Coarse Sediment Storage on the Trinity River: Recommendations and Correlations to Juvenile Chinook Salmon Rearing Habitat

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ABSTRACT

We used the 2014 Active Bar Mapping Report (McBain Associates 2015) and the validated SRH-2D hydraulic model (Bradley 2018) to describe coarse sediment storage and investigate relationships between coarse sediment storage and rearing habitat for Chinook Salmon from Lewiston Dam to the North Fork Trinity River (Restoration Reach). The Active Bar Mapping Report was prepared in June 2015 and used active bars as an index of coarse sediment storage in the 64-km TRRP Restoration Reach. The report documented locations, dimensions, and formative histories of active gravel bars, and found preliminary relationships linking gravel bar area and Chinook Salmon juvenile rearing habitat. Juvenile rearing habitat (Chinook Salmon) relationships were also explored using preliminary results from the Trinity River SRH-2D hydraulic model in an 8.6-km subreach between Johnson Point and Oregon Gulch (RKm 139.1–130.5). Results showed a trend of habitat persisting at active bar areas as the flows increased but were limited to the short subreach, and additional evaluation was recommended once the SRH-2D hydraulic model was complete.

The current report presents additional evaluations that expanded the active bar to juvenile rearing habitat relationships to the entire 64-km Restoration Reach. The updated results were used as a companion analysis to the geomorphic evaluations presented in the 2015 report. Findings from both physical and juvenile rearing habitat evaluations are synthesized to provide a basis for recommended future sediment storage conditions, proposing sediment storage targets based on these desired conditions, and providing management recommendations for achieving these targets. Coupled with ongoing habitat quantification efforts and other studies (e.g., sediment transport investigations), information from this investigation can be used to help define desired future channel form and function as part of the River Corridor Management Strategy, as well as inform similar plans for recovering river health and native fish populations to meet the goals of the Trinity River Record of Decision (ROD; DOI 2000).

1 BACKGROUND AND INTRODUCTION

In 1991 when the *Trinity River Maintenance Flow Study* (M&T 1997) and *Trinity River Flushing Flow Study* (Wilcock et al. 1995) were initiated, the mainstem of the Trinity River was dominated by a rectangular channel geometry via riparian encroachment, with few active bars in the entire 64-km Restoration Reach between Lewiston Dam and the North Fork Trinity River (Figure 1). This simplified channel morphology was considered a limiting factor for juvenile salmon production in the upper Trinity River.

The *Trinity River Flow Evaluation* (TRFE; USFWS and HVT 1999) developed a restoration strategy of creating a more complex, scaled-down, dynamic alluvial river as the foundation for fishery recovery. Achieving this strategy requires an increase in active alluvial features (gravel bars), maintained by coarse sediment augmentation, high flows, and channel rehabilitation. In 2007, a *Coarse Sediment Management Plan* (CSMP; M&T 2007) was prepared for the Trinity River Restoration Program (TRRP) that identified potential locations and volumes of coarse sediment placement and potential sources of coarse sediment. However, the CSMP did not prioritize placement locations, nor did it develop quantitative targets for increased coarse sediment storage to achieve the TRFE strategy. More recently, Gaeuman (2014) provided analyses in support of TRRP 2015 environmental permitting efforts and focused on (1) defining long-term gravel supply needs, and (2) recommending gravel augmentation locations and volumes. Gaeuman et al. (2016) represents an initial effort to define and identify a long-term planning strategy to help restore the Trinity River fishery based on an existing suite of management actions (mechanical rehabilitation of the channel and its floodplains, streamflow management, and sediment management). Both reports provide valuable descriptions of river conditions and acknowledge that additional collaboration and discussion among program partners is necessary to build on the concepts, conclusions, and recommendations they present.

The TRRP Physical Workgroup is charged with developing sediment management recommendations as part of an integrated management strategy that not only considers sediment management, but also includes other components such as large wood, flow releases, land use, and channel rehabilitation construction designs. This comprehensive strategy is contained within the *River Corridor Management Map and Strategy* (Gaeuman et al. 2016). However, coarse sediment storage targets remain undefined.

1.1 2014 Active Bar Mapping

In the absence of quantitative coarse sediment storage targets, there has been disagreement among TRRP partners on coarse sediment augmentation rates and placement locations. To help move the process forward and provide a long-term vision for future coarse sediment storage in the upper 64 km of the Trinity River (Figure 1), an initial effort was conducted in summer 2014 to inventory and map active gravel bar area exposed at 450 cfs within the Restoration Reach and use these results as an index for in-channel coarse sediment storage. This effort was described in *Trinity River Active Bar Mapping, Lewiston Dam to North Fork Trinity River Confluence, Summer 2014* (McBain Associates 2015; Appendix A), with “active” gravel bar areas defined as those bars exposed above the moderately low flows of 450 cfs water surface elevation up to a height where the substrate shows evidence of movement by Trinity River Record of Decision (ROD; DOI 2000) flows, up to the maximum flow release of 11,000 cfs. The 2015 report documented locations, dimensions, and formative histories of active gravel bars, as well as explored relationships linking active gravel bar area and Chinook Salmon (*Oncorhynchus tshawytscha*) juvenile rearing habitat. The report was prepared for Hoopa Valley Tribal Fisheries (HVTF) and results were presented to the Trinity River Gravel Augmentation Workgroup on March 18, 2015. Pertinent results from the 2015 report are summarized below.

Spatial distributions and relationships were explored to better understand reasons for the distribution, size, and frequency of mapped active bars (and therefore coarse sediment storage). Evaluating the spatial distribution of contemporary active bars included: (1) exploring longitudinal and cumulative active bar area and frequency in the Restoration Reach, (2) exploring this same distribution but on a subreach basis, and (3) computing active bar area per unit channel length. Each of these evaluations included reviewing the location and volume of past (1998–2010) gravel augmentation efforts (Krause 2012). Results identified two subreaches with substantial coarse sediment storage deficiencies, and recommended prioritizing management focus in these reaches.

In addition, active bar frequency and area were evaluated as a function of hydraulic and geomorphic variables using preliminary SRH-2D juvenile rearing habitat modeling data made available by the U.S. Bureau of Reclamation (USBR). Relationships between fry and pre-smolt Chinook Salmon rearing habitat and active gravel bars were explored using preliminary output from SRH-2D juvenile rearing habitat simulations within an 8.6-km (5.3-mile) subreach downstream of Dutch Creek (RKm 138.9). Results did not show clear relationships between juvenile rearing habitat to bar areas at lower flows; however, as flows increased, subreaches with high active bar areas represented some of the highest areas of modeled juvenile rearing habitat. Results were considered preliminary because model validation was not yet complete, and the refined model had not yet been applied to predict juvenile rearing habitat over the entire 64-km Restoration Reach. Based on encouraging preliminary juvenile rearing habitat modeling results, the report recommended expanding the analysis to the entire Restoration Reach once the SRH-2D model was completed and validated for the entire river.

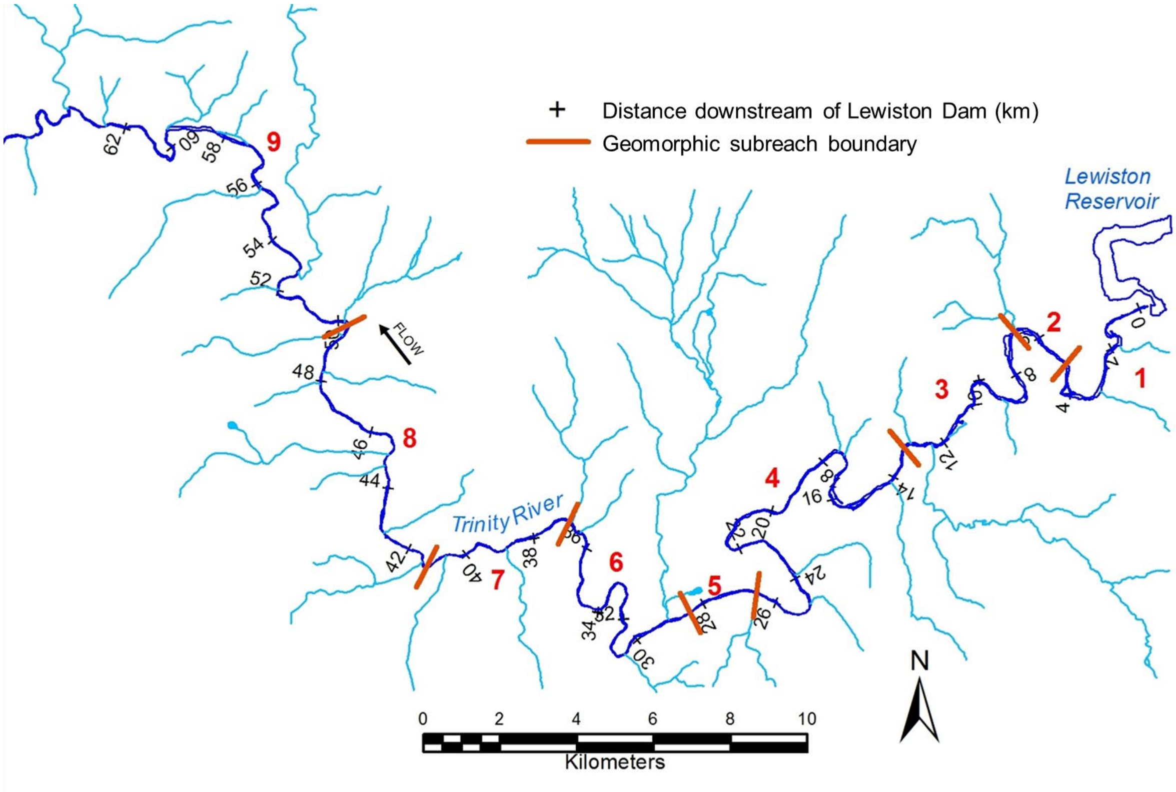

Figure 1. Map of the Trinity River showing nine geomorphic subreaches identified in the Restoration Reach from Lewiston Dam downstream to the North Fork Trinity River confluence (McBain Associates 2015). Geomorphic sub-reaches were defined based on morphology and gravel supply (Appendix A).

1.2 Expanded Analysis

Following the Active Bar Mapping report, the initial Trinity River SRH-2D model was completed (Bradley 2016) and then revised using updated topography and bathymetry (Bradley 2018). Having a calibrated and validated model for the entire 64-km Restoration Reach allowed the recommendations presented in the Active Bar Mapping report to be further evaluated by expanding the preliminary active bar area and juvenile rearing habitat relationships to the entire Restoration Reach.

For the current report, we used the updated SRH-2D model results to perform the expanded habitat relationship evaluations recommended in the 2015 report. We also evaluated additional ecological and biological attributes in relation to active bar area under the hypothesis that bar area contributes to a more diverse, naturally functioning river ecosystem. For example, we related active bar area to Chinook Salmon juvenile rearing habitat because it is hypothesized that greater active bar area creates channel complexity and diversity at higher flows when juvenile Chinook Salmon are at risk of being involuntarily flushed out of the system. Similarly, channel complexity was evaluated because increasing channel complexity is thought to improve juvenile Chinook Salmon rearing habitat and promote habitat for non-salmonid species (e.g., benthic macroinvertebrates, riparian plants). This report also explores possible relationships between Foothill Yellow-legged Frog (FYLF, *Rana boylii*) egg mass data and active bar area because active bars are preferred FYLF breeding habitat.

We recognize that several other fundamental drivers and collective contributors to juvenile rearing habitat are not considered in this report (e.g., large wood storage, underbank habitat, riparian vegetation, and floodplain connectivity) that may be limiting in the Trinity River. The data used in our analysis can only predict the impact that gravel has on physical habitat (depth and velocity) that is considered suitable for juvenile Chinook Salmon. However, this analysis provides data to support the hypothesis that active gravel bars can be beneficial for juvenile rearing habitat and channel complexity.

Based on this expanded analysis, this report provides a more thorough evaluation of the flow habitat relationships presented in the 2015 report, proposes future coarse sediment storage conditions (via active bar area), and recommends management actions to achieve these targets. These recommendations are based on (1) channel form and function, and (2) anticipated ecological and biological benefits (e.g., Chinook Salmon juvenile rearing habitat and channel complexity) as a function of mapped active gravel bars. Channel form and function are based on geomorphic opportunities and constraints in previously defined subreaches, and new ecological and biological responses to increased gravel storage are based on expanded relationships between habitat and active bar area. Results are intended to be used as part of a collaborative process to build on previously reported concepts, conclusions, and recommendations (e.g., Gaeuman et al. 2016) and results from concurrent complementary studies (e.g., Buxton 2021, Buxton and Bradley (accepted, in revision)) in support of a River Corridor Management Strategy for the TRRP.

2 OBJECTIVES

This report builds on the preliminary relationships between Chinook Salmon juvenile rearing habitat and active bar area presented in the 2015 Active Bar mapping report and uses the results of these relationships to evaluate the preliminary coarse sediment storage recommendations made in that report. To do this, the following objectives were established:

Objective 1. Expand on previous Chinook Salmon juvenile rearing habitat relationships by using updated hydraulic and fish habitat model results.

Objective 2. Refine recommended future conditions for coarse sediment storage to support: (1) increased Chinook Salmon juvenile rearing habitat, (2) enhanced ecological function, (3) improved channel form, and (4) increased physical processes needed to create and maintain a scaled-down, dynamic alluvial channel that is the foundation of the TRFE (USFWS and HVT 1999) and ROD (DOI 2000).

Objective 3. Refine coarse sediment storage (active bar area) targets by subreach based on expected juvenile rearing habitat benefits, accessibility, and geomorphic setting.

Objective 4. Refine management recommendations to best reach target coarse sediment storage conditions in each subreach.

The expanded habitat relationships are presented in Section 3, and coarse sediment storage conditions, targets, and management recommendations are presented in Section 4. Note that the target habitat and coarse sediment storage metrics in this report represent one line of evidence to help promote a scaled-down dynamic alluvial river. Ecological function and salmonid habitat are linked to a number of biological, chemical and thermal parameters, and coarse sediment storage is just one metric to help understand the best ways to implement management actions to improve juvenile rearing habitat and ecological conditions.

3 EXPANDED INVESTIGATIONS OF GRAVEL STORAGE AND SALMONID REARING HABITAT

The 2015 Active Bar Mapping report explored relationships between Chinook Salmon juvenile rearing habitat and active bar area using preliminary SRH-2D (Sedimentation and River Hydraulics Two-Dimension, a hydraulic model used on the Trinity River) model data (used to calculate habitat) that was applicable only to an 8.6 km reach from Johnson Point to Oregon Gulch, 41.1 km to 49.7 km downstream of Lewiston Dam (Subreach 8 in Figure 1). Following the 2015 report, hydraulic model validation was completed and the finalized SRH-2D model was expanded to the entire 64-km Restoration Reach in 2018.

The current analyses expanded upon the preliminary relationships by using active bar area to explore relationships to both Chinook Salmon rearing habitat and ecological function, (e.g., FYLF and channel complexity) for the entire reach. Several habitat relationships were explored, of which three were found to best illustrate active bar area relationships. The initial analyses that were explored and the final analyses that were used, along with their results and discussion, are described in this section.

3.1 Analytical Methods

Eleven analyses were conducted to evaluate potential relationships between active bar storage and ecological and geomorphic performance metrics. A description of all analyses in the order they were conducted, including supporting rationale, is shown in Table 1. For each analysis, we used linear regression to describe the relationship between active bar area and the response variable of interest at streamflows ranging from 375 cfs to 2,000 cfs, which was similar to the flows used in the original 2015 analysis. The analysis moved iteratively and explored additional metrics and alternative ways of summarizing the response variable based on previous results.

Table 1. Description and outcome of all analyses explored or considered. All analyses were conducted across all modeled streamflows. Initial analysis exploration was an iterative process, so analyses are presented in the order they were explored. Analyses in green were determined to best illustrate the relationship of active bar area and habitat, and are thus the main focus in this report.

Analysis #	**Description**	**Hypothesis***	**Outcome/ Comments**
1	Active bar area to fry and presmolt rearing habitat at the 200-m GRTS panel resolution.	*Increases in active bar area result in more suitable fry and presmolt rearing habitat*	Very poor relationships. The 200-m GRTS panels are too fine of a resolution and the extremely low and high variability in active bar area among panels skews results.
2	Active bar area to fry and presmolt rearing habitat for a 200-m GRTS panel and one panel immediately downstream (2 panels total).	Modified Analysis 1 by adding adjacent downstream panels to account for active bar habitat that extended into adjacent panels.	Very poor relationships. Resolution may still be too fine (see Analysis 1).
3	Active bar area to fry and presmolt rearing habitat for a 200-m GRTS panel and one panel immediately downstream and upstream (3 panels total).	Modified Analysis 1 by adding adjacent upstream and downstream panels to account for active bar habitat that extended into adjacent panels.	Very poor relationships. Resolution may still be too fine (see Analysis 1).
4	Active bar area to fry and presmolt rearing habitat at 1,000-m GRTS panel resolution.	Modified Analysis 1 by increasing GRTS panel size from 200 m to 1,000 m to control for variability in active bar area among segments.	Best relationship between fry and presmolt rearing habitat and active bar area. Analysis could be used to help inform recommendations.
5	Active bar area to fry and presmolt rearing habitat at geomorphic subreach resolution.	Modified Analysis 1 to explore the relationship of fry and presmolt rearing habitat within geomorphic subreach.	Found positive relationships at all modeled streamflows but unfortunately habitat and active bar area were also both related to subreach length, resulting in an unclear or spurious relation.
6	Active bar area to fry and presmolt rearing habitat at 1,000-m GRTS panel resolution within geomorphic subreaches.	Expand upon Analysis 4 and observe relationships at the geomorphic subreach level to better make recommendations.	Noticeable difference in relationships among subreaches and between subreaches and when all subreaches were combined.
7	Active bar area to redd numbers at the 200-m GRTS panel resolution.	*Increases in active bars area result in more spawning habitat (and increased redd numbers).*	Very poor relationships. Further data exploration tabled at this time.
8	Active bar area to channel complexity (Eqn (1))** at the 200-m GRTS panel resolution.	*Increases in active bar area increase channel complexity*	200-m panels are too fine of a resolution to calculate complexity.
9	Active bar area to channel complexity at the geomorphic subreach level.	Modified Analysis 8 by increasing resolution to geomorphic subreach level to better calculate complexity.	Found positive relationships at all modeled streamflows, but complexity and active bar area are confounded by subreach length.
10	Active bar area density (m^2/1,000 m of river) to channel complexity at the geomorphic subreach level.	Modified Analysis 9 changing active bar area to active bar density to account for different subreach lengths.	Best relationship of channel complexity when combining Subreach 5 and Subreach 6. Good analysis to help inform recommendations.
11	Active bar area to FYLF egg masses.	*Active bar area supports FYLF breeding habitat.*	Lack of relationships; however, data used had many data points for egg masses and were only collected on gravel bars. Analysis tabled at this time.

* Hypotheses with italics are original hypotheses, while the non-italicized hypotheses were developed by modifying the initial hypothesis listed above it.

** Channel complexity is defined in Section 3.1.2

3.1.1 Initial Analysis on Chinook Salmon Juvenile Rearing Habitat and Redd Placement

For all fish habitat to active bar relationships, we used the Chinook Salmon juvenile (fry and presmolt) rearing habitat values from the Trinity River SRH-2D model (Bradley 2018). Habitat was calculated in the Trinity SRH-2D model using binary criteria from Alvarez et al. (2013), where all habitat values that fit both the depth and velocity criteria were summed as habitat. We did not use habitat that considers cover because there is not a clear relationship between mapped cover and active bar area. Recently (June 2020), the Trinity River Fish Work Group recommended that capacity (Som et al. 2018) be adopted as the metric for Trinity River juvenile salmon rearing habitat. The analysis we present here used habitat calculated from the SRH-2D model because the recommendation to use capacity was not made until after our analysis was completed. In future efforts, the use of capacity can be used instead of the habitat from SRH-2D to be more consistent with other recent work products from the Trinity River.

We started our initial analysis (Analysis 1) by reconstructing the methods used in the Active Bar Mapping report. Rearing habitat at the 200-m length Generalized Random Tessellation Stratified (GRTS) panel resolution was compared to active bar area. GRTS Panels are equally spaced 200-m reaches spanning the upper 64-km of the Trinity River (320 panels total). GRTS panels were used to avoid spatially balancing our study design. No clear relationships between active bar area and Chinook Salmon juvenile rearing habitat were identified, but the analysis did suggest that active bar area may enhance or create habitat in adjacent panels. For example, if an active bar spanned over 2 panels or if an active bar created hydraulic features downstream (i.e., an eddy), it could create juvenile rearing habitat downstream. To account for active bars spanning multiple GRTS panels, fry and presmolt rearing habitat was extended to include habitat in the adjacent upstream and downstream panels (Analyses 2 and 3). The analyses suggested that clear patterns may be difficult to detect at the 200-m GRTS panel resolution because extremely high variability of active bar area in each panel skewed results (for example, some panels contained multiple small bars, versus some bars spanned multiple panels). To try and reduce this variability, the spatial resolution was aggregated to a 1,000-m GRTS panel resolution, resulting in 64 1,000-m GRTS panels (Analysis 4), and also to the geomorphic subreach level (Analyses 5 and 6). Analysis 4 resulted in positive relationships between active bar area and fish habitat at the 1,000-m GRTS resolution. Analysis 5 showed similar positive relationships, but the significance was unclear as active bar area was also related to geomorphic sub-reach length. Analysis 6 showed both positive and negative relationships between 1,000-m GRTS panel active bar area and habitat within and among geomorphic sub-reaches (additional detail is provided in Section 3.2.1).

The number of Chinook Salmon redds were regressed against active bar area at the 200-m GRTS panel scale but did not yield any significant trends (Analysis 7). Given that no clear patterns emerged from this data set, we did not evaluate either of these further.

3.1.2 Initial Analysis on Channel Complexity and FYLF

The relationship between channel complexity and active bar area was evaluated. A simple metric of channel complexity was estimated using Buffington et al. (2014):

$$complexity = \frac{wetted\ edge\ length\ (m)}{\sqrt{wetted\ channel\ area(m^2)}} \qquad \textit{Equation (1)}$$

where wetted edge length includes all wetted edges of banks, bars, islands, and other channel features; and the wetted channel area is the area of all wetted surface area in the active channel. At the 200-m GRTS panel resolution, complexity was not related to active bar area (Analysis 8, Table 1). The resolution was expanded to the geomorphic subreach level and was strongly related

(Analysis 9 and 10); however, further analysis determined that both active bar area and complexity were confounded with subreach length. Specifically, both complexity and active gravel bar area and density increased with reach length. Thus, conclusions were unable to be drawn.

Lastly, the relationship of FYLF egg mass data were evaluated relative to active bar area (Analysis 11). After initial data exploration, it was determined that the methods used to collect egg mass data biased the analysis, since egg mass data were collected at sites where eggs were most likely to be found, which was on active gravel bars only (D. Ashton, personal communication). Because the data only showed egg masses on certain active gravel bars, we were unable to identify a quantitative relationship to active bar area.

3.1.3 Final Analysis Methods

From initial data exploration, Analyses 4, 6, and 10 provided results that showed potentially meaningful relationships of active bar area to channel complexity and juvenile rearing habitat. These analyses will be the focus of the remainder of this report and are shaded green in Table 1.

Each of these three analyses evaluated active bar area relationships to habitat and complexity for modeled streamflows up to 2,000 cfs (375 cfs, 450 cfs, 750 cfs, 1,050 cfs, and 2,000 cfs). All analyses used streamflow from the nearest upstream USGS gage rather than Lewiston Dam releases, since local flows incorporate tributary accretion. We analyzed flows up to 2,000 cfs to be consistent with methods used in the Active Bar Mapping report, which mapped active bars located only within in the active channel. Above 2,000 cfs, juvenile rearing habitat is influenced by additional features (vegetation, floodplains) that are not related to active gravel bars.

- Analysis 4 examined the relationship between fry and presmolt rearing habitat and active bar area examined in Analysis 1 but used 1,000-m GRTS panels instead of 200-m GRTS panels. The larger area helped include active bars that spanned multiple GRTS panels and reduced variation among active bar area within GRTS panels. Data were natural-log transformed to better meet statistical assumptions of normality and homogeneity of variances. Separate linear regressions were performed for each modeled streamflow to evaluate the effect of active bar area on juvenile rearing habitat across streamflow. The slope from each regression were back transformed for interpretation to illustrate the increase in juvenile rearing habitat (m^2) for each 1,000 m^2 increase in active bar area.
- Analysis 6 expanded on Analysis 4 to evaluate fry and presmolt rearing habitat as a function of active bar area within geomorphic subreaches. Linear regression was performed on data at the 1,000-m GRTS panel resolution within each subreach. Since the geomorphic subreaches are not equidistant and contain a different number of 1,000-m GRTS panels, Subreaches 2 and 5 were removed from the analysis because they lacked enough segments to run a statistically meaningful regression (2 and 1, respectively; Table 2). In addition, Subreaches 1, 3, and 7 contained a low number of segments (5, 6, and 4, respectively; Table 2), but linear regressions were still performed. Results for Subreaches 1, 3, and 7 should be interpreted with caution because of the potential lack of power that is associated with small sample size in linear regression. Results and data were treated similarly to Analysis 4 in that data were natural log-transformed and regression slopes were back-transformed for presentation to illustrate the increase in juvenile rearing habitat (m^2) for each 1,000 m^2 increase in active bar area.
- Analysis 10 explored the relationship between channel complexity and active bar area at the geomorphic subreach level. Confounding issues present in Analysis 7 were accounted for by replacing active bar area with active bar density (m^2/1,000 m of river) in each geomorphic subreach. For this analysis, Subreach 5 was combined with Subreach 6 because (a) it is very short and (b) channel complexity in Subreach 5 contained the Indian Creek delta and was abnormally high compared to active bar density, thus was acting as an outlier on its own.

Table 2. Number of 1,000-m long GRTS panels per geomorphic subreach used in Analysis 6.

Geomorphic Subreach	Number of 1,000-m GRTS Panels
1	5
2*	2
3	6
4	14
5*	1
6	9
7	4
8	9
9	14

* Subreaches 2 and 5 were excluded in fish habitat analyses using geomorphic subreaches due to insufficient segments to conduct linear regression analysis. For complexity (Analysis 10), Subreach 5 was combined with Subreach 6.

3.2 Results and Discussion

Results are presented below and are grouped into two categories: (1) Relating Chinook Salmon juvenile rearing habitat to active bar area (Analysis 4 and 6), and (2) relating channel complexity to active bar density (Analysis 10).

3.2.1 Analysis 4 and 6: Chinook Salmon Juvenile Rearing Habitat

For Analysis 4, active bar area at the 1,000-m GRTS panel resolution had a significant ($p < 0.05$) and positive effect on both fry and presmolt rearing habitat at all streamflows evaluated (Figure 2). While these relationships were significant, some of the individual GRTS panels (regression points) had unusually high values and were considered outliers but not removed from the analyses (Figure 2). The outliers on the lower streamflow (375 and 450 cfs) charts (GRTS segments 1, 2, and 5 in geomorphic Subreach 1 for fry and segments 1, 2, 4, and 5 for presmolt) moved closer to the general trend of data as streamflows increased. At higher streamflows, GRTS Panel 9 and 10 for both fry and presmolts deviated from the common trend. It is unclear specifically why these panels deviated. One possibility is that the topography of these panels is such that it enhances the relationship between active bars and hydraulically suitable fish habitat more so than active bars in other panels. The rate of increases in fry and presmolt for every 1,000 m^2 increase in active bar area increased with streamflow up to 1,050 cfs and then dropped at 2,000 cfs (Figure 3). The relationships indicate that the relative amount of juvenile rearing habitat in relation to active bar area is the greatest at 1,050 cfs. We believe that this is driven by two mechanisms: (1) at lower flows, suitable habitat is focused in the mid-channel area. As flows increase, suitable habitat shifts to the active bars where depths and velocities in shallower areas along channel margins and ends of bars become important rearing habitat; and (2) at the highest modeled streamflow in this study (2,000 cfs) water surface elevation on active bars are high enough that depths and velocities are less suitable for rearing fry and presmolts. A more robust data collection effort at multiple streamflows on specific bars is required to test these hypotheses.

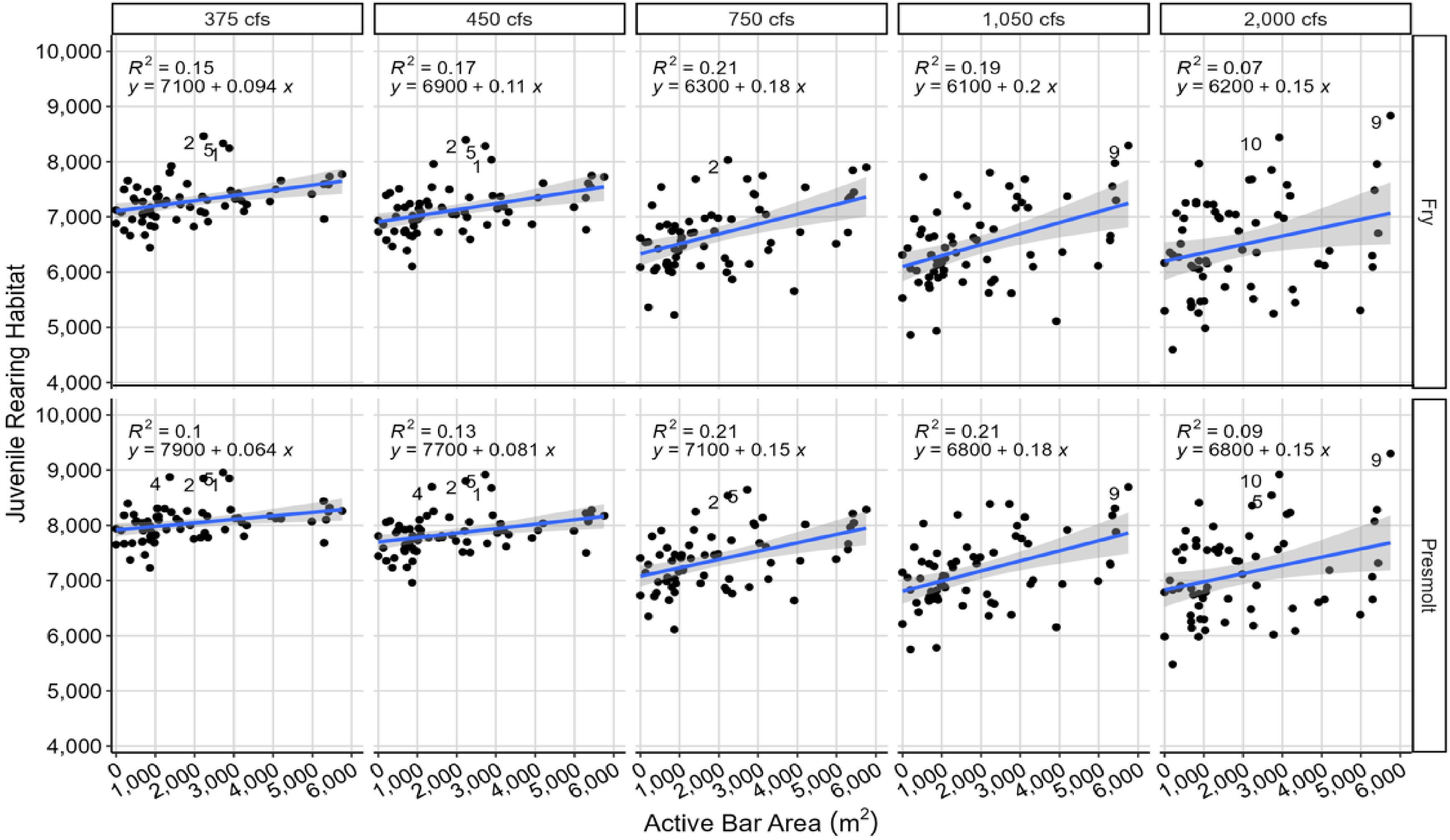

Figure 2. Fry and presmolt Chinook Salmon rearing habitat plotted against active bar area for all modeled streamflows and each 1,000-m long GRTS panel for the entire 64-km Restoration Reach (Analysis 4; data were natural log transformed for analysis). Regression lines are plotted as solid black lines and the 95% confidence intervals are indictated by the shaded grey around the blue line. Numbers next to selected data points represent individual GRTS panels that were outliers, and are labeled so their trend can be tracked across flow.

