

**Performance, evolution, and longevity of
constructed channel and floodplain features on
the Trinity River, California**

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TABLE OF CONTENTS

	<u>Page</u>
Table of Contents.....	iii
List of Figures.....	v
List of Tables	vi
1 Introduction.....	1
1.1 Effectiveness Monitoring Goals and Objectives.....	2
2 Overview of Methods	4
3 Side Channel Effectiveness Analyses.....	5
3.1 Side Channel Methods.....	5
3.2 Side Channel Results	13
3.3 Side Channel Discussion	19
4 Split-Flow Channel Effectiveness Analyses.....	22
4.1 Split-flow Channel Methods	22
4.2 Split-flow Channel Results	25
4.3 Split-flow Channel Discussion	28
5 Alcove Effectiveness Analyses.....	33
5.1 Alcove Methods.....	33
5.2 Alcove Results	34
5.3 Alcove Discussion	35
6 Channel Meander Effectiveness Analyses.....	39
6.1 Channel Meander Methods.....	39
6.2 Channel Meander Results	39
6.3 Channel Meander Discussion	40
7 Off-Channel Perennial Wetland Effectiveness Analyses	41
7.1 Off-Channel Perennial Wetland Methods.....	41
7.2 Off-Channel Perennial Wetland Results.....	42
7.3 Off-Channel Perennial Wetland Discussion	42
8 Summary and Recommendations	43
9 References.....	46
Appendix 1: Location Maps of Sites Included in Analysis	1-1
Appendix 2: General Site Information.....	2-1
Appendix 3: GCD Survey Dates All Analyses.....	3-1
Appendix 4: Flow Data.....	4-1
Appendix 5: Flow Duration Curves.....	5-1
Appendix 6: Side Channel Tables and Results	6-1
Side Channel GCD Results.....	6-1

Side Channel Length Analysis Results.....	6-3
Appendix 7: Split-flow channel Tables and Results.....	7-1
Constructed Split-flow Overall Percent Effectiveness	7-1
Constructed Split-flow Streamflow Conveyance Results.....	7-1
Constructed and Naturally Occurring Split-flow Channel GCD Results	7-3
Constructed and Naturally Occurring Split-flow Channel Aerial Photograph Analysis	7-5
Naturally Occurring Split-flow Channel Widths	7-6
Constructed Split-Flow Channel Widths	7-7
Appendix 8: Alcove Tables and Results.....	8-1
Alcove Overall Results	8-1
Alcove GCD Results.....	8-2
Appendix 9: Channel Meander Results	9-1
Overall Channel Meander Results	9-1
Channel Meander GCD Results.....	9-1
Appendix 10: Off-Channel Perennial Wetland Results.....	10-1
Off-channel Perennial Wetland GCD Results	10-1

LIST OF FIGURES

	<u>Page</u>
Figure 1. Example of the SRH-2D model output and wetted perimeter for a flow of 450 cfs at the Upper Junction City (UJC) site.	8
Figure 2. Linear interpolation of the relationship between predicted water surface elevation at the side channel hydraulic control and streamflow generated using the SRH-2D water surface elevation outputs at UJC.	10
Figure 3. 14-day flow duration curve for the USGS Junction City Gage for the January 1 through April 30 period, incorporating all available data between water year (WY) 2006 and WY 2019.	11
Figure 4. Example at Trinity House Gulch of the side channel flow connectivity at 450 cfs analysis.	12
Figure 5. Maximum deposition detected at side channel entrances in the GCD analysis.	14
Figure 6. Deposition detected by the GCD analysis that occurred throughout the side channels (including but not limited to the entrances).	15
Figure 7. Design and contemporary flow thresholds and percent exceedances for side channel entrances.	16
Figure 8. The difference at side channel features between wetted length under design conditions compared to contemporary conditions at a flow of 300 or 450 cfs, showing whether flow connectivity from the side channel entrance to the exit has been impaired under contemporary conditions.	18
Figure 9. Side channels grouped by the changes for the four metrics that were evaluated, with the percentage that each group represents in the total population.	19
Figure 10. 2016 aerial photographs showing the geomorphic setting of side channel R2 at Sawmill and side channel R4 at Lorenz Gulch.	21
Figure 11. Aerial photographs from 2014–2016 that show deposition occurring through time in the split-flow channel at Wheel Gulch, constructed in 2011.	24
Figure 12. Depth and velocity outputs extracted from the 2016 SRH-2D model shown as color maps at the Lowden Ranch site.	26
Figure 13. 2016 aerial photograph showing how total channel widths and medial bar widths were measured in GIS to compare the percentage that the medial bar makes up in the total channel width for both the constructed and naturally occurring split-flow features.	27
Figure 14. Ratio of bar width to total channel width at naturally occurring split-flow locations in 2016.	29
Figure 15. Total channel width and medial bar width at constructed split-flow locations.	30
Figure 16. Average flow conveyance at the constructed split-flow locations.	31
Figure 17. Flow conveyance in each channel at the naturally occurring split-flow locations.	32
Figure 18. Lower Steiner Flat example of an alcove constructed at the downstream end of an unvegetated gravel bar, which continued migrating downstream and filled the alcove within three years.	36
Figure 19. Aerial photographs showing two alcoves at the Sven Olbertson site constructed in 2008.	37
Figure 20. GCD results for maximum topographic change in the 48 alcoves that were evaluated.	38
Figure 21. GCD results for 15 channel migration features.	41
Figure 22. GCD results for the six off-channel wetland features.	43

LIST OF TABLES

	<u>Page</u>
Table 1. The five design features analyzed for effectiveness include: side channels, split-flow channels, alcoves, channel meanders, and off-channel wetlands.....	3
Table 2. Feature name, year constructed, and construction objective for the low-flow side channels evaluated for this analysis.	6
Table 3. List of low-flow side channels that were excluded in the analyses and rationale.	7
Table 4. SRH-2D model outputs of streamflow and water surface elevations that were used to describe stage–streamflow relationships for the UJC low-flow side channel.	9
Table 5. Side channel results for January to April 14-day flow duration.....	17
Table 6. Split-flow feature location, construction year, and feature name.....	23
Table 7. Site locations and number of alcoves at each site that were evaluated.	34
Table 8. Channel meander features by construction site evaluated for effectiveness.	39
Table 9. Site location, number of perennial off-channel wetlands, and the inundation flow.....	42
Table 2-1. River location, year built, and closest or most appropriate USGS streamflow gage for each construction site.	2-1
Table 3-1. Site construction year, date of the post-construction survey used in the GCD analysis, date of the contemporary survey used in the GCD analysis, and number of years the GCD analysis includes.	3-1
Table 4-1. Date of the peak flow for each water year and for each of the five USGS mainstem Trinity River gages.....	4-1
Table 6-1. Results of the GCD analysis and brief description of deposition and scour at each side channel.....	6-1
Table 6-2. Side channel length and the reported effectiveness for each side channel based on contemporary wetted length.	6-3
Table 7-1. Percent Effectiveness assigned to the six constructed split-flow channels.	7-1
Table 7-2. Results of the analysis to evaluate if constructed split-flow channels are conveying 20% of the total streamflow under contemporary conditions.	7-1
Table 7-3. GCD results at split-flow locations describing the deposition and erosion through time at constructed and naturally occurring split flows.	7-3
Table 7-4. Trends of deposition and erosion at constructed and naturally occurring split-flow locations that were captured in aerial photographs.	7-5
Table 7-5. Naturally occurring split-flow channels and the relationship between the total channel width and the width of the medial bar that forms.	7-6
Table 7-6. Constructed split flow total channel and medial bar widths, as well as the percentage of the total channel width that the medial bar comprises.	7-7
Table 8-1. Overall alcove results, showing the three categories of percent effectiveness and the number of alcoves within each category.	8-1
Table 8-2. Table of GCD results describing deposition and erosion at alcove locations.	8-2
Table 9-2. GCD descriptions for the channel migration features.	9-1
Table 10-1. Table describing the GCD results at off-channel perennial wetland features.	10-1

1 INTRODUCTION

The Trinity River Flow Evaluation Final Report (TRFEFR; USFWS and HVT 1999) and the Record of Decision (ROD; DOI 2000) provided the founding principles of rehabilitation on the Trinity River. The TRFEFR recommended three strategies to restore anadromous salmonid habitat to the Trinity River: (1) restoration streamflows, (2) sediment augmentation, and (3) mechanical channel rehabilitation. However, specifics on design criteria for channel rehabilitation projects were not addressed. These details were later specified in the Trinity River Channel Design Guide (CDG), which was developed to improve ongoing channel rehabilitation activities on the Trinity River, as directed by the Trinity River Restoration Program (HVT et al. 2011). In 2011, the CDG was completed to provide the detailed design-related criteria needed to improve recommendations for design elements. The CDG used a combination of empirical relationships and reference reach data that are specific to the Trinity River to provide guidelines for a variety of fundamental design features.

The CDG was intended to be a “living document” and be amended as rehabilitation sites evolved and additional design criteria were needed for new design features. To date, only minor updates to the CDG have been made (e.g., flood frequency and duration, riparian recruitment surface inundation targets). This report evaluates the evolution and longevity of five features commonly included in Trinity River restoration designs and fundamental to ROD goals: side-channels, split-flow channels, alcoves, channel meanders and off-channel perennial wetlands. Each of the five feature types was analyzed to assess physical change over time and whether they are still meeting the original design objectives. The results of this report are intended to be included in the CDG to provide better-informed design guidelines for future rehabilitation efforts.

In addition to the CDG, TRRP requested a Science Advisory Board review of Phase 1 channel rehabilitation projects constructed between 2005 and 2012 (Buffington et al. 2014). The emphasis of the review was to determine which features were performing as designed and if Phase 1 rehabilitation projects were on track to meet ROD objectives. Early in the Phase 1 review, it was determined that insufficient data existed to evaluate whether projects were meeting programmatic objectives (e.g., fish production). Therefore, the review focused on developing linkages between physical and biological response which could effectively inform rehabilitation in a timely, defensible, and transparent manner.

The purpose of this report is to develop metrics and evaluate the effectiveness of design features in rehabilitation sites constructed between 2005 and 2016. These metrics can be applied in future monitoring efforts which will further inform subsequent designs. A “feature” is defined here as a physical element in a rehabilitation design, such as: pool excavations, floodplains, large wood placements, boulder placements, channel realignment and the five features mentioned above. “Effectiveness” is defined slightly differently for each of the five feature-types, depending on the original design criteria; however, effectiveness is generally defined as “functioning at the design criteria under contemporary (i.e., 2016) conditions.” For example, if a side-channel constructed in 2012 was designed to flow at 300 cfs during winter baseflows, then effectiveness was graded based on whether that side-channel is still flowing at 300 cfs during winter baseflows in 2016.

The biological impact of feature function varies (1) longitudinally (due to natural accretion, sites further downstream could still provide some function if the flow threshold [the mainstem flow required to activate a feature] increased above the designed flow threshold), and (2) seasonally (i.e., during the critical rearing period for anadromous salmonids, January through April). To evaluate flow-related function of side-channels, with flow scaled by location and by critical time period, we examined the 14-day flow duration curves (FDC) for the January to April period for sub-reaches bounded by five US Geological Survey (USGS) streamflow gages. In this way we account for longitudinal differences in hydrology when evaluating the function of off channel features. Increased habitat complexity (i.e., off-channel features) improves rearing conditions for

juvenile salmonids by providing connectivity to velocity refuge at higher flows, predator avoidance, diverse foraging methods and resources, and a decrease in niche overlap (Nielsen 1992, Giannico 2000). The 450 cfs summer baseflow metric, the 14-day (300 cfs) January to April FDC, and additional effectiveness criteria for the five types of features are discussed in Section 3.

Originally a site-based evaluation was considered for this monitoring effort, where each rehabilitation site would be evaluated. We decided that a feature-based approach would provide better insight to patterns of success or shortcomings of specific design features. Twenty-three rehabilitation sites and approximately 2,000 design features were constructed between 2005 and 2016 throughout the 40-mile Restoration Reach of the Trinity River (Appendix 1: Location Maps of Sites Included in Analysis), which extends from Lewiston Dam to the North Fork Trinity River (TRRP 2019). A feature-based approach allows for geomorphic and biological setting comparisons. This way, locations throughout the 40 miles can be evaluated as being physically and/or biologically suitable for specific types of features.

Not all the approximately 2,000 design features were individually evaluated in this report which again focuses on five types: side-channels, split-flow channels, alcoves, channel meanders and off-channel wetlands. Other prominent design features (that were not evaluated in this study) include coarse sediment additions, large wood and boulder placements, constructed floodplains and transitional slopes. These were omitted because they are included in work that is currently being conducted by other program partners which are examining large wood and coarse sediment storage, and riparian recruitment. Additionally, design features vary in scale and complexity and some are nested within others. For example, a single side-channel may contain several boulder features, several large wood features, and multiple graded floodplain surfaces. Examination of a more complex design feature (such as a side-channel) considers interactions among some of the smaller-scale features contained within it and may aid in answering Priority Questions presented in Table 1. For example, if a large wood feature was placed at the entrance of a side-channel, did the orientation of that feature play a role in maintaining the effectiveness of the side-channel?

Evaluating specific constructed features helps to identify which have performed effectively and how placement of those features in different geomorphic and hydrologic settings impacts how they persist physically and/or hydrologically. This report is intended to inform the TRRP so they can (1) assess whether these features are meeting programmatic objectives outlined in the TRFEFR and the ROD, (2) make adaptive decisions on how, where or if these features should be included in future designs, and (3) for the TRRP design workgroup to modify the CDG as appropriate based on the findings of this report.

1.1 Effectiveness Monitoring Goals and Objectives

The primary goals of the analyses in this report are to (1) evaluate how the contemporary (i.e., in 2016) condition of five design feature types differs from as-built conditions, and (2) how physical changes relate to hydrological effectiveness. While this study examines biological effectiveness in side-channels (flow duration as an index of habitat quality), the focus is on physical geomorphic and hydrologic performance. Assessments of habitat quantity and quality are beyond the scope of this document, and are being done by others. We make the necessary assumption that as-built conditions represent design conditions unless otherwise noted. Then, based on examples of features that have evolved as intended, we provide recommendations to inform the TRRP design workgroup, which can be used to amend the CDG.

Table 1. The five design features analyzed for effectiveness include: side-channels, split-flow channels, alcoves, channel meanders, and off-channel wetlands. In addition to the selection criteria described in the preceding section, these five features were chosen because (1) they provide immediate benefits to juvenile salmonid rearing during the critical January through April time period, (2) they are highly complex and incorporate multiple design elements, (3) they are included in each of the five reaches defined in the CDG. The five feature types, the number evaluated, and the Priority Questions used to develop metrics for evaluating the features are provided.

Feature Name	Number Evaluated	Priority Questions
Side-channels	20	<ol style="list-style-type: none"> 1. Is there thalweg aggradation at the entrance? 2. Has the entrance flow threshold changed and if so, what is the new threshold? 3. What is the contemporary (2016) wetted side-channel length associated with the contemporary entrance flow threshold? 4. Does the contemporary flow entrance threshold provide critical rearing habitat during the January to April time period? 5. Does the geomorphic setting influence the function (connectivity, wetted area) of side-channels over time?
Split-flow Channels	14	<ol style="list-style-type: none"> 1. Are split-flow channels still conveying at least 20% of the total flow? 2. Have split-flow channels aggraded or eroded? 3. Is split-flow channel persistence/formation reliant on channel width or expansion?
Alcoves	48	<ol style="list-style-type: none"> 1. Has alcove dimension changed, including planform area, depth, and volume? 2. Did the alcove cut off or fill in? 3. Has the flow relationship between the alcove and the channel changed? 4. Does alcove placement location affect performance (upstream reaches vs. downstream reaches, geomorphic setting, connection to a high-flow or low-flow channel)? 5. Does the contemporary flow entrance threshold provide critical rearing habitat during the January to April time period?
Channel Meanders	15	<ol style="list-style-type: none"> 1. Are constructed meanders migrating laterally? 2. Are active bar features being created or maintained on the inside bend of constructed channel meanders? 3. Are the active bars evolving into floodplains at locations where channel migration is occurring?
Off-channel Wetlands	6	<ol style="list-style-type: none"> 1. Are off-channel wetlands still connected to the flowing channel? 2. Are off-channel wetlands aggrading?

The analyses focused on the following objectives:

1. Use the Priority Questions in Table 1 to develop metrics that are useful and objective for describing and evaluating design feature effectiveness.
2. Evaluate physical, hydrological, and biological effectiveness on a feature-by-feature basis to identify trends of successes and shortcomings of individual features and placement.
3. Provide design recommendations for each of the five feature types that can be presented to the TRRP design workgroup, incorporated into the CDG as appropriate, and applied to future Trinity River restoration projects.

2 OVERVIEW OF METHODS

This section provides a general overview. Specific methods for each of the five feature types are provided in their respective Sections (3 to 7). This investigation relied on existing documentation available through 2018 and US Geological Survey (USGS) streamflow data available through 2019. No additional field work was completed. Several sources were used to identify site locations, the number of features, feature names, years of construction, and other important attributes (Appendix 2: General Site Information). These sources include individual site design reports, the 2011 CDG, the 2012 Review of the Trinity River Phase 1 Projects (Buffington et al., 2014), and the TRRP feature online database (TRRP 2019). Information from all sources was combined to ensure a complete analysis; however, due to the large number of features constructed and varying degrees of as-built design documentation, the analyses may not include all features constructed. If a feature was not included in these sources, it may have inadvertently been excluded from the analyses.

Several metrics were used to evaluate effectiveness for each feature and are listed at the beginning of each feature section. The metrics relate to the physical geometry of the features, like changes in planform area, length, and depth, as well as hydrologic changes like flow thresholds and associated changes to flow duration, wetted area at specific flows, and flow conveyance. Biological effectiveness is evaluated by changes to flow duration during critical periods for salmon rearing. Three separate analytical tools were used to evaluate these changes: the SRH-2D hydraulic model developed by the Bureau of Reclamation for the TRRP (Bradley 2016, Bradley 2018), a geomorphic change detection (GCD) analysis, and aerial photograph analysis.

The SRH-2D model was developed for the 40-mile Restoration Reach and utilized 2016 topography (Bradley 2018). The model predicts spatial patterns of channel hydraulics including water depth, velocity, and shear stress, as well as the location, quantity, and quality of salmonid habitat. The model outputs for wetted area, water surface elevation, depth, and velocity were used to evaluate changes in planform area and flow conveyance, but outputs for salmonid habitat were not, as the primary focus of this report is on geomorphic and hydrologic performance.

The GCD was used to compare how topography at constructed sites has evolved from the baseline (design) condition to the contemporary (2016) condition. The topographic change analysis was used to infer sediment storage and channel migration changes resulting from managed releases and naturally occurring high flows on the Trinity River. Digital terrain models (DTM), developed from topographic surveys, including ground survey data, bathymetric data, and LiDAR data, completed by TRRP and GMA Hydrology (GMA 2017) were utilized in the GCD analyses. DTMs were sampled to 1 ft raster digital elevation models and exported to ArcGIS format for GCD analysis (Wheaton 2008). A minimum level of detection (MinLOD) of ± 1.5 ft was applied to the change detection to filter out topographic uncertainty due to different survey methods and different ground-surface types, under the assumption that 1.5 feet is greater than the cumulative error of all the survey types. No sensitivity analysis of the 1.5 ft threshold was conducted. If a feature registered change above the ± 1.5 ft threshold, then the change was considered a “real” change. The real change was used to make observations about features that may be filling with sediment through time or those that have already filled completely. Effectiveness was not simply graded based on whether deposition or erosion occurred; instead, it was based on whether deposition (or erosion) have occurred to such an extent that the feature is no longer meeting its design objectives.

The GCD analysis output included estimates of erosion, deposition, and net volumetric change between post-construction topographic surveys and 2016 surveys (Appendix 3: GCD Survey Dates All Analyses). In some cases, topographic change occurred at sites after construction was completed but prior to the post-construction survey being completed, which means that the GCD analysis did not capture those topographic change events. The GCD analysis was used primarily to measure deposition, erosion, and channel migration from project completion (or shortly thereafter) to 2016.

Aerial photographs have been taken annually during summer low-flow conditions between 2007 and 2016 and were used to make visual comparisons of feature development through time and to digitize channel length and width to evaluate changes in planform area. The aerial photographs were essential for identifying features to include in the evaluations and for measuring changes to features that occurred prior to post-construction surveys that may not be captured in the GCD analysis. Further, in many cases, the aerial photographs were used to double check (and sometimes supersede) SRH-2D model predictions (detailed in the following section).

Streamflow data from the USGS website was used for five mainstem Trinity River gages. USGS gaging stations utilized for each site are listed in Appendix 2. Peak flow data and daily average streamflow data can be found in Appendix 4: Flow Data. These data were used to make observations about how streamflow events may impact constructed feature effectiveness over the time period of analysis. 14-day flow duration curves for January to April (using 2005 to 2019 daily data) can be found in Appendix 5: Flow Duration Curves. These were used to evaluate changes in flow duration related to flow entrance thresholds at side-channels.

3 SIDE-CHANNEL EFFECTIVENESS ANALYSES

The metrics utilized to evaluate side-channel effectiveness include:

- Changes due to deposition or erosion,
- Changes in flow threshold at the side-channel entrance,
- Changes in wetted length at the design flow during baseflow conditions ranging from 300 to 450 cfs, and
- Changes to the 14-day January to April flow exceedance probability.

3.1 Side-channel Methods

Twenty low-flow side-channels were evaluated for these analyses, as identified in the TRRP Online Database and in the 2012 Phase I Review Report. Low-flow channels are designed to flow at either 300 or 450 cfs (Table 2). Sites closer to the dam were designed to flow at 300 cfs (the lowest winter base flow typically released by the dam), and downstream sites were designed to flow at 450 cfs. Typically, 450 cfs is Trinity River summer base flow and (approximately) winter baseflow (300 cfs release + tributary accretion). The sites closest to the dam were designed to function at all flows. Flows lower than 300 cfs do occur near the dam and some features have been observed to remain flowing, thus some side-channels have a design threshold that is actually lower than 300 cfs (Appendix 5: Flow Duration Curves). The 300 and 450 cfs thresholds are intended to target side-channel function during the January to April critical rearing period and during the summer baseflow period. The side-channels included in this report were identified in the TRRP Online Database and in the 2012 Phase I Review Report.

Of the 20 side-channels identified, three were not evaluated due to additional construction at their project sites, which created a condition where the 2016 topography used in the GCD analysis was not representative of natural evolution (Table 3). In addition, one side-channel from the TRRP data portal was not actually constructed, so it was also omitted and is labeled as “NA” in the Lower Steiner Flat site map. (Appendix 1). The primary metrics for evaluating side-channel effectiveness are changes due to deposition or erosion, changes in flow threshold at the side-channel entrance, and changes in side-channel wetted length at the design flow of 300–450 cfs. Effectiveness was calculated as a percentage for the change in flow threshold versus the design flow threshold and for the change in wetted length at the design flow. The calculations for effectiveness are discussed below under each task. Assessing habitat quantity and quality was beyond the scope of this study. The duration of positive flow during the critical rearing period is considered an index (not a direct measure) of habitat quality or quantity.

Table 2. Feature name, year constructed, and construction objective for the low-flow side-channels evaluated for this analysis. Low-flow side-channels were designed to flow at either 300 or 450 cfs.

Site Name	Year Constructed	River Mile	Feature Name	Objective for Construction ¹
Valdor Gulch	2006	74.8–75.7	R2	Increase rearing habitat, riparian cover and diversity, and topographic variability
Cableway	2008	110.1–110.6	R3	Increase rearing and spawning habitat
Dark Gulch	2008	105.5–107.0	R1	Increase rearing and spawning habitat
			R6	
Deadwood Creek	2008	110.6–110.8	R3	Increase rearing and spawning habitat, and riparian cover and diversity
Hoadley Gulch	2008	109.8–110.1	R5	Increase rearing and spawning habitat, and riparian cover and diversity
Sven Olbertson	2008	111.2–111.7	R1	Increase rearing and spawning habitat, and topographic variability
Sawmill	2009	108.8–109.7	R3	Increase rearing and spawning habitat, riparian cover and diversity, and topographic variability
Lowden Ranch	2010	104.4–105.3	R1	Increase rearing and spawning habitat
Reading Creek	2010	92.15–93.25	R3	Increase rearing and spawning habitat, riparian cover and diversity, and large wood debris (LWD)
Trinity House Gulch	2010	104.0–104.3	R2	Increase rearing habitat, riparian cover and diversity, and LWD
Wheel Gulch	2011	76.1	R2	Increase rearing habitat, riparian cover and diversity, topographic variability, and frog and turtle habitat
Lower Steiner Flat	2012	90.7	IC9	Increase rearing and spawning habitat, riparian cover and diversity, and topographic variability
			IC12	
Upper Junction City	2012	79.8–80.4	R6	Increase rearing and riparian
Lorenz Gulch	2013	89.8	R2	Increase rearing habitat, riparian cover and diversity, and topographic variability
			R4	
Limekiln Gulch	2015	99.7–100.6	R1	Increase rearing habitat and hyporheic flow connection
			R2	
Upper Douglas City	2015	93.6–94.6	IC2	Increase rearing, riparian, LWD, topographic variability, and frog and turtle habitat

¹ Construction objectives from individual site reports and/or from Buffington et al. 2014.

Table 3. List of low-flow side-channels that were excluded in the analyses and rationale.

River Mile	Location Name	Feature Name	Rationale for Exclusion from Analysis
105.5–107.0	Dark Gulch	R2	Additional construction completed in 2016 so 2016 topography not representative of natural evolution through time.
105.5–107.0	Dark Gulch	R4	Additional construction completed in 2016 so 2016 topography not representative of natural evolution through time.
93.9–96.9	Indian Creek	R8	Additional construction completed on side-channel during Upper Douglas City (UDC) project. Side-channel evaluated as part of UDC project and not as Indian Creek.
90.7	Steiner Flat	IC6	Never constructed

The side-channel evaluation Tasks include:

1. Use the GCD and aerial photographs to evaluate if deposition has been occurring at the entrance or throughout constructed side-channels and evaluate whether there is a geomorphic setting where side-channels experience less deposition over time.
2. Use SRH-2D model results to evaluate if the side-channel flow threshold has changed at the entrance, and if it has, evaluate the new flow threshold required to induce flow through the entrance to provide flow connectivity from the entrance to the exit.
3. Use 14-day flow duration curves generated for the mainstem Trinity River to evaluate the length of time between January and April (winter juvenile salmon rearing season) that side-channels are flowing at the new flow threshold.
4. Use SRH-2D wetted area outputs for the design flow of 300 or 450 cfs to measure the wetted length of side-channel available under contemporary conditions to evaluate if side-channel wetted length has changed or remained the same since construction.

To address side-channel Task 1, the GCD analysis was used to identify the extent of deposition or erosion at the side-channel entrance and throughout the side-channel. This was used as an informative tool to evaluate if deposition or erosion is impairing flow through the side-channel. To address Task 2, the SRH-2D model was used to predict the side-channel entrance flow threshold. The flow threshold was not met until the side-channel entrance was flowing and there was connectivity of flow through the entire side-channel. In some cases, however, the hydraulic model predicted flow thresholds higher than were known to occur. In such cases (e.g., if a channel was observed to be flowing at the 300 cfs baseflow and the model predicted a 600 cfs threshold) we held the observed value over the modeled value. For Task 3, the 14-day flow exceedance probability between January 1 and April 30 was used as a metric for effectiveness and was based on whether the side-channels are flowing during that time period under contemporary conditions for the same length of time as they did under as-built conditions. If the side-channel is flowing for fewer days under contemporary conditions, then the side-channel is less effective than it was under design conditions. For Task 4, the SRH-2D wetted area outputs were utilized.

First, the GCD results and aerial photos were examined to assess whether obvious deposition or erosion had occurred. Then the SRH-2D areal outputs for a given flow, coupled with the adjacent ground surface elevations, were used to evaluate the magnitude of flow needed to provide full flow connectivity under contemporary conditions (Figure 1).

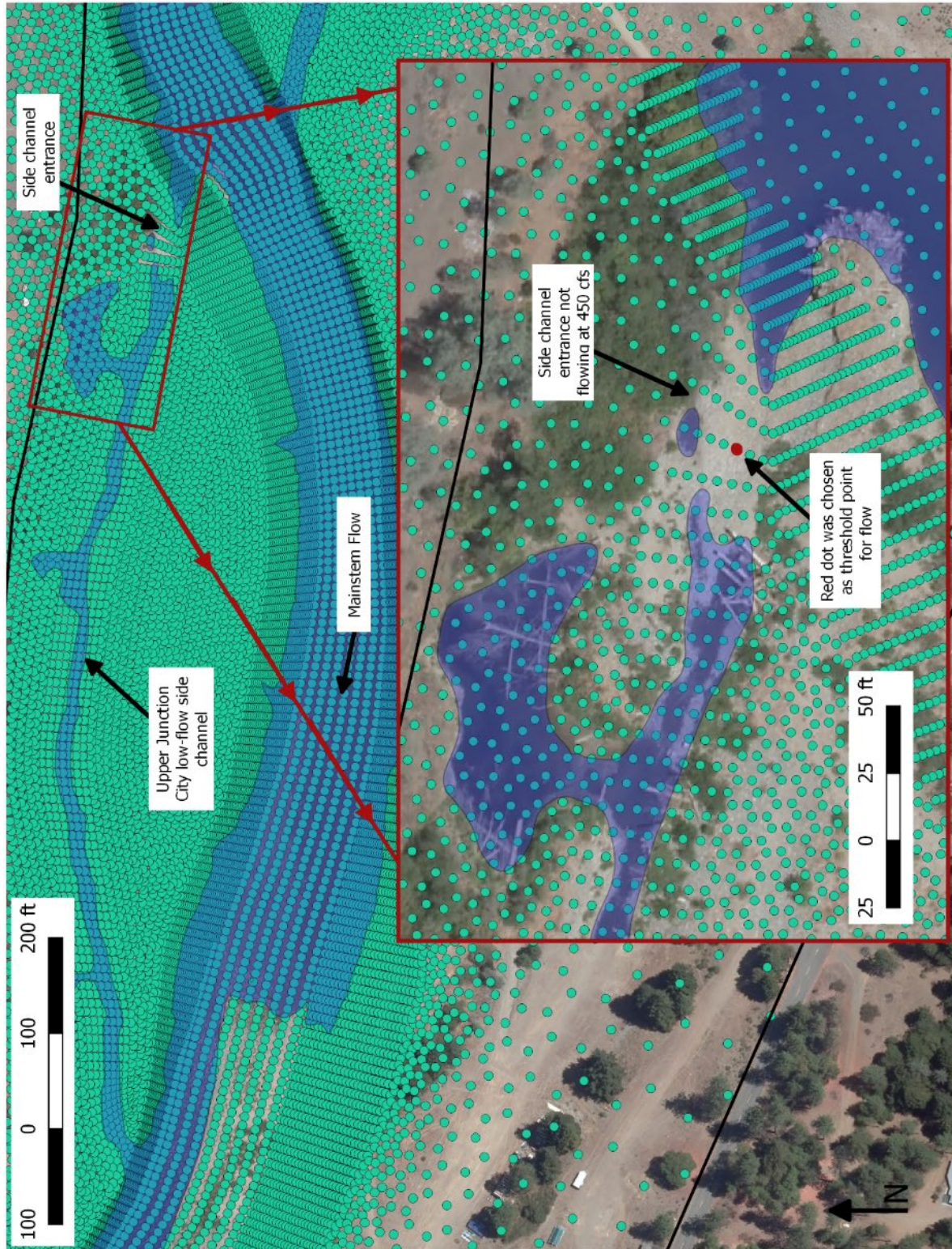


Figure 1. Example of the SRH-2D model output (green dots) and wetted perimeter (purple area) for a flow of 450 cfs at the Upper Junction City (UJC) site. The background map shows the UJC low-flow side-channel and mainstem Trinity River. The inset map shows a closer view of the side-channel entrance and available data points in that area. The red dot is the data point at this site represents the hydraulic control and was used to extract water surface elevations at various flows at this site.

