EVALUATING ANTHROPOGENIC IMPACTS ON SALMONID HABITAT WITH A TWO-DIMENSIONAL HYDRAULIC MODEL, MIDDLE FORK JOHN DAY RIVER, OREGON

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ABSTRACT

A broad-scale multi-disciplinary channel assessment of the Middle Fork John Day River, Grant County, Oregon, was performed in support of the recovery of listed salmonid species under the Endangered Species Act. The assessment recognized the high potential to reestablish physical processes and address limiting factors of the salmonid species within a four-mile reach in the Forrest Conservation Area, a property owned and operated by the Confederated Tribes of the Warm Springs Reservation of Oregon. A need for a more detailed hydraulic model and geomorphic investigation on this reach was identified to explore the impacts of anthropogenic activities on channel processes. Over the past 150 years, anthropogenic activities on the Forrest Conservation Area have disconnected the channel from more than fifty percent of the floodplain area primarily due to a historical railroad grade. Flow is currently conveyed through an entrenched artificial channel that has resulted in an increased channel slope and reduced length.

A two-dimensional hydraulic model was used to quantify the extent to which constructed features and human activities limit spawning, rearing, and holding habitat for listed salmonid species. Two topographic scenarios were simulated using Bureau of Reclamation's SRH-2D hydraulic model to define the existing conditions of the reach and to evaluate potential increases in habitat through the removal of the historical railroad grade. The first topographic scenario was developed based on conditions that exist within the reach today, while the second scenario represented the topography of the reach if the railroad grade was completely removed and flow was conveyed through its historical channel. Topographic data were suitable to model discharges at or exceeding bankfull discharge. Distributions of depth, velocity, and shear stress were examined to determine how and where changes would occur between the two modeled scenarios for select discharges between the 2-year and 100-year recurrence intervals. Using results from the model, several habitat indicators, including side channel access, floodplain connectivity, and high-quality high-flow habitat, were compared between existing conditions and removed railroad conditions to characterize potential improvements to habitat.

Results from the modeling effort indicate that completely removing the historical railroad grade may not be necessary. The model can be further applied to identify whether partial removal or strategic breaching of the railroad grade would be equally beneficial biologically to complete removal. Information from the modeling will be linked to geomorphic investigations and can be integrated with ecological processes to assist managers, partner agencies, and design committees in focusing resources towards implementation of sustainable rehabilitation strategies that gain the greatest biological benefit.

INTRODUCTION

Within the Middle Fork John Day River (MFJDR), substantial changes to channel processes and resulting habitat have occurred over the last century. Populations of several important fish species, including spring Chinook (*Oncorhynchus tshawytscha*), summer steelhead (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*), have markedly decreased. The Bureau of Reclamation (Reclamation) initiated assessments of channel processes in the MFJDR to develop planning tools that can be used collectively by partners within a subbasin to focus resources for identification and prioritization of floodplain connectivity and channel complexity rehabilitation/ protection projects. The John Day River is a tributary to the Columbia River and drains nearly 8,000 square miles. The Middle Fork subbasin originates in the Blue Mountains of the Malheur National Forest and flows 75 miles to its confluence with the North Fork John Day River north of Monument, Oregon.

Following completion of a broad-scale assessment of channel processes through a 23-mile stretch of the MFJDR located in Grant County, Oregon, Reclamation identified the need to conduct more detailed investigations of hydraulic and geomorphic processes on several smaller reaches, including the Forrest Conservation Area (FCA). The FCA encompasses a 4-mile reach of the MFJDR, owned and managed by the Confederated Tribes of the Warm Springs Reservation of Oregon. The entire FCA lies within a broad valley, the width of which is heavily influenced by multiple tributaries and accompanying alluvial fans. Numerous anthropogenic activities over the past 150 years have influenced the use of the FCA by salmonid fish species. In the early 1900's, Oregon Lumber Company built railroad tracks down the Middle Fork John Day River valley (Johns 1997). This rail line was constructed down the center of the floodplain of the FCA on top of a levee, causing a reduction in floodplain width by more than 50 percent, disconnection of several meander bends, and straightening of the channel. Although the railroad tracks were later removed, levees disconnecting historical channels and floodplain remained.