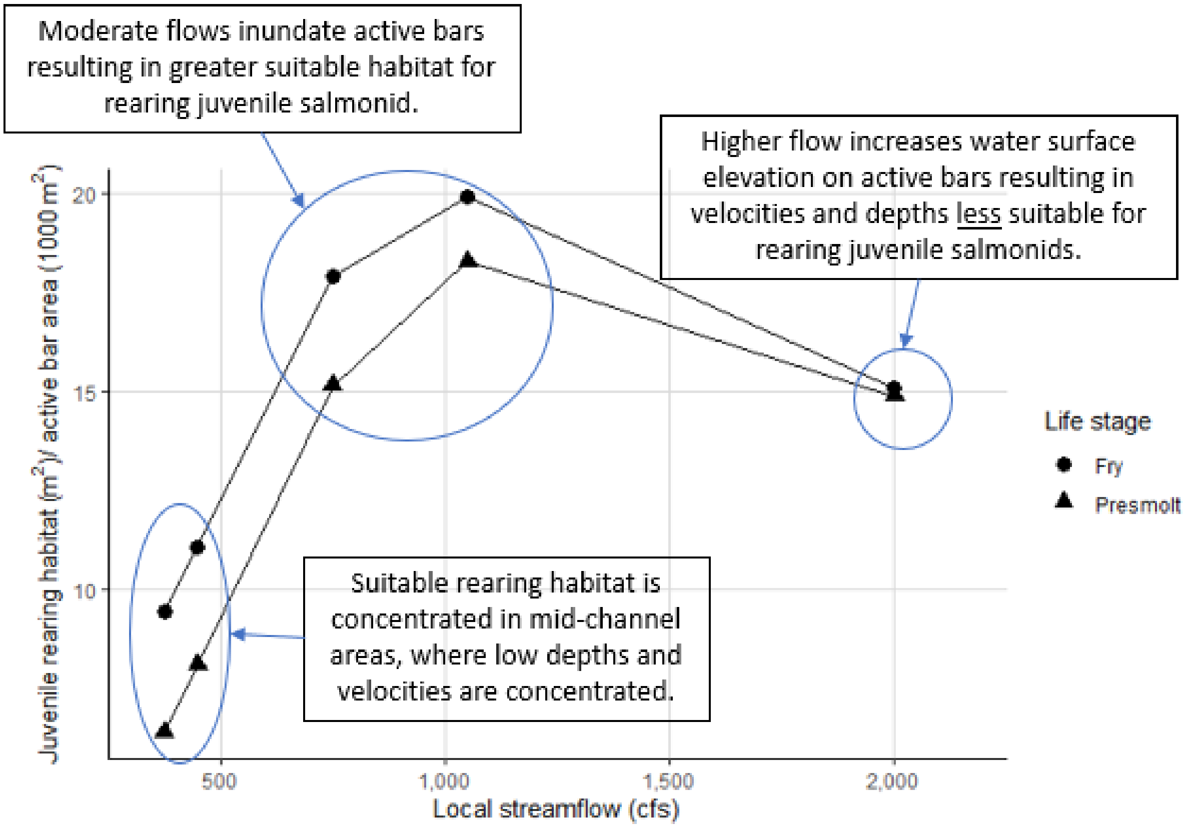

Figure 3. Back transformed regression slopes from Figure 2 scaled by 1,000 m^2 to illiustrate the increase in fry and presmolt rearing habitat (m^2) for every 1,000 m^2 increase in active bar area as a function of streamflow. Analysis was conducted at the 1,000 m GRTS panel resolution throughout the entire 64-km Restoration Reach (Analysis 4). Annotations are hypothesized mechanisms acting on the juvenile rearing habitat to active bar relationships. The y-axis represents change in habitat per increase in active bar area for the entire reach and is not restricted to habitat that overlaps with active bars.

In summary, results from Analysis 4 show the following:

- The greatest increase in both fry and presmolt rearing habitat occurred at 1,050 cfs (20 m^2/ 1,000 m^2 active bar area, and 18 m^2 /1,000 m^2 active bar area respectively, Figure 3).

  The higher increase of habitat per unit of active bar area at moderate flows within the active channel (750 and 1,050 cfs) suggests that active bar areas may be most important at this flow range where active bars are partially inundated (Figure 3). For example, at lower flows, we speculate that the majority of habitat is located in mid-channel areas that have generally suitable depth and velocities, but as flows increase and the mid-channel habitat becomes less suitable, active bars become more important for creating habitat as preferred depths and velocities shift to shallower areas along channel margins and at the upstream and downstream end of the bars. As flow increases, active bars are “drowned out” and depth and velocities become less suitable.
- The increase of habitat per unit of active bar area decreases at higher flows (Figure 3). While we do not have mechanistic evidence, the data support a theory that at higher flows the depths and velocities become deeper and swifter, respectively, making them less suitable for juvenile salmonids.

Given the large increase in habitat for each flow increase between 500 cfs and 750 cfs, we speculate that increase in stage at these flows begins to inundate active bars, which creates more suitable habitat on the margins of active bars (Figure 3). Higher flows (2,000 cfs) may inundate bars and increase depth and velocity to a point that is less suitable for juvenile Chinook Salmon. When the total amount of fry and presmolt rearing habitat in the 64-km restoration reach were plotted against streamflow, the greatest amount of habitat area occurred at the lowest streamflows modeled, then decreased as streamflows increased (Figure 4). This relationship suggests that at lower streamflows, suitable depths and velocities for fry and presmolts were met in more area of the wetted channel regardless of active bar area.

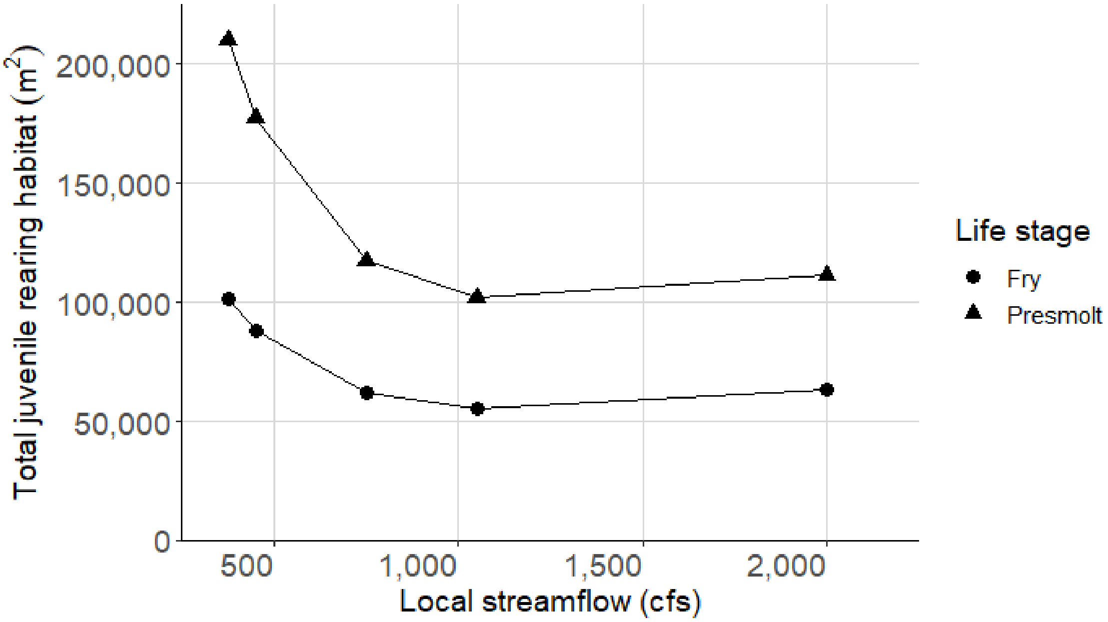

Figure 4. Total fry and presmolt rearing habitat (m^2)for the entire 64-km Restoration Reach derived from the Trinity River SRH-2D model plotted against streamflow.

For Analysis 6 (subreach level), most subreaches showed a positive relationship to active bar area as show in Figure 3. However, both fry and presmolt rearing habitat were negatively affected by increases in bar area at moderate streamflows (750 cfs and 1,050 cfs) in Subreaches 4 and 8 (Figure 5, Figure 6). This suggests that under existing conditions, in Subreaches 4 and 8, active bar area and flow do not interact as effectively as they do in other subreaches. If active bar area was increased in these subreaches, and the fish habitat and hydraulic model was re-run, it is plausible that the relationships may improve (i.e., the rate of increase in juvenile rearing habitat for each 1,000 m^2 of active bar area would increase). The reduced functionality of active gravel bars creating juvenile rearing habitat in Subreaches 4 and 8 provides a rationale to consider additional gravel supplementation in these subreaches. Other subreaches show that the percent change in juvenile rearing habitat increased with streamflow up to 1,050 cfs, but then decreased at 2,000 cfs. Subreach 6 showed a unique relationship where percent change in habitat continued to increase with streamflow (Figure 5, Figure 6). Possible explanations for this increase are likely linked to bar morphology (e.g., Reach 6 may have a more consistent bar slope across the range of analyzed flows), but additional analyses to evaluate bar morphology were not performed.

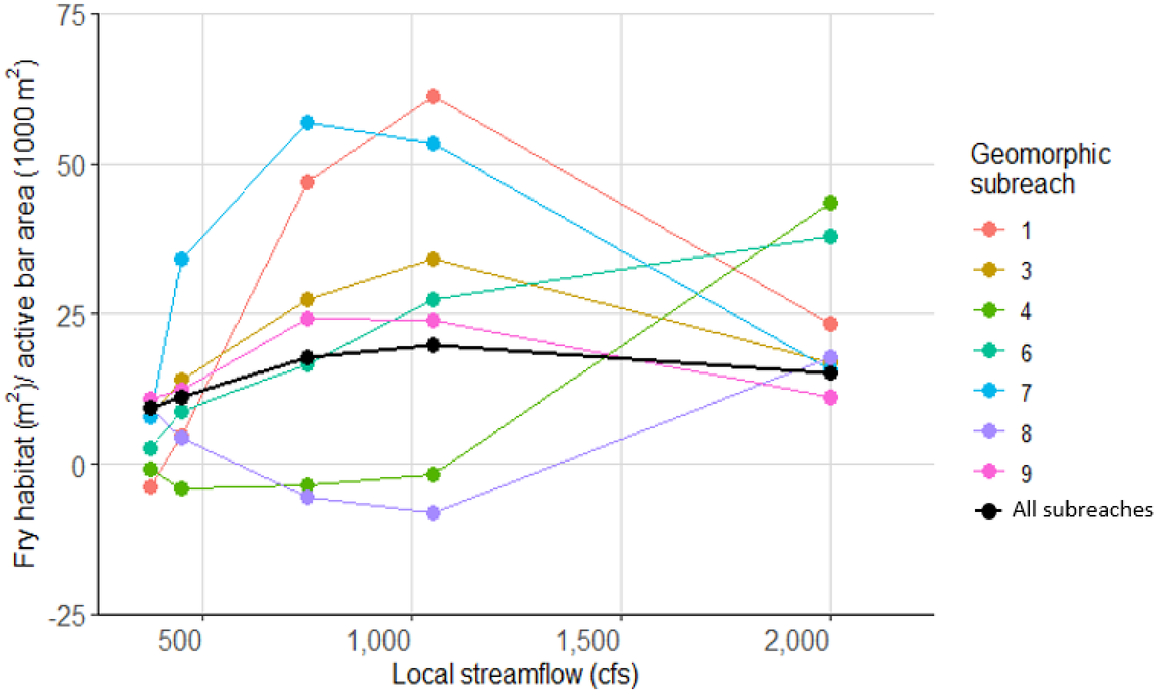

Figure 5. Change in fry rearing habitat (m^2) for every 1,000 m^2 increase in active bar area by geomorphic subreach plotted against streamflow (Analysis 6). The black line is from Figure 4 and represents the increase in fry rearing habitat (m^2) for every 1,000 m^2 increase in active bar area for the entire 64-km Restoration Reach,and includes Subreaches 2 and 5.

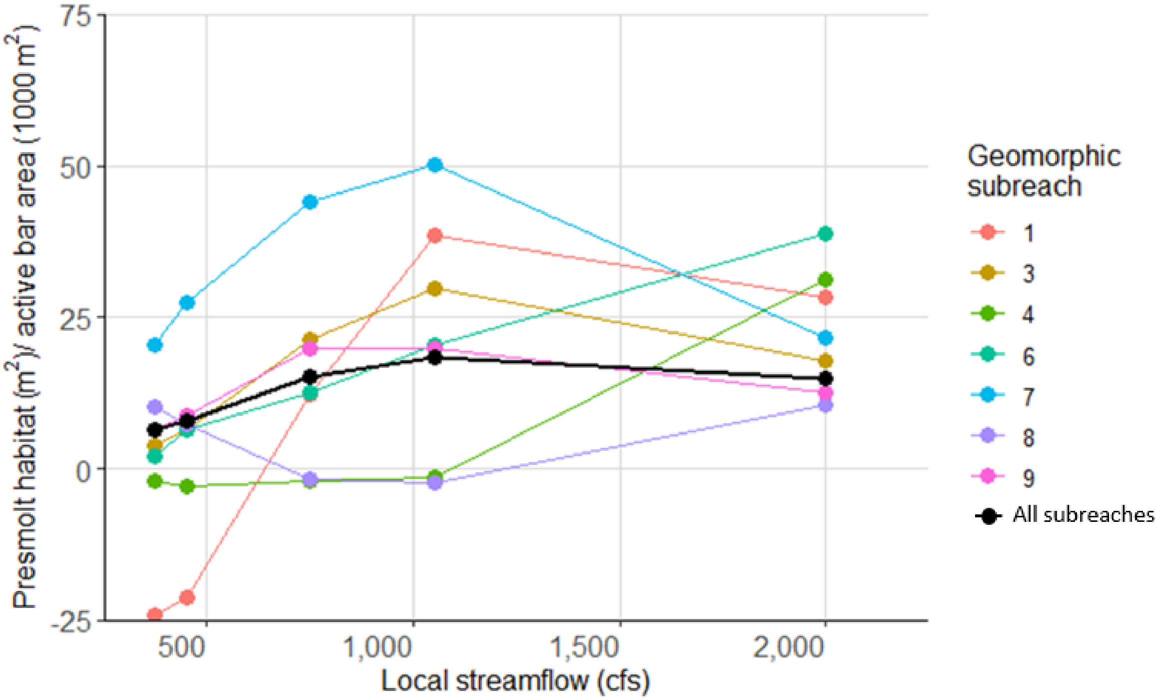

Figure 6. Change in presmolt rearing habitat (m^2) for every 1,000 m^2 increase in active bar area by geomorphic subreach plotted against streamflow (Analysis 6). The black line is from Figure 4 and represents the increase in presmolt rearing habitat (m^2) for every 1,000 m^2 increase in active bar area for the entire 64-km Restoration Reach,and includes Subreaches 2 and 5.

When comparing the streamflow-specific changes in rearing habitat per 1,000 m^2 increase in active bar area per geomorphic subreach to the total active bar area in each subreach, Subreaches 1, 4, 6 and 8 had similar active bar area but showed different rates of increases in fry and presmolt rearing habitat for the modeled streamflows (Figure 7, Figure 8, Figure 9). For example:

- Subreach 1 has a wide range of change in juvenile rearing habitat (m^2) per 1,000 m^2 increase in active bar area. The change ranged from –4 m^2/ 1,000 m^2 at 375 cfs to +61 m^2/ 1,000 m^2 at 1,050 cfs for fry, and –24 m^2/ 1,000 m^2 at 375 cfs to +39 m^2/ 1,000 m^2 at 1,050 cfs for presmolt.
- Subreach 4 rates are tightly clustered just under 0 m^2/ 1,000 m^2 but increased to +43 m^2/ 1,000 m^2 for fry and +31 m^2/ 1,000 m^2 for presmolts at 2,000 cfs (Figure 7, Figure 8).
- Subreach 6 gradually increased with streamflows from 375 cfs to 2,000 cfs for both fry and presmolts.
- Subreach 8 rates clustered between –8 m^2/ 1,000 m^2 at 1,050 cfs to +18 m^2/ 1,000 m^2 at 2,000 cfs for fry, and +2 m^2/ 1,000 m^2 at 1,050 cfs to +11 m^2/ 1,000 m^2 at 2,000 cfs for presmolts.

The variation across subreaches with similar amounts of active bar area (Figure 9) could be explained by additional variables outside of the data that were collected, including morphology of the active bar area. For example, over the same range of increasing streamflows, an active bar with a steep streamward slope is expected to have comparatively little habitat area increase relative to an active gravel bar with a gentle streamward slope (in other words, the bar with a gentle slope should show greater gains in habitat area per unit streamflow compared to the steeper-sloped bar). Inflections in these geomorphic (and thus habitat) relationships likely occur when the bar slope changes (e.g., flattens) and streamflows overtop the bar.

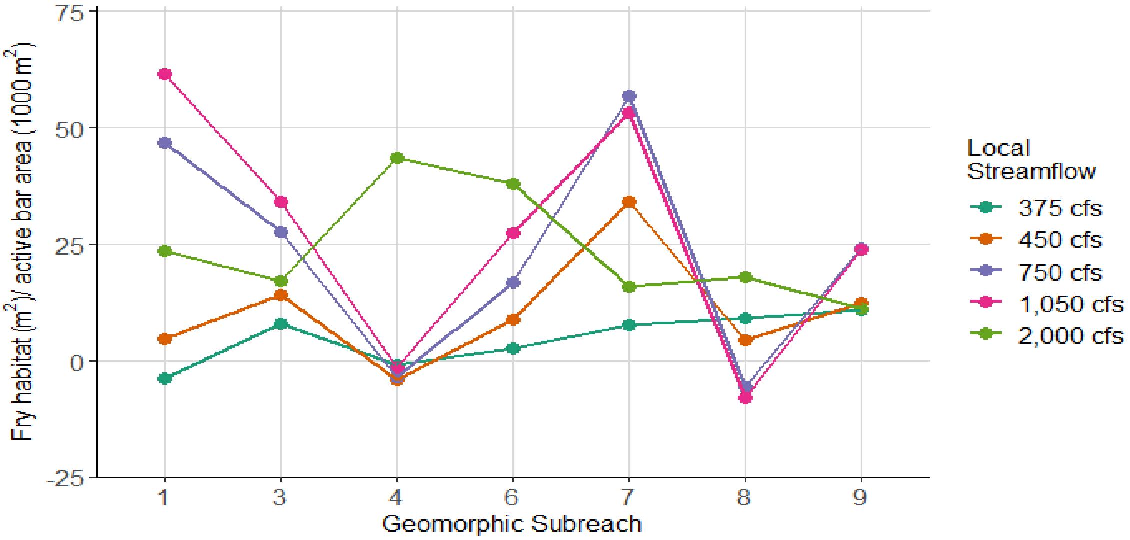

Figure 7. Streamflow-specific changes in fry rearing habitat (m^2) for every 1,000 m^2 increase in active bar area, plotted longitudinally by geomorphic subreach ordered from upstream to downstream.

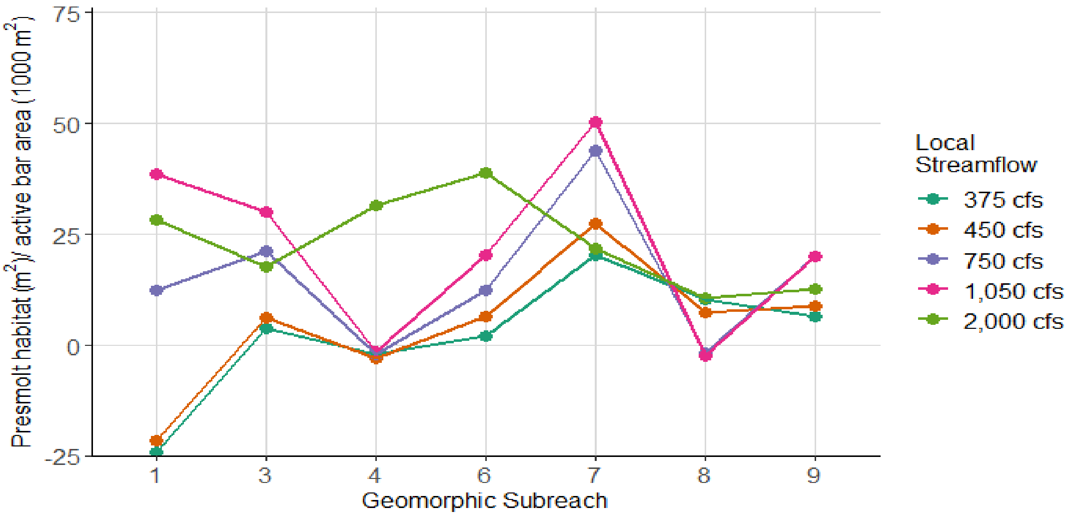

Figure 8. Streamflow-specific increases in presmolt rearing habitat (m^2) for every 1,000 m^2 increase in active bar area, plotted longitidually by geomorphic subreach ordered from upstream to downstream.

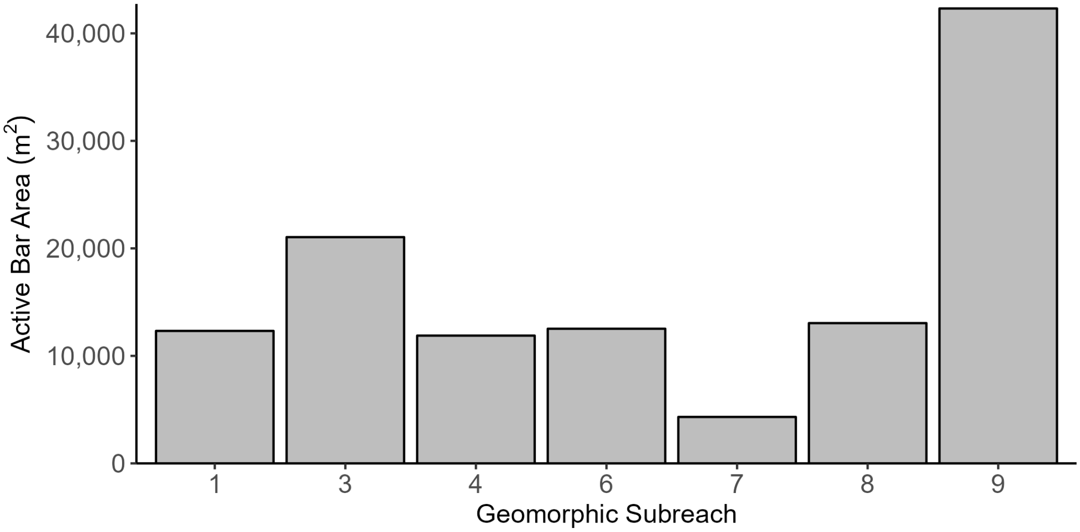

Figure 9. The total active bar area in each geomorphic subreach, for comparison with Figure 7 and Figure 8.

3.2.2 Analysis 10: Channel Complexity

The relationship between channel complexity (Equation 1) and active bar density in Analysis 10 was positive for all streamflows evaluated (Figure 10 through Figure 14). Increases in active bar area can correspond to increases in wetted edge length and subsequently increased channel complexity. Specifically, active bars can directly increase edge length by the presence in either medial or lateral locations, and active bars can indirectly increase edge length causing converging flows that can scour banks and make them more irregular. Interestingly, Subreach 4 had one of the highest complexity values (Table 3) and lowest active bar density values at all streamflows compared to the other subreaches. We conclude that active bar area does increase channel complexity; however, we caution that it is unlikely to be the most important variable controlling the complexity metric in Equation 1 because of the Subreach 4 results and the likelihood of other geomorphic features that can drive channel complexity.

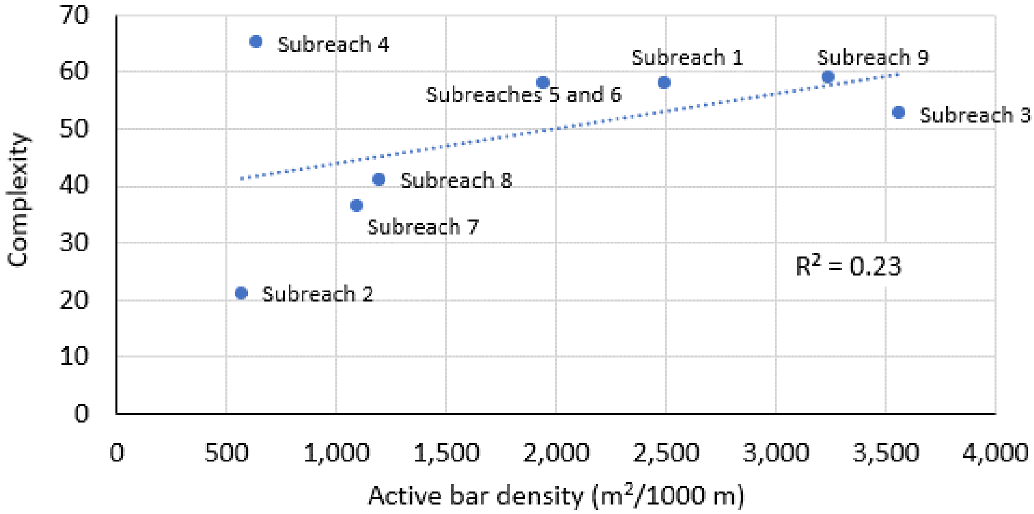

Figure 10. Relationship between active bar density and the channel complexity metric (Equation 1) at the geomorphic subreach level for 375 cfs.

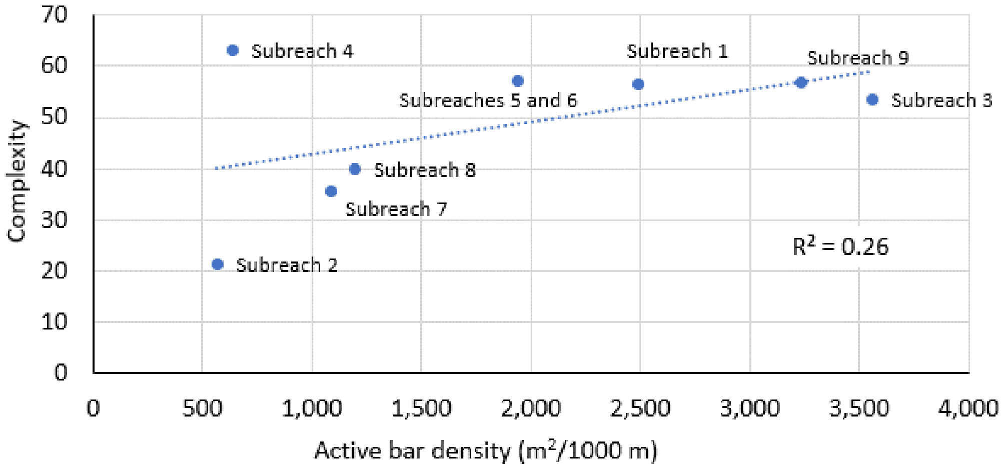

Figure 11. Relationship between active bar density and the channel complexity metric (Equation 1) at the geomorphic subreach level for 450 cfs.

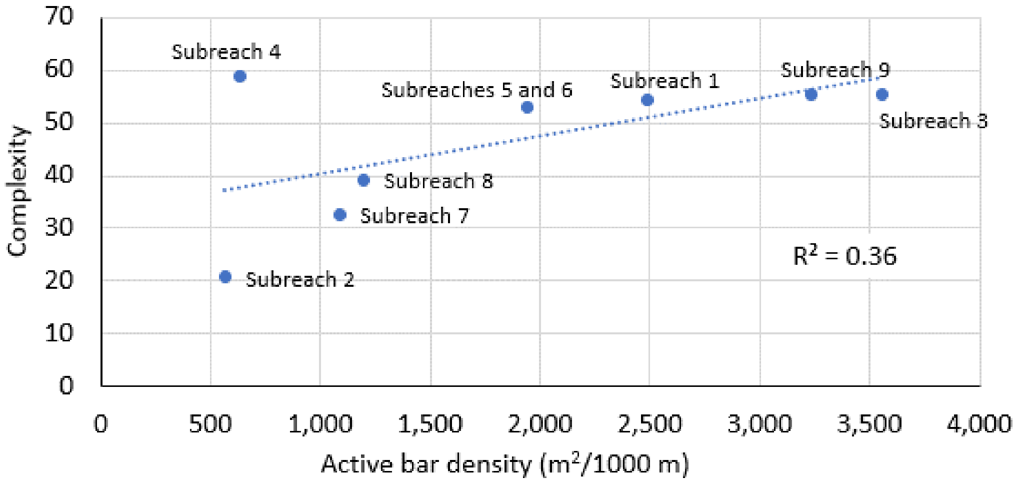

Figure 12. Relationship between active bar density and the channel complexity metric (Equation 1) at the geomorphic subreach level for 750 cfs.

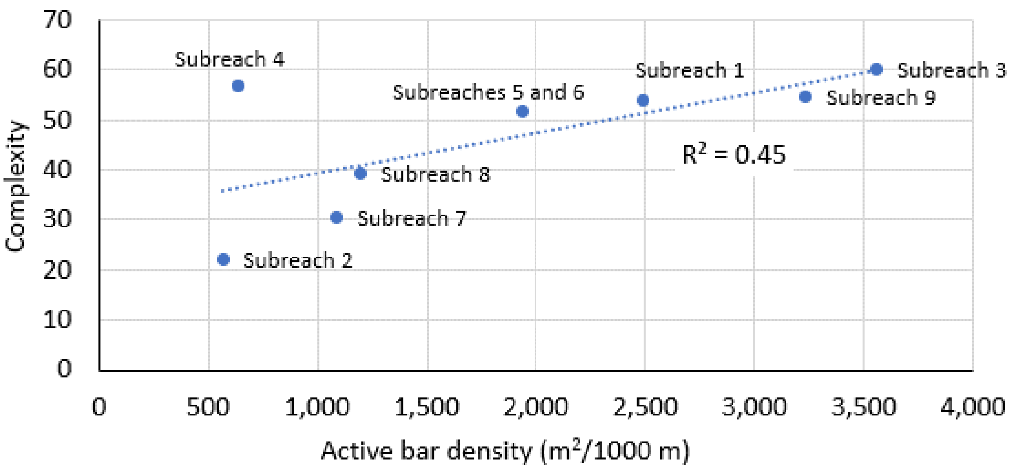

Figure 13. Relationship between active bar density and the channel complexity metric (Equation 1) at the geomorphic subreach level for 1,050 cfs.

