix A

Reach-based Ecosystem Indicators (REI) Version 1.1

The lower Entiat River reach assessment area includes Reach 1A-1E (RM 0.0-6.9). 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) (James White personal communication). 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
	Wide with terraces	2000-foot valley width; 600-foot terrace width	0.011 foot/foot	Confined	Variable

GENERAL CHARACTERISTICS: CHANNEL SEGMENT

Channel Characteristics	Valley Type	Elevation	Dominant Channel Type	Bed form Type	Channel Gradient	Sinuosity
	Confined	1033 feet – 708 feet	Rosgen B3c	Plane bed	0.011 foot/foot	1.1

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
Lower Entiat River reach (RM 0.0 - 6.9)	693	2.5 mi/mi^2

* Assuming all roads are “open”

Narrative:

Based on the available data, road density in the lower Entiat River is in **Unacceptable** condition. 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 – sapling/pole condition	52%
2001	Tommy Creek	640	~10	Shrub/seedling condition	< 1%
2006	Tinpan	9,247	<5	Grass/forb condition	3%

Data: Dams causing disturbance

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 (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 lower Entiat 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 lower Entiat River (RM 0.0 to 7.0). 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	3010
10	5220
50	7280
100	8190

Narrative:

The magnitude, timing, duration and frequency of peak flows 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. Several irrigation withdrawals reduce the low-flow discharge volume in the lower 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 lower Entiat River is considered **Adequate**.

Global climate change has the potential to change the streamflow characteristics of the lower Entiat River in the future, which is discussed in the body of the *Lower Entiat River Reach Assessment* 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 <u><</u>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: Seasonal Temperature Maxima (°C) - 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=temperature&scrolly=0&wria=46&sta=46A070

Year	Constituent	Criterion	Deployment		Max 7-day mean		ITS[b]
			max	Date/Time[a]	max	Date[a]	
2010	Water Temp	17.5	20.87	8/15/2010 5:00:00 PM	19.4	8/12/2010	4.1
2010	Air Temp	NA	37.42	7/25/2010 5:00:00 PM	35.6	7/27/2010	NA
2009	Air Temp	NA	26.37	4/7/2009 3:30:00 PM	22.6	4/8/2009	NA
2009	Water Temp	17.5	13.8	10/1/2008 6:00:00 PM	12.5	10/4/2008	0
2008	Air Temp	NA	35.94	8/16/2008 4:00:00 PM	32.9	8/16/2008	NA
2008	Water Temp	17.5	23.53	8/17/2008 4:30:00 PM	202.6	8/16/2008	22
2007	Air Temp	NA	35.9	8/2/2007 4:30:00 PM	32	7/30/2007	NA
2007	Water Temp	17.5	21.3	8/2/2007 6:00:00 PM	20.6	8/5/2007	26.8
2006	Water Temp	17.5	22.1	8/7/2006 5:30:00 PM	20.8	8/20/2006	26.4
2006	Air Temp	NA	40.2	7/23/2006 5:00:00 PM	37	7/24/2006	NA
2005	Air Temp	NA	35.9	8/5/2005 4:30:00 PM	34.5	8/7/2005	NA
2005	Water Temp	17.5	24.8	8/8/2005 5:30:00 PM	24.3	8/8/2005	93.4
2004	Air Temp	NA	41.1	7/25/2004 1:30:00 PM	36.4	7/25/2004	NA
2004	Water Temp	17.5	24.4	8/13/2004 4:30:00 PM	23.8	8/14/2004	83.8
2003	Air Temp	NA	37.4	7/30/2003 5:30:00 PM	35.3	7/29/2003	NA
2003	Water Temp	17.5	23.6	7/31/2003 5:00:00 PM	22.8	7/29/2003	52.6
2002	Air Temp	NA	36.24	8/13/2002 5:30:00 PM	32.8	8/12/2002	NA

