

## **RIVER RESTORATION ON THE ENTIAT RIVER**

**Mike Sixta, P.E., Hydraulic Engineer, U.S. Bureau of Reclamation, PO Box 25007, 86-68240, Denver, CO, 80225, [msixta@usbr.gov](mailto:msixta@usbr.gov)**

**Abstract:** The Entiat River is located on the east slope of the Cascade Mountains in north-central Washington. The Entiat flows approximately 53 miles from its headwaters to where it enters the Columbia River at river mile (RM) 483. Human-induced changes to channel processes have historically reduced the quality and availability of aquatic habitat. These changes have affected the abundance, productivity, spatial structure, and diversity of Upper Columbia River (UCR) spring Chinook salmon, UCR steelhead trout, and UCR bull trout populations to such a degree that they have been listed as threatened/angered under the Endangered Species Act (ESA). Recovery of these salmonid species has been mandated through a Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp). The recovery effort entails restoring viable populations through reducing or eliminating threats to the long term persistence of fish populations while maintaining widely distributed and connected populations across diverse habitats within native ranges.

Natural ecosystem processes operate at different spatial and temporal scales. To ensure a holistic approach to habitat restoration, assessments have been conducted using a hierarchical, top-down approach, telescoping from a subbasin scale, through a reach scale, to a project level scale at which habitat actions are implemented. Numerical hydraulic models have helped dictate the course of each level of assessment. Numerous models varying in both type and spatial scale have been completed throughout the lower 26 miles of the Entiat River. Assessments have built a physical context for the development of habitat restoration projects, identifying locations where protection or restoration is appropriate, including recognizing (and addressing) limiting factors of the local ESA salmonids. This was accomplished through characterization of the biological conditions, including fisheries and vegetation ecosystems, the geologic setting, anthropogenic constraints, geomorphic processes, subbasin hydrology, and hydraulic and sediment transport processes. Habitat restoration projects to date have been mostly localized in nature and consisted of the placement of in-channel structures to increase complexity, connection of off-channel habitat areas, and vegetation planting. The majority of the habitat restoration projects have occurred in the lower six river miles.

### **INTRODUCTION**

The Entiat River is located on the east slope of the Cascade Mountains in north-central Washington. The Entiat flows approximately 53 miles from its headwaters to where it enters the Columbia River at river mile (RM) 483. Comprised primarily of the Entiat and Mad River watersheds, the Entiat Subbasin is approximately 305,600 acres in size and bounded on the northeast by the Chelan Mountains and Lake Chelan drainage, and to the southwest by the Entiat Mountains. A location map of the Entiat Subbasin is shown in Figure 1.

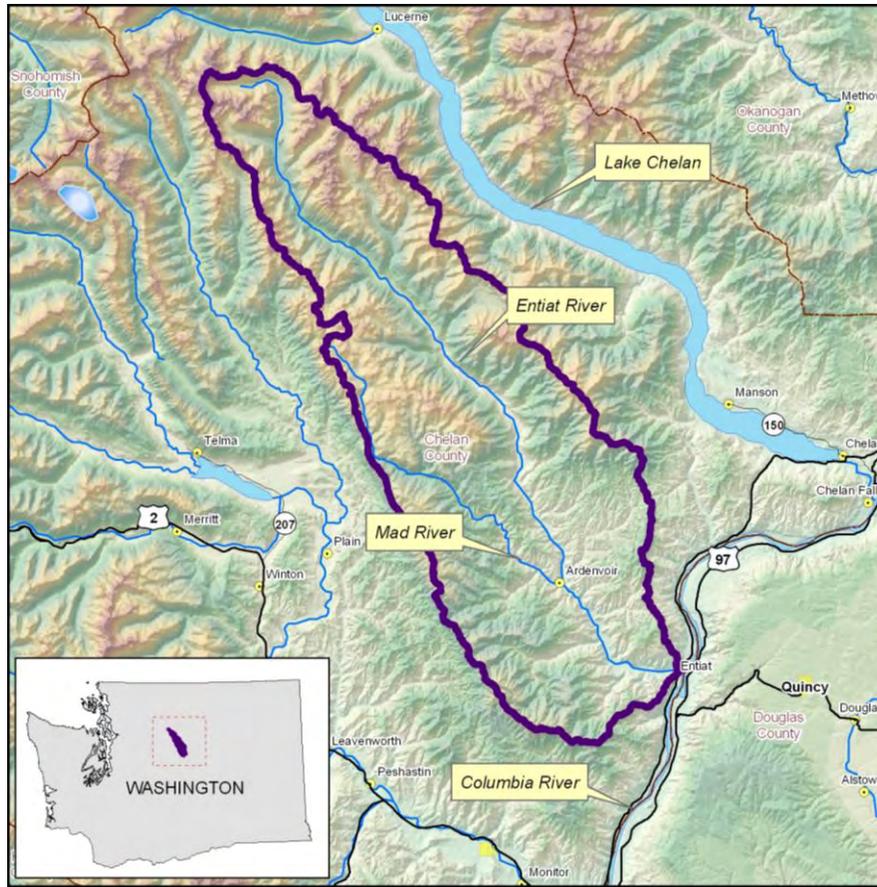


Figure 1: Entiat Subbasin location map.