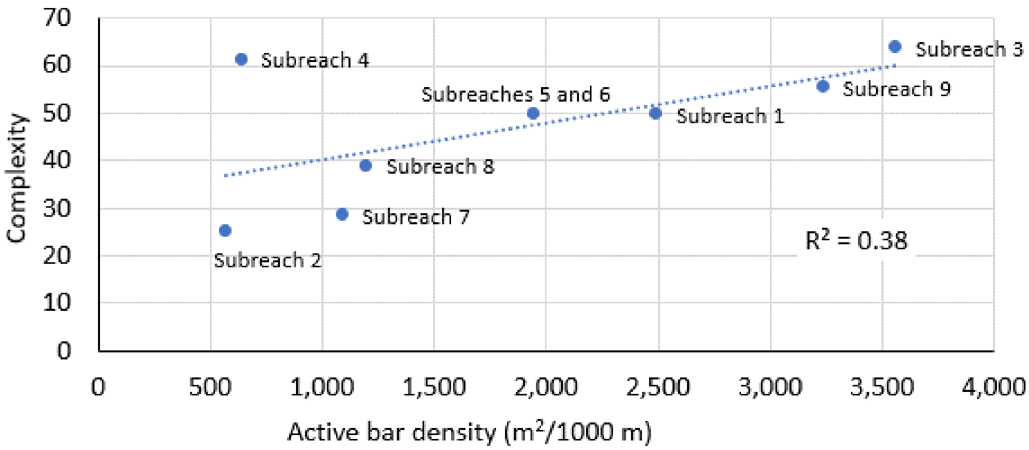

Figure 14. Relationship between active bar density and the channel complexity metric (Equation 1) at the geomorphic subreach level for 2,000 cfs.

Table 3. Complexity values (dimensionless) by subreach and streamflow based on Equation 1.

Subreach	**Complexity Metric (Equation 1)**						
	375 cfs	**450 cfs**	**750 cfs**	**1,050 cfs**	**2,000 cfs**	**Mean**	**± StD**
1	58.3	56.6	54.5	54.0	49.9	54.7	2.57
2	21.2	21.4	20.7	22.2	25.3	22.2	1.49
3	52.9	53.6	55.5	60.2	63.9	57.2	3.83
4	65.3	63.1	58.8	56.9	61.5	61.1	2.73
5 and 6	58.2	57.0	52.8	51.7	49.9	53.9	2.90
7	36.6	35.4	32.6	30.7	28.7	32.8	2.67
8	41.2	40.0	39.3	39.4	39.1	39.8	0.69
9	59.0	57.0	55.5	54.6	55.5	56.3	1.41

3.3 Predicting Fry and Presmolt Rearing Habitat Using Prior Active Bar Area Recommendations

To estimate how potential future coarse sediment augmentation and active bar storage may affect fry and presmolt rearing habitat, linear regression models from Analysis 4 (Figure 2) were applied to existing active bar area and to potential future active bar area recommended in 2015 for each subreach (Table 4). We estimated the total increase in fry and presmolt rearing habitat at the 1,000-m GRTS panel resolution (Table 5) and calculated the percent increase in fry and presmolt rearing habitat from existing to potential future active bar area if the recommendations were implemented (Table 6). We chose to apply the reachwide regression equations in Analysis 4 rather than the geomorphic subreach-specific regressions in Analysis 6 for predicting juvenile rearing habitat because we wanted to use a more robust model (more 1,000-m GRTS panels). In addition, the regression equations in Analysis 6 were not considered to be appropriate for estimating effects of coarse sediment augmentation on rearing habitat, because, as discussed in Section 3.1.3, regressions were not performed for geomorphic Subreaches 2 and 5 because they lacked enough 1,000-m GRTS panels to run a regression (Table 2), and regression equations for Subreaches 1, 3, and 7 had low sample size.

Chinook Salmon rearing habitat was predicted to increase for all subreaches at all streamflows except for Subreach 5 (Indian Creek delta) where no gravel addition recommendations were made because existing active bar area was already high (the highest of all the subreaches). The greatest increase in Chinook Salmon juvenile rearing habitat (m^2) among subreaches predictably corresponded with the greatest increase in potential future active bar area, specifically Subreaches 3, 8, and 9 (Table 5). This corresponded to the greatest increase in fry and presmolt rearing habitat from existing conditions occurring in Subreach 8 for all streamflows because the difference between the existing active bar area and potential active bar area was the greatest for all reaches (recommended increase from 2,500 m^2/1,000 m^2 to 5,400 m^2/1,000 m^2).

In general, the percent increase in fry and presmolt rearing habitat from existing to potential future active bar area increased as streamflow increased, peaking at 1,050 cfs (Table 6). As discussed in Section 3.2.1, we hypothesized that the amount of habitat peaks around streamflows of 1,050 cfs, then begins to decline as gravel bars become inundated at higher streamflows, resulting in depths and velocities less suitable for rearing Chinook Salmon fry and presmolt.

Table 4. Existing (2015) active bar area and potential future unit active bar area (as a proxy for gravel storage). Potential future unit bar area is based on comparisons of bar area in similar reaches (see discussion in Section 7 of 2015 Active Bar Mapping report, Appendix A).

	Mapping Subreach	**Mapping Subreach Description**	**Existing Unit Active Bar Area, m^2/1,000 m Channel**	**Potential Future Unit Active Bar Area, m^2/1,000 m Channel**	**Initial Rationale**
Gravel Augmentation and Channel Manipulation	1	Primary gravel source to the reach is from gravel augmentation. Bars have little to no sand. Active bars are a combination of construction sites, augmentation sites, and/or naturally formed bars. Moderate confinement, average slope = 0.0033.	2,700	2,700–3,600	Modest improvements with additional augmentation due to moderate confinement and higher slope, maintain existing active bar area and storage.
	2	Straight segment of channel without obstructions. Rush Creek delta causes low slope and results in very few active bars. No historic gravel augmentation other than immediately upstream at the Burner Hole. Low confinement, average slope = 0.0015.	100	100–1,100	Rush Creek backwater, no action recommended until channel gradient through Rush Creek delta is addressed.
	3	Primary gravel sources include Rush Creek and gravel augmentation. Low confinement, average slope = 0.0024.	3,600	3,600–6,500	Increase unit bar area and storage up to maximum mapped (6.5 m^2/m) to increase rearing habitat due to lower slope and confinement., Good access points.
	4	Low tributary sediment supply and no gravel augmentation. Subreach includes long straight narrow segments with few obstructions. High confinement, average slope = 0.0023.	600	1,100–2,700	Substantially increase active bars and storage (100%–400%) to help offset low tributary supply, upper limit is similar to Subreaches 6 and 7 (similar slope and confinement). Limited access points.
Channel Manipulation	5	Sediment supply from Indian Creek causes large gravel bars, overall fine sediment content of exposed bars increases. Moderate confinement, locally steep, average slope = 0.0031.	6,500	6,500	Highest 2014 unit bar area of all subreaches, no specific increase in active bars / storage recommended.
	6	Increasing tributary gravel supply (Weaver Creek, Reading Creek). Increased channel obstructions (e.g., boulders and bedrock) results in increased active bars. Moderate confinement, average slope = 0.0025.	1,300	1,300–2,700	Increase sediment storage via channel rehabilitation to increase the number of exposed active bars and storage. Assume less storage potential / retention and limited access in canyon Subreaches (6 and 7) compared to downstream lower confinement subreaches (8 and 9).
	7	Confined reach with bars associated with bedrock outcrops. Gravel bars are comparatively small relative to adjacent reaches and exhibit sequential (alternating) patterns. High confinement, average slope = 0.0026.	1,100	1,300–2,700	
	8	Decreased bar size and frequency, alternating bar pattern continues. Low confinement, average slope = 0.0016.	1,100	3,600–6,500	
	9	Large increase in sediment supply from tributaries resulting in increased bar size and increased sand content. Low confinement, average slope = 0.0023.	3,300	3,600–6,500	

Table 5. Range in increases of Chinook Salmon juvenile rearing habitat (m^2) from existing conditions (2014) active bar area, to potential future active bar area (from the 2015 Active Bar Mapping report presented in this report in Table 4) in each subreach at the 1,000-m GRTS panel resolution using regression equations presented in Figure 2. In the case of Subreaches 1,2,3, and 6, the lower bound of potential future active bar area is the same as the existing active bar area; therefore, there was no increase in Chinook Salmon juvenile rearing habitat at the lower bound (0 m^2/ 1,000 m^2 increase).

Active Bar Gravel Area (m^2/1,000 m)										
Subreach		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Existing Active Bar Area		2,700	100	3,600	600	6,500	1,300	1,100	1,100	3,300
Potential Future Active Bar Area (range)		2,700–3,600	100–1,100	3,600–6,500	1,100–2,700	6,500	1,300–2,700	1,300–2,700	3,600–6,500	3,600–6,500
Increase of Active Bar Area from Existing to Potential Future (range)		0–900	0–1,000	0–2,900	500–2,100	0	0–1,400	200–1,600	2,500–5,400	300–3,200
Life Stage	**Flow**	**Increase in Chinook Salmon Juvenile Rearing Habitat (m^2/1,000 m^2 of Bar Area) from Existing to Future Active Bar Area**								
Fry	375	0–139	0–121	0–536	62–281	N/A	0–194	26–219	358–894	48–584
	450	0–141	0–118	0–562	61–279	N/A	0–193	25–218	359–921	49–611
	750	0–159	0–112	0–729	59–285	N/A	0–202	25–227	386–1,115	56–785
	1,050	0–150	0–100	0–714	53–261	N/A	0–186	23–208	358–1,072	53–767
	2,000	0–108	0–81	0–465	42–201	N/A	0–141	18–159	266–731	37–503
Presmolts	375	0–192	0–182	0–701	92–408	N/A	0–278	38–316	508–1,209	65–766
	450	0–206	0–186	0–776	95–427	N/A	0–292	39–331	538–1,313	70–846
	750	0–260	0–197	0–1,127	102–486	N/A	0–341	43–384	644–1,771	91–1,217
	1,050	0–265	0–185	0–1,221	97–472	N/A	0–335	41–376	641–1,862	93–1,315
	2,000	0–198	0–150	0–851	78–370	N/A	0–260	33–292	490–1,342	69–920

N/A= No potential future increase in active bar area recommended for Subreach 5 because it had the highest existing unit bar area of all subreaches at the time of survey.

Table 6. Percent increase in Chinook Salmon juvenile rearing habitat from existing conditions (2014) active bar area to potential future unit active bar area. Upper and lower bounds are the percent increases from the minimum and maximum recommendations for gravel augmentation in the 2015 Active Bar Mapping report (presented in this report in Table 4). In the case of Subreaches 1,2,3, and 6, the lower bound of potential future unit active bar area is the same as the existing active bar area, and therefore there was no change in Chinook Salmon juvenile rearing habitat at the lower bound (0% increase). Percent increase in Chinook Salmon juvenile rearing habitat for the entire Restoration Reach was calculated using the estimated rearing habitat under existing and potential future active bar area for subreaches calculated at the subreach length.

Subreach		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Restoration Reach**
Length (km)		5.3	1.5	6.4	13.4	1.6	8.8	4.4	8.5	14.0	**63.7**
Life Stage	**Flow (cfs)**	**Percent Increase in Chinook Salmon Juvenile Rearing Habitat from Existing to Future Active Bar Area**									
Fry	375	0–9%	0–10%	0–31%	5–22%	N/A	0–14%	2–16%	27–66%	3–35%	5–28%
	450	0–10%	0–12%	0–38%	6–26%	N/A	0–17%	2–19%	32–82%	3–42%	6–34%
	750	0–17%	0–20%	0–68%	9–46%	N/A	0–28%	4–33%	56–163%	6–77%	9–62%
	1,050	0–20%	0–22%	0–78%	10–52%	N/A	0–32%	4–38%	65–193%	6–89%	10–71%
	2,000	0–15%	0–16%	0–55%	8–37%	N/A	0–24%	3–27%	46–126%	5–62%	8–50%
Presmolts	375	0–6%	0–7%	0–20%	3–14%	N/A	0–9%	1–11%	17–41%	2–23%	3–18%
	450	0–8%	0–8%	0–26%	4–18%	N/A	0–12%	2–14%	22–55%	2–29%	4–23%
	750	0–15%	0–16%	0–55%	8–37%	N/A	0–24%	3–27%	46–126%	5–62%	8–50%
	1,050	0–18%	0–20%	0–70%	10–47%	N/A	0–29%	4–34%	58–168%	6–80%	10–63%
	2,000	0–14%	0–16%	0–54%	8–37%	N/A	0–23%	3–27%	45–123%	5–61%	8–49%

N/A= No potential future increase in active bar area recommended for Subreach 5 because it had the highest existing unit bar area of all subreaches at the time of survey.

4 LINKING RESULTS TO OBJECTIVES

The habitat evaluations presented in the previous section follow the 2015 Active Bar Report (Appendix A) recommendations by providing a spatially expanded juvenile rearing habitat analysis. These results provide a companion juvenile rearing habitat analysis to the geomorphic evaluations presented in the 2015 report. Each objective in Section 2 is revisited below relative to both geomorphic and habitat-based evaluations.

4.1 Expanded Habitat Evaluations (Objective 1)

The analytical focus of this report has been to expand the 2015 preliminary habitat associations with active bar area. Our evaluation shows that Analysis 4, 6, and 10 were statistically most important. Using our analyses of active bar area and juvenile Chinook Salmon rearing habitat, we found that:

1. Chinook Salmon juvenile rearing habitat and channel complexity is positively related to active bar area, and
2. Using existing relationships, we predicted that additions of active bar area recommended in the initial Active Bar Mapping report would result in total increases to juvenile rearing habitat in the entire Restoration Reach ranging from 3 to 71% depending on life history stage and streamflow (Table 6).

This analysis suggests that increasing active bar area through coarse sediment augmentation and/or improved coarse sediment retention (i.e., roughness elements) will increase juvenile rearing habitat. However, we caution that there are many variables that can improve and affect juvenile rearing habitat. For example, large wood storage, underbank habitat, and improved connectivity between floodplains and in-channel habitat are important drivers and contributors to juvenile rearing habitat that may be more important than hydraulic habitat provided by active bars. The data we used in our analysis can only predict the impact that active bar area has on physical habitat (depth and velocity) that is considered suitable for juvenile Chinook Salmon. Active gravel bars also provide areas for food productivity that can be important for growth rates of juvenile salmonids; however, this analysis was outside the scope of this report.

4.2 Proposed Future Conditions and Coarse Sediment Storage Targets (Objectives 2 and 3)

Using active bars provides a systematic and consistent platform from which coarse sediment storage can be inferred, as active bars define recent alluvial features scaled to the ROD flow regime (by grain size, bar size, and bar dynamism) as discussed in Appendix A. The 2015 Active Bar Mapping report presented preliminary future sediment storage recommendations for each geomorphic subreach. The Chinook Salmon rearing habitat evaluations presented in Table 5 and Table 6 used the 2015 future active bar area recommendations as target conditions from which to estimate potential future fry and presmolt rearing habitat. Therefore, the active bar area recommendations from Appendix A, as carried forward into the juvenile rearing habitat evaluations presented in this report, now represent potential future targets from which increased juvenile rearing habitat via future gravel augmentation and other gravel management actions can be based.

Appendix A recommends Subreaches 4, 7, 8 and 9 to have some level of increased active bar area, while the remaining subreaches (other than Subreach 5) are recommended to either maintain current conditions or increase active bar area. If gravel management actions are implemented to achieve the higher range of recommended gravel augmentation for all subreaches (Table 4), the entire Restoration Reach could see increases of juvenile rearing habitat up to 3% to 71% for flows up to 2,000 cfs.

The relationship of active bar gravel area to juvenile rearing habitat in each subreach (Analysis 6) increases with streamflow from 375 cfs to 1,050 cfs, except for Subreaches 4 and 8, which currently show no clear relationship to juvenile rearing habitat at moderate streamflows (Figure 5, Figure 6). The analysis suggests that under existing conditions, the active bars in Subreaches 4 and 8 are not creating the same amount of juvenile rearing habitat as elsewhere. Potential reasons for this poor relationship were not quantitatively explored, but we speculate that they are attributed to specific bar or channel morphology (see related discussion in Section 3.2.1). Regardless, if gravel management actions are implemented in Subreaches 4 and 8, and the active bar mapping and habitat model were reconstructed, it is possible that the relationship between active bar and juvenile rearing habitat to improve over the 375–1,050 cfs flow range. The mechanism here is that whatever topographic configuration the bars were at the time of hydraulic modeling is not beneficial to habitat. While not certain, addition of more gravel at various locations that create more hydraulic habitat could lead to a positive relationship at those sub reaches and flows. As discussed elsewhere, there are multiple factors that can improve fish habitat, and active bar area is only one possible mechanism to do so, and may not always be the most effective way. We recommend more specific locational studies to identify the exact mechanisms that are creating the relationship between active bars and fish habitat. Although the results of the quantitative analysis do not provide high enough resolution to determine the amount of gravel needed, results suggest Subreaches 4 and 8 are priority candidates for additional coarse sediment.

In addition to juvenile rearing habitat, we found channel complexity was positively related to active bar area. We presume this is driven by active bars creating more wetted edge, which drives the channel complexity metric used here. For example, Subreaches 2 and 7 had the lowest complexity across modeled flows (Table 4) and the lowest unit bar area, also making them priority candidates for gravel augmentation.

4.3 Developing Management Recommendations (Objective 4)

Based on the initial work presented in Appendix A and the potential juvenile Chinook Salmon rearing habitat improvements that could be attained by increasing active bar area (gravel storage) described in the previous sections of this report, we make the following recommendations to best achieve target coarse sediment storage conditions in the 64-km Restoration Reach. These recommendations are made independently of augmentation logistics (e.g., accessibility), so implementation issues will still need to be investigated.

Recommendation 1. Prioritize coarse gravel augmentation as shown in Table 7. High, Medium, and Low priority is assigned to each geomorphic subreach based on maximum potential sediment storage increase (per identified subreach target) and associated potential juvenile rearing habitat increase.

Recommendation 2. Implement a multi-site coarse sediment augmentation and retention strategy within each subreach. Add coarse sediment at multiple locations to be most effective (i.e., multiple augmentation sites will help reach storage sites faster than a single site at the top of the reach as recommended in McBain & Trush (2007)). Related work by others in the Restoration Reach suggests a multi-site augmentation strategy is more effective at achieving a spatially balanced storage target compared to a single-site strategy. For example, Gaeuman (2020) reports: "The results of the gravel augmentation monitoring described in this report indicate that the augmented gravel propagates downstream slowly. It is therefore recommended that the TRRP immediately begin work to identify additional augmentation sites and obtain the environmental permitting necessary to implement augmentations at those sites. Varying the locations of gravel augmentations from year to year would promote local geomorphic change and increase gravel dispersion, which would likely produce greater habitat benefits over longer stretches of the river. It would also reduce the risk of local habitat simplification associated with the oversupply of gravel to a limited area, as has been suggested in related studies." The Gaeuman (2020) recommendations are fully consistent with the strategy recommended in the *Trinity River Coarse Sediment Management Plan* (M&T 2007).

Recommendation 3. In combination with Recommendation 2, use channel enhancements such as large wood and meanders to increase gravel storage potential and residence time. This will provide a much more efficient and effective way to integrate channel enhancements, large wood augmentation, and other roughness elements to create new storage areas.

Recommendation 4. Apply Recommendations 1–3 to Subreach 4 as part of a short-term coarse sediment augmentation effort to rapidly meet sediment storage targets in that subreach, and then maintain this storage with long-term augmentation as recommended in McBain & Trush (2007).

Table 7. Existing and target future active bar area (from Appendix A and Table 4 in this report), greatest potential percent increase in Chinook Salmon fry and presmolt rearing habitat (from Table 6, this report), and recommended priority subreaches for coarse sediment augmentation and/or channel manipulation.

Geomorphic Subreach	Existing Unit Active Bar Area, m^2/1,000 m Channel	Target Future Unit Active Bar Area, m^2/1,000 m Channel	Greatest Potential Percent Increase in Chinook Salmon Fry Rearing Habitat From 350–2,000 cfs	Greatest Potential Percent Increase in Chinook Salmon Presmolt Rearing Habitat From 350–2,000 cfs	Recommended Coarse Sediment Augmentation and Management Priority [1]
1	2,700	2,700–3,600	20%	18%	Low
2	100	100–1,100	22%	20%	Medium [2]
3	3,600	3,600–6,500	78%	70%	Medium
4	600	1,100–2,700	52%	47%	High
5	6,500	6,500	N/A	N/A	N/A
6	1,300	1,300–2,700	32%	29%	Medium
7	1,100	1,300–2,700	38%	34%	High
8	1,100	3,600–6,500	193%	168%	High
9	3,300	3,600–6,500	89%	80%	High

N/A = Geomorphic Subreach 5 is not recommended for coarse sediment augmentation and management due to existing high coarse sediment storage (Indian Creek delta).

[1] Habitat prioritization

- High priority: Minimum target future unit active bar area > existing, or > 2.0× target sediment storage increase (upper limit) and > 50% potential maximum habitat increase.
- Medium priority: ≥ 1.0× target sediment storage increase (upper limit) and 25%–50% potential maximum habitat increase.
- Low priority: ≥ 1.0 target sediment storage increase (upper limit) and < 25% potential maximum habitat increase.

[2] Priority increased from Low to Medium based on channel complexity recommendation in Section 4.2.

5 SUMMARY

A primary purpose of this report is to provide information that can help inform near- and long-term coarse sediment management goals. By correlating juvenile rearing habitat to active bar area (and thus gravel storage), results from this investigation can provide active bar area targets which may improve hydraulic habitat for juvenile Chinook Salmon (Table 7). The results provide a basis for future coarse sediment management and channel rehabilitation planning. The results and recommendations presented in this report should also be considered alongside other concurrent studies, e.g., Fine Sediment Synthesis (Buxton 2021), Channel Complexity (McBain Associates, in preparation), and Tributary Delta Monitoring and Synthesis (Buxton and Bradley (accepted, in revision)), to result in better integration, less redundancy, and better informed plans for recovering river ecological function as recommended by the TRFE (USFWS and HVT 1999) and as required by the ROD (DOI 2000). Lastly, the information presented here can be used, along with habitat quantification and other studies, as part of broader discussion and collaboration among TRRP partners to help define desired future channel form and function as part of the River Corridor Management Strategy.

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APPENDIX A. TRINITY RIVER ACTIVE BAR MAPPING, LEWISTON DAM TO NORTH FORK TRINITY RIVER CONFLUENCE, SUMMER 2014 (MCBAIN ASSOCIATES 2015)

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TRINITY RIVER ACTIVE BAR MAPPING LEWISTON DAM TO THE NORTH FORK TRINITY RIVER CONFLUENCE, SUMMER 2014

June 22, 2015

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1 INTRODUCTION

This report documents locations, dimensions and formative histories of active bars in the Trinity River from Lewiston Dam to the North Fork Trinity River confluence. A primary purpose of this effort is to provide support for near- and long-term management of sediment based on opportunities and constraints within a diversity of geomorphic reaches (primarily coarse sediment augmentation, consisting of gravel and cobble that is mobile by the ROD high flow regime).

Sediment management has been addressed previously in several documents, including the Coarse Sediment Management Plan (McBain & Trush 2007). Current recommendations of the Trinity River Restoration Program (TRRP) technical workgroups who are charged with developing sediment management recommendations (Gravel Augmentation and Physical Work Groups) are to integrate management of sediment, large wood, flow releases, land use and channel rehabilitation construction designs into a single, comprehensive strategy to be known as the River Corridor Management Map and Strategy.

This study provides information to be considered alongside investigations of sediment transport by way of informing plans for recovering river health and native fish populations, as required by the ROD. Coupled with ongoing habitat quantification efforts and other studies, this information can be used to define desired future channel form and function as part of the River Corridor Management Strategy (Figure 1). This report also begins to illuminate relationships between recent active bar deposits and variables that likely influence their formation, including channel confinement, previous gravel augmentation, hydraulics at high flows, and other factors. To begin relating active bar storage to fish habitat (as modeled on basis of water depth, velocity and cover), we have incorporated preliminary information on modeled flow/habitat relationships for fry and pre-smolt Chinook salmon in a subreach between Johnson Point and Oregon Gulch.

2 BACKGROUND

The Coarse Sediment Management Plan identified potential augmentation sites based on local geomorphic setting (e.g., inside of a forced meander, supplementing existing naturally formed bars); however, it did not filter potential augmentation locations based on access, land ownership, or coarse sediment storage needs. The Coarse Sediment Management Plan also did not quantify existing sediment storage, nor did it recommend future storage volumes, both of which are an important component of a long-term coarse sediment management plan. Accordingly, the objective of “increase and maintain coarse sediment storage” was given a high priority in the Integrated Assessment Plan or “IAP” (TRRP and ESSA 2009). The IAP identified mapping of active bars as a specific assessment strategy (along with computing coarse sediment storage based on sediment transport rates and loads).

Sediment budgets for the study reach have been estimated by Wilcock (2010), Gaeuman and Krause (2011), and Gaeuman (2013). Each of these are limited in the following ways: (1) they are applied over long reaches (e.g., > 5 km (3 miles)) between measurement locations, rather than at scales directly relevant to many management decisions, (2) they are based on computed storage changes between measurement locations rather than field measurements of storage, (3) they do not specifically relate to geomorphic thresholds for bar formation or channel dynamics needs, and (4) they do not specifically relate to fish habitat or river health, the two fundamental goals of the TRRP. While these sediment budget computations provide very helpful information on reach-scale computed changes in storage, actual bar storage provides a better linkage to the ROD goals of a scaled down alluvial channel and increased fish habitat than a computation of reach-scale sediment budget. Therefore, to supplement the computed sediment budgets and provide a better linkage to ROD goals, a field-based method for mapping active gravel bars was developed.

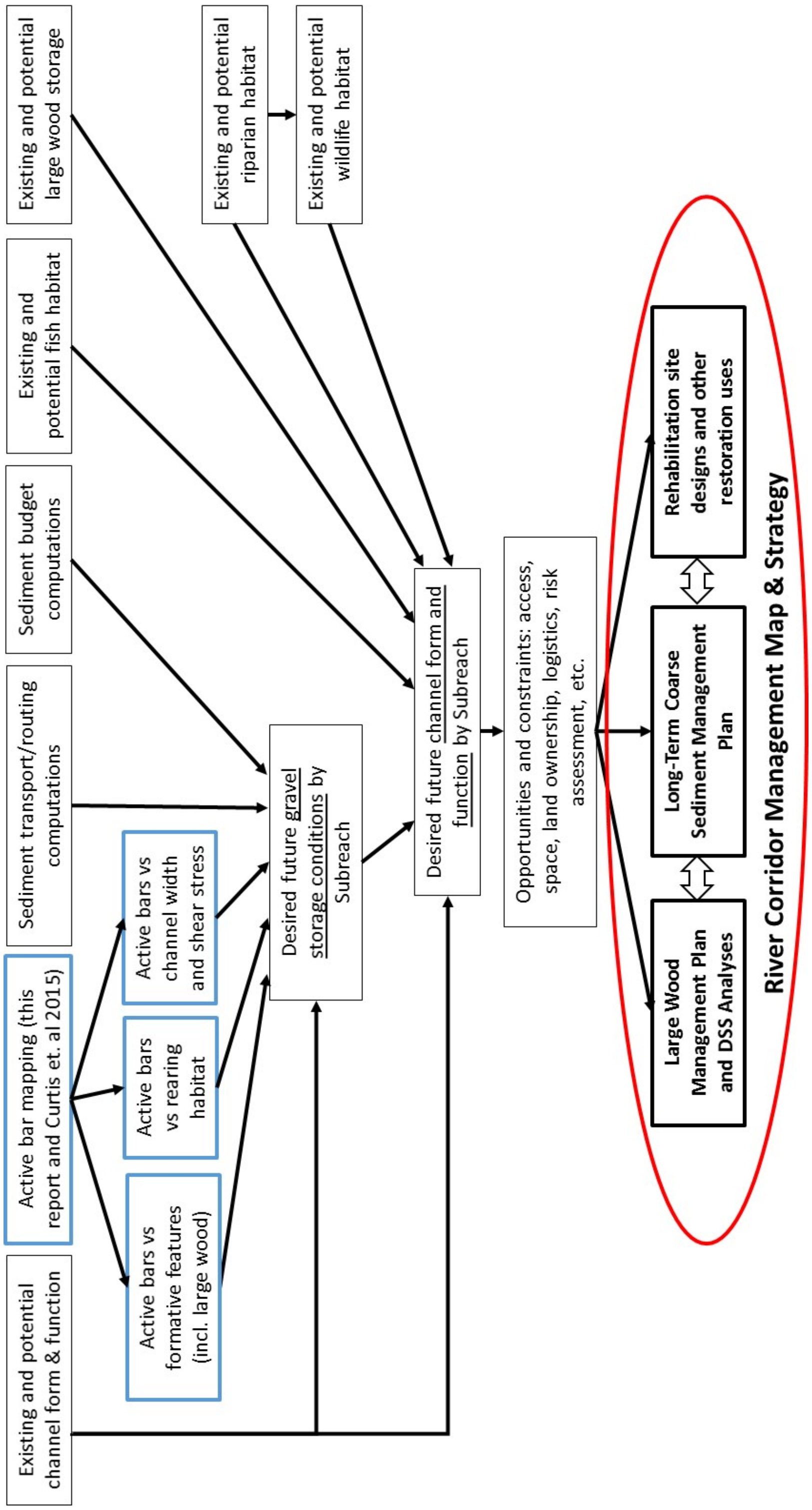

Figure 1. Active bar mapping and related evaluations (highlighted blue boxes) as one component of multiple TRRP Phase 2 planning studies intended to help define desired future gravel storage conditions, and help define desired future channel form and function by subreach. Once these conditions are defined, opportunities and constraints can be identified, ultimately providing a foundation for developing (1) a revised long-term Coarse Sediment Management Plan, (2) a Large Wood Management Plan, (3) improved rehabilitation site designs, and (4) an overall River Corridor Management Map and Strategy.