Year	Constituent	Criterion	Deployment		Max 7-day mean		ITS[b]
			max	Date/Time[a]	max	Date[a]	
2002	Water Temp	17.5	22.31	8/14/2002 5:00:00 PM	20.9	8/13/2002	16
2001	Water Temp	17.5	24.8	8/11/2001 4:59:20 PM	24	8/10/2001	73.1
2001	Air Temp	NA	37.3	8/10/2001 4:59:22 PM	35	8/10/2001	NA

[a] There may be other dates with the same maximum. Only the first date is shown for any given year.
[b] The "Index of Thermal Stress" (ITS) is the number of degree-days temperature exceeded the criterion. The criteria became more restrictive in 2007 so ITS numbers before and after this are not comparable. All data are used so deployments with different lengths may not be comparable.

Data Source 2: Graph 2, Water Quality Index (WQI) 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

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
fecal coliform bacteria	90	87	99	96	100	93	92	100	96	99	96	97	96	97	100	95	93
oxygen	89	95	94	93	92	96	92	90	95	93	89	92	95	93	84	92	95
pH	80	83	77	63	59	63	80	67	82	55	56	75	81	64	56	80	77
suspended solids	87	70	72	69	79	68	78	92	82	90	80	95	72	76	86	87	87
temperature	72	88	77	82	68	95	83	70	79	76	69	70	86	72	73	82	89
total persulf nitrogen	97	95	97	96	96	96	98	97	98	98	98	97	96	97	97	98	97
total phosphorus	97	80	87	70	81	80	91	93	94	95	100	91	100	100	98	96	99
turbidity	95	75	81	74	86	74	84	96	92	96	79	96	84	84	90	93	95
overall WQI	**90**	**85**	**87**	**79**	**78**	**77**	**91**	**83**	**94**	**80**	**81**	**89**	**91**	**85**	**83**	**94**	**93**
adjusted for flow	**n/a**	**84**	**88**	**79**	**77**	**83**	**90**	**83**	**92**	**81**	**80**	**88**	**91**	**84**	**82**	**92**	**92**