The primary historic disturbance processes in the Entiat Subbasin have been wildfire, flooding, mass soil and debris movement, and land use (Nelle et al. 2009). Land use changes have included floodplain and river channel modification projects and structures, grazing, road and residential development, agriculture (orchards), timber harvesting, transport of logs within river channel, dams for log storage ponds (splash dams) and hydropower generation, and recreation. The resulting disruption to natural channel processes are believed to have simplified channel conditions and historically reduced the quality and availability of aquatic habitat (CCCD 2004), affecting the abundance, productivity, spatial structure, and diversity of three native salmonid species. These include the Upper Columbia River (UCR) spring Chinook salmon, UCR steelhead trout, and UCR bull trout. Populations have diminished to such a degree that they have been listed as threatened or endangered under the Endangered Species Act (ESA).

The Entiat Subbasin has received a lot of attention with regards to habitat restoration. There have been a host of biological guidance documents generated over the past 15 years that include recommendations on developing implementation frameworks, and types and prioritization of restoration activities. Resource planning in the Entiat Valley began in 1993, with members of the Chelan Country Conservation District (CCCD), Natural Resources Conservation Service (NRCS), and U.S. Forest Service (USFS) securing support for a watershed planning effort for the Entiat Subbasin. Out of this effort came a stream inventory and analysis in 1995, which

inventoried the lower 20 miles of the Entiat River corridor. In 1998, the CCCD received funding to develop a watershed plan under the Washington State Watershed Planning Act; the Entiat Subbasin became part of the Water Resource Inventory Area (WRIA) 46. The final Entiat WRIA Management Plan was released in 2004 and addresses water quantity, water quality, instream flow, and habitat.

The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) issued its first Biological Opinion (BiOp) in 2004 (NMFS 2008) on the operation and maintenance of the Federal Columbia River Power System (FCRPS). This BiOp includes a Reasonable and Prudent Alternative (RPA), or a suite of actions, to protect local ESA-listed fish species across their life cycle. Habitat improvement projects are one aspect of this RPA. The BiOp is addressed by “Action Agencies,” the collective name for the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (ACOE), and U.S. Bureau of Reclamation (Reclamation). 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 stream flow, access, entrainment, and channel complexity limiting factors. Reclamation commitments to tributary habitat improvement for the FCRPS BiOp in the Entiat Subbasin began in 2005 with its involvement in the ongoing assessment work.

## **RESTORATION STRATEGY**

Many restoration projects fail because natural processes operating at different spatial and temporal scales, and how human activities affects these processes, are not well understood or considered (UCRTT 2008). Implementation of successful restoration projects requires an understanding of these natural processes and the factors that control them. The idea is that ecosystem processes operate at different scales and form a nested, interdependent system where one level influences other levels. Therefore, an understanding of one level is greatly informed by levels above and below it. This is considered to be a holistic approach to river restoration (UCRTT 2008).

A watershed scale assessment of current and historical conditions and disrupted processes is necessary to identify restoration opportunities that are consistent with re-establishing the natural processes and functions that create and maintain habitat. It is also essential to determine what restoration actions to implement and how to prioritize the actions. In general, restoration of watershed processes should precede or be conducted in conjunction with habitat enhancement (UCRTT 2008).

All efforts to restore salmon and steelhead habitat in the Upper Columbia Basin are guided by the Recovery Plan (UCSRB 2007), which states that effectiveness monitoring, coupled with adaptive management, is required to assist in the identification of limiting factors, to assess the effects of habitat actions, and to recover the listed species in the Entiat River Subbasin. To ensure a holistic approach to habitat restoration, Reclamation conducted assessments in the Entiat Subbasin using a hierarchical, top-down approach, telescoping from a subbasin scale (Tributary Assessment; TA), through a reach scale (Reach Assessment; RA), down to a project level scale (Alternatives Evaluation) at which habitat actions are implemented.

A TA is viewed as a coarse, watershed scale multidisciplinary investigation of a tributary river system involving multiple reaches to delineate and initially understand the interrelationships of physical processes and disturbance regimes operating at multiple scales. A RA is an investigation at a finer, reach scale with an integration of information and includes a diagnostic statement of the cause or nature of reach conditions to inform project area delineation, a prioritization for implementation activities, and an understanding of the cumulative effects and benefits. An Alternatives Evaluation is conducted at an even finer, project level scale that explores various reach treatment alternatives and the winnowing of those alternatives to a preferred alternative that addresses the established hypotheses guiding the best prospect for restoring habitat-forming processes.