This helped to identify the highest topographic point in the thalweg profile through the side-channel entrance that must be crested before allowing flow down the side-channel. After the side-channel control elevation was identified, the SRH-2D model output at the location of the control was determined and the relationship between the predicted water surface elevation and corresponding mainstem streamflow was used to create a rating curve relating total-channel streamflow to water surface elevation at the side-channel hydraulic control (Table 4, Figure 2). We acknowledge the resolution of the SRH-2D model may be too coarse to accurately predict flow thresholds in all circumstances. For example, in Figure 2, the SRH-2D model results suggest the side-channel entrance does not flow until 1,250 cfs, but the aerial photograph shows connectivity at 1,050 cfs and this value was held over the rating curve prediction. Whenever possible, the SRH-2D rating curve prediction was checked against other data sources such as aerial photographs or field observations. The contemporary flow threshold was then plotted on the 14-day January to April flow duration curve to evaluate if the side-channels have a lower flow exceedance under contemporary conditions.

Table 4. SRH-2D model outputs of streamflow (cfs) and water surface elevations (ft) that were used to describe stage–streamflow relationships (e.g., Figure 2) for the UJC low-flow side-channel. A value of zero means that there was no water flowing over that point for that magnitude of flow.

Site Name	Streamflow (cfs)	Water Surface Elevation (ft)
Upper Junction City Low-Flow Side-channel	450	0
	600	0
	750	0
	900	0
	1,050	0
	1,250	1,453.9
	1,500	1,454.1
	2,000	1,454.4
	2,500	1,454.7
	3,000	1,455.0
	3,500	1,455.4
	4,000	1,455.5
5,000	1,456.3	

Next, each side-channel flow threshold was plotted using the nearest USGS gage or the gage deemed most appropriate for estimating flow magnitude near the side-channel (Appendix 2). Effectiveness was determined on whether the contemporary flow threshold for the side-channel has reduced the number of days during the winter rearing period when juvenile fish could be utilizing the side-channel. The contemporary exceedance probability was divided by the exceedance probability at the time of design to compute effectiveness. For example, the Upper Junction City low-flow side-channel had an exceedance probability of 78% for a flow of 450 cfs at the time of construction. In 2016, the flow threshold had increased to 1,050 cfs which has an exceedance probability of 17% (the decrease is 61%). The contemporary flow exceedance (17%) divided into the designed exceedance of 78% equates to 22% effectiveness (Figure 3). Either the decrease in flow exceedance (61%) or effectiveness (22%) can be used to evaluate the change in function over time. In this report, we focus on effectiveness, computed as the percent change from design to contemporary condition.

To address side-channel Task 3, the SRH-2D model wetted area outputs were used to find the length of wetted channel under contemporary conditions at the design flow of 300 or 450 cfs (Figure 4). This metric was chosen to complement the evaluation of change in side-channel flow thresholds. Evaluating the length of wetted channel at 300 or 450 cfs informs TRRP about the potential length of side-channel that is accessible to fish even if the side-channel entrance is not flowing; effectively, the length of side-channel that is acting as an alcove when the entrance is cut off. The contemporary wetted length was measured solely from the SRH-2D (300 or 450 cfs) wetted area output and assumed that the model output is representative of actual conditions. Contemporary side-channel wetted length was only counted if the wetted length still had connection to the mainstem; disconnected wet sections in the middle of the side-channel were not counted. The “design” side-channel lengths were measured using the 2016 aerial photographs rather than from the design plans because in some cases side-channel alignments were adjusted to accommodate unforeseen conditions, such as shallow bedrock, or to preserve existing mature vegetation. Therefore, measuring the side-channel length from the 2016 air photographs is considered more accurate than the length provided in the construction drawings.

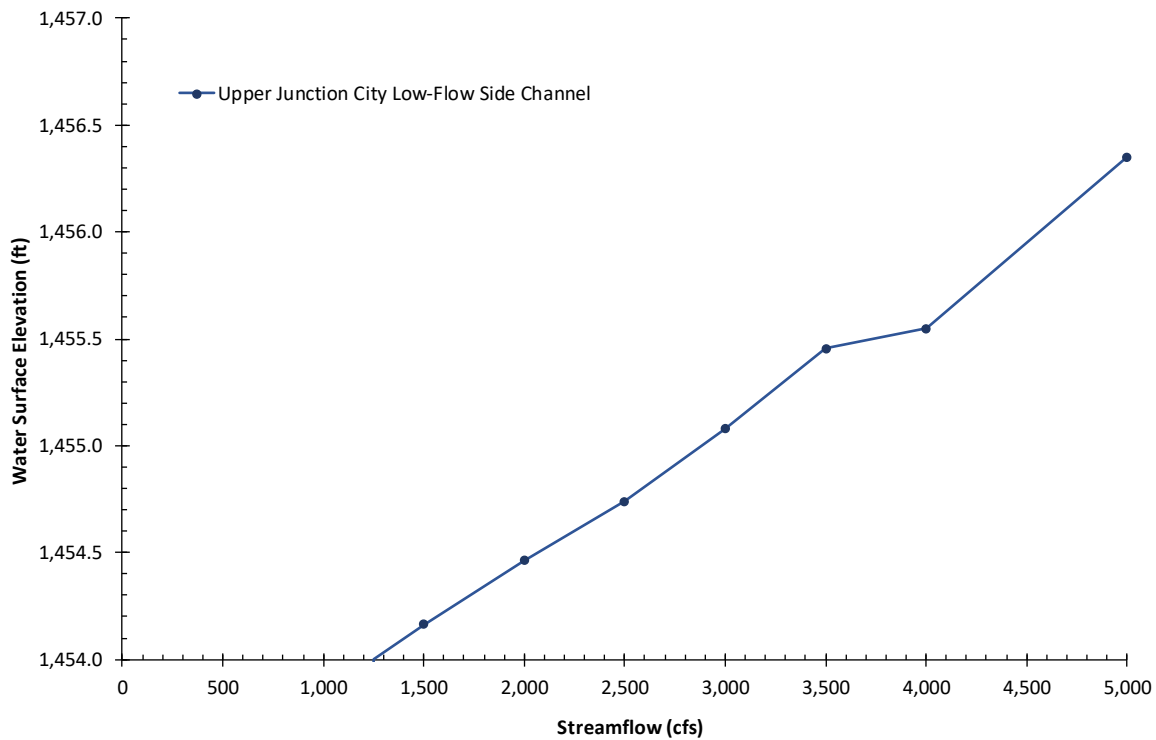


Figure 2. Linear interpolation of the relationship between predicted water surface elevation at the side-channel hydraulic control and total river streamflow generated using the SRH-2D water surface elevation outputs at UJC. The water surface elevations were extracted from the model for flows ranging from 450 cfs to 5,000 cfs (Figure 1), and the resulting rating curve above predicts that the side-channel will begin to flow at 1,250 cfs.

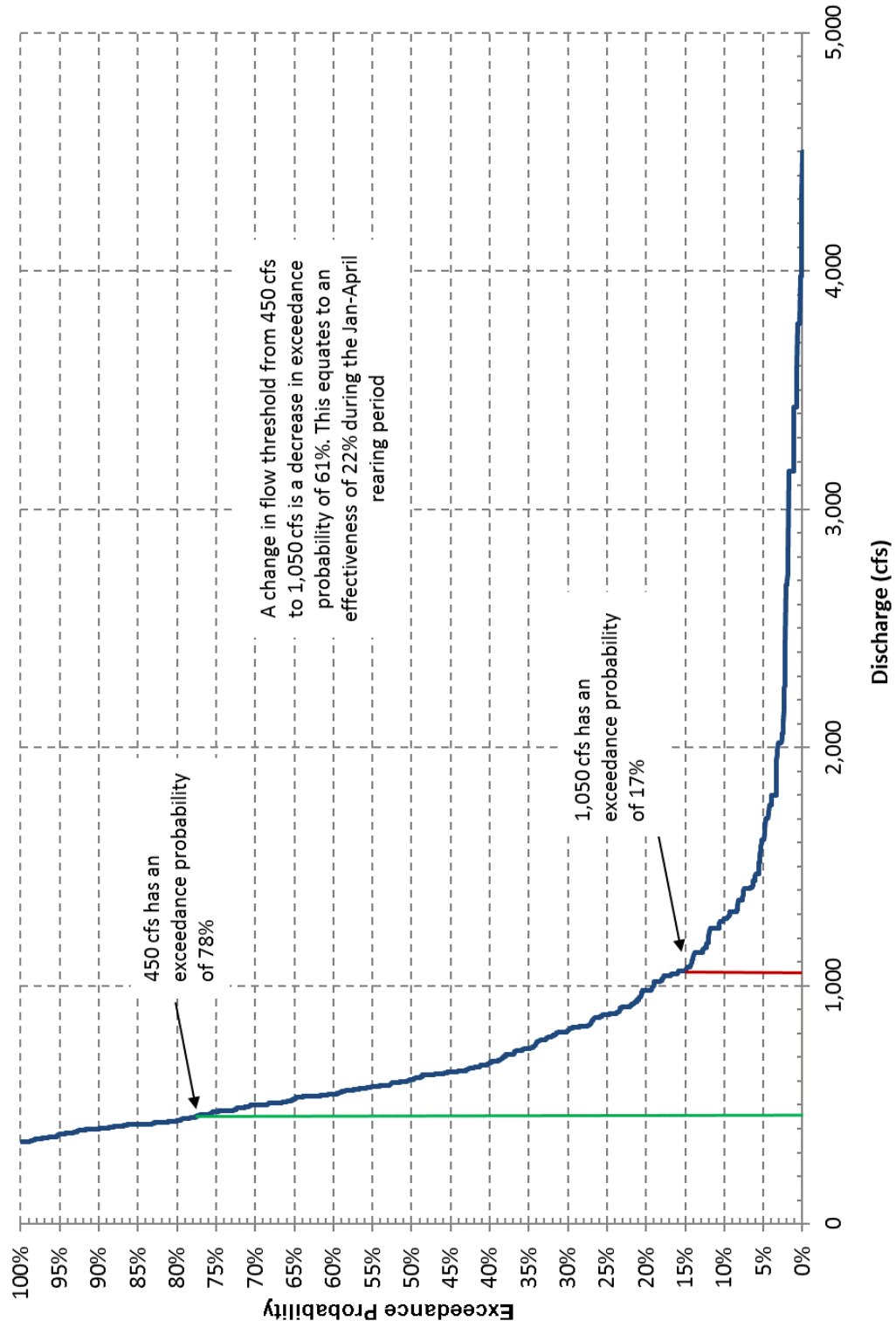


Figure 3. 14-day flow duration curve for the USGS Junction City Gage for the January 1 through April 30 period, incorporating all available data between water year (WY) 2006 and WY 2019. Flow exceedance curves were generated for the Trinity River at each of the mainstem USGS gages and were used to evaluate the exceedance probability at each side-channel. Effectiveness was based on the reduction in flow exceedance under contemporary conditions (1,050 cfs) compared to the flow exceedance at the design flow of 450 cfs. This site has an effectiveness of 22%.

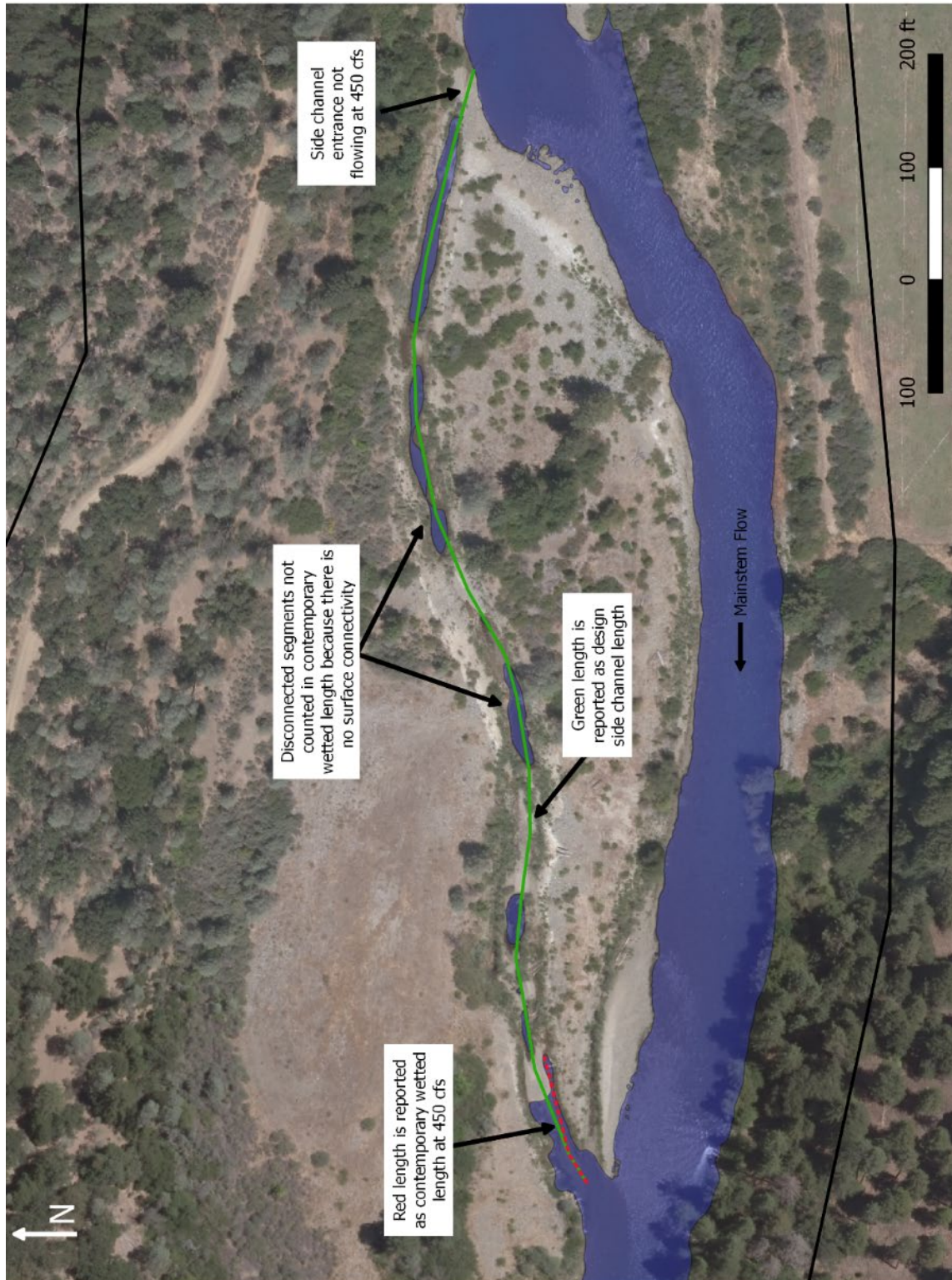


Figure 4. Example at Trinity House Gulch of the side-channel flow connectivity at 450 cfs analysis. The SRH-2D wetted perimeter output for 450 cfs is shown in blue. Effectiveness was evaluated by calculating the percent change in length between the design length and contemporary wetted length. Trinity House Gulch is a special case because there is less flow connectivity through the side-channel but there has been no deposition at the side-channel entrance; instead, channel erosion (downcutting) in the mainstem near the side-channel entrance is the reason for less flow conveyance into the side-channel.

3.2 Side-channel Results

Side-channel effectiveness is described broadly below. More detailed descriptions of side-channel results are presented in Appendix 6: Side-channel Tables and Results, including a description of the GCD results for each site and a table of design versus contemporary wetted channel length. Most (60%) of the side-channels showed deposition at the entrance (Figure 5). Of the 12 side-channels that had deposition at the entrance, four showed greater than 6.0 ft. Although eight (40%) of the side-channels showed no deposition at the entrance, only four (20%) had no deposition anywhere along their length (Figure 6). A large portion (45%) of side-channels had maximum deposition on the order of 1.5–3.0 ft (Figure 6).

The results of the flow threshold analysis showed that 12 side-channels (60%) had increased flow thresholds (and therefore decreased flow exceedance probabilities) required to induce flow through the entrance and provide full connectivity to the exit (Figure 7). Increases in flow thresholds ranged from 75 to 1,800 cfs (median = 675 cfs, Figure 7) and occurred even at sites where deposition was not detected. This can happen if the GCD level of detection failed to show deposition or if mainstem incision occurred. Effectiveness is computed as the ratio of the contemporary versus the designed flow exceedance probability, and results are presented in Figure 7 and in Table 5.

The side-channel length analysis was meant to complement the flow threshold analysis by providing the length of the side-channel that is wet and connected to the mainstem channel even if the side-channel entrance is not flowing (i.e., the length of side-channel that is acting as an alcove). The design flow for sites upstream of Limekiln Gulch is 300 cfs, for sites below (considering accretion) it is 450 cfs (Table 5). The results of the side-channel length analysis showed that 15 of the side-channels had decreased wetted length under contemporary (2016) conditions but that only one was completely dry at that flow (Figure 8). This means the other 14 side-channels still have wetted length at 450 cfs, even though the entrances were not flowing, effectively functioning as alcoves.

Combined, the results of the side-channel analysis showed that 10 (50%) out of 20 side-channels had deposition, increased flow thresholds, and decreased wetted channel lengths at the design flow (300 or 450 cfs). There were three side-channels (15%) that had no change and five (25%) that had deposition but no other change. Two (10%) that had no deposition but had an increased flow threshold and decreased channel length (Figure 9) were Valdor Gulch and Trinity House Gulch.

At Valdor Gulch, because the post-construction survey used in the GCD analysis was performed three years after construction was completed, it is likely that deposition occurred in the channel prior to the post-construction survey and that the design condition was not captured by the GCD. At Trinity House Gulch, the GCD may have missed aggradation at the inlet, and deposition within the length of the channel (which was detected by the GCD) appears to be responsible for a reduction in wetted length. Both of these phenomena appear in the 2016 aerial photograph at 440 cfs (Appendix 1: Location Maps of Sites Included in Analysis). Between 2006 and 2009, there were over 100 days where flows met or exceeded 4,500 cfs (Appendix 4: Flow Data). Sediment deposition during those three years might explain the changes in flow thresholds and wetted length. However, other factors such as erosion in the mainstem channel near the side-channel entrance could also be the reason for the changes; therefore, Valdor Gulch and Trinity House Gulch were separated into their own category.

Another special case occurs at Sven Olbertson and Upper Douglas City. Both sites show a slightly decreased channel length (Figure 8), some level of aggradation and yet exhibit no change in flow threshold (Table 5). This appears to be due to secondary inlets continuing to function near the upstream end of the feature, even after the primary inlet becomes plugged.

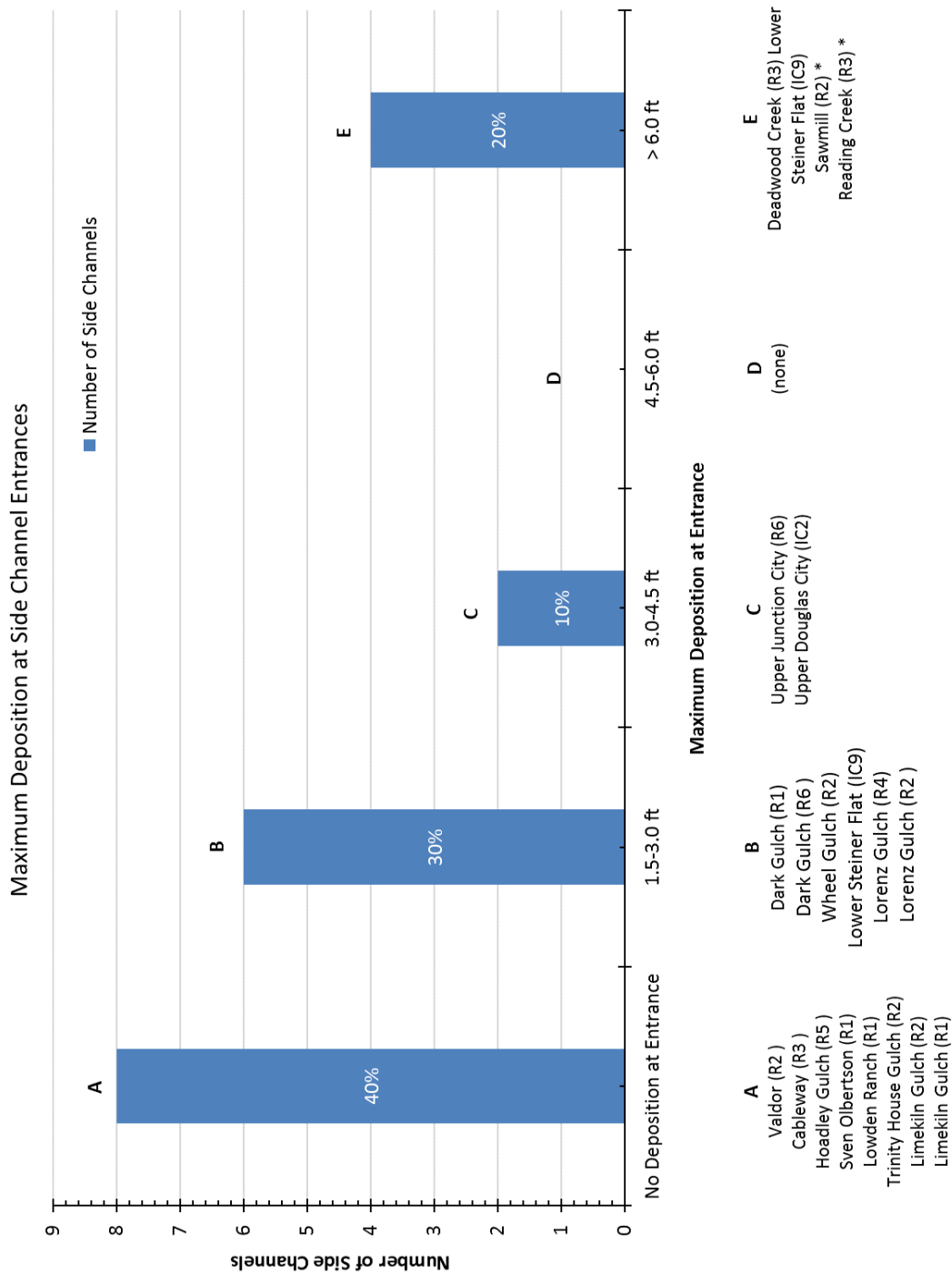


Figure 5. Maximum deposition detected at side-channel entrances in the GCD analysis. The x-axis increments are based on the GCD analysis increments of detection (called “bins”). The figure shows the number of side-channels within each bin, as well as the percent that each bin makes up in the total population. The bottom of the chart lists the side-channels in each bin. Sawmill and Reading Creek (*) are special cases because deposition occurred at these sites prior to the post-construction survey that was used in the GCD analysis. The GCD registered lower amounts of change, but those sites were added to the highest deposition bin because aerial photographs confirmed previous deposition that the GCD was unable to capture. Note that any scour that occurred in the side-channels is not depicted.

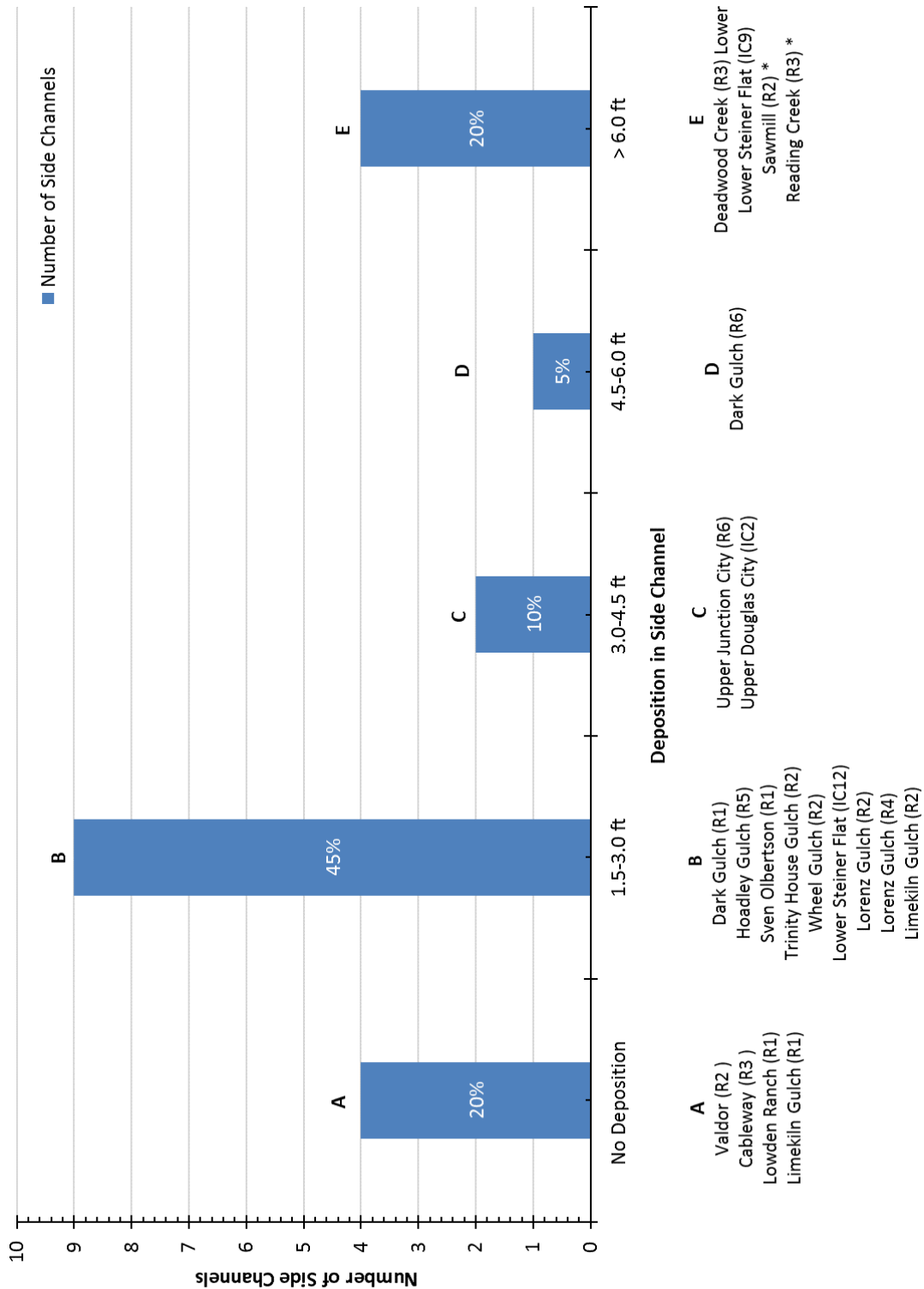


Figure 6. Deposition detected by the GCD analysis that occurred throughout the side-channels (including but not limited to the entrances). The number of side-channels within each bin is shown, as well as the percent that each bin makes up in the total population. The bottom of the chart lists the side-channels in each bin. Sawmill and Reading Creek (*) are special cases because deposition occurred at these sites prior to the post-construction survey used in the GCD analysis. The GCD registered lower amounts of change, but these sites were added to the highest deposition bin because aerial photographs confirmed previous deposition that the GCD was unable to capture. Note that any scour that occurred in the side-channels is not depicted.

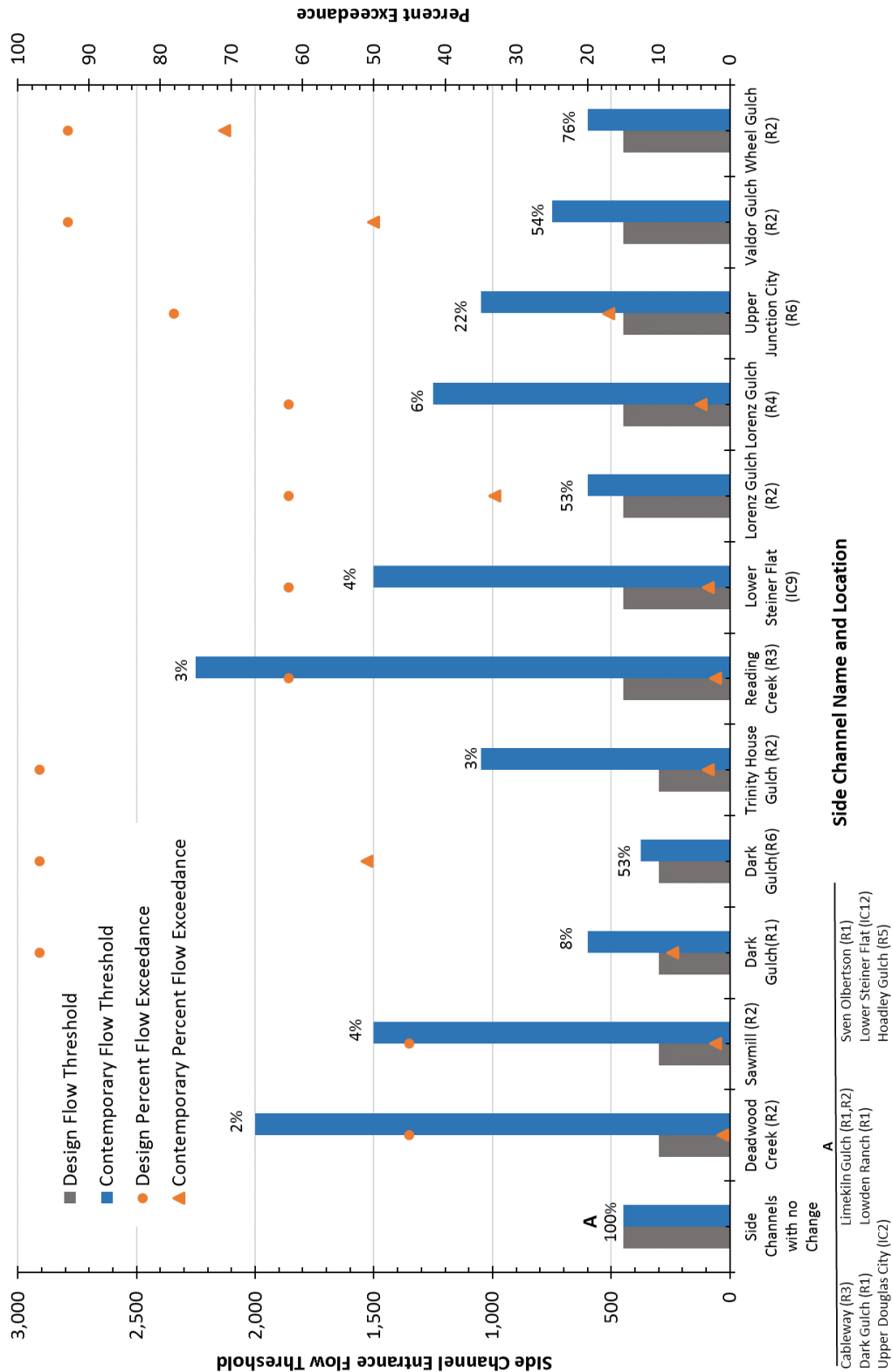


Figure 7. Design and contemporary flow thresholds and percent exceedances for side-channel entrances. The percent effective is reported for each side-channel based on reduction of percent exceedance. The percent exceedance values were calculated using 14-day flow duration curves created for all five USGS streamflow gages on the Trinity River using all available data between 2006 and 2019. Table 5 lists the USGS streamflow gage that was used for each site.

