Review of the Trinity River Restoration Program Following Phase 1, with Emphasis on the Program's Channel Rehabilitation Strategy

Prepared for Trinity River Restoration Program

April 2014

REVIEW OF THE TRINITY RIVER RESTORATION PROGRAM FOLLOWING PHASE 1, WITH EMPHASIS ON THE PROGRAM’S CHANNEL REHABILITATION STRATEGY

Prepared for
Trinity River Restoration Program

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1 INTRODUCTION

The Trinity River Restoration Program (hereafter the Program) requested that their Science Advisory Board (SAB) evaluate the channel rehabilitation projects built by the Program to mitigate the downstream effects of the Trinity and Lewiston Dams on naturally spawning salmon. Such projects were identified and recommended in the Program's flow evaluation study (USFWS and HVT 1999) and their efficacy was to be assessed after half of them were built (hereafter referred to as Phase 1). The rehabilitation projects involve mechanical alteration of the channel, riparian planting, wood placement, and gravel augmentation (bar placement and high-flow injection) to restore fish and wildlife habitat in accordance with the Record of Decision (ROD; USDOI 2000). These actions are part of the Program's management strategy of fostering a dynamic channel and floodplain system with a proper bed substrate and temperature regime for salmonids via managed dam releases, sediment augmentation or retention, and bank rehabilitation (USFWS and HVT 1999). The ultimate goal of these actions is to restore salmonid populations, with a specific focus on in-river production of presmolts from the restoration reach, which extends 64 kilometers along the mainstem river from Lewiston Dam to the confluence of the North Fork Trinity River.

The Program requested development of a review document that would assess Phase 1 activities within the context of the Program's foundational documents (USFWS AND HVT 1999; USDOI 2000) and provide direction for the second phase of implementing channel rehabilitation projects. In addition they posed a series of basic questions, including "Are we on the right track?" "Which rehabilitation projects and design elements are successful?" "What should be done for Phase 2?" The answer to these questions depends on how one defines success (i.e., what the goals and metrics are, and how much change is enough). As mentioned above, the primary geomorphic objectives of the Program are to create a dynamic fluvial system that would increase suitable fish and wildlife habitat and restore the wild salmon fishery, with the latter being, presumably, the *fundamental objective*. As such, it is important to note that the channel rehabilitation projects are *means* toward achieving the *fundamental objective*. For example, creation of fish habitat without a corresponding increase in fish production would not be considered a Program success. Moreover, to evaluate the rehabilitation projects in terms of the above objectives, multiple spatial and temporal scales must be considered beyond evaluation of as-built features and associated habitat at rehabilitation sites. In this regard, it is important to recognize that Program management activities aimed toward achieving a more dynamic river system involve not just channel form, but also the interplay of channel structure and geomorphic processes, seasonally dynamic flow regimes, and seasonally targeted water temperatures that collectively create a system-wide distribution of habitats that may exhibit considerable spatial and temporal variability in suitability for specific fish life stages. Success in meeting Program goals is ultimately measured in annual quantitative assessments of in-river production of juvenile salmonid fishes. Consequently, to form any view of successes achieved by the Program during Phase 1 required a substantial broadening of the scope and complexity of our task, making it more of a comprehensive review of Program activities.

In addition, we were charged with conducting an unconventional review for an advisory board. Rather than reviewing a report produced by the Program, the SAB was asked to compile information and develop a comprehensive report that would provide an independent and impartial assessment of Phase 1 activities and progress toward achieving Program goals and objectives, along with recommendations for Phase 2. This involved reviewing and synthesizing existing Program publications, as well as conducting original work using available data and the assistance of a support contractor. Given the preponderance of information and reports produced by the Program and the geographical separation among the SAB members, Program staff, Partners, and support contractor, this became a daunting task stretching over many months.

The report summarizes Phase 1 activities and the physical and biological responses from 2005-2011, followed by recommendations for Phase 2. A series of appendices (A-H) provide supporting information and analyses. Where possible, we used four spatial scales to capture changes over time: (1) *river system* or *restoration reach* ~ the 64 km (40 mile) mainstem river from Lewiston Dam to the North Fork Trinity River confluence; (2) *reach* ~ segments of the mainstem river having a particular set of characteristics, such as a given channel morphology, sediment load, or hydrology; (3) *project* or *site* ~ a length of mainstem channel and its floodplain and terrace that was influenced by a channel rehabilitation project, or in some cases, a suite of related projects; and (4) *design element* or *feature* ~ a component of a channel rehabilitation project, such as a side channel, bench, or skeletal bar (USFWS AND HVT 1999; HVT et al. 2011).

In conducting our review, it quickly became apparent that our task would be hampered by insufficient data and/or insufficient time since project implementation to observe geomorphic changes and associated fish population responses. Ideally, we would examine dynamic responses to different project designs at site and system scales and consequent changes in fish production. However, those data were not available. Instead, the available data mainly documented constructed changes in low-flow habitat, limited geomorphic responses, and fish abundance at system scales. The Program's habitat monitoring focusses on low-flow, juvenile, rearing habitat because it is a spatially and temporally consistent flow for sampling and because it is similar to flows during the critical winter and early spring rearing periods (Alvarez et al. 2013). Geomorphic responses were limited not from a lack of effort, but because of insufficient time since project completion and from physical constraints that were not fully appreciated in the foundational documents and associated conceptual models; in particular, the occurrence of mining terraces, bedrock boundaries, and legacy bed material (large sediment that is difficult for post-ROD flows to move) make the river less alluvial and less responsive than originally hypothesized. This is compounded by the fact that few geomorphically effective flows (i.e., wet-year and extremely wet-year ROD flows) occurred during the study period and many such events are needed over time to create a dynamic fluvial environment, particularly for this river system given the above physical constraints. Although the available data were informative and allowed some assessment of progress toward Program goals and objectives, additional information is needed to fully assess the synergistic effects of Program activities (management of flow, temperature, sediment, and channel morphology) over space and time to understand the effects on fish production. To move the Program Partners and the public toward better understanding the dynamic nature of the river system, our primary recommendation is that the Program focus immediate attention toward development of a Decision Support System (DSS). A DSS is a series of linked physical and biological models that will allow the Program to (1) predict site and system response to alternative management actions in relation to ROD and stakeholder objectives; (2) make such predictions in a timely fashion (ahead of monitoring results); (3) focus and refine monitoring efforts; and (4) provide a necessary tool for adaptive management. Additionally, it will help to better structure and integrate Program activities and increase the defensibility and transparency of management actions.

2 SUMMARY OF FINDINGS

2.1 Phase 1 Activities

Details of the Phase 1 channel rehabilitation activities are given in Appendices C and G and are summarized here. During Phase 1 (2005-2010), 15 rehabilitation projects were completed along the course of the restoration reach (Table 1, Figure 1). Projects were initially focused on removing riparian berms that had encroached on the river following dam closure, lowering floodplains to match the post-ROD flow regime, and creating point bars that would promote a dynamic river. The conceptual model for these activities was that if restraining features were removed, fluvial processes would take over, creating a more dynamic and complex river that, in turn, would offer more productive habitat for fish and wildlife (USFWS AND HVT 1999; USDOI 2000). It was also recognized that the river could not be restored to pre-dam conditions and that it would have to be scaled down to the post-ROD flow regime (USFWS AND HVT 1999). However, the initial rehabilitation projects produced little immediate dynamic geomorphic response. Consequently, the degree of mechanical intervention and complexity of projects increased over time. The intent of these more intensive projects was, in part, to create immediate habitat and to construct large-scale channel features that would interact with flood flows and drive more rapid channel changes. This change in design strategy was based on lessons learned and, in general terms, is a type of adaptive management, but represents a shift from the foundational notion that a more dynamic river could be created with minimal bank reconstruction (USFWS AND HVT 1999; HVT et al. 2011) . The rehabilitation strategy of minimal mechanical intervention was not well-defined in the flow evaluation report (USFWS and HVT 1999), and although nearly all features being used in present designs were anticipated in that document, there is a strong perception among some Partners and some of the public that channel rehabilitation projects are much larger and more complex than anticipated. Differences in the requisite degree of mechanical intervention and the expected habitat end point (e.g., driving fluvial processes *vs.* constructing habitats) have not been fully resolved within the Program or with the public. The size and design of the projects should match the Program's basic premise of promoting dynamic fluvial processes leading to a new channel form that is expected to provide significantly increased spawning and rearing habitat for anadromous salmonids (USFWS and HVT 1999). This is in keeping with the Program strategy that "restoring salmonid populations must be founded on rehabilitating and managing fluvial processes that create and maintain habitats vital to anadromous fish" (USFWS and HVT 1999). This instills the interplay of mechanical intervention with management of flow, sediment, and water temperature.

The stated goals for the early projects tended to be general, typically invoking ROD objectives without specifically articulating how they would be achieved beyond the concepts stated in the foundational documents (USFWS AND HVT 1999; USDOI 2000). Objectives have become more specific as projects have become more complex and as design guidelines have been developed (HVT et al. 2011). In addition, predictive numerical models are now being used by the Program to assess salmon rearing habitat availability and potential geomorphic responses for a given project design. However, fish population response has not been linked to habitat change over time through modeling efforts as called for in the Program's foundational documents, nor in most cases are the models used to compare predicted outcomes from alternative site designs. Projects have rarely been treated as opportunities for hypothesis testing. As such, the primary Program activities related to channel rehabilitation activities involve implementation and monitoring.

Several important advances have occurred with regard to the design process as it has evolved over time: (1) it is a collaborative effort, involving Program staff and Partners from a broad range of disciplines; (2) projects are designed through consensus-based decision making; (3) predictive models are increasingly being used; and (4) the Program has recently used the Stream Project decision model (Baker and Wilcock 2012) to evaluate design options, quantify public input, and convey options to the public.

Table 1

Channel Rehabilitation Sites Constructed in the Trinity River Restoration Reach during Phase 1 (from Appendix C, Section 1)

Phase 1 Site	Date Completed	Location (river miles)	Length (miles)
Pear Tree	2006	72.9 – 73.2	0.30
Elkhorn	2006	73.7 – 74.3	0.55
Valdor Gulch	2006	74.8 – 75.7	0.90
Conner Creek	2006	77.0 – 77.4	0.40
Hocker Flat	2005	78.0 – 79.1	1.10
Reading Creek	2010	92.2 – 93.1	0.90
Indian Creek-Vitzthum Gulch	2007	93.9 – 96.9	2.97
Trinity House Gulch	2010	104.0 – 104.4	0.40
Lowden Ranch	2010	104.4 – 105.3	0.89
Bucktail-Dark Gulch	2008	105.5 – 107.0	1.53
Sawmill	2009	108.9 – 109.7	0.80
Hoadley Gulch	2008	109.8 – 110.1	0.30
Lewiston Cableway	2008	110.2 – 110.5	0.28
Deadwood Creek	2008	110.5 – 111.0	0.50
Sven Olbertson	2008	111.2 – 111.6	0.41

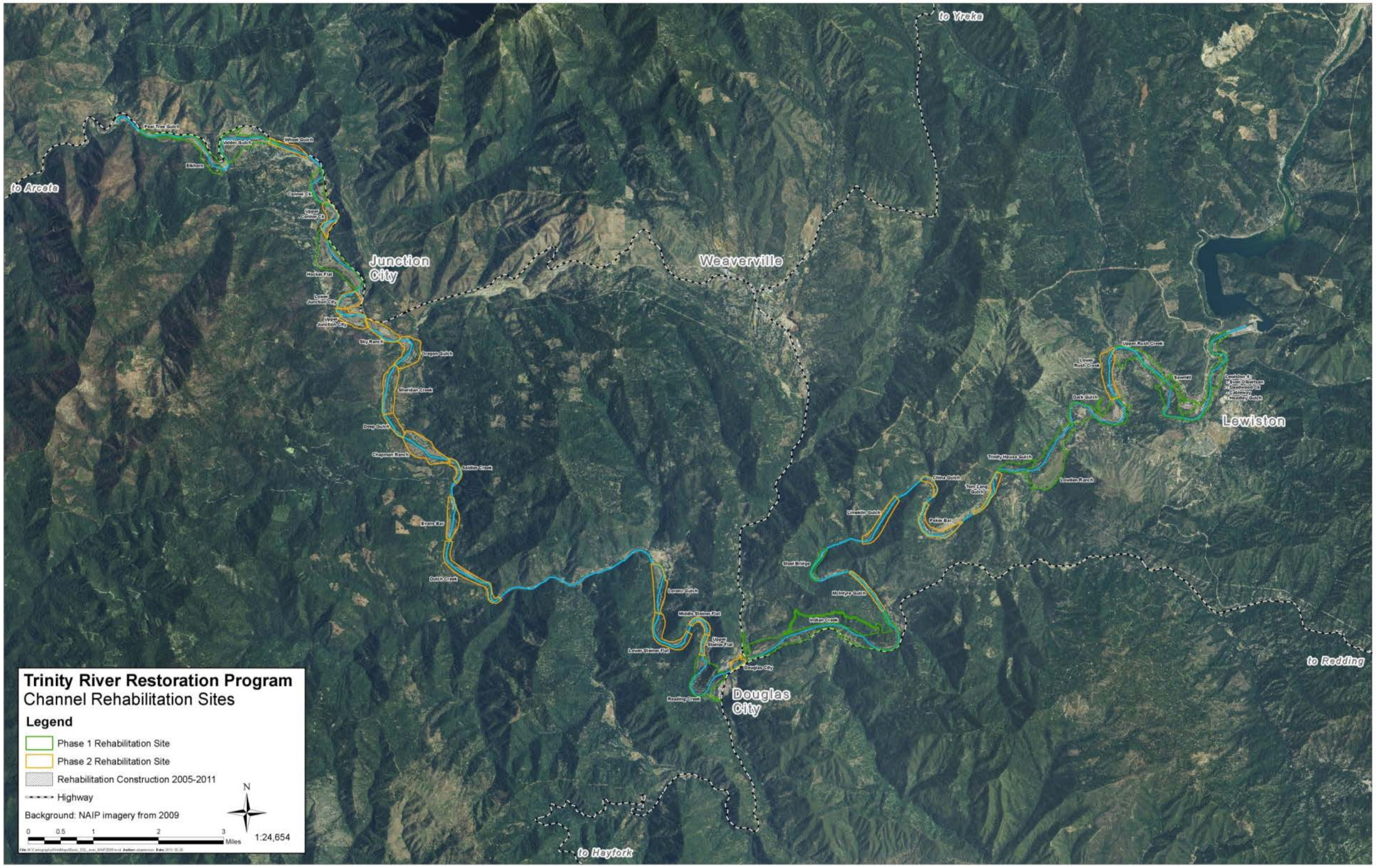


Figure 1

Phase 1 and 2 channel rehabilitation sites in the Trinity River restoration reach. See Appendix C for further detail.

2.2 Geomorphic Context and Channel Response

Channel response to rehabilitation actions depends on the geomorphic context (i.e., the physical setting of a specific site), which includes factors such as channel slope and confinement, bank and bed materials (alluvial versus bedrock), position in the stream network relative to tributary inputs of sediment and water, and the legacy of past natural and anthropogenic events. Geomorphic context constrains channel formation, sediment transport, and flow patterns; influences the dynamics of aquatic and riparian habitats; and predisposes the success or failure of rehabilitation actions. The notion of geomorphic context is well recognized by the Program and our discussion of the issue largely synthesizes existing Program knowledge. We then examine evidence of channel response to Phase 1 management activities in terms of whether the responses are consistent with Program objectives and hypotheses. Further detail of geomorphic topics is provided in Appendix C.

2.2.1 Geomorphic Context

The restoration reach is a partially confined gravel-bed river that exhibits a mixture of alluvial and bedrock-controlled channel morphologies, with alluvial tendencies increasing in the downstream direction (HVT et al. 2011; Beechie et al. 2012). Valley bottoms are narrow and sinuous, indicating frequent contact of the channel with valley walls and bedrock (Figure 1), although terraces and floodplains of various widths also are evident. There are no broad alluvial valleys or steep, narrow gorges. Overall, the channel is semi-alluvial (i.e., intermittently influenced by bedrock boundaries) and has been aptly described as “an alluvial channel working through a tapestry of bedrock controls” (HVT et al. 2011).

Channel characteristics exhibit only modest differences along the restoration reach (i.e., relatively small changes in channel slope, width, and planform pattern). An important question is what the historic variation of channel morphology and habitat was like and what variation might be possible under the current post-ROD flow regime (USFWS AND HVT 1999; HVT et al. 2011; Beechie et al. 2012). The post-ROD river is a single-thread channel with a straight to meandering planform, with meanders largely imposed by confining features. While valley widths are generally too small to support a braided channel form (i.e., an unstable multi-thread channel), an anabranching morphology (a relatively stable multi-thread channel) may be possible in some locations (HVT et al. 2011; Beechie et al. 2012). If sustained through dynamic flow regimes, anabranching would produce a more complex fluvial environment as a means toward enhanced fish habitat, akin to that envisioned by the Program’s foundational documents (USDOI 2000; USFWS AND HVT 1999). Building from analyses presented in the Design Guide (HVT et al. 2011), we find that opportunities for anabranching channels may have been more common during the pre-dam flow regime than under post-ROD flows, with current opportunities for sustained anabranching predominantly limited to the North Fork Reach (Figure 2). The potential effects of channel morphology on juvenile salmonid habitat and carrying capacity in the restoration reach were recently examined by Beechie et al. (2012) for different scenarios of rehabilitation actions and restoration of fluvial processes. Results indicated that juvenile salmonid production could be increased by 1.5 to 2 times the current capacity for the management scenarios examined.

Recent work also suggests that legacy effects of mining and pre-dam flooding may strongly affect channel form and process in the mainstem Trinity River (Krause 2012a, 2012b; Krause et al. 2010). As such, the geomorphic context of the rehabilitation sites is primarily set by local controls nested within larger-scale legacy (pre-dam) effects. The Design Guide (HVT et al. 2011) provides comprehensive and detailed recommendations for planning rehabilitation treatments within this sort of reach-scale geomorphic context. Furthermore, it is recognized that the semi-alluvial nature of the river limits the extent of dynamic alluvial morphology envisioned in the Program's foundational documents, which has led, in part, to an evolution of design strategy during the Phase 1 period, as discussed above (HVT et al. 2011; Appendix G).

The original notion presented in the foundational documents that a dynamic river could be created with minimal bank reconstruction is now seen as an over-simplification. Recognition of the existence of significant terraces and the semi-alluvial nature of the river necessitated a shift in rehabilitation strategy. It now seems that the most meaningful geomorphic context for rehabilitation may be the site scale, where juxtaposition of non-alluvial features, valley forms, mining debris, and deposits left by historic floods constrain the size, frequency, and relief of alluvial features and associated habitats that can be formed by rehabilitation practices. Despite the Program's recognition of geomorphic context in the design process (HVT et al. 2011), it should be considered in a more systematic way through comparison of alternative designs and predicted outcomes for different geomorphic environments, followed by targeted monitoring for evaluating physical and biological response of implemented restoration actions. For example, given the nature of the river, one might implement and test dynamic rehabilitation designs in predominantly alluvial reaches, but employ static designs in constrained and semi-alluvial reaches where habitat enhancement is desired, but cannot be achieved using the conceptual model of a dynamic alluvial river as envisioned in the Program's foundational documents. This dichotomy (i.e., driving dynamic habitat *vs*. building static habitat) leads to fundamentally different approaches, expectations, and measures of success in terms of geomorphic response and the dynamics of habitat availability for different locations within the restoration reach.

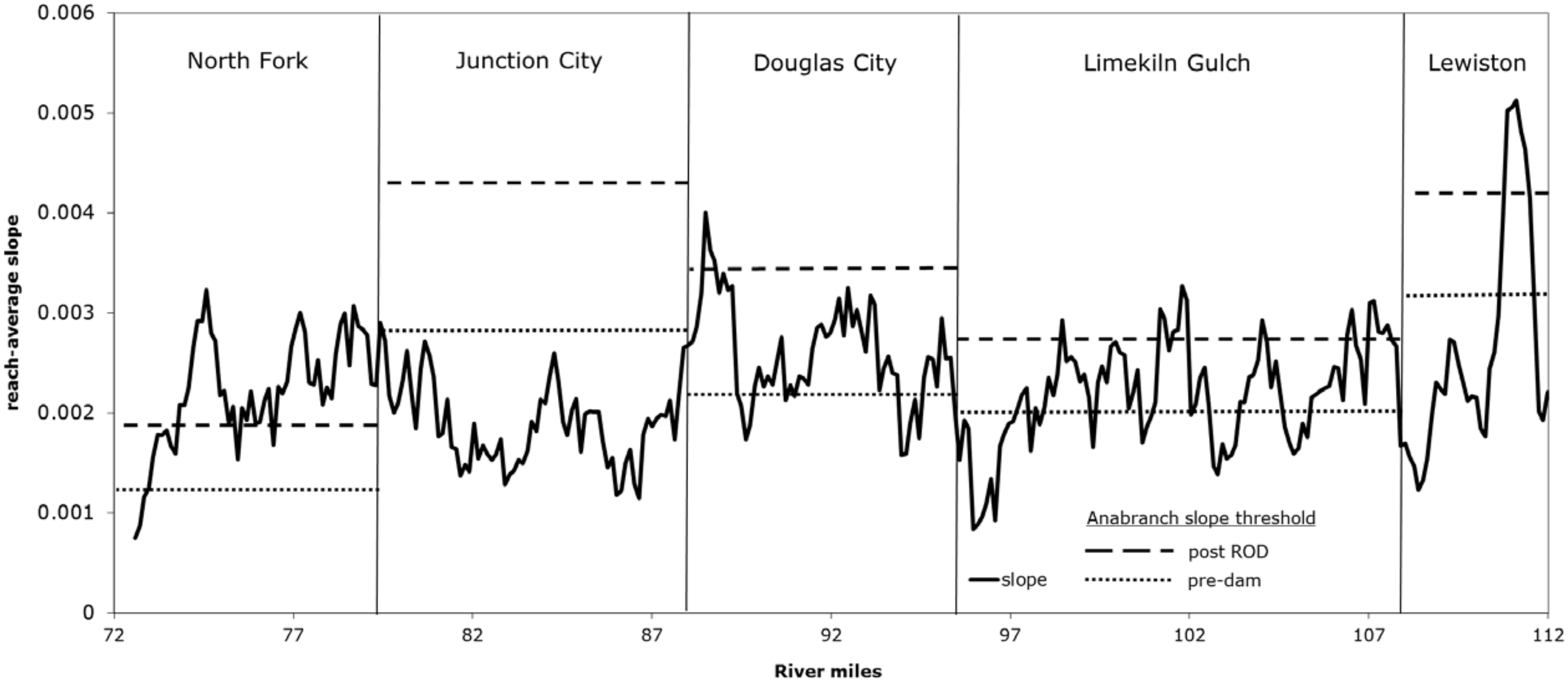


Figure 2
Reach-average channel slope compared with predicted slope thresholds for transition from meandering to anabranching channel morphology (Eaton et al. 2010) for pre-dam (dotted line) and post-ROD (dashed line) bankfull discharges in the five mainstem reaches identified in the Design Guide (HVT et al. 2011). Channel slopes above the threshold have increased anabranching potential. See Appendix C, Section 4.1.4, for further detail.

2.2.2 Channel Response

The Program's documentation of channel response to Phase 1 activities is somewhat limited and largely involves constructed changes at the rehabilitation sites. The data are limited, in part, due to the short time since implementation and whether or not sites have experienced geomorphically-effective high flows during that time (i.e., wet-year and extremely wet-year ROD flows). We first consider channel responses relative to established Program objectives, then examine other metrics and response to gravel augmentation.

2.2.2.1 IAP

The Program's Integrated Assessment Plan (IAP; TRRP and ESSA 2009b) established management objectives for implementing the ROD, as well as performance measures for assessing whether objectives are being met. In addition, the Integrated Habitat Assessment Project (IHAP; Alvarez et al. 2011) provided monitoring procedures for evaluating specific IAP objectives and the effectiveness of the Program's restoration actions. Monitoring of these performance measures provides a means of assessing physical and biological responses to rehabilitation actions at site and reach scales. In terms of channel response, we focus on IAP Objective 1 (*Create and maintain spatially complex channel morphology*) and its level 2 and 3 sub-objectives (Table 2). Monitoring reports and original analyses were used to assess the effects of rehabilitation projects in relation to IAP objectives (Appendix C, Sections 1 and 3).

Table 2

IAP Objectives Related To Creating and Maintaining Spatially Complex Channel Morphology (from Appendix C, Section 1)

Objectives			Priority
Level 1	**Level 2**	**Level 3**	
1. Create and maintain spatially complex channel morphology	1.1. Increase physical habitat diversity and availability	1.1.1 Increase the size, frequency, and topographic relief of bar/pool sequences	M
		1.1.2 Increase channel/thalweg sinuosity	H
		1.1.3 Increase geomorphic unit and substrate patch diversity	L
	1.2 Increase coarse sediment transport and channel dynamics	1.2.1 Increase and maintain target coarse sediment transport rates	H
		1.2.2 Frequently exceed channel migration, bed mobilization, and bed scour thresholds	H
		1.2.3. Encourage bed-level fluctuations on annual to multi-year time scales	L
		1.2.4 Route coarse sediment through all reaches	L

Objectives			
Level 1	**Level 2**	**Level 3**	**Priority**
	1.3 Increase and maintain coarse sediment storage	1.3.1 Increase bars, side-channels, alcoves, and other complex alluvial features	H
	1.4 Reduce fine sediment storage in the mainstem Trinity River	1.4.1 Transport fine sediment through mainstem at a rate greater than tributary input	H
		1.4.2 Reduce fine sediment supply from tributary watersheds	M
		1.4.3 Encourage fine sediment deposition on floodplains	L

Results show that in some cases, IAP objectives for channel response are being met, and are occurring through a mix of constructed and post-construction changes (Appendix C, Sections 6 and 7). For example, bar formation and growth was observed in the first 5 miles downstream of Lewiston Dam, indicating increased bed material storage associated with gravel augmentation (Wilcock 2010). In addition, early rehabilitation projects that included berm removal, feathered edging, and floodplain lowering have increased bed material sorting and substrate patch diversity, but have had little influence on the size, frequency, and relief of bar-pool sequences. Rehabilitation designs have evolved in response to include constructed bars, forced meanders, lowered floodplains, and side channels that utilize existing planform curvature and local forcing elements and are designed to work in combination over various spatial and temporal scales within rehabilitation sites. Although there has been limited time for flow and sediment management to alter habitat at the system scale or achieve dynamic morphology, geomorphic monitoring demonstrates the relative effectiveness of higher peak flows in 2011 at achieving geomorphic objectives regarding bed mobility and scour. Analysis of cross sections at restoration sites shows that peak flows in 2009 and 2010 resulted in minor bed mobility, while high flow releases in 2011 were much more effective at creating dynamic channel conditions through bed mobilization and scour; 27 of 35 cross-section pairs bracketing the 2011 high flow release exhibited an active bed over 20% or more of the channel width according to Program metrics (net scour or fill greater than 200 mm (typical D_{84} size of streambed sediment)).

However, not all IAP objectives could be assessed using the methods employed, and of those that were assessed, results were often inconclusive due to a high degree of variability within the limited spatial and temporal scales of measurement (Appendix C, Sections 6 and 7). Nevertheless, it is important to note that many of the sites and design features have not had sufficient exposure to repeated high flows since their construction and have had limited opportunity to evolve as designed. Consequently, lack of data necessary for any system-wide evaluation of the evolution of the restoration reach, its habitat, and fish population response preclude a comprehensive evaluation of Phase 1 activities. These factors point to the need for a longer monitoring period and more exposure to high flows before critically judging the overall effectiveness of rehabilitation actions based on IAP objectives for channel response.

2.2.2.2 Lateral Erosion and Deposition

Lacking data collected specifically for system-wide analyses, we used aerial photography to examine channel response in terms of lateral erosion and deposition. Aerial photography of the base-flow channel indicates some lateral erosion and deposition at both site and system scales following floods (Appendix C, Sections 3.3.2.2 and 6). Overall, the river has widened slightly since 2001 (Figure 3 shows greater lateral erosion than deposition). This analysis also shows that changes in the base-flow channel width at the rehabilitation sites (including both constructed changes and fluvial erosion or deposition) are small compared to changes in width outside of the sites. This is due to the fact that constructed reach lengths are relatively short (13 km) compared to the entire restoration reach (64 km) and because much of the construction occurs above the low-flow channel. However, we are not able to quantify the effects that Phase 1 rehabilitation actions may have had on fluvial processes and system-scale changes in lateral erosion or deposition with this analysis.

GIS analysis of the aerial photographs also suggests that ROD flows are capable of eroding riparian berms in some river segments (Figure 4) and may not require as much mechanical intervention as originally thought (USFWS AND HVT 1999). Our analysis indicates that from 2003 to 2011, 18% of the total berm area as mapped in 2003 may have been eroded by fluvial processes. Although the foundational documents indicated the ROD flows were incapable of eroding berms (USFWS AND HVT 1999), field observations after the large January 1997 flood revealed a range of impacts on berms, including complete removal in many locales (McBain and Trush 2000). Erosion of berms by ROD flows should be viewed as a positive outcome that may obviate the need for mechanical alteration of banks in some locations, but it does not indicate that rehabilitation projects are no longer needed. While our findings are encouraging, additional investigation is warranted because the analysis is based on remote sensing of aerial photography that includes some degree of uncertainty. Sources and magnitudes of uncertainty associated with the analysis are further discussed in Appendix C, Sections 3.3.2.2 and 4.4.

In addition to observed berm erosion, some detrimental encroachment of vegetation has occurred and some new berms are forming (e.g., HVT and McBain and Trush 2013; 2014), but this is expected given that berms, which are more commonly called levees, naturally occur on alluvial rivers, even those with unvegetated banks (Church 1972). The Program’s restoration strategy depends on a dynamic channel (USFWS AND HVT 1999) and, so far, monitoring has concentrated on vertical scour of the channel bed and bar flanks. Little attention has been paid to new bar formation and bank erosion, which are common on dynamic alluvial rivers. This process is potentially important because formation of new depositional surfaces could be providing habitat for young fish in previously unrecognized locations. The “recycling” or turnover of this sort of habitat, where recently deposited surfaces gradually become vegetated over time while fresh depositional surfaces form elsewhere, should be incorporated into the Program’s geomorphic and fish habitat monitoring.

The erosion and deposition results presented here are crude due to the limitations of aerial photography for accurately defining bank lines, but the general approach can be adapted to the Program’s existing monitoring efforts. Instead of using remotely-sensed bank lines, the wetted surface mapped in the field each year during fish habitat mapping, if precise enough, could be used to map bank lines and track erosion and deposition at sampled reaches. Mapped habitat patches from different sample years can be superimposed on the erosion and deposition patches to relate channel migration and the creation and loss of fish habitat.

Trees typically dominate the riparian berms, and the flow evaluation study assumed that direct tree toppling, from flows impinging on debris jams lodged against tree trunks, was the dominant process in berm erosion (USFWS and HVT 1999). The requisite streamflow for removing berms via tree toppling was estimated to be 14,000 cfs or higher (USFWS and HVT 1999), so if this is the only mechanism for berm removal, and the flow estimate is correct, the channel would be incapable of eroding berms under most ROD flows (USFWS and HVT 1999). However, another potential process for berm removal, which is common on migrating rivers, even those with forested riparian zones, is the under-cutting of banks via lateral scour (Thorne 1982; Nanson and Hickin 1986). This process is mentioned in the flow evaluation report (USFWS and HVT 1999), but is attributed to unregulated rivers. Bank erosion on regulated rivers is often diminished, but can occur (Bradley and Smith 1984; Dykaar and Wigington 2000). Consequently, some of the observed berm erosion may have been via bank undercutting (McBain and Trush 2000; Appendix C, Figure 4-8). More attention to bank erosion agents during routine monitoring could help to refine the assumptions regarding berm erosion in the flow evaluation report.

More detailed information regarding site and system response will be available in the future from digital elevation models (DEMs) that are being developed by the Program through a combination of terrestrial LiDAR (light detection and ranging) and bathymetric surveys (e.g., GMA 2012). These data will allow spatial analysis of changes in bed topography and sediment storage over time at a finer resolution than is currently monitored by the program. DEMs will also facilitate use of 2-dimensional flow and morphodynamic models for predicting physical and biological responses (when linked with a fish production model) and for assessing design options and management scenarios (e.g., Alvarez et al. 2011; Gaeuman 2013). Similarly, information regarding historic geomorphic changes and legacy events is forthcoming (Curtis and Guerrero in review; Krause 2012a, 2012b), which should provide context for observed responses and inform design of Phase 2 projects.

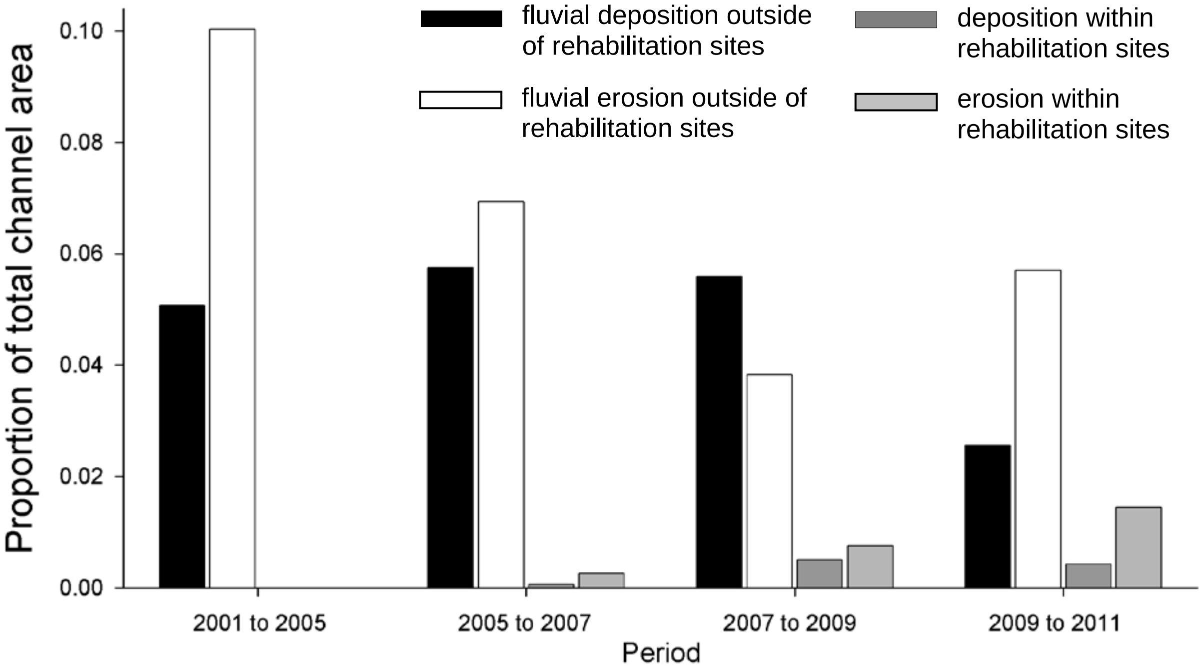


Figure 3
Lateral channel erosion and deposition inferred from changes in the position of the wetted channel edge observed on sequential aerial photographs (2001, 2005, 2007, 2009, and 2011) at summer base flow along the 64 km restoration reach. Values are expressed as a proportion of the total area of the wetted channel at base flow. Data are categorized in terms of whether erosion or deposition occurred outside or within rehabilitation sites. Changes in the wetted channel edge within rehabilitation sites may represent a combination of constructed changes and fluvial erosion or deposition. Peak flows for the Trinity River at Lewiston for each time period were respectively 7,640 (2005), 10,400 (2006), 6,890 (2008), and 12,300 (2011) cfs. The length of non-constructed channel is about five times that of the constructed channel. Construction influences are relatively small because much of the construction occurs above the low-flow channel and constructed reach lengths are relatively short (8.1 river miles) compared to the entire restoration reach (40 river miles). See Appendix C (Sections 3.3.2.2 and 4.4) for further detail of methods and results.

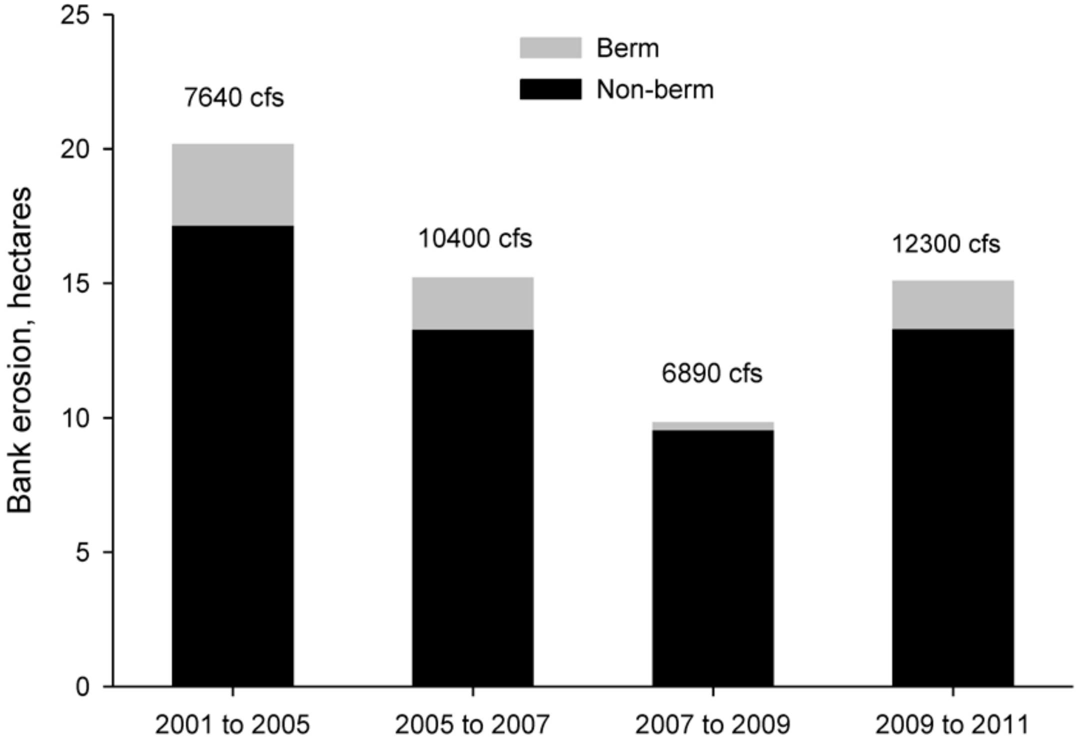


Figure 4
Bank erosion inferred from changes in the position of the wetted channel edge observed on sequential aerial photographs (2001, 2005, 2007, 2009, and 2011) at base flow along the 64 km restoration reach. Values at the top of each bar are peak flows for the Trinity River at Lewiston during the time period. Banks classified as berm or non-berm based on 2003 Program mapping. See Appendix C (Sections 3.3.2.2 and 4.4) for further detail of methods and results.

2.2.2.3 Gravel Augmentation

Gravel augmentation, including in-channel placement and high-flow injection of coarse sediment, is intended to offset sediment storage by the dams and to promote a mobile streambed, bar formation, and a supply of spawning gravels for salmonids. However, gravel augmentation has become a controversial element of rehabilitation activities due, in part, to concerns about pool filling and loss of holding habitat for adult salmonids. Recent investigation of the issue indicates that pool depths have generally increased throughout the restoration reach as a result of ROD flows and reduced fine sediment input from tributaries (Gaeuman and Krause 2013). However, pool depths have decreased near some rehabilitation sites, and terrace lowering is implicated as the cause, rather than gravel injections (Gaeuman and Krause 2013).

A recent case study documenting channel response to high-flow gravel injection at the Lowden Ranch site indicates that gravel injection dynamically built targeted bed forms as designed (Gaeuman 2013). However, major bar formation from gravel injection may be limited to injection points due to downstream dispersion of gravel.

At the restoration reach scale, gravel augmentation is the largest source of coarse sediment supplied to the river and has been input mainly in the upper portions of the restoration reach. Monitoring of coarse sediment transport indicates that bed load is actively moving through the system and that storage is increasing in all but the lower-most monitoring reach (Figure 5, Cell 4, Limekiln Gulch to Douglas City). During Phase 1, the largest increases in coarse sediment storage occurred in Cell 2 (Lewiston Gage to above Grass Valley Creek), where rehabilitation projects were concentrated (Gaeuman and Krause 2011). However, it is unclear how mechanical alteration of the channel may be altering sediment routing and storage. Reach-scale sediment routing has been predicted at the Lowden Ranch site (Gaeuman 2013), but system-wide sediment routing models have not been developed for the river at a scale that can resolve transport within and between rehabilitation reaches. Nor is it clear how the rehabilitation projects may be affecting fine sediment routing and storage, other than through mechanical removal of fine-grained riparian berms and floodplain lowering, which will locally promote overbank deposition that may enhance riparian communities.

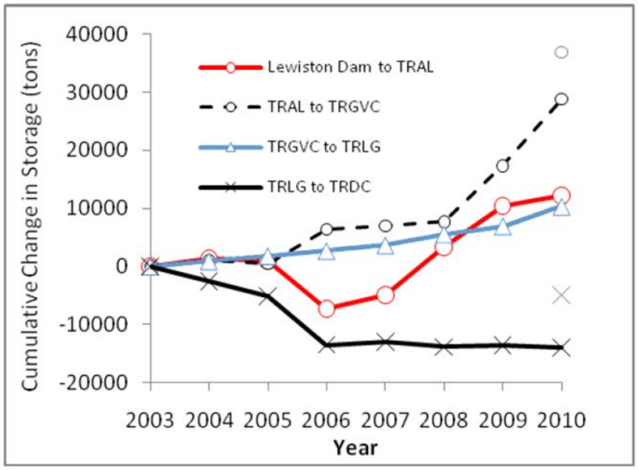


Figure 5

Cumulative changes in coarse sediment storage by budget cell for water years (WY) 2004-2010 with zero values assigned to WY2003. Cell 1=Lewiston Dam to TRAL (Trinity River at Lewiston), Cell 2=TRAL to TRGVC (Trinity River above Grass Valley Creek), Cell 3=TRGVC to TRLG (Trinity River at Limekiln Gulch), Cell 4=TRLG to TRDC (Trinity River at Douglas City). Solitary symbols indicate cumulative changes including fall 2010 construction placements (early WY2011) in budget cells 2 and 4. From Gaeuman and Krause (2011). See Appendix C, Section 7.1.3, for further discussion.

2.3 Physical Habitat Response for Anadromous Fish

As above, Program reports and original analyses were used to assess the effects of rehabilitation projects on the quantity and quality of habitat for anadromous salmon in relation to IAP objectives; specifically, sub-objectives 2.1.1 and 2.1.2 (Table 3). Results are summarized from Appendices A and C. The Program focusses mainly on juvenile rearing habitat, which is believed to be a limiting factor for Trinity River salmon. As such, more habitat information was available for juvenile salmon than adults. However, spawning surveys (redd and carcass counts) provide some information on adult habitat. We consider site- and system-scale response in turn for both juvenile and adult habitat availability. In all analyses, the results for juvenile habitat availability are preliminary due to a limited sample size to date (3 years of monitoring by the Program using the generalized random-tessellation stratified [GRTS] approach [Stevens and Olsen 2002; 2004]).

Table 3

IAP Objectives Related to Increasing Anadromous Fish Habitat (from Appendix C, Section 1)

Objectives			
Level 1	**Level 2**	**Level 3**	**Priority**
2. Increase/ improve habitats for freshwater life stages of anadromous fish to the extent necessary to meet or exceed production goals	2.1 Increase and maintain salmonid habitat availability for all freshwater (in-river and tributary) life stages	2.1.1 Increase/maintain salmonid fry and juvenile rearing habitat in the upper 40 miles of the mainstem Trinity River by a minimum of 400%[1] following rehabilitation of fluvial attributes	H(1)
		2.1.2 Increase/maintain spawning habitat quantity and quality to 2,550,000 square feet[2] in the upper 40 miles of the mainstem Trinity River	H(2)
		2.1.3 Create channel form that reduces loss of fry to stranding in the upper 40 miles of the mainstem Trinity River following rehabilitation during high flows	M
		2.1.4 Maintain or increase adult holding habitat from baseline conditions in the mainstem Trinity River	M
		2.1.5 Minimize physical impacts to lamprey habitat	M
		2.1.6 Minimize physical impacts to other native fish habitats	L
		2.1.7 Maintain or increase tributary habitat	M
	2.2 Improve riverine thermal conditions for growth and survival of natural anadromous salmonids	2.2.1 Provide optimal temperatures to improve spawning success of spring and fall-run Chinook salmon	H
		2.2.2 Improve thermal regimes for rearing growth and survival of juvenile steelhead, coho salmon, and Chinook salmon	H
		2.2.3 Improve thermal regimes for outmigrant salmonid growth and survival (dependent on water year)	H
		2.2.4 Minimize temperature impacts to other native fish habitats	L
	2.3 Enhance or maintain food availability for fry and juvenile salmonids	2.3.1 Increase and maintain macroinvertebrate populations	M

Notes:

1 This is an interim target provided in the IAP (TRRP and ESSA 2009b) and will be revisited and revised as the Program learns more; 400% is a starting point only for a measure of progress and does not reflect an estimate of the habitat increase needed to fully meet salmonid production goals.

2 This is an interim target provided in the IAP (TRRP and ESSA 2009b) and will be revisited and revised as the Program learns more.

2.3.1 Site Scale

2.3.1.1 Juvenile Rearing Habitat

Rehabilitation projects typically increased base flow juvenile rearing habitat availability for coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) at site scales (Table 4, Figure 6). Constructed increases in base-flow habitat varied widely across the sites (Table 4, Figure 6), depending on the size of the project and the design elements employed, but overall resulted in substantial increases compared to pre-construction habitat availability (Alvarez et al. 2011). To put these values in terms of potential biological importance, we use mean fish densities reported by Goodman et al. (2010) to determine potential increases in habitat capacity at the rehabilitation sites due to constructed increases in habitat (Table 5). Although fish density and habitat capacity are spatially variable along the restoration reach (Alvarez et al. 2011; Beechie et al. 2012), the Table 5 values provide useful indications of potential average changes, showing that the rehabilitation projects cause substantial increases in juvenile Chinook capacity and modest increases in coho capacity.

The reported changes in juvenile rearing habitat are obtained from measurements that are a near-census of all habitat at each rehabilitation site. As such, there is a high degree of confidence in the values compared to sampling only a portion of the total habitat at each site. However, the data may not be error free. In particular, uncertainty in the values may result from measurement errors and temporal variability of conditions (i.e., year-to-year variability of pre- and post-treatment habitat (noise) even at similar base-flow conditions) that has yet to be accounted for in Program monitoring due to the short sampling period to date. Consequently, the values reported here should be viewed as preliminary. In addition, while the constructed changes in habitat are substantial at site scales (Table 4), they comprise a relatively small amount of the total area in the restoration reach. As such, their effects on population response may be difficult to detect. On the other hand, small changes can be important if they occur in critical locations that address population bottlenecks or if populations respond nonlinearly to physical changes.

Table 4

Percent Change in Optimal and Total Rearing Habitat at Base Flow for Juvenile Chinook and Coho Salmon Within Rehabilitation Sites Following Construction

Reach	Rehabilitation Site	Fry Habitat		Presmolt Habitat	
		Optimal	Total	Optimal	Total
Lewiston	Sven Olbertson	145	67	204	57
	Lewiston Cableway and Hoadley Gulch	61	43	59	17
	Sawmill	96	42	88	29
Limekiln	Bucktail-Dark Gulch	33	28	28	22
	Lowden Ranch	140	140	177	121
	Trinity House Gulch	-32	45	-23	49
Douglas	Reading Creek	10	25	10	27

Notes:

1 Optimal habitat meets depth, velocity, and cover criteria, while total habitat includes all areas that meet any combination of depth, velocity, or cover criteria (Alvarez et al. 2011). Coho rearing habitat was limited to optimal habitat areas (Goodman et al. 2010; Martin et al. 2012).

2 Base flow is approximately 300 to 450 cfs.

3 Results are based on analyses of pre- and post-treatment data provided by the Program. Not all of the rehabilitation sites are included in this table because not all of the sites were assessed pre- and post-construction (e.g., Conner Creek, Valdor Gulch, Elkhorn, and Pear Tree Gulch) and not all were assessed using the same criteria (e.g., Indian Creek). See Appendix C, Section 7.2.1 and Alvarez et al. (2011) for further detail.

Table 5

Change in Potential Rearing Habitat Capacity at Base Flow for Juvenile Chinook and Coho Salmon Within Rehabilitation Sites Following Construction

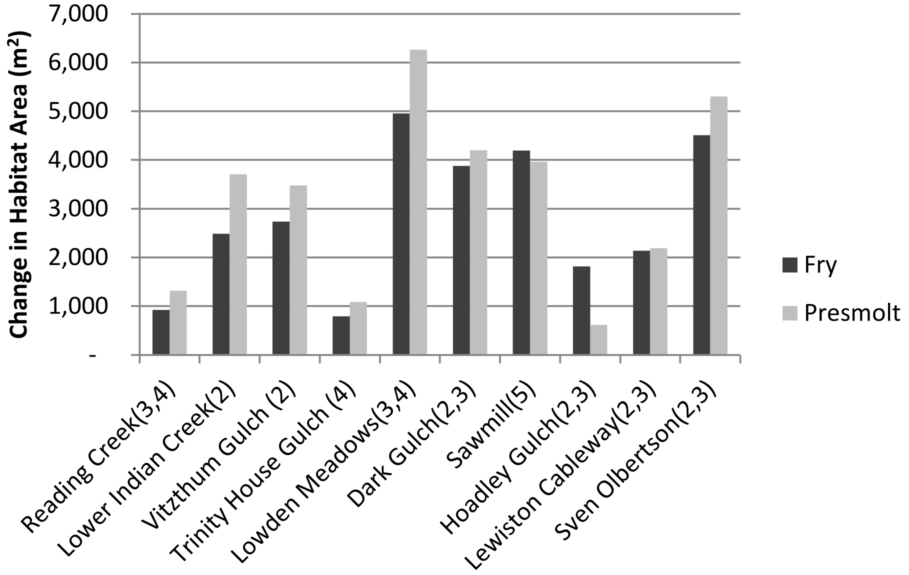
Reach	Rehabilitation Site	Chinook				Coho	
		Fry Habitat Capacity (# of fish)		Presmolt Habitat Capacity (# of fish)		Fry Habitat Capacity (# of fish)	Presmolt Habitat Capacity (# of fish)
		Optimal	Total	Optimal	Total	Optimal	Optimal
Lewiston	Sven Olbertson	13,213	58,179	14,284	55,682	93	266
	Lewiston Cableway and Hoadley Gulch	10,507	51,020	8,934	29,411	39	76
	Sawmill	20,186	54,128	16,942	41,643	61	114
Limekiln	Bucktail-Dark Gulch	7,418	50,000	6,235	44,121	21	36
	Lowden Ranch	9,157	63,962	12,760	65,778	89	230
	Trinity House Gulch	-1,152	10,245	-668	11,449	-21	-30
Douglas	Reading Creek	413	11,950	382	13,855	6	13

Notes:

1 See Table 4 notes for definitions of optimal and total habitat and for base flow values.

2 Rearing habitat capacity (# of fish) is calculated as habitat area (m^2) times mean fish density (fish/m^2) for values reported in Table 3 of Goodman et al. (2010).

(a)



(b)

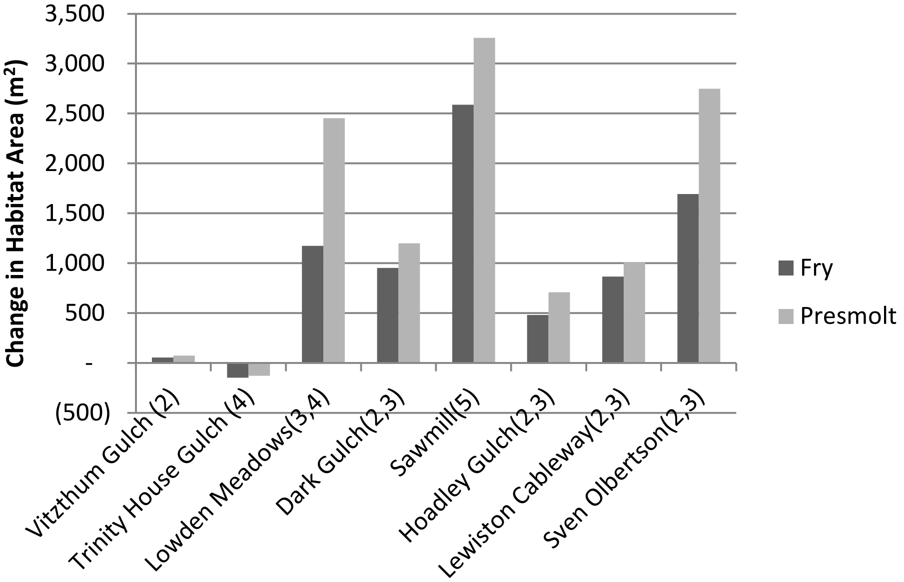


Figure 6

Change in (a) total and (b) optimal habitat area for juvenile Chinook and coho salmon at Phase 1 rehabilitation sites from pre- to post-construction condition at base flow ($8.6\ m^3{\cdot}s^{-1}$, 300 cfs). Note the change in vertical scale between panels. Data sources: (2) Goodman et al. (2010), (3) Alvarez et al. (2011), (4) unpub. Program data, and (5) Martin et al. (2012). See Appendix A, Section 2.1.5 for further detail.

The flow evaluation study (USFWS and HVT 1999) noted a constriction (dip) in juvenile salmon habitat under modest flows (about 350 to 2,000 cfs, Figure 7a), and one of the goals of channel rehabilitation is to alleviate this bottleneck by increasing habitat within this flow range. As part of our analysis, we examined the effect of rehabilitation activities on flow–habitat relations and this bottleneck (Appendix F). Although channel rehabilitation consistently increased the amount of juvenile rearing habitat, we find that the dip in habitat availability persists at modest flows when all habitat (constructed and naturally occurring) is considered (cf. Figures 7a and 8a). However, a nearly uniform flow–habitat relation is observed for constructed habitats (Figure 8b), demonstrating the successful removal of the bottleneck for these features.

Analysis of flow–habitat relations by design element shows that all in-river design element types provided fish habitat for both fry and presmolts across the range of flows examined (Figures 8c-i). Within a project reach, design elements provided about 48% of the total fry habitat at all flows and 44% of the presmolt habitat, indicating similar relative contributions for the two life-stages, although greater amounts of presmolt habitat were produced (Figure 8). This is likely due to the depth criteria range being larger for presmolt habitat than fry.

Although floodplain design elements provide only modest amounts of habitat (Figure 8g), they may provide important refuge during high-flow releases. Prior to floodplain construction, high flows may have forced juveniles out of the restoration reach due to channel confinement and lack of floodplain habitats.

Goodman et al. (2010) have also developed statistical models for elucidating site-scale controls on observed rearing habitat at base flow. They found that optimal habitat area was related to bank length and the proportion of low-slope channel (<0.2°) within a reach, while total habitat area was additionally related to bar length and longitudinal extent of channel rehabilitation within a sample site.

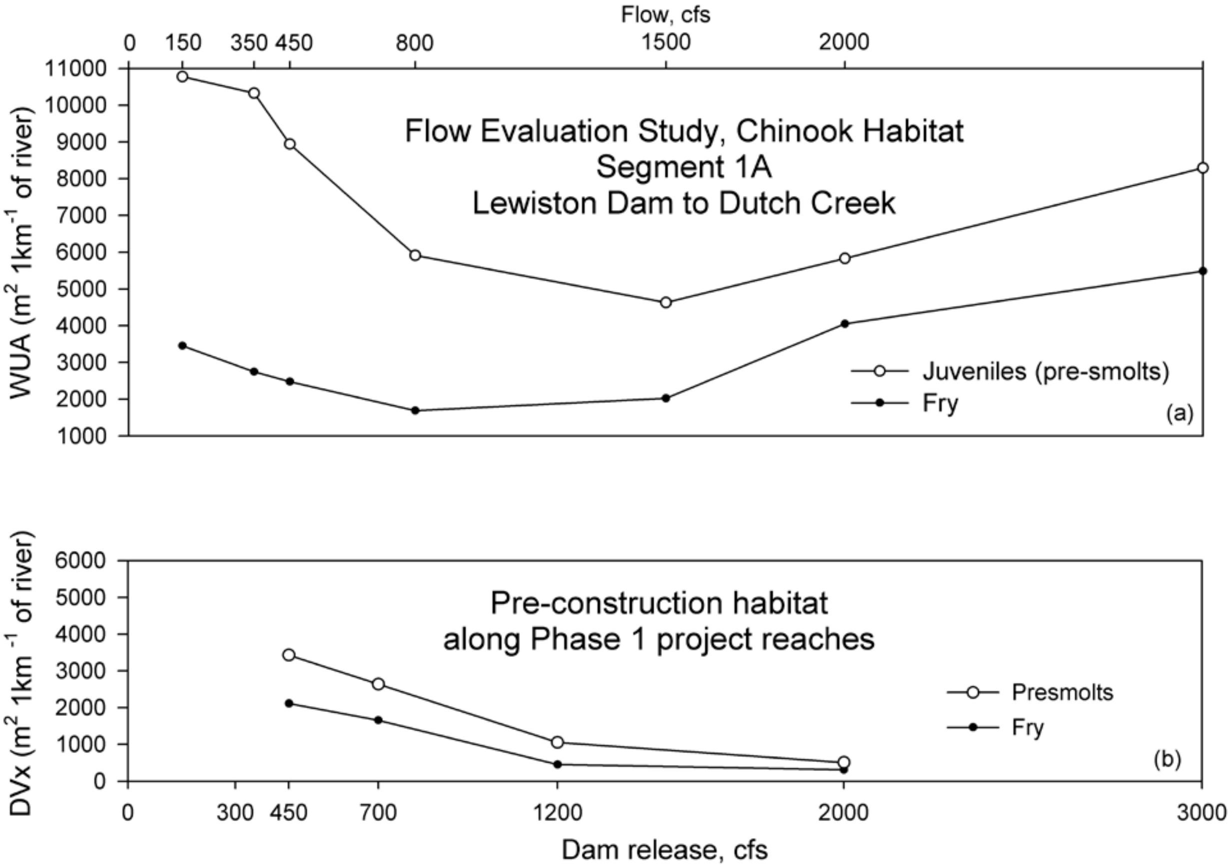


Figure 7

Physical habitat by streamflow for juvenile Chinook and coho salmon in (a) Segment 1A of the flow evaluation study (Lewiston Dam to Dutch Creek, USFWS and HVT 1999) and (b) select Phase 1 rehabilitation sites before construction (Cableway, Dark Gulch, Lowden Ranch, and Reading Creek). The flow evaluation study (USFWS and HVT 1999) reports habitat in terms of weighted useable area (a), while habitat at the Phase 1 sites is reported in terms of suitable depth and velocity (DVx). The depth criterion for presmolts in (a) was much higher (up to 3 m) than the present value used by the Program (< 1 m, b). The total centerline length of channel is 41.49 and 2.67 km, respectively, in panels (a) and (b). See Appendix F for further detail.

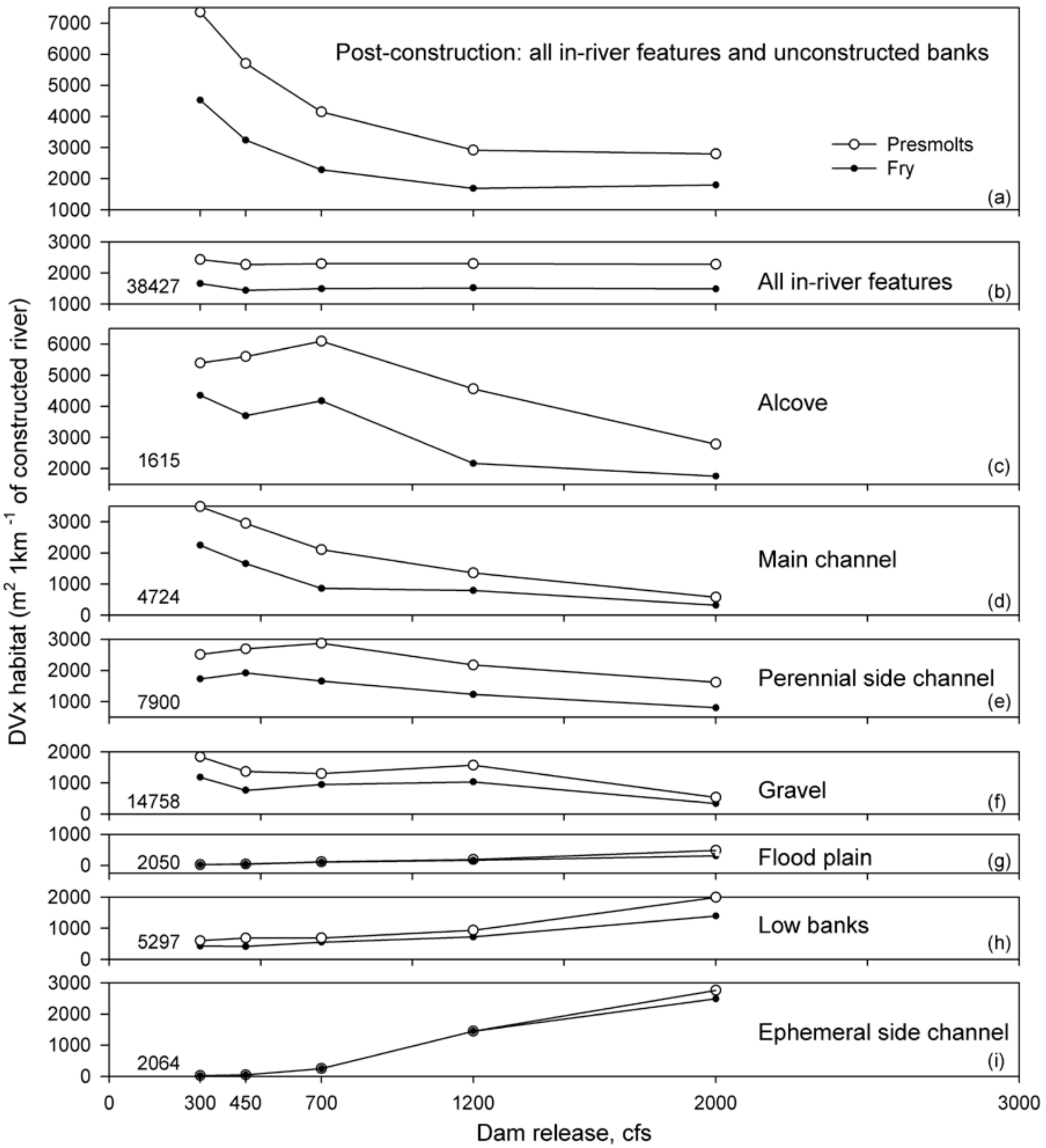


Figure 8

Suitable habitat area by streamflow for juvenile Chinook and coho salmon after channel construction at Phase 1 rehabilitation sites for which data were available (Table 3 of Appendix F). Suitable habitat is defined as meeting depth and velocity criteria (DVx) and is normalized by stream length for a given feature type. Panel (b) combines all feature types except aquatic non-river elements (wetlands and tributary connections). Numbers within each panel are the total footprint area at the sites (m^2) within the 2000 cfs wetted channel. See Appendix F for further detail.

2.3.1.2 Adult Spawning Habitat

An assessment of spawning gravel substrate at 12 sites on the mainstem river shows coarsening of both the streambed surface and subsurface due to a reduction in the percentage of fine material, which has improved spawning gravel conditions since 2000 (GMA 2010). This improvement likely results from successful management of fine sediment inputs from tributary basins and flushing flows in the mainstem river (GMA 2010). However, the effect of Phase 1 rehabilitation projects on reduction of fine sediment in the restoration reach is uncertain beyond the physical removal of berms (and the fine sediment stored within them) and floodplain lowering, which should promote fine sediment deposition during overbank flows.

In addition to changes in spawning gravel quality, redd and carcass counts provide direct observations of spawning habitat use in the restoration reach. However, the effects of Phase 1 activities on the abundance of Chinook salmon redds are inconclusive due to insufficient data and numerous confounding effects (e.g., multiple restoration treatments, interannual variability of physical and biological conditions, and inherent differences in site conditions). We present the available results in the interest of completeness (Figures 9 and 10), but stress that they are preliminary and no conclusions can be made at this time. Similar results were obtained for carcass counts of female Chinook and coho salmon (Appendix C, Section 7.2.2).

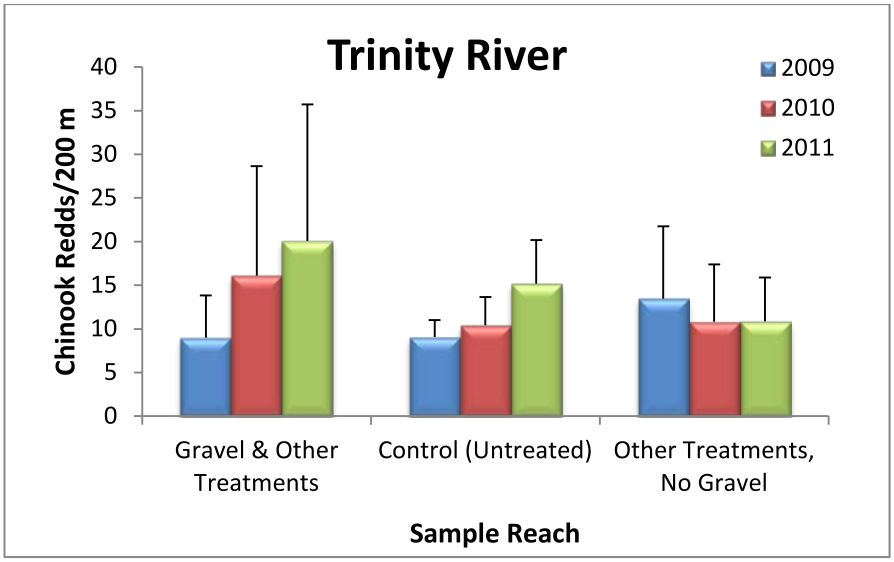


Figure 9

Mean redd densities and 95% confidence intervals for Chinook salmon (spring and fall runs) in 200-m segments of the restoration reach categorized by treatment: (i) gravel augmentation and other channel rehabilitation treatments, (ii) control (untreated), and (iii) treatments other than gravel augmentation. The figure examines whether spawners prefer gravel augmentation reaches. See Appendix C, Section 7.2.2 for further detail.

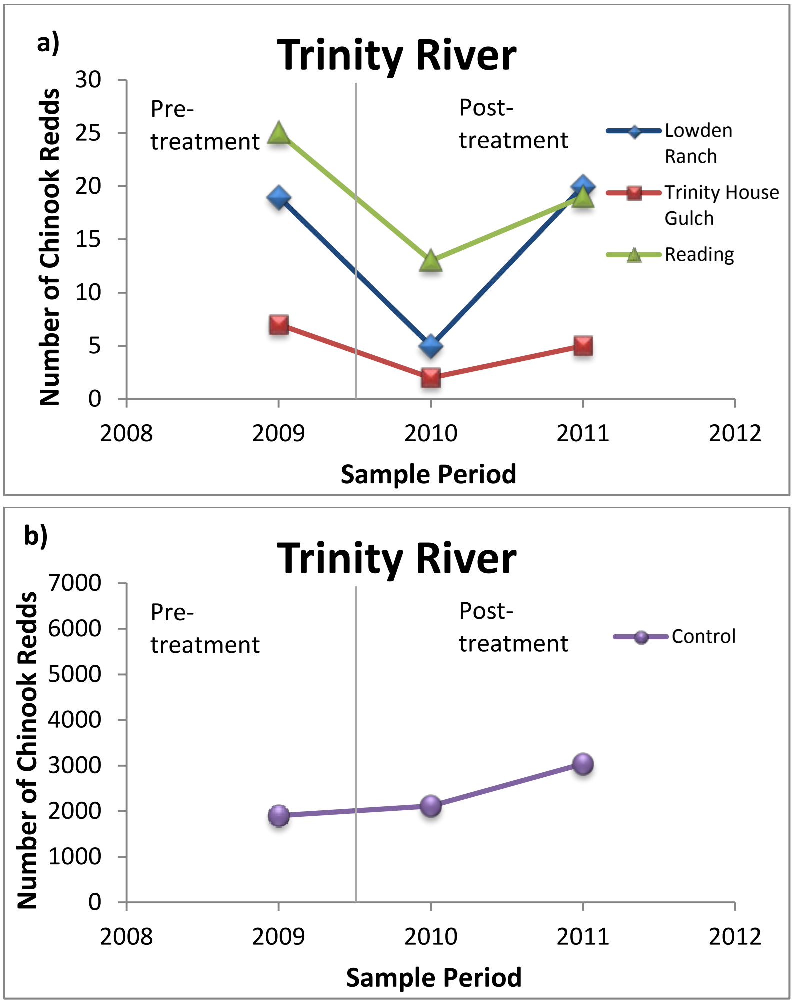


Figure 10

Number of Chinook salmon redds before-and-after channel rehabilitation, categorized by treatment: (a) gravel augmentation and other channel rehabilitation treatments and (b) control (untreated). Data in (a) were available for three rehabilitation sites, while data for (b) include control reaches throughout the restoration reach.

2.3.2 System Scale

2.3.2.1 Juvenile Rearing Habitat

System-scale monitoring shows that juvenile rearing habitat availability at base flow has not changed significantly over the three-year sampling period (Figure 11), but this is not surprising given the short sampling period and the paucity of high-flow events during that time. Independent analyses confirm the Figure 11 results and further investigate the spatial distribution of habit over time, the error structure of the data, and sources of variance (Appendix B).

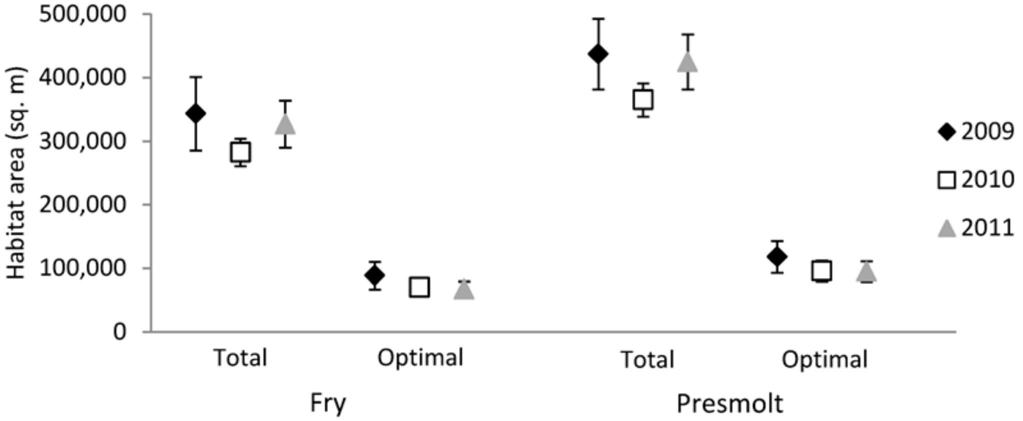


Figure 11
Total and optimal rearing habitat area for Chinook and coho salmon fry and presmolt estimated during base flow (14.4 m^3/s) from 2009-2011. Optimal habitat meets depth, velocity, and cover criteria, while total habitat includes areas that meet any combination of depth, velocity or cover criteria (Alvarez et al. 2011; 2013). Error bars indicate 95% confidence intervals. From Alvarez et al. (2013).

We conducted additional analyses to develop a retroactive model for examining system-wide rearing habitat over a broader time period. To examine juvenile habitat availability at system scales, we correlated observed base-flow habitat with base-flow channel characteristics determined from aerial photographs (Appendix E-1), an approach similar to that of Alvarez et al. (2011) and Goodman et al. (2012). Using this model as a surrogate for available fish habitat, we estimated habitat availability over space and time using a sequence of aerial photographs (Appendix E-1). Results indicate that juvenile rearing habitat availability has increased since 2001 (Figure 12), but the rate of increase has been slow (1.2-1.6% per year, 12-16% in total from 2001-2011). Nevertheless, these changes represent substantial potential increases in fish numbers. Assuming the mean fish densities reported by Goodman et al. (2010), the estimated increase in system-wide optimal habitat capacity for juvenile Chinook salmon from 2001 to 2011 is 130,202 fry and 94,946 presmolts. Similarly, the potential increase in total habitat capacity for juvenile Chinook salmon is 537,337 fry and 466,518 presmolts. We caution that our analyses were limited to base-flow habitat, which represents only a portion of the amount of habitat available over the course of an annual hydrograph (e.g., Figures 7 and 8), and does not include increases in juvenile habitat due to favorable changes in water temperatures; additional analyses across the full range of flows, temperatures, fish life stages, and spatial scales are needed to fully assess the effect of Program activities on habitat availability and fish production.

Although we observe system-wide increases in fish habitat, the results indicate no discernible effect of Phase 1 activities at this scale (i.e., no apparent difference in the trend of the data before/after 2005, Figure 12). To further explore this issue, we conducted statistical analyses to examine whether restoration activities were affecting local base-flow channel characteristics that, in turn, were correlated with local juvenile habitat availability, similar to the approach of Goodman et al. (2010). Results indicate that management activities are, indeed, having local effects. We find that observed changes in local channel characteristics (and thus juvenile rearing habitat) are related to the duration of high flows, upstream gravel augmentation, proximal construction activities, and streambank characteristics (alluvial *vs*. bedrock/resistant material) (Appendix E-1).

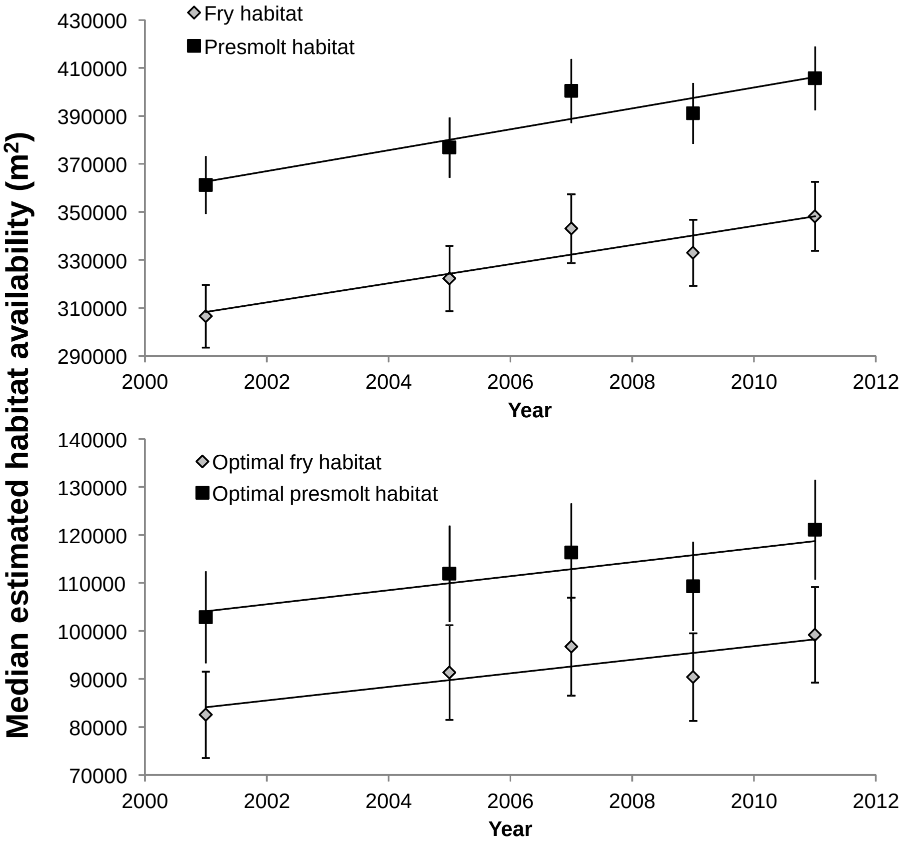


Figure 12

Increase in estimated total (top) and optimal (bottom) base-flow rearing habitat for juvenile Chinook and coho salmon in the Trinity River over the course of the Program, by life history stage. Phase 1 channel rehabilitation projects began in 2005. Vertical bars represent 95% confidence limits on estimates. Optimal habitat meets depth, velocity, and cover criteria, while total habitat includes areas that meet any combination of depth, velocity or cover criteria (Alvarez et al. 2011). See Appendix E-1 for further details.

We emphasize again that due to data limitations, the above analyses were focused only on the habitat available in the low-flow channel. Data for evaluating management-driven changes in juvenile fish habitats at higher flows is now being collected and should allow future documentation of system-wide changes in flow–habitat relations, similar to that demonstrated at site scales for the rehabilitation sites (Figure 8).

2.3.2.2 Adult Spawning Habitat

Spawning tends to be clustered near Lewiston Dam. As such, one of the Program sub-objectives is to spread the spatial distribution of suitable spawning habitat throughout the restoration reach. Recent analyses show that redds constructed by natural-origin spawners have spread further downstream from Lewiston Dam during the period from 2002-2011, but the trend is not statistically significant (Chamberlain et al. 2012) and it is unclear how it may be related to channel rehabilitation actions.

2.4 Water Temperature Regimes

Stream temperature is an important aspect of physical habitat for salmonids and the Program has been successful in managing stream temperatures within the restoration reach (Appendix A, Section 2.1.9). Overall, temperature targets were met more than 90% of the time during the summer holding period and more than 96% of the time during the two spawning periods. An examination of cumulative distributions of exceedances at Douglas City and North Fork Trinity River suggests that 60 to 70% of the exceedances were less than or equal to 1° F. These results indicate a high rate of compliance given the large number of variables associated with managing water temperature in a controlled, but large river system, exposed to tributary inflows and harsh air temperatures during summer months.

A more complex channel morphology has been created within the rehabilitation sites which, in turn, likely increases the spatial and temporal diversity of stream temperatures, offering a broader range of thermal habitats. Increased flows and shaping of the hydrograph in the post-ROD era may further modulate and diversify stream temperatures compared to pre-ROD conditions. We are not aware of any studies conducted by the Program to document the consequent effects of these factors on fish health and population response, but they have likely been beneficial and future investigation of the issue is warranted.

2.5 Fish Population Response

Documentation of fish population response to Phase 1 activities is limited. Although some positive changes in population metrics were observed during the Phase 1 period (Appendix A), mechanistic cause-and-effect relations are lacking. Here we summarize the observed responses in relation to IAP Objectives 3 and 4 (*Restore and maintain natural production of anadromous fish populations*) and specific sub-objectives as detailed in Appendix A.

We examined several data sets for natural-origin salmon (Chinook, coho, and steelhead): (1) abundance of juvenile Chinook salmon; (2) escapement of adult salmon; (3) proportion of adult salmon contributing to the total in-river run; (4) pre-spawning mortality; and (5) timing of smolt outmigration. In addition to target values specified by IAP objectives, we examined whether data trends showed any influence of Phase 1 activities (Appendix A).

The data show that the overall trend in abundance of natural-origin juvenile Chinook salmon generally increased from 2007 to 2012 for the larger Trinity basin (Figure 13a), but no systematic response was exhibited within the sub-basin containing the restoration reach (Figure 13b). Scaling the data by the number of spawners and resolving identified inconsistencies and needed corrections (Figure 13 caption) may further refine the relations shown here.

Spawning escapement trends during the Phase 1 period varied by species and phenotype and were sensitive to how sub-periods within the record were defined, making conclusions regarding the Phase 1 period tenuous (Appendix A, Section 2.1.1). The same was true for changes in the proportion of natural-origin adult salmon contributing to the total in-river run (Appendix A, Section 2.1.3). Nor were there any discernible effects of Phase 1 activities on pre-spawning mortality or smolt outmigration timing (Appendix A, Sections 2.1.10 and 2.1.11). The above results are not surprising given the recency of Phase 1 activities relative to the salmonid life cycle and the fact that several generations of fish may be needed before responses are detectable, not to mention the effect of factors beyond the control of the Program (e.g., ocean conditions, harvest, and hatchery management). The Program expects substantial increases in natural origin Chinook salmon populations within 3-4 brood cycles as a function of ensemble Program activities (management of flow, temperature, sediment, and channel structure) once dynamic fluvial processes have been restored (TRRP and ESSA 2009b).

The Program’s documentation of fish production provides valuable monitoring data, but is not mechanistically linked to Program activities, making it difficult to interpret the underlying cause-and-effect of observed changes in production. In-river fish production is the result of the dynamic nature of the river environment acting on fish life stages throughout the year from adult escapement through exiting of presmolts from the river. To quantify these interactions in the restoration reach, fish production models must now be linked with dynamic flow and dynamic water temperature models that interact with channel structure to describe the dynamic nature of habitat conditions available to in-river fish life stages. This linked modeling can be used to

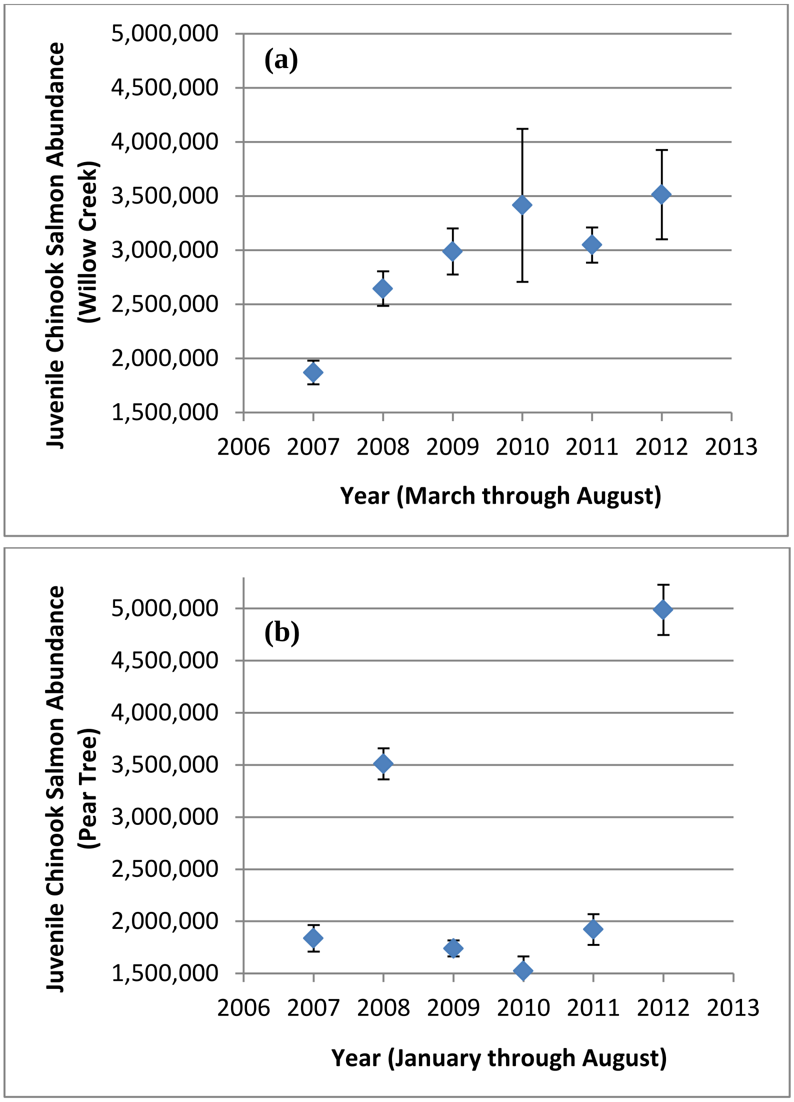


Figure 13

Abundance of natural-origin juvenile (Age-0) Chinook salmon over time for fish traps at (a) Willow Creek (near Willow Creek, CA, below the South Fork Trinity River confluence) and (b) Pear Tree (near Helena, CA, above the North Fork Trinity confluence). Error bars represent standard deviation. Trapping effort varied from year to year and this variation has not been accounted for in the figure. Potential corrections needed for the 2010 and 2011 Pear Tree data are currently being explored by the Program Partners. Data are from Pinnix et al. (2008; 2013), Harris et al. (2012), Davids et al. (2013), and Petros et al. (2013). The 2007 estimate for Willow Creek and the 2007 and 2008 estimates for Pear Tree were calculated using a Bayesian time-stratified spline-based method recommended by Schwarz et al. (2009); provided to Elizabeth Appy (Anchor QEA) by Bill Pinnix (USFWS) on March 5, 2014 and by Paul Petros (HVT) on March 10, 2014, respectively. See Appendix A, Section 2.1.2 for further discussion.

target data collection during monitoring and examine relative controls (designs, flow patterns, temperature regimes) on production (numbers and growth). For example, the linked dynamic models within SALMOD (Bartholow et al. 2000; 2003) were used to identify potential in-river fish production bottlenecks and inform the Program’s initial management strategy for implementing the ROD (USFWS AND HVT 1999). Unfortunately, the Program’s use of such models has not continued and, therefore, modeling results were not available for assessing Phase 1 activities. Re-examination of post-Phase 1 conditions via quantitative modeling may well show that major limitations (bottlenecks) to in-river salmonid production have evolved from the simplistic channel and low flows considered in the Program’s foundational documents (USFWS and HVT 1999). Certainly conditions have improved as a result of the collective actions during Phase 1. Targeting Phase 2 data collection efforts toward developing this capability within the framework of a DSS is much needed, as discussed in the next section.

3 CONCLUSIONS

A tremendous amount of work has been accomplished by the Program and its associated partnerships in a relatively short time: (1) securing the ROD, a framework for tackling a very large physical and biological management issue; (2) bridge replacement and relocation of structures from the floodplain; (3) implementing variable annual flow releases to provide physical salmonid habitat and restore riverine processes; (4) enhancing water temperatures to near optimum conditions; (5) reducing fine sediment loads; (6) managing the coarse sediment budget; (7) intensive and innovative habitat rehabilitation work; and (8) extensive environmental monitoring. These are all clear successes, with Phase 1 activities representing an element within this larger body of work by the Program. In addition, important lessons have been learned since establishing the ROD. First, the river is much less alluvial than originally envisioned. The original and perhaps over simplistic view of the river as being fully alluvial with riparian-stabilized berms along the length of the river is now known to apply only to a much smaller portion of the restoration reach (i.e., approximately 25% of the channel). This recognition along with evolving designs for rehabilitation projects now suggests the need for a dichotomy of project designs (i.e., those that specifically drive geomorphic processes over time, producing dynamic habitat response in alluvial sections of the river *vs*. building static habitat features intended to persist over time in less alluvial reaches). Second, river terraces from past mining activity may require extensive cutting in locations where floodplain habitat is being designed for juvenile fish to use during high-flow events. Third, large-scale channel features may be needed to interact with flood flows and drive more rapid changes.

Returning to the first question posed to us by the Program ("Are we on the right track?"), the short answer is yes, but additional work is needed to assess progress toward achieving the Program's *fundamental objective* (presumably the restoration of in-river fish production), as discussed below. The second question ("Which rehabilitation projects and design elements are successful?") is similarly hampered by insufficient information, particularly with regard to the Program's *fundamental objective*. Nevertheless, the available data suggest that the various channel design elements all contribute to increased juvenile salmonid habitat and reduce the usual constriction in habitat observed at modest flows (Section 2.3.1.1 and Appendix F). Side channels offer a potential means for maximizing habitat availability (Beechie et al. 202), but may be more prone to aggradation; so their potential benefits depend on the dynamic longevity of such features and they should only be located in reaches that have potential for an anabranching morphology (Figure 2). In addition, diversity of design elements and associated habitats is recommended, as this may promote species resilience to changing environmental conditions. Overall, the habitat created by the program has substantially increased the juvenile rearing capacity of the restoration reach and has likely had a positive effect on fish production, but the role of channel rehabilitation relative to other Program actions (e.g., management of flow, temperature, and sediment) remains to be demonstrated. The third question ("What should be done for Phase 2?") requires a longer answer and is addressed below within the context of our evaluation of Phase 1 activities.

In terms of Phase 1 rehabilitation projects, the Program is implementing the ROD, constructing fish rearing habitat, and monitoring physical and biological response relative to IAP objectives. However, given the current information available to us, we were not able to assess the efficacy of the Phase 1 actions with regard to the Program's *fundamental objective* of restoring in-river fish production. Certainly, Phase 1 activities are creating more suitable fish habitats and a more complex river, especially in terms of more spatially variable flow and water temperature regimes, but the effects on fish production are unclear due to insufficient data and insufficient time since project implementation to observe geomorphic changes and associated fish population responses. Although the Program is on track, the solution to this problem is not simply collecting more of the same data and waiting longer for the physical and biological responses to occur. Rather, there are several key elements missing from Program activities that inhibit assessing the efficacy of Phase 1 actions and progress toward the Program's *fundamental objective*:

1. The Program tends to be focused on *means objectives* (e.g., producing fish rearing habitat using channel designs and construction), rather than the *fundamental objective* of restoring in-river fish production. Similarly, many of the Program's monitoring efforts target *means objectives*, such as the availability and quality of juvenile fish habitat or the extent and degree of dynamic fluvial processes. Changes in trajectories of *means objectives* are only indicative of change toward desired improvements. Therefore, the ultimate metric is the change in the *fundamental objective* of in-river fish production, which is a function of the interactions of the *means objectives*. Toward this end, integrated modeling is needed to examine the synergistic effects of Program activities (management of flow, temperature, sediment, and channel morphology; all *means objectives*) over space and time to understand the effects on fish production (*fundamental objective*) and to evaluate the relative effects of different management actions.
2. The observed physical and biological responses to Phase 1 actions are encouraging, but rates of change are slow (Figure 12). Therefore, monitoring efforts must be supplemented by predictive models as described above to inform management actions in a timely manner and to facilitate adaptive management. The Program has recently begun to use quantitative models for predicting channel type, morphodynamics, and flow–habitat relations for evaluating design options and assessing site specific physical and biological responses (e.g., Alvarez et al. 2011; HVT et al. 2011; Beechie et al. 2012;

Gaeuman 2013), but these efforts require further integration and linkage to other Program activities, particularly fish production that supports a broader system-wide view and allows assessment of the relative effects of different management actions. In this regard, a fish production model is needed, such as SSS, the newer version of SALMOD (Bartholow et al. 2000, 2003).

3. To achieve the first two items above, Program activities and data collection must be more tightly integrated than they currently are. At the moment, Program activities are loosely organized around the ROD, but are not organized in a structured manner toward understanding system dynamics and documenting progress toward achieving the Program's *fundamental objective* of restoring in-river fish production. Annual compilation of data input to models that provide integration and an understanding of system dynamics and synergy will better inform management, foster understanding among stakeholders, and facilitate adaptive management. Toward this end, sharing of data and timely delivery of summaries for model input must be organized and scheduled.
4. The design process for channel rehabilitation projects is focused at site scales and does not yet consider the larger effects of rehabilitation actions, nor how individual projects may be interacting with one another and collectively affecting fish habitat and production. The same is true for other program activities (e.g., management of flow, temperature, and sediment). Nor are the relative effects of these activities on fish production known.
5. Formal, scientific hypothesis testing is needed. By its nature the Program is an applied effort, but it is nonetheless a science-based program and therefore requires stronger use of comparisons of alternative management actions and hypothesis testing for developing and writing study plans, making defensible decisions, and conveying results to peers and the public.
6. A formal adaptive management framework is needed, as called for in the ROD (USDOI 2000), to better structure and integrate Program activities and to increase the defensibility and transparency of management actions.

To address the above issues and to move the Program Partners and stakeholders toward a better understanding of the dynamic nature of the river system and the roles that specific *means objectives* may contribute toward fish production, our primary recommendation is that the Program focus immediate attention toward development of a Decision Support System (DSS). A DSS is a series of linked physical and biological models that allow the Program to (1) predict site and system response to alternative management actions in relation to ROD and stakeholder objectives; (2) make such predictions in a timely fashion (ahead of monitoring results); (3) focus and refine monitoring efforts to specifically assess predictions; and (4) provide a necessary tool for adaptive management and communication. Additionally, it will help to better structure and integrate Program activities and increase understanding of the roles of *means objectives* and thus the defensibility of management actions. In many ways, the DSS expands upon efforts started by the Program in defining Conceptual Models and Hypotheses (TRRP and ESSA 2009a).

The proposed DSS will shift the Program from the current focus on *means objectives* (i.e., producing fish rearing habitat using channel designs and construction) toward a focus on the *fundamental objective* (restoring in-river fish production) through a better understanding of the roles and synergistic effects of Program actions (management of flow, temperature, sediment, and channel morphology) over space and time to elucidate the effects on fish production. In addition, our intent is to more strongly focus Phase 2 on “science goals,” rather than the current focus on implementation and monitoring. This requires testing the primary assumptions upon which the foundational documents and implementation plan rests. As an example, basic assumptions could be stated as: There is a measurable relation between the habitat quantity and quality that exists during a given salmon escapement, spawning, and rearing season and the recruits produced. Further, that this relation can be quantified and manipulated in order to achieve a measurable increase or decrease of the in-river salmonid production from the restoration reach within a given year. A major trade-off between optimizing habitat conditions for fish populations and releasing high flows for driving geomorphic processes may exist within any given year. By developing hypotheses and protocols for continually testing the relations between Program-managed river conditions and fish population responses, specific recommendations for a given year can be evaluated ahead of time, trade-offs debated among Program Partners, and chosen implementation strategies explained to the public. Questions that may be addressed during annual flow scheduling might include: What is the adult run size? What is the predicted water year allocation to the Program? Can adequate high flows be released to drive geomorphic processes in a desired direction? If the estimated adult run size is much smaller than average (or expected), does optimizing habitat conditions at the expense of geomorphic flow releases make sense, or could adequate suitable habitat conditions be provided at critical times and still deliver high flows for dynamically shaping channel morphology that also gradually move juvenile fish onto the floodplain, providing refuge habitats from high velocities. Although the Program addresses these issues to a certain degree each year during their flow scheduling, the proposed DSS would help to refine, focus, and integrate relevant questions and activities with regard to the *fundamental objective* of restoring in-river fish production.

Substantial guidance for the development of a DSS is provided in Appendix H and Figure 14, which illustrate the integrated modeling framework envisioned for the Program. The basic concept is to develop linked quantitative models that formally incorporate channel structure, flow, and water temperature as driving variables for estimating suitable habitat conditions over space and time throughout the restoration reach, and link this information to fish population modeling for estimating life-stage success in terms of numbers, growth and general health on an annual basis. Appendix H identifies key elements that should be considered when developing a DSS for the Trinity River (e.g., start with the above linkages within the restoration reach to better understand their dynamics, then integrate with existing work in the Klamath Basin on SSS). This appendix suggests particular models that are potentially useful to the Program, but these should not be treated as strict prescriptions. Rather, we recommend that Program personnel consider multiple approaches and different candidate models and, based on their familiarity with the system and Program objectives, choose those that best meet their understanding of component linkages and the required monitoring needs as input.

The initial Program action for DSS development is implementation of a core modeling effort that links a fish production model to channel structure, flow, and water temperature, as they define the dynamic nature of suitable fish habitats through space and time (Figure 14). The response to alternative management actions using model simulations of potential in-river fish production can be used not only to assess management alternatives, but also to illustrate predictions (forecasts) of selected management actions for public discussion prior to actual implementation. Toward this end, scoping is needed to specify the requisite input parameters and scales of information needed to drive the flow, water temperature, and habitat models that provide input to the selected fish production model (i.e., identify all other physical and biological models that are to be integrated within the DSS framework and how each model will specifically inform the fish production model; Figure 14). It is also necessary to specify how the DSS will be informed by monitoring data, what decisions are to be evaluated (i.e., the specific decision alternatives), and whether the selected models can address those decisions.

Most if not all of the Program’s existing monitoring data would be incorporated into the various models linked to the chosen fish production model, such as SALMOD or its new version, SSS. Although prior applications of such modeling efforts have used mesohabitat units to describe fish habitat availability, the Program’s current habitat sampling approach (GRTS) and existing habitat units can be used instead, as desired. However, in order to implement a model such as SSS, the Program will need to expand their current habitat sampling efforts to (1) determine flow–habitat relations across the full range of managed flows with the assistance of 2D hydraulic models (Alvarez et al. 2011) at both constructed and non-constructed sites; (2) extrapolate measurements to describe habitat suitability throughout the restoration reach; and (3) ensure that habitat sampling and extrapolations are compatible with models that simulate the dynamic nature of flow, water temperature, and habitat suitability throughout the system over space and time.

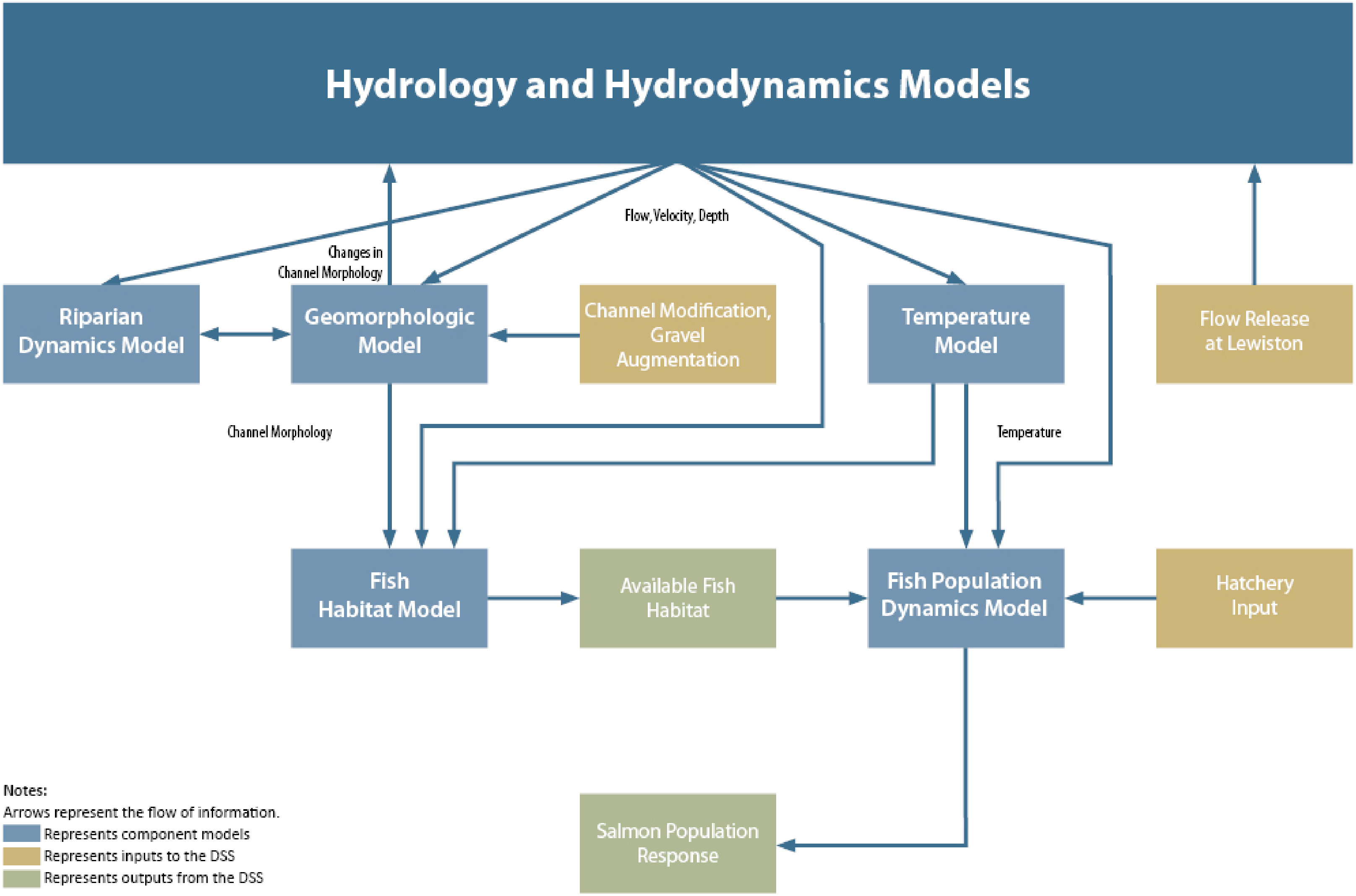


Figure 14

Model components of a Decision Support System for the Program. See Appendix H, Section 3.1 for further discussion.

The fish production model within the DSS does not supplant empirical data, such as smolt and habitat abundance, but in fact relies on such data and is tested and improved by it. The primary advantage of a DSS is rapid feedback, where possible outcomes of various management actions—either proposed or actual—can be compared and thus inform decisions, both for Phase 2 and the longer-term operation of the Program (i.e., continued gravel and flow augmentation following completion of the Phase 1 and 2 rehabilitation projects).

Beyond constructed changes in habitat, the site and system responses observed during Phase 1 are slow, and monitoring efforts must be supplemented by predictive models as part of a DSS to inform management actions in a timely manner and to facilitate adaptive management. A DSS also will integrate Program activities and provide for defensible decisions regarding workplan development, as recommended by the Independent Review Panel (Atkins 2012) and the SAB (2013).

In this regard, developing a collaborative plan for the efficient and timely flow of information among Program workgroups is essential. The plan should identify Program Partner and workgroup responsibilities for data sharing, model input, analysis, and integration. This must be organized and scheduled on an annual basis for populating the DSS. Program Partners and data collectors must place highest priority on identifying where data input may be needed from others and where and when their summaries are to be delivered to others.

4 RECOMMENDATIONS

Adaptive management is a guiding principle of the Program and a stated objective of the ROD (USDOI 2000). Implementing the Program in an adaptive management framework and assessing the efficacy of management actions requires a DSS; therefore developing a DSS and its core model elements discussed above (Figure 14), should be the highest priority for the Program in the upcoming year. Important next steps and detailed recommendations regarding the specifics of DSS development are provided in Appendix H (Sections 3 and 6).

Once the DSS is developed, we recommend that it be used along with other available information to:

1. Critically assess channel rehabilitation actions needed to achieve fish population objectives. What habitats and in which locations of the river are needed to achieve objectives at local and system scales? How do Program activities (rehabilitation projects and management of flow, temperature, and sediment) collectively affect salmonid populations? What are the synergistic effects and relative roles of different management activities?
2. Formally test the foundational hypothesis that a dynamic, complex channel can be created and that, together with other Program activities, will restore fish populations. To date, this has not been demonstrated, in part, because of slow physical and biological responses and the recency of restoration actions, which have not experienced many geomorphically effective flows. In this regard, modeling can help to test the above hypothesis and inform management actions in a more timely manner. Moreover, given the semi-alluvial nature of the river and limitations imposed by ROD flows and the volume of gravel introduced by augmentation, the original vision of a dynamic river with broad, active point bars may be too optimistic.
3. Critically evaluate the change in design strategy that has occurred (i.e., minimal *vs.* intensive mechanical intervention). A key factor to quantify in this regard is the response time for creating desired channel conditions and fish populations. The desired response time greatly influences the type of management actions (i.e., size, frequency, and degree of manipulation). Inherent in the Program's current approach of intensive, complex projects is the notion that more aggressive channel rehabilitation will shorten both the response time and the adaptive management learning cycle, thereby better informing Phase 2 designs. However, these assumptions remain to be tested and may be critically limited by the frequency and magnitude of ROD flows and the associated geomorphic work. In this regard, we also recommend that the Program pursue its investigation of ways to reshape the wet-flow and extremely wet-flow allocations to increase the magnitude and efficiency of geomorphic work that it can accomplish in relation to

desired channel conditions and resultant fish production. We also recommend that the Program consider the potential benefits of several large projects *vs*. many small ones. Are large channel rehabilitation projects more effective at meeting Program objectives than small ones, and which objectives are best met by each approach? Similarly, the benefits of projects designed to drive dynamic fluvial response in alluvial sections of the river *vs*. constructing static habitat in constrained and semi-alluvial reaches should be critically evaluated.

Based on our review of Phase 1 activities and the Program in general, we recommend the following additional actions:

- Phase 2 projects should continue to use opportunistic design strategies to promote dynamic alluvial reaches where possible, while working with local constraints on channel morphology in this semi-alluvial river. Designs should be based on models involving channel morphodynamics, flow–habitat relations, and fish production, rather than based on alluvial regime theory and reach-average channel characteristics (Eaton et al. 2010; HVT et al. 2011; Beechie et al. 2012). However, regime theory can be used to assess sustainability of a proposed channel type for the local channel slope, discharge, and bed load transport rate.
- Design objectives for Phase 1 projects were initially "motherhood and apple pie" statements—invoking ROD and IAP objectives without demonstrating how they would be achieved. In contrast, recent efforts are more defensible—employing mechanistic, predictive models to evaluate as-built changes, design alternatives, and site evolution. Phase 2 projects should continue the above, more rigorous efforts in combination with a DSS and fish production model.
- Incorporate into study plans metrics for quantifying juvenile fish numbers, growth, and health as major components of fish population modeling for estimating annual in-river fish production. Examine the role of annual water temperature regimes with regard to fish growth and general health across years. As the river system evolves in response to post-ROD management actions, the Program's foundational hypothesis of juvenile rearing habitat being the primary limiting factor may be expected to change. Use the DSS and fish population modeling as a surrogate for the actual fish population to periodically examine alternative population limiting hypotheses. For example, (1) juvenile fish production *vs*. adult escapement and (2) carrying capacity of physical habitat *vs*. water temperature and its effect on fish growth and health.
- Better articulate program and stakeholder objectives and explicitly identify the relations among objectives. The current management actions tend to address *means objectives* (e.g., create habitat), rather than *fundamental objectives* (e.g., increase fish production).

As a result, disagreement about science is often conflated with disagreement about objectives. This significantly hinders scientific advancement. Similarly, scientific disagreement should be explicitly incorporated into the process, comparing alternative models that represent the alternative scientific hypothesis about system dynamics; a process facilitated by a well-crafted DSS.

- Adopt rigorous hypothesis testing for Program activities and scientific investigations, which is critical for improving the effectiveness of such actions. Treat rehabilitation projects as opportunities to formally test the hypotheses and goals articulated by the ROD and IAP. The current management actions address, but frequently do not test, the stated hypotheses and objectives. In this regard, we recommend refinement of IAP objectives to make them testable hypotheses. We also recommend that the Program conduct more comparisons within and between restoration sites to better evaluate design elements and overall project performance; lack of information precluded us from doing this as part of our review. To the extent possible, develop process-based, mechanistic hypotheses.
- Integrate workgroup activities to better achieve Program objectives. The workgroups include interdisciplinary membership, but need better coordination and exchange of information across workgroups (development of a DSS should facilitate this integration). In addition, the internal review process of Program reports should be streamlined to disseminate findings more rapidly. Internal dissemination of information from one group to another, necessary for model input and analyses, must not be hindered by lengthy review process. Publication in peer-review journals also is encouraged to both have peer input and to better disseminate Program findings.
- Develop a system-wide 1D sediment routing model in concert with existing sediment transport monitoring and additional tracer studies to more finely resolve the sediment budget and the fate of gravel augmentation (i.e., whether the input gravel is building bars, providing spawning riffles, or filling pools).

5 ACKNOWLEDGEMENTS

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APPENDIX A
HIGH-LEVEL INDICATORS

Prepared for
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Prepared by
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LIST OF ACRONYMS AND ABBREVIATIONS

ARIMA	Auto Regressive Integrated Moving Average
cfs	cubic feet per second
CWT	coded wire tag
FL	fork length
GRTS	generalized random tessellation stratified
HVTFD	Hoopa Valley Tribal Fisheries Department
IAP	Integrated Assessment Plan
JW	Julian Week
km	kilometer
m^2	square meters
$m^3 \cdot s^{-1}$	cubic meters per second
mm	millimeter
Program	Trinity River Restoration Program
RKM	river kilometer
RM	river mile
ROD	Record of Decision
SAB	Scientific Advisory Board
TRH	Trinity River Hatchery
USFWS	U.S. Fish and Wildlife Service
WY	water year
YTFP	Yurok Tribal Fisheries Program

1 METHODS

1.1 Analysis of the Trinity River Restoration Program's Performance Measures

A suite of biological and physical measures was used to assess the Trinity River Restoration Program's (Program's) implementation and effectiveness during Phase 1. The 11 measures that were analyzed included performance measures developed by the Program Partners, and additional indicators identified in Program foundational documents and determined by the Scientific Advisory Board (SAB) to be important. Unless noted otherwise, the Program Partners developed the methods and data used in the assessments described below. If supported by available data, we conducted additional trend and graphical analyses to assess any potential effects of Program actions on the performance measures.

The Program Partners developed the term "performance measure" but have not formally defined its use. Rather, these measures are being used to judge the Program's success by providing a documented time series of the Program's performance with respect to fish habitat, physical processes, and riparian communities. They include monitoring how well Program elements are being implemented (e.g., are restoration water volume targets being met?), whether channel structure and morphology is changing in ways that benefit salmon (e.g., is juvenile rearing habitat increasing?), and whether the desired biological response is being produced (e.g., is the spawning escapement of naturally produced salmonids increasing?).

1.1.1 Spawning Escapement of Naturally Produced Salmonids

The Program Partners hypothesized that Program flow and habitat modifications will increase the production of juvenile salmon and escapement of naturally produced adult salmonids. Target escapement levels identified in the *Integrated Assessment Plan* (IAP; TRRP and ESSA 2009) are as follows:

- Increase escapement of natural-origin fall-run Chinook salmon to 62,000 adults.
- Increase escapement of natural-origin spring-run Chinook salmon to 6,000 adults.
- Increase escapement of natural-origin coho salmon to 1,400 adults.
- Increase escapement of natural-origin steelhead to 40,000 adults.

To assess these goals, overall escapement and the relative contributions of hatchery produced and naturally produced fish were estimated by the Program for each year from 1992 to 2011 based on sampling at two sites. Weirs were deployed each year on the mainstem Trinity River near Junction City in late spring and near the town of Willow Creek in late August. As stated in Sinnen et. al. 2011, most fall-run Chinook salmon spawning occurs upstream of Willow Creek, while the majority of spring-run Chinook salmon spawning occurs upstream of Junction City. Therefore, the Junction City site focused on sampling spring-run Chinook salmon, whereas the Willow Creek site focused on sampling fall-run Chinook and coho salmon, and fall-run steelhead. Since the Program estimated spring-run Chinook salmon escapement based on data collected at the Junction City weir, any spawning below the Junction City trap site would result in escapement being underestimated. Spring Chinook salmon spawning has been documented in the South Fork Trinity River, New River, Canyon Creek, and North Fork Trinity River.

The abundance of hatchery-produced fish was determined by the number of fish with hatchery marks observed in weir samples. For hatchery-origin Chinook salmon, fish were marked with an adipose fin clip and coded wire tag (CWT) at a constant rate (25%) at Trinity River Hatchery (TRH). This allowed weir counts to be expanded to estimate the total number of hatchery-origin fish escaping. The abundance of naturally produced fish in the run each year was estimated by subtracting hatchery abundance from total abundance observed at the weirs. For hatchery-origin steelhead, all fish released from TRH were marked with an adipose fin clip and right maxillary (i.e., jaw) clip, and no expansion of weir samples was required. For hatchery-origin coho salmon, all fish released from TRH were marked with a right maxillary clip, and no expansion of weir samples was required. Similar to Chinook salmon, the abundance of natural-origin coho salmon and steelhead in the run each year was estimated by subtracting hatchery abundance from total abundance.

Simple trend analysis was then used by the Program Partners to determine whether escapement of naturally produced salmon increased from 1992 to 2010 for each species. The exception to this approach was that for natural-run steelhead, the Program Partners used a general linear model to analyze trends in these data due to a large gap in the time series. They analyzed year as the independent variable and the natural log of steelhead as the dependent variable. Graphical analysis was used to determine whether the Program’s escapement goals were met.

For all four species or runs, we conducted additional analysis using least-squares trend analyses. Because Chinook salmon adults can spend 2 or more years at sea, and because the time series of data for all four species or runs is relatively short and results of trend analyses can be influenced by returns in a single year, we conducted analyses based on two time periods. First, we defined the pre-treatment as 1992 to 2002 and the treatment period as 2003 to 2011. We defined the treatment period based on the assumption that in-river actions affecting juvenile rearing in the restoration reach in 2001 would affect adult returns starting in 2003. Fish rearing in the treatment reach in 2001 would have been progeny from adults that spawned in 2000, and would return to spawn in 2003 (age 3). Second, we defined the pre-treatment period as 1992 to 2003 and the treatment period as 2004 to 2011. We defined this treatment period based on the assumption that in-river actions affecting juvenile rearing in the restoration reach in 2001 would affect adult returns starting in 2004. Fish rearing in the treatment reach in 2001 would have been progeny from adults that spawned in 2000, and would return to spawn in 2004 (age 4). For both analyses, we interpreted changes in the habitat that occurred prior to 2005 as due to early program activities that included Record of Decision (ROD) flow implementation (up to flow levels allowed by a court order), but not changes in habitat due to channel rehabilitation actions. Changes occurring on or after 2005 were interpreted as being associated with contemporary program actions.

Note that a harvest management plan exists for fall Chinook salmon in the Klamath River basin, including the Trinity River. However, the plan does not recognize the Program's spawning escapement goal as a management objective, and there is no Trinity-specific fall Chinook salmon harvest plan currently in place (ESSA and TRRP 2009). Also, the escapement goals discussed above for fall Chinook salmon are not adjusted for ocean and in-river harvest rates that vary each year and can affect overall spawning escapement.

1.1.2 Abundance of Natural-origin Juvenile Chinook Salmon

The Program Partners hypothesized that the cumulative restoration actions of the Program will increase the abundance of natural-origin juvenile (age-0) Chinook salmon emigrating from the restoration reach. Juvenile salmonid outmigrant trapping is conducted at the Pear Tree Gulch (river kilometer [RKM] 118) near Helena, California (Pear Tree rotary screw trap), and the Riverdale Campground (RKM 34) near Willow Creek, California (Willow Creek rotary screw trap). The expected response is a positive trend (i.e., the slope of the trend line is positive and statistically significantly different from zero) in the number of juvenile (age-0) Chinook salmon counted at the Willow Creek rotary screw trap from March to August and the Pear Tree rotary screw trap from January to August each year. The Pear Tree Trap site is located just upstream from the mouth of the North Fork Trinity River and only includes the treatment reach affected by the Program. The location of the Willow Creek trap results in estimates of smolt abundance that include outmigrants from an area of the watershed that is much larger than the treatment reach affected by the Program.

U.S. Fish and Wildlife Service (USFWS), Yurok Tribal Fisheries Program (YTFP), and Hoopa Valley Tribal Fisheries Department (HVTFD) staffs implement the outmigration monitoring program and have collected data since 1989. However, an intensive mark-recapture method was employed starting in 2002 to estimate abundance. Juvenile Chinook salmon collected during trapping operations and juvenile salmon from the TRH were marked and released, and estimates of trapping efficiency were developed based on recapture rates. Population estimates for both natural- and hatchery-origin juvenile Chinook salmon were generated for the March-to-August and January-to-August emigration period each year at the Willow Creek rotary screw trap and the Pear Tree rotary screw trap, respectively, using a Bayesian time-stratified spline-based method stratified by week of year developed by Schwarz et al. (2009), who evaluated tradeoffs between alternative monitoring methods for assessing smolt abundance, run timing, and condition.

Estimates from 2007 to 2012 for the Willow Creek rotary screw trap data and the Pear Tree rotary screw trap data were used to examine trends in juvenile Chinook salmon abundance over time because these data are collected annually, and the methods and effort have remained relatively constant since 2007. While juvenile Chinook salmon have been sampled at the Willow Creek and Pear Tree rotary screw traps since 1989, the level of effort and methods employed to estimate abundance were significantly different prior to 2007 compared to the mark-recapture methods currently used. According to Schwarz et al. (2009), the flow-based methods used to estimate smolt abundance captured the general shape of the outgoing migration quite well but may have underestimated the actual number of migrants leaving the system. Furthermore, the relationship between the flow-based and mark-recapture efficiencies was found to vary considerably across years. Thus, the Program Partners will be conducting additional analyses in the future and attempt to integrate the older (pre-2007) data into the trend analyses.

Also, it should be noted that the number of days the traps were sampled varied each year and data used in the analysis were not standardized for sampling effort. The Program Partners are currently synthesizing the juvenile abundance data across years and are developing a method to correct for variation in the sampling effort from year to year and relate estimated smolt production to spawner abundance. Given these limitations, the data developed by the Partners was used here to assess the overall trends among years.

1.1.3 Proportion of Naturally Produced Adult Salmon

The Program Partners expected that the proportion of naturally produced adult salmon in the river would increase as the rehabilitation of the fluvial processes continues, assuming that hatchery production remains constant or is reduced. To test this expectation, estimates of the proportion of naturally produced adult salmon were developed from data collected at the Junction City and Willow Creek weir sites each year from 1992 to 2011. The hatchery proportion of a run was determined by the number of fish with hatchery marks observed in the weir sample. For hatchery-origin Chinook salmon, a constant rate (25%) of fish at TRH was marked with an adipose fin clip and CWT. This allowed weir counts to be expanded to estimate the total number of hatchery-origin fish escaping. Subtracting hatchery-origin abundance from total abundance and dividing the product by total abundance allowed for estimation of the natural proportion of the run each year. For hatchery-origin steelhead, all fish were marked at TRH with an adipose fin clip and right maxillary clip and no expansion of weir samples was required. For hatchery-origin coho salmon, all fish released from TRH were marked with a right maxillary clip and no expansion of weir samples was required. Similar to Chinook salmon, subtracting hatchery-origin abundance from total abundance and dividing the product by total abundance allowed for estimation of the natural proportion of steelhead and coho salmon in the run each year.

The proportions of hatchery- and natural-origin fish were then applied to estimates of the total adult run (adding harvest and escapement estimates). In-river run sizes were normalized to hatchery escapement by the Program Partners to factor out some of the cyclic variation inherent in run-size data. The Partners assumed that if the TRH produced similar numbers of yearlings and fingerlings in similar health and condition every year, any change in the natural-to-hatchery ratio was due to changes in the natural population. The proportion of natural-origin salmon in the in-river run was calculated as shown in Equation 1-1 and the data were plotted to examine any relationships over time:

$$([\text{Natural-origin in-river run}]/[\text{Total in-river run (harvest + escapement)}]) * 100 \qquad (1\text{-}1)$$

For all four species or runs, we conducted additional analysis using least-squares trend analyses in a manner similar to that described in Section 1.1.1.

1.1.4 Distribution of Natural-origin Chinook Salmon Spawners

The Program Partners hypothesized that reinitiating channel-forming processes in the Trinity River will change the distribution of suitable salmon spawning habitat. This is expected to influence egg-to-fry survival, and fry-to-smolt survival when combined with improvements in juvenile rearing habitat. Over time, the distribution of spawners within the restoration reach is expected to be increasingly influenced by the distribution of optimum spawning and rearing habitat, rather than the higher density of strays in proximity to the TRH near Lewiston, California. Ultimately, the distribution of spawners is expected to shift downstream from Lewiston Dam as juvenile and adult spawning habitat is created through the Program’s actions. However, this redistribution is expected to take time.

To test this hypothesis, salmon redds in the Trinity River mainstem were surveyed and mapped each year from Lewiston Dam to Weitchpec (excluding the Burnt Ranch Gorge). The proportion of natural- and hatchery-origin Chinook salmon females was estimated by modeling the distribution of hatchery-marked fish among recovered spawner carcasses. The methods of this analysis are detailed in Chamberlain et al. (2012) and are summarized below.

The study area was divided into 14 reaches, as described in Table 1-5 (in Section 1.1.10). These reaches were surveyed between September and December each year on a weekly or biweekly basis. However, some reaches were excluded in some of the planned weekly samples due to logistical issues (i.e., extreme weather and high flows), and surveys were conducted during January in some years to encompass a greater proportion of coho salmon spawning. Each reach was navigated with a pair of inflatable rafts, one assigned to each bank. The crew on board each raft consisted of an observer and an oars person. Observers searched for the scoured oval pit and distinctive mound typical of a complete redd. All located redds were enumerated and locations determined by aerial photo interpretation or GPS. Data collected at each spawning location included the number of redds newly constructed since the previous survey and the cumulative number of redds to date. To aid the observers in differentiation of new redds from those counted on previous visits, a flag was hung in nearby vegetation and descriptors of redd location in relation to the flag were recorded (distance from bank; distance up or downstream from flag location). Chamberlain et al. (2012) used encounters with spawned female salmon carcasses to model spatiotemporal distribution of Chinook salmon (hatchery and natural origin) proportions and applied those to observed redds. A multiplier was used to account for differential rates of redd construction between the Chinook (1 redd per female) and coho (1.25 redds per female) salmon carcasses recovered in the survey. The specific details of the spatiotemporal-distribution modeling methods used to evaluate the mean distance from Lewiston Dam of redds constructed by natural-origin spawners from 2002 to 2011 can be found in Chamberlain et al. (2012).

1.1.5 Changes in Juvenile Chinook and Coho Salmon Rearing Habitat

The Program Partners hypothesized that Phase 1 actions will lead to increases in Chinook salmon and coho salmon rearing habitat area at rehabilitation sites and across the 64-kilometer (km) restoration reach. Although the maximum change in rearing habitat area was expected to occur at channel rehabilitation sites, the Program Partners also expected that the restoration strategy would create synergistic effects and improve habitat throughout the restoration reach immediately after construction. They anticipated that these effects would also occur through time as a result of high-flow events, riparian development, and large wood recruitment. The magnitude of change was expected to vary with specific rehabilitation site designs. The overall habitat objective according to the IAP (TRRP and ESSA 2009) is to “increase/maintain salmonid fry and juvenile rearing habitat in the upper 64 km (40 miles) of the mainstem Trinity River by a minimum of 400 percent following rehabilitation of fluvial attributes.”

To evaluate whether rearing habitat area changed over time, the Program Partners evaluated habitat in three ways. First, channel rehabilitation sites were assessed by measuring the quantity and quality of rearing habitat area before and after construction. Post-construction assessments generally began soon after construction and were repeated periodically to track changes at channel rehabilitation sites over time. The habitat mapping methods and criteria that were used are described in Goodman et al. (2010) and are summarized below. Rearing habitat criteria were divided into two fish developmental phases: fry (fish less than 50 millimeter [mm] fork length [FL]) and pre-smolt (fish greater than or equal to 50 mm FL). Optimal Chinook salmon rearing habitat for fry and pre-smolt included areas that simultaneously met depth, velocity, and distance-to-cover criteria. Suitable habitat included areas that met depth and velocity, or cover criteria, but not both. Total habitat included areas that met any combination of depth and velocity or cover criteria. Fry and pre-smolt coho salmon rearing habitat was limited to optimal habitat areas (i.e., all other areas were considered unsuitable).

Habitat parameters shown in Table 1-1 were measured within each sample site, geo-referenced, and processed into ArcGIS polygon shapefiles. Depth and mean water column velocity were measured using hand-held Price AA (JBS Energy) or Flow Tracker (Son Tek) flow meters on top of setting rods. Dominant in-water vegetation or wood escape cover was identified by visual estimate and delineated when present. Only habitat areas greater than or equal to 2 square meters (m^2; 22 square feet) were surveyed. GPS points were taken using a Trimble ProXH GPS receiver with a Zephyr antenna paired with a tablet PC. Spatial habitat data were analyzed in ArcMap (ESRI ver. 9.3) using the overlay toolset and Xtools Pro (Data East ver. 5.3) to calculate habitat polygon areas. The rearing habitat mapping provided a spatially explicit representation of rearing habitat areas within selected rehabilitation sites. River flows during rehabilitation site habitat assessment surveys were always at a low level and under conditions where a flow of 8.5 $m^3 \cdot s^{-1}$ (cubic meters per second; 300 cubic feet per second [cfs]) was released from Lewiston Dam from October to April each year. This level of flow was termed the “base flow,” which varied with the location of the rehabilitation project within the river system due to tributary accretion and flow conditions each year, and ranged from 8.3 $m^3 \cdot s^{-1}$ (293 cfs) to 20.3 $m^3 \cdot s^{-1}$ (717 cfs) in the main channel. Thus, investigators measured habitat under conditions where river flow was as similar as possible between the pre- and post-construction assessments.

Table 1-1
Guilds and Associated Habitat Criteria for Chinook and Coho Salmon Rearing Habitat Mapping

Habitat Guild	Variable	Criteria
Fry (<50 mm)	Depth	>0 to 0.61 m
	Mean water column velocity	0 to 0.15 m/sec
	Distance to cover	0 to 0.61 m
Pre-smolt (≥50 mm)	Depth	>0 to 1 m
	Mean water column velocity	0 to 0.24 m/sec
	Distance to cover	0 to 0.61 m

Source: Goodman et al. 2010

Second, to evaluate how rearing habitat area changed with river flow level, the quantity and quality of habitat at a subset of channel rehabilitation sites was assessed at various flows using the methods and criteria described above (Goodman et al. 2010).

Third, changes in the quantity and quality of rearing habitat area within the entire restoration reach were evaluated using a rotating panel revisit design (Table 1-2) as described in *Estimation of Age-0 Chinook and Coho Salmon Rearing Habitat Area at 12.7 cms within the Restoration Reach of the Trinity River-Annual Report 2010* (Goodman et al. In Review). For this approach, the sample universe was defined as the restoration reach. Units were selected using the generalized random tessellation stratified (GRTS) sample unit selection protocol. The rotating panel design comprises five panels with 16 GRTS sample sites within each panel. Two panels were sampled within each year, which represents 20% of the restoration reach. In the following year of sampling, one of the panels is repeated and one new panel is added until all five panels are sampled. In the fifth year, the first panel is sampled again and the pattern continues. The five panels make up 50% of the sample universe. By applying this study design annually, the synergistic effects of restoration actions could be documented. This documentation is expected to improve the understanding of how the Trinity River responds to specific management actions, such as any differential effects of stream flow allocations. Habitat area estimates for each site were developed for each life stage and habitat category under flow conditions associated with a release of 12.7 $m^3 \cdot s^{-1}$ (450 cfs) from Lewiston Dam using the methods and criteria described above (Goodman et al. 2010). Estimates for the entire restoration reach were developed by multiplying the mean value of the sample by the number of GRTS sample units in the restoration reach. Sample error was calculated using a neighborhood variance estimator and the resulting estimates were compared across years.

Table 1-2
The Rotating Panel Revisit Sampling Design for the Chinook and Coho Rearing Habitat Assessment

Panel	Year				
	2009	2010	2011	2012	2013
1	X				X
2	X	X			
3		X	X		
4			X	X	
5				X	X

Source: Alvarez et al. 2011

1.1.6 Change in Fine Sediment Storage in the Restoration Reach

Low flow in the mainstem Trinity River following construction of Lewiston and Trinity dams allowed large quantities of fine bed material (defined in the ROD as particles less than about 8 mm [5/16 inch] in diameter) to accumulate in the channel and along the banks. These fine sediments degrade aquatic habitat by reducing substrate permeability and by berm deposition that leads to formation of simple rectangular channel geometry (Wilcock et al. 1995).

The Program Partners hypothesized that decreasing fine bed material storage in the Trinity River would increase spawning gravel quality and decrease berm formation. Reducing the supply and storage of fine bed material in the mainstem Trinity River is among the primary objectives of the ROD flow regime and of watershed rehabilitation efforts undertaken by the Program. Related objectives from the IAP include the following:

- 1.4.1. Transport fine sediment through mainstem at a rate greater than tributary input
- 1.4.2. Reduce fine sediment supply from tributary watersheds

The objective of the Program is to decrease fine bed material equivalent to the quantity of material stored in riparian berms and the channel (USFWS and HVT 1999; USDOI 2000; TRRP and ESSA 2009). Fine bed material storage in a particular area over a particular time period is calculated according to Equation 1-2:

$$\Delta S_y = I_y + E_y \tag{1-2}$$

where:
ΔS_y = fine bed material storage

I_y = total amount of fine bed material that enters area I
E_y = total amount of fine bed material exported from the same area

The approach is described in more detail in the 2009 and 2010 sediment budget reports (Wilcock 2010; Gaeuman and Krause 2011).

Monitoring to assess changes in fine bed material storage and transport is conducted at the following mainstem sediment sampling sites located in the first 32.2 RKMs (20 river miles [RMs]) below Lewiston Dam:

- Trinity River at Lewiston
- Trinity River at Lowden Meadows
- Trinity River at Limekiln Gulch
- Trinity River at Douglas City

Monitoring of fine bed material at these sites makes use of the same bedload transport measurements needed for coarse sediment monitoring, plus concurrent sampling of the suspended load. The total fine bed material load is equal to the sum of the fine fraction of the bedload and the fraction of the suspended load greater than 0.5 mm in diameter. Suspended sediment less than 0.5 mm diameter is considered wash load in the Trinity River.

1.1.7 Change in Coarse Sediment Storage in the Restoration Reach

Trinity and Lewiston dams trap sediment delivered from the upstream watershed, reducing the supply of mobile coarse sediment to the mainstem Trinity River downstream of Lewiston Dam. The lack of coarse sediment supply to the mainstem Trinity River downstream of Lewiston Dam results in armoring of the bed surface and a deficit of sediment that would otherwise build bars and maintain aquatic habitat features. Downstream of Indian Creek, the reduction in coarse sediment attributable to reservoir trapping rapidly diminishes due to the cumulative coarse sediment supply from Indian, Weaver, Reading, and Browns creeks.

The Program Partners hypothesized that increasing coarse sediment storage in the Trinity River will result in increased bar amplitude and channel complexity. Increasing coarse sediment storage to pre-dam levels upstream from Indian Creek is an objective discussed in the flow study (USFWS and HVT 1999) and in the ROD (USDOI 2000). The following objectives were specified in the IAP (TRRP and ESSA 2009):

- Objective 1: Create and maintain spatially complex channel morphology

- Sub-objective 1.1: Increase physical habitat diversity and availability
- Sub-objective 1.2: Increase coarse sediment transport and channel dynamics
- Sub-objective 1.3: Increase and maintain coarse sediment storage

The performance measure related to sub-objectives 1.1 and 1.2 tracks changes in the supply of coarse sediment in response to flow and sediment management activities. The goal of the Program is to restore the movement of sediment, increase coarse sediment storage, and reestablish a balanced coarse sediment budget downstream of Lewiston Dam to Indian Creek by adding coarse sediment to the river at a rate approximately equal to the long-term transport rates of the ROD flow regime. Monitoring to assess sediment transport and coarse sediment storage changes is conducted at the same four mainstem sediment sampling sites discussed in Section 1.1.6 for fine sediment storage, located in the first 32.2 RKMs downstream from Lewiston Dam.

This section of mainstem river is subdivided into four sediment budget cells bounded by coarse sediment sampling sites and by Lewiston Dam. Coarse sediment storage is computed based on measurements of coarse sediment transport rates and loads at the four monitoring locations (Wilcock 2010). The sediment budget for each cell incorporates measured mainstem bedload fluxes, coarse sediment augmentation, and estimated bedload inputs from tributaries.

1.1.8 Volume of Water Released Annually for Restoration

The flow releases recommended by the ROD (USDOI 2000) are intended to accomplish a variety of objectives: promote fluvial process, control temperature, and improve habitat. More water is allocated for restoration releases in wet years than in dry years (Table 1-3).

Table 1-3
Restoration Release Water Volume Allocation

Predicted Water Year Type	Restoration Water Allocation (acre-feet)	Annual Probability of Occurrence (percent)
Extremely wet	815,000	12%
Wet	701,000	28%
Normal	647,000	20%
Dry	453,000	28%
Critically dry	369,000	12%

Source: USFWS and HVT 1999

The actual water year (WY) type is unknown when annual release schedules are planned and developed. An annual runoff forecast for the Trinity River is developed each year based on snow pack measurements and predictive modeling based on historical conditions and tributary inflows. The predictive models are used to determine the WY type for the Trinity River based on statistically averaged historical conditions from April 1 through September 30. Estimated tributary runoff is then added to the forecast to arrive at a forecast of the annual runoff at Lewiston, California, from October 1 through September 30 each year. The forecast is compared to threshold values to determine the forecasted WY type and the restoration release water volume associated with that WY type is planned for and implemented.

The Program Partners assume that annual WY predictions will occasionally inaccurately predict the actual WY experienced, but the total water volume allocated for restoration will balance out over time and meet the targets identified in Table 1-3. To provide an accounting metric that indicates whether actual restoration releases are in balance over time with the allocation targeted by the ROD (USDOI 2000), a measure was developed that tracks the actual releases of water compared to the water allocation predicted by the forecast each year. The measure is simply a water accounting metric and does not address how the actual flow releases performed in terms of achieving the Program's goals. The metric is termed the "restoration water volume ratio" and is calculated by dividing the restoration water volume released based on the forecasted WY type by the volume that should have been released based on the actual WY type that occurred each year. A value of 1.0 indicates that water releases are consistent with the targeted allocation for restoration, and values greater or less than 1.0 indicate that overall water releases are greater or less than the target allocation, respectively.

1.1.9 Temperature Targets

The Program Partners hypothesized that managing water temperature would increase habitat quality and improve salmonid production. The IAP (TRRP and ESSA 2009) states that flow volumes and timing are designed to address both habitat and temperature needs for all salmonid life stages. Water temperature is an especially important environmental factor that influences adult salmonid pre-spawn mortality.