This hierarchical approach differs from previous studies on the Entiat in that it is more quantitative based as opposed to physically based, drawing from geomorphic analyses, hydraulic modeling, geologic mapping, and hydrologic flood frequency analyses. Previous studies were largely driven from field observations, and lacked quantifiable and predictive channel processes. Reclamation utilized and added to the most current subbasin information to fill data gaps and validate/refine previous hypotheses.

### **TRIBUTARY ASSESSMENT**

A Tributary Assessment (TA) was completed by Reclamation on the lower 26 miles of the Entiat River (Godaire et al. 2009). The primary objective of the TA was to develop an improved understanding of the physical processes acting on the watershed to better identify restoration opportunities and address limiting factors that affect the survival and recovery of ESA-listed fish species. The vision was to provide resource managers and basin stakeholders with pertinent scientific information that would help with habitat restoration planning in the Entiat Subbasin, yielding the most effective path forward. This objective was met through the characterization of the geomorphic processes, geologic setting, anthropogenic constraints, hydraulic processes, subbasin hydrology, and biological conditions, including fisheries and vegetation ecosystems. Knowledge gained from local scientists and landowners, compiled data, and modeling results were synthesized to evaluate the potential physical and biological response to restoration actions. In particular, hydraulic modeling and geomorphic analyses helped define the spatial and temporal scale of river processes and offer a predictive tool to assess proposed actions.

The TA subdivided the lower 26 miles into three distinct valley segments and 17 geomorphic reaches. Valley segment boundaries were defined on the basis of changes in the channel gradient and geologic features that control channel morphology. Reach boundaries were defined much the same way, but on a finer scale to further delineate variations in geomorphic characteristics. This type of demarcation provides a context for customizing different river rehabilitation strategies based on specific characteristics of each river segment or reach. Figure 2 shows a longitudinal profile of the lower 26 miles with the valley segment boundaries. The distinct slope break between valley segment 1 and 2, at RM 16.1, is the result of a historic valley glacier nearly 25 miles long that once extended from its source at the headwaters of the Entiat. This area is now marked by a terminal moraine indicating the furthest downstream influence of the glacier. This boundary also marks a notable change in channel planform from a high gradient, dominantly single-thread channel with low sinuosity meanders downstream to a low gradient, multi-channel

pattern with high sinuosity meanders upstream. The boundary between valley segment 2 and 3, at RM 21.1, is defined by a change in slope from a low gradient meandering reach to a slightly higher gradient segment that still retains a meandering channel but has greater influence from tributary alluvial fans that create short, high gradient reaches with straight, single-thread channel morphology (Godaire et al. 2009).

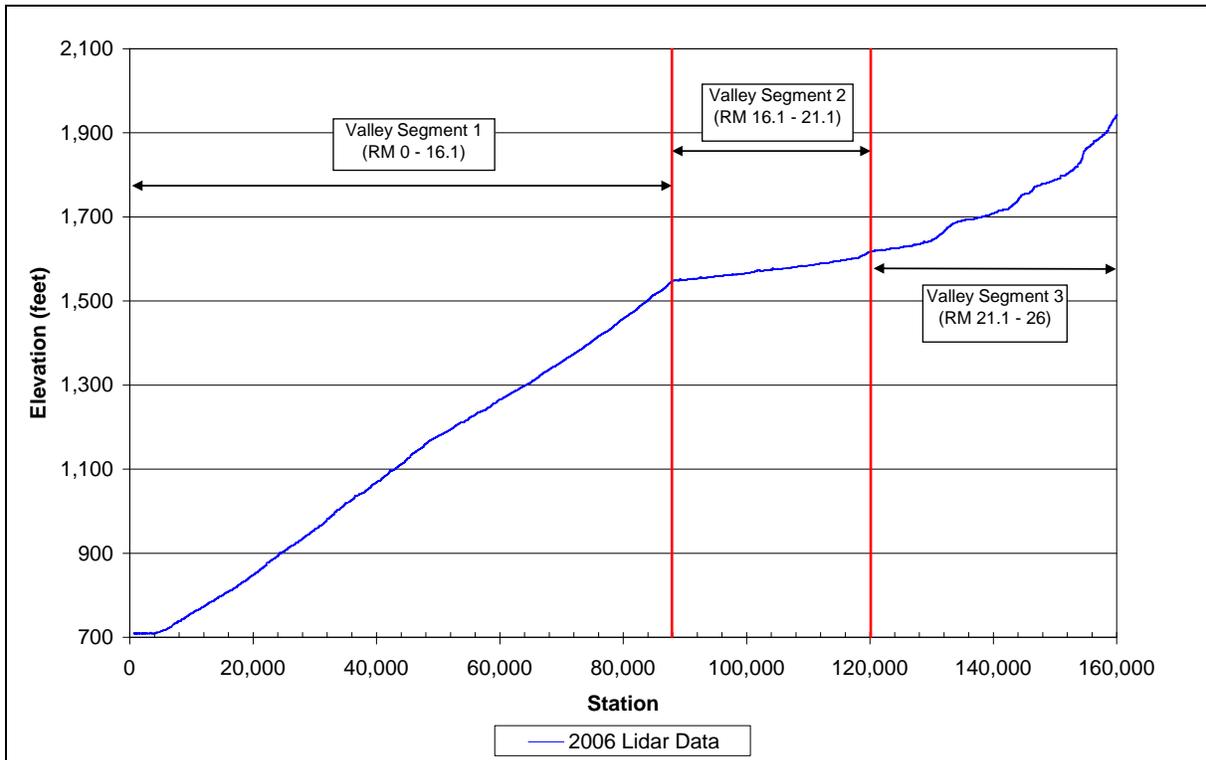


Figure 2: Longitudinal profile of lower 26 miles.