Table 5. Side-channel results for January to April 14-day flow duration

Site Name	Feature Name	Designed Entrance Flow Threshold (cfs)	Design Flow % Exceedance	Contemporary Entrance Flow Threshold (cfs)	Contemporary Flow % Exceedance	Reduction in % Exceedance	% Effectiveness
Sven Olbertson ¹	R1	300	45%	300	45%	0%	100%
Deadwood Creek ¹	R2	300	45%	2,000	1%	44%	2%
Cableway ¹	R3	300	45%	300	45%	0%	100%
Hoadley Gulch ¹	R5	300	45%	300	45%	0%	100%
Sawmill ¹	R2	300	45%	1,500	2%	43%	4%
Dark Gulch ²	R1	300	97%	600	8%	89%	8%
	R6	300	97%	375	51%	46%	53%
Lowden Ranch ²	R1	300	97%	300	97%	0%	100%
Trinity House Gulch ²	R2	300	97%	1,050	3%	94%	3%
Limekiln Gulch ²	R1	300	97%	300	97%	0%	100%
	R2	300	97%	300	97%	0%	100%
Upper Douglas City ³	IC2	450	62%	450	62%	0%	100%
Reading Creek ³	R3	450	62%	2,250	2%	60%	3%
Lower Steiner Flat ³	IC9	450	62%	1,500	3%	59%	4%
	IC12	450	62%	450	62%	0%	100%
Lorenz Gulch ³	R2	450	62%	600	33%	29%	53%
	R4	450	62%	1,250	3%	58%	6%
Upper Junction City ⁴	R6	450	78%	1,050	17%	61%	22%
Wheel Gulch ⁵	R2	450	93%	600	71%	22%	77%
Valdor Gulch ⁵	R2	450	93%	750	50%	43%	54%

1 Lewiston (11525500)

2 Limekiln (11525655)

3 Douglas City (11525854)

4 Junction City (11526250)

5 Above North Fork (11526400)

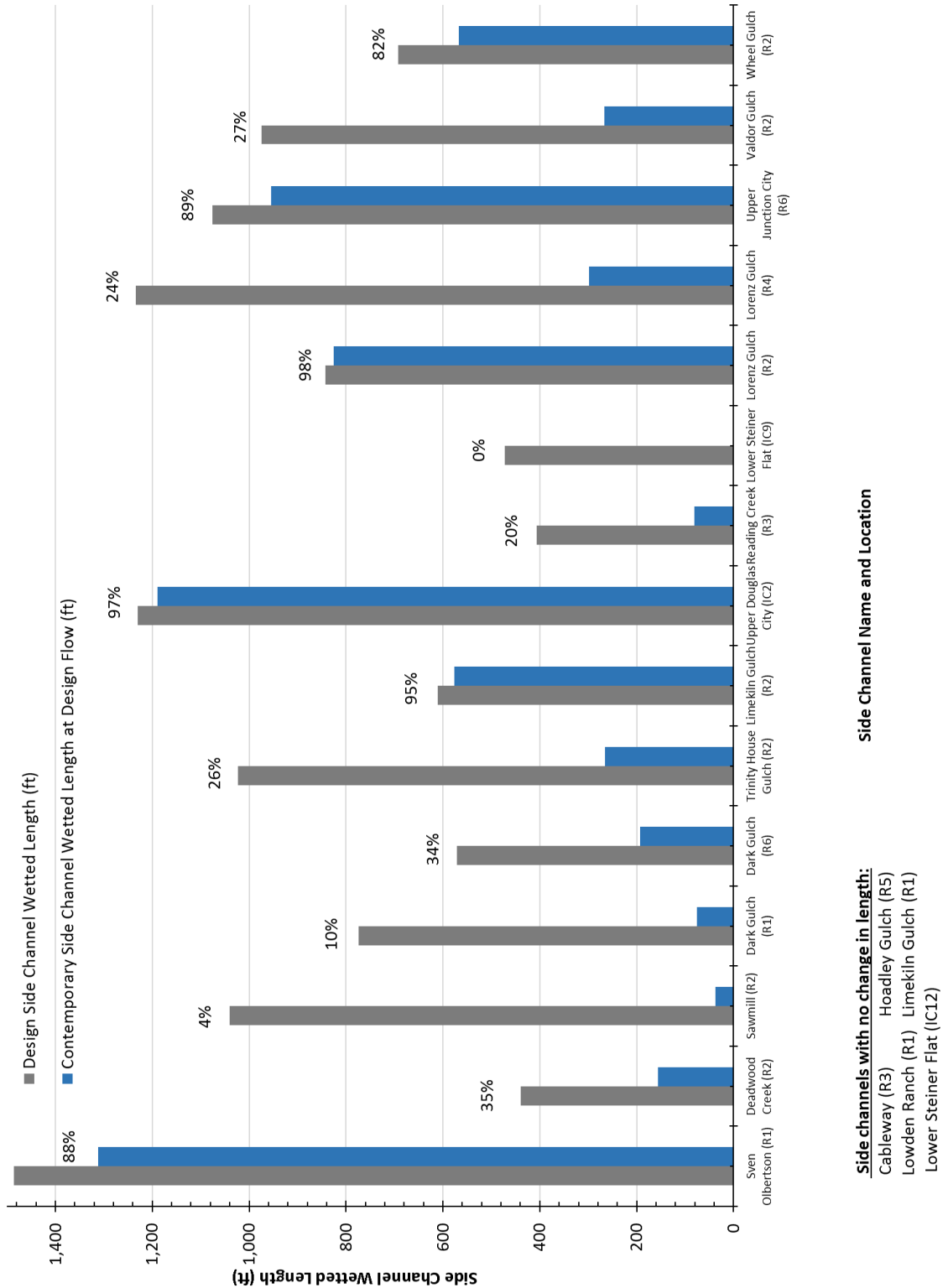


Figure 8. The difference at side-channel features between wetted length under design conditions compared to contemporary conditions at a flow of 300 or 450 cfs, showing whether flow connectivity from the side-channel entrance to the exit has been impaired under contemporary conditions. The percent effective is based on the change in wetted length. The side-channels that had no change in wetted length are listed in the bottom left. Contemporary side-channel lengths were based on SRH-2D wetted area outputs and assume that the model outputs are representative of real conditions.

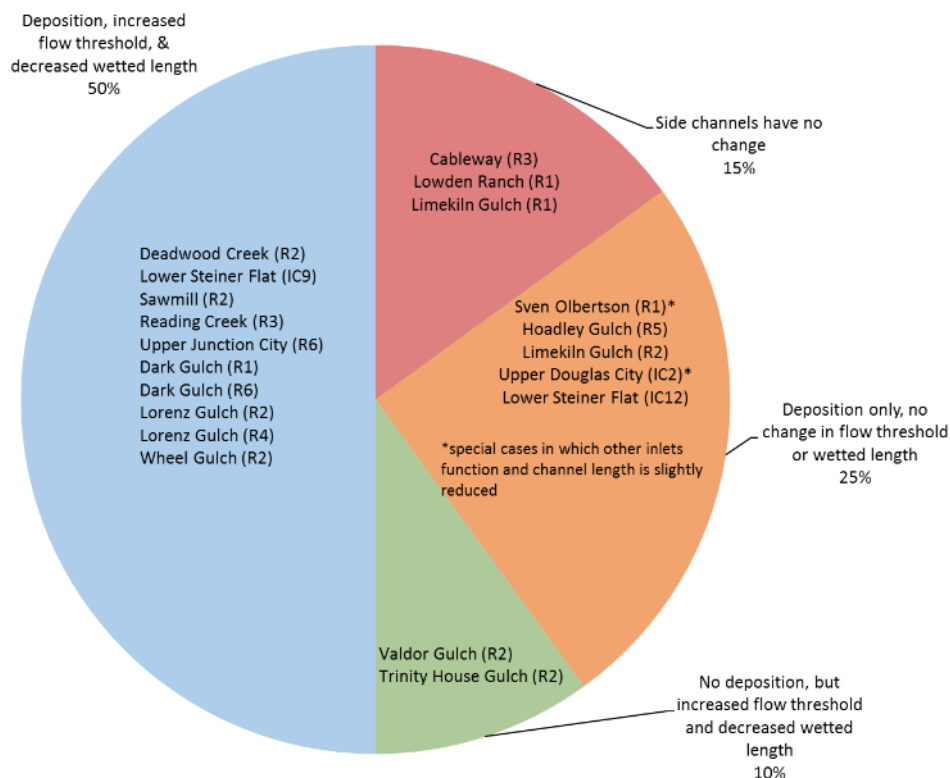


Figure 9. Side-channels grouped by the changes for the four metrics that were evaluated, with the percentage that each group represents in the total population. Overall, half of side-channels experienced some level of deposition, increased flow thresholds, and decreased wetted channel lengths.

3.3 Side-channel Discussion

Results of the side-channel analyses suggest that the geomorphic setting where the side-channels are constructed may be related to their long-term effectiveness and longevity. However, because side-channels have been constructed in many different geomorphic settings (e.g., straight sections of channel, along meander bends, across high floodplains, etc.), it is difficult to identify a single, best setting for side-channels. Regardless, there are still several examples of locations where side-channel effectiveness seems to increase or decrease given the geomorphic setting. For example, the side-channels Reading Creek R3 and Deadwood Creek R2 were both constructed on the inside bank in the middle of a large meander bend, and both showed more than 6 ft of deposition. At these sites, there are large gravel bars located nearby, so the gravel may be feeding directly into the side-channels. This suggests that side-channels may lose effectiveness if they are constructed in areas where deposition is likely to occur. The CDG currently recommends that side-channel entrances be placed either in a location that is not transporting (or depositing) sediment or design the side-channel such that it is capable of transporting any coarse sediment that may enter the side-channel; the findings of this study support the CDG recommendations.

Another geomorphic setting that may impact side-channel longevity is construction across wide, long, floodplain areas such as at Sawmill R2 and Lorenz Gulch R4 (Figure 10). Both of these side-channels exhibited deposition at the entrance and throughout the side-channel. The side-channel at Sawmill experienced greater deposition than the Lorenz Gulch R4 channel, with the difference potentially linked to the side-channel entrance position. The Lorenz Gulch R4 side-channel entrance is located adjacent to a riffle, while the Sawmill R2 side-channel entrance is located between riffle crests at the end of a run. The Sawmill R2 side-channel is also in a complex environment where the mainstem channel branches into three channels, with R2 being the middle channel (Figure 10). Since it is located at the end of a run, winds across a wide floodplain, and has

less flow than the other two channels, the energy dynamics may favor sediment deposition during high flows, causing the side-channel to fill with sediment. The CDG currently recommends that no more than two to three total channels be constructed at flow splits due to increased risk of sedimentation. The Sawmill site is a good example of this increased risk. Therefore, we propose revising the CDG to recommend a maximum of two channels be constructed.

Three of the most effective side-channels were Lewiston Cableway R3, Lowden Ranch R1, and Limekiln Gulch R1, all of which showed no signs of deposition on the GCD analysis. Other researchers have reported flow reductions at the Lewiston Cableway site due to incision in the mainstem (Boyce et al. 2020). All three of these side-channels are positioned in fairly straight sections of river and the entrances are either immediately upstream of the closest riffle crest or located directly adjacent to the riffle. Side-channels that do have deposition, but only between 1.5–3.0 ft, are Dark Gulch R1, Hoadley Gulch R5, Sven Olbertson R1 and Trinity House Gulch R2, all of which have entrances that are also immediately upstream or directly adjacent to riffle crests. Upper Douglas City is a special case where the upstream side-channel entrance has been plugged, but there is a second side-channel entrance downstream that did not have deposition and that provided flow to the side-channel. The second downstream entrance is also located directly upstream of a riffle crest. The CDG currently recommends that the entrance should be located on the outside of a meander bend, on the downstream portion, but upstream of the transverse bar to reduce the risk of sedimentation. The results of this study suggest that this recommendation should be expanded to include constructing side-channel entrances immediately upstream of or directly adjacent to riffle crests. Further, other researchers (Bolla, 2003; Burge, 2006; Kleinhans et al. 2012) found that side-channels form where the river widens as it approaches a riffle and that side-channel entrances should be located at the heads of riffles.

The results of this study suggest that large wood at the side-channel entrance plays a role in preventing sediment deposition. Side-channels that had only 1.5–3.0 ft of deposition, except the ones discussed above that were constructed at riffle crests, had large wood jams constructed at the entrances. This includes Wheel Gulch R2, Lower Steiner Flat IC12, Lorenz Gulch R2, and Limekiln Gulch R2. Other side-channels that have experienced deposition between 3.0 and 6.0 ft include Dark Gulch R6 and the upstream entrance of Upper Douglas City IC2, did not have constructed large wood jams at the entrances. One exception is Upper Junction City R6, which had experienced deposition of up to 4.5 ft and did have a constructed log jam at the entrance. However, the position of the side-channel entrance is very complex because it is located between two riffle crests and at the transition point between meander bends. Therefore, other factors are likely influencing deposition at the site. The CDG recommends against large wood placement at the side-channel entrance; however, results of this study suggest large wood placed at side-channel entrances may inhibit deposition and could improve longevity and function if wood placement creates a cross-channel flow gradient, steering sediment away from side-channel entrances.

In summary, the most successful side-channels appear to be ones where the side-channel entrance was constructed immediately upstream or directly adjacent to a riffle crest, had large wood constructed at the entrance, and were in a relatively straight section of river. The least successful side-channels appear to be ones that were constructed in areas with lower energy dynamics, such as on the inside bend of large meanders and across complex, multi-channel floodplains. Currently the CDG recommends that side-channels be constructed on the downstream side of the outside meander bend and that the entrances should be above the riffle crest. This study supports the CDG recommendation. The CDG also recommends avoiding constructing side-channels in depositional reaches, and this study provided additional examples of side-channels that have incurred sediment deposition from being constructed in those settings. The CDG does not currently recommend placing large wood at the side-channel entrances due to risk of causing sedimentation; however, this study found a positive relationship between large wood at the side-channel entrances and side-channels that have less deposition.



Figure 10. 2016 aerial photographs showing the geomorphic setting of side-channel R2 at Sawmill (top) and side-channel R4 at Lorenz Gulch (bottom). Both side-channels were constructed across wide floodplain areas and both have experienced deposition at the entrances. Deposition at Sawmill may have been greater because the flow splits into three channels, causing less flow and higher deposition in R3, and/or because the entrance is not positioned adjacent to or directly upstream of a riffle crest.

4 SPLIT-FLOW CHANNEL EFFECTIVENESS ANALYSES

The metrics utilized to assess split-flow effectiveness include:

- 20% flow conveyance under contemporary 450 cfs baseflow conditions

4.1 Split-flow Channel Methods

Split-flow channels are features where a section of single-thread mainstem channel splits into two threads of channel, separated by a medial bar, for a short distance (generally less than $\frac{1}{2}$ of a meander wavelength) before converging back to a single thread mainstem channel. Total channel widths and medial bar widths at naturally occurring split-flow features were compared to widths at constructed split-flow features to evaluate if constructed split-flow features are evolving through time to have similar dimensions as natural split-flow features. This provides insight on whether there is a channel width which supports medial bar formation and persistence. The naturally occurring split-flow features that were chosen for comparison are alluvial, unlike many bedrock islands that also occur on the Trinity River. Fourteen split-flow channels are included in the split-flow channel effectiveness evaluation. Six split-flow channels were constructed, and eight split-flow channels are naturally occurring or have evolved because of engineered changes adjacent to them. The naturally occurring split-flows have persisted since at least 2007.

The CDG suggests constructing split-flow channels so the smaller of the two channels conveys at least 20%, but less than 50%, of the flow. Split-flow effectiveness was evaluated using a 20% flow conveyance for 450 cfs under contemporary conditions. A total of 14 split-flow channel features were evaluated (Table 6). Six constructed split-flow features are listed in the TRRP online database; however, eight additional naturally occurring split-flow features were identified and included in the analyses. Split-flow channels were chosen because they provide channel complexity in otherwise semi-uniform sections of river, and because there is a naturally occurring population of split-flow channels, which provided an opportunity to compare natural and constructed split-flow channels. The reported percent effectiveness for each constructed split-flow channel was solely calculated based on whether each side of the split-flow channel was still conveying at least 20% of the total flow under contemporary conditions. Three additional evaluations (described for Tasks 1 and 3 below) were used to assess whether additional design measures can be taken to increase the longevity of split-flow features.

The split-flow channel effectiveness analysis Tasks include:

1. Use the GCD results and review aerial photographs to evaluate how the split-flow channel and medial bar geometry have evolved, including any deposition, erosion, or channel migration that has occurred.
2. Use SRH-2D depth and velocity model outputs to calculate the percent of total flow that each split is receiving under contemporary conditions at 450 cfs to evaluate if split-flow channels are still receiving 20% of the total flow. If split-flow channels are not flowing at 450 cfs under contemporary conditions, use SRH-2D wetted area outputs to determine new flow thresholds.
3. Use aerial photographs to evaluate if persistence of split-flow channels is reliant on a minimum channel width by comparing total channel widths and medial bar widths of both naturally occurring split-flow channels and constructed split-flow channels.
4. Use aerial photographs to measure bifurcation angles to examine whether a relation exists between bifurcation angle and split-flow effectiveness.

Table 6. Split-flow feature location, construction year, and feature name. The naturally occurring split-flows have persisted since at least 2007.

Site Name	River Mile	Year Constructed	Feature Name
Lowden Ranch	104.4–105.3	2010	R7
Upper Douglas City	93.6–94.6	2015	IC7
Reading Creek	92.2–93.2	2010	R5
Reading Creek	92.9	NA	No feature name, naturally occurring
Lower Steiner Flat	90.3	NA	No feature name, naturally occurring
Lorenz Gulch	89.8	2013	IC3
Lower Dutton Creek	88.9	NA	No feature name, naturally occurring
Dutch Creek	85.3	NA	No feature name, naturally occurring
Chapman Ranch	83.7	NA	No feature name, naturally occurring
Deep Gulch and Sheridan Creek	82.5	NA	No feature name, naturally occurring
Oregon Gulch	81.2	NA	No feature name, naturally occurring
Upper Junction City	79.8–80.4	2012	R4
Hocker Flat	78.8	NA	No feature name, split-flow channel developed as a result of the massive floodplain grading that occurred on the left bank.
Wheel Gulch	76.1	2011	R1

For Task 1, the GCD results were used to evaluate if the split-flow channels are aggrading, eroding, or migrating. The aerial photographs were used to further evaluate planform changes at each site (Figure 11).

To address Task 2, the SRH-2D model outputs for area and velocity were used to calculate streamflow to estimate if constructed split-flow channels are conveying at least 20% of the total flow under contemporary conditions. This analysis was completed for both the natural and constructed split-flow channels to compare the flow conveyance in constructed split-flow channels to the flow conveyance in naturally occurring split-flow channels. Comparing the two types provides insight on whether constructed split-flow channels are adjusting through time to achieve a channel geometry that is similar to naturally occurring split-flow geometry. Using the 2016 SRH-2D hydraulic model, surface triangular irregular networks (TINs) were built from the calculation mesh for depth and velocity at 450 cfs and confined to the 450 cfs wetted area polygon. At constructed split-flows, digitized cross sections were developed to assess the percentage of water flowing into the split channel versus the mainstem channel. Two different sets of cross sections were used to evaluate the percent flow in each constructed channel (i.e., the evaluation was completed twice at each site using two different sets of cross sections to evaluate the consistency of the model outputs; (Figure 12). The average of the two data sets was used to evaluate effectiveness. Using ArcGIS, average depths and velocities were extracted from the TINs at each cross section. The same analysis was conducted for the naturally occurring split-flows.



Figure 11. Aerial photographs from 2014–2016 that show deposition occurring through time in the split-flow channel at Wheel Gulch, constructed in 2011. The 2014 aerial photo is shown instead of the 2011 aerial photo because no noticeable change occurred between 2011 and 2014, and the 2014 image is of better quality. Note that deposition is occurring only within the right bank split-flow channel, which meanders, while no deposition is occurring in the left bank split-flow channel, which is straight. The reported streamflow on each aerial photograph is daily average streamflow from the Trinity River above North Fork gage (USGS # 11526400).

The standard formula was used to calculate streamflow (cfs) at each cross section:

$$Q = (A) \times (V)$$

Where:

Q = Streamflow, in cfs

A = Channel cross sectional area (ft²), computed by multiplying width by average depth

V = Flow velocity (ft/s)

To accomplish Task 3, medial bar and total channel widths at naturally occurring and constructed split-flow locations were measured and digitized using GIS (Figure 13). The ratio of medial bar width to total channel width was calculated for each split-flow channel to evaluate if the size of the medial bar that forms and persists is related to the total channel width. Then, a comparison of total channel width and medial bar width was made between the naturally occurring and constructed split-flow channels.

To accomplish Task 4, we digitized the centerline of each split-flow channel and projected them upstream to a point of convergence (Burge 2006) and measured this angle with a digital protractor. The method may under-estimate some angles as the alignment of the split-flow channel may differ from that of the entrance. We accounted for such anomalies by choosing the alignment of the entrance of the divergent channel where it seemed appropriate.

4.1 Split-flow Channel Results

Detailed descriptions of split-flow channel results for both constructed and naturally occurring split-flow channels can be found in Appendix 7: Split-flow channel Tables and Results. Flow conveyance was evaluated to determine how flow is distributed between the channels and whether that varies under contemporary conditions compared to design conditions. Effectiveness was calculated solely based on whether each side of the split-flow channel was conveying at least 20% of the flow under contemporary conditions. Medial bar widths and flow conveyance of naturally occurring split-flow channels were used as a comparison to assess whether there are width relations that allow split-flow channels to persist and if recommendations based on those channel dimensions could be added to the CDG.

The GCD and aerial photograph results showed that all six constructed split-flow channels experienced erosion on the medial bar and that three of the six had deposition in at least one of the channels. The GCD and aerial photographs showed that a few of the naturally occurring split-flow channels also experienced erosion of the medial bars, but not to the same degree as constructed split-flow channels.

Overall, the naturally occurring split-flow channels showed very little change in dimension or shape, which may be a function of the minimum channel width required for the medial bar to form. We compared the total channel width at low flow (bank to bank including both channel widths and the medial bar width) for the naturally occurring split-flow channels to the width of the medial bar, to assess whether there is a relationship between total width and medial bar width (Figure 14). The results show that the naturally occurring total channel width was between 170 and 240 ft, and that at seven of the eight split-flow channels, the medial bar width comprised 30 to 40% of the total channel width. This pattern suggests that the width of medial bars that form naturally may be related to the total channel width, which also suggests that the persistence of these features may be related to a minimum channel width.

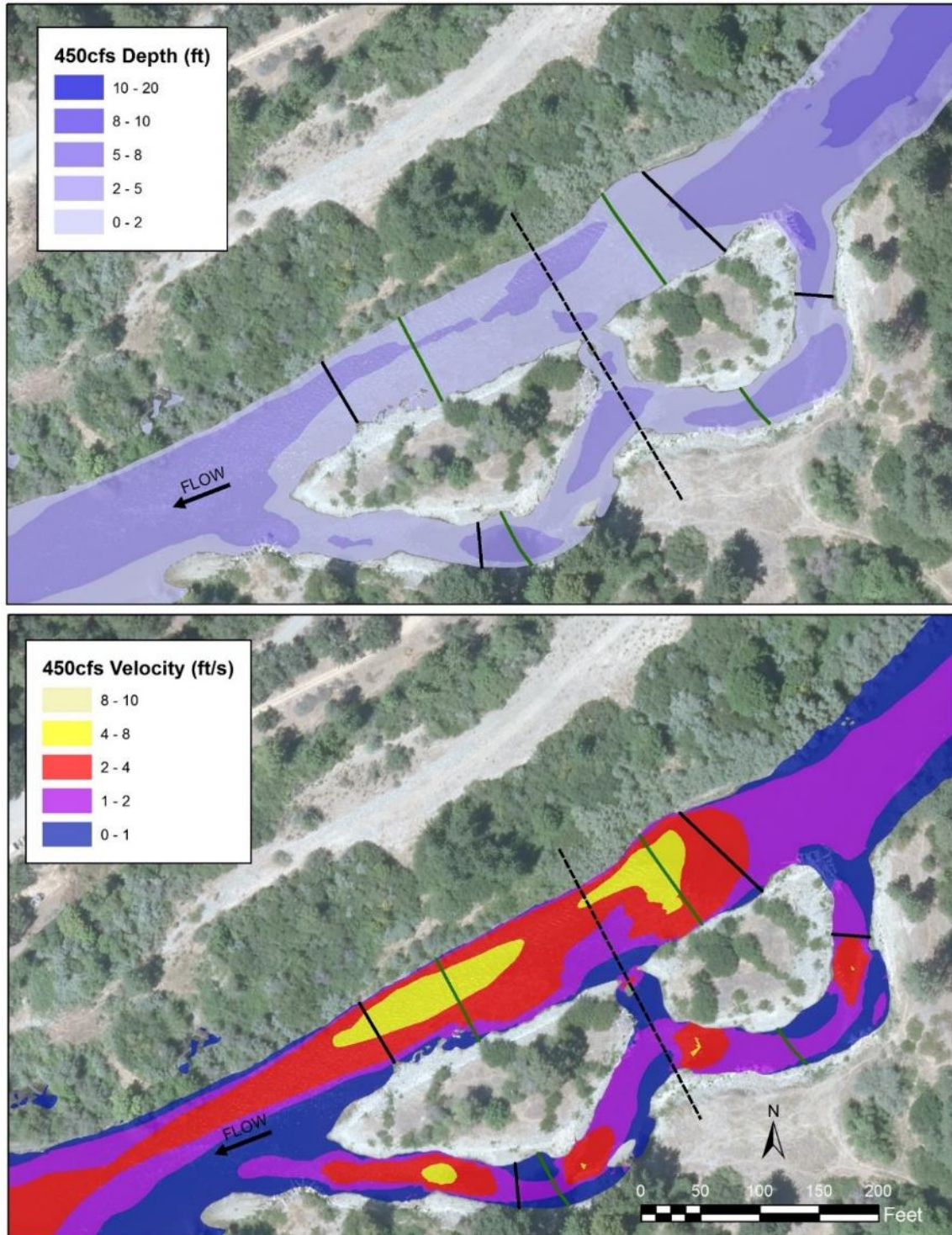


Figure 12. Depth and velocity outputs extracted from the 2016 SRH-2D model shown as color maps at the Lowden Ranch site. The black dashed line shows that for this analysis, the split-flow feature was separated into an upstream split-flow site and a downstream split-flow site. This was done so any flow changes due to the mainstem connection in the middle could also be assessed. The black and green solid lines are digital cross section locations where depth and velocity data were extracted from the SRH-2D model to calculate streamflow. Note that the streamflow was calculated twice at each constructed site to evaluate model output consistency (one green cross section placement and one black cross section placement) and the average streamflow was used to evaluate effectiveness.

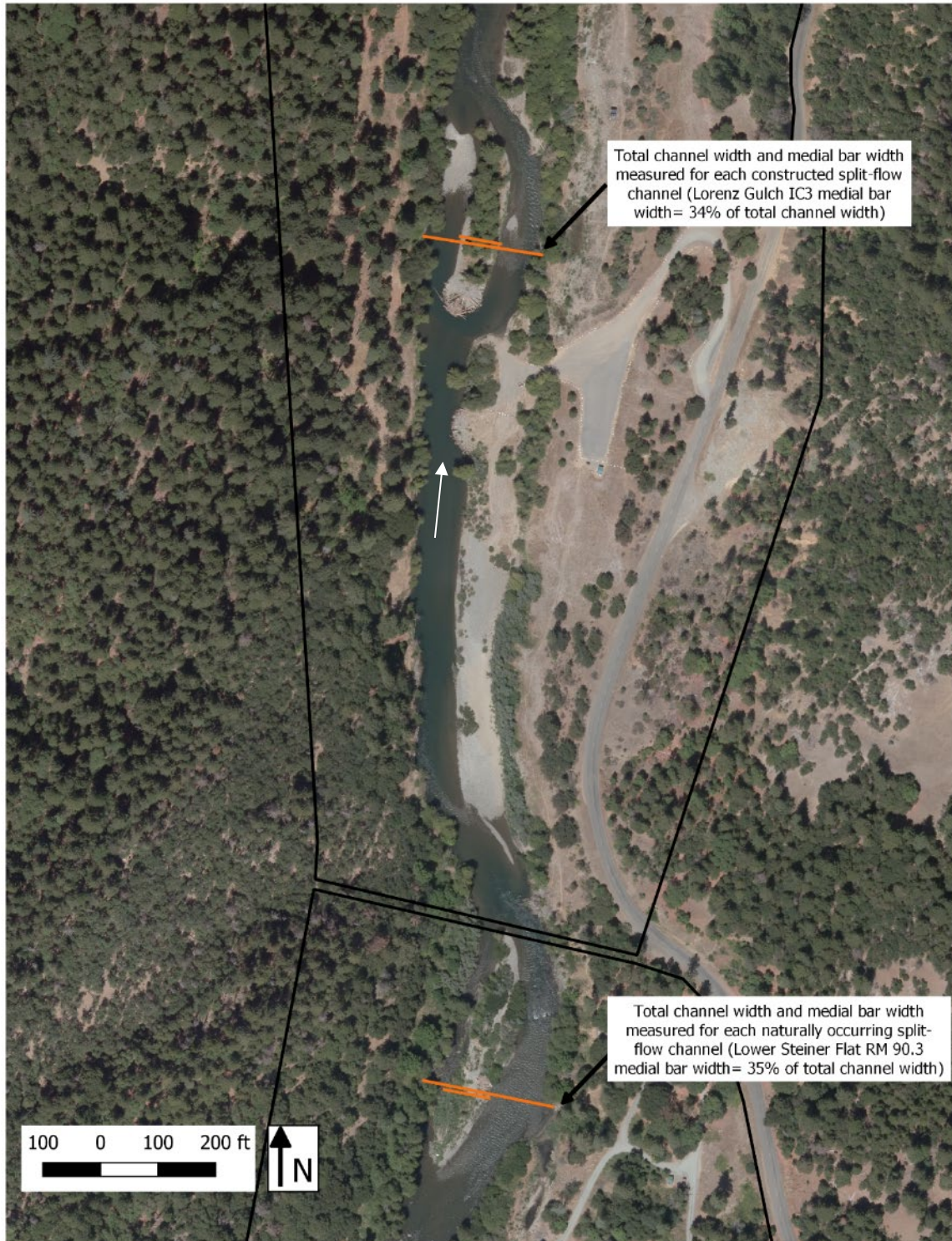


Figure 13. 2016 aerial photograph showing how total channel widths and medial bar widths were measured in GIS to compare the percentage that the medial bar makes up in the total channel width for both the constructed and naturally occurring split-flow features. This comparison evaluates whether total channel width is related to the size of the medial bar that forms and persists. This was also used to explore whether constructed split-flow channels are adjusting (eroding or aggrading) through time to achieve a balance between total channel width and medial bar width. Note that the percentage that the medial bar width makes up in the total channel width is very similar at these two sites.