Other notable human disturbances on the FCA included farming and grazing activities, which led to the development of irrigation diversions, possible draining of the floodplain through the excavation of drainage ditches, and riparian vegetation removal along the channel banks and throughout the floodplain. Flood management practices and beaver trapping further reduced channel complexity with the installation of over 300 bank protection features, clearing of gravel and debris plugs, and a lack of off-channel beaver ponds. Anthropogenic activities in the FCA have reduced channel and floodplain complexity, disconnected a substantial portion of the floodplain and several side channels, and limited the ability of the channel to migrate laterally. All of these modifications to historical channel processes have likely impacted the ability of the channel to create and maintain suitable spawning, rearing, and migration habitat for salmonids.

A two-dimensional (2D) hydraulic model through the FCA was developed to increase understanding of floodplain processes, side channel connectivity, and tributary inputs under existing conditions and to predict changes to these processes and resulting habitat if anthropogenic features are removed. Hydraulic parameters, including depth-averaged velocity, bed shear stress, and depth were compared across the areal extent of the floodplain for the existing conditions and a "Removed Human Features Scenario". In addition, potential changes to high quality high flow habitat, floodplain and side channel connectivity, and low flow habitat

features were examined to determine how removal of the human features could benefit habitat for salmonid species.

METHODS

Hydraulic Model

The model selected for this analysis was SRH-2D (Lai 2006), a depth-averaged, two-dimensional model that simulates hydraulics and was developed primarily for use by engineers to solve various hydraulic and sedimentation problems with an approach for coupled modeling of channels and floodplains. For this analysis, the fixed bed version of the model was selected and no sediment transport computations were performed. Model input data included a mesh representing a topographic surface and major features of interest, hydraulic roughness parameters, downstream water surface elevations, and inlet flows at the upstream boundary and tributaries.

Development of the Model Surface

The first step in constructing the hydraulic model was to obtain topographic data in a known survey datum for both above water topography and bathymetry. Topographic and bathymetric ground surveys were performed in 2005 and 2006 by contractors to Reclamation (Thomas/Wright, Inc. and David Evans and Associates) using a combination of GPS and total station surveys. Topographic LiDAR data were acquired in October 2006 to identify ground surface elevations, infrastructure, and vegetation within the floodplain of the study area (Watershed Sciences 2006). The LiDAR and topographic survey data were combined to develop the final model surface for input into the 2D hydraulic model.

Construction of the Modeling Mesh

The computational mesh was constructed using the Surface-Water Modeling System (SMS) software Version 10.0.0. The mesh contains elevation information at each node and roughness data for each cell (see next section for more information on establishing roughness parameters). The cell size of the mesh was varied based on the location of the cell. Within the channel and across other important topographic features (e.g., road embankment, levees, side channels, riprap), cells were limited to approximately 5 feet in the lateral direction (cross-stream) and approximately 10 to 15 feet in the longitudinal direction (downstream). The shorter dimension in the lateral direction is used to capture the more rapidly changing topography transverse to the stream flow with respect to horizontal distance. In the floodplain, cells were limited to 10 to 20 feet in both directions depending on the uniformity of the topography. The mesh consists primarily of quadrilateral elements, with triangular elements making up less than 20 percent of the entire mesh. The cell size of the channel was selected to maximize model computation efficiency by minimizing the number of cells to balance run time with model accuracy. Cell sizes throughout the modeled area were varied to ensure that important breaks in elevation were represented. Approximately 170,000 grid cells were used in the mesh.

The mesh boundaries in the lateral direction were digitized to at least capture all of the area inundated by a 100-year discharge. Channel margins and other significant breaks in the topography were also digitized into the mesh to ensure that mesh boundaries align with elevation

changes. Key topographic features represented in the mesh included the historical railroad grade, road and bridge embankments, channel margins, side channels, and tributaries.

Roughness Zones and Vegetation

Nine classifications of roughness were used to represent the study area. Within the extents of the mesh, roughness zones were spatially delineated using 2006 aerial photographs and the topography data from the model surface. Each roughness zone was assigned an appropriate Manning's n value for input to the 2D model. These values were adjusted for qualitative model calibration and also to examine the model sensitivity to variations in roughness. The sensitivity run values were determined by adding or subtracting .005 to or from the adjusted roughness value.

Table 1 – Roughness values used in the model development and in the sensitivity test.