Highlighted analysis efforts for the TA included a flood frequency analysis, yielding estimated recurrence interval flood values every river mile for the lower 32 miles. This information was utilized in an analysis of the flow and sediment regime in the Entiat watershed with a focus on the high flows that are responsible for the majority of channel geometry and position changes over time, as well as for determining flood recurrence interval values used in the hydraulic modeling. Detailed surficial geologic maps were also developed for this assessment and used in valley segment and reach delineations as well as for a geomorphic analysis, documenting historical anthropogenic activities and their effects on changes in morphology and vegetation. Additionally, a one-dimensional HEC-RAS hydraulic model of the lower 26 miles was created to assess subbasin trends in stream energy and channel capacity, map potential inundation areas for the 2-year and 100-year flood events, and complete an incipient motion analysis.

Key findings from the TA were that, on a broad scale, channel hydraulics and sediment transport are influenced by geologic features present in the landscape of the Entiat Valley rather than historically constructed features in the channel. The historical channel migration zone (HCMZ) containing the active channel and active floodplain has a width that is heavily controlled by geologic features rather than by human constructs. The high floodplain surfaces, older terraces,

and older alluvial fans have historically provided a limit to the rate and lateral extent of the active floodplain expansion for at least the last 1,000 years. The frequency of channel reworking varies by reach and is related to the extent of active channel and floodplain. A combination of processes including lateral erosion, debris flow, and mass wasting are providing annual sediment delivery to the channel. Anthropogenic impacts to the channel and floodplain processes in the lower 26 miles are generally localized, not extending far upstream or downstream of the impacted area.

The geomorphic reaches were ranked in order of habitat restoration opportunity based on channel complexity that was described by a number of geomorphic characteristics including active floodplain confinement, historical channel migration, side channel presence, large woody debris presence, stream power, and bar frequency. Reaches with unconfined active floodplains, substantial historical channel migration, presence of side channels, greatest amount of large woody debris, low stream power, and the highest frequency of bars in the active channel ranked highest in terms of channel complexity, having the greatest restoration potential. Results from this analysis revealed reaches falling into three main complexity categories; high, moderate, and low (see Figure 3). Reaches categorized as high complexity were those with the greatest natural potential for creating channel complexity that included off channel habitat, refuge, cover, and spawning. Using a combination of variables including impact, complexity, and habitat limiting factors, six reaches were identified as areas to focus refined efforts.

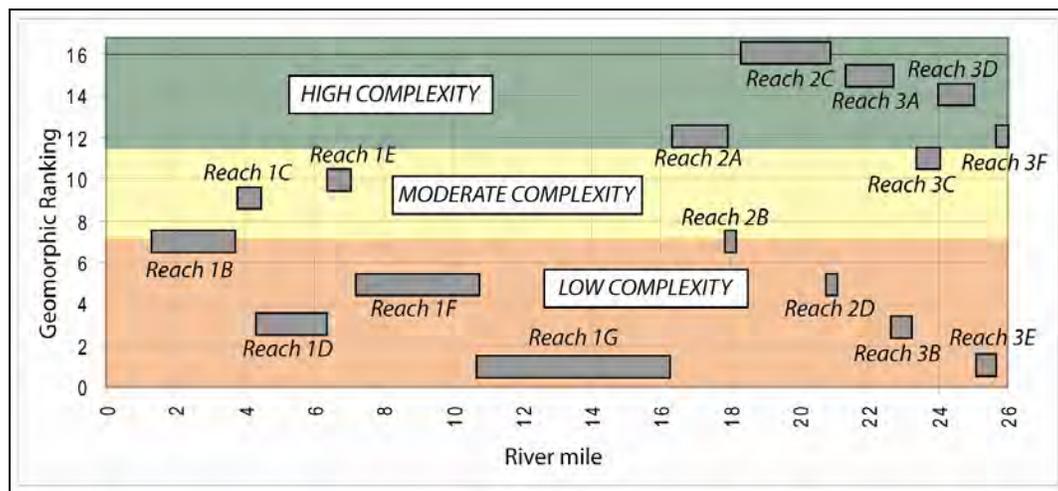


Figure 3: Channel complexity ranking based on geomorphic characteristics.