To explore if the same pattern exists in the constructed split-flow channels, the total channel widths and medial bar widths were also measured using aerial photographs. Results showed there is a relationship between total channel width and medial bar width, with wider channel widths having wider medial bars (Figure 15). For example, at both Lowden Ranch split-flow channels, the total channel width was nearly 250 ft and the medial bars comprise between 40 to 50% of that width. The Upper Douglas City and Reading Creek total channel width was much lower (approximately 150 ft) and the medial bars show severe erosion and have narrowed to between 10–20% of the total channel width. Wheel Gulch, which has the widest channel width at almost 300 ft, also had the widest medial bar width that comprises 51% of the total channel width. The most interesting cases are at Lorenz Gulch and Upper Junction City, where the total channel width was slightly more than 200 ft and the bar comprised 34% of that at both sites. This is very similar to the medial bar percentage and total channel widths seen in the naturally occurring split-flows. It is important to note that these are existing condition widths and not design widths. This is important because assuming that the current total channel width is the same as the design width, the medial bars have adjusted in size according to the total channel width. This suggests that there is a minimum channel width required for medial bars to persist.

The flow conveyance results showed that four of the six constructed split-flow locations still had a minimum of 20% of flow in each channel (Figure 16). The two split-flow locations that did not have at least 20% of flow in each channel were Upper Douglas City and Reading Creek, both of which had severe erosion of the medial bar that separates the split-flow channels. These sites also had the lowest bifurcation angles of all constructed split-flow channels at 14° and 20° respectively (Appendix 7, Table 7-7). The flow conveyance results for the naturally occurring split-flow channels showed that five of the eight split-flow locations had a minimum of 20% of flow in each channel, which is a similar ratio to the constructed channels (Figure 17). The three naturally occurring split-flows with less than 20% of the total flow in one channel also had the lowest bifurcation angles (20°, 24° and 33°, Appendix 7, Table 7-8). This shows that naturally occurring split-flow channels are persisting even if they have low bifurcation angles and one split is receiving less than 20% of the flow. This indicates that other factors besides flow or bifurcation angle, such as channel width or geomorphic setting within the mainstem, also have an impact on split-flow channel longevity.

4.1 Split-flow Channel Discussion

The split-flow channel analyses suggest that there is a linkage between channel width and medial bar persistence through time. This is most apparent for the naturally occurring split-flow medial bar widths, which for seven of the eight sites was 30–40% of the total width. The contemporary channel widths and medial bar widths of the constructed split-flow channels also show a pattern: wider channels have wider medial bars. The two least successful split-flow channels are Reading Creek and Upper Douglas City, where the medial bar has been eroded to such an extent that only a sliver remains. These two sites also have the narrowest total channel widths, approximately 150 ft, compared to all other constructed split-flow channels, which are 200 ft or greater. This suggests that a total channel width of 150 ft is not wide enough for a medial bar to persist. The narrowest naturally occurring split-flow channel width is 172 ft at river mile 85.3. The CDG provides recommended lengths for split-flow features but does not recommend a specific width. This study suggests that the constructed total channel width should be no less than 170 ft.

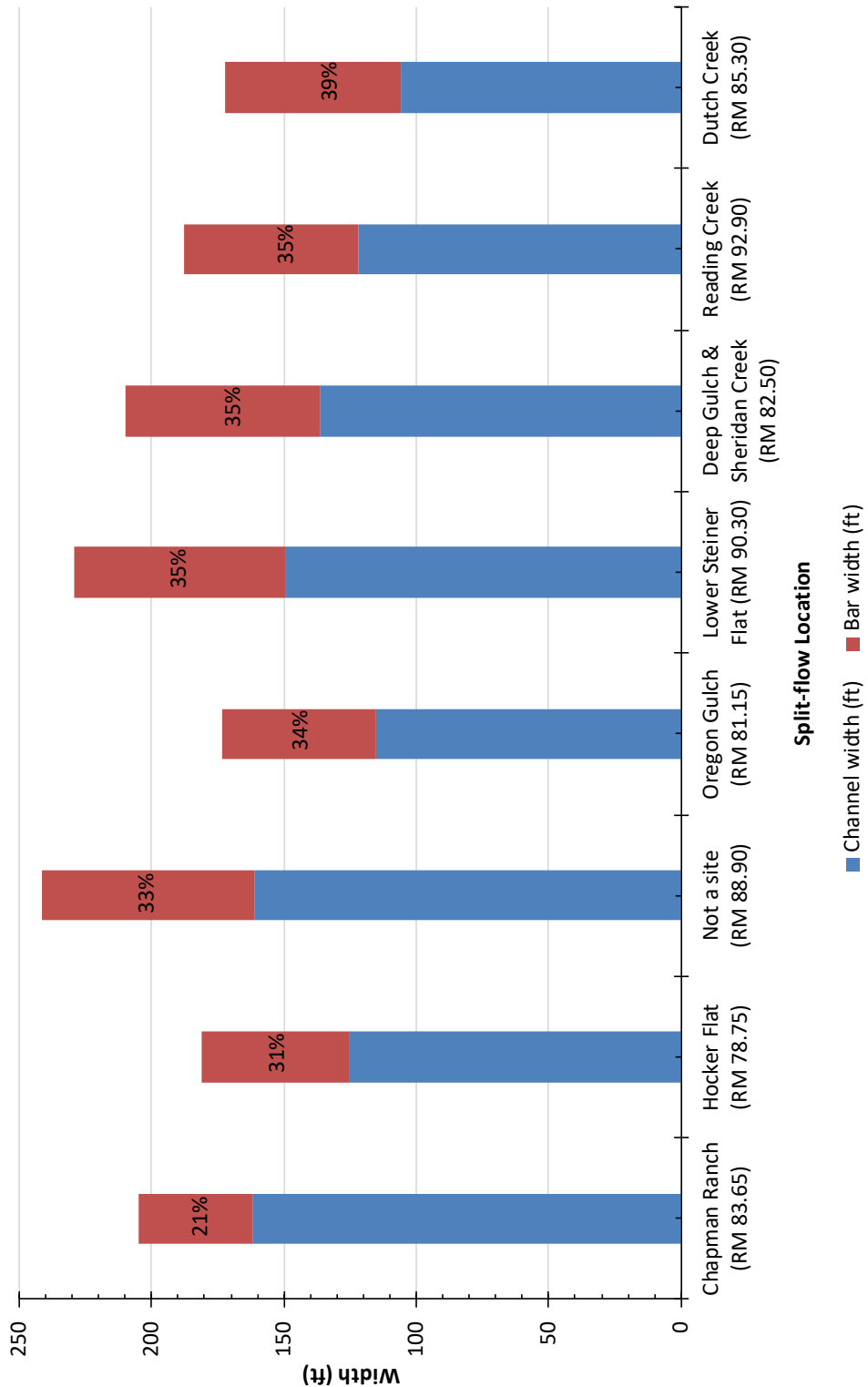


Figure 14. Ratio of bar width to total channel width at naturally occurring split-flow channel locations in 2016. The percentage of the total channel width made up of the medial bar is shown for each split-flow channel. River mile is shown for the naturally occurring split-flow channels because they don't have feature names. Note that seven of the eight split-flow locations have medial bar width between 30% and 40% of the total channel width. This suggests that there is a relationship between medial bar formation, persistence through time, and total channel width. "Not a site" means the split-flow channel occurs outside of any TRRP sites that have been named.

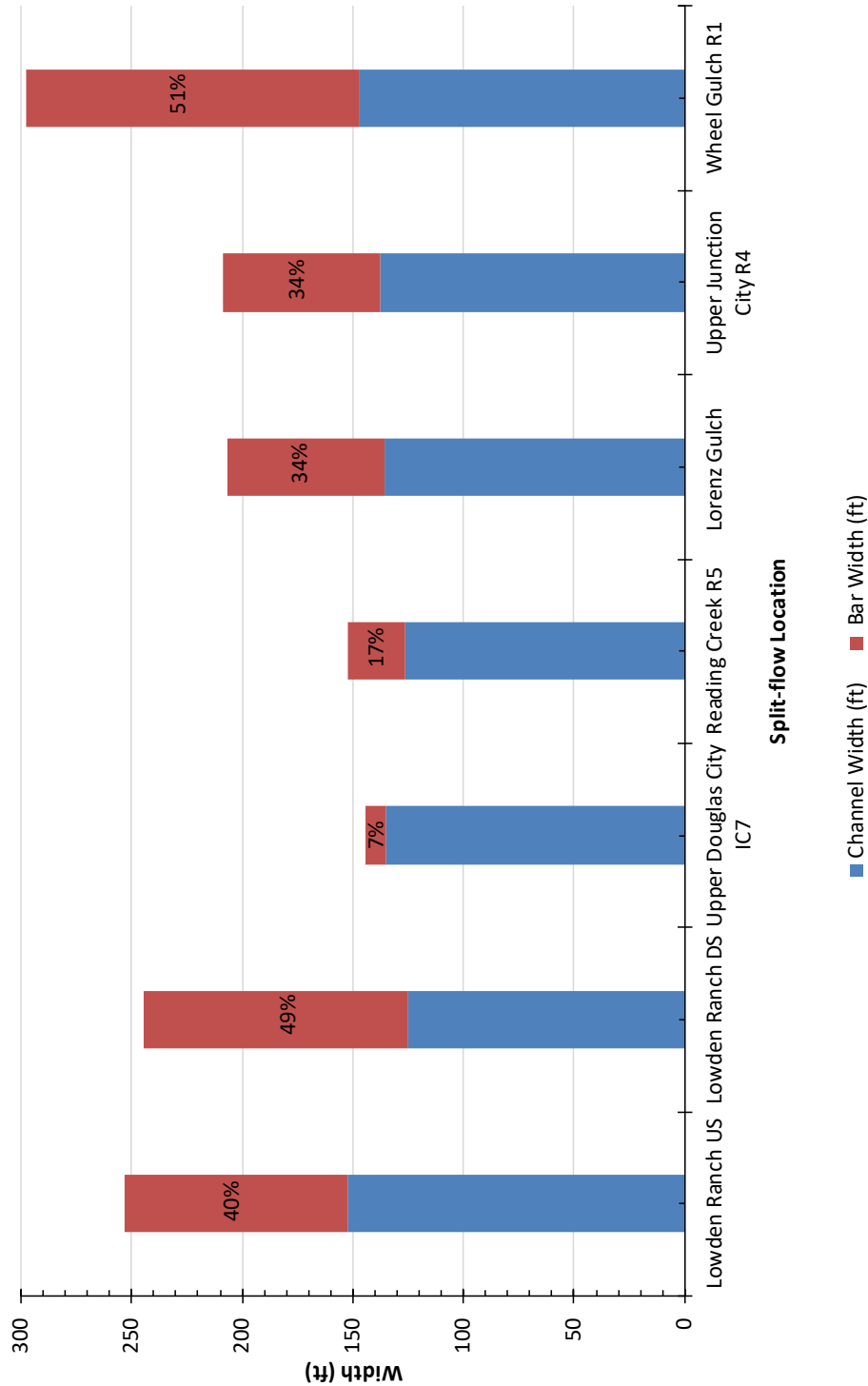


Figure 15. Total channel width and medial bar width at constructed split-flow channel locations. The percentage of the total channel width made up of medial bar is shown for each split-flow channel. The Lorenz Gulch and Upper Junction City split-flow channels have a very similar total channel width and medial bar percentage as the naturally occurring sites discussed (Figure 14). The Reading Creek and Douglas City split-flow channels have the narrowest total channel widths and have had the most erosion on the medial bars, which suggests that there may be a minimum channel width associated with longevity of medial bars. The results also show that as the total channel width increases, so does medial bar width, which suggests that total channel width influences the width of the medial bar that can persist at constructed split-flow channels.

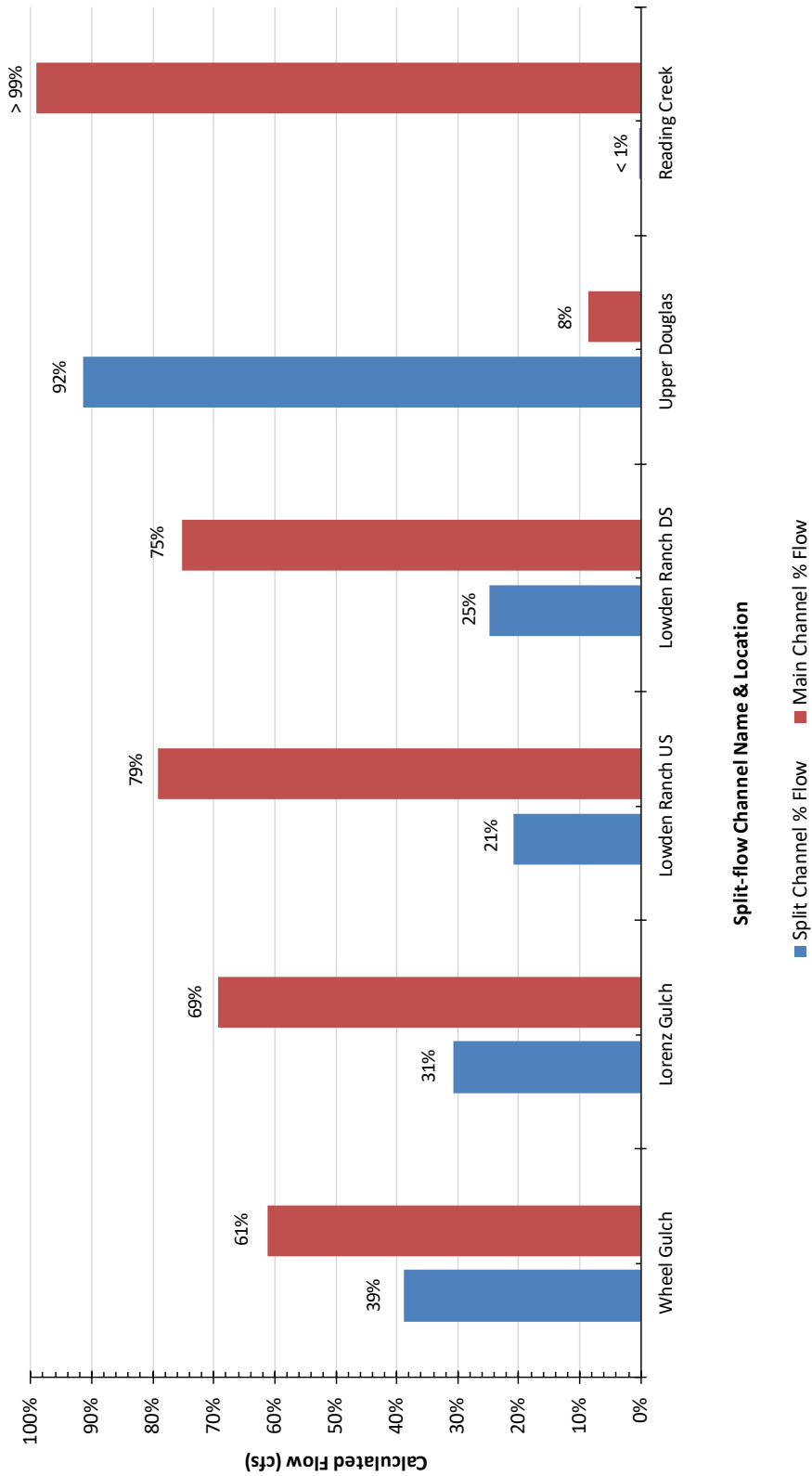


Figure 16. Average flow conveyance at the constructed split-flow channel locations. The reported percentages are the percent of flow in each split at that location. Note that Reading Creek and Upper Douglas City are the only two features where both splits no longer have at least 20% of flow. This could be a result of the severe erosion occurring on the medial bar at these sites.

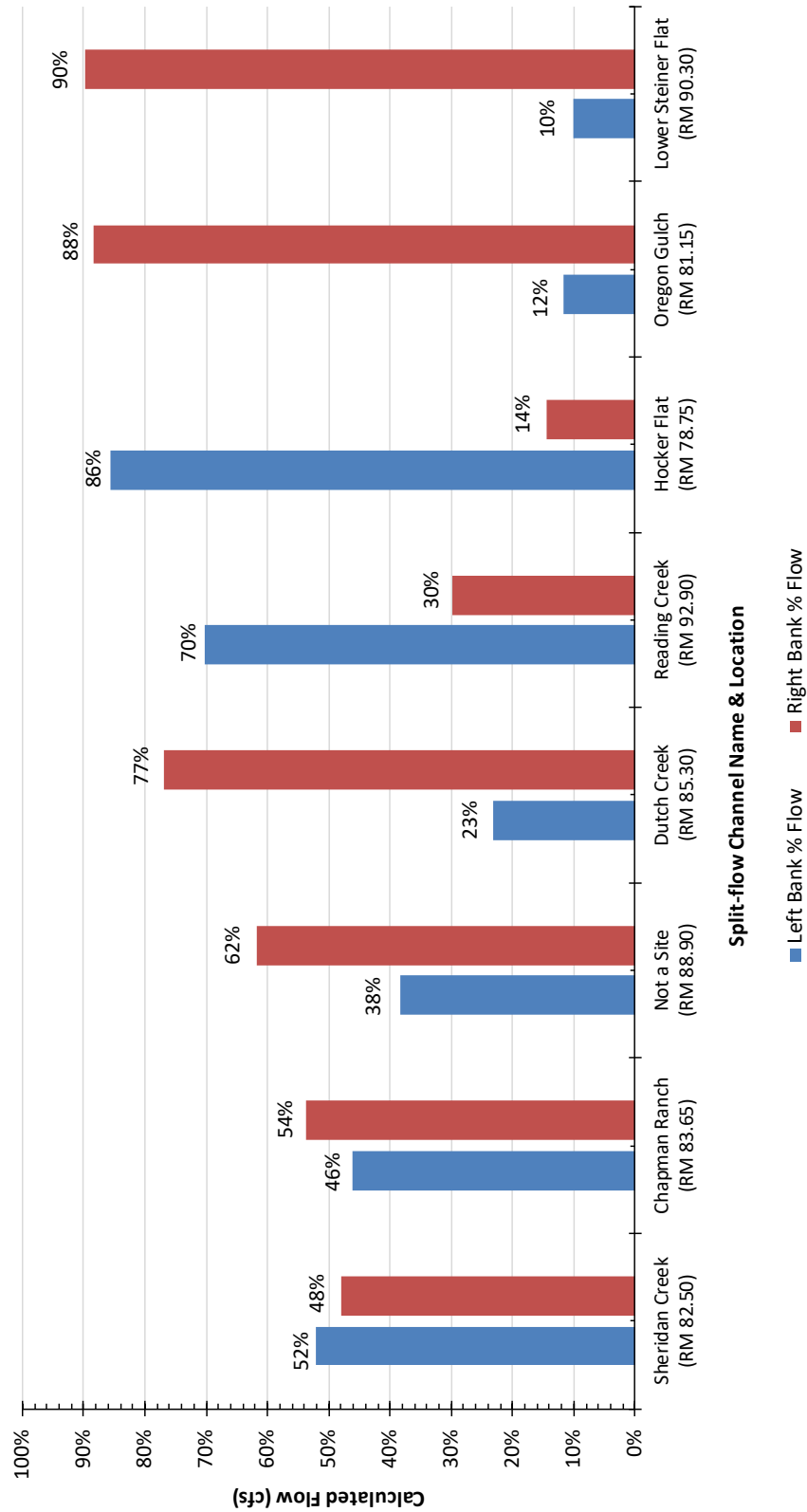


Figure 17. Flow conveyance in each channel at the naturally occurring split-flow channel locations. Note that five of the eight naturally occurring split-flow locations have at least 20% of the flow in each channel, which is similar to the ratio of constructed split-flow channels where each channel has at least 20% of flow (Figure 16).

All of the naturally occurring split-flow features were chosen because they have persisted since at least 2007, and the results show that the flow conveyance in each split-flow channel varies greatly from site to site, where some sites have near equal flow through both channels and others have greater than 85% of flow through one channel. The flow conveyance results suggest that a certain percentage of flow may not be necessary through each split-flow channel. The CDG suggests constructing split-flow channels so the smaller of the two channels conveys at least 20%, but less than 50%, of the flow. Under contemporary conditions, four of the six constructed split-flow channels meet that criterion, however, the natural split-flow feature results suggest that percent of flow conveyance in each channel may not be as important as channel width in constructing split-flow channels which will persist. At three of the eight naturally occurring split-flow channels, each side of the split-flow feature is very similar in size and flow conveyance is close to 50/50. This suggests that constructed split-flow channels can be close to the same size and still persist through time.

Bifurcation angles in all split-flows (natural and constructed) with at least 20% of the total flow in each channel ranged from 30° to 60° (Appendix 7, Tables 7-7 and 7-8). The CDG recommends that bifurcation angles of each split-flow channel should be approximately 40°. The two constructed split-flows which failed had very low divergent angles: Upper Douglas City at 14° and Reading Creek at 20°. The average of the 100% effective constructed split-flow divergent angles is 50°. Therefore, the findings of this report suggest that constructed bifurcation angles at split-flow channels be at least 40°, if not greater.

5 ALCOVE EFFECTIVENESS ANALYSES

The metrics utilized to evaluate alcove effectiveness include:

- Changes to the flow threshold between the alcove and the channel, and consequent changes to critical rearing habitat during the January to April time period.
- Changes in connectivity from the mainstem or side-channel (depending on where the alcove was constructed) due to deposition or erosion, and changes to the wetted area at the design flow of 300 or 450 cfs.
- Dimension changes in response to deposition or erosion, including planform area, depth, and volume.

5.1 Alcove Methods

The TRRP database identifies 48 alcoves (Table 7). Alcoves have been constructed in many settings, including along the mainstem, at side-channel exits, and adjacent to large depositional features. Alcoves are constructed primarily to provide immediate juvenile fish habitat. Effectiveness was graded based on geomorphic changes to the alcove that could potentially impact habitat availability, such as deposition or erosion, disconnection from the mainstem or side-channel (depending on where the alcove was constructed), and changes to the wetted area at the design flow of either 300 cfs or 450 cfs. The three upstream-most sites (Sven Olbertson, Sawmill and Lowden) were designed for 300 cfs.

The alcoves were grouped into three categories that report the % effectiveness: (1) Alcoves that had no change in deposition or erosion and are still connected at the design flow were assigned 100% effectiveness, (2) alcoves that were either filled-in with sediment or cut-off at the design flow were assigned 0% effective, (3) all other alcoves fall into an intermediate level of effectiveness. Because we did not quantify a volume-change estimate for each individual alcove, the specific % of effectiveness for each alcove in the intermediate category was not calculated. The alcove analysis Tasks were:

1. Use the GCD analysis results to evaluate if the alcove planform area, depth, and volume has changed through time due to deposition or erosion;

2. Use aerial photographs to evaluate how many alcoves are still functioning;
3. Use aerial photographs to evaluate how location and placement relates to persistence, such as placement in the upstream reaches versus the downstream reaches, the alcove angle to the channel, or connection to a high-flow versus low-flow channel; and,
4. Use SRH2D to evaluate the 300 cfs connection and the 2016 aerial photographs (flown at 435 cfs) to evaluate the 450 cfs connection.

Table 7. Site locations and number of alcoves at each site that were evaluated. The sites are listed from downstream to upstream. The feature names are from the TRRP feature database and from individual project design reports. If the feature name has “(all)” or “(number)” written next to it, then all or some of the alcoves were assigned one feature name as a group.

Site Name	River Mile	Number of Alcoves	Feature Name
Sven Olbertson	111.2–111.7	3	R1 (all)
Sawmill	108.8–109.7	4	R10, IC11
Lowden Ranch	104.4–105.3	2	R6, IC2
Limekiln Gulch	99.7–100.6	1	No feature name (pre-TRRP)
Indian Creek	93.9–96.9	12	R1 (all)
Upper Douglas City	93.6–94.6	4	IC4, IC3, IC1, IC4
Reading Creek	92.1–93.2	2	R5, R2
Lower Steiner Flat	90.7	3	IC14, IC15, IC16
Lorenz Gulch	89.8	4	R5, R4, R1, IC4
Upper Junction City	79.8–80.4	6	W6, R10 (3), W5, W4
Lower Junction City	78.8–79.8	3	IC3, R2, IC4
Wheel Gulch	76.1	1	R4
Valdor Gulch	74.8–75.7	1	R7
Elkhorn	73.7–74.4	1	R1
Pear Tree	72.9–73.3	1	R5

5.2 Alcove Results

Detailed descriptions of alcove overall results and GCD results can be found in Appendix 8: Alcove Tables and Results. Due to the large number of alcoves (48) and numerous alcoves occurring at some sites, the descriptions are brief and use placement indicators such as “the upstream,” “the middle,” or “the downstream” alcove, instead of a feature name. The primary objective for the alcove effectiveness evaluation was to assess how alcoves are persisting through time. Overall, 12 alcoves were found to be 100% effective, 18 alcoves are 0% effective, and 18 alcoves have an intermediate level of effectiveness that is between 0 and 100%.

The aerial photographs were used to assess the conditions at the most effective locations (i.e., where alcoves had no or little change through time) to determine if there is a geomorphic setting where alcoves persist the longest. The aerial photographs revealed that alcoves that are positioned at the downstream end of depositional features, such as gravel bars, are less likely to persist through time compared to ones that are placed in reaches where depositional features are fewer (Figure 18, Figure 19). One of the most persistent alcoves is located at the Sven Olbertson site, which was constructed in 2008. This alcove is located along the mainstem channel and has dense riparian vegetation around all sides. It is also located directly downstream of the dam and upstream of any major tributaries, which limits the sediment load coming into the area.

The GCD results showed that the majority of alcoves (67%) have experienced deposition and that 31% have experienced deposition on the order of 4.5–6.0 ft. Most of the alcoves that had extensive deposition were also filled with riparian vegetation. The GCD results also showed that 25% of alcoves had no noticeable change in deposition or erosion, and that 8% of alcoves experienced erosion instead of deposition (Figure 20). Several alcoves that were constructed between 2006 and 2010, including Pear Tree, Elkhorn, and Valdor Gulch, experienced significant deposition within the first 2 years of construction, which can be seen through the series of aerial photographs. However, because the post-construction surveys occurred several years after construction was completed, the GCD results did not capture the full amount of deposition.

The alcoves that showed no change on the aerial photographs or on the GCD analysis were spread over the entire 40 miles and do not occur within any one sub-reach of the river. For example, there are alcoves that have not experienced deposition at Sven Olbertson (RM 111.2–111.7), Limekiln Gulch (RM 99.7–100.6), Lorenz Gulch (RM 89.8), Lower Junction City (RM 78.8–79.8), and others in between. Five of the alcoves that have experienced no change were constructed at the upstream end of riffle crests, including alcoves at Lowden Ranch, Limekiln Gulch, Lorenz Gulch, Upper Junction City, and Lower Junction City.

The only sub-reach of the river where all alcoves have experienced significant deposition is downstream of Canyon Creek. This could be due to sediment input and increased flow from Canyon Creek, or it could be a result of some other factor such as alcove position or size. Compared to upstream reaches, the section of river downstream of Canyon Creek has had more than double the number of flows that have met or exceeded 4,500 cfs since 2006, suggesting that the increased frequency of channel-forming flows impacts the extent of deposition in these features. For example, since 2006, the USGS gage above the North Fork has had 232 days when daily average streamflows were above 4,500 cfs, while the Douglas City gage has only had 136 days and the Lewiston gage 100 days. However, because there are only four alcoves downstream of Canyon Creek, there is insufficient data to say conclusively that Canyon Creek is the major cause of downstream alcove aggradation.

5.1 Alcove Discussion

The alcove effectiveness analyses showed that alcove success is partially dependent on geomorphic location. Due to the many geomorphic settings and design objectives of alcoves, it is difficult to identify a single geomorphic setting that is most successful. However, the results suggest that there are at least two geomorphic settings where alcoves persist longer: (1) at the upstream extent of riffle crests, and (2) in straight, vegetated reaches far from large depositional bar features or other sediment sources. The recommendations in the CDG align with these results and specify that if alcoves are placed at the downstream end of side-channels that they be placed upstream of the next downstream riffle crest.

The CDG suggests constructing alcoves at a point where the channel approaches a floodplain or terrace at the upstream end of a riffle, which is consistent with the findings of this study. Out of the 48 alcoves evaluated, nine were constructed immediately upstream of riffle crests along the mainstem river. Of those nine alcoves, five have experienced no change and the other four have experienced 3.0–4.5 ft of deposition. Although these results are not conclusive, there were only 12 out of the 48 alcoves that showed no change, five of which were placed at the upstream end of riffle crests, suggesting that this is a geomorphic setting that can be successful for alcoves. The second setting where alcoves have persisted are those that have dense vegetation surrounding the alcoves and very few nearby depositional features; examples include the alcove in the Lorenz Gulch side-channel, Limekiln, and the mainstem alcove at Sven Olbertson.

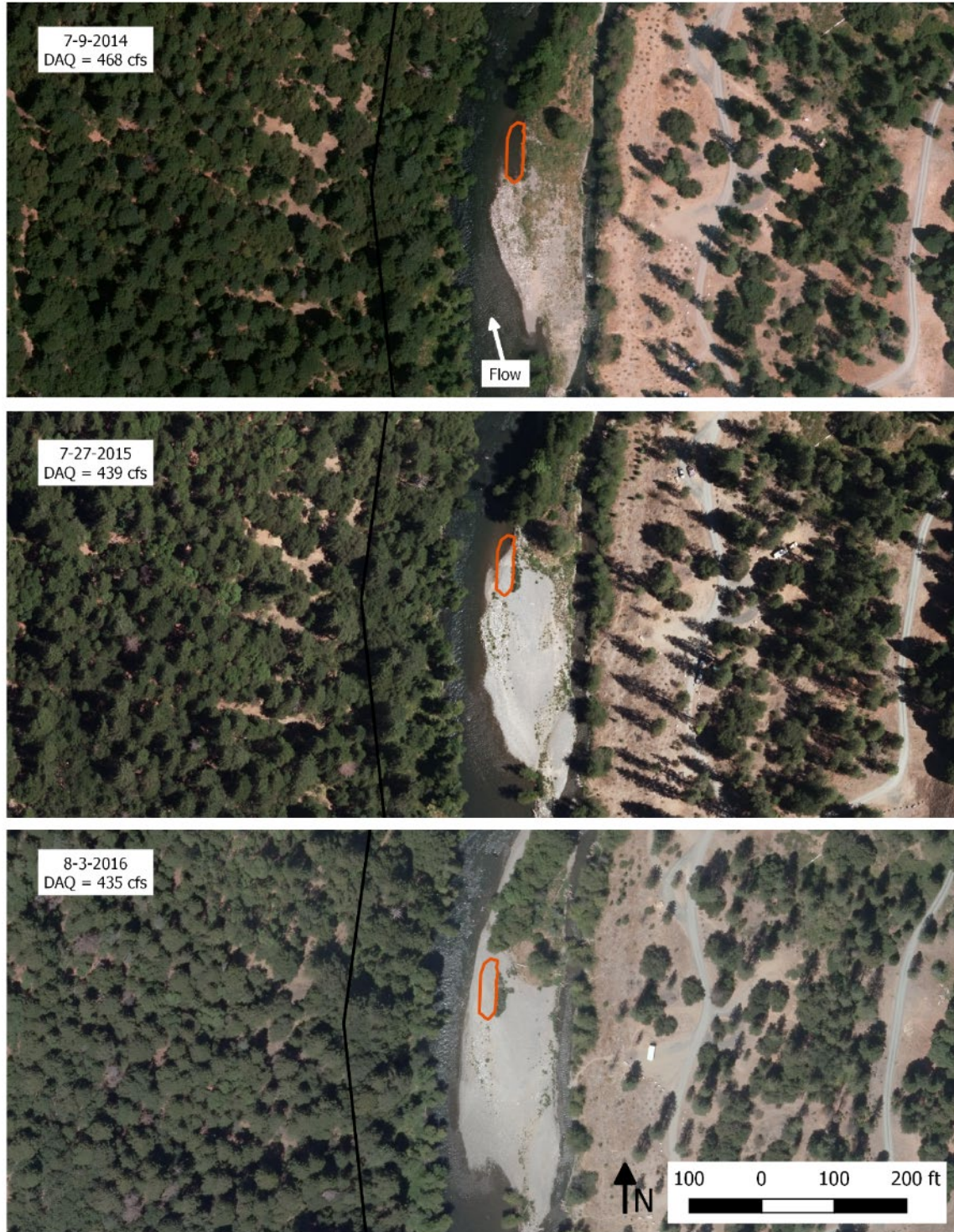


Figure 18. Lower Steiner Flat example of an alcove constructed at the downstream end of an unvegetated gravel bar, which continued migrating downstream and filled the alcove within three years. The alcove footprint is shown in orange. Additional sites with alcoves constructed in a depositional setting such as this one that also filled with sediment in the first few years include: Pear Tree, Elkhorn, Valdor Gulch, Wheel Gulch, and Sawmill. The reported flows are from the USGS Trinity River at Douglas City CA (gage # 11525854).