Gravel and sand storage have been semi-quantitatively mapped by Wilcock et al. (1995) and again by GMA (2003). This gravel and sand mapping was focused on estimating changes in surficial sand storage across the 64 km (40 mile) reach, and did not specifically focus on coarse sediment storage. McBain & Trush and Hoopa Valley Tribe (2004) mapped large-scale geomorphic features along the 64 km (40 mile) reach, and the USGS (Curtis and Guerrero, 2015) has done additional geomorphic mapping comparisons from aerial photography. TRRP staff has also conducted some exploratory substrate mapping, but this was not conducted over the entire 64 km (40 mile) study reach. Lastly, a reconnaissance-level evaluation of channel type in the 64 km (40 mile) reach was conducted in 2013 using a European stream classification system developed by Sindlar et al. (2012). All of the above information notwithstanding, developing a long term coarse sediment management plan will be greatly informed by (1) an accounting of the recent active bar area within the 64 km reach (an index of local coarse sediment storage), and (2) an estimate of potential active bar area based on the recent coarse sediment storage and local geomorphic setting, opportunities, and constraints. Using recent active bars provides a systematic and consistent platform from which gravel storage can be inferred, as active gravel bars define recent alluvial features scaled to the ROD flow regime (by grain size, bar size, and bar dynamism). Once these estimates have been made, recommendations can be provided to help refine short-and long-term coarse sediment augmentation strategies and help guide future coarse sediment augmentation efforts.

3 OBJECTIVES

The goal of this report is provide information to guide long-term sediment management as a component of the River Corridor Management Strategy, by pursuing the following objectives:

1. Develop a map of contemporary active gravel bars within the 64 km (40 mile) management reach between Lewiston Dam and North Fork Trinity River. In this context, we use contemporary to define bars that are formed and maintained by the post-ROD flow regime.
2. Explore relationships between active bar frequency and area with formative factors (forced meanders, bedrock obstructions, etc.).
3. Evaluate active bar frequency and surface area as an index of recent coarse sediment storage (determined from the results of Objectives 1 and 2), and use results to explore sediment storage potential as a function of geomorphic and/or hydraulic variables.
4. Re-evaluate potential sediment augmentation sites and volumes.

To accomplish these objectives, both field- and office-based data collection and analyses were performed, and are described in the following sections.

4 FIELD AND ANALYTICAL METHODS

Both field- and office-based data collection were performed to document active bar area, and evaluate potential active bar areas in the 64 km (40 mile) reach. Fieldwork was conducted between July and November 2014. Data collection and analytical methods are described below.

4.1 Active bar mapping (Objective 1)

The objective was to develop a GIS map of active bars to document their spatial organization, and identify associated causal factors. The mapping identifies how frequently bars occur in diverse geomorphic settings, and how bar formation might be managed (e.g., increased) through actions such as gravel augmentation, large wood augmentation, channel manipulation, and/or adding roughness elements.

4.1.1 Mapping procedure

To provide a consistent mapping platform, active bars were defined as recent coarse sediment deposits having: (1) their landward edge bound by a contact separating active fluvial transport and deposition under ROD flow regime, and/or (2) their streamward edge bound by the 12.7 cms (450 cfs) water edge, which (a) results in a near-constant summer low-flow water surface elevation throughout the 64 km (40 mile) reach and (b) provides a common datum from which all bars could be mapped. Although this field-based method uses similar criteria as Curtis and Guerrero (2015), it is more precise because boundaries were identified and mapped in the field using GPS rather than interpreted from air photos.

Identifying the streamward boundary of active bars was straightforward; however, landward boundaries were more complex, ranging from sharp to gradational. The following criteria were developed to help reduce subjectivity in mapping active bar contacts areas:

- Wetted edge contacts at each bar are completely exposed (i.e., dry); boundaries do not include areas of partial exposure, such as where water can be seen flowing between/around particles.
- Bar surfaces must show evidence of transport under ROD flow regime. Evidence of this includes surface imbrication, surface sorting (facies), and low particle embeddedness.
- Surface sediments must have a visually-estimated average particle size greater than 2 mm. Fine sediment deposits (i.e., 2 mm and smaller) are excluded unless the deposit is either a thin veneer or is small and localized relative to the bar area, estimated less than approximately 2%. A maximum average particle size was not established.
- The bar surface may be vegetated, but the vegetation density must not present hydraulic obstructions that prohibit coarse sediment transport. Areas where vegetation is trapping sediment while largely obstructing transport are excluded.
- The mapping area includes bars located along the mainstem Trinity River channel, in split channels capturing at least 20% mainstem flow (2.5 cms, 90 cfs), and at tributary deltas. Side channels where flow is less than 10% of the mainstem flow (1.25 cms, 45 cfs) were excluded, as these typically do not contain larger scale mobile alluvial features.
- Because mapping was performed using GPS equipment, a minimum bar width of 1.2 m (4 ft) was used based on an estimated accuracy of ± 0.6 m (2 ft).

Mapping was performed using a Trimble GeoXH hand-held GPS unit and was aided with a set of 2013 orthorectified aerial photograph base maps (1:2400 scale). The aerial photographs were taken in July 2013, during 12.7 cms (450 cfs) summer baseflows, showing flow conditions equivalent to those encountered during mapping. The base maps were used for field reference and location only.

At each bar, the following tasks were performed:

1. The bar was examined on the aerial photograph base map.
2. The bar and surrounding area was walked, and the identification criteria were applied to delineate the active bar area.
3. The bar area was defined using the hand-held GPS to create a polygon outlining the planform bar shape. Polygons were mapped as a sequential set of key point locations to allow for simple polygon delineation by the GIS analyst. Point spacing varied as a function of bar shape complexity, but included sufficient detail to capture an accurate planform portrayal. Starting and ending points were attributed as such to indicate when the polygon should be closed. Field attributes assigned to the polygons used a data dictionary in the hand-held GPS unit developed specifically for this project to provide a consistent terminology and point coding for the GIS analyst.
4. A centroid point was taken inside each polygon to provide a unique site identifier, and each bar was assigned a formative feature (see Section 4.2).
5. At least one photograph was taken at each polygon to show the landward contact. Photographs were logged in a field book using a corresponding to the bar centroid GPS identification number.

The above procedure was applied consistently throughout the project reach. An example showing mapping results and photographs at a single bar is shown in Figure 2.

4.1.2 Calibration and quality control

Mapping calibration, mapping status, and results checks were conducted prior to, during, and after the field mapping effort. Prior to the mapping effort, a calibration training exercise was performed to standardize field procedures; Four McBain Associates (MA) staff visited two reaches near Canyon Creek between river km 122.4 and 125.4 (river mile 76-78) and applied the field identification criteria to delineate bar areas, map active bar boundaries with the GPS, attribute formative features, and take photographs.

Immediately following calibration training, the field team mapped approximately half of the 64 km (40 mile) reach, and then returned to the office to review results with senior staff. A subset of mapped bars was reviewed (planform maps, polygon boundaries, and ground photographs) to discuss field methods and results. Areas where the field crew had mapping uncertainty were identified, and were revisited by both the field crew and MA senior staff to confirm and/or adjust polygon areas. Following this mid-mapping review, the field crews continued with mapping the remainder of the 64 km (40 mile) reach, finishing the field mapping in September 2014. At the conclusion of the field effort, a preliminary map was reviewed by MA senior staff, followed by final senior staff field verification over the entire 64 km (40 mile) project reach in November 2014.

4.1.3 Data management and analysis

Immediately following field mapping trips, the GPS was downloaded and data were processed. Later, active bar polygons were overlaid onto aerial photograph base maps, and a final map of active bar polygons was generated. After the map was completed, the active bar polygons were organized by their location (km downstream of Lewiston Dam), area, and attributes. The polygons and their corresponding data were then sorted longitudinally and grouped into 200 m (656 ft) segments for consistency with the TRRP SRH-2D model (Reclamation 2014).

Figure 2. Top photograph: Example mapping polygon (black line) showing GPS points delineating boundaries of the active bar surface. Yellow dots show terrestrial contacts, blue dots show water contacts, and red dot shows bar centroid. Photographs were taken at each bar to show the back-bar contact that separates mobile from immobile areas; camera icon at upstream end of the bar shows the location and aspect of this photograph. Bar location is 4.27 km (2.65 miles) downstream of Lewiston Dam in Subreach 3 (bar centroid ID number 100), within the limits of the Sawmill channel rehabilitation site. Bottom photograph: back-bar contact separating the mobile from immobile area (shown by dashed black line). View is from upstream end of the bar facing downstream, photograph location and aspect arrow are shown in the top photograph.

Nine distinct gravel mapping subreaches were identified during field mapping based on observed gravel storage (Figure 3). Each subreach has unique characteristics of gravel storage, geomorphic, and/or hydraulic setting. Data analyses include evaluations of subreaches, as described in the following sections. Subreach characteristics are described in Table 1.

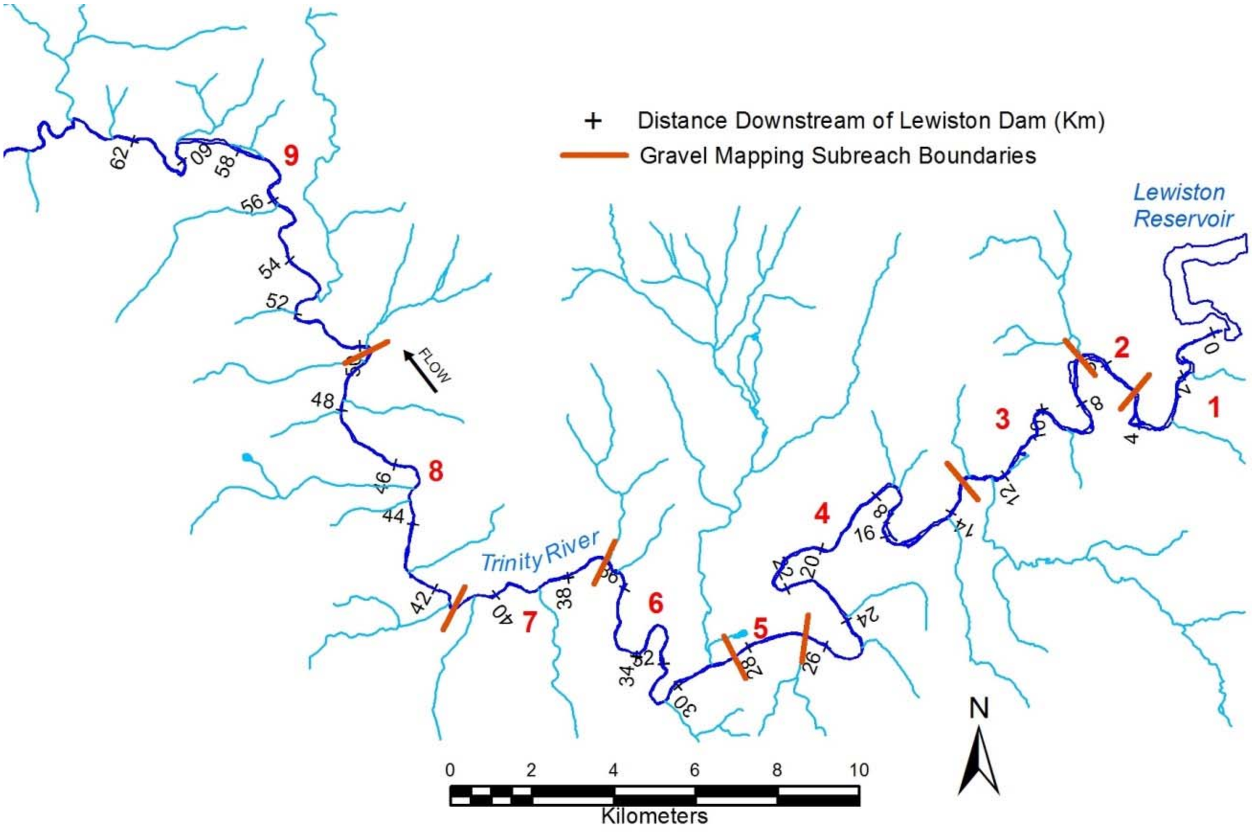

Figure 3. Map of the Trinity River showing the nine gravel mapping subreaches from Lewiston Dam downstream to the North Fork Trinity River confluence.

4.2 Relating Active Bar Frequency and Area to Forcing Mechanisms (Objective 2)

As part of the mapping procedure, each mapped bar was assigned a formative feature based on the aerial photographs and field observations. For example, when bars have been formed in association with a structure such as bedrock, piece of large wood, or a bridge pier, then bar formation was attributed to that structure. Where structural control was not apparent, bars were attributed to their hydraulic setting, such as channel expansion zones or constrictions.

In many cases, mapped areas can be characterized as active *portions* of bars, meaning that the bar itself has both mobile and immobile areas based on the field mapping criteria. Therefore, it is possible for large bars to exhibit multiple active areas (polygons) which are thereby delineated as “active bars”. In these cases, the formative feature is that of the “parent” feature (e.g., an island that is formed by channel expansion having two separately mapped individual active bar polygons will have both polygons attributed to the channel expansion).

A list of and explanation for formative features are shown in Table 2. In the case of bars formed by large wood, attribution included whether the large wood is a naturally deposited or a constructed feature, and was followed by measuring and recording the cross-sectional area of the aspect of the large wood mass influencing deposition.

Table 1. Geomorphic subreaches based on field observations of exposed mobile gravel bar.

Subreach	Distance downstream of Lewiston Dam (km, miles)	Reach length (km, miles)	Channel confinement and average subreach slope[1]	Observed gravel storage and characteristics affecting exposed mobile gravel bar occurrence, size, and frequency
1	0.0 - 5.30 (0.0 - 3.29)	5.30 (3.29)	Moderate confinement, slope = 0.0033	Primary gravel source to the reach is from gravel augmentation. Bars have little to no sand. Exposed bars are a combination of construction or augmentation sites and naturally-formed.
2	5.30 - 6.76 (3.29 - 4.20)	1.46 (0.91)	Low confinement, slope = 0.0015	Straight segment of channel without obstructions. Rush Creek delta causes low slope and results in very little storage and increased sand. No historic gravel augmentation.
3	6.76 - 13.12 (4.20 - 8.15)	6.36 (3.95)	Low confinement, slope = 0.0024	Primary gravel sources include Rush Creek and gravel augmentation. Bars have little to no sand.
4	13.12 - 26.55 (8.15 - 16.50)	13.44 (8.35)	High confinement, slope = 0.0023	Low tributary sediment supply and no gravel augmentation. Subreach includes long straight narrow segments with few obstructions.
5	26.55 - 28.16 (16.50 - 17.50)	1.61 (1.0)	Moderate confinement, locally steep, slope = 0.0031	Sediment supply from Indian Creek causes large gravel bars, overall fine sediment content of exposed bars increases.
6	28.16 - 36.93 (17.50 - 22.95)	8.77 (5.45)	Moderate confinement, slope = 0.0025	Increasing tributary gravel supply (Weaver Creek, Reading Creek). Increased channel obstructions (e.g., boulders and bedrock) results in increased bars.
7	36.93 - 41.28 (22.95 - 25.65)	4.35 (2.70)	High confinement, slope = 0.0026	Confined reach with bars associated with bedrock outcrops. Gravel bars are comparatively small to adjacent reaches and exhibit sequential (alternating) patterns.
8	41.28 - 49.73 (25.65 - 30.90)	8.45 (5.25)	Low confinement, slope = 0.0016	Decreased bar size and frequency, alternating bar pattern continues.
9	49.73 - 63.73 (30.90 - 39.60)	14.00 (8.70)	Low confinement, slope = 0.0023	Large increase in sediment supply from tributaries resulting in increased bar size and increased sand content.

[1] Slope computed from regression of 1997 California Department of Water Resources photogrammetry-based water surface profile.

Table 2. Formative feature types and definitions of their geomorphic or hydraulic setting that facilitates active bar formation.

Formative feature	Feature description and condition responsible for active bar formation
Bedrock	Bedrock outcrop in or adjacent to the channel causing active bar formation on the upstream or downstream side.
Large wood	Large wood accumulation (single piece or aggregate), natural or constructed, creating a hydraulic condition resulting in bar formation.
Constructed	Constructed surfaces (e.g., specific areas of channel rehabilitation areas) meeting mobile active bar criteria.
Delta	Delta deposit meeting active bar criteria or active bar formed by delta influence.
Island	Areas adjacent to islands where active bars have formed. Islands are often immobile vegetated former medial bars; active medial bars are attributed to channel expansions.
Bridge pier	Bar formation directly influenced by a bridge pier(s).
Forced meander	A meander bend caused, or “forced”, by a structural control (e.g., bedrock)
Channel confinement	Hydraulic constriction and grade control influencing upstream bar formation.
Channel expansion	Hydraulic expansion commonly associated with a rapid increase in channel width and/or slope reduction which causes bar formation. Bars formed are commonly medial bars or islands (former active bars) with smaller active gravel bars along their margins.
Alternate bar sequence	A sequence of two point bars, not caused by a structural “forcing” element, opposite and longitudinally offset from one another, connected by a riffle, and commonly completing a complete channel meander wavelength.

4.3 Evaluate Active Bar Frequency and Area as an index of Contemporary Coarse Sediment Storage (Objective 3)

The objective of this task was to evaluate active bar frequency and area as an index of contemporary coarse sediment storage (determined from the results of Objectives 1 and 2), and then estimate potential coarse sediment storage as a function of geomorphic and/or hydraulic variables, such as confinement, structure, shear stress, and other factors. Contemporary active bar area and frequency were determined from Objective 1, and formative structures (forcing mechanisms) were determined in Objective 2.

Data were first reviewed by plotting bar area with distance downstream from Lewiston Dam and then reviewing characteristics of storage by subreach. Following this evaluation, a series of relationships were explored by setting active bar area as the dependent variable and using a combination of geomorphic and hydraulic factors as independent variables to explore correlations. Independent variables for this evaluation included:

- Average channel width at 311 cms (11,000 cfs) and 170 cms (6,000 cfs), as determined by the SRH-2D model by 200 m (656 ft) segment.

- Average "channel" shear stress at 311 cms (11,000 cfs) and 170 cms (6,000 cfs), as determined by the SRH-2D model and computed by 200 m (656 ft) segment. Channel shear stress is the average boundary shear stress computed by the model for the entire 200 m (656 ft) panel length, but over a width determined by the hydraulic modelers to be representative of the active channel, which excludes overbank areas.
- Formative features, which were identified in the field and attributed to each mapped storage polygon (see Section 4.2).
- Large wood, by (1) number of pieces and (2) upstream-facing area influencing deposition.
- Gravel augmentation volumes for the 1998 – 2010 period, as reported by Krause (2012).

In addition to evaluating active bar frequency and area as a function of hydraulic and geomorphic variables, preliminary SRH-2D fish habitat modeling data made available by Reclamation (2014) provided an opportunity to explore additional potential relationships to mapped active gravel bar area. Unfortunately, this modeling output does not currently meet USFWS and HVT accuracy standards. Specifically, the SRH-2D output fails to align reasonably with field measurements. Efforts are underway to resolve these issues prior to releasing fish habitat simulations for further use.

However, with the understanding that model output were preliminary but represented the best simulations currently available within the project reach, we used modeled results to evaluate predicted fry and juvenile (pre-smolt) Chinook salmon rearing habitat associated with the active gravel bars. Modeled habitat results were provided by Reclamation (2014) for an 8.6 km (5.34 mile) reach from Johnson Point (41.12 km or 25.55 miles downstream of Lewiston Dam) to Oregon Gulch (49.73 km or 30.9 miles downstream of Lewiston Dam). Model output provided fish habitat predictions for four flows: 12.7 cms (450 cfs), 23.5 cms (830 cfs), 28.9 cms (1,020 cfs), and 43.9 cms (1,550 cfs), and included habitat computed using depth and velocity only ("Type 1"), cover only ("Type 2"), and depth, velocity, and cover ("Type 3"). To link modeled habitat results to mapped gravel bar area, only Type 1 habitat results (i.e., depth and velocity only, no cover) was used because it was most representative of the bar environment (bars were generally free of vegetation that could provide cover, and were located away from overhanging riparian vegetation canopy).

Type 1 fry and pre-smolt rearing habitat was evaluated for each of the four modeled streamflows in the 8.6 km (5.34 mile) reach by plotting habitat and gravel bar area with distance downstream from Lewiston Dam. Results for hydraulic, geomorphic, and fish habitat relationships are presented in Section 5.

4.4 Sediment Augmentation Site Re-Evaluation (Objective 4)

The Trinity River Flow Evaluation Final Report (USFWS and HVT 1999) and Coarse Sediment Management Plan (McBain & Trush 2007) evaluated the need for gravel augmentation on the upper 26.5 km (16.47 mile) reach between Lewiston Dam and Indian Creek due to post-dam coarse sediment supply limitations and low abundance of active bars. Based on results from Objectives 1-3, potential for active storage will be discussed as related to habitat needs, desired channel form, and river health. Additional factors such as access, land ownership, distance from gravel inputs, flood risk, association with large wood and other formative features, and local land use will also need to be considered. This will contribute to the re-evaluation of potential gravel augmentation sites and volumes for the River Corridor Management Strategy.

5 RESULTS AND DISCUSSION

A total of 302 active bars were mapped in the project reach. Mapping results were first reviewed based on the spatial distribution of contemporary active bars to explore overall gravel storage in the entire project reach and by subreach (Section 5.1). Following this, relationships were explored to evaluate bar area and inferred coarse sediment storage as a function of geomorphic and hydraulic variables (Section 5.2). Lastly, an initial evaluation of relationships between bar area and fish habitat was conducted for an 8.6 km (5.34 mile) section of Subreach 8 (Section 5.3).

5.1 Spatial sediment storage

Active bar polygons were sorted by area per 200 m (656 ft) panel and spatial arrangements were evaluated by plotting the data longitudinally. Charts were generated to illustrate:

- Active bar area and frequency from Lewiston Dam to the North Fork Trinity River confluence, including major tributaries and geomorphic subreach boundaries (Figure 4);
- Cumulative active bar area from Lewiston Dam to the North Fork Trinity River confluence, including major tributaries and geomorphic subreach boundaries (Figure 5);

Gravel bar area was also evaluated on a subreach basis. Charts were prepared to illustrate:

- Active bar area by subreach, including historic 1998 – 2010 augmentation volumes (in applicable subreaches), major tributaries, and mapping subreach boundaries (Figures 6 - 14);

Finally, active gravel bar area in each mapping subreach was computed on a unit-area basis (m^2 bar area / m channel), providing relative area for each subreach. These results were plotted alone and relative to longitudinal bar area frequency:

- Active bar unit area and historic 1998 - 2010 gravel augmentation by subreach (Figure 15);
- Active bar area and frequency, and unit area by subreach, from Lewiston Dam to the North Fork Trinity River confluence (Figure 16).

Active bar area in all subreaches was evaluated, and results show Subreaches 2 and 4 have the lowest unit active bar area (0.1 m^2/m and 0.6 m^2/m (0.328 ft^2/ft and 1.97 ft^2/ft), respectively) of all subreaches (Table 3). Using active bar area as an index of gravel storage, these results show Subreaches 2 and 4 have low gravel storage despite being located downstream of subreaches 1 and 3 which have received nearly all of gravel augmentation during the 1998 - 2010 period. Field observations provide evidence that sediment used to augment bedload has yet to move far (< 0.8 km or 0.5 miles) from sites of introduction (Gaeuman 2014), so augmented gravels have likely remained within the reaches they were introduced, for the most part.

Subreach 2 is the Rush Creek backwater, an area that will likely continue to have few active bars. Here, additional augmentation at upstream or in-reach sites is unlikely to drive substantial impacts in the near term (e.g., 10 years). In Subreach 4, we see potential for increasing storage in active bars via gravel augmentation and modest channel rehabilitation (placement of large wood or other obstructions, channel widening). Even though potential for development of active bars is generally expected to be lower in more confined subreaches, the two most confined subreaches (Subreaches 4 and 7) have markedly different active bar densities and relative areas, suggesting overriding effects of sediment supply and influence of numerous bedrock obstructions in Subreach 7. This observation suggests increased gravel supply and/or channel rehabilitation that incorporates features designed to increase gravel storage and create active bars may help increase Subreach 4 unit active bar area (and thus gravel storage).

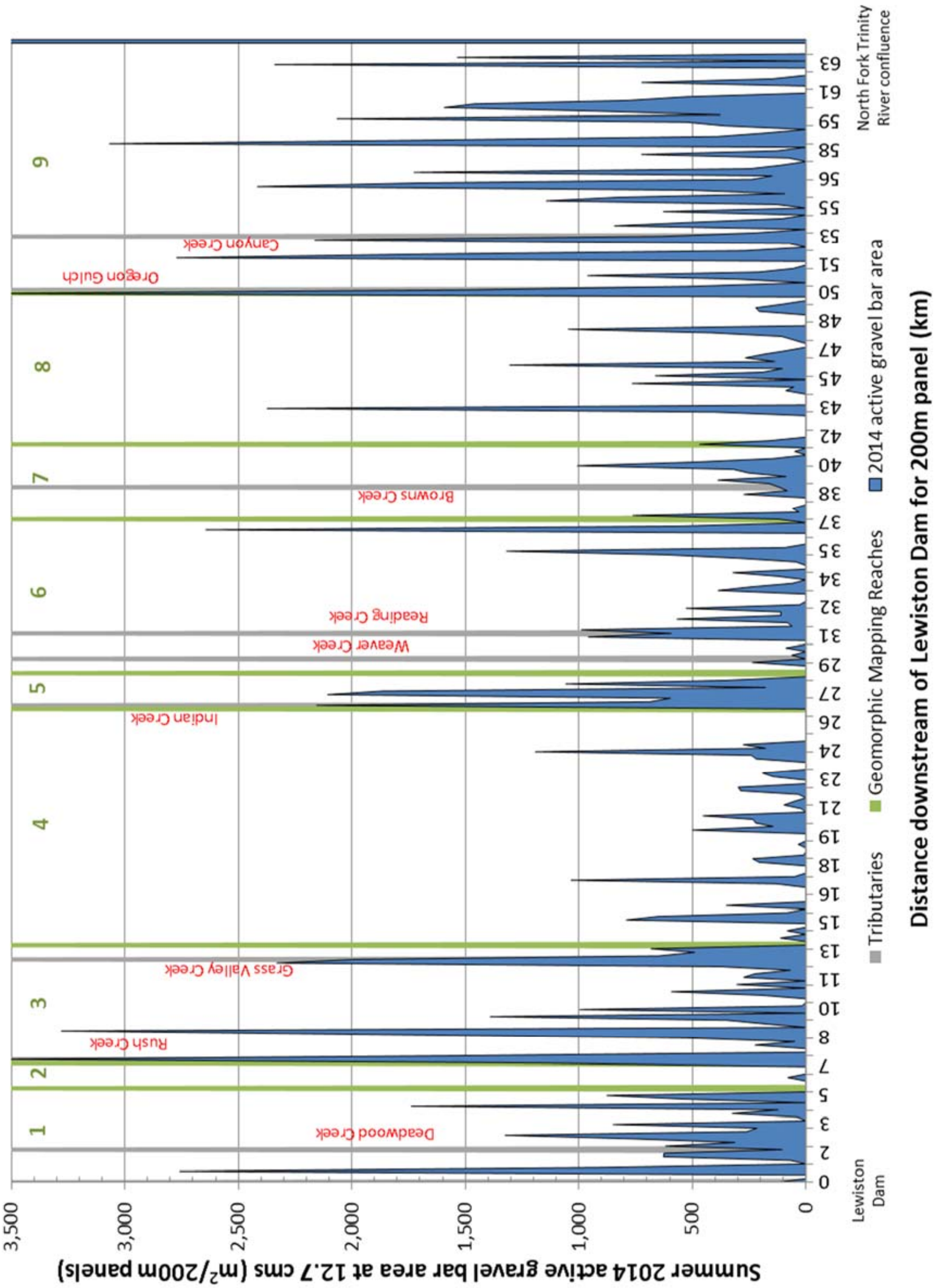

Figure 4. Active bar area and frequency by 200 m (656 ft) panel at 12.7 cms (450 cfs), Lewiston Dam to North Fork Trinity River confluence. Active bar area is shown as the blue shaded area, major tributaries are shown as labeled gray vertical lines, and geomorphic subreach boundaries are numbered and shown as green vertical lines.

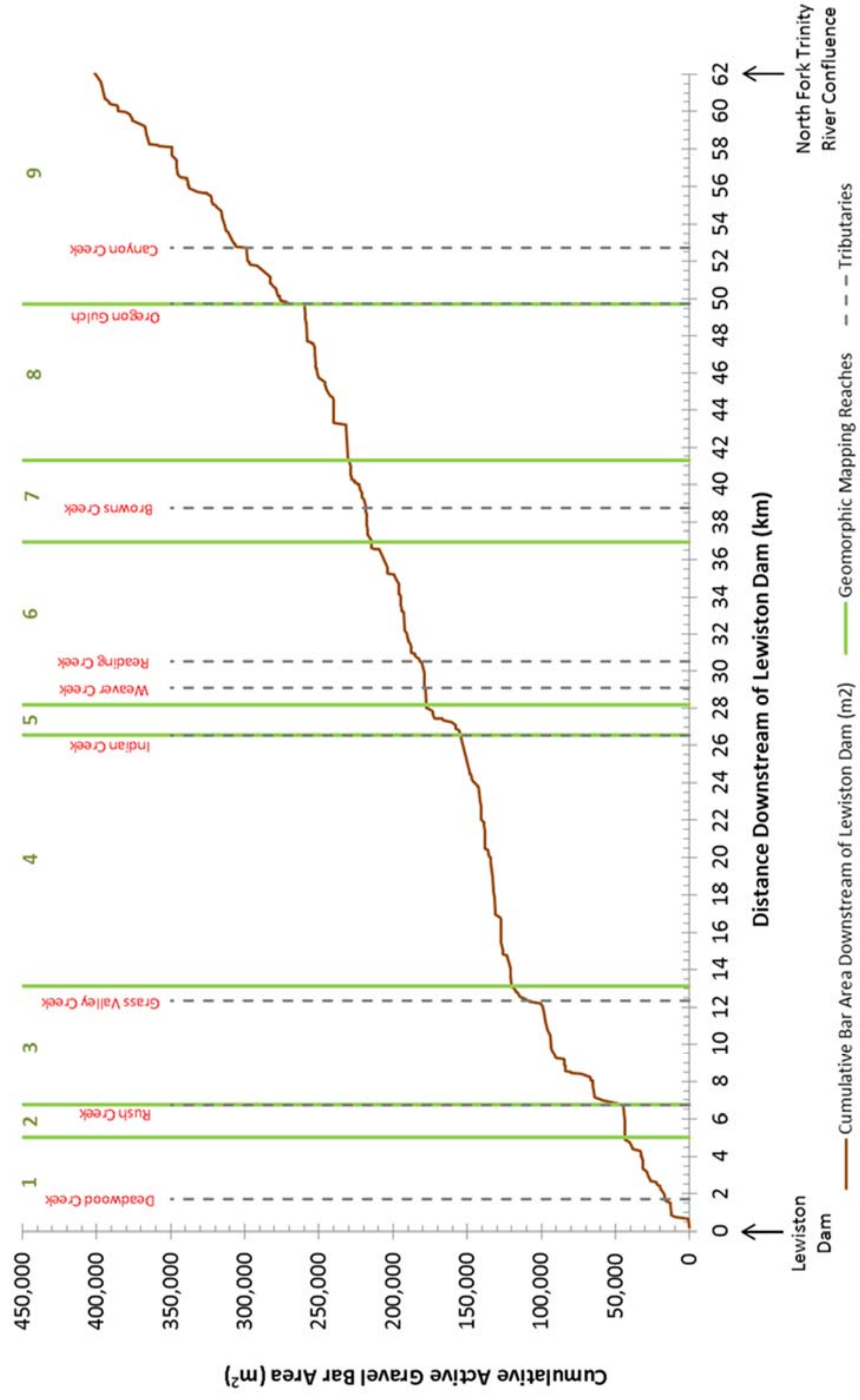

Figure 5. Cumulative active bar area from Lewiston Dam to the North Fork Trinity River confluence. Major tributaries are shown as labeled gray dashed vertical lines, and geomorphic subreach boundaries are numbered and shown as green vertical lines.