### REACH ASSESSMENT

Reach 3A (RM 21.1 – 22.7; a.k.a. Preston Reach) was ranked among five others in the TA as having the highest potential to improve steelhead and spring Chinook salmon habitat complexity by addressing present impacts. Reclamation recently completed a Reach Assessment (RA) on the Preston Reach (Lyon et al. 2009), from which the TA was used as a building block. The primary objective of the RA was to refine the TA findings and increase understanding of the channel's geomorphic processes. Environmental baseline conditions were also established that can be referenced to aid with monitoring efforts of implemented habitat actions.

The Preston Reach is generally characterized as having an unconfined floodplain (average floodplain width much greater than average active channel width) with high in-channel complexity and lateral controls consisting of alluvial fans, levees, and high terraces that constrain the channel position; further, the large size of the bed material near these controls creates a base level constraint, locally armoring the channel bed. The present impacts to the channel and floodplain in this reach are the presence of multiple levees and bank protection that limit channel migration and alter the instream hydraulics and geometry, accompanied by localized areas of cleared vegetation resulting in increased bank instabilities. Most notably, there are two levees in this reach (RM 21.8-21.9 and RM 22.1-22.3; both on river left), constructed in the 1970's, that have disconnected areas that were formerly part of the active channel, limiting lateral migration.

A two-dimensional hydraulic model (SRH-2D) was used to model this reach. Approximately 120,000 mesh elements were used to represent the Preston Reach terrain. The model terrain used a combination of LiDAR data for the overbank areas and on-the-ground survey data to represent the channel bathymetry. Numerical simulations were conducted for the 2- through 100-year recurrence interval floods for existing and proposed conditions. Proposed conditions consisted of full levee removal, lowering both levees to the surrounding floodplain elevation. Figure 4 shows a digital surface representation of existing versus proposed model conditions.

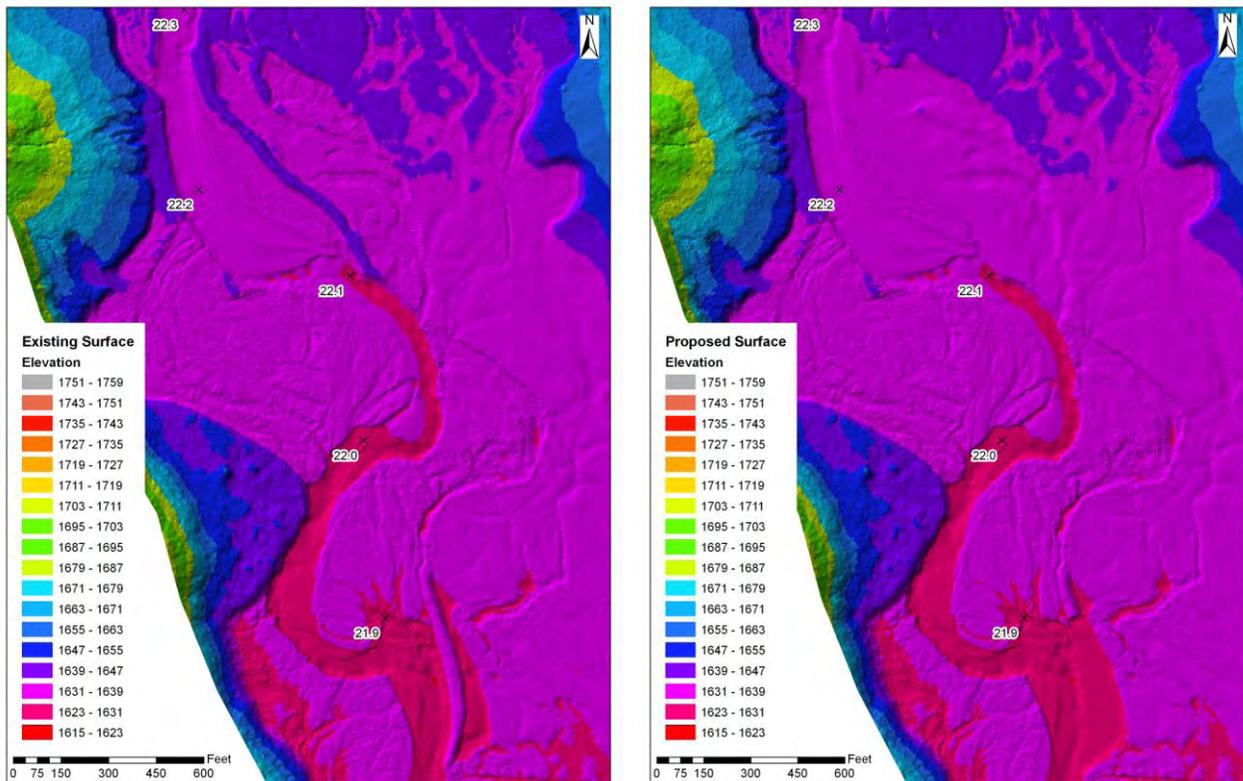


Figure 4: Existing (left) versus proposed (right) model conditions for Preston Reach.