Table 1-4 lists temperature targets identified in the ROD (USDOI 2000) for specific periods each year at temperature compliance points within the restoration reach, which include Douglas City (RKM 149.7; RM 93) and the North Fork (RKM 112.7; RM 70). The July 1 to September 15 target at Douglas City is for adult spring-run Chinook salmon summer holding. The September 15 to September 30 target at Douglas City is for spring-run Chinook salmon spawning. The

October 1 to December 31 target at the North Fork is for spring- and fall-run Chinook salmon, coho salmon, and steelhead spawning habitat.

Table 1-4

Trinity River Temperature Targets for Adults by Reach and Date

Target Reach	Dates	Temperature Target
Lewiston to Douglas City	July 1 to September 15	less than or equal to 60°F
Lewiston to Douglas City	September 15 to 30	less than or equal to 56°F
Lewiston to North Fork	October 1 to December 31	less than or equal to 56°F

Source: North Coast Regional Water Quality Control Board 1993

To evaluate whether temperature targets have been met, temperature data from gauges were accessed via the California Data Exchange Center. The mean temperature for each day was then compared to the target for that day. If daily mean temperature was below the target, the criteria was met, and if above, it was exceeded. Summing the number of days that the temperature exceeded the criteria for each period and dividing the product by the total number of days within the period calculated the proportion of time a criterion was met. To assess the relative magnitude of the exceedances, cumulative distributions of exceedances at Douglas City and North Fork Trinity River above threshold temperatures were plotted in 0.25° F increments and visually inspected.

1.1.10 Annual Estimates of Pre-spawn Mortality

This indicator estimates the incidence of pre-spawning mortality among Chinook salmon and coho salmon in the mainstem Trinity River. The Program Partners hypothesized that pre-spawn mortality rates will decrease as flow and habitat modifications are implemented and salmon spawning conditions improve.

Carcass and redd surveys have been conducted intermittently since 1955 by the California Department of Fish and Game, in cooperation with YTFP, HVTFD, and USFWS. The assessment methods are described in Sinnen et al. (2011) and summarized below. The mainstem Trinity River is surveyed annually from Lewiston Dam downstream to the Cedar Flat Recreational Area, and from Hawkins Bar to Weitchpec. The river reach from Cedar Flat to Hawkins Bar was not surveyed due to hazardous conditions. The study area was divided into 14 reaches, as described in Table 1-5. These reaches were surveyed between September and December each year on a weekly or biweekly basis. However, some reaches were excluded in some of the planned weekly samples due to logistical issues (i.e., extreme weather and high flows), and surveys were conducted during January in some years to encompass a greater proportion of coho salmon spawning.

Table 1-5
Mainstem Trinity River Spawner Survey Reach Descriptions

Reach ID	Start Location	End Location
1	Lewiston Dam (RKM 180.1)	Old Lewiston Bridge (RKM 176.9)
2	Old Lewiston Bridge (RKM 176.9)	Bucktail Launch (RKM 169.0)
3	Bucktail Launch (RKM 169.0)	Steel Bridge (RKM 158.8)
4	Steel Bridge (RKM 158.8)	Douglas City Campground (RKM 148.4)
5	Douglas City Campground (RKM 148.4)	Roundhouse Launch (RKM 132.7)
6	Roundhouse Launch (RKM 132.7)	Junction City Campground (RKM 125.5)
7	Junction City Campground (RKM 125.5)	North Fork Trinity Confluence (RKM 116.7)
8	North Fork Trinity Confluence (RKM 116.7)	Big Flat Launch (RKM 107.0)
9	Big Flat Launch (RKM 107.0)	Del Loma Access (RKM 92.2)
10	Del Loma Access (RKM 92.2)	Cedar Flat Recreation Area (RKM 78.5)
11	Cedar Flat Recreation Area (RKM 78.5)	Hawkins Bar (RKM 64.1)
12	Hawkins Bar (RKM 64.1)	Camp Kimtu (Willow Creek, RKM 41.7)
13	Camp Kimtu (Willow Creek, RKM 41.7)	Rolands Bar (RKM 20.3)
14	Rolands Bar (RKM 20.3)	Weitchpec (Trinity mouth RKM 0)

Source: Sinnen et al. 2011

Carcasses encountered during surveys were rated as follows to describe the degree of decomposition:

- Condition-1 was a carcass with at least one clear eye
- Condition-2 was a carcass where both eyes were cloudy
- Condition-3 denoted skeletal remains

Carcasses recovered during surveys were identified to species and gender, examined for hatchery clips and tags, and measured to the nearest centimeter in FL. Field crews examined all condition-1 and condition-2 female salmon for condition by a direct observation of their ovaries. Fish were classified as spawned if very few eggs had been retained, or un-spawned if a majority of eggs were retained. All condition-1 Chinook salmon carcasses were marked with a unique jaw tag and returned to moving water. All condition-2 and condition-3 carcasses were cut in half with a machete to prevent the fish from being recounted in subsequent surveys. The total numbers of Chinook and coho salmon females that had spawned and not spawned each year were summed and presented in a table along with the percent of females that had suffered pre-spawn mortality.

1.1.11 Proportion of Time that 80% of the Smolt Outmigration Passed the Willow Creek Trap by the Target Dates

The target dates for at least 80% emigration at Weitchpec are July 9 for Chinook salmon, June 4 for coho salmon, and May 22 for steelhead (USFWS and HVT 1999). The number of times that 80% of the smolt outmigration passed the nearest sampling point to Weitchpec, the Willow Creek trap, by the target dates each year was derived from weekly abundance indices for each age class of Chinook salmon, coho salmon, and steelhead for the 2001 to 2008 period. The methods used to derive weekly abundance indices, including trapping, biological sampling, and hatchery- and natural-origin estimates, are described in detail in *Juvenile Salmonid Monitoring on the Mainstem Trinity River at Willow Creek, California, 2001-2005* (Pinnix et al. 2007), *Juvenile Salmonid Monitoring on the Mainstem Trinity River at Willow Creek, California, 2006-2007* (Pinnix and Quinn 2009), and *Juvenile Salmonid Monitoring on the Mainstem Trinity River at Willow Creek, California, 2008* (Pinnix et al. 2010). The Program Partners could conduct similar trend analyses using data available on the estimated timing of juvenile Chinook salmon at the Pear Tree Trap site located just upstream from the mouth of the North Fork Trinity River.

To derive the percentage of salmonids that emigrated past the Willow Creek trap by July 9 (Chinook salmon), June 4 (coho salmon), and May 22 (steelhead) each year, the weekly abundance indices for natural-origin age-0 Chinook salmon and steelhead, and age-1+ coho salmon and steelhead, were summed between the first Julian Week (JW) that sampling occurred and either JW 27 (July 2 through July 8) for Chinook salmon, JW 22 (May 28 through June 3) for coho salmon, or JW 20 (May 14 through May 20) for steelhead. Note that the Trinity River Flow Evaluation Report sets the target date at May 22 for the emigration of 80% of steelhead juveniles; however, May 22 is the second day of JW 21. Therefore, for the steelhead analysis, the abundance indices were summed through the end of JW 20 (i.e., May 20). The abundance index totals through JW 27, JW 22, and JW 20 were then divided by the overall abundance index totals (excluding data collected in the fall [i.e., after August] between 2002 and 2004) for the sampling season to estimate the percentage of smolts that emigrated past the Willow Creek trap by the target dates each year. The percentage was then simply compared to the 80% target to determine if the target was achieved. The percentages were not adjusted for environmental conditions that could affect trap capture probability such as river flow and water temperature, other than the daily catch at the trap being expanded by the proportion of discharge sampled at the trap to estimate daily abundance indices (Index_{DC}), as described above.

2 RESULTS

2.1 Analysis of the Program's Performance Measures

The Program Partners considered the 2011 data reported here to be preliminary and subject to change, and typically did not use the 2011 data in their most recent statistical analyses. However, because the methods used to develop the performance measures have been applied consistently over time, it was assumed that any changes to the preliminary 2011 data would be small. Therefore, these data were included in our trend assessments because they provided the most recent data for informing trend within the short performance period.

2.1.1 Spawning Escapement of Naturally Produced Salmonids

Estimated escapement of naturally produced salmonids was variable for all species from 1992 to 2011 (Figures 2-1 through 2-4). Escapement of natural-origin fall-run Chinook salmon was consistently below the 62,000-fish goal throughout the 1992 to 2011 period. Escapement of natural-origin spring-run Chinook salmon reached or exceeded the 6,000-fish goal in 9 of the 19 years data were available during the 1996 to 2011 period. Escapement of natural-origin coho salmon reached or exceeded the 1,400-fish goal in 8 of 15 years during the 1997 to 2011 period. Escapement of natural-origin steelhead was consistently below the 40,000-fish goal during the 15 years data were available from 1992 to 2011.

For natural-origin fall-run Chinook salmon, no detectable increase in escapement over the 1992 to 2010 period was observed based on least-square trend analysis. However, the number of fall-run Chinook salmon adults escaping into the Trinity River has increased substantially since 2004. Results of least-square trend analysis indicated no statistically significant trend during the 1992 to 2002 pre-treatment period (slope = -220; 95% CI = -1,833 to 3,150; P = 0.879)[1]. However, there was a statistically significant, positive trend during the 2003 to 2011 treatment period (slope = 3,971; 95% CI = 1,699 to 6,415; P = 0.017). This means that on average, fall-run Chinook salmon escapement increased about 4,000 fish per year during this treatment period. Results of least-square trend analysis of the 1992 to 2003 pre-treatment and 2004 to 2011 treatment periods were similar. On average, fall-run Chinook salmon escapement increased by approximately 4,000 or 4,800 fish per year, depending on the treatment period selected.

For natural-origin spring-run Chinook salmon, no detectable increase in escapement over the 1992 to 2010 period was observed based on trend analysis. However, the number of spring-run Chinook salmon adults escaping into the Trinity River has increased substantially since 2005.

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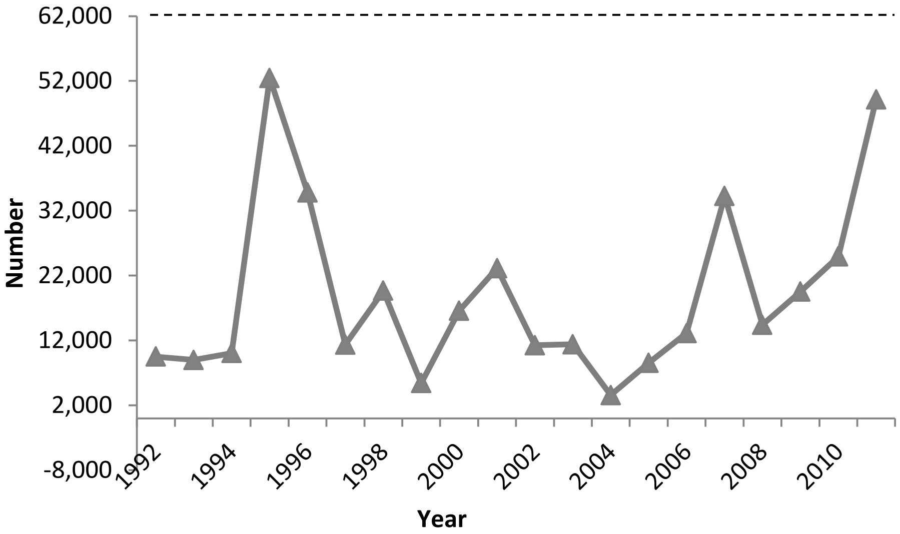
[1] Confidence intervals (CI) on the slope were based on 5,000 bootstrap samples.

Results of least-square trend analysis indicated no statistically significant trend during the 1992 to 2002 pre-treatment period (slope = 690; 95% CI = 218 to 1,406; P = 0.058). Likewise, there was no statistically significant trend during the 2003 to 2011 treatment period (slope = -217; 95% CI = -1,437 to 1,172; P = 0.679). In contrast, results of least-square trend analysis of the 1992 to 2003 pre-treatment indicated a statistically significant, positive trend (slope = 846; 95% CI = 532 to 1,448; P = 0.017), but again there was no statistically significant trend during the 2004 to 2011 treatment period (slope = 580; 95% CI = 9 to 1,286; P = 0.067).

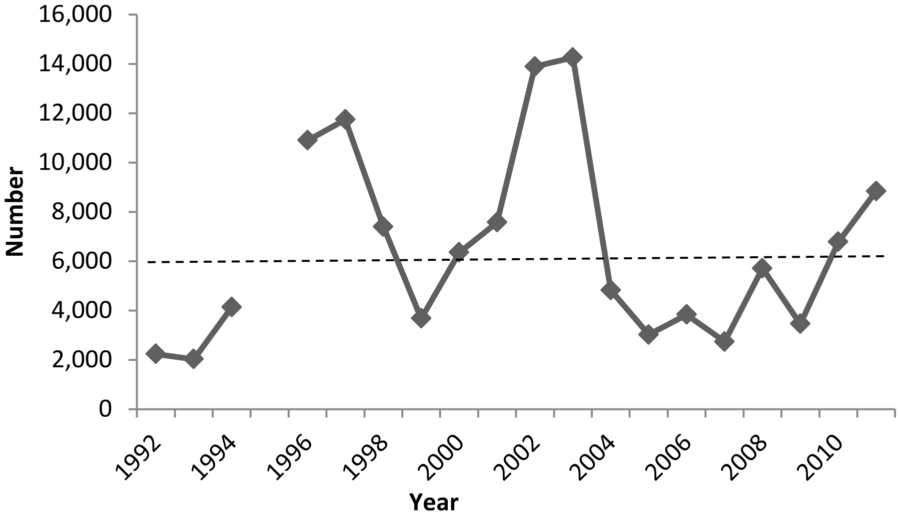
For natural-origin coho salmon, no statistically significant trend in escapement was observed over the 1997 to 2010 period, and escapement levels have been essentially flat since 2006. Results of least-square trend analysis indicated no statistically significant trend during the 1992 to 2002 pre-treatment period (slope = 201; 95% CI = -404 to 560; P = 0.496). There was a statistically significant negative trend during the 2003 to 2011 treatment period (slope = -653; 95% CI = -1,176 to 54; P = 0.044), indicating that on average, escapement decreased by approximately 650 fish each year from 2003 to 2011. Results of least-square trend analysis of the 1992 to 2003 pre-treatment period were similar to the 1992 to 2002 period (no trend). However, results from analysis of the 2004 to 2011 treatment period indicated no statistically significant trend in coho escapement (slope = -775; 95% CI = -1,514 to 111; P = 0.058). This contrasts with results from the 1992 to 2002 pre-treatment period, where least-square trend analysis indicated no statistically significant trend.

For natural fall-run steelhead, results of least-squares regression indicated that the trend in escapement during the 1992 to 2010 period was positive and significant (r^2 = 0.82; P = 0.001). There were insufficient continuous data to assess trend during the pretreatment period. Data were sufficient to assess trend during the treatment period; however, no statistically significant trend was observed during the 1992 to 2002 pre-treatment period (slope = 151; 95% CI = -199 to 808; P = 0.549). Results of least-square trend analysis of the 1992 to 2003 pre-treatment and 2004 to 2011 treatment periods were similar, where again the data were insufficient to assess trend during the pre-treatment period and no trend was observed during the treatment period.



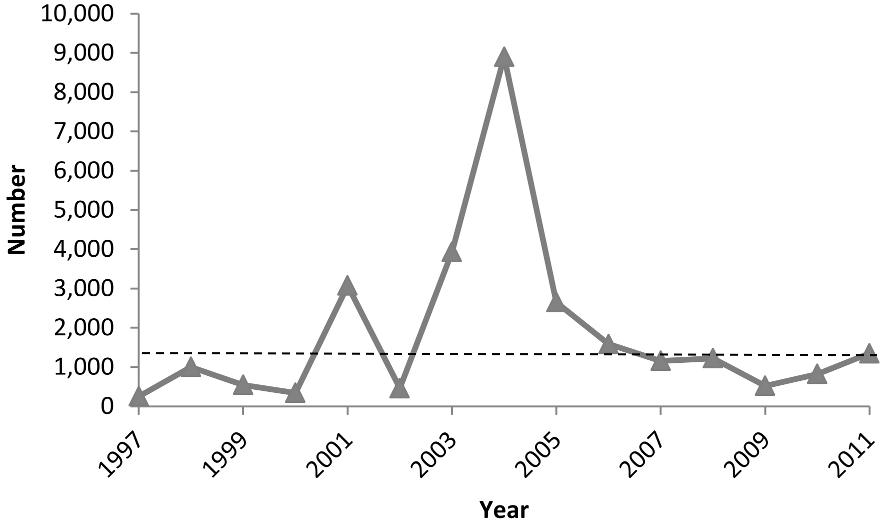
Note: The dashed line represents Program escapement goals.
Source: Trinity River Restoration Program Performance Measure: Spawning Escapement of Naturally Produced Salmonids (http://www.trrp.net/)

Figure 2-1
Escapement of Natural-origin Fall-run Chinook Salmon in the Trinity River from 1992 to 2011



Note: The dashed line represents Program escapement goals.
Source: Trinity River Restoration Program Performance Measure: Spawning Escapement of Naturally Produced Salmonids (http://www.trrp.net/)

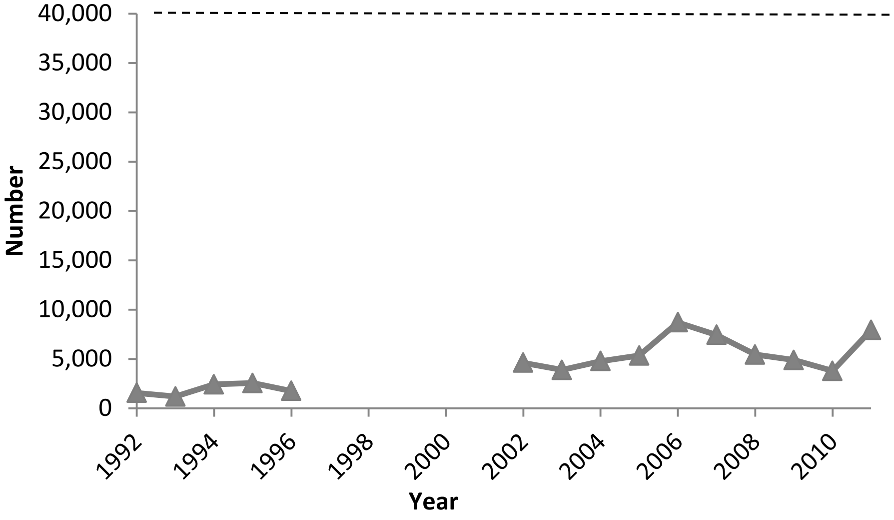
Figure 2-2
Escapement of Natural-origin Spring-run Chinook Salmon in the Trinity River from 1992 to 2011



Note: The dashed line represents Program escapement goals.
Source: Trinity River Restoration Program Performance Measure: Spawning Escapement of Naturally Produced Salmonids (http://www.trrp.net/)

Figure 2-3

Escapement of Natural-origin Coho Salmon in the Trinity River from 1997 to 2011



Note: The dashed line represents Program escapement goals.
Source: Trinity River Restoration Program Performance Measure: Spawning Escapement of Naturally Produced Salmonids (http://www.trrp.net/)

Figure 2-4

Escapement of Natural-origin Fall-run Steelhead in the Trinity River from 1992 to 2011

In summary, over the entire 1992 to 2010 period, results of trend analysis indicate that natural fall-run steelhead escapement increased significantly throughout the period although escapement remains well below the Program goal of 40,000 fish. There was no statistically significant trend in escapement of fall- and spring-run Chinook salmon during this period, or for coho salmon during the 1997 to 2010 period. Escapement of fall-run Chinook salmon remains well below the Program goal of 62,000 fish.

The escapement of spring-run Chinook salmon and coho salmon has been near or above Program goals since about 2001. However, for both spring- and fall-run Chinook salmon, spawning escapement began to increase coincident with implementation of Phase 1 channel rehabilitation restoration activities. Results of least-square trend analysis for natural-origin fall-run Chinook salmon indicated the trend in spawning escapement was statistically significant and positive during the 2003 to 2011 and 2004 to 2011 treatment periods. The Program Partners' hypothesis that Program flows and habitat modifications will increase the escapement of naturally produced adult salmon over time is supported by the increase in natural fall-run steelhead escapement observed during the 1992 to 2010 period and natural-origin fall-run Chinook salmon escapement observed during the 2003 to 2011 treatment period. The negative trend in natural-origin coho salmon escapement observed during the 2003 to 2011 treatment period is not consistent with this hypothesis.

The additional least-squares trend analyses points to trends being sensitive to the date ranges chosen for the analysis. For this reason, we reported trends associated with time periods that assumed both 2- and 3-year lags in adult returns. It suggests that these types of analyses should be continued in the future as the time series of data is extended, and that additional modeling approaches to data analysis should be considered.

Because the performance measures identified in this document are generally collected or estimated annually, it is appropriate to analyze the measures as a time series process. In this case, the Program represents a treatment or intervention. That is, the Program divides the time series into two segments: one consisting of all pre-treatment observations and one consisting of all treatment observations. The null hypothesis is that the level of the series before the treatment (b_{pre}) is the same as the level of the series during/after the treatment (b_{post}), or:

$$H_o: b_{pre} - b_{post} = 0 \qquad (2\text{-}1)$$

The hypothesis is tested by first empirically modeling serial dependence as a time series process using Auto Regressive Integrated Moving Average (ARIMA) models. After building the

ARIMA model, an intervention term (I_t) is added and the ARIMA equation becomes a noise component (N_t) (McDowall et al. 1980):

$$Y_t = f(I_t) + N_t \tag{2-2}$$

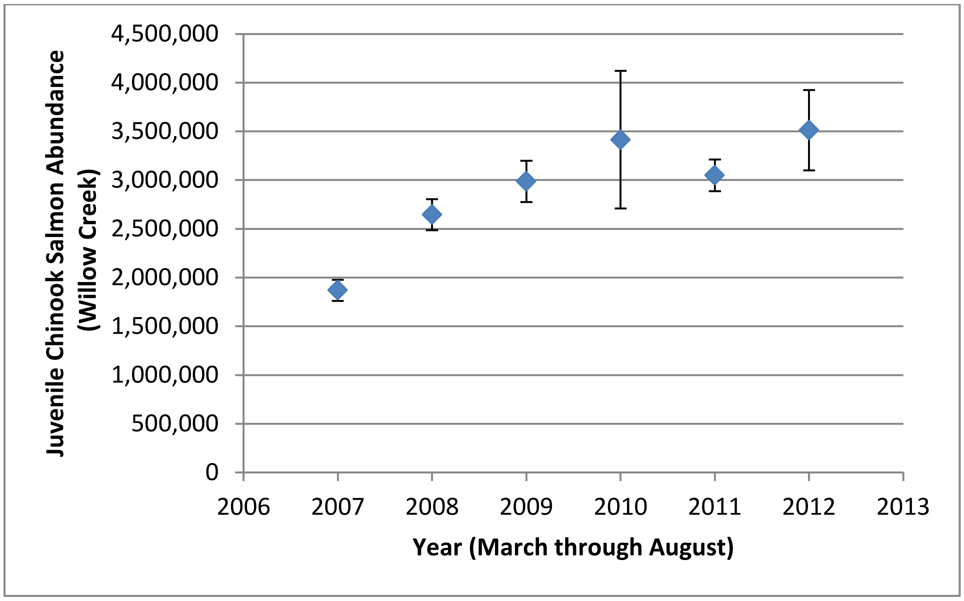
That is, the Y_t time series is composed of noise (errors) plus intervention. The $f(I_t)$ component can be modeled to correspond to several distinct types of treatments. For example, a treatment on the time series may be either abrupt (e.g., flow changes, addition of spawning gravels, reconnection of side channels, etc.) or gradual (e.g., restoration of riparian habitat) in onset and either permanent or temporary in duration. Because the Program is intended to create permanent effects, the intervention component can be modeled as abrupt-permanent or gradual-permanent effects. Although a t-test can be used to evaluate the significance of the estimated I_t parameter, it is also important to calculate the magnitude of the difference and its precision. This is used to determine if the treatment affected the performance measure.

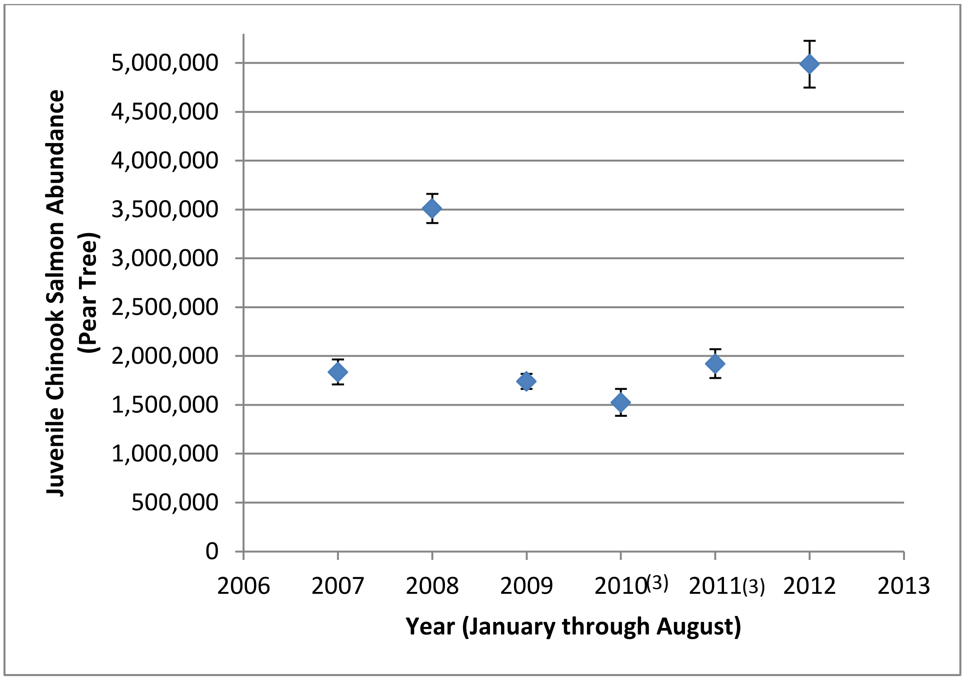
Although interrupted time series analysis is an appropriate method for analyzing the effects of the Program, the analysis requires many observations with no missing data. In some cases, at least 40 observations are needed to fit ARIMA models to the data. Currently, the performance measures identified in this report do not have a long enough data series to adequately model with ARIMA models. Because the Program represents a continuous process (rather than a discrete event), it may be necessary to fit multivariate ARIMA models to the data (*sensu* McCleary and Hay 1980).

2.1.2 Abundance of Natural-origin Juvenile (Age-0) Chinook Salmon

The overall trend in abundance of natural-origin juvenile (age-0) Chinook salmon at the Willow Creek rotary screw trap increased steadily from 2007 to 2010 and remained relatively flat between 2010 and 2012 (Figure 2-5 top). Abundance at the Pear Tree rotary screw trap increased between 2007 and 2008, declined to near the 2007 level starting in 2009 and remained fairly constant at the 2007 level between 2009 and 2011, and increased substantially in 2012 (Figure 2-5 bottom). However, inconsistencies in hatchery population estimates between Pear Tree and Willow Creek traps in 2010 and 2011 are being reviewed by the Program Partners and may result in a future correction of natural origin estimates for these 2 years (Pinnix 2014). The trends shown in Figure 2-5 will need to be updated once data inconsistencies for these 2 years are resolved.

The Program Partners plan to conduct additional analyses to assess whether juvenile Chinook salmon abundance is indeed increasing after accounting for variation in trapping effort from year to year and when the magnitude of the spawning population that produced the outmigrants, as well as habitat availability and temperature regimes experienced during rearing, have been incorporated into the analyses.





Notes:

1. Error bars represent standard deviation.
2. Trapping effort varied from year to year and this variation has not been accounted for in the figure.
3. There are potential corrections needed for 2010 and 2011 data that are currently being explored by the Program Partners.
4. Data are from Pinnix et al. 2010; Harris et al. 2012; Petros et al. 2013; Pinnix et al. 2013; and Davids et al. 2013.
5. The 2007 estimate for Willow Creek and the 2007 and 2008 estimates for Pear Tree calculated using the Bayesian time-stratified spline-based method recommended by Schwarz et. al. 2009 were provided to Elizabeth Appy (Anchor QEA) by Bill Pinnix (USFWS) on March 5, 2014 and by Paul Petros (HVT) on March 10, 2014, respectively.

Figure 2-5

2007 – 2012 Estimates of Abundance of Natural-origin Juvenile (Age-0) Chinook Salmon from the Willow Creek Rotary Screw Trap, March through August, (Top) and the Pear Tree Rotary Screw Trap, January through August (Bottom)

2.1.3 Proportion of Natural-origin Adult Salmon

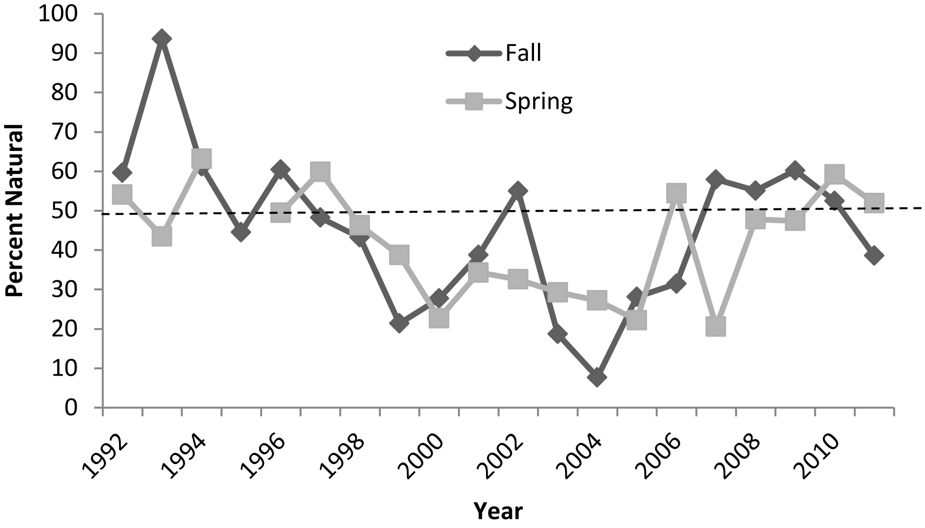
The proportion of natural-origin adult Chinook salmon, coho salmon, and steelhead contributing to the total in-river run varied from 1992 to 2011 (Figures 2-6 and 2-7). For fall- and spring-run Chinook salmon, the proportion of natural-origin fish returning to spawn declined from 1992 through 2004 (fall-run Chinook salmon) and 2005 (spring-run Chinook salmon), and then increased through 2010. The proportion of natural-origin fall- and spring-run Chinook salmon was near 50% in 4 or 5 of the past 6 years, and then decreased slightly in 2011. Results of least-square trend analysis indicated that for fall-run Chinook salmon there was a statistically significant, negative trend in the proportion of natural-origin spawners during the pre-treatment period (slope = -3.7; 95% CI = -6.6 to 0.6; P = 0.037). This indicates that the proportion of natural-origin spawners decreased about 4% per year during the pre-treatment period. In contrast, there was a statistically significant, positive trend during the treatment period (slope = 5.4; 95% CI = 0.6 to 9.3; P = 0.019), indicating that the proportion of natural-origin fall-run Chinook salmon increased over time during the treatment period by approximately 5% each year. Results of least-square trend analysis of the 1992 to 2003 pre-treatment were similar, where the proportion of natural-origin spawners decreased about 4% per year. However, results from analysis of the 2004 to 2011 treatment period indicated no statistically significant trend in the proportion of natural-origin fall-run Chinook salmon (slope = 5.418; 95% CI = -0.6 to 12.1; P = 0.055). This contrasts with results from the 2003 to 2011 treatment period, where least-square trend analysis indicated there was a statistically significant, positive trend during the period.

For spring-run Chinook salmon, there was a statistically significant, negative trend in the proportion of natural origin spawners during the pre-treatment period (slope = -2.8; 95% CI = -4.3 to -0.6; P = 0.011). In contrast, there was a statistically significant, positive trend during the treatment period (slope = 3.8; 95% CI = 1.4 to 5.8; P = 0.036), indicating that the proportion of natural-origin Chinook salmon increased over time during the treatment period by approximately 4% each year. These data generally support the hypothesis that Phase 1 activities will increase the production of natural-origin Chinook salmon over time. Results of least-square trend analysis of the 1992 to 2003 pre-treatment period were similar (a statistically significant negative trend in the proportion of natural origin spawners during the pre-treatment period). Results from analysis of the 2004 to 2011 treatment period indicated no statistically significant trend in the proportion of natural-origin spring-run Chinook salmon (slope = 4.3; 95% CI = 1.2 to 7.9; P = 0.061). This contrasts with results from the 2003 to 2011 treatment period, where least-square trend analysis indicated there was a statistically significant, positive trend during the period.

For coho salmon and steelhead, the proportion of natural-origin fish returning to spawn has been relatively constant since 1997 for coho salmon and since 2002 for steelhead, and averaged 13% and 36% during these periods, respectively. Results of least-square trend analysis indicated that for coho salmon, there was no statistically significant trend in the proportion of natural-origin spawners during the pretreatment period (slope = -1.5; 95% CI = -3.1 to 0.1; P = 0.138) or treatment period (slope = -0.3; 95% CI = -2.1 to 1.7; P = 0.770). Results of least-square trend analysis of the 1992 to 2003 pre-treatment and 2004 to 2011 treatment periods were similar.

For steelhead, there were not enough data to assess trend during the pretreatment period, and there was no statistically significant trend in the proportion of natural-origin spawners during the treatment period (slope = 0.5; 95% CI = -1.5 to 2.7; P = 0.712). Results of least-square trend analysis of the 1992 to 2003 pre-treatment and 2004 to 2011 treatment periods were similar. In general, these data do not support the hypothesis that Phase 1 activities will increase the production of natural-origin coho salmon and steelhead over time.

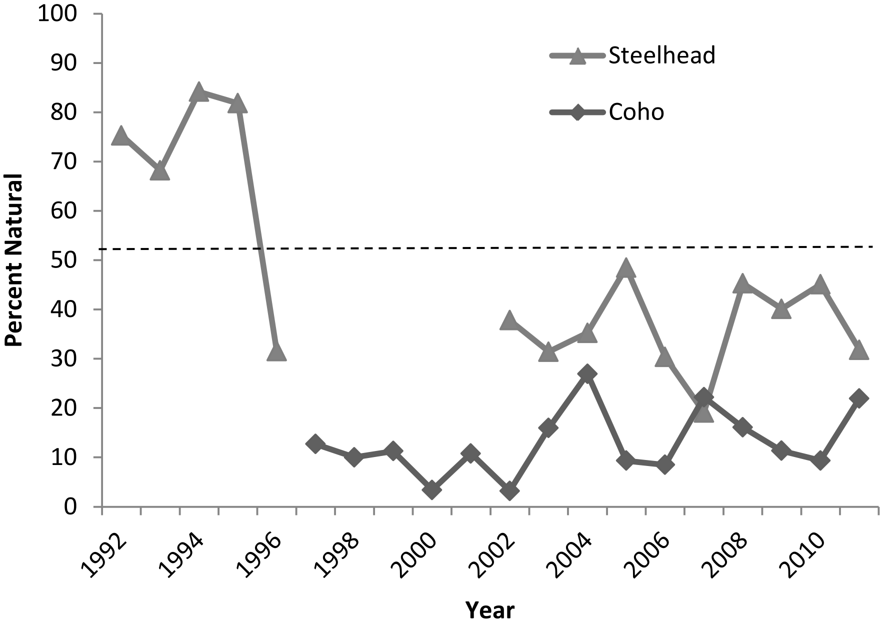
The different trends observed in the proportion of natural-origin fish escaping in recent years may have resulted from differences in habitat use preferences among species. Chinook salmon are mainstem spawners and are potentially more likely to have been influenced by Phase 1 actions than coho salmon and steelhead, which prefer to use tributary spawning habitat. Also, the additional least-squares trend analyses points to trends being sensitive to the date ranges chosen for the analysis. For this reason, we reported trends associated with time periods that assumed both 2- and 3-year lags in adult returns. It suggests that these types of analyses should be continued in the future as the time series of data is extended.



Note: The dashed line notes the 50th percentile, shown as a visual aid for the reader.
Source: Trinity River Restoration Program Performance Measure: Proportion of Natural Origin Salmonids Contributing to Total In-river Run (http://www.trrp.net/)

Figure 2-6

The Proportion of Natural-origin Adult Chinook Salmon Contributing to the Total In-river Run, 1992 to 2011



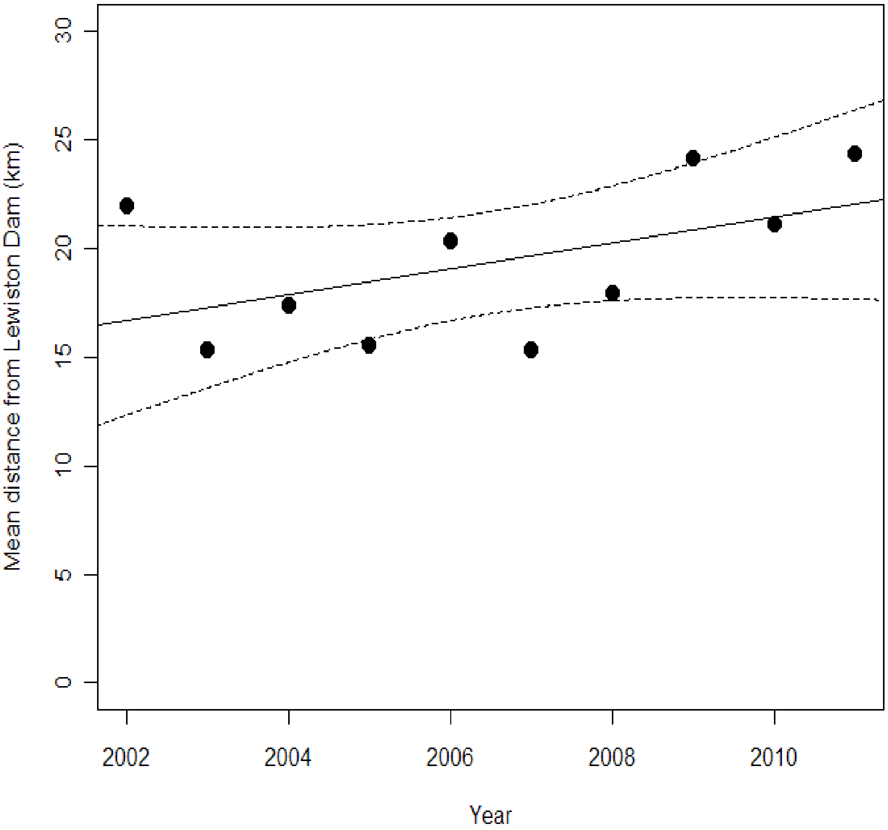
Note: The dashed line notes the 50th percentile, shown as a visual aid for the reader.
Source: Trinity River Restoration Program Performance Measure: Proportion of Natural Origin Salmonids Contributing to Total In-river Run (http://www.trrp.net/)

Figure 2-7

The Proportion of Natural-origin Adult Coho Salmon and Steelhead Contributing to the Total In-river Run, 1992 to 2011

2.1.4 Distribution of Natural-origin Chinook Salmon Spawners

The mean distance from Lewiston Dam of redds constructed by natural-origin spawners from Lewiston Dam to North Fork Trinity River shows a moderately positive, but not statistically significant, trend over the 2002 to 2011 period (r^2 = 0.17; P = 0.133; Chamberlain et al. 2012; Figure 2-8). Future analysis using additional time-series data will be required to determine whether any change in the mean distribution of natural-origin Chinook spawners is significant. At this point in the time series, these data do not support the hypothesis that reinitiating channel-forming processes in the Trinity River will shift the distribution of suitable habitat and salmon spawning downstream, but do suggest that such support may be forming. Given the short time frame physical processes have had to act on spawning habitat formation, the lack of a significant trend at this point in the time series is not unexpected.



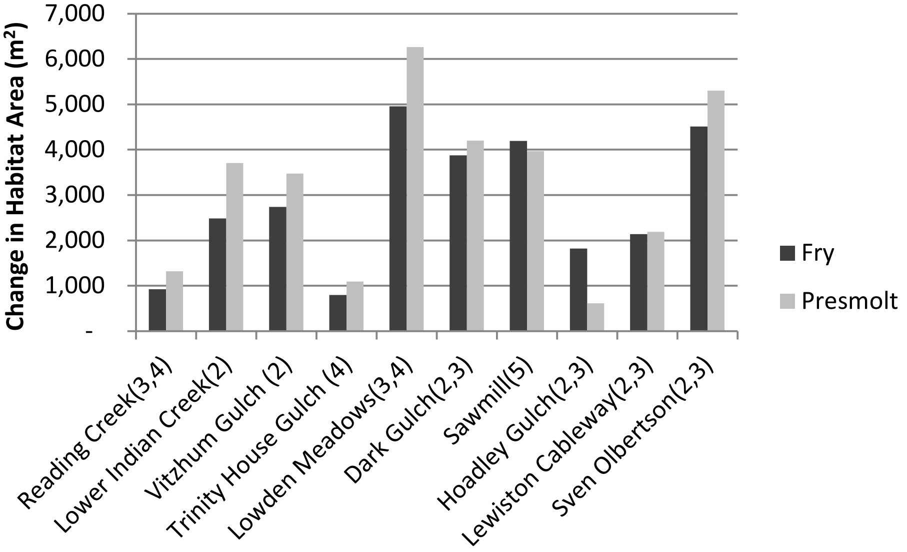
Notes: The solid line represents the trend between mean distance from Lewiston Dam and year, and dashed lines represent the 95% confidence limits.
Source: Trinity River Restoration Program Performance Measure: Distribution Natural-origin Chinook Salmon Spawners (http://www.trrp.net/)

Figure 2-8

Mean Distance from Lewiston Dam of Redds Constructed by Natural-origin Chinook Salmon Females

2.1.5 Changes in Juvenile Chinook and Coho Salmon Rearing Habitat

The change in estimated total fry and presmolt Chinook and coho salmon rearing habitat for 10 of the Phase 1 rehabilitation sites sampled to date is shown in Figure 2-9. Total rearing habitat area increased at all 10 sites after construction. Increases in fry and presmolt total habitat area ranged from approximately 800 to 5,000 m^2 and from 600 to 6,000 m^2, respectively, at base flows. Overall, the increase in total habitat area after rehabilitation site construction was consistent with the Program Partners' expectations that restoration actions will lead to immediate, site-specific increases in Chinook and coho salmon rearing habitat area.

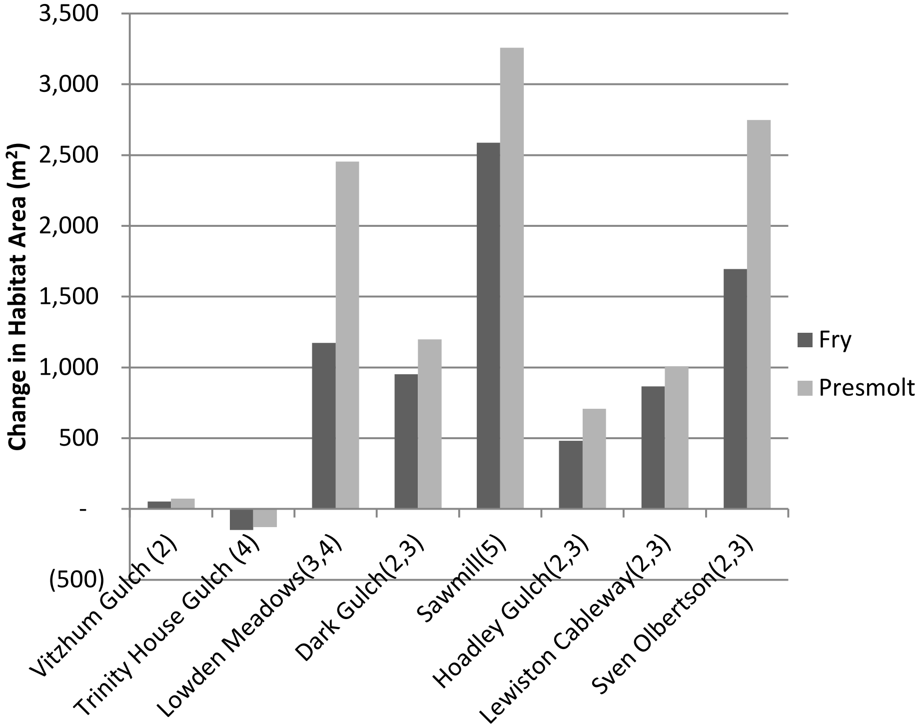


Notes: Data used to develop this figure were obtained from Goodman et al. 2010 (2), Alvarez et al. 2011 (3), preliminary data provided by Program Partners (4), and Martin et al. 2012 (5). All data were collected at base flow (8.6 m^3·s^{-1} [300 cfs]).

Figure 2-9

Change in Total Habitat Area for Juvenile Chinook and Coho Salmon at Restoration Sites from Pre- to Post-construction Condition at Base Flows

The change in estimated fry and presmolt Chinook salmon and coho salmon optimal rearing habitat area at base flows could be estimated for eight Phase 1 rehabilitation sites (Figure 2-10). The change in optimal fry habitat area at these sites from pre- to post-construction ranged from a decrease of approximately 150 m^2 at Trinity House Gulch to an increase of approximately 2,600 m^2 at Sawmill. The change in optimal presmolt habitat area at these sites from pre- to post-construction ranged from a decrease of approximately 130 m^2 at Trinity House Gulch to an increase of approximately 3,300 m^2 at Sawmill. The amount of optimal fry or presmolt habitat at Vitzhum Gulch was essentially unchanged following construction. In general, the increase in optimal habitat area after rehabilitation site construction was consistent with the Program Partners' expectations that restoration actions will lead to immediate, site-specific increases in Chinook salmon and coho salmon rearing habitat area. The two exceptions to this general observation were Vitzhum Gulch and Trinity House Gulch.



Notes: Data used to develop this figure were obtained from Goodman et al. 2010 (2), Alvarez et al. 2011 (3), preliminary data provided by Program Partners (4), and Martin et al. 2012 (5). All data were collected at base flow (8.6 $m^3 \cdot s^{-1}$ [300 cfs]).

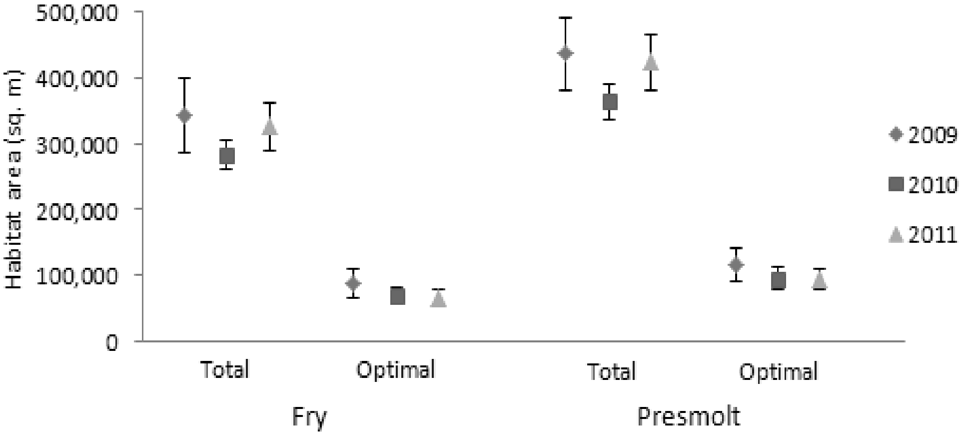
Figure 2-10

Change in Optimal Habitat Area for Juvenile Chinook and Coho Salmon at Restoration Sites from Pre- to Post-construction Condition at Base Flows

The changes in total and optimal habitat area shown in Figures 2-9 and 2-10 represent absolute values of change in area. However, we note there is a large variation in the scale of the various channel rehabilitation actions implemented to date. Therefore, future analyses that compare the amount of habitat formed among channel rehabilitation sites should be conducted with the data normalized by channel rehabilitation site scale (e.g., length), as reported in Martin et al. 2012.

Based on evaluations of system-wide responses to the rehabilitation projects, the area of estimated total and optimal fry and presmolt rearing habitat measured at flows associated with 12.7 $m^3 \cdot s^{-1}$ (450 cfs) being released from Lewiston Dam was unchanged during the 2009 to 2011 sampling period (Figure 2-11). Thus, these data do not provide support for the expectation that habitat area throughout the 64-km reach will increase through time as the Program is implemented.

Although no change in habitat area was detected from the 3 years of data, this was not unexpected given that the GRTS sampling design comprises a 5-year rotating panel. The Program Partners expect that the restoration strategy will create synergistic effects, increase habitat throughout the restoration reach immediately after construction and through time, and the increase will be detectable over time with the existing sampling regime.

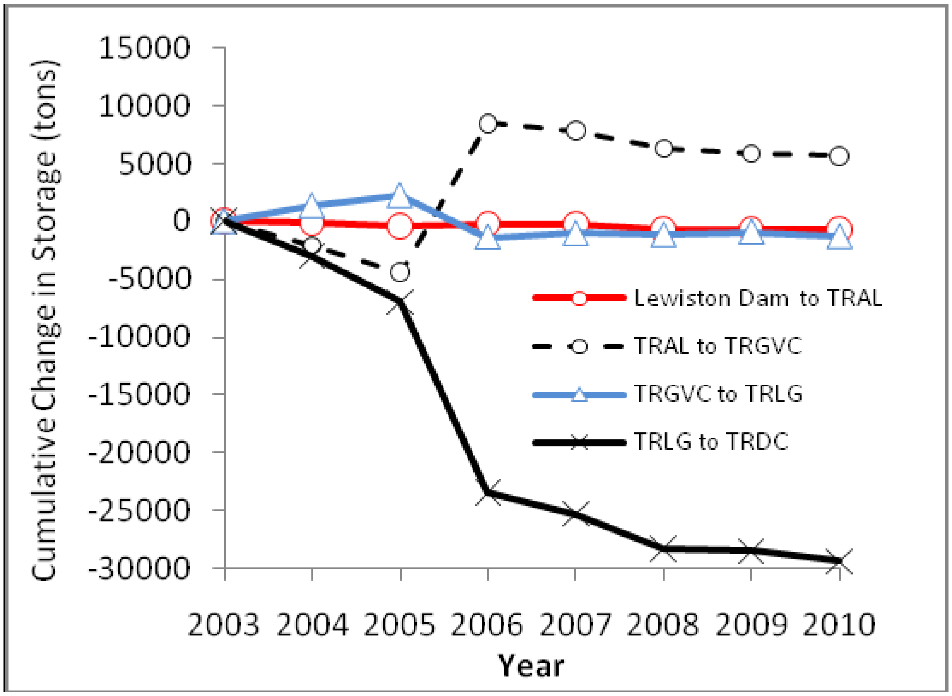


Notes: Error bars indicate a 95% confidence interval.
Source: Data and figure provided via personal communication from Damon Goodman (USFWS, Arcata, California) to Elizabeth Appy (Anchor QEA), May 30, 2013.

Figure 2-11
Total and Optimal Chinook and Coho Salmon Fry and Presmolt Rearing Habitat Available from 2009 to 2011 Under a Release of 12.7 $m^3 \cdot s^{-1}$ (450 cfs) from Lewiston Dam

2.1.6 Change in Fine Sediment Storage in the Restoration Reach

Fine bed material storage is decreasing through much of the Trinity River upstream of Reading Creek, and may be similar to pre-dam levels (Figure 2-12). Fine bed material inputs from tributaries are highly uncertain, however, and measurements of fine sediment storage throughout the mainstem channel (i.e., spawning gravels) are limited.



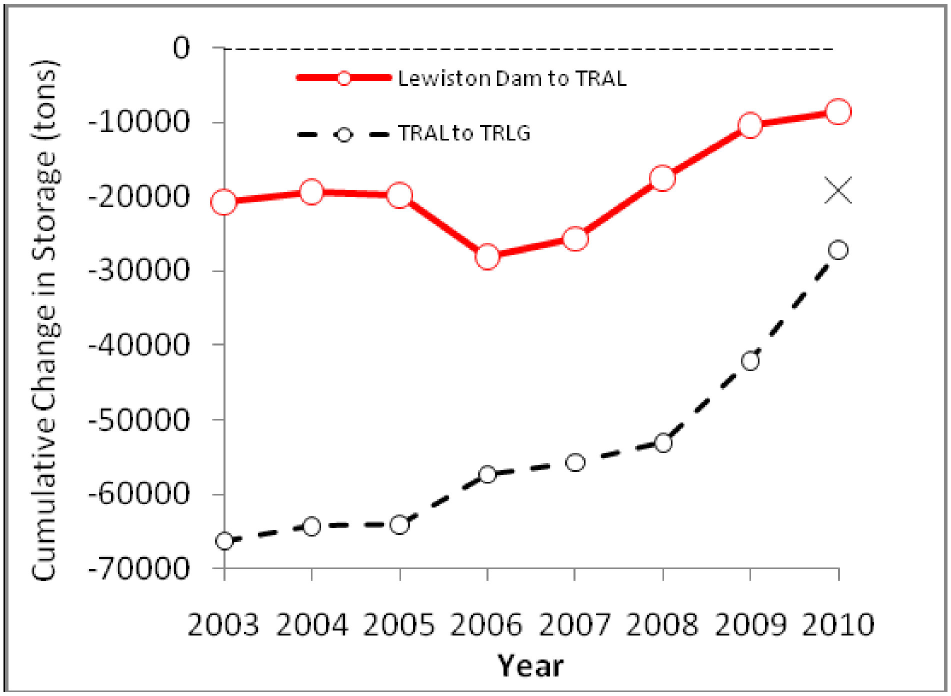
Notes:
A zero budget balance was assigned to WY 2003.
TRAL is the Trinity River at Lewiston, California.
TRGVC is the Trinity River above Grass Valley Creek.
TRLG is the Trinity River at Limekiln Gulch.
TRDC is the Trinity River at Douglas City.
Source: Trinity River Restoration Program Performance Measure: Change in Fine Sediment Storage (http://www.trrp.net/)

Figure 2-12

Cumulative Change in Fine Bed Material Storage for Water Years 2004 to 2010

2.1.7 Change in Coarse Sediment Storage in the Restoration Reach

Results of the 2010 bed-material sediment budget update (Gaeuman and Krause 2011) suggest that the coarse sediment deficit in the 20.9 RKM (13 RM) downstream from Lewiston Dam has been greatly reduced over the past decade (Figure 2-13). Cumulative changes in coarse sediment storage downstream from Lewiston Dam to Trinity River at Lewiston, from Trinity River at Lewiston to Trinity River above Grass Valley Creek, and from Trinity River above Grass Valley Creek to Trinity River at Limekiln Gulch increased, indicating increases in coarse sediment storage in these reaches. From Trinity River at Limekiln Gulch to Douglas City, no net increase in coarse sediment storage was observed (Gaeuman and Krause 2011). At present rates of input, the deficit indicated by the dashed line in Figure 2-13 should continue declining toward pre-dam coarse sediment storage levels. The movement of sediment into and out of reaches should balance over time once the coarse sediment deficit has been eliminated (Figure 2-14).

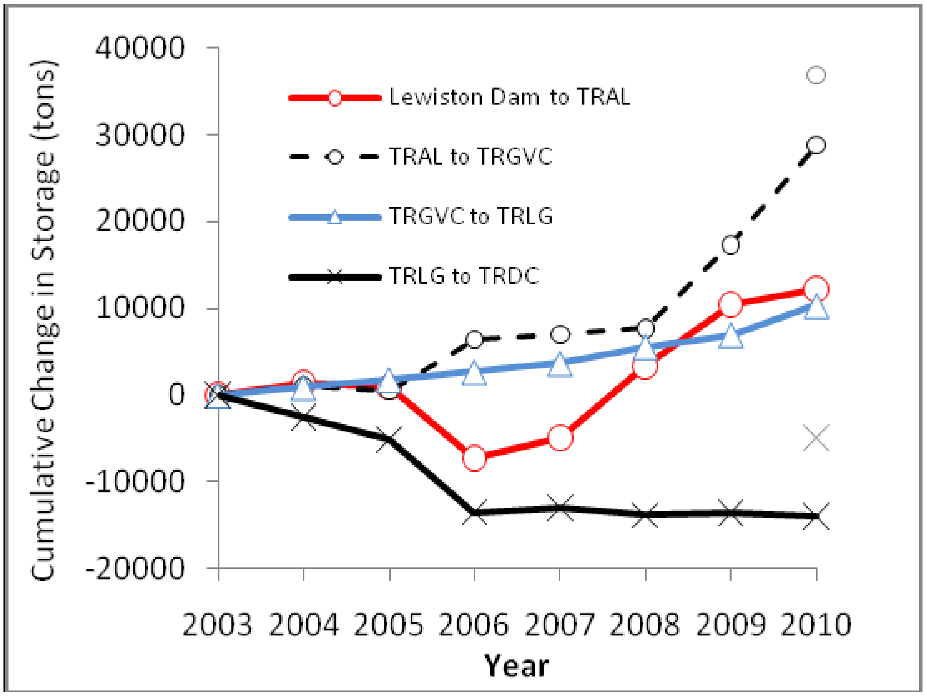


Notes: Data are presented for budget cell 1 (Lewiston Dam to Trinity River at Lewiston) and budget cells 2 and 3 combined (Trinity River at Lewiston to Trinity River at Limekiln Gulch), as of the end of WY 2010. The dashed line indicates the point at which the accumulated deficit in these reaches since dam closure is eliminated (Gaeuman and Krause 2011).

Source: Trinity River Restoration Program Performance Measure: Increase and Maintain Coarse Sediment Storage (http://www.trrp.net/)

Figure 2-13

Cumulative Change in Coarse Sediment Storage below Lewiston Dam since 2003



Notes:
A zero budget balance was assigned to WY 2003.
Cumulative change including fall 2010 construction placements (early WY 2011) in budget cells 2 and 4 (TRAL to TRGVC and TRLG to TRDC) are indicated with the solitary symbols.
Source: Trinity River Restoration Program Performance Measure: Increase and Maintain Coarse Sediment Storage (http://www.trrp.net/)

Figure 2-14

Cumulative Change in Coarse Sediment Storage by Budget Cell for Each Water Year, 2004 to 2010

2.1.8 Volume of Water Released Annually for Restoration

The forecasted WY was similar to the actual WY in 8 of 11 years (Table 2-1). In years where there was a difference, the actual WY was higher than that forecasted in 2005 and 2010, and lower than forecasted in 2008. The restoration water volume ratio averaged 0.943 from 2002 to 2011, which is less than the target value of 1.0. However, court-ordered restrictions from 2001 to 2004 resulted in a cumulative reduction of 563,000 acre-feet being released during that time period compared to ROD flow releases, which reduced the restoration water volume ratio to a level below the target value. Excluding the 2001 to 2004 period, the restoration water volume ratio averaged 1.025, indicating the target value was met during the 2005 to 2011 period. This is notable because the forecasted and actual WY types diverged in several years during the 2005 to 2011 period, as noted above. Overall, the assumption that the total water volume allocated for restoration each year will balance out over time and that the Program's water allocation targets will be met under the current implementation strategy appears valid under contemporary water management operations.

Table 2-1

Water Volume Accounting

Water Year	Forecast Water Year Type	Actual Water Year Type	Restoration Releases[1,2,3] (acre-feet)	Allocation based on Actual Water Year Type (acre-feet)	Volume Difference (acre-feet)
2001	Dry	Dry	379,600	453,000	(73,400)
2002	Normal	Normal	482,700	647,000	(164,300)
2003	Wet	Wet	448,100	701,000	(252,900)
2004	Wet	Wet	651,000	701,000	(50,000)
2005	Normal	Wet	647,600	701,000	(53,400)
2006	Extremely Wet	Extremely Wet	809,900	815,000	(5,100)
2007	Dry	Dry	453,700	453,000	700
2008	Normal	Dry	648,700	453,000	195,700
2009	Dry	Dry	445,500	453,000	(7,500)
2010	Normal	Wet	656,700	701,000	(44,300)
2011	Wet	Wet	721,800	701,000	20,800
Total for 2001 to 2011			6,345,300	6,779,000	(433,700)

Notes:

1. Restoration release volume based on average daily flow records for the Trinity River at Lewiston stream gage (#11525500) operated by the U.S. Geological Survey; measurement error is typically ± 5% to ± 8%.
2. Restoration water allocation was limited by a court order from 2001 to 2004; court-ordered volumes varied by year during the period.
3. Estimates for WY 2011 were provided by the Program (Krause pers. comm. 2012); the data are considered preliminary and are currently under review.

Sources: 2001 to 2010 data from Trinity River Restoration Program Performance Measure: Restoration Water Volume Accounting (http://www.trrp.net/); 2011 data updated by Anchor QEA, Phase 1 review support contractor.

2.1.9 Temperature Targets

Table 2-2 shows the number of days of temperature criteria exceedances within each target time period for the 1993 to 2011 period. Overall, there were 98 exceedances (6.7%) within the July 1 to September 14 period targeting the adult spring-run Chinook salmon summer holding; 10

exceedances (3.5%) for the September 15 to 30 period targeting spring-run Chinook salmon spawning; and 54 exceedances (3.1%) for the October 1 to December 31 period targeting Chinook salmon, coho salmon, and steelhead spawning. Temperature target performance was variable throughout the time series with no clear pattern present in the data. In general, exceedances during the July 1 to September 14 and September 15 to September 30 periods were limited to specific years. In contrast, exceedances during the October 1 to December 31 period were distributed across the reporting period; however, all of these exceedances occurred between October 1 and October 18 each year. The largest number of temperature exceedances occurred in 1993, 2003, 2005, and 2009 during the July 1 to September 14 period. Exceedances for the September 15 to September 30 period all occurred among 3 years (1994, 2009, and 2010).

For the 2001 to 2011 period, there were 80 exceedances (9.5%) within the July 1 to September 14 period, 6 exceedances (3.6%) for the September 15 to 30 period, and 30 exceedances (3.0%) for the October 1 to December 31 period. The general pattern of exceedances among periods was similar to the 1993 to 2011 period. This should be the case because adult salmonid temperature targets were established in 1994, and higher flow releases during summer and fall to aid spring-run Chinook salmon spawning began in 1991. Thus, pre-to-post ROD comparisons of temperature exceedances were not feasible.

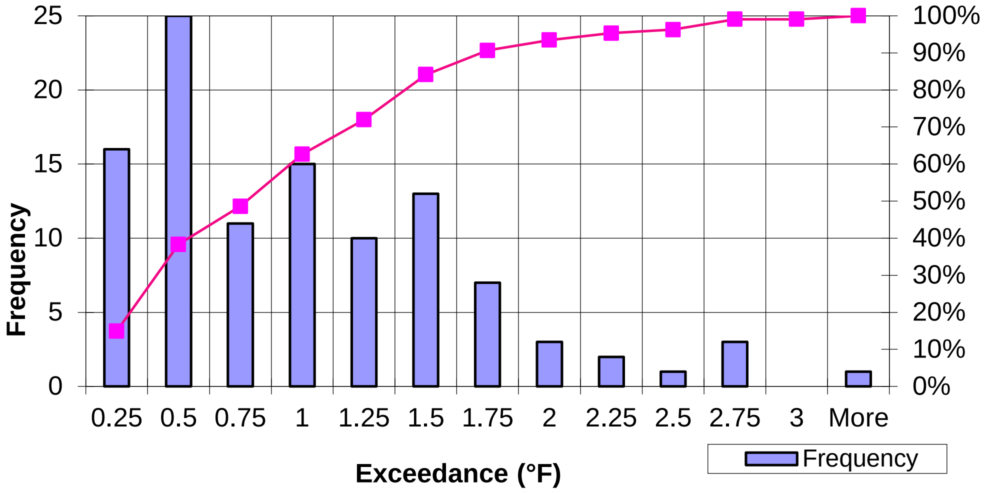
Overall, temperature targets were met more than 90% of the time during the summer holding period and more than 96% of the time during the two spawning periods. An examination of cumulative distributions of exceedances at Douglas City and North Fork Trinity River suggests that 60 to 70% of the exceedances were less than or equal to 1° F (Figures 2-15 and 2-16). Overall, this appears to be a high rate of compliance given the large number of variables associated with managing water temperature in a controlled but large river system exposed to harsh air temperatures during summer and tributary inflows. The vast majority of exceedances were small and occurred in specific years, which suggests that a review of operations in those years could potentially inform ways to improve future temperature management operations.

Table 2-2

Number of Temperature Criteria Exceedances for the Three Target Periods 1993 to 2011

Year	July 1 to September 14			September 15 to September 30			October 1 to December 31		
	Number of Exceedances	Number of days in time period	% Exceedance	Number of Exceedances	Number of days in time period	% Exceedance	Number of Exceedances	Number of days in time period	% Exceedance
1993	17	77	22%	0	15	0.0%	10	92	10.9%
1994	1	77	1.3%	4	15	26.7%	0	92	0.0%
1995	0	77	0.0%	0	15	0.0%	4	92	4.4%
1996	0	77	0.0%	0	15	0.0%	1	92	1.1%
1997	0	77	0.0%	0	15	0.0%	5	92	5.4%
1998	0	77	0.0%	0	15	0.0%	1	92	1.1%
1999	0	77	0.0%	0	15	0.0%	0	92	0.0%
2000	0	77	0.0%	0	15	0.0%	3	92	3.3%
2001	0	77	0.0%	0	15	0.0%	5	92	5.4%
2002	0	77	0.0%	0	15	0.0%	0	92	0.0%
2003	11	77	14.3%	0	15	0.0%	7	92	7.6%
2004	0	77	0.0%	0	15	0.0%	4	92	4.4%
2005	26	77	33.8%	0	15	0.0%	1	92	1.1%
2006	6	77	7.8%	0	15	0.0%	0	92	0.0%
2007	3	77	3.9%	0	15	0.0%	0	92	0.0%
2008	0	77	0.0%	0	15	0.0%	4	92	4.4%
2009	28	77	36.4%	5	15	33.3%	2	92	2.2%
2010	6	77	7.8%	1	15	6.7%	7	92	7.6%
2011	0	77	0.0%	0	15	0.0%	0	92	0.0%
Total	98	1,463	6.7%	10	285	3.5%	54	1,748	3.1%

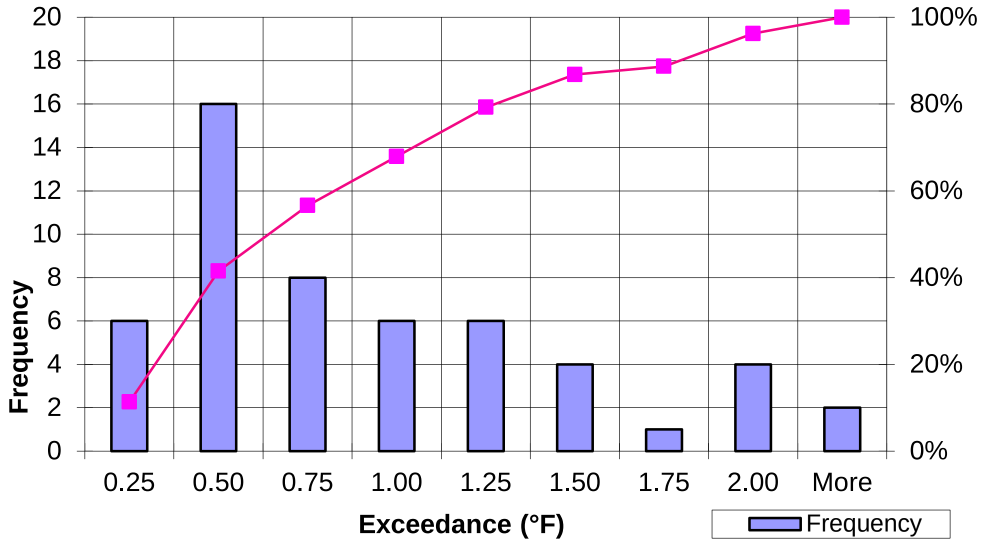
Source: Data provided via personal communication from Rod Wittler (U.S. Bureau of Reclamation, Trinity River Restoration Program, Weaverville, California) to John Ferguson (Anchor QEA, Phase 1 review support contractor), August 1, 2013.



Source: Data and figure provided via personal communication from Rod Wittler (U.S. Bureau of Reclamation, Trinity River Restoration Program, Weaverville, California) to John Ferguson (Anchor QEA, Phase 1 review support contractor), August 1, 2013.

Figure 2-15

Histogram of the Frequency of Temperatures Above Target Criteria at Douglas City from July 1 to September 30, 1993 to 2011 (excluding 1995)



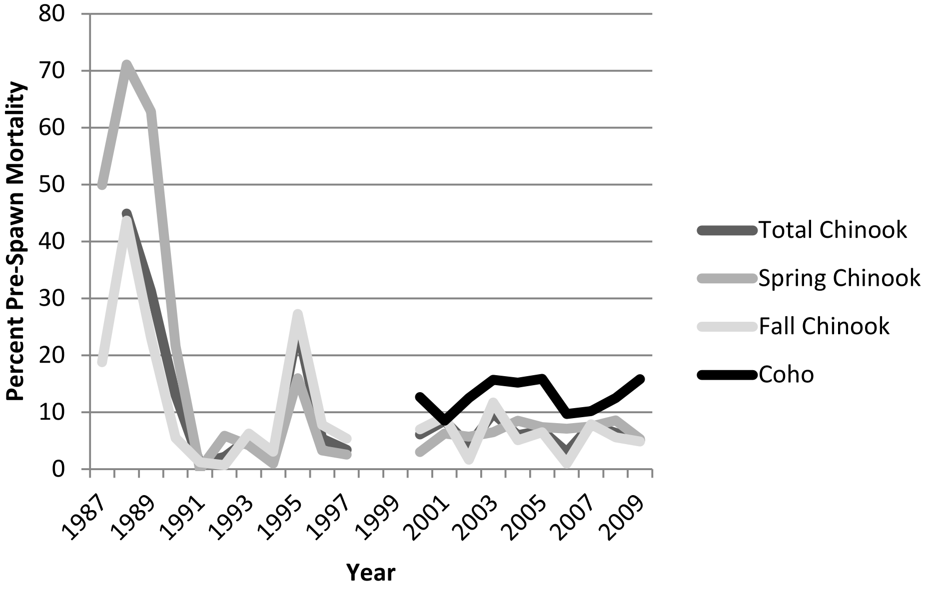
Source: Data and figure provided via personal communication from Rod Wittler (U.S. Bureau of Reclamation, Trinity River Restoration Program, Weaverville, California) to John Ferguson (Anchor QEA, Phase 1 review support contractor), August 1, 2013.

Figure 2-16

Histogram of the Frequency of Temperatures Above Target Criteria at North Fork Trinity River from October 1 to December 31, 1993 to 2011

2.1.10 Annual Estimates of Pre-spawn Mortality

Pre-spawning mortality ranged from 0.0 to 71.1% for spring-run Chinook salmon and 0.7 to 43.7% for fall-run Chinook salmon from the 1987/1988 to the 2009/2010 spawning season (Sinnen et al. 2011, Appendix 4; Figure 2-17). Pre-spawning mortality rates dropped substantially between 1988 and 1991 for both runs of Chinook salmon and also coho salmon. Since 1991, mortality rates for Chinook salmon have generally been below 10%, except for 1995. Mortality rates for coho salmon have been higher than for Chinook salmon and have ranged from 8.5 to 15.9% since 2000. When comparing data, it is important to note that differences in survey timing and periodicity occurred among years due to weather and budgetary constraints (Sinnen et al. 2011). In some years, surveys were conducted in January and covered a greater proportion of coho salmon spawning than other years. Also, pre-spawning mortality appears correlated with escapement numbers, suggesting there may be a density component to the metric (Sinnen et al. 2011). In general, since Phase 1 activities were initiated, there is no clear trend in the frequency of pre-spawning mortality, with the exception that coho salmon mortality has increased slightly since 2006.



Source: Figure developed by the Phase 1 review team based on Sinnen et al. 2011.

Figure 2-17
Percent Pre-spawn Mortality of Female Salmon Observed during Trinity River Spawning Surveys, 1987 to 2009

2.1.11 Proportion of Time That 80% of the Smolt Outmigration Passed the Willow Creek Trap by the Target Dates

Abundance indices are greatly influenced by river discharge and one must use caution when comparing indices of absolute numbers of fish passing a site between or among years. However, abundance indices are considered adequate indicators of migration timing and duration if sampling occurred in all weeks of the sampling period and encompassed the temporal duration of the outmigration based on the migration timing of the species and life stages (Pinnix et al. 2007; Pinnix and Quinn 2009; Pinnix et al. 2010). This was the case with these data; therefore, we believe the data can be used to represent overall outmigration timing trends.

The number of times that 80% of the smolt outmigration passed the Willow Creek trap by July 9 for Chinook salmon, June 4 for coho salmon, and May 21 for steelhead from 2002 to 2008 (Tables 2-3 through 2-6) is summarized as follows:

- Age-0 natural-origin Chinook salmon: the target was achieved in 6 out of 7 years (86% of the time; note that the target was nearly met in 2004, where 79% of the smolts outmigrated by the target date).
- Age-1+ natural-origin coho salmon: the target was achieved in 5 out of 7 years (71% of the time)
- Age-0 natural-origin steelhead: the target was achieved in 0 out of 7 years (0% of the time)
- Age-1+ natural-origin steelhead: the target was achieved in 4 out of 7 years (57% of the time)

Table 2-3
Percentage of Age-0 Natural-origin Chinook Salmon that Pass the Willow Creek Trap by July 9 Each Year Based on Abundance Indices

Chinook Salmon	2002	2003	2004	2005	2006	2007	2008
Total of all Weekly Abundance Indices for Season	525,160	256,512	158,184	1,488,578	79,845	635,906	909,415
Total of all Weekly Abundance Indices by July 9	490,489	229,386	125,173	1,387,083	64,391	630,980	738,378
Estimate of % of Total Fish Passed Willow Creek Trap by July 9	93%	89%	79%	93%	81%	99%	81%

Notes: Data used in this table are from Appendices 1 through 5 from Pinnix et al. (2007); Appendices 1 and 2 from Pinnix and Quinn (2009); and Appendix 1 from Pinnix et al. (2010).

Table 2-4
Percentage of Age-1+ Natural-origin Coho Salmon that Pass the Willow Creek Trap by June 4 Each Year Based on Abundance Indices

Coho Salmon	2002	2003	2004	2005	2006	2007	2008
Total of all Weekly Abundance Indices for Season	19,172	8,941	3,101	4,393	7,820	3,987	3,394
Total of all Weekly Abundance Indices by June 4	19,038	8,075	2,281	4,269	5,362	3,698	2,216
Estimate of % of Total Fish Passed Willow Creek Trap by June 4	99%	90%	91%	97%	69%	93%	65%

Notes: Data used in this table are from Appendices 1 through 5 from Pinnix et al. (2007); Appendices 1 and 2 from Pinnix and Quinn (2009); and Appendix 1 from Pinnix et al. (2010).

Table 2-5

Percentage of Age-0 Natural-origin Steelhead that Pass the Willow Creek Trap by May 21 Each Year Based on Abundance Indices

Age-0 Steelhead	2002	2003	2004	2005	2006	2007	2008
Total of all Weekly Abundance Indices for Season	26,965	38,218	6,357	26,526	28,539	6,806	47,932
Total of all Weekly Abundance Indices by July 9	5,710	7,830	942	16,499	5,106	766	1,334
Estimate of % of Total Fish Passed Willow Creek Trap by July 9	21%	20%	15%	62%	18%	11%	3%

Notes: Data used in this table are from Appendices 1 through 5 from Pinnix et al. (2007); Appendices 1 and 2 from Pinnix and Quinn (2009); and Appendix 1 from Pinnix et al. (2010).

The Trinity River Flow Evaluation Report sets the target date at approximately May 22 for the emigration of 80% of steelhead juveniles; however, May 22 is the second day of JW 21. Therefore, for this analysis, the abundance indices were summed through the end of JW 20, which occurs on May 20.

Table 2-6

Percentage of Age-1+ Natural-origin Steelhead that Pass the Willow Creek Trap by May 21[1] Each Year Based on Abundance Indices

Age-1+ Steelhead	2002	2003	2004	2005	2006	2007	2008
Total of all Weekly Abundance Indices for Season	15,455	20,451	42,887	35,370	20,695	72,124	25,854
Total of all Weekly Abundance Indices by May 211	10,743	17,524	36,362	28,809	11,635	60,393	18,670
Estimate of % of Total Fish Passed Willow Creek Trap by May 211	70%	86%	85%	81%	56%	84%	72%

Notes: Data used in this table are from Appendices 1 through 5 from Pinnix et al. (2007); Appendices 1 and 2 from Pinnix and Quinn (2009); and Appendix 1 from Pinnix et al. (2010).

The Trinity River Flow Evaluation Report sets the target date at approximately May 22 for the emigration of 80% of steelhead juveniles; however, May 22 is the second day of JW 21. Therefore, for this analysis, the abundance indices were summed through the end of JW 20, which occurs on May 20.

To summarize, the programmatic goal of having 80% or more of the smolts out-migrate from the system prior to the target dates each year was met for age-0 Chinook salmon only during the 2002 to 2008 period. The finding that few age-0 steelhead migrated past the trap by May 21 each year was not unexpected because steelhead use a wide range of life-history strategies and display a high degree of variability in their use of anadromy versus residency. Age-0 steelhead were not included in the programmatic goal. Steelhead typically migrate as age-2 or age-3 fish, but can also migrate as age-1 or age-4 fish (Quinn 2005). The age-0 steelhead observed at the Willow Creek trap were likely captured while moving within, but not out of, the Trinity River system.

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APPENDIX B
GRTS ANALYSIS

Prepared for
Trinity River Restoration Program

Prepared by
Trinity River Restoration Program's Scientific Advisory Board

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LIST OF ACRONYMS AND ABBREVIATIONS

CDF	cumulative distribution function
GRTS	Generalized Random Tessellation Stratified
HT	Horvitz-Thompson
km	kilometer
m	meter
m^2	square meter
$m^3 \cdot s^{-1}$	cubic meters per second
mm	millimeter
NBH	local neighborhood
Program	Trinity River Restoration Program
SAB	Scientific Advisory Board
SRS	simple random sample
USFWS	U.S. Fish and Wildlife Service

1 INTRODUCTION

The Scientific Advisory Board (SAB) conducted an independent assessment of the Trinity River Restoration Program's (Program) Generalized Random Tessellation Stratified (GRTS) design and analysis. Before we describe the methods used and the results of our review, we describe its scope briefly and how it has benefitted the Program in our view. The review went beyond a traditional review by also supplying alternative methodologies for the Program to consider and quantitative results of the analyses conducted. These results may be used to independently verify future data produced by the Program. The review was not simply a repeat of GRTS analyses already conducted by the Program Partners. Although R-code was provided by the U.S. Fish and Wildlife Service (USFWS) for this analysis, it was modified to produce the Trinity River GRTS design we evaluated and estimates of total response and confidence intervals. The review required development of R-code that was not supplied by USFWS.

Our review provides equations and references for the methods used in our GRTS design and analysis and R-code that can be used to repeat the GRTS design and total response estimates in future years. In addition, it included some analyses and methods that were not part of what has been reported by USFWS. For example, the review provided a unique graphical depiction of the differences in habitat areas at GRTS locations over space and time. These graphical depictions show the decrease in rearing habitat areas with distance from the dam, and also show the locations of positive and negative changes over time at each GRTS sample unit. The graphics demonstrate that in some years, increases or decreases in rearing habitat area depends on distance from Lewiston Dam; and it makes the direction and magnitude of these changes clear.

In addition, the review explored alternative assumptions about error structures using three alternative variance estimators: local neighborhood (NBH) variance estimator, simple random sample (SRS) variance estimator, and the Horwitz-Thompson (HT) variance estimator (Horvitz and Thompson 1952). We also performed an initial test of the GRTS design and analysis by applying them to Trinity River salmon redd data, for which census data were available. We then discussed how these census data might be utilized to further test the GRTS design. Furthermore, we discovered an error in the *spsurvey: Spatial Survey Design and Analysis* (spsurvey; version 2.4) program developed by Kincaid and Olsen (2012) that estimates the NBH variance. We notified the spsurvey developers, who corrected the error. We reanalyzed the data with the corrected spsurvey, which resulted in minute changes in the NBH variance estimates.

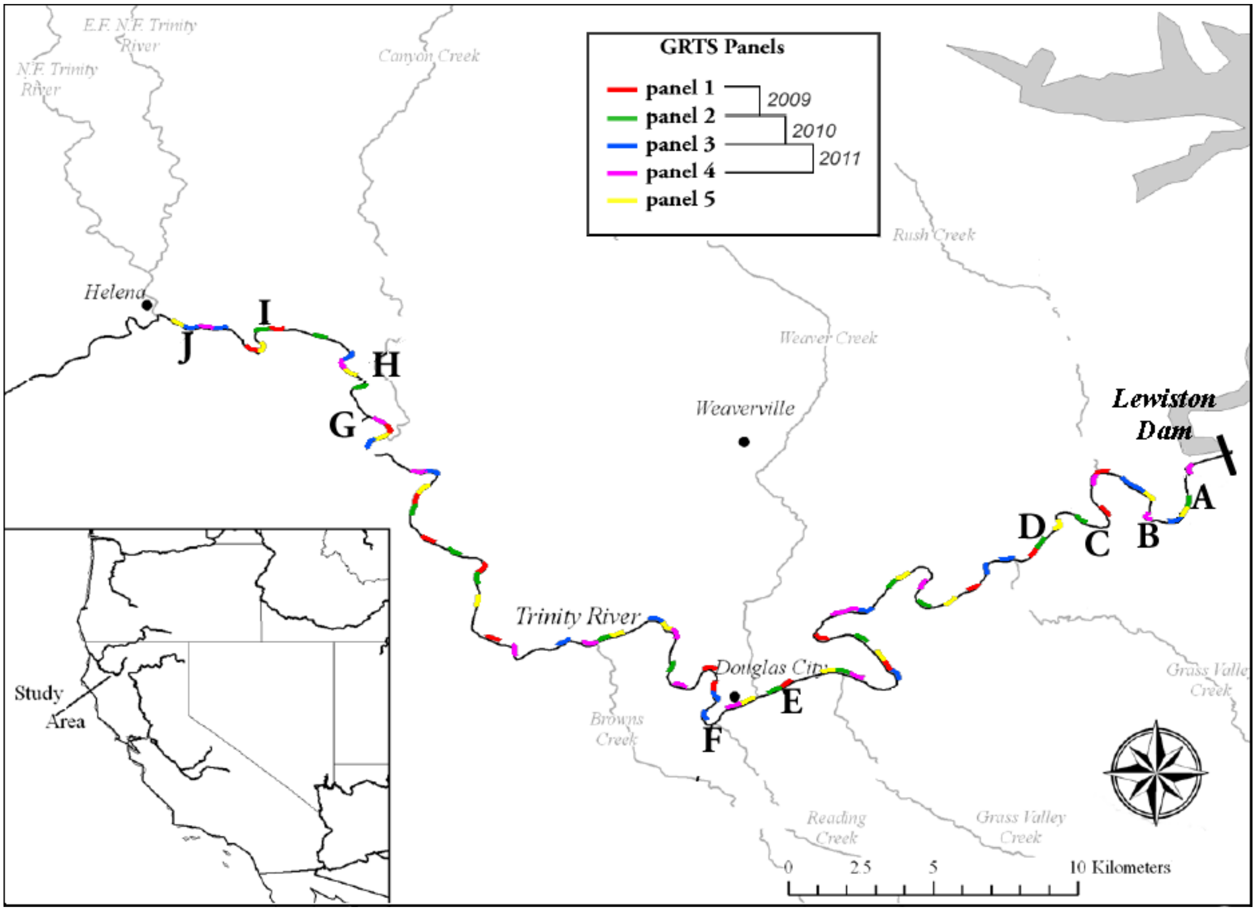
This review also provides a detailed discussion of how to evaluate alternatives to the design used by USFWS for the GRTS analysis, and identifies different sources of variance to consider and address in future power analyses. Finally, it identified methods that may be used to implement

GRTS in a situation where there are competing objectives of the design. Taken together, we believe the new information and analyses provided by this review will assist the Program Partners in their efforts to assess the current GRTS design, and potentially improve it in the future when evaluating the effects of Program actions on the Trinity River.

2 METHODS

2.1 Study Area

The study area is the restoration reach of the Trinity River extending from Lewiston Dam downstream to the North Fork Trinity River (Figure 1-1). Each rehabilitation project depicted in Figure 1-1 and its completion year are listed in Table 1-1.



Note:
Capital letters represent rehabilitation sites listed in Table 1-1. This is a modified version of the map found in Goodman et al. (2012). The map was modified to include the locations of all rehabilitation sites and all GRTS sample sites.

Figure 1-1
Map of Trinity River Restoration Reach, Generalized Random Tesselation Stratified Sample Units, Panels, and Rehabilitation Sites

Table 1-1

Key to Rehabilitation Site Locations

Rehabilitation Site Code in Figure 1-1	Site	Year Completed
A	Lewiston 4	2008
B	Sawmill	2009
C	Dark Gulch	2008
D	Lowden Ranch/Trinity House Gulch	2010
E	Indian Creek	2007
F	Reading Creek	2010
G	Hocker Flat	2005
H	Connor Creek	2006
I	Wheel Gulch	2011
J	Valdor Gulch/Elkhorn/Pear Tree Gulch	2006

2.2 Generalized Random Tessellation Stratified Design

To study the quantity and quality of juvenile salmonid rearing habitat area within the restoration reach over time, a GRTS sampling design was used (Stevens and Olsen 2004). The GRTS design was implemented using the R-statistical spurvey package, which consists of functions used for the design and analysis of probability surveys and is tailored for GRTS survey designs. The GRTS design was chosen because it results in sampling sites that are spatially balanced, that is, evenly dispersed over the spatial extent of the restoration reach.

In the GRTS design and analysis, the restoration reach was treated as a finite resource (i.e., a finite collection of discrete units), representing the universe from which samples are drawn (Kincaid 2012a). These discrete units were defined by partitioning the restoration reach into a total of 160 river segments of 400.0008 meters (m) in length from the North Fork Trinity River extending upstream to Lewiston Dam. The exception was the last segment closest to Lewiston Dam that was 194.1284-m long. To sample these discrete segments in the two-dimensional domain, GRTS requires a point associated with each segment. These points were determined as the midpoint along the centerline of each segment. The 160 river segments and their midpoints were defined in the shape file “pts400.shp” provided by USFWS, Arcata, California. The shape file uses the California State Plane Zone 1 projected coordinate system. Each segment had an equal probability of being sampled in the GRTS design, including the smallest segment.

Rearing habitat area data were collected over 3 years (2009 to 2011) and analyzed by year instead of being pooled across years. In each year, 32 sample units were drawn; therefore, the *a priori* probability that any particular segment was drawn was equal to 32/160 = 0.20. This probability is known as the inclusion probability of a sample unit and is used in the GRTS estimation procedure. The weights used in the estimation procedure are the reciprocals of these inclusion probabilities. R-code that may be used to generate the GRTS design for the restoration reach is provided in Table A-1 in Attachment 1. Main elements of the R-code developed for this analysis are provided so that others can reproduce the analysis.

To evaluate status and trends in rearing habitat availability through time, a rotating panel revisit design (McDonald 2003) was developed (CDFG et al. 2010). In this design, a GRTS sample of size 96 was drawn without replacement, consisting of 80 units assigned to five panels with 16 units each, and 16 units used as an oversample. Oversamples were defined in the event it was impossible to sample one or more of the panel units and an alternative unit was needed. Two panels were sampled within each year, representing 20% (32 units) of the total of 160 units in the restoration reach. In the following year of sampling, one of the panels was repeated and one new panel was added until all five panels were sampled (Table 1-2). In the fifth year, the first panel was sampled again and the pattern continued. The five panels constitute 50% (80 units) of the full restoration reach. During the 2009 to 2011 period, 40% of the 160 segments were sampled (four panels). The fifth panel will be sampled in 2012 and 2013.

Table 1-2
Rotating Panel Revisit Sampling Design for the Rearing Habitat Assessment on the Trinity River, California

Panel	Year				
	2009	2010	2011	2012	2013
1	X				X
2	X	X			
3		X	X		
4			X	X	
5				X	X

Source: Goodman et al. (2012)

Techniques developed to estimate salmonid rearing habitat within selected sample units were described by Goodman et al. (2010). To summarize, depth, velocity, and distance to cover criteria were developed for fry and presmolt life stages (Table 1-3). These criteria were used to map the amount of area in each GRTS segment sampled for each category. Habitat area sampling under GRTS was evaluated at a single index streamflow of 12.7 cubic meters per second ($m^3 \cdot s^{-1}$; 450 cubic feet per second) released from Lewiston Dam each year. As reported by Goodman et al. (2012):

> *…this streamflow was selected because: (1) it occurs during a time period with little effect from tributary accretions or storm events, (2) it is similar to streamflows in many areas of the restoration reach during much of the winter rearing period, and (3) it is unlikely to change in the near future because of its objective to meet adult spring-run Chinook Salmon temperature requirements. This measure of habitat at a single streamflow will provide an index of winter and early spring rearing habitat availability and in the future may be used with ongoing rehabilitation site assessments and two-dimensional hydrodynamic modeling studies to evaluate rearing habitat availability changes across the range of critical streamflows.*

Table 1-3

Fish Guilds and their Associated Habitat Criteria for Rearing Habitat Mapping

Habitat Type	Variable	Criteria
Fry (<50 mm)	Depth	>0 to 0.61 m
	Mean column velocity	0 to 0.15 m/sec
	Distance to cover	0 to 0.61 m
Presmolt (≥50 mm)	Depth	>0 to 1 m
	Mean column velocity	0 to 0.24 m/sec
	Distance to cover	0 to 0.61 m

Source: Goodman et al. (2012)

Notes:

Chinook salmon total habitat was defined as areas that meet combinations of depth/velocity and cover criteria. Optimal Chinook salmon habitat or coho salmon habitat was defined as areas that simultaneously meet depth, velocity, and cover criteria.

m = meter
mm = millimeter
m/sec = meter per second

Rearing habitat for Chinook and coho salmon was quantified for two different developmental stages of juvenile fish. First, fish with a total length of less than 50 millimeter (mm) as measured from their snout to the fork in their tail, or fork length (FL): this developmental stage is termed "fry." Second, fish with a FL of greater than or equal to 50 mm: this developmental stage is termed "presmolt" because these fish are larger than fry and will soon smolt and begin their migration out of the river system. Note that rearing habitat is a physical response variable based on area meeting depth, velocity, and distance to cover. It is not a biological response variable based on observed distributions of fish.

Following Alvarez et al. (2011), the fish rearing habitat was quantified (i.e., mapped) based on three criteria for each fish developmental stage: depth, velocity, and distance to cover. The criteria were based on studies of multiple observations of conditions juvenile fish choose when occupying rearing habitat (Goodman et al. 2010). Based on these observations, four metrics were developed by Goodman et al. (2010) to represent the range in the quality of habitats that fish have been observed to occupy. Note that depth and velocity were combined. First, the habitat was considered optimal for fish if it met both the depth/velocity and distance to cover criteria. Throughout this report, the optimal habitat category will be referred to as “dv_cover.” Second, habitat was considered suitable for fish if it met either of the depth/velocity criteria or the distance to cover criteria. Throughout this report, the suitable habitat category will be referred to as either “dv_ no_cover” or “cover_no_dv.” The third category was the total sum of the suitable and optimal habitat measured. Throughout this report, the total habitat category is referred to as “all.”

During GRTS sampling, the available habitat that met the optimal and suitable metric criteria was measured in square meters (m^2) and recorded for each GRTS sample unit each year. The rearing habitat mapping provided a spatially explicit representation of rearing habitat areas within selected rehabilitation sites when the sample units fell within a rehabilitation site boundary. For both fry and presmolt coho salmon, only optimal habitat was considered useable for rearing by Goodman et al. (2010).

2.3 Generalized Random Tessellation Stratified Analysis

2.3.1 Total Response and Cumulative Distribution Functions

Currently, there are 3 years (2009 to 2011) of GRTS survey data available for analysis containing a total of 96 samples: 16 from Panel 1 sites, 32 from Panel 2 sites, 32 from Panel 3 sites, and 16 from Panel 4 sites. GRTS analysis was carried out using the spsurvey package applied to a finite resource (Kincaid 2012b). The analysis included estimates of total restoration reach habitat area by fish development stage and depth/velocity and cover criteria. This resulted in eight unique habitat area estimates per year. For a given year and habitat type, the estimate of the population total of a response, T, for the entire restoration reach, is given by:

$$\hat{T} = \sum_{i=1}^{n} \frac{x_i}{P(u_i)} \tag{1-1}$$

where x_i is the habitat measure (m^2) of unit *i* and u_i is the *i*th unit drawn in the GRTS sample, and $P(u_i)$ is the *a priori* inclusion probability of unit *i* (Horvitz and Thompson 1952; Stevens and Olsen 2004).

The HT estimator of the variance of $\hat{T}$ is given by:

$$V_{HT}(\hat{T}) = \hat{T}^2 - \sum_{i=1}^{n} \frac{x_i^2}{P(u_i)} - \sum_{i \neq j} \frac{x_i x_j}{P(u_i u_j)} \tag{1-2}$$

where $P(u_i u_j)$ is the *a priori* pairwise inclusion probability for units u_i and u_j.

In the case of equal probability designs, as has been used for the Trinity River GRTS design,

$$P(u_i) = \frac{n}{N} \tag{1-3}$$

and

$$P(u_i u_j) = \frac{n(n-1)}{N(N-1)} \tag{1-4}$$

where *n* is the sample size and *N* is the number of river segments in the universe. For a single year of GRTS sampling in restoration reach, *n* = 32, and *N* = 160.

An alternative estimator of the variance of $\hat{T}$, developed over the last decade, is known as the NBH variance estimator developed by Stevens and Olsen (2003):

$$\hat{V}_{NBH}(\hat{T}) = \sum_{i=1}^{n} \sum_{u_j \in D(u_i)} w_{ij} \left[\frac{x_j}{P(u_j)} - \sum_{u_k \in D(u_i)} w_{ik} \frac{x_k}{P(u_k)} \right]^2 \tag{1-5}$$

where $D(u_k)$ is a NBH of the element u_i, and the weights w_{ij} are chosen to reflect the behavior of the pairwise inclusion probabilities for GRTS and are constrained so that $\sum_{i=1}^{n} w_{ij} = \sum_{j=1}^{n} w_{ij} = 1$. Simulation studies show that this NBH variance estimator is stable and nearly unbiased. Applications with real data have shown that it produces smaller variance than the HT estimator when an independent random sampling design is used. For the analysis of the restoration reach GRTS data, we used both the HT and the NBH estimator of variance of $\hat{T}$, and compared these variances to those derived using a SRS variance estimator, which is:

$$\hat{V}_{SRS}(\hat{T}) = \frac{n\sum_{i=1}^{n}\left(\frac{x_i}{P(u_i)} - \sum_{j=1}^{n}\frac{x_j}{P(u_j)n}\right)^2}{n-1} \tag{1-6}$$

The SRS variance estimator approximates the HT estimator by treating the sample as if it was an independent random sample, and then applying the HT variance formula. The spsurvey function “cont.analysis” was used to calculate the estimate of the total response, the NBH variance estimator, and the SRS variance estimator. The HT variance estimator described in Equation 1-2 was programmed in R outside of the spsurvey package (see Table A-2 in Attachment 1). The SRS variance estimator was included solely for the sake of comparison because a GRTS sample is not a simple independent random sample.

Cumulative distribution function (CDF) plots were constructed by year and habitat type. Each plot represents a particular type of fry or presmolt rearing habitat from 32 GRTS sample units (Goodman et al. 2012). Each y-value along the CDF represents the percentage of total restoration reach at or below a certain level of habitat area (x-value). For example, if a CDF of optimal fry habitat in 2010 passes through the point x= 500 m^2 and y = 50%, then 80 of the 160 segments have optimal fry habitat of 500 m^2 or less. The CDFs can be compared year-to-year to test whether the distribution of optimal or suitable rearing habit changed between years. The spsurvey function cont.analysis was used to calculate CDFs. The HT ratio estimator (i.e., the ratio of two HT estimators) was used to calculate estimates of the class proportions for the CDFs (Kincaid 2012c). The R-code for calculating the estimates of the total response and the CDF is provided in Table A-3 in Attachment 1.

2.3.2 Trend Analysis

To test for a significant trend in these data, we incorporated both pairwise comparisons between years and calculated trends for all 3 available years. Pairwise analyses included a test for changes in CDF using the spsurvey function “cdf.test” to test for changes in CDFs. For each habitat type, we tested for changes in CDF between three pairs of years: 2009 to 2010, 2009 to 2011, and 2010 to 2011. A Wald F statistic was used to determine whether a change in CDF was significant (Kincaid 2000; Kincaid 2012c).

For changes in habitat area between adjacent years, Wilcoxon Rank Sum Test was used. The Wilcoxon Rank Sum Test is a nonparametric statistical test that does not depend on the assumption of normally distributed errors (Conover 1980). We did not use the paired t test because it relies on normally distributed errors. Normal probability plots revealed departure from normality in some of the datasets of paired differences. Departure from normality was confirmed using Shapiro-Wilk tests (Royston 1995). Observations were paired by GRTS river segment. Therefore, years 2009 to 2010 were compared using GRTS segments contained in Panel 2, and 2010 to 2011 were compared using GRTS segments contained in Panel 3.

We also tested for change across all 3 years (2009 to 2011) by using the Unit Slope Analysis that evaluates differences in unit responses between consecutive years (at the same river segment) as “unit slopes” (McDonald et al. 2009). Using this method, the estimate of the trend is the average of the 32 slopes estimated over the years 2009 to 2011. We used a bootstrapping approach to avoid having to use the assumption that the unit slopes (differences at units between adjacent years) are normally distributed. We used 5,000 bootstrap replications to run a test of significance with a null hypothesis of a mean slope of zero against a two-sided alternative. The estimate of the mean of the slopes is:

$$\bar{\hat{\beta}} = \frac{\sum_{i=1}^{ns} \hat{\beta}_i}{ns} \tag{1-7}$$

where $\hat{\beta}_i$ is the observed difference in response at unit *i* between consecutive years, and ns is the number of slopes. Note that only units sampled in consecutive years during 2009 to 2011 enter into the mean slope calculation. All of the units in Panel 2 (2009 to 2010) and Panel 3 (2010 to 2011) are included in the calculation, for a total of $ns = 32$ slopes. The standard error of the trend estimate $\bar{\hat{\beta}}_i$ is given by:

$$SE(\bar{\hat{\beta}}) = \sqrt{\frac{\sum_{i=1}^{ns}\left(\hat{\beta}_i - \bar{\hat{\beta}}\right)^2}{(ns-1)ns}} \tag{1-8}$$

and the test statistic is given by:

$$t_{obs} = \frac{\bar{\hat{\beta}}}{SE(\bar{\hat{\beta}})} \tag{1-9}$$

The bootstrap test of the null hypothesis of "no trend" proceeds by resampling the deviations $\hat{\beta}_i - \bar{\hat{\beta}}$ (i = 1,2, …, ns) with replacement and recalculating the test statistic for each of these 5,000 bootstrap datasets. The bootstrap replications form an estimate of the sampling distribution of test statistics under the null hypothesis. The p-value is estimated as the proportion of the bootstrap replications of the test statistic that are further from zero than the observed test statistic, t_{obs} :

$$p - value = \frac{\sum_{b=1}^{5000} I(t_b^* < -|t_{obs}|) + I(t_b^* > |t_{obs}|)}{5000} \tag{1-10}$$

where $I()$ is an indicator function that takes on the value of 1 when the argument is true and the value 0 otherwise, and t_b^* is the b^{th} bootstrap replication of the test statistic. Notice that the alternative hypothesis is two-sided.

As an alternative to the bootstrapping approach outlined above, we used the NBH estimator of variance to account for possible spatial autocorrelation in the estimated slopes, then used a normal approximation to calculate the p-value. To do this, we used the spsurvey function "total.est" and used equal weighting of the slopes calculated at each segment.

2.3.3 Estimate vs. Census (Redd Counts)

As an initial test of the ability of the GRTS analysis to estimate a total resource, we used the redd census data collected during 2009 to 2011 (available online at http://www.fws.gov/arcata/fisheries/projectUpdates.html). Because redds can be censused, they provide an excellent test of sampling designs (Courbois et al. 2008). These census data were sampled using the same GRTS design that was used for habitat area, except number of redds was sampled instead of habitat area. For each year, we calculated a HT point estimate of the total response and its 95% confidence interval based on the GRTS sample of 32 river segments for that year. We then compared the point estimate of the total redd count and its 95% confidence interval to the actual total count from the census. To calculate the confidence interval, we used the NBH variance estimator and a normal approximation of the distribution of the estimator. The confidence interval was produced by the spsurvey function total.est. Redd data were used instead of habitat area because there is no census of habitat area for the full reach of interest. Furthermore, as demonstrated in the later sections of this report, redd data have a spatial pattern similar to the habitat area data: redd counts tend to decline with distance from Lewiston Dam.

3 RESULTS

3.1 Generalized Random Tessellation Stratified Design

The segments selected in the GRTS sampling are depicted in Figure 1-1. The units were sampled in such a way that a spatially balanced sample was drawn from the entire restoration reach. Currently, observations at four of the five panels have been sampled over the 2009 to 2011 period. In 2012 (the fourth year), Panels 4 and 5 will be sampled, and in 2013 (the fifth year), Panels 5 and 1 will be sampled.

3.2 Generalized Random Tessellation Stratified Analysis

3.2.1 Total Response and Cumulative Distribution Functions

Total response estimates by habitat type, which represent habitat areas over the entire restoration reach, are provided in Table 2-1 along with their associated standard errors, coefficients of variation, and 95% confidence intervals. Overall, total presmolt habitat area (ranging from 365,657 to 438,021 m^2) was more abundant than total fry habitat area (ranging from 283,263 to 344,308 m^2). However, suitable fry habitat area that met the cover criteria (cover_no_dv) was more abundant (ranging from 90,186 to 114,551 m^2) than suitable presmolt habitat area that met the cover criteria (cover_no_dv; ranging from 64,500 to 85,086 m^2) in each year of study.

Table 2-1

Total Habitat Area Estimates with Standard Errors and Confidence Intervals

Habitat	Year	Nsamp	T estimate	SE	CV	LCB 95%	UCB 95%
fry_dv_cover	2009	32	88,458	10,997	0.12	66,905	110,012
fry_dv_cover	2010	32	70,160	6,450	0.09	57,518	82,803
fry_dv_cover	2011	32	67,094	6,230	0.09	54,884	79,303
fry_dv_no_cover	2009	32	141,299	9,903	0.07	121,890	160,708
fry_dv_no_cover	2010	32	122,917	6,653	0.05	109,876	135,957
fry_dv_no_cover	2011	32	164,217	16,145	0.10	132,573	195,862
fry_cover_no_dv	2009	32	114,551	21,818	0.19	71,787	157,314
fry_cover_no_dv	2010	32	90,186	6,873	0.08	76,716	103,657
fry_cover_no_dv	2011	32	96,401	8,616	0.09	79,514	113,289
fry_all	2009	32	344,308	29,524	0.09	286,442	402,174
fry_all	2010	32	283,263	11,130	0.04	261,449	305,078
fry_all	2011	32	327,712	18,967	0.06	290,538	364,886
presmolt_dv_cover	2009	32	118,002	12,765	0.11	92,984	143,021
presmolt_dv_cover	2010	32	95,848	8,468	0.09	79,252	112,444

Habitat	Year	Nsamp	T estimate	SE	CV	LCB 95%	UCB 95%
presmolt_dv_cover	2011	32	95,024	8,345	0.09	78,669	111,380
presmolt_dv_no_cover	2009	32	234,933	15,833	0.07	203,901	265,964
presmolt_dv_no_cover	2010	32	205,309	9,285	0.05	187,111	223,507
presmolt_dv_no_cover	2011	32	262,202	19,309	0.07	224,357	300,046
presmolt_cover_no_dv	2009	32	85,086	20,240	0.24	45,417	124,756
presmolt_cover_no_dv	2010	32	64,500	4,610	0.07	55,465	73,535
presmolt_cover_no_dv	2011	32	68,470	6,272	0.09	56,178	80,763
presmolt_all	2009	32	438,021	28,505	0.07	382,153	493,890
presmolt_all	2010	32	365,657	13,397	0.04	339,400	391,914
presmolt_all	2011	32	425,696	22,171	0.05	382,242	469,151

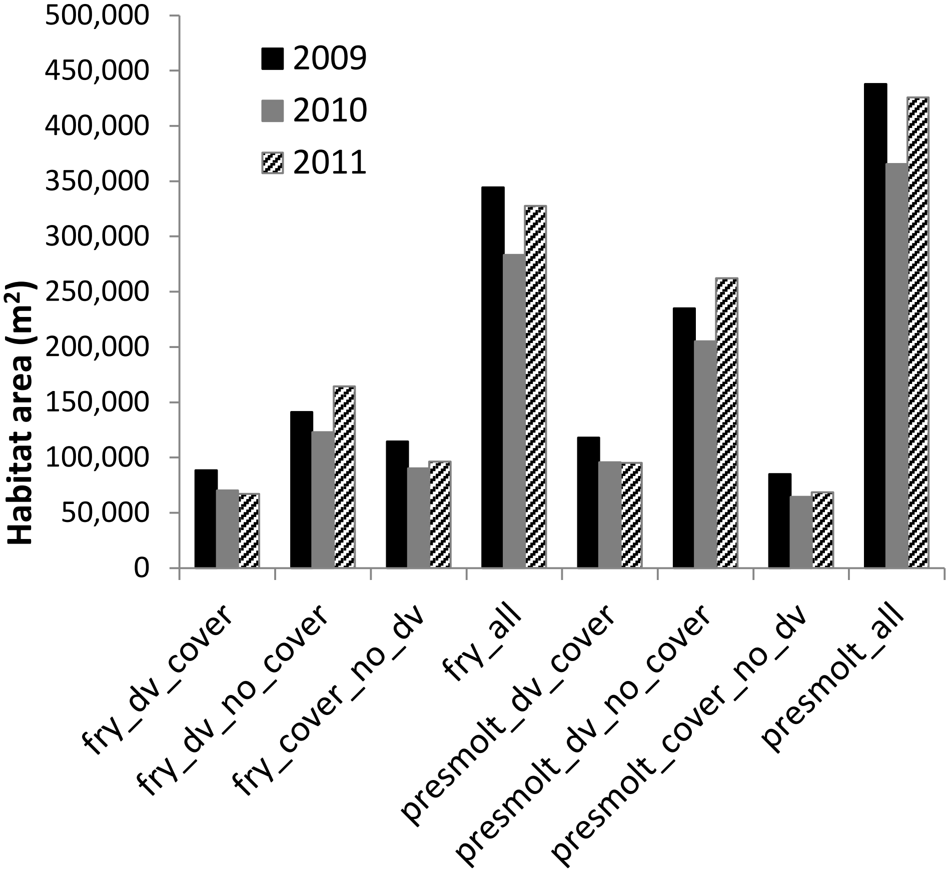
Notes:

- Nsamp represents the number of segments sampled.
- T estimate represents the total habitat estimate in $m^{2.}$
- SE represents the standard error.
- CV is the coefficient of variation.
- LCB 95% is the lower 95% confidence limit.
- UCB 95% is the upper 95% confidence limit.
- The NBH variance estimator was used to calculate SE, CV, and the 95% confidence intervals.

We used the NBH variance estimator because we found that, on average, it produced standard errors that were 22% smaller than the HT estimators and 30% smaller than the SRS estimators. Coefficients of variation, a measure of precision, were at 24% or less when using the NBH variance estimator. Use of the NBH estimator was justified because there was spatial structure in these data: observations closer together were more similar than observations that were far apart. This occurred because mapped habitat area tended to decline with distance from Lewiston Dam.

Also, there was a general negative change in total habitat area estimates between 2009 to 2010 and a positive change between 2010 to 2011. Habitat area of all types decreased from 2009 to 2010, and all except the optimum habitats increased from 2010 to 2011 (Figures 2-1 and 2-2). Also, for each category of habitat, the amount of habitat available to juvenile salmonids decreased with distance from Lewiston Dam (Figure 2-2). Estimates by habitat type and year are provided in Figure 2-1, and data upon which these total response estimators were based are depicted in Figures 2-2a through 2-2d, which show the spatial structure in the observations.

Plots of CDFs by rearing habitat category are shown in Figure 2-3 for the fry rearing habitat types and Figure 2-4 for the presmolt habitat types. The plots reveal a few subtle changes in the distribution of habitat areas. Notably, in 2010 the distributions of suitable fry habitat that met depth/velocity criteria (dv_no_cover), suitable presmolt habitat that met depth/velocity criteria (dv_no_cover), total fry habitat (all), and total presmolt habitat (all) are each shifted to the left (toward smaller areas per segment) compared to the 2009 and 2011 distributions.

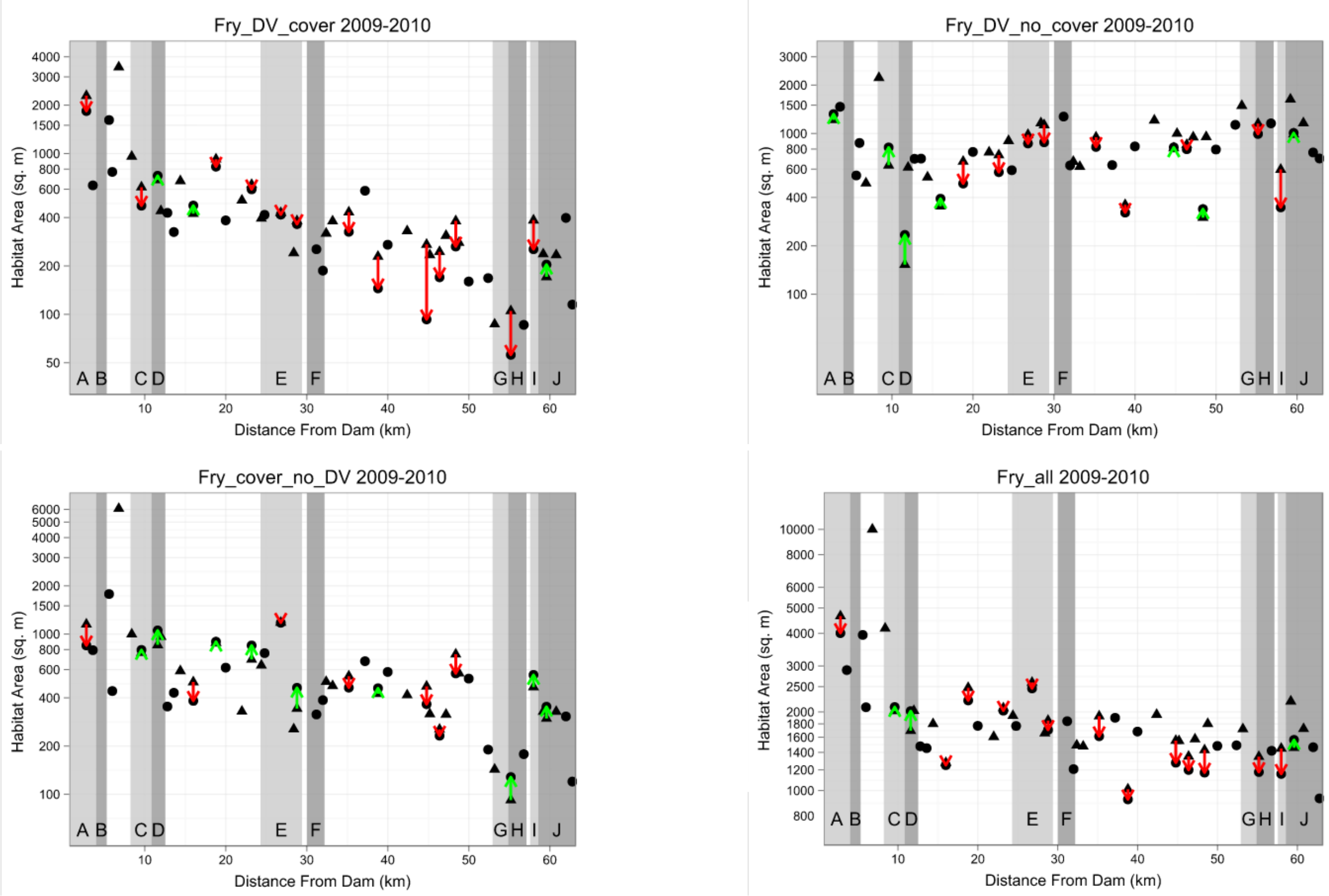


Notes:

- "Optimal" habitat met both the depth/velocity and distance to cover criteria (dv_cover).
- "Suitable" habitat met either the depth/velocity criteria or the distance to cover criteria (dv_no_cover or cover_no_dv).
- "All" habitat is the total sum of the suitable and optimal habitat measured.

Figure 2-1

Estimates of Habitat Area by Type and Fish Developmental Stage for 2009 to 2011

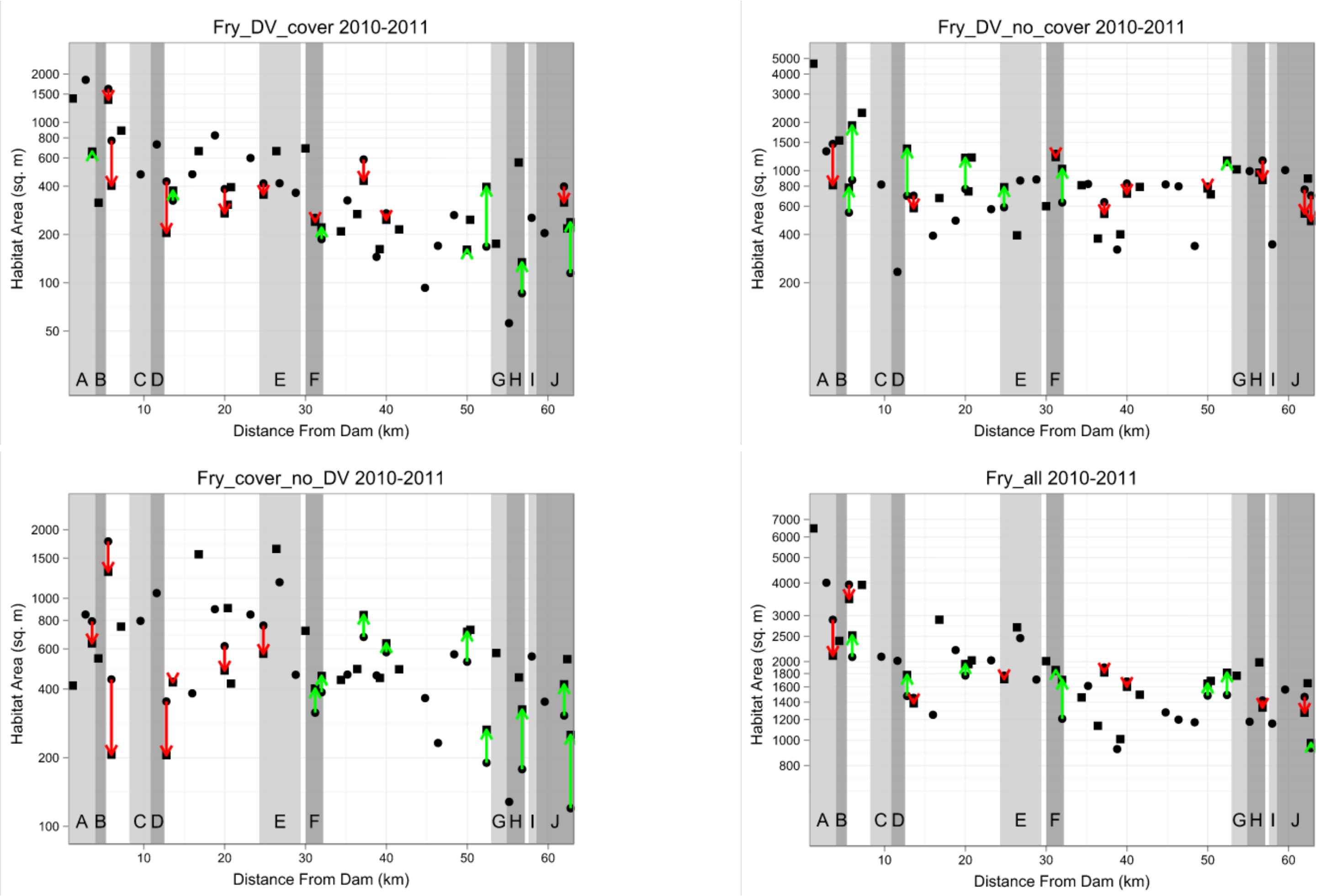


Notes:

- Letters A to J correspond to the rehabilitation projects listed in Table 1-1.
- Arrows show direction of change in habitat area at GRTS sites sampled in both 2010 and 2011.

Figure 2-2a

Fry Habitat Comparison 2009 (Triangles) to 2010 (Circles)

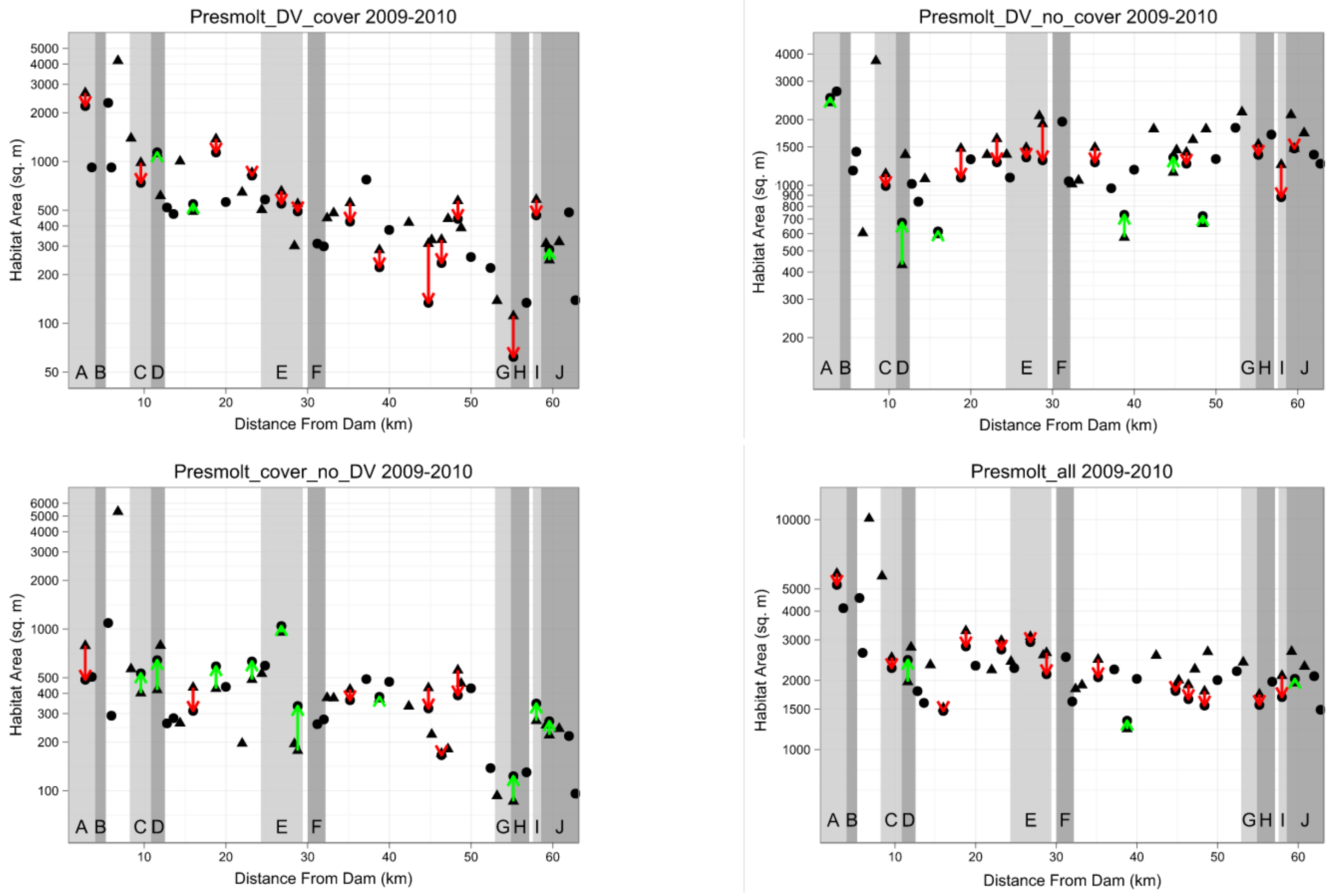


Notes:

- Letters A to J correspond to the rehabilitation projects listed in Table 1-1.
- Arrows show direction of change in habitat area at GRTS sites sampled in both 2010 and 2011.

Figure 2-2b

Fry Habitat Comparison 2010 (Circles) to 2011 (Squares)

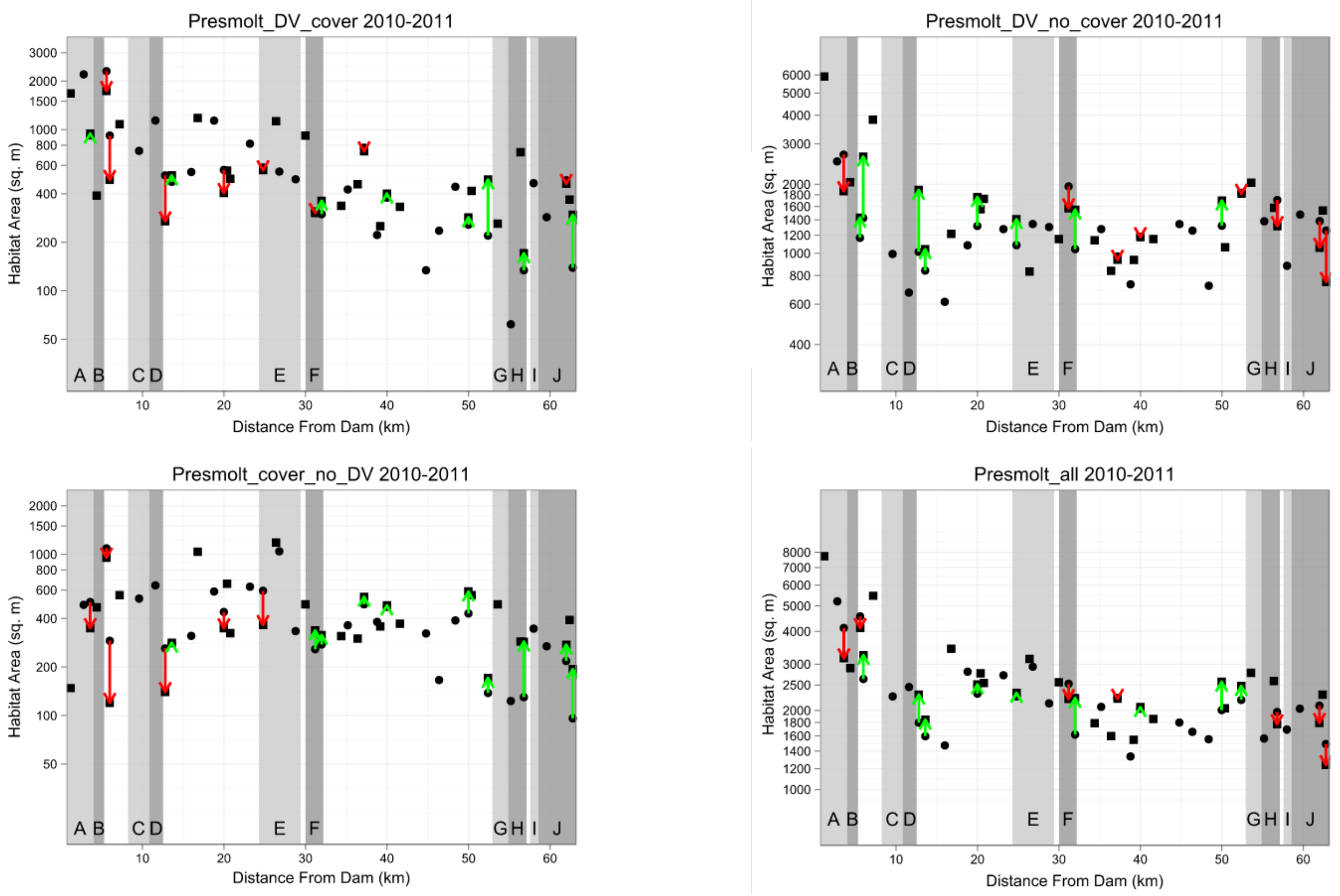


Notes:

- Letters A to J correspond to the rehabilitation projects listed in Table 1-1.
- Arrows show direction of change in habitat area at GRTS sites sampled in both 2009 and 2010.

Figure 2-2c

Presmolt Habitat Comparison 2009 (Triangles) to 2010 (Circles)



Presmolt_DV_cover 2010-2011

Presmolt_DV_no_cover 2010-2011

Presmolt_cover_no_DV 2010-2011

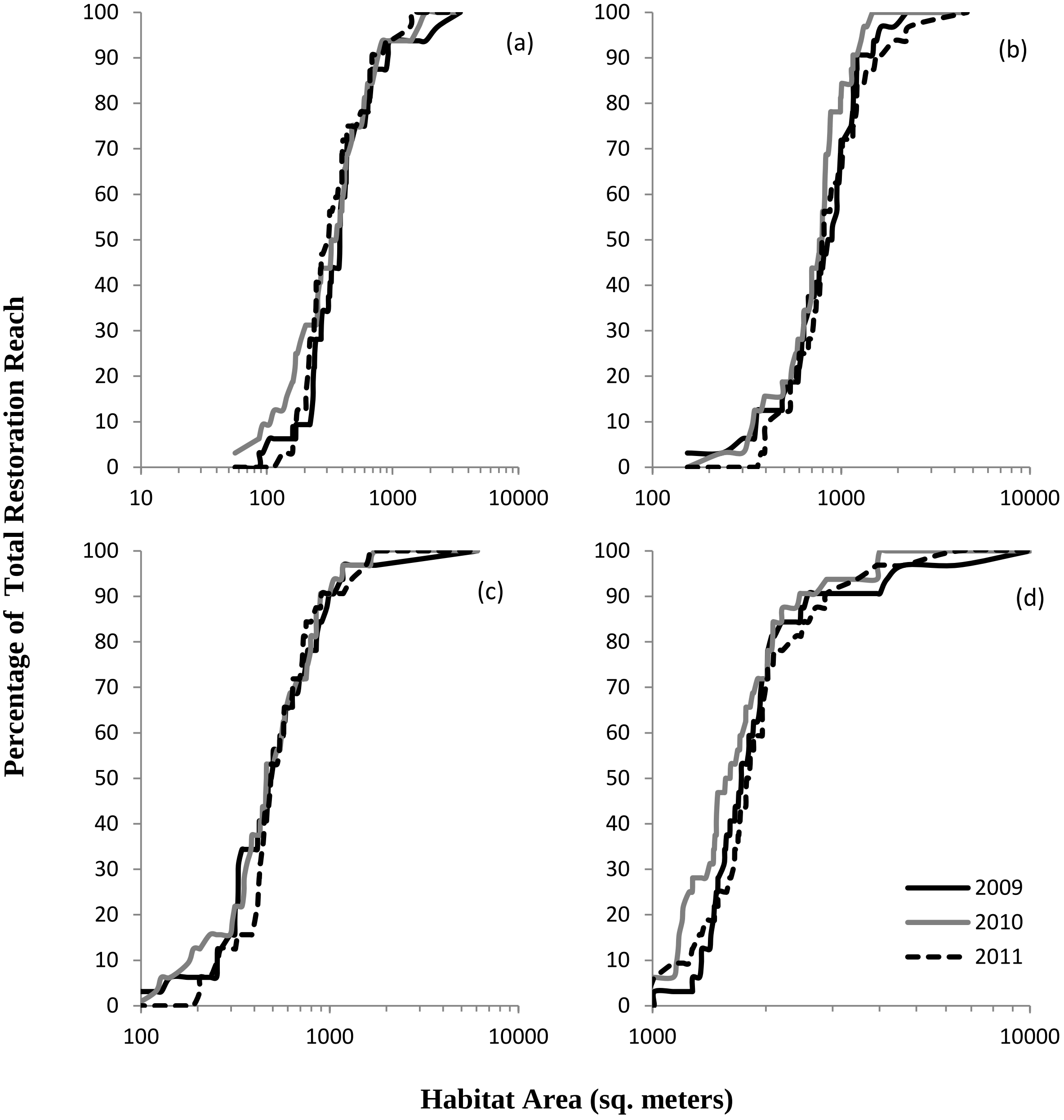
Presmolt_all 2010-2011

Notes:

- Letters A to J correspond to the rehabilitation projects listed in Table 1-1.
- Arrows show direction of change in habitat area at GRTS sites sampled in both 2010 and 2011.

Figure 2-2d

Presmolt Habitat Comparison 2010 (Circles) to 2011 (Squares)



Notes:

(a) optimal fry (dv_cover)

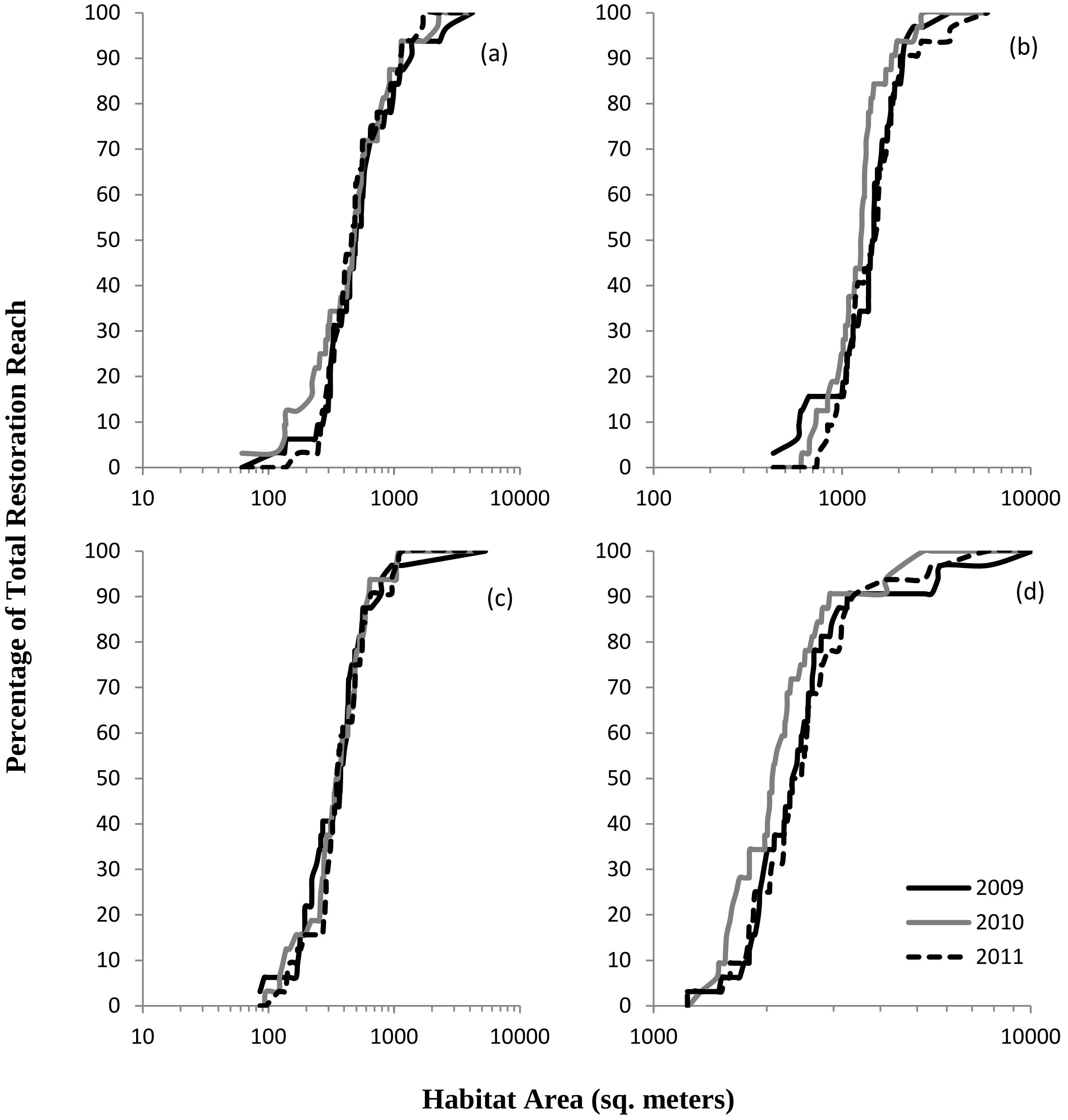
(b) suitable fry (dv_no_cover)

(c) suitable fry (cover_no_dv)

(d) total fry (all)

Figure 2-3

CDFs of Fry Habitat Areas



Notes:

(a) optimal presmolt (dv_cover)

(b) suitable presmolt (dv_no_cover)

(c) suitable presmolt (cover_no_dv)

(d) total presmolt (all)

The x axis is plotted on a log base 10 scale to show contrast between CDFs.