	Manning's Roughness Coefficient			
Roughness Classification	**Initial Value**	**Adjusted Value**	**High Sensitivity Run**	**Low Sensitivity Run**
Channel	0.039	0.039	0.044	0.034
Light Vegetation	0.043	0.045	0.050	0.040
Medium Vegetation	0.053	0.055	0.060	0.050
Heavy Vegetation	0.063	0.065	0.070	0.060
Bridge	0.039	0.039	0.044	0.034
Side Channel/ Historical Main Channel/ Tributary	0.039	0.042	0.047	0.037
Road and embankment	0.050	0.050	0.055	0.045
Levee	0.043	0.043	0.048	0.038
Steep Tributary with larger bed material than main channel	0.043	0.043	0.048	0.038

Boundary Conditions

Downstream boundary conditions for the model were derived from a one-dimensional (1D) hydraulic model of the MFJDR (Reclamation 2008). Results of the 1D model were used to determine the water surface elevation at the downstream boundary of the 2D model. The 1D model extends more than 10 miles below the downstream boundary for the 2D model and was run with downstream boundary conditions based on normal depth.

Upstream boundary conditions for the model consisted of inflow discharges. Discharges used in the model represent the 2-, 5-, 10-, 25-, 50-, and 100-year return periods and ranged from 562 cfs to 2,364 cfs. Flows were based on a hydrologic analysis conducted by Reclamation (2008), in which the National Flood Frequency equations were coupled with gaged data from the United States Geological Survey (USGS) gage on the Middle Fork John Day River at Ritter (14044000). This gage is located over 40 miles downstream from the FCA. Additional overbank discharges were evaluated for qualitative comparison of model results with high flow photographs. No seepage losses were accounted for throughout the length of the reach. The model was developed to evaluate lateral floodplain processes under high flows.

Subreach Delineation

The modeled section of river on the FCA covers three distinct subreaches (Figure 1), which are used in this paper to distinguish differences in hydraulic processes and potential rehabilitation actions. These subreaches were determined through geomorphic characteristics of the floodplain and channel (e.g. slope and geologic controls), results of the 2D hydraulic model, and a Level 2 Habitat Assessment completed by the USFS. The most upstream subreach, subreach 1, extends from River Mile (RM) 67.5, at the current Bridge Creek confluence with the MFJDR, downstream to RM 66.5, just upstream from Vinegar Creek. Within this subreach, Bridge Creek, Placer Creek, and Davis Creek all contribute flow and sediment to the system. The reach is mostly confined by Placer Gulch alluvial fan between RM 67.5 and 67.2 and by Davis Creek between 66.8 and 65.5. A short section of wider valley and side channel development is present between 66.8 and 67.2.

The second subreach lies between Vinegar Creek (RM 67.5) and Vincent Creek (RM 66.5), and is denoted as subreach 2. This subreach is the widest of the three subreaches, but more than 65 percent of its floodplain is disconnected due to the railroad grade. The existing channel is a straighter, steeper section of river than under pre-disturbance conditions. Disconnected oxbows have filled in some over time but remain present across the disconnected portion of the floodplain. Both Vinegar and Vincent Creek contribute substantial flows to the system. Vinegar Creek is a substantial contributor of coarse sediment through fluvial processes combined with episodic shallow landslides. Historical placer mining in Vincent Creek may have some impact on its sediment supply and delivery to the system.

The most downstream reach extends from RM 63.5, just downstream from Caribou Creek, to RM 65.5, just downstream from Vincent Creek. This subreach, denoted as subreach 3, is influenced in a few localized areas by the presence of the historical railroad grade, but not to the extent of the Vinegar to Vincent Creek subreach.

Conditions Examined

In addition to investigating the existing condition, the model was applied to evaluate how hydraulic parameters and habitat features may change following removal of human features. The “Removed Human Feature Scenario” included taking the remnant railroad grade down to the surrounding floodplain elevations and blocking off the channelized sections of river in a few localized areas between Vinegar and Vincent Creek. In addition, the topography of the model was modified so that the historical channel was more defined in several areas where the historical channels were disconnected or altered by farming and grazing activities. Figure 2 shows the modifications to the topography for the Removed Human Features Scenario between Vinegar and Vincent Creeks (subreach 2). In the subreaches 1 and 3, the only modification to the topography included removing the railroad grade.