Restoration of lateral connectivity was found to be a high priority for the Preston Reach. Therefore, the spatial distributions of various hydraulic parameters (flow depth, bed shear stress, and depth-averaged velocity) were examined for a range of flow events to determine differences between the existing and proposed conditions. Figure 5 shows the model results for the 2-year modeled flow depths near the vicinity of the proposed levee removals.

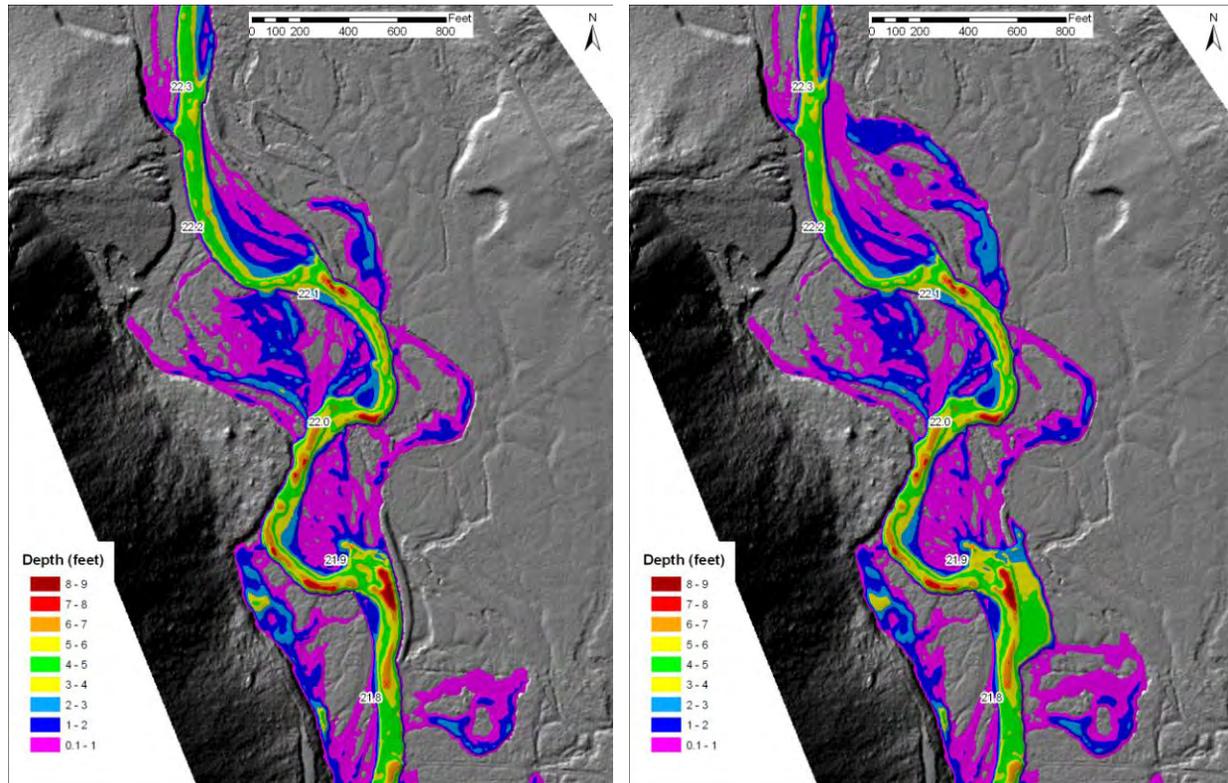


Figure 5: Existing (left) versus proposed (right) model results for 2-year flood depths.

Key findings from the RA were that ecosystem processes in the Preston Reach are in a moderately degraded state as a result of anthropogenic impacts. The geomorphic potential is interpreted to be altered because of reduced floodplain connectivity, lateral channel migration, and channel complexity created by large wood. The reach in general appears to currently have good channel form complexity as evidenced through meander bends, distinct (and repetitive) bed form types, frequent bed undulations/high mobility, large and numerous point bars, and localized pools in the majority of the meander bends at a low flow. There is some bank erosion occurring in the reach, but it appears to be a localized phenomenon. According to modeling results, both levees are able to contain the 100-year flood event, verifying loss of lateral connectivity. Complete removal of the upper levee opens up more floodplain access (6 acres) as compared to removal of the lower levee (1.2 acres). Additionally, the majority of the changes (both in-channel and overbank) between the existing and proposed conditions occurred within near proximity of the levee removals; effects of the proposed actions do not appear to propagate very far upstream or downstream of the levees. Lastly, the existing rock protection on the levees is creating a condition of increased bed erosion near the toe.