KEY

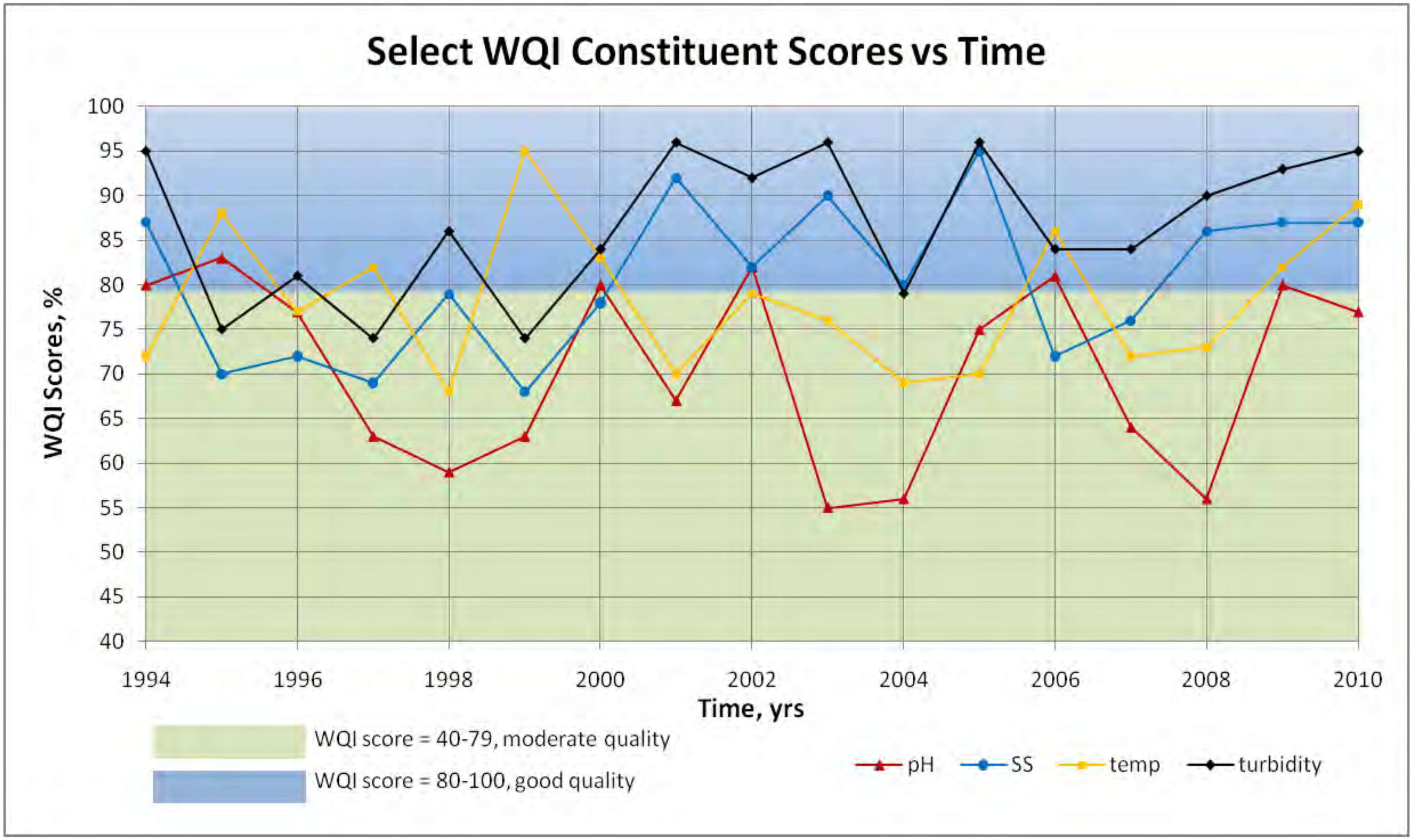
blue - good beige - moderate red - poor n/a - not sampled or not calculated