Figure 19. Aerial photographs showing two alcoves at the Sven Olbertson site constructed in 2008. The most successful alcove at this site, and one of the oldest functioning alcoves on the river, is shown in the center of each photograph. The GCD analysis and aerial photographs suggest that there has been no deposition in this alcove through time. This alcove is unique compared to others because it is surrounded by thick vegetation on all sides. The lack of sediment supply upstream of the alcove, the narrow mainstem channel width, and dense vegetation on the banks is likely why it has not aggraded. The Sven Olbertson site is the first downstream of the dam, so sediment input is limited. The reported flows are from the USGS Trinity River at Lewiston gage (gage # 11525500).

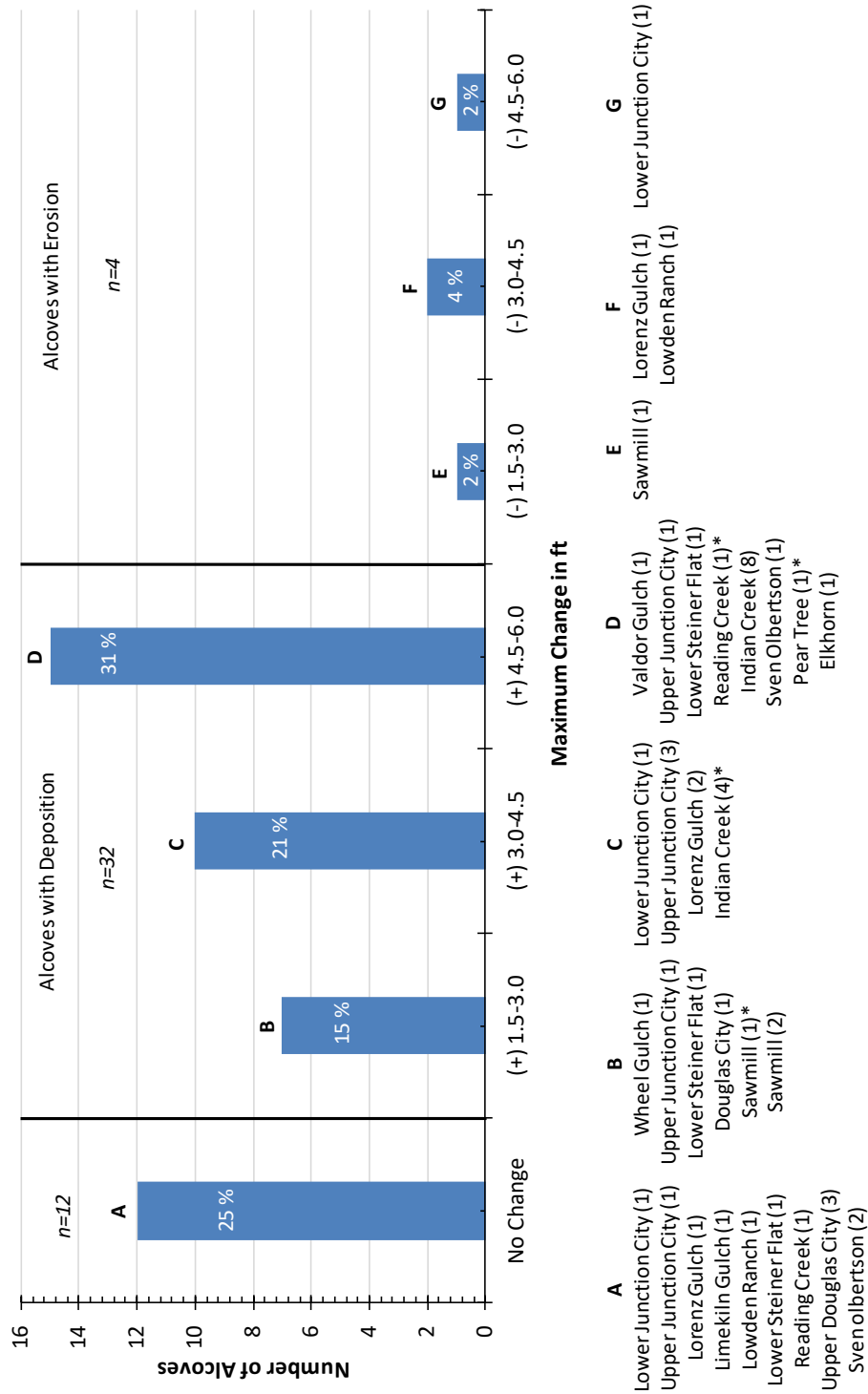


Figure 20. GCD results for maximum topographic change in the 48 alcoves that were evaluated. The graph is split into three sections to show the alcoves that had no change, alcoves with deposition, and alcoves with erosion. The alcoves were grouped based on the GCD “bins,” which register topographic change in increments of 1.5 ft. The percentage that each group makes up in the total population is shown within each bar. Below the graph, the sites and numbers of alcoves are listed for each group. Some sites have many alcoves, therefore individual feature names are not listed. Instead, the site name is listed and then in parenthesis the number of alcoves at that site that belong in that group is listed. The total number of alcoves at each site is shown in Table 7.

Overall, deposition remains the primary concern with constructed alcoves. The least successful setting for alcove construction is along or at the downstream end of large, active gravel bars. There are many examples of alcoves filling with sediment in this setting, including at Reading Creek, Lower Steiner Flat, Lower Junction City, Elkhorn, Valdor Gulch, and Pear Tree. One observation from the aerial photography is that the size of the particles filling the alcoves appears finer than the coarse fraction observed on nearby depositional features. This suggests that finer sediment is a concern for alcoves, and that the delivery method of fine sediment should be considered when choosing locations for alcoves. It may be that during high flow events alcoves that are surrounded by dense vegetation have a lower risk of sedimentation because the roughness provided by the vegetation causes settling to occur over a larger area instead of localizing in the alcove. However, this cannot be verified without additional field investigations.

6 CHANNEL MEANDER EFFECTIVENESS ANALYSES

The metrics utilized to evaluate channel meander effectiveness include:

- Increases to bank length and decreasing radius of curvature due to erosion and deposition.
- Presence/absence of bar formation within constructed meanders resulting in increased complexity.

6.1 Channel Meander Methods

A total of 15 mainstem Trinity River channel meanders (also referred to as channel migration features) were evaluated for effectiveness. Feature names were found in the TRRP online database, individual project design reports, and in the 2012 Phase I Review Report (Table 8). Meanders are constructed for many reasons, including to increase sinuosity, increase channel complexity, increase hydraulic diversity, decrease the radius of curvature, and improve rearing habitat. For the analysis, effectiveness at constructed channel meander locations was evaluated based on geomorphic changes, such as erosion or deposition, increased channel bank length, and the formation of other features (gravel bars and floodplains) as a response to migration.

Table 8. Channel meander features by construction site evaluated for effectiveness.

Site Name	Year Built	Number of Features	Feature Name(s)
Sawmill	2009	2	R2, R8
Lowden Ranch	2010	3	IC4, IC6, R3
Trinity House Gulch	2010	1	R1
Limekiln	2015	2	IC6, IC5
Upper Douglas City	2015	1	IC2
Reading Creek	2010	3	R2, R4, R5
Upper Junction City	2012	1	IC5
Lower Junction City	2014	2	IC1, IC4

The percent effectiveness for channel meander features were assigned by grouping the features into three categories: (1) 100% effectiveness if the migration feature shows both deposition on the inside bank of the meander bend and erosion on the outside bank of the meander bend, (2) intermediate effectiveness if there was either erosion occurring on the outside bank of the meander bend or deposition occurring on the inside bank of the meander bend, but not both, and (3) less effective if the channel migration feature shows no sign of migrating but has maintained its designed form. There was no 0% effectiveness category because no migration feature has reverted to its pre-design form.

The channel meander effectiveness Tasks were:

1. Use the GCD results to evaluate if the constructed channel meander features indicate deposition or erosion and if the features have continued to migrate into the bank (i.e., continue to increase bank length and decrease the radius of curvature); and
2. Use aerial photographs to make observations about how migration features are influencing other geomorphic feature formation, such as point bars and medial bars (i.e., is complexity increasing).

6.2 Channel Meander Results

Detailed descriptions of the GCD results for channel meander features can be found in Appendix 9: Channel Meander Results. Both the GCD and aerial photographs were used to evaluate the scale of deposition and erosion and to make observations about how the meanders are changing through time (Figure 21).

The GCD analysis showed that eight of the 15 channel migration features had no change, suggesting that they are not migrating. These features were classified as being less effective. One exception may be the Limekiln site; since it was constructed in 2015, only one year of potential channel evolution was evaluated with the GCD. Only two of the features, Upper Douglas City and the upstream-most migration feature at Lowden Ranch, are migrating in the expected way, where the outside bank is eroding while bar formation is occurring along the inside bank. These two sites were the only two assigned 100% effectiveness. The GCD results for the other five sites show intermediate effectiveness with the channel eroding into one bank or depositing on the opposite bank, but not both. . The downstream-most migration feature at the Lower Junction City site is the only feature where the GCD shows no erosion into the bank but there is significant deposition on the gravel bar on the opposite bank. This suggests that deposition increased because of the greater channel width and was able to persist even without further erosion into the opposite bank. This supports the findings of the split-flow channel analysis, which suggest that there is a minimum channel width requirement for in-stream depositional feature formation.

6.1 Channel Meander Discussion

The channel meander effectiveness analyses suggest that channel migration is occurring at slightly less than half of the channel migration design features. Only two of the seven migrating features have both erosion occurring on the outside bank and deposition occurring on the inside bank (and are classified as 100% effective); the remaining five features demonstrate one or the other. A promising observation is that none of the constructed channel migration features have retreated to pre-design form, meaning that although most have not continued to migrate, the increase in meander wavelength and sinuosity that is provided locally is persisting. The CDG states that there is concern that the remnant pre-dam grain sizes constrain some fluvial processes, resulting in less successful channel migration and avulsion. The CDG recommends that future channel meander projects take advantage of areas where grain sizes are finer and bank strength and vegetation would offer less resistance. This study suggests that to ensure that meanders continue to migrate, additional design analysis may be needed to 1) increase the shear stress acting on the outside bank during high flows, and/or 2) identify locations within the site where bank materials are more conducive to erosion under the post-dam ROD flow regime (e.g., gravels and cobble banks rather than pre-dam boulders).

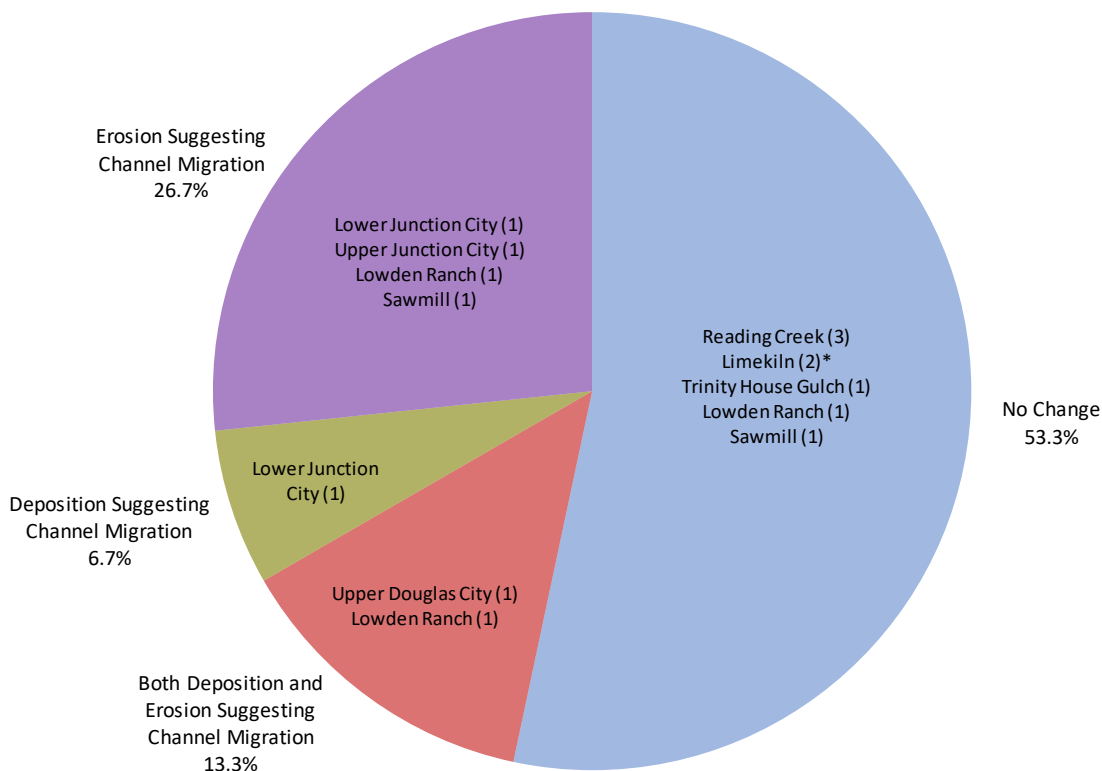


Figure 21. GCD results for 15 channel migration features. The two large, constructed meanders at Upper Douglas City and Lowden Ranch are considered to be the most effective migration features because erosion is occurring on the outside of the meander bend as it erodes into the bank, and deposition is occurring on bars on the inside bend of the meanders, completing the migration process. Because there is more than one migration feature at some sites, the number in parentheses notes how many migration features at that site fall into that group. *Note: Limekiln shows no change, but that could be due to only 1 year being evaluated.

7 OFF-CHANNEL PERENNIAL WETLAND EFFECTIVENESS ANALYSES

The metrics utilized to evaluate channel meander effectiveness include:

- Low flow connection at the design flow threshold (300 or 450 cfs).
- Changes in functional area due to erosion or deposition.

7.1 Off-Channel Perennial Wetland Methods

Six off-channel perennial wetland features were identified (Table 9). Although they represent a relatively small portion of overall design features, off-channel perennial wetlands were evaluated because they provide salmonid rearing habitat. Of all of the features evaluated in these analyses, off-channel wetlands are the most diverse in shape, size, and complexity, and there are no two off-channel wetland features that are exactly alike. Because of the small population size and high level of diversity, the off-channel wetlands were not assigned an effectiveness percentage like the other features. Instead, the results are discussed qualitatively.

Off-channel wetland features have been constructed for many reasons, but primarily to provide habitat for juvenile salmonids and other organisms such as turtles, frogs, and birds. The focus for evaluating off-channel features was primarily to assess if deposition is occurring and impacting the transition from open water to wetland to floodplain.

The primary tasks for assessing off-channel wetland features were:

1. Use the GCD results to evaluate if deposition is occurring and if it is limiting flow into wetland areas;
2. Use aerial photographs to make observations about other changes to off-channel wetlands such as changes in riparian vegetation and large wood storage; and
3. Use SRH-2D wetted area model outputs to evaluate whether the design flow threshold still engages off-channel wetland areas under contemporary conditions.

Table 9. Site location, number of perennial off-channel wetlands, and the inundation flow. Dates of construction for all features are summarized in Appendix 2: General Site Information.

Site Name	Number of Features	Feature Name	Flow Inundation (cfs)	Wetland Setting
Sven Olbertson	1	R1	300	On floodplain
Sawmill	1	C4	300	On floodplain
Lowden Ranch	2	R2, *	300	Constructed into side-channel
Lorenz Gulch	1	R5	450	On floodplain with connection to side-channel
Upper Junction City	1	W1	450	On floodplain

* The two small, off-channel ponds are considered to be one wetland feature due to small size and close proximity. The ponds are located immediately downstream of the split-flow channels at Lowden Ranch and they do not have assigned feature names. The footprints of the ponds are shown in the 100% design sheets for Lowden Ranch and in the 2012 Phase I Review report Appendix C, and in Appendix 1: Location Maps of Sites Included in Analysis of this report.

7.2 Off-Channel Perennial Wetland Results

Detailed descriptions of the GCD results for off-channel perennial wetlands can be found in Appendix 10: Off-Channel Perennial Wetland Results. Changes in deposition, erosion, and connectivity at the design flow (300 or 450 cfs) were evaluated. The GCD results showed a wide spectrum of changes at these sites and varied from having no change to having up to 6.0 ft of deposition and erosion (Figure 22). The aerial photographs showed no noticeable changes in large wood storage and the constructed wood jams appear stable through the photograph series.

The aerial photographs showed that all wetland features except for Sawmill were inundated at 450 cfs. However, the SRH-2D model suggested that the Sawmill wetland is wet at 450 cfs. The aerial photographs and SRH-2D model results also disagreed at the Upper Junction City feature, where the aerial photograph showed the feature as wet at 450 cfs but the model results did not. The aerial photographs were held as more reliable than the model results.

At Sven Olbertson, the wetland is disconnected at 300 cfs, but is still wet, and now has a contemporary flow threshold of 600 cfs. At Sawmill, the feature is dry at 450 cfs and since the SRH-2D model showed an erroneous result, the contemporary flow threshold is unknown. The upstream feature at Lowden Ranch is connected to the side-channels and appears to have had maintained good flow connectivity at the designed thresholds. Despite patchy deposition up to 4.5 feet, the wetland at Lorenz Gulch remains connected at 450 cfs. Likewise, at Upper Junction City, the off-channel wetland is connected at 450 cfs. With the exception of Sawmill, the wetland features were being maintained through time, although some are occasionally disconnected from the active channel.

7.1 Off-Channel Perennial Wetland Discussion

The perennial wetland features are the smallest population of features that were evaluated in this report. Designed function varies considerably, so changes in effectiveness (e.g., the 14-day FDC

for contemporary flow thresholds) was not evaluated. Due to the small population size, there are no strong relationships between wetland effectiveness and geomorphic setting. One observation is that although the larger wetland area at Lowden Ranch has some small patches of deposition, it is still functioning and flowing at low flows (observed at 300 cfs). The low volume of deposition at the Lowden Ranch features (constructed in 2010) and the Sven Olbertson feature (constructed in 2006) show that these features have potential to persist through time. Although the CDG discusses many elements that are incorporated into off-channel wetland features, there is currently no designated section that provides design recommendations for these features. The findings of these analyses suggest that a section should be added to the CDG that describes planform dimensions (lengths and widths), large wood and island design criteria, entrance orientation, and flow threshold criteria that are working well at the sites discussed above.

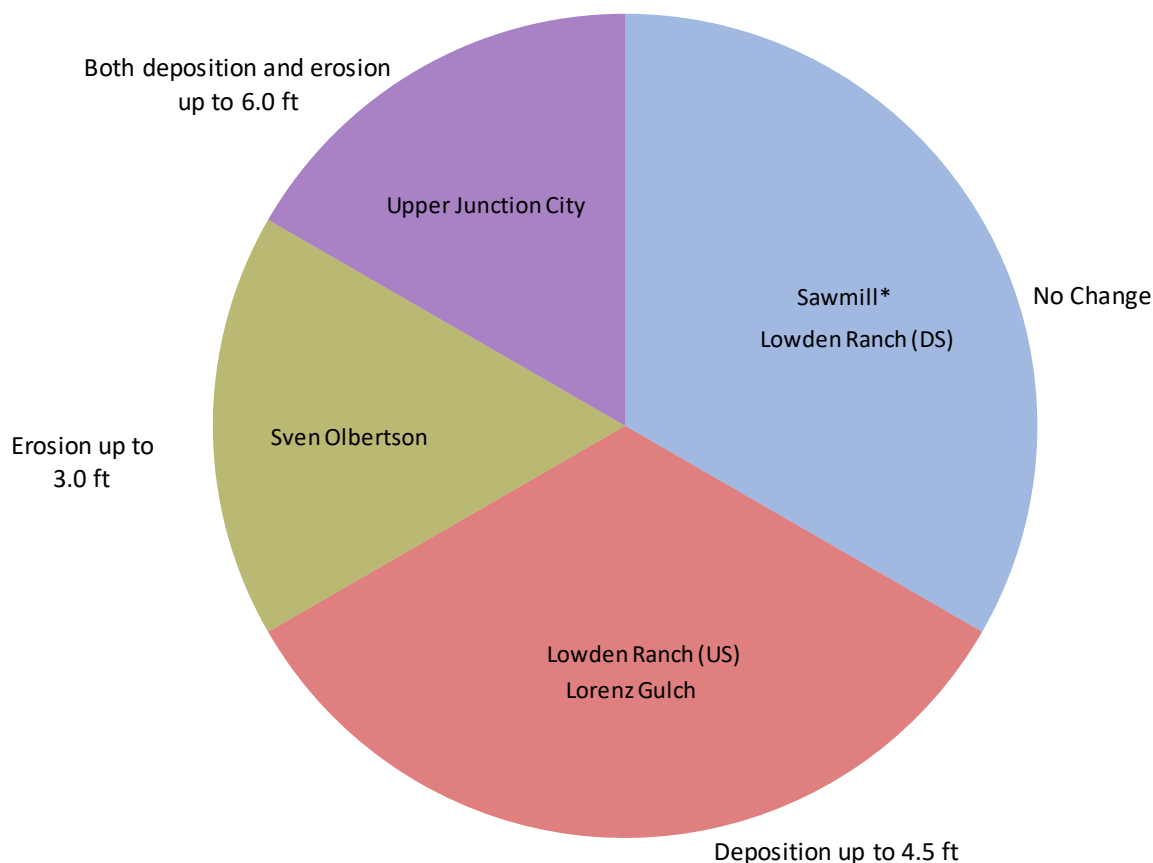


Figure 22. GCD results for the six off-channel wetland features. The group percentages are not calculated due to the low number of wetland features. Note that the “DS” and “US” next to Lowden Ranch indicate whether it is the downstream or upstream feature. Sawmill is shown with an asterisk because the post-construction survey was taken three years after construction, and therefore the GCD does not capture deposition or erosion that happened in between the end of construction and the post-construction survey.

8 SUMMARY AND RECOMMENDATIONS

Overall, the results of these analyses largely support the recommended design guidelines in the CDG. A summary of results from the previous sections, and corresponding recommendations for incorporating these results into a CDG revision, are listed below:

1. Side-channels:

- 1.1. The results for the side-channel analyses show a positive relationship between large wood jams at the side-channel entrances and less aggradation at the entrances. Therefore, the recommendation in the CDG that large wood should not be used for scour purposes at side-channel entrances should be reconsidered and additional research should be performed. Contemporary thinking on this topic suggests that the role of large wood at side-channel entrances should be to facilitate cross-channel hydraulics to steer sediment away from or through the side-channel entrance (Conor Shea, personal communication August 2020), rather than to induce local scour.
- 1.2. This analysis suggests that when constructing a low-flow side-channel, the total number of channels be limited to two. The aggradation at the Sawmill R3 side-channel is an example of why constructing more than two channels can cause sediment accumulation to occur.
- 1.3. This analysis also supports that side-channel entrances should be constructed immediately upstream of or adjacent to riffle crests.
- 1.4. Side-channels are a major element used in rehabilitation designs to improve or increase habitat. Literature is available that describes the characteristics of side-channels, including where they form and the mechanisms that produce long-term stable open channels. We recommend the Physical Workgroup conduct a literature review of side-channel characteristics, develop a white paper on design principles to update the CDG, and to provide a briefing to the Design Workgroup.

2. Split-flow Channels:

- 2.1. The split-flow channel analyses suggest that there is a minimum total channel width of 170 ft. Where split-flow channels are designed, constructed channels should target this minimum width to promote the longevity of the medial bars that form.
- 2.2. Additional research should be conducted regarding the CDG bifurcation angle recommendations for split-flows. The finding in this report suggest that 40° is likely a desirable minimum angle of departure for constructed split-flows.
- 2.3. The current design requirement of at least 20% flow conveyance in each split-flow channel may not be necessary to physically maintain the split-flow channel.

3. Alcoves:

- 3.1. The alcove analyses are in good agreement with the CDG recommendations, alcoves should be constructed in areas that have limited nearby depositional features.
- 3.2. The results of this study suggest that the delivery method for fine sediment on the Trinity River should be explored to see if deposition in alcoves is dominated by coarse sediment or fine sediment aggradation.

4. Channel Meanders:

- 4.1. The findings of this report support the design guideline recommendations in the CDG. However, if possible, additional design criteria to create increased shear stress on the bank where migration is desired should be included in the recommendations, since most constructed migration features are not actively migrating. More attention be given in the design stage to analyzing flow characteristics to ensure there is sufficient sediment transport capacity and the ability to generate bar sorting processes.

5. Off-Channel Perennial Wetland Features:

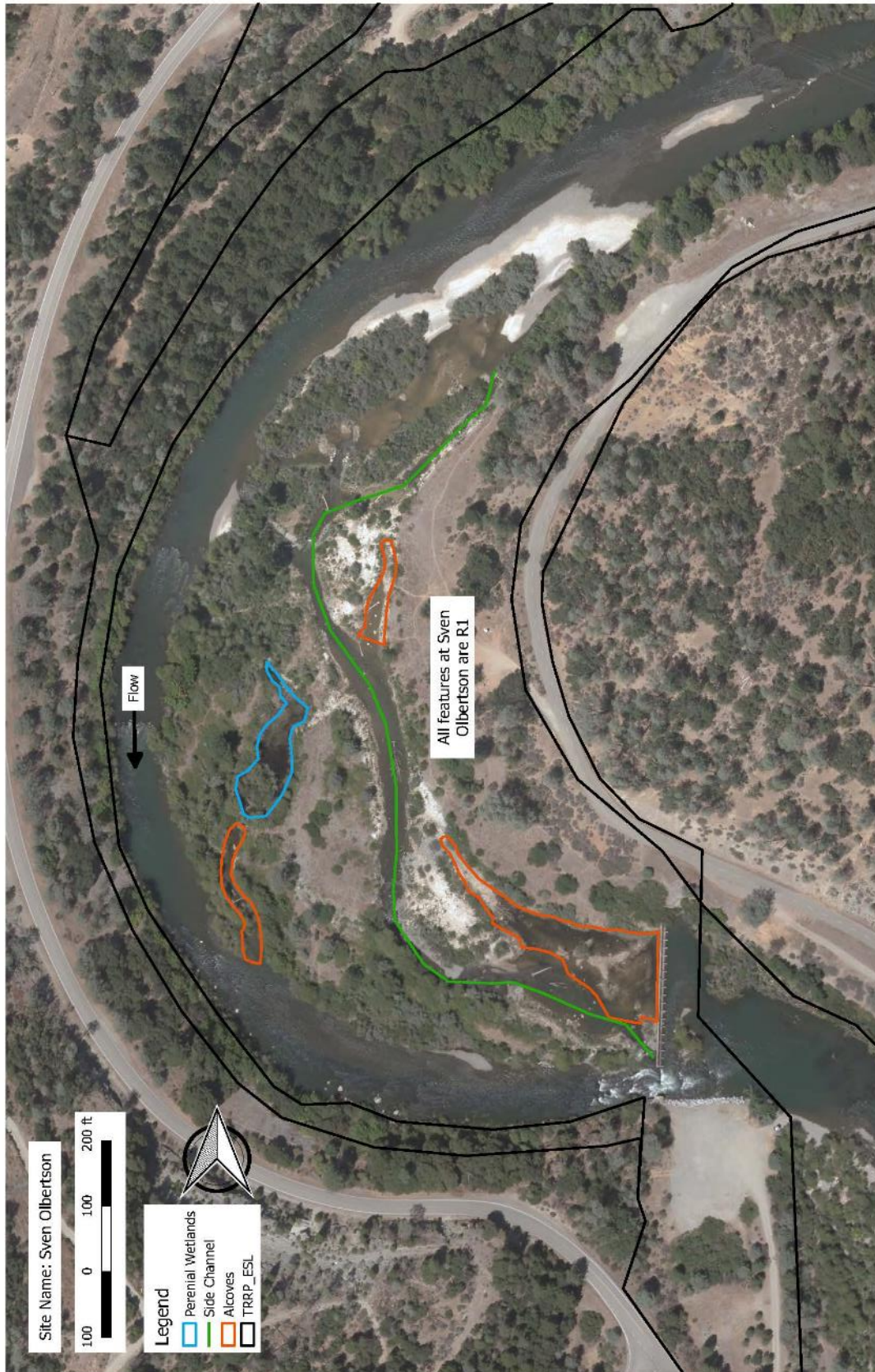
- 5.1. A section should be added to the CDG with recommendations specific to perennial off-channel wetland features, including recommended lengths, widths, and designs for island

- and large wood features. At a minimum, off-channel wetland applications should be discussed in the large wood or floodplain sections.
- 5.2. As with side-channels, flow thresholds for off-channel wetlands should provide access during the critical January to April juvenile salmonid rearing period.
6. Additional research and data collection needs:
 - 6.1. In many instances, the accuracy of the SRH-2D model was insufficient to adequately predict the side-channel entrance flow activation thresholds. Much of this inaccuracy may be due to the survey accuracy of hydraulic controls at side-channel entrances. Therefore, we recommend higher accuracy for future bathymetric surveys in these areas. For example, if they are mapped during high flows using multi-beam sonar, or if the LiDAR covers these areas, side-channel entrances should still be surveyed using higher resolution, more accurate methods, such as a total station or GPS/RTK high-resolution mapping.
 - 6.2. Relate habitat quality and quantity assessments in the side-channels and split channels to provide additional relevance the flow duration analyses (e.g., Boyce et al 2018).
 - 6.3. There is likely more involved with inducing medial bar formation than minimum width. It may require a confined reach upstream with sufficient sediment transport capacity entering a section with weak channel banks or one that is artificially over-widened. We recommend relating the channel width to shear stress to investigate whether the 170 feet represents a potential threshold for depositing gravel.
 - 6.4. In 3.1 above, we suggest above that alcoves be constructed in less dynamic areas. We also suggest investigating whether alcoves can be designed in more dynamic settings, so as to migrate and evolve as a bar develops. Such an investigation might include: sediment-blocking obstructions which facilitate spill into the back-bar area; mechanisms to create flushing through the back-bar area; exploring whether the elevation drop into the back-bar area, or proximity to riffles, is important for performance.
 7. Improvements to the design process
 - 7.1. The conceptual basis for some of the implemented design elements was incomplete. For example, this report documents meanders that were built with the shape of a meander, but not the functionality. Side-channels were built with the shape of a side-channel, but not necessarily with an understanding of the hydraulic and geomorphic mechanisms which create and maintain side-channels. Our recommendation is that rehabilitation designs should give more attention to ensuring that designs incorporate appropriate geomorphic and hydraulic processes rather than just creating desired forms. Specific attention should be paid to anticipated sediment routing through the side channel entrance, or placing side-channel entrances where sediment deposition is unlikely, as recommended in the CDG.
 - 7.2. Flow splits can persist if the ratio of sediment to discharge (Q_{si}/Q_i) is roughly equivalent. If the ratio is not, the channel with higher sediment ratio will start to fill diverting more discharge into the channel with less sediment. Kleinhans et al. (2008) identifies several factors that influence flow split stability including approach conditions and relative gradients in the split channel. For example, a gradient advantage in one channel will capture more discharge leading to potential abandonment of the other channel. The design needs to consider approach conditions, relative ratios of sediment and discharge, and relative gradients into the control sections.
 - 7.3. The hydraulics associated with wood placement at side-channel entrances should be carefully examined using 2D hydraulic models. Then with a clearly defined objective (e.g., to create cross-channel flow to steer sediment), wood placement designs can be better evaluated to enhance performance.