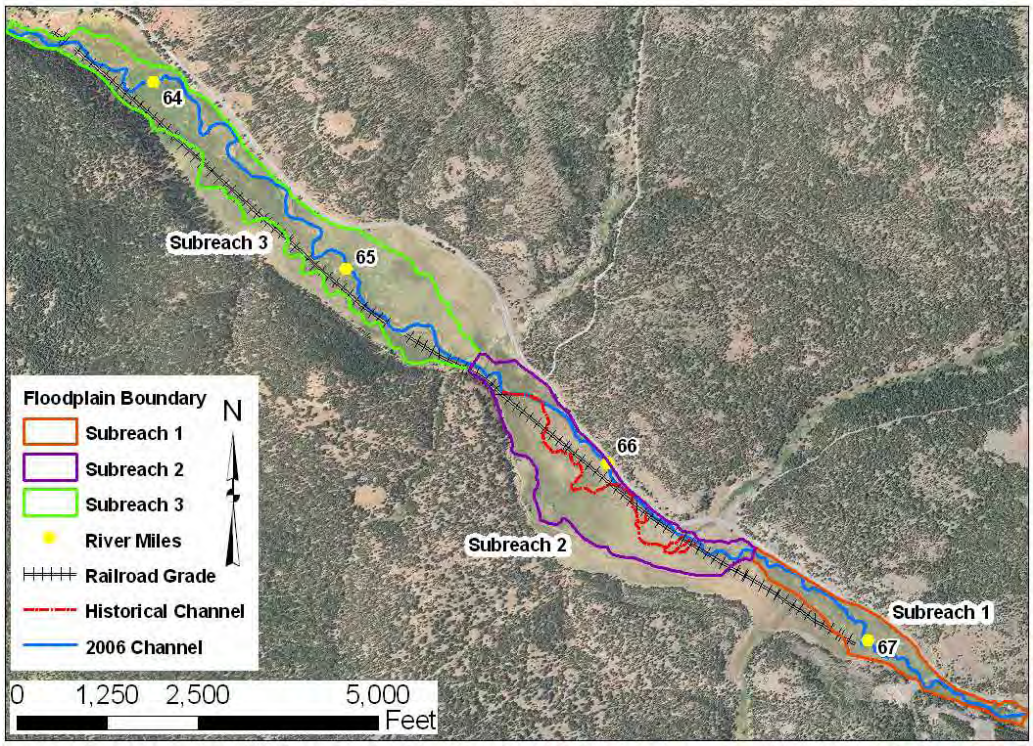

Figure 1. Delineation of subreaches on the FCA.

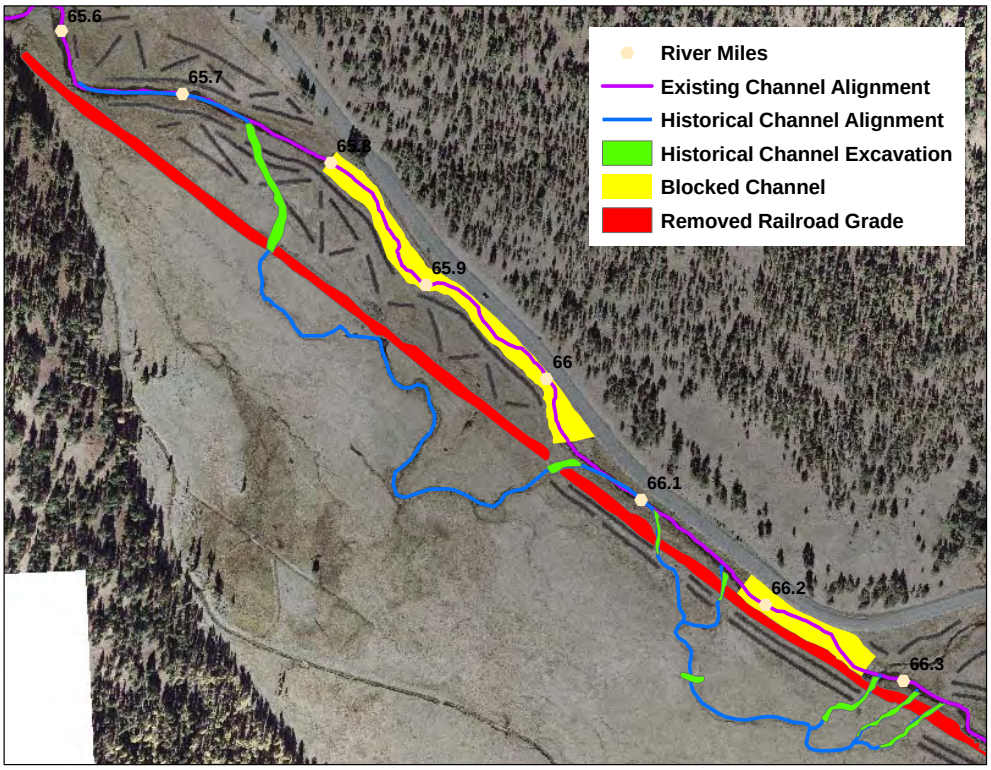

Figure 2. Topographic modifications for the Removed Human Features Scenario in Subreach 2, between Vinegar and Vincent Creeks.