Figure 2-4

CDFs of Presmolt Habitat Areas

3.2.2 Trend Analysis

Results of the CDF tests showed four significant changes out of 24 comparisons (Table 2-2):

- A statistically significant negative change in suitable fry habitat that met depth/velocity criteria (dv_no_cover) from 2009 to 2010
- A statistically significant positive change in total fry habitat (all) from 2010 to 2011
- A statistically significant positive change in suitable presmolt habitat that met depth/velocity criteria (dv_no_cover) from 2010 to 2011
- A statistically significant positive change in total presmolt habitat (all) from 2010 to 2011

In each of these cases, the 2010 distribution is shifted to the left (toward smaller habitat areas) compared to the 2009 or 2011 distributions. There were no significant changes in CDFs between the pair of years 2009 and 2011.

Table 2-2

Results of Wald F Tests Comparing Rearing Habitat Cumulative Distribution Functions between all Pairs of Years

Habitat Type	Yr1	Yr2	Med1	Med2	F	Num. d.f.	Den. d.f.	P-value	
fry_dv_cover	2009	2010	381	345	0.15	2	61	0.86	
fry_dv_cover	2009	2011	381	311	1.20	2	59	0.31	
fry_dv_cover	2010	2011	345	311	0.65	2	59	0.52	
fry_dv_no_cover	2009	2010	877	781	3.33	2	61	0.04	*
fry_dv_no_cover	2009	2011	877	801	0.97	2	59	0.38	
fry_dv_no_cover	2010	2011	781	801	1.43	2	59	0.25	
fry_cover_no_dv	2009	2010	488	463	0.09	2	61	0.91	
fry_cover_no_dv	2009	2011	488	489	1.09	2	59	0.34	
fry_cover_no_dv	2010	2011	463	489	0.91	2	59	0.41	
fry_all	2009	2010	1722	1588	2.17	2	61	0.12	
fry_all	2009	2011	1722	1797	0.64	2	59	0.53	
fry_all	2010	2011	1588	1797	3.62	2	59	0.03	*
presmolt_dv_ cover	2009	2010	497	479	0.73	2	61	0.48	
presmolt_dv_ cover	2009	2011	497	459	0.98	2	59	0.38	
presmolt_dv_ cover	2010	2011	479	459	0.07	2	59	0.93	

Habitat Type	Yr1	Yr2	Med1	Med2	F	Num. d.f.	Den. d.f.	P-value	
presmolt_dv_no_cover	2009	2010	1464	1266	2.96	2	61	0.06	
presmolt_dv_no_cover	2009	2011	1464	1483	0.57	2	59	0.57	
presmolt_dv_no_cover	2010	2011	1266	1483	6.68	2	59	0.00	*
presmolt_cover_no_dv	2009	2010	375	355	0.39	2	61	0.68	
presmolt_cover_no_dv	2009	2011	375	353	1.62	2	59	0.21	
presmolt_cover_no_dv	2010	2011	355	353	0.60	2	59	0.55	
presmolt_all	2009	2010	2367	2075	1.62	2	61	0.21	
presmolt_all	2009	2011	2367	2406	0.48	2	59	0.62	
presmolt_all	2010	2011	2075	2406	3.48	2	59	0.04	*

Notes:

- The asterisks denote significance at the $\alpha = 0.05$ level.
- The medians of the habitat area of sampled segments are columns ‘Med1’ and ‘Med2,’ corresponding to ‘Yr1’ and ‘Yr2,’ respectively.

Results of the Wilcoxon Signed-Rank Test for differences in mean habitat area for paired observations are given in Table 2-3. The span between 2009 and 2010 turned up a significant difference in mean habitat area. Four habitat types showed a statistically significant negative change between 2009 and 2010 at Panel 2: optimal fry habitat (dv_cover), total fry habitat (all), optimal presmolt habitat (dv_cover), and total presmolt habitat (all). None of the habitat types showed a significant change in area between 2010 and 2011 at Panel 3.

Table 2-3

Results of Wilcoxon Signed-Rank Test Using Panels from Adjacent Years to Test for Differences in Mean Habitat Area for Paired Observations

Habitat	Yr1	Yr2	M1	M2	Estimate	Statistic	Ndiff	P-value	
fry_dv_cover	2009	2010	538	452	-86	122	16	0.00	*
fry_dv_cover	2010	2011	425	377	-48	88	16	0.32	
fry_dv_no_cover	2009	2010	743	689	-54	95	16	0.18	
fry_dv_no_cover	2010	2011	847	923	76	61	16	0.74	
fry_cover_no_dv	2009	2010	605	599	-5	64	16	0.86	

Habitat	Yr1	Yr2	M1	M2	Estimate	Statistic	Ndiff	P-value	
fry_cover_no_dv	2010	2011	528	509	-19	75	16	0.74	
fry_all	2009	2010	1885	1740	-145	113	16	0.02	*
fry_all	2010	2011	1800	1810	9	65	16	0.90	
presmolt_dv_ cover	2009	2010	730	618	-111	126	16	0.00	*
presmolt_dv_ cover	2010	2011	580	527	-53	72	16	0.86	
presmolt_dv_no_ cover	2009	2010	1288	1179	-108	98	16	0.13	
presmolt_dv_no_ cover	2010	2011	1387	1494	107	58	16	0.63	
presmolt_cover_ no_dv	2009	2010	414	433	19	53	16	0.46	
presmolt_cover_ no_dv	2010	2011	373	360	-13	73	16	0.82	
presmolt_all	2009	2010	2431	2231	-200	116	16	0.01	*
presmolt_all	2010	2011	2340	2381	41	59	16	0.67	

Notes:

- Observations are paired by GRTS segment, which allows comparison between adjacent years according to the rotating panel design.
- Columns ‘M1’ and ‘M2’ represent the observed means in ‘Yr1’ and ‘Yr2,’ respectively.
- Column ‘Ndiff” represents the number of paired differences.
- Asterisks denote significance at the $\alpha = 0.05$ level.

The segment-specific changes in habitat areas for 2009 to 2010 and 2010 to 2011 are depicted in Figure 2-2. These plots reveal that site-specific differences in habitat area have an important spatial structure for 2010 to 2011. Trends in area data tended to be upward (green) for habitats within 30 kilometers (km) of Lewiston that met the cover criteria optimal (dv_cover) and suitable (cover_no_dv), but downward (red) at locations greater than 30 km downstream of Lewiston Dam. This is true for both fry and presmolt data. Also, trends tended to be upward (green) for suitable habitat that met the distance/velocity criteria (dv_no_cover) for units within 30 km of Lewiston Dam, but downward (red) for units located more than 30 km downstream from Lewiston Dam.

Results of the Unit Slope Analysis showed no significant upward trends in habitat area during the 2009 to 2011 period (Table 2-4). In contrast, two of the rearing habitat types (optimal fry and optimal presmolt) showed a significant downward trend in area. These results were unchanged regardless of whether bootstrapping was used with the assumption of independent observations (slopes), or whether a normal approximation was used along with the NBH variance estimator to account for spatial autocorrelation in the slopes.

Table 2-4

Results of Unit Slope Analysis using the Bootstrapping Approach and the Normal Approximation with the Localized Neighborhood Variance Estimator

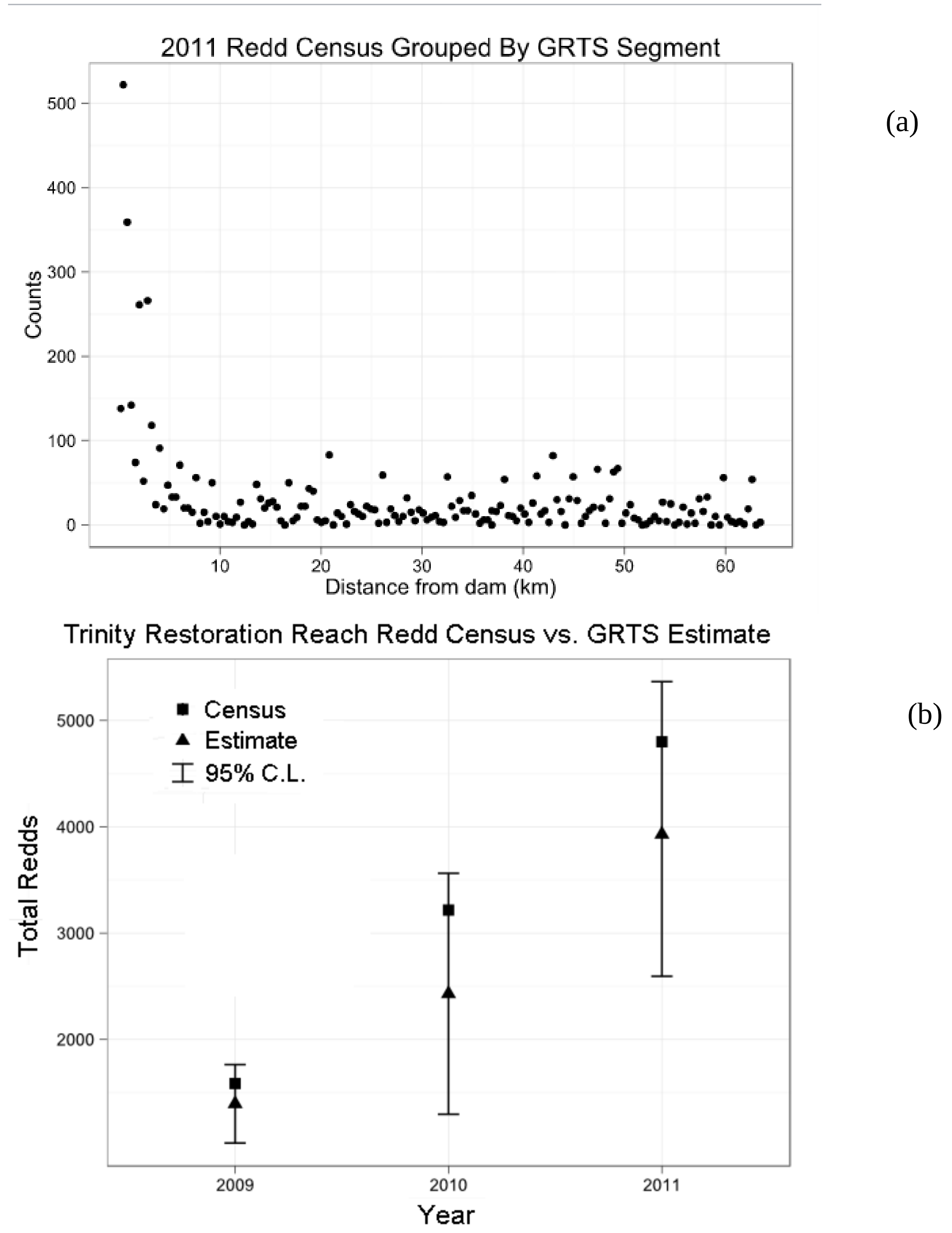
Habitat	Estimate	SE	Statistic	Nsamp	P-value	
Bootstrap						
fry_dv_cover	-66.8	23.5	-2.84	32	0.01	*
fry_dv_no_cover	11.1	54.1	0.21	32	0.84	
fry_cover_no_dv	-12.1	27.6	-0.44	32	0.66	
fry_all	-67.8	50.1	-1.35	32	0.19	
presmolt_dv_cover	-82.1	30.6	-2.69	32	0.02	*
presmolt_dv_no_cover	-0.6	74.3	-0.01	32	0.99	
presmolt_cover_no_dv	3.0	23.0	0.13	32	0.89	
presmolt_all	-79.8	67.2	-1.19	32	0.24	
Localized Neighborhood Variance (with normal approximation)						
fry_dv_cover	-66.8	18.0	-3.71	32	0.00	*
fry_dv_no_cover	11.1	45.8	0.24	32	0.81	
fry_cover_no_dv	-12.1	18.8	-0.64	32	0.52	
fry_all	-67.8	39.7	-1.71	32	0.09	
presmolt_dv_cover	-82.1	21.7	-3.78	32	0.00	*
presmolt_dv_no_cover	-0.6	62.5	-0.01	32	0.99	
presmolt_cover_no_dv	3.0	17.8	0.17	32	0.87	
presmolt_all	-79.8	55.1	-1.45	32	0.15	

Notes:

- ‘Estimate’ represents the sample mean of the slopes, and the statistic is an observed t-value.
- ‘Nsamp’ represents the number of slopes used for each estimate.
- The number of bootstrap replications of the test statistic was 5,000.
- The asterisks denote significance at the $\alpha = 0.05$ level.

3.2.3 Estimate vs. Census (Redd Counts)

The confidence intervals for the estimated total number of redds contained the true census value in all years (2009 to 2011), which indicates the GRTS sampling design adequately estimated the actual redd count each year. Confidence interval widths increased with an increased number of redds censused, and both the estimate and the census of total number of redds increased during the 2009 to 2011 period (Figure 2-5). The confidence interval widths were 738; 2,266; and 2,671 redds in 2009, 2010, and 2011, respectively. The point estimates for total redds were 1,395; 2,430; and 3,930 for 2009, 2010, and 2011, respectively. Similar to habitat area, the number of observed redds tended to decrease with distance from the Lewiston Dam. In addition, there is considerable local heterogeneity in the redd distribution (i.e., the observed redds tended to be clustered in specific areas).



Notes:

(a) The redd count data exhibits strong spatial dependence and decreasing redd counts with distance from Lewiston Dam.

(b) The confidence intervals encompass the known total redds.

Figure 2-5

GRTS Total Estimate Results Compared to Known Census

4 DISCUSSION

The GRTS analysis showed no significant upward trend in juvenile rearing habitat area across the entire 2009 to 2011 period for the eight habitat types studied. Two of the habitat types (fry_dv_cover and presmolt_dv_cover) showed a significant downward trend during this period. Each of these habitat types represents optimal habitat. Results of analyses of changes in CDF indicated there are significant changes in the distribution of habitat in the restoration reach between 2009 and 2010 and between 2010 and 2011. Between 2009 and 2010, there was a downward shift in the amount of suitable fry habitat (fry_dv_no_cover). Between 2010 and 2011, there was an upward shift in total fry (fry_all) and presmolt habitat (presmolt_all) and suitable presmolt habitat (dv_no_cover).

However, it is difficult to fully interpret these results until more years of data have been collected and the rotating panel revisit design has been fully implemented. This is because the results indicate important variability over time that may be due to random yearly variation, and if this is the case, the random variation over time needs to be considered as well as variation over space for an analysis of trend. Temporal variation may mask a trend in these data, and the only way to resolve this statistically is to collect additional years of data so that sufficient observations are available to estimate temporal variance in the different types of rearing habitat area.

At this juncture, it is worth evaluating the GRTS design to see if it is working as intended and determine ways to improve it further if needed (Pickard 2011). The possibility of stratification should also be explored (Stevens and Olsen 2004) and index sampling, simple random sampling, systematic sampling, stratified sampling, adaptive cluster sampling, and a spatially balanced design (e.g., GRTS) (Courbois et al. 2008) should be considered. Potential refinements to the current design could include adjusting the segment length of sampled units by exploring the effect of changing the current 400 m segments to 50 m, 100 m, or 200 m. For example, the restoration reach could be partitioned into confined and unconfined segments, areas adjacent to tributary inputs and not, modified and unmodified lengths, or upstream and downstream locations. In some instances, stratification produces a more representative sample and may reduce sampling variability.

Also, the number of years of study and number of sites visited per year should be evaluated. The Program Partners are currently undertaking a power analysis, which could be used to resolve several key design questions, including:

- Is the current strategy of sampling 32 sites per year delivering the desired precision of the estimator of total rearing habitat over the entire restoration reach?
- What is the precision necessary to evaluate the trend over time?

- What revisit structure should be used and how frequently should sites be revisited?
- Should all sample units receive equal weighting (the current method) or should units with more abundant resources be weighted more heavily?

The most important feature of any power analysis is determining the precision of the estimator of interest. In the case of the restoration reach, precision of the estimators of total response and trend drive the power analysis. The different sources of variation affecting the precision of the total response and trend estimators include spatial, temporal, and residual variation (Kaufmann et al. 1999). Spatial variation is the site-to-site variation. Temporal variation contains both synchronous variance due to variables such as flow and independent variation due to local effects at individual units. Residual variation is due to seasonal variation during sampling, crew-to-crew differences in applying the sampling protocol, and measurement error. As we have seen in the first three years of data, the ability to estimate long-term trends will depend not only on the spatial variance (characterizing the variability between samples in space), but also temporal variability. Temporal variability can obscure trends over time and may be caused by synchronous variation caused by an important variable linked to habitat area measure such as flow. The result of the power analysis will be an estimate of the number of years GRTS sampling is needed to produce a reliable estimate of trend.

Another important consideration is the time required for the ecosystem to respond to increased flow and rehabilitation projects (TRRP and ESSA 2009). It is difficult to predict how quickly different components of the ecosystem might respond. Reactions of physical processes to flow and sediment augmentation might be sudden, but response of suitable rearing habitat for juvenile fish and wildlife habitat may take more than a decade to develop. Furthermore, rates of change in habitat area may depend on the proportion of wetter water years in the future, with faster rates of increase associated with a higher proportion of wet water years.

Another issue to consider is the multi-discipline nature of the monitoring with differing goals. A key question is whether or not a single GRTS design can address multiple goals. The answer will depend on the types of data collected at the GRTS sites and the spatial distribution of the restoration reach. Optimizing the sampling design for one question will not necessarily result in an optimum design for other questions (Pickard 2009). One possibility for addressing this is the use of a master sample to integrate different programs and objectives (Larsen et al. 2008).

Results of the initial test of the ability of the GRTS design to estimate a total resource were positive. The confidence intervals for the estimated total number of redds (total response) based on the GRTS design contained the true value observed during census surveys for 2009 through 2011. In future work, the redd count data should be used to further test the GRTS design and analysis. Because the redd counts represent a census, the redd counts may be used to fully test the true accuracy and precision of the estimator of total responses as well as the NBH variance estimator. By drawing thousands of GRTS samples from the redd census, it is possible to calculate the known sampling distribution of both the total response and the NBH estimator. From these sampling distributions, both bias and variance of the total response NBH estimators may be calculated.

5 ACKNOWLEDGEMENTS

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ATTACHMENT 1

R-CODE USED TO GENERATE THE GRTS DESIGN AND ANALYZE REARING HABITAT DATA

Table A-1
R-Code that may be Used to Draw a Sample from the 160 Segments of the Trinity Restoration Reach

```
#An unstratified, equal probability, GRTS survey design was used in which each of the 160
#segments had an equal probability of being selected. There were 5 panels used, each
#containing a sample of size 16. There were 16 oversamples selected. Needed for input are the
#files pts400.shp and pts400.dbf that provide attribute data and the x and y coordinates of the
#midpoints of river segments. Coordinates are based on the California State Plane Zone #1
#projected coordinate system. The files used as inputs are Environmental Systems Research
#Institute, Inc. (ESRI) shapefiles. The ESRI projection file used in the analysis is specified by
#prjfilename= “center”. The output shape file, which includes information about which units
#were selected is given in the output shape file “grts400pts”.
#load spsurvey
library(spsurvey)
#assign directory
att <- read.dbf("pts400")
cat("The initial six lines in the attribute data frame follow:\n\n")
print(head(att))

Equaldsgn <- list(None=list(panel=c(Panel_1=16, Panel_2=16, Panel_3=16,
Panel_4=16,Panel_5=16), seltype="Equal",over=16))
cat("\nThe following information is printed by \"grts\" while it is executing:\n")
Equalsites <- grts(design=Equaldsgn,
            DesignID="ID400",
            type.frame="finite",
            src.frame="shapefile",
            in.shape="pts400",
            att.frame=att,
            prjfilename="center",
            out.shape="grts400pts")
```

Note:

This code was modified from code provided by the U.S. Fish and Wildlife Service.

Table A-2

R-code Used to Calculate the HT Variance Estimator

```
#Horvitz-Thompson Variance Estimator assuming EQUAL probability sampling
#See Horvitz and Thompson (1952; equation 11)
#inputs
#z are the observations (habitat measures in sampled units).
#N is the total number of segments in the restoration reach universe
#outputs
#Statistic is the population total estimate
#NResp is the number of sampled segments
#Estimate is the total population estimate (That)
#StdError is the standard error of the total population estimate
#LCB95Pct is the lower 95% confidence limit based on normal approximation
#UCB95Pct is the upper 95% confidence limit based on normal approximation
ht.total.est<-function(z, N)
{
#get rid of missing values
 iii<-!is.na(z)
 z<-z[iii]
 n<-length(z)
 P<-n/N
 P2<-n*(n-1)/(N*(N-1))
 T<-sum(z)/P
 V<-T*T - sum(z*z)/P
 mymat<-z%*%t(z)
 diag(mymat)<-0
 V<-V-sum(mymat)/P2
 my.dat<-data.frame(Statistic="Total",NResp=n,Estimate=T,StdError=sqrt(V),
   LCB95Pct=T-1.959964*sqrt(V),UCB95Pct=T+1.959964*sqrt(V))
 return(my.dat)
}
```

Table A-3
R-Code Used To Estimate CDFs And Response Totals

```
# Purpose: Population estimates for four habitat categories
# _dv_cover habitat satisfying both dv and cover criteria
# _dv_no_cover habitat satisfying the dv criteria but not the cover criteria
#_cover_no_dv habitat satisfying the cover criteria but not the depth/velocity criteria
#_all the total of the previous three habitat areas types.
# These are estimated  for two life stages (fry and presmolt)
# Programmer:  Damon Goodman modified from code from Tony Olsen
# Date: June 20, 2011
# Revised: February 13, 2012
# Revised: July17, 2012 by Richard. A. Hinrichsen for Phase 1 review

# Load the spsurvey library
library(spsurvey)

#Set working directory
# Read in fry and presmolt data from single file with design information
att<-read.table("GRTSDATA2011.csv",sep=",",header=T)

head(att)

# Create unique site IDs
att$siteID <- uniqueID(att$siteid)

# set up data frames for cont.analysis function population estimates.
# define which sites to use for indicator population estimates
sites_samp <- data.frame(siteID=att$siteID,
            Use=rep(TRUE, nrow(att)) )
# set up subpopulations for which estimates are required
subpop <- data.frame(siteID=att$siteID,
             Year=att$yr_sampled)
# set up design information
#adjust weights using inclusion probabilities for one year (0.20) instead of 5 years (0.50)
dsgn <- data.frame(siteID=att$siteID,
           wgt=att$wgt*5/2,
           stratum=att$stratum,
           xcoord=att$xcoord,
           ycoord=att$ycoord)
# set up variables to be estimated data.frame
data_cont <- data.frame(siteID=att$siteID,
   fry_dv_cover=att$fry_dv_cover,
   fry_dv_no_cover=att$fry_dv_no_cover,
```

```
    fry_cover_no_dv=att$fry_cover_no_dv,
    fry_all=att$fry_all,

    presmolt_dv_cover=att$presmolt_dv_cover,
    presmolt_dv_no_cover=att$presmolt_dv_no_cover,
    presmolt_cover_no_dv=att$presmolt_cover_no_dv,
    presmolt_all=att$presmolt_all,
    test=att$test)

Cont_Est <- cont.analysis(sites=sites_samp, subpop=subpop, design=dsgn, data.cont=data_cont,
   total=TRUE)
```

APPENDIX C
ANALYSIS OF CHANNEL REHABILITATION SITES

Prepared Under the Direction of
Trinity River Restoration Program's Scientific Advisory Board

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April 2014

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LIST OF ACRONYMS AND ABBREVIATIONS

AEAM	Adaptive Environmental Assessment and Management
cfs	cubic feet per second
CI	confidence interval
DTM	digital terrain model
DVC	depth, velocity, and cover
FL	fork length
GRTS	generalized random tessellation stratified
IAP	Integrated Assessment Plan
IHAP	Integrated Habitat Assessment Project
LWD	large woody debris
m2	square meters
$m^3 \cdot s^{-1}$	cubic meters per second
mm	millimeter
Program	Trinity River Restoration Program
RKM	river kilometer
RM	river mile
ROD	Record of Decision
SAB	Scientific Advisory Board
TRFEFR	Trinity River Flow Evaluation Final Report
USGS	U.S. Geological Survey
WY	Water Year

1 INTRODUCTION

The primary goal of the Trinity River Restoration Program (Program) is to restore and sustain the natural production of anadromous fish populations downstream of Lewiston Dam to pre-dam levels to facilitate dependent tribal, commercial, and sport fisheries' full participation in the benefits of restoration via enhanced harvest opportunities (TRRP and ESSA 2009; USBR 2009). The Trinity River Flow Evaluation Final Report (TRFEFR) recommended, and the Record of Decision (ROD; USDOI 2000) adopted, the following strategy that integrates restoration of riverine processes with the instream flow-dependent needs of salmonids (USFWS and HVT 1999):

> *The most practical strategy to achieve fish habitat rehabilitation is a management approach that integrates riverine processes and instream flow dependent needs. This management approach physically reshapes selected channel sections, regulates sediment input, and prescribes reservoir releases to (1) allow fluvial processes to reshape and maintain a new dynamic equilibrium condition and (2) provide favorable water temperatures.*

This strategy is intended to rehabilitate the Trinity River ecosystem to improve and maintain fish and wildlife resources through: 1) mechanical rehabilitation of the channel; 2) flow management to restore fluvial processes that create and maintain suitable salmonid habitat and to meet water temperature objectives for juvenile and adult salmonids; 3) coarse and fine sediment management; and 4) watershed restoration (USDOI 2000).

The Program implemented 15 channel rehabilitation projects between 2005 and 2010 as part of Phase 1 (Figure 1-1, Table 1-1). The remaining channel rehabilitation projects are scheduled to be completed by 2013 during Phase 2 of the Program. The 15 projects constituted approximately half of the projects initially envisioned by the TRFEFR and proposed in the ROD (USFWS and HVT 1999; USDOI 2000). Post-construction monitoring and evaluation of changes in habitat conditions at the project locations combined with the performance of other ROD elements has been conducted by the Program Partners in accordance with the objectives identified in the Program's Integrated Assessment Plan (IAP; TRRP and ESSA 2009), and adjusted as needed consistent with the Adaptive Environmental Assessment and Management (AEAM) framework identified in the ROD (Stalnaker and Wittler 2000).

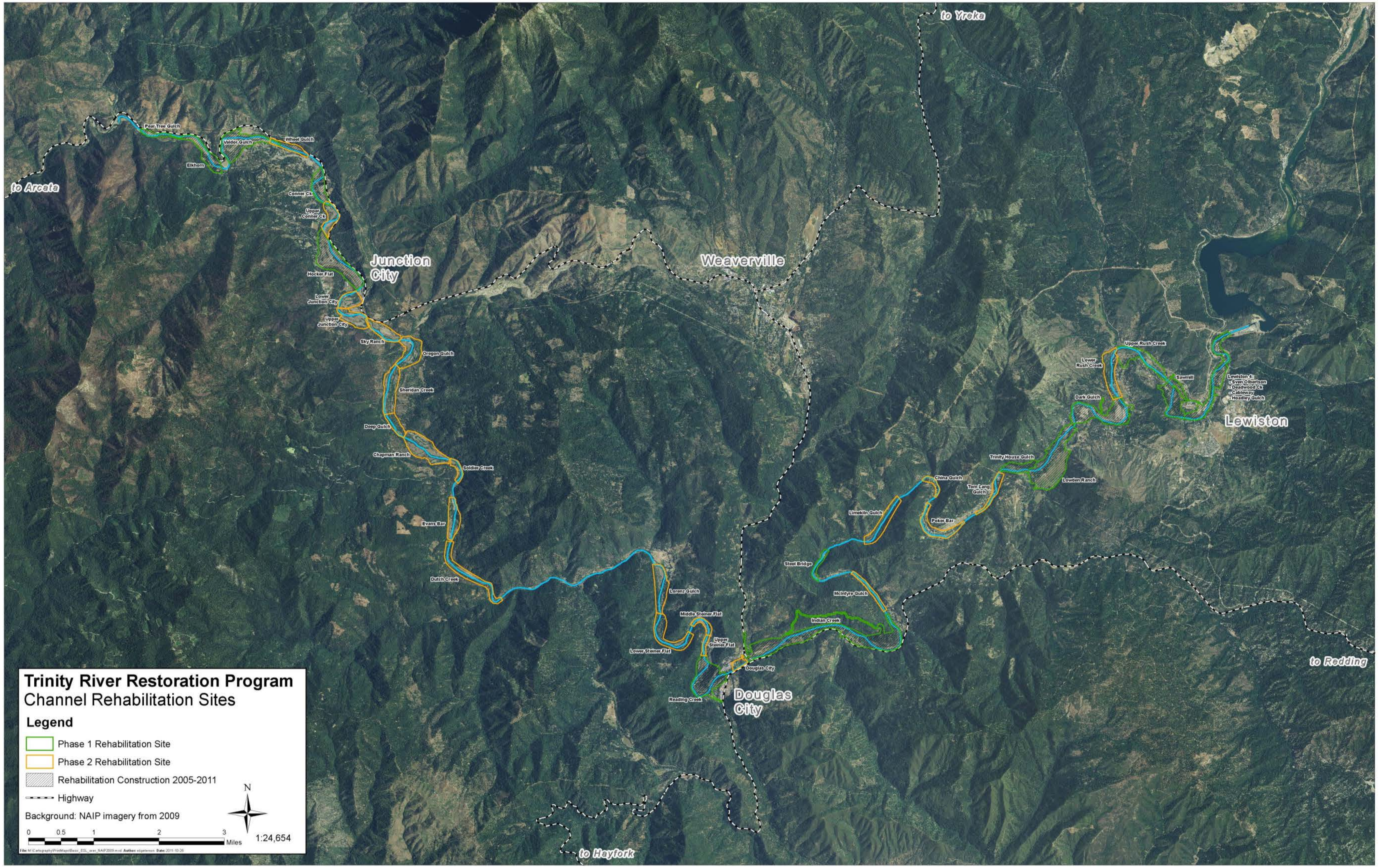


Figure 1-1

Phase 1 and Phase 2 Channel Rehabilitation Sites in the Trinity River Management Reach

Table 1-1
Channel Rehabilitation Sites Constructed in the Trinity River Management Reach during Phase 1

Phase 1 Site	Date Completed	Location (RM)	Length (miles)
Pear Tree	2006	72.9 – 73.2	0.30
Elkhorn	2006	73.7 – 74.3	0.55
Valdor Gulch	2006	74.8 – 75.7	0.90
Conner Creek	2006	77.0 – 77.4	0.40
Hocker Flat	2005	78.0 – 79.1	1.10
Reading Creek	2010	92.2 – 93.1	0.90
Indian Creek-Vitzhum Gulch	2007	93.9 – 96.9	2.97
Trinity House Gulch	2010	104.0 – 104.4	0.40
Lowden Ranch	2010	104.4 – 105.3	0.89
Bucktail-Dark Gulch	2008	105.5 – 107.0	1.53
Sawmill	2009	108.9 – 109.7	0.80
Hoadley Gulch	2008	109.8 – 110.1	0.30
Lewiston Cableway	2008	110.2 – 110.5	0.28
Deadwood Creek	2008	110.5 – 111.0	0.50
Sven Olbertson	2008	111.2 – 111.6	0.41

Performance monitoring of the Program’s Phase 1 channel rehabilitation projects is critical to informing Phase 2 channel rehabilitation designs. The Integrated Habitat Assessment Project (IHAP; Alvarez et al. 2011) was an effort to bring together individual assessments in geomorphology, aquatic and riparian habitat, and wildlife as envisioned in the IAP (TRRP and ESSA 2009). The IAP identified six primary objectives to guide development and prioritization of assessments and analysis as part of the AEAM framework:

- Objective 1: Create and maintain spatially complex channel morphology.
- Objective 2: Increase/improve habitat for freshwater life stages of anadromous fish to the extent necessary to meet or exceed production goals.
- Objective 3: Restore and maintain natural production of anadromous fish populations.
- Objective 4: Restore and sustain natural production of anadromous fish populations downstream of Lewiston Dam to pre-dam levels, to facilitate dependent tribal, commercial, and sport fisheries’ full participation in the benefits of restoration via enhanced harvest opportunities.
- Objective 5: Establish and maintain riparian vegetation that supports fish and wildlife.

- Objective 6: Rehabilitate and protect wildlife habitats and maintain or enhance wildlife population following implementation.

The IAP provides a systemic approach for monitoring progress made toward achieving the Program goals identified in the ROD. Each of the IAP's primary objectives includes sub-objectives specifying a hypothesis describing functional relationships within the Trinity River ecosystem, an assessment strategy and rationale, measures to judge progress and performance of the Program's elements and actions, expectations regarding response and monitoring timeframes and spatial scales, and any priority issues to address.

Numerous monitoring activities and technical analyses aimed at characterizing changes in fluvial geomorphology and associated anadromous fish habitat at the system and rehabilitation site scales have been completed or are in progress. These activities are guided by the hierarchy of objectives, assessment methodologies, and performance measures outlined in the IAP or identified by the Program's technical working groups, the Trinity Management Council, the Trinity River Adaptive Management Working Group, or the Program's Scientific Advisory Board (SAB).

Monitoring activities and technical analyses related to geomorphic processes are based on the objectives and assessment methodologies outlined in the IAP for Objective 1 (Table 1-2). The specific assessments recommended by the IAP to address Objective 1 include the following:

- Periodic mapping of channel complexity metrics
- Mainstem coarse sediment (bedload) transport and computations of mainstem coarse sediment budget
- Rush Creek tributary sediment delivery
- Mainstem fine sediment (suspended and bedload) transport
- Bed mobility and scour thresholds

Table 1-2

IAP Objectives Related To Creating and Maintaining Spatially Complex Channel Morphology

Objectives			Priority
Level 1	**Level 2**	**Level 3**	
1. Create and maintain spatially complex channel morphology	1.1. Increase physical habitat diversity and availability	1.1.1 Increase the size, frequency, and topographic relief of bar/pool sequences	M
		1.1.2 Increase channel/thalweg sinuosity	H
		1.1.3 Increase geomorphic unit and substrate patch diversity	L

Objectives			Priority
Level 1	Level 2	Level 3	
	1.2 Increase coarse sediment transport and channel dynamics	1.2.1 Increase and maintain target coarse sediment transport rates	H
		1.2.2 Frequently exceed channel migration, bed mobilization, and bed scour thresholds	H
		1.2.3. Encourage bed-level fluctuations on annual to multi-year time scales	L
		1.2.4 Route coarse sediment through all reaches	L
	1.3 Increase and maintain coarse sediment storage	1.3.1 Increase bars, side-channels, alcoves, and other complex alluvial features	H
	1.4 Reduce fine sediment storage in the mainstem Trinity River	1.4.1 Transport fine sediment through mainstem at a rate greater than tributary input	H
		1.4.2 Reduce fine sediment supply from tributary watersheds	M
		1.4.3 Encourage fine sediment deposition on floodplains	L

Monitoring activities and technical analyses related to anadromous fish habitat are based on the three levels of objectives and assessment methodologies outlined in the IAP for Objective 2 (Table 1-3). Of these, sub-objectives 2.1.1 and 2.1.2 are addressed by the channel rehabilitation monitoring activities and assessments relevant to this review. As described in the IAP, the initial priority for rehabilitation is the creation of rearing habitat for juvenile salmon from the fry through pre-smolt life stages (TRRP and ESSA 2009). Therefore, estimating the quantity and quality of suitable rearing habitat has been a high priority for the Program Partners.

Table 1-3

IAP Objectives Related to Increasing Anadromous Fish Habitat

Objectives			Priority
Level 1	Level 2	Level 3	
2. Increase/ improve habitats for freshwater life stages of anadromous fish to the extent necessary to meet or exceed production	2.1 Increase and maintain salmonid habitat availability for all freshwater (in-river and tributary) life	2.1.1 Increase/maintain salmonid fry and juvenile rearing habitat in the upper 40 miles of the mainstem Trinity River by a minimum of 400%[1] following rehabilitation of fluvial attributes	H(1)
		2.1.2 Increase/maintain spawning habitat quantity and quality to 2,550,000 square feet[2] in the upper 40 miles of the mainstem Trinity River	H(2)

Objectives			Priority
Level 1	**Level 2**	**Level 3**	
goals	stages	2.1.3 Create channel form that reduces loss of fry to stranding in the upper 40 miles of the mainstem Trinity River following rehabilitation during high flows	M
		2.1.4 Maintain or increase adult holding habitat from baseline conditions in the mainstem Trinity River	M
		2.1.5 Minimize physical impacts to lamprey habitat	M
		2.1.6 Minimize physical impacts to other native fish habitats	L
		2.1.7 Maintain or increase tributary habitat	M
	2.2 Improve riverine thermal conditions for growth and survival of natural anadromous salmonids	2.2.1 Provide optimal temperatures to improve spawning success of spring and fall-run Chinook salmon	H
		2.2.2 Improve thermal regimes for rearing growth and survival of juvenile steelhead, coho salmon, and Chinook salmon	H
		2.2.3 Improve thermal regimes for outmigrant salmonid growth and survival (dependent on water year)	H
		2.2.4 Minimize temperature impacts to other native fish habitats	L
	2.3 Enhance or maintain food availability for fry and juvenile salmonids	2.3.1 Increase and maintain macroinvertebrate populations	M

Notes:

1. This is an interim target provided in the IAP (TRRP and ESSA 2009) and will be revisited and revised as the Program learns more; 400% is a starting point only for a measure of progress and does not reflect an estimate of the habitat increase needed to fully meet salmonid production goals.
2. This is an interim target provided in the IAP (TRRP and ESSA 2009) and will be revisited and revised as the Program learns more.

The key assessments related to IAP Objectives 1 and 2 that were provided to the Phase 1 review team in draft or final form by the Program and the Program Partners are briefly discussed in Sections 3.3 and 3.4.

2 OBJECTIVES

This report reviews the information currently available to assess how well the Program's Phase 1 channel rehabilitation projects have performed after construction and over time. The objectives of this review are to: 1) synthesize the existing information regarding the Program's channel rehabilitation projects completed during Phase 1; 2) evaluate the project outcomes on an individual and combined basis relative to stated objectives, hypotheses, and the Program's mission; 3) identify any observed linkages between changes in fluvial forms and processes, critical attributes of fish habitat, and fish population responses; and 4) identify any data gaps and outline approaches for filling those gaps.

3 APPROACH

The review used existing information reported by the Program Partners and supplemented by additional analyses, as necessary and appropriate. The review considered the geomorphic context and flow exposure during the Phase 1 time period (2005 to 2011), differences in treatment types and objectives, and geomorphic and biological responses at the site and system scales. Because of differences in channel-forming factors affecting Phase 1 treatments and the scales involved, different approaches were employed to evaluate project effectiveness. Some of the same measurements and approaches were employed over different scales. Results are discussed in this report within the context of the geomorphic setting and land use history for each channel rehabilitation site.

The following questions guided the approach to evaluating the effects of direct channel manipulation at rehabilitation sites using results of monitoring programs and additional analyses:

1. Was the project constructed as designed?
2. Were the immediate goals of the project fulfilled?
3. Have the manipulations persisted?
4. Did the changes improve fish habitat?
5. Is the information in items 1 through 4, above, in a form that informs the key question: Is fish habitat quantity and quality increasing?

Channel rehabilitation treatments during Phase 1 can be generally grouped into two types of approaches:

- *Direct channel manipulation* (e.g., feathering edges, lowering of floodplains, construction of side channels and alcoves, wood placement) to alter channel morphology, flow patterns, and riparian vegetation in quasi-equilibrium with existing channel-forming processes; and
- *Restoration of natural channel processes* to enhance fluvial processes (e.g., bar formation) that lead to improved and more sustainable habitat conditions through changes in flow and sediment load (these effects are not confined to a particular site but generally extend over reaches).

The two approaches are intended to be complementary, such that altering channels by direct manipulation would also be sustained and propagated by enhancement of natural channel processes. For example, enhanced bed load transport might maintain the general form of point bars restored by bank feathering. However, side channel entrances might be blocked by upstream bar formation. Thus, active channel processes may limit or enhance the duration of intended positive effects of direct channel manipulations.

Evaluation of the success of actions intended to restore natural channel processes, including the addition of coarse sediment and changes in high flow regime (i.e., flow exposure), requires larger spatial scales and longer time periods than encompassed solely by the channel rehabilitation sites and their construction periods. For example, flow exposure influences the effects of coarse sediment addition, direct channel manipulation, and their interaction over time. Evaluating the effects of flow exposure on channel changes may be accomplished by relating geomorphic changes to the frequency, magnitude, and duration of high flow events (both the Program's flow releases and natural accretion flows), and through model simulations. Although it may not be possible at this stage of Program implementation to determine the specific effects of a particular flow, geomorphic changes can be assessed within the general context of Water Year (WY) type and its associated flow releases.

3.1 Geomorphic Context

Three primary factors affecting channel morphology, flow patterns, and fish habitat are local channel structure, flow regime, and bed load supply. All factors have been affected by a complex history of mining, large floods, and dam closure in the Trinity River; the legacy of these events is imprinted on more recent channel response to restoration practices. Local channel structure is directly manipulated at rehabilitation sites, while imposed changes in flow and sediment supply are intended to restore natural channel processes over broad reaches of river. At most rehabilitation sites, the channel has been subjected to changes in all three factors during the same period. Interactions between the three factors at various spatial and temporal scales, particularly when all three factors are altered simultaneously, can confound the evaluation of the effects of any one or a combination of treatments, and can complicate use of the results to develop predictions for how the channel structure will change over time. For example, the effect of a built log jam can be predicted and evaluated if changes due to flow and sediment are small or gradual, because such changes respond over a much longer time scale than changes due to the structure. Conversely, it is difficult to detect the effect of a new structure if the channel is also undergoing changes due to alterations in flow and sediment regimes.

Placing the effects of each rehabilitation site in a geomorphic context and analyzing effects of flow exposure and coarse sediment additions at a larger scale require a careful interpretation of geomorphic history, processes, and landforms at the appropriate scale. Reconstruction of the geomorphic history of the mainstem Trinity River and the legacy of these effects on current processes and landforms by Krause (2012a) has provided a valuable conceptual background for describing geomorphic context. Ongoing work by the Program Partners will help to specify how this is manifested at any location in the river. In the meantime, we assumed that these legacy effects are imprinted on local channel conditions such as gradient, channel pattern, and channel dimensions.

Channel and valley morphology influence how channels respond to variations in flow, sediment supply, and imposed structural changes. To analyze rehabilitation effectiveness in a geomorphic context, we used two spatial scales for channel length: link (lengths on the order of 10^3 m) and reach (lengths on the order of 10^2 m). The link scale includes aggregating reaches of different types into a larger scale reflecting overall downstream changes in flow and sediment supply or storage. Classifying or stratifying channels at the reach scale might help to evaluate how certain channel forms influence rehabilitation effectiveness and how such forms persist or evolve from one type to another under changing conditions. Link-scale channel designations were provided by the Channel Rehabilitation Design Guidelines (HVT et al. 2011) and by Krause (2012a); a reach classification was provided by Beechie et al. (2012).

Channel dimensions and characteristics (e.g., width, gradient, and bank characteristics) at the reach scale provide data to test the characterization of features by channel stratification. The reach scale is defined as 20 bankfull channel-widths, which conforms to the conventional minimum channel length used to approximate reach-averaged energy slope from topographic measures independent of discharge (e.g., Leopold and Skibitzke 1967). Given an average bankfull width of about 70 m (230 feet), we computed reach-averaged values of width and slope over a channel length of 1,400 m (4,593 feet), or seven 200-m (656-foot) segments centered on the middle segment, starting at the North Fork confluence. We extracted reach-averaged wetted width at 170 $m^3 \cdot s^{-1}$ (6,000 cubic feet per second [cfs]) and channel slope from values attributed to 200-m (656-foot) channel segments in the Phase 1 review data frame (Appendix D). Width values were generated from a polygon of wetted channel area at 6,000 cfs provided by the Program using values predicted from HEC-RAS (DWR 2007). This discharge approximates spring ROD flows during a normal water year (HVT et al. 2011). We assume a constant discharge given that downstream accretion of flow from tributaries during normal-year ROD flows is relatively minor (HVT et al. 2011). Channel slope values were calculated from water surface elevations derived from 2009 LiDAR data provided by the Program. Channel confinement and bank characteristics were mapped in the Trinity River from Lewiston Dam to the North Fork Trinity River in 2006 prior to construction of Phase 1 channel rehabilitation sites (Dave Gaeuman, Trinity River Restoration Program, unpublished data).

3.2 Flow Exposure

The magnitude and duration of high flow exposure is a major driver in shaping river channel morphology and producing changes in fish habitat. Other hydrograph components provide fish spawning and rearing habitat. The Trinity River is regulated such that high flows are lower in magnitude and shorter in duration than under pre-dam conditions. The magnitude and variability of flow during the rest of the year has also been reduced. The Program is striving to compensate for changes in river channel morphology and fish habitat caused by the altered flow and sediment regimes associated with the Trinity Dam by restoring fluvial processes scaled appropriate to a new sediment and flow regime. In Sections 5, flow exposure by reach and by site are reviewed to provide a context for evaluating changes in river channel morphology and fish habitat from actions performed by the Program.

Trinity River daily flows were estimated at various key locations (nodes) between Lewiston Dam and its confluence with the North Fork Trinity River for WYs 2003 to 2011. Flows were estimated using average daily flows from existing gages on the Trinity River, tributary average daily flows from gage data, and basin areas at key nodes. Key locations (nodes) along the Trinity River were determined based on locations of significant flow and/or sediment input changes and data availability. Nodes used in the analysis were located at U.S. Geological Survey (USGS) gage locations or immediately downstream of significant tributaries (Table 3-1).

Table 3-1

Trinity River Key Nodes – Lewiston Dam to North Fork Confluence (Upstream to Downstream)

Node Name	Node Type	Relevant USGS Gage Number	Relevant Period of Record
Lewiston	USGS Gage Location	11525500	10/1/2002 to 9/30/2011
Deadwood Creek	Tributary Confluence	11525520	Field measurements only
Rush Creek	Tributary Confluence	11525530	10/1/2002 to 10/28/2002; 4/17/2003 to 9/30/2011
Above Grass Valley	USGS Gage Location	11525540	4/1/2006 to 7/31/2006
Grass Valley Creek	Tributary Confluence	11525630	10/1/2004 to 9/30/2011
Trinity House Gulch	Tributary Confluence	None	None
Limekiln	USGS Gage Location	11525655	10/1/2002 to 9/30/2011
Indian Creek	Tributary Confluence	11525670	10/1/2004 to 9/30/2011
Weaver Creek	Tributary Confluence	11525750	Field measurements only
Reading Creek	Tributary Confluence	None	None
Douglas City	USGS Gage Location	11525854	10/1/2002 to 9/30/2011
Browns Creek	Tributary Confluence	11525900	Field measurements only

Node Name	Node Type	Relevant USGS Gage Number	Relevant Period of Record
Junction City	USGS Gage Location	11526250	10/1/2002 to 9/30/2011
Canyon Creek	Tributary Confluence	11526300	None
Above North Fork	USGS Gage Location	11526400	3/29/2005 to 9/30/2011

Methodologies for estimating average daily flows for the key nodes listed in Table 3-1 varied depending on the node type. USGS gage locations Lewiston, Limekiln, Douglas City, and Junction City have the full period of record from WYs 2003 to 2011; therefore, the flows were obtained directly from gage data. For USGS gage locations Above Grass Valley and Above North Fork, flows were obtained directly from gage data for the available period of record. For periods where gage data were not available, an interpolation method using basin area was used to estimate average daily flow.

Flows at confluences of the Trinity River and its tributaries were estimated by dividing the Trinity River into reaches that correspond to the USGS gage locations. Within each reach, basin areas were estimated for tributaries and for the Trinity River at the tributary confluences using USGS gage data and USGS StreamStats (Table 3-2).

Table 3-2
Trinity River and Major Tributaries Basin Areas – Lewiston Dam to North Fork Confluence (Upstream to Downstream)

Node Name	Trinity River Basin Area (Sq Mi)	Tributary Basin Area (Sq Mi)	Local Basin Area Upstream of Node (Sq Mi)
Lewiston	719	-	-
Deadwood Creek	728	9	-
Rush Creek	758	22	8
Above Grass Valley	762	-	4
Grass Valley Creek	800	36	2
Trinity House Gulch	803	3	-
Limekiln	810	-	7
Indian Creek	849	34	5
Weaver Creek	895	45	1
Reading Creek	931	31	5
Douglas City	931	-	-
Browns Creek	1,014	74	9
Junction City	1,057	-	43

Node Name	Trinity River Basin Area (Sq Mi)	Tributary Basin Area (Sq Mi)	Local Basin Area Upstream of Node (Sq Mi)
Canyon Creek	1,122	65	-
Above North Fork	1,137	-	15

For each day, flows at tributary confluence nodes were estimated using the following methodology:

1. Determine the difference in flow between the known upstream USGS gage location and known downstream USGS gage location
2. Subtract any known tributary gage flows
3. Divide the remaining flow difference between nodes by local basin areas and tributary basin areas for unknown flows
4. Add the corresponding flow to the previous node location

The only exception to using basin area to estimate unknown tributary flows was the Deadwood Creek tributary. For Deadwood Creek, measured gage data had a linear relationship to Rush Creek gage data for dates where concurrent data were available, so Deadwood Creek flow was estimated using this linear relationship.

Using the methodologies described above, average daily flows from WYs 2003 to 2011 were estimated for the 15 key nodes. For each node, we calculated the number of days that average daily flow exceeded specific discharge levels (6, 13, 28, 43, 57, 113, 170, and 227 $m^3 \cdot s^{-1}$ [300, 450, 1,000, 1,500, 2,000, 4,000, 6,000, and 8,000 cfs]) for three periods of each WY: 1) the entire WY (October 1 through September 30); 2) the spawning/incubation period (June 30 to October 31); and 3) the juvenile fish-rearing period (February 15 through June 30). Note that the adult spawning period (June 30 to October 31) includes data from 3 months of one WY, and 1 month of the following WY. The WY attribution is based on the calendar year of the spawning period (e.g., June 30 to October 31, 2003 is assigned to WY 2003).

3.3 Geomorphic Response

The following sections summarize existing analyses and assessments conducted by the Program Partners that were used during the review to evaluate the extent to which channel rehabilitation at Phase 1 project sites has helped achieve geomorphic sub-objectives stated in Objective 1 of the Program's IAP (TRRP and ESSA 2009). Existing analyses and assessments by the Program Partners were supplemented by additional analyses that further investigated active bed width at select channel cross sections in rehabilitation sites and lateral channel erosion and deposition inferred from changes in the wetted channel edge mapped at summer baseflow throughout the management reach. Information at rehabilitation sites was supplemented by information at reach and system scales to assist in interpreting the effects of Phase 1 implementation on geomorphic processes and associated physical habitat.

The restoration strategy involves a combination of channel rehabilitation, flows, and gravel augmentation to create a dynamic channel that builds and then maintains the required habitat. Inherent in this restoration strategy is the concept of response time to management actions to create the desired channel conditions. The desired response time greatly influences the type (e.g., size, frequency, degree of manipulation) of management actions. More frequent, higher magnitude flow releases and large, aggressive channel rehabilitation will shorten the response time. A short response time is desirable for achieving restoration goals. More frequent, high magnitude flow releases will also shorten the adaptive management learning cycle on constructed channel rehabilitation sites to better inform Phase 2 designs.

3.3.1 Existing Geomorphic Monitoring

Although a variety of geomorphic information was collected in the vicinity of channel rehabilitation sites prior to initiation of Phase 1 rehabilitation projects in 2004 (e.g., mapping of confinement and bank characteristics, extent of the riparian berm, and the area encompassed by dredge tailings), focused baseline geomorphic monitoring to evaluate the effects of future rehabilitation actions has not occurred at most sites.

The key assessments related to IAP Objective 1 that were provided to the Phase 1 review team in draft or final form by the Program Partners included the following:

- Geomorphic monitoring results reported for WYs 2009 through 2011 as part of the IHAP (Alvarez et al. 2011; McBain & Trush and HVT 2012)
- Geomorphic monitoring results reported in the WY 2010 Implementation Monitoring Report (Gaeuman in review)
- Sediment budgets (Wilcock 2004, 2010; Gaeuman and Krause 2011) based on annual monitoring of sediment transport (GMA 2001, 2002, 2006a, 2006b, 2007, 2008, 2009, 2010a, 2011)
- Trends in substrate composition (GMA 2003, 2010b)

Additional information regarding site and system scale response to management activities is found in reports related to baseline geomorphic monitoring at Trinity River proposed bank rehabilitation sites (HVT and McBain & Trush 2004); the Coarse Sediment Management Plan (McBain & Trush 2007a); recommended quantities and gradation for long-term coarse sediment augmentation downstream of Lewiston Dam (Gaeuman 2008); and the summary of mechanical extraction and augmentation of coarse and fine sediment on the Trinity River, 1912 to 2011 (Krause 2012b).

The 2011 spring high flow release reshaped the Wet WY allocation of 701,000 acre-feet into a flow release of approximately 312 $m^3 \cdot s^{-1}$ (11,000 cfs) on May 4. These peak flows were sustained for 3 days, and then decreased to 127 $m^3 \cdot s^{-1}$ (4,500 cfs) by May 9. The purpose of the experiment was to expedite geomorphic change and habitat creation at constructed Phase 1 channel rehabilitation sites and scour pools.

Analysis of geomorphic monitoring information after WY 2011, as well as focused studies related to quantifying channel complexity, linking sediment supply and channel complexity; and a system-wide geomorphic mapping effort to inform science-based river restoration (Curtis and Guerrero 2012) were in progress during the Phase 1 review. Although the results and conclusions of these studies are relevant to understanding the geomorphic effects of Phase 1 actions and their effectiveness at achieving Program goals, results from these studies were not available at the time of the Phase 1 review and are therefore not incorporated into this assessment. In addition to these focused efforts, results from several ongoing data collection and analysis programs designed to inform IAP Objective 1 were not available to the Phase 1 review team, including development and analysis of system-wide digital terrain models (DTMs) following high flow releases in WYs 2010, 2011, and 2012 (GMA 2012), and sediment transport monitoring and development of updated sediment budgets for WYs 2011 and 2012.

The sections that follow describe the objectives and relevant data collected as part of each key assessment listed above.

3.3.1.1 Geomorphic Monitoring Results Reported as Part of the Integrated Habitat Assessment Project

The goal of the IHAP is to evaluate the effectiveness of the Program's restoration actions to determine changes in salmonid habitat resulting from mechanical channel rehabilitation and restoration of fluvial processes necessary to create and maintain riverine habitats as envisioned in the IAP (TRRP and ESSA 2009). IHAP monitoring is designed to test specific IAP targets for fluvial geomorphic management by WY class (Table 3-3). Results contribute toward achieving Program goals and objectives by providing feedback to adaptively improve management actions.

Table 3-3
IAP Fluvial Geomorphic Targets by WY Class

Objective	Critically Dry (Peak = 1,500 cfs)	Dry (Peak = 4,500 cfs)	Normal (Peak = 6,000 cfs)	Wet (Peak = 8,000 cfs)	Extremely Wet (Peak = 11,000 cfs)
Bed Mobility	None	Mobilize the surface of in-channel alluvial features (e.g., spawning gravel deposits)	Mobilize matrix particles (D_{84}) on general channel bed surface and along flanks of alternate bar surfaces	Mobilize matrix particles (D_{84}) on alternate bar surfaces	Mobilize matrix particles (D_{84}) on alternate bar surfaces
Bed Scour	None	None	Channel bed scour and redeposition of gravels	Channel bed scour greater than 1x D_{84} depth and redeposition of gravels	Channel bed scour greater than 2x D_{84} depth and redeposition of gravels on face of alternate bars

Source:
TRRP and ESSA 2009

Specific geomorphic monitoring activities in WY 2009 included documenting changes in cross sections, longitudinal profiles, and planform topography, and evaluating bed mobility and bed scour at seven channel rehabilitation sites (Table 3-4). Geomorphic changes during WY 2009 resulted from the spring 2009 ROD flow release (classified as a Dry WY, but discharge was equivalent to Normal and Wet WY types at some locations due to accretion), as well as the 2009 winter peak flow downstream of Canyon Creek (113 $m^3{\cdot}s^{-1}$ [3,990 cfs] on March 2, 2009). Specific geomorphic monitoring activities in WY 2010 included documenting changes in cross sections and evaluation of bed mobility and bed scour at 10 generalized random tessellation stratified (GRTS) Panel 2 sites and four channel rehabilitation sites (Table 3-4). Geomorphic changes during WY 2010 resulted from the spring 2010 ROD flow release (classified as a Normal WY), as well as the 2010 winter peak flow downstream of Canyon Creek (121 $m^3{\cdot}s^{-1}$ [4,280 cfs] on February 5, 2010). Specific geomorphic monitoring activities in WY 2011 included documenting changes in cross sections and evaluating bed mobility and bed scour at 24 GRTS sites in Panels 2, 3, and 4, and 10 channel rehabilitation sites (Table 3-4). Geomorphic changes during WY 2011 resulted from the spring 2011 ROD flow release (averaging approximately 311 $m^3{\cdot}s^{-1}$ [11,000 cfs] and peaking at 348 $m^3{\cdot}s^{-1}$ [12,300 cfs]), as well as the winter tributary-generated peak flow that occurred between March 16 and 24 (approximately 348 $m^3{\cdot}s^{-1}$ [12,300 cfs] below Canyon Creek).

Table 3-4

IHAP Geomorphic Monitoring Conducting at Rehabilitation Sites

Site	WY 2009					WY 2010					WY 2011				
	XS	LP	PM	BB	BS	XS	LP	PM	BM	BS	XS	LP	PM	BM	BS
Sven Olbertson		x													
Deadwood Creek															
Lewiston Cableway	x		x	x		x									
Hoadley Gulch	x	x	x	x		x			x	x	x			x	x
Sawmill						x			x	x	x			x	x
Dark Gulch	x		x	x		x			x	x	x			x	x
Lowden Ranch															
Trinity House Gulch											x			x	x
Indian Creek	x	x	x			x			x	x	x			x	x
Reading Creek											x			x	x
Hocker Flat	x			x	x										
Connor Creek	x										x			x	x
Valdor Gulch	x	x	x	x	x	x			x	x	x			x	x
Elkhorn							x				x			x	x
Pear Tree Gulch											x			x	x

Source:
Alvarez et al. 2011; McBain & Trush and HVT 2012

Note:
1. XS = cross section survey, LP = longitudinal profile survey, PM = planform mapping, BM = bed mobility measured with tracer rocks, BS = bed scour measured with scour cores

3.3.1.2 WY 2010 Implementation Monitoring Report

The Program conducted analyses and reported results regarding the function and evolution of selected channel rehabilitation features and the geomorphic effects of coarse sediment augmentations in their WY 2010 Implementation Monitoring Report (Gaeuman in review). The report describes topographic changes at a subset of locations where channel rehabilitation projects and/or coarse sediment augmentations were implemented under the ROD during the time frame spanning 2007 through the spring flow release in 2010 (Table 3-5). The main topics considered in the report included the effects of coarse sediment augmentation on channel bed morphology within and downstream of coarse sediment augmentation sites, the performance of selected constructed features and design strategies at channel rehabilitation sites, and geomorphic responses to flow releases and other upstream management activities on select downstream reaches.

Table 3-5

Information Used in the WY 2010 Implementation Monitoring Report to Describe Topographic Changes at Rehabilitation Sites, 2007 to 2010

Site	Implementation Year(s)	Activity			Data Source Used in Implementation Monitoring Analysis
		Coarse Sediment Augmentation	Channel Rehabilitation	Bar Construction	
Diversion Pool	2008 – 2010	x			2008 topo, 2010 topo, 2001 photogrammetry
Cableway	2008		x	x	2009 ADCP
Hoadley Gulch	2008		x	x	2009 DTM, 2010 topo
Sawmill	2008 – 2010	x	x	x	2011 as-built, 2010 topo, 2010 tracer video
Hatchery	2007 – 2008			x	2001 photogrammetry, Civil design, 2009 DTM
Lowden Ranch	2010	x	x	x	2009 DTM, 2010 topo
Trinity House Gulch	2010		x	x	2010 DTM, 2010 topo
Indian Creek	2007		x		2009 DTM, 2010 topo

Source:
Information modified from Gaeuman in review
Notes:
DTM = digital terrain model

The primary analysis method used in the Gaeuman report (in review) is topographic differencing of DTMs representing ground and stream bed topography at two or more points in time.

Analyses are limited to projects implemented during the 2007 to 2010 time period because data collection efforts in earlier years were generally inadequate to support quantitative assessment of geomorphic changes, whereas projects implemented during the 2010 construction season had not yet undergone geomorphic change.

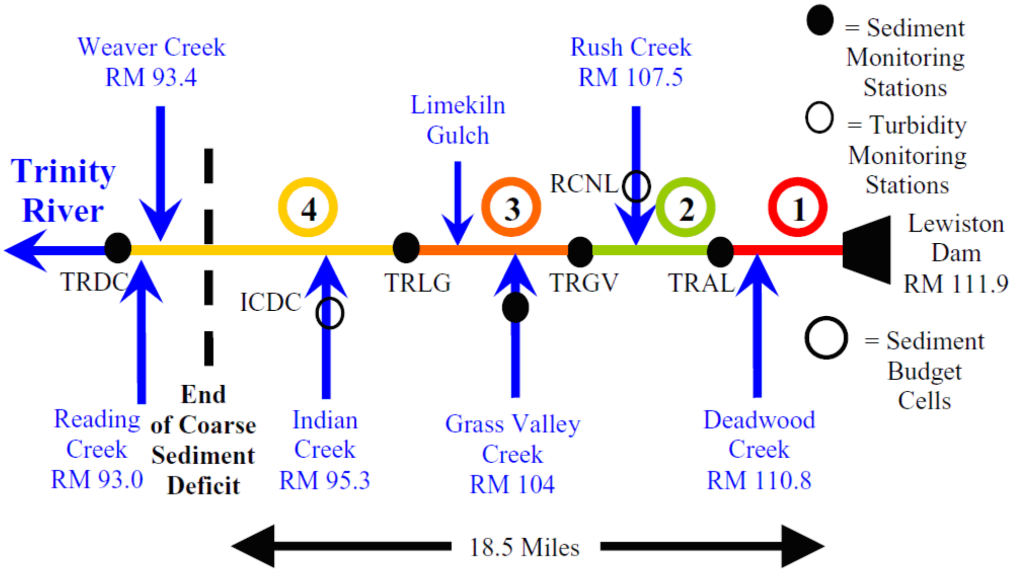
3.3.1.3 Sediment Budget Based on Annual Monitoring of Flow and Sediment Transport

Progress toward meeting sub-objectives 1.2 through 1.4 in the IAP related to sediment transport and storage in the mainstem Trinity River are evaluated within a sediment budget framework (Wilcock 2004). The sediment budget supports flow release scheduling, coarse sediment augmentation, tributary sediment control, and mechanical channel rehabilitation strategies. The sediment budget framework developed in 2004 identified four locations for monitoring flow, suspended sediment, and bed-material flux between Lewiston Dam and Douglas City:

- Trinity River at Lewiston – USGS gage 11525500
- Trinity River above Grass Valley Creek – GMA 11525540
- Trinity River at Limekiln Gulch – USGS gage 11525655
- Trinity River at Douglas City – USGS gage 11525854

The sediment budget framework (Wilcock 2004) also defined four budget cells between Lewiston Dam and Douglas City (Figure 3-1):

- Cell 1: Lewiston Dam to Trinity River at Lewiston
- Cell 2: Trinity River at Lewiston to Trinity River above Grass Valley Creek
- Cell 3: Trinity River above Grass Valley Creek to Trinity River at Limekiln Gulch
- Cell 4: Trinity River at Limekiln Gulch to Trinity River at Douglas City



Source:
Gaeuman and Krause 2011

Figure 3-1
Schematic of the Trinity River Sediment Budget Cells and Sediment Transport Monitoring Sites

A sediment budget for the mainstem Trinity River was prepared for the period 1981 to 2000 (Wilcock 2004) and subsequently updated for the period 2004 to 2009 (Wilcock 2010) and WY 2010 (Gaeuman and Krause 2011). Each sediment budget used streamflow data, sediment transport measurements, tributary delta volumetric estimates, particle-size distribution measurements, and streamflow and sediment transport modeling to estimate the inputs and outputs to mainstem sediment budget cells. Since at least WY 2002, sediment discharge and load have been estimated annually based on tributary and mainstem sediment transport monitoring (GMA 2001, 2002, 2006a, 2006b, 2007, 2008, 2009, 2010a, 2011). Surface and subsurface bed material have also been characterized periodically (GMA 2003, 2010b) and surveys of the Deadwood, Rush, and Indian Creek deltas and the lower Grass Valley Creek catchment ponds are conducted semi-annually. Analysis of sediment transport monitoring results and development of sediment budget updates for WY 2011 and WY 2012 were in progress at the time the Phase 1 review was conducted.

3.3.1.4 *Trends in Substrate Composition*

In 2000, the Program Partners conducted an investigation of spawning gravel on the mainstem Trinity River from Lewiston Dam to Junction City, where most mainstem salmon spawning occurs and where the channel has been most impacted by reduced flows and tributary-derived sediment deposition (GMA 2003). The objectives included the following:

- Establish baseline substrate composition and permeability conditions for long-term trend monitoring in the Trinity River and tributaries
- Assess the relationship between substrate composition and permeability
- Evaluate the longitudinal changes to gravel quality along the mainstem Trinity River to assess the influence of tributary derived sediments
- Estimate survival rate of eggs to fry emergence for Chinook salmon along the mainstem Trinity River

Sampling occurred at eight study sites selected to represent known spawning areas below key tributaries (Table 3-6). Monitoring activities at each site included cross section surveys, surface particle counts, bulk sampling, intragravel permeability measurements, and installation of scour cores. In 2009, sites sampled in 2000 were revisited and several additional sites were sampled (Table 3-6) (GMA 2010b).

Table 3-6

Sites where Substrate Composition and Permeability were Characterized in 2000 and 2009

Site	Location (RM)	Sampling Years			
		1991	2000	2001	2009
Lewiston	111.5		x		x
Old Lewiston Bridge	110.0				x
Rush Creek	108.0				x
Rush Creek	107.4		x		x
Poker Bar	102.7		x		x
Steel Bridge	99.2	x		x	x
Steel Bridge	99.0		x		x
Indian Creek	95.3		x		x
Steiner Flat	92.0		x		x
Steiner Flat	91.7	x		x	x
Evans Bar	84.1		x		x
Junction City	80.3		x		x

Note: Data are based on GMA 2003, 2010b.

3.3.2 Additional Geomorphic Analyses

In addition to the existing analyses and assessments conducted by the Program Partners, analyses were conducted during the Phase 1 review that further investigated active bed width at select channel cross sections in rehabilitation sites (Section 3.3.2.1) and lateral channel erosion and deposition inferred from changes in the wetted channel edge mapped at summer baseflow throughout the management reach (Section 3.3.2.2).

3.3.2.1 Active Bed Width at Cross Sections

Repeat survey of permanent channel cross sections has long been used to assess the effects of management activities on stream channel morphology and fish habitat. Repeat cross sections provide detailed information about channel change (e.g., scour and fill), but are limited to a specific location and survey time period. Cross sections have been established and repeatedly surveyed in the Trinity River management reach by many different entities for different purposes, including design and as-built documentation, implementation monitoring at channel rehabilitation and gravel injection sites, long-term effectiveness monitoring at channel rehabilitation and GRTS sites, sediment transport monitoring, hydraulic modeling, and development of bathymetric surfaces, among others. The Program maintains a database of all available cross sections surveyed in the management reach of the Trinity River, and this database was the source of all cross section data used during the Phase 1 review. Cross section sites were selected for analysis based on the following criteria:

- Sites were located in or near Phase 1 channel rehabilitation sites
- Sites were located in reaches unaffected by mechanical rehabilitation
- Sites occurred in proximity to different types of design features within rehabilitation sites
- Multiple surveys were conducted after January 1, 2000, such that paired surveys describe changes over defined project phases and time periods (see below)
- Surveys extended across a substantial portion of the 312 $m^3 \cdot s^{-1}$ (11,000 cfs) wetted channel width
- Surveys were free of datum shifts or other errors (i.e., consistent horizontal and vertical datums over all survey periods); the Program provided quality assurance/quality control for select cross section sites and surveys

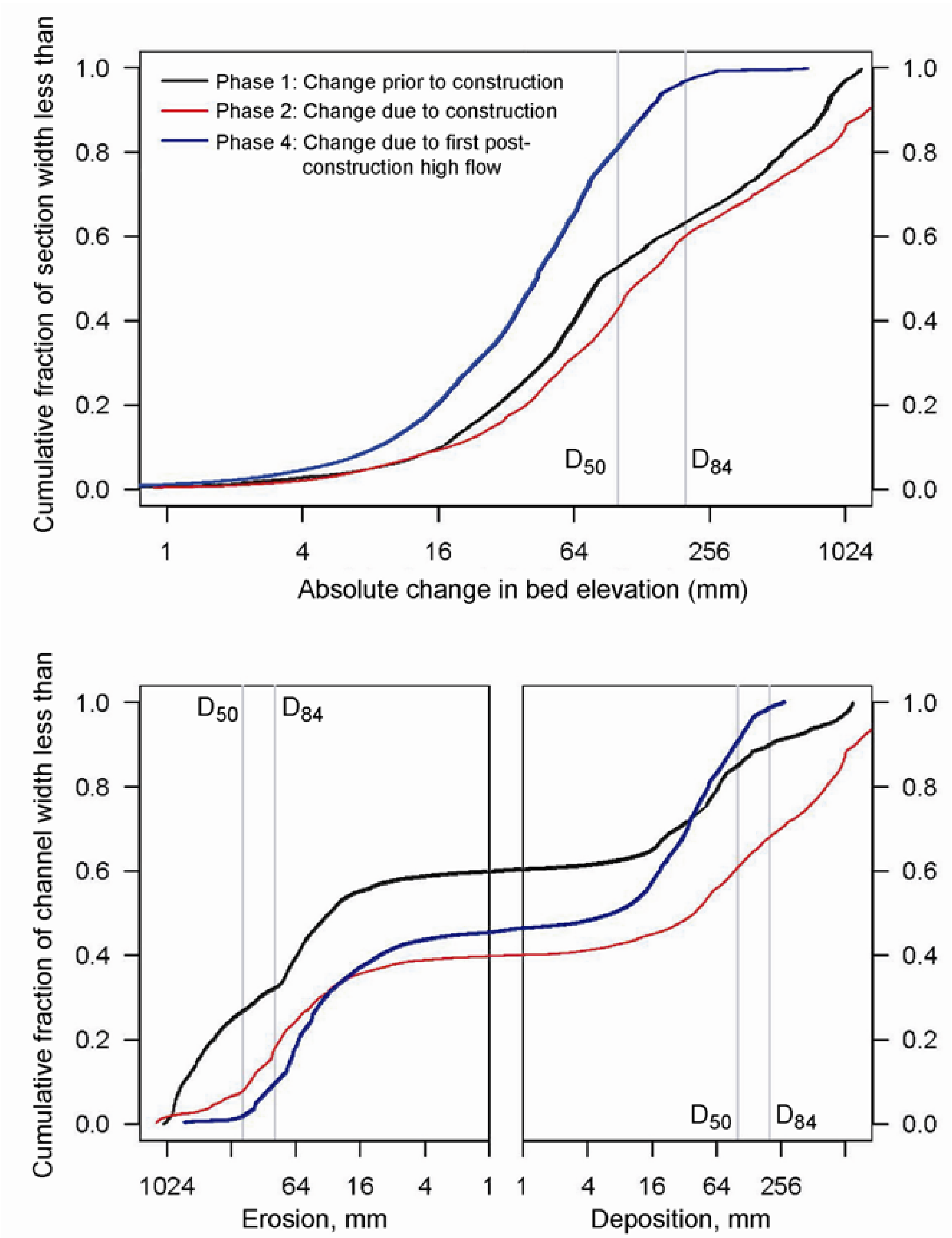
The primary metric in the SAB's analysis of channel change at cross sections was the absolute value of bed elevation change ($|\Delta Z|$). The absolute value of bed elevation change describes the combined effects of scour ($-\Delta Z$) and fill ($+\Delta Z$), either as an average for a cross section or as a cumulative frequency distribution describing the fraction of the section width that has been mobilized (hereafter referred to as "active bed width" (Figure 3-2). The thickness of the active bed is scaled to the approximate average D_{50} (100 mm [4 inches]) and D_{84} (200 mm [8 inches]) in the management reach of the Trinity River (Gaeuman personal communication). Hydraulic modeling of a 312-$m^3 \cdot s^{-1}$ (11,000-cfs) controlled flow release from Lewiston Reservoir (DWR 2007) was used to establish reference water surface elevations at cross sections for analysis of active bed width. Frequency distributions of active bed width were first developed for each cross section pair, and then the fraction of the cross section with active bed thickness equal to or greater than the approximate average D_{50} and D_{84} were identified (Figure 3-2). The measures of active bed width scaled to the D_{50} and D_{84} were then analyzed over the following rehabilitation project phases and time periods.

Project Phase:

1. Change prior to construction
2. Change due to construction
3. Change following construction but prior to a high flow
4. Change due to the first post-construction high flow
5. Change following the first post-construction high flow
6. Change due to construction and subsequent high flows combined

Time Period:

1. Period prior to the 2006 flow release
2. Period including the 2006 flow release
3. Period between the 2006 and 2011 high flow releases
4. Period including the 2011 high flow release



Note:

Vertical gray lines indicate the active bed thickness equal to or greater than the approximate average D_{50} and D_{84} in the management reach of the Trinity River.

Figure 3-2

Example of Cumulative Frequency Distributions Describing the Fraction of the Section Width that Has Been Mobilized (Referred to as Active Bed Width)

Several indices were developed to relate cross section geomorphic change to the energy available for transport (stream power) and flow exposure. Flow exposure was measured as the number of days during the period between surveys that mean daily flow exceeded 113 (4,000), 170 (6,000), and 241 $m^3 \cdot s^{-1}$ (8,500 cfs). Mean daily flows used in the analysis were selected based on estimates of bed mobility thresholds and initiation of significant bedload transport at sediment transport monitoring stations. Exceedance values assigned to each cross section are based on flows measured at the USGS gaging station in the associated reach (Table 3-7).

Table 3-7
USGS Streamflow Gages Used to Calculate Exceedance Index Values in Each Reach

Reach	USGS Gage Number
Lewiston	11525500
Limekiln	11525655
Douglas City	11525854
Junction City	11526250

Exploratory statistical analyses were conducted to look for significant project effects on channel change at surveyed cross sections associated with in-channel design features. The variables considered consisted of channel change metrics from pairs of successive surveys of the same cross section, change metrics from the 200-m (656-foot) data frame channel segments containing these cross sections, and indices of flow exposure. The analysis specifically considered the following variables:

For each pair of successive surveys of the same cross section:

- The active bed width exceeding 100 mm (4 inches; approximate D_{50}) of absolute bed elevation change between surveys
- The active bed width exceeding 200 mm (8 inches; approximate D_{84}) of absolute bed elevation change between surveys

For each SAB segment:

- The total area of lateral erosion or accretion (as inferred from changes in bankline between successive aerial surveys), expressed as a fraction of the total wetted area in the 200-m (656-foot) segment area during the first aerial survey
- The eroded berm area (as inferred from changes in bankline between successive aerial surveys, as a fraction of the total initial berm area mapped in 2006)

Each pair of successive surveys at a cross section was classified into the time periods and project phases defined above. For the purpose of statistical analyses, project phases were simplified to the following three categories:

- Pre-construction: The section is not a project section, or project construction did not begin until after the second survey.
- Construction: The section is an "in-channel" project section (i.e., the design feature code begins with "IC"), and construction occurred between the two surveys.
- Post-construction: The section is an "in-channel" project section, and both surveys were conducted after construction.

Linear models were used to explore relationships between channel change (as measured by the active bed width > D_{50} or D_{85}) and project phase, with or without one additional explanatory variable from the SAB metrics or indices.

3.3.2.2 Lateral Channel Erosion and Deposition

The Trinity River Flow Evaluation Report (USFWS and HVT 1999) states the following hypothesis associated with channel migration and fish habitat creation:

> *The riparian berm cannot be removed by TRD dam releases; therefore, habitat rehabilitation must be preceded by a one-time sequence of mechanical removal at strategic locations. Subsequent long-term habitat creation and maintenance must be accomplished by flow and sediment management prescriptions rather than mechanical means.*

To test this hypothesis and to assess the effectiveness of Phase 1 implementation at initiating lateral channel erosion and deposition, the SAB analyzed changes in the low-flow wetted channel edge (hereafter referred to as bankline). All banklines were digitized on screen from sequential aerial photography, except the 2009 bankline, which was derived from 2009 LiDAR returns (Table 3-8).

Table 3-8

Aerial Photography Flight Dates and Associated Streamflow Metrics at Lewiston

Flight Date[1]	Streamflow ($m^3 \cdot s^{-1}$)	Streamflow (cfs)	Wetted surface area (ha)	Mean width (m)	Digitizing Source
November 7, 2001	9.46	334	200.87	31.48	BOR
September 21, 2005	13.56	479	211.20	33.10	SS[2]
July 3, 2007	12.69	448	214.13	33.56	BOR
April 16, 2009	8.24	291	210.87	33.05	BOR
August 16, 2011	12.63	446	219.75	34.44	SS

Notes:
1. Personal communication, Eric Peterson, U.S. Bureau of Reclamation (BOR), Weaverville, CA
2. Stillwater Sciences

Changes in bankline position mapped over the entire management reach at relatively consistent summer baseflows provide an approximation of lateral channel erosion and deposition (ΔY) that generally coincides with the timing of juvenile fish habitat mapping and is more extensive than measurements of active bed width at cross sections. Lateral channel erosion is inferred where the bankline at the end of an analysis period (year two) occurs beyond the bankline (i.e., farther from the channel centerline) at the beginning of the period (year one) (Figure 3-3). Lateral channel deposition is inferred where the bankline at the end of the period occurs within the bankline (i.e., closer to the channel centerline) at the beginning of the period. The analysis identifies the magnitude, spatial extent, and timing of ΔY during four time periods (2001 to 2005, 2005 to 2007, 2007 to 2009, and 2009 to 2011) that generally correspond with the time periods defined above for the cross-section analysis. Banklines mapped from aerial photos were attributed to the 200-m data frame developed to support the Phase 1 review.

Figure 3-3

Illustration of Methods Used to Assess Inferred Lateral Channel Erosion and Deposition

Interpretation of the bankline location in areas of the geo-rectified aerial photography with vegetation and shade cover can result in erroneous erosion or deposition polygons. Many bank locations are hidden under terrestrial vegetation, so accurate delineation of the true bankline is difficult. Changes in stage due to local aggradation or degradation in baselevel controls (e.g., riffle crests) and small variations in summer baseflow at the time of aerial photo flights can also create bankline patterns erroneously inferred to be erosion or deposition, particularly in wide and shallow areas. But even where banklines are visible, hand tracing in GIS has some inherent error, assumed here to be about 1 m. Such non-overlapping lines create a series of very thin, sliver-shaped polygons. These slivers were filtered out using a polygon radius factor (*W*) and a shape factor (*SF*):

$$W = \frac{A}{P/2} \tag{3.1}$$

$$SF = W/r \tag{3.2}$$

where A is polygon area, P is polygon perimeter, and r is the radius of a circle having the same area as the polygon.

Figure 3-4 shows the relation between *W*, *SF*, and maximum width. The parameter *W* was the best predictor of maximum width, especially for *W* up to 0.8. Polygons with a maximum of 1-m width (approximately 3 ft) were removed by selecting records with a $W < 0.50$.

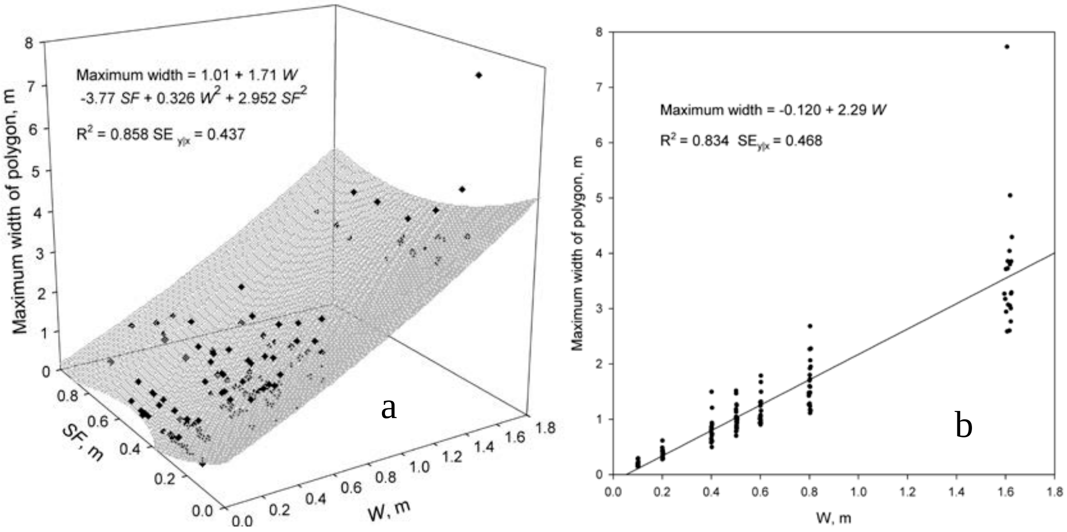


Figure 3-4

Paraboloid Regression of Maximum Polygon Width on *W* and *SF* (a) and Simple Linear Regression of Maximum Polygon Width on *W* (b). All Possible Models Up to (a) Were Fit, and the Simplest Model (b) Was Selected The Adjusted R^2 for the Full Model (a) Was 0.854, and 0.833 for the Selected One (b).

True erosion and deposition can be assessed by viewing changes on the geo-rectified aerial photography in GIS. For example, if well-vegetated banks were actually eroded, then tree or shrub crowns will show such changes by moving or disappearing. New deposition must be wide enough to extend beyond the band of tree crowns at the bank edge, which is typically about 6 m. True erosion and deposition was only spot-checked in this effort and not reported in detail. Changes due to construction (channel rehabilitation) were identified as such.

Lateral erosion of the riparian berm is inferred where polygons representing inferred erosion derived from the above steps coincide with riparian berm areas mapped in 2003 by the Program and contained in the file named 03geo.

In addition to sliver removal as described above, some lower sections of tributaries were mapped in some years, and not in others. These discrepancies showed as potential erosion or deposition depending on the sequence within a period. Likewise, the wing-walls at the Lewiston Dam outlet were not consistently mapped, and these discrepancies showed as potential erosion or deposition. The wing-wall boundaries as they occurred in the 2009 bankline were transferred to the other periods to reflect the static nature of the wing-walls, and the lower sections of the tributaries were also removed. The resulting set of polygons, which includes potential erosion, potential deposition, and no change polygons, was considered to have minimal line errors from digitizing (slivers) and was the starting point for all subsequent analyses; it is referred to as the *initial set*.

The initial set of polygons were separated into the following seven classes within GIS by a union between the initial set and the channel rehabilitation footprint (not including wood placement), built between the aerial photography dates that define the banklines. The resulting set is called the *combined overlay*:

1. Potential deposition (outside construction footprint)
2. Potential erosion (outside construction footprint)
3. No change (outside construction footprint)
4. Potential deposition within a construction footprint
5. Potential erosion within a construction footprint
6. No change within a construction footprint
7. Construction outside channel

The “no change within a construction footprint” reflects a discrepancy between the footprint boundary and the channel-change boundary derived from bankline differences. The channel-change boundary was considered the reference line, not the construction features (i.e., there are likely errors in as-built footprints). Therefore, if a construction boundary extended into a “no change” (channel) polygon, it was considered an error in the feature extent and was not counted. Changes within a construction footprint are labeled as such, but fluvial-induced changes may have contributed in non-construction years in a particular period.

To check data attribution and polygon areas by class, the following calculations were done:

1. Total area within the seven classes in the combined overlay was summed. The area within class 7 and the total of all polygons within the initial set should be equal.
2. Sub-totals of classes 1 and 4, 2 and 5, and 3 and 6 should equal the total for the initial set.
3. Sub-total for classes 1 and 4 should equal the total deposition in the initial set; likewise for erosion and no change.

The set of erosion polygons was overlaid on the mapped berm polygons to determine the potential berm erosion. The TRRP mapped the berms in 2003 and their polygons were in the shapefile set named <03geo.*> supplied by the TRRP with a file date of June 22, 2007. The total amount of berm erosion by period (2005 to 2007, 2007 to 2009, and 2009 to 2011) and for all of these periods were compared to the total berm area in 2003, and the total amount of erosion occurring in these periods.

Because dam releases during aerial photography differed (Table 3-8), and banklines follow wetted widths, an estimate of how much influence these variable dam releases had on erosion and deposition estimates was done as follows.

Stages for the highest and lowest discharges during aerial photography at the four USGS gages (Lewiston, Limekiln Gulch, Douglas City, and Junction City) were used to obtain an index stage difference (Table 3-9).

Table 3-9
Discharge and Stage at Gaging Stations for the High and Low Discharges During Aerial Photography

USGS gaging station number and name	Discharge, cfs	Stage, ft	Wetted channel width, ft
11525500 Trinity River at Lewiston, CA	291	3.62	110
	478	4.06	102
Difference:	**187**	**0.44**	**-8**
11525655 Trinity River at Limekiln Gulch	290	4.47	138
	479	4.92	142
Difference:	**189**	**0.45**	**4**
11525854 Trinity River at Douglas City, CA	321	1.91	117
	479	2.29	118
Difference:	**158**	**0.38**	**1**
11526250 Trinity River at Junction City, CA	351	1.50	113
	479	1.82	116
Difference:	**128**	**0.32**	**3**

A stage difference of 0.45 ft (0.137 m), which is the highest and provides a worst-case situation, was chosen as an index stage to be applied to 12 cross-sections that had a range of width increases with discharge (i.e., variable confinement) and had measurements at or near 291 and 479 cfs. Their mean, minimum, and maximum width changes were 2.3, 0.2, and 4.4 m, respectively. For displacement of either bankline, the mean, minimum, and maximum values were 0.9, 0, and 3.5 m, respectively. The average low-flow width for the restoration reach is about 33 m.

3.4 Biological Response

This section summarizes the evaluations implemented by the Program Partners to assess progress made towards achieving the sub-objectives identified in Table 1-3 related to increasing or improving habitats for freshwater life stages of anadromous fish through the implementation of Phase 1 channel rehabilitation projects. Habitat assessments—conducted at the sites and across the restoration reach, before and after the channel rehabilitation construction activities, and under low (base summer or winter) flows at all sites and various flows at a subset of sites—were used to assess changes in fish habitat quantity and quality that occurred during Phase 1. While the main focus of the habitat assessments has been on rearing habitat quantity and quality for fry and presmolts, monitoring of redds and carcasses along with spawning habitat assessments was conducted and used in this review to help interpret the effects of Phase 1 actions on overall changes in salmonid habitat for various life stages.

3.4.1 Existing Biological Monitoring

The key assessments related to changes in fish rearing habitat (IAP sub-objective 2.1.1) that were reported in draft or final form by the Program Partners prior to, or during, the SAB's Phase 1 Review included the following:

- Monitoring of juvenile Chinook salmon and coho salmon rearing habitat at rehabilitation sites (Alvarez et al. 2011; Goodman et al. 2010; Martin et al. 2012; Martin et al. in review)
- Monitoring of Chinook salmon and coho salmon rearing habitat within the 64-km (40-mile) restoration reach (Alvarez et al. 2011; Goodman et al. 2012)

More specific information about the general approaches and methods used to derive data for each of the key assessments is provided in Sections 3.4.1.1 and 3.4.1.2.

3.4.1.1 Rearing Habitat Assessment within Rehabilitation Sites

To evaluate whether rearing habitat area changed over time at individual rehabilitation sites, the Program Partners evaluated habitat in two ways. First, channel rehabilitation sites were assessed by measuring the quantity and quality of rearing habitat area before and after rehabilitation. Post-rehabilitation assessments generally began soon after construction and were repeated periodically to track changes at the sites over time. The habitat mapping methods and criteria that were used are described in Goodman et al. (2010) and are summarized below.

Rearing habitat criteria were divided into two fish developmental phases for Chinook and coho salmon: fry (fish less than 50-mm fork length [FL]) and pre-smolt (FL ≥ 50 mm). Three types of rearing habitat were considered: *optimal habitat* meets depth, velocity, and distance-to-cover criteria (DV, C), *suitable habitat* meets depth and velocity criteria, or cover criteria, but not both (DV or C), and *total habitat* includes all areas that meet any combination of depth, velocity or cover criteria (Alvarez et al. 2011). Because coho salmon demonstrate extremely high preference for optimal habitat areas over other habitat types (Goodman et al. 2010), coho rearing habitat was limited to optimal habitat areas (Martin et al. 2012).

Rearing habitat criteria were validated through a study conducted by Goodman et al. (2010). For this study, Chinook and coho salmon density differences were evaluated among the optimal and suitable mapped habitat categories to test whether mapped habitat areas were appropriate predictors of fish presence. For both species, mean fish densities were lowest in the habitat category that met neither the depth/velocity nor the escape cover criterion and were highest in the optimal habitat category meeting depth/velocity and cover criteria (Goodman et al. 2010). Significant differences were identified in fish density among habitat categories demonstrating the validity of the rearing habitat categories in predicting fish habitat use (Goodman et al. 2010).

Habitat parameters shown in Table 3-10 were measured within each channel rehabilitation site, geo-referenced, and processed into ArcGIS polygon shapefiles. Only habitat areas greater than or equal to 2 square meters (m^2; 22 square feet) were surveyed. The rearing habitat mapping provided a spatially explicit representation of rearing habitat areas within selected rehabilitation sites.

Table 3-10

Guilds and Their Associated Habitat Criteria for Chinook and Coho Salmon Rearing Habitat Mapping

Habitat Guild	Variable	Criteria
Fry (<50 mm)	Depth	>0 to 0.61 m
	Mean water column velocity	0 to 0.15 m/sec
	Distance to cover	0 to 0.61 m
Presmolt (≥50 mm)	Depth	>0 to 1 m
	Mean water column velocity	0 to 0.24 m/sec
	Distance to cover	0 to 0.61 m

Source: Goodman et al. 2010

River flows during rehabilitation site habitat assessment surveys were always at a low level and under conditions where a flow of 8.5 cubic meters per second ($m^3 \cdot s^{-1}$; 300.1 cfs) was released from Lewiston Dam from October to April each year. This level of flow was termed the "baseflow," which varied with the location of the rehabilitation project within the river system due to tributary accretion and flow conditions each year, and ranged from 8.3 $m^3 \cdot s^{-1}$ (293.1 cfs) to 20.3 $m^3 \cdot s^{-1}$ (716.8 cfs) in the main channel. Thus, investigators measured habitat under conditions where river flow was as similar as possible between the pre- and post-rehabilitation assessments.

Second, the Program Partners evaluated how rearing habitat area changed with river flow level at some channel rehabilitation sites under various flows using the methods and criteria described in Goodman et al. (2010). The Phase 1 review relied upon analyses conducted by the Program Partners of flow-habitat responses at a subset of sites (Hocker Flat, Bucktail-Dark Gulch, Lewiston Cableway, Lowden Ranch, and Reading Creek) as reported by Goodman et al. (2010), Alvarez et al. (2011), and Martin et al. (in review).

3.4.1.2 Rearing Habitat Assessment within the Primary Restoration Reach

Changes in the quantity and quality of rearing habitat area within the entire restoration reach were evaluated using a rotating panel revisit design (Table 3-11) as described in *Estimation of Age-0 Chinook and Coho Salmon Rearing Habitat Area at 12.7 cms within the Restoration Reach of the Trinity River-Annual Report 2010* (Goodman et al. 2012).

Table 3-11
Rotating Panel Revisit Sampling Design for the
Chinook and Coho Rearing Habitat Assessment

Panel	Year				
	2009	2010	2011	2012	2013
1	x				x
2	x	x			
3		x	x		
4			x	x	
5				x	x

For this approach, the sample universe was defined as the restoration reach. Units were selected using the GRTS sample unit selection protocol. The rotating panel design comprises five panels with 16 GRTS sample sites within each panel. Two panels are sampled within each year, which represents 20% of the restoration reach. In the following year of sampling, one of the panels will be repeated and one new panel will be added until all five panels are sampled. In the fifth year, the first panel will be sampled again and the pattern continues. The five panels make up 50% of the sample universe. By applying this study design annually, the synergistic effects of restoration actions could be documented. This documentation is expected to improve the understanding of how the Trinity River responds to specific management actions, such as any differential effects of stream flow allocations. Habitat area estimates for each site were developed for each life stage and habitat category under flow conditions associated with a release of 12.7 $m^3 \cdot s^{-1}$ (448.5 cfs) from Lewiston Dam using the methods and criteria described in Goodman et al. (2010).

For the Phase 1 review, rearing habitat data within the restoration reach were synthesized and analyzed graphically to evaluate progress made by the program in achieving IAP fish habitat objectives. When supported by Program data, total, suitable, and optimal rearing habitat areas for fry and presmolt life stages in 2009, 2010, and 2011 were calculated and shown graphically at three different scales: 1) Trinity River restoration reach by 200-m (656-foot) segment and for the entire reach; 2) five sub-reaches by 200-m (656-foot) segment and for each sub-reach; and 3) individual rehabilitation sites.

3.4.2 Additional Biological Analyses

In addition to the assessments focused on juvenile fish rearing habitat quantity and quality at low flow and various flow levels, the Program Partners have also conducted monitoring of redds and carcasses and spawning habitat assessments. Key assessments used for this review related to changes in spawning habitat (IAP sub-objective 2.1.2) include the following:

- Salmon spawner survey monitoring results as part of the Trinity River Basin Salmon and Steelhead Monitoring Project (Sinnen et al. 2011) and distribution and abundance of Chinook salmon redds results (Chamberlain et al. 2012)
- Chinook salmon spawning habitat mapping results (Goodman et al. 2010; Alvarez et al. 2011)

Specific information related to the general approaches and methods used to derive the spawning assessment data is provided in Sections 3.4.2.1 and 3.4.2.2.

3.4.2.1 Spawner Surveys—Redds and Carcasses

Spawner survey data were evaluated to assess the effects of Phase 1 actions on overall changes in salmonid habitat for various life stages. Carcass and redd surveys have been conducted intermittently since 1955 by the California Department of Fish and Game, in cooperation with Yurok Tribal Fisheries Program, Hoopa Valley Tribal Fisheries Department, and U.S. Fish and Wildlife Service. The assessment methods are described in Sinnen et al. (2011) and summarized below. Although data have been collected since 1955, the redd and carcass data provided by the Program for the Phase 1 review only included data for 2009, 2010, and 2011. The analysis was limited to these 3 years because the data collected from 2009 to 2011 was geospatially referenced and could be attributed to 200-m segments within the data frame. Prior to 2009, redd and carcass data were identified only to the nearest reach.

The mainstem Trinity River is surveyed annually from Lewiston Dam downstream to the Cedar Flat Recreational Area and from Hawkins Bar to Weitchpec. The river reach from Cedar Flat to Hawkins Bar was not surveyed due to hazardous conditions. The study area was divided into 14 reaches, as described in Table 3-12. These reaches were surveyed between September and December each year on a weekly or biweekly basis. However, some reaches were excluded in some of the planned weekly samples due to logistical issues (i.e., extreme weather and high flows), and surveys were conducted during January in some years to encompass a greater proportion of coho salmon spawning.

Table 3-12

Mainstem Trinity River Spawner Survey Reach Descriptions

Reach ID	Start Location	End Location
1	Lewiston Dam (RKM 180.1 [RM 111.9])	Old Lewiston Bridge (RKM 176.9 [RM 109.9])
2	Old Lewiston Bridge (RKM 176.9 [RM 109.9])	Bucktail Launch (RKM 169.0 [RM 105.0])
3	Bucktail Launch (RKM 169.0 [RM 105.0])	Steel Bridge (RKM 158.8 [RM 98.6])
4	Steel Bridge (RKM 158.8 [RM 98.7])	Douglas City Campground (RKM 148.4 [RM 92.2])
5	Douglas City Campground (RKM 148.4 [RM 92.2])	Roundhouse Launch (RKM 132.7 [RM 82.5])
6	Roundhouse Launch (RKM 132.7 [RM 82.5])	Junction City Campground (RKM 125.5 [RM 78.0])
7	Junction City Campground (RKM 125.5 [RM 78.0])	North Fork Trinity Confluence (RKM 116.7 [RM 72.5])
8	North Fork Trinity Confluence (RKM 116.7 [RM 72.5])	Big Flat Launch (RKM 107.0 [RM 66.5])
9	Big Flat Launch (RKM 107.0 [RM 66.5])	Del Loma Access (RKM 92.2 [RM 57.2])
10	Del Loma Access (RKM 92.2 [RM 57.3])	Cedar Flat Recreation Area (RKM 78.5 [RM 48.8])
11	Cedar Flat Recreation Area (RKM 78.5 [RM 48.8])	Hawkins Bar (RKM 64.1 [RM 39.8])
12	Hawkins Bar (RKM 64.1 [RM 39.8])	Camp Kimtu (Willow Creek, RKM 41.7 [RM 25.9])

Reach ID	Start Location	End Location
13	Camp Kimtu (Willow Creek, RKM 41.7 [RM 25.9])	Rolands Bar (RKM 20.3 [RM 12.6])
14	Rolands Bar (RKM 20.3 [RM 12.6])	Weitchpec (Trinity Mouth RKM 0 [RM 0])

Salmon redds were identified within each reach through visual observation and all located redds were enumerated. The redd locations were determined by aerial photo interpretation or GPS. Data collected at each spawning location included the number of redds newly constructed since the previous survey and the cumulative number of redds to date. Chamberlain et al. (2012) used encounters with spawned female salmon carcasses to model spatiotemporal distribution of Chinook salmon (hatchery and natural origin) proportions and applied those to observed redds. A multiplier was used to account for differential rates of redd construction between Chinook (1 redd per female) and coho (1.25 redds per female) salmon for the carcasses recovered in the survey.

Carcasses encountered during surveys were rated as follows to describe the degree of decomposition:

- Condition-1 was a carcass with at least one clear eye
- Condition-2 was a carcass where both eyes were cloudy
- Condition-3 denoted skeletal remains

Carcasses recovered during surveys were identified to species and gender, examined for hatchery clips and tags, and measured to the nearest centimeter in FL. Field crews examined all condition-1 and condition-2 female salmon for condition by a direct observation of their ovaries. Fish were classified as spawned if very few eggs had been retained, or un-spawned if a majority of eggs were retained. All condition-1 Chinook salmon carcasses were marked with a unique jaw tag and returned to moving water. All condition-2 and condition-3 carcasses were cut in half with a machete to prevent the fish from being recounted in subsequent surveys.

Redd and carcass data were summarized and analyzed graphically to help interpret the effects of Phase 1 rehabilitation actions on overall changes in fish habitat and progress made by the Program in achieving IAP fish habitat objectives. Redd data were only analyzed for Chinook salmon, and carcass data were only analyzed for Chinook salmon and coho salmon due to a lack of data for other species. Female only and total carcasses were both included in the analysis. The number of redds and carcasses in 2009, 2010, and 2011 were summed and shown graphically at three different scales: 1) individual rehabilitation sites; 2) the five sub-reaches of the mainstem river identified in the channel design guide (HVT et al. 2011; discussed further in Section 4); and 3) the entire 64-km (40-mi.) restoration reach. At each scale, the data were attributed to 200-m segments for analysis using the data frame (Appendix D), with values reported both in terms of the total number and density of observations (i.e., number of redds or carcasses per 200-m segment). Data for the individual rehabilitation sites were grouped by the design guide sub-reaches and compared with controls in each sub-reach (i.e., areas where no rehabilitation occurred). In addition, to determine if gravel augmentation may have influenced spawning locations the density of redds was calculated for gravel treatment areas (i.e., areas where gravel augmentation occurred) and compared to control areas (i.e., areas where no treatment of any kind occurred) and other treatment areas (i.e., areas where rehabilitation activities other than gravel augmentation occurred). However, the analysis is confounded by the fact that gravel augmentation areas frequently included other treatments.

3.4.2.2 Spawning Habitat Assessments

In 2007 and 2008, a spawning habitat guild validation study was conducted by the Program Partners to compare actual redd locations to predicted spawning habitat using guild criteria (Goodman et al. 2010). The study was conducted from the top of the Hoadley Gulch site at Old Bridge in Lewiston to the Rush Creek boat launch (river kilometers [RKMs] 170 to 172.7 [RMs 106 to 107.3]) and from the top of the Salt Flat site to the bottom of the Dark Gulch site (RKMs 165.5 to 177.3 [RMs 103.8 to 110.2]). The investigators mapped redd locations at a dam release of 7 $m^3 \cdot s^{-1}$ (305 cfs) after 98% of redds had been surveyed in that reach as part of the Trinity River spawner surveys. Spawning habitat areas based on guild criteria were mapped at a different time when redds were no longer visible to avoid surveyor bias at dam releases of 309 and 296 cfs. Redd validation analyses were conducted by overlaying the redd locations with the mapped spawning habitat areas. Redd locations were then tallied as either occurring within or outside of mapped habitat areas using GIS. Overall, 64% of the redd locations were found outside of the mapped spawning habitat areas (Goodman et al. 2010), which indicates that additional effort will be required to assess preferred spawning areas.

Because of the results reported in Goodman et al. (2010), as part of the 2009 IHAP (Alvarez et al. 2011) an investigation was conducted to redefine Chinook salmon spawning habitat by modifying the criteria in order to improve predictions of spawning habitat. The approach was expanded to include alteration of depth, velocity, and substrate criteria, and to evaluate the inclusion of additional physical variables to map spawning habitat. The first part of the study compared spawning habitat mapping predictions to redd locations similar to and in the same location as Goodman et al. 2010, but applied refined criteria to define spawning habitat, particularly a reduction in the substrate size. Results of this validation exercise indicated that

55% of redds were located in areas identified as spawning habitat. Although this is a better result than the Goodman et al. 2010 investigation, the percentage was lower than the acceptable level of 70% for use as an assessment technique, and indicates that the mapped areas were not good predictors of spawning habitat availability.

The second part of the investigation evaluated the potential inclusion of additional variables based on habitat information collected at both redds and randomly selected unused areas and a comparison of the results using multivariate analysis. The results of this analysis indicated that spawning habitat was best approximated using more variables and the best approximating model included water velocity, escape cover, water depth, distance to nearest redds, distance to shore, surface substrate, and habitat type. The study concluded that including these variables into future assessments would improve the predictive power of spawning habitat mapping (Alvarez et al. 2011).

Due to the difficulty the Program Partners have experienced mapping and predicting spawning habitat within the restoration reach, changes in spawning habitat area as a result of channel rehabilitation could not be reliably evaluated in this review and are not discussed further. However, we note that estimates of spawning habitat area within the restoration reach are necessary in order to evaluate the progress the Program has made towards achieving IAP sub-objective 2.1.2.

4 GEOMORPHIC CONTEXT

Analyzing underlying geomorphic conditions at a range of scales can provide a physical context for the dynamics of habitat formation and inform explanations and predictions regarding the effectiveness and duration of rehabilitation practices. The central issues involve channel morphology and the flow of watershed products through valley forms that influence how channels evolve. In this section, we examine channel morphology over a range of scales to find patterns that could lead to recommendations where certain practices would be most effective. We analyze underlying tendencies for channel planforms to develop under altered flow and sediment regimes. We summarize the history of channel disturbances that have strongly imprinted on channel forms and processes. Finally, we describe how resistant structural elements in channels and along valley walls constrain alluvial processes that rehabilitation practices attempt to influence.

4.1 Channel Morphology and Planform

Patterns of channel morphology are commonly hierarchical (Frissell et al. 1986). For example, valley morphology (width, slope, degree of alluvial fill) affects the planform shape of the channel (e.g., straight, meandering, braided) which, in turn, influences the reach types that develop (e.g., cascade, pool-riffle, plane-bed channels) and their characteristic channel units (e.g., riffles and pools that form the building blocks of the reach morphology) (Grant and Swanson 1995; Montgomery and Buffington 1997). Channel behavior such as scour and fill, channel migration, and response to disturbance are also associated with channel types. These relations motivate explorations of the potential hierarchy in channel morphology and process within the Trinity River. At the link scale (channel lengths on the order of 10^3 m), the association of certain channel planforms with valley forms and average channel dimensions might suggest where changes in flow and sediment supply would most likely enhance channel forms to create more diverse and productive habitat for salmonids. At the reach scale (lengths on the order of 10^2 m), if differences in channel behavior such as stability and response to channel rehabilitation can be associated with certain reach types, then predictions of channel response to treatments at new sites could be improved. For this purpose, we examined whether reach-average channel morphology (slope, width) varies hierarchically with existing link- and reach-scale classifications that have been developed for the Trinity River.

4.1.1 Link Scale

The mainstem Trinity River is a partially confined gravel-bed river with a mix of alluvial and bedrock-controlled channel morphologies. A small-scale view of valley forms of the study reach of the Trinity River shows limited variability compared to adjacent valleys in the Scott River, Mad River, and South Fork Trinity River. Valley bottoms are narrow and sinuous, indicating frequent contact of the channel with valley walls and bedrock, although terraces and floodplains of various widths are also evident. There are no broad alluvial valleys or steep, narrow gorges. This suggests that variation in channel form at a smaller scale may also be limited, and a hierarchy in scale may not be well manifested.

The channel design guide (HVT et al. 2011) recognizes five link-scale divisions of the mainstem river between Lewiston Dam and the North Fork Trinity River confluence that were chosen based on gage locations and major tributary confluences (Figure 4-1). The Program refers to these divisions as “reaches,” so we have retained that terminology:

- Lewiston Reach (USGS gage 11525500) extending from Lewiston Dam (RM 112.1) to the confluence with Rush Creek at RM 107.9
- Limekiln Reach (USGS gage 11525655) extending from the confluence of Rush Creek (RM 107.9) to the confluence with Indian Creek (RM 95.5)
- Douglas City Reach (USGS gage 11525854) extending from the confluence of Indian Creek (RM 95.5) to the confluence with Browns Creek (RM 88.0)
- Junction City Reach (USGS gage 11526250) extending from the confluence of Browns Creek (RM 88.0) to the confluence with Canyon Creek (RM 79.3)
- North Fork Reach (USGS gage 11526400) extending from the confluence of Canyon Creek (RM 79.3) to the confluence with the North Fork Trinity River (RM 72.2)

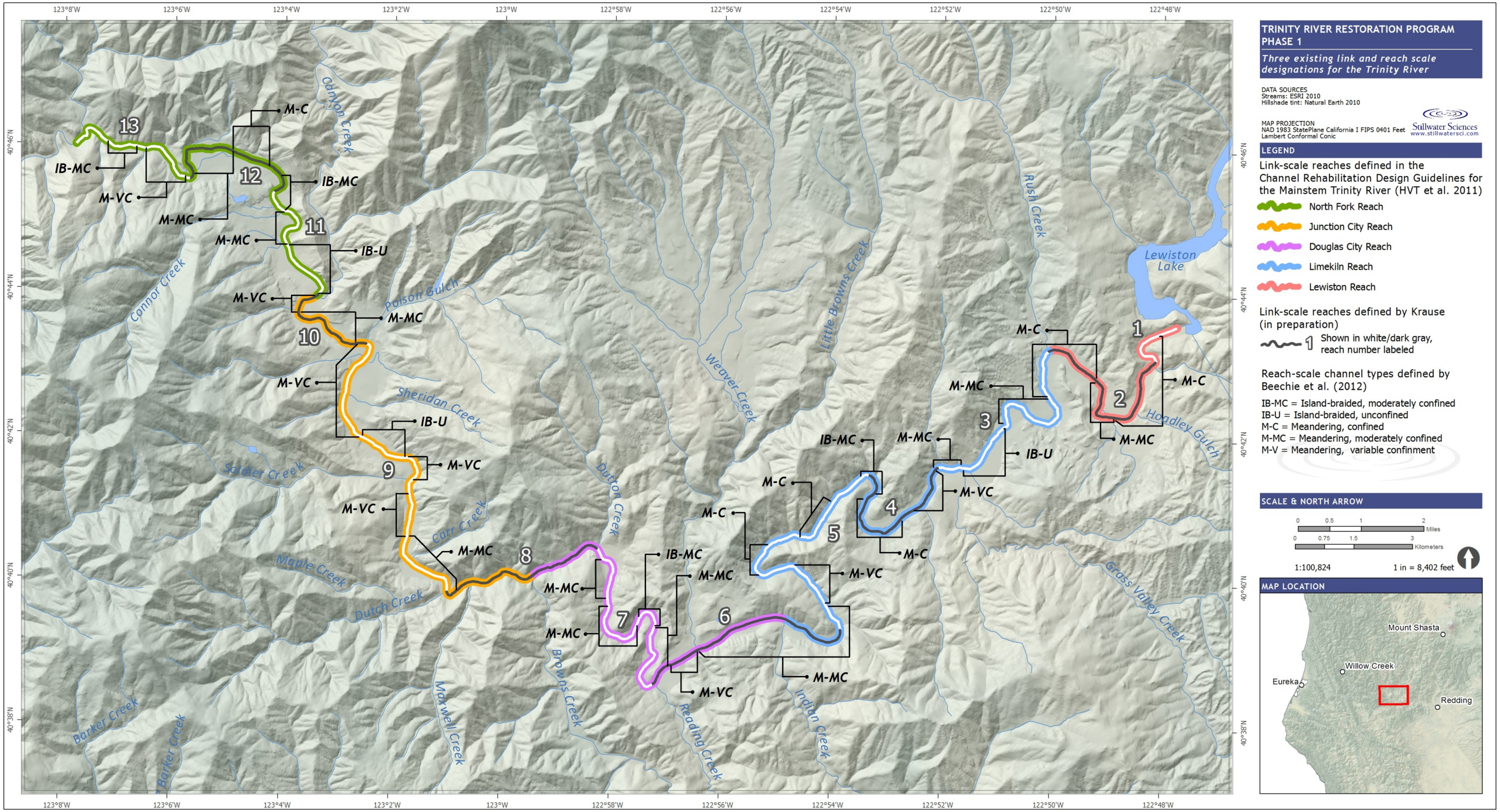


Figure 4-1

Three Existing Link- and Reach-scale Designations for the Trinity River

In addition, Krause (2012a) designates 13 link-scale divisions along the mainstem river that are bounded by significant sediment sources (tributaries and historical mining input locations), limbs of large sediment wedges, and changes in valley and channel morphology.

Spatial variation of reach-average channel slope and width were compared with the above link-scale divisions to see whether morphologic hierarchy exists within the restoration reach of the Trinity River. Average values of slope and wetted width were determined over channel reaches that were 20 bankfull widths in length. Channel slope was calculated from 2009 LiDAR data and wetted width was modeled for a constant discharge of 6,000 cfs, corresponding with a normal-year ROD flow (Section 3.1). We assume a constant discharge given that downstream accretion of flow from tributaries during spring ROD releases is relatively minor (HVT et al. 2011): less than 10% increase in flow between Lewiston Dam and the North Fork Trinity River confluence during a normal-year release. Tributary accretion of flow is more pronounced during naturally occurring winter floods (HVT et al. 2011), but our focus is on ROD flows.

Our analyses indicate that reach-average slope and wetted width do not vary strongly with either of the above link-scale classifications (Figures 4-2 and 4-3), although the design guide classification does discriminate the Lewiston and Douglas City reaches as having broader ranges of slope (Figure 4-4). In the study area, channel slope and wetted width exhibit a spectrum of downstream variation (i.e., small-scale oscillations superimposed on larger-scale ones) that are likely amenable to wavelet analysis (e.g., McKean et al. 2008, 2009), but do not show obvious correlation with the existing link-scale classifications. In addition, the lack of a downstream increase in predicted wetted width (Figure 4-2) is an artifact of using a constant discharge, but is similar to what would occur during a normal-year spring ROD release given the small amount of tributary accretion during such events (HVT et al. 2011). A similar pattern of downstream changes in wetted width is observed in low-flow (450 cfs) LiDAR data obtained in 2009, suggesting that the pattern of wetted widths may hold across a range of uniform flows. In the long term, channel morphology will respond to both the spring ROD releases and the naturally-occurring winter floods, but again, our focus is on the ROD flows.

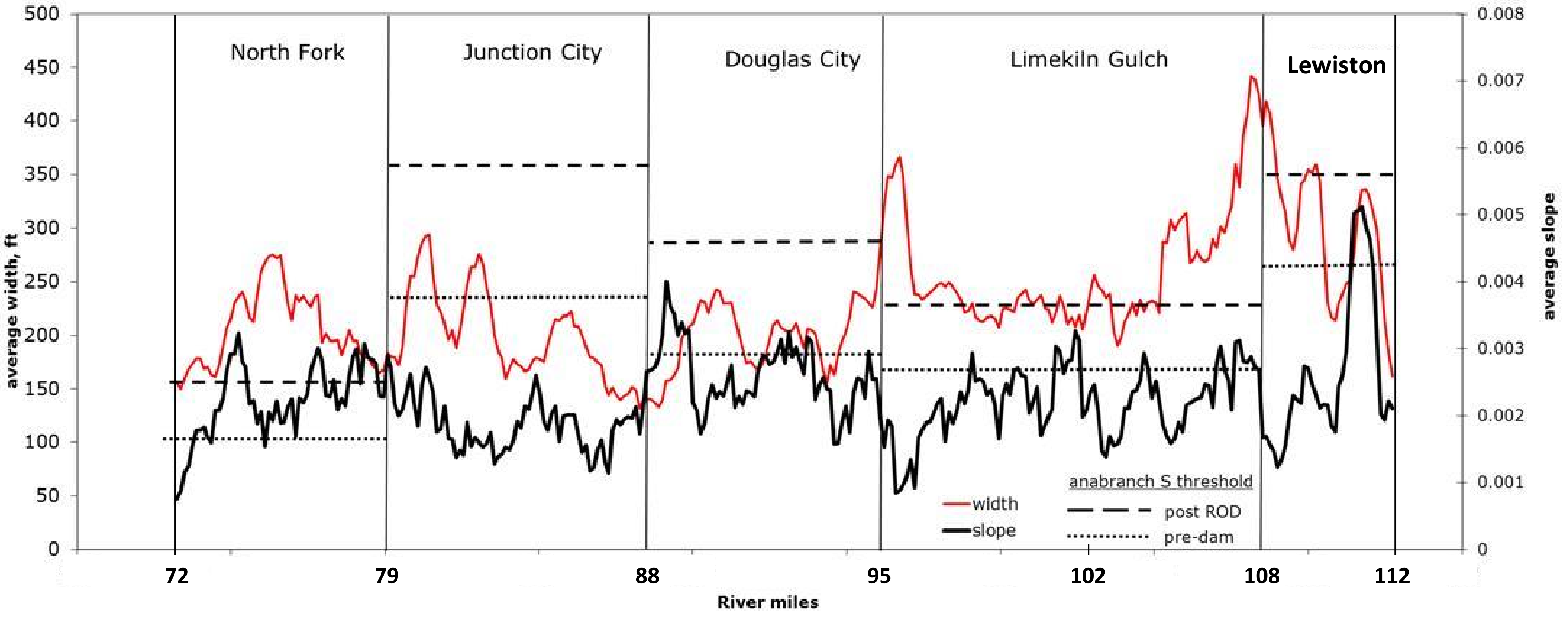


Figure 4-2

Spatial Variation in Reach-average Channel Slope and Wetted Width Within the Five Link-scale Divisions of the Mainstem River Identified in the Channel Design Guide (HVT et al. 2011). Wetted Width is Predicted for a Uniform Discharge of 6,000 cfs. Also Shown Are Slope Thresholds for Transition from Meandering to Anabranching Channel Morphology (Eaton et al. 2010) for Pre-dam (Dotted Line) and Post-ROD (Dashed Line) Bankfull Discharges. Slopes Above the Threshold Have Increased Anabranching Potential. Modified from HVT et al. (2011).

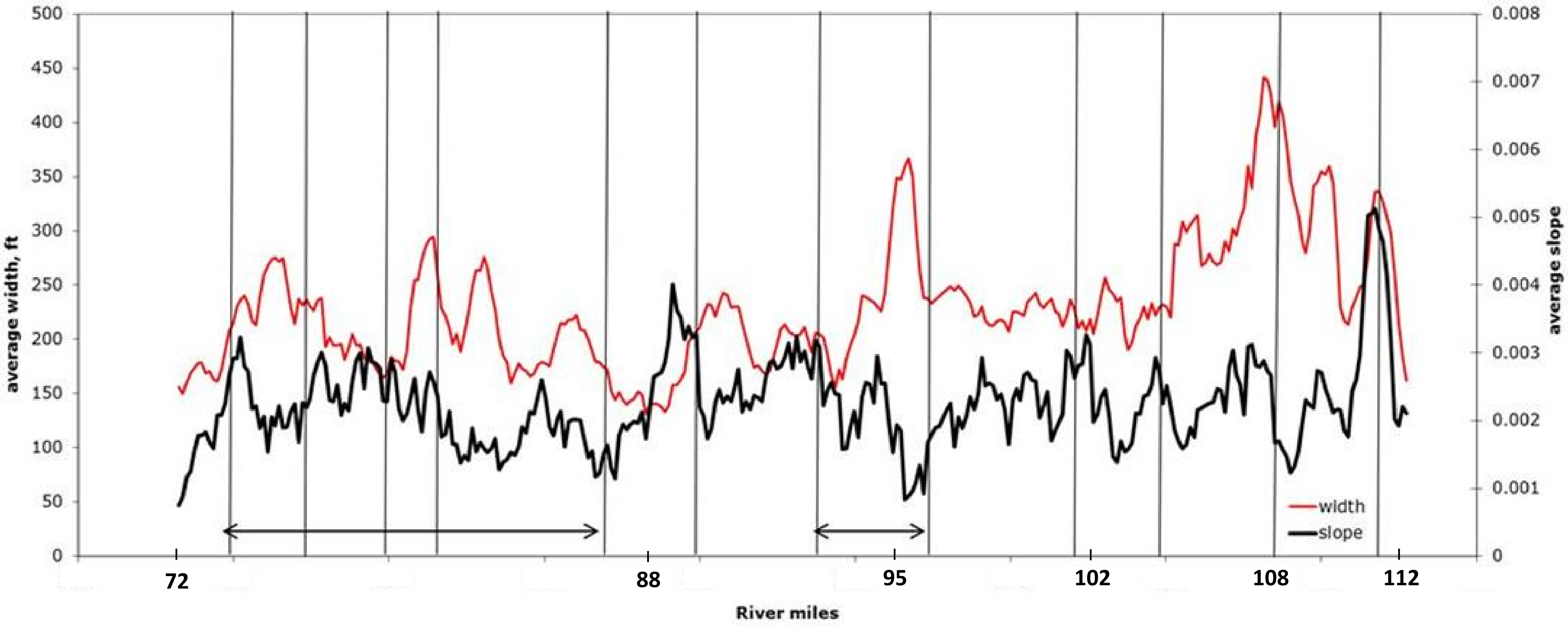


Figure 4-3

Variations in Reach-average Wetted Width (6,000 cfs) and Slope in the Study Reach Compared to Krause's (2012a) Link-scale Divisions for the Mainstem River. Double Arrows Delineate the Extent of Mining-derived Sediment Wedges Near Douglas City and Junction City.

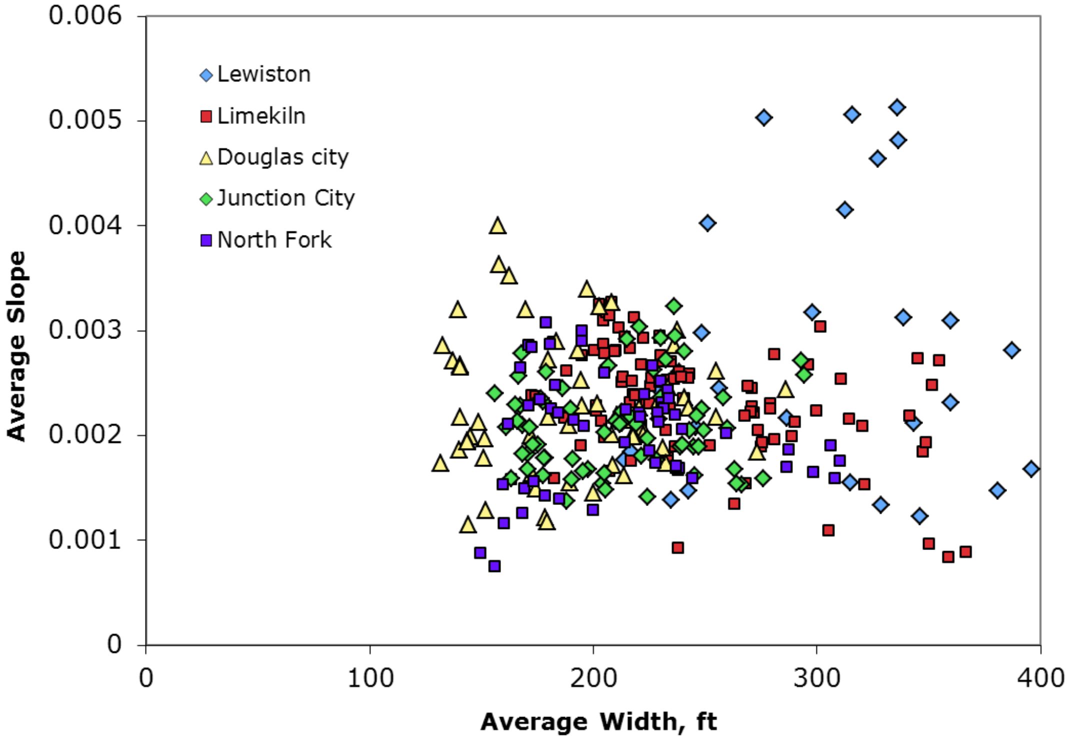


Figure 4-4

Reach-average Width Versus Reach-average Slope for Link-scale Divisions of the Mainstem River Identified in the Channel Design Guide (HVT et al. 2011).

4.1.2 Reach Scale

Channels can be readily classified at the reach scale by planform shape (e.g., straight, meandering, or braided) (Leopold and Wolman 1957; Montgomery and Buffington 1997). Such channel types are associated with specific hydraulic conditions, channel behavior, and habitat characteristics. Furthermore, changes in flow, sediment supply, and bank strength can cause a transition from one planform to another. The reach scale, therefore, offers some general interpretations and predictions linking changes in flow and sediment, channel morphology, and habitat structure. Primary geomorphic factors influencing rehabilitation design include valley/bedrock confinement, composition of bed and bank material, sediment supply, and hydrology.

Discriminant functions predict that the Trinity River would inherently have a single-thread channel pattern for the post-ROD flow and sediment regimes (HVT et al. 2011). However, the actual channel pattern is affected by geologic controls (e.g., bedrock outcrops), as well as historic and modern changes in flow (e.g., former dam operations, ROD flow regime), bank erodibility (e.g., riparian berms, tailings piles, removal of stabilizing features at rehabilitation sites), and sediment supply (e.g., sediment trapping in upstream dams, gravel mining, gravel augmentation). Individual reaches of the mainstem Trinity River vary between a straight channel, active meanders formed in alluvium, and passive meanders constrained by bedrock and resistant banks (HVT et al. 2011).

Beechie et al. (2012) used cluster analysis to identify five groups of reaches with similar confinement, planform, and channel slope: confined meandering, moderately confined meandering, variably confined meandering, moderately confined island-braided, and unconfined island-braided (Figure 4-1). Chanel confinement was defined as the ratio of valley width to bankfull channel width. They found that confined meandering reaches have high widths, and that island-braided reaches have high slopes. Locally high slopes are common in braided channels. However, a scatter plot of wetted width at 6,000 cfs and reach-average slope (Figure 4-5) did not show a clear distinction between reach types in our analysis of their classification.

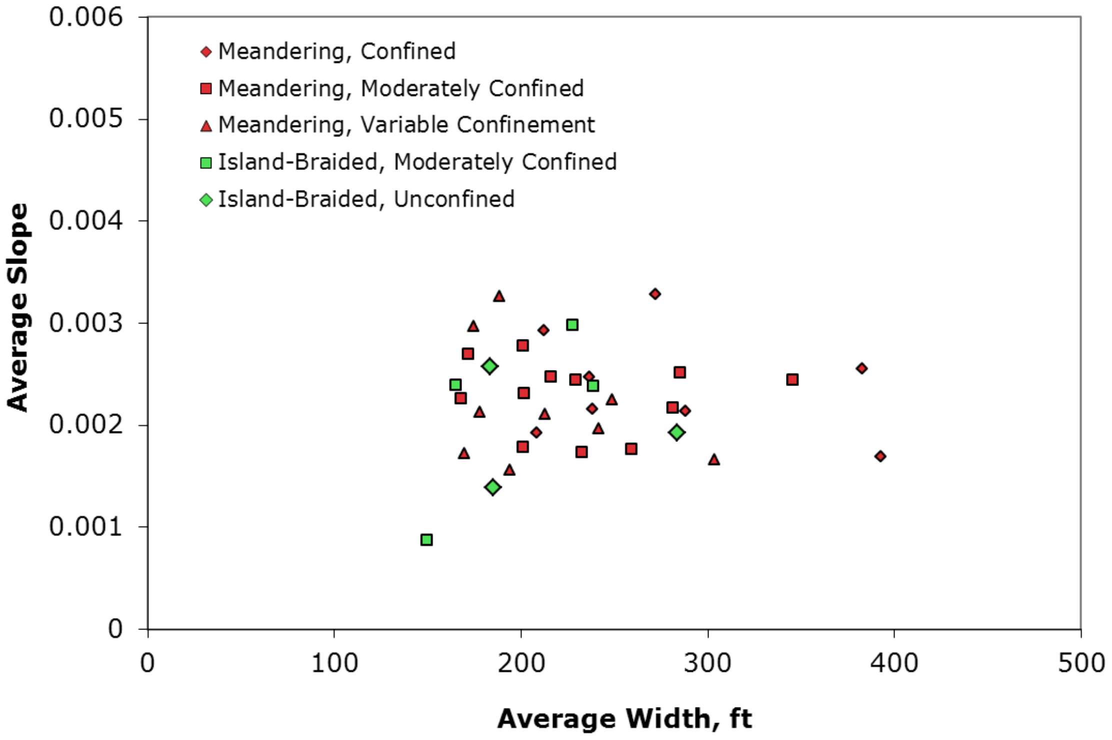


Figure 4-5

Reach-average Width Versus Reach-average Slope for Reaches Delineated by Beechie et al. (2012)

4.1.3 Hierarchy in Channel Designations

As indicated above, reach-average channel slope and wetted width are not well correlated with existing link-scale division of the mainstem river (Figures 4-2 and 4-3) or with reach-scale planform (Figure 4-5). In contrast, the frequency of reach types identified by Beechie et al. (2012) differs strongly among the five links designated by HVT et al. (2011). The degree of confinement of meanders generally decreases in downstream links, and braided reaches are most prevalent in the downstream-most link. These trends may reflect a general downstream widening of the valley walls and an accommodation of more multi-thread channels. There are exceptions to these trends and not all reaches, including the gorge in the Douglas City link, were classified by Beechie et al. (2012). Even if these hierarchical relations between links and reach planform exist, it is not apparent how they may inform us of trends in channel behavior or provide new information that would aid rehabilitation planning at any scale.

4.1.4 Tendencies for Channel Planforms

Tendencies for bar formation and lateral instability can be inferred from a mechanistic model developed by Eaton et al. (2010) that predicts channel planform based on regime theory and linear stability theory. Using bankfull dimensions and bed-surface particle sizes measured at 13 reference reaches, HVT et al. (2011) computed slope thresholds marking transitions from single-thread channels (straight or meandering), anabranching channels (relatively stable multi-thread channels), and braided channels (unstable multi-thread channels) at link scales for pre-dam and post-ROD flow regimes. Building from their analysis, we plotted the slope threshold between single-thread and anabranching channels (Figure 4-2) using the weakest vegetative bank strength (grass) to avoid underestimating tendencies for multiple bar formation. Results indicate that the potential for anabranching may have been more common during the pre-dam flow regime than in the current post-ROD regime (Figure 4-2). The threshold between anabranching channels and braided channels (not shown) falls above all local slope values for both flow regimes. These results suggest that tendencies for active deformation and proliferation of bars have been reduced by dam closure, and that the North Fork Reach has the highest potential for multithread channels. This analysis would be improved by additional reference reaches to provide a more detailed delineation of slope thresholds, and by additional bed material sampling, given that the predictions are sensitive to particle size.

An alternative analysis by Beechie et al. (2012) used field diagrams of channel slope and bankfull discharge from reference reaches in the Pacific Northwest to predict channel planforms in the Trinity River and effects of post-ROD flow regimes. The channel pattern most likely to develop in each restoration reach was identified by defining slope–discharge domains for channel patterns in reference reaches, and then overlaying channel slope and channel-forming discharge values for Trinity River restoration reaches. They found similar results as those of HVT et al. (2011) at a coarser scale. Higher flows promote the transition from a single-thread planform (straight or meandering) to an island-braided planform. Of 37 reaches, 31 would maintain a single-thread planform, four would tend to transition from single-thread to island-braided during wet years, and two would already be island-braided during normal water years.

4.2 Legacy of Sediment Inputs and Redistribution

Extreme historical sediment inputs and their redistribution by large floods in the twentieth century are a major factor in the geomorphic context of reaches at any scale in the Trinity River. The morphology of the Trinity River channel and floodplains has been profoundly altered by intensive hydraulic and dredge mining since the 1860s. Hydraulic mining supplied several orders of magnitude more sediment than would have been supplied under natural conditions, sufficient to aggrade the channel and valley bottom several feet (Krause et al. 2010). Analysis of the longitudinal profile indicates the persistence of two major sediment wedges (Krause 2012a; Figure 4-3). The largest sediment wedge apparently originated from mining debris delivered to the Trinity River from the La Grange Mine via Oregon Gulch. A detrended profile indicates that this sediment wedge is 22.7 km (14.1 miles) long and has a peak height of 4.5 m (14.8 feet). The second sediment wedge occurs between the Weaver and Indian creek confluences near Douglas City. It is 8.2 km (5.1 miles) long and has a peak height of 3.2 m (10.5 feet). Riffle crests that are influenced or controlled by bedrock occur within intervening reaches, but not within the two major sediment wedges, nor in five smaller sediment wedges that appear as positive anomalies in the detrended profile. The distribution of such riffle crests suggests that sediment wedges may have forced alluvial channel types in locations that would have been less alluvial or bedrock. The limits of the major sediment wedges correspond by definition to the link delineations of Krause (2012a), but they do not correspond with those of HVT et al. (2011) (Figures 4-2 and 4-3).

Dredge mining that occurred subsequent to hydraulic mining overturned more than 70% of the floodplains, resulting in large tailing piles of coarse sediment (gravel, cobble, and boulder) up to 12 m (40 feet) high that confine the river to a narrow floodplain in places (Krause et al. 2010). Large floods in the mid-twentieth century reworked some of this material and formed valley-scale bars that persist as hydraulic controls (Krause 2012a). The historic flood of 1964 deposited large deltas at tributary mouths. The tributary deltas survived this and later floods mainly because reservoir storage has reduced peak flows. Other disturbances to the sediment regime include historic sand and gravel mining and restoration actions, including delta channelization, construction of artificial spawning riffles, pool dredging, coarse sediment augmentation, and high-flow releases (Krause et al. 2010).

4.3 Channel Structure

Channel structure includes resistant elements that restrict remolding of the channel by streamflow. The Trinity River has alluvial attributes (McBain & Trush 1997), but channel evolution in many reaches is affected by resistant elements that constrain interactions between flow, sediment transport, and channel morphology. The Trinity River has been categorized as "…an alluvial channel working through a tapestry of bedrock controls" (HVT et al. 2011). Despite the consistency of predictions of meander planforms in the Trinity River based on theories of the behavior of alluvial channels, actual planforms are pervasively influenced by bedrock boundaries, valley confinement, and the legacy of large sediment inputs reworked by large floods. The channel frequently runs against valley walls where it was relocated by gold dredgers (Krause et al. 2010), and some large meanders are passive insofar as they are formed against curving valley walls (HVT et al. 2011).

Intermittent outcrops, valley bends, and constrictions can govern the form, size, and location of pools and bars and thereby stabilize channel morphology (Lisle 1986). In some cases these structural features may prevent channel migration, but they nonetheless promote local scour and fill, diversify sedimentary conditions, and can thereby increase habitat complexity. Given that channel migration in the Trinity River is limited, additional features such as large wood may be effective at increasing channel complexity, especially in channels confined by valley walls and dredge tailings (HVT et al. 2011).

Interactions of structure and alluvial processes create complexity in channel morphology that cannot be resolved by stratifying reaches by tributary junctions and other gross features. An important distinction for channel reaches in the Trinity River is whether they are alluvial (having purely granular bed and bank boundaries) or semi-alluvial (having intermittent bedrock boundaries) (Turowski 2012). Even infrequent bedrock exposures can indicate strong structural controls on channel morphology (Turowski et al. 2008). In the Trinity River, purely alluvial reaches are associated with large sediment wedges.