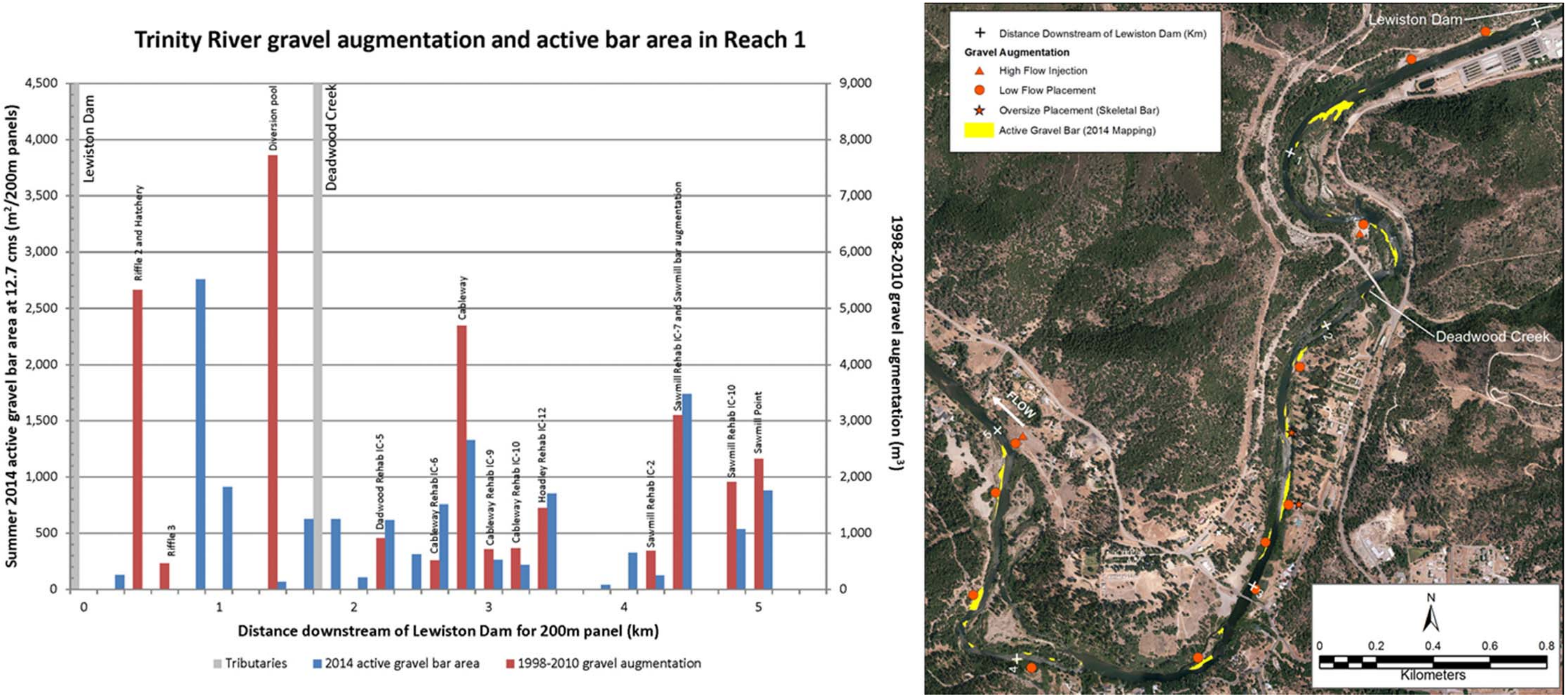

Figure 6. Subreach 1 (0.0 – 5.3 km (0.0 – 3.29 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel, including 1998 – 2010 gravel augmentation volumes (from Krause 2012) and major tributaries. Right: 2014 orthorectified aerial photograph of Subreach 1 showing all mapped polygons in yellow (per blue columns in left-hand chart).

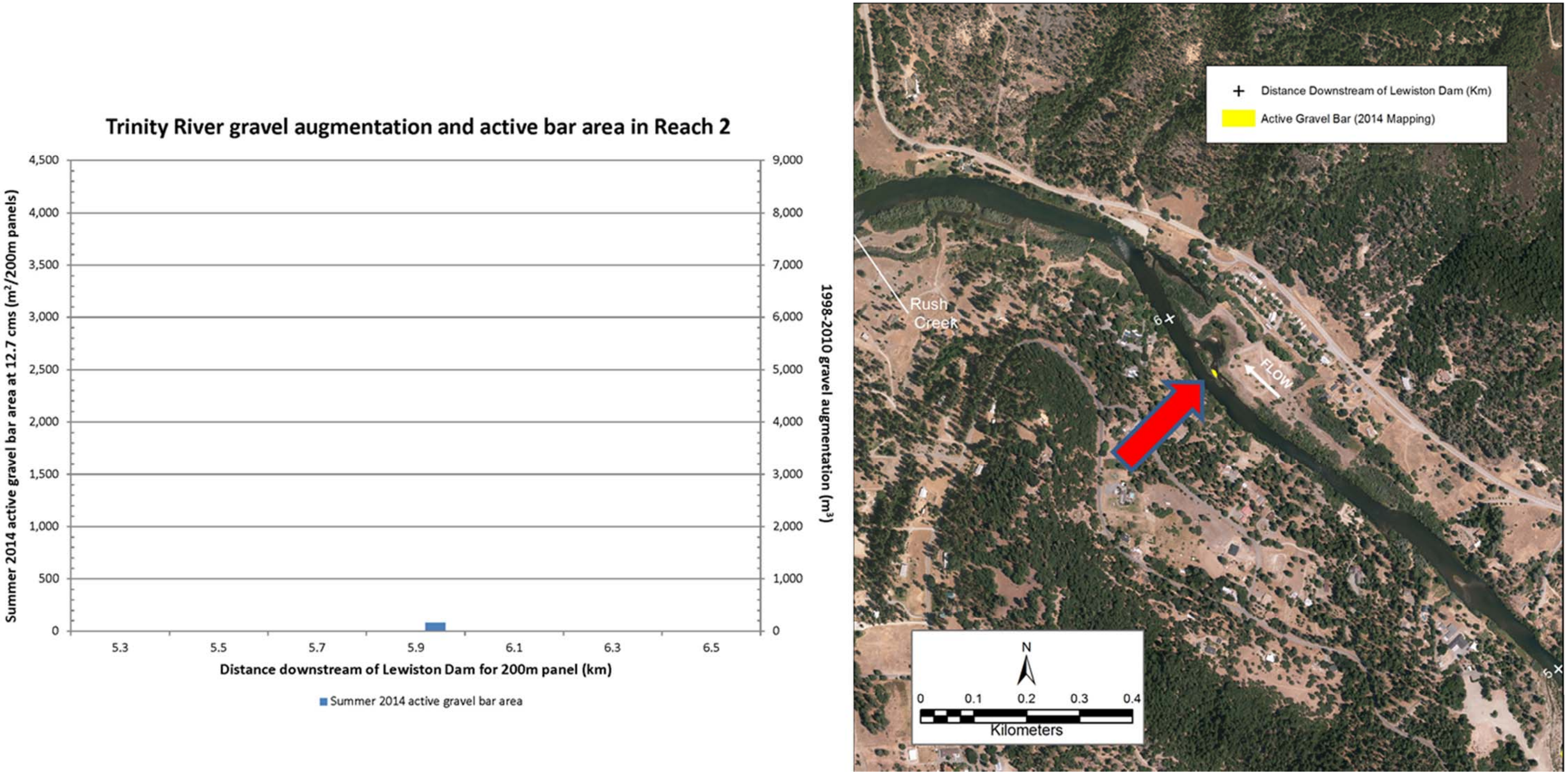

Figure 7. Subreach 2 (5.30 – 6.76 km (3.29 – 4.20 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel. No gravel augmentation was conducted in this subreach from 1998 – 2010. Right: 2014 orthorectified aerial photograph of Subreach 2 showing the single mapped polygon in yellow (per blue columns in left-hand chart), highlighted by red arrow.

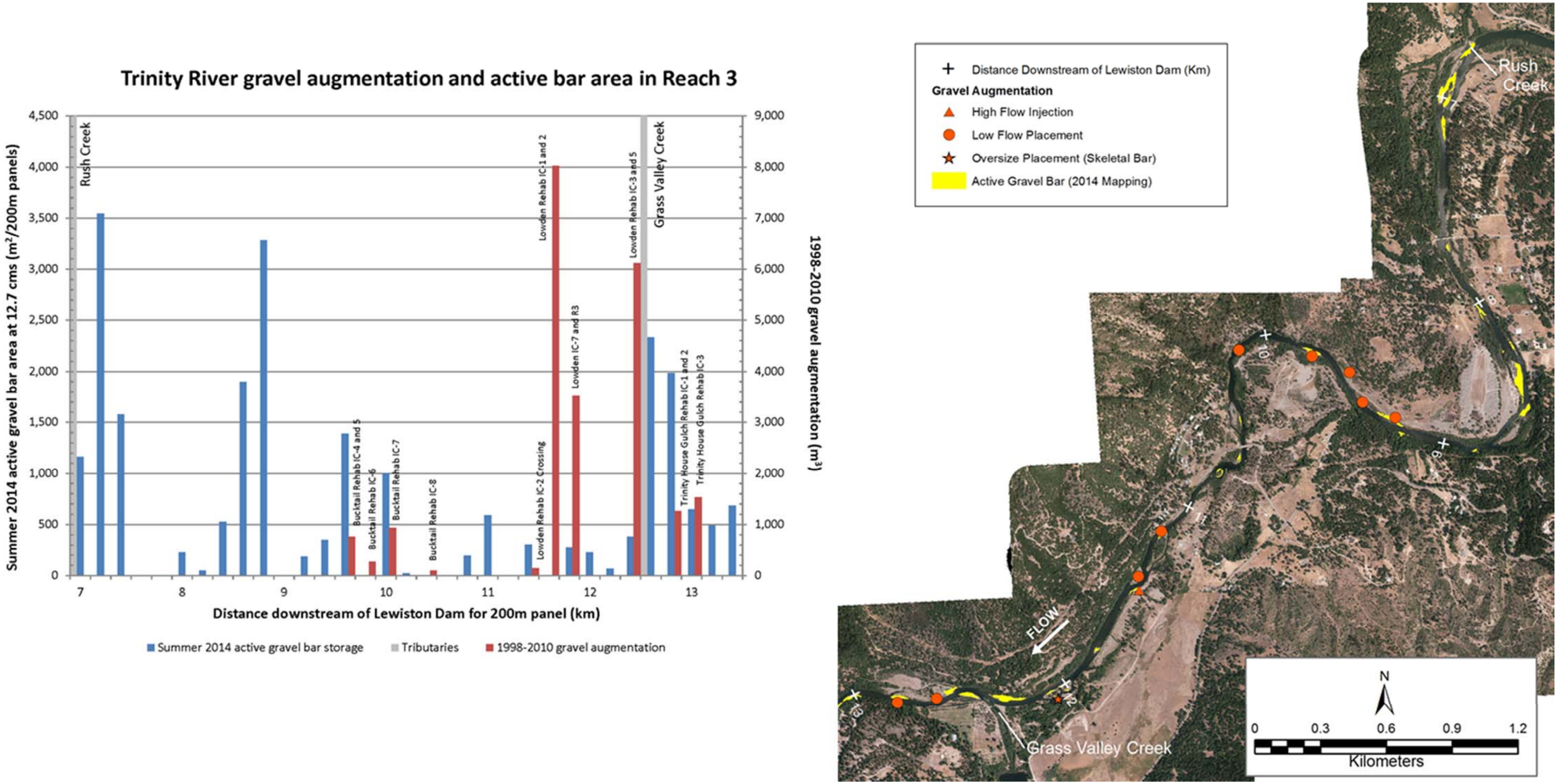

Figure 8. Subreach 3 (6.76 – 13.12 km (4.20 – 8.15 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel, including 1998 – 2010 gravel augmentation volumes (from Krause 2012) and major tributaries. Right: 2014 orthorectified aerial photograph of Subreach 3 showing all mapped polygons in yellow (per blue columns in left-hand chart).

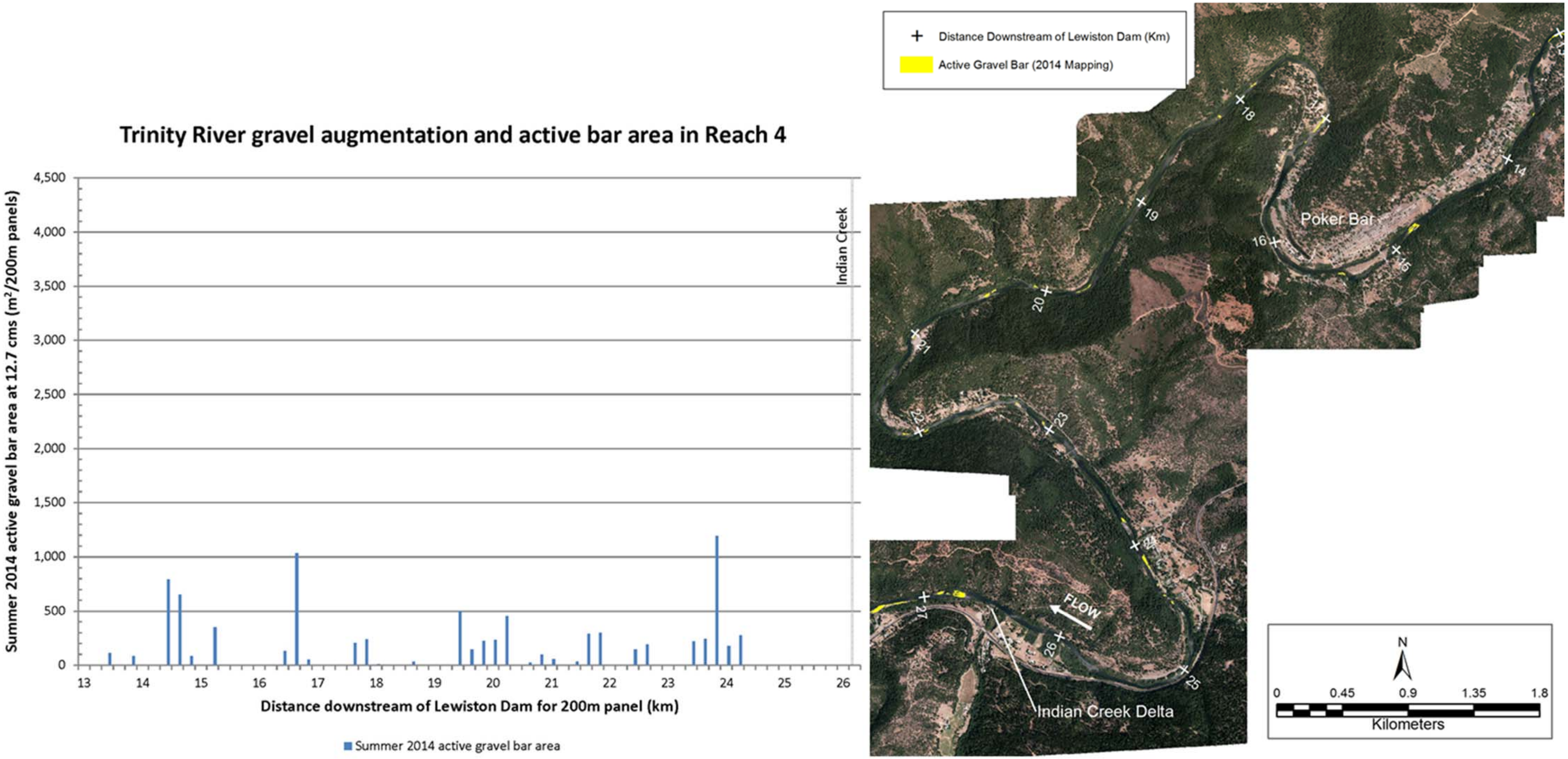

Figure 9. Subreach 4 (13.12 – 26.55 km (8.15 – 16.50 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel. No gravel augmentation was conducted in this subreach from 1998 – 2010. Right: 2014 orthorectified aerial photograph of Subreach 4 showing all mapped polygons in yellow (per blue columns in left-hand chart).

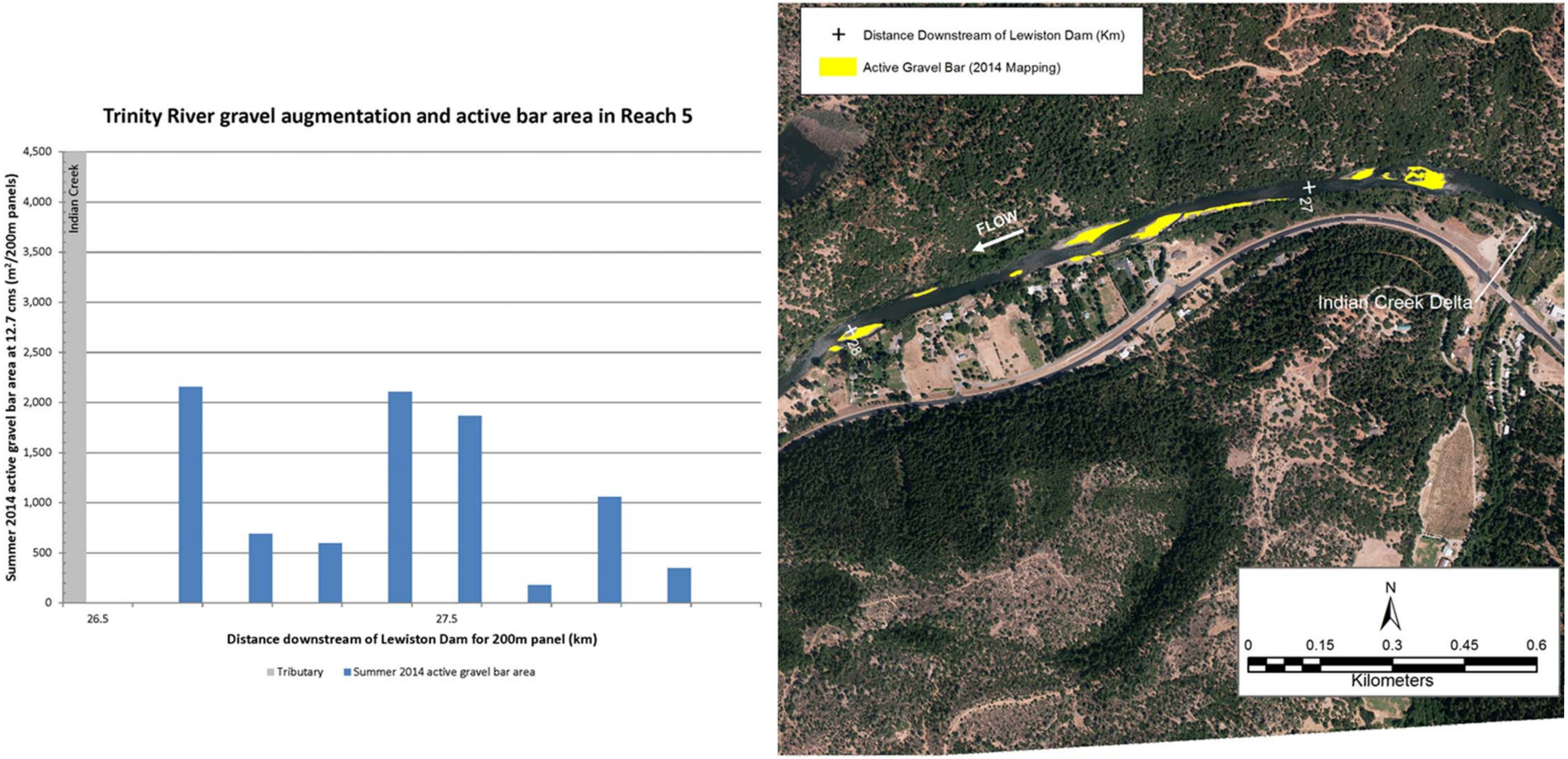

Figure 10. Subreach 5 (26.55 – 28.66 km (16.50 – 17.50 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel, and major tributary. No gravel augmentation was conducted in this subreach from 1998 – 2010. Right: 2014 orthorectified aerial photograph of Subreach 5 showing all mapped polygons in yellow (per blue columns in left-hand chart).

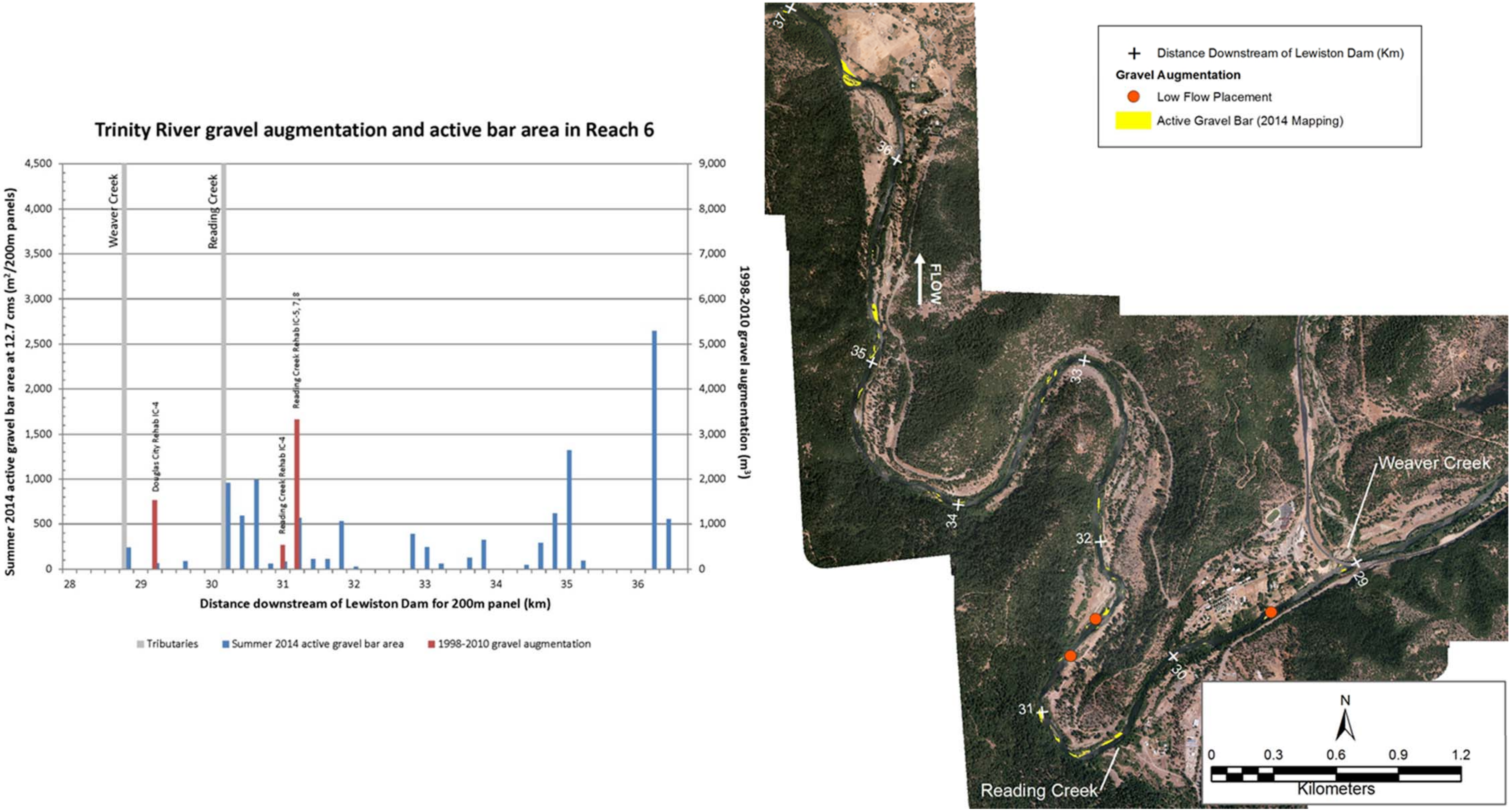

Figure 11. Subreach 6 (28.66 - 36.93 km (17.50 – 22.95 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel, including 1998 – 2010 gravel augmentation volumes (from Krause 2012) and major tributaries; this subreach is the farthest downstream of Lewiston Dam where gravel placement has occurred (skeletal bars). Right: 2014 orthorectified aerial photograph of Subreach 6 showing all mapped polygons in yellow (per blue columns in left-hand chart).

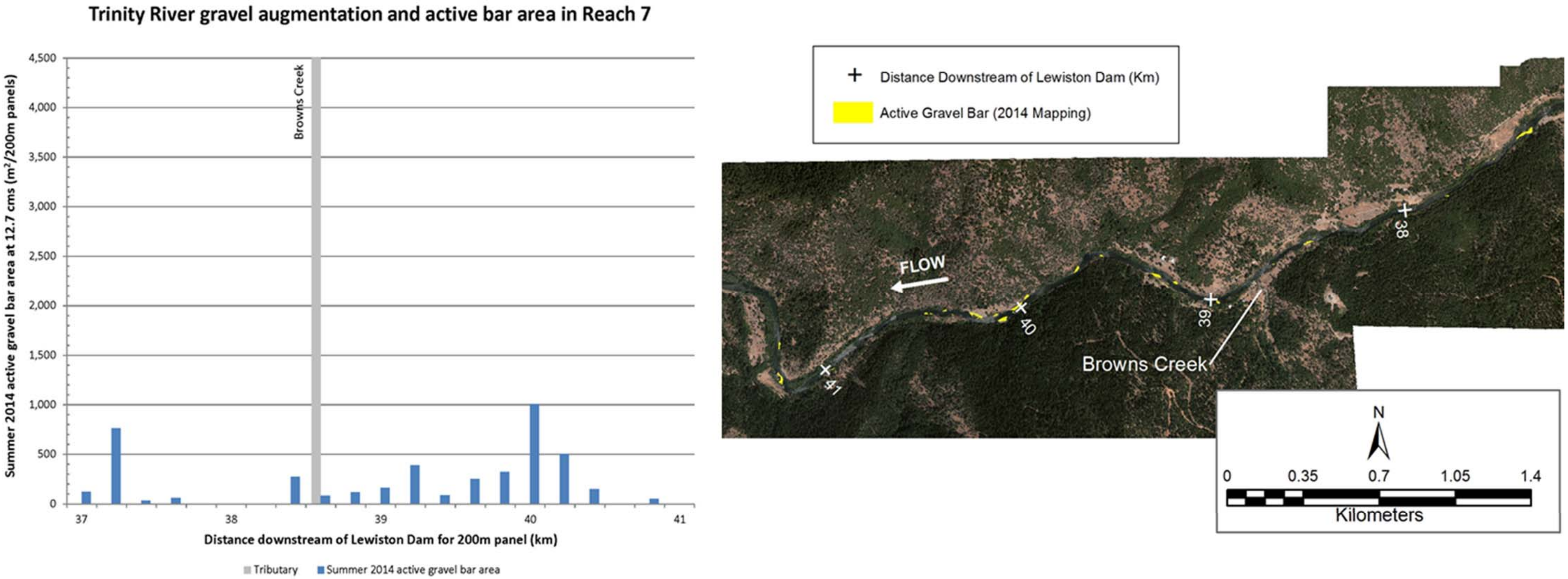

Figure 12. Subreach 7 (36.93 – 41.28 km (22.95 – 25.65 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel, and major tributary. Right: 2014 orthorectified aerial photograph of Subreach 7 showing all mapped polygons in yellow (per blue columns in left-hand chart).

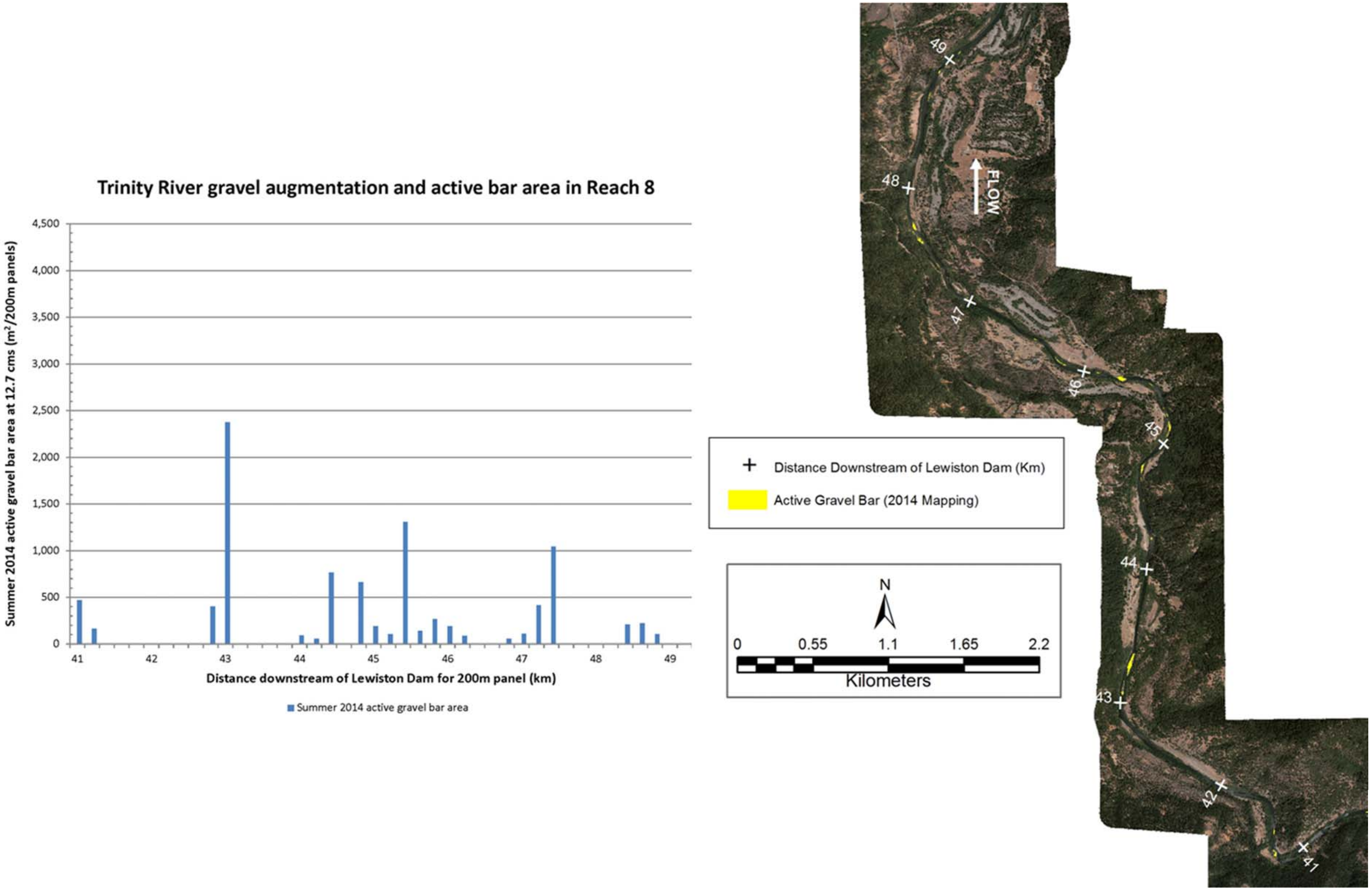

Figure 13. Subreach 8 (41.28 – 49.73 km (25.65 – 30.90 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel. Right: 2014 orthorectified aerial photograph of Subreach 8 showing all mapped polygons in yellow (per blue columns in left-hand chart).