RESULTS

Hydraulic Parameters

Hydraulic parameters (flow depth, bed shear stress, and depth averaged velocity) were evaluated longitudinally along the channel thalweg and also based on area across the channel and floodplain to determine how and where change occur between existing conditions and the Removed Human Feature Scenario. Longitudinal changes in the parameters were examined by digitizing a line along the existing and historical channel thalwegs and extracting values from the model results. To evaluate the areal distributions, Triangulated Irregular Networks (TINs) of depth, velocity, and bed shear stress were created in ArcGIS for both conditions and compared to determine the magnitude of the differences between each scenario. Aerial distributions provide insight into changes in the spatial distribution of the hydraulic parameters. The following sections describe the model results of flow depth, depth-averaged velocity, and bed shear stress.

Depth

Differences in flow depth between the existing conditions and the Removed Human Features Scenario are most notable in subreach 2 between the Vinegar and Vincent Creeks. Almost no changes in flow depth are present in subreach 1 for any of the flows modeled. With the railroad removed and portions of the channelized section of the river blocked, the floodplain along the south western side of the valley is characterized by greater depths, and the historic channel becomes activated (Figure 3). Reduced depths were simulated in the existing channel that was blocked under the Removed Human Features Scenario. Depth reductions were also predicted in some localized floodplain areas due to an increase in accessible floodplain area. In other words, as more flow can access and inundate a greater area due to removal of the railroad, the depth of the previously inundated area is reduced and spread across a greater area. These results indicate increased floodplain connectivity across the floodplain of subreach 2 under the Removed Human Features Scenario. Within subreach 3, changes in flow depth only occurred in a few localized areas. In these areas, flow depths on the floodplain directly adjacent to the channel are generally reduced due to an increase in the total accessible floodplain area resulting from removal of the railroad grade. With the railroad grade removed, increases in the flow depth were predicted in previously disconnected floodplain areas, including along the railroad grade.

Evaluation of longitudinal changes in depth along the existing channel thalweg indicates substantial decreases in depth in subreach 2 under the Removed Human Features Scenario (Figure 4). Depths drop to less than one foot for a 2-year discharge where the existing channel is blocked. Just upstream from where the channel is blocked, however, short distances of dramatically increased depths were simulated due to back water impacts from the blocked section of the channel. Figure 5 illustrates depths along the historical channel thalweg, portions of which are not activated for a 2-year discharge under existing conditions. These areas become activated with depths between 1 and 4 feet when the railroad grade is removed.