Alluvial reaches may be most suitable for promoting active bar formation, channel migration, and shallow habitats for emergent fry by removing rooted banks (riparian berms) and injecting gravel to maintain continuity in bed load transport. Semi-alluvial reaches may be most suitable for training the channel to encounter large outcrops and tight bends against resistant material, thereby forming deep pools and complex habitat assemblages (HVT et al. 2011). In either type of channel, smaller features such as large wood can create local diversity.

4.4 Erosion and Deposition Along the Channel Margin

Potential channel changes, as reflected by overlapping banklines mapped over time, indicate that erosion has generally exceeded deposition, and fluvial changes are larger than those due to construction (Figure 4-6). Given that erosion exceeded deposition for all periods except 2007 to 2009, channel widening would be expected and such is the case (Table 3-8). Some of these differences may be due to differing discharges during aerial photography, but surface area or width is not well-correlated with discharge at the dam or downstream at Junction City (Tables 3-8 and 4-1).

Table 4-1

Discharge Magnitudes at Upper and Lower Stations as Related to Wetted Surface Area at Low Flow

	Discharge, cfs		Ratio of Wetted Surface Area to that in 2001
Photography Date	**Lewiston**	**Junction City**	
November 7, 2001	334	NA	1.000
September 21, 2005	479	524	1.051
July 3, 2007	448	455	1.066
April 16, 2009	291	554	1.050
August 16, 2011	446	570	1.094

Note:
The Spearman rank correlation for wetted surface area ratio to Lewiston discharge is 0.20, and the same for Junction City discharge.

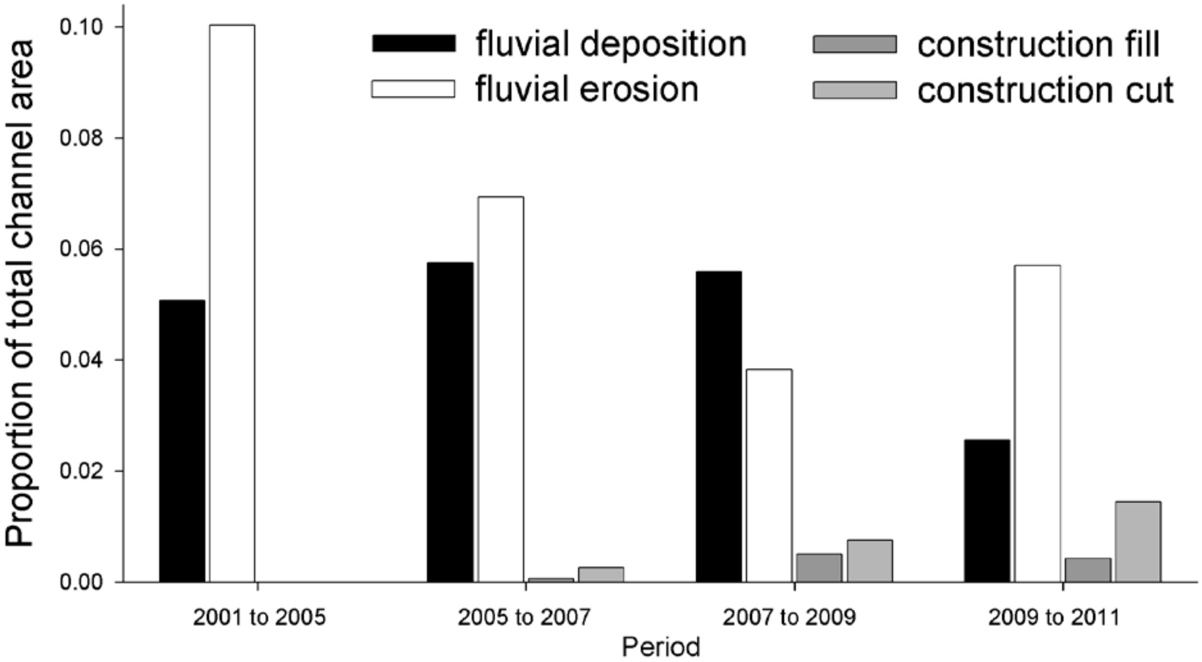


Figure 4-6

Putative Erosion and Deposition by Period and Influence. Construction Influences Are Relatively Small Because Much of it Occurs Above the Low-Flow Channel, and Constructed Reach Lengths Are Relatively Short (8.1 River Miles) Compared to the Entire Restoration Reach (40 River Miles). The Channel Area for a Given Period is or the Earlier Year (e.g., 2001 for 2001 to 2005).

Summary statistics for the four periods (Table 4-2) provide a fuller description of how bankline shifts are distributed among the types of changes. The results from the raw line work (data-set 1) are shown along with the combined set (data-set 2) so that sensitivity to sliver removal and other minor editing is apparent. Sliver removal comprised about 0.3 percent of the original areas, while tributary removal amounted to about the same. The total amount of area removed was about 0.7 percent.

Some process errors occurred when creating the combined data set. Some polygons did not line up correctly due to line errors in the original files, resulting in duplicate, overlapping polygons. These were manually removed and edited to match the original shapes and total areas in the initial data set. After such editing, the maximum error in total area occurred in the 2009 to 2011 period, and it was 0.009 percent. Most of this was within the “no change” class; errors in the other periods were about three orders of magnitude smaller.

Table 4-2

Changes in Mapped Channel Margins by Time Period and Data Set

Data-set 1: Polygons as extracted in GIS with no modification

Period	**2001 to 2005**		**2005 to 2007**		**2007 to 2009**		**2009 to 2011**	
Class	**n**	**Hectares**	**n**	**Hectares**	**n**	**Hectares**	**n**	**Hectares**
Potential deposition	3182	11.0938	3580	12.6715	4031	14.9791	1153	6.3625
Potential erosion	3391	20.8898	3479	16.9583	4089	10.3467	1632	15.2486
No change	16	190.3291	22	198.5473	10	200.5265	16	204.5107
Total:	6589	222.3126	7081	228.1771	8130	225.8523	2801	226.1218

Data-set 2: The above data set without small slivers and tributary junctions, and wing-wall adjustments

Period	**2001 to 2005**		**2005 to 2007**		**2007 to 2009**		**2009 to 2011**	
Class	**n**	**Hectares**	**n**	**Hectares**	**n**	**Hectares**	**n**	**Hectares**
Potential deposition	1425	10.2083	1690	12.1543	1612	11.9693	520	5.3929
Potential erosion	1814	20.5454	1672	14.6469	1483	8.2047	1120	12.0108
No change	12	190.3221	14	198.0309	5	199.2143	14	202.7496
Construction deposition	0	0	36	0.1218	74	1.0913	28	0.8978
Construction erosion	6	0.0131	30	0.5428	70	1.6155	79	3.0604
Construction no change	2	0.0004	22	0.5010	55	1.3059	54	1.7733
Total:	3259	221.0894	3464	225.9977	3299	223.4011	1815	225.8848

Note:
Construction outside the channel (class 7, see methods) is not included so that the spatial domain is constant for data sets. The results of data-set 1 as compared to data-set 2 show the sensitivity to sliver removal. Construction changes are left out of data-set 1 because they are so small.

The potential erosion of the riparian berm (Figure 4-7) follows the trend in erosion over time (Figure 4-6). The total berm area as mapped in 2003 is 38.20 hectares, and the total potential berm erosion since 2003 is 6.97 ha, or 18%. Examples of berm erosion at three locations are shown in Figure 4-8.

During spot-checking of polygons, the most significant mapping errors were due to bank edges hidden by tree canopies. Although changes are clearly occurring and visible on aerial photography (Figure 4-8), the amount of erosion and deposition reported here is likely an over-estimate because of the errors in banklines. As an alternative to remote-sensing, bank erosion and deposition could be directly measured by mapping banklines during the Program’s juvenile fish habitat surveys. In this way, habitat could be connected with an accurate characterization of channel migration.

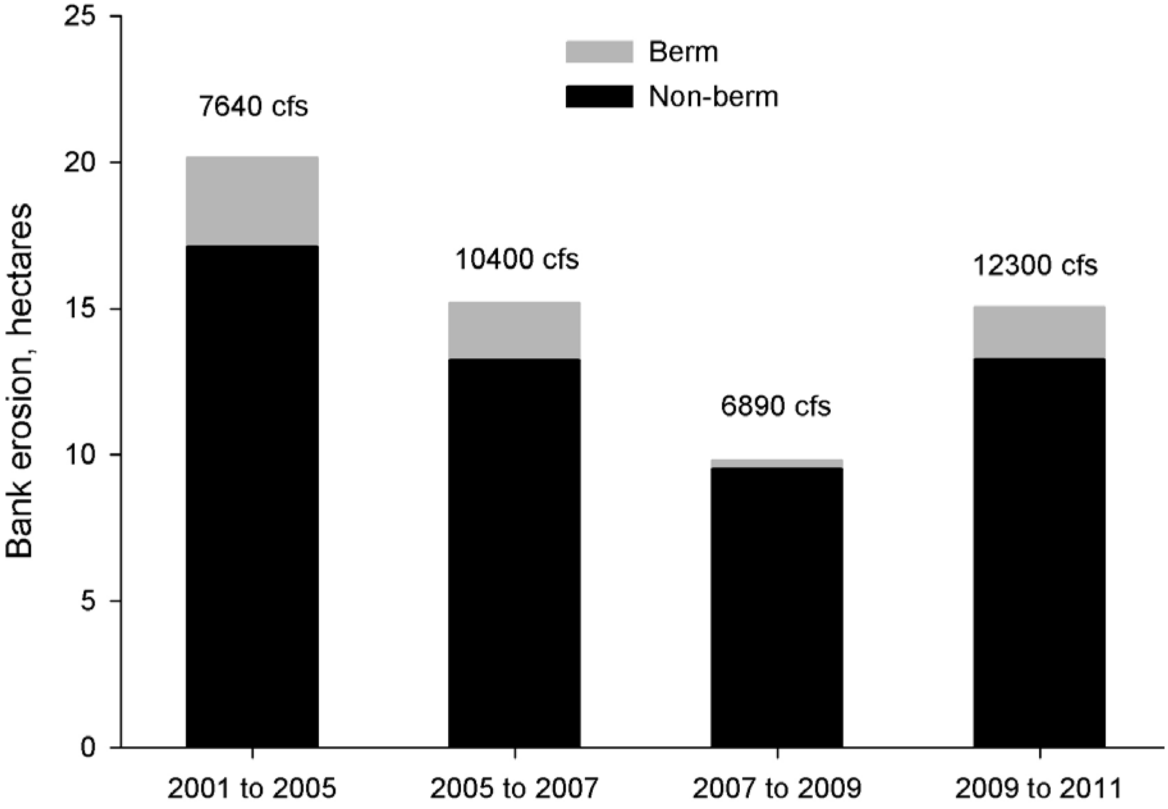


Figure 4-7

Potential Bank Erosion by Period for Non-Bermed and Bermed Margins. Maximum Peak Flow Values Occurring Within the Period Are Placed Above the Bars.

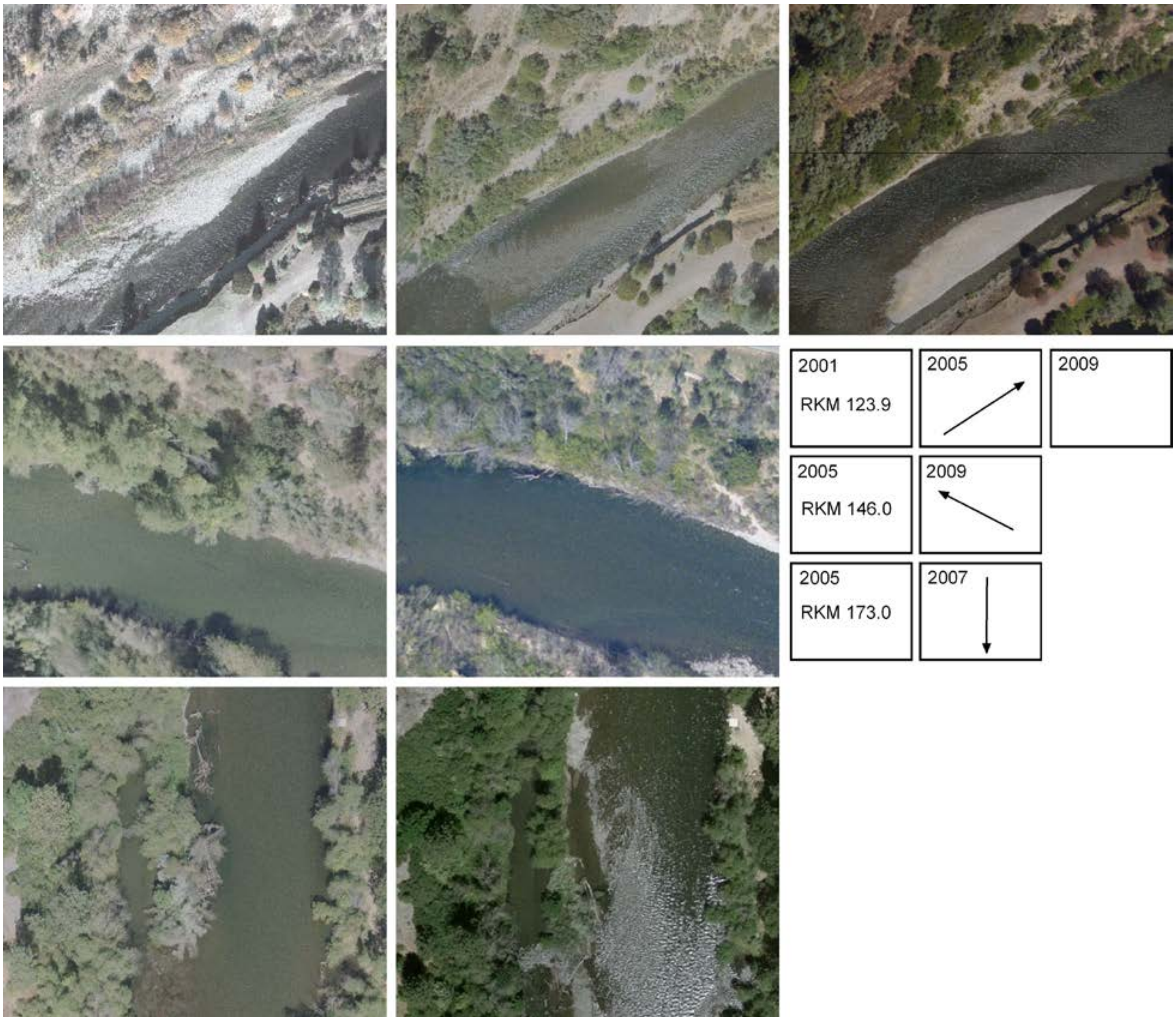


Figure 4-8

Berm Erosion Examples at Three Locations. Mapped Polygons Are Not Shown. The Key Shows Aerial Photography Year, Streamflow Direction, and Nearest River Kilometer.

4.5 Summary and Conclusions

The Trinity River in the study reach is predominantly a semi-alluvial channel that is confined to various degrees by valley walls and is not prone to form multiple bars or braided planforms, particularly after peak flows and sediment supply were reduced by the Trinity Dam. As a result, contrasts in channel planform are not strong. The primary channel distinction that provides a general geomorphic context for channel rehabilitation is between alluvial and semi-alluvial reaches. Different opportunities and risks for successful treatments in alluvial and semi-alluvial channels can be recognized where the distinction between reach types is strong. Existing reach designations are not based solely on this distinction because of other factors that influence channels. The survey of bank materials and confinement by Dave Gaeuman (unpublished data) and forthcoming geomorphic mapping by USGS should help to designate reaches based on their alluvial tendencies and help to test a hypothesis that alluvial reaches were originally semi-alluvial reaches that have since been covered by sediment wedges of mining debris (Krause 2012a).

Alluvial tendencies are strongest in the downstream reaches (Junction City and North Fork) because of cumulative tributary inputs and an extensive sediment wedge centered at Oregon Gulch. We would expect that spawning and young-of-the-year habitats would tend to be prevalent in these reaches and rehabilitation treatments to enhance these habitats would be inherently effective. However, spawning salmon tend to congregate near the hatchery at the dam site and thus lower reaches may not be utilized to capacity by adult spawners and young-of-the-year. Therefore, regardless of geomorphic tendencies, improving spawning and rearing habitats in upper reaches might be most effective in increasing fish populations.

Simplistic reach stratification may be of limited value in the Trinity River. The legacy of disturbance originating from mining in and around the Trinity River has left a complex imprint on subsequent channel-forming processes. Channels have been relocated by dredgers, large sediment wedges impose anomalies in sediment supply, and valley-scale bars that were formed more than 5 decades ago by reworking of mining debris still control local base levels. Truncation of sediment supply and reduction of flood flows by dams perpetuate these disturbances. Interactions between alluvial channel forms, coarse deposits of mining debris, and non-alluvial boundaries in semi-alluvial reaches under a new sediment and flow regime further complicate our ability to predict and manage channel evolution and draw from knowledge gained from simpler alluvial systems. Site-specific analysis of how historical disturbances affect contemporary channel evolution is forthcoming (Krause 2012a).

As a result, the most meaningful geomorphic context for rehabilitation may be found at the scale of an individual rehabilitation site. At each site, the juxtaposition of non-alluvial features, valley forms, mining debris, and bar features left by large floods constrain the alluvial features and associated habitats that can be formed by rehabilitation practices and be modified by flow releases and sediment control measures. On the other hand, the variety of channels at this scale presents a diversity of opportunities for habitat improvement, and the variety of treatments that have been applied at single sites reflects this reality. Analyzing the geomorphic context that presents opportunities as well as constraints at each site would be well served by the experience and capability of Program Partners and other professionals that have worked in the Trinity River. The Design Guide (HVT et al. 2011) provides comprehensive and detailed recommendations for planning rehabilitation treatments within a reach-scale geomorphic context. Rather than using relations between mean channel variables of similar reaches in the Trinity River or reference sites of alluvial channels elsewhere to predict rehabilitation effectiveness, analysts could use morpho-dynamic models that are applicable to both alluvial and semi-alluvial channels. Channel stratification (e.g., alluvial vs. semi-alluvial) can differentiate between potentially effective treatments, but planning approaches, including contextual analysis and modeling, can be consistent among the range of channel types.

The boundaries of a local contextual analysis for a rehabilitation site should be selected to include major upstream and downstream controls on channel forming processes. Valley-scale bars in the Trinity River commonly determine major drops and controls in the channel profile that strongly influence the hydraulics of intervening reaches (Krause 2012a). If a reach that is targeted by morphodynamic modeling does not lie inside the governing hydraulic controls, the model is not likely to generate accurate results. Recognition of major control sections is vital to the design of side channels. It is recommended that major hydraulic controls created by valley-scale bars be mapped at each rehabilitation site, and designs and analyses be developed and reviewed accordingly.

5 FLOW EXPOSURE

Flow exposure at channel rehabilitation sites is described using flow frequency (exceedance) statistics, the magnitude of peak flow experienced, and the duration of high flows that cause geomorphic change.

5.1 Flow Frequency (Exceedance)

Trinity River daily flows were estimated at various key locations (nodes) between Lewiston Dam and its confluence with the North Fork Trinity River for WYs 2003 to 2011. These data were then used to estimate the number of days that flow exceeded specific discharges (300, 450, 1,000, 1,500, 2,000, 4,000, 6,000, and 8,000 cfs) at each channel rehabilitation site location for the three reporting periods each year. The resulting values were attributed to the data frame. The exceedance data are provided in Attachment A.

For the June to October time period, flows at all sites are primarily influenced by flow releases from Lewiston Dam. Flows almost always exceed 300 cfs (95% of days at the Sven Olbertson site and 100% of days at the Pear Tree site). Accretion occurs from tributary inflow. Flows rarely exceed 4,000 cfs (less than 2% of days at both Sven Olbertson and Pear Tree sites).

For the February 15 to June time period, flows at upstream sites near Lewiston Dam are dependent on flow releases from the dam. Also, inputs from tributaries (i.e., accretion) increase flows that rehabilitation sites in the main channel are exposed to each year as distance from Lewiston Dam increases. This trend where rehabilitation sites located farther downstream from the dam experience higher flows, and therefore more exceedances above specific thresholds, is most prevalent under lower flow conditions. As discharge from the dam increases, it increasingly dominates river flow to where under very high flow conditions the number of exceedances all of the restoration sites are exposed to becomes more similar. For example, both Sven Olbertson and Pear Tree were exposed to flows above 8,000 cfs approximately 2% of the time from 2003 to 2011 (Attachment A Tables A-1 and A-15).

5.2 Peak Flow Magnitude and Duration

Daily flow data were also used to estimate annual peak flow experienced at each channel rehabilitation site. These flows are provided in Table 5-1.

Table 5-1
Peak Flows at Channel Rehabilitation Site Locations

Site	Key Node Assumed	Estimated Peak Flow (cfs)[1]								
		2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Sven Olbertson	Trinity River at Lewiston	***2,780***	***6,350***	***7,640***	***10,400***	***4,810***	***6,890***	***4,630***	***7,480***	***12,300***
Deadwood	Trinity River immediately below Deadwood Creek	2,812	6,361	7,690	10,453	4,830	6,911	4,641	7,506	12,325
Lewiston Cableway	Trinity River immediately below Deadwood Creek	2,812	6,361	7,690	10,453	4,830	6,911	4,641	7,506	12,325
Hoadley Gulch	Trinity River immediately below Deadwood Creek	2,812	6,361	7,690	10,453	4,830	6,911	4,641	7,506	12,325
Sawmill	Trinity River immediately below Deadwood Creek	2,812	6,361	7,690	10,453	4,830	6,911	4,641	7,506	12,325
Dark Gulch	Trinity River immediately below Rush Creek	2,928	6,440	7,695	10,399	4,811	7,013	4,899	7,367	12,440
Lowden Ranch	Trinity River above Grass Valley Creek	2,917	6,454	7,588	10,258	4,758	7,018	5,003	7,239	12,442
Trinity House Gulch	Trinity River immediately below Grass Valley Creek	3,038	6,546	7,737	10,354	4,773	7,091	5,109	7,278	12,553
Indian Creek	Trinity River immediately below Indian Creek	3,064	6,479	7,822	10,277	4,727	7,238	5,492	7,096	12,669
Reading Creek	Trinity River at Douglas City	***6,240***	***9,540***	***7,980***	***12,500***	***4,810***	***7,510***	***6,090***	***7,450***	***12,900***
Hocker Flat	Trinity River immediately below Canyon Creek	10,621	17,384	9,299	26,531	5,018	7,559	7,629	7,920	13,131
Conner Creek	Trinity River immediately below Canyon Creek	10,621	17,384	9,299	26,531	5,018	7,559	7,629	7,920	13,131
Valdor Gulch	Trinity River above NF Trinity River	10,956	17,958	9,474	***28,800***	***5,140***	***7,640***	***7,890***	***7,980***	***13,000***
Elkhorn	Trinity River above NF Trinity River	10,956	17,958	9,474	***28,800***	***5,140***	***7,640***	***7,890***	***7,980***	***13,000***
Pear Tree	Trinity River above NF Trinity River	10,956	17,958	9,474	***28,800***	***5,140***	***7,640***	***7,890***	***7,980***	***13,000***

Notes:

1. Peak flow rates in ***bold italic*** text are known peaks from gage records; all other values were estimated using the hydrologic analyses methods described in Section 3.2.

As shown in Table 5-1, the peak flow exposure at channel rehabilitation sites is typically controlled by flow releases. However, during WYs 2003, 2004, and 2006, winter tributary accretion flows were high enough to cause the peak flow dates to change for lower sites (from Reading Creek to Pear Tree). In other years, tributary accretion flows may extend the duration of peak flows by 1 or 2 days. Estimated peak flow dates for two locations are provided in Table 5-2.

Table 5-2

Estimated Peak Flow Dates by Year for Upstream and Downstream Locations

Years	Peak Flow Date(s)	
	Upstream Location[1]	Downstream Location[2]
2003	May 1 – 2	December 28
2004	May 16 – 18	February 17
2005	May 10 – 13	May 9 – 13
2006	May 24 – 26	December 30
2007	May 1 – 5	May 1 – 5
2008	May 8 – 9	May 8 – 9
2009	May 1 – 5	May 3 – 6
2010	May 2 – 4	May 2 – 5
2011	May 4 – 6	May 3 – 7

Notes:

1. Upstream location is Trinity River at Lewiston key node (Sven Olbertson site).
2. Downstream location is Trinity River at Douglas City key node (Reading Creek site).

For WYs 2003, 2004, and 2006, years when winter tributary accretion flows impact peak flow timing at lower sites, peak flows are typically shorter in duration than peak flows controlled by flow releases.

The duration of high flows (above 6,000 cfs) is provided in Table 5-3. A flow rate of 6,000 cfs was selected for review as it represents a flow rate that can cause geomorphic change.

Table 5-3
Duration of Flows Greater than 6,000 cfs at Channel Rehabilitation Site Locations

Site	Key Node Assumed	Number Of Days In Water Year Above 6,000 cfs								
		2003	2004	2005	2006	2007	2008	2009	2010	2011
Sven Olbertson	Trinity River at Lewiston	0	4	6	20	0	7	0	5	7
Deadwood	Trinity River immediately below Deadwood Creek	0	4	7	27	0	7	0	5	7
Lewiston Cableway	Trinity River immediately below Deadwood Creek	0	4	7	27	0	7	0	5	7
Hoadley Gulch	Trinity River immediately below Deadwood Creek	0	4	7	27	0	7	0	5	7
Sawmill	Trinity River immediately below Deadwood Creek	0	4	7	27	0	7	0	5	7
Dark Gulch	Trinity River immediately below Rush Creek	0	10	7	24	0	7	0	5	7
Lowden Ranch	Trinity River above Grass Valley Creek	0	10	7	21	0	7	0	5	7
Trinity House Gulch	Trinity River immediately below Grass Valley Creek	0	10	8	25	0	7	0	5	7
Indian Creek	Trinity River immediately below Indian Creek	0	10	8	24	0	7	0	5	8
Reading Creek	Trinity River at Douglas City	0	9	10	35	0	8	0	6	8
Hocker Flat	Trinity River immediately below Canyon Creek	3	13	14	44	0	10	2	8	9
Conner Creek	Trinity River immediately below Canyon Creek	3	13	14	44	0	10	2	8	9
Valdor Gulch	Trinity River above NF Trinity River	3	13	14	46	0	10	2	8	11
Elkhorn	Trinity River above NF Trinity River	3	13	14	46	0	10	2	8	11
Pear Tree	Trinity River above NF Trinity River	3	13	14	46	0	10	2	8	11

6 SITE-SCALE RESPONSE

This section summarizes existing available information regarding the design objectives, site characteristics, and geomorphic and biological responses at Phase 1 channel rehabilitation sites. Sites are discussed according to the approximate order in which they were constructed. Additional information about individual channel rehabilitation site designs is provided in Attachment B.

6.1 Hocker Flat

Location: RMs 78.0 to 79.1
Year constructed: 2005

6.1.1 Design Objectives

The Hocker Flat project was designed to increase habitat for salmonids, particularly rearing habitat, and increase habitat complexity for riparian-dependent wildlife species. The design sought to maximize channel rehabilitation and minimize implementation cost and complexity by emphasizing mechanical changes that would facilitate geomorphic changes (e.g., channel migration and bar building resulting in increased sinuosity) during high flows. Natural riparian regeneration was anticipated on constructed floodplains.

6.1.2 Site Description

The Hocker Flat site begins at the confluence of Canyon Creek (RM 79.1), located immediately downstream of Junction City, and extends 1.1 miles downstream through a low amplitude meander bend. An extensive and dynamic delta, composed of coarse-grained sediment, occurs at the Canyon Creek confluence. Vegetated riparian berms occurred along the channel margins and separated the low flow channel from historical point bars and floodplains. In the vicinity of the Jim Smith pilot bank rehabilitation site, the floodplain was inundated at high flows and a high-flow side channel occurred at the upland edge of the floodplain. The right bank at the upstream and downstream ends of the Hocker Flat site was armored with riprap where the channel impinges on Highway 299. Adjacent terraces were occupied by dredger tailings.

The Hocker Flat site, constructed in the fall of 2005, was the first rehabilitation site implemented following the ROD. It consisted of seven in-river and seven upland design elements (Figures 6-1a and 6-1b; Table 6-1). At the upstream end of the site, riparian vegetation was removed and the berm recontoured (R-2). Downstream and along the left bank, the existing surface was lowered (R-4) to inundate a depth of 0.3 m (1 foot) at 170 $m^3 \cdot s^{-1}$ (6,000 cfs). Along the right bank through the Jim Smith bank rehabilitation site, riparian vegetation was removed and the riparian berm was recontoured, dredger tailings were removed, and the floodplain surface was lowered (R-5) to inundate at 170 $m^3 \cdot s^{-1}$ (6,000 cfs). At the downstream left bank of the Hocker Flat site, riparian vegetation was removed and the bank edge was feathered (R-6). In addition, aquatic habitat in a small tributary on the left bank was enhanced (R-7) to increase ponding during seasonal flood events. Excavated materials were placed between dredger tailings and in off-channel aggregate pits to create terraces. Constructed floodplains were revegetated with pole cuttings and rooted nursery stock.

Table 6-1

Design Features Constructed at the Hocker Flat Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-2	Floodplain (6,000 cfs) and point bar with coarse sediment addition	79.0 – 79.2	Left bank
R-4	Floodplain (6,000 cfs)	78.7 – 78.9	Left bank
R-5	Floodplain (6,000 cfs) and point bar with coarse sediment addition	78.4 – 78.7	Right bank
R-6	Floodplain (6,000 cfs) and point bar with coarse sediment addition	78.2 – 78.4	Left bank
R-7	Wetland	78.2 – 78.3	Left bank floodplain

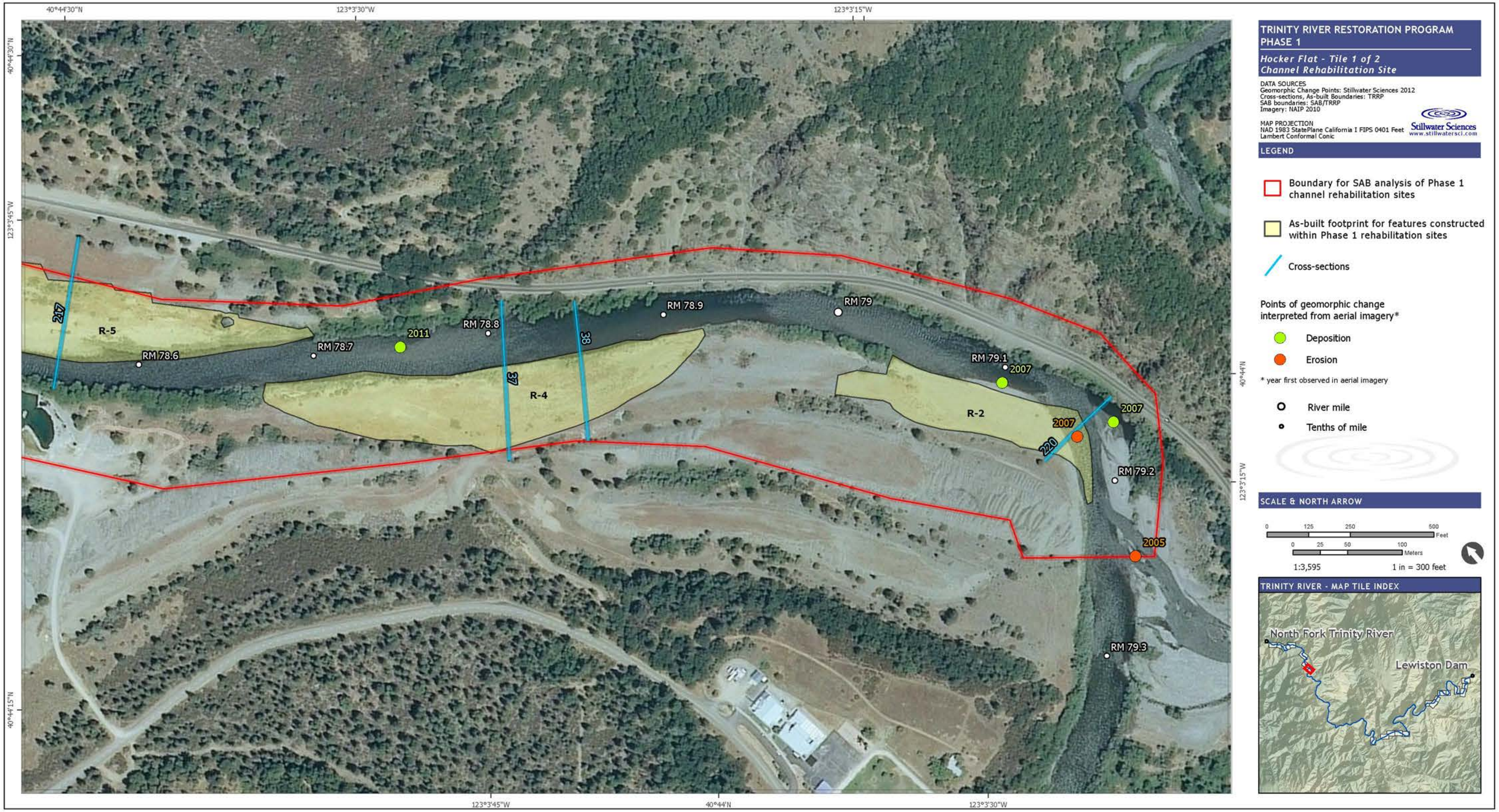


Figure 6-1a

Design Features at the Hocker Flat Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

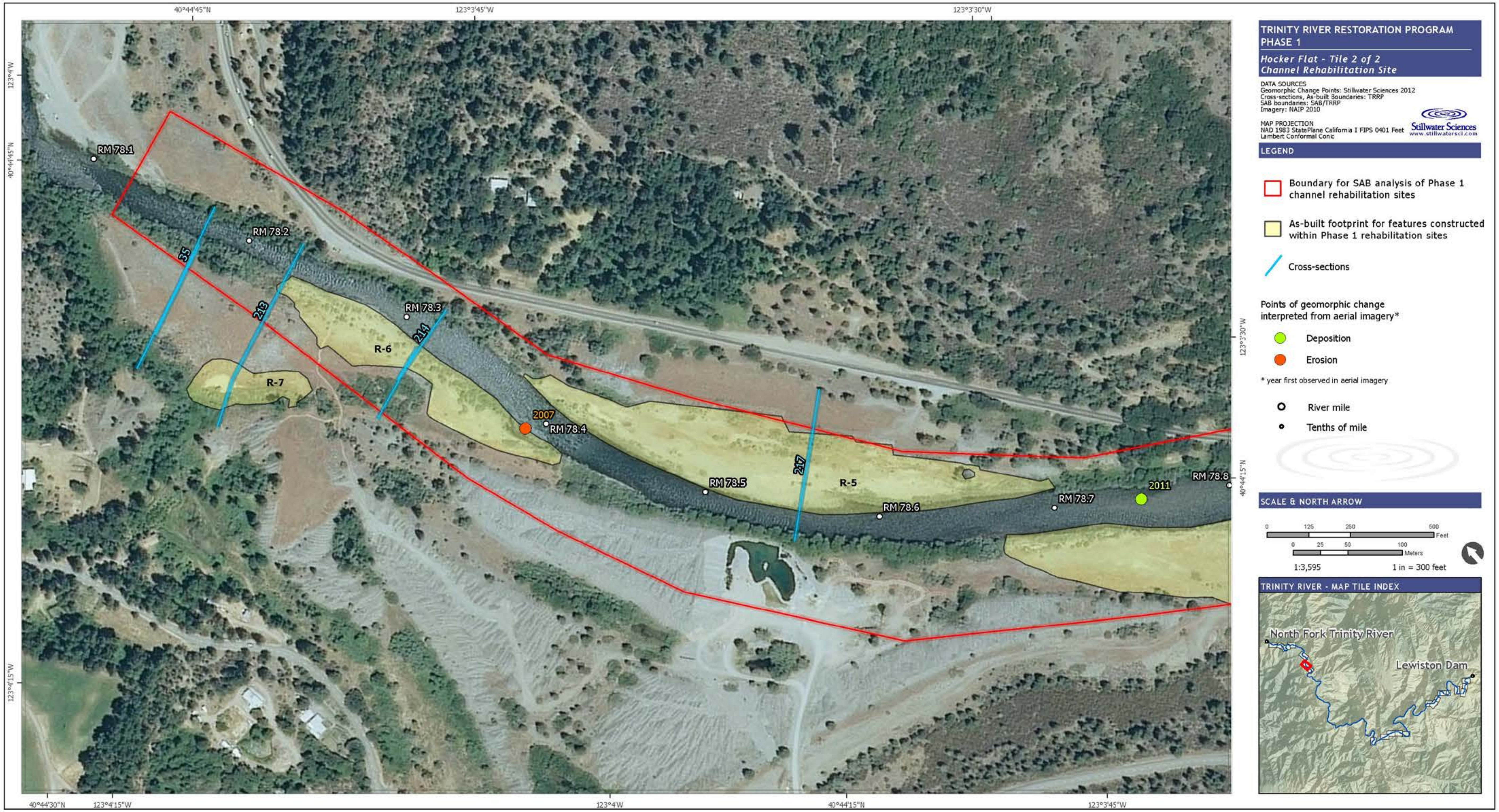


Figure 6-1b

Design Features at the Hocker Flat Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

6.1.3 Geomorphic Response

Focused geomorphic monitoring to evaluate performance of design features occurred at the Hocker Flat site during the following periods:

- WY 2003 prior to construction (HVT and McBain & Trush 2004)
- WY 2005 following construction and following the December 2005 peak winter flood (756 $m^3{\cdot}s^{-1}$ [26,700 cfs] at Hocker Flat) (HVT and McBain & Trush 2007)
- WY 2006 following the spring 2006 ROD release (peak release of approximately 283 $m^3{\cdot}s^{-1}$ [10,000 cfs] for 3 days) (HVT and McBain & Trush 2007)
- WY 2009 following winter and spring peak flows (Dry WY flows released at Lewiston were approximately 122 $m^3{\cdot}s^{-1}$ [4,300 cfs] but reached approximately 232 $m^3{\cdot}s^{-1}$ [8,200 cfs] downstream of Canyon Creek due to tributary accretion) (Alvarez et al. 2011)

Baseline geomorphic monitoring conducted in WY 2003 at the Hocker Flat site consisted of cross section surveys, substrate characterization, and bed mobility and scour experiments. Complete mobility of geomorphic features did not occur as a result of the 2003 flow release (Wet WY in which flow did not reach the expected mobility threshold of 170 $m^3{\cdot}s^{-1}$ [6,000 cfs]).

Monitoring in WYs 2005 and 2006 consisted of re-surveying five cross sections, evaluating channel bed mobility and scour using marked rocks and scour cores, and characterizing channel substrate at cross sections using facies mapping and pebble counts. The lateral bar constructed at the inside of the bend (R-2) migrated downstream between 2005 and 2007. In the same vicinity and time period, a medial bar developed at the outside of the bend at the downstream extent of the Canyon Creek delta. The upper end of R-6 eroded between the 2005 and 2007 monitoring (presumably during the 2006 peak flows), forming a small alcove that persisted into 2011. In the context of the fluvial geomorphic objectives outlined in the TRFEFR and ROD, bed mobility objectives were met during the December 2005 peak winter flood but were not met by the spring ROD release. Only one cross section recorded scour from the December flood that was deep enough to meet TRFEFR objectives, and no scour cores recorded scour from the spring release that was deep enough to meet TRFEFR objectives.

Monitoring results at the Hocker Flat site in WY 2009 showed minimal topographic change at cross sections and little scour, indicating that Wet WY channel migration bed scour targets were not met (Alvarez et al. 2011). Limited mobility of D_{84} rocks on bar flanks during the 113 $m^3{\cdot}s^{-1}$ (3,990 cfs) winter peak flow indicated that TRFEFR management targets for a Dry WY were not met. Based on the WY 2009 bed mobility and bed scour results, flow thresholds that mobilize, scour, and redeposit coarse bed material were minimally crossed. Geomorphic monitoring results reported for WY 2010 did not include the Hocker Flat site (McBain & Trush and HVT 2012).

Interpretation of aerial photography and banklines indicated that the channel has migrated approximately 18 m (60 feet) at the upper end of the site (in the vicinity of R-1), where the channel aggraded in response to the 2006 winter storm event (Table 6-2). In this general vicinity, a low relief transverse feature developed in response to hydraulics established around the leading edge of the remnant riparian berm during high flow. A mid-channel bar at R-4 became emergent after the 2011 high-flow releases, and an elongated medial bar formed near the cross-over between R-4 and R-5 (RMs 78.7 to 78.8).

Table 6-2

Geomorphic Changes Observed in Aerial Photography at the Hocker Flat Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
79.3	Erosion	Retreat of Canyon Creek delta	2001 – 2011	None	All
79.2	Erosion	Left bank bar retreat	2005 – 2007	R-2	2006
79.2	Deposition	Bar growth	2005 – 2007	None	2006
79.1	Deposition	Left bank bar growth	2005 – 2007	R-2	2006
78.7 – 78.8	Deposition	Bar growth	2009 – 2011	R-4	2011
78.4	Erosion	Left bank bar retreat	2005 – 2007	R-6	2006

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at seven cross section locations within the Hocker Flat rehabilitation site (Table 6-3). Cumulative distributions for active bed width at cross sections analyzed within the site are provided in Attachment C. During the period between construction in the fall of 2005 and the first exposure to a high flow release in May 2006, 20% or more of the channel width was active >200 mm at cross sections 35, 37, and 39; yet the WY 2006 and WY 2011 high flow releases resulted in relatively little ±200 mm bed activity at these cross sections. The response during the first exposure to winter high flows was predominantly depositional. These cross sections bisect lowered floodplains where berms and associated riparian vegetation were removed, and the post-construction condition of the floodplain surface may have been predisposed to change more readily during the first year of exposure to winter high flows, after which, the bed may have become less responsive. Analysis of inferred lateral erosion and deposition resulting from fluvial processes at cross sections (Table 6-3) and throughout the Hocker Flat site (Figure 6-2) support the interpretation that constructed floodplains have experienced relatively little geomorphic change since construction. Constructed floodplains that increase channel widths and reduce bed shear stresses might be expected to trend toward depositional response and experience less dynamic change than rehabilitation areas treated with in-channel features (e.g., constructed bars and meanders).

Table 6-3
Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Hocker Flat Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs Exceedance
								>100 mm	>200 mm			
35	78.17	273	none	July-03	December-05	2	A	0.47	0.29	0.03	78.26	31
				December-05	April-06	3	A	0.29	0.21	0.03		23
				April-06	August-06	4	B	0.12	0.06	0.07		23
37	78.81	268	R-4	April-03	July-03	1	A	0.05	0.00	0.03	60.40	0
				July-03	December-05	2	A	0.00	0.00	0.03		31
				December-05	December-05	3	A	0.13	0.04	0.03		0
				December-05	April-06	3	A	0.73	0.55	0.03		23
				April-06	August-06	4	B	0.04	0.00	0.09		23
				August-06	October-08	5	C	0.03	0.00	0.04		10
				October-08	August-09	5	C	0.00	0.00	0.04		2
				August-09	October-11	5	D	0.22	0.00	0.02		20
38	78.85	268	R-4	April-03	July-03	1	A	0.05	0.00	0.03	60.40	0
				July-03	November-05	2	A	1.00	0.98	0.03		31
				November-05	April-06	3	A	0.47	0.30	0.03		23
				April-06	August-06	5	B	0.00	0.00	0.09		23
213	78.29	273	R-6	April-06	October-08	4	B	0.12	0.07	0.07	78.26	33
				October-08	August-09	5	C	0.09	0.04	0.07		2

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs Exceedance
								>100 mm	>200 mm			
214	78.31	272	R-6	October-08	August-09	5	C	0.05	0.01	0.06	76.54	2
				August-09	October-11	5	D	0.07	0.00	0.01		20
217	78.48	270	R-5	October-08	September-09	5	C	0.06	0.01	0.08	84.08	2
				September-09	October-11	5	D	0.12	0.03	0.02		20
220	79.16	265	R-2	April-06	October-08	4	B	0.27	0.19	0.50	52**.92**	33
				October-08	August-09	5	C	0.15	0.08	0.23		2

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to energy and flow exposure: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

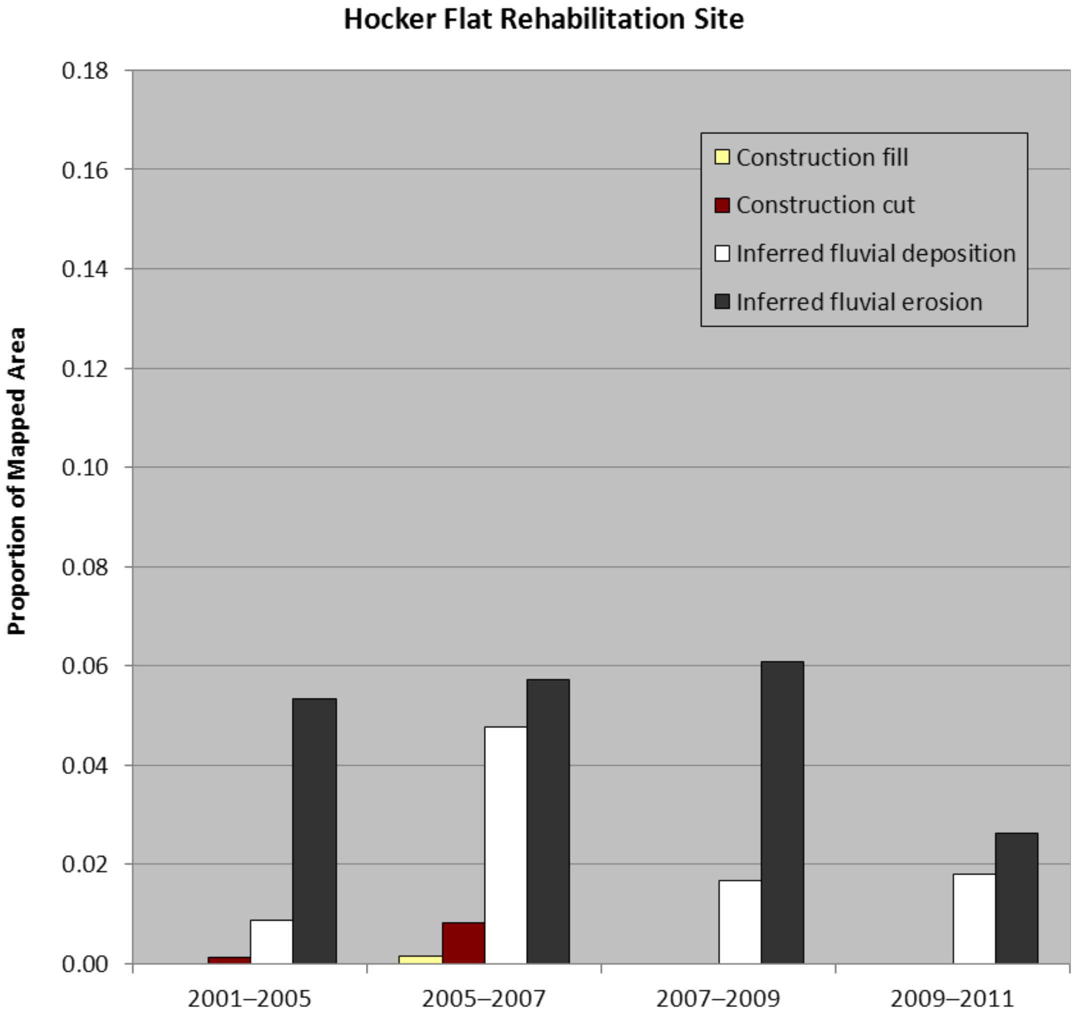


Figure 6-2
Lateral Erosion and Deposition Inferred from Banklines in the Hocker Flat Rehabilitation Site

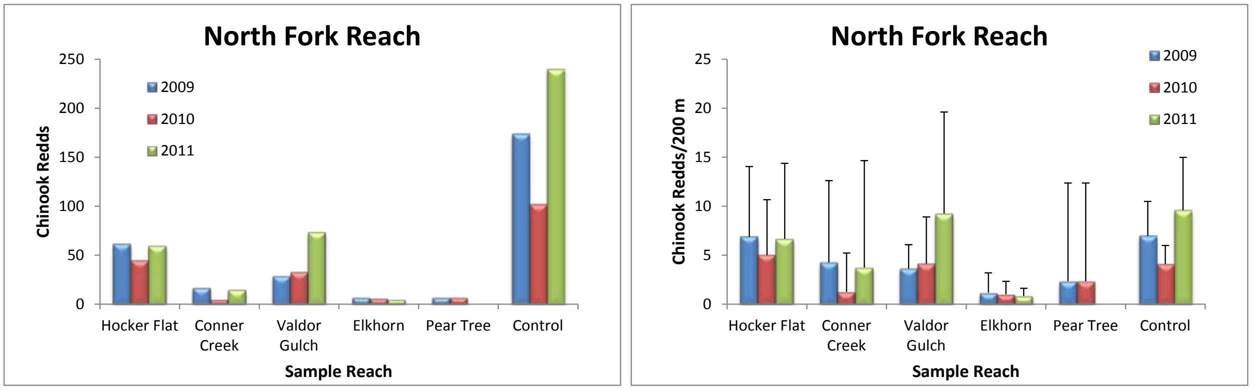
6.1.4 Biological Response

Pre- and post-construction juvenile fish rearing habitat evaluations at this site occurred in 2003 (at flows of 17 $m^3 \cdot s^{-1}$ [600 cfs]), 2008 (at flows of 20.3 $m^3 \cdot s^{-1}$ [716.9 cfs]), and 2009 (at flows of 13.99 $m^3 \cdot s^{-1}$ [494.05 cfs]). The 2008 post-construction evaluation occurred during the third WY following construction, and after the site had experienced several high flow in 2006 and 2008 (Table 5-3) (Goodman et al. 2010). Additionally, riparian areas established in some locations between the times when construction and the post-construction evaluations were completed (Goodman et al. 2010).

Goodman et al. (2010) and Alvarez et al. (2011) indicate the pre-construction assessment at Hocker Flat was conducted using a different method than other sites; in particular, it did not include any cover criteria and used site-specific depth and velocity criteria. Data collected after construction used the standard habitat guild criteria. Because of differences in the methods used during pre- and post-construction surveys, we did not estimate changes in juvenile rearing habitat after construction compared to pre-construction at Hocker Flat.

Hocker Flat experienced extensive vegetation removal and floodplain re-contouring with no large wood installations and little structural complexity added to the floodplain. This likely contributed to the treatment yielding the lowest amount of optimal and total Chinook and coho salmon fry and presmolt habitat 3 years after construction, as compared to five other Phase 1 sites (Alvarez et al. 2011). Re-contouring the floodplain enabled water to spread onto the floodplain as streamflow increased, which facilitated coarse sediment deposition and development of mid-channel bars, and created salmonid habitat at lower streamflows. However, as streamflow increases, these features become submerged and little structural complexity exists on the floodplain to reduce water velocities and provide shelter from higher water velocities for juvenile fish. These factors likely contributed to a flat relationship between flow and the density ($m^2 \cdot m^{-1}$) of optimal and total fry and presmolt habitat at streamflows that ranged between 13 and 70 $m^3 \cdot s^{-1}$ (459 and 2,472 cfs) (Alvarez et al. 2011). Goodman et al. (2010) reported similar results (i.e., no relationship) when they compared the amount of optimal habitat and one suitable habitat category (no DV, C) across a range of flows, and a strongly negative relationship between the other suitable category (DV, no C) across the same range of flows (Goodman et al. 2010). These results suggest that at Hocker Flat, the primary design objective of increasing the diversity of habitat was not achieved with the project's design elements, and the floodplain habitat that was created was not suitable as rearing habitat for salmonids at higher flows, as was originally expected at the time of site design.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Hocker Flat site, untreated sites (controls), and other rehabilitation sites within the North Fork Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 45 to 62, which made up 15.2 to 22.7% of redds counted within the North Fork Reach and 1.3 to 1.9% of redds counted in the Trinity River (Figure 6-3). Mean densities of Chinook salmon redds (redds per 200 m [656 feet]) within the Hocker Flat site were similar to those counted in control sites (Figure 6-3).

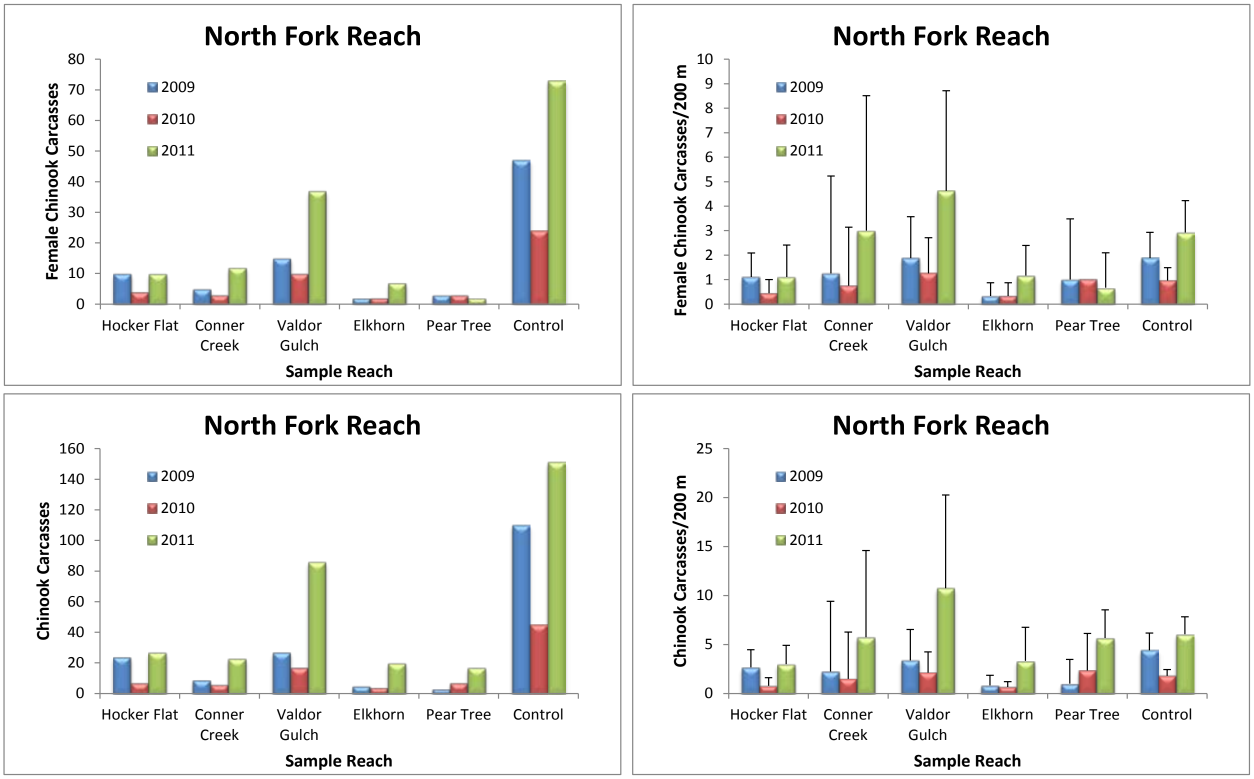


Note:
Densities are mean values with 95% CI.

Figure 6-3
Numbers and Densities (redds per 200 m) of Chinook Salmon (Spring and Fall Chinook) Redds Counted within Different Treatment Sites and Control Sites within the North Fork Reach during 2009 to 2011

Chinook and coho carcasses were also sampled within the Hocker Flat treatment site during 2009 to 2011. Although we report numbers and densities for both female carcasses and total carcasses (includes both male and female carcasses), our analyses focused primarily on females because they tend to be more faithful to a given site. That is, female carcasses are likely found near the location where they spawned.

No coho carcasses were collected during the survey period in the treatment site. Numbers of female Chinook salmon carcasses sampled within the Hocker Flat site during 2009 to 2011 ranged from 4 to 10 (Figure 6-4), which made up 7.1 to 12.2% of the female carcasses sampled within the North Fork Reach and 0.2 to 0.6% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Hocker Flat site were generally less than those in the control sites (Figure 6-4).



Note:
Densities are mean values with 95% CI.

Figure 6-4

Numbers and Densities (carcasses per 200 m) of Female Chinook and Total Chinook Salmon Carcasses Sampled within Different Rehabilitation Sites and Control Areas within the North Fork Reach during 2009 to 2011

6.2 Conner Creek

Location: RMs 77.0 to 77.4
Year constructed: 2006

6.2.1 Design Objectives

Design documents provided no specific hypotheses for the Conner Creek rehabilitation approach, other than the general ROD hypothesis that the construction changes, when combined with high flows and sediment management, will restore a dynamic alluvial river and improve salmonid habitat. The design objectives were to restore alluvial processes, increase Chinook salmon rearing habitat for fry and juveniles, and remove riparian berms along the right bank to promote bar development and channel migration. Alternating erosion and deposition during high flows was expected to increase sinuosity and channel complexity. High flows interacting with the right bank were expected to expand existing bars located upstream of the project area, and associated erosion along the left bank was expected to create a left bank point bar about one-third of the way through the site. The left bank point bar would then direct flow to the right bank, causing scour and promoting development of a right bank bar at the downstream end of the site. Constructed floodplains were expected to support vegetation and promote natural recruitment of woody riparian vegetation.

6.2.2 Site Description

The Conner Creek site begins at RM 77.4 approximately 1.6 miles downstream of the Canyon Creek confluence and extends 0.40 mile downstream. The project is located along the right bank on the inside of a meander bend. Near the middle of the site, Conner Creek joins the Trinity River from the left bank. Before rehabilitation, a right bank berm with dense riparian vegetation separated the low flow channel from former floodplain areas. Large stockpiles of unvegetated dredger tailings were located between upland areas and Highway 299. Channel migration into the left bank is limited by infrastructure and bedrock.

The Conner Creek site consisted of four in-river design elements located along the right bank (Figure 6-5; Table 6-4). A riparian berm located in the upper one-third of the site was recontoured and a bench constructed (R-2) to inundate at 13 $m^3 \cdot s^{-1}$ (450 cfs) to provide salmonid rearing habitat at summer baseflows. Behind and downstream of the bench, a floodplain (R-5) was lowered and sloped (i.e., feathered edge) to inundate at 170 $m^3 \cdot s^{-1}$ (6,000 cfs). The existing terrace behind the riparian berm was recontoured (R-4) and a high-flow scour channel was constructed (R-3) to inundate at 187 $m^3 \cdot s^{-1}$ (6,600 cfs) to provide connectivity. Spoils from excavated areas were used to construct a terrace by filling dredger swales. Constructed floodplains (R-3, R-4, and R-5) were planted with black cottonwood, arroyo willow, shiny willow, and red willow. Large wood was placed along feathered edges and on constructed floodplains.

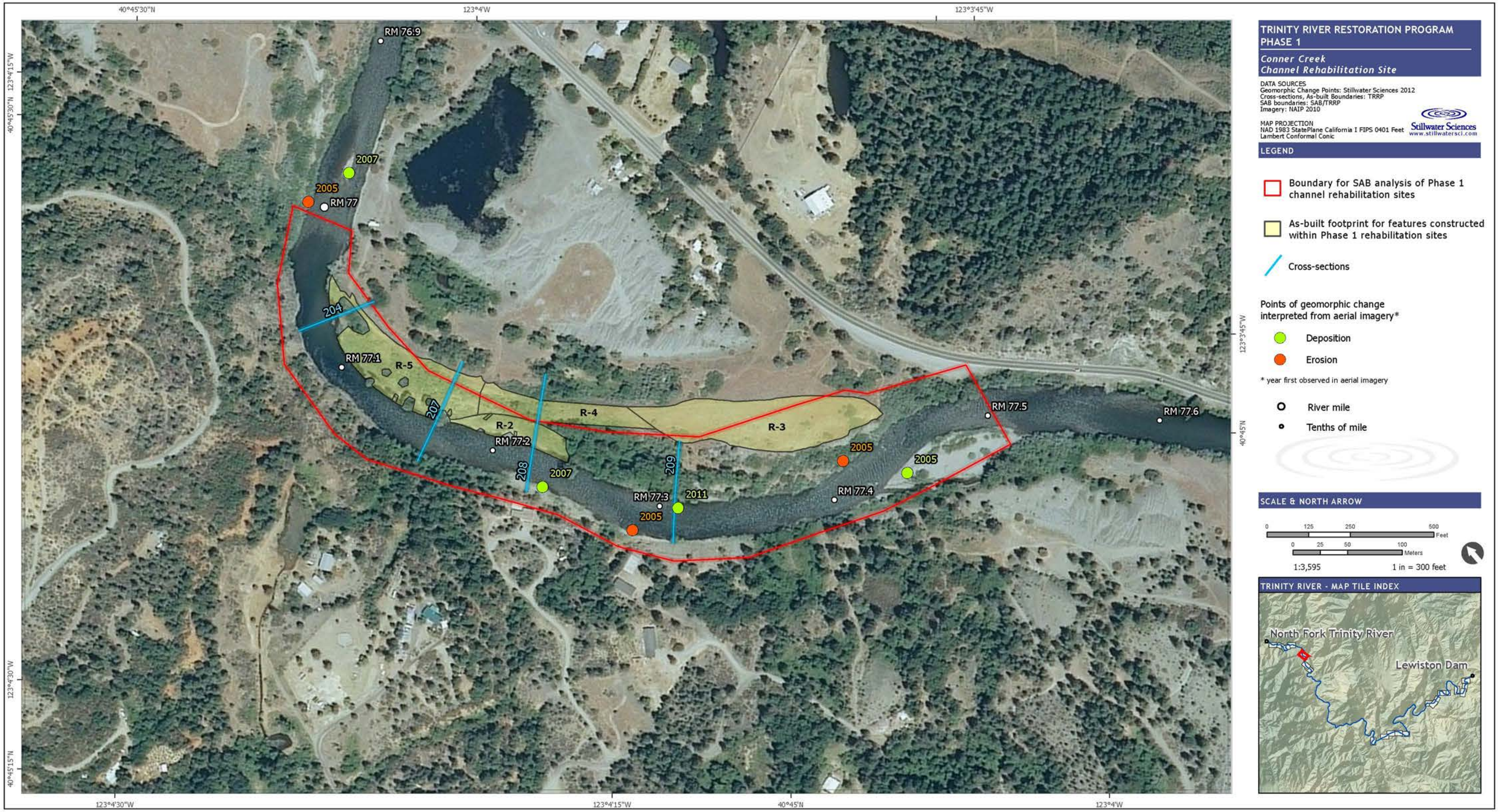


Figure 6-5

Design Features at the Connor Creek Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-4

Design Features Constructed at the Conner Creek Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-2	Floodplain (6,000 cfs) and bench (450 cfs)	77.2	Right bank
R-3	Floodplain (6,000 cfs)	77.3 to 77.4	Right bank
R-4	Re-contouring (6,000 cfs)	77.2 to 77.3	Right bank
R-5	Floodplain (6,000 cfs) and feathered edge (300 cfs) with wood placements	77.1 to 77.2	Right bank

6.2.3 Geomorphic Response

Five cross sections were surveyed in WY 2007 following construction and monitored in WY 2009 after the peak flow (Dry WY release of 233 $m^3 \cdot s^{-1}$ [8,228 cfs] recorded at the Trinity River above North Fork Trinity River) (Alvarez et al. 2011). Little topographic change occurred during WY 2009 (i.e., no significant change in cross section area). Topographic differences between the October 2007 post-construction survey (McBain & Trush and HVT unpublished data) and the WY 2009 surveys show more significant channel changes that vary by cross section. Channel migration occurred at only one cross section, where the thalweg scoured about 0.45 m (1.5 feet) and shifted 1.8 m (5.9 feet) toward the right bank. Geomorphic monitoring results reported for WY 2010 did not include the Connor Creek site (McBain & Trush and HVT 2012).

Monitoring was conducted again at the Connor Creek site in WY 2011, which included cross section topography, bed mobility, and bed scour and deposition at cross sections 204 and 208 (HVT and McBain & Trush 2012). Results indicated bar development and maintenance of channel geometry above the 13 $m^3 \cdot s^{-1}$ (450 cfs) water surface elevation at cross section 204, consistent with design objectives at this location. The channel has not migrated laterally since construction at either cross section. The bed and bars were mobilized and met TRFEFR and ROD objectives. Scour depths, however, did not meet the > 2.0 D_{84} TRFEFR and ROD bed scour objective.

Interpretation of aerial photography and banklines indicated that between 2001 and 2011, the main channel widened and shifted toward the right bank at the upper end of the site near R-3 (RMs 77.4 to 77.5) (Table 6-5). Scour of the right bank occurred during the 2006 high flow release and continued through 2011. Between 2009 and 2011, a riffle developed along the right bank at the inside of the bend near RM 77.3, presumably during the 2011 high flows. The opposing left bank retreated between 2001 and 2005, with continued retreat occurring through 2011. An associated bar formed downstream on the left bank between RMs 77.2 and 77.3, and persisted through 2011. Immediately downstream of the site at RM 77.0, the main flow path shifted toward the left bank between the 2001 and 2005, causing erosion of a bar along the left bank. By 2007, a bar began forming on the right bank and persisted into 2011.

Table 6-5
Geomorphic Changes Observed in Repeat Aerial Photography at the Conner Creek Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
77.4 – 77.5	Deposition	Left bank bar growth	2001 – 2011	None	All
77.4 – 77.5	Erosion	Right bank bar and bank retreat	2001 – 2011	R-3	All
77.3	Deposition	Right bank bar growth	2009 – 2011	None	2011
77.3	Erosion	Left bank retreat	2001 – 2011	None	All
77.2 – 77.3	Deposition	Left bank bar growth	2005 – 2007	None	2006
77.0	Erosion	Left bank bar retreat	2001 – 2011	R-5	All
77.0	Deposition	Bar growth	2005 – 2011	R-5	2006

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at four cross section locations within the Connor Creek rehabilitation site. All four cross sections showed a relatively active bed (≥20% of the channel width active >200 mm) during WY 2011. Changes at these cross sections are typified by the left bank scour and associated right bank deposition seen in cross section 204. Fluvial processes at the site are trending toward bar building along the right bank, as anticipated by berm removal and floodplain lowering along the inside margin of the large amplitude bend in which the site occurs. Analysis of inferred lateral erosion and deposition resulting from fluvial processes at cross sections (Table 6-6) and throughout the 0.40-mile site length (Figure 6-6) suggest less lateral channel erosion following project construction in 2006, but that planform changes have consistently increased since that time, particularly during WY 2011.

Table 6-6

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Connor Creek Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
204	77.07	282	R-5	October-07	August-09	5	C	0.37	0.27	0.03	87.46	12
				August-09	September-10	5	C	0.26	0.10	0.03		8
				September-10	August-11	5	D	0.71	0.46	0.05		12
				July-03	October-07	6	B	0.53	0.32	0.04		77
207	77.17	281	R-5	October-08	August-09	5	C	0.05	0.01	0.07	70.26	2
				August-09	November-11	5	D	0.37	0.23	0.06		20
208	77.22	281	R-2, R-4	November-10	August-11	5	D	0.39	0.19	0.06	70.26	12
				July-03	November-10	6	B	0.77	0.65	0.06		97
209	77.31	280	R-3	October-07	October-08	5	C	0.25	0.06	0.08	69.07	10
				October-08	August-09	5	C	0.08	0.02	0.08		2
				August-09	November-11	5	D	0.46	0.34	0.27		20
				July-03	October-07	6	B	0.75	0.55	0.10		77

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

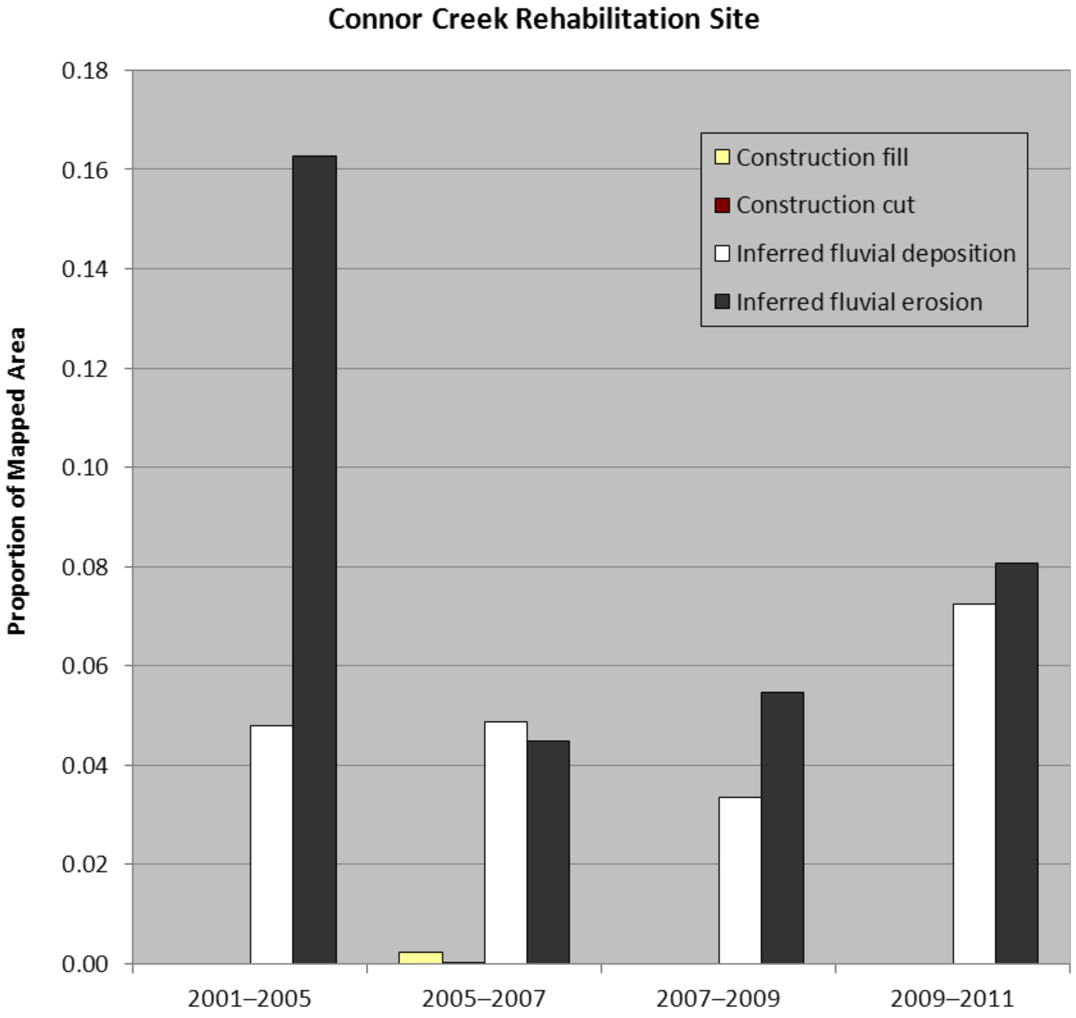


Figure 6-6

Lateral Erosion and Deposition Inferred from Banklines in the Connor Creek Rehabilitation Site

6.2.4 Biological Response

No pre- or post-construction juvenile fish rearing habitat assessments have been conducted at the Conner Creek channel rehabilitation site; therefore, there are no results to provide.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Conner Creek site, untreated sites (controls), and other rehabilitation sites within the North Fork Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 5 to 17, which made up 2.5 to 5.7% of the redds counted within the North Fork Reach and 0.1 to 0.5% of the redds counted in the Trinity River (Figure 6-3). Mean densities of Chinook salmon redds (redds per 200 m [656 feet]) within the Conner Creek site were similar to those counted in control sites (Figure 6-3).

Chinook and coho salmon carcasses were also sampled within the Conner Creek site during 2009 to 2011. No coho carcasses were collected during the survey period in the treatment site. Numbers of female Chinook salmon carcasses sampled within the Conner Creek site during 2009 to 2011 ranged from 3 to 12 (Figure 6-4), which made up 6.1 to 8.5% of the female carcasses sampled within the North Fork Reach and 0.2 to 0.3% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Conner Creek site were similar to those in the control sites (Figure 6-4).

6.3 Valdor Gulch

Location: RMs 74.8 to 75.7
Year constructed: 2006

6.3.1 Design Objectives

Design documents provided no specific hypotheses for the Valdor Gulch rehabilitation approach, other than the general ROD hypotheses that construction changes, working in combination with high flows and sediment management, will restore a dynamic alluvial river and improve salmonid habitat. Design objectives included increasing Chinook salmon spawning and rearing habitat at flows between 8 and 57 $m^3{\cdot}s^{-1}$ (300 and 2,000 cfs), removing berms and associated riparian vegetation to promote bar development and channel migration, and lowering floodplain surfaces to function under ROD flows. High flows interacting with constructed features were expected to increase sinuosity and channel complexity by expanding existing bars, scour banks, and developing bars. Lowering of a remnant bar feature to inundate at 170 $m^3{\cdot}s^{-1}$ (6,000 cfs) was expected to provide suitable replanting surfaces and promote natural recruitment that would increase the structure and diversity of the woody riparian community.

6.3.2 Site Description

The Valdor Gulch site is located upstream of Lime Point between RMs 74.8 and 75.8. West and East Valdor Gulch meet the Trinity River midway through the site. Valdor Gulch consisted of nine in-river and two upland design elements (Figures 6-7a and 6-7b; Table 6-7).

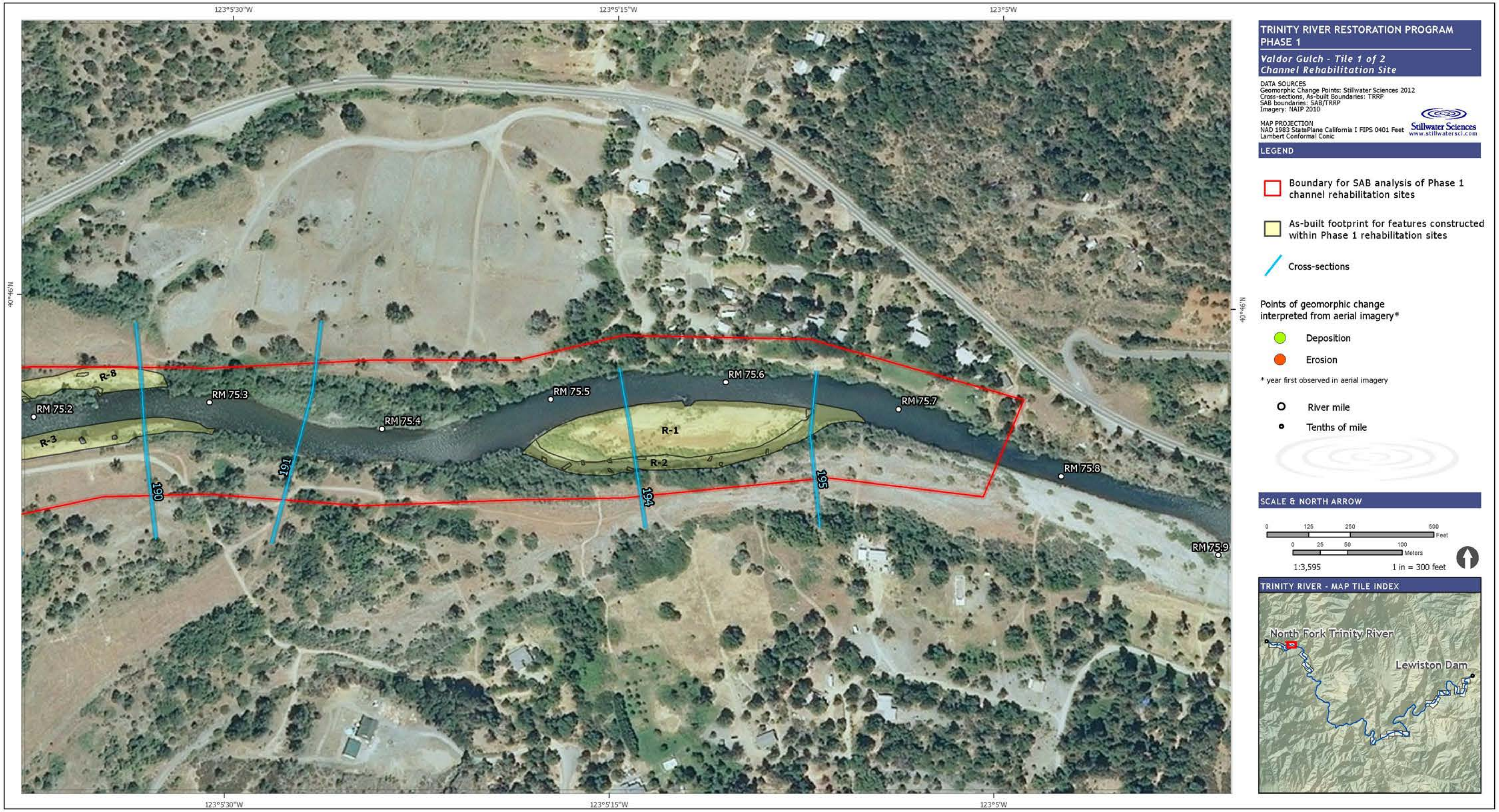


Figure 6-7a

Design Features at the Valdor Gulch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

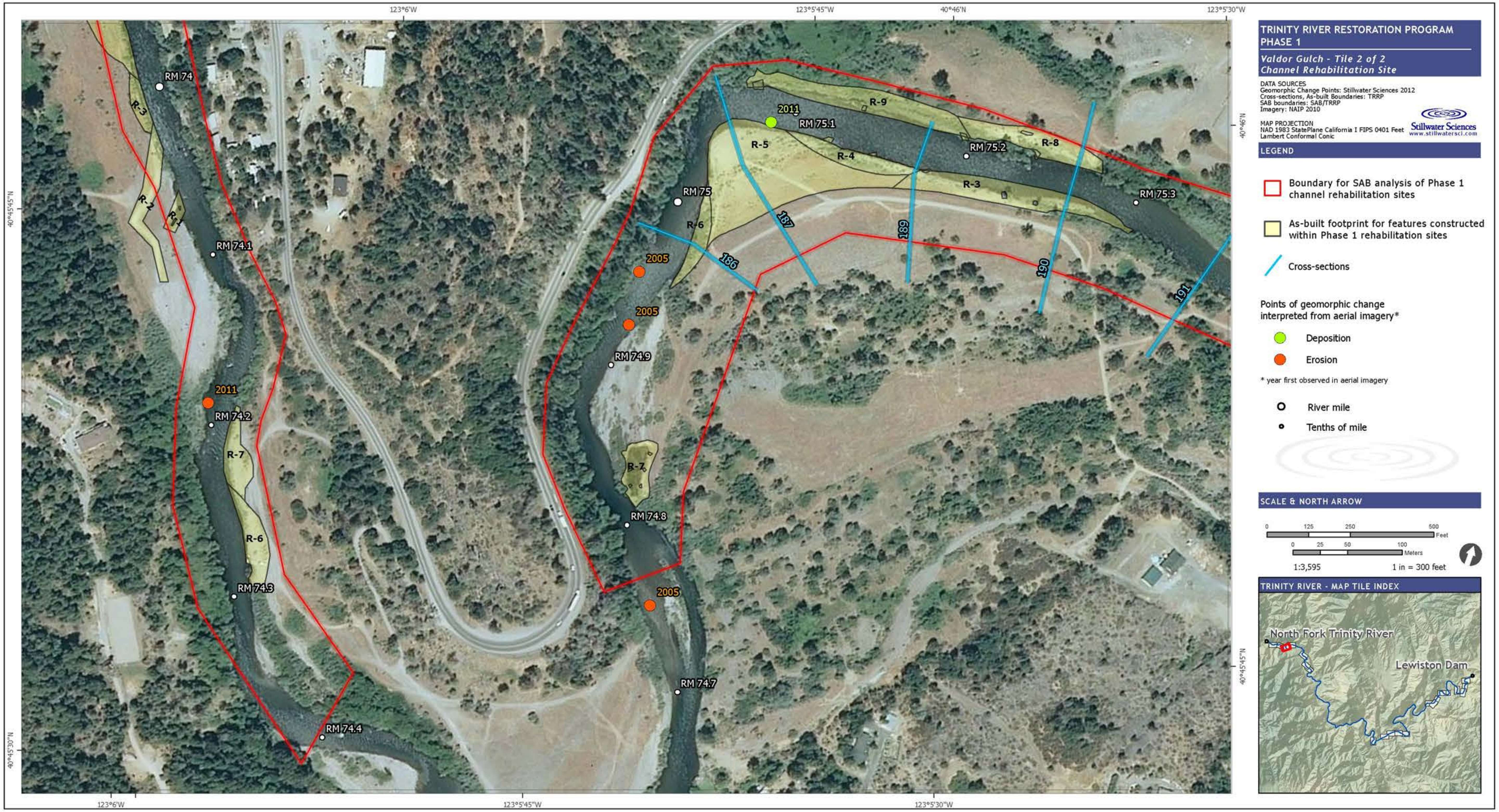


Figure 6-7b

Design Features at the Valdor Gulch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-7

Design Features Constructed at the Valdor Gulch Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Floodplain (6,000 cfs) with lower surfaces (4,000 cfs)	75.5 – 75.7	Left bank
R-2	Low flow side channel (450 cfs) with wood placements	75.5 – 75.7	Left bank
R-3	Feathered edge with wood placements	75.2 – 75.3	Left bank
R-4	Floodplain (2,000 cfs) with wood placements	75.1 – 75.2	Left bank
R-5	Floodplain (6,600 cfs)	75.0 – 75.2	Left bank
R-6	Floodplain (2,000 cfs)	75.0	Left bank
R-7	Alcove with wood placements	74.8	Left bank
R-8	Floodplain (6,600 cfs)	75.2 – 75.3	Right bank
R-9	Feathered edge with wood placements	75.1 – 75.2	Right bank

The floodplain at the upstream end of the site (R-1) was lowered to inundate at 114 to 170 $m^3 \cdot s^{-1}$ (4,000 to 6,000 cfs) and the adjacent high flow channel on the left bank (R-2) was excavated to inundate at 13 $m^3 \cdot s^{-1}$ (450 cfs), providing juvenile rearing habitat. Large wood was added to the side channel and placed at the head of the island. Vegetation removal, bank feathering, and floodplain lowering in downstream areas (R-3, R-4, R-8, and R-9) were designed to increase channel widths, promote bar growth, and enhance alternating scour and deposition. At the downstream end of the site, the berm was removed, banks were feathered, and the floodplain was lowered (R-5 and R-6) to promote development of existing left bars. An alcove (R-7) was constructed at the downstream end of the site in the vicinity of an existing point bar and scour channel feature. High flows in excess of 170 $m^3 \cdot s^{-1}$ (6,000 cfs) were expected to inundate the bar and maintain the alcove. Riparian vegetation was planted within many of the site features, and large wood was incorporated into many of the site features to provide habitat for fry and juvenile salmonids. Feathered edges and lowered floodplains throughout the site were intended to reduce the likelihood of future berm formation and riparian encroachment along the low water's edge and provide immediate rearing habitat. Two upland terraces were constructed to hold overburden without impacting the 100-year floodplain.

6.3.3 Geomorphic Response

Geomorphic monitoring conducted in WY 2009 to assess the effects of the winter peak flow (113 $m^3 \cdot s^{-1}$ [3,990 cfs] and comparable to Dry WY TRFEFR objectives) and ROD high flow release (comparable to Wet WY TRFEFR objectives) included topographic surveys and bed mobility scour experiments in the vicinity of R-1 (cross section 194), R-3 and R-8 (cross sections 190 and 189), and R-5 (cross section 187) (Alvarez et al. 2011). Bed mobility results from the winter peak flow indicated that TRFEFR management targets for bed mobility and scour during a Dry WY were not met. Bed elevation changes determined from repeat topographic surveys at the site indicated that alluvial features were being maintained, but new alluvial features were not developing. Comparison of cross section topography before and after the spring release indicated a thalweg shift at one cross section of approximately 9.1 m (29.9 feet) between WY 2007 and WY 2008, and an additional 4.5 m (14.8 feet) between WY 2008 and WY 2009. Other cross sections monitored in WY 2009 changed little, suggesting that the WY 2009 spring release was insufficient to significantly alter the bed surface through the reach. The alcove (R-7) aggraded approximately 0.15 m (0.5 foot) in WY 2009, and surface water connection with the mainstem channel was not maintained during low flow. The entrance to the constructed side channel (R-2) scoured and was flowing during summer baseflows in WY 2009. Rapid assessment of the side channel in February 2011 (Gaeuman in review) indicated aggradation, and although it functioned at winter baseflow, the inlet was dry during 2010 summer baseflow.

Geomorphic monitoring was conducted at Valdor Gulch again in WY 2010 in the vicinity of R-5 (cross section 187) and R-3 and R-8 (cross section 190), where channel rehabilitation included removing riparian vegetation to decrease channel confinement and encourage deposition and growth of alternate bar morphology (McBain & Trush and HVT 2012). Since construction, the thalweg at cross section 187 shifted 12.1 m (39.7 feet) toward the right bank and aggraded 0.95 m (3.12 feet), as intended by design. Farther upstream at cross section 190, the thalweg shifted 2.5 m (8.2 feet) to the right bank and aggraded 0.36 m (1.18 feet). Mobility and scour monitoring at cross section 190 indicated little bed mobility, and although the bed surface was locally reworked, little scour occurred.

Geomorphic monitoring was conducted at Valdor Gulch again in WY 2011 (HVT and McBain & Trush 2012). Cross section 187 was monitored for topography only, and cross section 190 was monitored for topography, bed mobility, and bed scour and deposition. Results indicate the site is partially performing as intended along the cross sections monitored. Post construction bar growth suggests alternate bar morphology is developing, particularly at cross section 190. The channel became more confined due to floodplain deposition and channel scour (most notably at cross section 190) during WY 2011. No bank erosion or lateral migration was observed. Full bed mobility occurred on bars flanks, and TRFEFR and ROD bed mobility objectives met. Bed scour exceeded 2.0 D_{84}, and deposition ranged from 1.0 to >2.0 D_{84}, largely meeting TRFEFR and ROD bed scour objectives. Up to 0.6 m of sand deposition on the constructed floodplain was attributed to high fine sediment loads during the 388 $m^3 \cdot s^{-1}$ (13,700 cfs) peak ROD release and newly-established (post-construction) riparian vegetation.

Interpretation of aerial photography and banklines indicated that the left bank bar located at the meander bend near RM 75.1 grew between 2009 and 2011, possibly related to mobilization of floodplain material at R-5 and/or increases in coarse sediment supply from upstream sources during the 2011 high flow release (Table 6-8). Since 2001, bars located along the right and left banks between RMs 74.9 and 75.0 have diminished in size, resulting in an overall widening of the low-flow channel through this segment. The bar located along the right bank at the downstream end of the site progressively detached from the bank as the main flow path shifted toward the right bank.

Table 6-8
Geomorphic Changes Observed in Repeat Aerial Photography at the Valdor Gulch Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
75.1	Deposition	Left bank bar growth	2009 – 2011	R-4, R-5	2011
74.9 – 75.0	Erosion	Right bank bar retreat	2001 – 2011	R-6	All
74.9	Erosion	Left bank bar retreat	2001 – 2011	R-6	All
74.7 – 74.8	Erosion	Right bank bar scour, forming medial bar	2001 – 2011	NA	All

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at seven cross section locations within the Valdor Gulch rehabilitation site (Table 6-9). The bed was relatively inactive until WY 2011, when three cross sections (187, 190, and 191) showed a relatively active bed (26 to 30% of the channel width active >200 mm). Changes at cross sections 187 and 190 reflect in-channel erosion and associated deposition on the left bank point bar and constructed floodplain surfaces where removing the berm and lowering floodplain elevations worked in combination with local planform curvature to successfully create more dynamic and complex channel morphology. Although construction did not occur at cross section 191, constructed floodplains upstream and downstream appear to have helped build the right bank bar as part of an alternate bar sequence. Analysis of inferred lateral erosion and deposition resulting from fluvial processes throughout the 0.90-mile site length (Figure 6-8) suggest that less lateral channel erosion occurred following project construction in 2006, and relatively more deposition occurred during WY 2011.

Table 6-9

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Valdor Gulch Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
186	74.98	299	R-6	October-08	August-09	5	C	0.20	0.14	0.05	79.50	2
				March-03	October-08	6	B	0.37	0.24	0.07		87
187	75.06	298	R-5	October-07	October-08	5	C	0.31	0.24	0.07	74.96	10
				October-08	August-09	5	C	0.18	0.08	0.07		2
				August-09	August-10	5	C	0.16	0.07	0.07		8
				August-10	August-11	5	D	0.44	0.30	0.10		12
				March-03	October-07	6	B	0.61	0.53	0.02		77
189	75.18	297	R-3, R-4, R-9	October-07	October-08	5	C	0.14	0.02	0.03	50.86	10
				October-08	August-09	5	C	0.20	0.01	0.03		2
				March-03	October-07	6	B	0.49	0.38	0.00		77
190	75.26	297	R-3, R-8	October-08	October-08	2	C	0.20	0.06	0.03	50.86	0
				October-08	November-08	5	C	0.00	0.00	0.03		0
				November-08	August-09	5	C	0.04	0.00	0.03		2
				August-09	August-10	5	C	0.05	0.01	0.03		8
				August-10	September-11	5	D	0.60	0.39	0.08		12
				March-03	October-08	6	B	0.72	0.63	0.00		87
191	75.35	296	none	March-03	November-11	6	D	0.54	0.26	0.08	53.57	109
194	75.54	294	R-1, R-2	October-07	October-08	5	C	0.44	0.19	0.09	56.07	10
				October-08	August-09	5	C	0.06	0.00	0.09		2
				October-05	October-07	6	B	0.97	0.93	0.03		46
195	75.65	293	R-2	October-08	August-09	5	C	0.41	0.11	0.04	44.47	2
				March-03	October-08	6	B	0.75	0.48	0.04		87

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

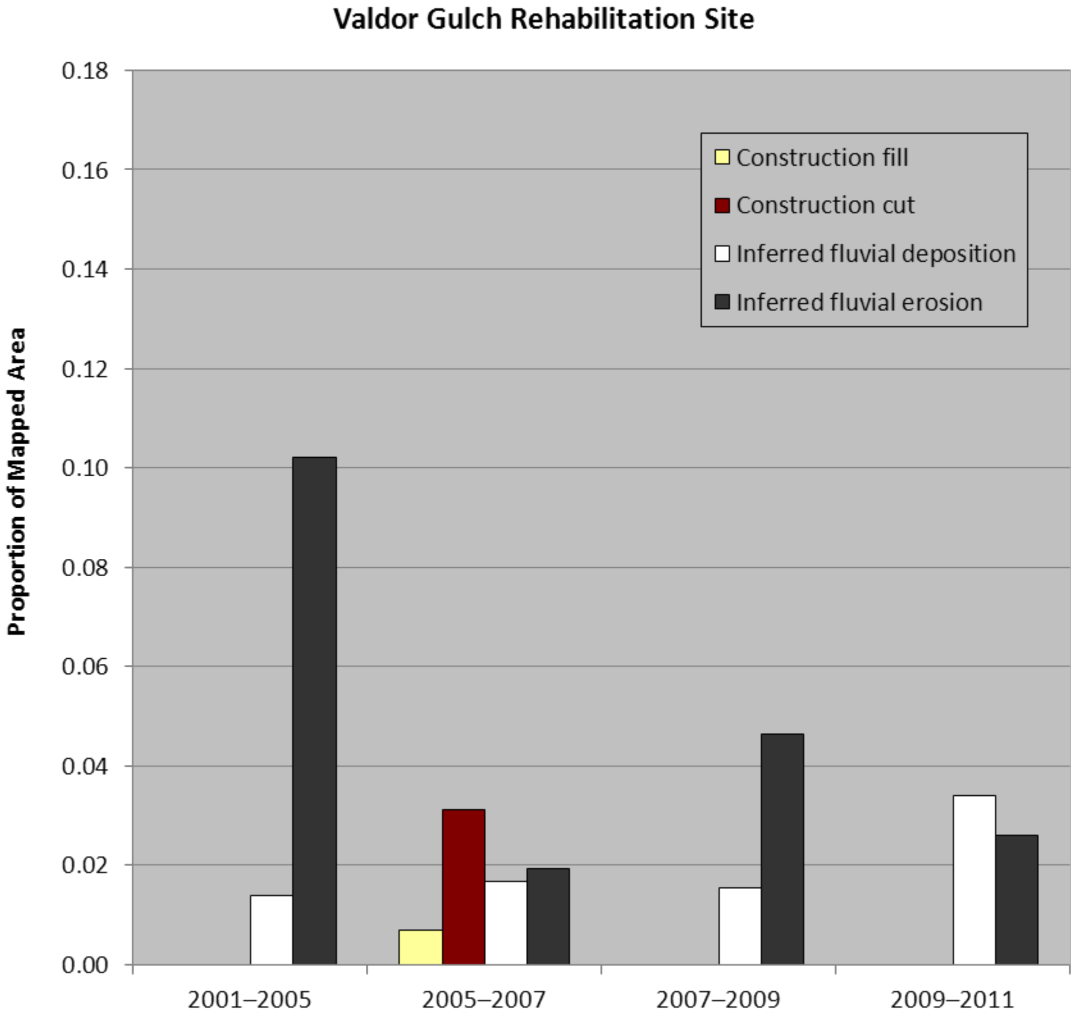


Figure 6-8
Lateral Erosion and Deposition Inferred from Banklines in the Valdor Gulch Rehabilitation Site

6.3.4 Biological Response

A pre-construction habitat assessment and validation occurred at the Valdor Gulch site, but no post-construction assessments have been conducted so it is not possible to evaluate how the channel rehabilitation actions impacted rearing habitat at this site.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Valdor Gulch site, untreated sites (controls), and other rehabilitation sites within the North Fork Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 29 to 74, which made up 9.8 to 18.8% of the redds counted within the North Fork Reach and 0.9 to 1.6% of the redds counted in the Trinity River (Figure 6-3). Mean densities of Chinook salmon redds (redds per 200 m [656 feet]) within the Valdor Gulch site were similar to those counted in control sites (Figure 6-3).

Chinook and coho salmon carcasses were also sampled within the Valdor Gulch site during 2009 to 2011. Two coho salmon carcasses (one male and one female) were sampled in 2010 in the site. Numbers of female Chinook salmon carcasses sampled within the Valdor Gulch site during 2009 to 2011 ranged from 10 to 37 (Figure 6-4), which made up 18.3 to 26.2% of the female carcasses sampled within the North Fork Reach and 0.7 to 0.8% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Valdor Gulch site were generally greater than those in the control sites (Figure 6-4).

6.4 Elkhorn

Location: RMs 73.7 to 74.3
Year constructed: 2006

6.4.1 Design Objectives

The Elkhorn rehabilitation project was designed to increase hydraulic and geomorphic complexity, salmonid rearing habitat, riparian-dependent wildlife habitat, and habitat for foothill yellow-legged frog. An additional goal was to design a project where flows independent of ROD releases would maintain the site. The modifications were designed to facilitate alluvial river forms and processes over time, resulting in the development of point bars and floodplain habitat that did not exist before construction.

6.4.2 Site Description

The Elkhorn site is located between RMs 73.7 and 74.3. The project contained seven in-river and two upland design elements (Figure 6-9; Table 6-10). An alcove (R-1) was designed to provide year-round juvenile fish habitat at 13 $m^3 \cdot s^{-1}$ (450 cfs) and be maintained by high flow (187 $m^3 \cdot s^{-1}$ [6,600 cfs]) routed through a nearby constructed side channel (R-2). Vegetation removal and floodplain lowering on the left bank near the downstream end of the site (R-3 and R-4) were designed to promote meandering and formation of alternate bars at approximately 6,600 cfs. Construction of a feathered edge (R-5) on the left bank at the downstream end of the site was designed to encourage point bar development and lateral migration of the left bank. The floodplain at the upstream end of the site (R-6) was lowered to induce an increase in sinuosity and the berm was removed (R-7) to promote development of alternate bars and create salmonid rearing habitat. Excavated material was disposed of in two upland design features.

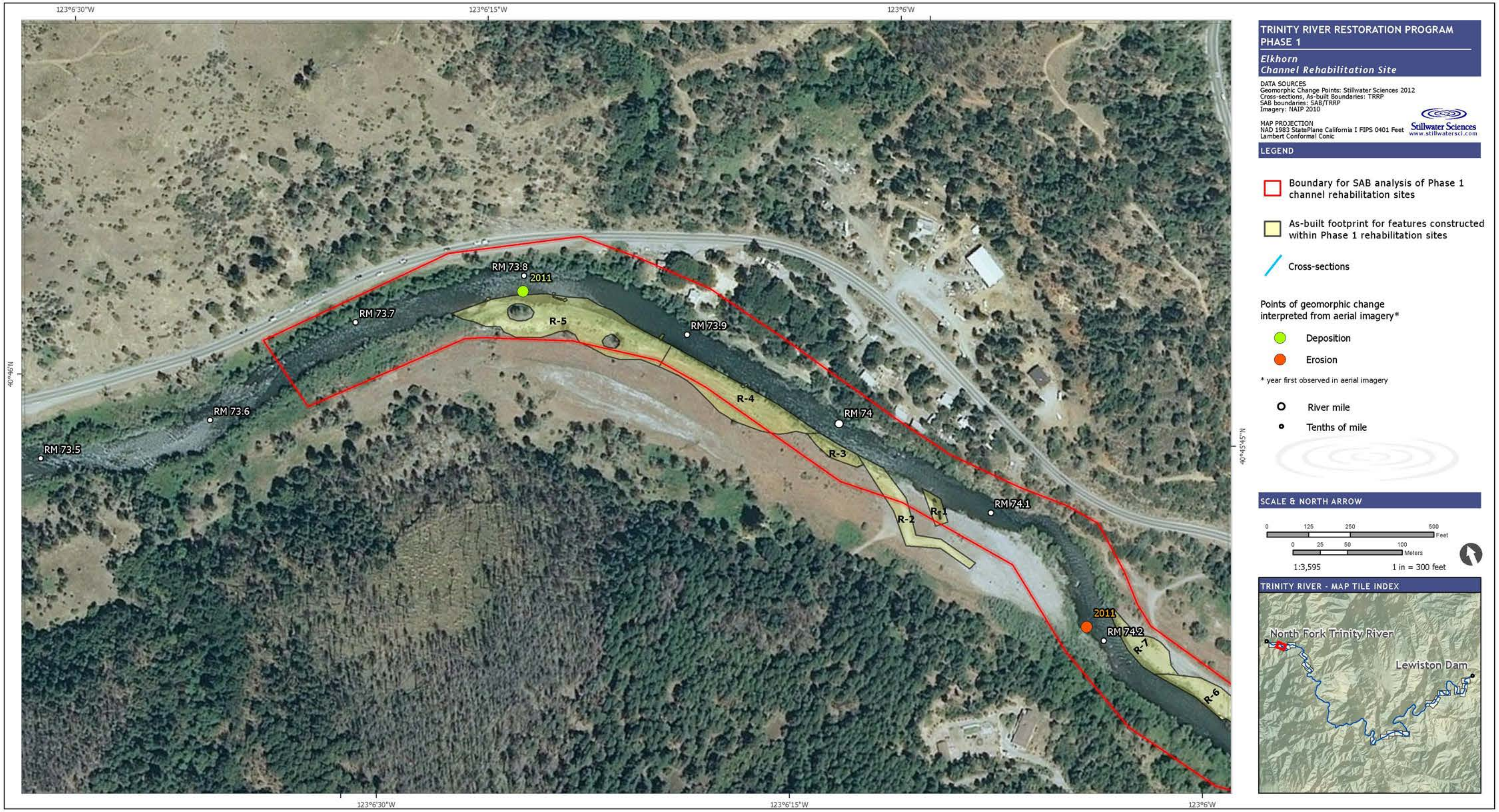


Figure 6-9

Design Features at the Elkhorn Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-10

Design Features Constructed at the Elkhorn Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Alcove (450 cfs) with wood placements	74.1	Left bank
R-2	High flow side channel (6,600 cfs)	74.0 – 74.1	Left bank and floodplain
R-3	Vegetation removal	74.0	Left bank
R-4	Floodplain (6,600 cfs)	73.9 – 74.0	Left bank
R-5	Feathered edge with point bar and wood placements	73.8 – 73.9	Left bank
R-6	Floodplain (6,600 cfs)	74.2 – 74.3	Right bank
R-7	Berm removal and grubbing	74.2	Right bank

6.4.3 Geomorphic Response

The first post-construction geomorphic monitoring occurred at the Elkhorn site in WY 2011 with cross section topography surveys, and bed mobility and bed scour monitoring (HVT and McBain & Trush 2012). Full bed mobility was measured on bar surfaces, meeting TRFEFR and ROD bed mobility objective. Bed scour ranged from 1.0 to > 2.0 D_{84}, and deposition ranged from < 1.0 to > 2.0 D_{84}. TRFEFR and ROD bed scour objectives were partially met. Although some significant topographic changes occurred within the low-flow active channel, cross section topography remained relatively unchanged above the 13 $m^3 \cdot s^{-1}$ (450 cfs) water surface. A medial bar was removed from within the low-flow channel and a bar began forming along the left bank. No bank erosion or lateral migration as intended by design.

Interpretation of aerial photography and banklines indicated that alternating point bars at the upstream end of the site changed little in planform between 2001 and 2011 (Table 6-11). Bank retreat occurred along the bar flank near RMs 74.1 to 74.2 between 2009 and 2011. Near the lower end of the site, the point bar in the vicinity of R-5 grew slightly between 2009 and 2011.

Table 6-11

Geomorphic Changes Observed in Repeat Aerial Photography at the Elkhorn Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
74.2	Erosion	Left bank bar and bank retreat	2009 – 2011	R-6 and R-7	2011
73.8	Deposition	Left bank bar growth	2009 – 2011	R-5	2011

No cross sections suitable for the active bed analysis were located within the Elkhorn rehabilitation site. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 0.55-mile site length suggest relatively high rates of lateral erosion during the 2001 to 2005 and 2007 to 2009 periods, and relatively high rates of accretion in the intervening periods of 2005 to 2007 and 2009 to 2011 (Figure 6-10). The relative magnitude of inferred lateral erosion following construction in 2006 was low relative to the period prior to construction, whereas inferred lateral deposition during the post-construction period was greater than in the period prior to construction.

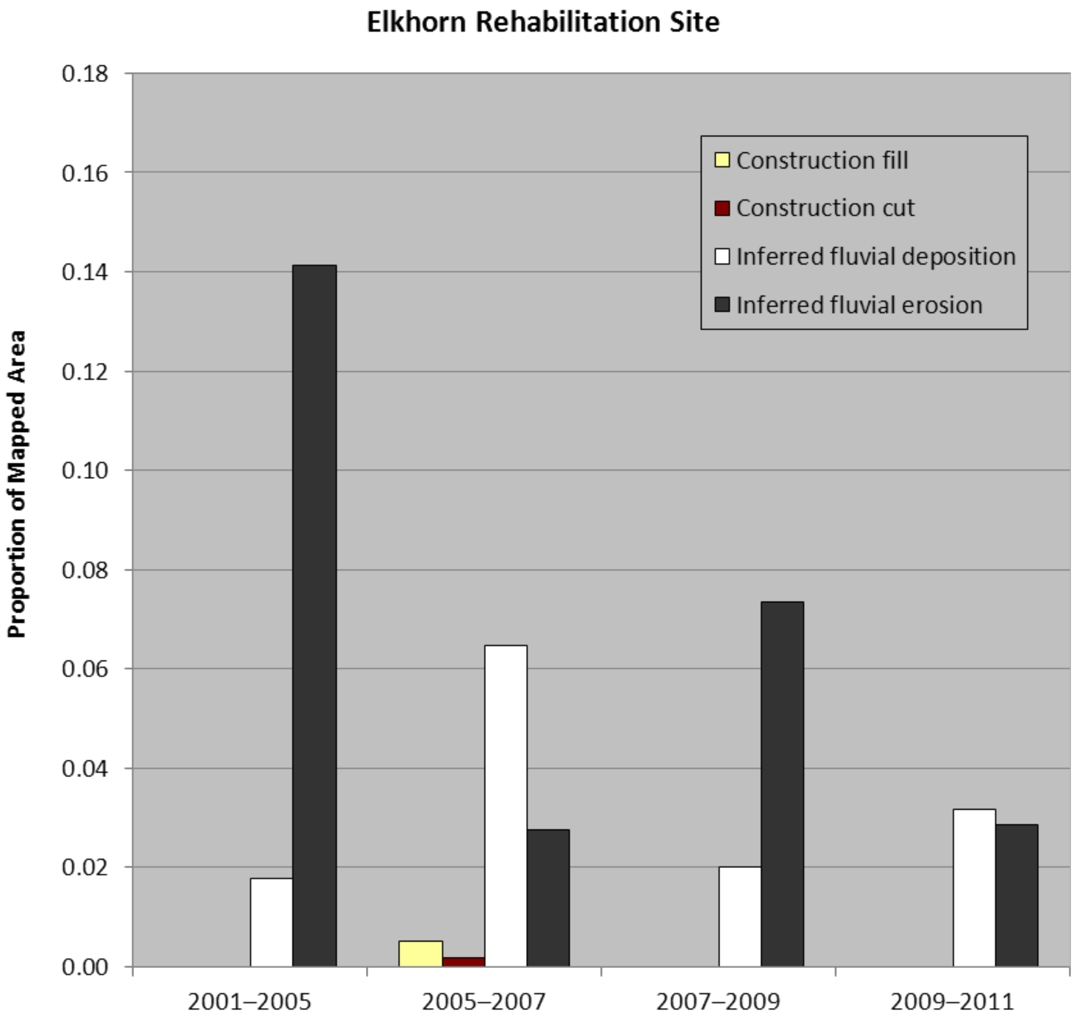


Figure 6-10

Lateral Erosion and Deposition Inferred from Banklines in the Elkhorn Rehabilitation Site

6.4.4 Biological Response

No pre- or post-construction juvenile fish rearing habitat assessments have been conducted at the Elkhorn rehabilitation site; therefore, no results are provided.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Elkhorn site, untreated sites (controls), and other rehabilitation sites within the North Fork Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 5 to 7, which made up 1.3 to 3.0% of the redds counted within the North Fork Reach and 0.1 to 0.2% of the redds counted in the Trinity River (Figure 6-3). Mean densities of Chinook salmon redds (redds per 200 m [656 feet]) within the Elkhorn site were lower than those counted in control sites (Figure 6-3).

Chinook and coho salmon carcasses were also sampled within the Elkhorn site during 2009 to 2011. No coho salmon carcasses were collected during the survey period in the site. Numbers of female Chinook salmon carcasses sampled within the Elkhorn site during 2009 to 2011 ranged from 2 to 7 (Figure 6-4), which made up 2.4 to 5.0% of the female carcasses sampled within the North Fork Reach and 0.1 to 0.2% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Elkhorn site were generally less than those in the control sites (Figure 6-4).

6.5 Pear Tree Gulch

Location: RMs 72.9 to 73.2
Year constructed: 2006

6.5.1 Design Objectives

The project was designed to increase and improve salmonid habitat, particularly juvenile rearing habitat. It was also intended to improve habitat for riparian-dependent wildlife and foothill yellow-legged frog. Similar to other projects constructed in 2006, an important goal was to design a project where flows independent of ROD releases would maintain the site. The modifications were designed to facilitate alluvial river forms and processes over time, resulting in the development of point bars and floodplain habitat at 187 $m^3 \cdot s^{-1}$ (6,600 cfs).

6.5.2 Site Description

The Pear Tree Gulch site is located approximately 6 miles downstream of the Canyon Creek confluence at approximately RM 73.2 and extends 0.30 mile downstream. Pear Tree Gulch meets the Trinity River at the upstream end of the site. Prior to construction, a gravel bar existed at the upstream end of the site near the right bank and historical floodplains occurred along the lower two thirds of the site. The bedrock canyon wall confines the left bank.

Pear Tree Gulch was one of the nine original pilot bank rehabilitation sites. After construction in the early 1990s, the upstream edge of the point bar was mobilized frequently enough to prevent extensive development of riparian vegetation. However, high flows after 1998 have been insufficient to prevent riparian encroachment along the low flow wetted edge, inhibiting flow connectivity between the main channel and the right-bank floodplain.

The Pear Tree Gulch project was constructed in the fall of 2006 and consisted of five in-river elements and one upland design element constructed on the right bank (Figure 6-11; Table 6-12). Vegetation removal, bank feathering, and floodplain lowering (R-1, R-2, and R-3) were designed to induce meandering, floodplain development, and natural recruitment of riparian vegetation, with floodplain inundation on lowered surfaces occurring at 187 $m^3 \cdot s^{-1}$ (6,600 cfs). A scour channel (R-4) and low-water alcove (R-5) were constructed to create off-channel habitat for juvenile fish. Excavated material was disposed of in an upland terrace.

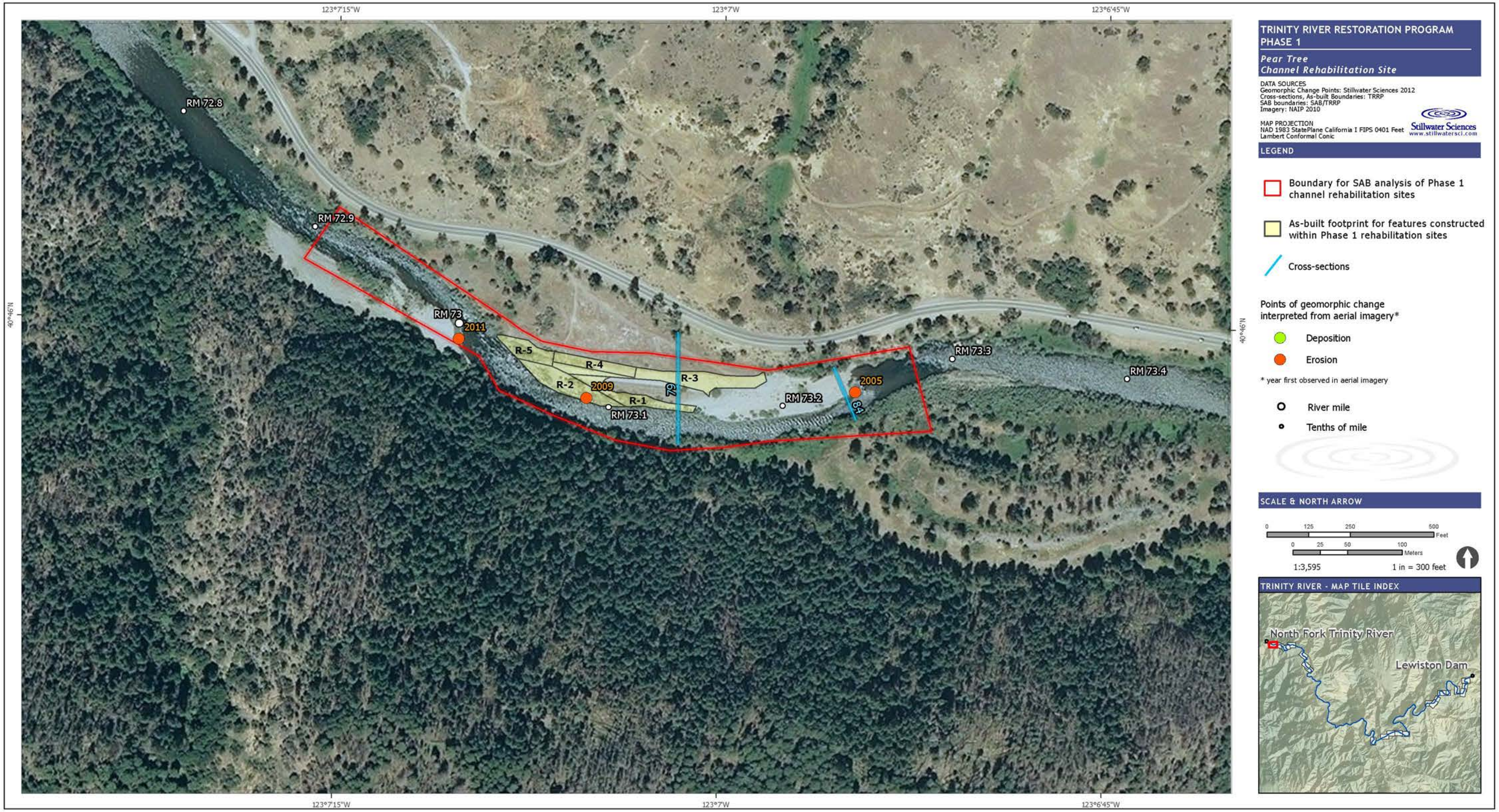


Figure 6-11

Design Features at the Pear Tree Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-12

Design Features Constructed at the Pear Tree Gulch Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Vegetation removal	73.1	Right bank
R-2	Feathered edge	73.1	Right bank
R-3	Floodplain (6,600 cfs)	73.1 – 73.2	Right bank and floodplain
R-4	High flow scour channel	73.1	Right bank and floodplain
R-5	Alcove	73.0	Right bank

6.5.3 Geomorphic Response

Geomorphic monitoring occurred at the Pear Tree Gulch site during WY 2009 and WY 2011 (Alvarez et al. 2010; McBain & Trush and HVT 2012). Profiles of the scour channel (R-4) and alcove (R-5) surveyed before and after the WY 2009 spring flow release (233 $m^3 \cdot s^{-1}$ [8,230 cfs] measured at the mainstem Trinity River above North Fork Trinity River) showed little geomorphic change. Debris lines and sand deposition in the high flow channel provided evidence that flow occupied the channel in WY 2009. Deposition at the upstream and downstream entrances to the alcove prohibited connectivity with the mainstem at summer and winter baseflows. Geomorphic monitoring results reported for WY 2010 did not include the Pear Tree Gulch site (McBain & Trush and HVT 2012).

Geomorphic monitoring in WY 2011 included cross section topography, bed mobility, and bed scour and deposition at cross sections 79 and 38+10 (HVT and McBain & Trush 2012). The Pear Tree Gulch site at cross section 39 experienced full bed mobility and up to 0.8 m erosion and deposition during the 388 $m^3 \cdot s^{-1}$ (13,700) ROD peak, meeting TRFEFR and ROD bed mobility objectives. No bank erosion or lateral migration occurred at the cross sections, as anticipated by design. The ROD spring release caused some erosion and deposition of the floodplain and high flow scour channel.

Interpretation of aerial photography and banklines indicated little change, other than retreat of the right bank channel margin near RM 73.2 between 2005 and 2009 and retreat of the left bank point bar downstream of R-5 between 2009 and 2011 (Table 6-13).

Table 6-13
Geomorphic Changes Observed in Repeat Aerial Photography at the Pear Tree Gulch Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
73.25	Erosion	Right bank bar retreat	2001 – 2011	None	All
73.1	Erosion	Right bank bar retreat	2005 – 2009	R-2	Not Applicable
73.0	Erosion	Left bank bar retreat	2009 – 2011	None	2011

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at two cross sections (79 and 84) located within the Pear Tree Gulch site (Table 6-14). Both cross sections showed a relatively active bed (45 to 50% of the channel width active >200 mm) related primarily to deposition along the right bank portions of the channel. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 0.30-mile site length (Figure 6-12) indicated little planform change since project construction.

Table 6-14

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Pear Tree Gulch Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
79	73.14	314	R-1, R-3	October-10	September-11	5	D	0.73	0.47	0.03	86.03	12
				September-05	October-10	6	B	0.81	0.71	0.04		66
84	73.23	313	None	September-10	September-11	5	D	0.74	0.48	0.07	61.85	12
				October-02	September-10	6	B	0.57	0.32	0.07		101

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

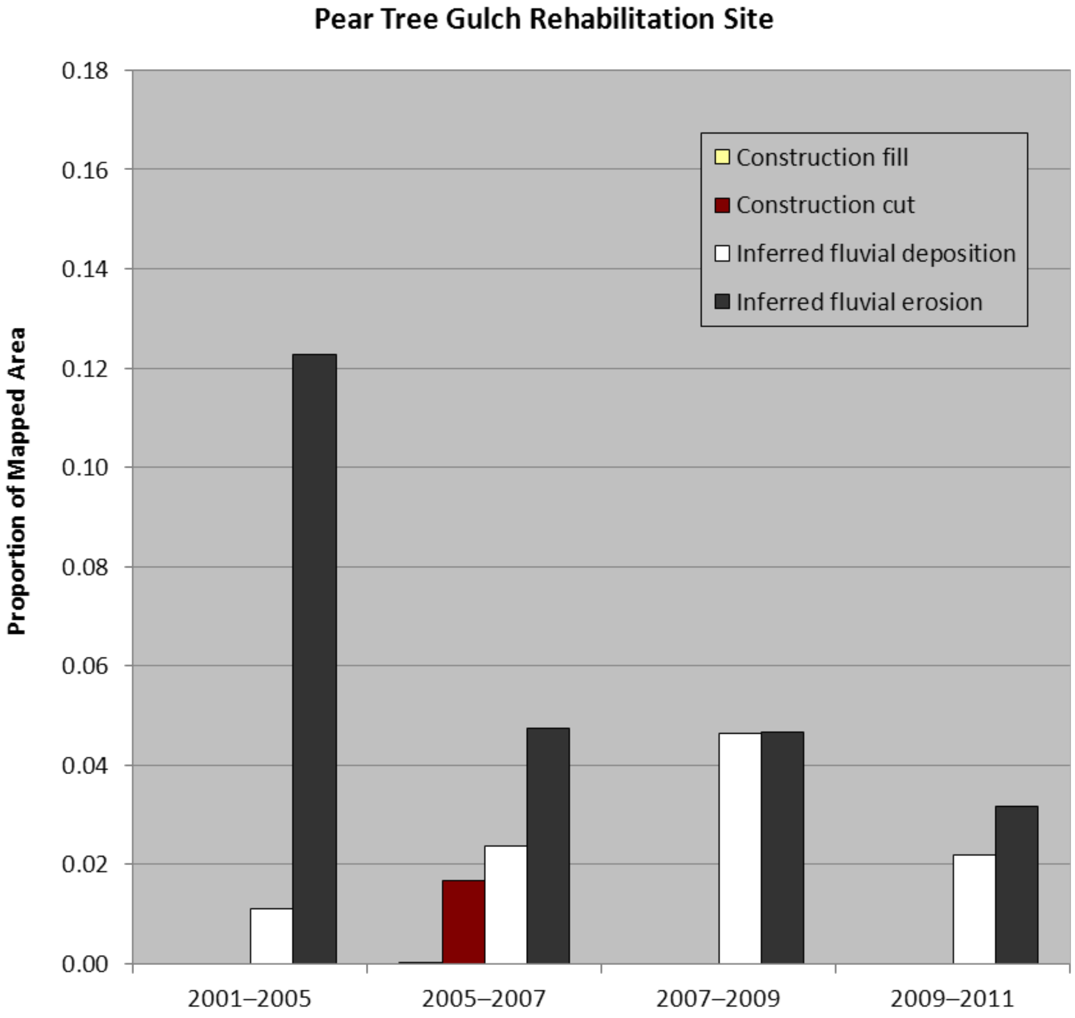


Figure 6-12

Lateral Erosion and Deposition Inferred from Banklines in the Pear Tree Gulch Rehabilitation Site

6.5.4 Biological Response

No pre- or post-construction juvenile fish rearing habitat assessments have been conducted at the Pear Tree Gulch site; therefore, no results are provided.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Pear Tree Gulch site, untreated sites (controls), and other rehabilitation sites within the North Fork Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 0 to 7, which made up 0.0 to 3.5% of the redds counted within the North Fork Reach and 0.0 to 0.2% of the redds counted in the Trinity River (Figure 6-3). Mean densities of

Chinook salmon redds (redds per 200 m [656 feet]) within the Pear Tree Gulch site were less than those counted in control sites (Figure 6-3).

Chinook and coho salmon carcasses were also sampled within the Pear Tree Gulch site during 2009 to 2011. No coho salmon carcasses were collected during the survey period in the site. Numbers of female Chinook salmon carcasses sampled within the Pear Tree Gulch site during 2009 to 2011 ranged from 2 to 3 (Figure 6-4), which made up 1.4 to 6.5% of the female carcasses sampled within the North Fork Reach and 0.0 to 0.2% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Pear Tree Gulch site were generally less than those in the control sites (Figure 6-4).

6.6 Indian Creek

Location: RMs 93.9 to 96.9
Year constructed: 2007

6.6.1 Design Objectives

The Indian Creek site includes a wide range of actions over 3 miles of river. The design emphasized: 1) excavating notches in the riparian berm that were intended to induce erosion of intervening berm areas; and 2) construction of a low flow side channel that, combined with vegetation removal and floodplain lowering, would induce channel migration into the remaining berm areas. The design at the downstream portion of the site also intended to lower flood elevations and prevent flood damage at the Indian Creek subdivision. Indian Creek is the only rehabilitation site where hazard mitigation was identified as a primary design objective.

6.6.2 Site Description

Indian Creek confluence occurs at RM 95.6 near the upstream extent of the Indian Creek site, and the Weaver Creek confluence occurs at the downstream extent. Vitzhum Gulch enters the Trinity River from the right bank within the site. Before construction, the relatively straight reach had densely vegetated riparian berms along both banks, a high-flow channel on the right bank behind the berm, and subtle meanders and in-channel bars near the middle of the reach.

Rehabilitation at the Indian Creek site consisted of ten in-river design elements (Figures 6-13a through 6-13d; Table 6-15). In the upstream portion of the site, 13 “notches” were removed from the riparian berm (R-1) to connect the channel to the floodplain behind the berm, improve availability of off-channel habitats for juvenile fish at flows above 57 $m^3{\cdot}s^{-1}$ (2,000 cfs), and increase the potential for high flows to erode remaining berm sections. In the middle portion of the site, the berm was removed and the bank re-contoured (R-2, R-3, and R-4) to reduce stranding potential and promote bank erosion and bar development. In the lower portion of the site, low-flow channels were constructed (R-7 and R-8) to create rearing habitat, reduce upstream water surface elevations, promote erosion of remnant berms, and recruit large wood. Vegetation was selectively removed and the berm re-contoured (R-6 and R-9), and floodplains adjacent to the right bank side channel were lowered (R-8) to inundate at 6,000 cfs, promote lateral migration, reduce upstream water surface elevations, and improve sediment routing. Large wood was placed in the constructed side channel and along feathered edges. A small wetland was enhanced on the right bank at the downstream end of the Indian Creek site (R-10). Constructed floodplains and the low-flow side channel margins were planted. Spoils from excavated areas were used to construct a terrace within dredger swales.

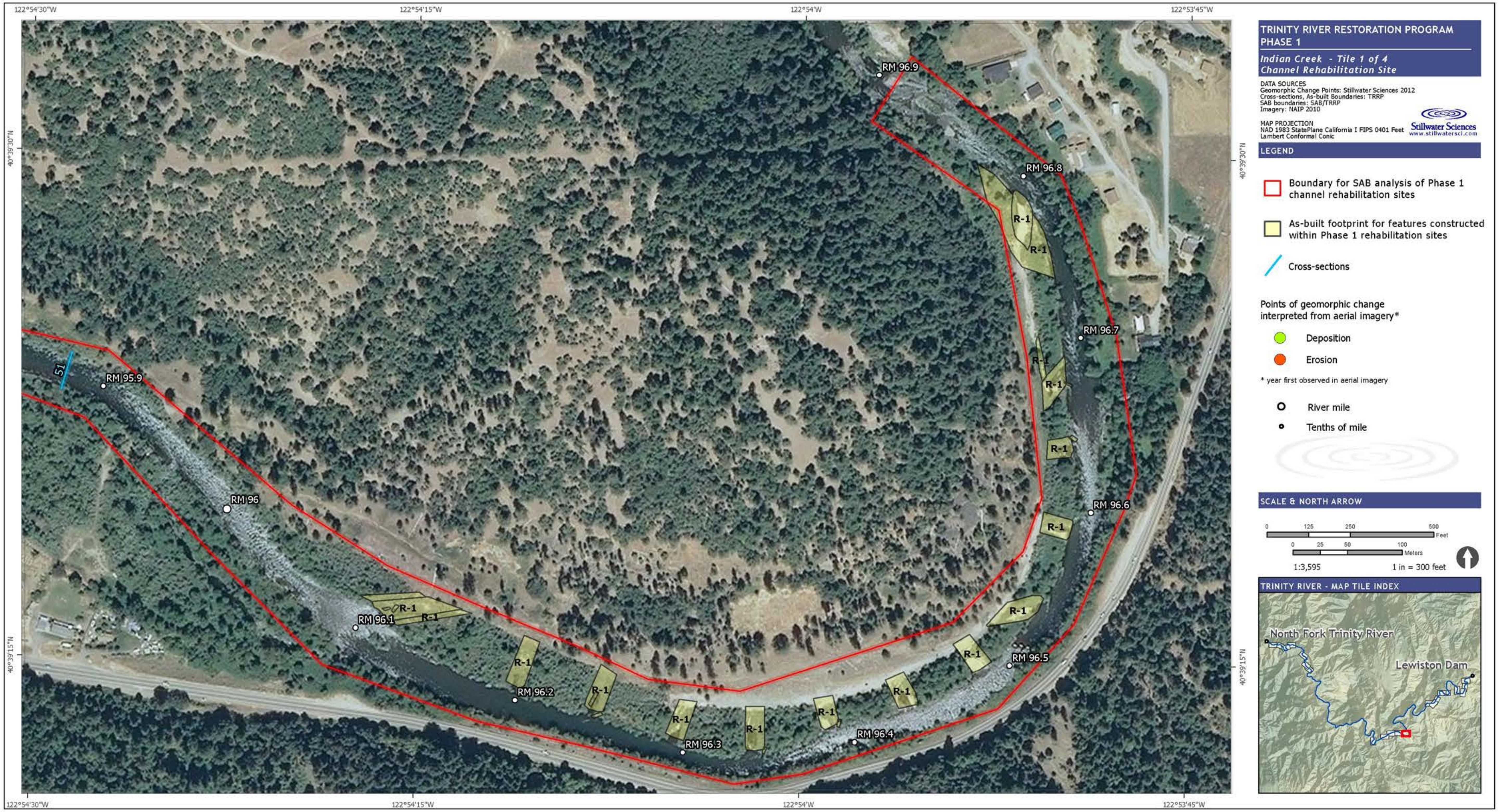


Figure 6-13a

Design Features at the Indian Creek Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

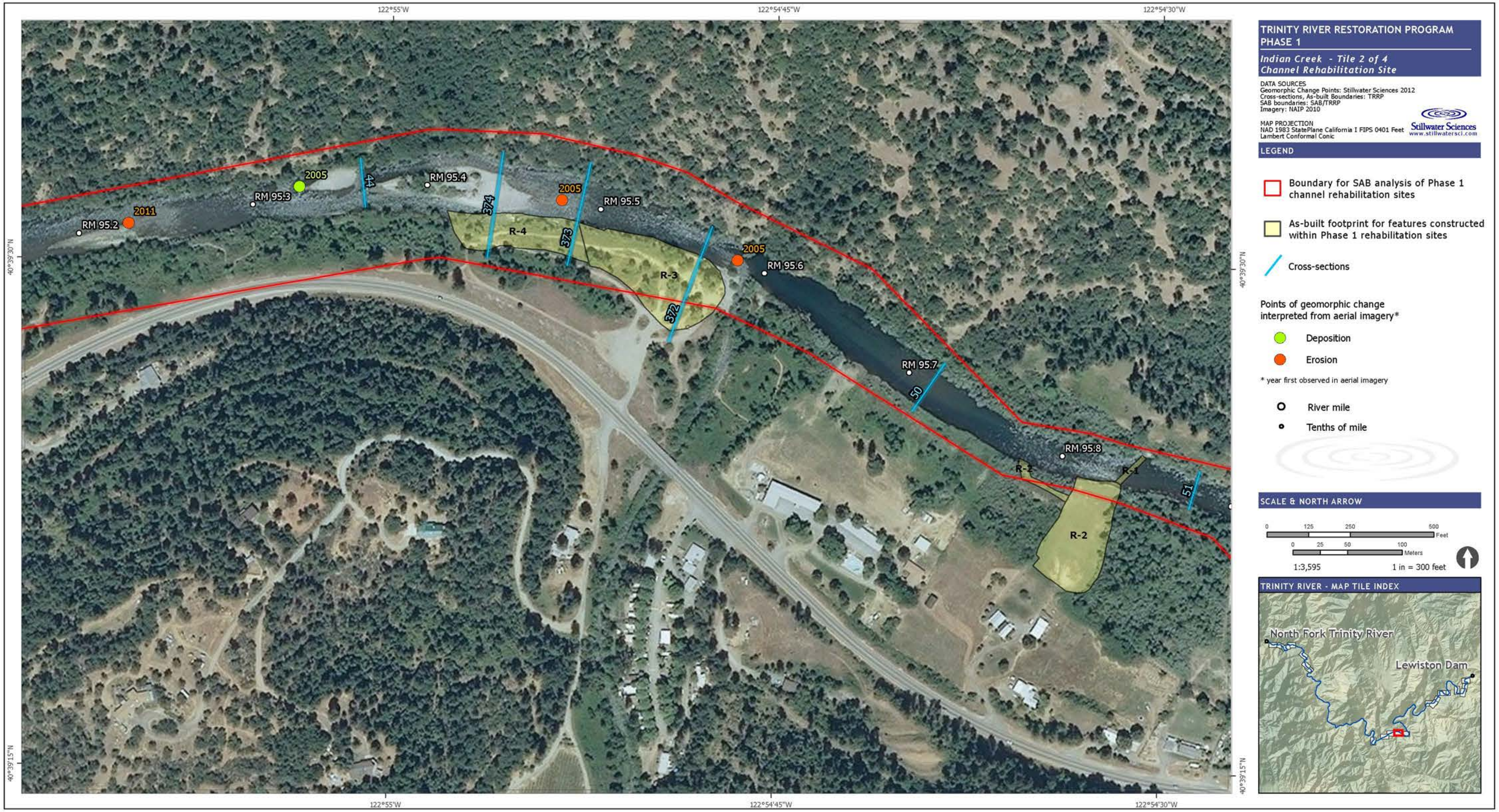


Figure 6-13b

Design Features at The Indian Creek Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Figure 6-13c

Design Features at the Indian Creek Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

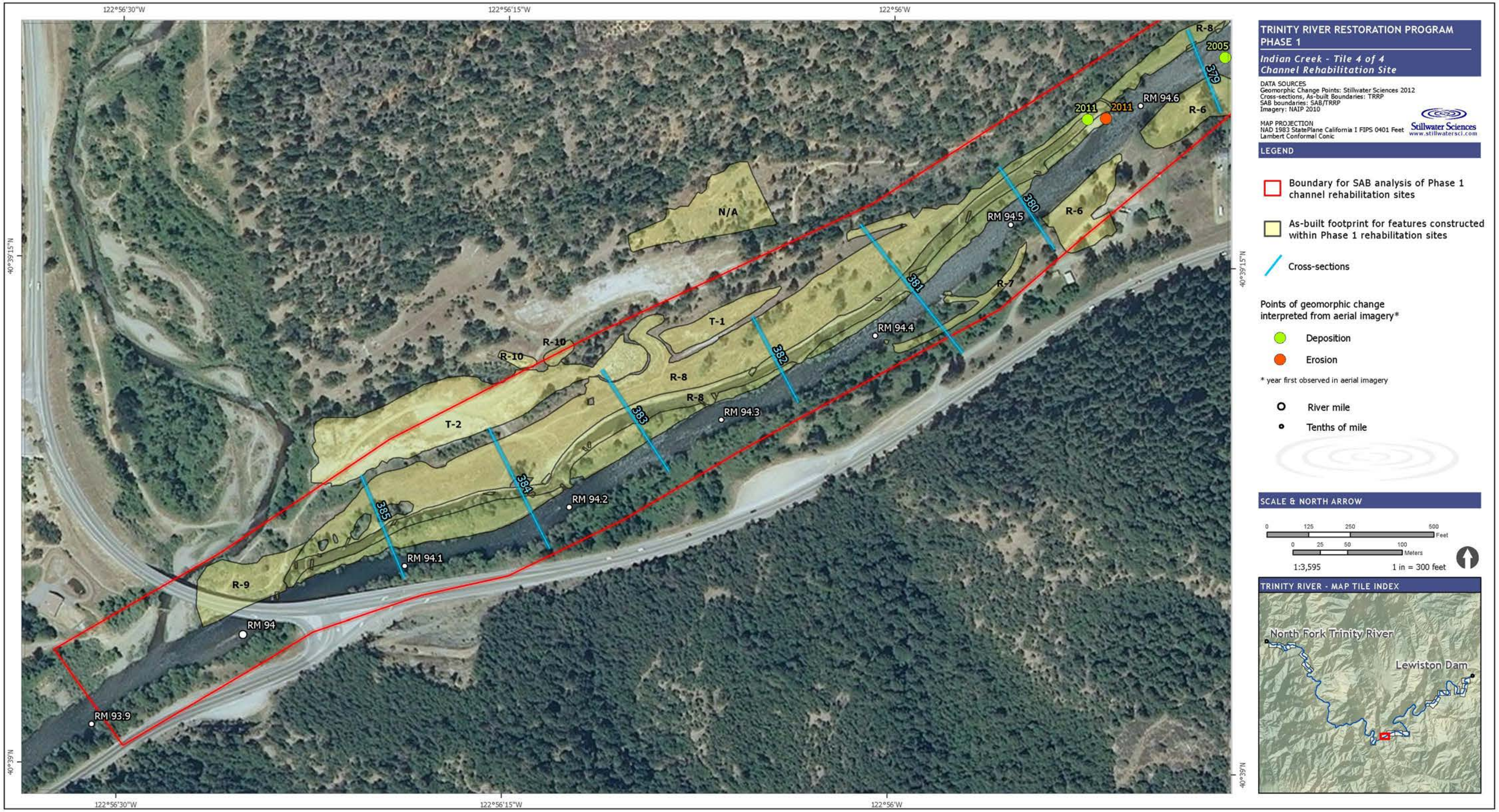


Figure 6-13d

Design Features at the Indian Creek Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width and Erosion and Deposition Observed in Aerial Photography

Table 6-15

Design Features Constructed at the Indian Creek Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Berm notches (2,000 cfs) with wood placements	96.1 – 96.8	Right bank
R-2	Recontouring, clearing, and grubbing	95.8	Left bank and floodplain
R-3	Berm removal	95.5 – 95.6	Left bank and floodplain
R-4	Clearing and grubbing	95.4 – 95.5	Left bank and floodplain
R-6	Recontouring, clearing, and grubbing	94.5 – 94.7	Left bank and floodplain
R-7	High-flow channel (6,000 cfs)	94.4 – 94.5	Left bank and floodplain
R-8	Floodplain lowering (6,000 cfs) with high flow side channel and wood placements	94.0 – 94.6	Left bank and floodplain
	Low-flow side channel with wood placements		
	Clearing and grubbing	94.6 – 94.7	Right bank
R-9	Selective vegetation removal	94.0	Left bank and floodplain
R-10	Connect existing wetland area	94.2	Left bank and floodplain

6.6.3 Geomorphic Response

Geomorphic monitoring activities at the Indian Creek site in WY 2009 following the spring high flow release (153 $m^3 \cdot s^{-1}$ [5,420 cfs]) included surveying two cross sections and a side channel longitudinal profile (Alvarez et al. 2011). Cross section surveys indicated minor scour and aggradation in the main channel and aggradation in the side channel. Surveys showed only minor topographic change and little or no change in alluvial features, indicating management targets were not met. The side channel entrance maintained flow at summer baseflows observed during 2009. Topography in the vicinity of berm notches was surveyed on four occasions following construction (September 2007, April 2008, October 2008, and August 2009). High-flow events in 2008 (184 $m^3 \cdot s^{-1}$ [6,500 cfs] for 7 days) and 2009 (153 $m^3 \cdot s^{-1}$ [5,420 cfs] for 1 day) caused only minor adjustments in notch area (<1%) and notch filling (13% net aggradation), and the notches generally remained in their initially constructed configuration with little or no berm erosion.