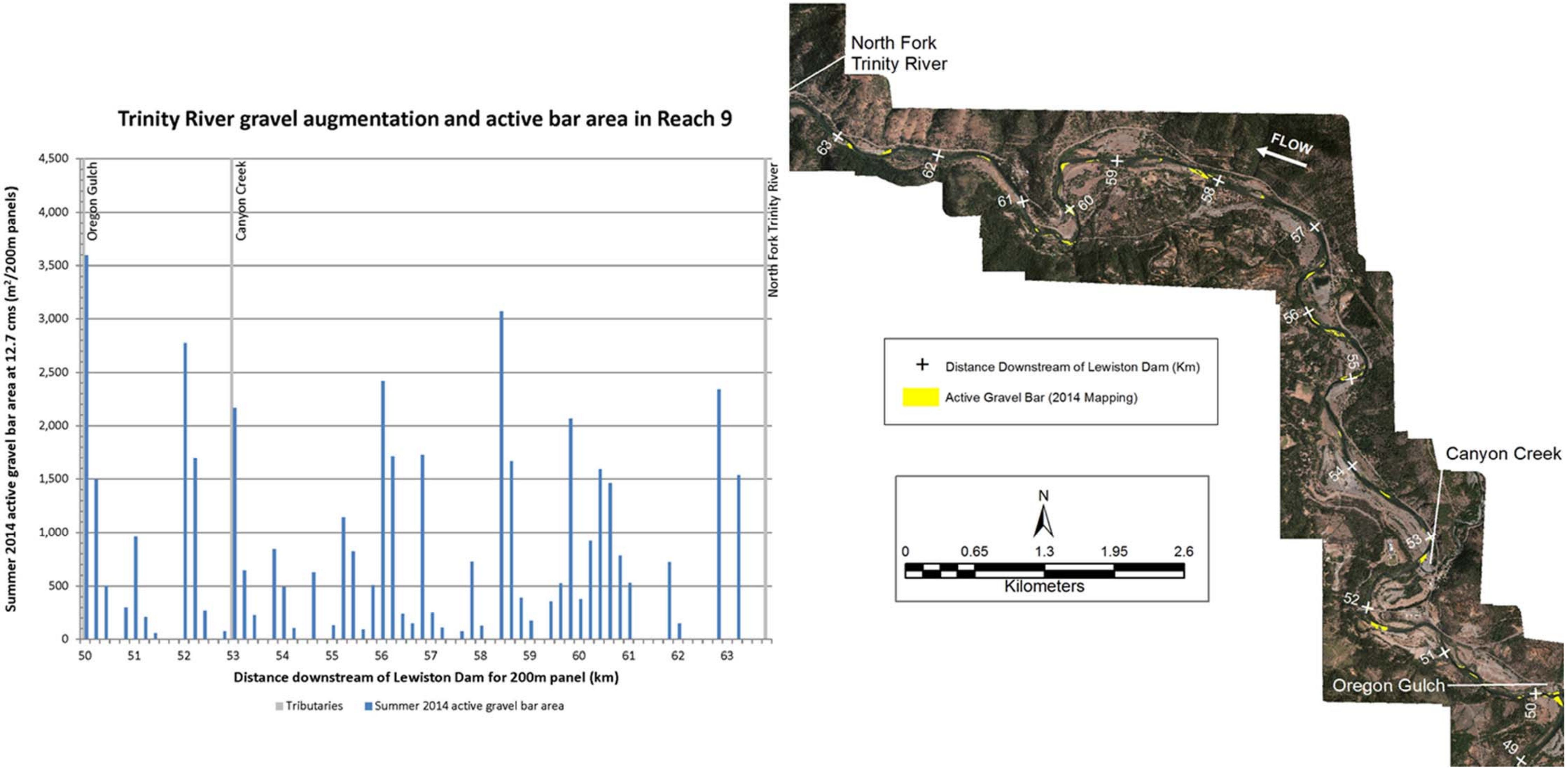

Figure 14. Subreach 9 (49.73 – 63.73 km (30.90 – 39.60 miles) downstream of Lewiston Dam). Left: chart showing active bar area and frequency per 200 m (656 ft) panel, and major tributaries. Right: 2014 orthorectified aerial photograph of Subreach 9 showing all mapped polygons in yellow (per blue columns in left-hand chart).

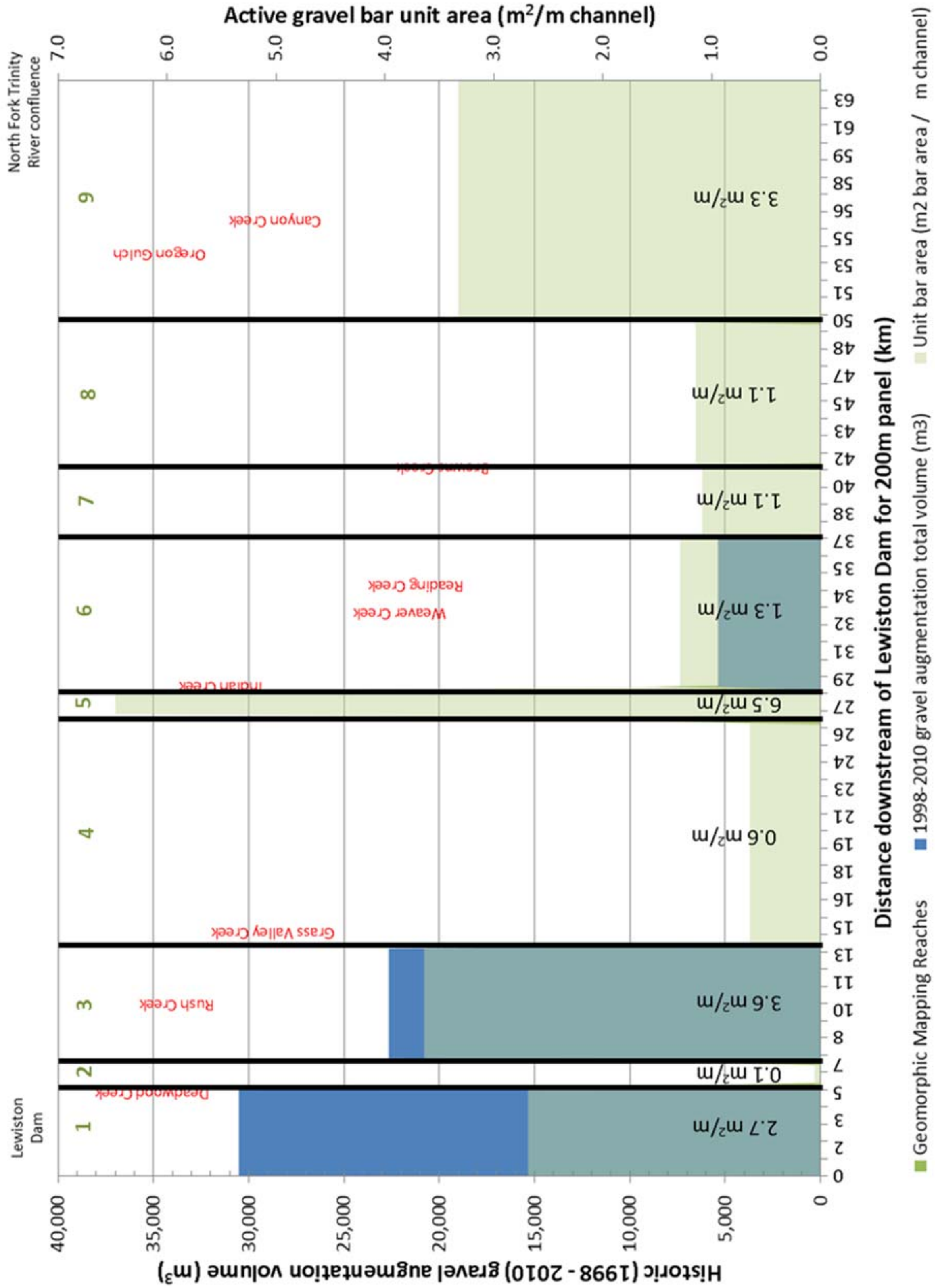

Figure 15. Comparison of active bar unit area (m^2/m) and 1998 - 2010 gravel augmentation volume (m^3) by subreach.

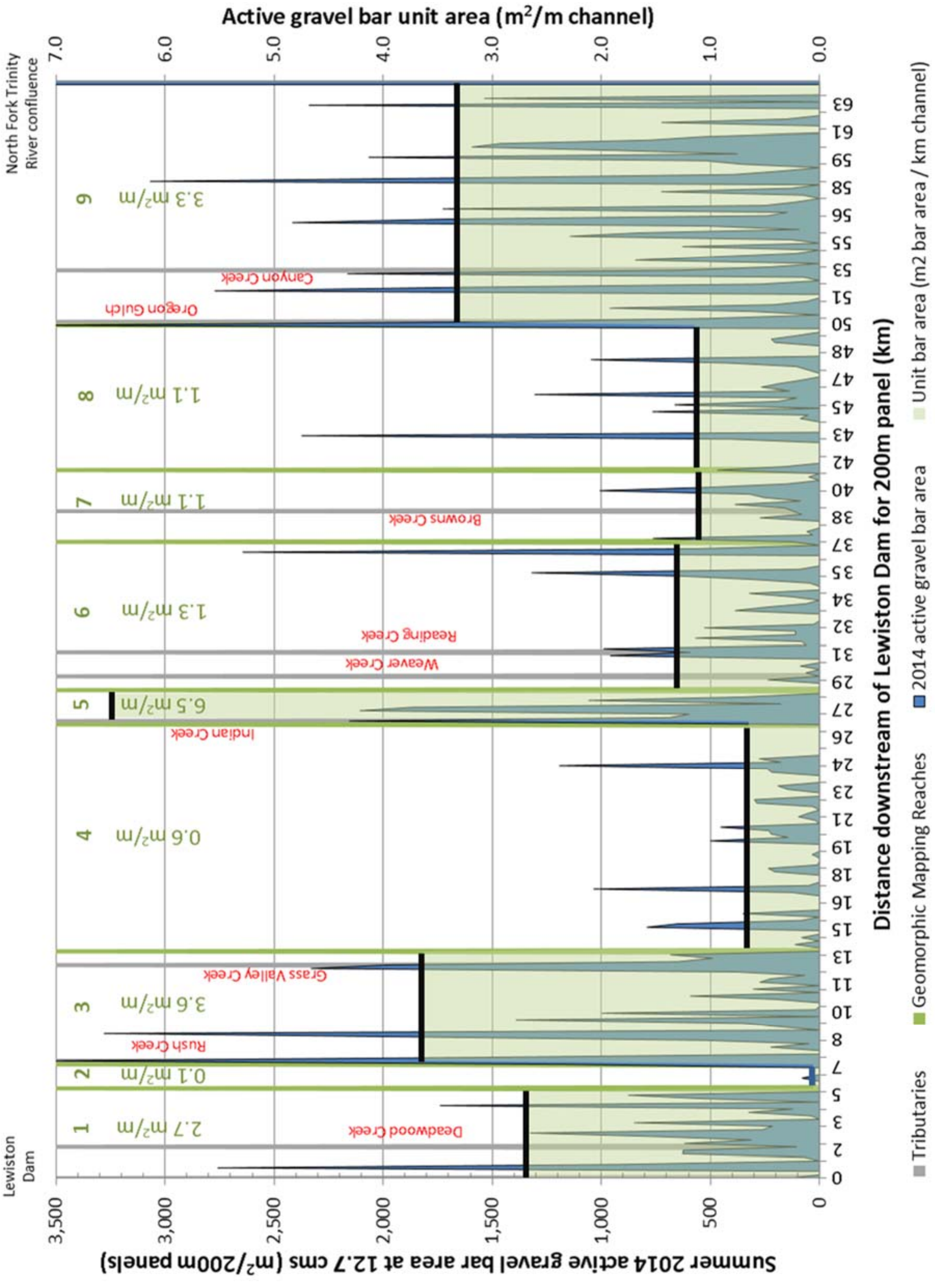

Figure 16. Active bar area and frequency by 200 m (656 ft) panel at 12.7 cms (450 cfs), Lewiston Dam to North Fork Trinity River confluence (per Figure 4), showing unit bar area (m^2/m) as shaded green columns.

Table 3. Summary of mapped bars by subreach and bar area per 200 m (656 ft) panels

Mapping Subreach	Mapping subreach length, km (miles)	Total number of mapped active bars	Median individual active bar size, m^2 (ft^2)	Total active bar area, m^2 (ft^2)	Unit bar area, m^2/m (ft^2/ft)	1998 – 2010 gravel augmentation volume, m^3 (yd^3)
1	5.30 (3.29)	36	141 (1,518)	13,199 (142,073)	2.7 (8.9)	30,529 (39,930)
2	1.46 (0.91)	3	352 (3,789)	80 (861)	0.1 (0.3)	0
3	6.36 (3.92)	42	225 (2,422)	23,378 (251,639)	3.6 (11.8)	22,665 (29,645)
4	13.44 (8.35)	49	93 (1,001)	8,557 (92,107)	0.6 (2.0)	0
5	1.61 (1.00)	16	195 (2,099)	9,002 (96,897)	6.5 (21.3)	0
6	8.77 (5.45)	48	59 (635)	11,118 (119,673)	1.3 (4.3)	5,390 (7,050)
7	4.35 (2.70)	31	93 (1,001)	4,369 (47,028)	1.1 (3.6)	0
8	8.45 (5.25)	37	103 (1,109)	9,403 (101,213)	1.1 (3.6)	0
9	14.00 (8.70)	114	125 (1,345)	45,911 (494,182)	3.3 (10.8)	0

5.2 Active bar area relationships

We evaluated whether hydraulic and geomorphic variables could be linked to active bar mapping results, and then used as inference for gravel storage. These relationships were evaluated using a combination of (1) SRH-2D hydraulic modeling output for 170 cms (6,000 cfs) and 311 cms (11,000 cfs) and streamflows (the same magnitude as peak releases likely under Extremely Wet and Normal water supplies), and (2) geomorphic variables that, from field observation, appear related to active bar occurrence. The relationships that were explored consider only a single independent variable (i.e. active bar area as a function of large wood), yet multiple factors might combine to influence bar formation (e.g., large wood plus channel expansion); evaluating complex combinations of variables was left to future efforts.

5.2.1 Active bar area as a function of channel width

Wider channels with low confinement typically have less hydraulic energy than confined channels for a given slope, and the hypothesis that active gravel bar area may increase as confinement decreases was explored. Confinement was defined on the basis of total channel width for 170 cms (6,000 cfs) and 311 cms (11,000 cfs) modeled water surfaces at each 200 m (656 ft) panel, according to output from SRD-2D. The relationship was first evaluated by plotting channel width for both flows and the active bar area, longitudinally through the study reach (Figures 17a and 17b). We then reduced channel width variability by fitting the data with a 3,000 m (9,840 ft) moving average trend line. Data were then plotted to depict active bar area as a function of channel width per 200 m (656 ft) panel (Figures 18a and 18b).

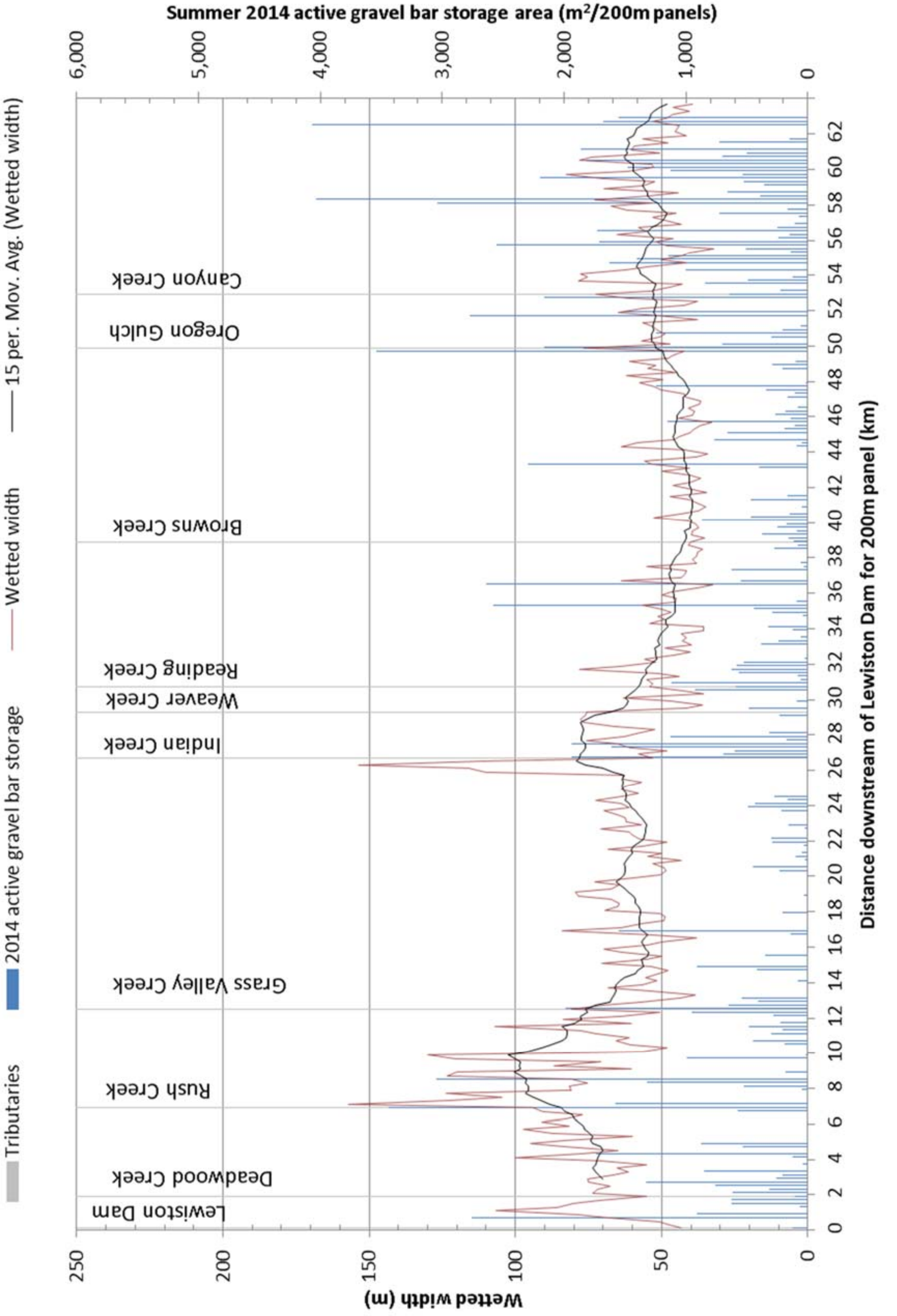

Figure 17a. Active bar area and frequency, with 170 cms (6,000 cfs) wetted channel width by 200 m (656 ft) panel and 3,000 m (9,840 ft) channel width moving average (black line).

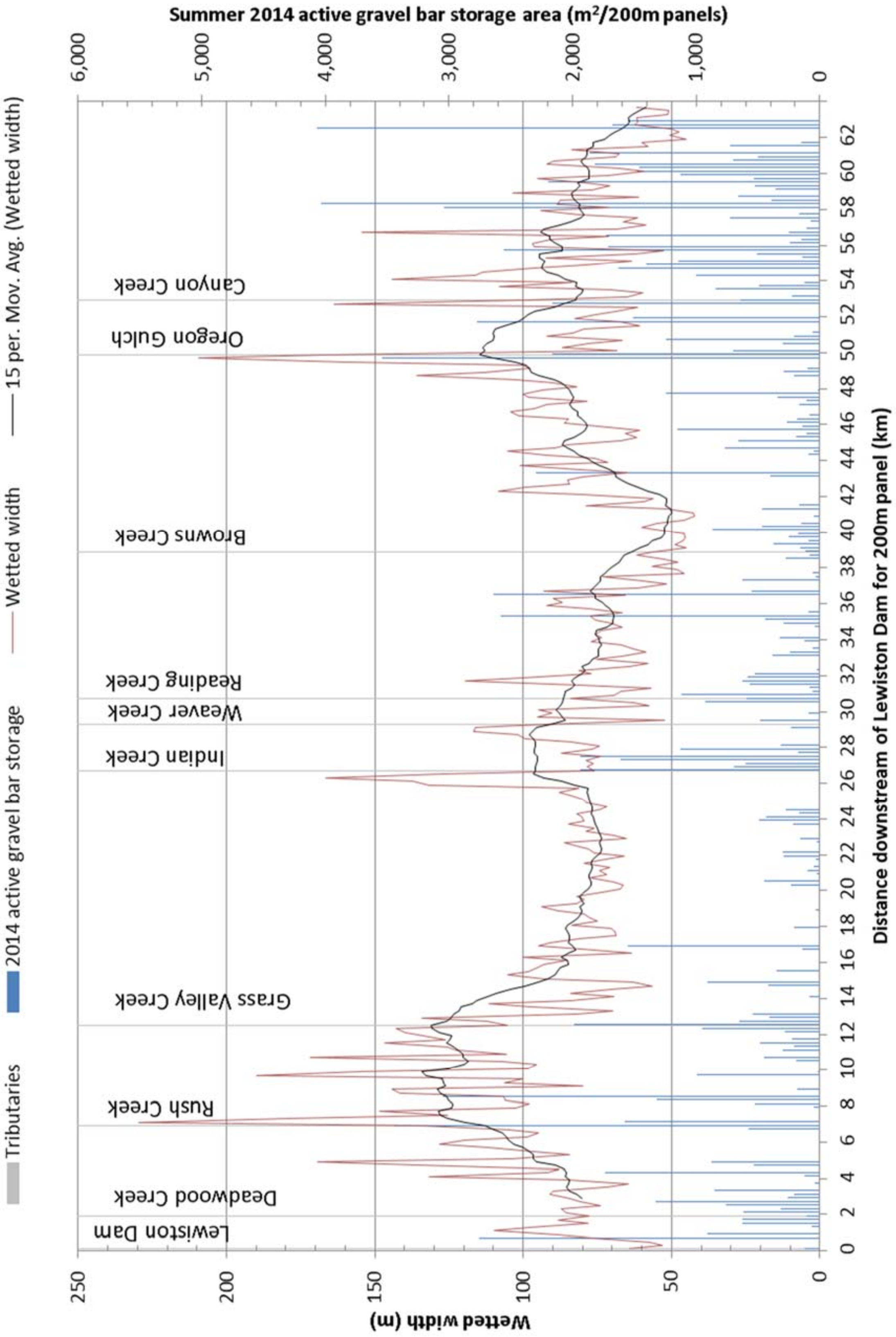

Figure 17b. Active bar area and frequency, with 311 cms (11,000 cfs) wetted channel width by 200 m (656 ft) panel and 3,000 m (9.840 ft) channel width moving average (black line).

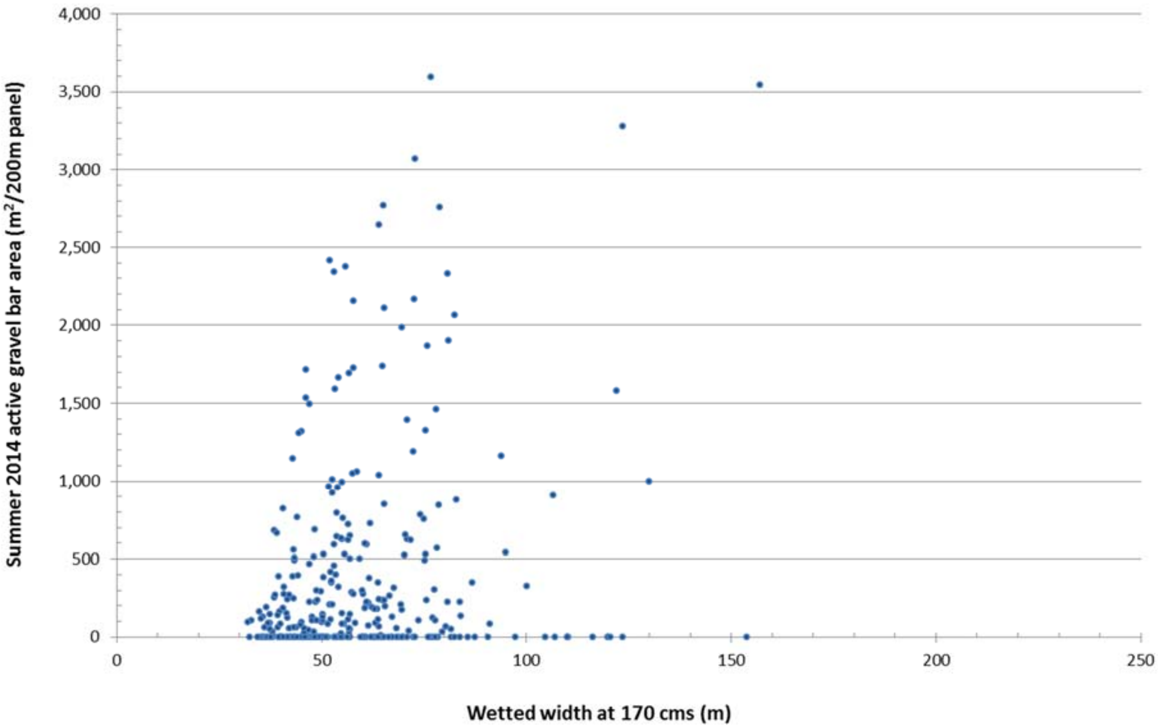

Figure 18a. Active bar area by 200 m (656 ft) panel as a function of 170 cms 6,000 cfs) wetted channel width by 200 m (656 ft) panel.

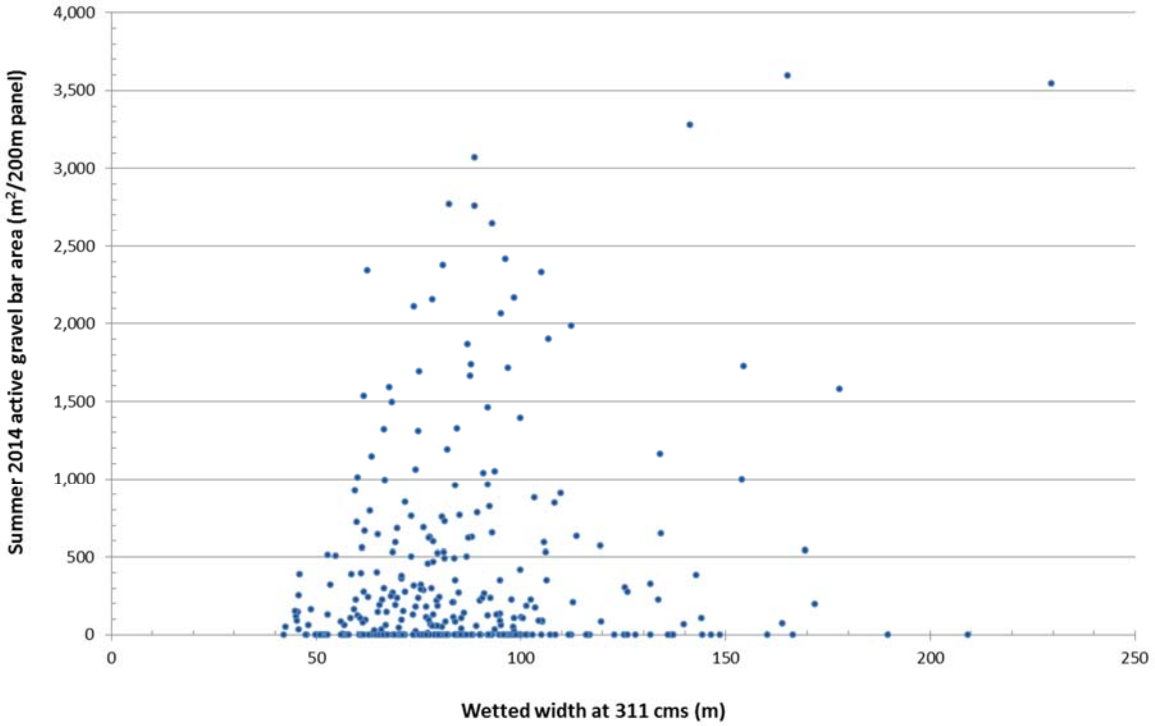

Figure 18b. Active bar area by 200 m (656 ft) panel as a function of 311 cms (11,000 cfs) wetted channel width by 200 m (656 ft) panel.

Results (Figures 17a and 17b) appear to show a general relationship between active gravel bar area for both the 200 m (656 ft) channel width and the moving average, but also a poor relationship when active bar area is plotted as a function of channel width within 200 m (656 ft) segments (Figures 18a and 18b).

5.2.2 Active bar area as a function of shear stress

We also explored our data in an attempt to find support for the idea that bar formation is encouraged in reaches with low confinement. We expected that shear stress would show a strong relationship to bar formation because it embodies multiple, pertinent hydraulic variables (hydraulic radius, channel slope) that better represent hydraulic energy than channel width alone. As with channel width, boundary shear stress was computed from the SRH-2D model at 170 cms (6,000 cfs) and 311 cms (11,000 cfs) flows. The average "channel" boundary shear stress over the entire 200 m (656 ft) panel was computed, which, rather than computing shear stress for the entire 311 cms (11,000 cfs) wetted channel width, the SRH-2D model used a narrower width to help eliminate overbank areas with low shear stress (e.g., resulting from shallow flows and high hydraulic roughness from vegetation). The resulting average "channel" shear stress per 200 m (656 ft) panel is theoretically more representative of the shear stress in the active channel area and over the active gravel bars. Mapped bar area and the corresponding computed panel-averaged channel shear stress were plotted (Figures 19a and 19b).