higher scores -> better water quality, maximum possible score: 100

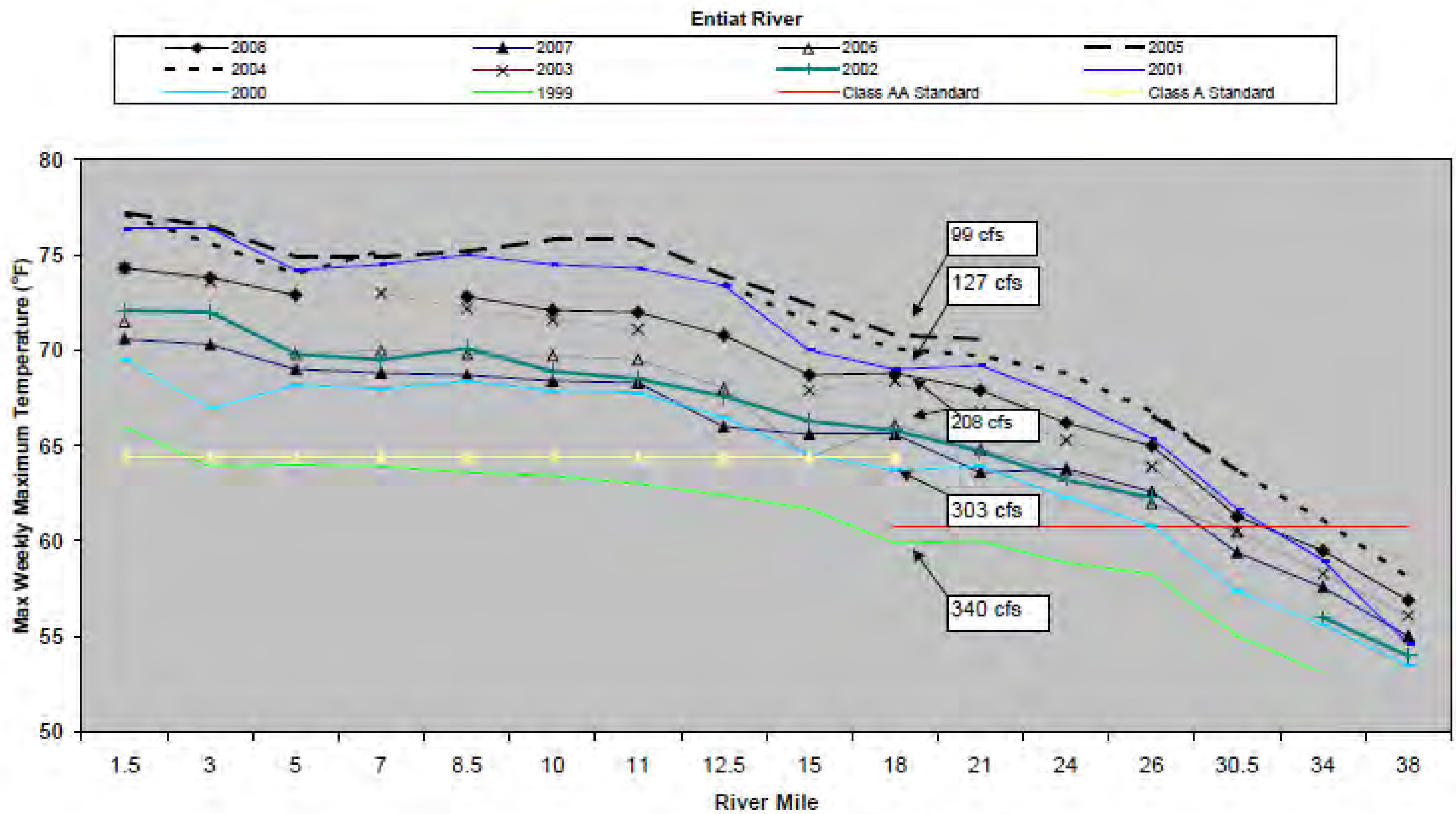
The Water Quality Index is designed to rate general water quality based on monitoring conducted by Ecology's Freshwater Monitoring Unit. Monitoring results from monthly grab samples have been converted to scores ranging from 1 to 100. In general, scores less than 40 indicate water quality did not meet expectations or was poor. Scores of 40 through 79 indicate moderate quality, and scores of 80 and greater indicate water quality met expectations and was good.

For temperature, pH, fecal coliform bacteria, and dissolved oxygen, the index expresses results relative to levels required to maintain beneficial uses (based on criteria in Washington’s Water Quality Standards, WAC 173-201A). For nutrient and sediment measures, where standards are not specific, results are expressed relative to expected conditions in a given region.

Excel spreadsheet of select Water Quality Index Constituent Scores verses Time taken from Graph 2, 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.



Data Source 3: Water temperature information received from USFS 2007.



Narrative:

Data Source 1: Washington State, Department of Ecology, Seasonal Temperature Maxima historical records from 2001 to 2010 show that the MDMT was exceeded 9 out of 10 times (90 percent) and the 7-DADMax was exceeded 9 out of 10 times (90 percent).

Data Source 2: Washington State, Department of Ecology, Water Quality Index Scores by Constituent historical records from 1994 to 2010 show that the water quality index for water temperature was rated as "moderate" 10 out of 17 times (59 percent) and rated as "good" 7 out of 17 times (41 percent).

Data Source 3: The Entiat River is classified as a Class A (excellent) stream from its confluence with the Columbia River to the boundary of the Wenatchee National Forest at approximately RM 26 and as a Class AA (extraordinary) stream from the National Forest boundary to its headwaters. It supports beneficial uses including domestic, industrial, and agricultural water supply and primary contact recreation (CCCD 2004).