Geomorphic monitoring in WY 2010 following the spring high flow release (200 $m^3 \cdot s^{-1}$ [7,070 cfs]) included surveying three cross sections and conducting bed mobility and scour experiments in the constructed side channel (McBain & Trush and HVT 2012). Surveyed cross sections indicated no change (i.e., bar formation, scour, or thalweg migration), except for bank erosion (approximately 1 m) along constructed channel margins, suggesting that channel capacity and related hydraulic conditions intended to reduce infrastructure flooding were unaffected. The constructed side channel (R-8) showed up to 0.2 m (0.7 foot) of aggradation and up to 1.5 m (4.9 feet) of widening. Partial bed mobility and up to 16 cm of scour occurred in places within the side channel, consistent with design objectives.

Surveys following the 388 $m^3 \cdot s^{-1}$ (13,700) ROD peak in WY 2011 showed 0.3 to 0.6 m of aggradation across most of both cross sections below the 13 $m^3 \cdot s^{-1}$ (450 cfs) water surface, indicating reduced channel capacity (HVT and McBain & Trush 2012). No bank erosion, lateral channel migration, or topographic changes above the 13 $m^3 \cdot s^{-1}$ (450 cfs) water surface in the main channel occurred along the monitored cross sections in WY 2011. Bed mobility was not measured due to vandalism of survey markers. The side channel remained open and flowing during summer baseflows, and observations indicated the side channel maintained itself.

Monitoring at the Indian Creek confluence in WY 2011 included topography at cross section 37 and topography, bed mobility, and bed scour and redeposition at cross section 373 (HVT and McBain & Trush 2012). The spring ROD release was successful in meeting the lateral migration objective. The increased channel capacity at cross section 372 also suggests the design objective of reducing upstream water surface elevations was met. Channel capacity decreased at cross section 373. Bed mobilization at cross section 373 met TRFEFR and ROD objectives. Scour depths only partially met the $> 2\ D_{84}$ TRFEFR and ROD objective.

Monitoring in WY 2011 also occurred at a cross section located in the vicinity of the Vitzthum Gulch side channel entrance (HVT and McBain & Trush 2012). Flow function and berm erosion design objectives could not be evaluated as a part of this monitoring because the survey did not cross all of the side channel entrance. The WY 2011 ROD release resulted in a small sand deposit on the right bank just above the 13 $m^3 \cdot s^{-1}$ (450 cfs) water surface elevation. TRFEFR and ROD bed mobility and bed scour objectives were met for this cross section.

The WY 2010 Implementation Monitoring Report (Gaeuman in review) assessed geomorphic changes in limited areas of the Indian Creek site. Measurements of water surface elevation in the vicinity of the Indian Creek subdivision during the 2005 spring flow release (approximately 198 $m^3 \cdot s^{-1}$ [7,000 cfs]) and during the 2010 release (approximately 184 $m^3 \cdot s^{-1}$ [6,500 cfs]) indicated that construction of the project was successful at lowering water surface elevations. Differences between the 2009 DTM and 2010 topographic data indicated aggradation (0.3 to 1 m [1 to 3 feet]) and growth of the bar at the downstream end of the subdivision (between RM 94.6 and 94.7) in response to 2009 and 2010 flow releases. Bar expansion was accompanied by erosion of the left bank. A rapid assessment of the constructed side channel (R-8) in February 2011 (Gaeuman in review) indicated gravel accumulation in the vicinity of the upstream inlet, reducing the baseflow wetted width to about 1 m (4 feet). Flow into the next side channel inlet was vigorous (1.1 to 1.4 $m^3 \cdot s^{-1}$ [40 to 50 cfs]), with a depth of more than 1 foot and cross section area of about 3 m^2 (30 square feet). Additional geomorphic changes observed at the site during WY 2010 included thalweg incision near the right bank and an overall loss of stored sediment volume.

Interpretation of aerial photography and banklines indicated little change in the berm notches between 2001 and 2011 (Table 6-16). Along the relatively straight reach between RMs 94.6 and 95.4, a series of mid-channel and lateral bars appear to have migrated downstream between April 2009 and August 2011. Downstream migration of the bar near RM 94.6 aggraded the upstream inlet to the low-flow side channel (R-8).

Table 6-16

Geomorphic Changes Observed in Repeat Aerial Photography at the Indian Creek Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
95.6	Erosion	Gradual retreat of Indian Creek delta	2001 – 2011	None	All
95.5	Erosion	Gradual migration of medial bar	2001 – 2011	R-3	All
95.3	Deposition	Gradual growth of right bank bar	2001 – 2011	None	All
95.2	Erosion	Left bank lateral bar retreat	2009 – 2011	None	2011
95.0	Erosion	Left bank bar retreat	2009 – 2011	None	2011
95.0	Deposition	Right bank bar growth	2009 – 2011	None	2011
94.9	Deposition	Medial bar growth	2009 – 2011	None	2011
94.7	Erosion	Gradual migration of medial bar	2001 – 2011	None	All
94.6 – 94.7	Deposition				
94.6 – 94.7	Erosion	Gradual retreat of left bank	2001 – 2011	None	All
94.6	Erosion	Right bank bar migration	2009 – 2011	R-8	2011
94.6	Deposition				

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at 11 cross section locations within the Indian Creek site (Table 6-17). Most of the cross sections analyzed at the site showed a relatively active bed (≥20% of the channel width active >200 mm) during WY 2010, particularly: 1) in the vicinity of the midchannel bar and downstream lateral bar from RM 95.5 to

RM 95.3; and 2) in the relatively straight plane bed channel from RM 94.5 to RM 94.2. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 3-mile site length suggest lateral erosion and deposition by fluvial processes steadily decreased during the first three mapping periods (2001 to 2009) then increased during the 2009 to 2011 period (Figure 6-14). Bankline retreat was typically more dominant than bankline accretion, particularly during the 2009 to 2011 period.

Table 6-17

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Indian Creek Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3] >100 mm	Active Bed[3] >200 mm	Lateral Erosion and Deposition[4]	ω	6,000 cfs
385	94.10	145	R-8	August-08	July-09	5	C	0.41	0.12	0.01	83.25	0
384	94.18	144	R-8	August-08	July-09	5	C	0.48	0.30	0.03	87.42	0
383	94.26	144	R-8	August-08	July-09	5	C	0.20	0.10	0.03	87.42	0
382	94.34	142	R-8	August-08	July-09	5	C	0.11	0.01	0.01	59.62	0
				July-09	January-11	5	C	0.62	0.48	0.01		6
381	94.43	143	R-7, R-8	August-08	July-09	5	C	0.14	0.01	0.04	99.31	0
				July-09	January-11	5	C	0.63	0.45	0.04		6
380	94.51	142	R-8	August-08	July-09	5	C	0.30	0.09	0.01	59.62	0
				July-09	January-11	5	C	0.39	0.24	0.01		6
379	94.64	141	R-6	August-08	July-09	5	C	0.37	0.07	0.04	58.07	0
44	95.36	135	none	October-02	October-11	6	D	0.48	0.33	0.12	46.74	76
374	95.44	134	R-4	August-08	July-09	5	C	0.36	0.18	0.07	43.26	0
				July-09	January-11	5	C	0.65	0.45	0.07		6
373	95.49	134	R-4	August-08	July-09	5	C	0.18	0.05	0.07	43.26	0
				July-09	January-11	5	C	0.83	0.48	0.07		6
372	95.56	133	R-3	August-08	July-09	5	C	0.52	0.13	0.05	34.99	0
				July-09	January-11	5	C	0.87	0.64	0.05		5

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

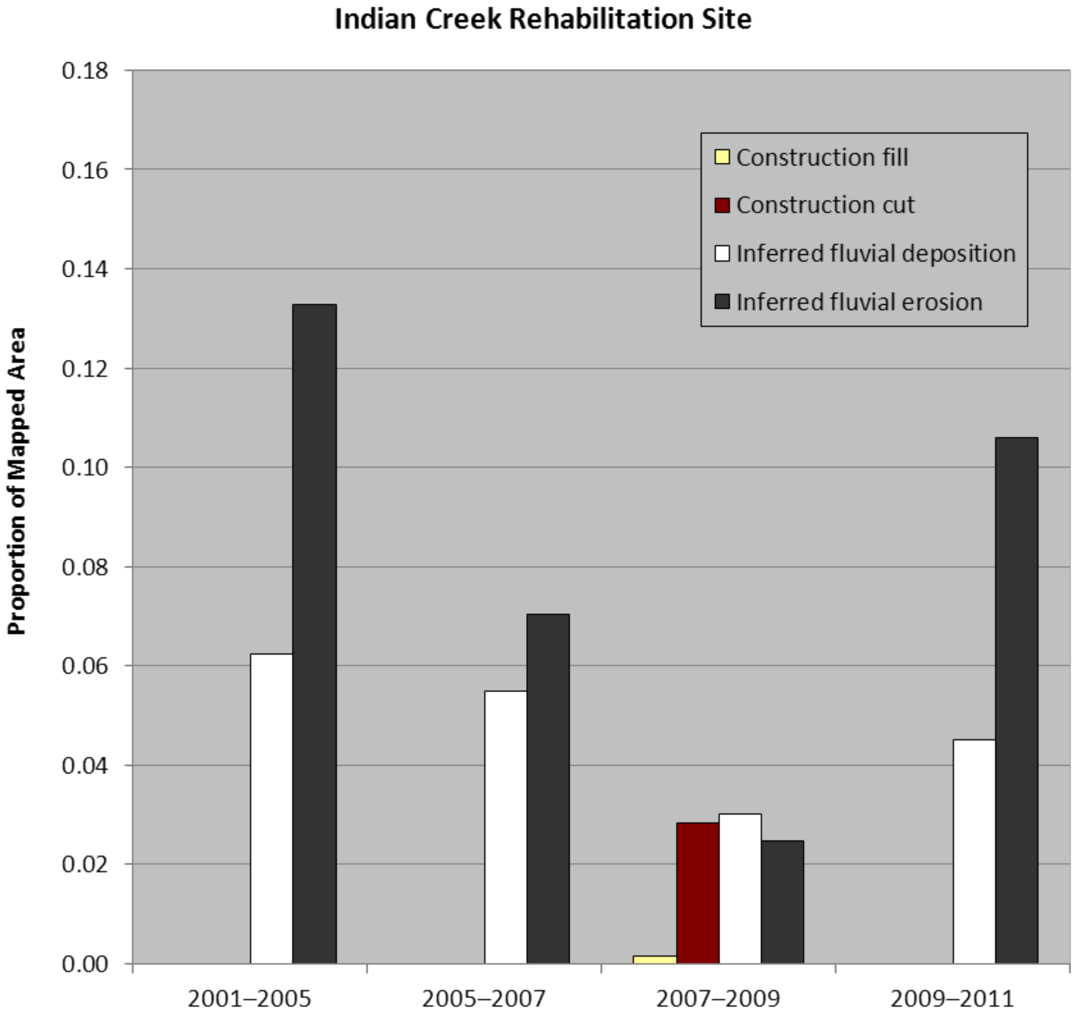


Figure 6-14

Lateral Erosion and Deposition Inferred from Banklines in the Indian Creek Rehabilitation Site

6.6.4 Biological Response

Pre- and post-construction evaluations were conducted at the Indian Creek site in 2007 at baseflow (12.4 $m^3 \cdot s^{-1}$ [437.9 cfs]) and April 2008 at baseflow (11.6 $m^3 \cdot s^{-1}$ [409.6 cfs]), respectively. Similar to the Hocker Flat site, Goodman et al. (2010) indicate that the pre-construction assessment at Indian Creek was conducted using a different method than other sites and only included the collection of data for the suitable habitat category of DV, no C; therefore, no changes in optimal habitat between pre- and post-rehabilitation could be assessed. The pre-construction evaluation began upstream of the Vitzhum Gulch site at an island complex and extended downstream of the Indian Creek site to the confluence with Weaver Creek.

This area was divided into two subsections for the post-construction assessment, Vitzhum Gulch and Lower Indian Creek, to target areas that changed the most from bank rehabilitation actions (Goodman et al. 2010). Pre- (2007) and post-construction (April 2008) habitat monitoring at Vitzhum Gulch evaluated the change in suitable (i.e., DV, no C) habitat and indicated that baseflow habitat increased 224% for fry and 71% for presmolts (Figure 6-15). These increases occurred within the 13 constructed riparian berm notches that imitated backwater or alcove type habitat (Goodman et al. 2010). After high flows occurred during the spring of 2008, this site was reassessed in September 2008 at baseflow (13.4 $m^3 \cdot s^{-1}$ [473.2 cfs]) and the results indicated that fry and presmolt habitat had decreased by 24% and 12%, respectively, due to fine sediment being deposited within some of the berm notches.

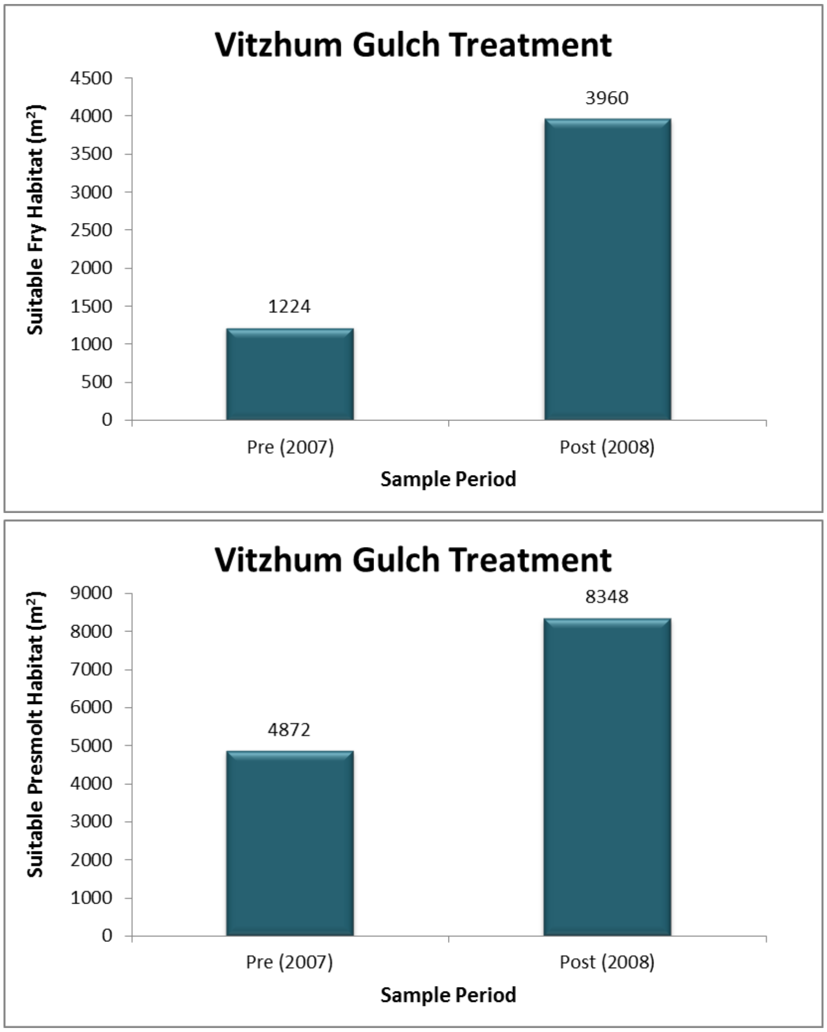


Figure 6-15

Change in Suitable Rearing Habitat (DV, No C) for Fry and Presmolts at the Vitzhum Gulch Site Before (Pre) and After (Post) Rehabilitation

Pre- (2007) and post-construction (April 2008) fish habitat monitoring at Lower Indian Creek at baseflow evaluated the change in suitable habitat and indicated that fry habitat increased by 242% and presmolt habitat increased by 115% (Goodman et al. 2010) (Figure 6-16). Goodman et al. (2010) attribute some of this increase to the construction of a side channel that parallels approximately 900 m (2,953 feet) of the main channel. The constructed side channel contributed 25% of the fry habitat and 24% of the presmolt habitat that was surveyed (Goodman et al. 2010).

Goodman et al. (2010) conducted a multiple flow survey at a segment of the Lower Indian Creek site and mapped habitat availability at four streamflows between 375 and 2,170 cfs after construction. Optimal habitat for fry decreased by 34% (167 m^2 [1,798 square feet]) between low flow and high flow levels. Presmolt habitat availability did not change substantially with stream flow level (Goodman et al. 2010). Fry and presmolt rearing habitat within the depth/velocity criteria and outside of the cover criterion decreased with streamflow by 79% (1,430 m^2 [15,392 square feet]) and 70% (2,463 m^2 [26,511 square feet]), respectively. The decrease in habitat abundance with increasing streamflow was attributed to the steep slope of the constructed stream banks within the side channel (Goodman et al. 2010).

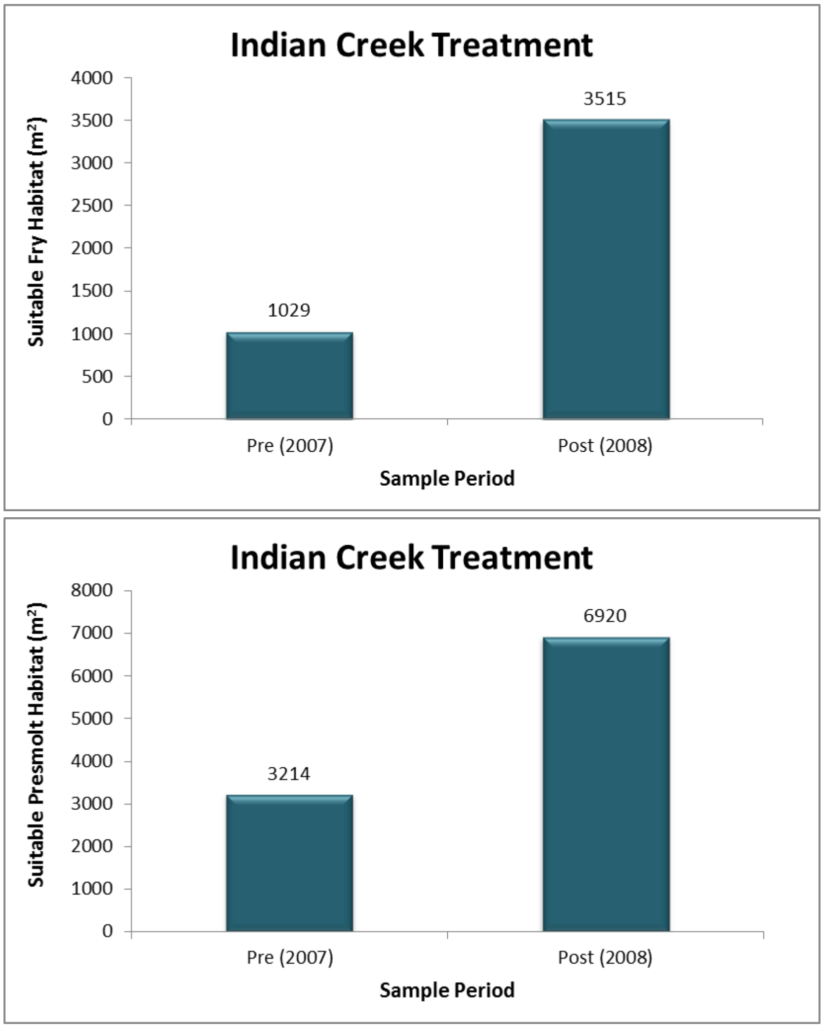
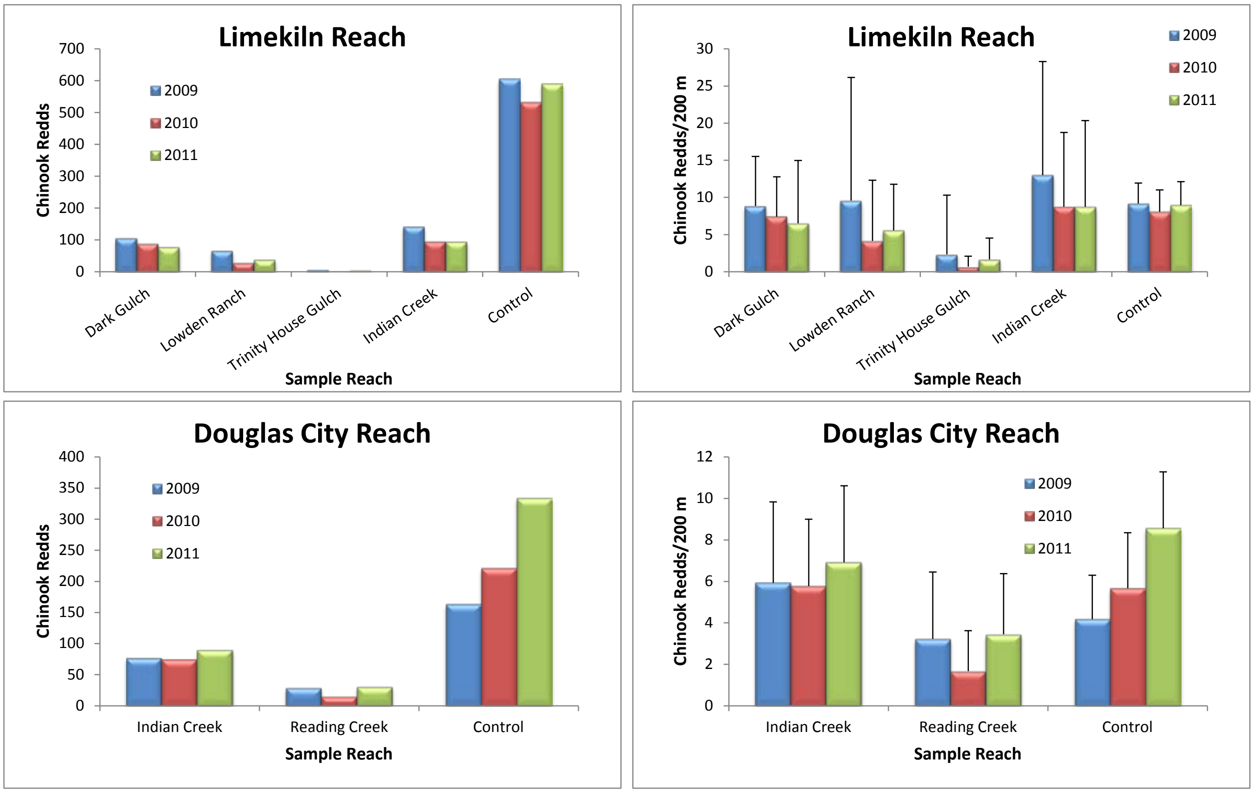


Figure 6-16

Change in Suitable Rearing Habitat (DV, No C) for Fry and Presmolts at the Indian Creek Site Before (Pre) and After (Post) Rehabilitation

Chinook salmon redds (spring and fall Chinook combined) were counted within the Indian Creek site, untreated sites (controls), and other rehabilitation sites within the Limekiln and Douglas City reaches during 2009 to 2011 (based on data within the data frame). Within the Limekiln Reach, numbers of redds ranged from 96 to 143, which made up 11.9 to 15.4% of the redds counted within the Limekiln Reach and 2.1 to 4.4% of the redds counted in the Trinity River (Figure 6-17). Within the Douglas City Reach, numbers of redds ranged from 75 to 90, which made up 19.8 to 28.6% of the redds counted within the Douglas City Reach and 1.9 to 2.4% of the redds counted in the Trinity River (Figure 6-17). Mean densities of Chinook salmon redds (redds per 200 m [656 feet]) within the Indian Creek site were similar to those counted in control sites in both reaches (Figure 6-17).

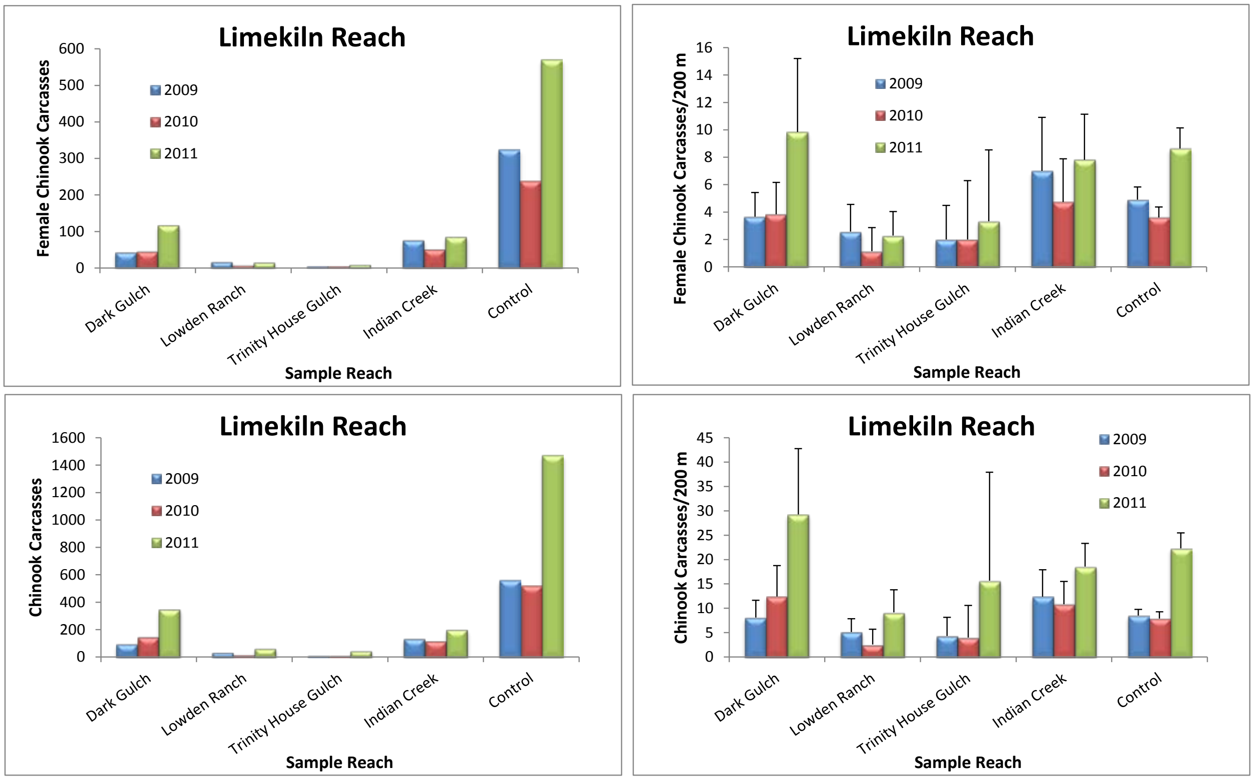


Note:
Densities are mean values with 95% CI.

Figure 6-17

Numbers and Densities (redds per 200 m) of Chinook Salmon (Spring and Fall Chinook) Redds Counted within Different Rehabilitation Sites and Control Sites within the Limekiln and Douglas City Reaches during 2009 to 2011

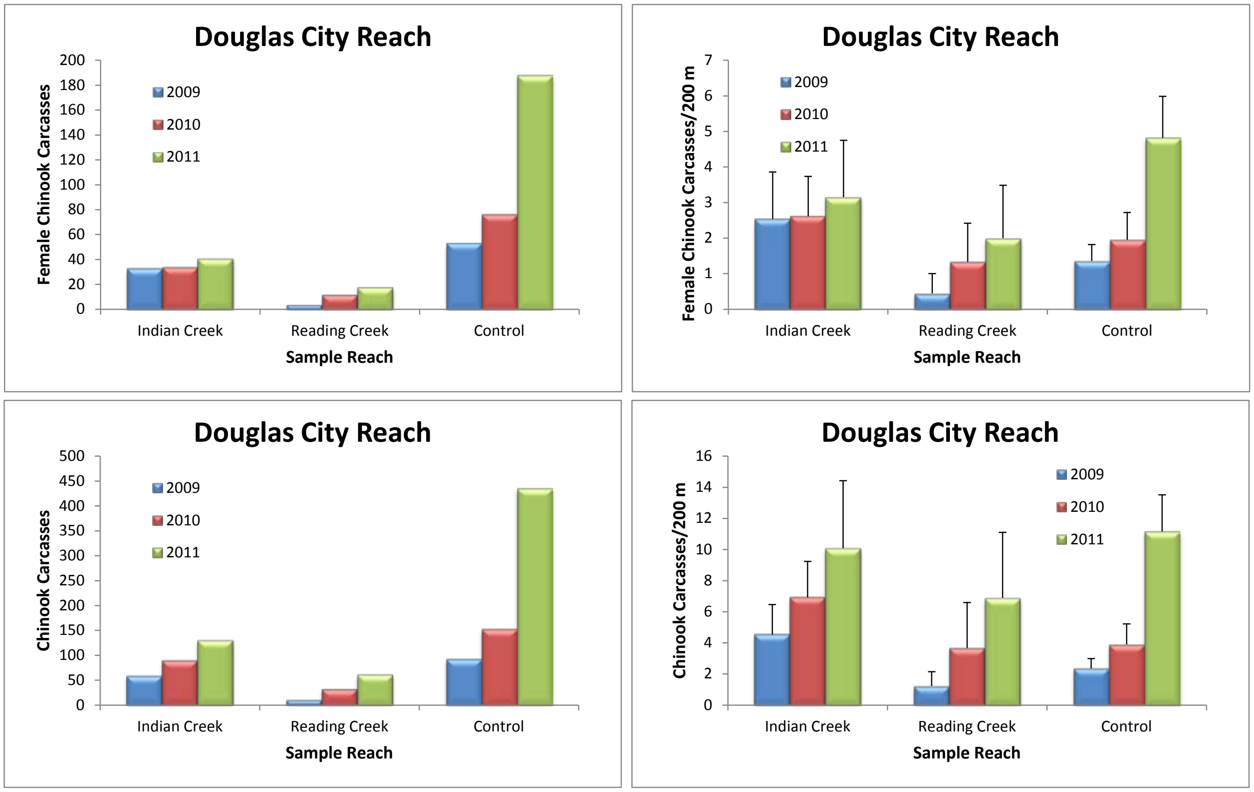
Chinook salmon carcasses were sampled within the Indian Creek site during 2009 to 2011. Within the Limekiln Reach, numbers of female carcasses sampled within the Indian Creek site during 2009 to 2011 ranged from 52 to 86 (Figure 6-18), which made up 10.8 to 16.4% of the female carcasses sampled within the Limekiln Reach and 1.7 to 4.3% of the female carcasses sampled in the Trinity River. Within the Douglas City Reach, numbers of female carcasses sampled within the Indian Creek treatment site ranged from 33 to 41 (Figure 6-19), which made up 16.6 to 36.7% of the female carcasses sampled within the Douglas City Reach and 0.8 to 2.6% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Indian Creek site were not statistically different from those in the control sites in both reaches (Figures 6-18 and 6-19).



Note:
Densities are mean values with 95% CI.

Figure 6-18

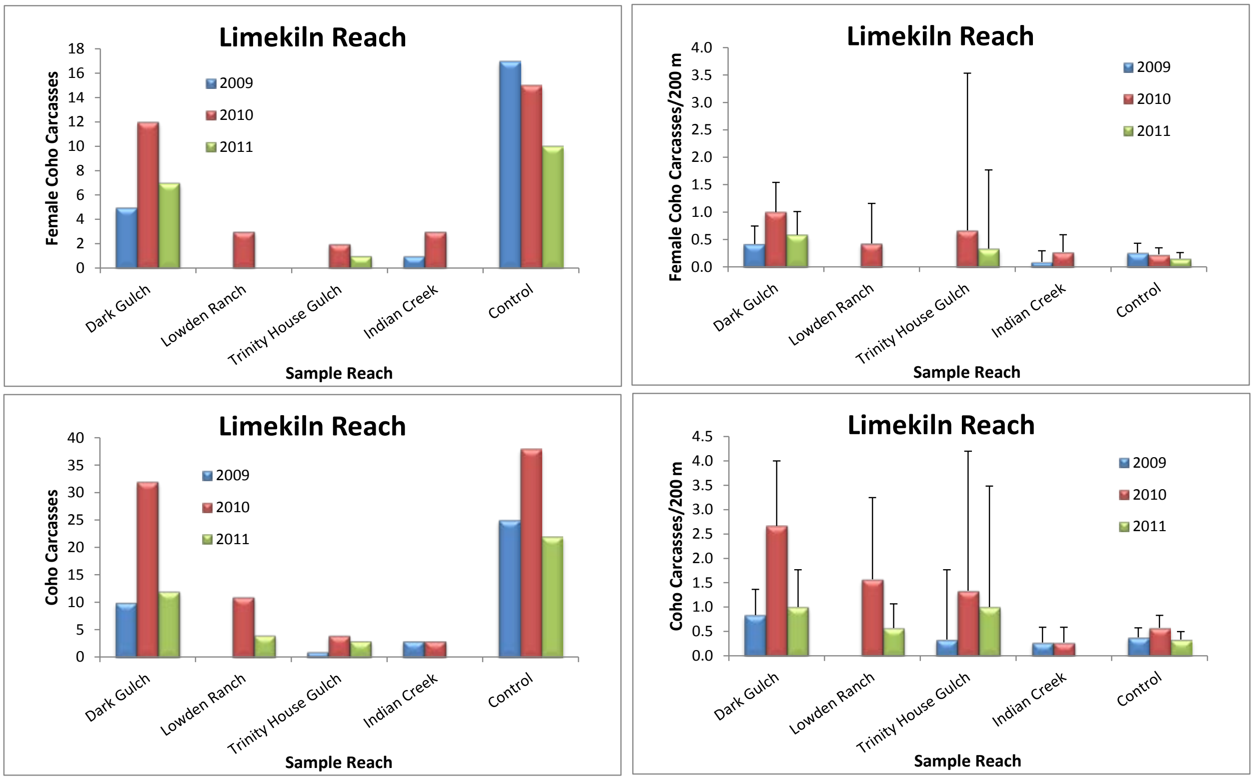
Numbers and Densities (carcasses per 200 m) of Female Chinook and Total Chinook Carcasses Sampled within Different Treatment Reaches and Control Areas within the Limekiln Reach during 2009 to 2011



Note:
Densities are mean values with 95% CI.

Figure 6-19
Numbers and Densities (carcasses per 200 m) of Female Chinook and Total Chinook Carcasses Sampled within Different Treatment Reaches and Control Areas within the Douglas City Reach during 2009 to 2011

Coho salmon carcasses were also sampled within the Indian Creek site during 2009 to 2011. No coho salmon carcasses were sampled in the Indian Creek site within the Douglas City Reach. Within the Limekiln Reach, numbers of female carcasses sampled within the site during 2009 to 2011 ranged from 0 to 3 (Figure 6-20), which made up 0.0 to 8.6% of the female carcasses sampled within the Limekiln Reach and 0.0 to 1.3% of the female carcasses sampled in the Trinity River. Mean densities of female coho salmon carcasses in the Indian Creek site were similar to those in the control sites (Figure 6-20).



Note:
Densities are mean values with 95% CI.

Figure 6-20

Numbers and Densities (carcasses per 200 m) of Female Coho and Total Coho Carcasses Sampled within Different Treatment Reaches and Control Areas within the Limekiln Reach during 2009 to 2011

6.7 Lewiston Four

Four nearly contiguous channel rehabilitation sites were built in the first 2 miles downstream of Lewiston Dam in 2008 and are collectively referred to as the Lewiston Four: Sven Olbertson, Deadwood Creek, Lewiston Cableway, and Hoadley Gulch. Much of the information compiled by the Program (e.g., as-built shapefiles of design features) is aggregated to describe the Lewiston Four sites as a whole rather than as individual rehabilitation sites.

6.7.1 Sven Olbertson

Location: RMs 111.2 to 111.6
Year constructed: 2008

6.7.1.1 Design Objectives

The Sven Olbertson rehabilitation site is located directly downstream of the hatchery spawning area, and it was hypothesized that the site would provide stable, high quality fry and juvenile rearing habitat in side channels. The general design objectives included increasing and sustaining the availability, quantity, and quality of salmonid habitat between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs) and reducing redd superimposition. Additional design objectives included increasing coarse sediment supply and storage, creating alternate bars, increasing large woody debris (LWD) in side channel habitats, preserving selective vegetation for riparian habitat and LWD recruitment, and minimizing in-channel work.

6.7.1.2 Site Description

Sven Olbertson is the first site downstream of Lewiston Dam and upstream-most of the Lewiston Four. The site begins at approximately RM 111.6 just and extends 0.41 mile downstream to just upstream of the coarse sediment injection point located on the right bank at RM 111.1. An existing low flow side channel on the right bank connected ponds and supported riparian vegetation along the low water edge prior to construction. The lack of high flows and coarse sediment input and backwater effects from a weir at the downstream end of the site limited the potential for dynamic changes in channel morphology and aquatic habitat.

The Sven Olbertson project consisted of three design elements (Figure 6-21; Table 6-18). The existing low-flow side channel was enhanced and moved (R-1) to improve connectivity with the mainstem. The project included construction of three side channel inlets (R-1) to increase long-term sustainability, each inlet containing wood elements to promote sour and reduce the risk of aggradation. A barrier was removed to improve surface water connection between the existing upstream side channel and the downstream pond, and wood was added to the side channel to improve salmonid rearing habitat. Fill was placed in the downstream pond to reduce its area, and connectivity between the side channel inlet and the main river was increased by removing a portion of the concrete weir (IC-2). Alcoves were constructed at two locations along the low-flow side channel (R-1). Vegetation removal and recontouring of floodplains designed to inundate at discharges ranging from 28 to 170 $m^3 \cdot s^{-1}$ (1,000 to 6,000 cfs) was expected to alleviate scour within the side channel complex when ROD releases exceeded 170 $m^3 \cdot s^{-1}$ (6,000 cfs). After construction, the side channel margins and floodplain areas were vegetated.

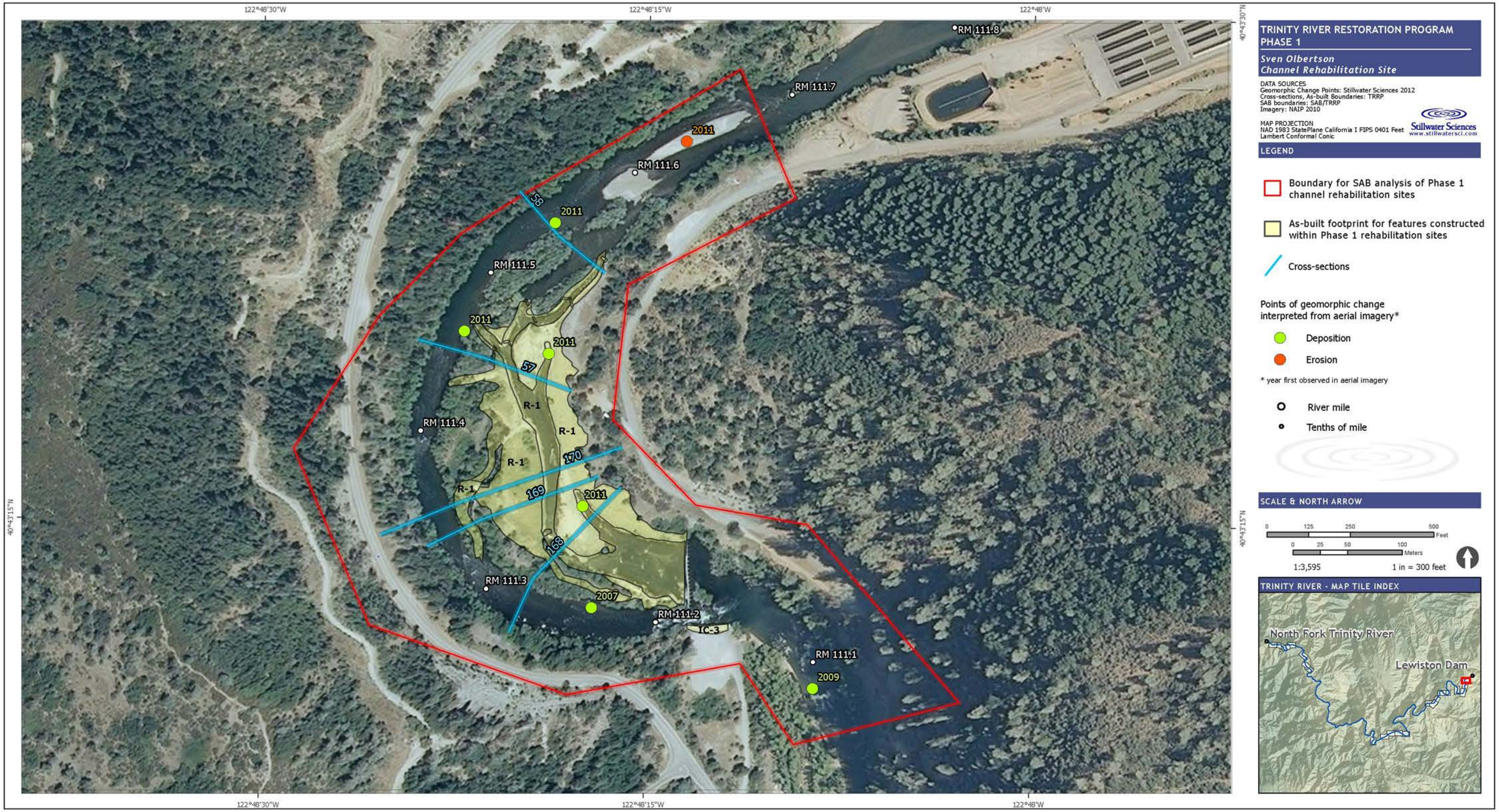


Figure 6-21

Design Features at the Sven Olbertson Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-18

Design Features Constructed at the Sven Olbertson Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Low flow side channel (300 cfs) with wood placements	111.2 – 111.5	Left bank and floodplain
	Floodplain (1,500 – 8,000 cfs)		
	High flow scour channel (2,000 cfs) and alcove		
IC-2	Weir removal	111.2	Mid-channel
IC-3	Rock slope protection	111.2	Right bank

6.7.1.3 Geomorphic Response

Geomorphic monitoring performed at the site before and after the WY 2009 spring release peak flow (131 $m^3 \cdot s^{-1}$ [4,630 cfs], measured at Lewiston) included two cross sections and a long profile through the side channel (Alvarez et al. 2011). One of the cross sections showed relatively little topographic change, while the other showed up to 0.6 m (2.0 feet) of aggradation. Longitudinal profile surveys conducted before and after the spring release showed aggradation in the mainstem channel upstream of the side channel entrance, but entrance elevations did not change. The side channel aggraded up to 1.2 m (3.9 feet) and scoured up to 0.6 m (2.0 feet) in the vicinity of obstructions (e.g., bedrock, boulders, and large wood). Bedrock controls locally reduced the side channel slope, causing some deposition. In addition, some of the constructed pools associated with large wood and boulder placements at the side channel entrance filled. Rapid assessment of the side channel in February 2011 (Gaeuman in review) indicated that all three inlets aggraded since construction in 2008. Maximum baseflow depth over the three hydraulic controls was 0.2 m (0.6 foot), and flow area over the controls ranged from 0.3 to 0.7 m^2 (3.6 to 7.5 square feet). The results indicated that although the entrance remained open, a surface water connection into the side channel may not be maintained in the future. Geomorphic monitoring results reported for WY 2010 by McBain & Trush and the Hoopa Valley Tribal Fisheries Council (2012) did not include the Sven Olbertson site.

In 2000, a spawning gravel quality study site was established at RM 11.5 in the reach now encompassed by the Sven Olbertson site. Repeat sampling of the site in 2009 indicated that spawning gravel coarsened and the quality improved since 2000, likely due to the introduction of coarse sediment, flushing of the finer fractions, and/or reduction in the supply of fine sediment (GMA 2010a).

Interpretation of aerial photography and banklines indicated that coarse sediment additions within the Hatchery site and the upper end of the Sven Olbertson site dispersed downstream between 2001 and 2011 (Table 6-19). Two bars located between RMs 111.5 and 111.7 coalesced and migrated downstream approximately 28 m^2 (300 feet), aggrading the side-channel entrance (R-1). Between 2009 and 2011, a smaller bar formed in the vicinity of the side channel entrance near RMs 111.4 and 111.5. A left bank bar formed near RMs 111.2 and 111.3 between 2005 and 2007. Two branches of the main side-channel located near RMs 111.3 and 111.5 were partially filled with sediment between 2009 and 2011. At the downstream end of the site, a point bar formed along the right bank at the inside of the meander in the vicinity of the coarse sediment injection point.

Table 6-19
Geomorphic Changes Observed in Repeat Aerial Photography at the Sven Olbertson Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
111.6 – 111.7	Erosion	Erosion of medial bar	2001 – 2011	Coarse sediment additions upstream of site	All
111.5 – 111.6	Deposition	Left bank bar growth	2001 – 2011	Coarse sediment additions upstream of site	All
111.5	Deposition	Side-channel filling	2009 – 2011	R-1	2011
111.45	Deposition	Left bank bar growth	2009 – 2011	R-1	2011
111.3	Deposition	Side-channel filling	2009 – 2011	R-1	2011
111.25	Deposition	Left bank bar growth	2005 – 2007	R-1	2006
111.0 – 111.1	Deposition	Right bank bar growth	2007 – 2011	R-1 and coarse sediment additions made at injection point near RM 111.2	2011

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at four cross section locations within the Sven Olbertson rehabilitation site (Table 6-20). Cross sections 57 and 170 showed a relatively active bed (≥20% of the channel width active >200 mm) during periods not directly influenced by construction. Most of the changes were related to aggradation and erosion in the side channel and adjacent floodplain areas. Analysis of bankline changes suggested pronounced lateral erosion and deposition (17% of the mapped area) due to fluvial processes at cross sections 57 and 58 in the upstream portion of the site (Table 6-20), while changes elsewhere in the 0.41-mile site length were smaller (Figure 6-22).

Table 6-20

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Sven Olbertson Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3] >100 mm	Active Bed[3] >200 mm	Lateral Erosion and Deposition[4]	ω	6,000 cfs
169	111.34	6	R-1	April-04	October-11	6	D	0.70	0.55	0.03	58.41	52
170	111.35	6	R-1	July-00	March-09	2	B	0.81	0.57	0.19	58.41	41
				March-09	July-09	4	C	0.48	0.23	0.06		0
57	111.45	5	R-1	April-04	August-06	1	B	0.47	0.37	0.17	53.48	33
				August-06	March-09	2	C	0.57	0.40	0.04		7
				March-09	July-09	4	C	0.19	0.03	0.04		0
58	111.55	5	R-1	April-04	August-06	1	B	0.30	0.06	0.17	53.48	33
				August-06	March-09	2	C	0.38	0.09	0.04		7

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

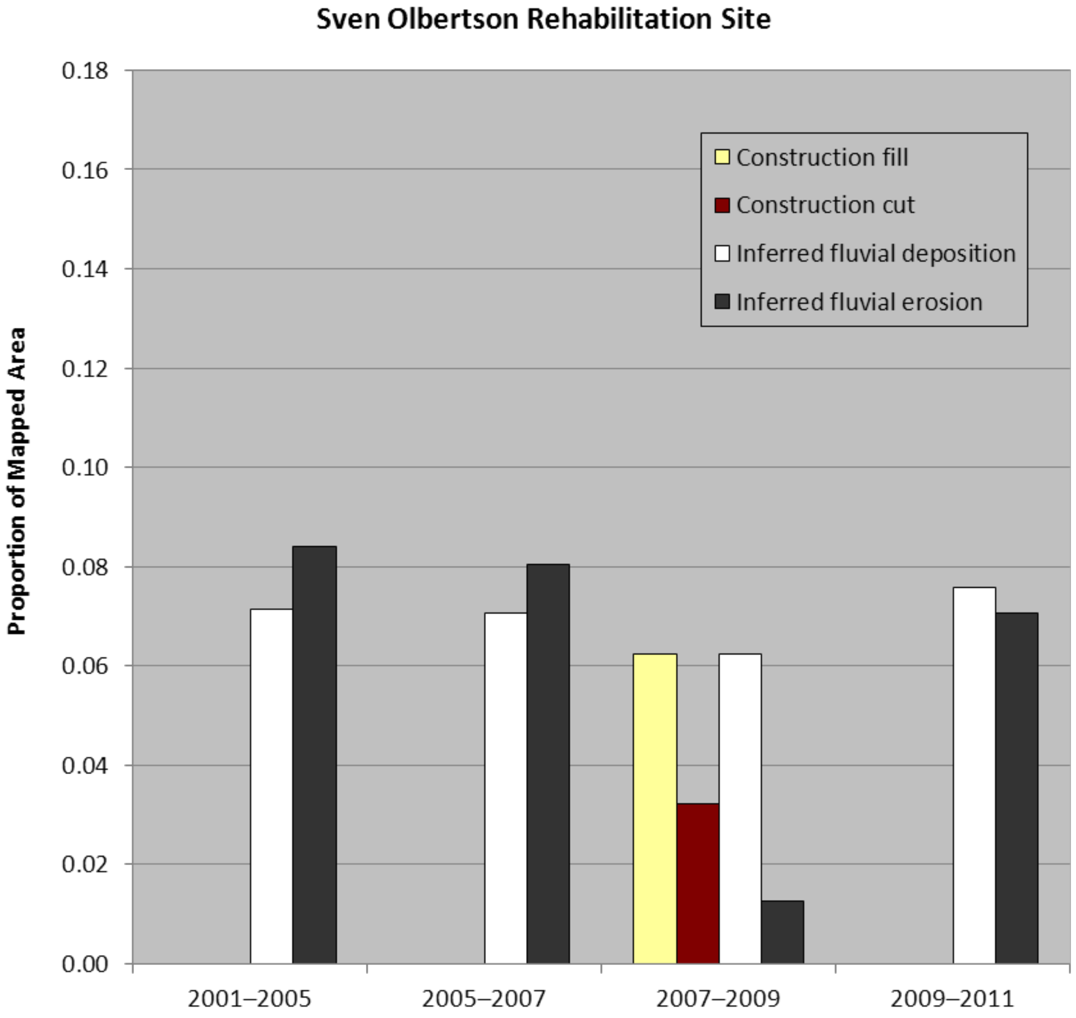


Figure 6-22
Lateral Erosion and Deposition Inferred from Banklines in the Sven Olbertson Rehabilitation Site

6.7.1.4 Biological Response

Pre- and post-construction rearing habitat evaluations were conducted in 2008 and 2009 at baseflows (8.6 $m^3 \cdot s^{-1}$ [303.7 cfs] in the main channel and 1.06 $m^3 \cdot s^{-1}$ [37.43 cfs] in the constructed side channel). After construction, optimal fish habitat (DV, C) in the main channel decreased by 14 and 13% for fry and presmolts, respectively (Alvarez et al. 2011). The proportional increase in total habitat in the main channel was 9 and 4% for fry and presmolts, respectively. The proportional increase in optimal habitat (DV, C) in the side channel was 719 and 1,034% for fry and presmolts, respectively, and the proportional increase in total habitat in the side channel was 192 and 200% for fry and presmolts, respectively. Throughout the entire site, optimal habitat increased by 145 and 204%, and total habitat increased by 67 and 57% for fry and presmolts, respectively (Figure 6-23).

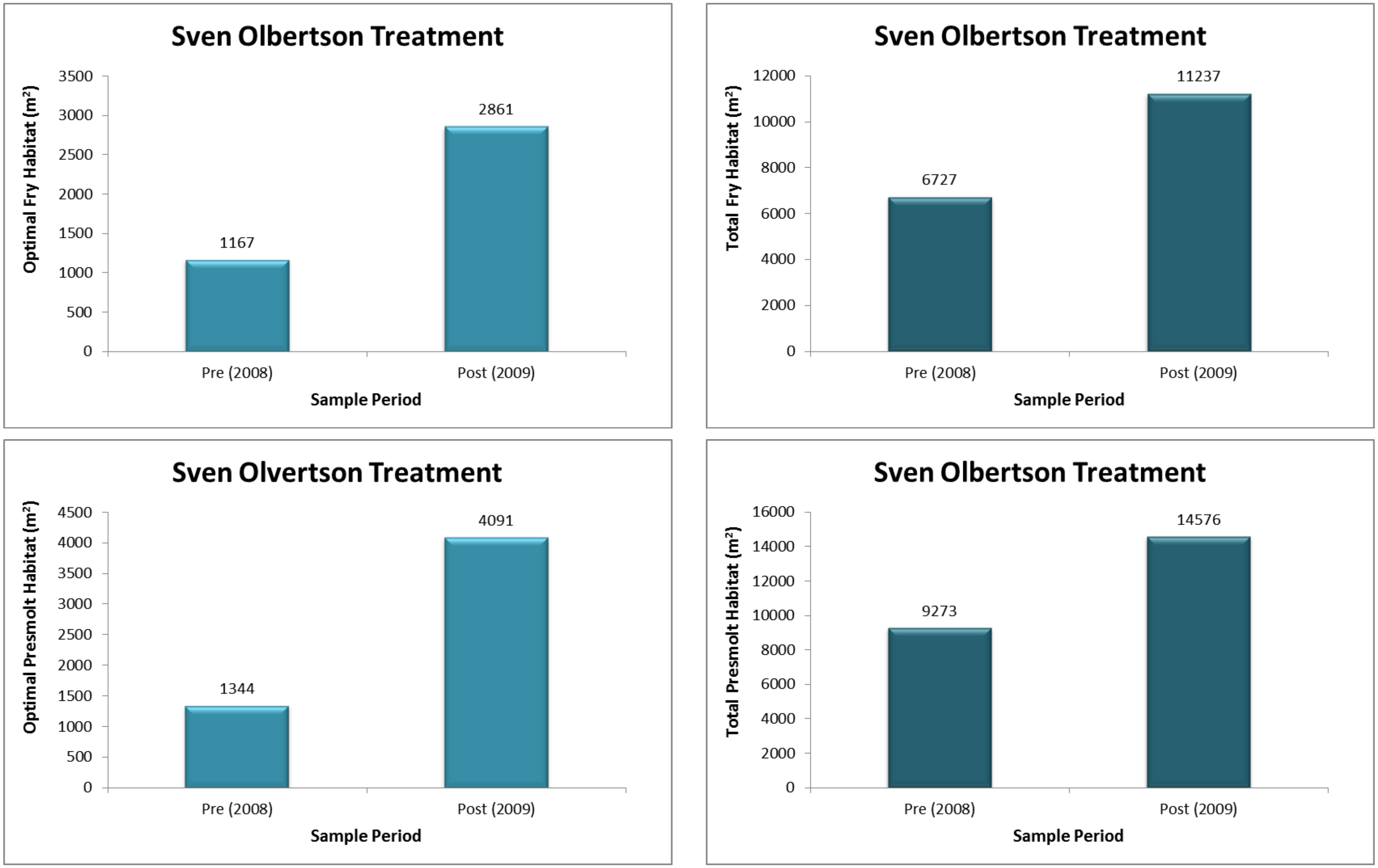
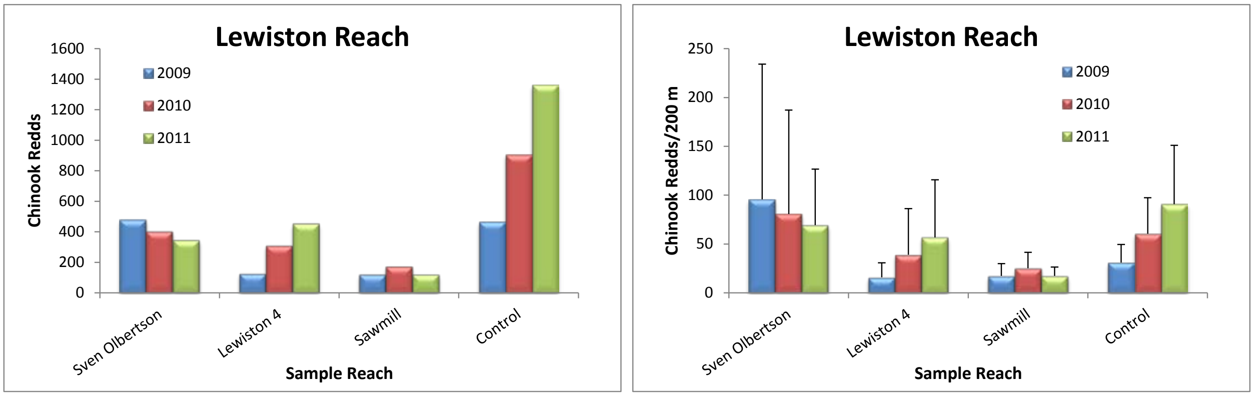


Figure 6-23

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Sven Olbertson Site in 2008 (Pre-construction) and 2009 (Post-construction)

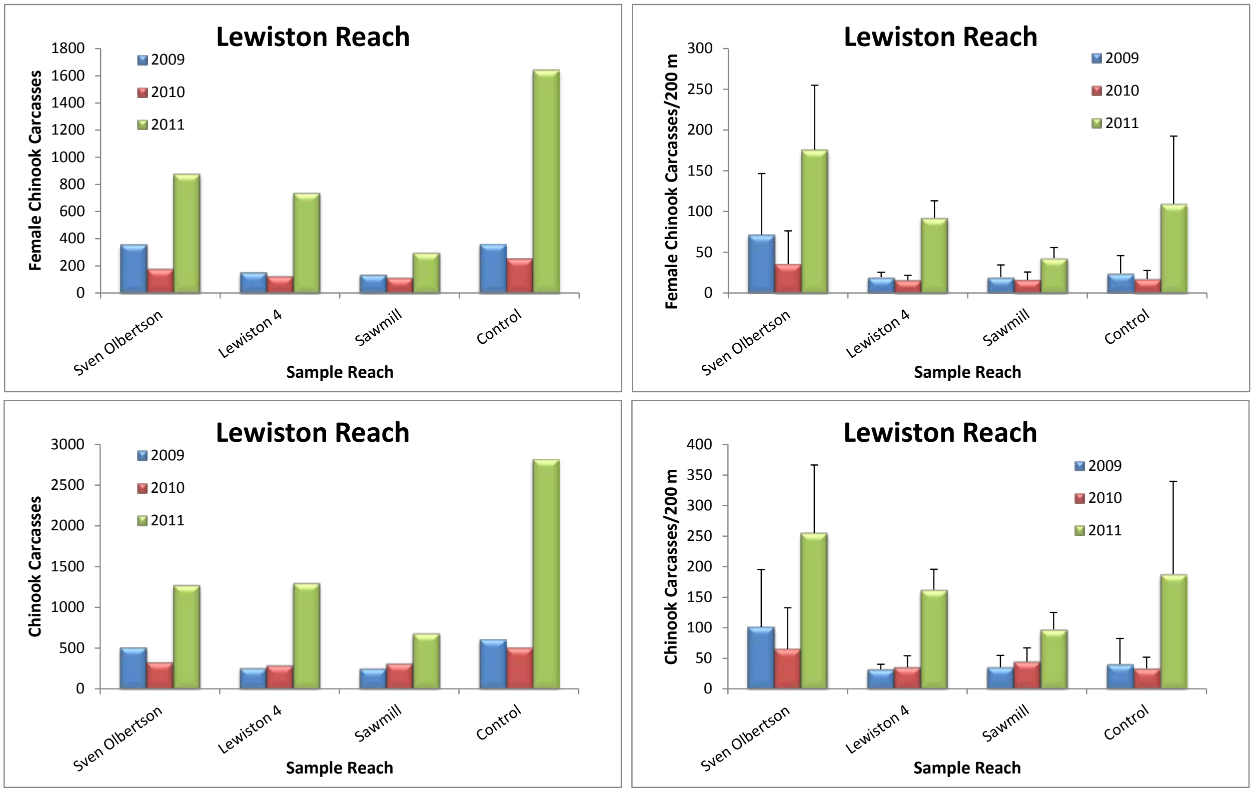
Chinook salmon redds (spring and fall Chinook combined) were counted within the Sven Olbertson site, untreated sites (controls), and other rehabilitation sites within the Lewiston Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 347 to 479, which made up 15.2 to 40.1% of the redds counted within the Lewiston Reach and 7.4 to 14.9% of the redds counted in the Trinity River (Figure 6-24). Interestingly, both total numbers and mean densities of Chinook salmon redds decreased over time in the site, while numbers and densities increased over the same period in the control sites (Figure 6-24). Nevertheless, mean densities of Chinook salmon redds within the Sven Olbertson site were not statistically different from those in the control sites.



Note:
Densities are mean values with 95% CI.

Figure 6-24
Numbers and Densities (redds per 200 m) of Chinook Salmon (Spring and Fall Chinook) Redds Counted within Different Rehabilitation Sites and Control Sites within the Lewiston Reach during 2009 to 2011

Chinook salmon carcasses were sampled within the Sven Olbertson site during 2009 to 2011. Numbers of female carcasses sampled within the site during 2009 to 2011 ranged from 177 to 879 (Figure 6-25), which made up 24.7 to 35.5% of the female carcasses sampled within the Lewiston Reach and 13.4 to 19.8% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Sven Olbertson site were not statistically different from those in the control sites (Figure 6-25).

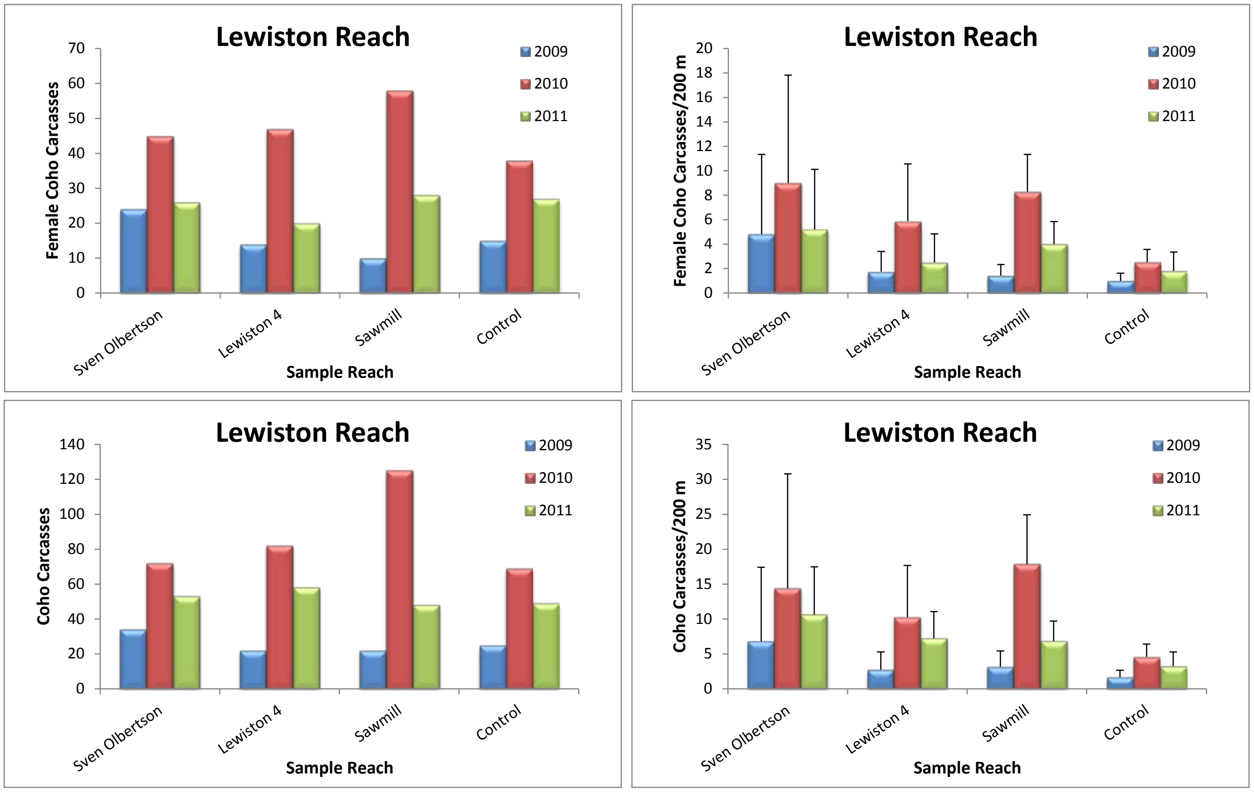


Note:
Densities are mean values with 95% CI.

Figure 6-25

Numbers and Densities (carcasses per 200 m) of Female Chinook and Total Chinook Salmon Carcasses Sampled within Different Rehabilitation Sites and Control Sites within the Lewiston Reach during 2009 to 2011

Coho salmon carcasses were also sampled within the Sven Olbertson site during 2009 to 2011. Numbers of female carcasses sampled within the site during 2009 to 2011 ranged from 24 to 45 (Figure 6-26), which made up 23.9 to 38.1% of the female carcasses sampled within the Lewiston Reach and 19.5 to 27.6% of the female carcasses sampled in the Trinity River. Although mean densities of female coho salmon carcasses found in the Sven Olbertson site were greater than those in the control sites, the large variability in carcasses among segments within the site prevented the difference from being significant (Figure 6-26).



Note:
Densities are mean values with 95% CI.

Figure 6-26

Numbers and Densities (carcasses per 200 m) of Female Coho and Total Coho Carcasses Sampled within Different Rehabilitation Sites and Control Sites within the Lewiston Reach during 2009 to 2011

6.7.2 Deadwood Creek, Lewiston Cableway, and Hoadley Gulch

Location: RMs 109.8 to 111.0
Year constructed: 2008

6.7.2.1 Design Objectives

The Deadwood Creek, Lewiston Cableway, and Hoadley Gulch rehabilitation sites are located within a primary spawning reach of the Trinity River and were designed to immediately increase fry and juvenile salmonid rearing habitat at 8 to 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs) and increase fry production by reducing redd superimposition. Additional objectives included creating complex and dynamic alluvial channel morphology, restoring floodplain connectivity, and improving riparian habitat.

Specific site design objectives at the Deadwood Creek site included constructing alluvial bars with coarse sediment additions, encouraging channel migration, lowering of floodplain surfaces to inundate between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs), and removing riparian vegetation along the low water's edge. Specific objectives at the Lewiston Cableway site included constructing alternating point bars with coarse sediment additions, removing existing fine sediment storage, restoring floodplain connectivity through removal of riparian vegetation along the backside of constructed bars, and improved side channel inlet connectivity. Specific objectives at the Hoadley Gulch site included constructing a point bar with coarse sediment additions, extending the riffle gradient downstream through gravel augmentation and removal of grade control structures, removing remnant dredger tailing piles, reducing fine sediment storage in berms, and adding a side channel.

6.7.2.2 Site Description

The Deadwood Creek site begins downstream of the Deadwood Creek confluence at approximately RM 111 and extends 0.2 mile downstream. The rehabilitation area is located on the left bank downstream of the Trinity Dam Boulevard bridge in the vicinity of an established medial bar. A dense band of riparian vegetation was established along the left channel bank and edges of the medial bar. The Deadwood Creek project included one in-river and one in-channel design element (Figure 6-27a; Table 6-21). The in-river element focused on removing the riparian berm along a point bar and constructing a low-flow side channel (R-3). Large wood was placed within the low-flow side channel to provide fry and juvenile rearing habitat. Existing riparian vegetation at the upstream end of the site was left in place, and the area was revegetated after construction with woody riparian species, rushes, and sedges. The in-channel element included placing 1,100 cubic yards of gravel in the main channel to construct a bar (IC-5) designed to provide increased channel complexity and narrow the low flow channel width.

Note that the Deadwood Creek design summary fact sheet discusses R-3 and IC-5 as the only two features associated with this channel rehabilitation site (Attachment B). In the design footprint shapefile provided by the Program that the Phase 1 review team used to develop Figure 6-27a, below, feature R-3 (right bank) is associated with feature IC-6 (left bank), and IC-5 is not identified in the file. Thus, the Program's source information is inconsistent regarding the location and labeling of feature IC-5, and we assumed it was constructed as IC-6 and as shown in Figure 6-27a.

The Lewiston Cableway site is located downstream and contiguous to the Deadwood Creek site. The site begins at approximately RM 110.5 and extends 0.45 mile downstream. Before the area was rehabilitated, both banks were densely vegetated and grade control structures occurred in the mainstem channel and low-flow side channel. Rehabilitation consisted of one in-river and five in-channel design elements (Figure 6-27a; Table 6-21). Gravel was placed to construct a sequence of alternating bars (IC-6, IC-8, IC-9, and IC-10), and grade control structures in the main channel were removed (IC-7 and IC-8) to allow transverse and point bars to develop. Large wood was placed on the constructed bars. The entrance to an existing low-flow side channel (R-3) was enlarged, and portions of the side channel were modified to increase salmonid spawning and rearing habitat.

The Hoadley Gulch site, located on the densely vegetated right bank immediately downstream of the Old Lewiston Bridge, is downstream and contiguous to the Lewiston Cableway site. The site begins at RM 110.1 near the Hoadley Gulch confluence and extends 0.25 mile downstream. Rehabilitation consisted of one in-river, two in-channel, and one upland design elements (Figure 6-27b; Table 6-21). A low-flow side channel (R-5) was constructed to increase salmonid spawning and fry and juvenile rearing habitat when ROD releases are between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs). Two entrances were designed to ensure long term maintenance, and large wood was added to provide cover for fry and juvenile salmonids. R-5 also included lowering existing tailing piles to inundate at 170 $m^3 \cdot s^{-1}$ (6,000 cfs), thus providing suitable surfaces for riparian recruitment and habitat for salmonid rearing. After construction, this area was revegetated to increase long-term woody riparian structural diversity and create a complex herbaceous understory away from the summer baseflow channel. Rushes and sedges were planted along the channel margin. The in-channel element consisted of 1,500 cubic yards of gravel placed on the right bank of the main channel to construct a point bar (IC-12). The bar was intended to increase coarse sediment supply, narrow low flow channel widths, reduce radius of curvature, increase sinuosity, reduce the likelihood of riparian encroachment, and provide salmonid spawning and rearing habitat between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs). Grade control in the main channel was removed (IC-11) to allow a steeper gradient, improve boat passage, and maintain the integrity of the pool tail. Spoils from excavated areas were placed between tailing piles to construct a terrace (U-3).

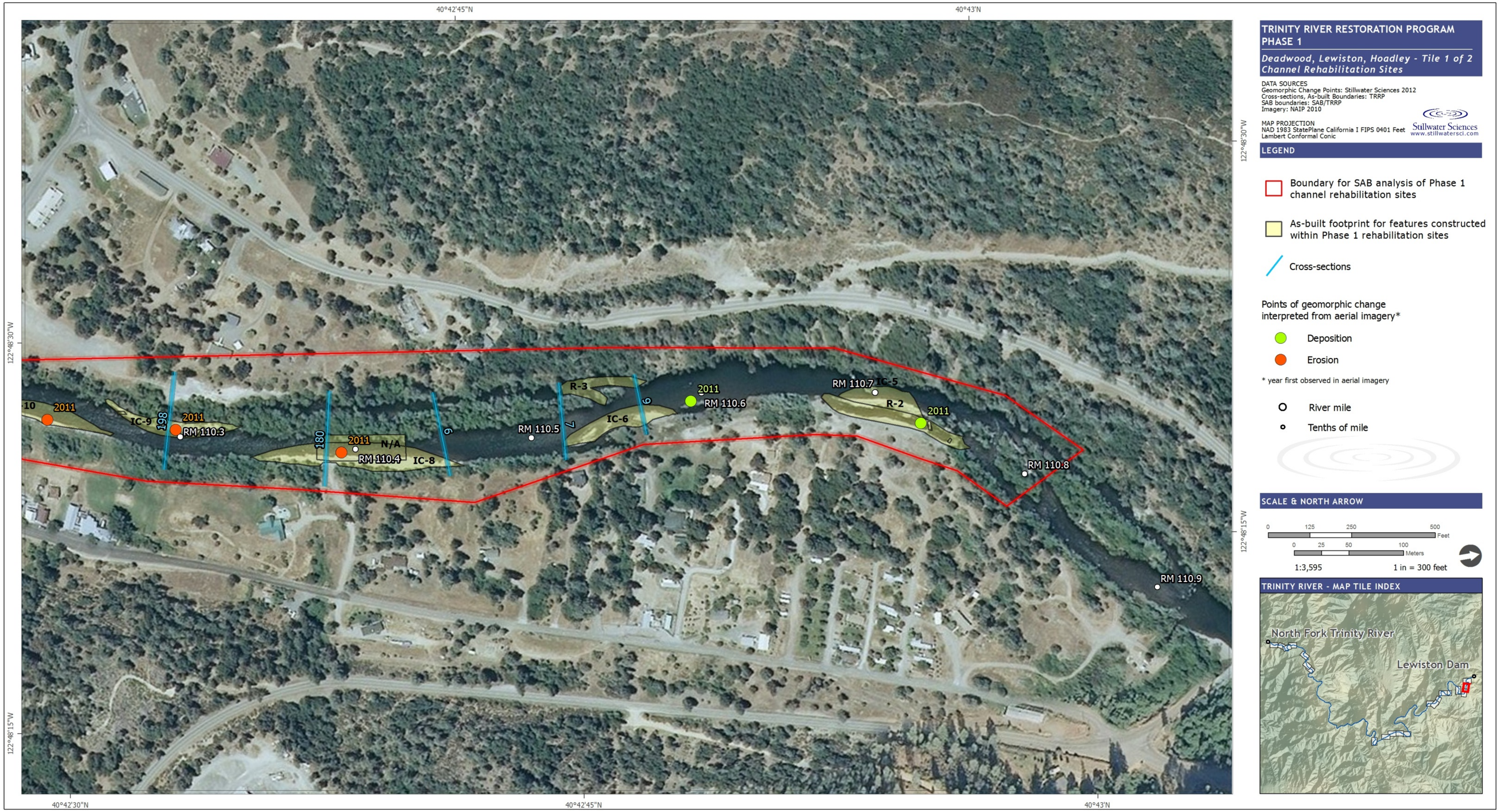


Figure 6-27a

Design Features at the Deadwood Creek, Lewiston Cableway, and Hoadley Gulch Rehabilitation Sites, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

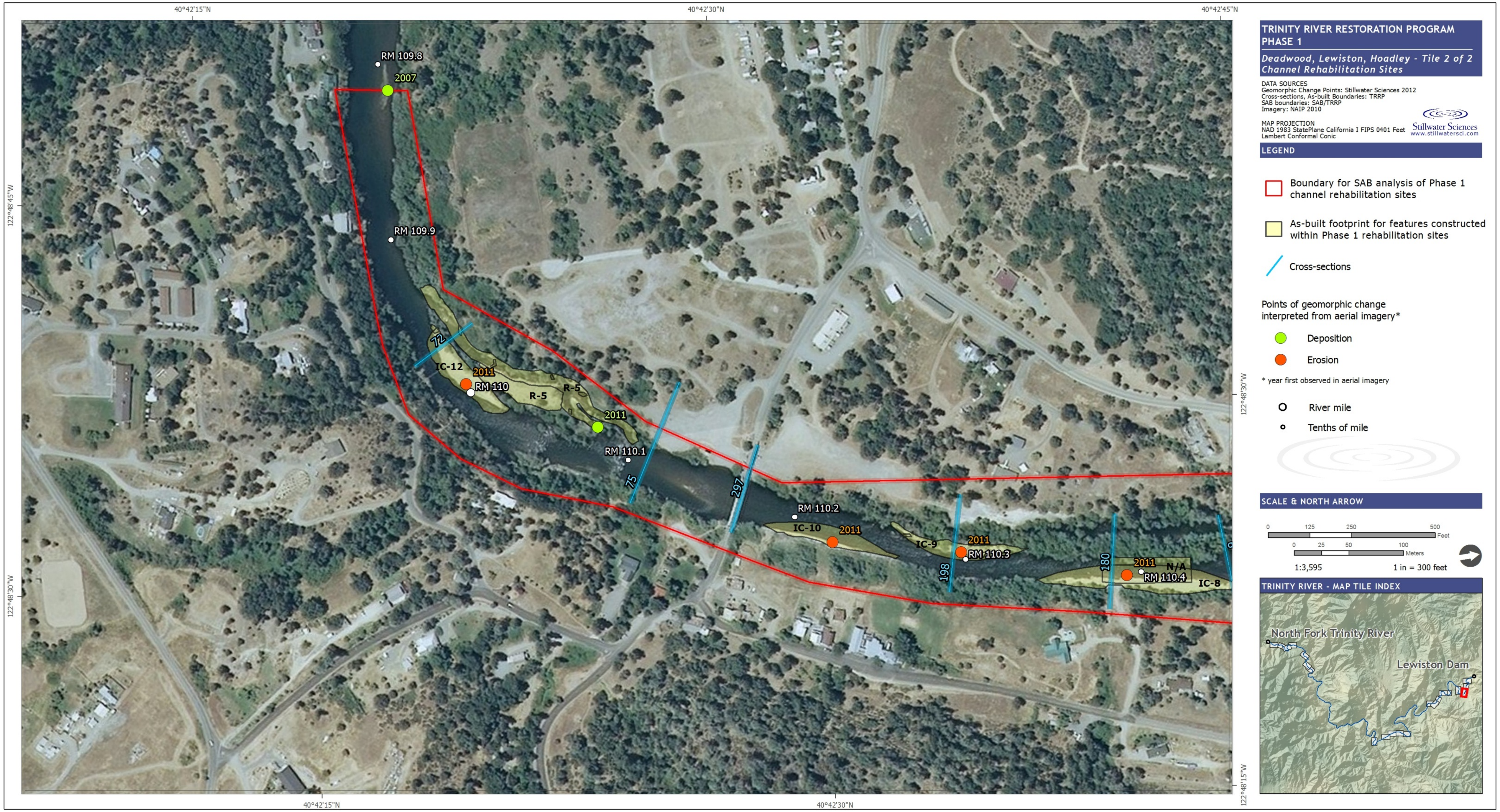


Figure 6-27b

Design Features at the Deadwood Creek, Lewiston Cableway, and Hoadley Gulch Rehabilitation Sites, including Cross Sections analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-21
Design Features Constructed at the Deadwood Creek, Lewiston Cableway, and Hoadley Gulch Rehabilitation Sites

Site	Feature ID	Feature	Location (RM)	Position
Deadwood Creek	R-3	Low flow side channel (300 cfs) with wood placements	110.7	Left bank
	IC-5	Point bar (500 cfs) with coarse sediment addition	110.7	Left bank
Lewiston Cableway	R-3	Low flow side channel entrance (300 cfs)	110.5 – 110.6	Right bank
	IC-6	Point bar (500 cfs) with coarse sediment addition	110.5 – 110.6	Left bank
	IC-7	Boulder grade control removal	110.5	Mid-channel
	IC-8	Point bar (500 cfs) with coarse sediment addition	110.4	Left bank
		Boulder grade control removal	110.45	Mid-channel
	IC-9	Point bar (500 cfs) with coarse sediment addition	110.3	Right bank
	IC-10	Point bar (500 cfs) with coarse sediment addition	110.2 – 110.3	Left bank
Hoadley Gulch	R-5	Low flow side channel (300 cfs) with wood placements	109.9 – 110.1	Right bank and floodplain
		Floodplain (6,000 cfs)	110.0 – 110.1	
	IC-11	Grade control removal	110.1	Right bank
	IC-12	Point bar (500 cfs) with coarse sediment addition	110.0	Right bank

6.7.2.3 Geomorphic Response

6.7.2.3.1 Deadwood Creek

Geomorphic monitoring was not conducted at the Deadwood Creek rehabilitation site as part of the WY 2009 or WY 2010 IHAP monitoring efforts (Alvarez et al. 2010; McBain & Trush and HVT 2012). In February 2011, a rapid assessment of the side channel (R-2) constructed at the site indicated significant inlet aggradation since construction in 2008 (Gaeuman in review). The maximum depth over the inlet control was 0.09 m (0.3 foot), and the total flow area over the control was approximately 0.3 m^2 (3.6 square feet). Aggradation was related to downstream progradation of the active front of the bar-island complex located immediately upstream. Interpretation of aerial photography and banklines indicated that the constructed low-flow side channel aggraded, widened, and shifted laterally toward the center of the main channel during the 2011 flow release. A narrow medial bar also formed at the lower end of the site near RM 110.6 (Table 6-22).

Table 6-22
Geomorphic Changes Observed in Repeat Aerial Photography at the Deadwood Creek, Lewiston Cableway, and Hoadley Gulch Rehabilitation Sites

Site	RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
Deadwood Creek	110.8	Deposition	Side channel filling	2009 – 2011	R3 and IC-6	2011
Lewiston Cableway	110.6	Deposition	Medial bar growth	2009 – 2011	None	2011
	110.4	Erosion	Left bank bar retreat	2009 – 2011	IC-8	2011
	110.3	Erosion	Right bank bar retreat	2009 – 2011	IC-9	2011
	110.2	Erosion	Left bank bar retreat	2009 – 2011	IC-10	2011
Hoadley Gulch	110.1	Deposition	Side-channel filling	2009 – 2011	R-5	2011
	110.0	Erosion	Right bank bar retreat	2009 – 2011	IC-12	2011
	109.8	Deposition	Medial bar growth	2005 – 2011	Not Applicable	2006

6.7.2.3.2 Lewiston Cableway

Topographic surveys, cross sections, and bed mobility monitoring occurred at the Lewiston Cableway site before and after the WY 2009 flow release (peak flow 131 $m^3 \cdot s^{-1}$ [4,630 cfs] measured at Lewiston) (Alvarez et al. 2011). Topography surveyed during the WY 2009 monitoring was combined with photogrammetry, LiDAR, and total station survey data to analyze changes in coarse sediment recruitment piles and associated deposition, channel radius of curvature, sinuosity, and alternate bar formation in the reach immediately downstream. Overall changes resulting from the WY 2009 high flow release were as follows:

- At the upstream end of the site, the right bank side channel entrance (R-3) and the left bank point bar (IC-6) aggraded, while the main channel scoured. Up to 0.38 m (1.25 feet) of scour and aggradation occurred in this area.
- The point bar (IC-8) at the USGS cableway scoured and aggraded up to 0.23 m (0.75 foot). Cross sections showed bed lowering at the coarse sediment recruitment pile (IC-8) and in the thalweg, creating a net increase in channel cross sectional area and decrease in channel confinement.
- The downstream right bank point bar (IC-9) aggraded up to 0.38 m (1.25 feet).

- The downstream left bank point bar (IC-10) scoured and aggraded up to 0.38 m (1.25 feet).

Bed mobility was monitored at two cross sections in the vicinity of IC-8. Dry WY bed mobility management targets were met at the first cross section, but were only partially met at the second. Point bars constructed to confine the low flow channel and removal of boulder grade control structures increased the hydraulic gradient through the site and helped to transfer coarse sediment from constructed bars to downstream areas. The WY 2009 release did not change the number and aerial extent of alluvial features at the site or significantly change topographic complexity. The effectiveness of the constructed bars at steering high flow was investigated during the 2009 high flow release using an acoustic Doplar current profiler (Gaeuman in review). Results indicated that flow though the site was directed predominantly downstream, with few lateral velocity components.

Only topographic surveys occurred at the Lewiston Cableway site as part of WY 2010 IHAP geomorphic monitoring (McBain & Trush and HVT 2012). Results indicated that the WY 2010 flow release (peak flow 187 $m^3 \cdot s^{-1}$ [6,6100 cfs] measured at Lewiston) was sufficient to maintain constructed features, but was insufficient in meeting design objectives and associated IAP objectives related to dynamic bar morphology and later channel migration. Differences between the 2009 DTM and 2010 topography at the downstream end of the Lewiston Cableway site indicated localized erosion of the constructed bars and associated downstream deposition (Gaeuman in review). During a rapid assessment of the constructed side channel (R-3) in February 2011, the inlet maintained a surface water connection to the side channel (Gaeuman in review).

Interpretation of aerial photography and banklines suggested that the constructed bar features (IC-6, IC-8, IC-9, and IC-10) initially constricted low-flow channel widths by approximately one-third, but retreat of these bars between April 2009 and August 2011 locally expanded channel widths (Figure 6-28; Table 6-22). The most downstream bar feature (IC-10) appeared to have completely eroded by the end of WY 2011.

6.7.2.3.3 Hoadley Gulch

Geomorphic monitoring conducted before and after the WY 2009 spring flow release (131 $m^3 \cdot s^{-1}$ [4,630 cfs]) included topographic surveys and bed mobility monitoring (Alvarez et al. 2011). Longitudinal profile surveys conducted to evaluate constructed side channel (R-5) connectivity and complexity indicated that the relatively dynamic side channel is maintaining itself. Both side channel entrances remained open following the 2009 flow release, scour occurred in the vicinity of both entrances, and the thalweg changed position along most of its length. Up to 0.6 m (2.0 feet) of scour and fill also occurred around wood structures placed during construction and where vegetation was left in place. Surveys at the single cross section surveyed at the site indicated little topographic change across the constructed bar (IC-12), suggesting the bar is self-maintaining. New alluvial features were not observed at the site. Geomorphic monitoring did not occur at the Hoadley Gulch site as part of the WY 2010 IHAP monitoring effort.

The WY 2010 Implementation Monitoring Report (Gaeuman in review) reported geomorphic changes at the Hoadley Gulch site based comparison of 2009 and 2010 topographic data. Minor incision occurred in the main channel upstream of the side channel (R-5) entrances, and both entrances appeared to have aggraded by 1.0 to 1.5 feet. A rapid assessment of the side channel in February 2011 indicated the more upstream of the two inlets maintained a strong surface water connection to the mainstem, due in part to the influence of the downstream boulder step on water surface elevations, but the more downstream of the two inlets functioned poorly (Gaeuman in review).

Repeat geomorphic monitoring performed at the Hoadley Gulch site in WY 2011 indicated that the site is performing as intended along the monitoring cross section (HVT and McBain & Trush 2012). Erosion along the constructed right bank point bar suggested coarse sediment recruitment and supply, as intended by design. Scour and redeposition in the side channel, combined with observations that the side channel entrance remained open and flowing during summer baseflows, suggests that the side channel is being maintained.

Interpretation of aerial photography and banklines indicated that between April 2009 and August 2011, the low-flow side channel entrance near RM 110.1 aggraded with coarse sediment, the margin of the constructed bar near RM 110.0 receded, and a medial bar that initially formed between 2005 and 2007 near RM 109.8 persisted (Table 6-22).

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at eight cross section locations within the Deadwood Creek, Lewiston Cableway, and Hoadley Gulch rehabilitation sites (Table 6-23). Bed activity was greater than 200 mm over 20% or more of the cross section width (excluding construction periods) only at cross sections 72 and 297, and only for the period including the WY 2011 high flow release. The erosion and deposition patterns are notable at cross section 72, where scour occurred in the constructed low-flow side channel (R-5) and deposition occurred on the point bar (IC-12) constructed on the right bank in 2008. Lateral erosion and accretion inferred from banklines was relatively high in these two cross section areas (Table 6-23). Lateral erosion inferred from banklines over the 1.08-mile site length declined from 2001 to 2009 and then increased during the 2009 to 2011 period, presumably due to the WY 2010 high flow release (Figure 6-28). Conversely, lateral accretion was lowest during the 2001 to 2005 and 2009 to 2011 periods but high during the 2005 to 2007 period, presumably due to the WY 2006 high flow release.

Table 6-23

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Deadwood, Lewiston Cableway, and Hoadley Gulch Rehabilitation Sites[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3] >100 mm	Active Bed[3] >200 mm	Lateral Erosion and Deposition[4]	ω	6,000 cfs
72	109.97	17	IC-12, R-5	November-04	February-09	2	B	0.56	0.44	0.08	46.04	36
				February-09	April-09	3	C	0.21	0.03	0.05		0
				April-09	October-10	4	C	0.15	0.01	0.05		5
				October-10	August-11	5	D	0.49	0.35	0.11		7
75	110.11	16	none	July-00	September-11	6	D	0.62	0.33	0.14	49.92	53
297	110.17	16	none	October-06	April-08	1	C	0.07	0.00	0.10	49.92	0
				April-08	July-08	1	C	0.07	0.01	0.10		7
				July-08	April-09	2	C	0.30	0.24	0.10		0
				April-09	September-09	4	C	0.07	0.01	0.10		0
				September-09	April-10	5	C	0.12	0.02	0.10		0
				April-10	December-10	5	C	0.13	0.03	0.10		5
				December-10	April-11	5	C	0.09	0.02	0.10		0
				April-11	December-11	5	D	0.31	0.23	0.14		7
198	110.27	15	IC-9	February-09	September-11	4	D	0.25	0.13	0.18	43.56	12
180	110.39	14	CW Aug, IC-8	April-04	November-04	1	A	0.17	0.05	0.35	48.33	4
				November-04	August-06	1	B	0.18	0.06	0.30		29
				August-06	February-09	2	C	0.23	0.18	0.26		7
				February-09	April-09	3	C	0.10	0.03	0.26		0
				April-09	August-09	4	C	0.11	0.04	0.26		0
				August-09	August-10	5	C	0.04	0.00	0.26		5

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
				August-10	May-12	5	D	0.40	0.18	0.03		7
6	110.45	13	IC-8	May-04	February-09	2	B	0.42	0.23	0.24	12.79	40
7	110.52	13	IC-6	May-04	February-09	2	B	0.45	0.22	0.24	12.79	40
9	110.57	12	IC-6, R-3	May-04	February-09	2	B	0.78	0.58	0.05	29.01	40

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

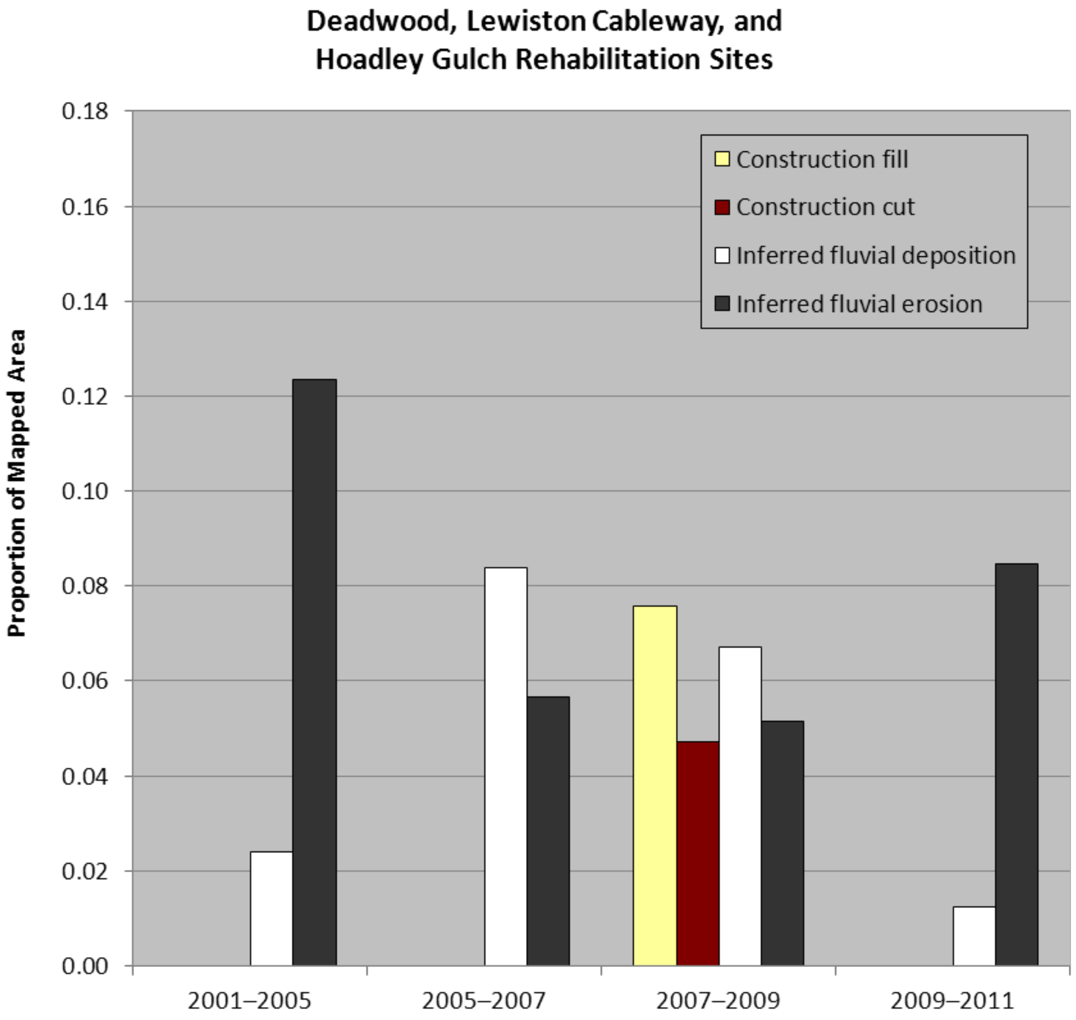


Figure 6-28

Lateral Erosion and Deposition Inferred from Banklines in the Deadwood Creek, Lewiston Cableway, and Hoadley Gulch Rehabilitation Sites

6.7.2.4 Biological Response at the Lewiston Four Sites

No pre- or post-construction juvenile fish rearing habitat assessments have been conducted at the Deadwood Creek channel rehabilitation site; therefore, no results are provided.

Pre- and post-construction evaluations were conducted at Lewiston Cableway in 2008 and 2009 at baseflows (8.6 or 8.7 $m^3{\cdot}s^{-1}$ [303.7 or 307.2 cfs]) in the main channel. The constructed side channel was not evaluated prior to construction because prior to construction, the existing side channel did not receive flow from the main channel at winter baseflows. Pre- (2008) and post-construction (2009) habitat monitoring at Lewiston Cableway evaluated the change in optimal (DV, C) and suitable (DV, no C; and no DV, C) habitat and indicated that in the main channel there was a decrease in the proportion of optimal habitat of 13 and 12% for fry and presmolts, respectively. There was also a proportional increase in suitable habitat (DV or C) that varied. Suitable habitat for fry increased approximately 10%; suitable habitat defined as DV, no C decreased by 2% and suitable habitat defined as C, no DV increased by 33% for presmolts. The proportional increase in total habitat in the main channel was relatively unchanged after construction. The construction of side channels increased the amount of optimal habitat at the site by 1,130 and 1,204 m^2 (12,163 and 12,960 square feet) for fry and presmolts, respectively. The construction of side channels increased the amount of total habitat at the site by 2,039 and 2,402 m^2 (21,948 and 25,855 square feet) for fry and presmolts, respectively. Throughout the entire site, optimal habitat increased by 69 and 64%, and total habitat increased by 53 and 36% for fry and presmolts, respectively (Figure 6-29).

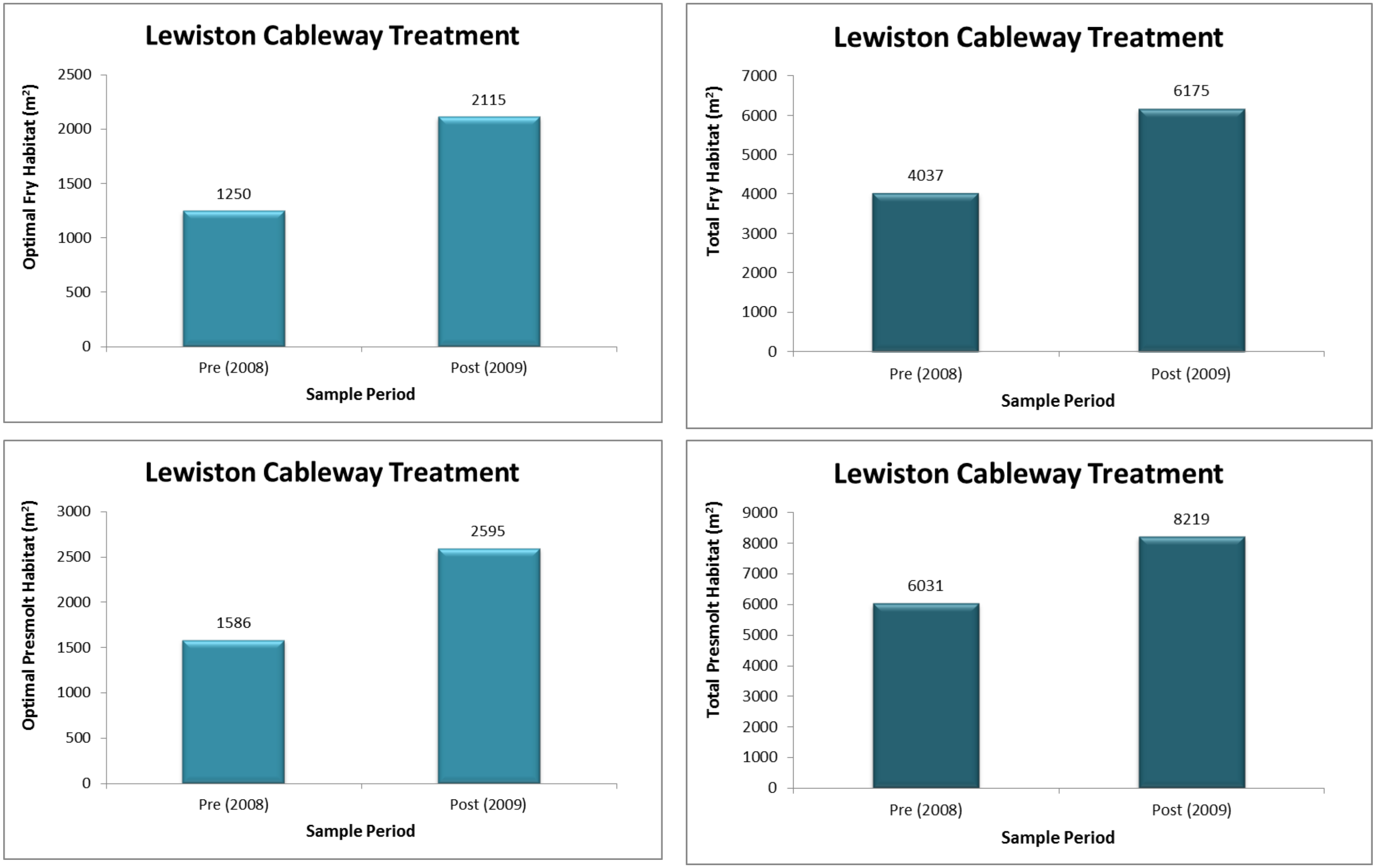


Figure 6-29

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Lewiston Cableway Site in 2008 (Pre-construction) and 2009 (Post-construction)

Based on the habitat measurements made over different flow levels, Lewiston Cableway shows increasing habitat formation with increased flow after construction (Alvarez et al. 2011). This trend is attributed to the low-lying floodplain and its vegetation and trees that were not disturbed during construction (Alvarez et al. 2011). The increase in habitat during low flows after construction is thought to be due to water that is pushed into a wooded grassy alcove in the middle of the site within the mainstem, and the addition of alternating bars of gravel during construction, which helps to mitigate the loss of habitat within the side channel at flows between 20 and 40 $m^3 \cdot s^{-1}$ (706 and 1,412 cfs) (Alvarez et al. 2011). In addition, the secondary side channel that turns into an alcove at low flows has large amounts of cover, which also contributed to an increase in habitat at low flows after construction (Alvarez et al. 2011). The largest proportional increase in fry and presmolt total and optimal habitat between pre- and post-construction occurred at the discharge rate of 11.1 $m^3 \cdot s^{-1}$ (391.9 cfs), and the smallest proportional increase in fry and presmolt total and optimal habitat occurred at the highest discharge rate of 52.7 $m^3 \cdot s^{-1}$ (1,861 cfs).

Pre- and post-construction evaluations at Hoadley Gulch were conducted in 2008 and 2009 at baseflows (8.6 or 8.7 $m^3 \cdot s^{-1}$ [303.7 or 307.2 cfs]) in the main channel, and the constructed side channel was not evaluated prior to construction because it did not exist at that time. Pre- (2008) and post-construction (2009) habitat monitoring at Hoadley Gulch evaluated the change in optimal (DV, C) and suitable (DV, no C; and no DV, C) habitat, and indicated that the proportional increase in optimal habitat (DV, and C) in the main channel was 30 and 35% for fry and presmolts, respectively. The proportional increase in suitable habitat (DV or C) varied. Suitable habitat defined as DV, no C increased 9% for fry, and suitable habitat defined as C, no DV increased by 49% for fry. Suitable habitat defined as DV, no C decreased 14% for presmolts, and suitable habitat defined as C, no DV increased by 53% for presmolts. The proportional increase in total habitat in the main channel was 19% for fry, whereas total presmolt habitat decreased by 6% overall. The decrease in habitat for presmolts was attributed to decreases associated with the DV, no C category as follows: 1) the addition of gravel filled in fry and presmolt habitat along a margin where there was vegetation and pushed it out to the edge of the constructed bar; and 2) deposition of gravel at the lower portion of the site in the center of the main channel decreased water depths and caused velocities to increase (Alvarez et al. 2011). The construction of side channels increased the amount of optimal habitat at the site by 196 and 244 m^2 (2,109 and 2,626 square feet) for fry and presmolts, respectively. The construction of side channels increased the amount of total habitat at the site by 857 and 1,191 m^2 (9,225 and 12,820 square feet) for fry and presmolts, respectively. Throughout the entire site, optimal habitat increased by 51 and 53%, and total habitat increased by 35 and 6% for fry and presmolts, respectively (Figure 6-30).

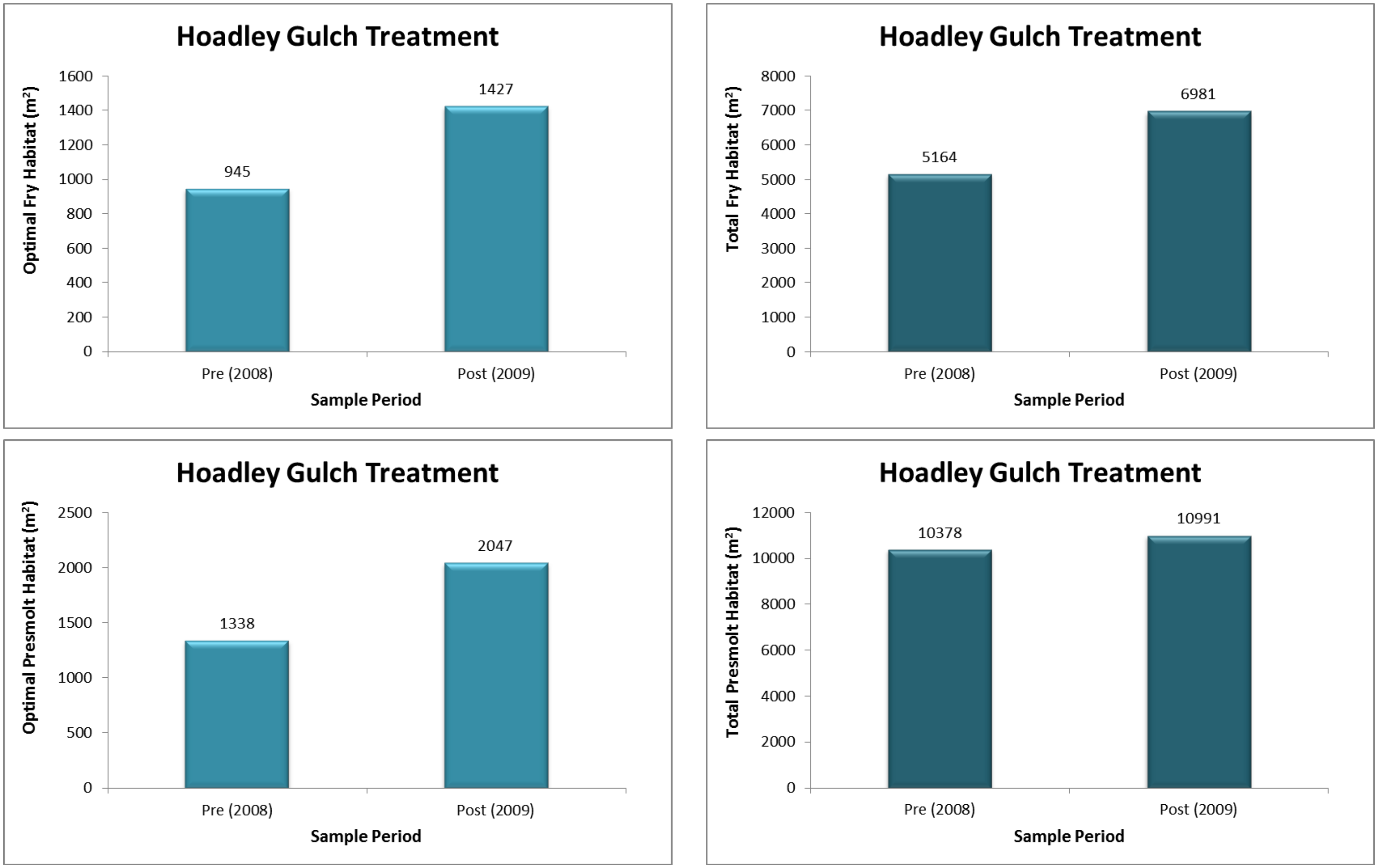


Figure 6-30

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Hoadley Gulch Site in 2008 (Pre-construction) and 2009 (Post-construction)

Chinook salmon redds (spring and fall Chinook combined) were counted within the Lewiston Four (Deadwood Creek, Lewiston Cableway, and Hoadley Gulch) sites, untreated sites (controls), and other rehabilitation sites within the Lewiston Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 127 to 455, which made up 10.6 to 19.9% of the redds counted within the Lewiston Reach and 4.0 to 9.8% of the redds counted in the Trinity River (Figure 6-24). Both total numbers and mean densities of Chinook redds increased over time in the site and control sites (Figure 6-24). Mean densities of Chinook redds within the Lewiston Four sites were not significantly different from those in the control sites.

Chinook carcasses were sampled within the Lewiston Four sites during 2009 to 2011. Numbers of female carcasses sampled within the treatment sites during 2009 to 2011 ranged from 124 to 739 (Figure 6-25), which made up 15.4 to 20.8% of the female carcasses sampled within the Lewiston Reach and 8.6 to 14.6% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook carcasses in the Lewiston Four sites were not statistically different from those in the control sites (Figure 6-25).

Coho carcasses were also sampled within the Lewiston Four sites during 2009 to 2011. Numbers of female carcasses sampled within the treatment site during 2009 to 2011 ranged from 14 to 47 (Figure 6-26), which made up 19.8 to 25.0% of the female carcasses sampled within the Lewiston Reach and 16.1 to 20.4% of the female carcasses sampled in the Trinity River. Although mean densities of female coho carcasses found in the Lewiston Four sites were greater than those in the control sites, the large variability in carcasses among segments within the treatment sites prevented the difference from being significant (Figure 6-26).

6.8 Bucktail–Dark Gulch

Location: RMs 105.5 to 107.0
Year constructed: 2008

6.8.1 Design Objectives

The Bucktail-Dark Gulch project was designed to increase the structural complexity of salmonid habitat, thereby increasing the range of anadromous salmonid life history stages supported by riverine habitat. The design also sought to increase sinuosity and promote complex floodplain riparian habitat by reactivating floodplains.

6.8.2 Site Description

The Bucktail-Dark Gulch site begins approximately 0.25 miles downstream from the Salt Flat Bridge and extends downstream to the Bucktail Bridge. The site can be separated into two areas: 1) Dark Gulch, which includes the upstream portion of the project along the right bank; and 2) Bucktail, which includes the downstream portion of the project along the left bank. Prior to construction in the Dark Gulch area, riparian vegetation occupied berms along the low-flow channel margin and large dredger tailings occupied the back edge of the adjacent floodplain terrace. Several ponds occurred within dredger tailings at the downstream end of the right bank terrace. A medial bar occurred at the outside of the meander bend forced by the left bank valley wall. Human infrastructure at the upstream end of Dark Gulch is a constraint to channel migration. At the downstream end of Dark Gulch, a high-flow channel cut the floodplain terrace behind the riparian berm. The Bucktail area is located on the inside of a meander forced by the right bank valley wall. The historical Bucktail pilot bank rehabilitation site is located along the left bank in the vicinity of a naturally formed gravel bar. Downstream of the pilot bank rehabilitation site, a riparian berm ran the length of the left bank.

Bucktail-Dark Gulch was constructed in the fall of 2008 and consisted of six in-river, five in-channel, and three upland design elements (Figures 6-31a and 6-31b; Table 6-24). At Dark Gulch, the riparian berm was recontoured and associated floodplains were lowered (R-1, R-2) to inundate at 170 $m^3 \cdot s^{-1}$ (6,000 cfs), high-flow and low-flow side channels were constructed (R-1, R-2, and R-4), and gravel was placed to form bars and riffles (IC-4, IC-5, and IC-6). Spoils from excavated areas were used to construct a terrace (U-1) over dredger swales. At Bucktail, gravel placed on the naturally formed gravel bar (IC-7) was intended to facilitate bar growth and lateral channel migration toward the left bank. Downstream, the riparian berm was notched, logs were placed in the notches, and gravel was placed on top of the logs (R-3 and IC-8). At the downstream end of Bucktail, an existing side channel was enhanced along the right bank near the Bucktail Bridge. Large wood was placed in the constructed side channel and along feathered edges. Off-channel wetland enhancement (U-2) at the Bucktail-Dark Gulch site was designed to provide western pond turtle habitat as well as over-summering opportunities for coho salmon.

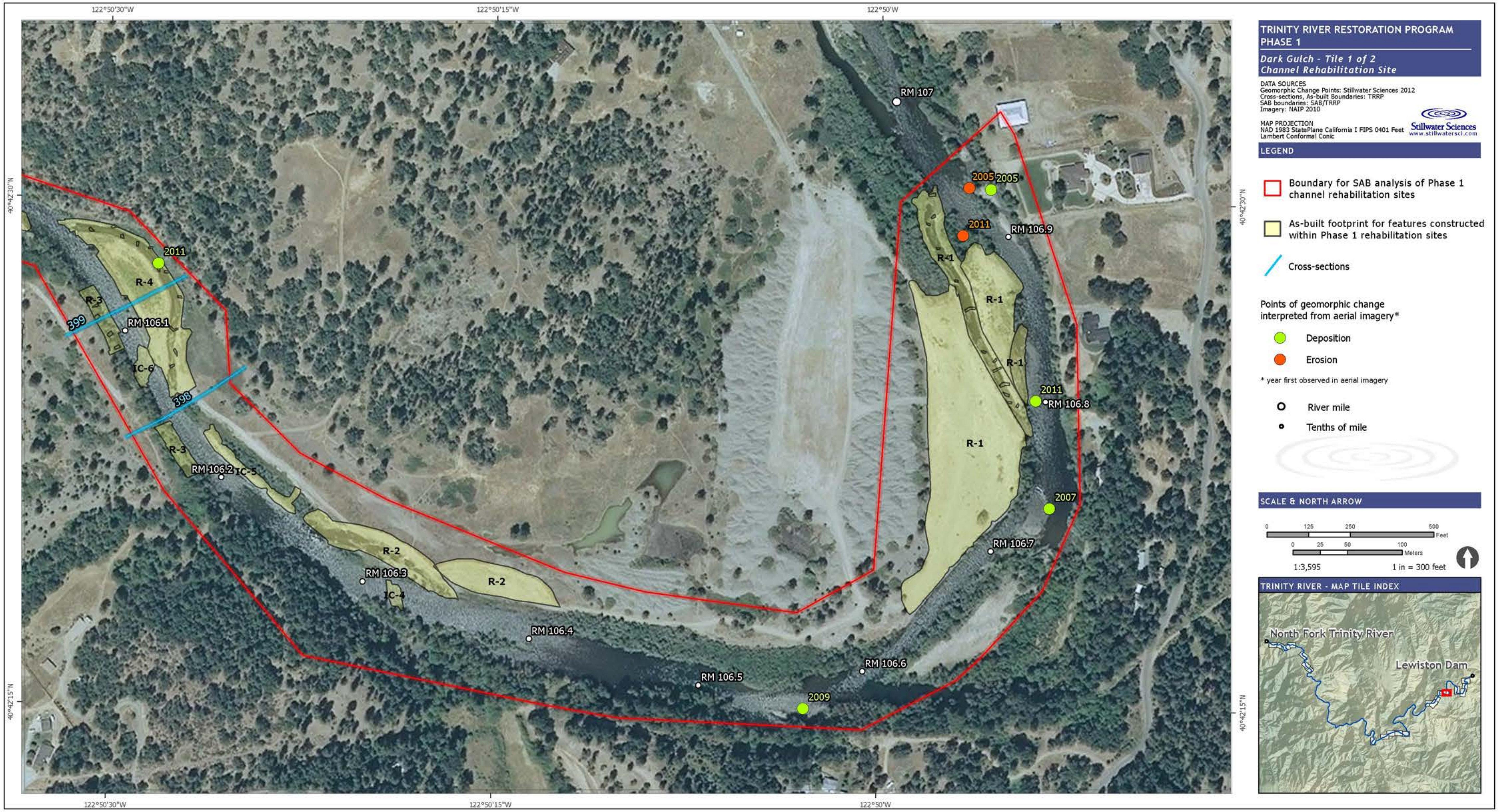


Figure 6-31a

Design Features at The Bucktail–Dark Gulch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

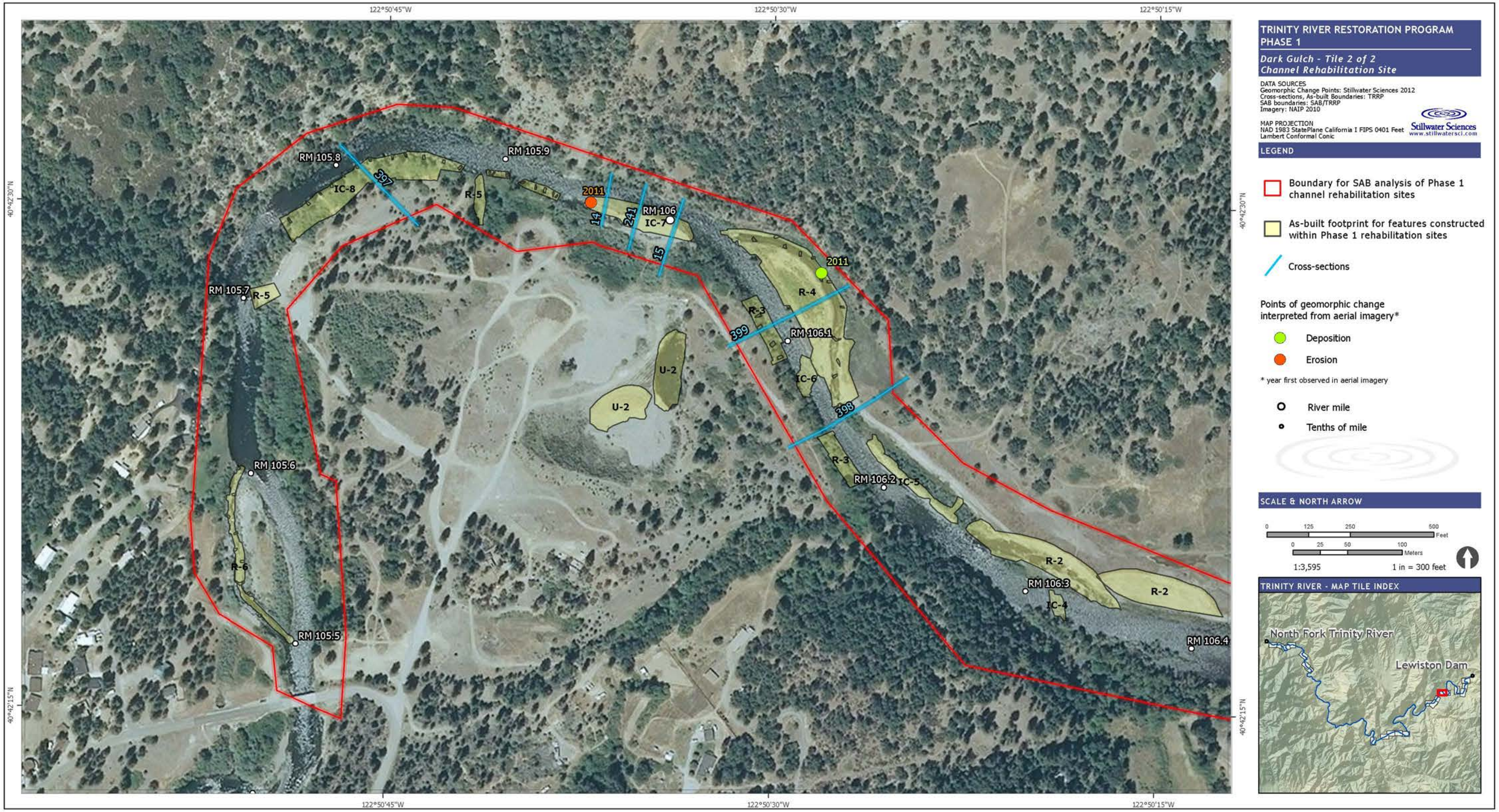


Figure 6-31b

Design Features at the Bucktail–Dark Gulch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-24
Design Features Constructed at the Bucktail–Dark Gulch Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Floodplain (6,000 cfs) and side channel	106.6 – 106.9	Right bank and floodplain
R-2	Floodplain (6,000 cfs) and side channel	106.3 – 106.4	Right bank and floodplain
R-3	Wood habitat development in low flow channel	106.1 – 106.2	Left bank
R-4	Side channel	106.0 – 106.2	Right bank and floodplain
R-5	Drainage improvement	105.9	Left bank and floodplain
	River access enhancement via vegetation clearing	105.7	Left bank
R-6	Side channel (300 cfs)	105.5 – 105.6	Right bank and floodplain
IC-4	Riffle with coarse sediment addition	106.3	Mid-channel
IC-5	Transverse bar with coarse sediment addition	106.2	Right bank
IC-6	Riffle with coarse sediment addition	106.1	Mid-channel
IC-7	Gabion grade control removal	106.05	Mid-channel
	Coarse sediment addition to existing bar	106.0	Left bank
IC-8	Coarse sediment addition with wood placements	105.7 – 105.9	Left bank

6.8.3 Geomorphic Response

Topographic surveys, cross section surveys, and bed mobility monitoring occurred in WY 2009 to assess the effects of winter peak flows and the dry year flow release (131 $m^3 \cdot s^{-1}$ [4,626 cfs]) (Alvarez et al. 2011). Isopachs show minor scour and aggradation (0.38 m [1.25 feet]) of coarse sediment placed at IC-7 and downstream along the left bank in the vicinity of the root wads designed to trap coarse sediments and facilitate bar formation. Four of the five cross sections repeatedly surveyed at the Dark Gulch site experienced little change during WY 2009, with up to 0.3 m (1 foot) of main channel aggradation occurring at the sixth cross section (cross section 399) that bisected a lowered floodplain (R-3) and a constructed low-flow side channel (R-4). Bed mobility monitoring at IC-7 indicated that Dry WY management targets for bar flank movement were met. The combined isopach, cross section, and bed mobility results indicated that the WY 2009 spring release met TRFEFR geomorphic management targets for a portion of IC-7, but channel migration and bar formation did not occur as intended.

Geomorphic monitoring was repeated at the Dark Gulch site in WY 2010 (Normal WY) following a high flow release of 187 $m^3 \cdot s^{-1}$ (6,610 cfs) (McBain & Trush and HVT 2012). Cross sections surveyed in the vicinity of IC-7 indicated up to 0.5 m (1.6 feet) of mainstem channel aggradation and an associated shift in thalweg position toward the right bank. Other cross sections and topographic surveys showed little change. Winter floods did not mobilize or scour the bed in the vicinity of marked rocks and scour chains installed across R-3 and R-4. The spring high flow release also resulted in little scour (2 to 3 cm) in these areas. Bed mobility monitoring indicated partial mobility between the crest and flank of the constructed bar surface (IC-7).

Design objectives for maintaining perennial flow in the right bank side channel (R-4) were not met due to aggradation in the first 100 m (328 feet) of the side channel (half the constructed length). A rapid assessment of side channels at the Dark Gulch site in February 2011 (Gaeuman in review) indicated that the more upstream of the two side channels constructed at the Dark Gulch site (R-1) maintained a strong baseflow surface water connection, while the more downstream of the two side channels at the site (R-4) was plugged at the inlet and filled with sediment along its length. Aggradation was attributed to the long path length relative to the main channel, the location of the inlet near a convergence of riffles, and its orientation with respect to the flow and sediment transport path across the floodplain.

Changes in spawning gravel quality were not investigated within the Dark Gulch rehabilitation site, but a study site located upstream of the site at RM 107.4 was surveyed in 2000 and again 2009. Repeat sampling at the site indicated that spawning gravel coarsened and the quality improved since 2000 due to flushing of the finer fractions and/or reduction in the supply of fine sediment (GMA 2010a).

Geomorphic monitoring at the Dark Gulch site was repeated again in WY 2011 (HVT and McBain & Trush 2012). In WY 2011, the side channel continued to fill with sediment and perennial flow in the side channel was not maintained. Farther upstream at XS 1791+30, the cross section showed only slight lowering (< 0.1 m) within the 13 $m^3 \cdot s^{-1}$ (450 cfs) channel. Changes along the remainder of the cross section were negligible. No bank erosion, channel migration, or floodplain deposition was observed. The WY 2011 results are similar to results reported for this cross section in WY 2010 (McBain & Trush and HVT 2012). At cross section 399, negligible topographic change occurred over the cross section except for up to 0.6 m of side channel aggradation. No bank erosion, channel migration, or floodplain deposition was observed. Where measured, bed mobility objectives were partially met, and bed scour objectives were not met.

Interpretation of aerial photography and banklines indicated that during WY 2011, the bar located along the right bank near RM 106.9 grew towards the left bank, the downstream bar face migrated into the constructed side channel exit on the left bank (R-1), and the side channel aggraded (Table 6-25). Downstream of this point, a bar formed on the left bank and a medial bar formed in the vicinity of IC-4 (between RM 106.5 and 106.6). The R-4 constructed side channel partially filled between 2009 and 2011, and coarse sediment additions along the left bank (IC-6, IC-7, and IC-8) remained relatively stable.

Table 6-25
Geomorphic Changes Observed in Repeat Aerial Photography at the Dark Gulch Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
106.9	Erosion	Bar migration toward right bank	2001 – 2011	None	NA
106.9	Deposition				
106.9	Erosion	Lateral bar and bank retreat	2009 – 2011	R-1	2011
106.8 – 106.9	Deposition	Lateral bar growth	2009 – 2011	R-1	2011
106.75	Deposition	Lateral bar growth	2005 – 2011	None	2006
106.55	Deposition	Medial bar growth	2007 – 2011	R-1	Not Applicable
106.1	Deposition	Side-channel filling	2009 – 2011	R-4	2011
106.0	Erosion	Left bank bar retreat	2009 – 2011	IC-7	2011

Active bed width scaled to the approximate average D_{50} (100 mm [4 inches]) and D_{84} (200 mm [8 inches]) in the management reach of the Trinity River was analyzed at five cross section locations within the Bucktail-Dark Gulch rehabilitation site (Table 6-26). Overall, cross sections analyzed within the Dark Gulch site showed little bed activity. Three cross sections (15, 14, and 241) that bisect a lateral bar where coarse sediment was added in 2008 (IC-7) showed a relatively active bed (13 to 55% of the channel width active >200 mm) during the period including the high flow release in WY 2011. Results at these cross sections and from analysis of banklines in the vicinity of these cross sections indicate coarse sediment added at the site was transferred downstream by lateral erosion of the upstream bar flank and associated accretion at the downstream bar tail, consistent with the design intent. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 1.53-mile site length indicated little change since 2001, with the exception of a decrease in erosion during 2007 to 2009 (Figure 6-32).

Table 6-26
Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Bucktail-Dark Gulch Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3] >100 mm	Active Bed[3] >200 mm	Lateral Erosion and Deposition[4]	ω	6,000 cfs
241	105.57	49	IC-7	March-09	July-09	4	C	0.10	0.04	0.03	49.13	0
				July-09	November-11	5	D	0.30	0.13	0.16		13
397	105.81	51	IC-8	March-09	July-09	4	C	0.11	0.05	0.06	54.94	0
14	105.96	49	IC-7	June-00	July-01	1	A	0.00	0.00	0.14	49.13	0
				July-01	July-02	1	A	0.02	0.00	0.14		2
				July-02	July-03	1	A	0.01	0.00	0.14		0
				July-03	October-11	6	D	0.72	0.55	0.16		58
15	106.01	49	IC-7	June-00	July-01	1	A	0.00	0.00	0.14	49.13	0
				July-01	July-02	1	A	0.00	0.00	0.14		2
				July-02	April-03	1	A	0.11	0.00	0.14		0
				April-03	July-03	1	A	0.12	0.00	0.14		0
				July-03	April-09	2	B	0.38	0.27	0.11		45
				April-09	July-09	4	C	0.14	0.00	0.03		0
				July-09	October-11	5	D	0.32	0.24	0.16		13
399	106.09	48	R-3, R-4	March-09	August-09	4	C	0.25	0.09	0.04	55.51	0
				August-09	November-09	5	C	0.07	0.00	0.04		0
				November-09	August-10	5	C	0.20	0.02	0.04		5

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

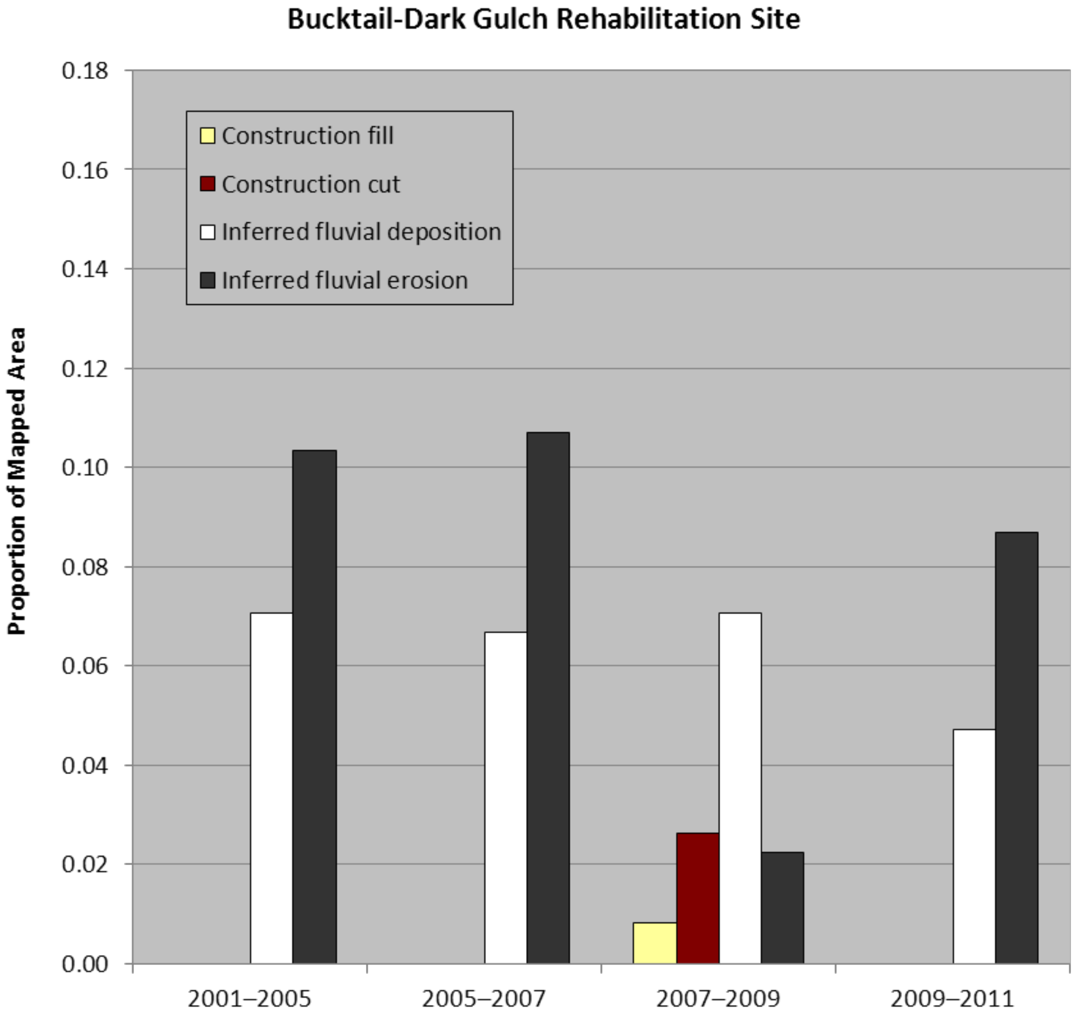


Figure 6-32

Lateral Erosion and Deposition Inferred from Banklines in the Bucktail-Dark Gulch Rehabilitation Site

6.8.4 Biological Response

Pre- and post-construction evaluations were conducted in 2008 and 2009 at baseflows (8.5 and 10.3 $m^3 \cdot s^{-1}$ [300.2 and 363.7 cfs]) in the main channel. The side channels were evaluated; however, there were side channels that did not exist in pre-construction condition that were not evaluated prior to rehabilitation. Pre- (2008) and post-construction (2009) habitat monitoring at the Bucktail-Dark Gulch site evaluated the change in optimal (DV, C) and suitable (DV, no C; and no DV, C) habitat, and indicated that the proportional increase in optimal habitat (DV, and C) in the main channel was 23 and 19% for fry and presmolts, respectively. The proportional increase in suitable habitat (DV or C) varied. Suitable habitat defined as DV, no C increased by 40 and 19% for fry and presmolts, respectively; suitable habitat defined as C, no DV decreased 10 and 18% for fry and presmolts, respectively. The proportional increase in total habitat in the main channel was 19 and 13% for fry and presmolts, respectively. Total habitat increased by 619 m^2 (6,663 square feet) for fry and 848 m^2 (9,128 square feet) for presmolts in side channel 1; increased by 795 m^2 (8,557 square feet) for fry and 825 m^2 (8,880 square feet) for presmolts in side channel 2; and decreased 1% for fry and increased 16% for presmolts in side channel 3. Optimal habitat increased by 97 m^2 (1,044 square feet) for fry and 154 m^2 (1,658 square feet) for presmolts in side channel 1; increased by 186 m^2 (2,002 square feet) for fry and 198 m^2 (2,131 square feet) for presmolts in side channel 2; and increased by 10 m^2 (108 square feet) for fry and presmolts in side channel 3. Throughout the entire site, optimal habitat increased by 33 and 28%, and total habitat increased by 28 and 22% for fry and presmolts, respectively (Figure 6-33).