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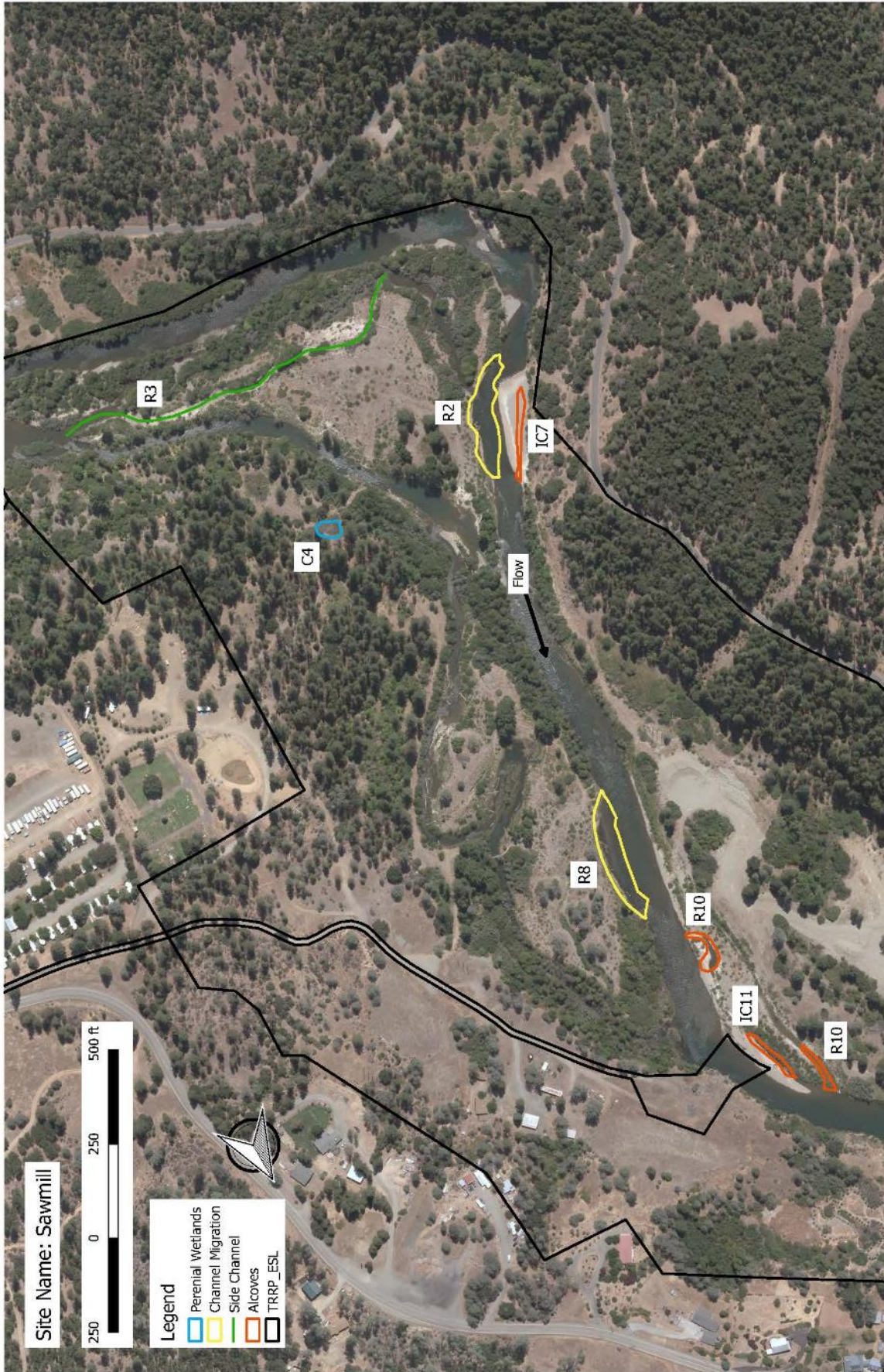
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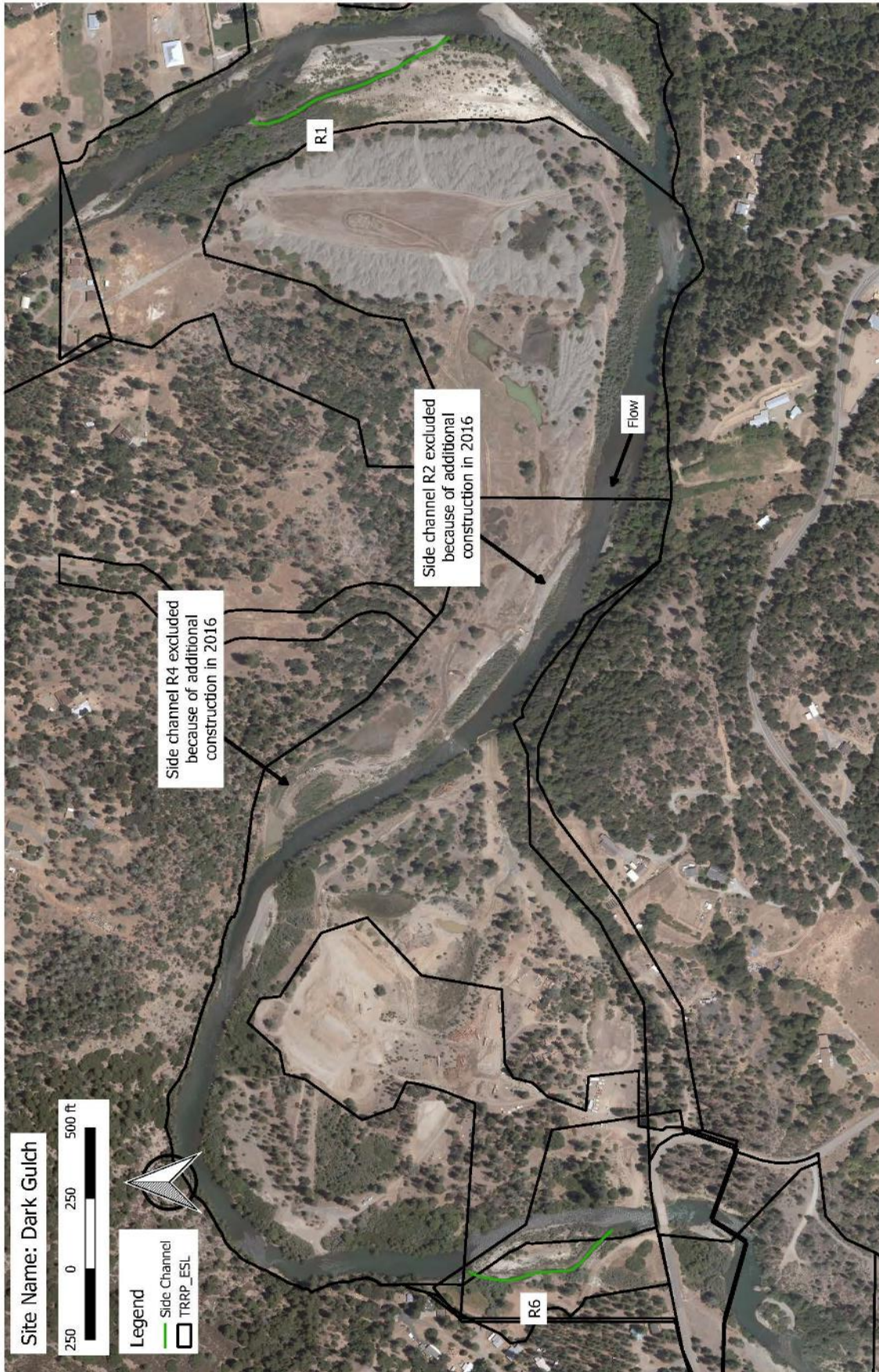
APPENDIX 1: LOCATION MAPS OF SITES INCLUDED IN ANALYSIS



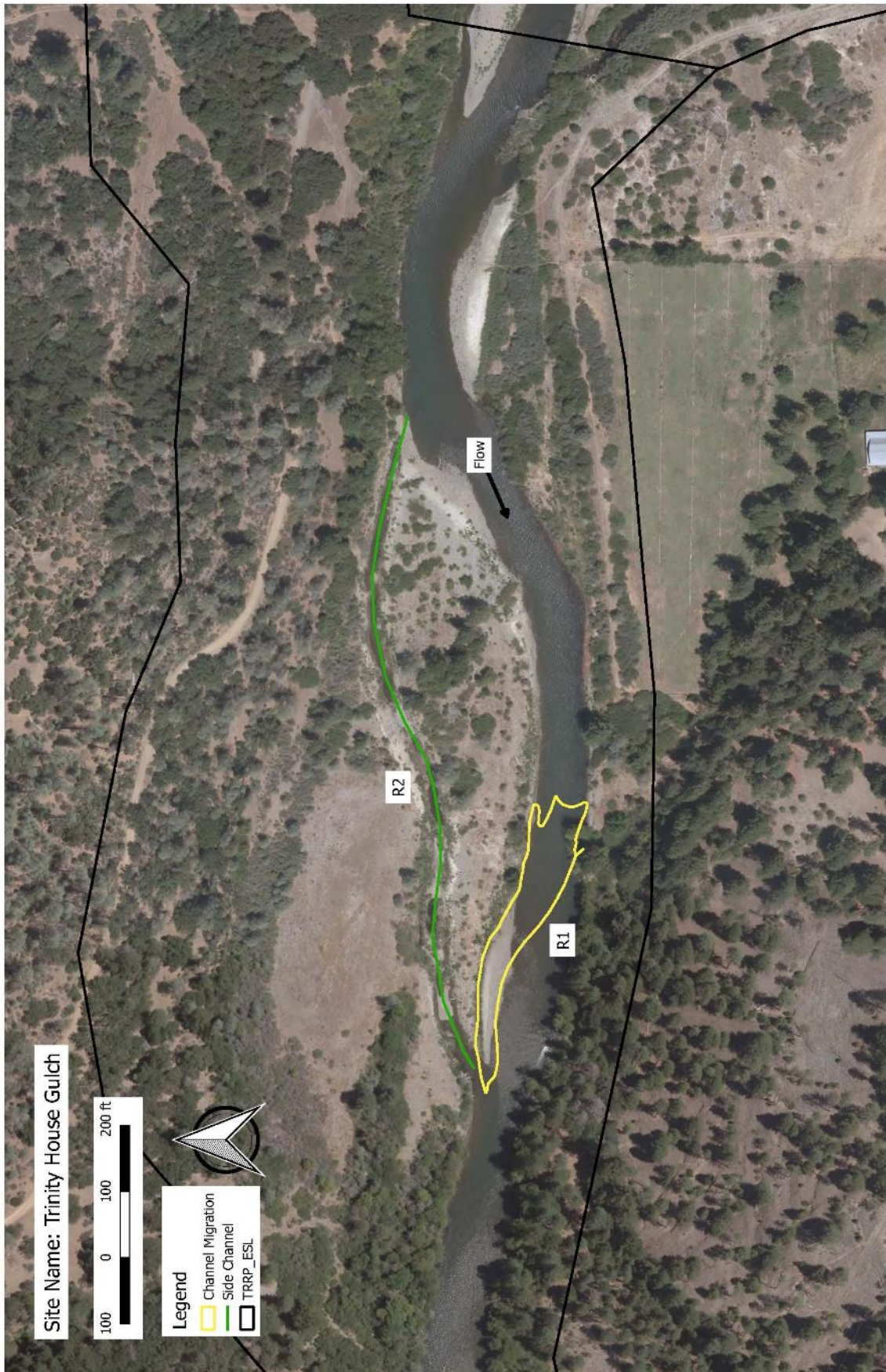


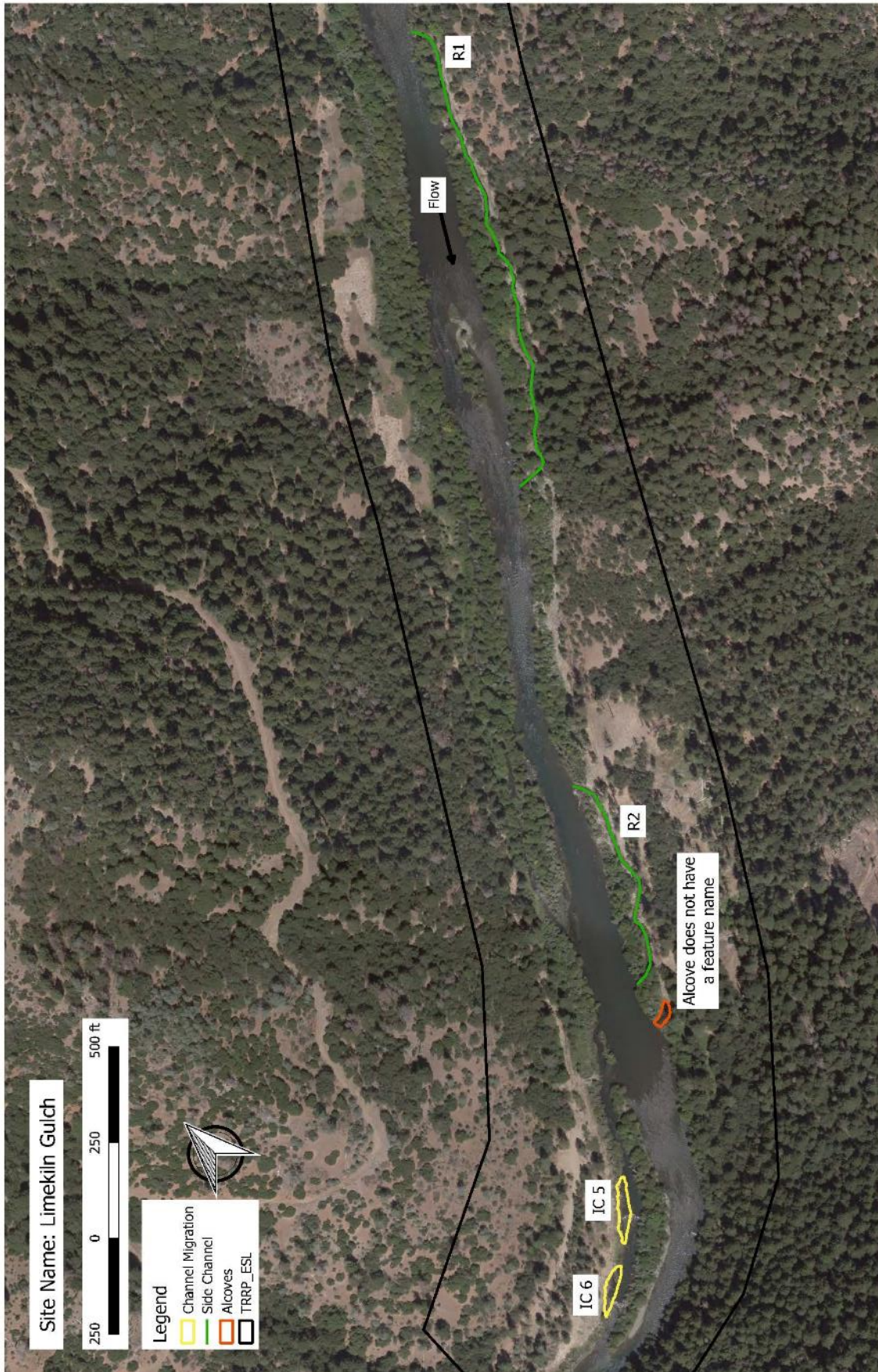


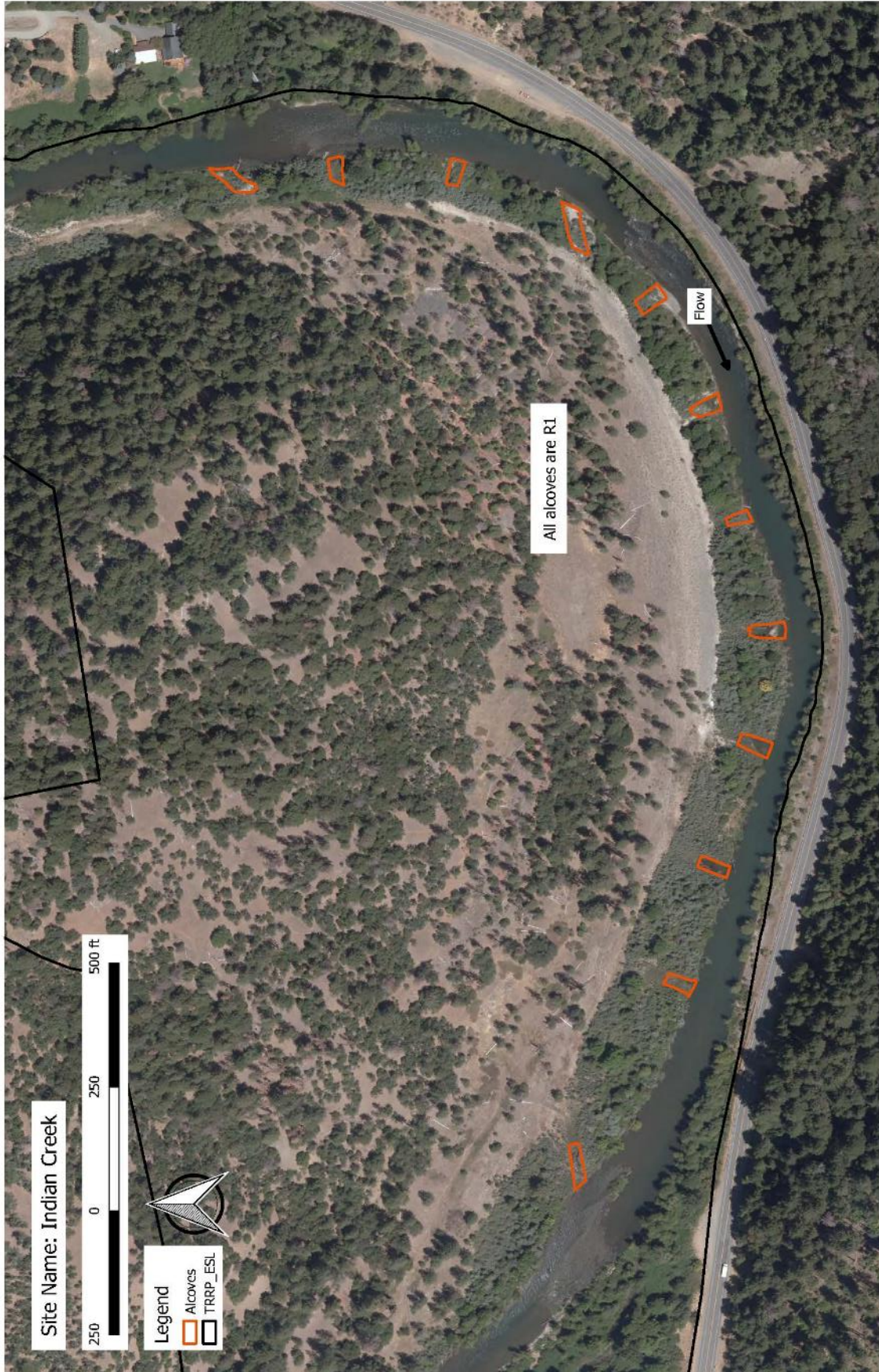




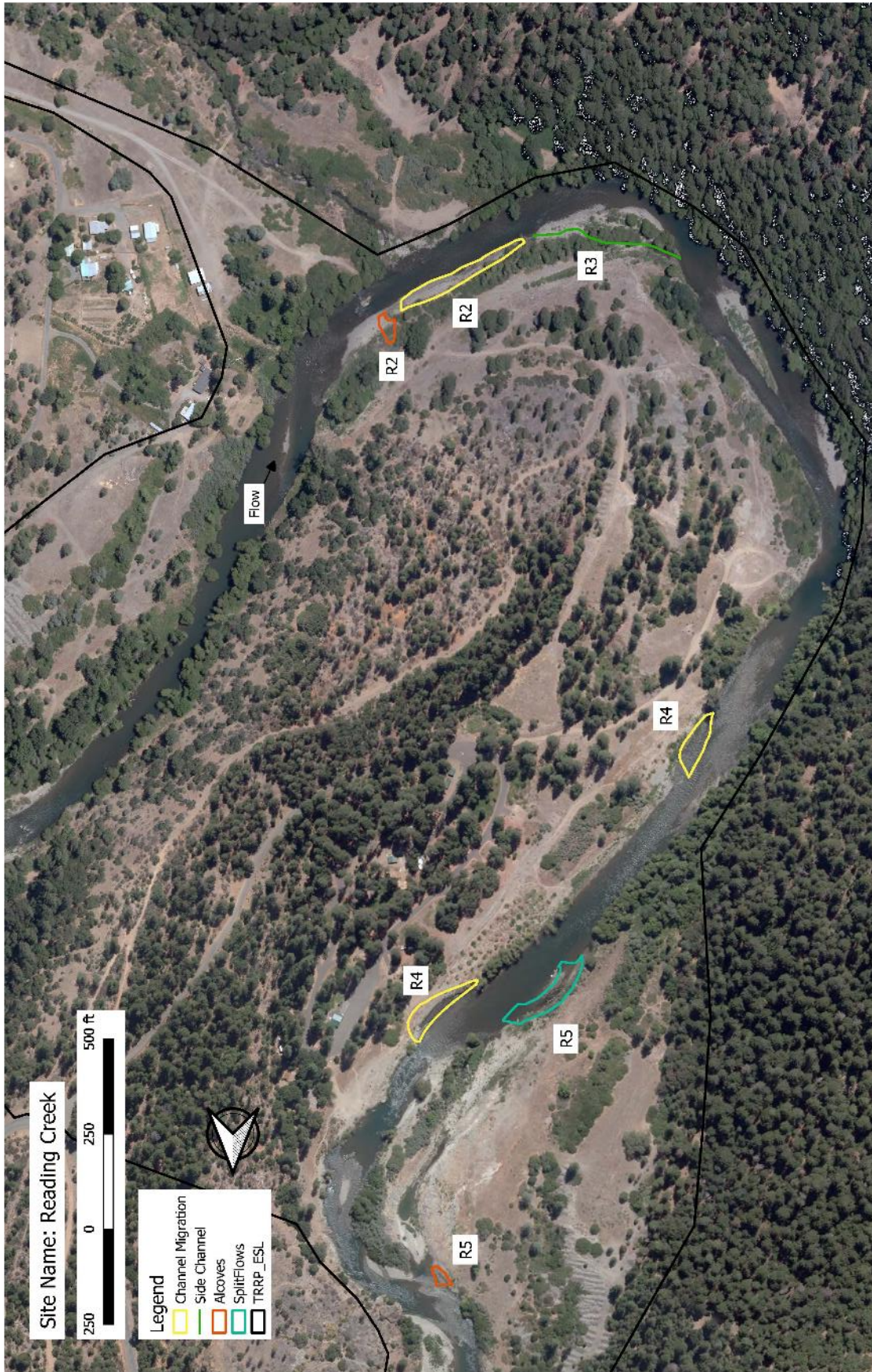


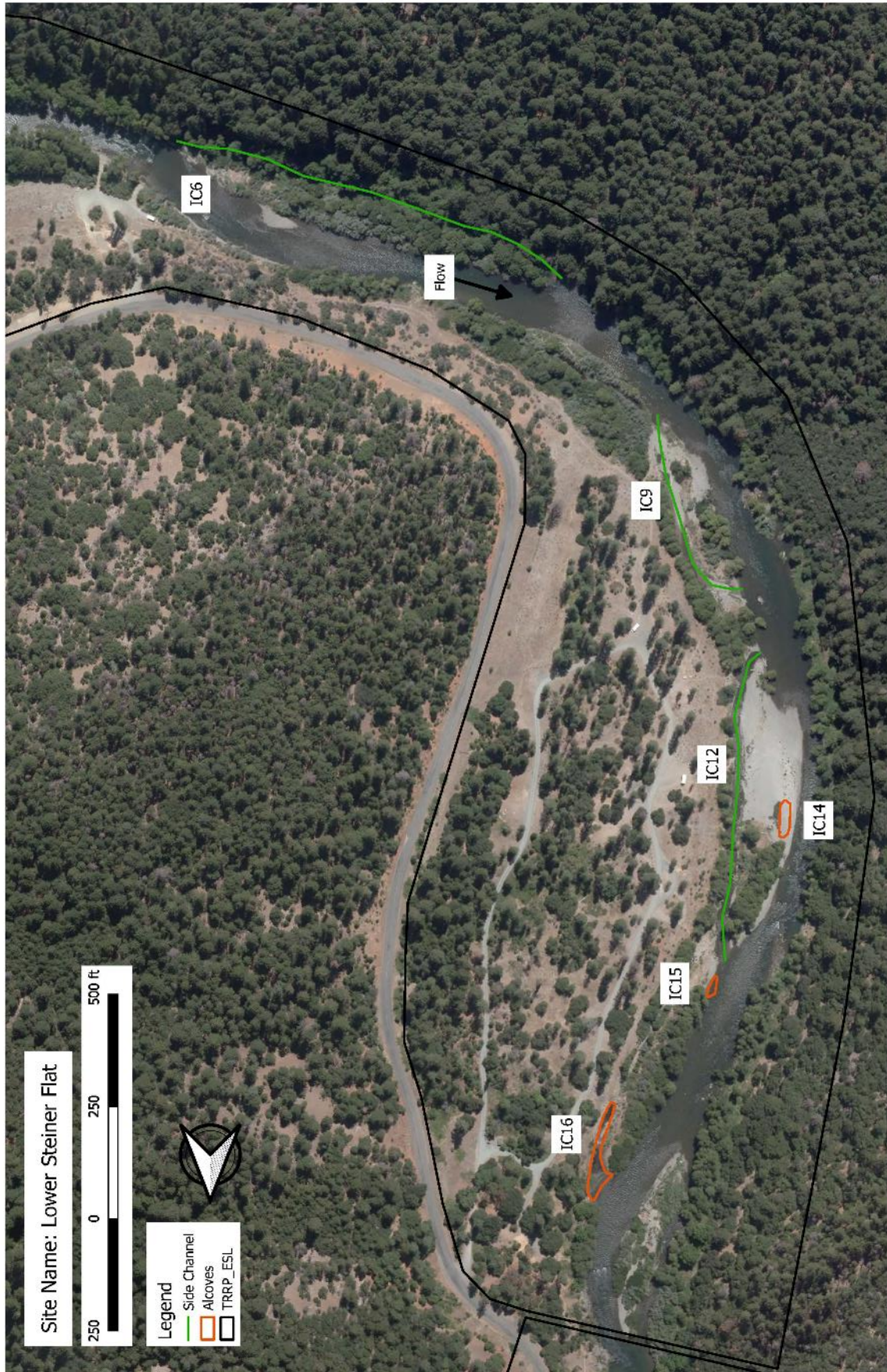


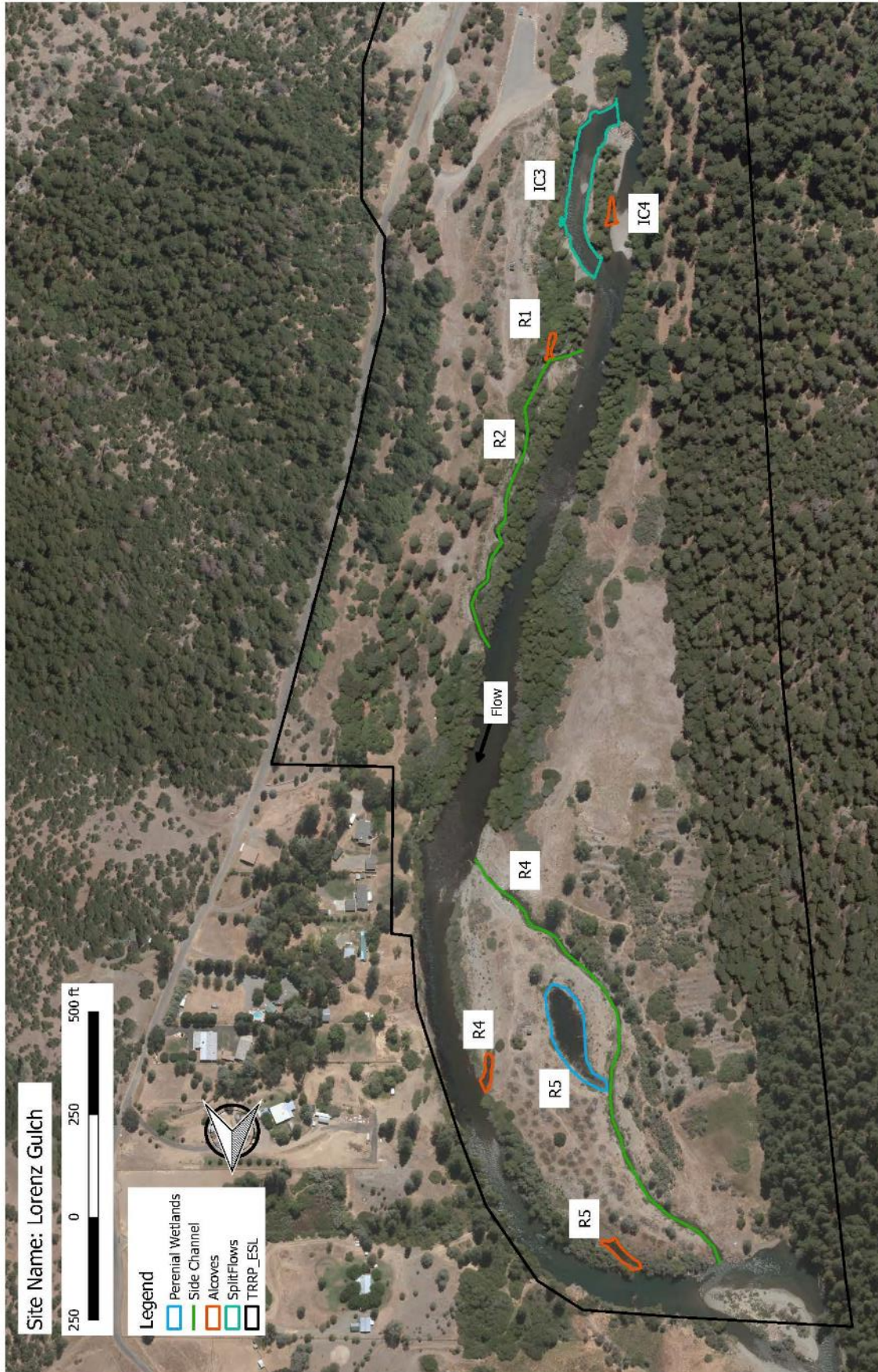


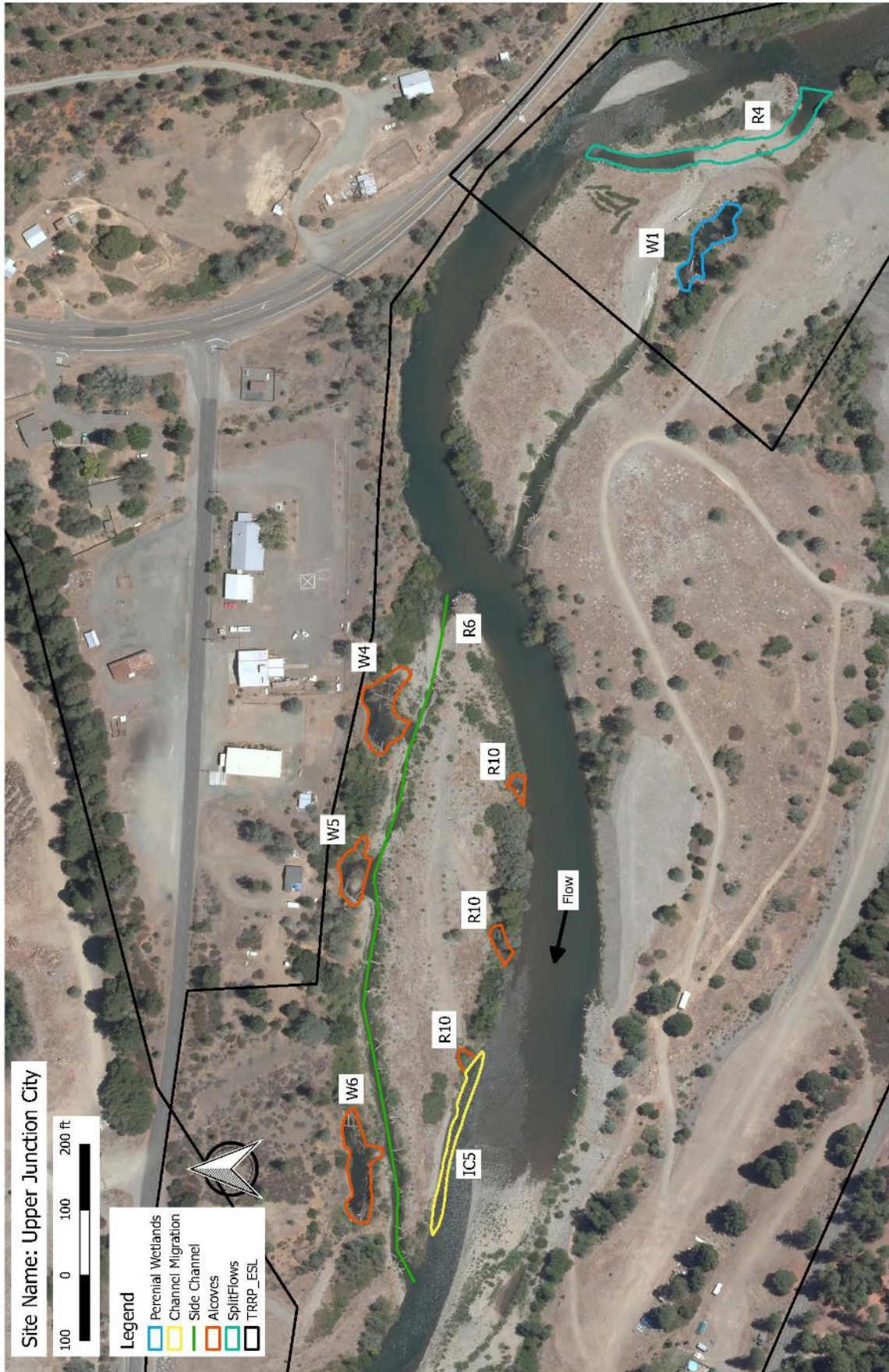






















APPENDIX 2: GENERAL SITE INFORMATION

Table 2-1. River location, year built, and closest or most appropriate USGS streamflow gage for each construction site. Note: some of the natural features evaluated for this analysis (e.g., split-flow channel locations) are not associated with construction sites and are not shown in this table.