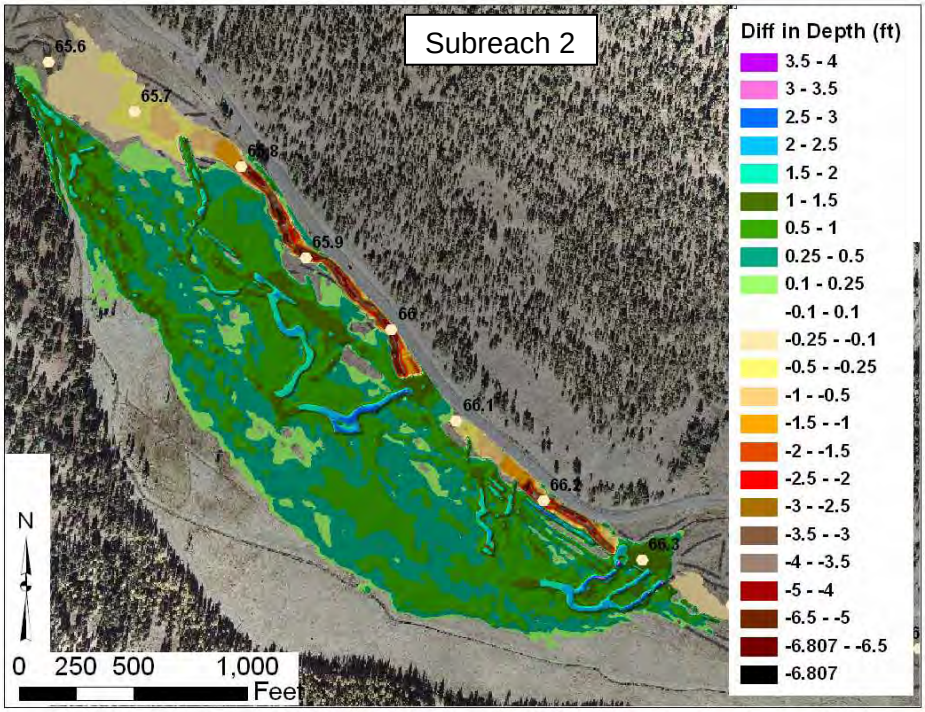

Figure 3. Difference in depth between existing conditions and Removed Human Features Scenario for a 10-year discharge. A positive value indicates an increase when the railroad grade is removed.

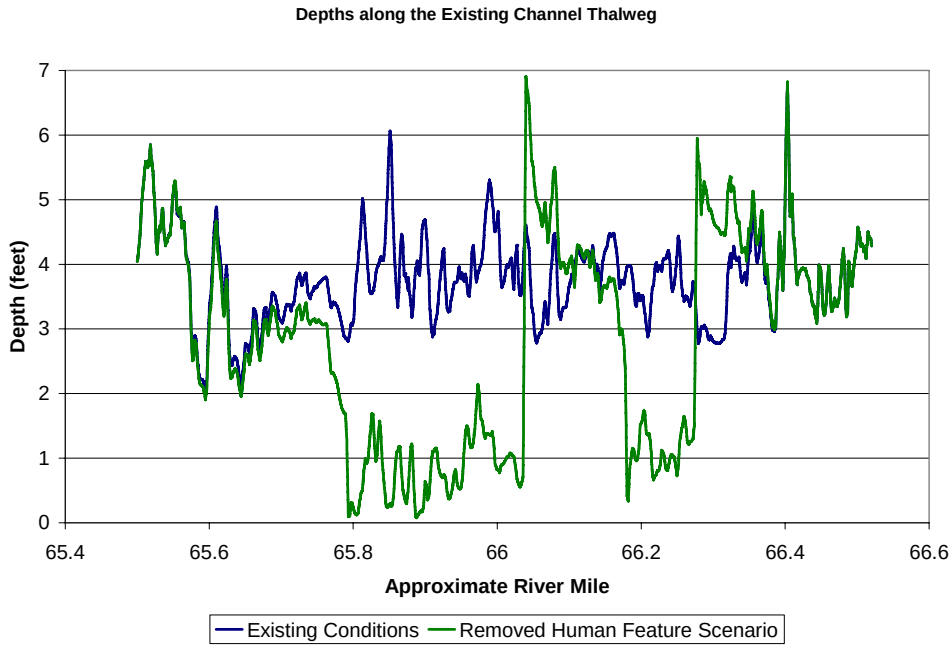

Figure 4. Comparison of channel depths along the existing channel thalweg for the existing conditions and Removed Human Feature Scenario at a 2-year discharge.