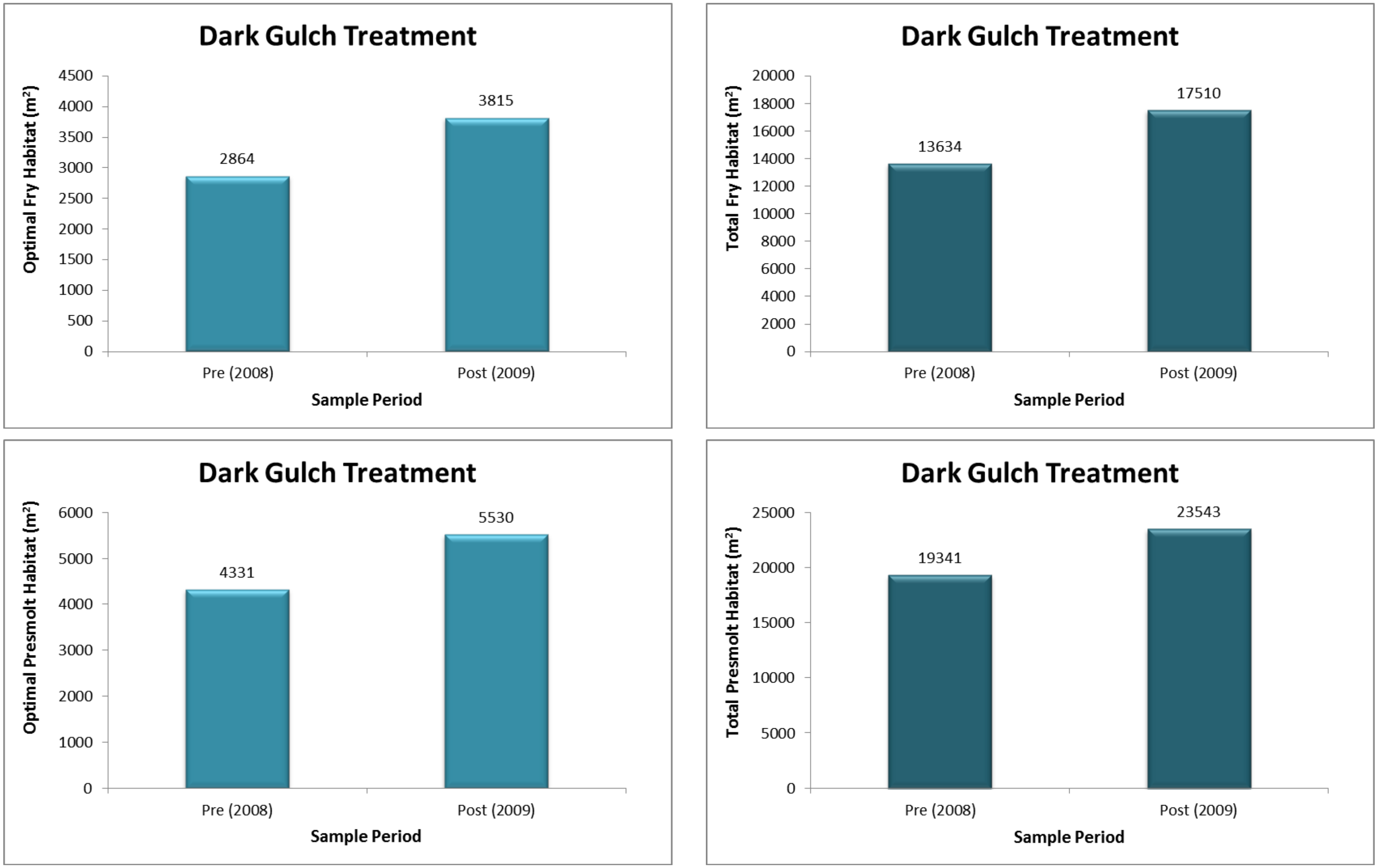


Figure 6-33

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Dark Gulch Site in 2008 (Pre-construction) and 2009 (Post-construction)

Two areas within this site were identified for flow-habitat mapping: Upper Dark Gulch that included a future side channel along the right bank and the Lower Dark Gulch (Bucktail) site that included a future side channel along the right bank as well as coarse sediment augmentation along the left bank. For the Bucktail site, habitat mapping studies conducted over a range of flows from 8.5 to 57 $m^3 \cdot s^{-1}$ (300.2 to 2,013 cfs) indicated that the change in total fry and presmolt habitat between the pre- and post-construction condition peaked around 20 $m^3 \cdot s^{-1}$ (706 cfs), whereas the amount of change in optimum habitat declined throughout the flow range. As reported by Alvarez et al. (2011), the shape of the flow-to-habitat relationship was relatively unchanged at the Lower Dark Gulch site after construction, although fry and presmolt habitat increased at all flows (Alvarez et al. 2011). Rearing habitat was generally shown to increase with flow at this site both before and after rehabilitation (Alvarez et al. 2011).

For the Upper Dark Gulch site, habitat mapping studies conducted over a range of flows from 8.5 to 61 $m^3 \cdot s^{-1}$ (2,150 cfs) indicated that the change in total fry and presmolt habitat peaked around 20 $m^3 \cdot s^{-1}$ (706 cfs) flow. The change in optimum habitat also peaked around 20 $m^3 \cdot s^{-1}$ (706 cfs) and then the change declined significantly when measured at flows of 34 and 57 $m^3 \cdot s^{-1}$ (1,200 and 2,013 cfs). Prior to construction, the flow-to habitat relationship based on optimal habitat at this site was U-shaped (Alvarez et al. 2011). After construction, large increases in suitable (DV, no C) fry and presmolt habitat were observed at the site. These increases were attributed to lowering the floodplain between the side channel and mainstem, allowing water to overtop the banks of the side channel at high flows. However, lower values of optimal habitat for both guilds were observed at higher flows, which were attributed to the removal of vegetation during construction (Alvarez et al. 2011).

Chinook salmon redds (spring and fall Chinook combined) were counted within the Bucktail-Dark Gulch site, untreated sites (controls), and other rehabilitation sites within the Limekiln Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 78 to 106, which made up 9.6 to 11.1% of the redds counted within the Limekiln Reach and 1.7 to 3.3% of the redds counted in the Trinity River (Figure 6-17). Mean densities of Chinook redds within the Bucktail-Dark Gulch site were not significantly different from those in control sites (Figure 6-17).

Chinook carcasses were sampled within the Bucktail-Dark Gulch site during 2009 to 2011. Numbers of female carcasses sampled within the treatment site ranged from 44 to 118 (Figure 6-18), which made up 9.4 to 14.8% of the female carcasses sampled within the Limekiln Reach and 2.3 to 3.5% of the female carcasses sampled in the Trinity River. Mean densities of female

Chinook carcasses in the Bucktail-Dark Gulch site were similar to those in the control sites (Figure 6-18).

Coho carcasses were also sampled within the Bucktail-Dark Gulch site during 2009 to 2011. Numbers of female carcasses sampled within the site during 2009 to 2011 ranged from 5 to 12 (Figure 6-20), which made up 21.7 to 38.9% of the female carcasses sampled within the Limekiln Reach and 5.2 to 5.8% of the female carcasses sampled in the Trinity River. Mean densities of female coho carcasses in the Bucktail-Dark Gulch site were greater than those in the control sites (Figure 6-20).

6.9 Sawmill

Location: RMs 108.9 to 109.7
Year constructed: 2009

6.9.1 Design Objectives

The Sawmill rehabilitation site design sought to increase and sustain the availability, quantity, and quality of salmonid habitats between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs), and to increase and sustain the quality and quantity of riparian vegetation. Design elements were expected to sustain dynamic and complex channel morphology through channel migration, maximize rearing habitat availability, and promote natural riparian recruitment while reducing the risk of encroachment.

6.9.2 Site Description

The large and complex Sawmill rehabilitation site consisted of six in-river, four in-channel, and three upland design elements (Figure 6-34; Table 6-27). In the upstream portion of the site, the floodplain was lowered in two areas (R-1 and R-2) to inundate at 114 $m^3 \cdot s^{-1}$ (4,000 cfs), thus providing refuge for fry and juvenile salmonids during high flows and a surface for riparian regeneration and planting. Large wood was placed throughout constructed floodplain surfaces to provide roughness, velocity breaks, and cover for juvenile salmonids. A bench (R-2) was constructed adjacent to the existing side channel to inundate at 28 $m^3 \cdot s^{-1}$ (1,000 cfs) and provide juvenile salmonid rearing habitat up to 57 $m^3 \cdot s^{-1}$ (2,000 cfs). Large wood and plantings were added along the left bank to reduce the risk of the side channel re-entering the main channel, as well as provide immediate habitat benefits for salmonids. A point bar was constructed on the left bank (IC-2) to increase main channel sinuosity and promote channel migration, and two nearby gabions (IC-1 and IC-2) were modified to return a natural slope. Downstream, the entrance to an existing side channel was moved upstream, re-opening 366 m (1,200 feet) of the side channel (R-3) to winter baseflows. Large wood and plantings were added throughout the side channel to provide immediate fry and juvenile rearing habitat. Dredger tailings piles were removed to inundate the new surface (R-6) at 170 $m^3 \cdot s^{-1}$ (6,000 cfs).

In the downstream portion of the site, large floodplain areas (R-8) were designed to inundate from the side channel at 43 and 170 $m^3 \cdot s^{-1}$ (1,500 and 6,000 cfs). Existing riparian and upland vegetation was retained, and plantings and large wood were incorporated to increase cover for fry and juvenile salmonids. Two channels through the floodplain (R-8) were designed to flow between 71 and 170 $m^3 \cdot s^{-1}$ (2,500 and 6,000 cfs). Large wood and plantings were added to provide cover and rearing opportunities for fry and juvenile salmonids. In addition to providing salmonid habitat, these high flow channels increased topographic variability within the floodplain and increased the potential for natural riparian regeneration. Five alternating point bars (IC-7 through IC-11) were constructed in the middle and downstream portion of the site to increase coarse sediment storage and sinuosity and encourage channel migration. The bars were constructed from coarse sediment ranging in size from 0.25 to 4 inches to facilitate transport by ROD flows in excess of 170 $m^3 \cdot s^{-1}$ (6,000 cfs). Constructed meanders (R-2 and R-8) were incorporated near two of the point bars (IC-7 and IC-10). Another constructed floodplain located on the left bank at the downstream end of the site (R-10) was designed to inundate at 170 $m^3 \cdot s^{-1}$ (6,000 cfs), and the surface was sloped into a high flow scour channel along the back side of the floodplain. An alcove was included at the downstream end of the R-10 scour channel.

Three upland terraces were incorporated into the design to provide access to potential gravel sources while not impacting the 100-year flood elevation. Off-channel wetland construction and enhancement was intended to provide western pond turtle habitat and coho over-summering habitat.

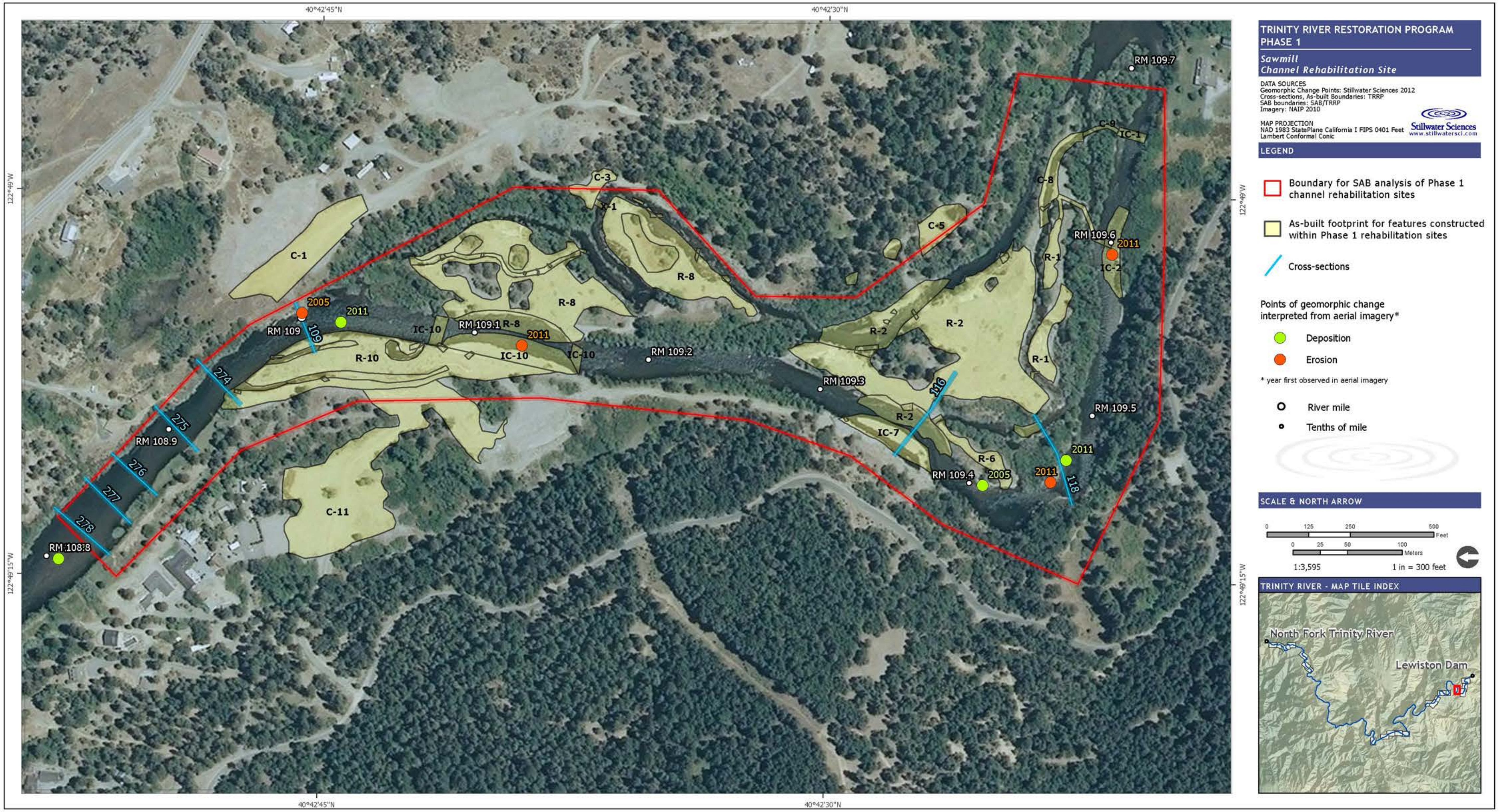


Figure 6-34

Design Features at the Sawmill Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-27
Design Features Constructed at the Sawmill Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-1	Floodplain (4,000 cfs)	109.5–109.6	Right bank and floodplain
R-2	Floodplain (4,000–8,000 cfs)	109.3–109.6	Right bank and floodplain
	Bench (1,000 cfs)		
	Side channel meander with wetland area and wood placements	109.3–109.4	
	Channel meander with wood placements	109.3–109.4	Right bank
R-3	New low flow side channel entrance with wood placements	??	??
R-6	Floodplain (6,000 cfs)	109.4	Right bank
R-8	Upstream floodplain (1,500–6,000 cfs) with wood placements	109.2–109.3	Right bank and floodplain
	Floodplain (1,500–6,000 cfs) and high flow scour channels (2,500) with wood placements	109.1–109.2	
	Channel meander with wood placements	109.1	Right bank
R-10	Floodplain (6,000 cfs) and scour channel with alcove and wood placements	108.9–109.1	Left bank and floodplain
IC-1	Remove gabions	109.65	Mid-channel
IC-2	Point bar with coarse sediment addition	109.6	Left bank
	Remove gabion wiring	109.6	Mid-channel
IC-7	Point bar with coarse sediment addition	109.3–109.4	Left bank
	Grade control [boulder] removal	109.35	Mid-channel
IC-10	Point bar with coarse sediment addition	109.1–109.2	Left bank
	Grade control [boulder] removal	109.1 & 109.15	Mid-channel

6.9.3 Geomorphic Response

The Sawmill rehabilitation site was constructed in 2009. The first post-construction geomorphic monitoring began in 2010 with topography, bed mobility, and bed scour and redeposition monitoring at cross sections 116 and 118 (McBain & Trush and HVT 2012). Repeat monitoring was conducted in WY 2011 (HVT and McBain & Trush 2012). Results indicate partial bed mobility and no net topographic change in constructed bar topography. Main channel aggradation at the toe of the constructed bar and erosion along the right bank toe suggest channel migration toward the right bank, as intended by design. Topographic change did not occur on the constructed floodplain. The side channel at cross section 116 showed no net topographic change. The smaller side channel at cross section 118 similarly showed no net change in topography; however, measured scour provided evidence of coarse sediment transport, suggesting side channel objectives were met. TRFEFR and ROD bed mobility and scour objectives were partially met.

The WY 2010 Implementation Monitoring Report (Gaeuman in review) assessed geomorphic changes at the Sawmill site. The Sawmill site design included two constructed channel meanders intended to increase the sinuosity in the relatively straight reach between Cemetery Hole and Sawmill Pool. The constructed bars at these locations were designed to maintain or enhance the constructed channel alignment by steering flow toward the right bank and encourage channel migration in that direction. The effectiveness of these bars/meander features at steering flow was assessed during the 2010 flow release by spreading straw across the water surface upstream from each of the bars and observing the path taken by the floating material. The straw showed that surface streamlines were directed across both bar/meander features with little steering intended by the design. The geomorphic response of these bars to the 2010 flow release was investigated by comparing as-built topography with 2010 topography. The topographic differences for the IC-10/R-8 bar and meander indicated that degradation was the dominant process on the bar top and face, and aggradation dominated throughout most of the right bank where the meander bend was excavated. The topographic differences for the IC-7/R-2 bar and meander indicated widespread aggradation across the bar and excavated bend. Comparisons between as-built cross-sections and 2010 conditions show similar results. Topographic differences also show incision in the vicinity of the Cemetery side channel entrance, where the gabion grade control structure was removed. Rapid assessment of the Cemetery side channel conducted in February 2011 indicated a large cross section of flow entering the side channel (Gaeuman in review).

The lower portion of the Sawmill site coincides with the Sawmill coarse sediment injection point. Sonar surveys of Sawmill Pool were conducted by boat before and after the 2008 spring release (Normal WY) to assess the response in the pool and downstream reach. Topographic differences derived from the two surveys, supported by other evidence, indicated that sediment introduced during the 2008 release deposited as a submerged bar on river left opposite and downstream from the injection point rather than in the pool. This conclusion motivated a larger volume of augmentation during the 2009 release (Dry WY). The WY 2009 and WY 2010 releases were incapable of clearing the augmented material from the pool. The combined effects of sediment injection and addition of 5,700 cubic yards (8,550 tons) of coarse sediment within the Sawmill rehabilitation site resulted in a sequence of two medial bars forming in the first 1,000 feet downstream from Sawmill Hole. Comparison of streambed topography from the 2009 DTM with topography surveyed in summer 2010 showed more than 4 feet of aggradation adjacent to and downstream of the augmentation point, as well as localized bed aggradation up to a few feet around the perimeter of a medial bar developing roughly 500 feet downstream. Little bed elevation change occurred farther downstream. The results indicated that coarse sediment augmentation as of the summer of 2010 had not produced enough aggradation in the Lower Sawmill reach to significantly increase flood risk to nearby structures.

Interpretation of aerial photography and banklines suggested that the constructed bar at RM 109.6 (IC-2) significantly eroded during 2011 flow release (Table 6-28). Several small bars evolved along the right-bank at the bend located near RMs 109.4 to 109.5, becoming more apparent following the 2011 flow release. The constructed bar and meander near RM 109.1 lost much of its relief in 2011, although the meander planform was retained. Mobilization of the constructed floodplain on the left bank (R-10) appeared to transfer coarse sediment into the low-flow channel at RM 109.0.

Table 6-28
Geomorphic Changes Observed in Repeat Aerial Photography at the Sawmill Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
109.6	Erosion	Left bank bar retreat	2011	IC-2	2011
109.45	Deposition	Right bank bar growth	2009 – 2011	None	2011
109.45	Erosion	Right bank bar retreat	2009 – 2011	None	2011
109.4	Deposition	Right bank bar growth	2001 – 2011	None	All
109.1	Erosion	Left bank bar retreat	2011	IC-10	2011
109.0	Deposition	Left bank bar growth	2011	R-10	2011
109.0	Erosion	Right bank bar retreat	2001 – 2005	Gravel augmentation pile not part of constructed features	Not Applicable
108.8	Deposition	Medial bar growth	2005 – 2007	None	2006

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at eight cross section locations within the Sawmill rehabilitation site (Table 6-29). Six of the eight cross sections (cross section 109 and bathymetric cross sections 274 to 278) occur at the downstream end of the site and primarily record the influence of coarse sediment injections at Sawmill Point, the effects of which are described above. The other two cross sections (116 and 118) occur in the upstream portion of the site: cross section 118, which bisects a point bar and side channel at the apex of the bend, showed a relatively active bed (≥20% of the channel width active >200 mm) from 2004 to 2010 and in response to the WY 2011 flow release, largely due to an expected pattern of erosion along the left bank of the main channel and associated deposition along the right bank. Cross section 16, which bisects a constructed bar and meander (IC-7 and R-2), showed a relatively inactive bed in response to the WY 2011 flow release despite addition of coarse sediment along the left bank (IC-7) and channel excavation along the right bank (R-2). These results, combined with relatively little lateral erosion and deposition inferred from banklines in the cross section area (Table 6-29), suggest the design features did not perform as intended. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 0.80-mile site length indicated a peak in lateral erosion during the 2005 to 2006 period, presumably due to the WY 2006 high flow release, followed by a peak in accretion during 2007 to 2009 (Figure 6-35). The WY 2011 release appeared to have little effect on lateral erosion or accretion at the site.

Table 6-29

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Sawmill Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
278	108.83	26	none	June-10	June-11	5	D	0.46	0.23	0.01	13.13	7
277	108.85	26	none	June-10	June-11	5	D	0.57	0.25	0.01	13.13	7
276	108.87	26	none	June-10	June-11	5	D	0.63	0.34	0.01	13.13	7
275	108.90	26	none	June-10	June-11	5	D	0.58	0.45	0.01	13.13	7
274	108.94	26	R-10	June-10	June-11	5	D	0.48	0.07	0.01	13.13	7
109	109.00	25	R-10	July-00	May-12	6	D	0.89	0.77	0.05	14.98	53
116	109.36	22	IC-7, R-2	October-10	August-11	5	D	0.23	0.09	0.02	49.40	7
118	109.46	21	None	October-10	August-11	5	D	0.38	0.23	0.03	63.54	7
				November-04	October-10	6	B	0.82	0.63	0.29		41

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

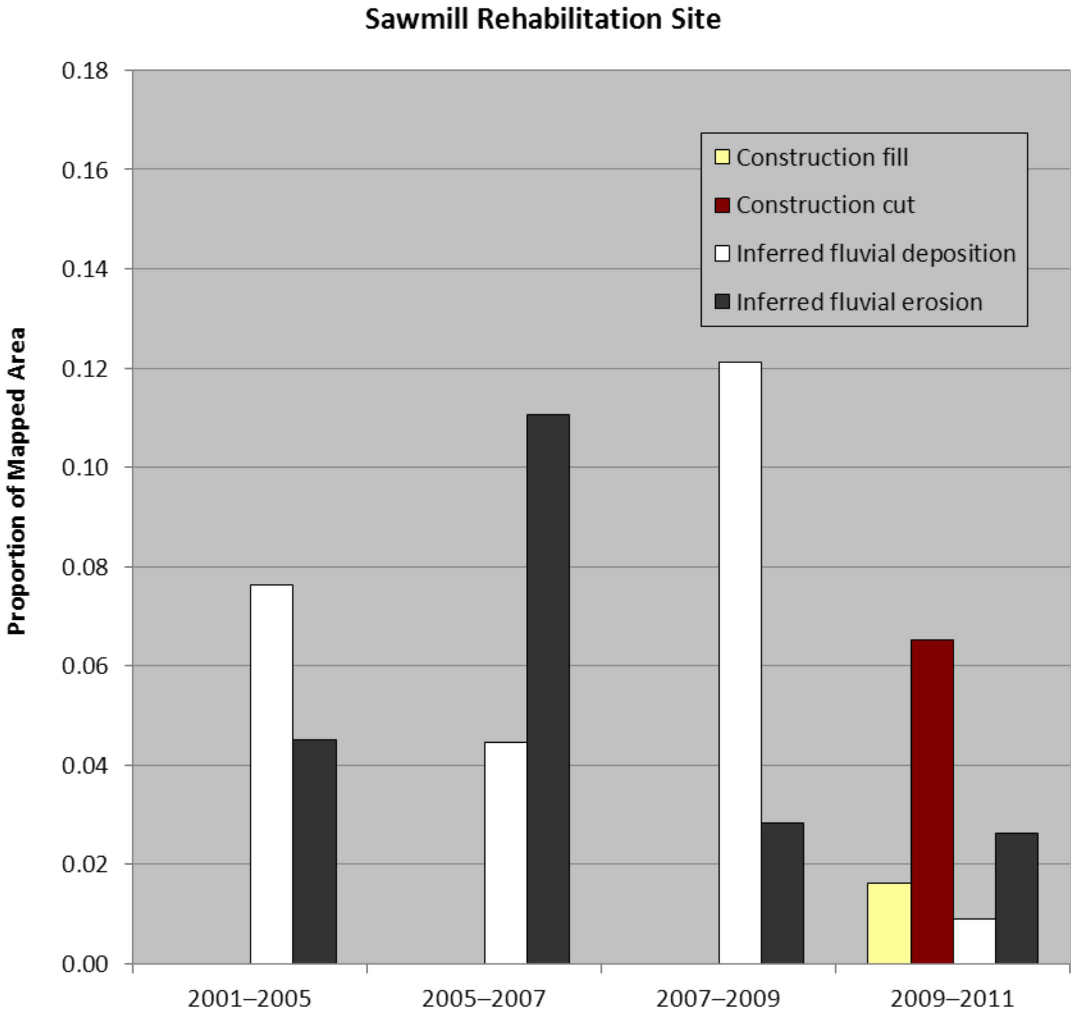


Figure 6-35
Lateral Erosion and Deposition Inferred from Banklines in the Sawmill Rehabilitation Site

6.9.4 Biological Response

Pre- and post-construction evaluations were conducted in 2009 and 2010 at baseflows (8.3 and 8.5 $m^3 \cdot s^{-1}$ [293.1 and 300.2 cfs] in the main channel and between 0.3 and 1.4 $m^3 \cdot s^{-1}$ [10.6 and 49.4 cfs] in the side channels). Pre- (2009) and post-construction (2010) habitat monitoring at Sawmill evaluated the change in optimal (DV, C) and suitable (DV, no C; and no DV, C) habitat, and indicated that in the main channel there was a proportional increase in optimal habitat (DV, and C) of 68 and 60% for fry and presmolts, respectively. There was also a proportional increase in suitable habitat (DV or C) that varied. Suitable habitat for fry increased approximately 6% (DV, no C) and 18% (no DV, C), but suitable habitat defined as DV, no C decreased by 6% and suitable habitat defined as C, no DV increased by 5% for presmolts. The proportional increase in total habitat in the main channel was 20% and 7% for fry and presmolts, respectively, after construction.

The rehabilitation of the Cemetery side channel led to an increase of 65% and 61% of optimal habitat for fry and presmolts, respectively. Suitable habitat changes varied after construction. The suitable habitat (DV, no C) decreased 38% (fry) and 29% (presmolts) while the no DV, C habitat increased 49% (fry) and 46% (presmolts). Total habitat within this side channel increased 20% and 11% for fry and presmolts, respectively. Substantial increases in habitat were observed in the Sawmill side channel. Optimal habitat increased approximately 400% for fry and presmolts. Total habitat for fry and presmolts increased 363% and 328%, respectively. Suitable habitat for fry increased 350% (DV, no C) and 318% (no DV, C). Suitable habitat for presmolts increased 278% (fry) and 284% (presmolts). Throughout the entire site, optimal habitat increased by 96 and 88%, and total habitat increased by 42 and 29% for fry and presmolts, respectively (Figure 6-36).

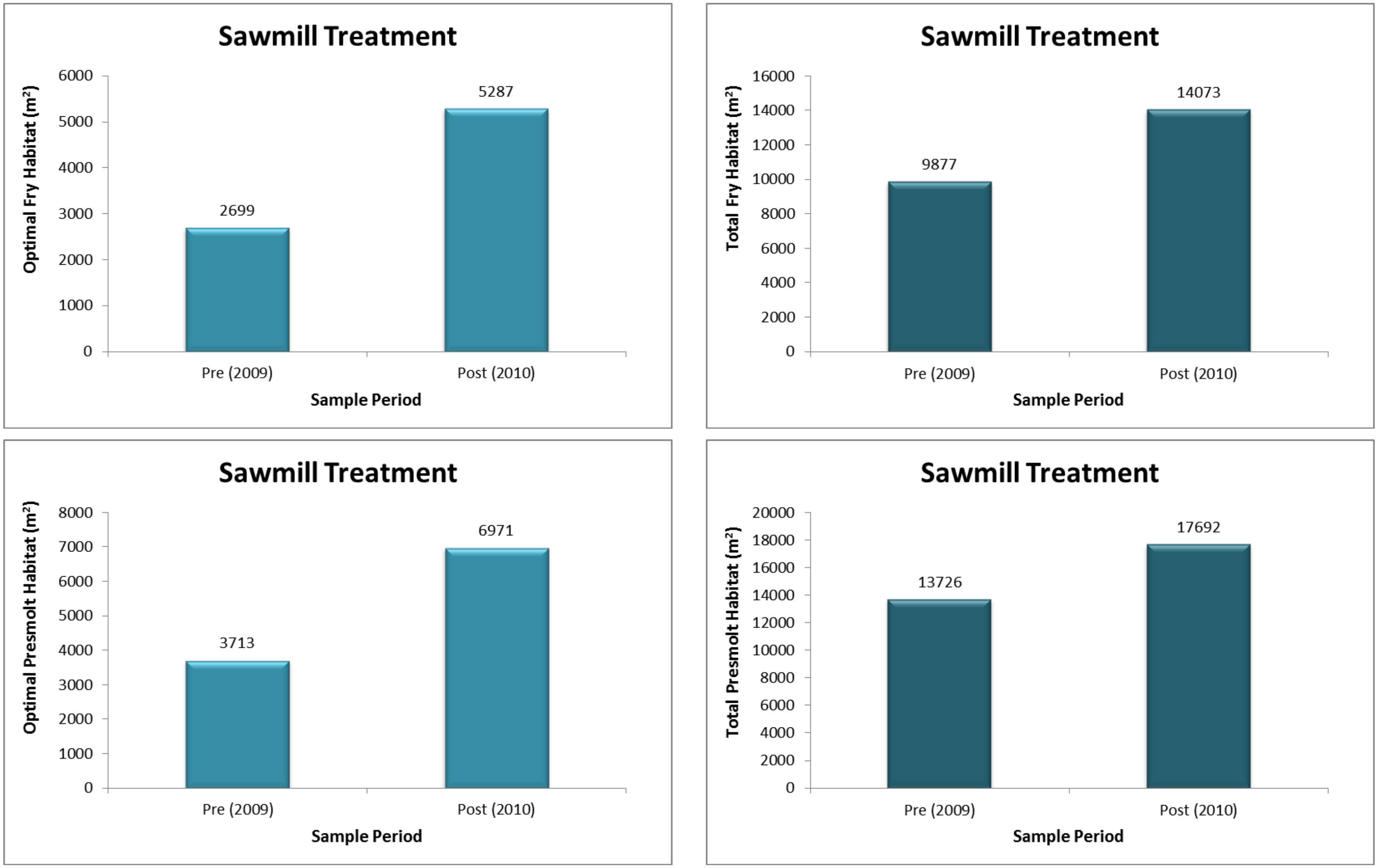


Figure 6-36

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Sawmill Site in 2009 (Pre-construction) and 2010 (Post-construction)

Chinook salmon redds (spring and fall Chinook combined) were counted within the Sawmill site, untreated sites (controls), and other rehabilitation sites within the Lewiston Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 122 to 176, which made up 5.3 to 10.2% of the redds counted within the Lewiston Reach (Figure 6-24) and 2.6 to 5.0% of the redds counted in the Trinity River (Figure 7-6). Mean densities of Chinook salmon redds within the Sawmill site were significantly less than those in the control sites (Figure 6-24).

Chinook salmon carcasses were sampled within the Sawmill site during 2009 to 2011. Numbers of female carcasses sampled within the site during 2009 to 2011 ranged from 112 to 300 (Figure 6-25), which made up 8.4 to 16.8% of the female carcasses sampled within the Lewiston Reach and 5.9 to 8.5% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Sawmill site were generally less than those in the control sites (Figure 6-25).

Coho salmon carcasses were also sampled within the Sawmill treatment site during 2009 to 2011. Numbers of female carcasses sampled within the site during 2009 to 2011 ranged from 10 to 58 (Figure 6-26), which made up 15.9 to 30.9% of the female carcasses sampled within the Lewiston Reach and 11.5 to 25.1% of the female carcasses sampled in the Trinity River. Densities of female coho salmon carcasses in the Sawmill site were greater than those in the control sites (Figure 6-26).

6.10 Reading Creek

Location: RMs 92.2 to 93.1
Year constructed: 2010

6.10.1 Design Objectives

The Reading Creek design sought to increase and sustain the availability, quantity, and quality of salmonid habitat between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs), and to increase and sustain the quality and quantity of riparian vegetation while preserving the continuity of the riparian canopy. The specific objectives included increasing channel sinuosity and complexity by constructing bars that encourage channel migration. Objectives also included providing immediate habitat for juvenile Chinook salmon, coho salmon, and steelhead when flow releases from Lewiston Dam are between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs); increasing spawning quality and quantity; increasing large wood storage; preserving existing riparian vegetation; and promoting natural riparian vegetation recruitment while reducing the risk of riparian encroachment. The general reach-scale design strategy stated that the addition of coarse sediment and mechanical rescaling of channel banks, in combination with flow releases, would promote dynamic physical processes that would sustain complex channel morphology. The Reading Creek design included creating a channel separated from the main channel by a small island/berm, with the anticipation that the main channel would move into the new channel during a high flow.

6.10.2 Site Description

The site begins upstream of the Reading Creek confluence and continues through a forced bend. Redding Creek meets the Trinity River on the left bank at RM 93.1. Prior to construction, portions of the mainstem channel were confined laterally and vertically by riparian encroachment, berms, valley walls, dredger tailings, and bedrock.

The Reading Creek project consisted of four in-river, five in-channel, and five upland design elements (Figure 6-37; Table 6-30). Activities included lowering floodplain surfaces on both banks, building transverse and point bars, and constructing a new high-flow channel at the downstream end of the site. Along the right bank at the upstream end of the site, the floodplain was excavated (R-2) to allow inundation at 170 $m^3{\cdot}s^{-1}$ (6,000 cfs), the riparian berm was removed and the bank was recontoured, a point bar (IC-3) was constructed in association with an inundation surface (R-2) designed to induce meandering, and a high flow side channel (R-2) was constructed to inundate at 57 $m^3{\cdot}s^{-1}$ (2,000 cfs). The side channel connects with an alcove at its downstream end. A low flow side channel (R-3) was also constructed within the path of an existing high flow channel and point bar near RM 92.95.

In the downstream portion of the site, a series of forced meanders (R-4 and R-5) and constructed bars (IC-4 through IC-7) were built to increase channel sinuosity and complexity, decrease the radius of curvature, and improve the likelihood of future channel migration. Floodplains were constructed on both banks (R-4 and R-5) to inundate at 170 $m^3{\cdot}s^{-1}$ (6,000 cfs), and a high flow side channel was excavated into the constructed floodplain on the left bank. Large wood was placed along feathered edges, in side channels, and on constructed floodplains. Five upland terraces were designed to hold material generated as a result of floodplain construction without impacting the 100-year floodplain and store coarse sediment for use during future coarse sediment augmentation.

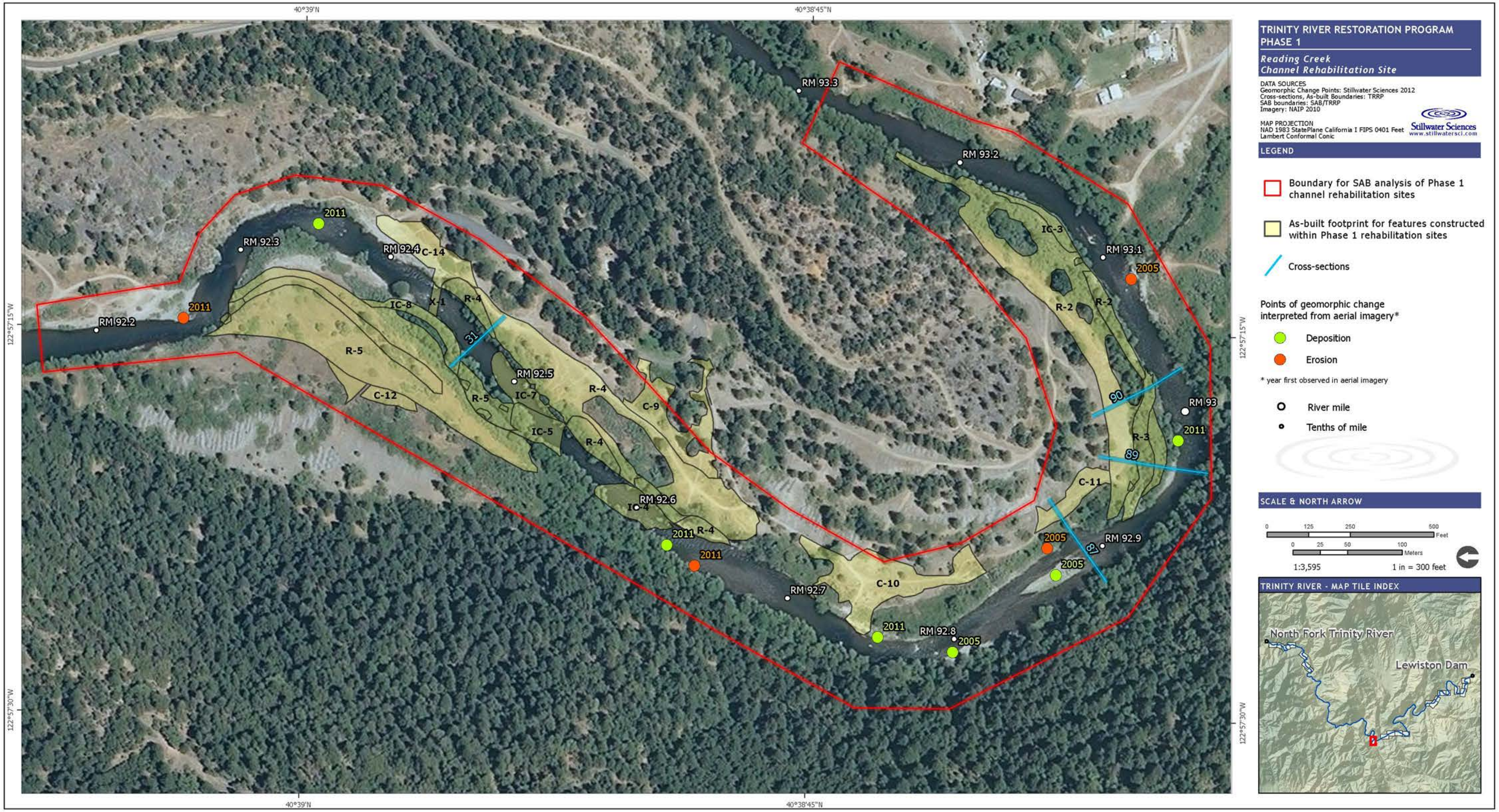


Figure 6-37

Design Features at the Reading Creek Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-30

Design Features Constructed at the Reading Creek Rehabilitation Site

Feature ID	Feature	Location (RM)	Position
R-2	Floodplain (5,000 cfs) and high flow scour channel with alcove and wood placements	92.9 – 93.2	Right bank
	Inundation surface (2,000 cfs)	93.0 – 93.1	Right bank
R-3	Low flow side channel (300 cfs) with wood placements	92.9 – 93.0	Right bank
R-4	Floodplain (6,000 cfs) with benches (500 cfs)	92.4 – 92.7	Right bank
R-5	Floodplain (6,000 cfs) and high flow scour channel with alcove (300 cfs) and wood placements	92.3 – 92.5	Left bank
	Main channel alignment [meandering] and feathered edge	92.5	Left bank
IC-3	Point bar (500 cfs) with coarse sediment addition (0.25 – 4 in. dia.)	93.1 – 93.2	Right bank
IC-4	Transverse bar (500 cfs) with coarse sediment addition (0.25 – 4 in. dia.)	92.6	Mid-channel
IC-5	Transverse bar (500 cfs) with coarse sediment addition (0.25 – 4 in. dia.)	92.5	Mid-channel
IC-6	Point bar (500 cfs) with coarse sediment addition (0.25 – 4 in. dia.)	92.4 – 92.5	Left bank
IC-7	Point bar (500 cfs) with coarse sediment addition (0.25 – 4 in. dia.)	92.5	Right bank

6.10.3 Geomorphic Response

Construction of the Reading Creek site occurred in 2010 prior to geomorphic monitoring reported for WY 2009 by Alvarez et al. (2011), and geomorphic monitoring was not reported as part of the in the WY 2010 Implementation Monitoring Report (Gaeuman in review) or the WY 2010 IHAP monitoring effort (McBain & Trush and HVT 2012).

WY 2011 monitoring at the Reading Creek site included cross section 1077+75, which crosses the narrow upstream-most portion of the constructed terrace (HVT and McBain & Trush 2012). Flows in WY 2011 caused significant erosion and redeposition in the channel below the $13\ m^3 \cdot s^{-1}$ (450 cfs) water surface, including 27 m of thalweg movement from the right to left bank. A new medial bar replaced a left bank bar. Minor bank erosion occurred below the terrace surface, but the surface itself remained unchanged by the spring ROD release. Full bed mobility indicated that TRFEFR and ROD bed mobility objectives were met. Cross section topography showed net scour > 2.0 D_{84}, meeting TRFEFR and ROD bed scour objectives.

Interpretation of aerial photography and banklines suggested that the right bank point bar near RM 93.0 and the medial bar located immediately downstream near RM 92.9 enlarged between April 2009 and August 2011 (Table 6-31). Associated retreat of the right bank occurred adjacent to the medial bar, presumably from flow-deflection. Since 2001, the channel-spanning riffle feature near RM 92.8 appeared to evolve from a wide, cobble-boulder riffle to a broad, gravel-cobble bar centered primarily along the left bank. The changes have shifted the main flow path toward the right bank. Beginning near RM 92.6, the constructed meanders (R-4 and R-5) and bars (IC-4 through IC-7) increased topographic complexity but much of the intended increase in sinuosity was not retained following the 2011 flow release. At the downstream end of the site where flow is deflected by bedrock on the left-bank (RMs 92.2 to 92.3), the 2011 flow release resulted in development of a bar on the right bank and aggradation in the vicinity of the exit to the high flow side channel.

Table 6-31
Geomorphic Changes Observed in Repeat Aerial Photography at the Reading Creek Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
93.1	Erosion	Gradual retreat of Reading Creek delta	2001 – 2011	None	All
93.0	Deposition	Right bank bar growth	2009 – 2011	R-2 and IC-3	2011
92.9	Deposition	Gradual medial bar growth	2001 – 2011	None	All
92.9	Erosion	Gradual retreat of right bank	2001 – 2011	None	All
92.8	Deposition	Left bank bar growth	2001 – 2011	None	All
92.75	Deposition	Right bank bar growth	2009 – 2011	None	2011
92.65	Erosion	Left bank bar migration	2009 – 2011	R-4 and IC-4	2011
92.60	Deposition				
92.35	Deposition	Medial bar growth	2009 – 2011	R-4, R-5, IC-6, and IC-7	2011
92.25	Erosion	Right bank bar retreat	2009 – 2011	R-5	2011

Active bed width scaled to the approximate average D_{50} (100 mm) and D_{84} (200 mm) in the management reach of the Trinity River was analyzed at five cross section locations within the Reading Creek rehabilitation site: two in the downstream portion of the site (31 and 457) and three in the upstream portion of the site (87, 89, and 90) (Table 6-32). The three cross sections distributed around the apex of the bed at the upstream end of the reach experienced a relatively active bed (29 to 45% of the channel width active >200 mm) in response to the WY 2011 high flow release (Table 6-32). Changes were primarily related to deposition at the point bar located on the inside of the meander bend and at the head of the medial bar at the downstream end of the meander. These patterns were also apparent in bankline changes from 2009 to 2011. Lowering of the floodplain at the inside of the meander bend and construction of low flow and high flow channels within it may have influenced these deposition patterns, as was intended by the design. Farther downstream at cross section 457, erosion occurred along the left bank and deposition occurred on the lateral bar on the left bank (29% of the channel width active >200 mm). These changes were not directly related to site construction. The cross section located in the downstream portion of the site experienced little change prior to 2011 and was not surveyed following the WY 2011 flow release. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 0.90-mile site length indicated a gradual decline in lateral erosion since 2001 and more bankline changes related to fluvial deposition during the 2005 to 2009 period (Figure 6-38). WY 2011 resulted in relatively little lateral erosion or accretion at the site compared to other time periods.

Table 6-32

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Reading Creek Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
31	92.47	158	IC-8, R-4	October-06	April-08	1	C	0.10	0.05	0.08	117.62	0
				April-08	July-08	1	C	0.11	0.05	0.08		8
				July-08	April-09	1	C	0.07	0.02	0.08		0
				April-09	September-09	1	C	0.08	0.04	0.08		0
				September-09	April-10	1	C	0.03	0.01	0.08		0
457	92.71	156	Unknown	April-11	December-11	4	D	0.54	0.29	0.11	40.76	8
87	92.89	155	None	March-08	August-08	1	C	0.21	0.06	0.15	51.02	8
				August-08	April-11	2	C	0.47	0.28	0.15		6
				April-11	August-11	4	D	0.70	0.43	0.18		8
89	92.97	154	R-2, R-3	March-08	December-10	2	C	0.67	0.49	0.09	56.82	14
				December-10	October-11	4	D	0.61	0.37	0.10		8
90	93.03	154	R-2, R-3	October-01	December-09	1	B	0.38	0.18	0.09	56.82	65
				December-09	October-11	6	D	0.71	0.45	0.10		14

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

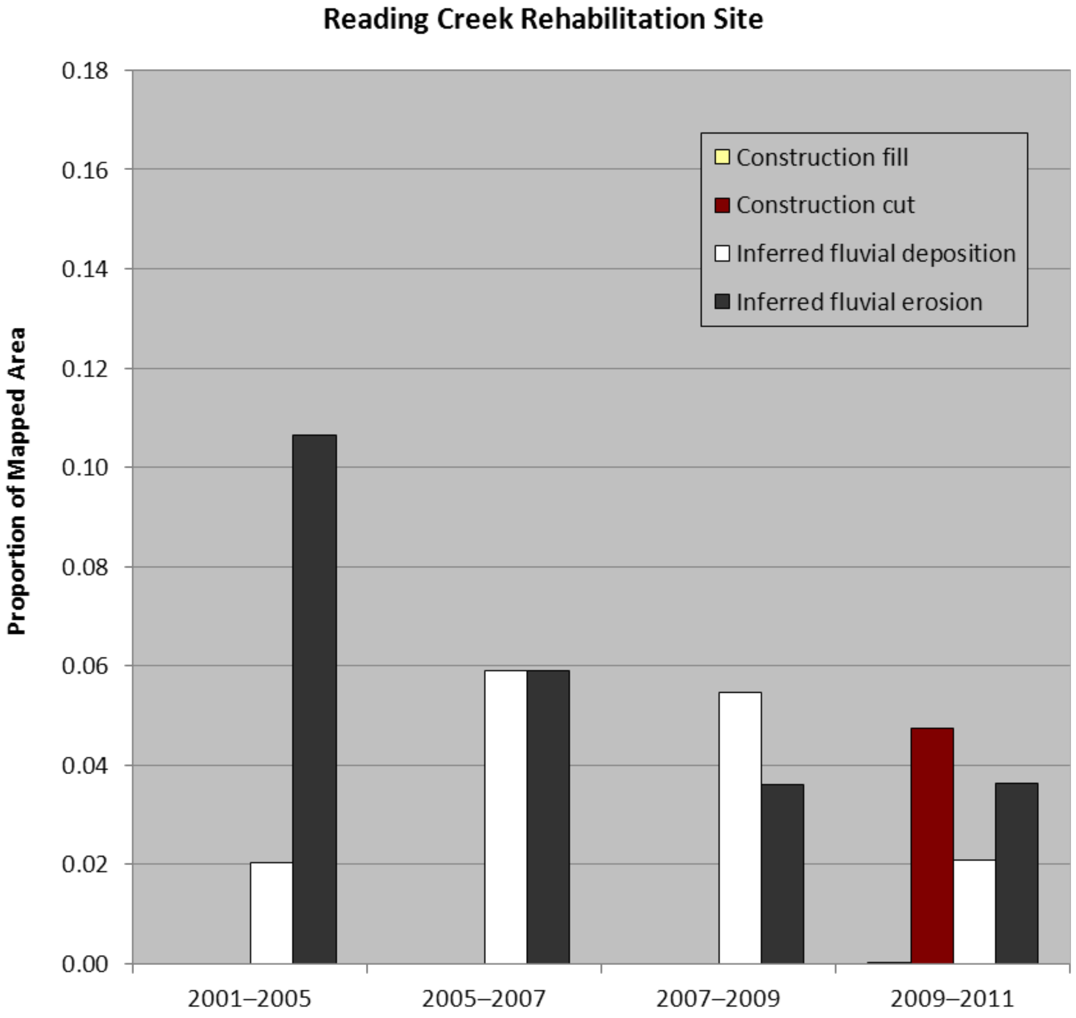


Figure 6-38
Lateral Erosion and Deposition Inferred from Banklines in the Reading Creek Rehabilitation Site

6.10.4 Biological Response

Pre- and post-construction rearing habitat surveys were conducted at the Reading Creek rehabilitation site in 2009 (9.9 $m^3 \cdot s^{-1}$ [349.6 cfs]) and 2011 (after WY 2011 high flow; 10.5 $m^3 \cdot s^{-1}$ [370.8 cfs]) at baseflow. Total fry and presmolt rearing habitat across the whole site increased by 25% and 27%, respectively, after construction (Martin et al. in review). Optimal habitat increased 10% at baseflow for both fry and presmolt life stages (Martin et al. in review)(Figure 6-39).

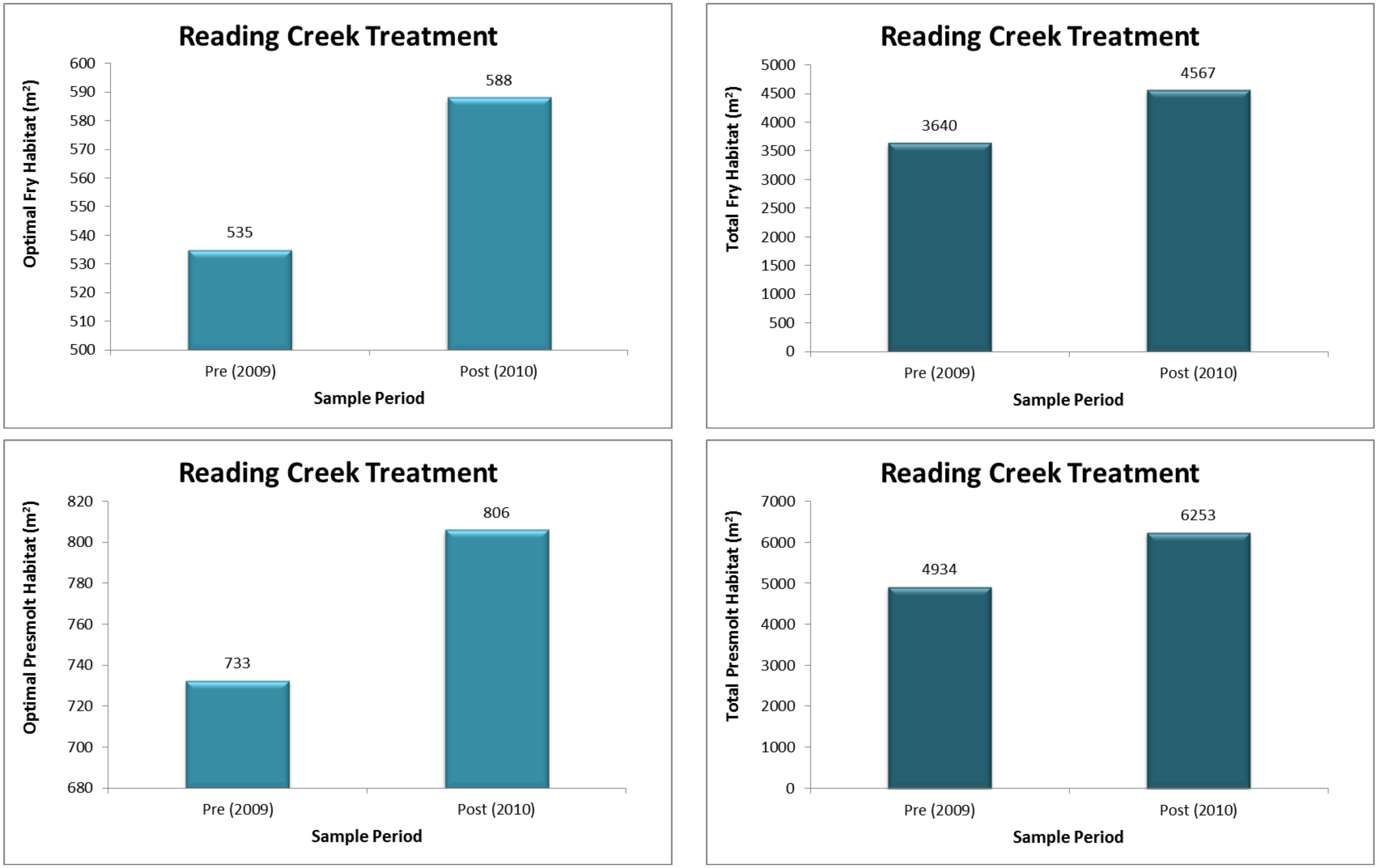


Figure 6-39

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Reading Creek Site in 2009 (Pre-construction) and 2011 (Post-construction)

A portion of the rehabilitation site was mapped at multiple flows ranging from 9.9 to 69.4 $m^3 \cdot s^{-1}$ (349.6 to 2,450.8 cfs) (Martin et al. in review). Increases in optimal and total habitat were detected across all flows. The smallest increases in habitat occurred at the lowest flows and the largest increases were observed at the highest flows (Martin et al. in review). At a discharge of 62.0 $m^3 \cdot s^{-1}$ (2,189.5 cfs) optimal habitat increased after construction by 56% and 58% for fry and presmolt life stages and total habitat increased by 81% and 97%, respectively. The shape of the curve shifted slightly to the right for optimal habitat and the slope of the curve at higher flows was slightly steeper after construction. There was a slight change to the shape of the total habitat curve where habitat was increasing after construction at the highest mapped flows instead of remaining stable (flat-lined) (Martin et al. in review). Flow-habitat mapping was conducted with the intent of evaluating the effects on rearing habitat of various construction elements as summarized below from Martin et al. (in review).

The R-5 forced meander was constructed in conjunction with IC-5 and IC-7 to increase channel sinuosity, decrease radius of curvature, increase channel complexity and improve the likelihood of future channel migration toward the left bank (HVT and McBain & Trush 2010 as cited in Martin et al. in review). Habitat areas before and after construction were summed from the top of the IC-5 transverse bar to the bottom of the flow-habitat mapping area to evaluate the effects these features had (in conjunction with the 2011 spring high flow event) on rearing habitat. Winter baseflow total habitat increased by 119% for fry and 107% for presmolt throughout this section (Martin et al. in review). Smaller increases of 16% and 19% were observed for optimal fry and presmolt winter baseflow habitat, respectively. Optimal habitat increases of 1,401% for fry and 1,618% for presmolt as well as a 369% gain in fry total habitat and 441% increase for presmolt total habitat were observed at a discharge of 62.0 $m^3 \cdot s^{-1}$ (2,189.5 cfs).

The primary goal of the R-4 500-cfs benches was to increase bankfull channel width and encourage sediment deposition within the mainstem channel flows (HVT and McBain & Trush 2010). A secondary goal of the R-4 500-cfs benches was to provide temporary habitat at intermediate flows (HVT and McBain & Trush 2010). Fry total habitat increased 286 m^2 (3,078 square feet) or 106% and presmolt total habitat increased 385 m^2 (4,144 square feet) or 132% (Martin et al. in review). In pre-construction conditions, total habitat decreased with increasing flows. In contrast, post-construction conditions exhibited increases in total habitat as flows overtopped the benches. Optimal habitat around the R-4 benches displayed some increases in habitat and the shape of the streamflow-to-habitat curve changed dramatically. Pre-construction optimal habitat decreased sharply between the low and intermediate discharge, then increased slowly. Post-construction optimal habitat availability remained relatively stable across flows.

It was hypothesized that the constructed point bars (IC-6 and IC-7) would increase rearing habitat at low flows (HVT and McBain & Trush 2010). However, the 357 $m^3 \cdot s^{-1}$ (12,600 cfs) high flow event transported most of the gravel placed in these locations downstream. The post-construction edge of water was very close to the pre-construction conditions within the IC-7 and IC-8 areas. For this reason, there was no evaluation of habitat change due to bar construction.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Reading Creek site, untreated sites (controls), and other rehabilitation sites within the Douglas City Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 15 to 31, which made up 4.8 to 10.8% of redds counted within the Douglas City Reach and 0.4 to 0.9% of redds counted in the Trinity River (Figure 6-17). Mean densities of Chinook salmon redds within the Reading Creek site were less than those in control sites (Figure 6-17).

Chinook and coho salmon carcasses were sampled within the Reading Creek site during 2009 to 2011. Only one coho salmon carcass was sampled in the Douglas City Reach during the survey period. Numbers of female Chinook carcasses sampled within the Reading Creek site during 2009 to 2011 ranged from 4 to 18 (Figure 6-19), which made up 4.4 to 9.8% of the female carcasses sampled within the Douglas City Reach and 0.2 to 0.9% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Reading Creek site were less than those in the control sites (Figure 6-19).

6.11 Lowden Ranch

Location: RMs 104.4 to 105.3
Year constructed: 2010

6.11.1 Design Objectives

The stated objectives of the Lowden Ranch rehabilitation project were to provide immediate refugia for anadromous juveniles at flows between 8 and 198 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs), improve coarse sediment storage, increase large wood storage, create dynamic and complex channel morphology, preserve existing riparian vegetation and herpetile habitat where possible, and promote riparian vegetation recruitment. The project was intended to increase sinuosity, hydraulic diversity, and channel complexity in a relatively straight and structurally simple reach.

The Lowden Ranch project was the most complicated project implemented to date, and included coarse sediment additions, constructed point bars, benches, floodplains, alcoves, side channels and associated off-stream rearing habitat, and a main channel realignment. In addition, off-channel wetland construction and enhancement was intended to provide western pond turtle habitat and off-channel over-summering opportunities for coho salmon. The design was developed in three segments. The upper section focused on side channel and off-channel rearing habitat. The middle section was designed to create dynamic and complex channel morphology through construction of a forced meander and point bar. The main channel flow was expected to occupy a chute over the point bar and then erode laterally to re-establish a more sinuous alignment. The downstream section focused on accelerating growth of an existing medial bar through channel widening and coarse sediment augmentation. The anastomosing planform of the lower section was expected to remain stable. The potential for deposition to occlude the anabranches and create a single low-flow channel was reduced by constructing islands and large wood structures at the island heads near the anabrach entrances. Flow expansion was also expected to encourage deposition far enough upstream of the entrances to avoid any effect.

6.11.2 Site Description

The Lowden Ranch site begins at RM 105.30 and extends 0.9 mile downstream, ending near the confluence of Grass Valley Creek. The upper portion of the site contains bedrock and boulder grade controls. Prior to construction, a left bank floodplain was inundated at 127 $m^3 \cdot s^{-1}$ (4,500 cfs). The middle section of the site is straight, low gradient, and contained a gravel bar used for spawning. Mine tailings occurred in piles and pits. In the downstream section of the site, the relatively straight reach with an entrenched plane bed channel was confined by tailings piles and terraces.

The site design was composed of nine in-river, seven in-channel, and two upland design elements (Figures 6-40a and 6-40b; Table 6-33). In the upper portion of the site, a low-flow side channel (R-1) was designed to flow from 8 to 71 $m^3 \cdot s^{-1}$ (300 to 2,500 cfs). A point bar (IC-1) was constructed to raise the baseflow water surface elevation near the side channel entrance, and LWD was placed at the island head to encourage scour and sediment transport. Pools and riffles were incorporated into the side channel to provide edge length and rearing habitat at winter baseflow, as well as refuge for juvenile fish at intermediate discharges. Willow clumps and sedges were planted along the side channel to provide cover for juvenile salmon and steelhead. Additional off-channel rearing habitat (R-2) was provided in side channel branches designed to flow between 43 and 127 $m^3 \cdot s^{-1}$ (1,500 and 4,500 cfs). The design included replacing the straight, plane-bed channel with a more sinuous planform through channel realignment (R-3) and a constructed point bar/floodplain on the right bank (IC-2). The Program fed roughly 1,500 cubic yards of coarse sediment into the flow near the constructed point bar during the 2010 spring high-flow release so that hydraulic forces would redistribute the material into a natural bar form. Potential outcomes of the sediment injection were simulated using SRH-2D, a 2-dimensional hydraulic and morphodynamic model. A large adjacent floodplain area on the left bank (R-5) was lowered to increase overbank flow conveyance, increase local channel deposition, help provide connectivity between the main channel and the perennial ponds near the back edge of the feature, and provide an area for riparian planting. A low bench (R-4) was cut into the downstream edge of this lowered floodplain to facilitate growth of an existing medial bar and provide refugia for juvenile salmonids during flows from 43 to 198 $m^3 \cdot s^{-1}$ (1,500 to 7,000 cfs). An alcove (R-6) was constructed at the downstream end of the lowered floodplain to provide additional rearing habitat at 43 to 198 $m^3 \cdot s^{-1}$ (1,500 to 7,000 cfs). In the downstream portion of the site, split-flow channels (R-7) with anastomosing morphology were designed to increase salmonid rearing habitat. Terraces were lowered (R-8 and R-9) to create mid-channel islands between the split-flow channels. Coarse gravel augmentation (IC-3 through IC-7) was designed to constrict the main channel flow, encourage flow into the split channels, help shape the mid-channel islands, and supply spawning-size coarse sediment. Two upland elements were constructed to receive spoils from the project.

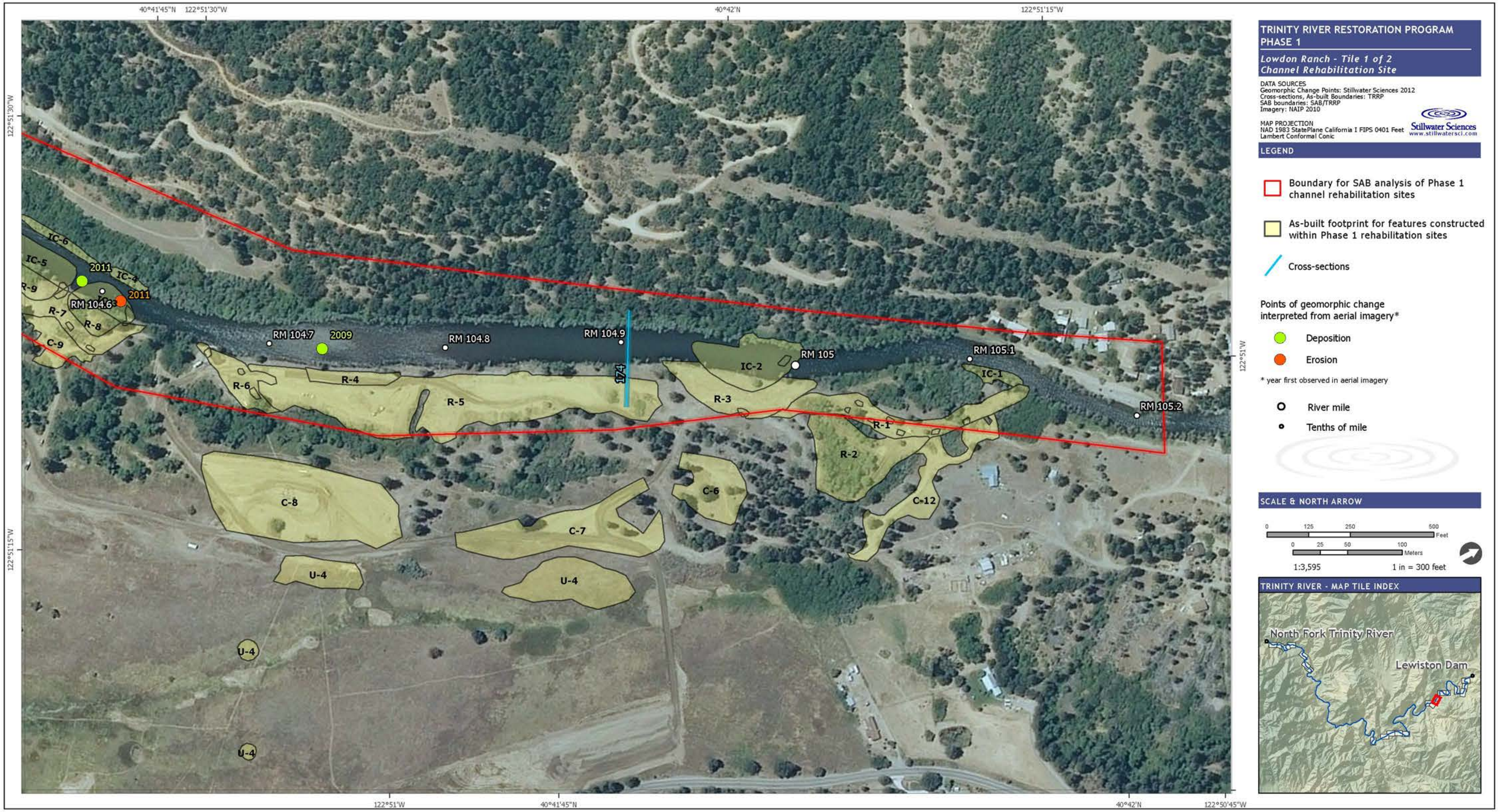


Figure 6-40a

Design Features at the Lowden Ranch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

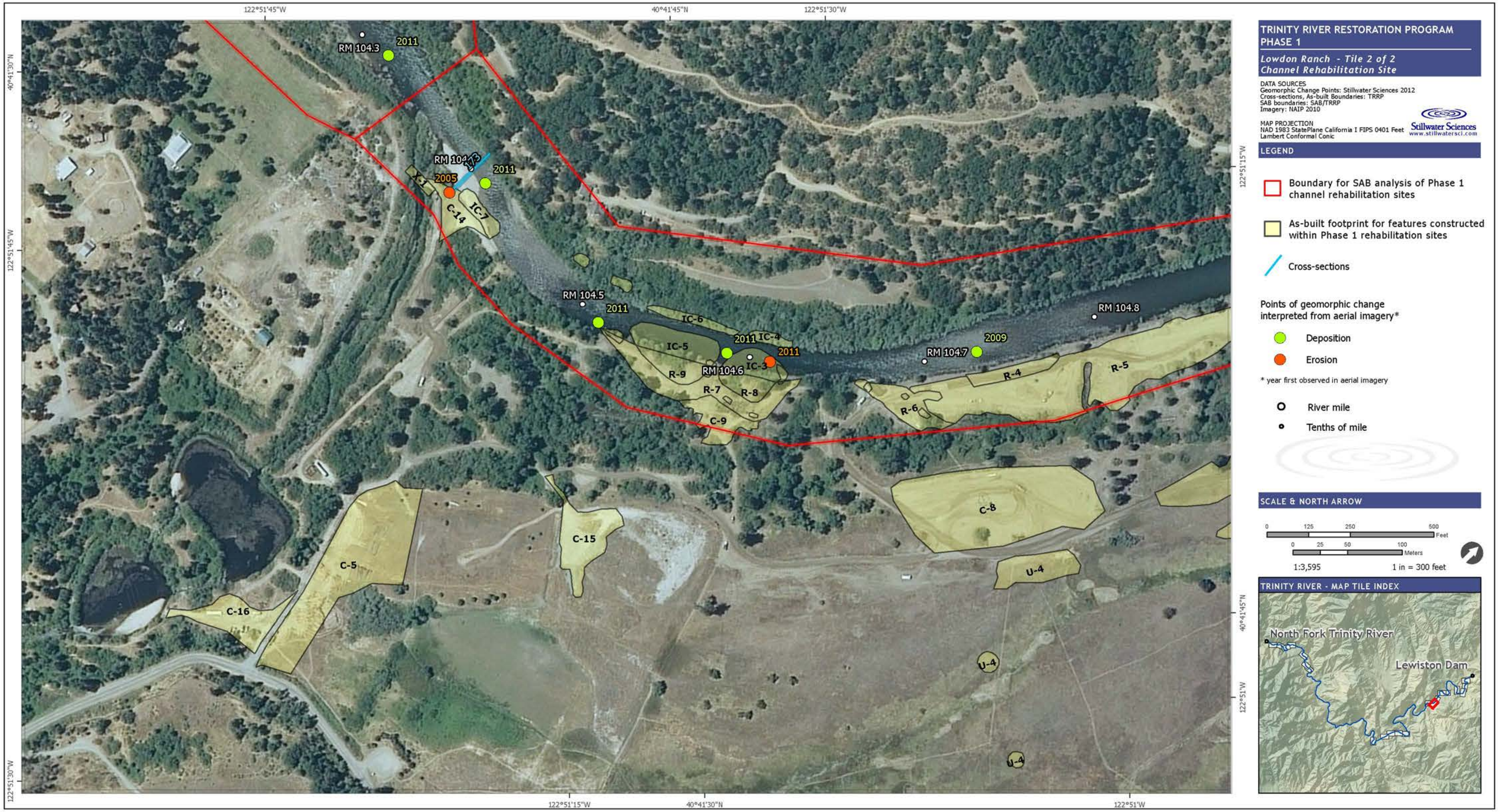


Figure 6-40b

Design Features at the Lowden Ranch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-33
Design Features Constructed at the Lowden Ranch Rehabilitation Site

Feature ID	Feature	Location (RMs)	Position
R-1	Low flow side channel (300 cfs) with wood placements	105.0 – 105.1	Left bank and floodplain
R-2	Off-stream rearing habitat (1,500 cfs) with wood placements	105.0 – 105.1	Left bank and floodplain
R-3	Main channel alignment (anastomosing) with wood placements	104.9 – 105.0	Left bank
R-4	Low bench (1,500 cfs)	104.7 – 104.8	Left bank
R-5	Floodplain lowering (6,000 cfs)	104.7 – 104.9	Left bank and floodplain
R-6	Alcove (1,500 cfs)	104.7	Left bank
R-7	Main channel alignment (anastomosing) with split-flow channels	104.5 – 104.6	Left bank and floodplain
R-8	Mid-channel island creation via terrace lowering	104.6	Left bank
R-9	Mid-channel island creation via terrace lowering	104.5 – 105.6	Left bank
IC-1	Point bar with coarse sediment addition and wood placements	105.1	Left bank
IC-2	Point bar/constructed floodplain (7,000 cfs) with alcove and chute (4,500 cfs)	105.0	Left bank
IC-3	Transverse bar (island) with coarse sediment addition	104.6	Left bank
IC-4	Main channel alignment (anastomosing)	104.6	Right bank
IC-5	Transverse bar (island) with coarse sediment addition	104.5 – 104.6	Left bank
IC-6	Main channel alignment (anastomosing)	104.5 – 104.6	Right bank
IC-7	Coarse sediment addition	104.4	Left bank

6.11.3 Geomorphic Response

Construction occurred in 2009, and no geomorphic monitoring for the site is reported as part of the WY 2009 or WY 2010 IHAP monitoring efforts (Alvarez et al. 2011; McBain & Trush and HVT 2012).

The WY 2010 Implementation Monitoring Report (Gaeuman in review) assessed geomorphic changes at the Lower Lowden/Trinity House Gulch coarse sediment augmentation site and the Lowden Ranch rehabilitation site. Detailed topographic surveys followed the WY 2010 flow release in an area encompassing the coarse sediment injection location and Wellock Pool just downstream, and in the Ponderosa Pool area downstream from Trinity House Gulch. Comparison of the 2010 data with the 2009 DTM indicated that deposition in the more upstream of the two survey areas was concentrated in the new bar that formed at the injection point. Deposition of the new bar at the injection point constricted flow, causing scour in the central part of the channel and on the right bank. Less than half of the injected coarse sediment volume was deposited in the immediate vicinity of the injection, and at least 900 cubic yards of bed material was routed through Wellock Pool. The Ponderosa Pools area was dominated by degradation rather than deposition. The results imply that a total of about 2,000 cubic yards of bed material was unaccounted for, most likely due to transport beyond the downstream boundary of the Ponderosa Pools survey area. The Lowden Ranch site was constructed in the fall of 2010, and no monitoring results relevant to design performance were available at the time the 2010 WY Implementation Report was produced (Gaeuman in review).

The WY 2011 high-flow injection at Lowden Ranch introduced approximately 2,900 tons of gravel, with the goal of developing a medial bar downstream. The Program's 2-dimensional hydraulic and morphodynamic modeling of the coarse sediment injection correctly predicted substantial aggradation near the injection point and deposition on the target bar, but under-predicted the magnitude of deposition and failed to identify some areas of scour (Gaueman 2012). Height of the target bar increased by about 2 feet, bed relief throughout the response reach increased by 25 to 30%, and a new alternate bar sequence was created. Scour through much of the response reach resulted in a loss of bed material storage. Development of the medial bar near RM 104.7 resulting from coarse sediment injection during the WY 2011 flow release was readily observed in aerial photography from August 2011.

Other notable post-construction changes that occurred during the WY 2011 release included erosion of the constructed bar (IC-3) on the margin of the island to the anastomosing channel network, aggradation at the downstream end of the island, and development of a small lateral bar immediately downstream (Table 6-34). At the downstream end of the site near the Grass Valley Creek confluence, the left bank aggraded with coarse sediment, and the bar on the opposite right bank grew.

Table 6-34
Geomorphic Changes Observed in Repeat Aerial Photography at the Lowden Ranch Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
104.7	Deposition	Medial bar growth	2007 – 2011	R-4 and R-5	Primarily 2011
104.6	Erosion	Left bank and medial bar migration	2011	IC-3	2011
104.6	Deposition				
104.5	Deposition	Left bank bar growth	2011	IC-5 and R-7	2011
104.4	Deposition	Right bank bar growth	2011	None	2011
104.4	Erosion	Left bank and bar retreat	2005 – 2011	IC-7	Primarily 2011

Few cross sections were available to analyze bed activity within the Lowden Ranch site. Of the two cross sections suitable for analysis, only cross section 173 located at the Grass Valley Creek confluence had an active bed (90% of the channel width active >200 mm) (Table 6-35). The large changes at cross section 173 during the period from March 2008 to May 2012 reflect development of a bar on the right bank, a shift in the thalweg toward the left bank, and associated left bank erosion. These patterns were also apparent in bankline changes from 2009 to 2011. The site design called for placement of 600 cubic yards of coarse sediment at this location during the WY 2010 high flow release, and the erosion and deposition patterns likely reflect evolution of this material in combination with increased coarse sediment supply from injection upstream. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 0.9-mile site length indicated relatively large variations in lateral erosion and accretion during the periods mapped (Figure 6-41).

Table 6-35

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Lowden Ranch Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3] >100 mm	Active Bed[3] >200 mm	Lateral Erosion and Deposition[4]	ω	6,000 cfs
173	104.40	62	None	March-08	May-12	6	D	0.94	0.90	0.57	56.90	20
174	104.91	58	R-5	October-06	April-08	1	C	0.06	0.03	0.11	59.81	0
				April-08	July-08	1	C	0.09	0.02		59.81	7
				July-08	April-09	1	C	0.03	0.00		59.81	0
				April-09	September-09	1	C	0.09	0.03		59.81	0
				September-09	April-10	1	C	0.11	0.02		59.81	0

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

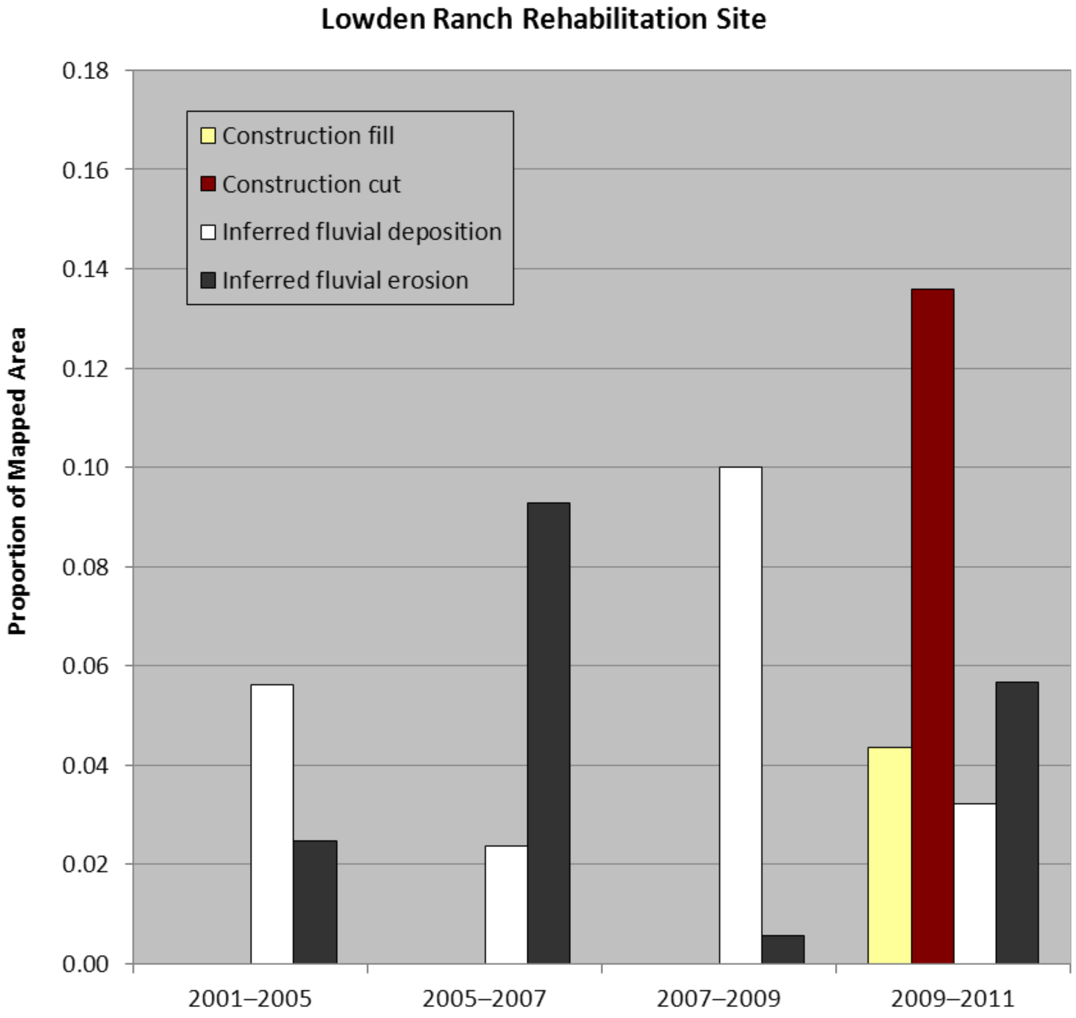


Figure 6-41

Lateral Erosion and Deposition Inferred from Banklines in the Lowden Ranch Rehabilitation Site

6.11.4 Biological Response

Pre- and post-construction evaluations at Lowden Ranch were conducted in 2009 and 2011 (after the WY 2011 high flow) at baseflows (9.9 and 10.5 $m^3 \cdot s^{-1}$ [349.6 and 370.8 cfs]). Pre- (2009) and post-construction (2011) habitat monitoring at Lowden Ranch evaluated the change in optimal (DV, C) and suitable (DV, no C; and no DV, C) habitat and indicated that in the main channel there was a proportional decrease of 1% in fry optimal habitat (DV, and C) and a proportional increase of 6% of presmolt habitat. There was also a proportional increase in suitable habitat (DV or C) that varied. Suitable habitat for fry increased approximately 124% for the DV, no C category and decreased 11% for the no DV, C category. Similarly, suitable habitat defined as DV, no C increased by 84% and suitable habitat defined as C, no DV decreased by 28% for presmolts. The proportional increase in total habitat in the main channel was 43% and 46% for fry and presmolts, respectively, after construction. Habitat increases also resulted from the construction of side channels, an alcove, and a pond/wetland. As a result, for the entire site, total fry and presmolt habitat at baseflow increased 140% and 121%, respectively, while optimal habitat increased 140% and 177% for fry and presmolts, respectively (Figure 6-42).

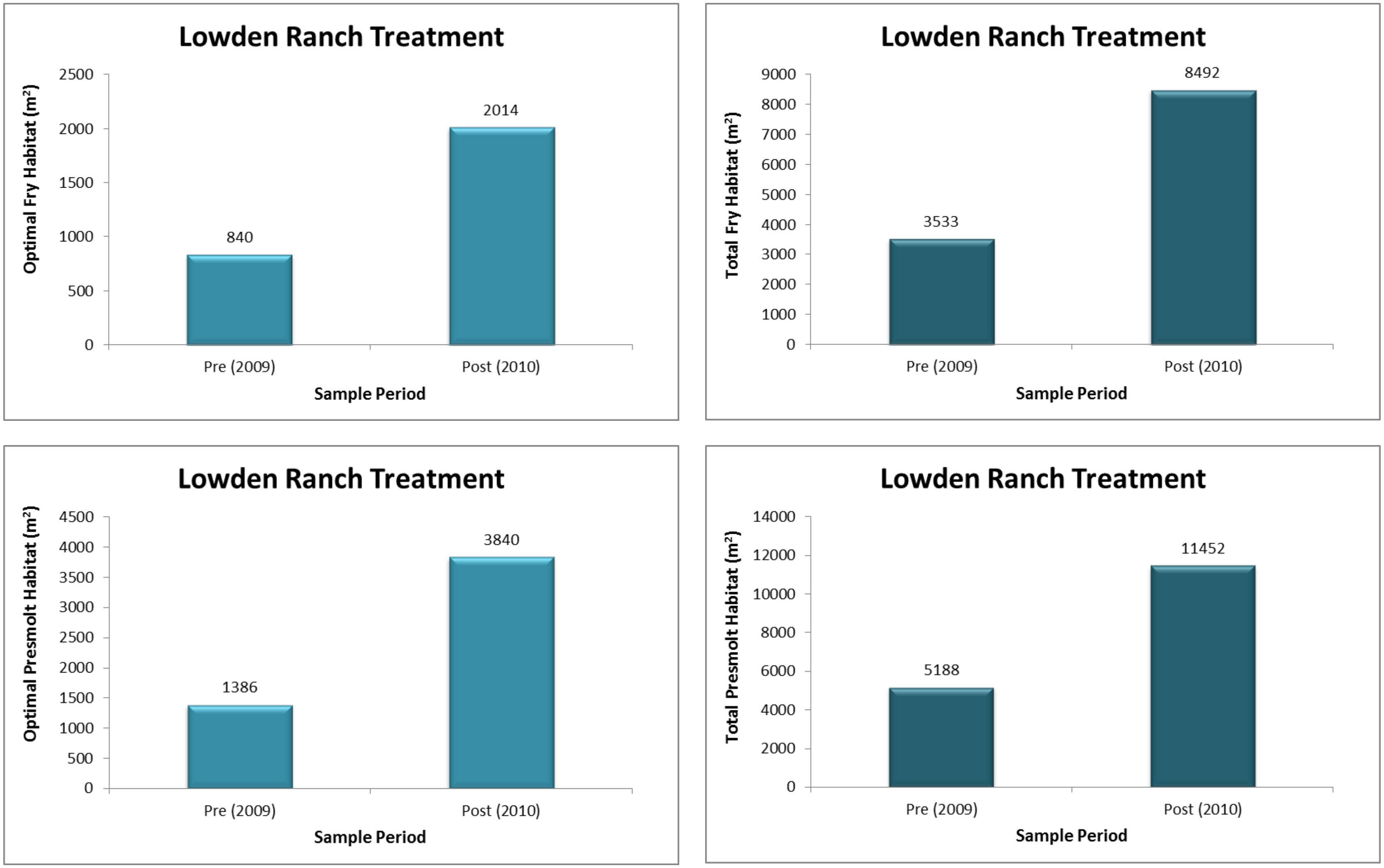


Figure 6-42

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Lowden Ranch Site in 2009 (Pre-construction) and 2011 (Post-construction)

The Lowden Ranch rehabilitation site was mapped at a range of flows over an area that included the main channel forced meander (IC-2 and R-3), the side channel/pond complex (R-1 and R-2) on river left and the gravel augmentation area (Martin et al. in review). This area exhibited increases in optimal and total habitat at all flows after construction (Martin et al. in review). The highest increases occurred at the highest comparable flow of 53.9 $m^3 \cdot s^{-1}$ (1,903 cfs). At this discharge, optimal habitat increased 641% and 452% for fry and presmolt respectively. For the same flow, fry and presmolt total habitat increased 231% and 252%. The shape of the stream flow to habitat curve changed somewhat for total habitat (Martin et al. in review). A decrease in total habitat was present at lower flows; however, the slope of the curve at higher flows increased after construction. The shape of the flow-optimal habitat curve changed dramatically (Martin et al. in review). Pre-construction, optimal habitat peaked at 12.7 $m^3 \cdot s^{-1}$ (448 cfs). After construction, optimal habitat increased as the discharge rose above 12.7 $m^3 \cdot s^{-1}$ (448 cfs). There was no suitable fry habitat pre-construction at 53.9 $m^3 \cdot s^{-1}$ [1,903.5 cfs] in the DV, no C category. This illustrated the confined, riparian dominated nature of the channel edges at Lowden Ranch prior to rehabilitation. Post-construction fry suitable habitat (DV, no C) values were estimated at 935 m^2 (10,064 square feet).

Changes to rearing habitat from specific rehabilitation actions are summarized below from Martin et al. (in review).

Mainstem habitat areas were isolated from off-channel habitat to evaluate the effect of the two treatment types (forced meander and gravel augmentation). Total fry habitat in the mainstem at winter baseflow increased by 47% after construction and presmolt total habitat increased 49% after construction in the mainstem. There was a 1% decrease in optimal habitat for fry and an increase of 6% for presmolt. The increases in mainstem total habitat resulted from two changes. The first adjustment occurred where the IC-2 forced meander was constructed. An alcove was included on the downstream end of the bar. This alcove contributed to the habitat increases as well as the eddy formed on river left downstream of the meander.

To quantify changes in habitat initiated by the meander construction, an entire wavelength of river was analyzed, assuming the constructed forced meander was half of a wavelength. At winter baseflow, total presmolt habitat within this section of river increased 1,036 m^2 (11,151 square feet) or 77% after construction. Rearing habitat increased within this section at all measured flows. The second mainstem section that exhibited positive increases in habitat occurred downstream of the gravel injection site adjacent to the R-4 low bench. The mid-channel bar area (area above low flow wetted edge) increased from 236 to 558 m^2 (2,540 to 6,006 square feet), a 136% increase. It also migrated towards the left bank (looking downstream), which caused an increase in slow water below the bar. As a result, winter baseflow total habitat increased 1,048 m² (11,281 square feet), or 69%, upstream and downstream of the bar where slow water was created. The post-construction flow-habitat curve exhibited a dip around the 34 $m^3 \cdot s^{-1}$ (1,200 cfs) point. This occurred when the water overtopped the bar. Habitat began to increase again at higher flows as the water spread out across the left bank (Martin et al. in review).

Constructed off channel habitats including the R-1 side channel, R-2 ponded area, and R-6 alcove/high flow channel were evaluated to compare habitat creation (Martin et al. in review). The three features did not exist prior to construction at the surveyed flows. Therefore results are focused on post-construction results. Also, optimal habitat results for all three features exhibited a similar response as total habitat (the curve looked the same, but with lower values); therefore, the reporting focuses on total habitat. The ponded area had the highest habitat values of the three features at all flows except 23.0 $m^3 \cdot s^{-1}$ (812 cfs) where the alcove/high flow channel had slightly more habitat (Martin et al. in review). It was at this flow that the alcove became a connected and flowing side channel, which explains the large increase in habitat. Percent optimal habitat was calculated for all three features at all flows. The ponded area and alcove/high flow channel had the highest values observed of any features evaluated to date. Percent optimal habitat within ponded area ranged from 85% at winter baseflow to 63% at the highest flows. Percent optimal habitat for the side channel ranged from 33% (at 12.7 $m^3 \cdot s^{-1}$ [448.5 cfs]) to 67% at the highest flow and the alcove/high flow channel had values ranging from 29% (at 12.7 $m^3 \cdot s^{-1}$ [448.5 cfs]) to 79% (at 37.4 $m^3 \cdot s^{-1}$ [1,320.8 cfs]).

Overall, Lowden Ranch had the third highest optimal habitat density observed at any rehabilitation site (i.e., 5.2 m²/m), following the Sven Olberston and Sawmill rehabilitation sites (Martin et al. in review). Lowden Ranch also had the third highest total habitat density amongst monitored sites.

Chinook salmon redds (spring and fall Chinook combined) were counted within the Lowden Ranch site, untreated sites (controls), and other rehabilitation sites within the Limekiln Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 29 to 67, which made up 3.9 to 7.2% of the redds counted within the Limekiln Reach and 0.8 to 2.1% of the redds counted in the Trinity River (Figure 6-17). Mean densities of Chinook salmon redds within the Lowden Ranch site were not significantly different from those counted in control sites (Figure 6-17).

Chinook and coho salmon carcasses were sampled within the Lowden Ranch site during 2009 to 2011. Three female coho carcasses were collected in the site during the survey period. Numbers of female Chinook salmon carcasses sampled within the site during 2009 to 2011 ranged from 8 to 18 (Figure 6-18), which made up 2.0 to 3.8% of the female carcasses sampled within the Limekiln Reach and 1.1 to 2.6% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Lowden Ranch site were significantly less than those in the control sites (Figure 6-18).

6.12 Trinity House Gulch

Location: RMs 104.0 to 104.4
Year constructed: 2010

6.12.1 Design Objectives

The goals of the Trinity House Gulch rehabilitation design were to increase and sustain salmonid habitat between 8 and 198 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs), and to increase and sustain riparian habitat while preserving continuity of canopy that is important for wildlife. Specific site design objectives included increasing channel sinuosity, decreasing radius of curvature, and increasing channel complexity by constructing transverse bars and a forced meander, and by selectively removing mature riparian vegetation along the low water's edge. Additional geomorphic objectives included increasing coarse sediment storage, increasing large wood storage, and encouraging channel migration. The design intended to provide immediate habitat for juvenile Chinook and coho salmon and steelhead. The design also intended to preserve existing riparian vegetation, promote natural riparian vegetation recruitment, increase woody riparian structural diversity, improve local seed sources for natural riparian regeneration, and reduce the risk of riparian encroachment. The general reach-scale design strategy for the site stated that the addition of coarse sediment and mechanical rescaling of channel banks, in combination with flow releases, was expected to promote dynamic physical processes that were intended to sustain complex channel morphology.

6.12.2 Site Description

The Trinity House Gulch rehabilitation site is located immediately downstream of Grass Valley Creek. The site consisted of three in-river and three in-channel construction elements (Figure 6-43; Table 6-36). A large floodplain along the left bank (R-1) was lowered to inundate at flows of 170 $m^3 \cdot s^{-1}$ (6,000 cfs), provide refugia from high-flow conditions for fry and juvenile salmonids, increase geomorphic complexity, leave a local seed source for natural riparian recruitment (select riparian vegetation was preserved), and provide a surface that could sustain riparian vegetation. A low-flow channel (R-2) was designed to flow across the back edge of the constructed floodplain and provide spawning habitat at flows between 8 and 28 $m^3 \cdot s^{-1}$ (300 and 1,000 cfs). The side channel was designed to include pools and riffles and an alcove at the downstream end. Selected trees were retained along the low-flow side channel; large wood, willow clumps, and sedges were placed along the side channel to provide immediate cover and shade for juvenile salmonids at flows between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs).

A series of constructed bars (point bars IC-1, IC-2, and IC-3) were designed to reduce the slope of the mainstem channel and foster channel migration into a forced meander (R-1), thereby increasing sinuosity and geomorphic complexity. The forced meander (R-1) was designed to encourage channel migration, increase channel sinuosity, and improve rearing habitat for Chinook salmon, steelhead, and coho salmon fry and juveniles when flows are between 8 and 57 $m^3 \cdot s^{-1}$ (300 and 2,000 cfs).

The Trinity House Gulch tributary channel was realigned (R-3) with an historical channel to provide better adult and juvenile salmonid access into the tributary. A terrace was designed to hold all of the material generated as a result of the floodplain construction without impacting the 100-year floodplain, store coarse sediment that could be used in future coarse sediment augmentation programs, and provide a suitable area for upland revegetation.

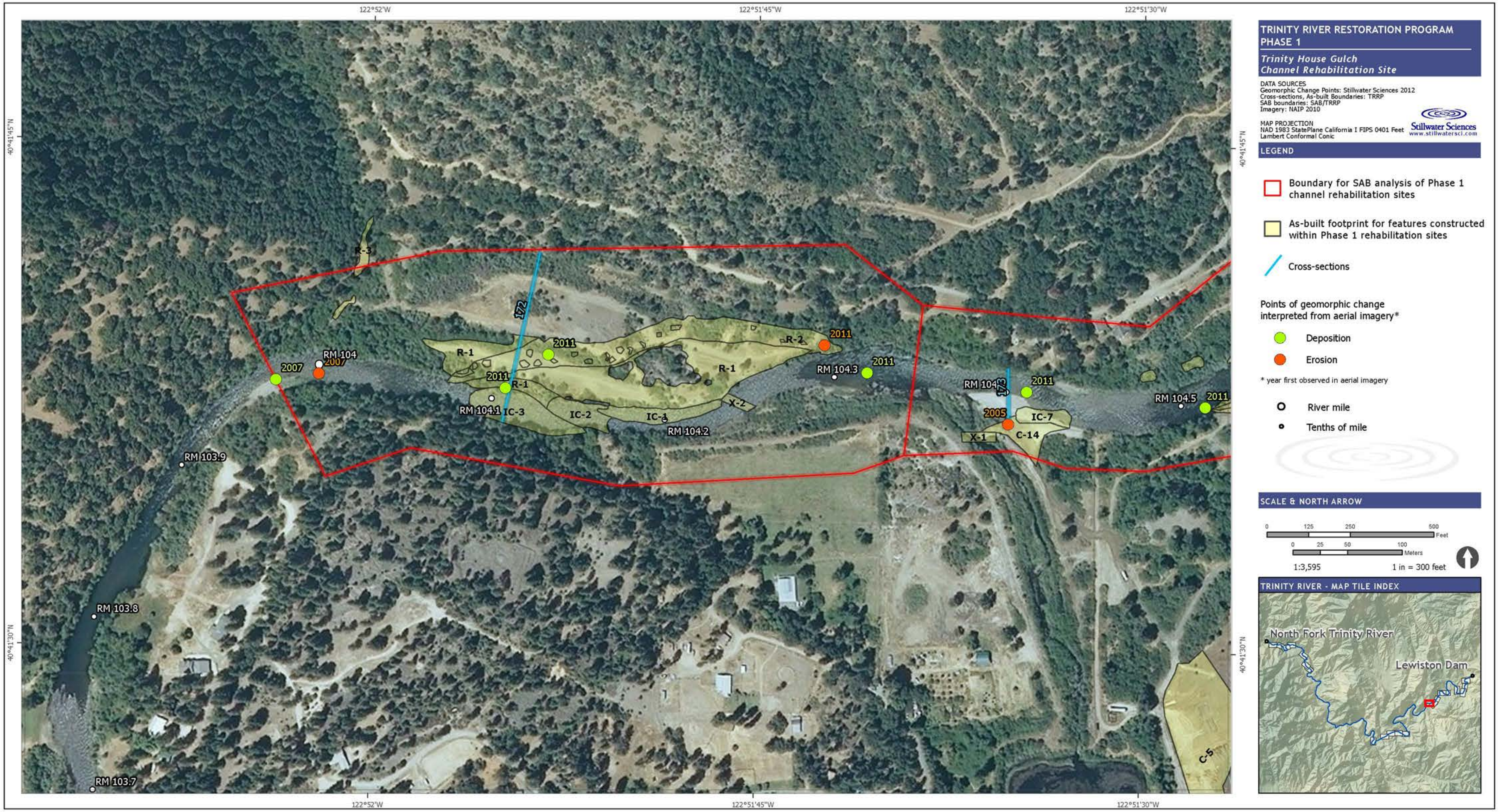


Figure 6-43

Design Features at the Trinity House Gulch Rehabilitation Site, including Cross Sections Analyzed for Active Bed Width, Erosion, and Deposition Observed in Aerial Photography

Table 6-36
Design Features Constructed at the Trinity House Gulch Rehabilitation Site

Feature ID	Feature	Location (RM)	Position[c]
R-1	Floodplain (6,000 cfs) with revegetation	104.1 – 104.3	Right bank and floodplain
	Main channel alignment (meandering)	104.1	Right bank
R-2	Low flow side channel (300 cfs) with benches, alcove, and wood placements	104.1 – 104.3	Right bank and floodplain
R-3	Tributary (Trinity House Gulch) enhancement	104.0	Right bank and floodplain
IC-1	Point bar (500 cfs) with coarse sediment addition (0.125 – 4 in. dia.)	104.2	Right bank
IC-2	Transverse bar (500 cfs) with coarse sediment addition (0.125 – 4 in. dia.)	104.1 – 104.2	??
IC-3	Point bar (500 cfs) with coarse sediment addition (0.125 – 4 in. dia.) and wood placements	104.1	??

6.12.3 Geomorphic Response

Construction of the site occurred in 2010 Post-construction geomorphic monitoring began in WY 2011 with cross section surveys, bed mobility, and bed scour and redeposition monitoring at cross section 1680+15 and cross section 1689+75 (HVT and McBain & Trush 2012). Trinity House Gulch showed significant geomorphic changes following the WY 2011 release, in part due to the recently constructed surfaces experiencing high flows and upstream coarse sediment augmentation. Substantial changes to designed features indicate that some design objectives were not met (e.g., side channel elimination at cross section 1689+75), while other changes show that design objectives were met (channel migration, increased geomorphic complexity). At cross section 1680+15, most change within low-water channel below 13 $m^3 \cdot s^{-1}$ (450 cfs), including an approximately 25 m shift in the main channel thalweg toward the left bank, 0.6 m scour of the constructed point bar on the left bank, 1.8 m of thalweg aggradation, and up to approximately 0.6 m of side channel aggradation. Substantial topographic change at cross section 1689+75 included capture of the side channel by the main channel, removal of the berm separating the side channel from the main channel, an approximately 24 m shift in the main channel thalweg toward the right bank, and up to 1.2 m of aggradation across the left bank bar. Bed mobility objectives were met, and bed scour objectives were partially met.

Interpretation of aerial photography and banklines suggested that lateral bar formation and bank retreat near the Grass Valley Creek confluence increased local channel sinuosity. The entrance to the constructed low-flow side channel (R-2) eroded, and the side channel outlet and associated constructed meander (R-1) significantly aggraded in 2011 (Table 6-37). The three constructed bars (IC-1, IC-2, and IC-3) completely scoured in 2011. At the downstream end of the site near RM 104.0, the lateral bar migrated downstream.

Table 6-37
Geomorphic Changes Observed in Repeat Aerial Photography at the Trinity House Gulch Rehabilitation Site

RM	Geomorphic Change	Description	Aerial Photographic Interval	Associated Design Feature	Associated High Flow Event
104.3	Deposition	Left bank lateral (point) bar growth	2011	None	2011
104.3	Erosion	Right bank lateral bank retreat	2011	R-2	2011
104.1 – 104.2	Deposition	Side-channel filling	2011	R-2	2011
104.1	Deposition	Right bank lateral bar growth (within channel realignment)	2011	R-1	2011
104.0	Erosion	Left bank lateral (point) bar migration	2005 – 2007	None	2006
104.0	Deposition				

Like the Lowden Ranch rehabilitation site, few cross sections were available to analyze the activity within the Trinity House Gulch rehabilitation site. Suitable cross section data that did not include the effects of construction was limited to cross section 172, which showed a relatively active bed (29% of the channel width active >200 mm) during WY 2011 (Table 6-38). Cross section 172 bisects a constructed bar (IC-3), constructed meander (R-1), and constructed low flow side channel (R-2). The large changes that occurred during WY 2011 reflect erosion of the main channel along the left bank and massive aggradation of the right bank bar and side channel exit. These patterns were also apparent in bankline changes from 2009 to 2011. Although aggradation of the side channel exit was not intended by the design, it is not clear from the design documents if development of the bar along the right bank was intended. Analysis of lateral channel erosion and deposition inferred from changes in bankline positions over the 0.4-mile site length indicated relatively large variations in lateral erosion and accretion during the periods mapped (Figure 6-44).

Table 6-38

Active Bed Width and Inferred Lateral Erosion and Deposition at Cross Sections within the Trinity House Gulch Rehabilitation Site[6]

Cross Section ID	RM	Data Frame	Feature ID	Survey 1	Survey 2	Project Phase[1]	Time Period[2]	Active Bed[3]		Lateral Erosion and Deposition[4]	ω	6,000 cfs
								>100 mm	>200 mm			
172	104.11	64	IC-3, R-1, R-2	March-08	March-11	2	C	0.95	0.88	0.09	52.87	12
				March-11	August-11	4	D	0.40	0.29	0.01		8

Notes:

1 Project phases: (1) change prior to construction, (2) change due to construction, (3) change following construction but prior to a high flow, (4) change due to the first post-construction high flow, (5) change after the first post-construction high flow, (6) change due to construction and subsequent high flows combined

2 Time periods: (A) period prior to the 2006 high flow release, (B) period including the 2006 high flow release, (C) period between the 2006 and 2011 high flow releases, (D) period including the 2011 high flow release

3 Fraction of 11,000 cfs cross section width with active bed thickness (erosion and deposition) greater than 100 mm (average D_{50}) and 200 mm (average D_{84})

4 Total area of lateral erosion or deposition inferred from changes in bankline between successive aerial surveys, expressed as a fraction of the total area mapped in the 200-m data frame segment

5 Indices relating geomorphic change at cross sections to flow and sediment factors responsible for change: ω = unit stream power; 6,000 cfs = number of days during the period between surveys that mean daily flow measured at the USGS gaging station in the associated reach exceeded 6,000 cfs.

6 Surveys that include the WY 2011 high flow release are shaded gray

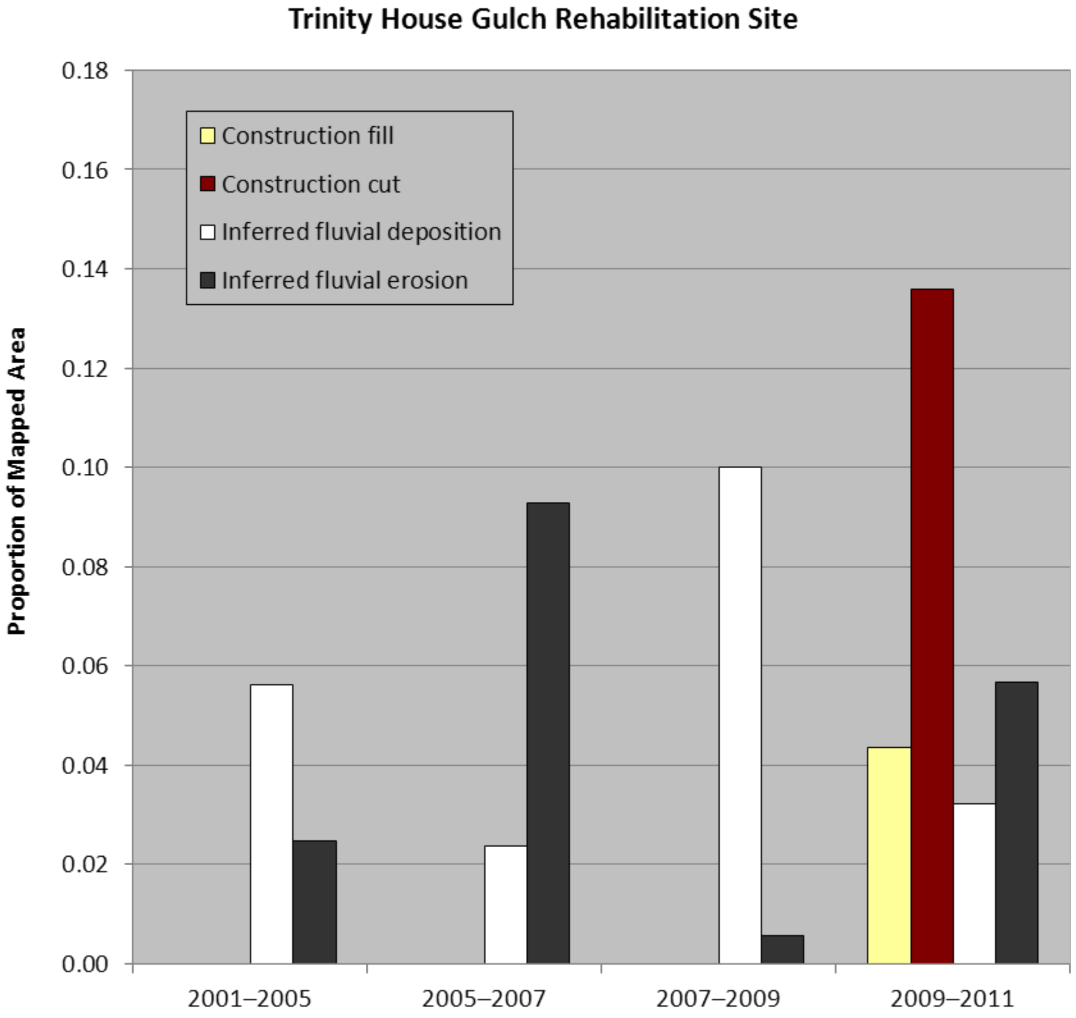


Figure 6-44

Lateral Erosion and Deposition Inferred from Banklines in the Trinity House Gulch Rehabilitation Site

6.12.4 Biological Response

Pre- and post-construction evaluations were conducted in 2010 and 2011 (after WY 2011 high flow) at baseflows (14.3 and 13.6 $m^3 \cdot s^{-1}$ [505.0 and 480.3 cfs]). Construction designs at Trinity House Gulch included gravel bar additions (IC-1 and IC-3), a main channel meander (R-1) and low flow side channel construction (R-2).

In the main channel, there was a proportional decrease of 57% and 51% in fry and presmolt optimal habitat (DV, and C), respectively. There was also a proportional increase in suitable habitat (DV or C) that varied. Suitable habitat for fry increased approximately 79% for the DV, no C category and decreased 39% for the no DV, C category. Similarly, suitable habitat defined as DV, no C increased by 66% and suitable habitat defined as C, no DV decreased by 44% for presmolts. The proportional increase in total habitat in the main channel was 13% and 19% for fry and presmolts, respectively, after construction. Habitat increases also resulted from the construction of an alcove. Construction of the alcove provided 115 m^2 (1,238 square feet) and 160 m^2 (1,722 square feet) of optimal fry and presmolt habitat, respectively, and 559 m^2 (6,017 square feet) and 662 m^2 (7,126 square feet) of total fry and presmolt habitat, respectively. For the entire site, total fry and presmolt habitat at baseflow increased 45% and 49%, respectively, while optimal habitat decreased by 32% and 23% for fry and presmolts, respectively (Figure 6-45).

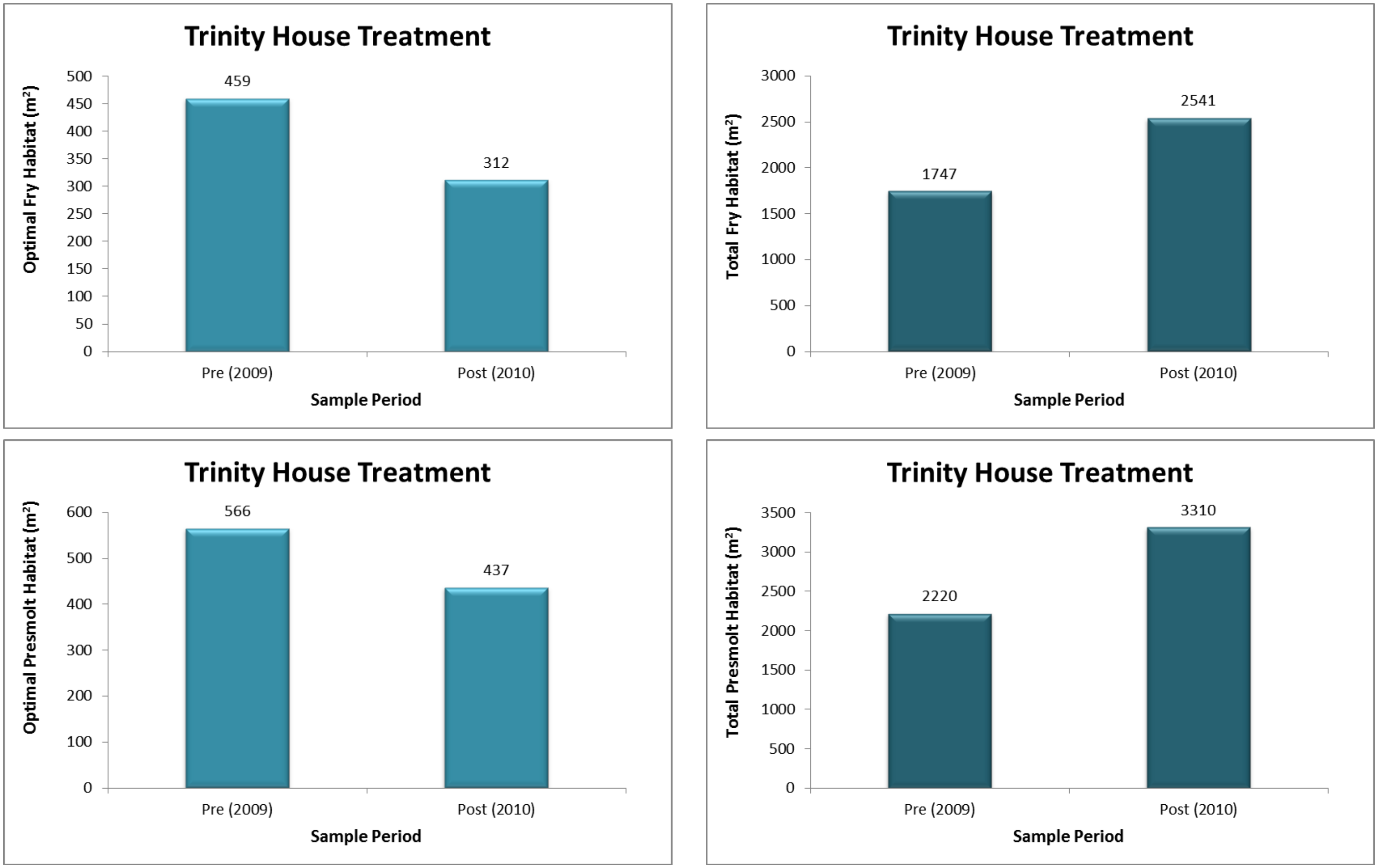


Figure 6-45

Optimal (DV, C) and Total Fry and Presmolt Habitat Measured at the Lowden Ranch Site in 2009 (Pre-construction) and 2011 (Post-construction)

The high flow event that occurred after construction in May 2011 closed off the side channel entrance to low flows and relocated much of the gravel that was placed (Martin et al. in review); 61% of the increase in total habitat at the site resulted from the alcove still being present at the downstream end of the side channel after construction and after high flows (Martin et al. in review). Much of the constructed gravel bars were mobilized and the R-1 area on river right (forced meander) was filled in with alluvial material. Therefore, changes in habitat were not analyzed around these features (Martin et al. in review).

Chinook salmon redds (spring and fall Chinook combined) were counted within the Trinity House Gulch site, untreated sites (controls), and other rehabilitation sites within the Limekiln Reach during 2009 to 2011 (based on data within the data frame). During 2009 to 2011, numbers of redds ranged from 2 to 7, which made up 0.3 to 0.8% of the redds counted within the Limekiln Reach and 0.1 to 0.2% of the redds counted in the Trinity River (Figure 6-17). Mean densities of Chinook salmon redds within the Trinity House Gulch site were less than those counted in control sites (Figure 6-17).

Chinook and coho salmon carcasses were sampled within the Trinity House Gulch site during 2009 to 2011. Three female coho carcasses were collected in the treatment site during the survey period. Numbers of female Chinook carcasses sampled within the treatment site during 2009 to 2011 ranged from 6 to 10 (Figure 6-18), which made up 1.3 to 1.8% of the female carcasses sampled within the Limekiln Reach and 0.2 to 0.5% of the female carcasses sampled in the Trinity River. Mean densities of female Chinook salmon carcasses in the Trinity House Gulch site were less than those in the control sites (Figure 6-18).

7 SUMMARY

The restoration strategy recommended in the TRFEFR (USFWS and HVT 1999) and adopted in the ROD (USDOI 2000) intends to improve and maintain fish and wildlife resources in the mainstem Trinity River through a combination of mechanical channel rehabilitation, flow and sediment management, and watershed restoration (USDOI 2000). Evaluating responses to rehabilitation in the Trinity River management reach must therefore consider the combined effects of these actions at site and reach scales.

Performance measures established in the hierarchy of IAP objectives (TRRP and ESSA 2009) provides the necessary framework to identify responses at site and reach scales and evaluate the overall progress toward achieving restoration goals during Phase 1. Assessing physical and biological responses to the Program's restoration actions within rehabilitation sites based on specific IAP objectives, however, is limited by lack of monitoring of rehabilitation sites and untreated control reaches at multiple points in time following post-construction, channel-forming flows. The WY 2011 release was the largest by the Program since mechanical rehabilitation began, and critical information about the geomorphic and habitat responses to the event at the site, reach, and system scales is forthcoming from work being conducted by the Program Partners.

Where detailed physical monitoring was conducted from WY 2009 to WY 2011, not all priority IAP objectives could be assessed using the methods employed, and of those that were assessed, results were often inconclusive due to a high degree of variability within the limited spatial and temporal scales of measurement. In addition, many of the sites and design features within sites have not had sufficient exposure to repeated channel-forming flows since their construction to evolve as intended by design. These factors point to the need for more spatially distributed monitoring approaches that are applied to more sites (including control reaches), as well as the need for more exposure to channel-forming flows before critically judging the overall effectiveness of rehabilitation actions based on IAP objectives.

Given these factors, the following conclusions can be drawn regarding the relative effectiveness of channel rehabilitation within the context of relevant IAP objectives.

7.1 Geomorphic Responses

The distinction between alluvial and semi-alluvial channel boundaries provides the primary geomorphic context for channel rehabilitation within the Trinity River management reach. The legacy of disturbance, however, has left a complex overprint on channel-forming processes occurring within the present, post-ROD flow and sediment regime. The most meaningful geomorphic context for rehabilitation may now be the site scale, where juxtaposition of non-alluvial features, valley forms, mining debris, and deposits left by historic floods constrain the size, frequency, and relief of alluvial features and associated habitats that can be formed by rehabilitation practices. The Channel Rehabilitation Design Guidelines for the Trinity River (HVT et al. 2011) provides comprehensive and detailed recommendations for planning rehabilitation treatments based on these types of features at site and reach scales. Forthcoming site-specific analysis of the effects of historical disturbances on contemporary channel evolution (Krause 2012a) and forthcoming detailed geomorphic mapping by the USGS (Curtis and Guerrero 2012) will advance the Program's ability to plan and design restoration actions within the opportunities and constraints of specific channel types. With the recent availability of detailed DTMs developed from annual channel bathymetry surveys (GMA 2012), appropriate treatments and anticipated responses in alluvial and semi-alluvial channels can be evaluated using 2-dimensional hydrodynamic and morphodynamic models, like those used to evaluate responses to coarse sediment injection at the Lowden Ranch site in 2011 (Gaeuman in review).

Physical responses to channel rehabilitation and the relative effectiveness of these actions at achieving Program goals related to dynamic and complex channel morphology at the site and reach scales are qualitatively discussed within the context of IAP Objective 1, including the following four sub-objectives (see Table 1-2):

- Sub-objective 1.1: Increase physical habitat diversity and availability
- Sub-objective 1.2: Increase coarse sediment transport and channel dynamics
- Sub-objective 1.3: Increase and maintain coarse sediment storage
- Sub-objective 1.4: Reduce fine sediment storage in the mainstem Trinity River

7.1.1 Physical Habitat Diversity and Availability

Recognition of specific linkages between geomorphic change and baseflow habitat formation at Phase 1 channel rehabilitation sites is limited by physical and biological (i.e., habitat area) data collected at different times with different goals and objectives, and in a manner that was not designed to facilitate linking geomorphic process and habitat change. At many of the sites where geomorphic data have been collected at multiple points in time following construction, biological habitat data have typically been collected only once shortly after construction. There has been a limited amount of time (i.e., repeated exposure to channel forming flows) for flow and sediment management to alter habitat diversity and availability at the system scale or achieve the dynamic morphology intended by many in-channel design features within rehabilitation sites.

At this point in the Program's implementation, objectives related to increasing physical habitat diversity and availability (sub-objective 1.1) are closely tied to the relative effectiveness of direct channel manipulations at individual rehabilitation sites (see Section 6). Results from geomorphic monitoring at channel rehabilitation sites from WY 2009 through WY 2011 suggests that some site design objectives related to physical habitat diversity (e.g., increasing bars, side channels, alcoves, and other complex alluvial features) are being met (HVT and McBain & Trush 2012). Similar changes have been observed at other sites since construction, although the Program lacks documentation quantifying these changes. Post-construction development of bar and pool morphology is evident at some sites (e.g., Mid-Valdor Gulch at cross section 187 and Conner Creek at cross section 204). Topographic changes along cross sections suggested objectives to increase bars, side channels, alcoves, and other complex alluvial features were largely met; that many alluvial features are being maintained, and new features are being created. Topographic changes along cross sections also suggest changing channel sinuosity at some sites (e.g., Sawmill at cross section 116). Six of the twelve pools monitored at cross sections within GRTS panels became deeper in WY 2011, and four of those six pools had deposition on their adjacent bars. Over the short available record, all of the monitored channel rehabilitation sites showed bed level fluctuations within the low flow (i.e., 13 $m^3 \cdot s^{-1}$ [450 cfs]) channel that met TRFEFR and IAP objectives (HVT and McBain & Trush 2012).

Feathered edging and floodplain lowering, the earliest site treatments administered by the Program at rehabilitation sites, have had relatively little influence on the size, frequency, and topographic relief of bar and pool morphology. Constructed floodplains that increase channel widths and reduce bed shear stresses might be expected to trend toward depositional responses along channel margins with less dynamic in-channel change, as evidenced by changes observed on constructed floodplains within the Connor Creek and Valdor Gulch sites. Feathered edging and floodplain lowering have likely increased substrate patch diversity by creating more hydraulic complexity and increasing bed material sorting, but there is little information documenting this response. More emphasis could be placed on documenting the effects of rehabilitation actions on bed surface texture and particle size as it pertains to physical habitat formation.

In-channel rehabilitation treatments that involve constructing bars through gravel placement, bank and floodplain excavation to create forced channel meanders, and engineered log structures have created greater channel complexity. Design of in-channel features has evolved considerably from the initial application of constructed bars designed to increase sediment storage and channel complexity, such as those at the Lewiston Four sites, to more integrated combinations of constructed bars, forced meanders, and adjacent lowered floodplains designed to dramatically steer flow, such as those at the lower Sawmill, lower Reading Creek, Lowden

Ranch, and Trinity House Gulch sites. The immediate effects of these in-channel features have been to increase channel sinuosity, reduce radius of curvature, and in some cases alter local channel morphology. The limited work by the Program to assess the effectiveness of these features at steering flow during channel-forming flows, as intended by design, indicates only modest steering. Most of these treatment types have only recently been implemented and in most cases, the long-term effects of these treatments have not yet been evaluated. This is also the case for engineered log structures like those constructed at Lowden Ranch, for which little is known about their performance relative to design objectives. Combinations of in-channel features placed to utilize existing planform curvature and local forcing elements, offers perhaps the most effective approach to increasing the size, frequency, and topographic relief of bar and pool sequences.

Monitoring by the Program Partners is not designed to rigorously evaluate changes in channel sinuosity and channel migration resulting from thalweg shifts and bank erosion. The relatively small amount of lateral erosion and accretion inferred from changes in bankline position suggests that changes in sinuosity have been small, but that the 2011 ROD high flow release effectively increased lateral erosion throughout the management reach (Figure 7-1). The relationship between bankline changes, lateral erosion and accretion, and increased sinuosity requires further exploration.

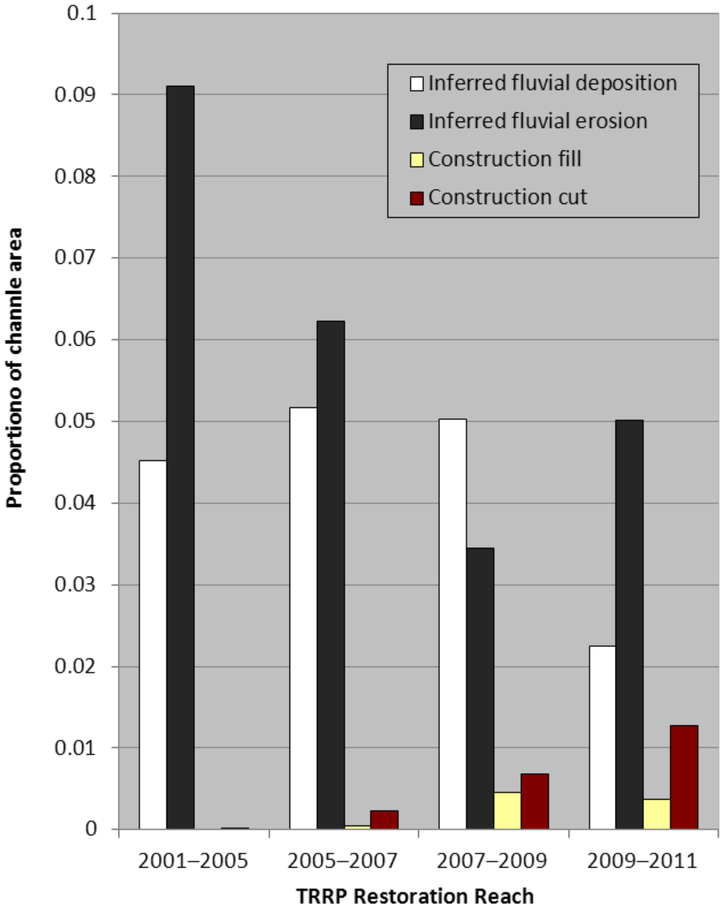


Figure 7-1
Total Inferred Lateral Erosion and Accretion in the Trinity River Management Reach

To thoroughly evaluate physical responses at rehabilitation sites under the IAP framework, most of the specific objectives related to physical assessment require a longer monitoring period that includes repeated exposure to channel-forming flow events and planform topography adequate to conduct isopach analyses at site, reach, and system scales rather than topographic analysis at cross sections. Most rehabilitation features are now designed to work in combination over various length scales, and evaluation of their performance relative to design objectives is better suited to analysis of spatially distributed bed elevation changes than bed elevation changes at cross sections. The Program now develops post-construction DTMs and annually surveys channel bathymetry over the management reach following high flow releases (GMA 2012). These data will be critical in characterizing spatially distributed bed elevation changes; assessing the size, frequency, and relief of bar/pool sequences; and calculating site or unit specific changes in sediment storage. These data will also provide the means to use 1-dimensional and 2-

dimensional hydrodynamic and morphodynamic models to predict channel response under different design alternatives and flow management scenarios.

7.1.2 Coarse Sediment Transport and Channel Dynamics

Specific Level 3 objectives identified in the IAP (Table 1-2) for increasing coarse sediment transport and channel dynamics include: 1) frequently exceeding channel migration, bed mobilization, and bed scour thresholds; 2) encouraging bed-level fluctuations on annual to multi-year time scales; 3) increasing and maintaining target coarse sediment transport rates; and 4) routing coarse sediment through all reaches.

Management objectives for bed mobility were partially or fully met during the WY 2009 ROD flow releases (Dry WY), but based on the variable occurrence and depth of scour and the lack of apparent spatial patterns, management objectives for scour were not fully met (Alvarez et al. 2011). Cross sections showed only minor bed level fluctuations in most instances, indicating maintenance of features but a lack of dynamic channel forming processes (Alvarez et al. 2011). During the WY 2010 ROD release (Normal WY), the bed surface was partially to fully mobilized at all monitoring sites and measured scour depths indicated minor bed material reworking by flows between 57 and 113 $m^3 \cdot s^{-1}$ (2,000 and 4,000 cfs) (McBain & Trush and HVT 2012). Most channel cross sections still showed little change. Responses at rehabilitation sites were varied, with some design features performing as intended, some experiencing unintended changes, and some experiencing little change (discussed in detail for individual sites in Section 6). The WY 2011 ROD release met TRFEFR and ROD bed mobilization objectives for the monitored GRTS Panel 2, 3, and 4 sites. The spring 2011 ROD release was successful in mobilizing all surfaces monitored (n=33), averaging 92% mobilization for the D84 (range = 36% to 100%) and averaging 97% mobilization for the D50. The spring 2011 ROD release partially met the TRFEFR bed scour objective for an Extremely Wet WY. Of the 101 scour chains recovered, 49 recorded relative scour less than the local D84, 20 chains recorded relative scour between 1.0 and 2.0 D84 diameters, and 32 chains recorded relative scour greater than or equal to 2.0 D84. Scour occurred locally, sometimes in isolated areas across the monitoring surface. Measured deposition did not correlate well with the measured scour.

Active bed width (i.e., fraction of cross section width undergoing net scour or fill equal to or greater than the approximate average D_{50} and D_{84}) at cross sections is one potentially useful measure of channel dynamism. We statistically tested the hypothesis that rehabilitation treatments are effective at increasing active bed width in response to high flow compared to changes in active bed width prior to construction. No significant differences ($p < 0.05$) were detected in pre- and post-treatment active bed width at cross sections bisecting in-channel or in-river features, including when flow exceedance and stream power variables were included as covariates. However, of the 35 cross section pairs we analyzed where surveys bracketed the WY 2011 high flow release, 27 (77%) had an active bed insofar as 20% of the width showed net scour or fill of 200 mm (8 inches) or more. These results suggest that the WY 2011 ROD high flow release was effective at increasing channel dynamism through bed mobilization and scour. Additional analysis of active bed width conducted over a range of important reference water surface elevations at a cross section would help inform the effectiveness of design approaches tied to specific flow magnitudes.

High flow releases, gravel augmentation, and in-channel treatments undoubtedly enhance bed activity, but these effects may not be reflected by existing cross section surveys and bed mobility/scour experiments. Data collected at existing cross sections is limited to specific locations that may not represent overall channel behavior or the performance of a specific design feature. While some design features are intended to increase morphologic changes (e.g., gravel injection, constructed bars, channel realignment with constructed meanders, and engineered log jams), other features are designed to persist with relatively little change (e.g., constructed side channels and constructed floodplains designed to discourage riparian encroachment), and thus a lack of change (e.g., scour or fill) may indicate a favorable outcome. Many cross section sites traverse multiple features designed to be both dynamic and relatively stable. Furthermore, many of the post-construction monitoring cross sections traversing in-channel design features were installed within the last 2 years and long-term records are not yet available to evaluate the effectiveness of these features designed to dynamically evolve under repeated high flows occurring over multiple years. Detailed DTMs developed from bathymetry and topographic mapping data (GMA 2012) will categorically improve assessment of bed fluctuations at various spatial scales and allow sediment storage changes to be estimated. Detailed bathymetric and topographic data will also allow prediction of geomorphic and physical habitat (e.g., depth and velocity) responses to direct manipulation and sediment injection using 2-dimensional models.

The Program has noted pool aggradation downstream of coarse sediment injection sites and has offered site-specific recommendations for the quantity, size distribution, and timing of augmentation to minimize the effects of coarse sediment additions on pools (Gaeuman 2008; Gaeuman in review). Coarse sediment stored in pools will eventually route downstream if flow patterns directed at the formative structural elements (e.g., channel bend or large rock outcrop) remain. Additional analysis by the Program Partners to evaluate the effects of coarse sediment additions on pool fill and scour using detailed bathymetry data is forthcoming. Detailed bathymetry data will also enable 2-dimensional hydrodynamic and morphodynamic modeling to predict the effects of coarse sediment additions on channel topography, as demonstrated by the Program's use of SRH-2D to evaluate the potential effects of the 2011 high flow injection at

Lowden Ranch. Injections similar to 2011 at Lowden Ranch during high flow releases tend to promote the transport of added gravel through pools and onto downstream bars.

Judging whether the IAP objective to increase coarse sediment transport rates is being met is best informed by results from sediment budgeting that indicate equilibrium in sediment transport is being maintained between reaches with a higher level of sediment storage and bar formation, rather than by assessing transport rates at specific locations. Transport rates measured since 2004 at the four gaging stations indicate transfer of coarse sediment from budget cell 1 through budget cell 4 (Wilcock 2010; Gaeuman and Krause 2011). The net increase in storage in budget cell 3 is 4.5 times the volume of gravel augmentation in the reach, indicating mainstem transport from upstream (Gaeuman and Krause 2011). Transport rates are much larger in the lower portion of the study reach between Indian Creek and Douglas City due to flow accretion and sediment supply from Indian, Weaver, and Reading creeks (Wilcock 2010). Substantial tributary inputs play a key role in producing the more dynamic, alluvial character of the Trinity River in this reach and downstream. Equilibrium has apparently not been achieved, but continuity in coarse bed material transport has been restored. Continuity in coarse bed material transport is more important for restoring alluvial processes, and some degree of disequilibrium between inputs and outputs at the reach or link scale is inevitable considering variable tributary inputs and uncertainties in prescribing the volume of coarse sediment additions at injection points and channel rehabilitation sites.

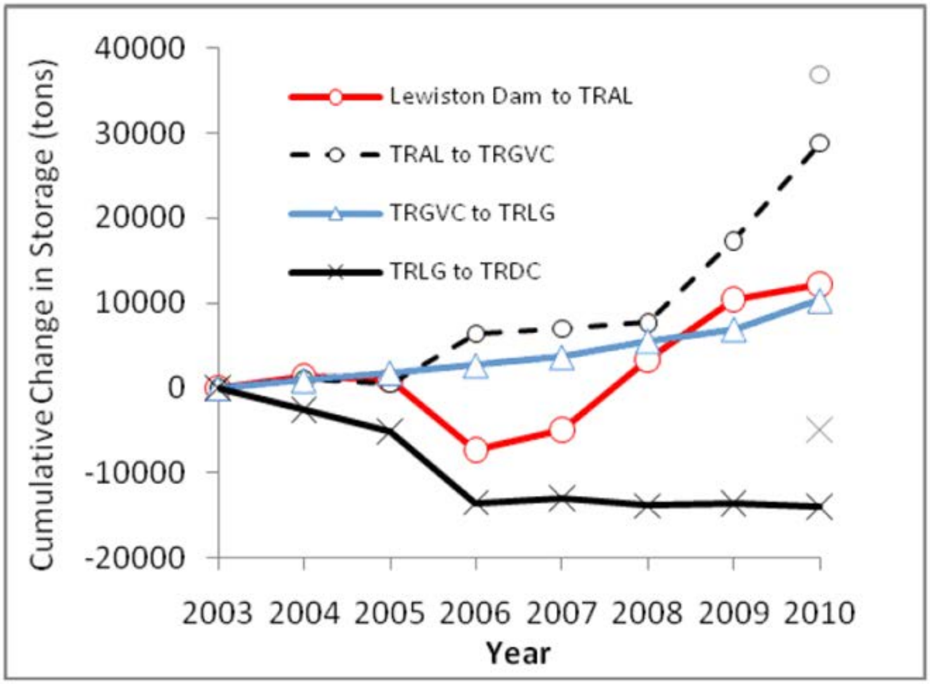
7.1.3 Coarse Sediment Storage

Replacing coarse sediment lost from storage since Trinity Dam closure is among the management objectives discussed in the TRFEFR (USFWS and HVT 1999). Since 2003, tributary inputs and gravel augmentation has increased sediment storage in budget cells 1 through 3 (Figure 7-2). The inputs reduced the coarse sediment deficit to where it is approximately equivalent to 1 to 3 years of annual coarse sediment yield. Changes in storage relative to the deficit are shown in Figure 7-3 (Gaeuman and Krause 2011). Additional observations regarding storage of coarse bed material in the Trinity River management reach upstream of Douglas City include the following:

- Storage of coarse bed material increased in much of the management reach upstream of Douglas City during 2004 through 2009. Increase in storage is roughly proportional to the quantity of coarse sediment added to the river in 2008 and 2009. These quantities are also comparable to the amount of coarse bed material moved during the 2006 Wet WY release (Wilcock 2010).
- The largest increase in sediment storage was in budget cell 2, where channel rehabilitation sites were concentrated (Gaeuman and Krause 2011).