Temperature exceedances in the summer months have been identified throughout the record, beginning in 1960. Occasional temperature exceedances may have occurred naturally prior to settlement of the Entiat valley; however, it is impossible to determine the magnitude or frequency of this type of historical exceedance given the existing data record. It is likely that the number and frequency of exceedances has increased largely due to the removal of riparian plants and warm-water irrigation returns.

The water temperature data and information contained in the Entiat Watershed Management Plan suggests that water temperature is At Risk primarily due to development and clearing of the riparian vegetation (CCCD 2004).

Summary: Based on the Washington State, Department of Ecology historical records for Seasonal Temperature Maxima and Water Quality Index Scores by Constituent and the information provided by USFS 2007, the lower Entiat River reach may be **At Risk** in regard to temperature.

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: Graph 2, 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: 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: Graph 2, 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: 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; 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 James White.

	Reach 1B	Reach 1C	Reach 1D	Reach 1E	Average for Study Area
Fines	4.36 %	3.39 %	2.75 %	2.33 %	3.48 %
Sand	14.00 %	6.08 %	12.44 %	8.29 %	11.90 %
Gravel	11.08 %	8.25 %	9.23 %	10.0 %	10.12 %
Coarse Gravel	21.33 %	17.71 %	17.92 %	19.38 %	19.70 %
Cobble	36.39 %	39.06 %	36.16 %	35.52 %	36.42 %
Small Boulder	11.79 %	23.78 %	20.67 %	21.57 %	17.02 %
Large Boulder	0.59 %	1.39 %	0.40 %	2.14 %	0.86 %
Bedrock	0.00 %	0.00 %	0.05 %	0.00 %	0.02 %
Other	0.46 %	0.35 %	0.38 %	0.76 %	0.47 %
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Data: ISEMP 2011 provided by James White.

River Miles:	**RM 0.7 - 3.7**	**RM 3.7 - 4.3**	**RM 4.3 - 6.3**	**RM 6.3 - 6.9**	**RM 0.7 - 6.9**
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**	**Average for Study Area**
Pebble Count Data:					
D50 (mm)	31.4	102.5	96.8	99	94.0
D84 (mm)	124	293	279	290	266
Dominant Substrate:	Cobble	Cobble	Cobble	Cobble	Cobble
Embeddedness:	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Fine Sediment:	<12 %	<12 %	<12 %	<12 %	<12 %

Interpretation:

River Miles:	**RM 0.7 - 3.7**	**RM 3.7 - 4.3**	**RM 4.3 - 6.3**	**RM 6.3 - 6.9**	**RM 0.7 - 6.9**
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**	**Reach 1B – 1E**
Dominant Substrate	Adequate	Adequate	Adequate	Adequate	Adequate
Embeddedness	Adequate	Adequate	Adequate	Adequate	Adequate
Fine Sediment	Adequate	Adequate	Adequate	Adequate	Adequate

Narrative:
Substrate data excludes the sites of PUD Side, Harrison Lower Side, Hanan-Detwiler Ditch, Knapp-Wham Ditch, and Wilson Side Channel due to extraneous high counts of fine substrate that are not representative of the main-stem channel. No distinction has been made between bedload and bed armor in the lower Entiat River substrate counts. Bed armor grain sizes (D50 and D85) are larger than the general pebble count data reported here with an average D50 of 154mm and an average D84 of 343mm.

With regard to fine sediment filling in spawning gravel or otherwise increasing stream embeddedness, high transport capacity and competency in the lower Entiat River precludes the accumulation of fine sediment resulting in an overall **Adequate** condition within the entire reach assessment area. Up to 20 percent fines (sand and silt) has been documented by USFS bed sample monitoring since 1993, which may affect spawning gravels particularly within the influence of the backwater formed by Lake Entiat (CCCD 2004).

GENERAL INDICATOR: LARGE WOODY DEBRIS (FREQUENCY)

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

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

Data: Individual log counts provided by ISEMP. Most individual logs are part of log jams; Visual counts of log jams performed during 2011 RA field work.

