Simulated Habitat as an Indicator of Upstream Conditions

Supplemental Analysis for the Instream Flow Study

Wallowa Falls Hydroelectric Project

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Introduction

The Preliminary License Proposal (PLP) for the Wallowa Falls Hydroelectric Project (Project) included a provision to reroute the powerhouse tailrace from the West Fork to the East Fork Wallowa River. The reroute would restore full natural flows to the lower 2600 feet of the East Fork. Bull trout inhabit the lower 4100 feet of the bypassed reach, referred to as the “habitat section of the bypassed reach” in the PLP. Natural flows will be restored to all but the uppermost 1500 feet of the habitat reach. This analysis addresses habitat conditions in the 1500 feet of the habitat section located upstream of the proposed tailrace outfall.

The new license is expected to include a provision for a minimum instream flow greater than the existing minimum of 0.5 cfs. An instream flow study was performed to identify minimum flows that would protect bull trout habitat in Project- affected waters. The study included a habitat simulation component, based on flow and velocity data collected at stream transects located in a designated study reach.

The model used to simulate habitat, Physical Habitat Simulation (PHABSIM) model, was developed with the assumption that the stream transects have even water surfaces. This assumption limited the spatial extent the study reach in the East Fork bypassed reach. Most of the bull trout habitat in the East Fork bypassed reach is characterized by boulder-strewn, high gradient cascades. The turbulent flows and hydraulic jumps created by such features preclude the use of PHABSIM in these waters. However, a reach of approximately 1600 feet, starting at the mouth of the stream, was identified as a suitable PHABSIM study reach. The lower gradients and smaller substrate promoted more laminar flows and even water surfaces. Within this lowest reach of the bypassed reach, study transects were established for the collection of hydraulic data that was later used in PHABSIM to simulate bull trout habitat.

The results of the PHABSIM simulation efforts led PacifiCorp to recommend 4 cfs as a suitable minimum flow for the protection of bull trout habitat. However, the study reach upon which this recommendation was based is located entirely downstream of the planned outfall of the rerouted tailrace. Stakeholders have expressed concern that the PHABSIM results may not necessarily represent habitat dynamics in the high-gradient reach upstream of the tailrace outfall.

PacifiCorp believes that bull trout habitat dynamics upstream of the proposed outfall are adequately represented by the relationship between habitat and flow developed in the downstream PHABSIM study reach. The results of the PHABSIM analysis indicates that habitat suitability in the study reach is primarily velocity-driven; that is, the change in the amount of suitable habitat as a function of flow is determined largely by changes in channel velocities (as opposed to other habitat variables, such as water depth or substrate). As such, PacifiCorp assumes that the PHABSIM results also serve as a representative (and perhaps even conservative) index of instream habitat-flow relations in the high-gradient reach upstream of the tailrace outfall. For example, PacifiCorp’s recommended flow of 4 cfs would also provide suitable bull trout habitat in the high-gradient reach, because water velocities in the higher-gradient reach at 4 cfs are expected to be similar to, if not more rapid than, water velocities in the downstream reach.

Objectives

The goal of this analysis is to identify whether habitat-flow relationships in the downstream PHABSIM study reach can be used as an index of habitat conditions in the high-gradient reach upstream of the tailrace outfall. In the following analysis, the reach below the proposed outfall is referred to as the lower segment of the bull trout reach (lower segment). The reach upstream of the proposed outfall is referred to as the upper segment of the bull trout reach (upper segment). As described above, because PHABSIM analysis was not possible in the turbulent upper segment, PacifiCorp assumes that the results from the PHABSIM study reach in the lower segment also provide a representative (and perhaps even conservative) index of instream habitat-flow relations in upper segment. In the analysis that follows, we evaluate this assumption by using average reach velocity as a surrogate for simulated habitat. Specific objectives include:

1. Estimate the average reach velocity over a range of flows in the lower and upper segments of the bypassed reach;
2. Determine the range of flows over which the lower segment serves as an index for the upper segment;
3. Discuss the limitations of the index.

Methods

Average reach velocity was calculated for both segments between flows of 0.8 cfs and 40 cfs. This range was selected to maintain consistency with the flow range that was explored for the instream flow study. Velocity was calculated with the Manning's equation, which is an empirical method for predicting average water velocity at a cross section. This analysis assumes that cross-sectional velocity represents average reach velocity. Manning's equation states that:

$$V = (k/n)\ (R_h^{2/3})\ (S^{1/2})$$

where:

- V is the cross-sectional average velocity (feet per second, fps) at a transect
- k is a conversion factor (1.49 $ft^{1/3}/s$)
- n is Manning's roughness coefficient (unitless)
- R_h is the hydraulic radius (ft), calculated as (area of wetted cross section)/(wetted perimeter)
- S is the slope of the hydraulic grade line, equal to slope of water surface for steady, uniform flow

In the paragraphs below, PacifiCorp addresses each variable in Manning's equation. Inputs for each variable were selected to provide average velocities representative of the upper and lower segments.