- Storage increases in cell 3 since 2003 were gradual, largely because little coarse sediment augmentation occurred there. Most of the increase was due to mainstem transport from upstream (Gaeuman and Krause 2011).
- Budget cell 4 showed a consistent decline in storage since 2004, likely representing a recovery from post-dam aggradation (caused by lack of capacity to transport tributary inputs) rather than growth of a coarse sediment deficit (Gaeuman and Krause 2011).
- Larger quantities of coarse bed material evacuation will occur in an Extremely Wet WY release, and it may be desirable to build up an in-channel surplus of coarse bed material in anticipation of such an event (Wilcock 2010).

The effects of WY 2011 on sediment storage are forthcoming in an update to the sediment budget for this period.

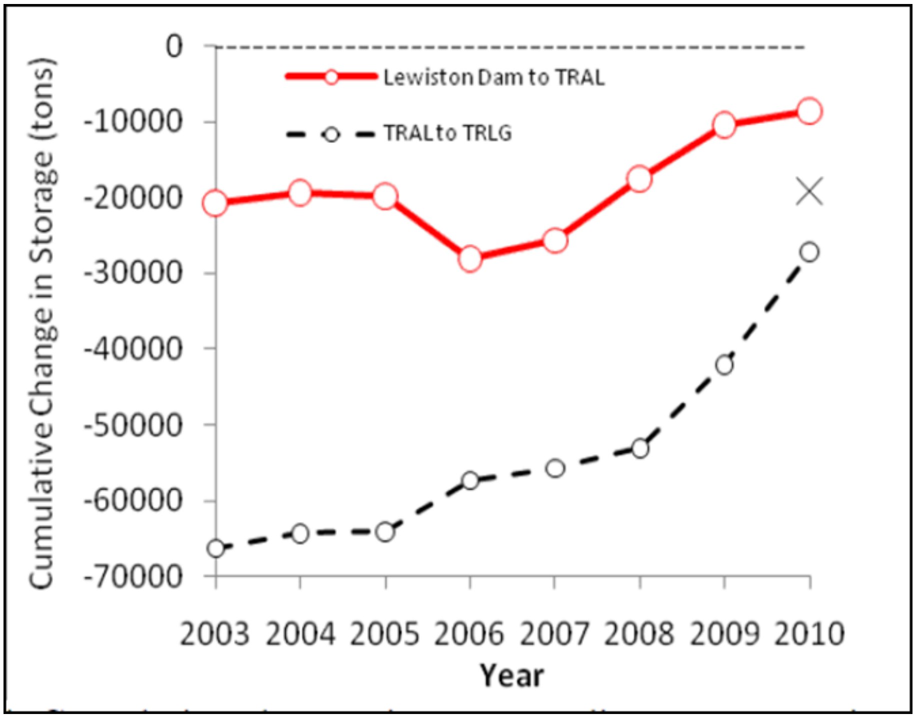


Source:
Gaeuman and Krause 2011

Note:
Cumulative changes including fall 2010 construction placements (early WY 2011) in budget cells 2 and 4 are indicated with solitary symbols.

Figure 7-2

Cumulative Changes in Coarse Sediment Storage by Budget Cell for WYs 2004 to 2010 with Zero Budget Balance Assigned to WY 2003



Source:
Gaeuman and Krause 2011

Note:
The X indicates the cumulative change in budget cells 2 and 3 as of January 2011 prior to the 2011 high flow release.

Figure 7-3

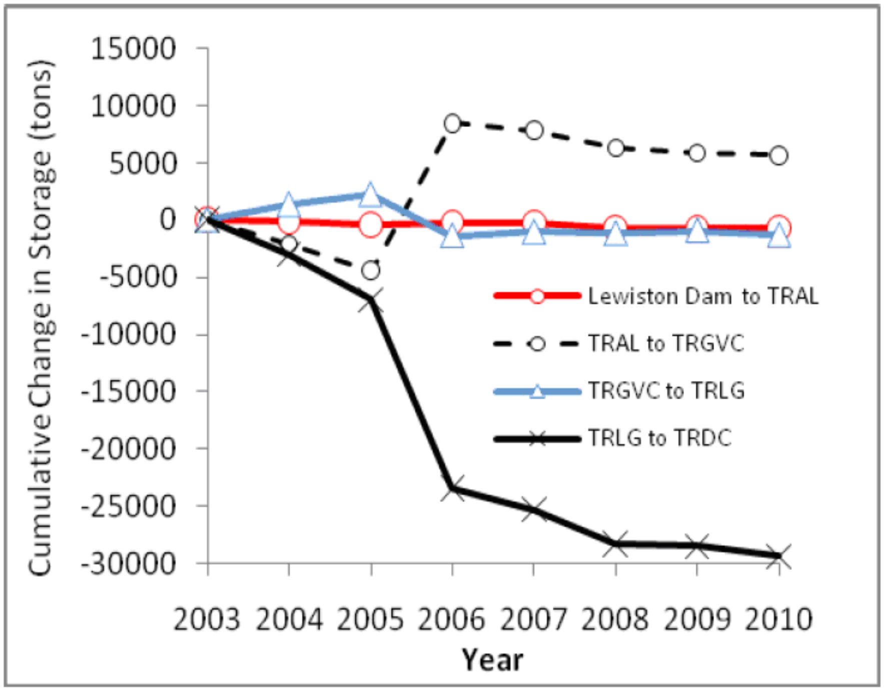
Cumulative Changes in Coarse Sediment Storage since Dam Closure in Budget Cell 1 and in Budget Cells 2 and 3, combined as of the end of WY 2010

Conversion of mass storage change to average bed elevation change in each sediment budget cell yields an increase of 0.16 foot in cells 1 and 2, an increase of 0.05 foot in cell 3, and a decrease of 0.07 foot in cell 4. Even if one assumes that deposition occurs on bars that occupy one-quarter of the channel area, the effect on bar height (4 times the values) over 7 years is modest in all cases. This suggests that major bar construction from gravel injection may only be significant near injection points where deposition is greatest. Some in-channel deposition has been observed in the form of incipient gravel bars in the 5 miles of river closest to Lewiston Dam, which correlates with the increased storage of coarse bed material associated with gravel augmentation (Wilcock 2010). The magnitude of coarse bed material storage needed to recover active bar and pool topography is unknown (Wilcock 2010), but morphodynamic modeling in which increased sediment supply is imposed on the existing channel topography would inform this question. Linking estimated coarse bed material storage changes at the reach scale (i.e., a budget cell) to storage changes in bedforms at the site-specific scale (channel rehabilitation and gravel injection sites) is an important next step in monitoring the effectiveness of rehabilitation efforts. Detailed DTMs developed from annual bathymetric and topographic surveys (GMA 2012) provide a powerful tool for making this link through volume differencing at the site, reach, and system scales.

7.1.4 Fine Sediment Storage

Treatments to reduce storage of fine bed material (0.5 to 8 mm) in the mainstem Trinity River have included control of tributary sources, physical removal of berms, and flushing by peak flows. Sediment budgeting indicates the following regarding fine bed material storage in the Trinity River (Figure 7-4):

- The budget for fine bed material was roughly in balance for the 2004 to 2009 period, suggesting that fine bed material in the 18.5 miles of the Trinity River immediately downstream of Lewiston Dam was controlled over this period by watershed actions and dam releases (Wilcock 2010.
- The 2004 to 2009 observations of a balanced fine bed material budget and a surplus of coarse bed material storage reverse the trends observed in the 1990s, when fine bed material accumulated and coarse bed material was evacuated during the high flows of 1996 to 1998 (Wilcock 2010).
- The Program’s management actions have produced a large decrease in fine bed material storage in budget cell 4, but little change in budget cells 1 and 3. An increase in fine bed material storage in budget cell 2 was due to post-fire debris flow inputs. Results suggest that the quantity of fine bed material stored upstream of Douglas City is approximately less than or equal to the quantity prior to Trinity Dam closure (Gaueman and Krause 2011).
- Compared to changes in fine bed material volume in the channel, large volumes (21,000 to 81,000 tons, depending on estimates of berm volume) remain in long-term storage in natural levees along stream banks upstream of Douglas City. Fine bed material constitutes approximately 12% of these deposits (Gaueman and Krause 2011).
- Investigation of spawning gravel substrate at 12 sites on the mainstem Trinity River from Lewiston Dam to Junction City generally indicated coarsening of the surface and subsurface, reduction in percent fines, and an overall improvement in spawning gravel conditions over the 2000 to 2009 time period (GMA 2010a).



Source:
Gaeuman and Krause 2011

Figure 7-4
Cumulative Changes in Fine Bed Material Storage for WYs 2004 to 2010 with Zero Budget Balance Assigned to WY 2003

As described above, coarse sediment supply has been increased so that there is continuity in transport throughout the management reach, the coarse bed material deficit created by Trinity Dam closure is being filled, substantial areas of the bed have become active, and bar formation is being enhanced, at least locally. Fine sediment has been reduced so that in-channel supply has been reduced, and the bed surface has been winnowed of much of the excess fine sediment. Large volumes of fine sediment remain in storage in natural levees along the banks, but this material is mostly inactive and does not exchange significantly with sediment transport in the channel.

The TRFEFR and ROD did not address the importance of large wood in the Trinity River management reach, and as a consequence, large wood has not been incorporated as a significant channel-forming feature in channel rehabilitation site designs until very recently. The Program Partners have placed a growing emphasis on the role of large wood in the Trinity River, and a more systematic treatment of large wood is needed (Cardno Entrix and CH2MHill 2011). This perspective would necessarily include the past, present, and anticipated future supplies of large wood to the channel, and an understanding of large wood transport rates and residence times in different reaches, large wood storage volumes by size classes, and the effects of large wood on channel forming processes as they pertain to the creation and maintenance of anadromous salmonid habitat. These concepts are best addressed within the framework of a large wood budget, much like coarse and fine sediment management issues are addressed by the sediment budget.

7.2 Biological Responses

Biological responses to channel rehabilitation and the relative effectiveness of these actions at achieving Program goals related to anadromous salmonid habitat formation and production are qualitatively discussed within the context of the two primary sub-objectives outlined in the IAP for Objective 2 (see Table 1-3).

7.2.1 IAP Sub-objective 2.1.1 – Increase/Maintain Salmonid Fry and Juvenile Rearing Habitat

Juvenile fish habitat was assessed at three different scales—site, reach, and river—to determine if implementation of the channel rehabilitation projects is meeting sub-objective 2.1.1. The change in low-flow juvenile rearing habitat at the site scale following channel rehabilitation was variable and ranged from -32% for fry habitat at Trinity House Gulch to 204% for optimal presmolt habitat at Sven Olbertson (Table 7-1).

Table 7-1
Percent Change in Optimal (DV, C) and Total Habitat at Base Flow for Fry and Presmolts within Rehabilitation Sites following Channel Rehabilitation

Reach	Rehabilitation Site	Fry Habitat		Presmolt Habitat	
		Optimal	Total	Optimal	Total
Lewiston	Sven Olbertson	145%	67%	204%	57%
	Lewiston Four	61%	43%	59%	17%
	Sawmill	96%	42%	88%	29%
Limekiln	Bucktail-Dark Gulch	33%	28%	28%	22%
	Lowden Ranch	140%	140%	177%	121%
	Trinity House Gulch	-32%	45%	-23%	49%
Douglas	Reading Creek	10%	25%	10%	27%

Notes:

1 Optimal habitat meets depth, velocity and cover criteria, while total habitat includes all areas that meet any combination of depth, velocity or cover criteria (Alvarez et al. 2011).

2 Base flow is approximately 300 to 450 cfs.

3 Results are based on analyses of pre- and post-treatment data provided by the Program. Not all of the rehabilitation sites are included in this table because not all of the sites were assessed pre- and post-construction (e.g., Conner Creek, Valdor Gulch, Elkhorn, and Pear Tree Gulch) and not all were assessed using the same criteria (e.g., Indian Creek). The Lewiston Four set includes only the Cableway and Hoadley Gulch projects.

The Program Partners estimated habitat formation before and after construction at Reading Creek, Lowden Ranch, Bucktail-Dark Gulch, and Lewiston Cableway under various flows (Alvarez et al. 2011). There was variability in the data reported, which was understandable given the structural diversity of the five sites evaluated, whether optimal and total habitat area was being mapped, and which life stage of fish (fry and presmolt) was examined. Overall, the amount of optimal and total habitat for fry and presmolts increased at all flow levels at all sites when comparing pre- to post-construction conditions, except for upper Dark Gulch. At upper Dark Gulch, the amount of optimal fry and presmolt habitat decreased between pre- and post-construction conditions at the highest flows. This decrease in optimal habitat at higher flows is attributed to the removal of vegetation on the floodplain during construction (Alvarez et al. 2011). As far as the shapes of the relationships, the results were positive at Lewiston Cableway and Bucktail, meaning that as flow increased, optimal and total habitat also increased. In contrast, increased flow at Lowden Ranch, Reading Creek, Upper Dark Gulch, Indian Creek, and Hocker Flat resulted in flat, declining, or “U” shaped relationships. This suggests that habitat formation at different flows can be positive, but is site specific and is strongly influenced by localized conditions at each channel rehabilitation site.

In addition to assessing changes in the amount of habitat at the rehabilitation site scale, we also evaluated habitat changes at the reach (the five sub-reaches developed by HVT et al. [2011]) and river scales. Because pre-construction and optimal habitat area data were lacking for several sites, and rehabilitation actions were not implemented within the Junction City Reach, we assessed change in total fry and presmolt habitat area within the Lewiston, Limekiln, and Douglas City reaches only (Figure 7-5) based on data collected by the Program Partners under base flow conditions.

On an absolute basis, the change in total fry habitat area in the Lewiston (12,661 m^2) and Limekiln (12,365 m^2) reaches was similar, but was much larger than the change in the Douglas City reach (3,412 m^2). On a relative basis, change in total fry habitat area displayed the opposite pattern among reaches, where change was greatest in the Douglas City Reach (73%), followed by the Limekiln (61%) and Lewiston (56%) reaches.

Similarly, the absolute change in total presmolt habitat area was comparable in the Limekiln (15,033 m^2) and Lewiston (12,070 m^2) reaches, but was smaller for the Douglas City (5,025 m^2) reach. On a relative basis, change in presmolt habitat area was similar to fry, where change was greatest in the Douglas City Reach (62%), followed by the Limekiln (48%) and Lewiston (31%) reaches. The variation in habitat area produced by rehabilitation actions among reaches was likely a result of the number and types of actions implemented within each reach.

Overall, based on pre- and post-construction census of habitat conducted by the Program Partners, the rehabilitation actions implemented during Phase 1 increased fry and presmolt habitat area by 28,438 and 32,128 m^2, respectively (Figure 7-5). This resulted in a relative increase in fry and presmolt habitat across the entire 64-km restoration reach of 56% and 41%, respectively.

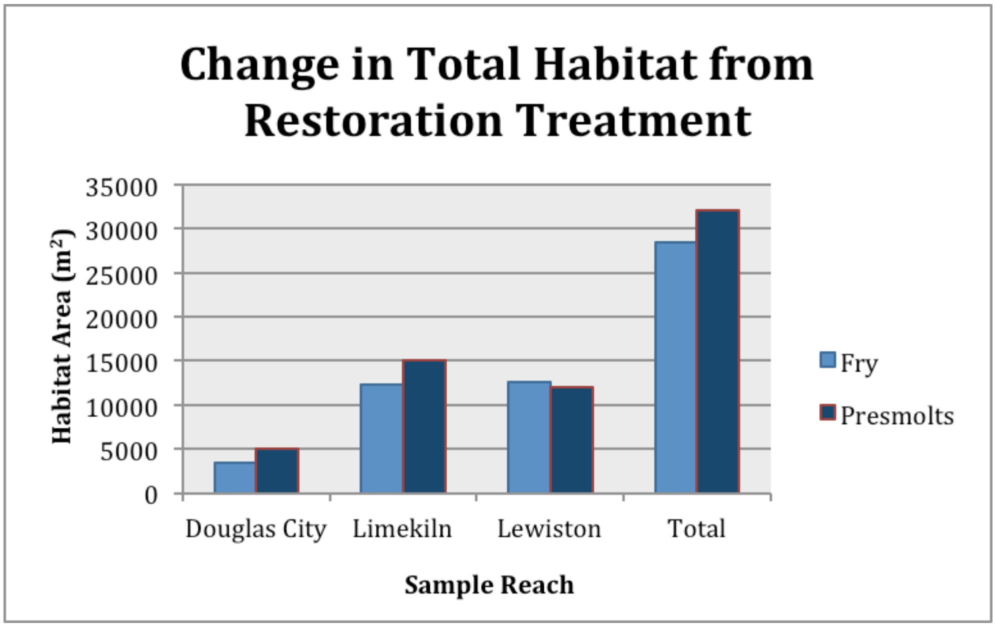


Figure 7-5

Change in Total Habitat Area (m^2) for Fry and Presmolts by Restoration Reach

The total pre- and post-construction habitat data indicate that rehabilitation actions have increased habitat availability for fry and presmolt juvenile salmon. Relative to the IAP sub-objective 2.1.1, which calls for increasing available rearing habitat for juvenile salmon by 400% in the upper 40 miles of the mainstem Trinity River, none of the implemented projects resulted in an increase of that magnitude (Table 7-1); the largest constructed increase in habitat was on the order of 200%. However, creating a 400% increase in habitat area was achieved using certain features within some rehabilitation sites. This included optimal fry habitat in side channels constructed at the Sawmill site, and optimal and suitable fry and presmolt habitat in side channels constructed at the Sven Olbertson site. Moreover, it is emphasized that the 400% goal is an interim target that is being re-evaluated by the Program as more information is gained.

7.2.2 IAP Sub-objective 2.1.2 – Increase/Maintain Spawning Habitat Quantity and Quality

To date, the Program has focused more effort on measuring changes in juvenile rearing habitat than adult spawning habitat. There has been no systemic, reach-wide accounting of spawning habitat area or change in area over time. However, as discussed above, an assessment of spawning gravel substrate at 12 sites on the mainstem Trinity River from Lewiston Dam to Junction City generally indicated coarsening of the surface and subsurface, reduction in percent fines, and an overall improvement in spawning gravel conditions over the 2000 to 2009 time period (GMA 2010b).

Alvarez et al. (2011) and Goodman et al. (2010) attempted to validate spawning habitat criteria by mapping spawning habitat and overlaying observed redd locations. In two studies, redds occurred within predicted spawning habitat areas 36 or 55% of the time, depending on the substrate size criterion selected during mapping. Alvarez et al. (2011) and Goodman et al. (2010) concluded the mapped areas (i.e., the habitat criteria used) were not good predictors of spawning habitat availability, and fell short of an acceptable level (i.e., 70%) needed to enable the Program Partners to use the predictions as a restoration assessment technique.

The Program Partners collected and provided adult redd and carcass count data for the 2009 to 2011 period, which we loaded into the database and analyzed. The use of rehabilitation sites by spawners over time was variable. Within some sites, the numbers and densities of redds and female carcasses increased during the period 2009 to 2011, while in other sites the number and density of redds and female carcasses stayed the same or decreased during the 2009 to 2011 period. This may be related to the fact that not all rehabilitation sites were designed to increase spawning habitat. Across the restoration reach, numbers of Chinook redds (both spring and fall Chinook) increased over time in the Trinity River (Figure 7-6). The increase was most apparent in the Lewiston Reach, where most of the Chinook spawned. The Douglas City and North Fork reaches had the lowest numbers of redds.

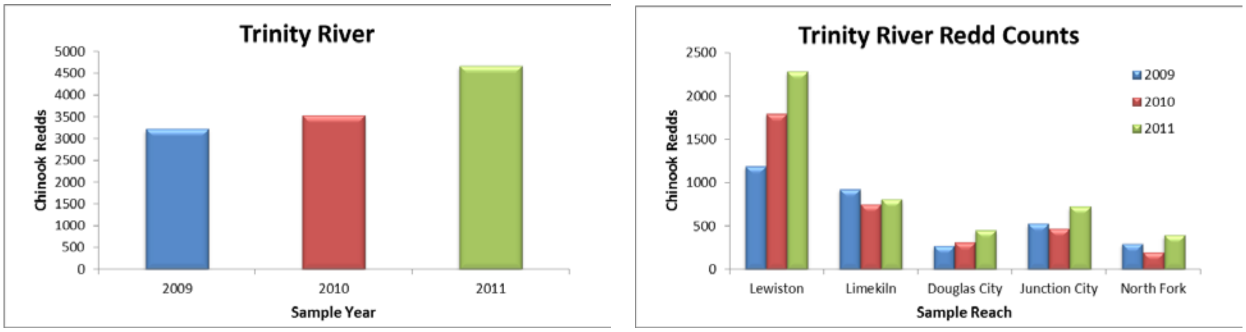
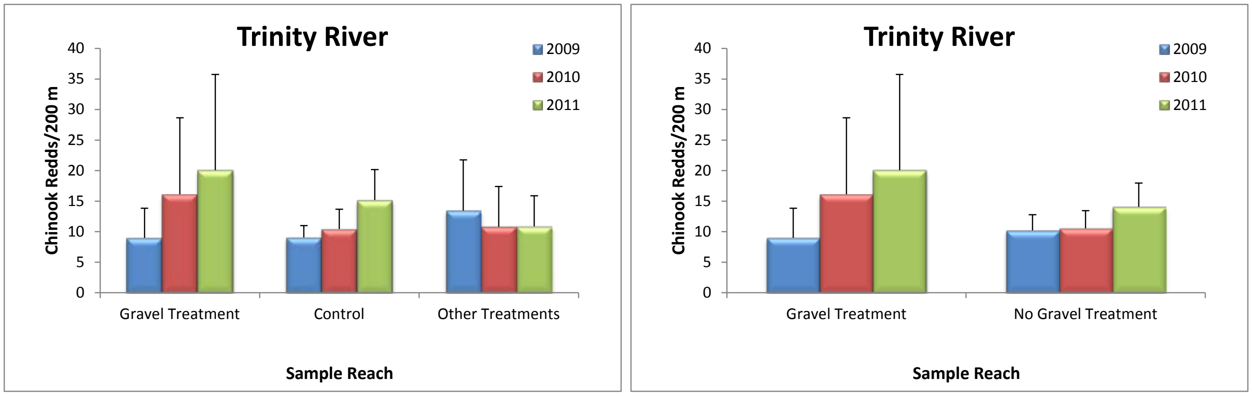


Figure 7-6

Numbers of Chinook Redds (Spring and Fall Chinook) Counted from 2009 to 2011 across the Entire Restoration Reach and within Each Geomorphic Reach

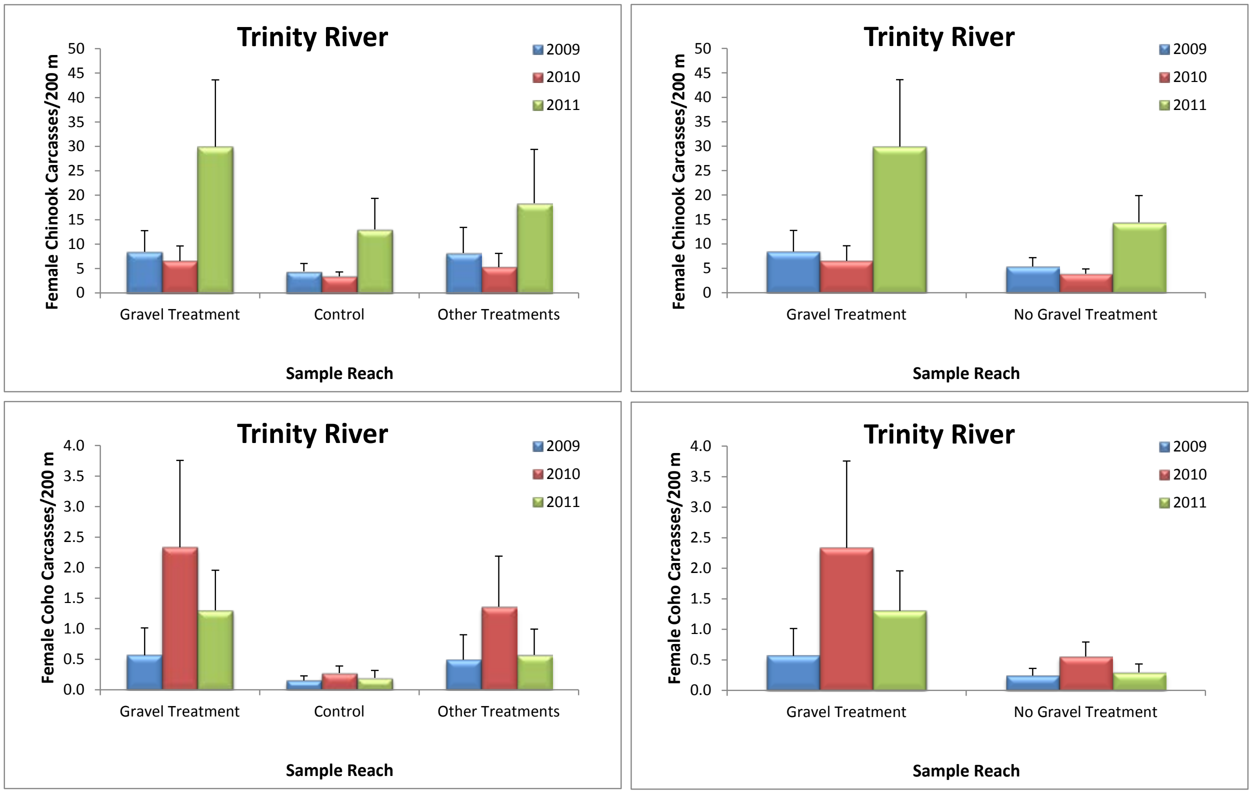
A more appropriate evaluation of redd and carcass data would be to compare changes in redd and female carcass densities over time within sites that received gravel augmentation and those that did not. This should remove some of the variability in mean densities of redds and carcasses among rehabilitation sites. However, the effects of Phase 1 activities on the abundance of redds and carcasses are inconclusive due to insufficient data and numerous confounding effects (e.g., multiple restoration treatments, interannual variability of physical and biological conditions, and inherent differences in site conditions). We present the available results in the interest of completeness (Figures 7-7 and 7-8), but stress that they are preliminary and no conclusions can be made at this time.



Note: The graph on the right compares gravel treatment segments with no gravel segments; the graph on the left includes both control segments and segments with other treatments.

Figure 7-7

Mean Redd Densities and 95% Confidence Intervals for Chinook Salmon (Spring and Fall Runs) Categorized by Treatment: (i) Gravel Augmentation and Other Channel Rehabilitation Treatments, (ii) Control (Untreated), and (iii) Treatments Other Than Gravel Augmentation.



Note: The graphs on the right compare gravel treatment segments with no gravel segments; the graphs on the left include both control segments and segments with other treatments.

Figure 7-8

Mean Carcass Densities and 95% Confidence Intervals for Female Chinook (Spring and Fall Runs) and Coho Salmon Categorized by Treatment: (i) Gravel Augmentation and Other Channel Rehabilitation Treatments, (ii) Control (Untreated), and (iii) Treatments Other Than Gravel Augmentation.

Since there has been no systemic, reach-wide accounting of spawning habitat area or change in area over time, we are not able to assess the Program’s progress towards achieving sub-objective 2.1.2 to “increase/maintain spawning habitat quantity and quality to 2,550,000 square feet in the upper 40 miles of the mainstem Trinity River.”

8 CONCLUSIONS

The previous section provides results from evaluations of how Program actions (mechanical channel rehabilitation, flow and sediment management, and watershed restoration) changed the physical characteristics of the restoration reach, and how adult salmon responded to any changes. Geomorphological data used in the evaluations were observations (e.g., cross sections, topography or sediment) conducted at various locations, but for multiple purposes. These data were a subset of a broader dataset available to us. They were selected based on Phase 1 review objectives and analyzed outside of the data frame developed during the Phase 1 review. Biological data were collected both within channel rehabilitation sites and throughout the restoration reach. All biological data provided by the Program Partners were analyzed to estimate changes in juvenile rearing habitat and adult spawner abundance and location over time. The juvenile rearing habitat data used were all of the census data reported by the Partners. The adult spawner abundance and location data were analyzed using the data frame developed during the Phase 1 review.

Because the geomorphological and biological data were collected independently, results of change analyses were reported separately in the previous section. But ultimately the results need to be integrated. Therefore, this section describes conclusions about any apparent relationships between the physical and biological results, or in other words, between changes in channel structure and morphology and fish habitat quantity or spawner abundance and location.

Sensu lato, our review of the geomorphic context within the restoration reach for channel rehabilitation indicated the alluvial tendencies of the Trinity River are strongest in downstream reaches (Junction City and North Fork). This is primarily because of cumulative tributary inputs and an extensive sediment wedge centered at Oregon Gulch. Given this geomorphic context and the success of Phase 1 enhancement of rearing and spawning habitat at some sites, similar Phase 2 channel rehabilitation projects should also be successful in downstream reaches. However, the spatial distribution of spawning salmon is currently skewed toward Lewiston Dam and the lower reaches may not be utilized to capacity by adult spawners and fry. Since continued improvement in spawning and rearing habitat in the upper reaches is also likely needed to meet Program goals, monitoring and modeling to predict how existing in-channel features in the upper reaches change over time should also be a focus of Phase 2 actions.

There is ample evidence that juvenile fish-rearing habitat changed at constructed sites, although the response varied. The largest proportionate increases occurred at the Lowden Ranch, Sven Olbertson, and Sawmill rehabilitation sites. In contrast, increases at Reading Creek and Trinity House Gulch, which were also recently constructed, were smaller and negative in some cases.

This variability warrants further data collection and analysis. Among reaches where pre- and post-construction sampling of channel rehabilitation sites was conducted, the largest proportionate increase in habitat occurred in the Douglas City Reach for both fry and presmolts. The largest absolute increase in total habitat area was in the Lewiston Reach for fry and the Limekiln Reach for presmolts. The changes likely resulted from the scale of projects, elements used, and number of individual rehabilitation projects located within these reaches, rather than characteristics of the reaches themselves.

At the entire restoration reach scale and across all channel rehabilitation sites, total fry and presmolt habitat increased 56% and 41%, respectively, during Phase 1. These proportionate changes in rearing habitat area are lower than the 400% goal identified in the IAP, but it is recognized that this is an interim target that is being re-evaluated by the Program as more information is gained.

Many in-channel treatments were only recently implemented, and in most cases the long-term effects of these treatments have not yet been evaluated in terms of both physical and biological (habitat) responses. Examples include engineered log jams, changes in channel sinuosity, and channel migration resulting from thalweg shifts and bank erosion. Also, we are not yet able to assess the effectiveness of combining in-channel features with existing planform curvature and local forcing elements to increase the size, frequency, and topographic relief of bar and pool sequences. Nonetheless, results of our analyses indicate that in-channel rehabilitation treatments that involve constructing bars through gravel placement, excavating banks and floodplains to create forced channel meanders, and creating log structures have increased channel complexity and support progress toward achieving a key Program goal.

Two observations relative to specific design elements resulted from our evaluations. First, changes in fry and presmolt rearing habitat from constructing side channels were quite large (e.g., Sven Olberston and Sawmill). Thus, this element provided immediate benefits in terms of habitat area. Second, feathered edging and floodplain lowering, the earliest design elements administered by the Program at rehabilitation sites (e.g., Hocker Flat, Elkhorn, and Pear Tree) had little influence on the size, frequency, and topographic relief of bar and pool morphology. This is because these measures were primarily designed to reduce bar elevation and increase shallow flooding over a range of flows, and not alter bar-pool morphology. The potential of this design element may have been limited by a lack of habitat diversity and complexity on new shallow areas created on the floodplains and bars to complement the general improvement in habitat defined by velocity–depth relations.

The lessons from Hocker Flat were learned early and incorporated by the Program Partners into subsequent Phase 1 designs with successful results. Overall, geomorphic monitoring at more recently constructed sites suggests the objectives to increase the size and distribution of complex alluvial features (e.g., bars, side channels, and alcoves) were largely met, many alluvial features are being maintained, and new features are being created. Channel sinuosity is changing at some sites (e.g., Sawmill) and the development of bar and pool morphology is evident at others (e.g., Valdor Gulch).

Program monitoring indicates that bed-level fluctuations occurred within the low-flow channel at all rehabilitation sites, and that these responses met TRFEFR and IAP objectives (HVT and McBain & Trush 2012). Furthermore, results of bed mobility and scour chain experiments demonstrated substantial activity of the streambed during the 2011 high-flow release. Prior to this event, management objectives for scour were not being met (Alvarez et al. 2011), which emphasizes the importance of high-flow events. Enhanced bed activity during such events will help to achieve the Program’s goals of creating juvenile rearing habitat and improving spawning habitat by flushing fine sediment from interstitial spaces.

Storage of coarse bed material increased in much of the management reach upstream of Douglas City from 2004 to 2009. Some in-channel deposition has been observed in the form of incipient gravel bars in the 5 miles of river closest to Lewiston Dam, which correlates with the increased storage of coarse bed material associated with gravel augmentation. Therefore, major bar construction from gravel injection may only be significant near injection points where deposition is greatest. The magnitude of coarse bed material storage needed to recover active bar and pool topography is unknown (Wilcock 2010). Morphodynamic modeling in which increased sediment supply is imposed on the existing channel topography would inform this question and should be considered during Phase 2.

While many changes in river channel morphology and habitat were apparent based on the evaluations conducted, several aspects of Phase 1 could not be addressed. Although creating wider channels with bars and injecting gravel can improve some habitat characteristics, it can also cause pools to fill, and impact other habitats. We were aware of this issue, but could not address it with the available information. Investigation of the effects of coarse sediment additions on pool fill and scour using detailed bathymetric data is forthcoming from the Program Partners and should enable 2-dimensional hydrodynamic and morphodynamic modeling to predict the effects of coarse sediment additions on channel topography. This was demonstrated by the Program’s use of SRH-2D to evaluate the potential effects of the 2011 high flow injection at Lowden Ranch, including whether the gravel injection promoted the transport of added gravel through pools and onto downstream bars.

Currently, estimates of the amount of spawning habitat in the restoration reach are not available to inform how habitat area has responded to changes in coarse sediment injection, mobility, and storage. However, investigation of spawning gravel substrate at 12 sites on the mainstem Trinity River from Lewiston Dam to Junction City indicated an improvement in spawning gravel quality. From 2000 to 2009, surface and subsurface substrate became coarser and the percentage of fine material was reduced, likely as a result of fine sediment mitigation in tributary basins and flushing flows in the mainstem river (GMA 2010a).

Our review indicates that further sampling and analysis will be required to identify linkages between geomorphic processes and habitat change, and to relate responses to Program actions and goals. Examples include the relations between bankline changes, lateral erosion and accretion, and increased sinuosity, and how these relations influence shallow water habitat formation. Understanding responses to the 2011 high-flow experiment and how gravel injection improves rearing habitat, but may impact adult holding habitat, are especially pertinent. Monitoring biological (juvenile fish density, redd location and density, and habitat area) and key physical attributes at specific sites is needed to test hypotheses of how juvenile rearing and adult spawning habitat respond to changes in channel morphology over time. Also, a better understanding is needed of large wood transport rates and residence times in different reaches, large wood storage volumes by size classes, and the effects of large wood on channel-forming processes as they pertain to the creation and maintenance of anadromous salmonid habitat.

While progress has been made during Phase 1 toward achieving the Program’s goals, quantifying how much is still required was generally not possible. The analyses described here were limited by a lack of integration between physical and biological (habitat) monitoring programs, and a lack of monitoring data from treated and untreated reaches after channel-forming flow events following construction. However, analyses underway by the Program Partners will inform many key uncertainties. For example, the WY 2011 release was the largest by the Program since mechanical rehabilitation began. Needed information about the geomorphic and habitat responses to the event at the site, reach, and system scales will be forthcoming from work currently being conducted. Ongoing, site-specific analysis of the effects of historic disturbances on contemporary channel evolution and detailed geomorphic mapping by the USGS will also advance the Program’s ability to plan and design restoration actions within the opportunities and constraints of specific channel types. Also, the Program now develops post-construction DTMs and annually surveys channel bathymetry over the management reach following high-flow releases. These data will be critical in characterizing spatially distributed bed elevation changes; assessing the size, frequency, and relief of bar/pool sequences; and calculating site or unit-specific changes in sediment storage.

To summarize, progress has been made toward most of the six physical and biological IAP sub-objectives addressed in this appendix. The one exception may be the goal to increase adult spawning habitat, because habitat area has not been quantified. However, the quality of spawning habitat showed signs of improving, and adult salmon responded to gravel injections. Importantly, fish rearing habitat clearly changed following channel rehabilitation, and the morphology and dynamic nature of the river is beginning to change within the restoration reach in ways that support shallow water habitat formation, a key Program goal.

Given our review of the geomorphic context within the restoration reach for channel rehabilitation and the progress made during Phase 1 toward achieving the Program’s goals, channel rehabilitation projects implemented during Phase 2 are expected to increase or improve salmon spawning and rearing habitat in the restoration reach and make further progress toward achieving the Program’s goals.

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ATTACHMENT A
FLOW EXCEEDENCE AND PHASE 1 CHANNEL REHABILITATION SITES

Table A-1

Number of Days that Flow Exceeded Specific Discharges at Sven Olberston

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	133	144	292	133	138	326	115	147	281	110	137	277	92	148	216
450	62	116	138	85	109	173	70	124	151	82	86	189	61	100	135
1,000	61	65	96	80	63	113	63	44	77	80	44	143	41	9	43
1,500	61	44	75	78	45	93	63	41	74	75	41	121	32	1	33
2,000	30	5	34	67	29	75	58	35	67	74	36	101	25	0	25
4,000	0	0	0	18	1	18	16	0	16	39	21	52	7	0	7
6,000	0	0	0	4	0	4	6	0	6	19	7	20	0	0	0
8,000	0	0	0	0	0	0	0	0	0	13	3	13	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	119	141	341	69	150	228	117	153	317	106	151	240	994	1,309	2,518
450	69	74	117	65	64	103	69	125	160	70	107	145	633	905	1,311
1,000	68	42	80	47	17	51	65	38	73	64	51	85	569	373	761
1,500	59	40	69	33	2	35	65	35	70	64	35	69	530	284	639
2,000	59	39	68	19	2	21	64	31	65	56	25	57	452	202	513
4,000	11	0	11	7	0	7	17	0	17	15	0	15	130	22	143
6,000	7	0	7	0	0	0	5	0	5	7	0	7	48	7	49
8,000	0	0	0	0	0	0	0	0	0	7	0	7	20	3	20

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-2
Number of Days that Flow Exceeded Specific Discharges at Deadwood

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To Oct	Total (WY)	February 15 To June	June To Oct	Total (WY)	February 15 To June	June To Oct	Total (WY)
300	135	144	317	137	140	339	136	147	309	130	137	307	121	150	289
450	62	116	138	85	109	173	70	127	154	82	89	191	61	100	136
1,000	62	65	97	80	64	114	63	44	77	80	44	143	41	9	43
1,500	61	44	75	78	45	93	63	41	74	75	41	129	32	1	33
2,000	42	17	48	72	34	81	62	39	71	74	36	101	25	0	25
4,000	0	0	0	18	1	18	16	0	16	39	21	52	7	0	7
6,000	0	0	0	4	0	4	7	0	7	20	7	27	0	0	0
8,000	0	0	0	0	0	0	0	0	0	13	3	13	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	141	363	98	151	268	133	153	354	136	152	326	1,163	1,315	2,872
450	69	74	117	65	66	103	69	126	163	70	107	145	633	914	1,320
1,000	68	42	80	47	17	51	65	38	73	64	53	87	570	376	765
1,500	59	40	69	33	2	35	65	35	70	64	35	69	530	284	647
2,000	59	39	68	19	2	21	64	31	65	56	25	57	473	223	537
4,000	11	0	11	7	0	7	17	0	17	15	0	15	130	22	143
6,000	7	0	7	0	0	0	5	0	5	7	0	7	50	7	57
8,000	0	0	0	0	0	0	0	0	0	7	0	7	20	3	20

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-3

Number of Days that Flow Exceeded Specific Discharges at Lewiston Cableway

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	135	144	317	137	140	339	136	147	309	130	137	307	121	150	289
450	62	116	138	85	109	173	70	127	154	82	89	191	61	100	136
1,000	62	65	97	80	64	114	63	44	77	80	44	143	41	9	43
1,500	61	44	75	78	45	93	63	41	74	75	41	129	32	1	33
2,000	42	17	48	72	34	81	62	39	71	74	36	101	25	0	25
4,000	0	0	0	18	1	18	16	0	16	39	21	52	7	0	7
6,000	0	0	0	4	0	4	7	0	7	20	7	27	0	0	0
8,000	0	0	0	0	0	0	0	0	0	13	3	13	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	141	363	98	151	268	133	153	354	136	152	326	1,163	1,315	2,872
450	69	74	117	65	66	103	69	126	163	70	107	145	633	914	1,320
1,000	68	42	80	47	17	51	65	38	73	64	53	87	570	376	765
1,500	59	40	69	33	2	35	65	35	70	64	35	69	530	284	647
2,000	59	39	68	19	2	21	64	31	65	56	25	57	473	223	537
4,000	11	0	11	7	0	7	17	0	17	15	0	15	130	22	143
6,000	7	0	7	0	0	0	5	0	5	7	0	7	50	7	57
8,000	0	0	0	0	0	0	0	0	0	7	0	7	20	3	20

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-4

Number of Days that Flow Exceeded Specific Discharges at Hoadley Gulch

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	135	144	317	137	140	339	136	147	309	130	137	307	121	150	289
450	62	116	138	85	109	173	70	127	154	82	89	191	61	100	136
1,000	62	65	97	80	64	114	63	44	77	80	44	143	41	9	43
1,500	61	44	75	78	45	93	63	41	74	75	41	129	32	1	33
2,000	42	17	48	72	34	81	62	39	71	74	36	101	25	0	25
4,000	0	0	0	18	1	18	16	0	16	39	21	52	7	0	7
6,000	0	0	0	4	0	4	7	0	7	20	7	27	0	0	0
8,000	0	0	0	0	0	0	0	0	0	13	3	13	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	141	363	98	151	268	133	153	354	136	152	326	1,163	1,315	2,872
450	69	74	117	65	66	103	69	126	163	70	107	145	633	914	1,320
1,000	68	42	80	47	17	51	65	38	73	64	53	87	570	376	765
1,500	59	40	69	33	2	35	65	35	70	64	35	69	530	284	647
2,000	59	39	68	19	2	21	64	31	65	56	25	57	473	223	537
4,000	11	0	11	7	0	7	17	0	17	15	0	15	130	22	143
6,000	7	0	7	0	0	0	5	0	5	7	0	7	50	7	57
8,000	0	0	0	0	0	0	0	0	0	7	0	7	20	3	20

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-5

Number of Days that Flow Exceeded Specific Discharges at Sawmill

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	135	144	317	137	140	339	136	147	309	130	137	307	121	150	289
450	62	116	138	85	109	173	70	127	154	82	89	191	61	100	136
1,000	62	65	97	80	64	114	63	44	77	80	44	143	41	9	43
1,500	61	44	75	78	45	93	63	41	74	75	41	129	32	1	33
2,000	42	17	48	72	34	81	62	39	71	74	36	101	25	0	25
4,000	0	0	0	18	1	18	16	0	16	39	21	52	7	0	7
6,000	0	0	0	4	0	4	7	0	7	20	7	27	0	0	0
8,000	0	0	0	0	0	0	0	0	0	13	3	13	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	141	363	98	151	268	133	153	354	136	152	326	1,163	1,315	2,872
450	69	74	117	65	66	103	69	126	163	70	107	145	633	914	1,320
1,000	68	42	80	47	17	51	65	38	73	64	53	87	570	376	765
1,500	59	40	69	33	2	35	65	35	70	64	35	69	530	284	647
2,000	59	39	68	19	2	21	64	31	65	56	25	57	473	223	537
4,000	11	0	11	7	0	7	17	0	17	15	0	15	130	22	143
6,000	7	0	7	0	0	0	5	0	5	7	0	7	50	7	57
8,000	0	0	0	0	0	0	0	0	0	7	0	7	20	3	20

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-6

Number of Days that Flow Exceeded Specific Discharges at Dark Gulch

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	144	325	137	146	346	136	149	331	136	138	328	136	151	332
450	69	118	173	86	125	184	77	133	181	109	106	242	61	98	136
1,000	62	65	97	84	64	118	63	45	78	81	44	145	42	10	44
1,500	61	44	75	80	48	98	63	42	75	75	39	128	32	1	33
2,000	47	19	50	73	35	82	62	39	71	74	35	114	25	0	25
4,000	0	0	0	20	2	20	17	0	17	38	20	51	6	0	6
6,000	0	0	0	10	0	10	7	0	7	20	7	24	0	0	0
8,000	0	0	0	0	0	0	0	0	0	9	2	9	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	142	364	136	153	350	136	153	365	136	153	365	1,226	1,329	3,106
450	72	75	123	69	90	123	73	132	189	96	125	191	712	1,002	1,542
1,000	68	42	80	47	16	50	65	39	74	64	52	86	576	377	772
1,500	59	40	69	33	2	35	65	35	70	64	35	69	532	286	652
2,000	59	39	68	21	2	23	64	31	65	57	26	58	482	226	556
4,000	13	0	13	7	0	7	17	0	17	16	0	16	134	22	147
6,000	7	0	7	0	0	0	5	0	5	7	0	7	56	7	60
8,000	0	0	0	0	0	0	0	0	0	7	0	7	16	2	16

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-7

Number of Days that Flow Exceeded Specific Discharges at Lowden Ranch

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	144	326	137	146	346	136	148	330	136	138	323	135	147	318
450	72	117	180	86	129	186	79	133	189	114	111	250	61	96	134
1,000	62	65	97	84	64	118	63	47	80	80	43	143	42	10	44
1,500	61	44	75	80	48	98	63	41	74	75	39	128	33	1	34
2,000	40	9	40	75	37	84	62	39	71	74	34	113	25	0	25
4,000	0	0	0	19	2	19	16	0	16	37	19	50	6	0	6
6,000	0	0	0	10	0	10	7	0	7	20	7	21	0	0	0
8,000	0	0	0	0	0	0	0	0	0	4	0	4	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	146	349	136	153	357	136	153	365	136	153	365	1,225	1,328	3,079
450	72	73	121	70	92	126	76	131	191	96	129	195	726	1,011	1,572
1,000	68	42	80	47	16	50	65	39	74	64	52	86	575	378	772
1,500	59	40	69	34	2	36	65	35	70	64	35	69	534	285	653
2,000	53	28	57	23	2	25	64	31	65	57	27	59	473	207	539
4,000	13	0	13	8	0	8	17	0	17	15	0	15	131	21	144
6,000	7	0	7	0	0	0	5	0	5	7	0	7	56	7	57
8,000	0	0	0	0	0	0	0	0	0	7	0	7	11	0	11

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-8

Number of Days that Flow Exceeded Specific Discharges at Trinity House Gulch

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	140	328	137	153	346	136	153	364	136	153	356	136	153	365
450	94	116	230	103	133	229	125	137	250	131	131	291	68	123	167
1,000	63	65	105	84	64	118	63	47	80	81	44	145	43	11	45
1,500	62	43	76	82	50	102	63	42	75	80	39	133	33	1	34
2,000	42	11	42	80	39	89	62	39	71	75	34	120	25	0	25
4,000	0	0	0	20	2	20	17	0	17	38	20	51	6	0	6
6,000	0	0	0	10	0	10	8	0	8	20	7	25	0	0	0
8,000	0	0	0	0	0	0	0	0	0	6	1	6	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	152	366	136	153	364	136	153	365	136	153	365	1,226	1,363	3,219
450	81	89	150	79	111	154	113	138	246	120	137	251	914	1,115	1,968
1,000	68	43	81	48	16	51	66	39	78	66	52	88	582	381	791
1,500	59	40	69	34	2	36	65	35	70	64	36	70	542	288	665
2,000	57	33	62	31	2	33	64	31	65	58	28	60	494	217	567
4,000	15	0	15	8	0	8	17	0	17	16	0	16	137	22	150
6,000	7	0	7	0	0	0	5	0	5	7	0	7	57	7	62
8,000	0	0	0	0	0	0	0	0	0	7	0	7	13	1	13

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-9

Number of Days that Flow Exceeded Specific Discharges at Indian Creek

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	144	341	137	153	356	136	151	365	136	151	356	136	149	363
450	118	117	269	136	133	298	136	136	287	136	132	299	85	97	168
1,000	65	65	114	85	64	120	64	47	82	89	45	159	44	12	46
1,500	63	43	80	82	48	100	63	41	74	81	41	139	33	1	34
2,000	44	13	44	78	37	87	62	39	71	80	36	130	25	0	25
4,000	0	0	0	20	2	20	17	0	17	38	20	53	6	0	6
6,000	0	0	0	10	0	10	8	0	8	21	7	24	0	0	0
8,000	0	0	0	0	0	0	0	0	0	9	2	9	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	152	353	136	153	364	136	153	365	136	153	365	1,226	1,359	3,228
450	96	90	169	111	117	195	136	140	280	132	137	295	1,086	1,099	2,260
1,000	68	43	82	51	17	54	68	39	82	73	53	96	607	385	835
1,500	59	40	69	36	3	38	65	36	72	65	38	73	547	291	679
2,000	52	23	52	31	2	33	64	31	65	59	29	61	495	210	568
4,000	18	0	18	8	0	8	17	0	17	17	0	17	141	22	156
6,000	7	0	7	0	0	0	5	0	5	8	0	8	59	7	62
8,000	0	0	0	0	0	0	0	0	0	7	0	7	16	2	16

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-10

Number of Days that Flow Exceeded Specific Discharges at Reading Creek

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	145	352	137	153	357	136	153	365	136	153	365	136	153	365
450	136	119	285	137	125	305	136	137	299	136	137	307	108	106	209
1,000	68	62	121	85	63	124	72	47	94	115	45	187	40	8	43
1,500	64	42	87	83	40	94	64	41	76	83	41	149	30	1	31
2,000	46	13	51	68	16	68	62	39	72	81	37	134	25	0	25
4,000	0	0	0	22	2	22	17	0	17	56	20	74	6	0	6
6,000	0	0	0	9	0	9	10	0	10	22	7	35	0	0	0
8,000	0	0	0	0	0	0	0	0	0	13	3	13	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	153	366	136	153	365	136	153	365	136	153	365	1,226	1,369	3,265
450	137	104	253	136	121	232	136	143	285	136	137	326	1,198	1,129	2,501
1,000	71	42	85	53	17	56	80	41	103	96	55	125	680	380	938
1,500	61	40	72	34	2	36	67	36	77	73	41	85	559	284	707
2,000	59	39	68	31	2	33	65	33	71	66	31	68	503	210	590
4,000	18	0	18	8	0	8	19	0	19	25	0	25	171	22	189
6,000	8	0	8	0	0	0	6	0	6	8	0	8	63	7	76
8,000	0	0	0	0	0	0	0	0	0	7	0	7	20	3	20

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-11

Number of Days that Flow Exceeded Specific Discharges at Hocker Flat

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	153	365	137	153	366	136	153	365	136	153	365	136	153	365
450	136	137	306	137	143	323	136	138	319	136	138	334	136	134	335
1,000	112	67	204	116	65	204	121	50	165	136	47	214	62	15	77
1,500	78	43	135	89	47	120	79	44	102	128	43	201	37	2	42
2,000	70	39	107	85	39	102	68	41	81	114	40	181	28	0	30
4,000	6	0	13	35	3	35	23	0	23	62	21	102	7	0	7
6,000	0	0	3	13	0	13	14	0	14	24	8	44	0	0	0
8,000	0	0	0	2	0	2	4	0	4	14	4	19	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	153	366	136	153	365	136	153	365	136	153	365	1,226	1,377	3,287
450	137	128	299	136	140	315	136	146	310	136	139	358	1,226	1,243	2,899
1,000	99	43	125	67	19	71	134	51	183	120	64	196	967	421	1,439
1,500	75	41	88	52	14	54	87	39	107	103	47	131	728	320	980
2,000	61	40	73	37	2	39	71	33	80	88	39	100	622	273	793
4,000	21	0	21	10	0	10	23	1	23	32	1	32	219	26	266
6,000	10	0	10	2	0	2	8	0	8	9	0	9	80	8	103
8,000	0	0	0	0	0	0	0	0	0	6	0	6	26	4	31

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-12

Number of Days that Flow Exceeded Specific Discharges at Conner Creek

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February15 To June	June To October	Total (WY)
300	136	153	365	137	153	366	136	153	365	136	153	365	136	153	365
450	136	137	306	137	143	323	136	138	319	136	138	334	136	134	335
1,000	112	67	204	116	65	204	121	50	165	136	47	214	62	15	77
1,500	78	43	135	89	47	120	79	44	102	128	43	201	37	2	42
2,000	70	39	107	85	39	102	68	41	81	114	40	181	28	0	30
4,000	6	0	13	35	3	35	23	0	23	62	21	102	7	0	7
6,000	0	0	3	13	0	13	14	0	14	24	8	44	0	0	0
8,000	0	0	0	2	0	2	4	0	4	14	4	19	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To Jun	Jun To October	Total (WY)	February 15 To Jun	Jun To October	Total (WY)	February 15 To Jun	Jun To October	Total (WY)	February 15 To Jun	Jun To October	Total (WY)	February 15 To Jun	Jun To October	Total (WY)
300	137	153	366	136	153	365	136	153	365	136	153	365	1,226	1,377	3,287
450	137	128	299	136	140	315	136	146	310	136	139	358	1,226	1,243	2,899
1,000	99	43	125	67	19	71	134	51	183	120	64	196	967	421	1,439
1,500	75	41	88	52	14	54	87	39	107	103	47	131	728	320	980
2,000	61	40	73	37	2	39	71	33	80	88	39	100	622	273	793
4,000	21	0	21	10	0	10	23	1	23	32	1	32	219	26	266
6,000	10	0	10	2	0	2	8	0	8	9	0	9	80	8	103
8,000	0	0	0	0	0	0	0	0	0	6	0	6	26	4	31

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-13

Number of Days that Flow Exceeded Specific Discharges at Valdor Gulch

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	153	365	137	153	366	136	153	365	136	153	365	136	153	365
450	136	137	310	137	144	323	136	138	320	136	138	337	136	140	341
1,000	115	67	208	122	65	213	123	50	168	136	48	215	66	16	81
1,500	80	43	137	91	47	125	80	44	104	129	43	202	37	3	43
2,000	70	39	109	85	39	104	68	41	81	117	40	185	28	0	30
4,000	7	0	14	36	3	36	25	0	25	62	21	103	8	0	8
6,000	0	0	3	13	0	13	14	0	14	24	8	46	0	0	0
8,000	0	0	0	2	0	2	6	0	6	14	4	20	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	153	366	136	153	365	136	153	365	136	153	365	1,226	1,377	3,287
450	137	123	299	136	141	317	136	146	313	136	141	358	1,226	1,248	2,918
1,000	100	44	128	76	19	80	135	53	185	123	65	205	996	427	1,483
1,500	76	42	91	54	15	56	87	40	110	106	49	141	740	326	1,009
2,000	61	40	73	38	1	39	72	34	82	88	41	103	627	275	806
4,000	22	0	22	10	0	10	23	1	23	33	1	33	226	26	274
6,000	10	0	10	2	0	2	8	0	8	11	0	11	82	8	107
8,000	0	0	0	0	0	0	0	0	0	7	0	7	29	4	35

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-14

Number of Days that Flow Exceeded Specific Discharges at Elkhorn

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	153	365	137	153	366	136	153	365	136	153	365	136	153	365
450	136	137	310	137	144	323	136	138	320	136	138	337	136	140	341
1,000	115	67	208	122	65	213	123	50	168	136	48	215	66	16	81
1,500	80	43	137	91	47	125	80	44	104	129	43	202	37	3	43
2,000	70	39	109	85	39	104	68	41	81	117	40	185	28	0	30
4,000	7	0	14	36	3	36	25	0	25	62	21	103	8	0	8
6,000	0	0	3	13	0	13	14	0	14	24	8	46	0	0	0
8,000	0	0	0	2	0	2	6	0	6	14	4	20	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	153	366	136	153	365	136	153	365	136	153	365	1,226	1,377	3,287
450	137	123	299	136	141	317	136	146	313	136	141	358	1,226	1,248	2,918
1,000	100	44	128	76	19	80	135	53	185	123	65	205	996	427	1,483
1,500	76	42	91	54	15	56	87	40	110	106	49	141	740	326	1,009
2,000	61	40	73	38	1	39	72	34	82	88	41	103	627	275	806
4,000	22	0	22	10	0	10	23	1	23	33	1	33	226	26	274
6,000	10	0	10	2	0	2	8	0	8	11	0	11	82	8	107
8,000	0	0	0	0	0	0	0	0	0	7	0	7	29	4	35

Notes:
cfs – cubic feet per second
WY – Water Year

Table A-15

Number of Days that Flow Exceeded Specific Discharges at Pear Tree

Flow (Cfs)	2003			2004			2005			2006			2007		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	136	153	365	137	153	366	136	153	365	136	153	365	136	153	365
450	136	137	310	137	144	323	136	138	320	136	138	337	136	140	341
1,000	115	67	208	122	65	213	123	50	168	136	48	215	66	16	81
1,500	80	43	137	91	47	125	80	44	104	129	43	202	37	3	43
2,000	70	39	109	85	39	104	68	41	81	117	40	185	28	0	30
4,000	7	0	14	36	3	36	25	0	25	62	21	103	8	0	8
6,000	0	0	3	13	0	13	14	0	14	24	8	46	0	0	0
8,000	0	0	0	2	0	2	6	0	6	14	4	20	0	0	0

Flow (Cfs)	2008			2009			2010			2011			2003 To 2011		
	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)	February 15 To June	June To October	Total (WY)
300	137	153	366	136	153	365	136	153	365	136	153	365	1,226	1,377	3,287
450	137	123	299	136	141	317	136	146	313	136	141	358	1,226	1,248	2,918
1,000	100	44	128	76	19	80	135	53	185	123	65	205	996	427	1,483
1,500	76	42	91	54	15	56	87	40	110	106	49	141	740	326	1,009
2,000	61	40	73	38	1	39	72	34	82	88	41	103	627	275	806
4,000	22	0	22	10	0	10	23	1	23	33	1	33	226	26	274
6,000	10	0	10	2	0	2	8	0	8	11	0	11	82	8	107
8,000	0	0	0	0	0	0	0	0	0	7	0	7	29	4	35

Notes:
cfs – cubic feet per second
WY – Water Year

ATTACHMENT B
DESIGN SUMMARY FACT SHEET

Phase 1 – Design Summary Fact Sheet for Hocker Flat

Project Name:	Hocker Flat Rehabilitation Site
Project Location:	River Mile 78.0 to 79.1
Project Ownership: (Private/Public)	Private and Public (BLM)
Principal Designer(s):	Scott Kennedy
Date Design Completed:	Fall 2004
Total Earthwork Volume: (Cut & Fill)	93,400 CY
Year Constructed:	2005
Total Cost of Construction:	$774,250
Construction Contractor:	Erick Ammon, Inc.
Design Hypotheses (Goal/Objective) (Reach Scale):	Increase the diversity and area of habitat for salmonids, particularly habitat suitable for rearing. Increase the structural and biological complexity of habitat for various species of wildlife associated with riparian habitats. Integrate known fluvial and ecological theories and relationships with the sites measured physical and biological attributes and evaluate the response over a definitive time frame. Maximize the rivers ability to rehabilitate itself during high flows and reduce implementation cost and complexity.
Hypothesized Design Evolution (Reach Scale):	Channel migration and subsequent bar building, increased sinuosity, natural riparian regeneration on constructed floodplains

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Tailings Pile – Gravel Source	0	Not constructed. No work is performed here because this gravel source is being actively naturally recruited.
R-2	Floodplain and Gravel Bar	14,800 Cut	Re-activate floodplain to facilitate meandering and increase the quantity of rearing habitat on the gravel bar over a range of flows. Provide an area for the natural recruitment of riparian vegetation.
R-3	Floodplain	0	Not constructed. Design team chose to retain existing functional features and use this area as an untreated control.
R-4	Floodplain	37,300 Cut	Re-activate the floodplain and encourage channel migration into the left bank that shows signs of scour and where a faint gravel bar is forming on the right bank.

R-5	Floodplain and Gravel Bar	30,400 Cut	Re-activate floodplain to facilitate meandering and increase the quantity of rearing habitat on the gravel bar over a range of flows. Provide an area for the natural recruitment of riparian vegetation.
R-6	Floodplain and Gravel Bar	7,000 Cut	Re-activate floodplain to facilitate meandering and increase the quantity of rearing habitat on the gravel bar over a range of flows. Provide an area for the natural recruitment of riparian vegetation.
R-7	Wetland	3,900 Cut	Increase quantity of wetland habitat adjacent to Hocker Creek.
R-8	Floodplain	0	Not constructed. Design team chose to retain existing functional features and use this area as an untreated control.
U-1	Terrace	14,000 Fill	Stockpile area for excavated material.
U-2	Terrace	21,000 Fill	Stockpile area for excavated material.
U-3	Terrace	17,100 Fill	Stockpile area for excavated material.
U-4	Terrace	30,400 Fill	Stockpile area for excavated material.
U-5	Terrace	7,900 Fill	Stockpile area for excavated material.
U-6	Terrace	3,000 Fill	Stockpile area for excavated material.
U-7	Contractor Use Area	0	Temporary contractor use area for access, staging, material storage, etc.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
8/2002	Topographic Surveying	Total station and GPS surveying to supplement the 2001 photogrammetry
1/2003	Begin Developing Alternatives	Collaborative process involving all Program Partners
3/2004	50% Design Presented	
6/2004	Public Scoping Meeting	
9/2004	90% Designs Due	
2/2005	Construction Begins	
?	Site is Replanted	Site is replanted after earthwork completion

Design Analysis Performed

Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. floodplain water elevation surface for FEMA requirements	COE HEC-RAS
1-D Hydraulic Analysis	To determine 6,000 cfs design floodplain elevations	2004; COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	AutoDesk Land Development Desktop

Design Criteria
Do not change water surface elevation for FEMA 1% chance annual flood
Floodplains should be inundated to 0.5' of water depth when 6,000 cfs is flowing in the river
Positive drainage must occur from all constructed surfaces back to the river to reduce the chance of fish stranding
Design Constraints
In-channel earthwork was not allowed.
Avoid disrupting or impacting existing gravel mining operation on left bank
Changing the water surface elevation for flood flows is not permitted under FEMA regulations without the submission and acceptance of letters of map revision.
Avoid performing construction activities adjacent to or across the river from the bedrock outcrop and hole that is on the right bank just upstream of area R-4
Avoid earthwork activities or the removal of riparian vegetation near the left bank gravel mining operation downstream of area R-4. The landowner does not want the river to migrate into the gravel mine until gravel mining operations are complete.
Design Modifications Made in the Field During Construction
One large pine tree was saved at the upstream end of -R5. The contractor excavated around the tree, leaving it on a small island in the floodplain.
Designer Notes
The team realized immediately after construction that not enough effort went into the removal of willow roots along the river's edge. Significant re-growth of willows would likely quickly occur.
Citation/References
Hocker Flat Environmental Assessment/Draft Environmental Impact Report (August 2004)

Phase 1 – Design Summary Fact Sheet for Conner Creek

Project Name:	Conner Creek Rehabilitation Site
Project Location:	River Mile 77.0 to 77.4
Project Ownership: (Private/Public)	Private and Public (BLM)
Principal Designer(s):	HVT Design Team (Robert Franklin, HVT; Scott McBain, Fred Meyer, John Bair, M&T; Rose Patenaude, Jeff Anderson & Associates)
Date Design Completed:	July 15, 2006
Total Earthwork Volume: (Cut & Fill)	19,400 yd3 Cut and 19,400 yd3 Fill
Year Constructed:	2006
Total Cost of Construction:	$210,900
Construction Contractor:	Erick Ammon, Inc.
Design Hypotheses (Goal/Objective) (Reach Scale):	Although no hypotheses provided in Connor Creek design documentation, the design was meant to achieve the ROD’s general hypotheses: Channel rehabilitation combined with high flow management and sediment management will restore a dynamic alluvial river and the high quality salmonid habitat provided by an alluvial river. Objectives: Restore alluvial processes; increase Chinook salmon rearing habitat for fry and juveniles; removal of riparian berms along right bank to promote bar development and channel migration; and lowering of remnant bar feature to an elevation inundated by flows of 6,000 cfs or more will provide riparian planting and natural recruitment opportunities (M&T 2004).
Hypothesized Design Evolution (Reach Scale):	Although no predicted design evolution document is available, it was hypothesized that construction of Conner Creek was expected to evolve in the following way: As high flows begin to work in conjunction with right bank construction, existing subtle bars upstream of the project area will continue to expand, continuing left bank erosion, creating a point bar on the left bank 1/3 way through the project, which then causes right bank scour midway through the project and right bank bar development at the downstream end of the project. Over time, this bank erosion and bar deposition should increase site sinuosity and complexity. Floodplains constructed to be inundated by flows of 6,000 cfs or more will provide suitable planting surfaces and promote natural riparian recruitment that will increase woody riparian structure and diversity.

Individual Features - Design Purpose			
Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Feathered Edge	N/A	Remove riparian vegetation to promote bar formation. This feature was removed from the 90% drawings after the WY2005 flood did a majority of the work originally proposed. A large wood pile was deposited in this location during this high flow event and also negated the need for work here.
R-2	450 cfs Floodplain (Note: all designed surfaces were called floodplains to facilitate permitting)	3,500 yd3 Cut	Remove riparian encroached banks to a depth that would be inundated by flows of 500 cfs or greater. This should encourage channel migration into the right bank, discourage future riparian encroachment, and continue the meander sequence established by the WY2005 flood in area R-1
R-3	6,000 cfs Floodplain	12,400 yd3 Cut	Area R-3 constructed a floodplain surface designed to be inundated by flows of 6,000 cfs and greater. The purpose was to reconnect floodplain surface to ROD flows promoting natural floodplain function (sand deposition and natural riparian regeneration). This surface also provided riparian planting opportunities that were intended to mitigate losses associated with Areas R-2 and R-5 construction. Several alders were left in place to increase riparian structure and diversity, provide a local seed source for natural recruitment, preserve canopy continuity, and potentially become contribute large wood. Riparian plantings were designed increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. Post construction, R-3 was revegetated with willow and cottonwood cuttings.
R-4	Re-contouring	0	Area R-4 graded the existing surface between Areas R-3 and R-5 to reduce stranding of juvenile salmonids during spring ROD releases.
R-5	Feathered Edge	3,500 yd3 Cut	Remove riparian berm, construction of Area R-5 sloped the bank back at a 10H:1V into existing ground. This constructed element was intended to remove riparian vegetation and sand associated with the berm along the right bank, expand the bankfull channel, promote right bank bar development, enhance the existing meander sequence, reduce likelihood of future riparian encroachment, and provide salmonid rearing habitat at flows of 300 to 2,000 cfs.

U-1	Terrace	7,400 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment and organic material that would improve current growing surface.
U-2	Terrace	12,000 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment and organic material that would improve current growing surface.

Design Milestone Timeline		
Date (Month/Year)	Milestone	Notes (Reference Document)
11/2001	Baseline Topography Generated	American Aerial Surveys and BOR Digital Mapping (Photogrammetry) of prepared topography and orthophotography for existing conditions. Data collected November 7, 2001.
1/2004	Design Started	Design Team Members Selected Sites and Design Process Began
7/2004	Fieldwork completed	Water surface elevations, Cross sections, and minor bathymetry and topography.
8/2004	Conceptual Design Completed	Submitted to TRRP August, 2004. Presented at Conceptual Design to Design Team in September, 2004 which included field tour of site.
11/2004	Description of Proposed Action and Alternatives document for environmental assessment.	TRRP staff prepared distributed a draft description of alternatives for the Canyon Creek sites in November, 2004.
12/2004	50% Designs Revised and Submitted to TRRP	Submitted to TRRP December, 2004
5/2005	50% Revegetation Designs Completed and Submitted	Submitted to TRRP May, 2005.
6/2005	Revised 50% Civil and Riparian Designs Presented	Presented to Design Team on June 14, 2005
6/2006	90% Designs Completed and Submitted	Submitted to TRRP June, 2006.
7/2006	100% Stamped and Signed drawings and supporting files Completed and Submitted	Submitted to TRRP July, 2006.
7/2006	Stamped and Signed FEMA letter submitted	Submitted to TRRP July, 2006.
11/2006	Construction Completed	
1/2007	As-Built Surveys Completed	Distributed to the Design Team January, 2007
3/2007	Revegetation Complete	

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	July 2006; COE HEC-RAS (vers. N/A) between RM 76.9 and RM 77.4
1-D Hydraulic Analysis	To determine 500 cfs and 6,000 cfs design floodplain elevations	December 2004; COE HEC-RAS (vers. 3.0) between RM 76.9 and RM 77.4
Topographic Terrain Model Development	To determine cut and fill volumes, and to develop construction drawings	7/06; AutoDesk Land Development Desktop 2005, Map 2005
Design Criteria		
From M&T (2004)		
Feathered edge slope: 10H:1V Area 3 "floodplain" inundated by 500 cfs Area 5 floodplain inundation begins at 6,000 cfs – flows approximately 1 foot deep at 7,000 cfs. Spoils and other design elements cause increases in 100-yr flood elevations not to exceed 1 ft.		
Design Constraints		
Left bank residence did not want large cottonwoods removed as they provided view and sound barriers to HWY 299		
Left bank bedrock constrains channel migration		
Riparian mitigation requires 1 to 1 recovery from a minimum of 50% planting and the remainder from natural recruitment		
Increase in 100-year flood elevation not to exceed one foot		
No impacts to structural integrity of HWY 299 embankment		
Design Modifications Made in the Field During Construction		
During construction ten trees originally proposed to be removed were left in place on pedestals 3 to 6 feet higher than finished grade. Three of these trees were black cottonwood the remaining seven trees were white alder.		
Several pieces of large wood were also added in the R-5 feathered edge.		

References

McBain & Trush, Inc. (M&T) 2004. Trinity River – Conner Creek (RM 77.3) Design Alternatives Technical Memorandum, Prepared for the Trinity River Restoration Program, August 31, 2004.

Phase 1 – Design Summary Fact Sheet for Valdor Gulch

Project Name:	Valdor Gulch Rehabilitation Site
Project Location:	River Mile 74.8 to 75.7
Project Ownership: (Private/Public)	Private
Principal Designer(s):	HVT Design Team (Robert Franklin, HVT; Scott McBain, Fred Meyer, John Bair, M&T; Rose Patenaude, Jeff Anderson & Associates)
Date Design Completed:	July 15, 2006
Total Earthwork Volume: (Cut & Fill)	38,900 yd3 Cut and 38,900 yd3 Fill
Year Constructed:	2006
Total Cost of Construction:	$422,850
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Although no hypotheses provided in Valdor Gulch design documentation, the design was meant to achieve the ROD's general hypotheses: Channel rehabilitation combined with high flow management and sediment management will restore a dynamic alluvial river and the associated high quality salmonid habitat. Objectives: Restore alluvial processes; increase Chinook salmon spawning, and rearing habitat for flows between 300 and 2,000 cfs; remove riparian vegetation along right and left banks to promote bar development and channel migration; and lower surfaces adjacent to the mainstem channel to function as a natural floodplain under ROD flows.
Hypothesized Design Evolution (Reach Scale):	Although no clear written design evolution is available it is hypothesized that construction of Valdor Gulch was expected to evolve in the following way: As high flows begin to work in conjunction with the constructed right bank, existing subtle bars upstream of the project area will continue to expand causing right bank scour at the upstream end of the project and right bank bar development at the downstream end of the project. Bar development will increase site sinuosity and complexity. The lowering of a remnant bar feature to an elevation inundated by flows of 1.5 year recurrence flows (6,000-6,600 cfs) or facilitated successful riparian revegetation and promoted natural riparian recruitment thereby increasing woody riparian structure and diversity.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	6,000 cfs Floodplain	10,000 yd3 Cut	The purpose of Area R-1 was to lower an existing bar feature to an elevation inundated by flows of 6,000 cfs. To increase floodplain complexity, areas of the existing surface were lowered an additional

			1 and 2 feet below the 6,000 cfs water surface elevation to allow flows of 5,000 cfs and 4,000 cfs access the design surface. The left bank along the mainstem channel was sloped back at a 10H:1V angle removing mature riparian vegetation along the low water's edge. Riparian plantings were designed increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. Post construction, R-1 was revegetated with willow and cottonwood cuttings. A large tree was retained on the island (along mainstem right bank) to increase topographical diversity.
R-2	450 cfs Side Channel	4,000 yd3 Cut	Excavate existing high flow channel to an elevation inundated by flows of 450 cfs or more. Provide Chinook fry and juvenile rearing opportunities when flows are 450 cfs or more. Large wood was added in the side channel as single piece and up to ~ 6 pieces were placed at the head of the island. Large wood was incorporated into the site (post-construction) and was meant to maintain the low flow channel.
R-3	Feathered Edge	500 yd3 Cut	Construction of Area R-3 consisted of grubbing and ripping existing vegetation along the low water's edge while sloping the bank back at a 10H:1V angle into existing ground. Construction expanded the bankfull channel width from an existing 120 ft to 160 ft. The purpose of the design was to encourage deposition on an existing subtle left bank bar feature promoting bar development that increased channel sinuosity and right bank scour into Area R-8. It was also expected that ROD flows would scour riparian seedlings reducing the risk of riparian establishment along mainstem channel. Some large wood was incorporated into the site (post-construction) and several standing trees were maintained in the upstream portion of the R-3 as seed trees and to maintain topographical diversity.
R-4	2,000 cfs Floodplain (Revised term: Surface)	4,000 yd3 Cut	Area R-4 removed existing vegetation along the low water's edge (grubbing and ripping the root system) and lowered the surface down to be inundated by flows of 2,000 cfs or more. Construction of this surface in combination with Area R-9 expanded the bankfull channel from 140 ft to 220 ft. This constructed element was intended to promote right bank bar development, enhance the existing upstream meander sequence, reduce likelihood of future riparian encroachment, and provide rearing habitat at flows greater than 2,000 cfs.

			Large wood was incorporated into the site (post-construction) to provide immediate habitat for fry and juvenile salmonids.
R-5	6,600 cfs Floodplain	10,500 yd3 Cut	Area R-5 removed existing vegetation and sand berm along the left bank low water's edge (grubbing and ripping the root system) sloping the existing surface at a 10H:V angle from the low water's edge into the designed 6,600 cfs floodplain surface. This constructed element was intended to work in conjunction with upstream and downstream project elements and existing bedrock along the right bank; promoting coarse sediment deposition on the existing subtle left bank bar, reducing riparian encroachment and berm formation along the low water's edge, and providing fry and juvenile salmonid habitat for all flows. Riparian plantings were designed increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. Post construction, R-5 was revegetated with willow and cottonwood cuttings.
R-6	2,000 cfs Floodplain	3,000 yd3 Cut	Area R-6 removed existing vegetation along the left bank low water's edge (grubbing and ripping the root system) lowering the surface down to be inundated by flows greater than 2,000 cfs. Construction of this surface expanded the bankfull channel from 140 ft to 180 ft. This constructed element was intended to work in conjunction with an existing transverse bar feature, promote additional bar development, extend the existing upstream meander sequence, reduce likelihood of future riparian encroachment, and provide immediate rearing habitat at flows greater than 2,000 cfs.
R-7	Alcove	1,400 yd3 Cut	This design element was constructed at the downstream end of an existing point bar and scour channel feature. High flows in excess of 6,000 cfs were expected to inundate the bar and high flow scour channel, episodically scouring and maintaining the Alcove feature. The purpose of this feature was to increase fry and rearing habitat when flows are less than 2,000 cfs. Large wood incorporated within the alcove during construction was intended to increase cover structure for fry and juvenile salmonids.
R-8	6,600 cfs Floodplain	2,800 yd3 Cut	Area R-8 removed existing vegetation along the right bank low water's edge (grubbing and ripping the root system) lowering the surface down to be inundated by flows greater than 6,600 cfs. This constructed element was intended to work in conjunction with Project Area R-3, promoting right bank bar development, extending the existing upstream meander sequence, and reducing riparian

			encroachment along the low water's edge. Riparian plantings were designed increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. Post construction, R-8 was revegetated with willow and cottonwood cuttings.
R-9	Feathered Edge	2,200 yd3 Cut	Construction of Area R-9 consisted of grubbing and ripping existing vegetation along the low water's edge while sloping the bank back at a 10H:1V angle approximately 70 ft and daylighting into existing ground at a 2H:1V slope. Construction expanded the bankfull channel width from an existing 145 ft to 220 ft (in combination with Area R-4). The purpose of the design was to encourage deposition along the right bank promoting bar development that increased channel sinuosity and left bank scour into Area R-4. It was also expected that ROD flows would scour riparian seedlings along the low waters edge reducing the risk of riparian establishment along mainstem channel. Large wood was incorporated into the site (post-construction) in this area and large trees (alders) were left standing to increase habitat diversity.
U-1	Terrace	33,900 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain, feathered edge, and side channel construction without impact to the 100 year floodplain, store coarse sediment and organic material that would improve current growing surface.
U-2	Terrace	5,000 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain and feathered edge construction without impact to the 100 year floodplain, store coarse sediment and organic material that would improve current growing surface.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
11/2001	Baseline Topography Generated	American Aerial Surveys and BOR Digital Mapping (Photogrammetry) of prepared topography and orthophotography for existing conditions. Data collected November 7, 2001.
1/2004	Design Started	Design Team Members Selected Sites and Design Process Began
7/2004	Fieldwork completed	Water surface elevations, Cross sections, and minor bathymetry and topography data collected
8/2004	Conceptual Design Completed	Submitted to TRRP August, 2004. Presented at Conceptual

		Design to Design Team in September, 2004 which included field tour of site.
11/2004	Description of Proposed Action and Alternatives document for environmental assessment.	TRRP staff prepared distributed a draft description of alternatives for the Canyon Creek sites in November, 2004.
12/2004	50% Designs Revised and Submitted to TRRP	Submitted to TRRP December, 2004
5/2005	50% Revegetation Designs Completed and Submitted	Submitted to TRRP May, 2005.
6/2005	Revised 50% Civil and Riparian Designs Presented	Presented to Design Team on June 14, 2005
6/2006	90% Civil and Riparian Designs Completed and Submitted	Submitted to TRRP June, 2006.
7/2006	100% Stamped and Signed drawings and supporting files Completed and Submitted	Submitted to TRRP July, 2006.
7/2006	Stamped and Signed FEMA letter submitted	Submitted to TRRP July, 2006.
11/2006	Construction Completed	
1/2007	As-Built Surveys Completed	Distributed to the Design Team January, 2007
3/2007	Revegetation Completed	

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	July 2006; COE HEC-RAS (vers. N/A) between RM 76.9 and RM 77.4
1-D Hydraulic Analysis	To determine design surface elevations for specific inundation thresholds. Used in preparing 50% to 100% designs and determining depth to groundwater.	July 2006; COE HEC-RAS (vers. N/A) between RM 76.9 and RM 77.4
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	7/06; AutoDesk Land Development Desktop 2005, Map 2005
As-built vs. 100% Design Comparison	Site as-builts were assessed relative to the 100% civil designs using surface overlays and calculated cut-fill volumes	Spring 2007; AutoDesk Land Development Desktop

Design Criteria
Limited written design criteria is available for this site
Feathered edge slope: 10H:1V

Floodplain inundation begins at 6,600 cfs – flows approximately 1 foot deep at 7,600 cfs. Riparian vegetation roots along the low water's edge are to be ripped 1 foot deep Floodplain surfaces are to be ripped 1 foot deep
Design Constraints
Left bank residence did not want large cottonwoods removed as they provided view and sound barriers to HWY 299 Left bank bedrock constrains channel migration Riparian mitigation requires 1 to 1 recovery from a minimum of 50% planting and the remainder from natural recruitment Increase in 100-year flood elevation not to exceed one foot No impacts to structural integrity of HWY 299. No construction activities to take place within the low flow channel.
Design Modifications Made in the Field During Construction
During construction two white alders originally proposed to be removed were left in place on pedestals 3 to 6 feet higher than finished grade within Area R-1. All wood placed at the site was at the direction of the Trinity River Restoration Program staff during construction. Approximately 10 white alders were left in place at Area R-8 extending into Area R-9 and a trench dug along the backside to encourage scour and eventual uprooting of the alders left in place. Plantings included first year (woody riparian both rooted and pole stock) and second year (herbaceous) plantings; rooted stock from first year plantings and all second year plantings were never implemented. Berm left at entrance of downstream alcove

Phase 1 – Design Summary Fact Sheet for Elkhorn

Project Name:	Elkhorn Rehabilitation Site
Project Location:	Trinity River Mile 73.7 to 74.25
Project Ownership: (Private/Public)	Private/ Public (USFS and BLM)
Principal Designer(s):	Teresa Connor
Date Design Completed:	July 2006
Total Earthwork Volume: (Cut & Fill)	22,450 CY Cut (Engineers Estimate)
Year Constructed:	2006
Total Cost of Construction:	$244,032
Construction Contractor:	Erick Ammon, Inc.
Design Hypotheses (Goal/Objective) (Reach Scale):	Increase the diversity and amount of habitat for salmonids, particularly habitat suitable for rearing. Increase rearing habitat for juvenile salmonids, including coho and Chinook salmon and steelhead. Increase the structural and biological complexity of habitat for various species of wildlife associated with riparian habitat. Increase hydraulic and fluvial geomorphic diversity and complexity Measure/demonstrate the ecological response to changes in flow regimes, morphological features, and aquatic, riparian, and upland habitats Provide a self-maintaining project where adequate maintenance flows are likely to occur independent of future Trinity Dam flows. Increase the quality and quantity of habitat for foothill yellow-legged frog (all stages).
Hypothesized Design Evolution (Reach Scale):	Modifications proposed are designed to enable the river to move in the direction of an alluvial river, but rely on the river itself to modify its own form and function over time. These modifications are expected to result in the development of point bars and floodplain habitat that do not presently exist.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Alcove (450 cfs)	660 CY Cut	Continuously inundated (approx 1-2 feet deep) at low flows. Provide year-round juvenile fish habitat and will be maintained as associated high-flow channels route water through them. Add additional complexity to the riverine environment.
R-2	High Flow Side Channel (6,600 cfs)	1,370 CY Cut	Provide off-channel habitat for juvenile salmon as well as a variety of aquatic organisms at higher flows (greater than 6,600 cfs)
R-3	Vegetation	0 CY	Removal of vegetation in key locations will promote the river

	Removal		processes necessary for the restoration and maintenance of Trinity River alternate bars, therefore enhancing salmonid rearing habitat.
R-4	Floodplain (6,600 cfs)	4,500 CY Cut	Lower the river's edge to be in communication with the river at the 1.5 year flow (~6,600 cfs). Intended to increase the potential that the river will meander out of the channel, and would also increase the likelihood that the Trinity River would reflect more of the Healthy River attributes of an alluvial river.
R-5	Feathered Edge	15,000 CY Cut	A gently sloping surface 10:1 from the low flow water's edge. Intended to increase the potential that the river will meander out of the channel. Develop a point bar along river left and encourage lateral migration into the left bank.
R-6	Floodplain (6,600 cfs)	920 CY Cut	Recruit riparian vegetation onto the 1.5-year recurrence interval floodplain. Reactive floodplain to facilitate river-induced sinuosity that results in complexity of floodplain habitat.
R-7	Berm Removal and Grubbing	0 CY	Removal of berms and vegetation in key locations will promote the river processes necessary for the restoration and maintenance of Trinity River alternate bars, therefore enhancing salmonid rearing habitat.
U-1	Upland Area River left	21,530 CY Fill	Establish a suitable location for disposal of excavated material and, to a reasonable extent, establish native upland vegetation.
U-2	Upland Area River right	920 CY Fill	Establish a suitable location for disposal of excavated material and, to a reasonable extent, establish native upland vegetation.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
10/2002	Topographic Surveying	Total station and GPS surveying to supplement the 2001 photogrammetry
10/2002	Design Started	
10/2004	50% Conceptual Designs	
6/2006	Design Completed	Design drawings
Fall/2006	Construction Completed	
?	Site is Replanted	Site is replanted after earthwork completion

Design Analysis Performed

Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	12/2004; USCOE HEC-RAS

Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	Spring 2006; AutoDesk Land Development Desktop
As-built vs. 100% Design Comparison	Using surface overlays cut-fill volumes were used to assess how sites were built relative to the 100% design documents	Spring 2007; AutoDesk Land Development Desktop
Design Criteria		
Floodplains were designed to be inundated to a min depth of 6 inches under the 1.5-year flow (~6,600 cfs).		
Floodplain surface was designed to ensure adequate sloping of the bank toward the river to ensure drainage and minimize the opportunity for stranding juvenile salmonids.		
Design Constraints		
No construction work will occur below the river edge at low-water, summer baseflows.		
Do nothing to increase the flood risk in the general vicinity, and to not raise the water surface elevation in the FEMA zones.		
Design Modifications Made in the Field During Construction		
Changed design elevations near large trees in order to “save” the trees, leaving remnant islands of grey pine Oregon ash, and alder in the R-5 feathered edge to increase topographical diversity.		
Large wood added to R1 alcove and R5 feathered edge. Tree trunks are buried in river bank.		
Designer Notes		
Citation/References		
Canyon Creek Suite of Rehabilitation Sites Environmental Assessment/Draft Environmental Impact Report (February 2006)		

Phase 1 – Design Summary Fact Sheet for Pear Tree Gulch

Project Name:	Pear Tree Gulch Rehabilitation Site
Project Location:	Trinity River Mile 72.9 to 73.2
Project Ownership: (Private/Public)	Public (BLM)
Principal Designer(s):	Scott Kennedy
Date Design Completed:	June 2006
Total Earthwork Volume: (Cut & Fill)	9,900 CY Cut (Engineers Estimate)
Year Constructed:	2006
Total Cost of Construction:	$108,000 (Approx.)
Construction Contractor:	Erick Ammon, Inc.
Design Hypotheses (Goal/Objective) (Reach Scale):	-Increase the diversity and amount of habitat for salmonids, particularly habitat suitable for rearing. -Increase rearing habitat for juvenile salmonids, including coho and Chinook salmon and steelhead. -Increase the structural and biological complexity of habitat for various species of wildlife associated with riparian habitat. -Increase hydraulic and fluvial geomorphic diversity and complexity -Measure/demonstrate the ecological response to changes in flow regimes, morphological features, and aquatic, riparian, and upland habitats -Provide a self-maintaining project where adequate maintenance flows are likely to occur independent of future Trinity Dam flows. -Increase the quality and quantity of habitat for foothill yellow-legged frog (all stages).
Hypothesized Design Evolution (Reach Scale):	Modifications proposed are designed to enable the river to move in the direction of an alluvial river, but rely on the river itself to modify its own form and function over time. These modifications are expected to enhance the development of point bars and allow the river to access the floodplain habitat at the 1.5 year flow (~6,600 cfs).

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Vegetation Removal	0 CY	Reactivate floodplain and gravel bar to facilitate river-induced meandering and floodplain development.
R-2	Feathered Edge	6,000 CY Cut	Intended to increase the potential that the river will meander out of the channel

R-3	Floodplain (6,600 cfs)	3,000 CY Cut	Intended to increase the potential that the river will meander out of the channel. Provide an area for the natural recruitment of riparian vegetation.
R-4	Scour Channel	200 CY Cut	Create off-channel habitat that would provide velocity refuge for fish during various flow regimes. Add additional complexity to riverine environment.
R-5	Low Water Alcove	700 Cy Cut	Create off-channel habitat that would provide velocity refuge for fish during various flow regimes. Provide year-round juvenile fish habitat and will be maintained as associated high-flow channels route water through them.
U-1	Terrace	9,900 CY Fill	Establish a suitable location for disposal of excavated material and, to a reasonable extent, establish native upland vegetation.
U-2	Terrace	0	Not constructed. This alternate location for an upland terrace was not needed.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
6/2004	Site Visit	Design Team Members discussed various design features that would make the restoration of Pear Tree Gulch successful.
8/2004	Topographic Surveying	Total station and GPS surveying to supplement the 2001 photogrammetry
Fall 2006	Construction Complete	
?	Site is Replanted	Site is replanted after earthwork completion

Design Analysis Performed

Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	Feb 2005; COE HEC-RAS
1-D Hydraulic Analysis	To determine 6,600 cfs design floodplain elevations	COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	June 2006; AutoDesk Land Development Desktop

Design Criteria
Floodplains were designed to be inundated to a depth of 6 inches under the 1.5-year flow (~6,600 cfs)
Floodplain surface was designed to ensure adequate sloping of the bank toward the river to ensure drainage and minimize the opportunity for stranding juvenile salmonids.
Do not change water surface elevation for FEMA 1% chance annual flood.

Design Constraints
Changing the water surface elevation for flood flows is not permitted under FEMA regulations without the submission and acceptance of letters of map revision.
Access to river left made it difficult for construction, therefore no construction on river left.
No construction work will occur below the river edge at low-water, summer baseflows.
A berm was left at the mouth of the alcove because earthwork in the main channel was not permitted. We must rely on winter high flows or spring fishery flows to remove the berm.
Design Modifications Made in the Field During Construction
U-2 was not needed, therefore was not constructed. All spoils were placed in the U-1 area.
Designer Notes
Citation/References
Canyon Creek Suite of Rehabilitation Sites Environmental Assessment/Draft Environmental Impact Report (February 2006)

Phase 1 – Design Summary Fact Sheet for Indian Creek

Project Name:	Indian Creek
Project Location:	RM 93.9 to RM 96.9
Project Ownership: (Private/Public)	BLM, DFG, multiple private parcels
Principal Designer(s):	Joe Riess, TRRP
Date Design Completed:	March 2007
Total Earthwork Volume: (Cut & Fill)	77,800 yd cut; 64,700 yd fill 32,100 yd tailings processed for coarse sediment supply. Net yield was approximately 10,000 yd, significantly less than expected.
Year Constructed:	2007
Total Cost of Construction:	Contract award was $1,846,777
Construction Contractor:	Oregon Mountain Constructors
Design Hypotheses (Goal/Objective) (Reach Scale):	This site includes a wide range of actions over 3 miles of river. Various hypotheses associated with specific design features are given below.
Hypothesized Design Evolution (Reach Scale):	Hypotheses for future evolution at this site were controversial. It was hypothesized that excavation of notches in area R-1 would cause the remaining 'berm' on river right to erode away, although there was significant disagreement within the program on the potential for that to occur. It was also hypothesized that excavation in area R-8 would induce channel migration, and that some of the narrow islands created by side channel construction would eventually erode away.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Berm notches	Excavate 50-ft-wide notches in the berm on river right every 250 feet. 2.54 acres; 8,000 yd cut.	Improve the hydraulic connectivity between the channel and the floodplain area behind the berm and the availability of off-channel habitat at flows of about 2000 cfs and above; increase the potential for ROD flow releases to erode the remaining sections of berm.
R-2	Recontouring, clearing and grubbing	Poorly-drained lawn and brush on river left. 1.24 acres; 400 yd cut; 400 yd fill	Reduce stranding potential.

R-3	Berm removal	1.59 acres; 4,500 yd cut	Promote bank erosion and bar development.
R-4	Clearing and grubbing	0.94 acres	Increase flow conveyance during floods, promote bank erosion and bar development, allow natural recruitment of cottonwoods and willow species.
R-5	No work		
R-6	Recontouring, clearing and grubbing	1.4 acres; 400 yd cut; 400 yd fill	Increase high-flow habitat availability, promote bank erosion and bar development, Increase flow conveyance during floods, allow natural recruitment of cottonwoods and willow species.
R-7	High-flow channel (6000 cfs)	0.29 acres; 700 yd cut	Reduce stranding potential.
R-8	Terrace lowering to 6000 cfs floodplain	Includes high-flow side channel; 8.07 acres; 30,400 yd cut	Promote lateral migration, reduce upstream water surface elevations, improve sediment routing, provide area for riparian planting, provide source material for coarse sediment processing.
R-8	Low-flow side channel	3.07 acres; 32,600 yd cut	Create rearing habitat, reduce upstream water surface elevations, promote erosion of remnant berm, recruit large wood to the channel.
R-8	Clearing and grubbing	0.6 acres	Reduce upstream water surface elevations, encourage lateral channel migration.
R-9	Selective vegetation removal	0.93 acres	Reduce upstream water surface elevations, encourage lateral migration of Weaver Creek away from Hwy 299 bridge embankment.
R-10	Connect existing wetland area	0.14 acres; 800 yd cut	Create additional wetland habitat, provide area for riparian planting.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
July 2005	Design Started	Field trip with Program Partners and design group
Jan. 2006	Conceptual Design Completed	
Nov. 2006	VE Study Completed	Indian Creek Channel Rehabilitation Project, 50-percent Design, Trinity River Restoration Program, Central Valley Project
Jan. 25-26, 2007	Test pits	To determine gravel yields from processing material from terrace lowering
March 2007	Final Design completed	
June 26, 2007	Contract awarded	
July 24, 2007	Begin construction	
Dec. 2007	Civil construction completed	
Jan. 2009	Revegetation completed	Nov. 2008 through Jan. 2009

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	March 2007, COE HEC-RAS and GeoRAS
Cut and Fill analysis	To determine cut and fill volumes, based on 2001/2005 terrain model	March 2007, AutoDesk Civil3D 2007
Design Criteria		
The design concept was based on ideas contained in programmatic documents that emphasize the removal of riparian vegetation and berm deposits. The concept of berm removal was modified to excavation of a side channel in area R-8 when it was found during test pitting that no topographic berm was present in that area. The concept of berm removal was modified to excavation of a series of notches in area R-1 due to a lack of space for spoiling excavated materials on river right, poor access for hauling spoils in that location, and to experiment with selective berm removal. The design for the downstream end of the site was substantially driven by an objective to lower flood elevations and prevent flood damage at the Indian Creek subdivision on the left bank.		
Design Constraints		
Bedrock and valley wall on river right through the upstream and central parts of the project site. Residential development on river left in the center of the project site. Hwy 299 on river left in the upstream and downstream parts of the project site.		
Design Modifications Made in the Field During Construction		
TRRP staff supervised the placement of a small amount of large woody debris in the R-8 side channel, on the R-8 floodplain, and in the R-1 notches during construction. A very small amount of wood was placed along the main channel banks.		

Citations and other information
The Hoopa Valley Tribe authored two documents describing the Tribe’s opinions on the berm notching work performed in area R-1. These are
Rationale for recommended rejection of the Vitzhum Gulch Rehabilitation Site as one of the 44 Record of Decision channel rehabilitation sites implemented by the Trinity River Restoration Program, Dec. 2007
and
Performance of Vitzhum Gulch Rehabilitation Site in response to May 2008 high flow release, Aug. 2008.

Phase 1 – Design Summary Fact Sheet for Sven Olbertson

Project Name:	Sven Olbertson
Project Location:	Lewiston California RM 111.19 to 111.63
Project Ownership: (Private/Public)	100% Public
Principal Designer(s):	Hoopa Valley Tribe Design Group (Fred Meyer, Robert Franklin, John Bair, Scott McBain, Tony Barela)
Date Design Completed:	Final Technical Memorandum June 1, 2007; 100% Design Drawings February, 19 2008.
Total Earthwork Volume: (Cut & Fill)	10,800 yd3 Cut; 12,500 yd3 Fill (additional fill supplied from Deadwood Creek construction)
Year Constructed:	2008
Total Cost of Construction:	$131,400
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals: Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages. Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. Site Design Objectives to Achieve Programmatic Goals: Increase fry and juvenile rearing habitat, increase fry production by reducing redd superimposition Increase coarse sediment storage and supply Minimize in-channel work Eliminate standing water upstream of concrete weir Preserve selective vegetation for habitat and LWD recruitment Preserve pool downstream of concrete weir Create alternate bars Increase side channel habitat Increase LWD in side channel Construction mass balance (no import or export of material) Improve fishing access
Hypothesized Design Evolution (Reach Scale):	Sven Olbertson is located directly downstream of the primary spawning reach of the Trinity River. It is hypothesized that Sven Olbertson will provide fairly static long term high quality side channel habitat that emphasized fry and juvenile salmonid rearing.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Low Flow Side Channel Complex	10,800 yd3 Cut	Construction of the side channel complex included three upstream entrances with the purpose of increasing long term sustainability. Wood was included at the entrances to promote entrance sour and

			reduce risk of side channel entrance aggradation. A large flow barrier separating the existing upstream side channel from the downstream pond was removed to connect the upstream side channel to the downstream pond, increasing side channel length, slope, and complexity. The inclusion of large woody debris within the low flow side channel provided immediate benefits to fry and juvenile salmonid rearing habitat. The large downstream pond was filled in, reducing area by 50%. Combined with the connection to the upstream side channel and removal of the "Pond Discharge Weir" existing stagnant water conditions were replaced with slow current providing salmonid rearing habitat where there was none previously. Post construction, the side channel margins were revegetated with willow and cottonwood cuttings; rushes and sedges were planted along the channel margin
R-1	Floodplain (inundation varies)	Included in R-1 Earthwork Estimate	Floodplain surfaces were designed to inundate between 1,500 cfs and 8,000 cfs. The purpose was to provide suitable surface for planting and natural riparian recruitment. Additionally the floodplain surfaces are expected to alleviate scour within the side channel complex as ROD releases exceed 6,000 cfs. Riparian plantings were designed increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. On Constructed surfaces inundated at lower discharges (i.e., 1,500-2,000 cfs) were targets for sedge and rush plantings to promote larger areas of herbaceous dominated cover. Post construction, R-1 was revegetated with willow and cottonwood cuttings; rushes and sedges were planted along the channel margin
R-1	High Flow Scour Channel and Alcove	Included in R-1 Earthwork Estimate	Lowering of the existing surfaces provides flow into a small pond and wetland feature. To reduce stranding a high flow scour channel and alcove were designed and constructed between the wetland and mainstem channel. This feature is designed to flow when Lewiston Dam releases are 2,000 cfs.
IC-1	Point Bar	2,000 yd3 Fill	Removed from plans after the 90% design review. Rational for removing feature: reduce channel crossing and impact to existing spawning area; large coarse sediment source "Bear Island" directly upstream will build bar during high flow releases in excess of 6,000 cfs.
IC-2	Pond Discharge	7 yd3 Concrete	This was a recommendation made in the October 2007 Value

	Weir Removal	removed and spoiled off site	Engineering Lewiston – Dark Gulch Final Report. The purpose of this design component was to increase slope through the existing pond, providing fry and juvenile salmonid habit where there was none prior to construction. Additionally this design feature reduced risk of mainstem capture through the side channel over alternative design which proposed complete removal or notching of the concrete weir.
IC-3	Rock Slope Protection	1,300 tons (2 and ¼ ton rock and #1 rock)	ROD flows were scouring the existing bank and high flow injection location. The purpose of this design element was to fortify and rebuild the existing long term coarse sediment injection location.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
4/2006	Design Started; Initial R-8 Design Team Meeting	Design Process Began: Design Team Members Selected Sites and Prepare Draft Environmental Study Limits.
6/2006	Field Assessments of Sites and Preliminary Concept Discussions	Field Trip to Sites (June meeting agenda; meeting notes).
July 4, 2006	Prepare Trinity River Bank Rehabilitation Sites Draft Overall Project Objectives and Lewiston Rehabilitation Sites Project Objectives	Initially prepared by HVT Design Team: Presented to Program Partners, comments received and incorporated in to draft document – Final document never completed. (Draft Project Objectives, July 2006)
8/2006	Preliminary Conceptual Design Drawings Completed and Submitted to Design Team	Presented conceptual design to Design Team on 9/2006.
11/2006	Conceptual Design Alternatives and Draft Design Document	Submitted to Program Partners 11/2006 for review
3/2007	Site Visit and Review of Conceptual Design Alternatives	Site visit conducted March 16, 2007 resulting in site visit notes and selection of proposed action.
6/2007	90% Design Technical Memorandum and Drawings Completed	Submitted to the design team members 6/2007 for review
10/2007	VE Study Completed	VE Study Document Name: "Lewiston – Dark Gulch Channel Rehabilitation Sites"
1/2008	90% Design Review Meeting	Final meeting to review and comment on design drawings -
1/2008	90% Design Specifications	Lewiston Dark Gulch Rehabilitation Sites 90% Design Specifications submitted to design team by TRRP staff
3/2008	100% Stamped Civil Design Drawings Completed	Lewiston-Dark Gulch Rehabilitation
4/2008	Signed Flood Letter	Final flood letter signed and submitted to TRRP
11/2008	Construction Completed	
1/2009	As-Built Surveys Completed	Submitted to TRRP January, 2009

12/2008	Revegetation Completed	
Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To evaluate side channel alignment and provide recommendations.	2006 through 2007; COE HEC-RAS
1-D Hydraulic Analysis	To determine design surface elevations for specific inundation thresholds. Used in preparing 50% to 100% designs and determining depth to groundwater.	2006 through 2008; COE HEC-RAS
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements based on 50%, 90%, and 100% design Drawings	June 2007 through January 2008; COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	2006 through 2007; AutoDesk Land Development Desktop 2006
Design Criteria		
Low flow channel width: Wlf = 60-70 feet.		
Discharge to inundate floodplain: Qfp = 500 to 4,000 cfs.		
Bank full channel width: Wbf = 120-150 feet.		
Discharge to inundate point bar or medial bar: Qb = 500 to 2,000 cfs.		
Meander wavelength: λ = 600 to 800 feet.		
Water depth in constructed side channel is 1 ft deep minimum when flows are 300 cfs.		
Water depth in constructed side channel pools may exceed 2 ft deep when flows are 300 cfs.		
ROD flow peaks are the highest flows likely to impact this project.		
Design Constraints		
Turbidity from in-channel work		
Avoid capture of mainstem channel as a result of construction		
Avoid impact to bridges and roads		
No cabled large wood structures		
Design Modifications Made in the Field During Construction		
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.		

Phase 1 – Design Summary Fact Sheet for Deadwood Creek

Project Name:	Deadwood Creek
Project Location:	Lewiston California RM 110.46 to 110.96
Project Ownership: (Private/Public)	Access and staging area are private. Construction area 75% public and 25% private
Principal Designer(s):	Hoopa Valley Tribe Design Group (Fred Meyer, Robert Franklin, John Bair, Scott McBain, Tony Barela)
Date Design Completed:	Final Technical Memorandum June 1, 2007; 100% Design Drawings February, 19 2008.
Total Earthwork Volume: (Cut & Fill)	1,700 yd3 Cut; 1,100 yd3 Coarse Sediment Fill
Year Constructed:	2008
Total Cost of Construction:	$70,000
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals: Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages. Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. Site Design Objectives to Achieve Programmatic Goals: Increase fry and juvenile rearing habitat, increase fry production by reducing redd superimposition Increase coarse sediment storage and supply through construction of alluvial bars Encourage channel migration Preserve selective vegetation for habitat and LWD recruitment Preserve existing complex habitat Increase side channel habitat Improve fishing access
Hypothesized Design Evolution (Reach Scale):	Deadwood Creek is located within the primary Trinity River spawning reach and was designed to immediately increase fry and juvenile salmonid rearing habitat. It is hypothesized that construction including: coarse sediment additions, lowering of adjacent surfaces to be inundated by ROD flows, and removal of riparian vegetation along the low water's edge; in combination with ROD releases and long term gravel augmentation will sustain a complex dynamic alluvial channel morphology.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-3	Low Flow Side Channel	1,700 yd3 Cut	Construction of the side channel included removal of an existing riparian berm present along the low water's edge on the inside of a pre-dam point bar. Large wood placed within the low flow side

			channel was to provide immediate fry and juvenile rearing habitat. This feature is ½ meander wavelength long and reflects characteristics of a scour channel typically present on the backside of alluvial bar features. As much existing riparian vegetation as feasible was left in place to increase riparian structure and diversity, provide a local seed source for natural recruitment, and preserve canopy continuity. Riparian planting was implemented along the right bank of the side channel to increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. Post construction, this area was revegetated with willow and cottonwood cuttings,; rushes and sedges were planted along the channel margin
IC-5	Point Bar	1,100 yd3 Fill	This bar was included to immediately increase sediment storage and supply, provide increased channel complexity, and narrow the low flow channel width to reduce the risk of riparian vegetation reestablishing along the low water's edge.

Design Milestone Timeline		
Date (Month/Year)	Milestone	Notes (Reference Document)
4/2006	Design Started; Initial R-8 Design Team Meeting	Design Process Began: Design Team Members Selected Sites and Prepare Draft Environmental Study Limits.
6/2006	Field Assessments of Sites and Preliminary Concept Discussions	Field Trip to Lewiston Sites (June meeting agenda; meeting notes).
July 4, 2006	Prepare Trinity River Bank Rehabilitation Sites Draft Overall Project Objectives and Lewiston Rehabilitation Sites Project Objectives	Initially prepared by HVT Design Team: Presented to Program Partners, comments received and incorporated in to draft document – Final document never completed. (Draft Project Objectives, July 2006)
8/2006	Preliminary Conceptual Design Drawings Completed and Submitted to Design Team	Presented conceptual design to Design Team on 9/2006.
11/2006	Conceptual Design Alternatives and Draft Design Document	Submitted to Program Partners 11/2006 for review
3/2007	Site Visit and Review of Conceptual Design Alternatives	Site visit conducted March 16, 2007 resulting in site visit notes and selection of proposed action.
6/2007	90% Design Technical Memorandum and Drawings Completed	Submitted to the design team members 6/2007 for review
10/2007	VE Study Completed	VE Study Document Name: "Lewiston – Dark Gulch Channel Rehabilitation Sites"

1/2008	90% Design Review Meeting	Final meeting to review and comment on design drawings -
1/2008	90% Design Specifications	Lewiston Dark Gulch Rehabilitation Sites 90% Design Specifications submitted to design team by TRRP staff
3/2008	100% Stamped Civil Design Drawings Completed	Lewiston-Dark Gulch Rehabilitation
4/2008	Signed Flood Letter	Final flood letter signed and submitted to TRRP
11/2008	Construction Completed	
1/2009	As-Built Surveys Completed	Submitted to TRRP January, 2009
12/2008	Revegetation Completed	

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To evaluate side channel alignment and provide recommendations.	2006 through 2007; COE HEC-RAS
1-D Hydraulic Analysis	To determine design surface elevations for specific inundation thresholds. Used in preparing 50% to 100% designs and determining depth to groundwater.	2006 through 2008; COE HEC-RAS
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements based on 50%, 90%, and 100% design Drawings	June 2007 through January 2008; COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	2006 through 2007; AutoDesk Land Development Desktop 2006

Design Criteria
Low flow channel width: Wlf = 60-70 feet.
Discharge to inundate floodplain: Qfp = 500 to 4,000 cfs.
Bank full channel width: Wbf = 120-150 feet.
Discharge to inundate point bar or medial bar: Qb = 500 to 2,000 cfs.
Meander wavelength: λ = 600 to 800 feet.
Water depth in constructed side channel is 1 ft deep minimum when flows are 300 cfs.
Water depth in constructed side channel pools may exceed 2 ft deep when flows are 300 cfs.
ROD flow peaks are the highest flows likely to impact this project.

Design Constraints
100 year flood water surface elevation not to increase by more than 1 foot

Turbidity from in-channel work
Avoid impact to bridges and roads
Avoid any impact to private landowners including: Houses, wells, and out-buildings.
No cabled large wood structures
Design Modifications Made in the Field During Construction
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

Phase 1 – Design Summary Fact Sheet for Lewiston Cableway

Project Name:	Lewiston Cableway
Project Location:	Lewiston California RM 110.18 to 110.46
Project Ownership: (Private/Public)	100% Public – California Department of Fish and Game
Principal Designer(s):	Hoopa Valley Tribe Design Group (Fred Meyer, Robert Franklin, John Bair, Scott McBain, Tony Barela)
Date Design Completed:	Final Technical Memorandum June 1, 2007; 100% Design Drawings February, 19 2008.
Total Earthwork Volume: (Cut & Fill)	3,800 yd3 Cut; 5,100 yd3 Coarse Sediment Fill
Year Constructed:	2008
Total Cost of Construction:	$250,000
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals: Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages. Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. Site Design Objectives to Achieve Programmatic Goals: Increase fry and juvenile rearing habitat, increase fry production by reducing redd superimposition Protect Lewiston bridge and private property Increase coarse sediment storage and supply through construction of alternating bars Remove existing fine sediment storage Restore floodplain connectivity Increase sinuosity Reduce fine sediment storage (excavate Hoadley Gulch delta, remove berms, eliminate grate control structures) Increase side channel habitat Allow geomorphic process the ability to restore a more natural slope though reach.
Hypothesized Design Evolution (Reach Scale):	Lewiston Cableway is located within the primary Trinity River spawning reach and was designed to immediately increase fry and juvenile salmonid rearing habitat. It is hypothesized that construction including: coarse sediment additions in the form of alternating point bars, removal of riparian vegetation along the backside of constructed bars, and the re-opening of the existing side channel entrance, in combination with ROD releases and long term gravel augmentation will sustain a complex dynamic alternating bar morphology and low flow side channel.

Individual Features - Design Purpose

Code	Type	Earthwork (CY)	Purpose

		(Cut or Fill)	
R-3	Low Flow Side Channel (Entrance)	500 yd3 Cut	R-3 opened the existing entrance cut off by aggradation and provided a second entrance for an existing side channel. The purpose of this feature is to increase salmonid spawning and fry and juvenile rearing habitat.
R-3	Low Flow Side Channel (Exit)	3,300 yd3 Cut	This feature was not constructed. The design intended to increase flow into the side channel conveying 50% of the mainstem discharge.
IC-6	Coarse Sediment Addition	600 yd3 Fill (1/4 - 5 in) 500 yd3 Fill (5 – 12 in)	Area IC-6 constructed a point bar and downstream alcove along the left bank. To increase bar stability during dam releases greater than 6,000 cfs a 3 foot layer of 5 – 12 inch coarse sediment was placed within the construction boundary. The bar was then completed using ¼ to 5 inch coarse sediment. The purpose of this design feature is to increase coarse sediment storage, direct flows into the low flow side channel (Area R-3), reduce radius of curvature, increase sinuosity, narrow low flow channel widths, reduce likelihood of riparian encroachment, and provide spawning and rearing habitat for salmonids for flows ranging between 300 and 2,000 cfs.
IC-7	Grade Control Removal	70 tons of boulders removed from grade control	Removal of 1 to 3 foot boulders will allow mainstem slope to adjust through the Lewiston Cableway Reach allowing alluvial features such as transverse and point bars to develop within the active channel. As part of the grade control removal 50 ft of the existing grade control along the left bank was left in place to reduce right bank scour risk and impacts to existing homes.
IC-8	Coarse Sediment Addition	1,000 yd3 Fill (1/4 -5 in) 1,500 yd3 Fill (5 – 12 in)	Area IC-8 constructed a point bar along the left bank. To increase bar stability during dam releases greater than 6,000 cfs a 3 foot layer of 5 – 12 inch coarse sediment was placed within the construction boundary. The bar was then completed using ¼ to 5 inch coarse sediment. The purpose of this design feature is to increase coarse sediment storage, direct flows into the low flow side channel (Area R-3), reduce radius of curvature, increase sinuosity, narrow low flow channel widths, reduce likelihood of riparian encroachment, and provide spawning and rearing habitat for salmonids for flows ranging between 300 and 2,000 cfs.
IC-8	Grade Control Removal	100 tons of boulders removed from grade control	Removal of 1 to 3 foot boulders will allow mainstem slope to adjust through the Lewiston Cableway Reach allowing alluvial features such as transverse and point bars to develop within the active channel.

IC-9	Coarse Sediment Addition	400 yd3 Fill (1/4 - 5 in)	Area IC-9 constructed a point bar along the right bank. The purpose of this design feature is to increase coarse sediment storage, reduce radius of curvature, increase sinuosity, narrow low flow channel widths, reduce riparian encroachment, and provide spawning and rearing habitat for salmonids for flows ranging between 300 and 2,000 cfs.
IC-10	Coarse Sediment Addition	1,000 yd3 Fill (1/4 -5 in)	Area IC-10 constructed a point bar along the left bank completing the third bar in an alternating bar sequence. The purpose of this design feature is to increase coarse sediment storage, reduce radius of curvature, increase sinuosity, narrow low flow channel widths, reduce riparian encroachment, and provide spawning and rearing habitat for salmonids for flows ranging between 300 and 2,000 cfs.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
4/2006	Design Started; Initial R-8 Design Team Meeting	Design Process Began: Design Team Members Selected Sites and Prepare Draft Environmental Study Limits.
6/2006	Field Assessments of Sites and Preliminary Concept Discussions	Field Trip to Lewiston Sites (June meeting agenda; meeting notes).
July 4, 2006	Prepare Trinity River Bank Rehabilitation Sites Draft Overall Project Objectives and Lewiston Rehabilitation Sites Project Objectives	Initially prepared by HVT Design Team: Presented to Program Partners, comments received and incorporated in to draft document – Final document never completed. (Draft Project Objectives, July 2006)
8/2006	Preliminary Conceptual Design Drawings Completed and Submitted to Design Team	Presented conceptual design to Design Team on 9/2006.
11/2006	Conceptual Design Alternatives and Draft Design Document	Submitted to Program Partners 11/2006 for review
3/2007	Site Visit and Review of Conceptual Design Alternatives	Site visit conducted March 16, 2007 resulting in site visit notes and selection of proposed action.
6/2007	90% Design Technical Memorandum and Drawings Completed	Submitted to the design team members 6/2007 for review
10/2007	VE Study Completed	VE Study Document Name: “Lewiston – Dark Gulch Channel Rehabilitation Sites”
1/2008	90% Design Review Meeting	Final meeting to review and comment on design drawings -
1/2008	90% Design Specifications	Lewiston Dark Gulch Rehabilitation Sites 90% Design Specifications submitted to design team by TRRP staff
3/2008	100% Stamped Civil Design Drawings Completed	Lewiston-Dark Gulch Rehabilitation

<table>
<tr><td>4/2008</td><td>Signed Flood Letter</td><td>Final flood letter signed and submitted to TRRP</td></tr>
<tr><td>11/2008</td><td>Construction Completed</td><td></td></tr>
<tr><td>1/2009</td><td>As-Built Surveys Completed</td><td>Submitted to TRRP January, 2009</td></tr>
<tr><td colspan="3">Design Analysis Performed</td></tr>
<tr><td>Type of Analysis</td><td>Reason Performed</td><td>Date Completed & Software Used</td></tr>
<tr><td>1-D Hydraulic Analysis</td><td>To evaluate side channel alignment and provide recommendations.</td><td>2006 through 2007; COE HEC-RAS</td></tr>
<tr><td>1-D Hydraulic Analysis</td><td>To determine design surface elevations for specific inundation thresholds. Used in preparing 50% to 100% designs and determining depth to groundwater.</td><td>2006 through 2008; COE HEC-RAS</td></tr>
<tr><td>1-D Hydraulic Analysis</td><td>To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements based on 50%, 90%, and 100% design Drawings</td><td>June 2007 through January 2008; COE HEC-RAS</td></tr>
<tr><td>Topographic Terrain Model Development</td><td>To determine cut and fill volumes and for development of construction drawings</td><td>2006 through 2007; AutoDesk Land Development Desktop 2006</td></tr>
<tr><td colspan="3">Design Criteria</td></tr>
<tr><td colspan="3">Low flow channel width: Wlf = 60-70 feet.</td></tr>
<tr><td colspan="3">Discharge to inundate floodplain: Qfp = 500 to 4,000 cfs.</td></tr>
<tr><td colspan="3">Bank full channel width: Wbf = 120-150 feet.</td></tr>
<tr><td colspan="3">Discharge to inundate point bar or medial bar: Qb = 500 to 2,000 cfs.</td></tr>
<tr><td colspan="3">Meander wavelength: λ = 600 to 800 feet.</td></tr>
<tr><td colspan="3">Water depth at entrance to side channel is 1 ft deep minimum when flows are 300 cfs.</td></tr>
<tr><td colspan="3">Water depth within side channel pools may exceed 2 ft deep when flows are 300 cfs.</td></tr>
<tr><td colspan="3">ROD flow peaks are the highest flows likely to impact this project.</td></tr>
<tr><td colspan="3">Design Constraints</td></tr>
<tr><td colspan="3">100 year flood water surface elevation not to increase by more than 1 foot. Proximity of existing houses reduced this design constraint to 0 feet.</td></tr>
<tr><td colspan="3">Turbidity from in-channel work</td></tr>
<tr><td colspan="3">Avoid impact to Old Lewiston Bridge</td></tr>
<tr><td colspan="3">Avoid any impact to private landowners including: Houses, wells, and out-buildings.</td></tr>
<tr><td colspan="3">No cabled large wood structures</td></tr>
</table>

Lewiston water supply
Design Modifications Made in the Field During Construction
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.
Area R-3 (Side Channel Exit) was not constructed due to spawning within the flowing channel.

Phase 1 – Design Summary Fact Sheet for Hoadley Gulch

Project Name:	Hoadley Gulch
Project Location:	Lewiston California RM 109.80 to 110.10
Project Ownership: (Private/Public)	90% Public – California Department of Fish and Game and 10% Private – Terrace area
Principal Designer(s):	Hoopa Valley Tribe Design Group (Fred Meyer, Robert Franklin, John Bair, Scott McBain, Tony Barela)
Date Design Completed:	Final Technical Memorandum June 1, 2007; 100% Design Drawings February, 19 2008.
Total Earthwork Volume: (Cut & Fill)	5,000 yd3 Cut; 8,400 yd3 Fill (includes space for Lewiston Cableway cut); 1,500 yd3 Coarse Sediment Fill
Year Constructed:	2008
Total Cost of Construction:	$120,000
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals: Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages. Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. Site Design Objectives to Achieve Programmatic Goals: Increase fry and juvenile rearing habitat, increase fry production by reducing redd superimposition Reduce fine sediment storage in berms Increase coarse sediment storage and supply through construction of alternating bars Restore floodplain connectivity Preserve existing pool habitat Increase side channel habitat Extend riffle gradient downstream with gravel augmentation and grade control removal.
Hypothesized Design Evolution (Reach Scale):	Hoadley Gulch is located within the primary Trinity River spawning reach and was designed to immediately increase fry and juvenile salmonid rearing habitat. It is hypothesized that construction including: coarse sediment additions in the form a point bar, lowering of upstream grade control structures, removal of remnant dredger tailing piles, and the addition of a side channel connecting dredger pools, in combination with ROD releases and long term gravel augmentation will sustain a complex dynamic alternating bar morphology and low flow side channel. These design features will provide salmonid habitat for all life stages and flow releases.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose

R-5	Low Flow Side Channel	1,000 yd3 Cut	R-5 constructed a low flow side channel, connecting as series of dredger pools to the mainstem Trinity River. Two entrances were designed to insure long-term self-maintenance. The purpose of this feature was to increase salmonid spawning and fry and juvenile rearing habitat when ROD releases are between 300 and 2,000 cfs. Large wood was added to this feature to provide cover and immediately benefit fry and juvenile salmonids. In addition to salmonid benefits this feature increases groundwater saturation and elevation improving natural recruitment and planting success.
R-5	Floodplain	4.000 yd3 Cut	Area R-5 lowers existing tailing piles to an elevation inundated by flows of 6,000 cfs. The purpose of this design was to provide a suitable riparian planting and natural recruitment surface as well as provide fry and juvenile salmonid rearing opportunities when ROD releases exceed 6,000 cfs. As much existing riparian vegetation as feasible was left in place to increase riparian structure and diversity, provide a local seed source for natural recruitment, and preserve canopy continuity. Riparian plantings were designed to increase long-term woody riparian structural diversity and a complex herbaceous understory away from the summer baseflow channel. Woody plantings were to occur in the year following construction and the herbaceous plantings were to occur after three years or when suitable conditions developed. Post construction, This area was revegetated with willow and cottonwood cutting,; rushes and sedges were planted along the channel margin
IC-11	Grade Control Removal	160 tons of 1 to 3 ft boulders removed	IC-11 lowered the right bank portion (approximately 60 ft) of an existing 100 ft long boulder weir. The purpose of IC-11 was to allow a slightly steeper gradient to establish upstream, improve boat passage over the boulder weir, and maintain pool tail integrity while directing flows into the low flow side channel.
IC-12	Coarse Sediment Addition	1,500 yd3 Fill (1/4 -5 in)	Area IC-12 constructed a point bar along the right bank. The purpose of this design feature is to increase coarse sediment storage, narrow low flow channel widths, reduce radius of curvature, increase sinuosity, reduce likelihood of riparian encroachment, and provide spawning and rearing habitat for salmonids for flows ranging between 300 and 2,000 cfs.
IC-13	Coarse Sediment Addition	2,500 yd3 Fill (1/4 -5 in)	Post-50% design review a 2,000 yd3 medial bar downstream of the constructed side channel was removed from the construction drawings.
U-3	Terrace	8,400 yd3 Fill	The purpose of Terrace U-3 was to provide a fill area for macerated vegetation and coarse sediment extracted from the Lewiston

			Cableway and Hoadley Gulch sites. Fill was placed in-between tailing piles constructing a terrace suitable for upland planting.

Design Milestone Timeline		
Date (Month/Year)	Milestone	Notes (Reference Document)
4/2006	Design Started; Initial R-8 Design Team Meeting	Design Process Began: Design Team Members Selected Sites and Prepare Draft Environmental Study Limits.
6/2006	Field Assessments of Sites and Preliminary Concept Discussions	Field Trip to Sites (June meeting agenda; meeting notes).
July 4, 2006	Prepare Trinity River Bank Rehabilitation Sites Draft Overall Project Objectives and Lewiston Rehabilitation Sites Project Objectives	Initially prepared by HVT Design Team: Presented to Program Partners, comments received and incorporated in to draft document – Final document never completed. (Draft Project Objectives, July 2006)
8/2006	Preliminary Conceptual Design Drawings Completed and Submitted to Design Team	Presented conceptual design to Design Team on 9/2006.
11/2006	Conceptual Design Alternatives and Draft Design Document	Submitted to Program Partners 11/2006 for review
3/2007	Site Visit and Review of Conceptual Design Alternatives	Site visit conducted March 16, 2007 resulting in site visit notes and selection of proposed action.
6/2007	90% Design Technical Memorandum and Drawings Completed	Submitted to the design team members 6/2007 for review
10/2007	VE Study Completed	VE Study Document Name: “Lewiston – Dark Gulch Channel Rehabilitation Sites”
1/2008	90% Design Review Meeting	Final meeting to review and comment on design drawings -
1/2008	90% Design Specifications	Lewiston Dark Gulch Rehabilitation Sites 90% Design Specifications submitted to design team by TRRP staff
3/2008	100% Stamped Civil Design Drawings Completed	Lewiston-Dark Gulch Rehabilitation
4/2008	Signed Flood Letter	Final flood letter signed and submitted to TRRP
11/2008	Construction Completed	
1/2009	As-Built Surveys Completed	Submitted to TRRP January, 2009
12/2008	Revegetation Completed	

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To evaluate side channel alignment and provide recommendations.	2006 through 2007; COE HEC-RAS

1-D Hydraulic Analysis	To determine design surface elevations for specific inundation thresholds. Used in preparing 50% to 100% designs and determining depth to groundwater.	2006 through 2008; COE HEC-RAS
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements based on 50%, 90%, and 100% design Drawings	June 2007 through January 2008; COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	2006 through 2007; AutoDesk Land Development Desktop 2006
Design Criteria		
Low flow channel width: Wlf = 60-70 feet.		
Discharge to inundate floodplain: Qfp = 500 to 4,000 cfs.		
Bank full channel width: Wbf = 120-150 feet.		
Discharge to inundate point bar or medial bar: Qb = 500 to 2,000 cfs.		
Meander wavelength: λ = 600 to 800 feet.		
Water depth in constructed side channel is 1 ft deep minimum when flows are 300 cfs.		
Water depth in constructed side channel pools may exceed 2 ft deep when flows are 300 cfs.		
ROD flow peaks are the highest flows likely to impact this project.		
Design Constraints		
100 year flood water surface elevation not to increase by more than 1 foot. Proximity of existing houses reduced this design constraint to 0 feet.		
Turbidity from in-channel work		
Avoid impact to Old Lewiston Bridge		
Avoid any impact to private landowners including: Houses, wells, and out-buildings.		
No cabled large wood structures		
Maintain existing deep pool habitat		
Design Modifications Made in the Field During Construction		
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.		

Phase 1 – Design Summary Fact Sheet for Dark Gulch

Project Name:	Dark Gulch Rehabilitation Site
Project Location:	River Mile 105.5 to 107.0
Project Ownership: (Private/Public)	Private and Public (BLM)
Principal Designer(s):	Scott Kennedy
Date Design Completed:	February 2008
Total Earthwork Volume: (Cut & Fill)	39,000 CY (Engineers Estimate)
Year Constructed:	2008
Total Cost of Construction:	$1.4 M (Approx.)
Construction Contractor:	Erick Ammon, Inc.
Design Hypotheses (Goal/Objective) (Reach Scale):	Increase the structural complexity of the types of riverine habitat available and thereby increase the range of anadromous salmonid life history stages that can be supported. Reactivate the floodplain to facilitate river-induced sinuosity that results in complex riparian floodplain habitat.
Hypothesized Design Evolution (Reach Scale):	Channel migration and subsequent bar building, increased sinuosity, natural riparian regeneration on constructed floodplains

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Side Channel and Floodplain	22,600 Cut	Increase amount of area inundated by fishery flow releases and increase channel complexity.
R-2	Side Channel and Floodplain	6,000 Cut	Increase amount of area inundated by fishery flow releases and increase channel complexity.
R-3	Wood Habitat Development	-	Placement of large wood with root balls in low-flow channel to provide rearing habitat for fish.
R-4	Side Channel	5,600 Cut	Provide low-flow rearing habitat off of the mainstem in a historic split flow channel which now only flows at 1,500 cfs.
R-5	Drainage Improvement	200 Cut	Connect a depression to the river to reduce stranding and provide rearing habitat at discharges above baseflow.
R-5	River Access Enhancement	-	Clear vegetation to improve access to river for people for recreational purposes.
R-6	Side Channel	200 Cut	Increase and improve quantity and quality of rearing habitat in existing side channel.
IC-1	Gravel Bar	0	Not constructed. Construction right-of-entry not obtained.
IC-2	Gravel Bar	0	Not Constructed. Construction right-of-entry not obtained.

IC-3	Gravel Bar	0	Not Constructed. Construction right-of-entry not obtained.
IC-4	Coarse Sediment Addition	40 Fill	Create small riffle to enhance flow into R-2 side channel.
IC-5	Coarse Sediment Addition	600 Fill	Increase coarse sediment supply and channel sinuosity.
IC-6	Coarse Sediment Addition	230 Fill	Create small riffle to enhance flow into R-4 side channel
IC-7	Grade Control Removal	-	Remove historic non-functional damaged wire and rock gabion structure
IC-7	Coarse Sediment Addition	1,500 Fill	Increase coarse sediment supply.
IC-8	Coarse Sediment Addition and Wood Habitat	640 Fill	Increase coarse sediment supply and add wood within the low-flow channel to provide rearing habitat.
U-1	Terrace	34,200 Fill	Stockpile area for material excavated on the right bank (except for project area R-6)
U-2	Wetland Expansion	250 Cut	Enlarge existing wetland to provide additional wetland habitat.
U-2	Terrace	250 Fill	Stockpile area for material excavated for wetland expansion.
U-3	Terrace	1,800 Fill	Stockpile area for material excavated on left bank and from right-bank project area R-6.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
5/2006	First site visit	Conceptual design brainstorming session with small group of Program Partners
6/2006	Concepts presentation to program partners	Took larger group of Program Partners on site visit after presentation.
7/2006	30% designs prepared	
10/2006	Topographic Surveying	Total station and GPS surveying to supplement 2005 TRRP TIN.
11/2006	Meeting to gain consensus on 30% designs.	
10/2007	Value engineering	
1/2008	90% designs submitted	
2/2008	Final designs complete	
?	Site is Replanted	Site is replanted after earthwork completion

Design Analysis Performed

Type of Analysis	Reason Performed	Date Completed & Software Used

1-D Hydraulic Analysis	To determine 100 yr. floodplain water elevation surface for FEMA requirements	1/2008; ACOE HEC-RAS
1-D Hydraulic Analysis	To determine design surface elevations for side channels and floodplains	
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	1/2008; AutoDesk Land Development Desktop
Design Criteria		
Do not change water surface elevation for FEMA 1% chance annual flood		
Side channels should contain flowing water when the total river discharge is equal to or above the values shown on the plans.		
Floodplains should be inundated at when the total river discharge is equal to or above the values shown on the plans.		
Design Constraints		
Changing the water surface elevation for flood flows is not permitted under FEMA regulations without the submission and acceptance of letters of map revision.		
Construction easements were not obtained for several parcels so portions of the original design were not able to be constructed. IC-1, 2, and 3 are features that could not be constructed.		
Construction alternatives for IC8 were limited by proximity of private property just outside the construction zone.		
Areas of existing high quality habitat within the project area reduced the overall footprint of the project because it was considered desirable to minimize adverse effects to existing habitat.		
A limited amount of gravel was available for coarse sediment augmentation.		
The river banks adjacent to the Browns Mountain Road bridge are experiencing scour; construction alternatives were avoided that might worsen this condition.		
Design Modifications Made in the Field During Construction		
?		
Designer Notes		
Citation/References		
Lewiston-Dark Gulch Environmental Assessment/Draft Environmental Impact Report (November 2007)		

Phase 1 – Design Summary Fact Sheet for Sawmill

Project Name:	Sawmill
Project Location:	River Mile 108.88-109.73
Project Ownership: (Private/Public)	Entirely public with a single private landowner at the downstream edge of the site (river left), which did constrain gravel volume and adjust the exit condition of a side channel to mitigate flood concerns.
Principal Designer(s):	Hoopa Valley Tribe and McBain & Trush
Date Design Completed:	March 2009
Total Earthwork Volume: (Cut & Fill)	88,000 yd3 Cut 88,000 yd3 Fill plus 10,700 yd3 coarse sediment additions (although only 5,000 yd3 placed due to BOR requirement)
Year Constructed:	2009
Total Cost of Construction:	$2,056,078 ($148,991/acre)
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals 1) Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages.2) Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. More specific site goals to achieve programmatic goals can be found on page 3 of the Design Report.
Hypothesized Design Evolution (Reach Scale):	Sustain dynamic and complex channel morphology through channel migration; maximize rearing habitat availability; promote natural riparian recruitment but reduce the risk of encroachment.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
IC-1	Remove Gabion	0 (Only wire was removed)	Return natural slope and thalweg to channel increasing channel complexity and fish habitat; Reduce boating hazard posed by failing wire gabion.
IC-2	Remove Gabion	0 (Only wire was removed	Return natural slope and thalweg to channel increasing channel complexity and fish habitat; Reduce boating hazard posed by failing wire gabion.
IC-2	Point Bar	750 yd3 Fill (1/4 to 4 inch coarse sediment)	IC-2 constructed a left bank point bar with the purpose of increasing coarse sediment storage, increasing channel sinuosity, and maintaining a pool tail associated with the IC-2 gabion removal to reduce the risk of a mainstem head cut propagating upstream causing the low flow side channel to be cut off. Sawmill design documents recommend thalweg surveys to monitor for potential mainstem head

			cut.
R-1	Floodplain	1,920 yd3 cut	Lower existing surface to inundate at a flow 4,000 cfs to provide high flow refuge for fry and juvenile salmonids and provide a surface suitable for natural riparian regeneration and planting that will increase the continuity of riparian canopy cover between the mainstem channel, side channels, and upland vegetation.
R-2	Floodplain	32,600 yd3 cut	R-2 constructed a variable floodplain surface designed to inundate when releases from Lewiston Dam are between 4,000 and 8,000 cfs. The purpose of this design was to provide variable inundation thresholds that would provide off channel salmonid fry and juvenile rearing for all ROD flows above 4,000 cfs. In addition this variable surface would provide riparian planting opportunities that would increase structural diversity and continuity of riparian canopy and allow monitoring of natural riparian recruitment success on surfaces in close proximity for a variety of inundation thresholds. Large wood was placed throughout the constructed floodplain surface to provide a roughness element causing velocity brakes and cover for fry and juvenile salmonids as flows surpassed 4,000 cfs.
R-2	1,000 cfs Bench	Included in 32,600 yd3 Cut above	Surfaces adjacent to the side channel were constructed to inundate when releases from Lewiston Dam are 1,000 cfs. The purpose of these features was to provide wetland planting locations and provide salmonid fry and juvenile rearing habitat when flows are 1,000 to 2,000.
R-2	Side Channel Meander	Included in 32,600 yd3 Cut above	The side channel meander feature within Area R-2 increased side channel length with the primary purpose of reducing the existing slope which would increase fry and juvenile salmonid rearing habitat and allow coarse sediment to aggrade increasing side channel spawning habitat. Large wood, clump plantings, and pole cuttings were added along the left bank to reduce the risk of the side channel reentering the mainstem at this location as well as provide immediate habitat benefits for salmonids.
R-2	Channel Meander	Included in 32,600 yd3 Cut above	Accompanies a left bank constructed point bar to increase channel sinuosity, reduce the radius of curvature, and promote channel migration. Combined with upstream gravel infusions and ROD releases a dynamic complex alluvial channel will evolve. A large wood structure consisting of vertical pilings with cross logs with the purpose of inducing pool and bank scour adjacent to the structure.
R-3	New Low Flow Side Channel Entrance	1,260 yd3 cut	R-3 moves an existing side channel entrance upstream re-opening a 1,200 ft side channel to winter baseflows. Large wood, pole cuttings, sedges, and clump planting were added throughout the side channel

			to provide immediate fry and juvenile rearing habitat.
R-6	Floodplain	Included in 32,600 yd3 Cut above	Remove dredger tailings piles to inundate when flows are 6,000 cfs. The purpose of R-6 was to provide a surface suitable for natural riparian regeneration and planting that will increase the continuity of riparian canopy cover between the mainstem channel, side channels, and upland vegetation.
IC-7 through IC-11	Alternating point bars	10,000 yd3 Fill	These point bar features were designed to increase mainstem sinuosity and coarse sediment storage, reduce radius of curvature and encourage channel migration into both banks. Right bank point bars and IC-9L (5,000 yd3) were removed by BOR after the 100% was completed due to downstream aggradation and landowner concerns. Point bars were constructed from coarse sediment ranging in size from ¼ to 4 inches to facilitate transport by ROD flows in excess of 6,000 cfs (TRRP recommendation). IC- 7 and IC-10 left bank point bars were built in conjunction with right bank meander excavation to expedite channel migration. These features were built with the same meander wavelength, low flow channel width, and bankfull only differing in mainstem slope. IC-7 and IC-10 also included the removal of boulder grade control structures with the purpose of allowing a natural slope and thalweg to propagate upstream and downstream increasing sinuosity and channel complexity. Continued short term coarse sediment additions on right bank bars (IC-7 and IC-10) was envisioned to maintain local sediment balance and combined with ROD flows promotes physical processes that lead to a dynamic alluvial complex channel morphology supporting salmonids at all life stages and flows.
R-8	Upstream Floodplain	32,760 yd3 Cut	The upstream portion of the R-8 floodplain constructed surfaces designed to inundate from the side channel when flows from Lewiston dam are between 1,500 and 6,000 cfs. Existing riparian and upland vegetation was left in place to provide a local seed source and maintain existing riparian structure. Clump plantings, pole cuttings, and large wood were incorporated into the design to increase cover and immediately benefit fry and juvenile salmonids when flows exceed 1,500 cfs.
R-8	Floodplain and High Flow Scour Channels	Included in 32,760 yd3 Cut above	The downstream portion of the R-8 floodplain constructed surfaces designed to inundate from the side channel and mainstem when flows from Lewiston dam are between 1,500 and 8,000 cfs. Existing riparian and upland vegetation was left in place to provide a local seed source and maintain existing riparian and upland structure. Clump plantings, pole cuttings, and large wood were incorporated into the design to increase cover and immediately benefit fry and

			juvenile salmonids when flows exceed 1,500 cfs. Two scour channels through the R-8 floodplain originating from the side channel are designed to flow between 2,500 and 6,000 cfs. Large wood and clump plantings were added to provide cover and rearing opportunities for fry and juvenile salmonids as flows accessed these features. In addition to providing salmonid habitat these scour channels increase topographic variability within the floodplain increasing natural riparian regeneration success.
R-8	Channel Meander	Included in 32,760 Cut above	Accompanies a left bank constructed point bar to increase channel sinuosity, reduce the radius of curvature, and promote channel migration. Combined with upstream gravel infusions and ROD releases a dynamic complex alluvial channel will evolve. Loose logs were places with root wads on the bank and tops in the channel as an alternative to the R-2 wood structure with the purpose of encouraging pool and bank scour.
R-10	Floodplain and Scour Channel	17,530 Cut	The R-10 floodplain was designed to inundate when flows exceed 6,000 cfs. The R-10 floodplain slopes away from the river into a high flow scour channel along the backside of floodplain with the purpose of recharging groundwater elevations from the backside of the constructed floodplain. An alcove was included at the downstream end of the scour channel. Large wood. clump plantings, and riparian pole cuttings were added to the floodplain surface, scour channel, and alcove to provide immediate cover for fry and juvenile rearing habitat for all flows. R-10 provides a suitable surface for riparian planting and natural regeneration that will increase the continuity of riparian canopy cover between the mainstem channel and upland vegetation.
U-1, U-2, and U-3	Terrace	30,500 yd3 and 38,700 yd3 and 18,500 yd3 Fill Respectively	The purpose of these terrace designs was to provide easy access to a potential long term gravel source while not impacting the 100 year flood elevation.