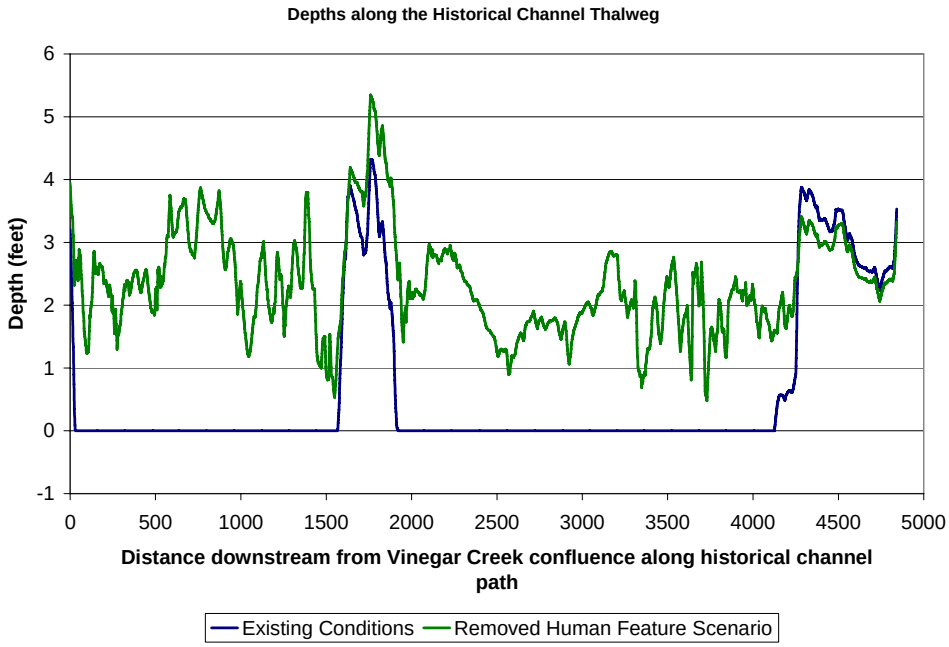

Figure 5. Comparison of channel depths along the historical channel thalweg for the existing conditions and Removed Human Feature Scenario at a 2-year discharge.

Velocity and Bed Shear Stress

Similar to changes in flow depths, spatial changes in velocities and shear stresses are primarily present in subreach 2 with small areas of localized changes in subreach 3 and minimal changes in in subreach 1. Both the areal and longitudinal comparisons clearly predict substantially reduced velocities in the existing channel in subreach 2. Reductions of 7 feet per second (ft/s) are predicted in the channelized portion of the existing channel that was blocked under the Removed Human Features Scenario. Within the historical channel, velocities increase up to 5 ft/s when the railroad grade is removed and the channel becomes activated. For a 2-year discharge, velocities along the floodplain adjacent to the historical channel typically increase by 0.25 to 2 ft/s, and increases for a 10-year discharge typically range between 1 and 2 ft/s. Along the historical channel thalweg, velocities are generally between 1 and 5 ft/s during a 2-year discharge for the Removed Human Features Scenario.

Bed shear stress follows patterns similar to depth-averaged velocities with most changes noted in subreach 2. Under existing conditions, the existing channel in subreach 2, between Vinegar and Vincent Creeks, acts as a transport reach, in which all incoming sediment is transported through the reach to the next downstream reach (Reclamation, 2008). These conditions indicate that the channel in its current configuration appears to be supply-limited in subreach 2. Bed shear stresses in subreach 2 average just over 1 lb/sf during a 2-year discharge under existing conditions, indicating that the channel could mobilize small cobbles. However, the capacity of the existing channel to transport sediment exceeds the actual sediment supplied to the reach. Bed shear stresses along the historical channel thalweg average close to 0.4 lb/sf during a 2-year discharge when the railroad grade is removed, which would mobilize coarse gravels. These results suggest that removing the railroad and routing flows through the historical channel could

promote more dynamic equilibrium, thereby increasing the lateral channel migration (erosion and depositional processes) associated with the historical channel and adjacent floodplain.

DISCUSSION- LINKING HYDRAULICS TO HABITAT

Floodplain Connectivity

For the purposes of this analysis, connected floodplain was defined as the area with depth exceeding 0.5 feet outside of the low flow channel, including side channels with depths exceeding 0.5 feet. These criteria were evaluated for all discharges modeled. Under existing conditions, subreaches 1 and 3 are fairly well inundated during most flood events with 18 to 32 percent of floodplain connected during a 2-year discharge, 35 to 50 percent of the floodplain connected during a 5-year discharge, and 46 to 60 percent of the floodplain connected during a 10-year discharge. Floodplain connectivity in subreach 2 is much more limited under existing conditions, with only 8 to 18 percent of the floodplain connected for a 2- to 10-year discharge, respectively. By removing the historical railroad grade and allowing flow to access the disconnected portion of the floodplain, the area of connected floodplain in subreach 2 increases by more than 200% for the flows modeled.

Side Channel connectivity

Side channel connectivity was evaluated for the existing conditions and the Removed Human Features Scenario. Side channels were considered connected if they conveyed flows between the 2- and 10-year discharges through a noticeable topographic path located outside of the main channel. Within the FCA, side channels are often comprised of a network of multiple, interconnected channels rather than one distinct channel. Results of the model suggest that most side channels are activated under existing conditions in subreaches 1 and 3. Side channel connectivity was predicted to experience the greatest increase from existing to Removed Human Feature conditions in subreach 2 between Vinegar and Vincent Creeks.