Site	River Mile	Year Built	Trinity River USGS Gage
Sven Olbertson	111.2–111.7	2008	Trinity River at Lewiston CA (11525500)
Deadwood Creek	110.6–110.8	2008	Trinity River at Lewiston CA (11525500)
Cableway	110.1–110.6	2008	Trinity River at Lewiston CA (11525500)
Hoadley Gulch	109.8–110.1	2008	Trinity River at Lewiston CA (11525500)
Sawmill	108.8–109.7	2009	Trinity River at Lewiston CA (11525500)
Dark Gulch	105.5–107.0	2008	Trinity River blw Limekiln Gulch near Douglas City CA (11525655)
Lowden Ranch	104.4–105.3	2010	Trinity River blw Limekiln Gulch near Douglas City CA (11525655)
Trinity House Gulch	104.0–104.3	2010	Trinity River blw Limekiln Gulch near Douglas City CA (11525655)
Limekiln Gulch	99.7–100.6	2015	Trinity River blw Limekiln Gulch near Douglas City CA (11525655)
Indian Creek	93.9–96.9	2007	Trinity River blw Limekiln Gulch near Douglas City CA (11525655)
Upper Douglas City	93.6–94.6	2015	Trinity River at Douglas City CA (11525854)
Reading Creek	92.15–93.25	2010	Trinity River at Douglas City CA (11525854)
Lower Steiner Flat	90.7	2012	Trinity River at Douglas City CA (11525854)
Lorenz Gulch	89.8	2013	Trinity River at Douglas City CA (11525854)
Upper Junction City	79.8–80.4	2012	Trinity River at Junction City CA (11526250)
Lower Junction City	78.8–79.8	2014	Trinity River at Junction City CA (11526250)
Hocker Flat	78.0–79.3	2005	Trinity River abv NF Trinity River near Helena CA (11526400)
Wheel Gulch	76.11	2011	Trinity River abv NF Trinity River near Helena CA (11526400)
Valdor Gulch	74.8–75.7	2006	Trinity River abv NF Trinity River near Helena CA (11526400)
Elkhorn	73.7–74.4	2006	Trinity River abv NF Trinity River near Helena CA (11526400)
Pear Tree Gulch	72.9–73.3	2006	Trinity River abv NF Trinity River near Helena CA (11526400)

APPENDIX 3: GCD SURVEY DATES ALL ANALYSES

Table 3-1. Site construction year, date of the post-construction survey used in the GCD analysis, date of the contemporary survey used in the GCD analysis, and number of years the GCD analysis includes. For most sites the initial survey used is the soonest survey that was completed post construction. However, Sheridan Creek/Deep Gulch, Chapman Ranch, and Oregon Gulch are newly constructed or not yet constructed. At these sites, the GCD analysis used the 2009 or 2012 survey and 2016 survey to evaluate some naturally occurring features at the sites that have persisted through time.

Site	Year Built	Date of Initial Survey Used for GCD	Date of Most Recent Survey Used for GCD	# Years GCD Evaluates
Hocker Flat	2005	2006	2016	10
Elkhorn	2006	2012	2016	4
Pear Tree Gulch	2006	2009	2016	8
Valdor Gulch	2006	2009	2016	8
Indian Creek	2007	2009	2016	8
Cableway	2008	2009	2016	8
Dark Gulch	2008	2009	2016	8
Deadwood Creek	2008	2009	2016	8
Hoadley Gulch	2008	2009	2016	8
Sven Olbertson	2008	2009	2016	8
Sawmill	2009	2012	2016	4
Lowden Ranch	2010	2011	2016	5
Reading Creek	2010	2011	2016	5
Trinity House Gulch	2010	2011	2016	5
Wheel Gulch	2011	2012	2016	4
Lower Steiner Flat	2012	2013	2016	3
Upper Junction City	2012	2013	2016	3
Lorenz Gulch	2013	2012	2016	4
Lower Junction City	2014	2015	2016	1
Upper Douglas City	2015	2015	2016	1
Limekiln Gulch	2015	2015	2016	1
Sheridan Creek/Deep Gulch	2016	2009	2016	8
Chapman Ranch	Not Constructed	2009	2016	8
Oregon Gulch	Not Constructed	2009	2016	8
Dutch Creek	Not Constructed	2012	2016	4
Lower Dutton Creek	Not Constructed	2012	2016	4

APPENDIX 4: FLOW DATA

Table 4-1. Date of the peak flow for each water year and for each of the five USGS mainstem Trinity River gages. The reported peak flows are instantaneous peaks not daily averages. The table also shows the number of days where Daily Average Streamflow (DAQ) met or exceeded 4,500 cfs from the start of a specific WY through the end of WY 2016. For example, from the start of WY 2006 through the end of WY 2016, there were 100 flows that met or exceeded 4,500 cfs at the Lewiston gage. Summarizing flows this way makes it possible to quickly find the number of flows greater than 4,500 cfs that have occurred at each project site by matching the year of construction to the WY. For example, Lowden Ranch and Reading Creek were both constructed in 2010. This table shows that at Lowden Ranch (Limekiln gage), there have been 48 DAQ flows that have met or exceeded 4,500 cfs, while at Reading Creek (Douglas City gage), there have been 60 DAQ flows that have met or exceeded 4,500 cfs.

Water Year	Gage	Number of Days where DAQ \geq 4,500 cfs since the start of that WY to the end of WY 2016	Peak Flow in that WY (cfs)
2006	Lewiston (11525500)	100	10,400 (5/24/06)
	Limekiln (11525655)	113	10,100 (5/25/06)
	Douglas City (11525854)	136	12,500 (12/30/05)
	Junction City (11526250)	158	16,700 (12/31/05)
	Above North Fork (11526400)	232	28,800 (12/31/05)
2007	Lewiston (11525500)	54	4,810 (5/1/07)
	Limekiln (11525655)	66	4,700 (5/2/07)
	Douglas City (11525854)	81	4,810 (5/2/07)
	Junction City (11526250)	88	4,490 (5/2/07)
	Above North Fork (11526400)	157	5,140 (5/2/07)
2008	Lewiston (11525500)	49	6,890 (5/8/08)
	Limekiln (11525655)	65	7,160 (5/9/08)
	Douglas City (11525854)	78	7,510 (5/9/08)
	Junction City (11526250)	88	7,210 (5/9/08)
	Above North Fork (11526400)	150	7,640 (5/9/08)
2009	Lewiston (11525500)	39	4,630 (5/1/09)
	Limekiln (11525655)	54	5,420 (5/9/09)
	Douglas City (11525854)	66	6,090 (5/4/09)
	Junction City (11526250)	76	6,500 (5/5/09)
	Above North Fork (11526400)	129	7,890 (5/5/09)
2010	Lewiston (11525500)	39	7,480 (5/3/10)
	Limekiln (11525655)	48	6,970 (5/2/10)
	Douglas City (11525854)	60	7,450 (5/4/10)
	Junction City (11526250)	69	7,660 (5/4/10)
	Above North Fork (11526400)	119	7,980 (5/4/10)
2011	Lewiston (11525500)	29	12,300 (5/4/11)
	Limekiln (11525655)	37	12,600 (5/7/11)
	Douglas City (11525854)	43	12,900 (5/5/11)
	Junction City (11526250)	52	13,700 (5/4/11)

Water Year	Gage	Number of Days where DAQ \geq 4,500 cfs since the start of that WY to the end of WY 2016	Peak Flow in that WY (cfs)
	Above North Fork (11526400)	95	13,000 (5/7/11)
2012	Lewiston (11525500)	19	6,180 (5/7/12)
	Limekiln (11525655)	25	6,310 (5/9/12)
	Douglas City (11525854)	27	6,480 (5/7/12)
	Junction City (11526250)	32	6,290 (5/7/12)
	Above North Fork (11526400)	65	6,990 (5/9/12)
2013	Lewiston (11525500)	13	4,590 (5/3/13)
	Limekiln (11525655)	14	4,590 (5/3/13)
	Douglas City (11525854)	21	4,760 (5/4/13)
	Junction City (11526250)	21	6,340 (12/2/12)
	Above North Fork (11526400)	44	9,360 (12/2/12)
2014	Lewiston (11525500)	13	3,460 (9/18/14)
	Limekiln (11525655)	14	3,460 (9/21/14)
	Douglas City (11525854)	19	3,280 (9/19/14)
	Junction City (11526250)	19	3,480 (9/19/14)
	Above North Fork (11526400)	40	4,680 (3/10/14)
2015	Lewiston (11525500)	13	8,830 (5/4/15)
	Limekiln (11525655)	14	8,580 (5/5/15)
	Douglas City (11525854)	19	9,100 (5/5/15)
	Junction City (11526250)	19	9,690 (2/7/15)
	Above North Fork (11526400)	39	13,000 (2/7/15)
2016	Lewiston (11525500)	9	9,600 (5/9/16)
	Limekiln (11525655)	9	10,600 (5/10/16)
	Douglas City (11525854)	14	11,100 (5/10/16)
	Junction City (11526250)	13	11,200 (5/10/16)
	Above North Fork (11526400)	29	13,100 (1/17/16)

APPENDIX 5: FLOW DURATION CURVES

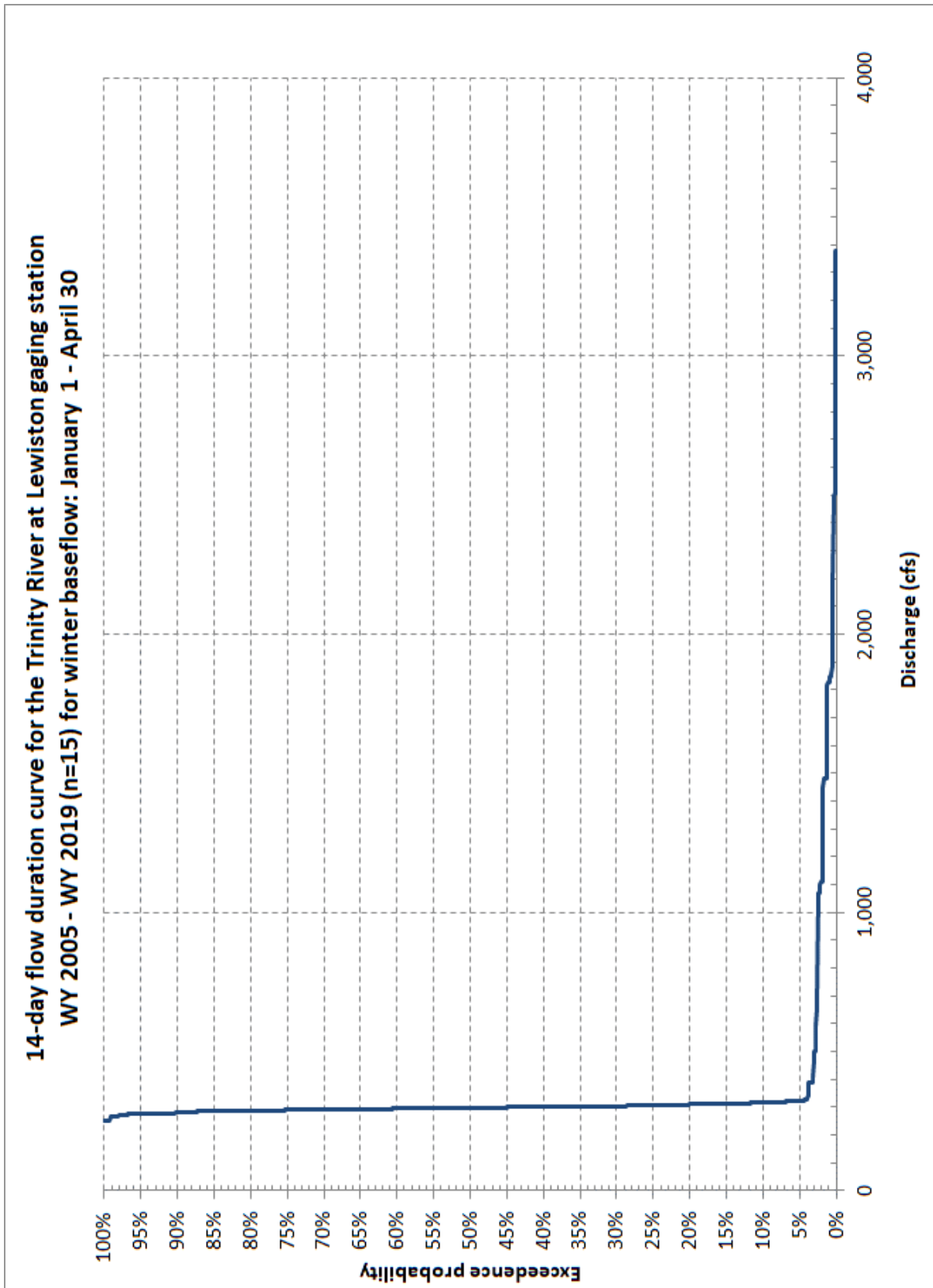


Figure 5-1. 14-Day flow duration curve for the Trinity River at the USGS Lewiston gaging station.

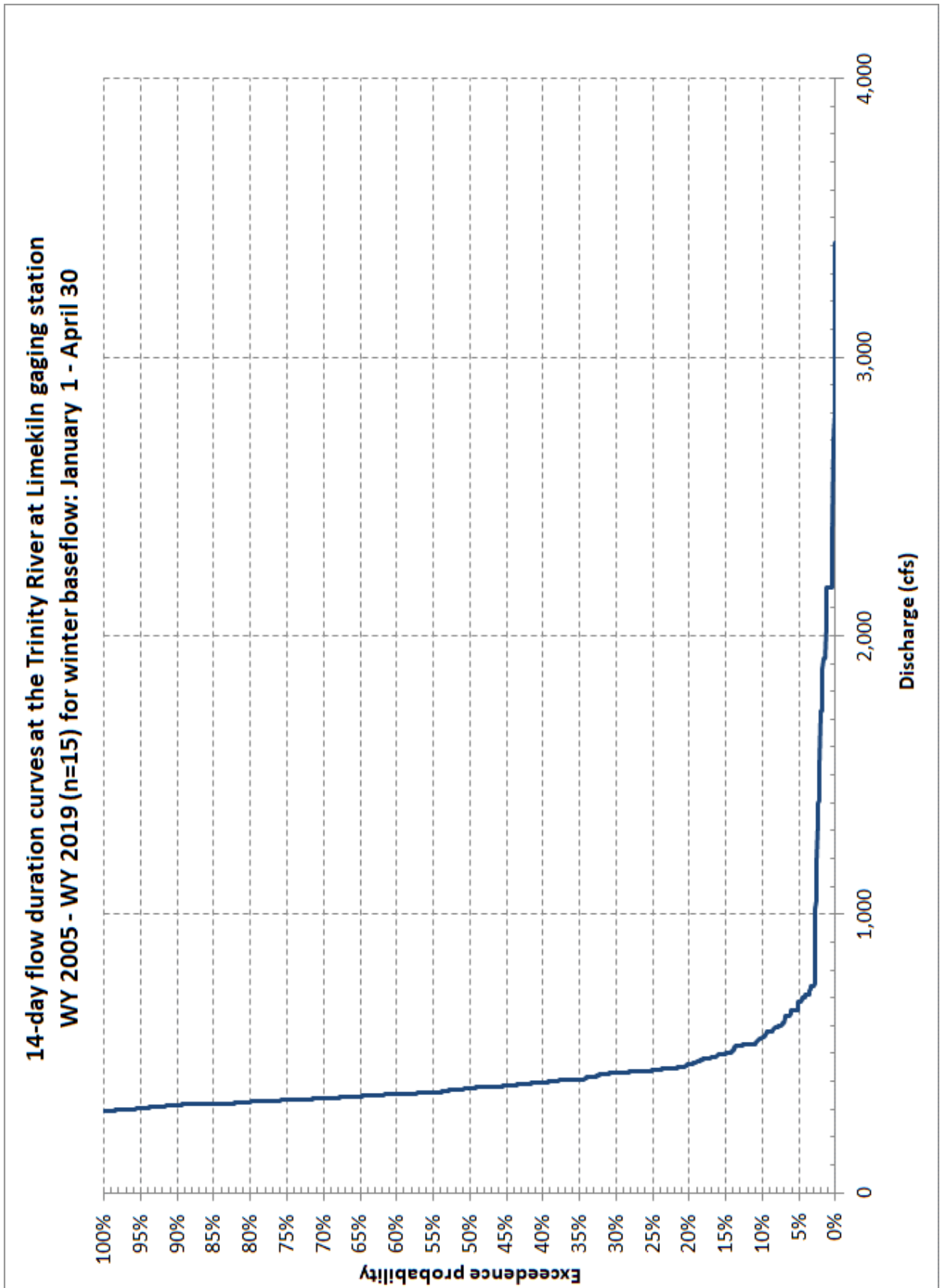


Figure 5-2. 14-day flow duration curve for the Trinity River at the USGS Limekiln gaging station.

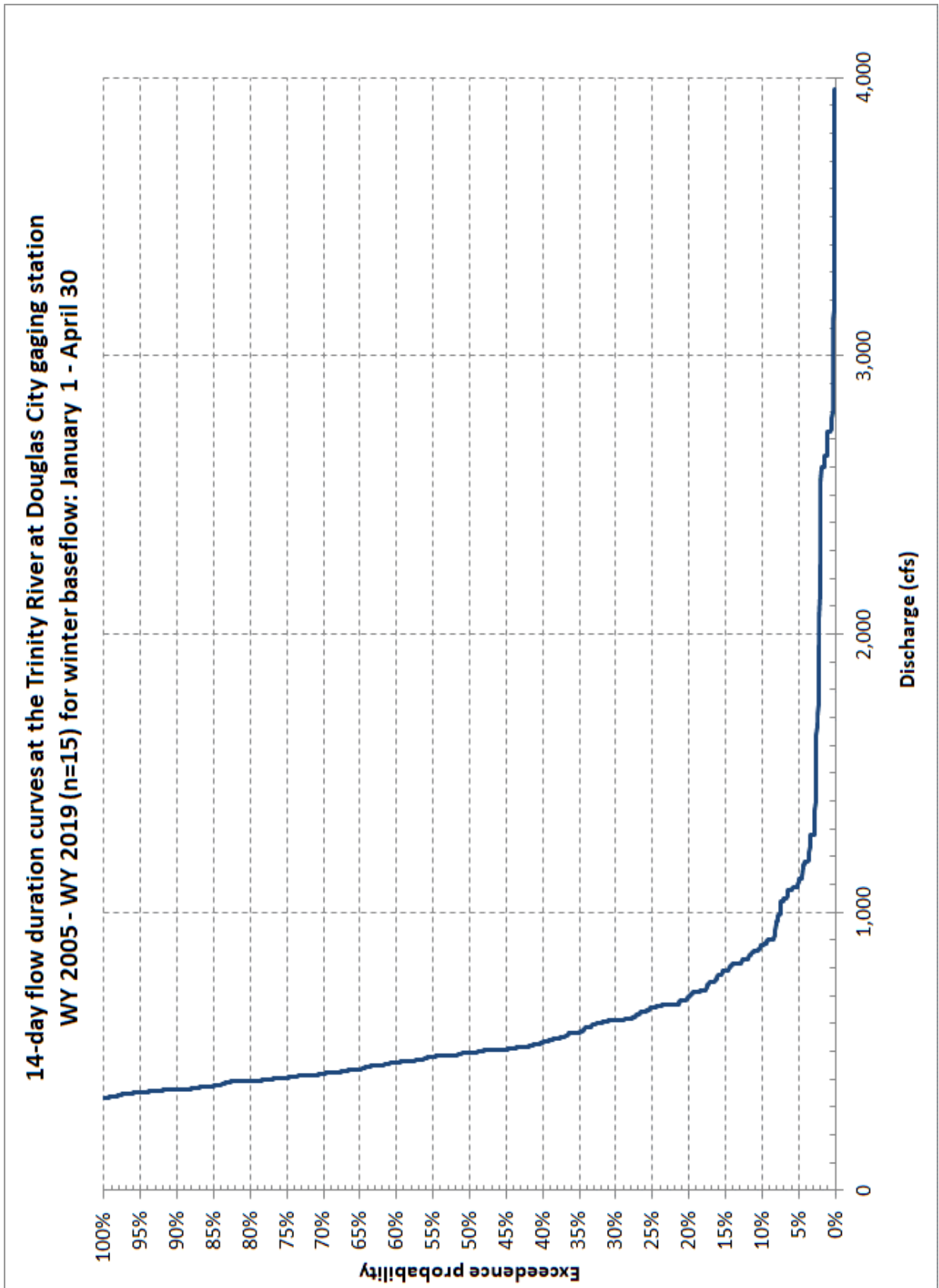


Figure 5-3. 14-day flow duration curve for the Trinity River at the USGS Douglas City gaging station.

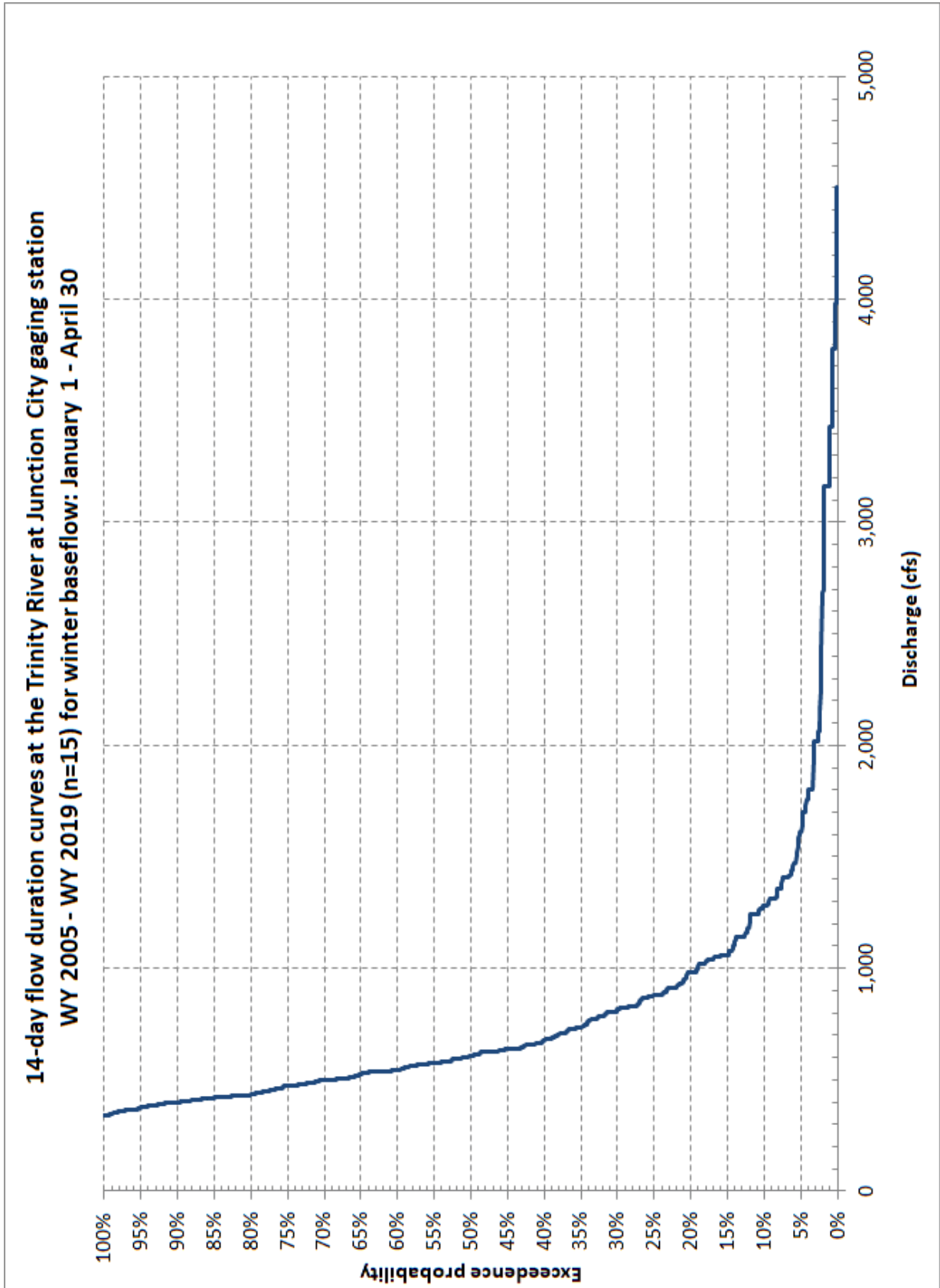


Figure 5-4. 14-day flow duration curve for the Trinity River at the USGS Junction City gaging station.

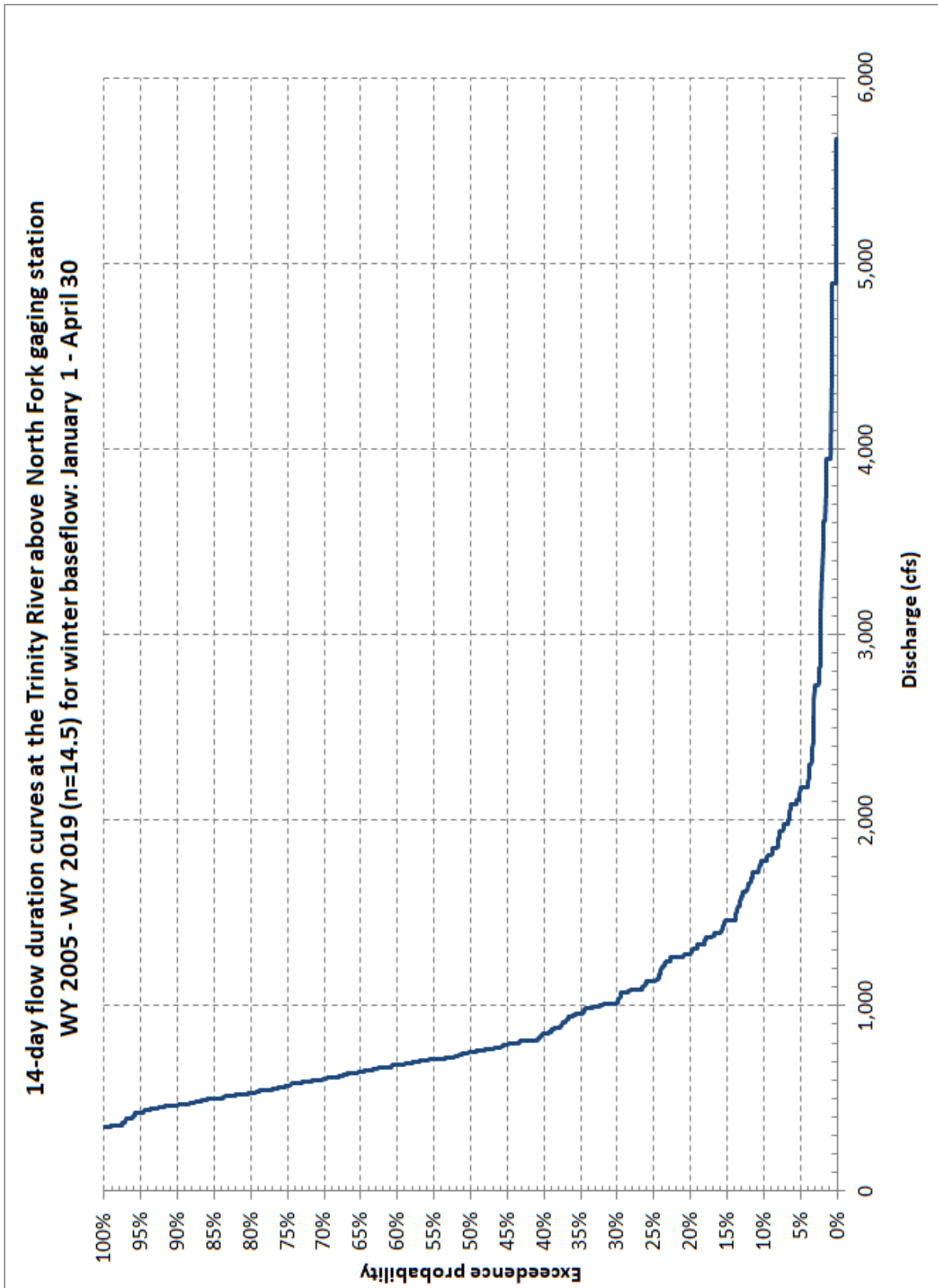


Figure 5-5. 14-day flow duration curve for the Trinity River at the USGS Trinity River above North Fork gaging station.