The scatter in Figures 19a and 19b does not appear to show any improved relationship compared to using wetted width. First, it is possible that the average channel shear stress value for the entire 200 m (656 ft) panel is not representative of the active bar itself, since other geomorphic features are also present within the panel boundary (e.g., riffles, pools, and other bars may all be present in a single 200 m (656 ft) panel); each geomorphic feature represents higher- or lower-energy zones, and their influence relative to the size of the active bar may result in a non-representative result. Second, it is possible that 200 m (656 ft) is too short of a distance to accurately capture reach-scale hydraulics potentially responsible for active bar number and frequency, and that average channel shear stress computed for a greater distance (greater than one meander wavelength) may be more representative. Although these possibilities explores the active bar – average channel shear stress relationship at different scales (isolating shear stress to just the mapped active bar polygons and computing average channel shear stress over an expanded channel distance), both should be considered for future study. In addition, exploring Shields parameter as an independent variable should also be considered for additional study, since Shields parameter should be a better predictor than shear stress because it includes both shear stress and grain size.

5.2.3 Active bar area as a function of formative feature

As part of the field mapping procedure, each mapped bar was assigned a formative feature based on the mapping team's field observations and the aerial photographs. Formative features were grouped and counted to evaluate if certain feature(s) were more frequently associated with active bars (Table 4 and Figure 20). Unlike the previous channel width and shear stress evaluations which were evaluated on a 200 m (656 ft) panel basis, 200 m (656 ft) panel boundaries were not applied for evaluating mapped active bars as a function of their formative feature since many active bars cross panel boundaries (avoids double counting). Mapped active bars with the largest average area were attributed to channel construction sites, deltas, bridge piers, and forced meanders; each of these formative features resulted in an average active bar area of 682 m^2 (7,340 ft^2), ranging from 557 m^2 (5,995 ft^2) to 763 m^2 (8,212 ft^2). The remaining features included channel expansions, channel confinements, alternating bar sequences, islands, bedrock, and large wood (with active bar areas ranging from 407 m^2 to 122 m^2, respectively).

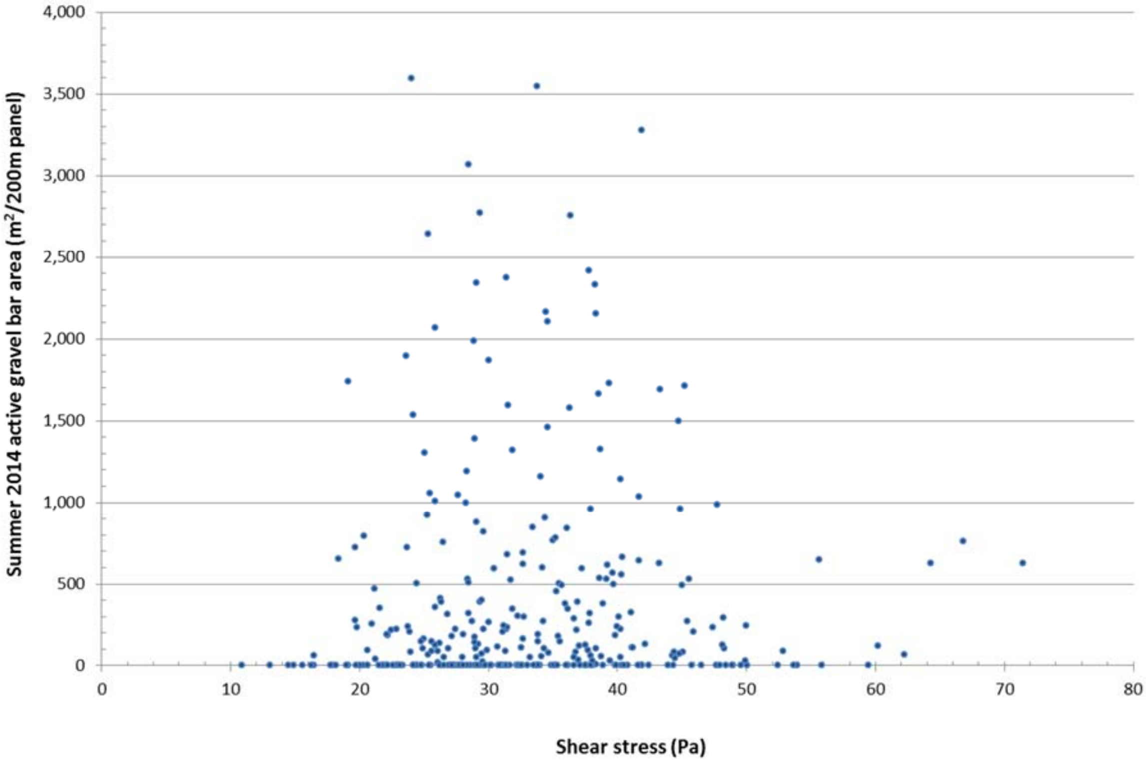

Figure 19a. Active bar area by 200 m (656 ft) panel as a function of 170 cms (6,000 cfs) average channel shear stress by 200 m (656 ft) panel.

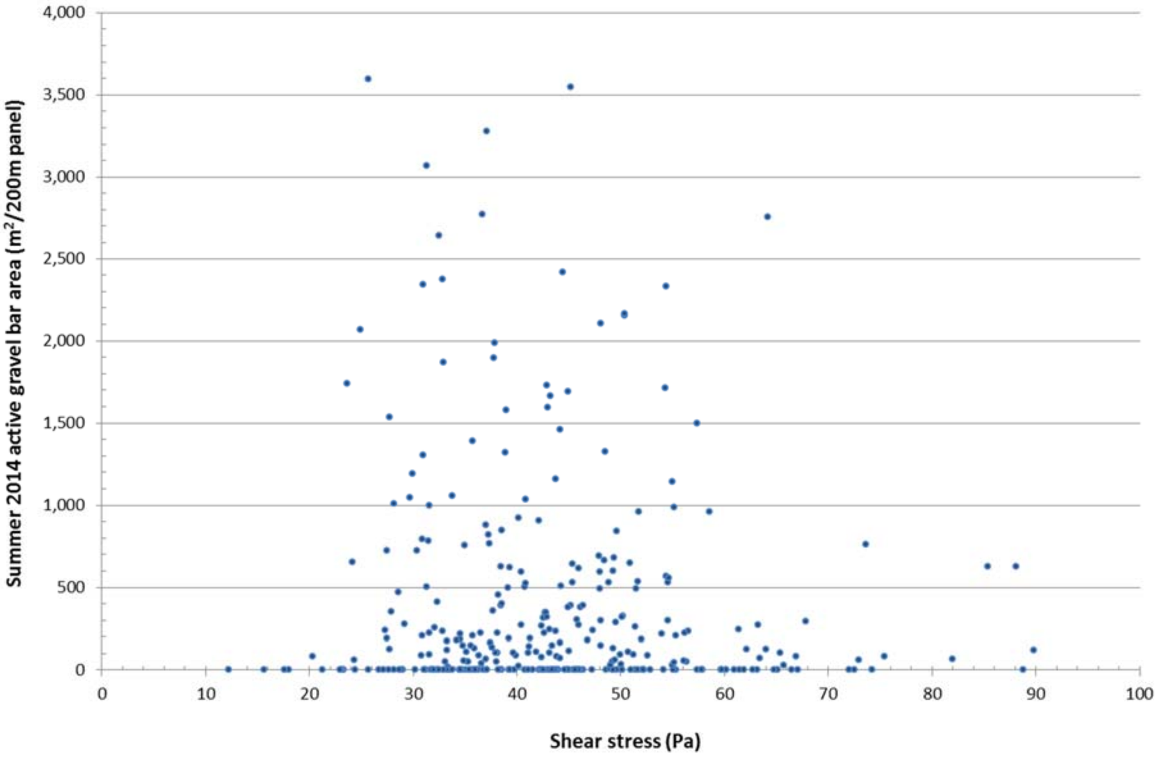

Figure 19b. Active bar area (by 200 m panel) as a function of 311 cms (11,000 cfs) average channel shear stress by 200 m (656 ft) panel.

5.2.4 Active bar area as a function of large wood

Of the 302 total active bars mapped, only 11 were attributed as having large wood as their formative feature; of these 11 bars, eight were formed from a single piece of large wood and were relatively small size, averaging 62 m^2 (667 ft^2). The remaining three bars were formed from aggregated wood ranging from three to ten pieces; these data are summarized in Table 5, and active bar area (m^2, ft^2) as a function of large wood number and bar influencing aspect area are shown as Figures 21 and 22, respectively.

The largest mapped wood aggregation (n=10 pieces) was an engineered log jam (ELJ) that was built as part of the Wheel Gulch channel rehabilitation site, and resulted in the largest of the mapped active bars formed by large wood (Table 5). The data regressions shown in Figures 21 and 22 are driven by this site and therefore should not be used in a predictive manner; however, Figure 22 suggests a positive relationship between the size of the large wood body and the active gravel bar area, which despite the overall low number of active bars formed by large wood (3.6 % of total active bars mapped), helps lend strength to recommendations for adding large wood where additional gravel storage is desired. Moreover, these relationships can be reexamined in the future if large wood additions are made with the objective of storing gravel, thereby increasing the sample size beyond the 11 shown here. Also, with more data, the effect of large wood placement can be assessed (e.g., point bar vs. channel margin vs. medial bar).

Table 4. Summary of active bars by formative feature, showing the number in each category, range in mapped area (maximum and minimum), and average active bar size.

Formative feature type	**No. of mapped active bars**	**Average bar area, m^2 (ft^2)**	**Maximum bar area, m^2 (ft^2)**	**Minimum bar area, m^2 (ft^2)**
Constructed	33	763 (8.213)	4,159 (44,767)	35 (377)
Delta	12	754 (8.116)	3,914 (42,130)	26 (280)
Bridge Pier	4	655 (7,050)	1,436 (15,457)	224 (2,411)
Forced Meander	66	557 (5,995)	3,408 (36,683)	3 (32)
Alternating Bar Sequence	20	407 (4,381)	1,739 (18,718)	36 (388)
Channel expansion	73	327 (3,520)	2,514 (27,060)	6 (65)
Channel confinement	28	300 (3,229)	2,381 (25,629)	19 (205)
Island	11	223 (2,400)	999 (10,753)	6 (65)
Bedrock	44	165 (1,776)	762 (8,202)	3 (32)
Large Wood	11	122 (1,313)	674 (7,255)	12 (129)
TOTAL:	302			

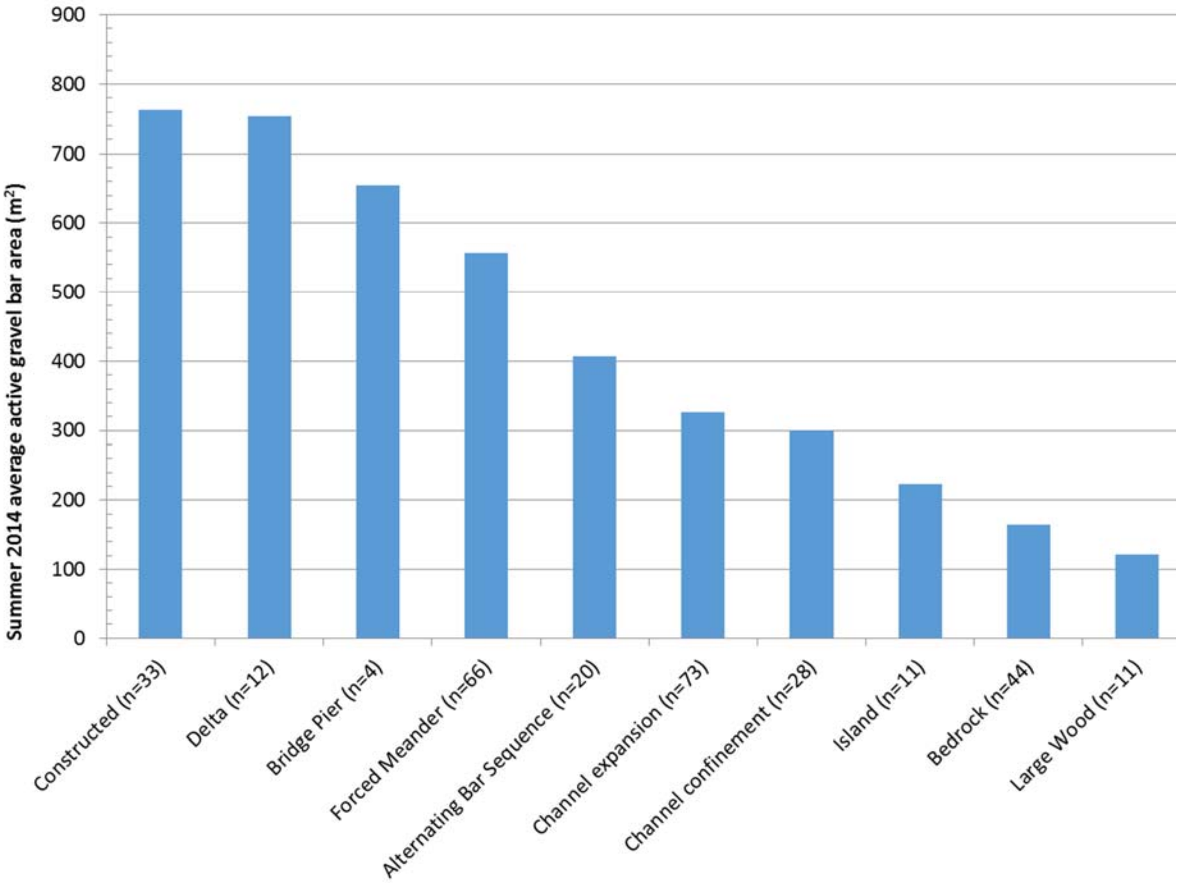

Figure 20. Active bar area by formative feature. Formative feature labels include the number of active bars in each category (e.g., 11 bars are attributed to a large wood).

5.2.5 Active bar area as a function of past gravel augmentation

Twenty six 200 m (656 ft) panels were identified where past (1998 – 2010) gravel augmentation occurred. Five of these 26 panels had past gravel augmentation but did not include any mapped active bars. For each of these 200 m (656 ft) panels, total mapped active bar area (m^2 / 200 m panel (ft^2/656 ft panel)) was plotted as a function of gravel augmentation volume in that panel (m^3) (Figure 23).

The resulting plot does not show a strong relationship, suggesting that contemporary 12.7 cms (450 cfs) active gravel bar area in these panels is not related to past gravel augmentation volume. This can be explained, in part, by augmented gravels routing out of the 200 m (656 ft) panel from which they were introduced (this is particularly true where gravel augmentation was performed by high flow injection, which immediately disperses the gravel downstream).

Table 5. Active gravel bars formed by large wood, including bar identification number and location, the cross-sectional area of the aspect of the large wood mass influencing deposition ("bar influencing aspect area"), number of large wood pieces present, and active gravel bar area.

Bar centroid identification number	**Distance downstream of Lewiston Dam, km (miles)**	**Bar-influencing aspect area, m^2 (ft^2)**	**Number of large wood pieces**	**Active Gravel Bar Area, m^2 (ft^2)**
398	2.45 (1.52)	4.2 (45.2)	1	11.9 (128.1)
66	21.34 (13.26)	9.7 (104.4)	1	28.6 (307.8)
9	52.94 (32.90)	6.3 (67.8)	1	29.0 (312.2)
589	29.89 (18.57)	7.9 (85.0)	1	33.7 (362.7)
311	2.01 (1.25)	13.9 (149.6)	3	45.9 (494.1)
1151	56.20 (34.92)	3.4 (36.6)	1	46.5 (500.5)
82	50.54 (31.40)	1.9 (20.5)	1	46.7 (502.7)
1049	56.05 (34.83)	13.9 (149.6)	1	68.7 (739.5)
1013	58.73 (36.49)	5.6 (60.3)	1	169.4 (1,823.4)
479	28.05 (17.43)	9.3 (100.1)	5	186.1 (2,003.2)
12	57.57 (35.77)	52.0 (559.7)	10	674.2 (7,257.0)

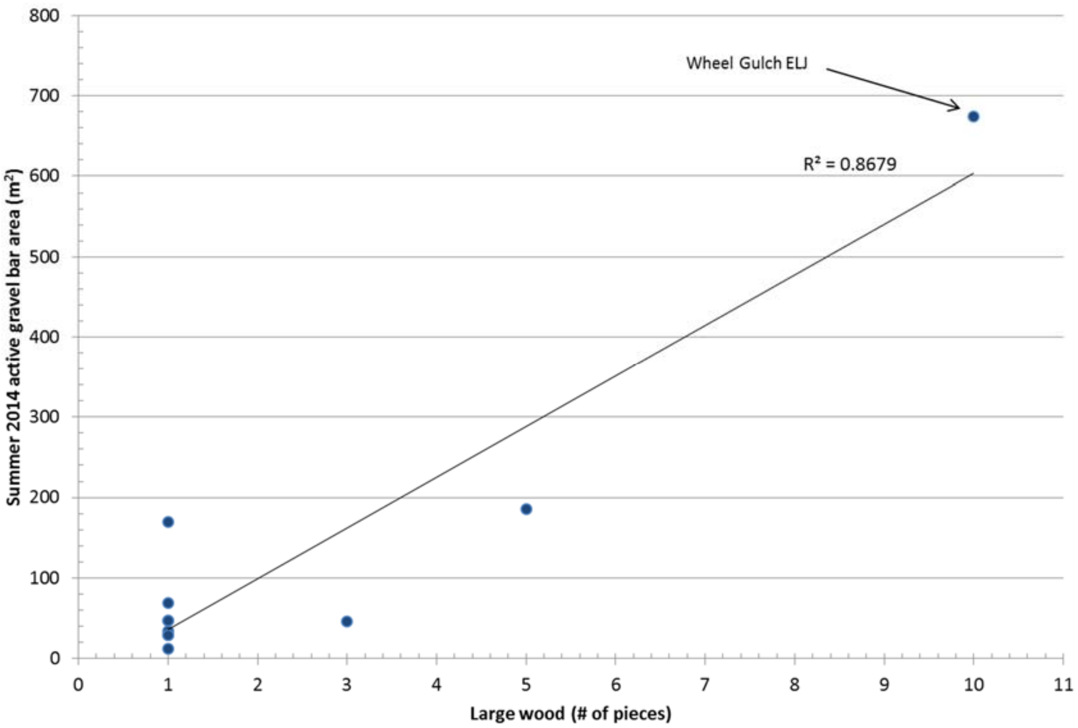

Figure 21. Active bar area as a function of the number of large wood pieces per bar.

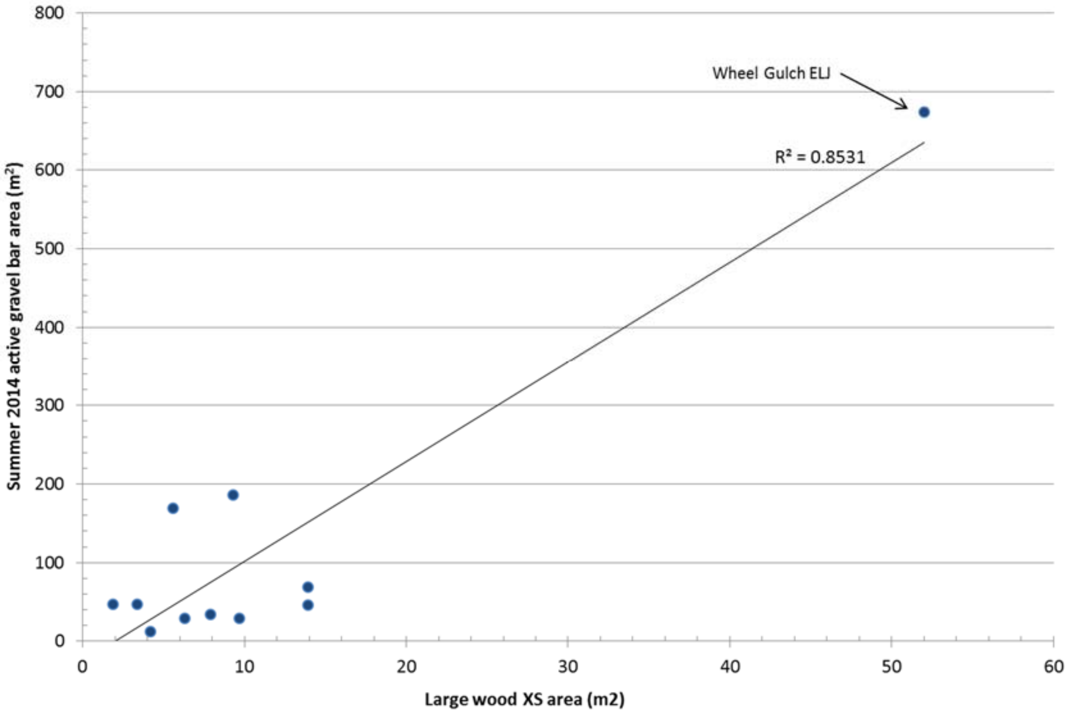

Figure 22. Active bar area as a function of bar influencing aspect area. The data fit and regression is driven by the bar constructed at the Wheel Gulch site; future large wood additions, if made, will provide an opportunity to supplement these data. As of now, the results are suggestive but the regression should not be used in a predictive manner.

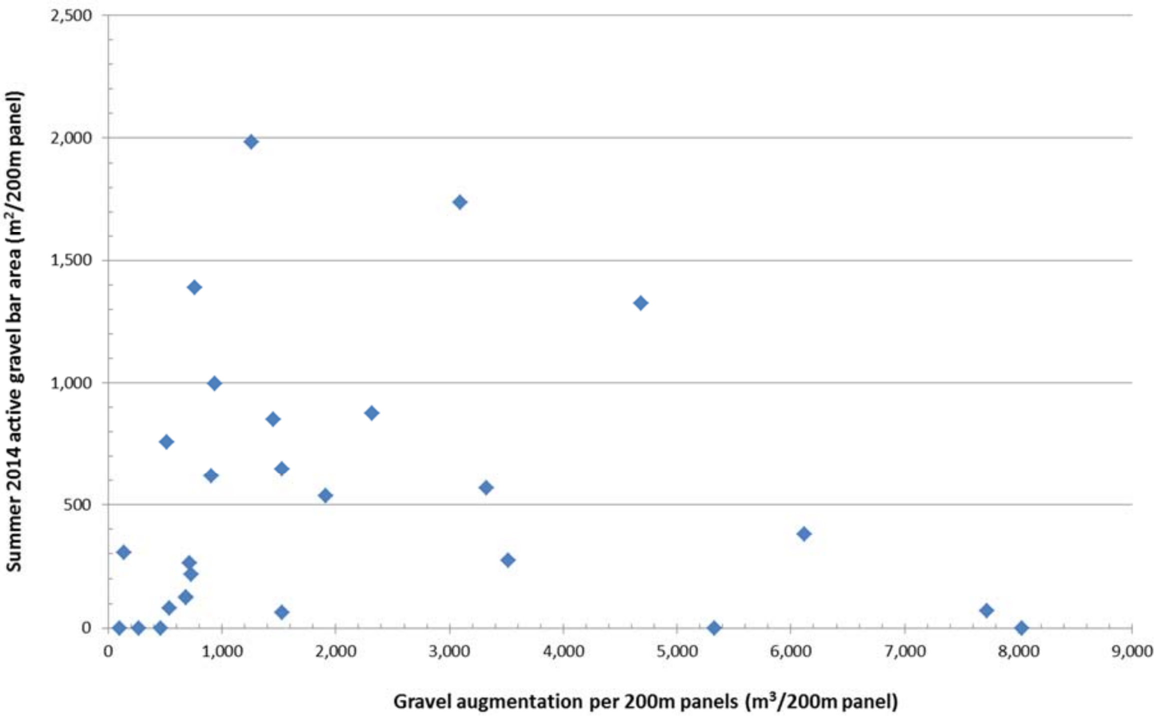

Figure 23. Active bar area by 200 m (656 ft) panel as a function of past (1998 – 2010) gravel augmentation.

5.3 Simulated fry and juvenile (pre-smolt) Chinook salmon rearing habitat as a function of active bar area

Preliminary output from SRH-2D fish habitat simulations at four streamflows were used to explore relationships between fry and juvenile (pre-smolt) Chinook salmon rearing habitat and active gravel bars within the Subreach 8 modeling reach (41.1 to 49.7 km (25.5 to 30.9 miles) downstream of Lewiston Dam). Model output for fry and pre-smolt, as well as mapped active gravel bar area, were grouped by 200 m (656 ft) panel and plotted longitudinally (Figure 24).

Initial review showed that habitat for some bars extended into adjacent downstream 200 m (656 ft) panels (little to no habitat was found at the upstream end of the mapped active bars). To account more fully for active bar habitat, model output for each mapped active bar was extended to also include habitat in the adjacent downstream panel. Results for this analysis are presented in Figure 25 as “at site plus next unit downstream”. Reviewing Figures 24 and 25 also revealed that because all modeled fry and pre-smolt rearing habitat for each streamflow was included, results include some habitat not adjacent to or otherwise associated with the mapped active bars. Results were further refined by removing all modeled habitat areas (polygons) located greater than 6 m (20 ft) from the mapped active gravel bar boundary from the data set; this assumes these polygons are not created by or otherwise influenced by the active gravel bars.

Information in Figures 24 and 25 show both fry and pre-smolt rearing habitat associated with both mapped active bars as well as non-bar areas; notably, simulated habitat associated with channel features other than active bars decrease as streamflows increase, at rates greater than habitat associated with active bars (where simulations indicate more habitat remains).

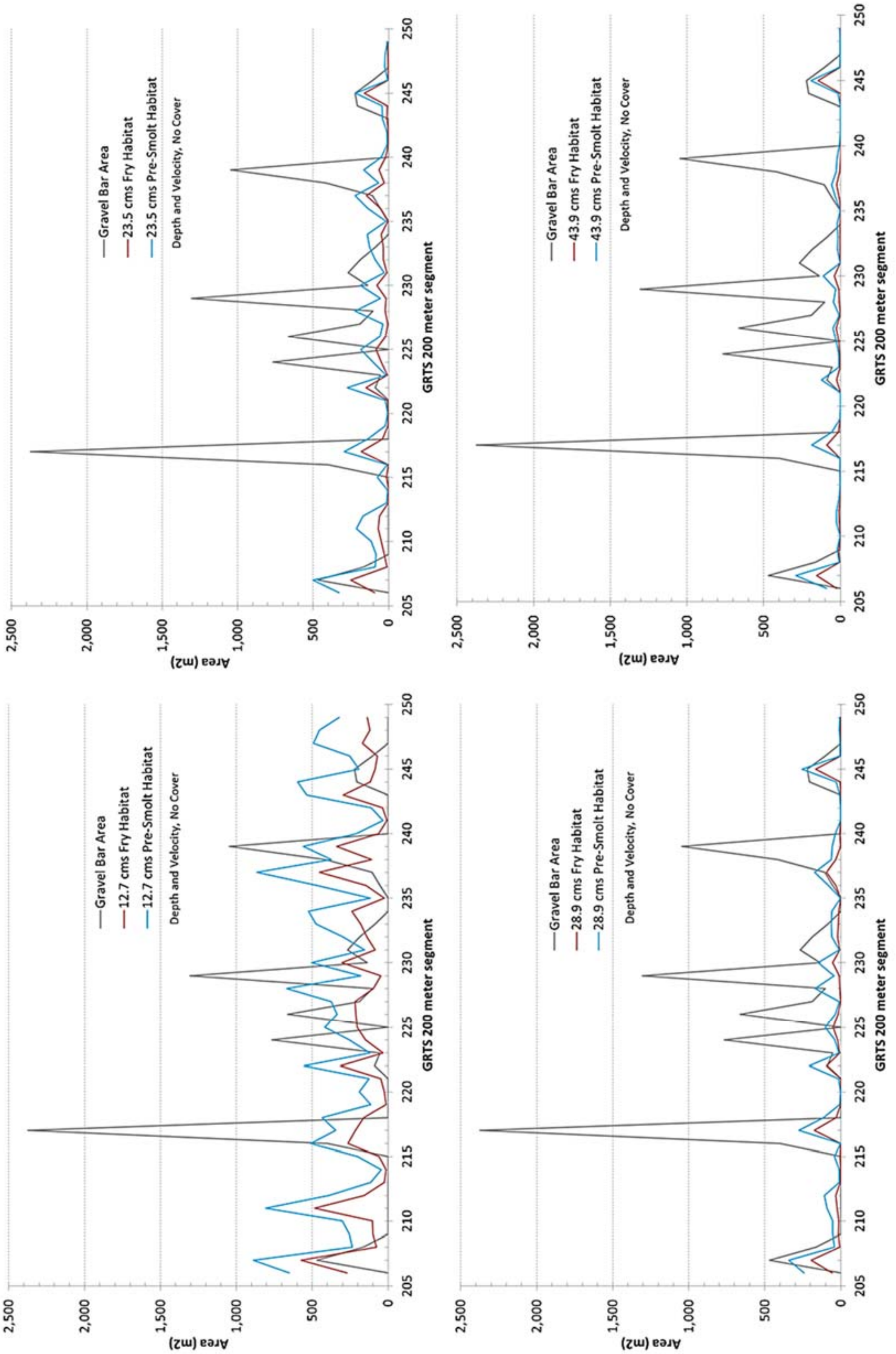

Figure 24. Longitudinal plots of Type 1 fry and pre-smolt rearing habitat, and mapped active bar area within the SRH-2D fish habitat modeling reach (41.1 to 49.7 km (25.5 to 30.9 miles) downstream of Lewiston Dam). Clockwise from upper left: 12.7 cms (450 cfs), 23.5 cms (830 cfs), 28.9 cms (1,020 cfs), and 43.9 cms (1,550 cfs) modeled streamflows.