Slope

Water surface gradient was measured at 4 cfs during PacifiCorp's habitat survey in April 2012. PacifiCorp reviewed the data from the habitat survey, and determined that the lower segment had an overall of 4.2%, and the upper segment had a slope of 10.2%.

Hydraulic Radius

Hydraulic radius requires knowledge of specific channel dimensions at a given flow, including wetted cross-sectional area and wetted perimeter. Calculations of hydraulic radius are available for each of the 13 study transects over the full range of flows explored in the instream flow study. For this analysis, PacifiCorp selected two representative transects. Transect number 8 was considered representative of the lower segment. Transect number 14, located at the transition between the lower and upper segment, was considered representative of the upper segment. Images of these transects, and the reaches they represent, are provided in Attachment A. .

The unique relations between flow and hydraulic radius at the two transects were used in Manning's equation to estimate average channel velocity in both segments between flows of 0.8 cfs and 40 cfs.

Manning's N

The Manning's n roughness coefficient is an empirical value. Published literature provides a wealth of n values, pertaining to synthetic, paved, earthen, vegetated, and natural channels, plus any number of permutations for each category. This analysis used roughness coefficients provided by Yochum and Bledsoe (2010) for high-gradient streams. Yochum and Bledsoe (2010) developed a series of observation-based n-values for cascade, step pool, and plane bed stream reaches. Yochum and Bledsoe's (2010) research is particularly valuable because n-values were assessed in their study reaches at low, mid, and bank-full flows. Traditionally, a single value of n is selected based on the channel form, and applied over a range of flows. However, in high-gradient streams, flow resistance tends to decrease as flows increase.

Dynamic n-values, representing low, mid, and bankful flows, were selected from two of Yochum and Bledsoe's (2010) stream reaches that had gradients and channel forms similar to the upper and lower segments (Table 1). PacifiCorp then applied a logarithmic function to Yochum and Bledsoe's (2010) three discrete n-values, which provided continuous n-values over the range of minimum flow alternatives. To develop the function, PacifiCorp assumed a "Low" flow of 0.8 cfs (the existing minimum flow), a "Mid" flow value of 4 cfs (the flow at which the channel bottom fills with water), and a "Bankful" flow of 40 cfs (based on PacifiCorp's observations in the field). The relationships between flow and n-value are provided in Attachment B. .

Table 1. Selected Manning's *n* values

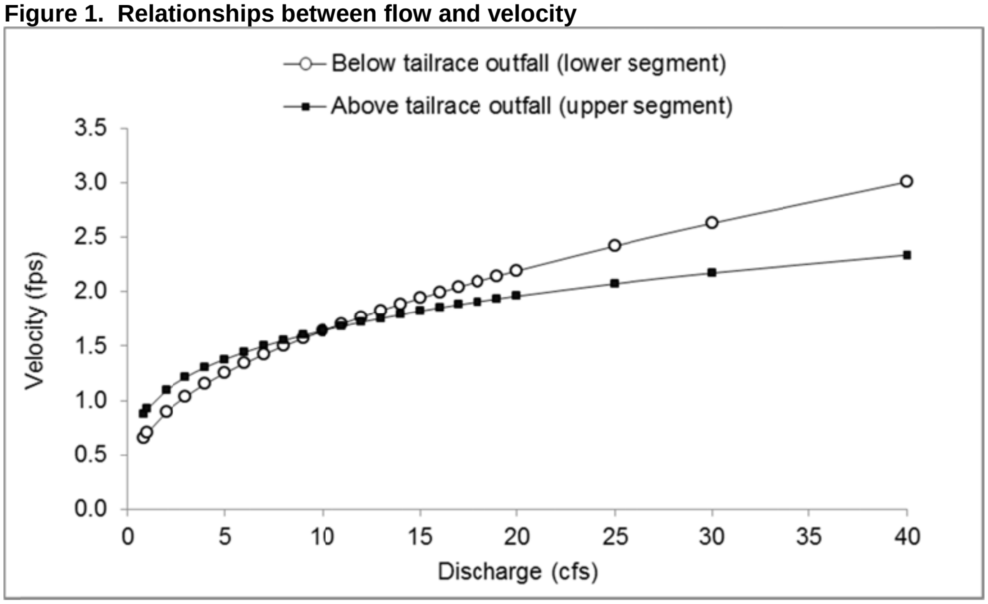
Flow	Lower Segment[1]	Upper Segment[2]
Low (0.8 to 4 cfs)	.2	.20
Mid (4 to 39 cfs)	.17	.19
Bankful (40 cfs +)	.095	.17

Results

Average reach velocities in the upper and lower segments are similar up to flows of approximately 20 cfs. When flows are lower than 11 cfs, average velocities in the upper segment are slightly greater than in the lower segment by 0.03 fps to 0.22 fps. At flows between 12 cfs and 20 cfs, the lower segment has slightly higher average velocities, ranging from 0.02 fps to 0.19 fps greater than the upper segment.