## ALTERNATIVES EVALUATION

The final assessment scale in Reclamation's hierarchical approach to river restoration is the Alternatives Evaluation; the project level scale at which a habitat action is implemented. At this stage, various iterations of project features and layouts are evaluated and brought before an interdisciplinary team (IDT) through a Habitat Subcommittee (HSC) forum for consensus with the ultimate goal of choosing a preferred alternative. The IDT consists of various disciplines including biologists, geologists, geomorphologists, engineers, and regulatory personnel. Usually, a preliminary screening on a first cut of conceptual alternatives is conducted by the IDT through a verbal fatal flaws analysis. A parallel process that occurs in conjunction with evaluating alternatives is bringing in all affected landowners for project plan dissemination, answering questions, and addressing concerns with the eventual goal of project implementation acceptance.

Habitat restoration projects are currently ongoing in the Preston Reach. The majority of implemented restoration projects to date however, prior to completion of the TA, have occurred in the lower six miles. These projects have consisted of the placement of in-channel structures, connection of off-channel habitat areas, and vegetation planting. The overarching principle behind adding in-channel structures is disturbance. Disturbance plays a pivotal role in channel evolution and habitat productivity (Saldi-Caromile et al. 2004). Habitat restoration activities should accommodate and encourage disturbance where possible (Reeves et al. 1995). Although passive restoration techniques (e.g. levee breaching/removal, relict channel reconnection) are recommended as long-term solutions to improve channel forming processes, very few opportunities exist to implement these types of actions amid existing land use and floodplain development patterns in the lower Entiat (lower 10 river miles).

One such example of an implemented habitat restoration project, and one of the few areas in the lower portion of the river to present an off-channel connection opportunity, is the Harrison Side Channel Reconnection project. The left overbank area in the Harrison project area (RM 3.8 – 4.2) had been cut off from all main channel flows below the 100-year event through the historic practices of levee building. This has resulted in channelization and subsequent down cutting of the main channel. The biological goal of the project was to increase the amount of off-channel spawning and juvenile rearing habitat in addition to locally re-establishing floodplain function. This was accomplished through establishing a perennial connection of relict channel paths through levee breaching and lowering. Numerous proposed alternatives were developed with an IDT through an HSC forum. Each alternative was addressed either qualitatively or quantitatively in an Alternatives Evaluation Report (AER). Based on biological impact/benefit, hypothesized geomorphic affects, cost/benefit analyses, construction feasibility/logistics, and landowner willingness, a preferred alternative was selected.

The preferred alternative consisted of establishing a connection directly to the main channel by notching an existing levee to an elevation that provides perennial flow. In addition, the portion of levee immediately downstream of the notch was lowered, restoring floodplain functionality to an area approximately 2.7 acres in size. These actions decreased the main channel stream power, and raised the particle sizes at incipient motion, helping keep the main channel from experiencing any further incision. Design and evaluation of the preferred alternative was conducted through the use of a two dimensional SRH-2D hydraulic model. Model results helped

set the side channel entrance invert elevation to ensure perennial flow would be maintained. Figure 6 shows the project area along with the implemented project features (preferred alternative). Figure 7 shows the project immediately after construction.