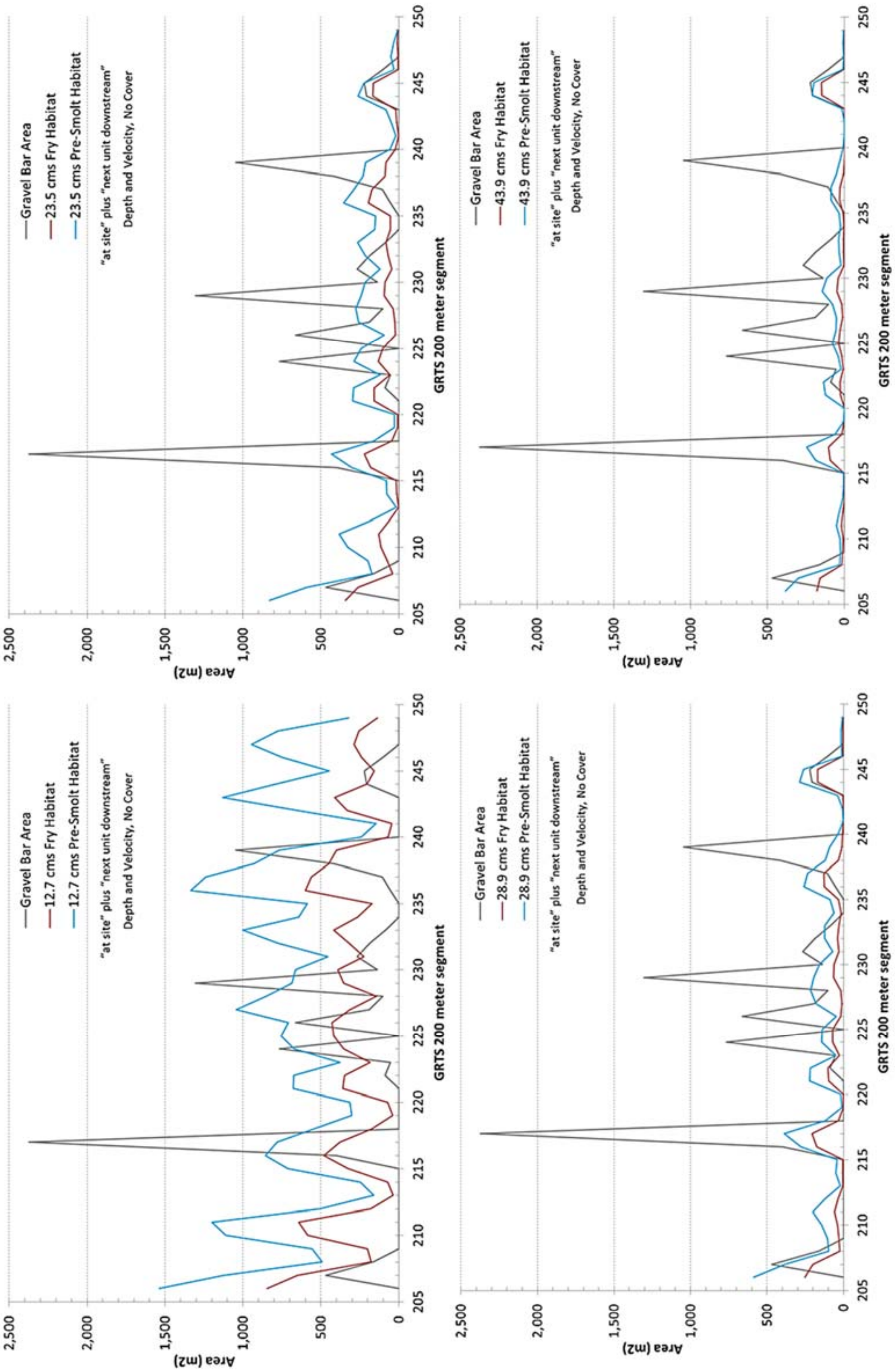

Figure 25. Longitudinal plots of Type 1 fry and pre-smolt rearing habitat and mapped active bar area within the SRH-2D fish habitat modeling reach (41.1 to 49.7 km (25.5 to 30.9 miles) downstream of Lewiston Dam); gravel bar area in each 200 m (656 ft) segment is paired with habitat area within that same segment ("at site") plus the habitat within the adjacent downstream 200 m segment ("next unit downstream"). Clockwise from upper left: 12.7 cms (450 cfs), 23.5 cms (830 cfs), 28.9 cms (1,020 cfs), and 43.9 cms (1,550 cfs) modeled streamflows.

6 SUMMARY

Summer 2014 active gravel bar mapping provided an inventory of active gravel bar area exposed at 12.7 cms (450 cfs) from Lewiston Dam downstream to the North Fork Trinity River. This area, if viewed as an index of available gravel storage, provides important insight to contemporary gravel storage and helps provide a basis for future coarse sediment management and channel rehabilitation planning in this reach.

Four objectives were developed for this report:

Objective 1. Develop an existing active gravel bar map of the primary 64 km management reach between Lewiston Dam and North Fork Trinity River.

Objective 2. Explore relationships between existing active bar frequency and area with forcing mechanisms (forced meanders, bedrock obstructions, etc.).

Objective 3. Evaluate active bar frequency and area as an index of contemporary coarse sediment storage (determined from the results of Objectives 1 and 2), and use results to explore potential coarse sediment storage as a function of geomorphic and/or hydraulic variables such as channel type, confinement, structure, and other factors.

Objective 4. Re-evaluate potential coarse sediment augmentation sites and volumes to inform development of the long-term coarse sediment management plan.

Collectively the goal of these objectives are to provide a basis to support short- and long-term coarse sediment augmentation management actions from Lewiston Dam to the North Fork Trinity River, and provide recommendations for future coarse sediment management based on contemporary active bar area.

Spatial distributions and relationships were explored to better understand reasons for the distribution, size, and frequency of mapped active bars (and therefore gravel storage). Evaluating the spatial distribution of contemporary active bars included (1) exploring active bar area and frequency (longitudinal and cumulative) from Lewiston Dam to the North Fork Trinity River confluence, (2) exploring this same distribution but on a subreach basis, and (3) computing active bar unit area. Each of these evaluations included reviewing past (1998-2010) gravel augmentation efforts (location and volume). Results show Subreaches 2 and 4 have the lowest gravel storage (0.1 m^2/m and 0.6 m^2/m, or 0.328 ft^2/ft and 1.97 ft^2/ft, respectively) of all subreaches (Table 3 and Figure 16). Using bar area as an index of gravel storage, results show unit bar area and inferred gravel storage in Subreaches 2 and 4 are substantially lower than their adjacent reaches and are the lowest of the nine subreaches; however, management efforts should prioritize Subreach 4 due to physical constraints in Subreach 2 caused by the Rush Creek delta.

Exploring relationships between contemporary active bars and selected geomorphic, hydraulic, and fish habitat variables was less conclusive than the spatial distributions and resulting unit bar area results. Evaluating channel width and shear stress did not show correlations either for the entire 64 km (40 mile) reach (Figures 18a and 18b, and 19a and 19b) or for individual mapping subreaches. Exploring relationships between formative features and more specifically large wood provided better results (Figures 20 through 22), suggesting a relationship between bar size and the size of the bar-influencing aspect area of the large wood accumulation which, although based on few data points and influenced by a constructed large wood jam significantly larger than naturally-deposited wood, suggests a positive relationship between large wood and bar area, and provides opportunity for future evaluation if large wood is added with a goal of bar formation. Lastly, reviewing active bar area as it relates to past (1998-2010) gravel augmentation volume did not show an apparent relationship (Figure 23). Although field observations suggest gravels are not moving very far (< 0.8 km or 0.5 miles) from their introduction site (Gaeuman 2014), augmented gravels have likely moved downstream from their introduction site and out of the 200 m panel from which they were introduced. In addition, gravel augmentation volumes used for this evaluation were introduced over a 13 year period (1998-2010) that ended four years prior to the 2014 active bar mapping, and although a portion of these introduced gravels are likely contributing to main channel coarse sediment storage, they have transported and deposited downstream but have not deposited as active bars.

Spatial distributions and relationships between preliminary “Type 1” fry and pre-smolt habitat modeling for the 8.6 km reach from Johnson Point to Oregon Gulch (41.1 km to 49.7 km (25.5 to 30.9 miles) downstream of Lewiston Dam) and active bar area were also explored. The longitudinal charts (Figures 24 and 25) show both fry and pre-smolt rearing habitat associated with mapped active bars persisting over the range of modeled flows (12.7 cms to 43.9 cms (450 to 1,550 cfs)). These results are considered preliminary because model validation is underway, and the refined model has not yet been applied to predict rearing habitat over the entire 64 km (40 mile) reach. While the results show a trend of habitat persisting at active bar areas, simulations of fish habitat have yet to prove accurate when compared to field observations along channel margins, where low velocities and shallow depths are most abundant. Therefore, the initial comparison of modeled fish habitat with active bar area in Subreach 8 is primarily illustrative of a recommended future analysis if and when the modeled habitat relationships better match field measurements. In addition, it was not possible as part of this study to pursue any additional analysis of relationships between active bars and modeled habitat for juvenile life stages of anadromous salmonids.

The fourth objective of this report was to re-evaluate potential coarse sediment augmentation sites and volumes to inform development of the long-term coarse sediment management plan. This objective is addressed in the following Recommendations section.

7 RECOMMENDATIONS

This report represents a component of a broader effort currently focused on evaluating coarse sediment management and channel rehabilitation activities (Figure 1). The results presented and conclusions discussed are initial steps towards assessing relationships between bar area (storage), channel form and function, and fish habitat. This work was intended to stimulate additional discussion, analyses, and integration, and to provide a platform for additional investigation and collaboration with other efforts to help define desired future gravel storage conditions and desired channel form and function (e.g., those performing sediment budgeting and routing computations, large wood management plan, and existing and potential fish habitat).

As such, the objective to re-evaluate potential coarse sediment augmentation sites and volumes to inform development of the long-term coarse sediment management plan was somewhat premature, since collaboration with others is needed to first define desired future conditions for gravel storage, fish habitat, and channel form and function. To determine these desired future conditions, the following steps are recommended:

1. Channel form and function: work with co-collaborators to develop an approach of desired conditions on a subreach basis based on geomorphic opportunities and constraints (confinement, slope, bedrock controls, infrastructure, and natural coarse sediment supply);
2. Fish habitat: expand relationships explored in this report, both by distance (i.e., include all mapping subreaches) and potentially evaluate on a subreach basis for certain subreaches with desirable habitat densities.
3. Integrate 1) and 2) to develop future desired coarse sediment storage conditions, which in turn can be used to help develop the long-term coarse sediment management plan and River Corridor Management Strategy.

From the perspective of this report alone, initial recommendations for future active bar area (gravel storage) are presented in Table 6, and are based on comparisons of bar area in similar reaches. These recommendations are preliminary, and are again intended to stimulate discussion and refinement based on the three steps above. The primary recommendation is to increase active bar area (storage) in mapping Subreach 4 from the existing 0.65 m^2/m (2.1 ft^2/ft) to at least 1.1 m^2/m (3.6 ft^2/ft), and up to 2.7 m^2/m (8.8 ft^2/ft). To provide some illustration of what these bar areas look like in the field, Figure 28 illustrates an example of a 0.65 m^2/m (2.1 ft^2/ft) active bar area value in mapping Subreach 4, and Figure 29 illustrates a range of active bar areas in mapping Subreach 7 ranging from 0.70 m^2/m (2.3 ft^2/ft) to 5.0 m^2/m (16.4 ft^2/ft).

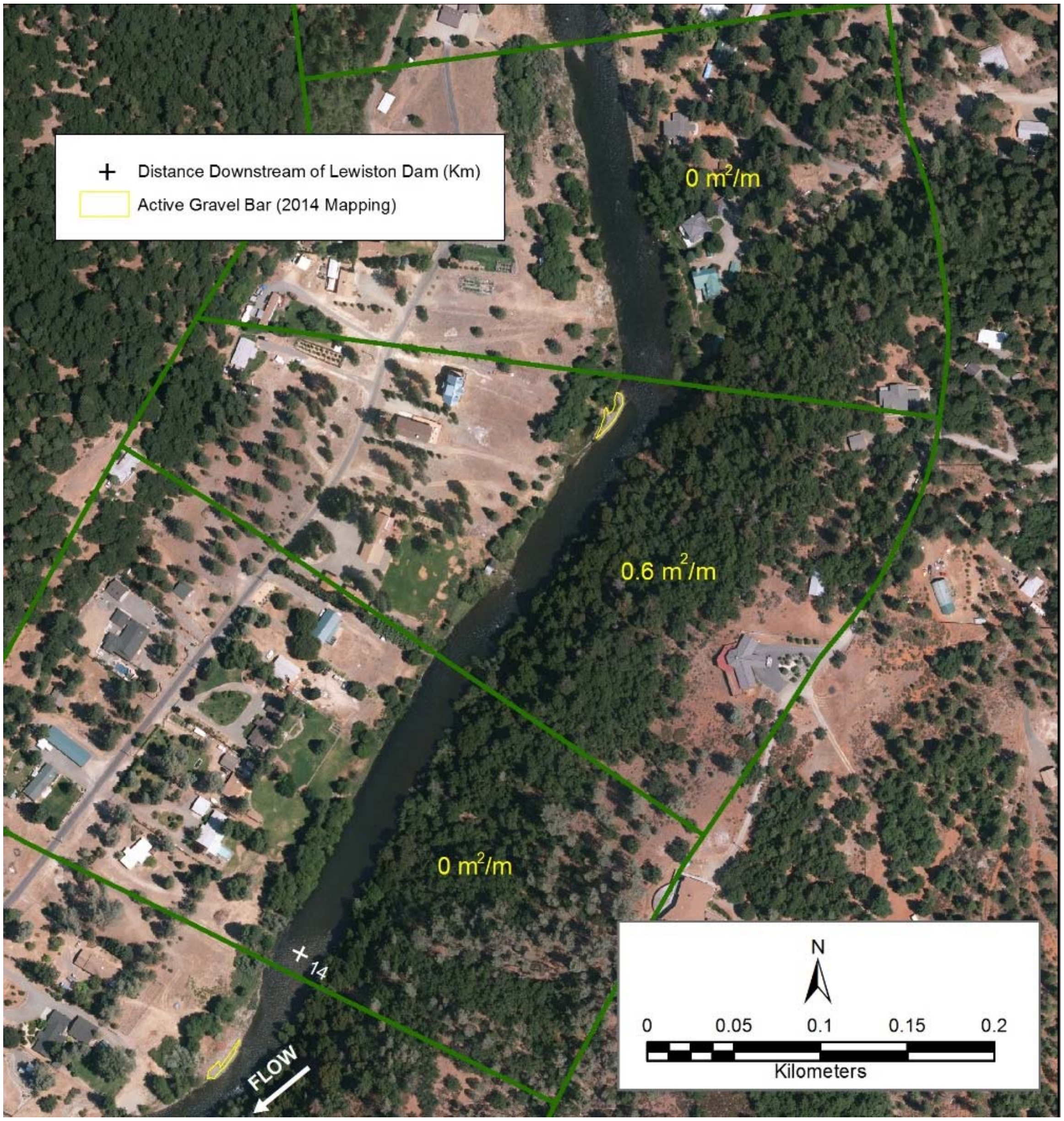

Figure 28. Example section of mapping Subreach 4 illustrating an example of a 0.65 m^2/m (2.1 ft^2/ft) active bar area value, with zero active bar areas in adjacent 200 m (656 ft) sample units.

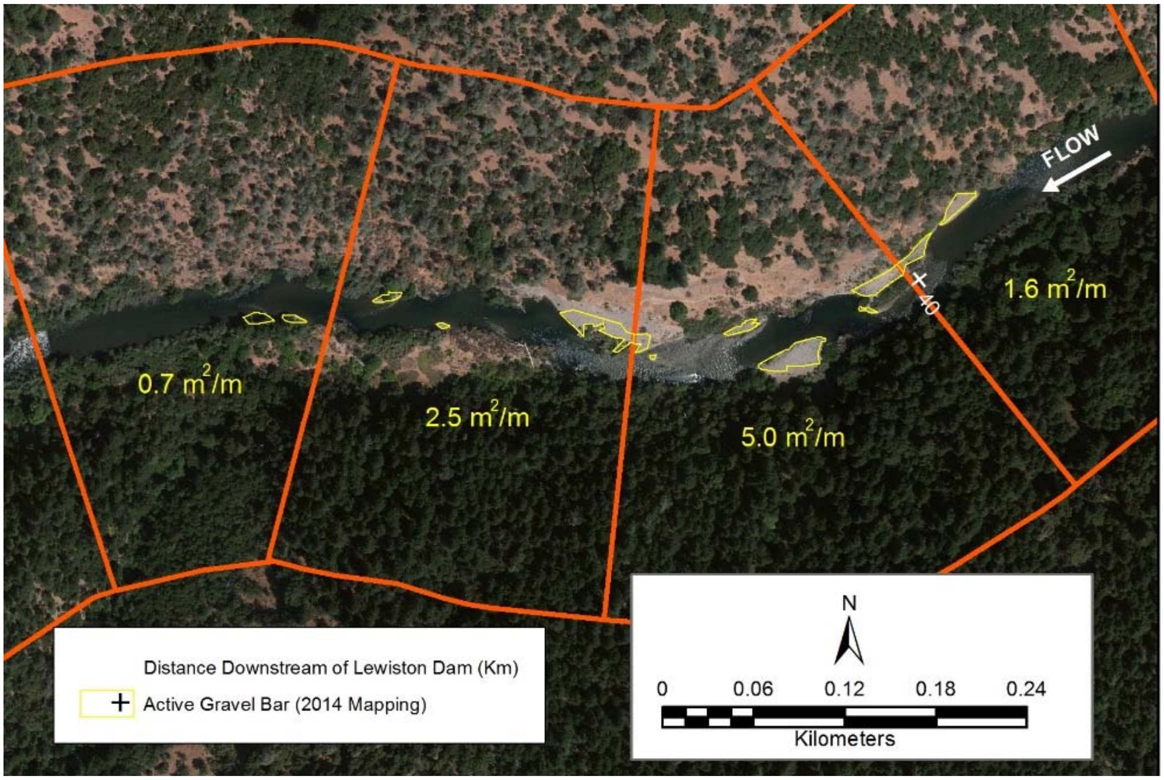

Figure 29. Example section of mapping Subreach 7 illustrating a range of active bar area values between 0.70 m^2/m (2.3 ft^2/ft) to 5.0 m^2/m (16.4 ft^2/ft) active bar areas in adjacent 200 m (656 ft) sample units.

To help translate these increased active bar areas to storage values in mapping Subreach 4, the 0.65 m^2/m (2.1 ft^2/ft) translates to an active bar area of 8,557 m^2 (2.11 acres) in the reach. Increasing to 1.1 m^2/m (3.6 ft^2/ft) and 2.7 m^2/m (8.8 ft^2/ft) would increase active bar area to 14,480 m^2 (3.58 acres) and 35,542 m^2 (8.78 acres), respectively. If we assumed a 1 m (3.28 ft) depth of bar area, an additional 5,924 m^3 (7,748 yd^3) and 26,986 m^3 (35,296 yd^3), respectively, of additional gravel storage would be needed. If an average annual coarse sediment augmentation rate of 1,460 m^3/year (1,909 yd^3/yr) (Gaeuman 2014) was added at the upstream end of mapping Subreach 4, and assuming a 100% efficiency of this augmentation into new active bars, would take 4 years and 18.5 years, respectively, to achieve these potential storage targets. If a more reasonable 50% efficiency was assumed, then it would take 8 years and 37 years, respectively, to achieve these potential targets. Therefore, it would be much more efficient and effective to quickly add this storage to the reach (with channel manipulation, large wood augmentation, and other roughness elements to create these storage areas) as part of a short-term coarse sediment augmentation effort and then maintain this storage with long-term augmentation as recommended in the 2007 Coarse Sediment Management Plan (McBain & Trush 2007).

Table 6. Initial recommended future unit bar areas and rationale. Mapping Subreaches 1-4 would have active bar areas and gravel storage increased by a combination of gravel augmentation and channel rehabilitation (achieving increased sediment retention via channel manipulation, including large wood placement and other roughness elements such as geomorphically suitable obstructions), whereas Subreaches 5 through 9 would achieve active bar area and storage increases from channel rehabilitation projects only.

	Mapping Subreach	**Mapping subreach description**	**Existing unit active bar area, m^2/m channel (ft^2/ft)**	**Potential future unit active bar area, m^2/m channel (ft^2/ft)**	**Initial rationale**
Gravel augmentation and channel manipulation	1	Primary gravel source to the reach is from gravel augmentation. Bars have little to no sand. Active bars are a combination of construction sites, augmentation sites, and/or naturally-formed bars. Moderate confinement, average slope = 0.0033.	2.7 (8.9)	2.7 – 3.6 (8.9 – 11.8)	Modest improvements with additional augmentation due to moderate confinement and higher slope, maintain existing active bar area and storage.
	2	Straight segment of channel without obstructions. Rush Creek delta causes low slope and results in very few active bars. No historic gravel augmentation other than immediately upstream at the Burner Hole. Low confinement, average slope = 0.0015.	0.1 (0.3)	0.1 – 1.1 0.3 – 3.6)	Rush Creek backwater, no action recommended until channel gradient through Rush Creek delta is addressed.
	3	Primary gravel sources include Rush Creek and gravel augmentation. Low confinement, average slope = 0.0024.	3.6 (11.8)	3.6 – 6.5 (11.8 – 21.3)	Increase unit bar area and storage up to maximum mapped (6.5 m^2/m) to increase rearing habitat due to lower slope and confinement, and good access.
	4	Low tributary sediment supply and no gravel augmentation. Subreach includes long straight narrow segments with few obstructions. High confinement, average slope = 0.0023.	0.6 (2.0)	1.1 – 2.7 (3.6 – 8.9)	Substantially increase active bars and storage (100% - 400%) to help offset low tributary supply, upper limit is similar to Subreaches 6 and 7 (similar slope and confinement). Limited access points.
Channel manipulation	5	Sediment supply from Indian Creek causes large gravel bars, overall fine sediment content of exposed bars increases. Moderate confinement, locally steep, average slope = 0.0031.	6.5 (21.3)	6.5 (21.3)	Highest 2014 unit bar area of all subreaches, no specific increase in active bars / storage recommended.
	6	Increasing tributary gravel supply (Weaver Creek, Reading Creek). Increased channel obstructions (e.g., boulders and bedrock) results in increased active bars. Moderate confinement, average slope = 0.0025.	1.3 (4.3)	1.3 – 2.7 (4.3 – 8.9)	Increase sediment storage via channel rehabilitation to increase the number of exposed active bars and storage. Assume less storage potential / retention and limited access in canyon subreaches (6 and 7) compared to downstream lower confinement subreaches (8 and 9).
	7	Confined reach with bars associated with bedrock outcrops. Gravel bars are comparatively small to adjacent reaches and exhibit sequential (alternating) patterns. High confinement, average slope = 0.0026.	1.1 (3.6)	1.3 – 2.7 (4.3 – 8.9)	
	8	Decreased bar size and frequency, alternating bar pattern continues. Low confinement, average slope = 0.0016.	1.1 (3.6)	3.6 – 6.5 (11.8 – 21.3)	
	9	Large increase in sediment supply from tributaries resulting in increased bar size and increased sand content. Low confinement, average slope = 0.0023.	3.3 (10.8)	3.6 – 6.5 (11.8 – 21.3)	

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APPENDIX B. CHINOOK HABITAT ESTIMATES FROM REGRESSION ANALYSIS AND POTENIAL FUTURE BAR AREA

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Life Stage	Flow (cfs)	Subreach	Slope	Intercept	Existing Gravel	Lower Gravel Recommendations	Upper Gravel Recommendations	Existing Habitat	Low Habitat Recommendations	Upper Habitat Recommendations
fry	375	1	0.0094	7.1044	2,700	2,700	3,600	1,569	1,569	1,708
fry	450	1	0.0110	6.9081	2,700	2,700	3,600	1,348	1,348	1,489
fry	750	1	0.0179	6.3312	2,700	2,700	3,600	911	911	1,070
fry	1,050	1	0.0199	6.0980	2,700	2,700	3,600	762	762	912
fry	2,000	1	0.0151	6.1982	2,700	2,700	3,600	739	739	847
fry	375	2	0.0094	7.1044	100	100	1,100	1,229	1,229	1,350
fry	450	2	0.0110	6.9081	100	100	1,100	1,011	1,011	1,130
fry	750	2	0.0179	6.3312	100	100	1,100	572	572	684
fry	1,050	2	0.0199	6.0980	100	100	1,100	454	454	554
fry	2,000	2	0.0151	6.1982	100	100	1,100	499	499	581
fry	375	3	0.0094	7.1044	3,600	3,600	6,500	1,708	1,708	2,244
fry	450	3	0.0110	6.9081	3,600	3,600	6,500	1,489	1,489	2,051
fry	750	3	0.0179	6.3312	3,600	3,600	6,500	1,070	1,070	1,799
fry	1,050	3	0.0199	6.0980	3,600	3,600	6,500	912	912	1,626
fry	2,000	3	0.0151	6.1982	3,600	3,600	6,500	847	847	1,312
fry	375	4	0.0094	7.1044	600	1,100	2,700	1,288	1,350	1,569
fry	450	4	0.0110	6.9081	600	1,100	2,700	1,069	1,130	1,348
fry	750	4	0.0179	6.3312	600	1,100	2,700	626	684	911
fry	1,050	4	0.0199	6.0980	600	1,100	2,700	501	554	762
fry	2,000	4	0.0151	6.1982	600	1,100	2,700	539	581	739
fry	375	5	0.0094	7.1044	6,500	6,500	6,500	2,244	2,244	2,244
fry	450	5	0.0110	6.9081	6,500	6,500	6,500	2,051	2,051	2,051
fry	750	5	0.0179	6.3312	6,500	6,500	6,500	1,799	1,799	1,799
fry	1,050	5	0.0199	6.0980	6,500	6,500	6,500	1,626	1,626	1,626
fry	2,000	5	0.0151	6.1982	6,500	6,500	6,500	1,312	1,312	1,312
fry	375	6	0.0094	7.1044	1,300	1,300	2,700	1,376	1,376	1,569
fry	450	6	0.0110	6.9081	1,300	1,300	2,700	1,155	1,155	1,348
fry	750	6	0.0179	6.3312	1,300	1,300	2,700	709	709	911
fry	1,050	6	0.0199	6.0980	1,300	1,300	2,700	577	577	762
fry	2,000	6	0.0151	6.1982	1,300	1,300	2,700	599	599	739
fry	375	7	0.0094	7.1044	1,100	1,300	2,700	1,350	1,376	1,569
fry	450	7	0.0110	6.9081	1,100	1,300	2,700	1,130	1,155	1,348
fry	750	7	0.0179	6.3312	1,100	1,300	2,700	684	709	911
fry	1,050	7	0.0199	6.0980	1,100	1,300	2,700	554	577	762
fry	2,000	7	0.0151	6.1982	1,100	1,300	2,700	581	599	739
fry	375	8	0.0094	7.1044	1,100	3,600	6,500	1,350	1,708	2,244
fry	450	8	0.0110	6.9081	1,100	3,600	6,500	1,130	1,489	2,051
fry	750	8	0.0179	6.3312	1,100	3,600	6,500	684	1,070	1,799
fry	1,050	8	0.0199	6.0980	1,100	3,600	6,500	554	912	1,626
fry	2,000	8	0.0151	6.1982	1,100	3,600	6,500	581	847	1,312
fry	375	9	0.0094	7.1044	3,300	3,600	6,500	1,661	1,708	2,244
fry	450	9	0.0110	6.9081	3,300	3,600	6,500	1,440	1,489	2,051
fry	750	9	0.0179	6.3312	3,300	3,600	6,500	1,014	1,070	1,799
fry	1,050	9	0.0199	6.0980	3,300	3,600	6,500	859	912	1,626
fry	2,000	9	0.0151	6.1982	3,300	3,600	6,500	809	847	1,312

Life Stage	Flow (cfs)	Subreach	Slope	Intercept	Existing Gravel	Lower Gravel Recommendations	Upper Gravel Recommendations	Existing Habitat	Low Habitat Recommendations	Upper Habitat Recommendations
presmolt	375	1	0.0064	7.9163	2,700	2,700	3,600	3,257	3,257	3,449
presmolt	450	1	0.0081	7.6976	2,700	2,700	3,600	2,739	2,739	2,945
presmolt	750	1	0.0151	7.0783	2,700	2,700	3,600	1,785	1,785	2,045
presmolt	1,050	1	0.0183	6.8067	2,700	2,700	3,600	1,481	1,481	1,746
presmolt	2,000	1	0.0149	6.8283	2,700	2,700	3,600	1,380	1,380	1,578
presmolt	375	2	0.0064	7.9163	100	100	1,100	2,759	2,759	2,941
presmolt	450	2	0.0081	7.6976	100	100	1,100	2,221	2,221	2,407
presmolt	750	2	0.0151	7.0783	100	100	1,100	1,204	1,204	1,401
presmolt	1,050	2	0.0183	6.8067	100	100	1,100	921	921	1,105
presmolt	2,000	2	0.0149	6.8283	100	100	1,100	937	937	1,088
presmolt	375	3	0.0064	7.9163	3,600	3,600	6,500	3,449	3,449	4,150
presmolt	450	3	0.0081	7.6976	3,600	3,600	6,500	2,945	2,945	3,721
presmolt	750	3	0.0151	7.0783	3,600	3,600	6,500	2,045	2,045	3,172
presmolt	1,050	3	0.0183	6.8067	3,600	3,600	6,500	1,746	1,746	2,968
presmolt	2,000	3	0.0149	6.8283	3,600	3,600	6,500	1,578	1,578	2,429
presmolt	375	4	0.0064	7.9163	600	1,100	2,700	2,849	2,941	3,257
presmolt	450	4	0.0081	7.6976	600	1,100	2,700	2,312	2,407	2,739
presmolt	750	4	0.0151	7.0783	600	1,100	2,700	1,299	1,401	1,785
presmolt	1,050	4	0.0183	6.8067	600	1,100	2,700	1,009	1,105	1,481
presmolt	2,000	4	0.0149	6.8283	600	1,100	2,700	1,010	1,088	1,380
presmolt	375	5	0.0064	7.9163	6,500	6,500	6,500	4,150	4,150	4,150
presmolt	450	5	0.0081	7.6976	6,500	6,500	6,500	3,721	3,721	3,721
presmolt	750	5	0.0151	7.0783	6,500	6,500	6,500	3,172	3,172	3,172
presmolt	1,050	5	0.0183	6.8067	6,500	6,500	6,500	2,968	2,968	2,968
presmolt	2,000	5	0.0149	6.8283	6,500	6,500	6,500	2,429	2,429	2,429
presmolt	375	6	0.0064	7.9163	1,300	1,300	2,700	2,979	2,979	3,257
presmolt	450	6	0.0081	7.6976	1,300	1,300	2,700	2,447	2,447	2,739
presmolt	750	6	0.0151	7.0783	1,300	1,300	2,700	1,444	1,444	1,785
presmolt	1,050	6	0.0183	6.8067	1,300	1,300	2,700	1,147	1,147	1,481
presmolt	2,000	6	0.0149	6.8283	1,300	1,300	2,700	1,121	1,121	1,380
presmolt	375	7	0.0064	7.9163	1,100	1,300	2,700	2,941	2,979	3,257
presmolt	450	7	0.0081	7.6976	1,100	1,300	2,700	2,407	2,447	2,739
presmolt	750	7	0.0151	7.0783	1,100	1,300	2,700	1,401	1,444	1,785
presmolt	1,050	7	0.0183	6.8067	1,100	1,300	2,700	1,105	1,147	1,481
presmolt	2,000	7	0.0149	6.8283	1,100	1,300	2,700	1,088	1,121	1,380
presmolt	375	8	0.0064	7.9163	1,100	3,600	6,500	2,941	3,449	4,150
presmolt	450	8	0.0081	7.6976	1,100	3,600	6,500	2,407	2,945	3,721
presmolt	750	8	0.0151	7.0783	1,100	3,600	6,500	1,401	2,045	3,172
presmolt	1,050	8	0.0183	6.8067	1,100	3,600	6,500	1,105	1,746	2,968
presmolt	2,000	8	0.0149	6.8283	1,100	3,600	6,500	1,088	1,578	2,429
presmolt	375	9	0.0064	7.9163	3,300	3,600	6,500	3,384	3,449	4,150
presmolt	450	9	0.0081	7.6976	3,300	3,600	6,500	2,875	2,945	3,721
presmolt	750	9	0.0151	7.0783	3,300	3,600	6,500	1,954	2,045	3,172
presmolt	1,050	9	0.0183	6.8067	3,300	3,600	6,500	1,653	1,746	2,968
presmolt	2,000	9	0.0149	6.8283	3,300	3,600	6,500	1,509	1,578	2,429