River Miles:	RM 0.7 - 3.7	RM 3.7 - 4.3	RM 4.3 - 6.3	RM 6.3 - 6.9
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**
Large wood per mile (in-channel only):	88.0	36.7	42.0	361.7
Small (>20 feet long, 4-6 inches diameter)	60	3	34	27
Medium (> 20 feet long, 6-12 inches diameter)	120	12	19	84
Large (> 20 feet long, >12 inches diameter)	84	7	31	106
Total individual large and medium logs	204	19	50	190
Log Jams (10 or more logs per jam)	7	2	5	2

Reach	RM	Log Jam Count	Location	Notes
1E	6.7	1	Head of island	Natural
1E	6.5	1	Head of island	Natural
1D	5.1	1	Head of island	Natural
1D	5	1	Outlet of side channel	Natural
1D	4.8	1	Head of island	Natural
1D	4.8	1	Head of island	Natural
1D	4.3	1	Head of island	Natural

Reach	RM	Log Jam Count	Location	Notes
1C	3.8	1	Head of island	Natural
1C	3.7	1	Bank	Natural
1B	2.5	1	Outside of bend	Constructed
1B	1.3	1	Mid-Channel	Constructed
1B	1.3	1	Inside of bend	Constructed
1B	1.3	1	Inside of bend	Constructed
1B	1.3	1	Outside of bend	Constructed
1B	0.9	1	Head of island	Natural
1B	0.7	1	Head of island	Natural
Log jams not counted in Reach 1A				

Interpretation:

River Miles:	**RM 0.7 - 3.7**	**RM 3.7 - 4.3**	**RM 4.3 - 6.3**	**RM 6.3 - 6.9**
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**
Large Wood Per Mile	At Risk	Unacceptable	At Risk	At Risk

Narrative:

Reaches 1B, 1D, and 1E meet the criteria of more than 20 medium/large pieces of woody debris, however they are lacking in recruitment potential and are **At Risk**. **Reach 1C** lacks the criteria of more than 20 medium/large pieces of woody debris per mile as well as the recruitment potential to accumulate additional LWD and is **Unacceptable**. A specific indicator has not been identified for adequate, at risk, and unacceptable conditions with regard to the number of log jams per mile in the lower Entiat River, but a target condition of 5 to 10 log jams per mile is supported by this report. Side channels and ditches were excluded from final counts.

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 2011 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 0.7 - 3.7**	**RM 3.7 - 4.3**	**RM 4.3 - 6.3**	**RM 6.3 - 6.9**
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**
Average of all pools per mile	208	268	128	132
Estimated large pools per mile	2	0	1.5	3.3

Narrative:
Pool counts from ISEMP data include all sizes of pools; estimates of large pools were made from 2011 field work performed for this assessment. As discussed in the body of the *Reach Assessment*, the target condition for large pools is between 3.5 to 4 pools per mile. Recent efforts to create pools using channel-spanning rock weirs or log jams have proven ineffective. Very large flows are required to scour the bed armor sufficiently to create a large pool. A large structure is required to maintain the pool between large flow events; otherwise, it will fill in with coarse bedload. Based on this condition and the general lack of cover and instream structure capable of maintaining large pools, the entire lower Entiat River assessment area is **At Risk**. Historic conditions were also likely lacking large pools and may also have been considered at risk given the criteria provided above.