APPENDIX 6: SIDE-CHANNEL TABLES AND RESULTS

Side-channel GCD Results

Table 6-1. Results of the GCD analysis and brief description of deposition and scour at each side-channel. The post-construction survey was not always completed immediately after construction, and the GCD analysis does not capture change that occurred between the end of construction and the date of the post-construction survey.

Site Name (year constructed)	Feature Name	Deposition at Entrance (yes/no)	Description of Deposition at Entrance (ft)
Sven Olbertson (2008)	R1	No	Very little change at upstream end of side-channel; lower end of side-channel has 1.5–3.0 ft of deposition
Deadwood Creek (2008)	R3	Yes	Completely filled, 1.5 to > 6.0 ft of deposition
Cableway (2008)	R3	No	No deposition at the entrance but up to 6 ft of scour approximately 180 ft downstream of the entrance
Hoadley Gulch (2008)	R5	No	Little change at the entrance, but 1.5–3.0 ft of deposition scattered throughout
Sawmill (2009)	R3	Yes	Extreme aggradation; however, the GCD does not capture it well, likely because the deposition happened prior to the post-construction survey.
Dark Gulch (2008)	R1	Yes	1.5–3.0 ft of deposition at the entrance in the upstream third of the side-channel
	R6	Yes	1.5–3.0 ft of deposition at the entrance and scattered throughout. Up to 6.0 ft of deposition in the downstream third of the side-channel.
Lowden Ranch (2010)	R1	No	Deposition of 1.5–3.0 ft in the main channel but scour of 1.5–3.0 ft through the side-channel
Trinity House Gulch (2010)	R2	No	1.5–3.0 ft of scour in main channel at the side-channel entrance with no deposition. Very few, small patches of 1.5–3.0 ft of deposition scattered throughout.
Limekiln Gulch (2015)	R1	No	No change at entrance and very little change throughout
	R2	No	No change at entrance but 1.5–3.0 ft of deposition scattered throughout
Upper Douglas City (2015)	IC2	Yes	1.5–4.5 ft of deposition at upstream-most entrance. However, a second side-channel entrance immediately downstream keeps the side-channel flowing
Reading Creek (2010)	R3	Yes	1.5–3.0 ft of deposition through side-channel. However, most of the deposition likely occurred before the post-construction survey and was not captured well by the GCD.
Lower Steiner Flat (2012)	IC 6	Yes	1.5–6.0 ft of deposition shown at entrance but very little change throughout.
	IC9	Yes	1.5 to > 6.0 ft through the entire side-channel, including the entrance
	IC12	Yes	1.5–3.0 ft of deposition at the entrance and some deposition scattered throughout

Site Name (year constructed)	Feature Name	Deposition at Entrance (yes/no)	Description of Deposition at Entrance (ft)
Lorenz Gulch (2013)	R2	Yes	1.5–3.0 ft of deposition at entrance and through entire side-channel
	R4	Yes	1.5–3.0 ft of deposition at entrance and scattered deposition throughout
Upper Junction City (2012)	R6	Yes	1.5–4.5 ft of deposition at entrance but 1.5–4.5 ft of scattered scour throughout rest of the side-channel
Wheel Gulch (2011)	R2	Yes	1.5–3.0 ft of deposition at side-channel entrance. 1.5–3.0 ft of scour where the split channel and side-channel diverge.
Valdor Gulch (2006)	R2	No	No change through the entire side-channel

Side-channel Length Analysis Results

Table 6-2. Side-channel length and the reported effectiveness for each side-channel based on contemporary wetted length. The table is organized based on percent effectiveness. The “design” side-channel length was digitized using the 2016 aerial image. The “contemporary” side-channel length was digitized based on the 2016 SRH-2D model 450 cfs wetted area output. The 450 cfs wetted perimeter output does not always have good agreement with the 2016 aerial image, so the length analysis is based on the assumption that the 450 cfs wetted area output is correct.

Site Name	Feature Name	Design Side-channel Length at 450 cfs (ft)	Contemporary Side-channel Wetted Length at 450 cfs (ft)	Side-channel Length Reduction (ft)	% Effective
Lower Steiner Flat	IC6	919	0	919	0%
	IC9	472	0	472	0%
Dark Gulch	R1	774	68	706	9%
Trinity House Gulch	R2	1,024	118	906	11%
Sawmill	R3	1,040	169	871	16%
Reading Creek	R3	407	81	326	20%
Lorenz Gulch	R4	1,234	298	935	24%
Valdor Gulch	R2	974	267	707	27%
Deadwood Creek	R3	440	198	242	45%
Upper Junction City	R6	1,076	955	121	89%
Sven Olbertson	R1	1,486	1,368	118	92%
Upper Douglas City	IC2	1,230	1,190	41	97%
Lorenz Gulch	R2	843	826	17	98%
Hoadley Gulch	R5	804	798	6	99%
Wheel Gulch	R2	692	692	0	100%
Dark Gulch	R6	571	571	0	100%
Lewiston	R3	1,240	1,240	0	100%
Limekiln	R1	1,316	1,316	0	100%
	R2	610	610	0	100%
Lowden Ranch	R1	738	738	0	100%
Steiner Flat	IC12	705	705	0	100%

APPENDIX 7: SPLIT-FLOW CHANNEL TABLES AND RESULTS

Constructed Split-flow Overall Percent Effectiveness

Table 7-1. Percent Effectiveness assigned to the six constructed split-flow channels. The percent effectiveness for these features was solely calculated based on if each side of the split-flow channel was still conveying 20% of flow under contemporary condition. The additional analyses completed for split-flow channels were used to further the evaluation qualitatively and to provide insight on CDG recommendations.

Site Name	Feature Name	Each Side of Split-Flow Channel Conveys 20% of Total Flow Under Contemporary Condition (Y/N)?	% Effective
Lowden Ranch US	R7	Yes	100%
Lowden Ranch DS	R7	Yes	100%
Upper Douglas City	IC7	No	0%
Reading Creek	R5	No	0%
Lorenz Gulch	IC3	Yes	100%
Upper Junction City	R4	Yes	100%
Wheel Gulch	R1	Yes	100%

Constructed Split-flow Streamflow Conveyance Results

Table 7-2. Results of the analysis to evaluate if constructed split-flow channels are conveying 20% of the total streamflow under contemporary conditions. The table sections labeled “Green and Black Cross Section Placement” show the depth and velocity data that were extracted along the digital cross section lines from the SRH-2D model outputs, which were used to calculate streamflow for each flow split. The average values from the two data sets were used to evaluate effectiveness. The “US” and “DS” labels are used for “upstream” and “downstream”.

Green Cross Section Placement						
Name	Average Depth (ft)	Average Velocity (ft)	Average Length (ft)	Calculated Flow (cfs)	% Flow	Total Calculated Flow (cfs)
Lowden Ranch split US	2.2	1.1	38	95	23%	414
Lowden Ranch main US	0.9	3.8	92	320	77%	
Lowden Ranch split DS	2.8	0.8	51	118	30%	395
Lowden Ranch main DS	1.2	3.1	78	277	70%	
Upper Douglas split	0.6	1.1	51	31	7%	446
Upper Douglas main	1.8	2.6	91	415	93%	
Reading Creek split	0	0.2	13	1	1%	420
Reading Creek main	3.33	1.2	103	419	99%	
Lorenz Gulch split	1.9	2.4	70	320	71%	451
Lorenz Gulch main	5.7	0.4	57	132	29%	
Wheel Gulch split	2.4	1.3	2	158	40%	391
Wheel Gulch Main	1.9	2.2	56	233	60%	

Black Cross Section Placement						
Name	Average Depth (ft)	Average Velocity (ft)	Average Length (ft)	Calculated Flow (cfs)	% Flow	Total Calculated Flow (cfs)
Lowden Ranch split US	1.6	1.7	31	82	19%	434
Lowden Ranch main US	1.6	2.4	95	352	81%	
Lowden Ranch split DS	2.1	1.0	37	79	20%	405
Lowden Ranch main DS	1.6	3.4	58	326	80%	
Upper Douglas main	2	2.4	85	409	90%	455
Upper Douglas split	1.1	0.9	46	46	10%	
Reading Creek split	0.87	0.1	25	2	1%	397
Reading Creek main	2.58	1.3	120	394	99%	
Lorenz Gulch split	1.9	2.3	66	289	68%	427
Lorenz Gulch main	2.2	1.0	62	138	32%	
Wheel Gulch split	1.7	1.9	49	152	37%	407
Wheel Gulch Main	1.5	2.0	84	255	63%	
Average Calculated Streamflow Used to Evaluate Effectiveness						
Name	Average Depth (ft)	Average Velocity (ft)	Average Length (ft)	Calculated Flow (cfs)	% Flow	Total Calculated Flow (cfs)
Lowden Ranch split US	1.9	1.4	35	88	21%	424
Lowden Ranch main US	1.2	3.1	93	336	79%	
Lowden Ranch split DS	2.5	0.9	44	99	25%	400
Lowden Ranch main DS	1.4	3.2	68	302	75%	
Upper Douglas main	1.9	2.5	88	412	91%	450
Upper Douglas split	0.8	1.0	49	39	9%	
Reading Creek split	0.62	0.2	19	2	1%	409
Reading Creek main	2.95	1.3	112	407	99%	
Lorenz Gulch split	4	0.7	59	135	31%	439
Lorenz Gulch main	1.9	2.4	68	304	69%	
Wheel Gulch split	2	1.6	50	155	39%	399
Wheel Gulch Main	1.7	2.1	70	244	61%	

Constructed and Naturally Occurring Split-flow Channel GCD Results

Table 7-3. GCD results at split-flow locations describing the deposition and erosion through time at constructed and naturally occurring split-flow channels. Please refer to Appendix 3: GCD Survey Dates All Analyses for the range of years the GCD evaluates. River miles (RM) are listed in place of feature names for the naturally occurring split-flow channels.

Site Name	Feature Name	Was there Deposition or Erosion?	Description of Deposition/Erosion
Lowden Ranch (upstream)	R7	Erosion	3.0–6.0 ft of erosion at the very upstream extent of the medial gravel bar. 3.0–4.5 ft of erosion along the full extent the medial bar on the main channel side.
Lowden Ranch (downstream)	R7	Primarily erosion	Up to 3.0 ft of erosion along the upstream extent of the medial bar on the main channel side. Up to 1.5 ft of deposition in the middle channel that separates the upstream and downstream flow splits.
Reading Creek	RM 92.9	Erosion	Between 1.5–3.0 ft of erosion along the medial bar on the split-flow channel side. Otherwise, no change.
Reading Creek	R5	Primarily erosion	The GCD does not capture the change at this site because it occurred prior to the post-construction survey used in the analysis. The medial bar and vegetation were eroded away between 2010 and 2011. There only remains a small medial bar and small split-flow channel.
Upper Douglas City	IC7	Erosion	3.0 to >6.0 ft of erosion over the entire medial bar resulting in loss of most of the bar (log jam at upstream end of bar still present). 1.5–3.0 ft of deposition immediately downstream of medial bar (likely medial bar material that has been transported slightly downstream).
Lower Steiner Flat	RM 90.3	Both deposition and erosion	Small patches of both deposition and erosion between 1.5–3.0 ft through split-flow channel and on medial bar. Very little change overall.
Lower Dutton Creek	RM 88.9	Very little change	GCD shows very small patches of deposition and erosion in the split-flow channels. There are some small patches of erosion up to 4.5 ft at the downstream end of the medial bar. Overall, very little change.
Dutch Creek	RM 85.3	No change	GCD shows erosion and deposition occurring on the banks in the vicinity of the flow split, but no change occurring in the split-flow channels or on the medial bar.
Chapman Ranch	RM 83.65	Both deposition and erosion	Deposition on the medial bar of up to 4.5 ft. Large swaths of erosion in both channels, primarily between 1.5–3.0 ft but up to 4.5 ft.
Deep Gulch and Sheridan Creek	RM 82.5	Both deposition and erosion	Very little change overall, but small patches of 1.5–3.0 ft of deposition in the split-flow channel as well as one patch of erosion up to 4.5 ft.
Oregon Gulch	RM 81.15	Primarily erosion	Erosion greater than 6.0 ft over a large area of the medial bar closest to the right bank (bar almost completely gone in 2016). Some erosion up to 6.0 ft or greater also along the edges of the medial bar closest to the left bank. Small patches of deposition 1.5–3.0 ft at the upstream end of the left bank medial bar.

Site Name	Feature Name	Was there Deposition or Erosion?	Description of Deposition/Erosion
Upper Junction City	R4	Both deposition and erosion	3.0 to >6.0 ft of erosion at the upstream end of the medial bar extending across the main channel to the right bank. Up to 3.0 ft of deposition through the main channel immediately downstream of the erosion that described. 1.5–3.0 ft of deposition immediately downstream of the split-flow channel entrance (acts as a plug in the split-flow channel).
Hocker Flat	RM 78.75	Both deposition and erosion	Patches of deposition up to 3.0 ft along the right bank split-flow channel and on the medial bar. Primarily 1.5–3.0 ft of erosion, with up to 4.5 ft along the left bank of the mainstem channel.
Wheel Gulch	R1	Primarily deposition	4.5–6.0 ft of erosion at the upstream end of the medial gravel bar. 3.0–6.0 ft of deposition immediately upstream of the erosion described and across the entrance to the split-flow channel. 1.5–3.0 ft of deposition along the downstream extent of the medial bar on the split-flow channel side.

Constructed and Naturally Occurring Split-flow Channel Aerial Photograph Analysis

Table 7-4. Trends of deposition and erosion at constructed and naturally occurring split-flow locations that were captured in aerial photographs.

Natural or Constructed	Site Name	Aerial Photographs Used in Evaluation	Aerial Photograph Description of Change
C	Lowden Ranch R7 (upstream)	2011, 2012, 2015, 2016	Between 2011 and 2012, a large portion of the round gravel island was eroded away on the right bank flow-split side. Erosion has continued through 2016, creating a gum-drop shaped island. Very little change has occurred in the left bank flow-split channel.
C	Lowden Ranch R7 (downstream)	2011, 2012, 2015, 2016	Erosion has occurred on the downstream gravel island like the upstream island. The log jams have persisted through time on both islands. Vegetation has colonized both islands.
C	Upper Douglas City IC7	2015, 2016	The medial bar has eroded significantly in width, but the log jam remains in place at the upstream end.
C	Reading Creek R5	2010, 2011, 2012, 2015, 2016	Construction of the split-flow channel can be seen in the 2010 aerial photograph, but most of the medial bar was eroded before the 2011 photograph. However, a small amount of deposition on the medial bar between 2012 and 2016 has resulted in the flow-split persisting even with a small medial bar.
N	Reading Creek (RM 92.9)	2007, 2012, 2014, 2016	Naturally occurring split-flow channel that has existed since at least 2007. Split-flow medial bar has become elongated and vegetated through time but appears stable.
N	Lower Steiner Flat (RM 90.3)	2007, 2012, 2014, 2016	Naturally occurring split-flow channel that has existed since at least 2007. The size and shape of the bar have remained consistent through time. Bar has mature vegetation.
N	River Mile 88.9	2007, 2012, 2014, 2016	Naturally occurring split-flow channel that has existed since at least 2007. The size and shape of the bar have remained consistent through time.
N	Dutch Creek (RM 85.3)	2007, 2012, 2014, 2016	Naturally occurring split-flow channel that has existed since at least 2007. The size of the medial bar has grown over time and has become more vegetated.
N	Chapman Ranch (RM 83.65)	2007, 2012, 2014, 2016	Naturally occurring split-flow channel that has existed since at least 2007. The size of the medial bar fluctuates through time and the right bank split-flow channel had very little flow in 2014, possibly due to additional deposition.

Natural or Constructed	Site Name	Aerial Photographs Used in Evaluation	Aerial Photograph Description of Change
N	Sheridan Creek (RM 82.5)	2007, 2012, 2014, 2016	Naturally occurring split-flow channel and medial bar appear stable through time.
N	Oregon Gulch (RM 81.15)	2007, 2012, 2014, 2016	Two naturally occurring medial bars that create 3 split-flow channels. The medial bar closest to the right bank has eroded through time and was almost completely gone by 2016. The medial bar closest to the left bank appeared stable and was mostly vegetated.
C	Upper Junction City R4	2013, 2014, 2015, 2016	Deposition began between 2013 and 2014 in the upstream portion of the split-flow channel. The split-flow channel entrance was completely blocked with a sediment wedge at baseflow between 2014 and 2015. Sediment wedge remains in 2016.
N	Hocker Flat (RM 78.75)	2005, 2008, 2012, 2016	Massive floodplain grading on the left bank that slightly widened the channel resulted in the formation of a flow split and medial bar adjacent to the grading. There is no split-flow channel in the 2005 as-built photograph, but formation of a medial bar began by 2008 and was fully formed in the 2012 photograph. The medial bar and split flow persist in 2016.
C	Wheel Gulch R1	2014, 2015, 2016	Deposition is increasing through time at the entrance and a large gravel bar is forming in the downstream half of the split-flow channel.

Naturally Occurring Split-flow Channel Widths

Table 7-5. Naturally occurring split-flow channels and the relationship between the total channel width and the width of the medial bar that forms.

Site Name	Total Channel Width (Bank to Bank Across Split-flow channels and Medial Bar) (ft)	Width of Medial Bar (ft)	% Total Channel Width of Medial Bar
Reading Creek (RM 92.9)	188	66	35%
Lower Steiner Flat (RM 90.3)	229	79	35%
River mile 88.9	241	80	33%
Dutch Creek (RM 85.3)	172	67	39%
Chapman Ranch (RM 83.65)	205	43	21%
Sheridan Creek (RM 82.5)	210	73	35%
Oregon Gulch (RM 81.15)	174	59	34%
Hocker Flat (RM 78.75)	181	56	31%

Constructed Split-Flow Channel Widths

Table 7-6. Constructed split-flow total channel and medial bar widths, as well as the percentage of the total channel width that the medial bar comprises. The “US” and “DS” are for “upstream” and “downstream.”

Site Name	Total Channel Width (Bank to Bank Across Split- flow channels and Medial Bar) (ft)	Width of Medial Bar (ft)	% Total Channel Width of Medial Bar
Lowden Ranch US	253	101	40%
Lowden Ranch DS	245	120	49%
Upper Douglas City IC7	144	9	7%
Reading Creek R5	153	26	17%
Lorenz Gulch	207	71	34%
Upper Junction City R4	209	71	34%
Wheel Gulch R1	298	151	51%

Constructed and Natural Split-Flow Bifurcation Angles

Table 7-7. Constructed split-flow feature location, construction year, feature name, bifurcation angle and flow conveyance.

Site/Feature Name	River Mile	Year Constructed	Bifurcation Angle	Each Side of Split-Flow Channel Conveys 20% of Total Flow Under Contemporary Condition (Y/N)?
Lowden Ranch R7	104.4–105.3	2010	56°	Yes
Upper Douglas City IC7	93.6–94.6	2015	14°	No
Reading Creek RC5	92.2–93.2	2010	20°	No
Lorenz Gulch IC3	89.8	2013	60°	Yes
Upper Junction City R4	79.8–80.4	2012	55°	Yes
Wheel Gulch R1	76.1	2011	30°	Yes

Table 7-8. Natural split-flow feature location, feature name, bifurcation angle and flow conveyance. The naturally occurring split-flows have persisted since at least 2007.

Site/Feature Name	River Mile	Year Constructed	Bifurcation Angle	Each Side of Split-Flow Channel Conveys 20% of Total Flow Under Contemporary Condition (Y/N)?
Reading Creek	92.9	NA	37°	Yes
Lower Steiner Flat	90.3	NA	33°	No
Lower Dutton Creek	88.9	NA	60°	Yes
Dutch Creek	85.3	NA	30°	Yes
Chapman Ranch	83.7	NA	44°	Yes
Deep Gulch and Sheridan Creek	82.5	NA	30°	Yes
Oregon Gulch	81.2	NA	24°	No
Hocker Flat	78.8	NA	20°	No

APPENDIX 8: ALCOVE TABLES AND RESULTS

Alcove Overall Results

Table 8-1. Overall alcove results (composite of connectivity and CGD evaluations), showing the three categories of percent effectiveness and the number of alcoves within each category.

% Effectiveness	Location of Alcove	# of Alcoves
100% = No Change in Deposition or Erosion and Connected at design flow of 300 or 450 cfs	Lower Junction City	1
	Upper Junction City	1
	Lorenz Gulch	1
	Limekiln Gulch	1
	Lowden Ranch	1
	Lower Steiner Flat	1
	Reading Creek	1
	Upper Douglas City	3
	Sven Olbertson	2
	Total in Category	12
Intermediate = Undefined Percent Effectiveness that is Between 0 and 100%	Lorenz Gulch	1
	Lowden Ranch	1
	Lower Junction City	3
	Upper Junction City	4
	Indian Creek	4
	Lower Steiner Flat	1
	Upper Douglas City	3
	Sven Olbertson	1
	Total in Category	18
0% = Completely Filled-in with Sediment and or Cut-off at the design flow of 300 or 450 cfs	Valdor Gulch	1
	Indian Creek	8
	Pear Tree	1
	Elkhorn	1
	Lower Steiner Flat	1
	Upper Junction City	1
	Reading Creek	1
	Sawmill	4
	Total in Category	18

Alcove GCD Results

Table 8-2. Table of GCD results describing deposition and erosion at alcove locations.

Site Name	Number of Alcoves	Was there Deposition or Erosion?	GCD Results of Deposition and Erosion
Sven Olbertson	3	No change and deposition	The two upstream alcoves show no change. The downstream alcove has up to 6.0 ft of deposition in the upstream half.
Sawmill	4	Both deposition and scour	There are three alcoves clustered together on the left bank. One shows no change on the GCD analysis, but it was filled before the post-construction survey. One has up to 3.0 ft of deposition, and one has up to 3.0 ft of scour. Aerial photographs show that the upstream alcove experienced deposition after it was constructed; however, additional construction after 2012 placed large wood and the alcove was turned into a large gravel bar. The SRH-2D results for 300 cfs show all four to be disconnected.
Lowden Ranch	2	Scour	Very little deposition or scour in downstream alcove. Up to 4.5 ft of scour in the upstream alcove.
Limekiln Gulch	1	No change	No scour or deposition in alcove.
Indian Creek	12	Deposition	All alcoves have deposition between 1.5 and 4.5 ft. Several alcoves have deposition up to 6.0 ft or greater. Two alcoves do not have deposition according to the GCD analysis; however, the SRH-2D 450 cfs flow and aerial photographs show that all alcoves are cut off at 450 cfs. This is likely because the post-construction survey was taken in 2009 so it does not capture deposition that occurred between 2007 and 2009.
Douglas City	4	No change and Deposition	Very little change in any of the alcoves except for the very short, narrow downstream alcove, which has up to 3.0 ft of deposition.
Reading Creek	2	No change and Deposition	No deposition or erosion directly in the downstream alcove. No deposition or erosion shown at the upstream alcove; however, the alcove is not visible on aerial images, which suggests that the alcove was filled-in prior to the post-construction survey, similar to the side-channel.
Lower Steiner Flat	3	Both deposition and scour	Some areas of deposition up to 3.0 ft in the downstream alcove. No deposition or scour in the alcove located at the side-channel confluence; however, the area immediately around the alcove has scoured up to 4.5 ft, effectively absorbing the alcove into the main channel. The upstream alcove has completely been filled with up to 6.0 ft of deposition.
Lorenz Gulch	4	Both deposition and scour	Deposition of up to 4.5 ft at the entrance of the downstream-most alcove. No change in the alcove located on the mainstem adjacent to the pond. Up to 3.0 ft of scour in the alcove that is on the right bank at the side-channel entrance. Up to 4.5 ft of deposition in the alcove located in the split-flow channel.

Site Name	Number of Alcoves	Was there Deposition or Erosion?	GCD Results of Deposition and Erosion
Upper Junction City	6	Deposition	Deposition throughout 5 of 6 alcoves. The upstream alcove in the side-channel has the most deposition, up to 6.0 ft. The middle and downstream alcoves in the side-channel have deposition of up to 4.5 ft. The mainstem upstream alcove has very little change, the mainstem middle alcove has deposition up to 3.0 ft, and the mainstem downstream alcove has deposition up to 4.5 ft. Deposition in the alcoves is visible on aerial photographs.
Lower Junction City	3	Both deposition and scour	Very little change in the upstream alcove. The middle alcove has up to 4.5 ft of deposition with at least 1.5 ft of deposition throughout. The downstream alcove has eroded up to 6.0 ft, creating more of a split-flow channel feature than an alcove feature.
Wheel Gulch	1	Deposition	Aerial photographs show the alcove as mostly filled and vegetated. The GCD shows up to 3.0 ft of deposition at the alcove entrance.
Valdor Gulch	1	Deposition	The alcove is mostly filled and is disconnected from the mainstem. The GCD shows deposition of up to 4.5 ft through most of the alcove and deposition of up to 6.0 ft in the center. However, aerial photographs show that some deposition occurred prior to the post construction survey in 2009 that was not captured in the GCD analysis.
Elk Horn	1	Deposition	The alcove is filled and vegetated. The GCD shows deposition of 1.5–4.5 ft throughout the alcove; however, aerial photographs show that some deposition occurred prior to the post-construction survey in 2009, so some deposition was not captured in the GCD analysis.
Pear Tree	1	Deposition	The alcove has been filled and is thickly vegetated. The GCD results show up to 4.5 ft of deposition. The site was constructed in 2006 but the post-construction survey used in the GCD analysis was surveyed in 2009. However, more deposition occurred because aerial photographs show that deposition occurred prior to 2008. Therefore, the GCD does not capture all deposition.

APPENDIX 9: CHANNEL MEANDER RESULTS

Overall Channel Meander Results

Table 9-1. Overall results of effectiveness for migration features.

Description of Effectiveness	Feature location	# of Features
100% Effective = Erosion occurring on the outside bank and deposition occurring on the inside bank.	Upper Douglas City	1
	Lowden Ranch	1
Intermediate Effectiveness = Feature shows sign of either erosion on the outside bank or deposition on the inside bank but not both.	Lower Junction City	2
	Upper Junction City	1
	Sawmill	1
	Lowden Ranch	1
Less Effective = Feature shows no sign of continued migration; however, it has maintained its designed form.	Reading Creek	1
	Limekiln Gulch	1
	Trinity House Gulch	1
	Lowden Ranch	1
	Sawmill	1

Channel Meander GCD Results

Table 9-2. GCD descriptions for the channel migration features.

Site Name	Number of Channel Migration Features	Description of Deposition and Erosion at Migration Features
Sawmill	2	Tiny patches of deposition up to 3.0 ft in the downstream migration feature, but very little change. Patches of erosion on the outside bend and in the channel up to 4.5 ft at the upstream meander. Deposition seen on the gravel bar at the upstream meander occurred because the bar was constructed after the post-construction survey occurred.
Lowden Ranch	3	Overall, there is erosion between 3.0 and 6.0 ft occurring along the right bank in the vicinity of the migration features. However, the downstream most feature only has up to 4.5ft of erosion in its footprint and the middle migration feature has no change in its footprint. The upstream migration feature has up to 4.5 ft of deposition at the downstream end on the outside of the meander and up to 4.5 ft of erosion on the inside of the meander. Otherwise, there is also very little change in the footprint of the upstream migration feature.
Trinity House Gulch	1	There is a small patch of erosion up to 3.0 ft at the downstream end of the feature, otherwise there is no change.
Limekiln	2	No change was detected at either migration feature but the GCD only captures one year of change.

Site Name	Number of Channel Migration Features	Description of Deposition and Erosion at Migration Features
Upper Douglas City	1	At the downstream end of the migration feature, there is erosion greater than 6.0 ft on the outside of the meander and deposition up to 6.0 ft on the inside of the meander. At the upstream end, there is no change along the outside of the bend and erosion up to 4.5 ft on the inside of the bend. All of this suggests that the feature is migrating over time.
Reading Creek	3	No change detected at the downstream migration feature. No change detected at the middle migration feature. No change detected at the upstream migration feature. Aerial photographs support that very little change has occurred through time at the migration features.
Upper Junction City	1	There has been erosion greater than 6.0 ft through the migration feature, suggesting that it is continuing to migrate into the right bank.
Lower Junction City	2	The GCD analysis shows no change within the downstream migration feature; however, there has been significant deposition up to 6.0 ft directly adjacent to the migration feature. This suggests that widening the channel at this location has allowed for more deposition. There has been significant erosion greater than 6.0 ft immediately downstream of the upstream migration feature. There has also been erosion up to 6.0 ft in the channel directly adjacent to the upstream migration feature.

APPENDIX 10: OFF-CHANNEL PERENNIAL WETLAND RESULTS

Off-channel Perennial Wetland GCD Results

Table 10-1. Table describing the GCD results at off-channel perennial wetland features.

Site Name	Number of Features	Was there Deposition or Erosion?	Description of Deposition/Erosion
Sven Olbertson	1	Primarily deposition	The upstream feature has small, scattered patches of deposition up to 3.0 ft. The downstream feature has up to 3.0 ft of scour spread evenly through the feature. The features are wet but disconnected from the mainstem at 3000 cfs and there is flow connectivity through the entire site at 600 cfs.
Sawmill	1	No change	The GCD shows no change at this feature. The SRH-2D wetted area output suggests the feature is dry at 300 cfs, and the aerial photograph shows it as dry. Since the post-construction survey used in the GCD analysis was not taken until 3 years after construction was completed, it is possible that deposition occurred prior to the survey and is not captured in the GCD.
Lowden Ranch	2	Primarily deposition	The two small downstream off-channel ponds were lumped together as one feature for description. The GCD results show some erosion and deposition happening around the two ponds but no change directly in the features. The SRH-2D model shows the downstream wetlands to be disconnected at 300 cfs. The large, upstream, constructed wetland area shows one large patch and many small patches of deposition through the pond and island areas. Deposition is primarily up to 3.0 ft but in some areas is up to 4.5 ft. There are also some very small, scattered patches of erosion up to 3.0 ft. This upstream feature is connected to the mainstem at all flows.
Lorenz Gulch	1	Deposition	The large off-channel pond that was built directly adjacent to the side-channel R4 shows deposition over the entire area of the pond up to 3.0 ft and a large portion of the pond up to 4.5 ft.
Upper Junction City	1	Both deposition and erosion	The GCD shows large patches of both deposition and erosion up to 6.0 ft in the off-channel pond. The aerial photographs show that the pond is wet but not directly connected at 450 cfs.