Between Bridge Creek and Vinegar Creek, a short section (0.4 miles) of unconfined floodplain is separated from upstream and downstream portions of the subreach where the floodplain is heavily constricted by bedrock or alluvial fan deposits. Under both modeled conditions, this area is well inundated and consists of several interconnected side channels during a 2-year discharge. The total length of potential side channel connectivity in this subreach is estimated to be approximately 0.7 miles. Side channel connectivity in subreach 2 is limited to one small area with approximately 660 feet of side channel just upstream of the Vinegar Creek confluence under existing conditions. However, the total length of accessible side channel connectivity increases to almost 1.8 miles with the railroad grade removed. Most of these side channels are interlinked and lie along the southwest side of the historical channel and floodplain. In subreach 3, the floodplain is well-connected under existing conditions, and therefore existing side channels are also well-connected. The total length of side channels activated during flows with a magnitude of a 10-year discharge or less is approximately 2 miles under existing conditions. Following removal of the railroad grade, additional side channels add approximately 1,600 feet of length to the total length of potential side channel connectivity through the subreach.

High Quality High Flow Habitat

High-quality high-flow habitat was defined as areas experiencing greater than 0.5 feet of flow depth with velocities less than 2 ft/s. Areas meeting these criteria accounted for 2 to 33 percent

of the floodplain area under existing and proposed conditions depending on the discharge simulated and the reach analyzed. In comparing the floodplain area meeting the criteria in the existing and Removed Human Features conditions, the most notable changes were predicted in subreach 2 with smaller areas of localized changes in subreach 3. Within subreach 2, total high-quality high-flow habitat area increased from 2 to 11 acres during a 2-year discharge, from 4 to 16 acres during a 5-year discharge, and from 5.5 to 18 acres during a 10-years discharge. Increases in subreach 3 were less than 1 acre for the 2-, 5-, and 10-year discharges. Almost no changes were predicted in subreach 1 between Bridge and Vinegar Creeks.

CONCLUSIONS

Two-dimensional hydraulic modeling was performed to evaluate existing hydraulic conditions and resultant habitat for high flows on the FCA of the MFJDR. The model was also utilized to investigate the potential for increased habitat following the removal of a railroad grade, reconnection of a historical channel, and blockage of an existing channelized portion of the river. Several key conclusions can be drawn from the modeling results, including:

1. Subreach 2 is the most impacted of all three reaches. Removing the railroad grade in this location and blocking portions of the existing channelized river will force flow into its historical channel and result in substantially increased floodplain connectivity, side channel connectivity, and high-flow high quality habitat.
2. Subreaches 1 and 3 have well-connected floodplains under existing conditions. Removal of human features has almost no impact on subreach 1. Small, localized areas of floodplain and habitat may benefit from removal of the railroad in subreach 3, but the amount of increased off-channel habitat is predicted to be small relative to subreach 2.
3. Model results can be used to assist the landowners, managers, and other stakeholders in deciding where to prioritize rehabilitation efforts in order to realize the greatest biological benefit. Currently, the railroad grade through the FCA is listed on the National Register of Historical Places. While it is recognized that the railroad grade has historical significance through the property, it also limits habitat for ESA-listed and other culturally important fish species in the region. The model results may be used to identify (1) locations where the railroad grade has the greatest impact on habitat and could be removed or breached as a rehabilitation action and (2) locations where the railroad grade has relatively little impact on channel dynamics and floodplain connectivity through the reach and could remain intact without further limiting habitat.

Results from the 2D model will continue to be evaluated in conjunction with a geomorphic analysis and used as tools to investigate additional rehabilitation actions and subsequent results on habitat.

REFERENCES

Bureau of Reclamation. 2008. *Middle Fork and Upper John Day River Tributary Assessments, Grant County, Oregon*: U.S. Department of the Interior, Bureau of Reclamation. Denver, CO.

Johns, S., 1997. *Bates-Austin remembered (A Brief History)*. Excerpts available online at: http://www.precious-testimonies.com/TestimonyLivesOn/Bates.htm (accessed June 1, 2007 and October 11, 2007).

Lai, Y.G. 2006. Theory and User's Manual for SRH-W, Version 1.1. U.S. Department of the Interior, Bureau of Reclamation. Denver, CO.

Watershed Sciences. 2006. LiDAR Remote Sensing Data Collection: Desolation Creek, Middle Fork John Day River and John Day River, Oregon. Portland, OR.