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. Manmade 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	260	6.7	1E	connected	Island populated by pioneering vegetation only
floodplain	perennial	L	780	6.6	1E	connected	Wilson Side Channel; human-made; regulated by culverts
split flow	perennial	R	320	6.5	1E	connected	Log jam at apex of island
floodplain	seasonal	L	260	6.4	1E	connected	Primarily an overflow/flood channel with minor LWD at inlet
split flow	perennial	R	630	6.4	1E	connected	Log jam at apex of island; side channel is cutting off
floodplain	perennial	L	280	6.3	1D	connected	Logs beginning to accumulate on island; grass vegetation only
floodplain	N/A	L	1600	6.3	1D	disconnected	Cut off by levee
split flow	perennial	L	200	6.3	1D	connected	No LWD at head of island; island is slowly unraveling
floodplain	seasonal	L	650	5.6	1D	connected	Only accessed during large floods (greater than 2-year event)
floodplain	perennial	R	430	5.5	1D	connected	No surface connection at low flows, only hyporehic

Side Channel Type	Flow Duration	Bank	Length (feet)	Location (RM)	Reach	Connection	Notes
floodplain	perennial	R	300	5.3	1D	connected	No surface connection at low flows, only hyporehic; LWD at inlet
floodplain	N/A	R	1600	5.2	1D	disconnected	Inlet blocked at Hanan-Detwiler diversion; human-made.
split flow	perennial	R	420	5.1	1D	connected	LWD at head of island
floodplain	seasonal	L	400	4.8	1D	connected	Very small; only active during floods exceeding 2-year recurrence interval.
floodplain	perennial	R	475	4.7	1D	connected	LWD metering flow at inlet; best side channel in the lower Entiat
floodplain	seasonal	R	200	4.4	1D	connected	LWD partially blocking flow at inlet
split flow	perennial	R	150	4.3	1D	connected	Nearly equal split flow around a small island with LWD at apex of island.
floodplain	N/A	R	630	4	1C	disconnected	Historic channel formed by backwater from Kellogg Mill; disconnected by levee
floodplain	perennial	L	1300	3.9	1C	connected	Harrison side channel; inlet filling with sediment; human-made
floodplain	perennial	L	350	3.7	1C	connected	Located at and maintained by diversion
floodplain	seasonal	L	390	1.6	1B	connected	Accumulating LWD at inlet
split flow	perennial	L	1100	1.5	1B	connected	Part of "below the bridge" project; side channel slowly filling with sediment
Many split flow and floodplain side channels below RM 1.0 resulting from Columbia River backwater; connected							

Narrative:

The reach assessment area is not characterized by many significant side channels, oxbows, ponds or other off-channel habitat, which is largely a natural condition of the lower Entiat River. There are a handful of side channels and several acres of floodplain that would otherwise be active if not for anthropogenic features such as levees. For this reason, off-channel habitat is considered **At Risk**.

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 (the disconnected area is the 2-year floodplain area behind levee). Areas located behind levees that have been strategically breached or removed (Wilson Side Channel and Hatchery area in Reach 1E and Harrison Side Channel in Reach 1C) were not included in the total "disconnected area" measurements.

River Miles:	RM 0.7 - 3.7	RM 3.7 - 4.3	RM 4.3 - 6.3	RM 6.3 - 6.9	Total
Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**	**All Reaches**
Levee Total (length)	2,493 feet	3,986 feet	3,492 feet	1,022 feet	10,992 feet
Push-up Levee (length)	1,299 feet	3,986 feet	981 feet	435 feet	6,701 feet
Disconnected Area	18.2 acres	9.1 acres	9.5 aces	0 acres	36.8 acres

Narrative:

The Entiat River is naturally confined and characterized by a relatively narrow active floodplain. Human features have disconnected the river from its active floodplain in several locations. Therefore, the floodplain connectivity indicator is considered **At Risk**.

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 2006—Lower Entiat River

Reach	RM	Bank	Type	Length (feet)	Rate (feet/year)	Bank Material
1E	6.6	Left	Lateral	150	2.5	Qa3
1D	6.2	Right	Lateral	110	1.8	Qaf1
1D	5.6	Left	Lateral	65	1.1	Qa2
1D	5.4	Right	Lateral	140	2.3	Qa2
1D	5.0	Left	Lateral	95	1.6	Qa2
1B	2.5	Left	Downstream	170	2.8	Qa2
1B	1.7	Left	Lateral	125	2.0	Qa2
Significant widening in Reach 1A resulting from backwater condition						

* Nearly all migration was observed between 1945 photo and next available photo suggesting most migration was the result of the 1948 flood.