As discharge increases above 20 cfs, the average velocities in the two stream segments continue to increase, but at considerably different rates. Velocities in the lower segment increase rapidly, whereas velocities in the upper segment increase at a more moderate rate. Average velocities in the lower segment are greater than in the upper segment by 0.30 fps (25 cfs) to 0.60 fps (40 cfs). The relationships between flow and average velocity are displayed in Figure 1.

Figure 1. Relationships between flow and velocity



[1] n for transitional between plane bed and step pool, Figure 2 (Yochum and Bledsoe, 2010).

[2] n for cascade, Figure 3, *ibid.*

Conclusions

PacifiCorp believes that the instream flow study performed in the lower segment represents conditions in the upper segment over the range of potential minimum flow releases considered by the study (0.8 cfs to 8 cfs, and unimpaired flows up to 16 cfs). This analysis demonstrates that, when flows are less than 20 cfs, average velocities are similar between the two segments. At these relatively low flows, average velocity appears to be largely a function of bed roughness. This observation is consistent with the findings of Wilcox (2005), whose research in high-gradient headwater streams in the Rocky Mountains indicated that bed roughness creates “very large flow resistance values at lower discharges.” As further testament to the importance of bed roughness at low flows, we point to the n-values provided by Yochum and Bledsoe (2010): the two channel reaches that most nearly approximate the East Fork bypassed reach have identical n values of 0.20 at low flows[3]. Other variables, such as gradient or channel form, appear to be less important in explaining variation in average velocity at low flows.

As discharge increases above 20 cfs, average velocities in the two segments begin to diverge. Increased turbulence appears to be the driver behind the moderate velocity increases in the upper segment. The cascade channel form that characterizes the upper segment provides substantial spill resistance, defined as the flow resistance that occurs when rapidly flowing water impacts standing waters (Yochum, et al., 2012). Upon impact, energy dissipation occurs in the form of turbulent flows. Accordingly, as discharge increases above 20 cfs, we see (1) lower velocities in high-gradient cascade segment where spill resistance is high, and (2) comparatively higher velocities in the in the low gradient, plane bed segment, where channel form is conducive to laminar flow. This observation is supported by the findings of Comiti, et al. (2007), which suggest that flow resistance increases with gradient. These studies can be applied to PacifiCorp’s findings in the East Fork bypassed reach. When flows exceed 20 cfs, differences in channel form, flow resistance, and velocity between the two segments prevent direct application of the habitat-flow relationships to the upper segment of the bypassed reach. However, there should be little need to estimate habitat conditions above 20 cfs because the range of minimum flow alternatives explored in the PHABSIM study only extends to 8 cfs.

The results of the above analysis supports PacifiCorp’s assumption that the PHABSIM results from the lower segment also serve as a representative index of instream habitat-flow relations in the upper segment, in particular for flows less than 20 cfs. As described previously, habitat suitability in the PHABSIM study reach is primarily velocity-driven. The above analysis indicates that PacifiCorp’s recommended flow of 4 cfs would also provide suitable bull trout habitat in the upper segment, because water velocities in the more-turbulent upper segment at flows less than 20 cfs are similar, if not somewhat higher, than in the lower segment.

[3] As discussed in the Methods section, n-values diverge in the two reaches as flows increase, commensurate with the decreasing effect of channel roughness at higher flows.

References

Comiti, F., Mao, L., Wilcox, A., Wohl, E., & Lenzi, M. (2007). Field-Derived Relationships for Flow Velocity and Resistance in High-Gradient Streams. *Journal of Hydrology, 340*, 48-62.

Wilcox, A. C. (2005). *Dissertation: Interactions Between Flow Hydraulics and Channel Morphology in Step-Pool Streams.* Fort Collins: Colorado State University, Department of Geosciences.

Yochum, S., & Bledsoe, B. (2010). *Flow Resistance Estimation in High-Gradient Streams.* The 4th Federal Interagency Hydrologic Modeling Conference, June 27-July 1, 2010, Las Vegas, Nevada.

Yochum, S., Bledsoe, B., David, G., & Wohl, E. (2012). Velocity Prediction in High-Gradient Channels. *Journal of Hydrology*, 84-98.

Attachment A. Segment Photographs

Upper Segment at 4 cfs

Upper Segment at 4 cfs

Representative Transect number 14 at 8 cfs

Remarks

- The red line in the representative transect photograph demarks the transect location at water surface
- The yellow arrow in all photographs depicts flow direction

Lower Segment at 4 cfs

Representative Transect number 8 at 8 cfs

Lower Segment at 4 cfs

Remarks

- The red line in the representative transect photograph demarks the transect location at water surface
- The yellow arrow in all photographs depicts flow direction

Attachment B. Flow and Manning's N