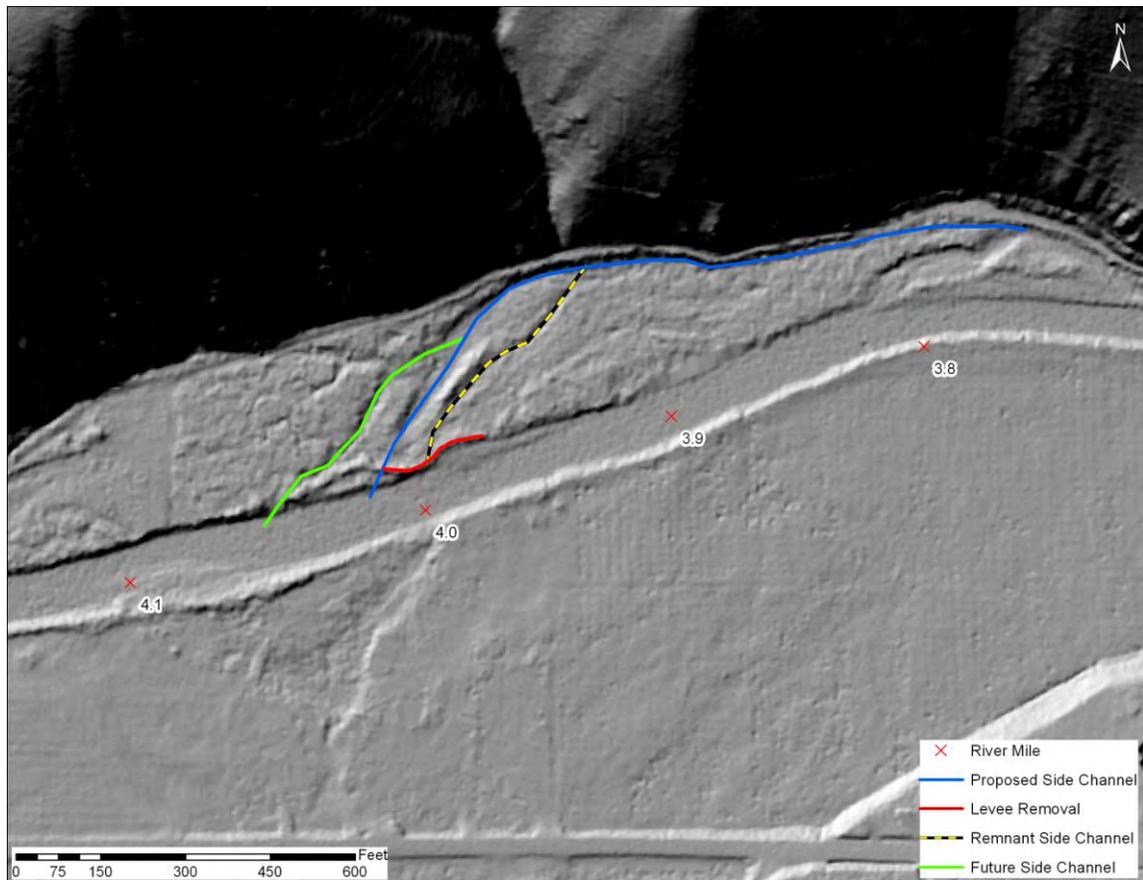


Figure 6: Preferred alternative for the Harrison Side Channel Reconnection project.



Figure 7: Harrison side channel entrance post construction.

## **SUMMARY AND CONCLUSIONS**

Human-induced changes to channel processes have historically reduced the quality and availability of aquatic habitat on the Entiat River, affecting the abundance, productivity, spatial structure, and diversity of ESA-listed native salmonid species. Recovery of these species, through habitat restoration, has been mandated through a Biological Opinion. Natural ecosystem processes operate at different spatial and temporal scales forming an interdependent system where one level influences other levels. To ensure a holistic approach to habitat restoration, assessments have been conducted using a hierarchical, top-down approach, telescoping from a subbasin scale, through a reach scale, down to a project level scale at which habitat actions are implemented.

Numerical hydraulic models have helped dictate the course of each level of assessment. Numerous models varying in both type and spatial scale have been completed throughout the lower 26 miles of the Entiat River. A one-dimensional HEC-RAS hydraulic model of the lower 26 miles was created to assess subbasin trends in stream energy and channel capacity, map potential inundation areas, and complete an incipient motion analysis. Both one-dimensional (HEC-RAS) and two-dimensional (SRH-2D) hydraulic models have been generated at reach scales (3-5 miles) as well as at project level scales (<1 mile) to evaluate, and in the case of project level analysis, design, proposed habitat restoration alternatives. From these efforts came subbasin and reach assessments in addition to implementation of localized habitat projects through alternatives evaluations. Habitat restoration projects to date have been mostly localized in nature and consisted of the placement of in-channel structures to increase complexity, re-connection of off-channel habitat areas, and vegetation planting.

## REFERENCES

- Chelan County Conservation District (CCCD). 2004. *Entiat Water Resource Inventory Area (WRIA) 46 Management Plan*: Prepared for the Entiat WRIA Planning Unit by the Chelan County Conservation District; 318 pp. plus appendices. Submitted pursuant to Washington Watershed Planning Act, Chapter 173-546.
- Godaire, J., Russell K., and J. Bountry. 2009. *Entiat Tributary Assessment*. Chelan County, Washington. U.S. Department of Interior, Bureau of Reclamation, Technical Service Center, Denver, CO.
- Lyon, E.W., Mcaffee, R., Sixta, M., Archibald, P., and D. Hopkins. 2009. *Preston Reach Assessment*. U.S. Department of Interior, Bureau of Reclamation, Pacific Northwest Region, Boise, ID.
- National Marine Fisheries Service (NMFS). 2008. *Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program (Revised and reissued pursuant to court order, NWF v. NMFS, Civ. No. CV 01-640-RE (D. Oregon)), May 5, 2008, F/PNR/2005/05883*.
- Nelle, P., Bouwes, N., Beasley, C., Ward, M.B., and J. Monahan. 2009. *Monitoring Strategy for the Upper Columbia Basin*. Appendix B: An Implementation Strategy for an Intensively Monitored Watershed Program in the Entiat River Subbasin. Prepared for: Bonneville Power Administration, Entiat Watershed Planning Unit, Upper Columbia Salmon Recovery Board.
- Reeves, G. H., L.E. Benda, K.M. Burnett, P.A. Bisson, and J.R. Sedell. 1995. *A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the pacific northwest*: American Fisheries Society Symposium. 17, 334-349.
- Saldi-Caromile, K., K. Bates, P. Skidmore, J. Barenti, and D. Pineo. 2004. *Stream Habitat Restoration Restoration Guidelines: Final Draft*. Co-published by the Washington Departments of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, WA.
- Upper Columbia Regional Technical Team (UCRTT). 2008. *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region*. April, 2008. Prepared for Upper Columbia Salmon Recovery Board. 113 pp.
- Upper Columbia Salmon Recovery Board (UCSRB). 2007. *Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan*. Wenatchee, WA.