Data: Human features analysis by Reclamation.

River Miles:	RM 0.7 - 6.9
Levee/Push-up Levee	10,992 feet
Riprap (length)	6,047 feet

Narrative: Migration measured only where observed in the photo record; migration in all other locations was negligible or the channel was straightened. Overall migration in the lower Entiat River is very low as a result of natural bank armoring from glacial outwash material. Channel migration is not significantly affected by riprap and levees throughout most of the lower Entiat River; the channel has been naturally confined for thousands of years. For these reasons, bank stability, and channel migration are **Adequate**.

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 0.7 - 6.9
Average Mean Daily Flow (USGS gage 12452990 near Entiat)	502 cubic feet per second
Average Wetted Width	70 feet
Bankfull Width	100 feet
Bankfull Width/Depth Ratio	20
Average Active Floodplain Width is the 2-year inundation area	160 feet
Entrenchment Ratio	1.6
Rosgen Channel Type	B3c

Narrative: Regarding vertical channel stability, the lower Entiat River is very stable. The channel is incised by more than 20 feet in some locations, but as is discussed in the body of the Reach Assessment, the incision that has occurred within the lower Entiat River is natural and has taken place over several thousands of years. Human disturbance has not significantly increased or changed the rate or amount of incision in the lower Entiat River. 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 2006 aerial photos and LiDAR interpretation.

Riparian Buffer (30-meter width):	Acres	Percentage
Mature Trees	38.1	46.6%
Small Trees and Shrubs	18.3	22.4%
Grass or pasture	15.9	19.5%
Orchard	7.8	9.6%
Other (disturbed or bare ground)	1.6	1.9%

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

Disturbance within a 10m buffer from the bankfull banks	Acres	Percentage
Undisturbed area	31.8	82.5
Disturbed area	6.7	17.5

Narrative:

Undisturbed riparian areas are assumed to consist of a species structure and composition that is natural and appropriate for the lower Entiat River. With very low rates of bank erosion and LWD recruitment potential, riparian areas located farther from the bank provide less habitat benefit (and less habitat benefit potential) than those areas located near the bank. For these reasons, the riparian composition and structure is evaluated primarily from within the 30-meter buffer rather than the entire 2-year floodplain. Over 20 percent of the 30-meter buffer area consists of other than native species; riparian vegetation structure is therefore **At Risk**.

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.

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.

River Miles:	RM 0.7 - 3.7	RM 3.7 - 4.3	RM 4.3 - 6.3	RM 6.3 - 6.9
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**
0-25% Cover:	52.71%	51.33%	45.26%	45.96%
26-50% Cover:	9.67%	11.55%	6.23%	10.15%

River Miles:	RM 0.7 - 3.7	RM 3.7 - 4.3	RM 4.3 - 6.3	RM 6.3 - 6.9
Habitat Reach:	**Reach 1B**	**Reach 1C**	**Reach 1D**	**Reach 1E**
51-75% Cover:	7.82%	8.33%	4.66%	8.30%
76-100% Cover:	29.81%	28.79%	43.85%	35.59%

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

Seral Stage (10-meter width):	Acres	Percentage
Mature Trees	17.5	45.3%
Small Trees and Shrubs	10.6	27.5%
Grass or pasture	9.0	23.4%
Orchard	0.8	2.2%
Other (disturbed or bare ground)	0.6	1.5%
Mature Trees	17.5	45.3%

Narrative:

Greater than 70 percent of riparian buffer zone (10 meter width along both banks) is in the shrub/seedling to large tree 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 less than an average of about 42 percent of the 10-meter buffer area. Based on the seral stage of vegetation within the 10-meter buffer and riparian cover measurements, the canopy cover condition is **Unacceptable**.

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