Design Milestone Timeline		
Date (Month/Year)	Milestone	Notes (Reference Document In Work Cited at end, by Title)
6/13/2007	First TRRP group float to site	R-8 Site Visit Notes.
8/2007	Initial Concepts	Sawmill Concepts and Sawmill Site Description Form
2007	Comments to TRRP on initial design concepts	Summary of Remaining 8 Rehabilitation Sites, Site Descriptions and Design Concepts.

7/14/2007	30% Design Concepts Presented to TRRP	Sawmill 30% Design Concepts
4/15/2008	TRRP authors 50% Design Concepts	Remaining 8 Rehabilitation Sites, 50% Design Concepts Alternatives.
11/2008	VE Study Completed	Sawmill, Upper Rush Creek, and Steel Bridge Sites-30 Percent Design Value Engineering Final Report
3/4/2009	Completion of 90% Designs	Sawmill 90% Designs
3/17/2009	Completion of 100% Designs	Sawmill 100% Designs
7/2009	TRRP modification of 100% designs to eliminate coarse sediment features	Hamman (TRRP) formal correspondence to HVT regarding design alternations needed
N/A	As-built documentation	Sawmill Rehabilitation Site: Post Implementation Report
Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	May 2008 50% designs and 100% designs February 2009; COE HEC-RAS
1-D Hydraulic Analysis	To determine side channel entrance and exit conditions and floodplain surface elevations.	May 2008; COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	March 2009; AutoCAD Civil 3D ,2008
Groundwater Analysis	To recommend riparian planting methods for certain surfaces (stinger vs. backhoe).	May 2009; AutoCAD Civil 3D ,2008
2-D Hydraulic, Shear Stress, and Velocity Analysis	Preliminary demonstration of the capabilities of a 2-D model to assess and improve Trinity River designs. Directly used to evaluate bar shape and height above summer baseflow water surface elevation.	March 31, 2011; MDSWMS vers. 2.3.12b
Design Criteria		
Channel geometry design criteria on page 18 (Table 3) of Design Report, outlining ranges for low flow channel width, bankfull channel width and meander wavelength; ROD flows (Table 4 of Design Report) to inundate floodplain surfaces and point and medial bars.		
Trinity River Record of Design and Trinity River Flow Evaluation Study Final Report guidelines for channel rehabilitation design purpose and objectives.		
Design Constraints		
FEMA 100 year flood elevation		

Downstream landowner/flood concerns regarding coarse sediment augmentation volumes and the potential for additional aggradation downstream of the project reach.
Design Modifications Made in the Field During Construction
Entrance to Cemetery Side Channel increased by contractor while removing water control plug at inlet. Resulted in increased proportion of flow into the side channel complex relative to the main stem.
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff. Placement of a giant log jam feature that included logs pile driven into the bank at the R-8 meander. This feature is intended to increase pool depth and expedite right bank scour.
Realignment of the exit geometry of side channel within the R-10 feature to accommodate landowner concerns of aesthetics and flooding.
Excavated pond used to provide rock wash water was left within the R-10 floodplain.
A large wetland feature was added along the right side of the side channel upstream of the low water side channel crossing into R-2.

Work Cited:

Davis, Andrea. June 18, 2007. R-8 Site Visit Notes as distributed to the TRRP IDT Work Group.

Davis, Andrea. October 1, 2007. Summary of Remaining 8 Rehabilitation Sites, Site Descriptions and Design Concepts, including a written summary letter to Mr. John Klochak, Trinity River Restoration Program, Weaverville, CA.

Hamman, Mike. July 2009. Formal correspondence to Hoopa Valley Tribe justifying removal of coarse sediment from the 100% design due to flood concerns. Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe and McBain & Trush, Inc. June 26, 2007. Sawmill Concepts and Sawmill Site Description Form. Prepared for the Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe and McBain & Trush, Inc. July 14, 2007. Sawmill 30% Design Concepts. Prepared for the Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe and McBain & Trush, Inc. November 3, 2007. Technical Exhibit Sawmill Revegetation Plan. Prepared for the Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe and McBain & Trush, Inc. March 2009. Sawmill 90% Designs. Prepared for the Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe and McBain & Trush, Inc. March 2009. Sawmill 100% Designs. Prepared for the Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe and McBain & Trush, Inc. April 15, 2009. TRINITY RIVER – SAWMILL (River Mile [RM] 108.88-109.73) AND READING CREEK (RM 92.7-93.4) REHABILITATION SITES. FINAL DESIGN TECHNICAL MEMORANDUM. Prepared for the Trinity River Restoration Program, Weaverville, CA.

Hoopa Valley Tribe. August 29, 2009. Formal correspondence to the Trinity River Restoration Program responding to the letter sent by Executive Director Mike Hamman regarding the coarse sediment that was removed from the 100% design.

Klochak, John. November 1, 2007. TRRP Responses to HVT Comments. Trinity River Restoration Program, Weaverville, CA.

Riess, Joe. November 5, 2007. R-8 Final Concepts. Trinity River Restoration Program. Weaverville, CA.

Trinity River Restoration Program. April 15, 2008. Remaining 8 Rehabilitation Sites, 50% Design Concepts Alternatives.

USBOR. November 18, 2008. Trinity River Restoration Project-Sawmill, Upper Rush Creek, and Steel Bridge Sites-30 Percent Design Value Engineering Final Report. USDOI Bureau of Reclamation Technical Service Center, Denver, CO.

Phase 1 – Design Summary Fact Sheet for Reading Creek

Project Name:	Reading Creek
Project Location:	River Mile 92.2 to 93.1
Project Ownership: (Private/Public)	Private and Public
Principal Designer(s):	Hoopa Valley Tribe Design Group (Fred Meyer, Andrea Hilton, John Bair, Scott McBain, Bill Trush) with assistance from Dave Gaeuman (Field review of expansion and contraction locations between RM 92.4 and 92.7) and Andreas Krause (Coarse sediment size recommendation)
Date Design Completed:	Upper Reading Creek (RM 92.7 to 93.1), April 15, 2009 and Lower Reading Creek (RM 92.2 to 92.7), March 25, 2010.
Total Earthwork Volume: (Cut & Fill)	Excavation: 66,860 yd3; Coarse Sediment Augmentation: 5,900 yd3
Year Constructed:	Earthwork 2010; Revegetation N/A
Total Cost of Construction:	$1,848,135
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals: Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages. Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. Site Goals to Achieve Programmatic Goals: Increase channel sinuosity, decrease radius of curvature, and increase channel complexity through constructing point and transverse bars; Expedite natural channel slope and thalweg development by widening the active channel and constructing transverse and point bars; Increase large wood storage; Sustain dynamic and complex channel morphology by encouraging channel migration; Provide immediate habitat for Chinook salmon, coho salmon, and steelhead juveniles when flow releases from Lewiston Dam are between 300 and 2,000 cfs; Increase spawning quality and quantity downstream of Lewiston Dam; Preserve existing riparian vegetation wherever possible; Promote natural riparian vegetation recruitment by creating favorable physical conditions; Increase woody riparian structural diversity; Improve local seed sources for natural riparian regeneration; and Reduce the risk of riparian encroachment.
Hypothesized Design Evolution (Reach Scale):	Although no clear reach scale design evolution was provided within the Reading Creek Design Reports, a general reach scale design strategy was included. The reach strategy states that the addition of coarse sediment and mechanical rescaling of channel banks in combination with flow releases will promote

			dynamic physical processes that are intended to sustain complex channel morphology. Vegetation design evolution: Revegetated areas should be greater in square footage and more structurally complex than existing vegetation at the site over the long term.
Individual Features - Design Purpose			
Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Floodplain and High Flow Channel	24,000 yd3 Cut	Not constructed – no access granted by landowner.
R-2	Floodplain and High Flow Scour Channel	15,000 yd3 Cut	Area R-2 scaled a large pre-dam bar (with a ½ meander wavelength of approx. 1,600 ft) into a series of alternating bars (with a ½ meander wavelength of approx. 500 ft). In addition the R-2 design removed the riparian berm constructing a floodplain surface designed to be inundated by flows of 5,000 cfs at the upstream end and 6,000 cfs at the downstream end. A high flow scour channel through the floodplain is designed to provide topographic complexity; direct flows back to the mainstem; and maintain an alcove at the downstream end of the site. The Area R-2 design preserved some areas of existing woody riparian and upland vegetation, providing additional floodplain complexity, as well as a maintaining seed sources for natural riparian regeneration. This design provided a suitable surface for riparian planting, thereby increasing long-term woody riparian structural diversity. As much existing riparian vegetation as feasible was left in place to increase riparian structure and diversity, provide a local seed source for natural recruitment, and preserve canopy continuity. Riparian plantings were designed increase long-term woody riparian structural diversity. Post construction, R-2 will be revegetated with willow and cottonwood cuttings. Clump plantings and large wood were incorporated into the designs along the low water's edge of alcoves located at the downstream end the constructed high flow scour channels, to improve fry and juvenile rearing habitat for Chinook, steelhead, and Coho when flow releases from Lewiston Dam are between 300 and 2,000 cfs.
R-2	2,000 cfs Inundation Surface	(Excavation volume included above)	As part of the R-2 floodplain design, a 2,000 cfs inundation surface, approximately ½ meander wavelength in length (approx. 500 feet) was constructed across from the Reading Creek confluence. This surface was designed to encourage future channel migration resulting from bank erosion caused by high Trinity River and Reading Creek flows pushing into the right bank and Reading Creek delta deposits. Long-term this is intended to foster dynamic and complex channel

			morphology. In the short term, lowering of this surface to inundate during a flows of 2,000 cfs should provide rearing habitat and velocity refugia for Chinook, steelhead, and Coho fry and juveniles.
R-3	Low Flow Side Channel	5,000 yd3 Cut	Area R-3 constructed a low flow side channel between Area R-2 and an existing point bar at RM 92.95. The constructed side channel follows the path of an existing high flow scour channel. The R-3 side channel was designed to leave the existing point bar feature at RM 92.95 intact, as well as much of the existing riparian vegetation along the constructed side channel. Constructed pools, large wood, clump plantings, and sedge plantings were added to the design to provide rearing habitat for Chinook, steelhead, and Coho fry and juveniles when flow releases from Lewiston Dam are between 300 and 2,000 cfs.
R-4	6,000 cfs Floodplain (included construction of three expansion areas)	19,500 yd3 cut	Area R-4 designed and constructed multiple elements, including the construction of three benches (expansion areas) along the mainstem channel 500 feet long and inundated by flows of 500 cfs. These 500 cfs surfaces increased bankfull channel width from an existing average of 110 feet to a constructed average of 160 feet. These constructed expansion areas are intended to encourage coarse sediment deposition within the main channel, resulting in a more sinuous and complex mainstem channel. The 500 cfs surfaces also provide temporary habitat at intermediate flows. Area R-4 also lowered an existing 3.5 acre surface (pre-dam floodplain), to an elevation designed to inundate when flows are 6,000 cfs. The constructed floodplain was designed to provide riparian planting opportunities and high flow refuge for juvenile salmonids during winter floods and spring ROD releases. The design retained existing cottonwoods, Oregon ash, and desirable willow species increasing floodplain complexity, reducing riparian mitigation requirements, and providing a local seed source for natural recruitment. Riparian plantings were designed increase long-term woody riparian structural diversity. Post construction, R-4 will be revegetated with willow and cottonwood cuttings with rushes and sedges planted along the side channel margin
R-5	6,000 cfs Floodplain and High Flow Scour Channel and Alcove	20,600 yd3 cut	Area R-5 constructed a 2.5 acre, 6,000 cfs floodplain, and high flow scour channel along the left bank between RM 92.25 and 92.55. The Area R-5 floodplain was constructed to begin to inundate when flows are 6,000 cfs providing off-channel rearing opportunities when flows exceed 6,000 cfs. Although limited, areas of existing woody riparian vegetation, was left in place providing additional floodplain complexity, as well as a maintaining seed sources for natural riparian regeneration. This design provides a suitable surface for riparian planting, thereby increasing long-term woody riparian structural diversity. Riparian plantings were designed to increase long-term

			woody riparian structural diversity. Post construction, R-5 will not be revegetated because a river crossing to deliver materials and equipment is not permitted. A high flow scour channel approximately 750 ft long and 50 ft wide was constructed through the center of the 6,000 cfs floodplain. The high flow scour channel was designed to redirect juvenile salmonids foraging on the floodplain during spring releases back into the main channel, as well as provide topographic variation to the floodplain surface. The high flow scour channel exits into an alcove at the downstream end. The design incorporates clump plantings and large wood placed along the low water's edge of the alcove to provide rearing habitat for Chinook, steelhead, and coho fry and juveniles when flow releases from Lewiston Dam are between 300 cfs and 2,000 cfs
R-5	Forced Meander and Feathered Edge	(Excavation volume included above)	A forced meander and feathered edge (expansion and contraction) were constructed along the left bank within the R-5 construction area between RM 92.4 and 92.53. The forced meander was constructed to the invert of the existing channel. This feature was designed in conjunction with coarse sediment augmentations at IC-5, IC-6, and IC-7 to increase channel sinuosity, decrease radius of curvature, increase channel complexity, and improve the likelihood of future channel migration towards the left bank. The feathered edge was constructed immediately downstream of IC-6; is approximately 250 ft long by 75 ft wide; and was designed to widen the bankfull channel width to 160 feet. This design is intended to increase channel sinuosity, reduce radius of curvature, and increase channel complexity. Bedrock along the right bank inhibits right bank scour and channel migration. Vegetation along the low water's edge was designed to be over-excavated to remove as much root mass as possible, reducing the risk of future riparian re-encroachment from re-growth.
IC-1	Point Bar	1,000 yd3 Fill	Not constructed – no access granted by landowner.
IC-2	Point Bar	1,100 yd3 Fill	Not constructed – no access granted by landowner.
IC-3	Point Bar	1,000 yd3 Fill	Construction of Area IC-3 included the removal of an existing point bar containing sand and willows, replaced by a coarse sediment mix ranging in size from ¼ inch to 4 inches. Although the Coarse Sediment Management Plan for the Trinity River suggests that coarse sediment augmentation below Indian Creek is not needed from a sediment budget respective because sediment supply below Indian Creek is much greater than that of upstream reaches (McBain & Trush, Inc., 2007). Therefore, the constructed point bar is not intended to satisfy coarse sediment storage objectives but, rather to jumpstart geomorphic processes including increased sinuosity, decreased radius of curvature, increased future channel migration, and reduce the risk

			of riparian encroachment. This point bar should improve existing low flow salmonid rearing habitat.
IC-4	Transverse Bar	700 yd3 Fill	This feature is designed to raise low flow water surface elevations directly upstream, encourage sediment deposition in conjunction the widening of the bank full channel as part of the R-4 construction, redistribute slope through this overly steep reach, and redirect flow into the right bank to encourage channel migration and overall channel complexity.
IC-5	Transverse Bar	1,100 yd3 Fill	This feature is designed to redistribute slope through this overly steep reach and direct flow into the newly constructed left bank forced meander associated with the construction of Area R-5.
IC-6	Point Bar	2,100 yd3 Fill	Point bar IC-6 3 was constructed from coarse sediment ranging in size from ¼ inch to 4 inches. Although the Coarse Sediment Management Plan for the Trinity River suggests that coarse sediment augmentation below Indian Creek is not needed from a sediment budget respective because sediment supply below Indian Creek is much greater than that of upstream reaches (McBain & Trush, Inc., 2007). Therefore, the designed point bar was not intended to satisfy coarse sediment storage objectives but rather to jumpstart geomorphic processes, including increased sinuosity, decreased radius of curvature, increased future channel migration into the left bank forced meander, reduced risk of detrimental riparian encroachment, improved existing low flow salmonid rearing habitat, and an increase in channel complexity. A two-dimensional model of the Lower Reading Creek site was developed to evaluate point bar design alternatives. As part of the Reading Creek 2D modeling, shear stress through Lower Reading Creek for existing conditions along with two bar designs were evaluated for a Normal Water ROD peak flow of 6,000 cfs. Both bar designs increased shear stress along the low water's edge over existing conditions however, a tear drop shaped point bar with an alcove at the downstream end increased shear stress over a crescent shaped bar (HVT et. al., 2011).
IC-7	Point Bar	1,000 yd3 Fill	Point bar IC-7 was constructed to extend the R-5 feathered edge into the mainstem channel, narrowing the low flow channel width to 70 feet. In addition IC-7 is designed in conjunction with the R-5 forced meander to reduce radius of curvature, reduce the risk of riparian encroachment along the low water's edge, and redirect flow into the right bank bedrock. As constructed this feature should increase channel complexity improving habitat for all salmonid life stages.
U-1	Terrace	28,500 yd3 Fill	Not constructed – no access granted by landowner.

U-2	Terrace	18,700 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment that could be used in future coarse sediment augmentation programs, and provide a suitable area for upland planting.
U-3	Terrace	2,500 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment that could be used in future coarse sediment augmentation programs, and provide a suitable area for upland planting.
U-4	Terrace	6,200 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment that could be used in future coarse sediment augmentation programs, and provide a suitable area for upland planting.
U-5	Terrace	16,200 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment that could be used in future coarse sediment augmentation programs, and provide a suitable area for upland planting.
U-6	Terrace	23,600 yd3 Fill	Terrace construction was designed to hold material generated as a result of floodplain construction without impact to the 100 year floodplain. Although no planting is recommended stockpile Area U-6 could be sieved at a later time for future coarse sediment augmentation projects.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
June 2007	Initial problem statement, design hypothesis, and design ideas.	Site Description Form Prepared by TRRP staff edited and submitted by HVT Design Team
June 2007	Initial Design Concepts Presented	PDF of design concepts submitted by HVT Design Team
November 2007	Conceptual Design and design descriptions completed	Prepared by TRRP staff the Conceptual Design was presented to the design team early 2008.
June, 2008	30% Design Proposed Action and Alternative	Presented at the August 2008 Design Team Meeting
July 2008	TRRP Alternative Side Channel Alignment	Tech memo sent to HVT design group July 31, 2008 and discussed with design team August 2008.
June 2009	50% Designs and Analysis Presented	2D modeling was conducted on Reading Creek and Lowden Ranch. Trinity House Gulch was incorporated in to the Lowden Ranch 2D modeling and evaluated Chinook fry rearing at 300

		cfs for existing and 50% design conditions. The 2D technical memo “Preliminary demonstration of the capabilities of a 2D model to assess and improve Trinity River rehabilitation designs” was submitted to the TRRP in March 2011.
November 2008	Value Engineering Study recommended conducting a separate VE study for the Reading Creek Site	No VE Study was completed for Reading Creek however elements of this VE study pertaining to floodplain elevations and side channel impacts on natural recruitment of riparian vegetation were incorporated into the Reading Creek designs.
October 2009	Draft Design Drawings and Technical Memorandum Submitted	Draft Final Design Technical Memorandum submitted along with design drawings; Comments received and incorporated into Final tech memo and drawings.
February 2010	Final Stamped Design Drawings and Technical Memorandum Submitted	Final design drawings and technical memorandum submitted to TRRP February, 2010.
March 2010	Signed Flood Letter	Final flood letter signed and submitted to TRRP March 2010
11/2010	Construction Completed	
1/2011	As-Built Surveys Completed	Submitted to TRRP January, 2011
N/A	Revegetation Completed	Pending implementation

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	April 28, 2010; COE HEC-RAS
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	February 2, 2010; AutoCAD Civil 3D ,2008
2-D Hydraulic, Shear Stress, and Velocity Analysis	Preliminary demonstration of the capabilities of a 2-D model to assess and improve Trinity River designs. Directly used to evaluate bar shape and height above summer baseflow water surface elevation.	March 31, 2011; MDSWMS vers. 2.3.12b
Geotechnical Investigations	Evaluate depth and composition of substrate within construction footprint and to evaluate if subsurface bedrock constraints exist.	December 2009, BOR

Design Criteria
Low flow channel width at point bars: 75-90 feet
Bankfull channel width: 150 to 160 feet
Floodplain to begin inundation (hinge point) at 6,000 cfs

Discharge to inundate point bar or medial bar 500 to 2,000 cfs
Meander wavelength between 1,000 feet
Floodplain to begin inundation (hinge point) ranges between 5,000 and 6,000 cfs
Coarse sediment augmentation size range between 1/4 and 4 inches
Invert elevation of constructed channels are one foot deep when flows at Lewiston are 450 cfs
Pool depths within channel may exceed two feet.
Design Constraints
Upstream landowner did not grant access to upper Reading Creek site resulting in Areas R-1, IC-1, IC-2, and U-1 not being constructed.
Proximity of BLM Douglas City Campground and perceived dangers associated with an attractive nuisance. Closure of campground during construction.
Shallow bedrock along R-5 high flow scour channel design alignment
Exposed bedrock along channel margins and within the active channel
Access to Areas IC-7 and R-5
USGS Gage was within construction footprint and had to be moved.
Increase in 100-year flood elevation not to exceed one foot
Design Modifications Made in the Field During Construction
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.
Large boulders were placed within the active channel to secure large wood placed in the channel at the upstream end of the R-5 forced meander medial bar.
R-5 scour channel alignment was adjusted toward the mainstem channel due to presence of shallow bedrock in the design alignment. This alignment adjustment was discussed with the HVT design team prior to re-alignment.
No revegetation will occur on Floodplain R-5 as designed due to river crossing.
Vegetation was removed from a bar surface outside the construction footprint to the river side of R-3.
Campground was refurbished prior to leaving construction site.
Organic material incorporated into upland planting areas to increase planting success.
Up to 6 inches of fines were added to all floodplain surfaces.

Phase 1 – Design Summary Fact Sheet for Lowden Ranch

Project Name:	Lowden Ranch Rehabilitation Site
Project Location:	Lewiston, CA. River Mile 104.4 to 105.3
Project Ownership: (Private/Public)	Mostly Public (DWR, BLM) and three private landowners
Principal Designer(s):	Nancy Snodgrass with Dave Gauman's vision.
Date Design Completed:	March 29th, 2010
Total Earthwork Volume: (Cut & Fill)	104,216 CY Cut/19,100 CY Fill
Year Constructed:	Summer 2010
Total Cost of Construction:	$ 3,048,000
Construction Contractor:	Eric Ammon, Inc.
Design Hypotheses (Goal/Objective) (Reach Scale):	Three Goals: 1) increase availability, quantity and quality of fish habitat between 300 cfs and 7,000 cfs for all life stages. 2) Increase quality and quantity of coarse sediment. 3) Increase quality and quantity of riparian vegetation and wetlands while preserving continuity important for wildlife. Seven Objectives: 1) provide immediate refugia for anadromous juveniles at flows between 300 cfs and 7,000 cfs. 2) Improve coarse sediment storage. 3) Increase large wood storage. 4) Create dynamic and complex channel morphology. 5) Preserve existing natural riparian vegetation where possible. 6) Preserve existing herpetiles habitat where possible. 7) Promote natural riparian vegetation recruitment through creating favorable physical conditions. Objectives specific to each design feature are described in the Final Design Technical Report for this site.
Hypothesized Design Evolution (Reach Scale):	This reach was set up in three different segments; upper, middle and lower. The evolution of the upper section is such that efforts were made to help ensure the side channel entrance remains open especially for the health of the offstream rearing habitat feature (R-2). Long term gravel additions at IC-1 could help maintain favorable side channel entrance conditions. The offstream rearing habitat could fill in over time, but would remain a wetland area and ultimately be beneficial regardless. The evolution of middle section is such that it was designed to help create dynamic and complex channel morphology. The forced meander and point bar would optimally function in a cyclically unstable manner in which the main channel flow alternately re-occupies the chute over the point bar and then erodes laterally to re-establish the more sinuous alignment. Such a cycle, which has been observed in other rivers, would continuously rejuvenate the bar surface over time (periods of a few decades). A

	somewhat less beneficial but possibly more probable outcome is that the forced meander maintains a configuration similar to as-built for an extended period. The future of this feature could be managed by ongoing replenishment of gravel eroded from the bar if this feature is selected to be a long-term gravel augmentation point. The channel in the downstream end of this section was widened to accelerate the development of an incipient medial bar that was present prior to project construction. The intent is for this bar to continue to grow, ultimately producing a vegetated mid-channel island. Upstream coarse sediment augmentation is key for driving the desired future evolution. The anastomosing planform of the lower section is expected to remain stable for an extended period, due to the lower slope and relatively low stream power. However, It is possible that excess deposition could plug anabranches, and cause the river to revert to a single low-flow channel. The potential for that outcome was reduced by constructing the islands high and rough enough so that little flow is conveyed across them, and by constructing large-wood structures at their inlets. The upstream flow expansion provided by R-4 and R-5 are also expected to reduce deposition in the anabranch entrance area by encouraging bedload to drop out of transport farther upstream.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
IC-1	Point Bar	1,500 CY Fill	To help maintain side channel entrance (R-1). Point Bar will raise the water surface elevation at baseflow to encourage water to flow into R-1. LWD was placed on the upstream edge of IC-1 located on the downstream side of the entrance to R-1 to encourage scour and sediment transport thus helping to keep the side channel entrance open.
R-1	Low Flow Side Channel	6,000 CY Cut	Designed to flow at 300 cfs at 1.5 feet deep to about 2,500 cfs where the surrounding area is getting wet. Pools and riffles incorporated into design. Purpose was to provide edge length and rearing habitat at winter baseflow and refuge from fast current at intermediate discharges. Willow clumps and sedges planted along side channel to provide immediate and long term habitat benefits for all Chinook, Steelhead, and coho fry and juvenile life stages.
R-2	Off-Stream Rearing habitat	6,000 CY Cut	Provide additional off channel rearing habitat at flows between 1,500 cfs to 4,500 cfs.

R-3	Main Channel Realignment	11,500 CY Cut	Realign main channel to increase local channel complexity by replacing a straight plane-bed section with the bed topography and hydraulic variability such as riffle crossing, pool at the bend apex. Increased sinuosity also provides more edge length which provides more opportunities for juvenile habitat.
IC-2	Point Bar/Constructed Floodplain	9,000 CY Fill	This constructed surface on river right is designed to force a meander bend in the main channel, provide juvenile refuge in the alcove. The surface is designed to inundate at approximately the bankfull flow (7,000 cfs) near its center and toward the R-3 constructed channel. The surface is lower near the right bank, creating a chute that leads into the alcove at the downstream end of the feature. The sill controlling flow into the chute is intended to inundate at about 4,500 cfs.
R-4	Low Bench	1,100 CY Cut	Provide accommodation room for a medial bar to continue to grow. The bench also provides juvenile refuge during flows from 1,500 cfs to 7,000 cfs.
R-5	Floodplain Lowering	22,000 CY Cut	Provide an area for riparian planting, increase overbank flow conveyance to increase local deposition in the channel, help to provide connectivity between the main channel and the perennial ponds near the back edge of the feature.
R-6	Alcove	6,000 CY Cut	Provide additional rearing habitat at 1,500 to 7,000 cfs flow regimes. A deeper hole was designed to capture sediment from the scour channel which should help keep the entrance to the alcove open and functioning as designed.
R-7	Anastomosing Channel	18,000 CY Cut	Greatly increase rearing habitat by adding edge length, cover and creating dynamic and complex channel morphology.
R-8	Terrace Lowering	700 CY Cut	Create mid channel islands for the construction of the anastomosing channel. Existing trees were saved where possible to provide immediate cover.
R-9	Terrace Lowering	1,500 CY Cut	Create mid channel islands for the construction of the anastomosing channel. Existing trees were saved where possible to provide immediate cover.
IC-3	Coarse Gravel Addition	3,000 CY Fill	Help shape mid channel islands and constrict main channel conveyance to force flow into the constructed anabranches. Supply river with coarse sediment for spawning.
IC-4	Main Channel Realignment	500 CY Cut	Provide enough area for the river to meander around the constructed islands of the anastomosing channel.
IC-5	Coarse Gravel Addition	5,000 CY Fill	Help shape mid channel islands and constrict main channel for the construction of the anastomosing channel. Supply river with coarse sediment for spawning.

IC-6	Main Channel Realignment	600 CY Cut	Provide enough area for the river to meander around the constructed islands of the anastomosing channel.
IC-7	Course Sediment Addition (added before construction)	600 CY	This area was considered as a high flow gravel injection site. The desired amount of gravel was 2,500 CY yet modeling results revealed a change in the 100-year water surface elevation greater than allowable, thus the amount was reduced to 600 CY. This gravel was placed prior to construction of the rest of the site during the spring release high flow event of 7,000 cfs.
U-1	Upland	72,000 CY	This upland area is designed for all spoils of the project and is located on river left where most of the activities exist. This high terrace is located near the existing roadway so that the historical meadow is least impacted. Fines were added to the top 12 inches of the upland for better plant survival and to minimize invasive species.
U-2	Upland	2,000 CY	This upland area is located on river right where minimal excavation occurred.
Wetland Enhancement	Wetland		Gain a positive restoration response from frogs, toads, and turtles at Lowden Ranch based on changes in wetlands on-site. Determine the effectiveness of restoration efforts for aquatic species. Sand and other desired material from excavation will be saved and used for the wetland enhancement.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
11/07	Remaining 8 Rehabilitation Sites: Final Site Description and 50% Design Concepts	TRRP Report/Memo
5/2009	Save Tree Areas site visit	Met with McBain & Trush personnel and identified save tree areas within project site.
6/2009	Field visit to identify potential wetland enhancement habitat	Some discussion about creating additional habitat for herpetiles at Lowden Ranch.
7/2009	2-D Modeling results concluded that BOR design features were chosen to move forward.	TRRP Inter-Disciplinary Team Meeting-Synopsis, July 28th & 29th, 2009.
7/2009	Save Trees delineation by McBain & Trush personnel.	Emailed 7/14/2009 by McBain & Trush personnel.
9/2009	30% Conceptual Design and Report Completed	Presented Conceptual Design to Design Team
4/2010	Final Design Technical Report	

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
Topographic Survey	Surveyed xsects and existing ground to verify existing surface is valid.	
2-D Hydraulic Analysis	To help determine which design features to move forward that best meets all goals and objectives.	McBain & Trush; USGS software MD-SWMS
2-D Hydraulic Analysis	To help determine which design features to move forward that best meets all goals and objectives.	BOR; SRHW 2-D model
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	4/2010; COE HEC-RAS
1-D Hydraulic Analysis	To determine actual flow split between the main channel and side channel and to analyze water surface elevation profile through the reach.	4/2010; COE HEC-RAS
Geologic Investigation	BOR conducted field exploration to geologically characterize available stream-side deposits. Twenty test pits were dug and a report was finalized in 2009 by the TRRP.	2009 (BOR, 2009)
Depth to Groundwater	Eight piezometers installed in some test pits to determine groundwater elevation primarily used for revegetation.	10/08
Temperature Analysis	Yurok Tribe installed 4 temperature probes in existing perennial pond to determine if temperatures are adequate for fish survival in offstream ponds.	7/09
Topographic Terrain Model Development	To determine cut and fill volumes and for development of construction drawings	3/2010; 2008 Civil 3D
Design Criteria		
Floodplain was designed to be inundated at the 6,000 cfs flow		
Side Channel was designed to flow 1.5 ft deep at baseflow of 300 cfs.		
Design Constraints		
Do nothing to increase the flood risk in the general vicinity, and to not raise the water surface elevation in the FEMA zones by more than one foot.		
Design Modifications Made in the Field During Construction		
LWD was designed in the field at IC-1, R-1, R-2, R-3		

R-2 entrance and exit was excavated lower than designed. The thalweg in R-2 matches the thalweg in R-1
Designer Notes
Citation/References
BOR, 2009. Trinity River Restoration Project – Gravel Replenishment Study in Trinity River County at Readings Bar, Steel Bridge, Lowden Ranch and Sawmill Sites –Geology Report. US Department of Interior, Mid-Pacific Region, Geolog Branch, MP-230.
TRRP, 2008. Remaining 8 Rehabilitation Sites: 50% Design Concept Alternatives. Paper document.
USFWS and Hoopa Valley Tribe, 1999. Trinity River Flow Evaluation – Final Report.
Cardno Entrix and CH2MHill, 2010. Trinity River Restoration Program – ELJ On-Site Implementation Follow-up Trip Report – Final Report.

Phase 1 – Design Summary Fact Sheet for Trinity House Gulch

Project Name:	Trinity House Gulch
Project Location:	River Mile 104.0 – 104.4
Project Ownership: (Private/Public)	Both private and public ownership
Principal Designer(s):	Hoopa Valley Tribe Design Group (Fred Meyer, Andrea Hilton, John Bair, Scott McBain) with assistance from Dave Gaeuman (Implemented proposed side channel alignment) and Andreas Krause (Coarse sediment size recommendation)
Date Design Completed:	February 25, 2010
Total Earthwork Volume: (Cut & Fill)	Cut: 37,100 yd3; Fill: 37,100 yd3; Coarse Sediment Added 3,500 yd3
Year Constructed:	Earthwork: 2010; Revegetation N/A
Total Cost of Construction:	$518,400
Construction Contractor:	Erick Ammon
Design Hypotheses (Goal/Objective) (Reach Scale):	Programmatic Goals: Increase and sustain the availability, quantity, and quality of anadromous fish habitat between 300 cfs and 2,000 cfs for all life stages. Increase and sustain the quality and quantity of riparian vegetation while preserving continuity of canopy important for wildlife. Site Goals to Achieve Programmatic Goals: Increase channel sinuosity, decrease radius of curvature, and increase channel complexity by constructing transverse bars and a forced meander, and by selectively removing mature riparian vegetation along the low water's edge; Increase coarse sediment storage; Increase large wood storage; Sustain dynamic and complex channel morphology by encouraging channel migration; Provide immediate habitat for Chinook salmon and coho salmon, and steelhead juveniles when flow releases from Lewiston Dam are between 300 and 2,000 cfs; Preserve existing riparian vegetation wherever possible; Promote natural riparian vegetation recruitment through creating favorable physical conditions; Increase woody riparian structural diversity; Improve local seed sources for natural riparian regeneration; Reduce the risk of riparian encroachment.
Hypothesized Design Evolution (Reach Scale):	Although no clear reach scale design evolution was provided within the Trinity House Gulch Design Report, a general reach scale design strategy was included. The reach strategy states that the addition of coarse sediment and mechanical rescaling of channel banks in combination with flow releases will promote dynamic physical processes that are intended to sustain complex channel morphology. Vegetation design evolution: Revegetated areas should be greater in square

	footage and more structurally complex than existing vegetation at the site over the long term.

Individual Features - Design Purpose

Code	Type	Earthwork (CY) (Cut or Fill)	Purpose
R-1	Floodplain	Combined Areas R-1 and R-2 cut 32,000 yd3 from the existing surface	Designed to inundate when releases from Lewiston Dam are 6,000 cfs. Select riparian vegetation was saved. The purpose of this floodplain construction was to provide high flow refugia for fry and juvenile salmonids, increase geomorphic complexity, leave a local seed source for natural riparian recruitment, and provide a surface that can sustain planted riparian vegetation. As much existing riparian vegetation as feasible was left in place to increase riparian structure and diversity, provide a local seed source for natural recruitment, and preserve canopy continuity. Riparian plantings were designed increase long-term woody riparian structural diversity. Post construction, R-1 will be revegetated with willow and cottonwood cuttings with rushes and sedges planted along the side channel margin
R-1	Forced Meander		Designed to encourage channel migration, increase channel sinuosity, and reduce radius of curvature to improve rearing habitat for Chinook, steelhead, and coho fry and juveniles when flows are between 300 and 2,000 cfs.
R-2	Low Flow Side Channel		Area R-2 constructed a new low flow side channel with pools and riffles, and an alcove at the downstream end. The constructed side channel riffles were intended to provide spawning habitat when flow are between 300 and 1,000 cfs. Selected trees along the low flow side channel were saved to provide immediate cover and shade habitat benefits. Large wood, willow clumps, and sedges were placed along the side channel to provide immediate and long-term habitat benefits for Chinook, steelhead and coho fry and juvenile life stages when flows are 300 to 2,000 cfs. Based on hydraulic evaluations by D. Gaeuman (Gaeuman, 2008) and HVT design team (HVT et. al., 2010) the side channel alignment should have a reasonably high probability of self-maintenance given the steep gradient through the project area between RM 104.1 and 104.4.
R-3	Tributary (Trinity House Gulch) Enhancement	Cut - 300 yd3	Construction realigned Trinity House Gulch into a historic channel, providing better access for adult and juvenile salmonids.
IC-1	Pont Bar	Coarse Sediment Augmentation Fill	Increase coarse sediment storage (coarse sediment ranging in size from 1/8 to 4 inches), foster channel migration, increase sinuosity,

		= 1,000 yd3	reduce mainstem channel slope, increase geomorphic complexity, and reduce risk of riparian encroachment.
IC-2	Transverse Bar	Coarse Sediment Augmentation Fill = 500 yd3	Construction of the IC-2 transverse bar, increases coarse sediment storage (coarse sediment ranging in size from 1/8 to 4 inches), redistributes low flow slope within the main channel, increases low flow pool depth directly upstream, and directs flow into the R-1 forced meander to increase channel complexity at low flows and encourage channel migration at higher flows
IC-3	Point Bar	Coarse Sediment Augmentation Fill = 2,000 yd3	Increase coarse sediment storage (coarse sediment ranging in size from 1/8 to 4 inches), foster channel migration, increase sinuosity, reduce mainstem channel slope, increase geomorphic complexity, and reduce risk of riparian encroachment.
U-1	Terrace	Fill – 34,000 yd3	Terrace construction was designed to hold all material generated as a result of floodplain construction without impact to the 100 year floodplain, store coarse sediment that could be used in future coarse sediment augmentation programs, and provide a suitable area for upland planting.
R-1	Floodplain Revegetation	None	The revegetation planting pattern is designed to promote greater riparian patch interior and corridor width, and increase the area and structural diversity of remnant riparian vegetation by planting tree and shrub species next to each other. The constructed side channel, alcoves, and forced meander will be revegetated using willow clumps, pole plantings, sedges, and rushes in hydrologically appropriate areas for each species. Large wood will be placed in concert with the riparian planting to increase structural diversity and provide immediate low flow rearing habitat. Side channel margins along the low water's edge are to be revegetated with riparian hardwoods, sedges and rushes to immediately improve the complexity of aquatic habitats in the 300 cfs to 2,000 cfs range.
R-2 and IC-3	Large Woody Debris		Placed inside channel and alcoves to provide structural diversity and immediate low flow rearing habit.

Design Milestone Timeline

Date (Month/Year)	Milestone	Notes (Reference Document)
June 2007	Initial problem statement, design hypothesis, and design ideas.	Site Description Form Prepared by TRRP staff edited and submitted by HVT Design Team
June 2007	Initial Design Concepts Presented	PDF of design concepts submitted by HVT Design Team
November 2007	Conceptual Design and design descriptions completed	Prepared by TRRP staff the Conceptual Design was presented to the design team early 2008.

June, 2008	30% Design Proposed Action and Alternative	Presented at the August 2008 Design Team Meeting
July 2008	TRRP Alternative Side Channel Alignment	Tech memo sent to HVT design group July 31, 2008 and discussed with design team August 2008.
June 2009	50% Designs and Analysis Presented	2D modeling was conducted on Reading Creek and Lowden Ranch. Trinity House Gulch was incorporated in to the Lowden Ranch 2D modeling and evaluated Chinook fry rearing at 300 cfs for existing and 50% design conditions. The 2D technical memo "Preliminary demonstration of the capabilities of a 2D model to assess and improve Trinity River rehabilitation designs" was submitted to the TRRP in March 2011.
November 2008	Value Engineering Study recommended conducting a VE study for Trinity House Gulch and Lowden Ranch	No VE Study was completed for Trinity House Gulch.
October 2009	Draft Design Drawings and Technical Memorandum Submitted	Draft Final Design Technical Memorandum submitted along with design drawings; Comments received and incorporated into Final tech memo and drawings.
February 2010	Final Stamped Design Drawings and Technical Memorandum Submitted	Final design drawings and technical memorandum submitted to TRRP February, 2010.
March 2010	Signed Flood Letter	Final flood letter signed and submitted to TRRP March 2010
11/2010	Construction Completed	
1/2011	As-Built Surveys Completed	Submitted to TRRP January, 2011
N/A	Revegetation Completed	Pending implementation

Design Analysis Performed		
Type of Analysis	Reason Performed	Date Completed & Software Used
1-D Hydraulic Analysis	To evaluate side channel alignment and provide recommendations.	July 31, 2008; COE HEC-RAS
1-D Hydraulic Analysis	To determine design surface elevations for specific inundation thresholds. Used in preparing 50% to 100% designs and determining depth to groundwater.	July31, 2008; COE HEC-RAS
1-D Hydraulic Analysis	To determine 100 yr. Floodplain Water Elevation Surface for FEMA requirements	April 28, 2010; COE HEC-RAS
Geotechnical Investigations	Evaluate depth and composition of substrate within construction footprint and to evaluate if subsurface bedrock constraints exist.	December 2009, BOR
Habitat Modeling	To evaluate differences between existing and	February 2010, MD SWMS version 2.3.1b

	design conditions for Chinook fry rearing habitat at a flow of 300 cfs.	
Topographic Design	To determine cut and fill volumes and for development of construction drawings	February 2, 2010; AutoCAD Civil 3D ,2008
2-D Hydraulic, Shear Stress, and Velocity Analysis	Preliminary demonstration of the capabilities of a 2-D model to assess and improve Trinity River designs. Directly used to evaluate bar shape and height above summer baseflow water surface elevation.	March 31, 2011; MDSWMS vers. 2.3.12b
Design Criteria		
Floodplain to begin inundation (hinge point) at 6,000 cfs		
Coarse sediment augmentation size range between 1/8 and 4 inches		
Invert elevation of constructed channels are one foot deep when flows at Lewiston are 450 cfs		
Pool depths within channel may exceed two feet.		
Low flow channel width between 60 and 70 ft		
Bankfull channel width between 140 and 160 ft		
Discharge to inundate point bar or medial bar 500 to 2,000 cfs		
Meander wavelength between 700 and 950 ft		
Design Constraints		
Increase in 100-year flood elevation not to exceed one foot		
Limited spoils area; Vegetation and excavated material must be disposed of on site		
Left bank confinement from constructed levee/berm between RM 104.3 and 104.2 and valley wall between 104.05 and 104.2		
Shallow bedrock within side channel alignment		
Access – use of conveyor belt to place coarse sediment on right bank.		
Design Modifications Made in the Field During Construction		
Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.		

Several trees were removed from the historic Trinity House Gulch (tributary) and placed adjacent to the channel to help redirect flows along the valley wall.
Benches were constructed adjacent to side channel to increase side channel complexity
Organic material incorporated into upland planting areas to increase planting success.
Up to 6 inches of fines were added to all floodplain surfaces.
Large wood jam placed at downstream end of side channel.
Several rows of clump plantings perpendicular to flow were added in the constructed floodplain
Willows were harvested for clump plantings from save tree area – this area is now been added to revegetation plan.

ATTACHMENT C

FREQUENCY DISTRIBUTIONS OF ACTIVE BED WIDTH FOR CROSS SECTION PAIRS IN PHASE 1 CHANNEL REHABILITATION SITES

Key to project phases and time periods

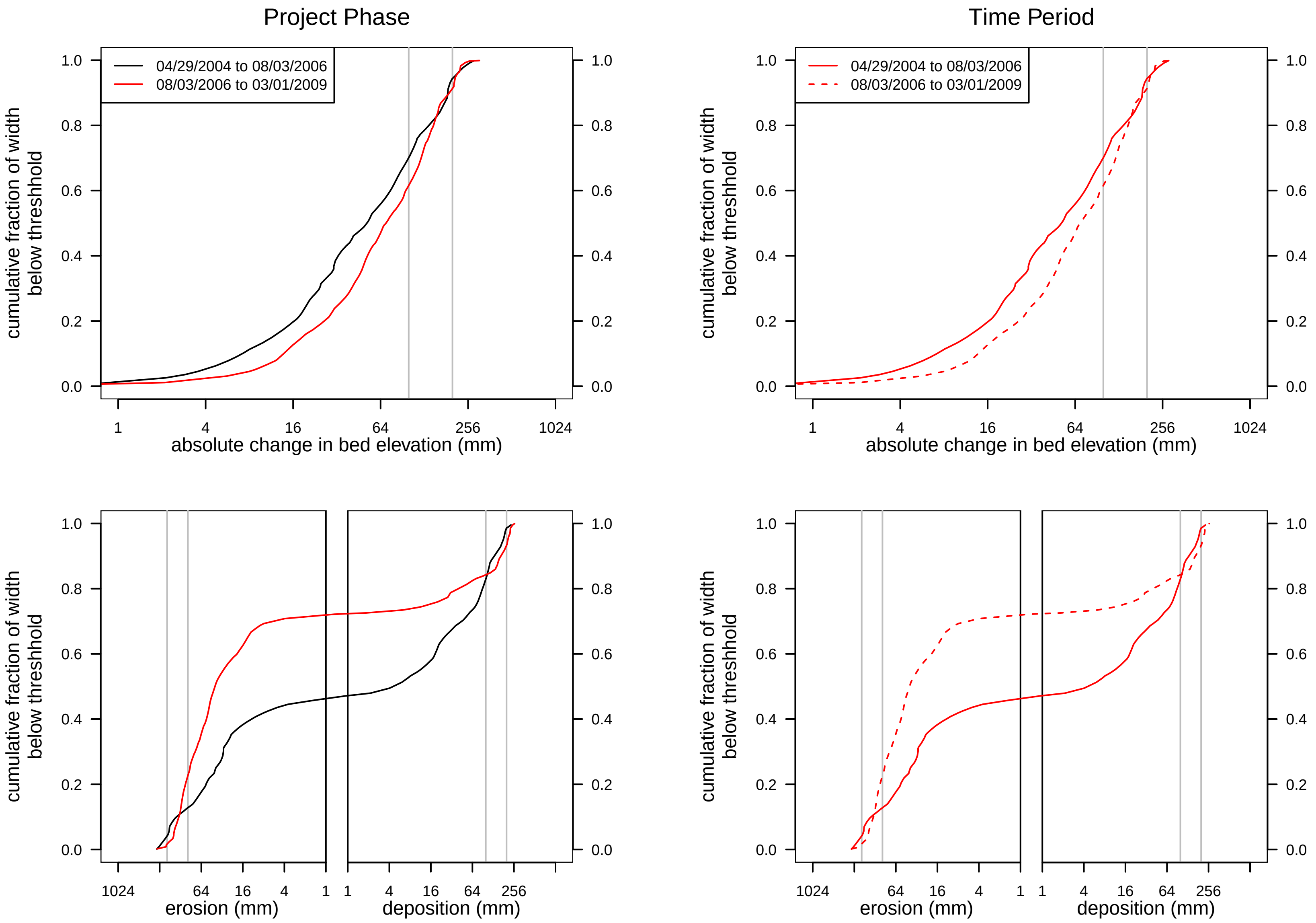
Project Phase

——	1	change prior to construction
——	2	change due to construction
┄┄┄	3	change following construction but prior to a high flow
——	4	change due to the first post-construction high flow
┄┄┄	5	change after the first post-construction high flow
┄┄┄	6	change due to construction and subsequent high flows combined

Time Period

——	A	period prior to the 2006 high flow release
——	B	period including the 2006 high flow release
┄┄┄	C	period between the 2006 and 2011 high flow releases
——	D	period including the 2011 high flow release

Lewiston Dam Site
Cross section Station ID 58 (2075+00), KM 179.52



Lewiston Dam Site
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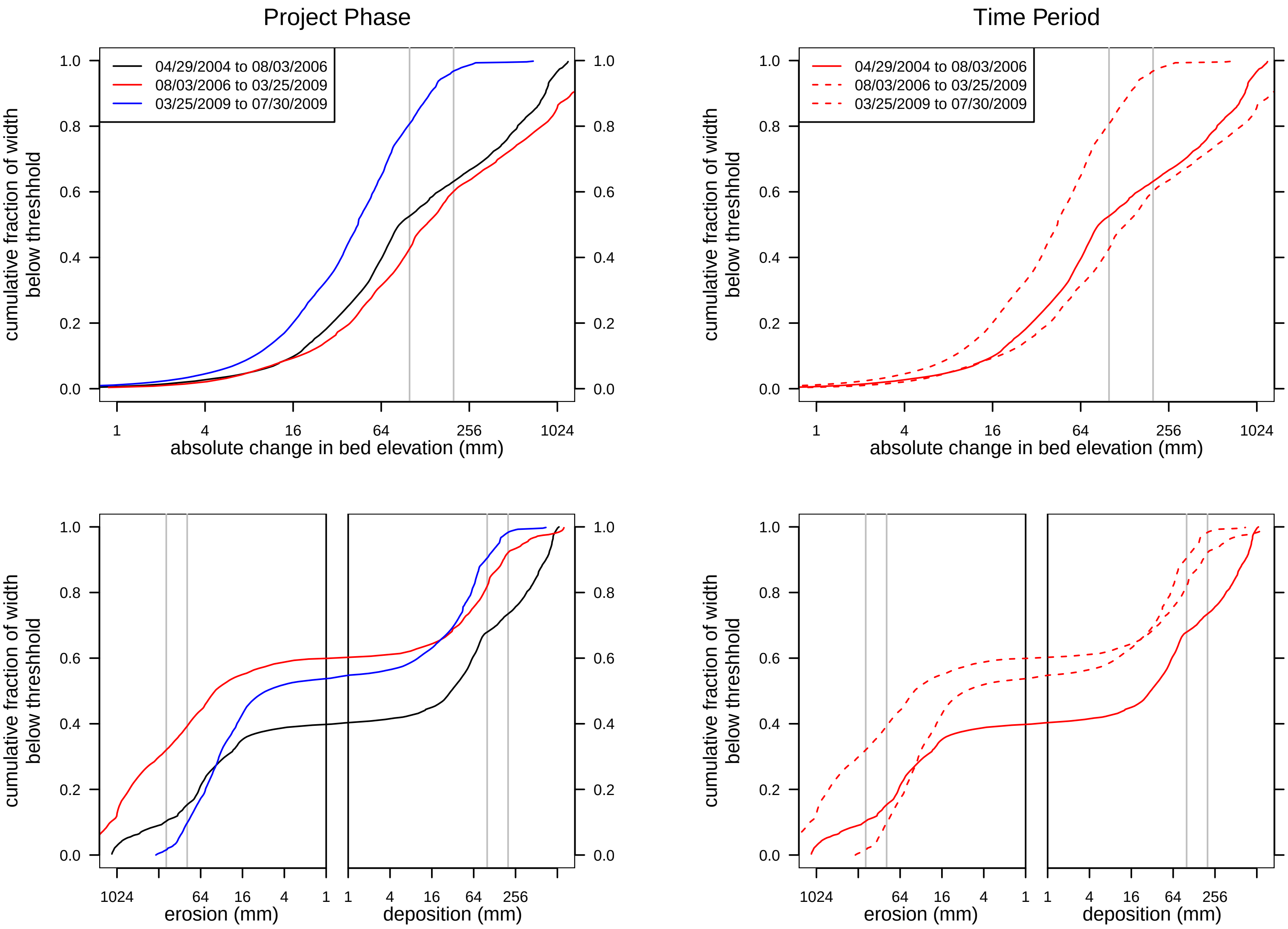
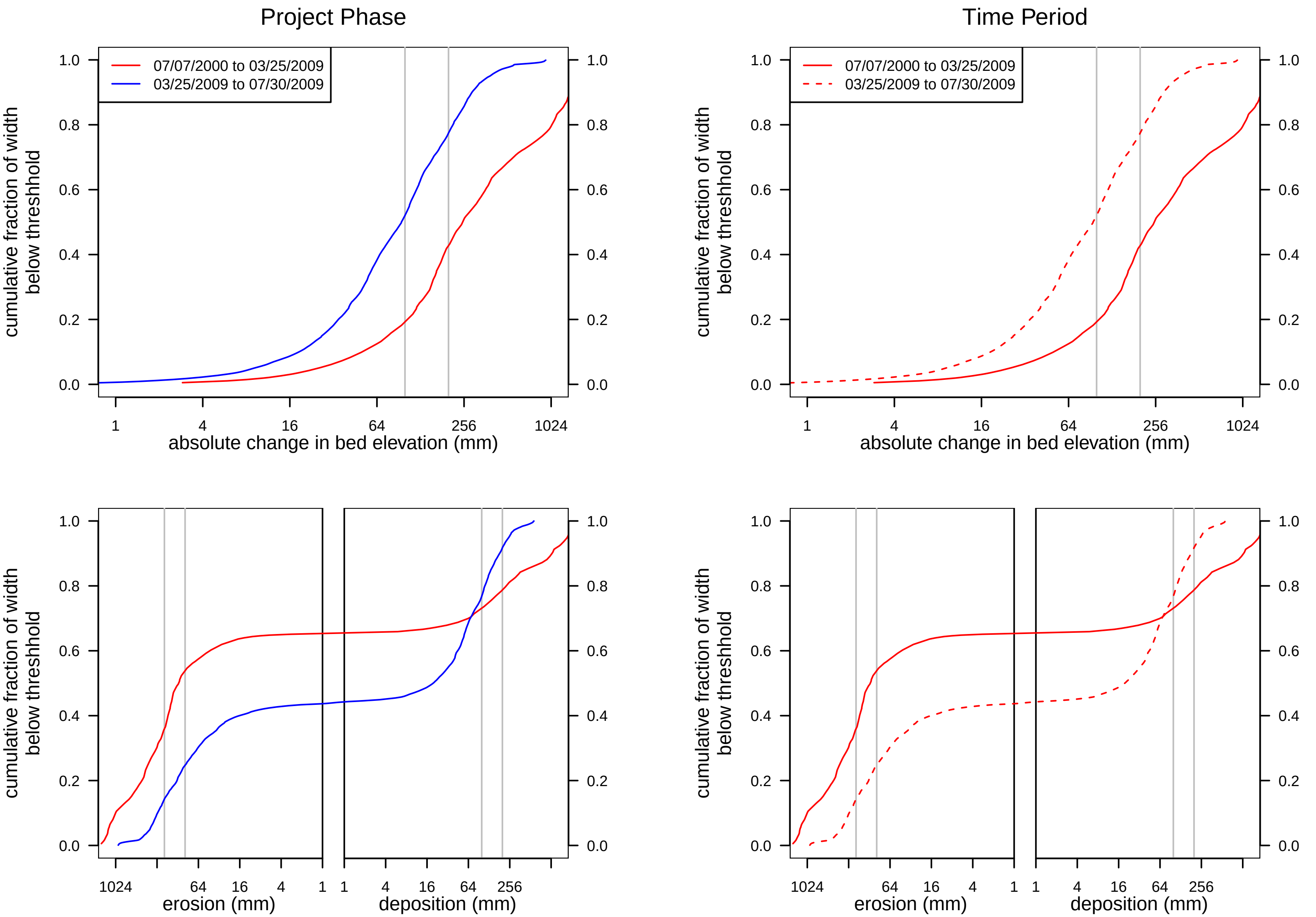


Sven Olbertson Side Channel
Cross section Station ID 170 (2064+40), KM 179.20



Sven Olbertson Side Channel
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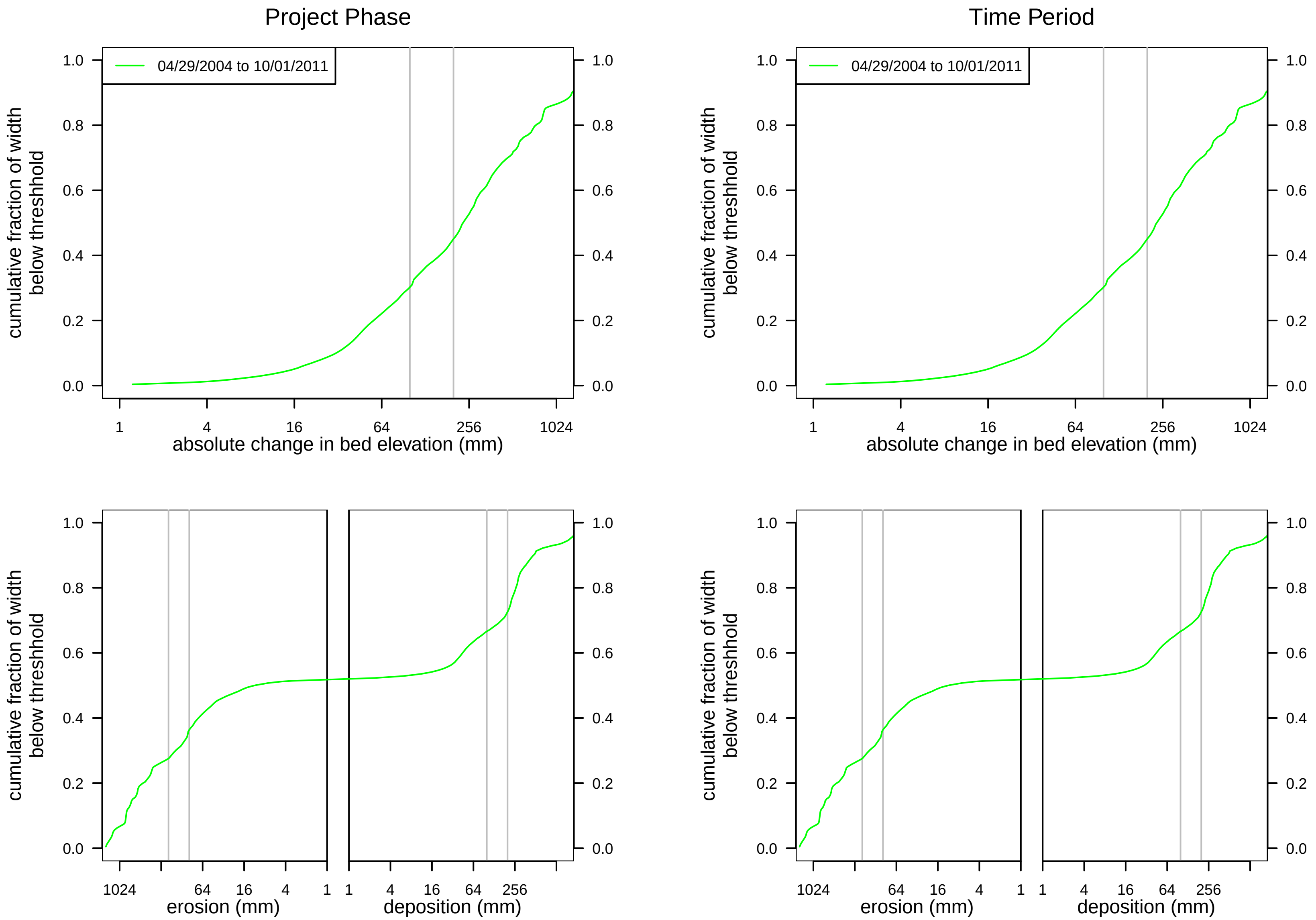
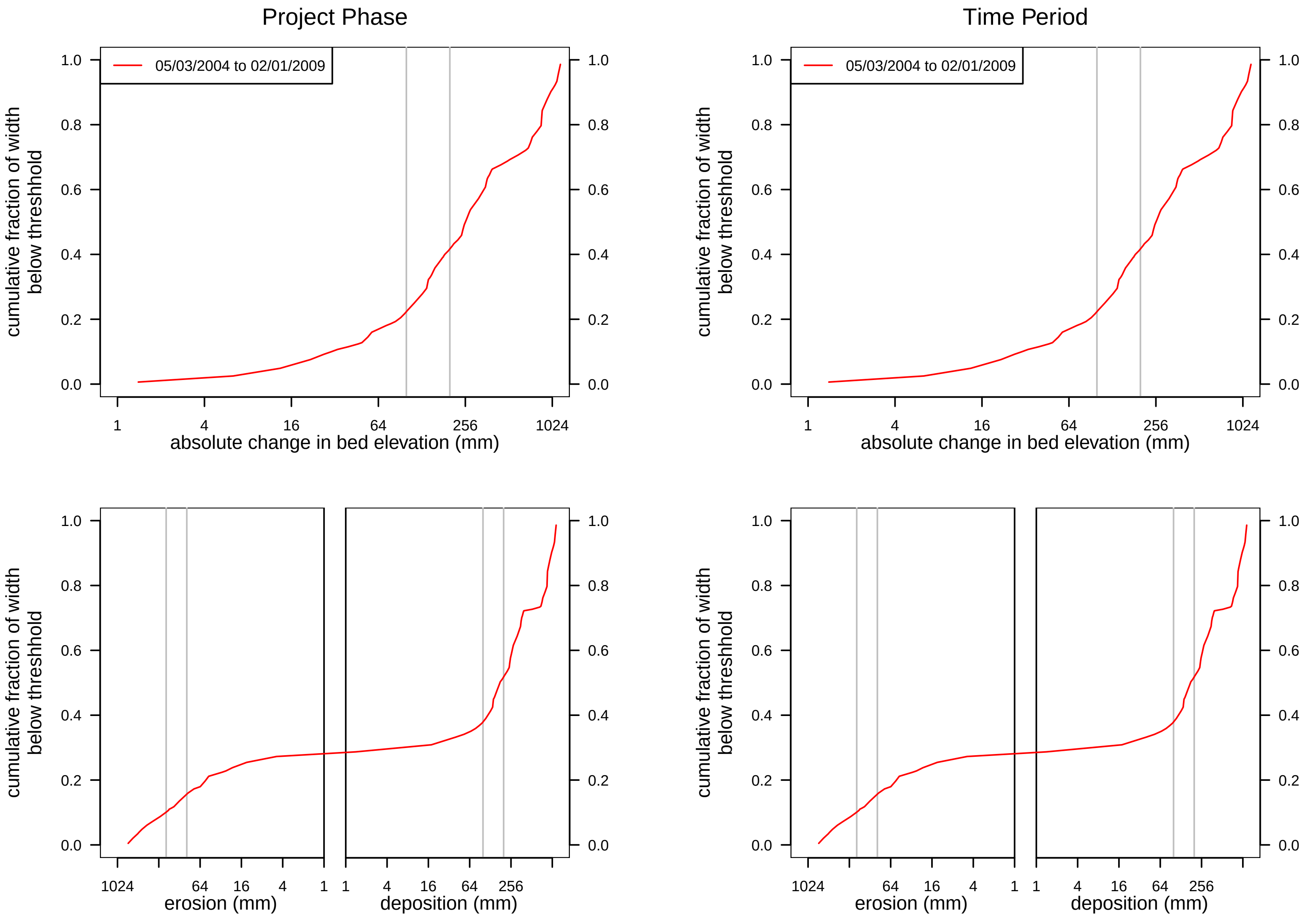


Below New Lewiston Bridge
Cross section Station ID 9 (2021+50), KM 177.94



Below New Lewiston Bridge
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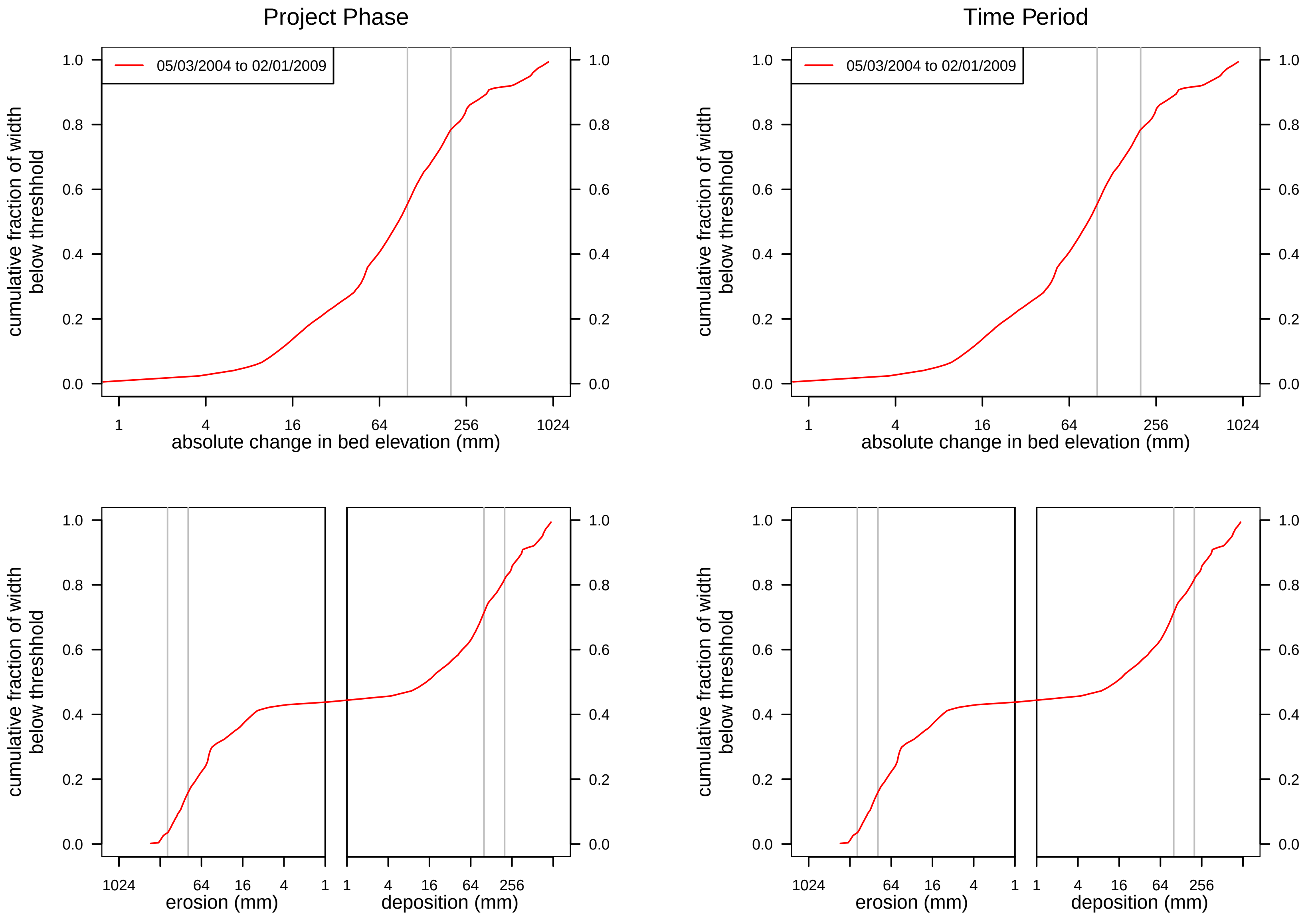

Below New Lewiston Bridge
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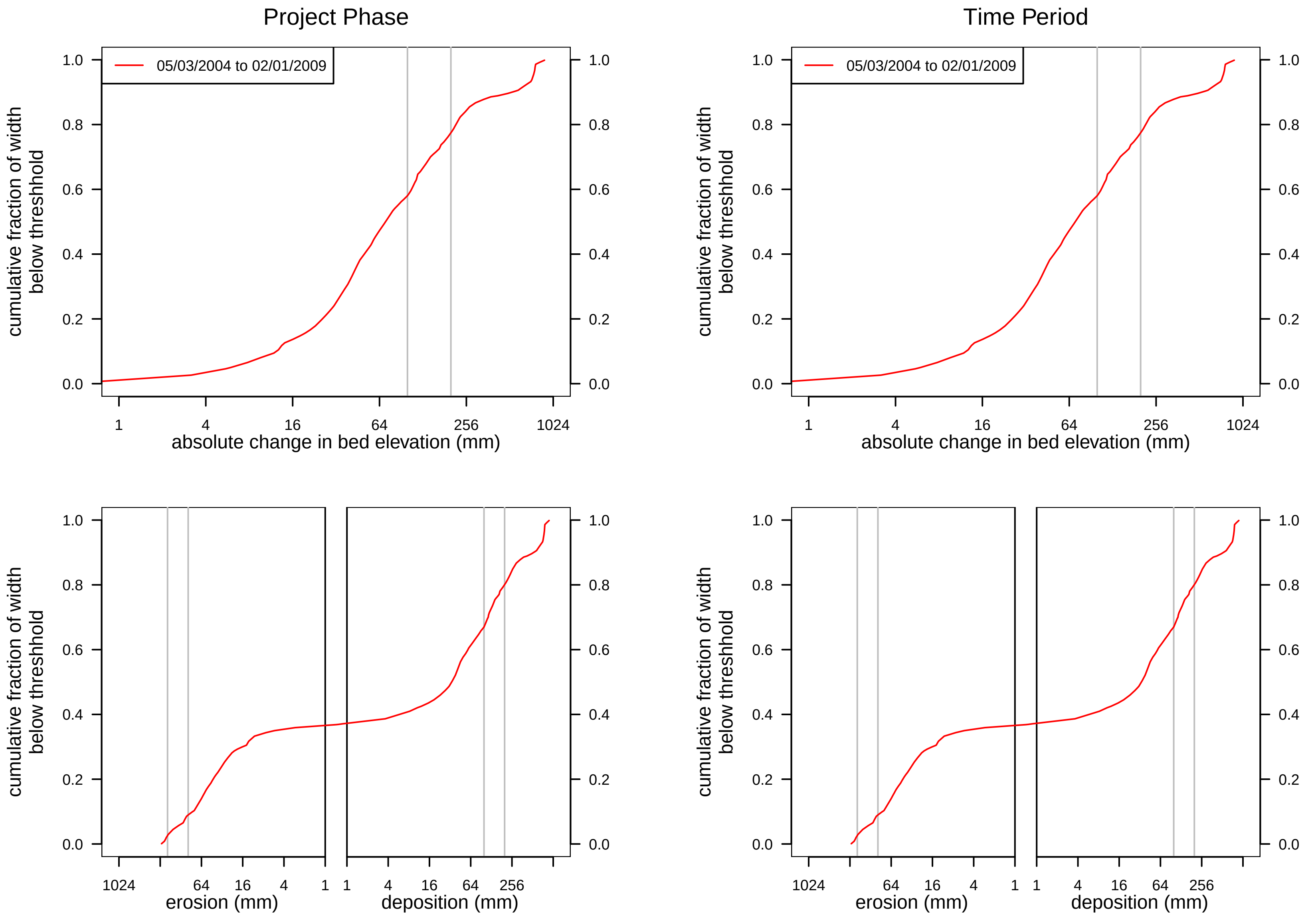
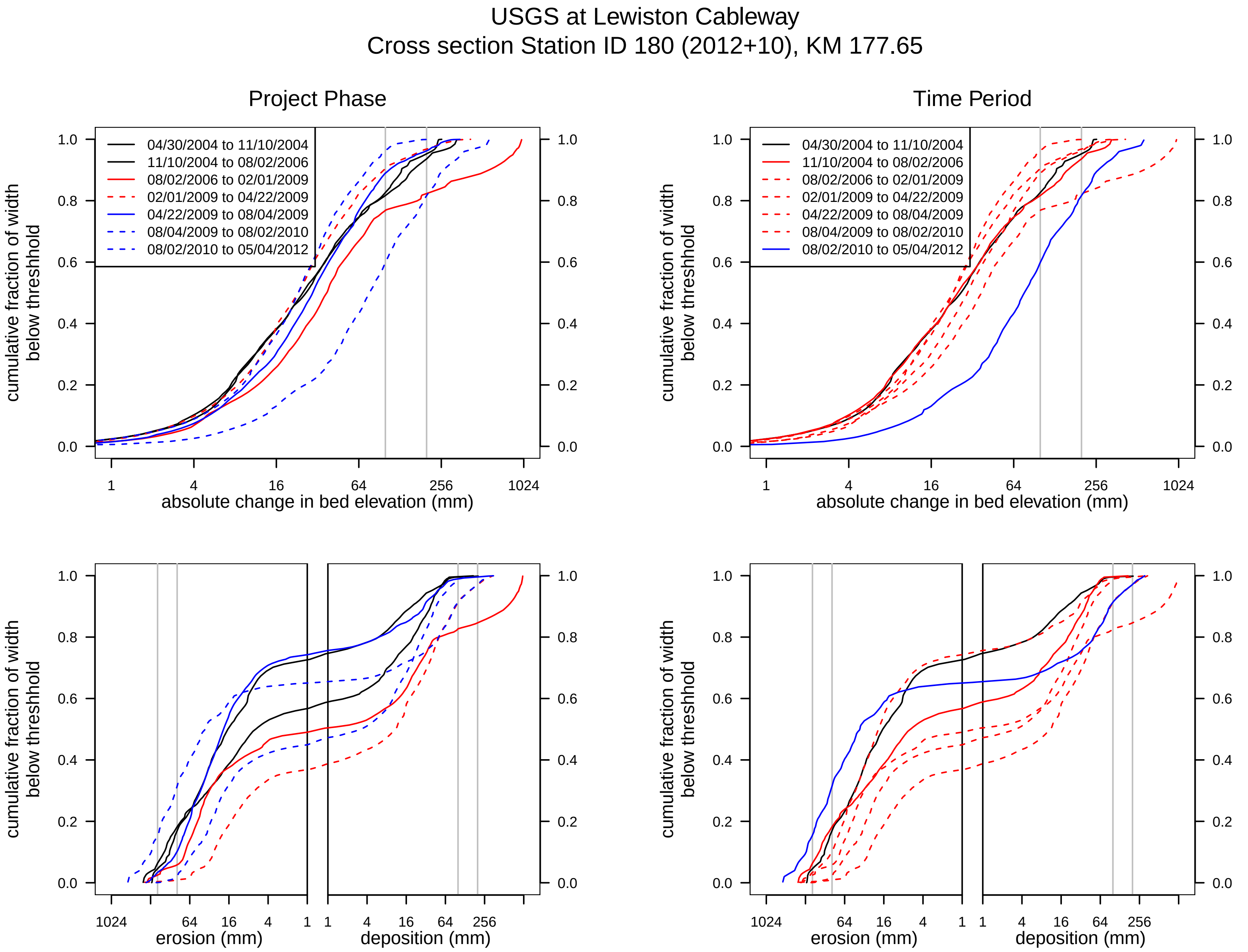
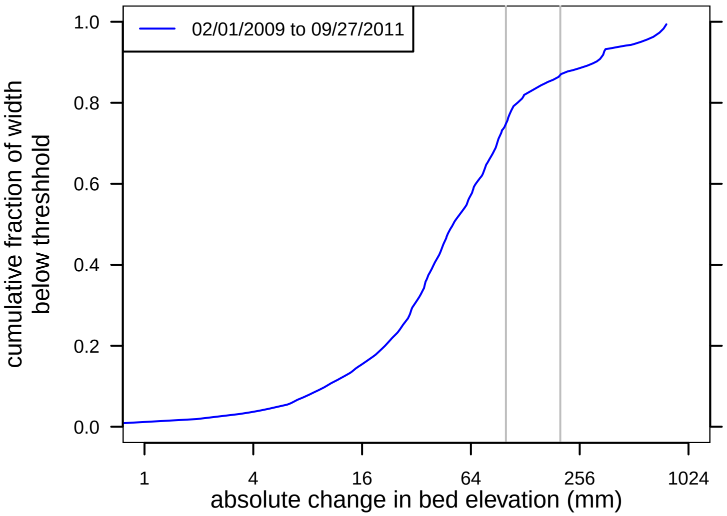
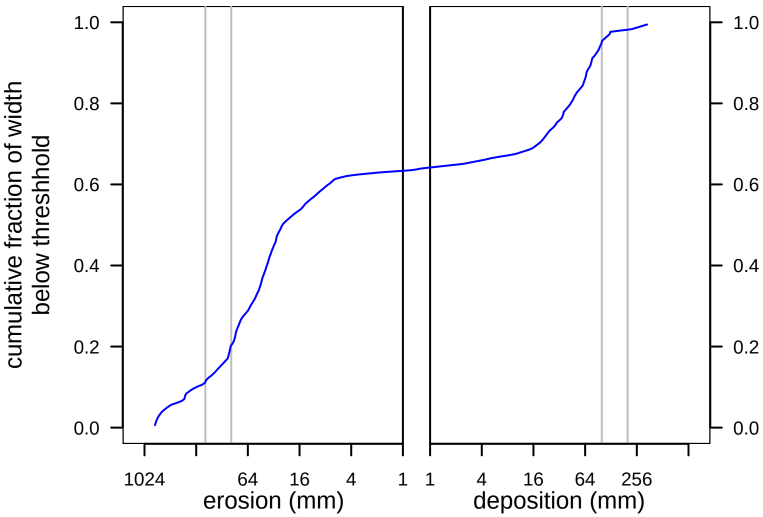



USGS at Lewiston Cableway
Cross section Station ID 180 (2012+10), KM 177.65
Project Phase
Time Period
04/30/2004 to 11/10/2004
11/10/2004 to 08/02/2006
08/02/2006 to 02/01/2009
02/01/2009 to 04/22/2009
04/22/2009 to 08/04/2009
08/04/2009 to 08/02/2010
08/02/2010 to 05/04/2012
cumulative fraction of width below threshold
0.0
0.2
0.4
0.6
0.8
1.0
1
4
16
64
256
1024
absolute change in bed elevation (mm)
erosion (mm)
deposition (mm)

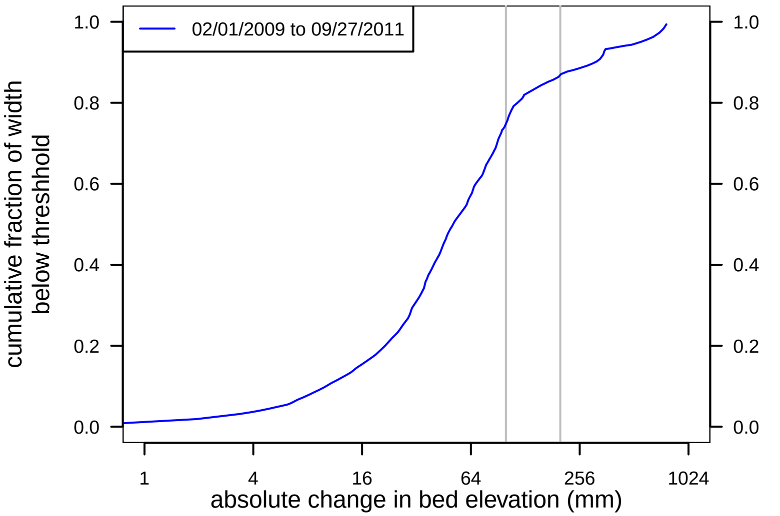
USGS at Lewiston Cableway
Cross section Station ID 198 (2007+50), KM 177.46

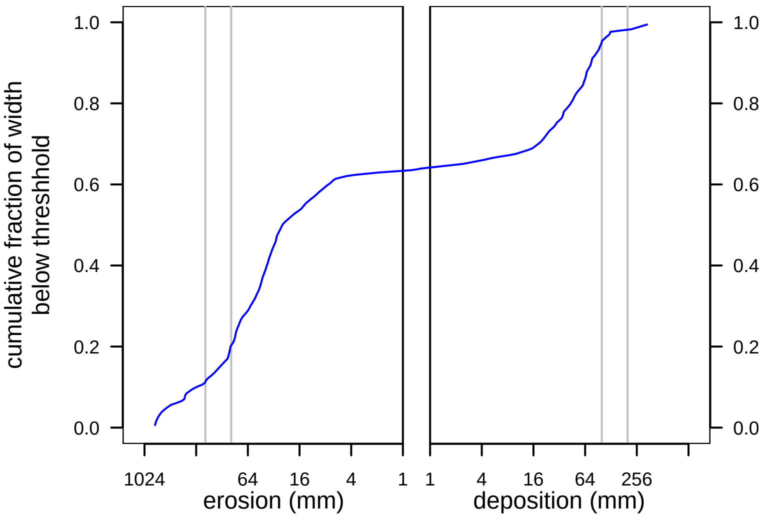
Project Phase



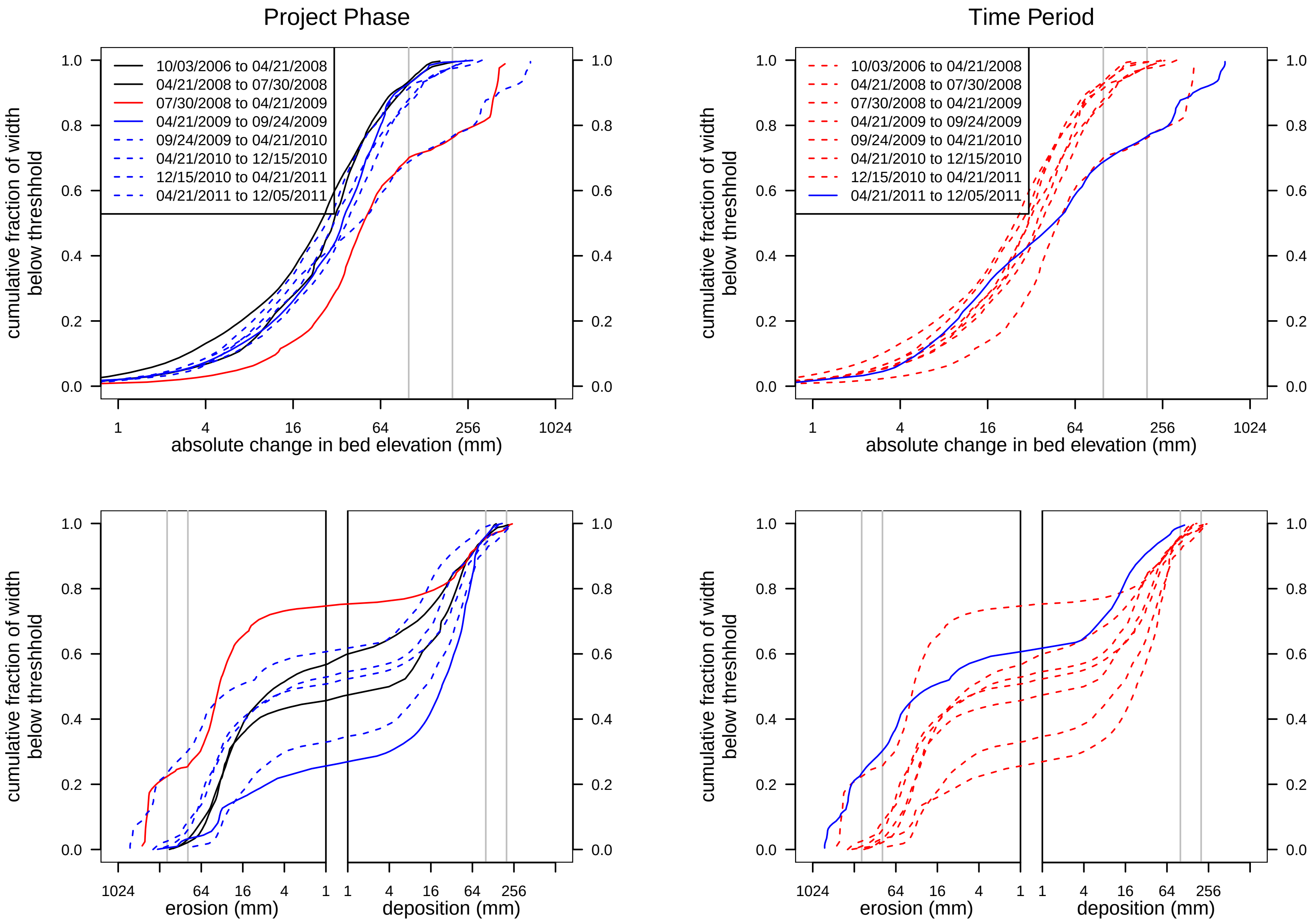


Time Period

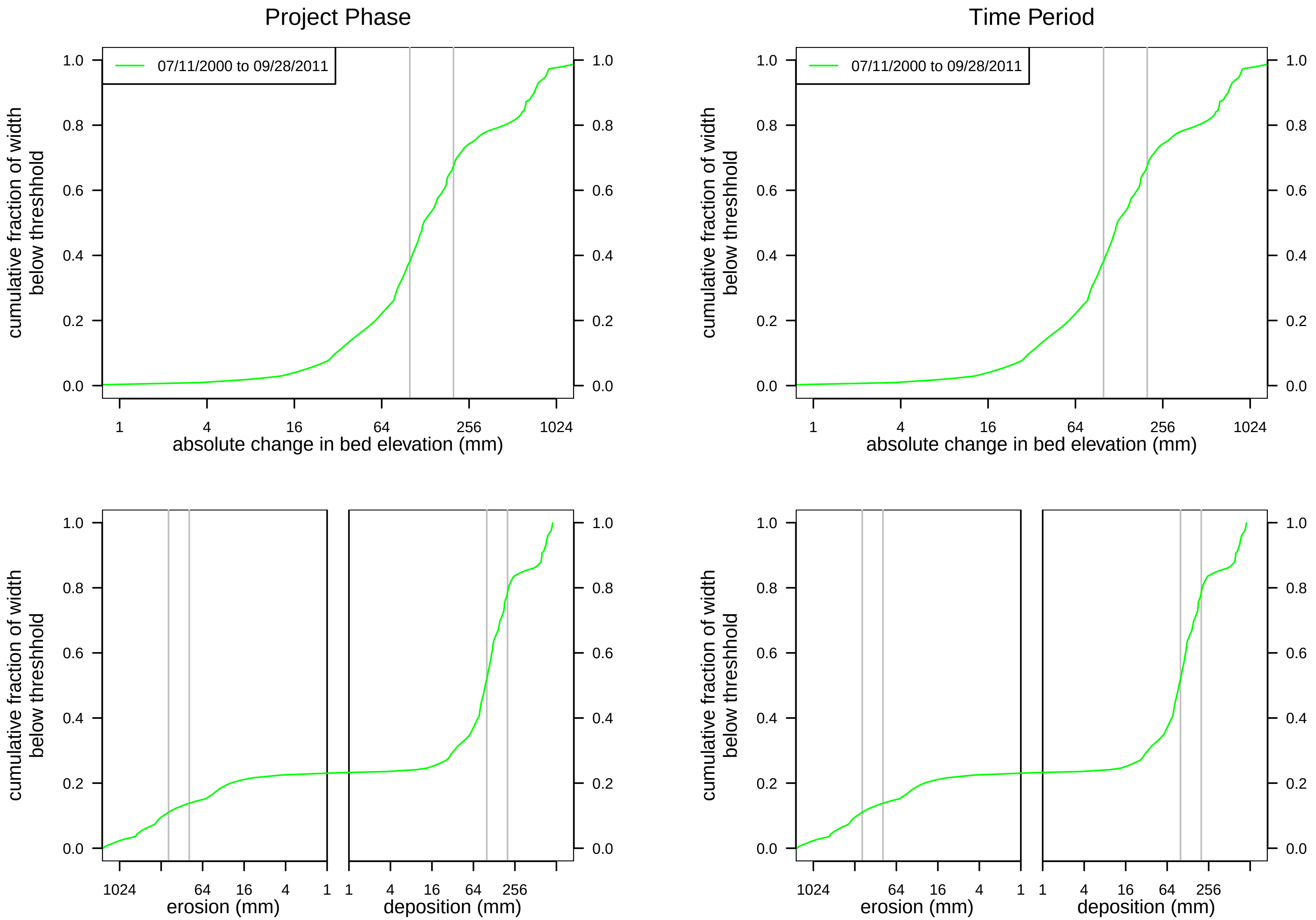




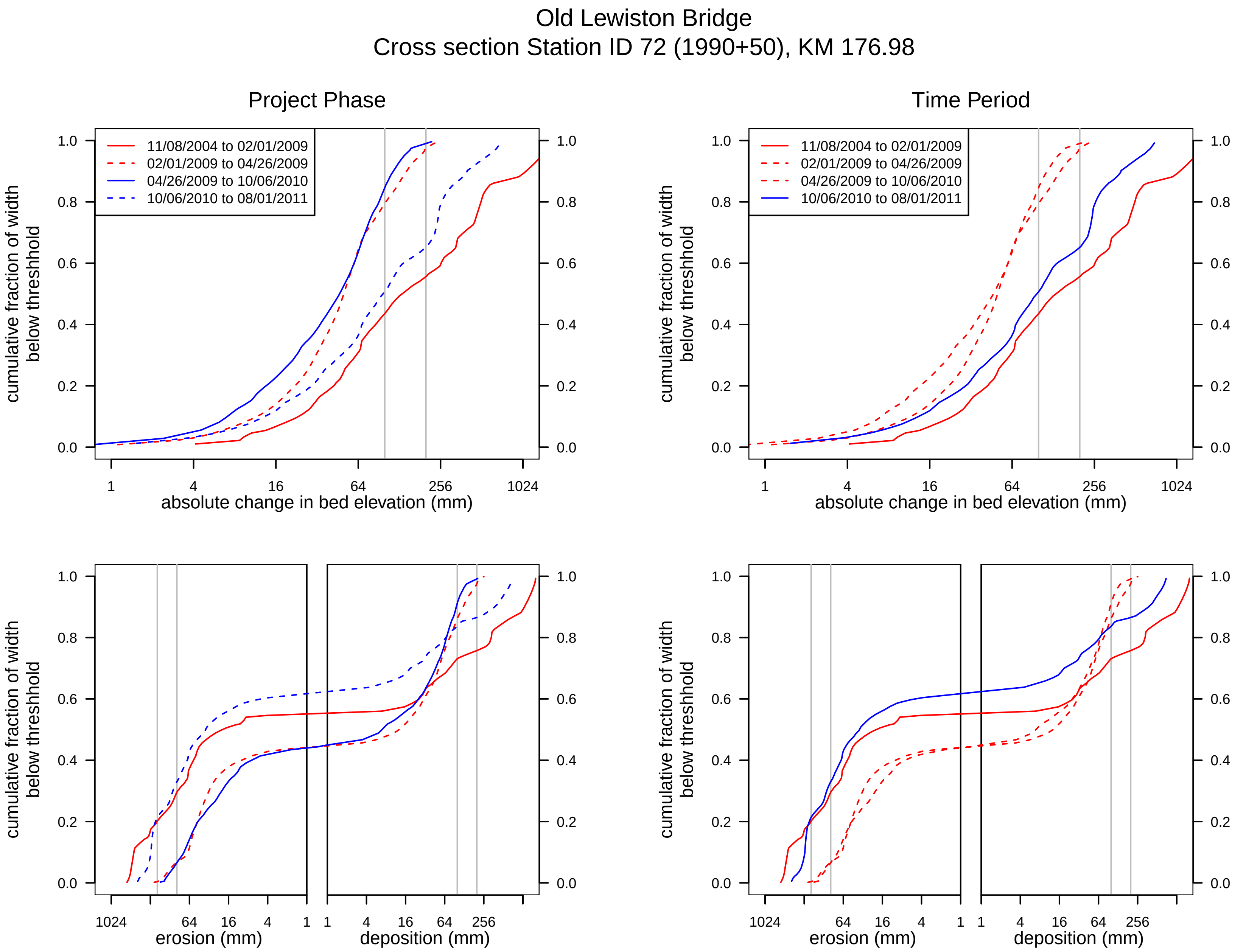
Old Lewiston Bridge
Cross section Station ID 297 (Trinity River at Lewiston), KM 177.30



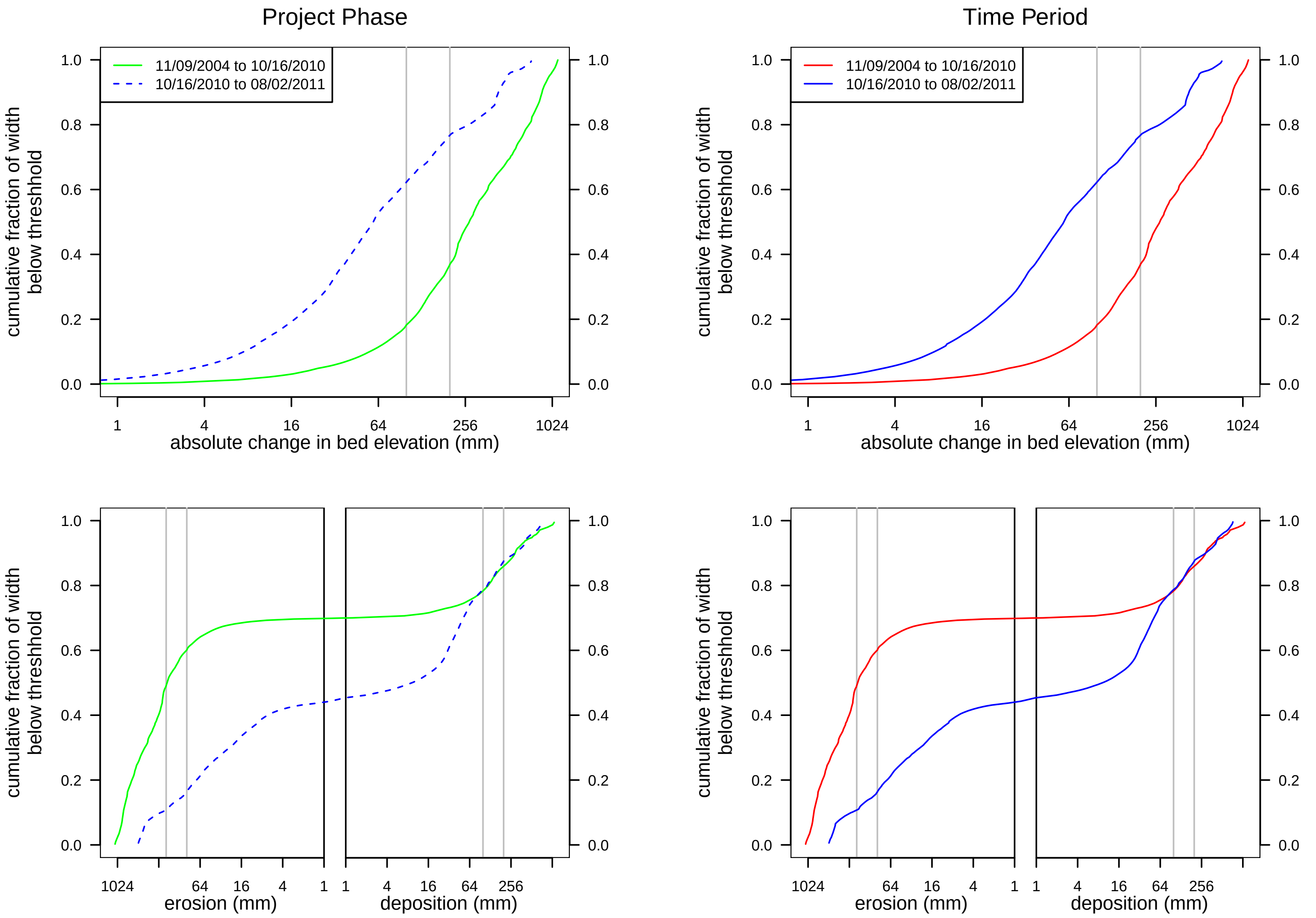
Old Lewiston Bridge
Cross section Station ID 75 (1997+80), KM 177.21


Project Phase

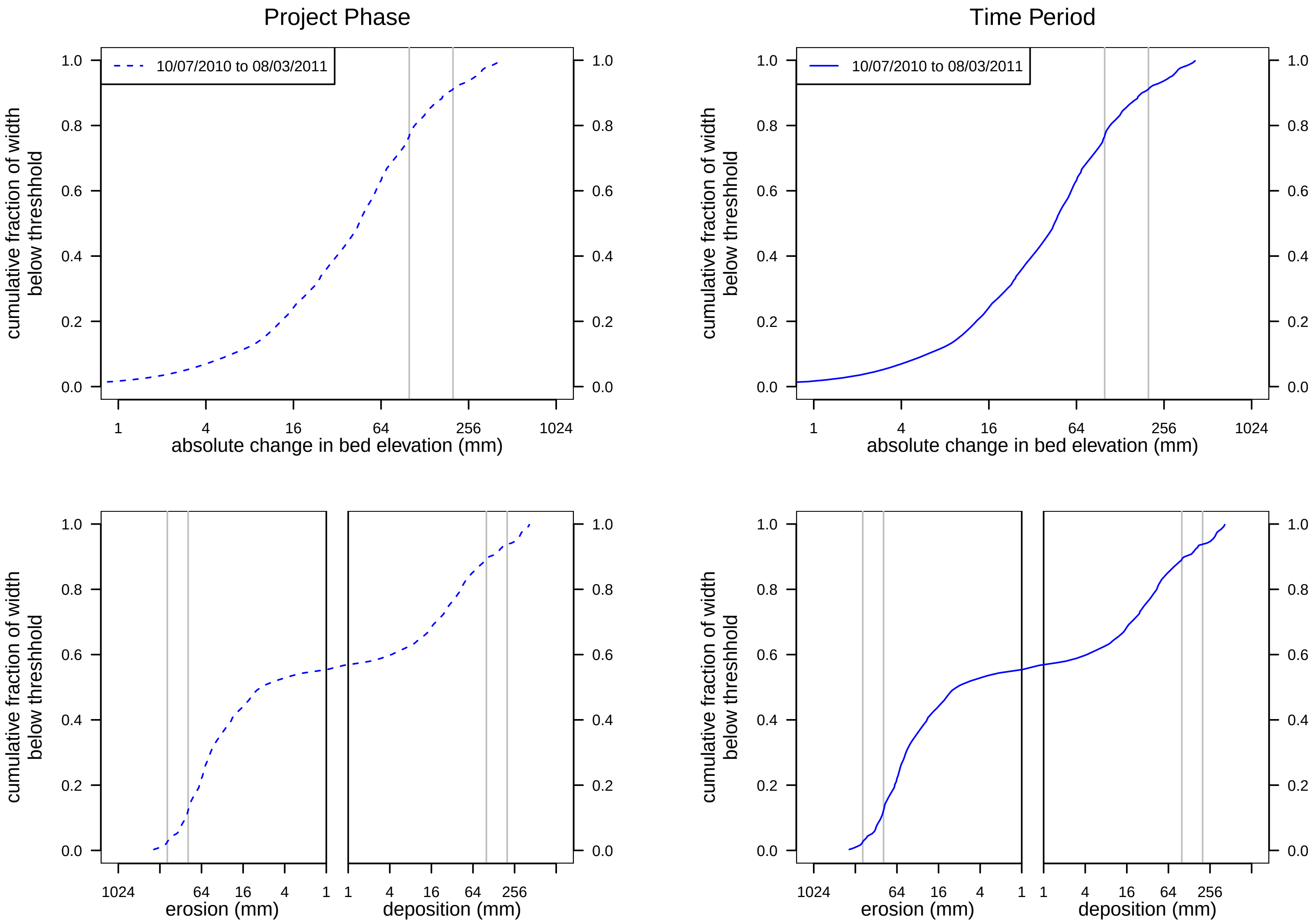
Time Period


Old Lewiston Bridge
Cross section Station ID 72 (1990+50), KM 176.98
Project Phase
Time Period
11/08/2004 to 02/01/2009
02/01/2009 to 04/26/2009
04/26/2009 to 10/06/2010
10/06/2010 to 08/01/2011
cumulative fraction of width below threshold
absolute change in bed elevation (mm)
erosion (mm)
deposition (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1
4
16
64
256
1024

Sawmill
Cross section Station ID 118 (1964+50), KM 176.16



Sawmill
Cross section Station ID 116 (1959+00), KM 175.99



Sawmill
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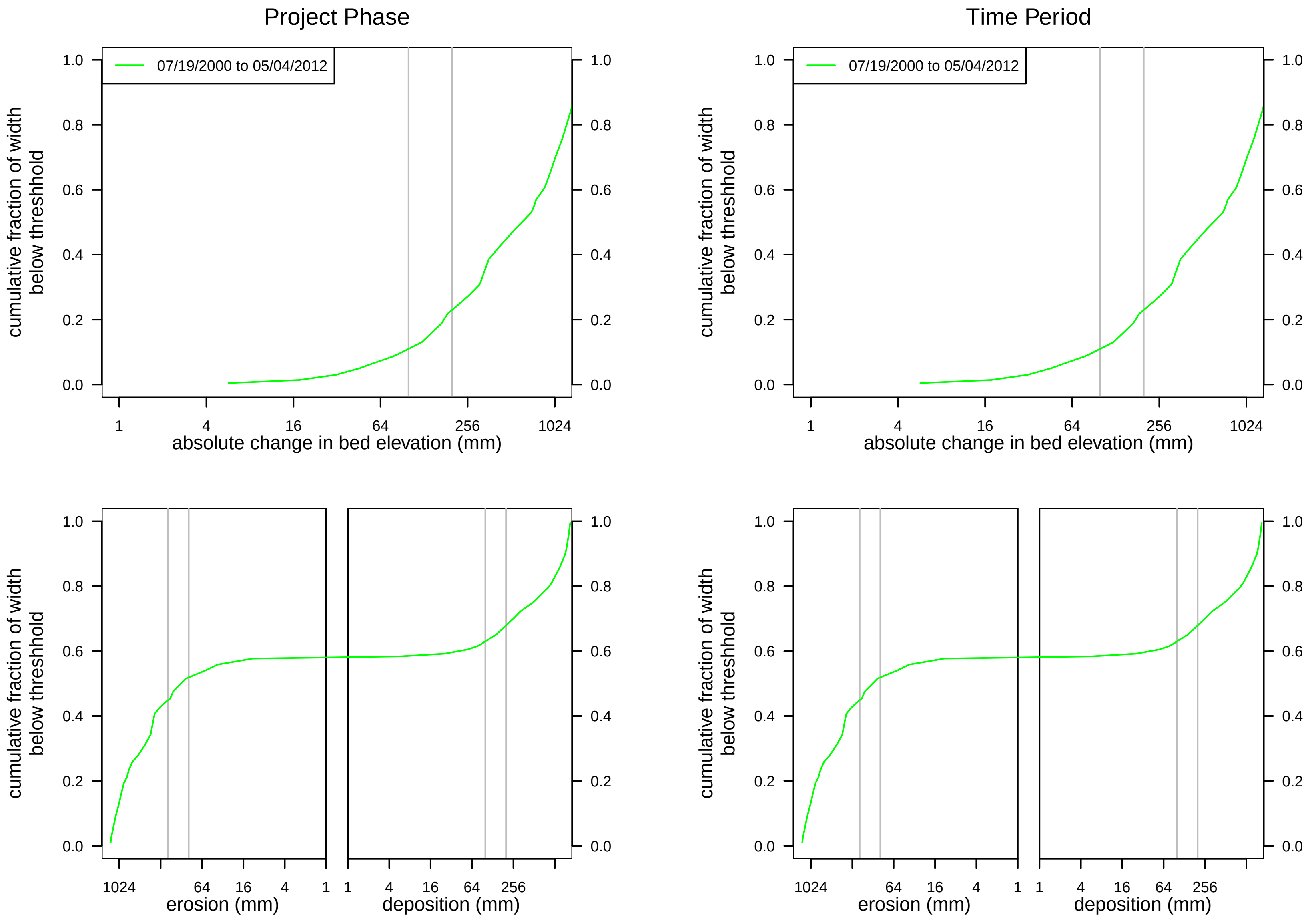
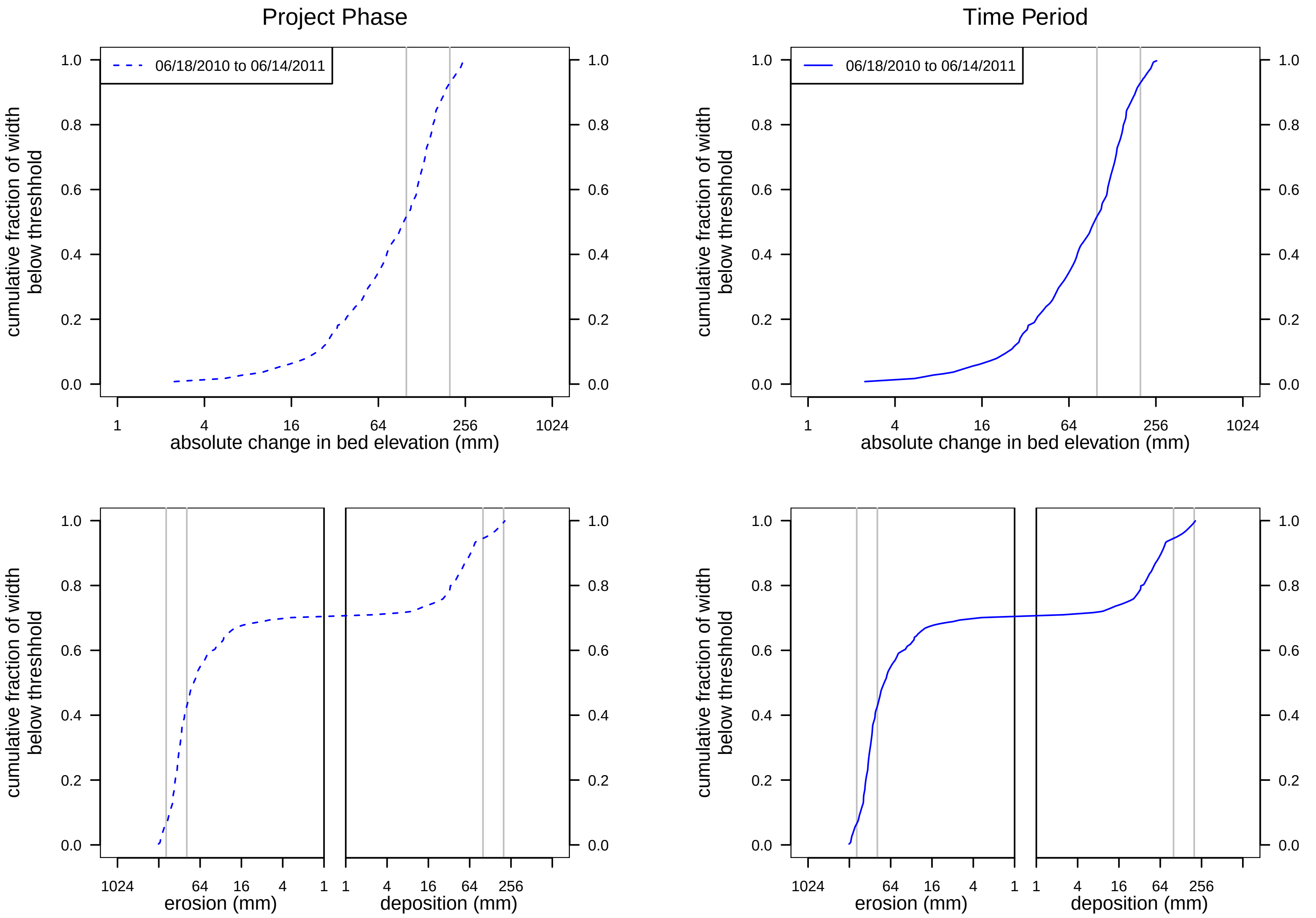


Sawmill
Cross section Station ID 274 (Bathy_XS1), KM 175.32



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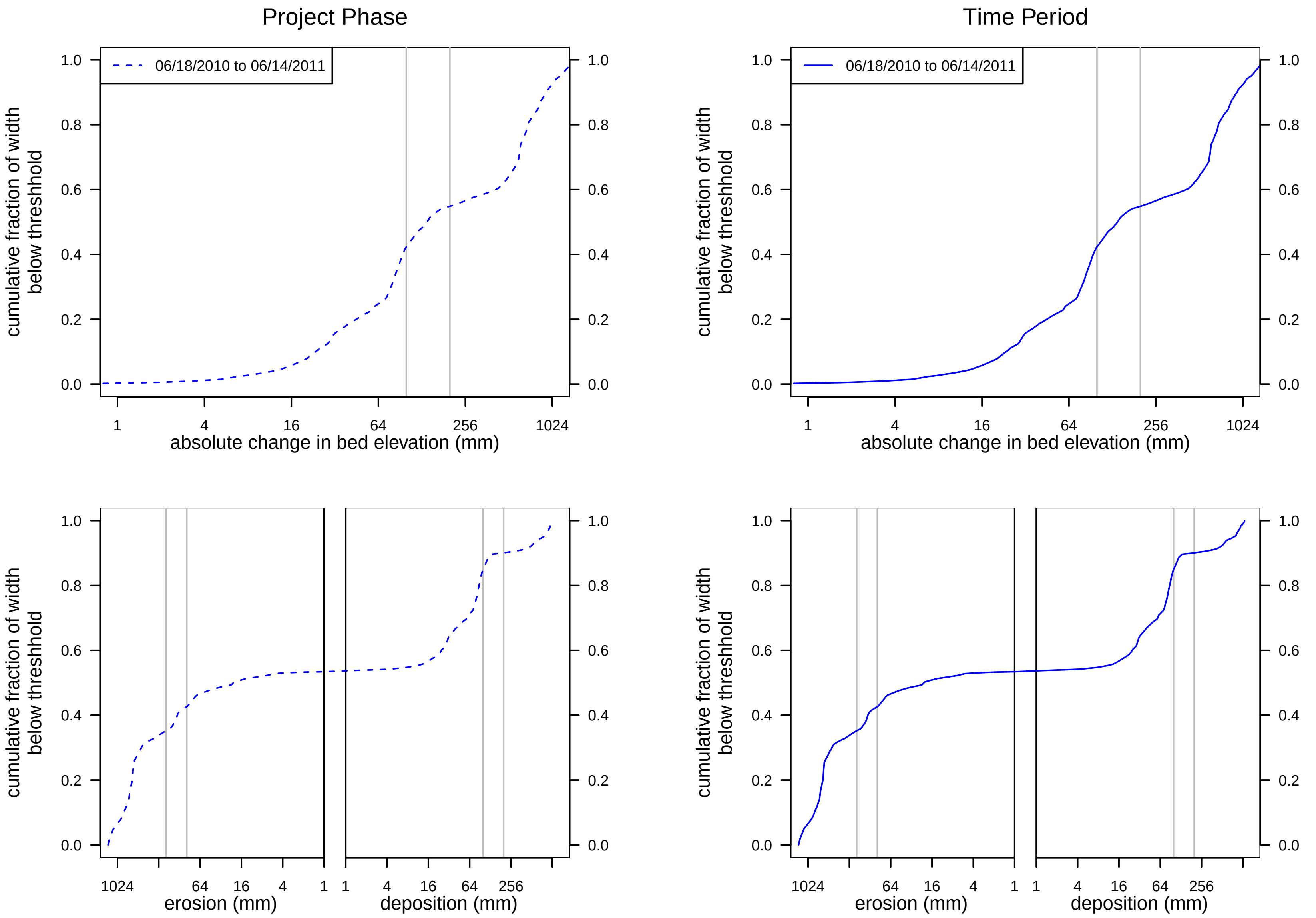

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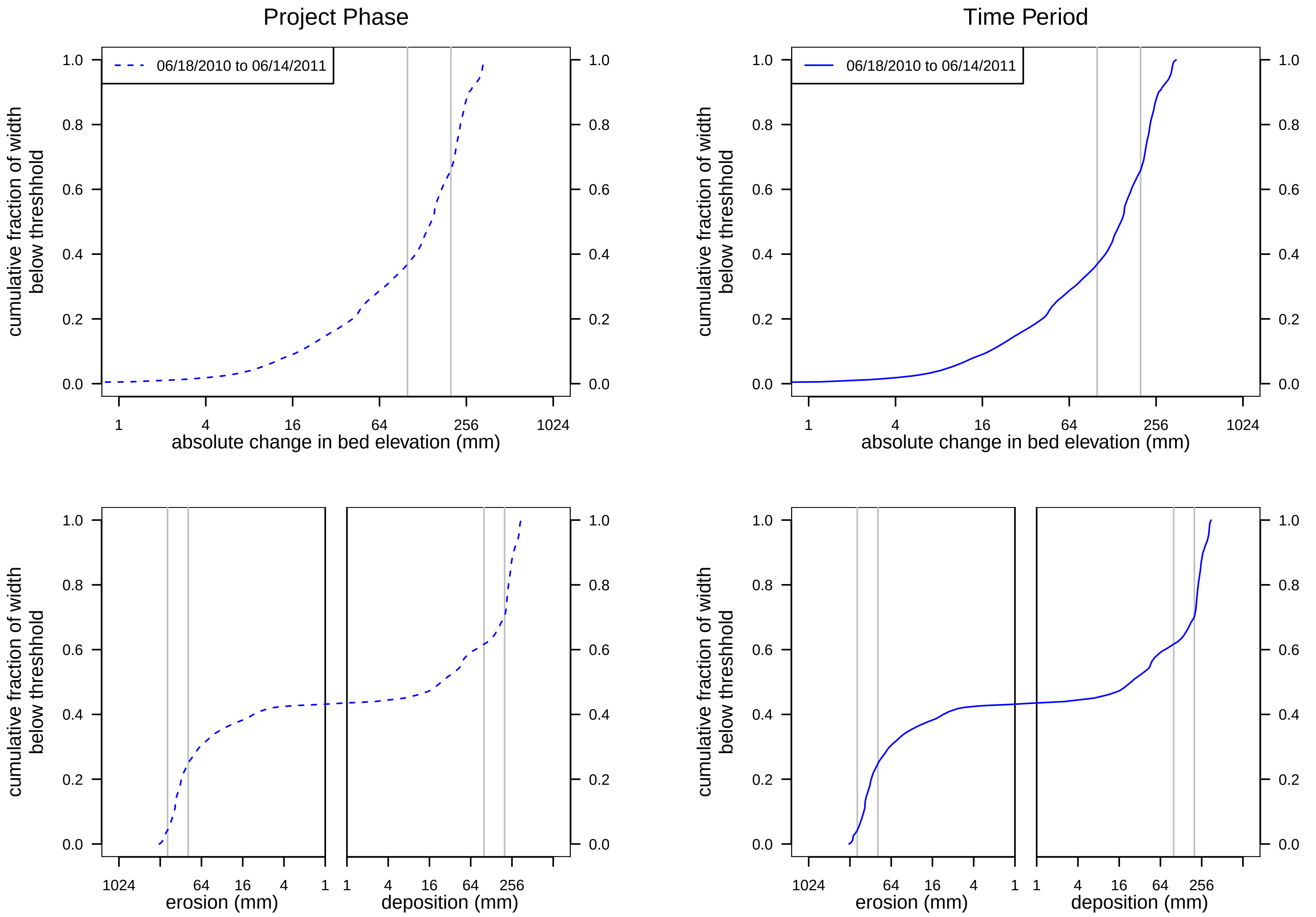

Sawmill
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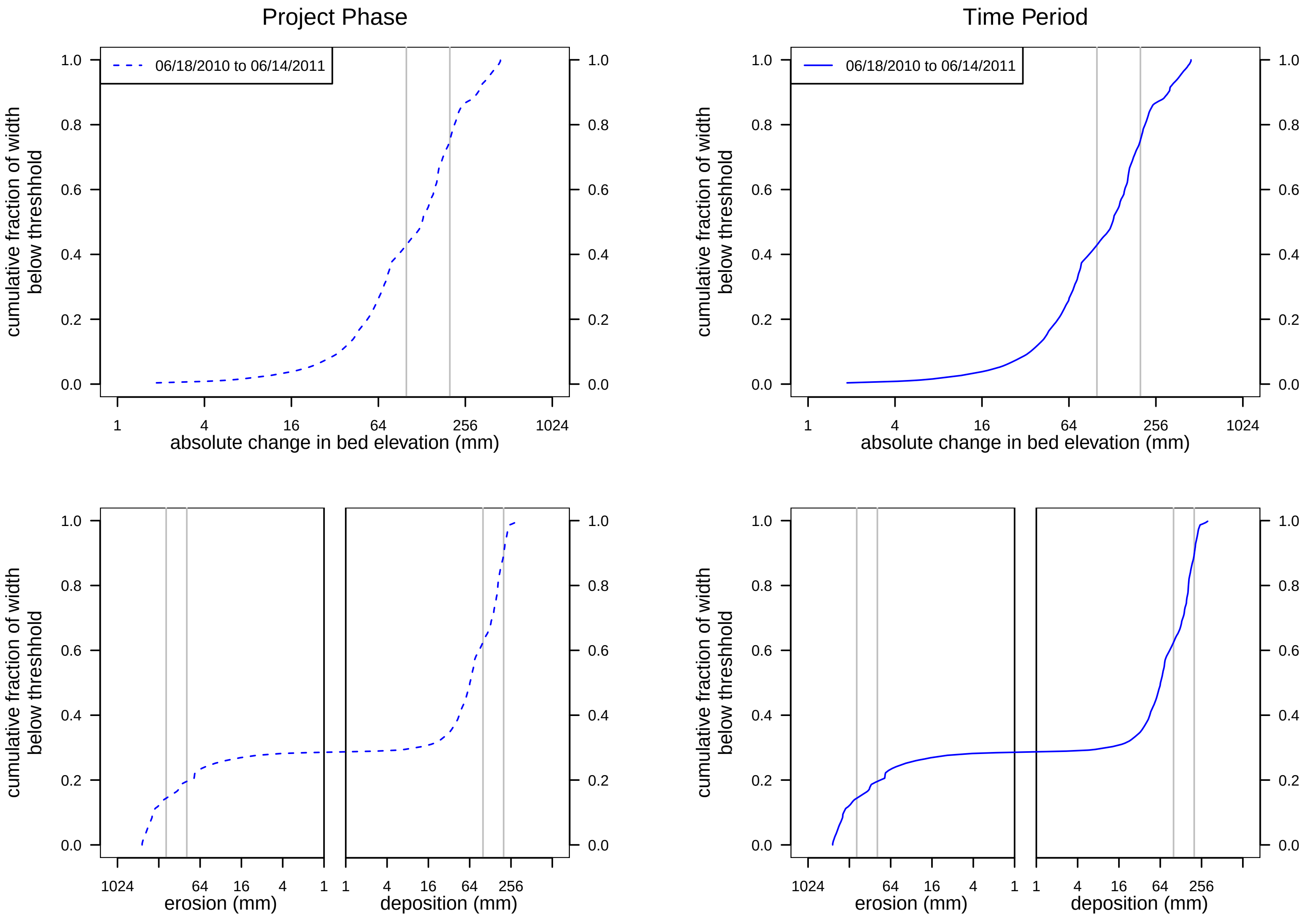
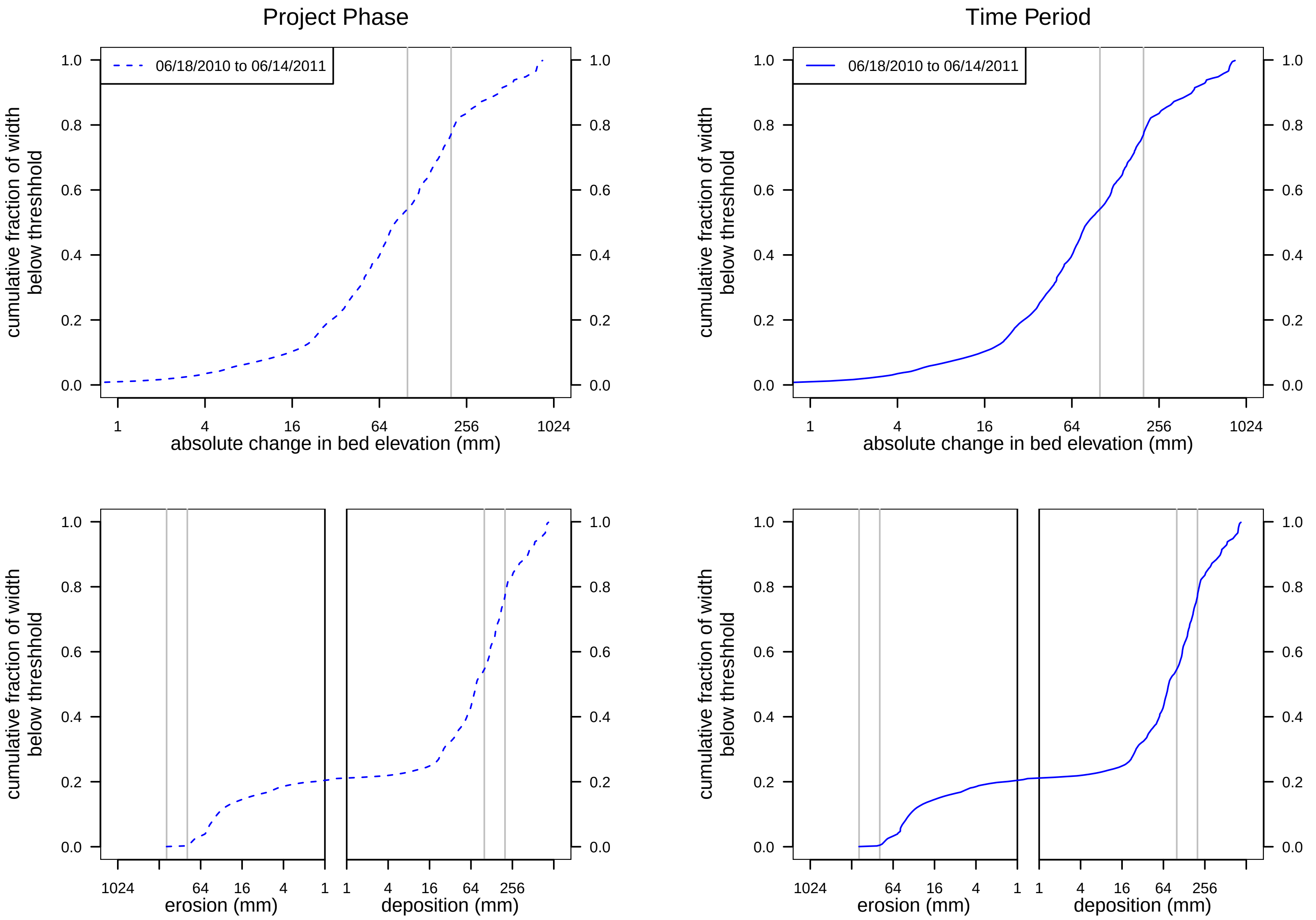
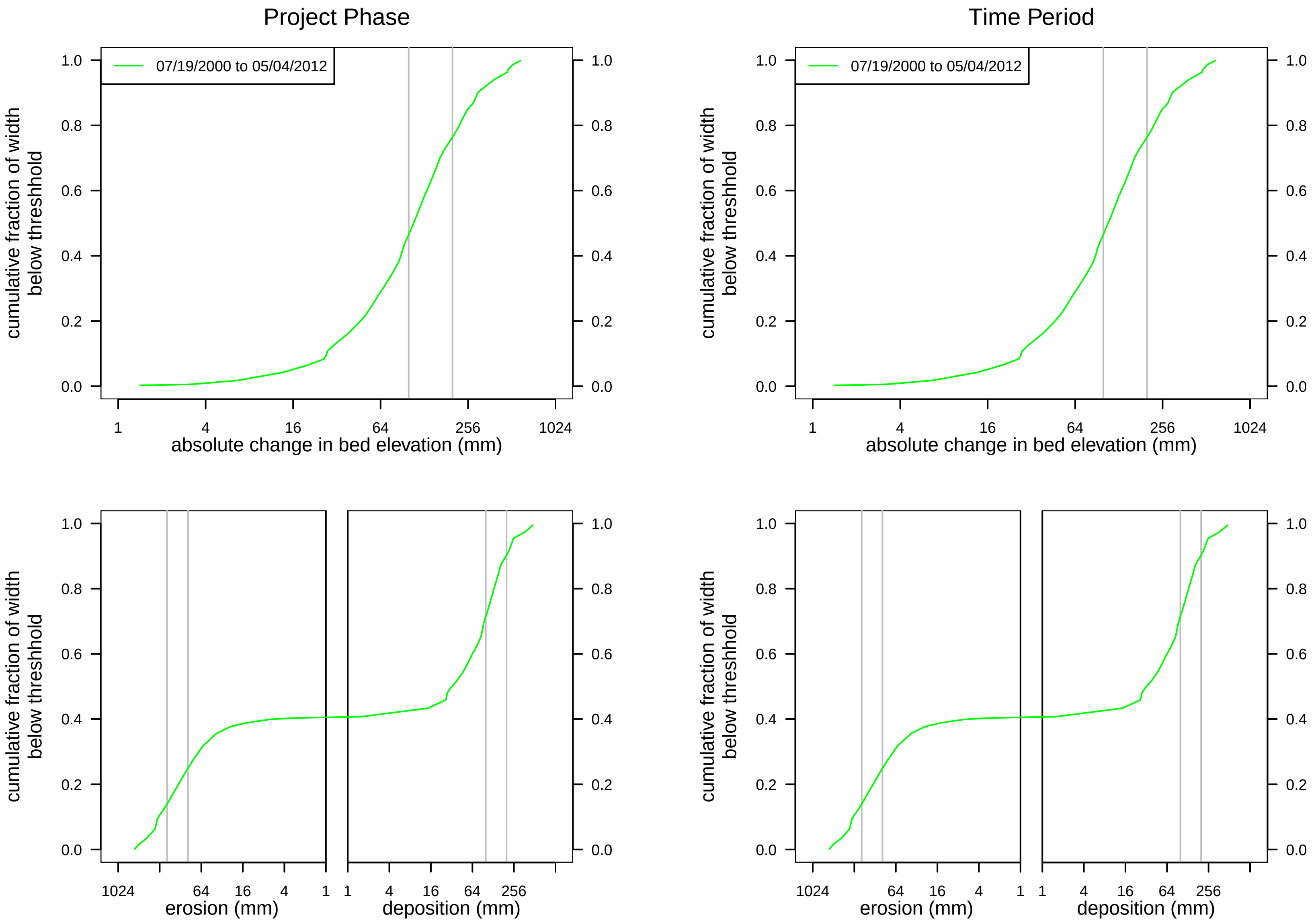


Sawmill
Cross section Station ID 278 (Bathy_XS5), KM 175.14



Rush Creek Delta
Cross section Station ID 102 (1883+85), KM 173.72



Project Phase

Time Period

Bucktail
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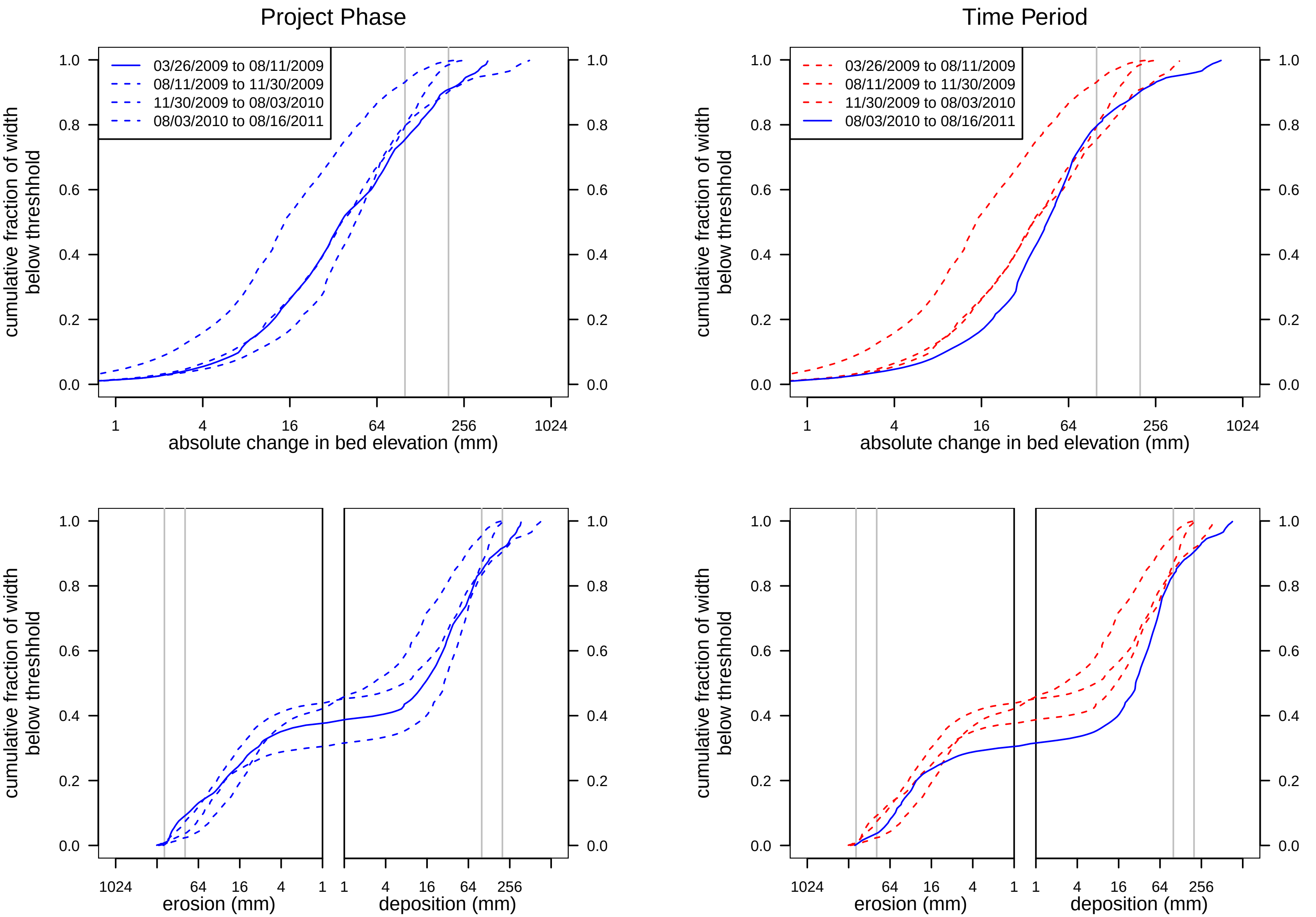
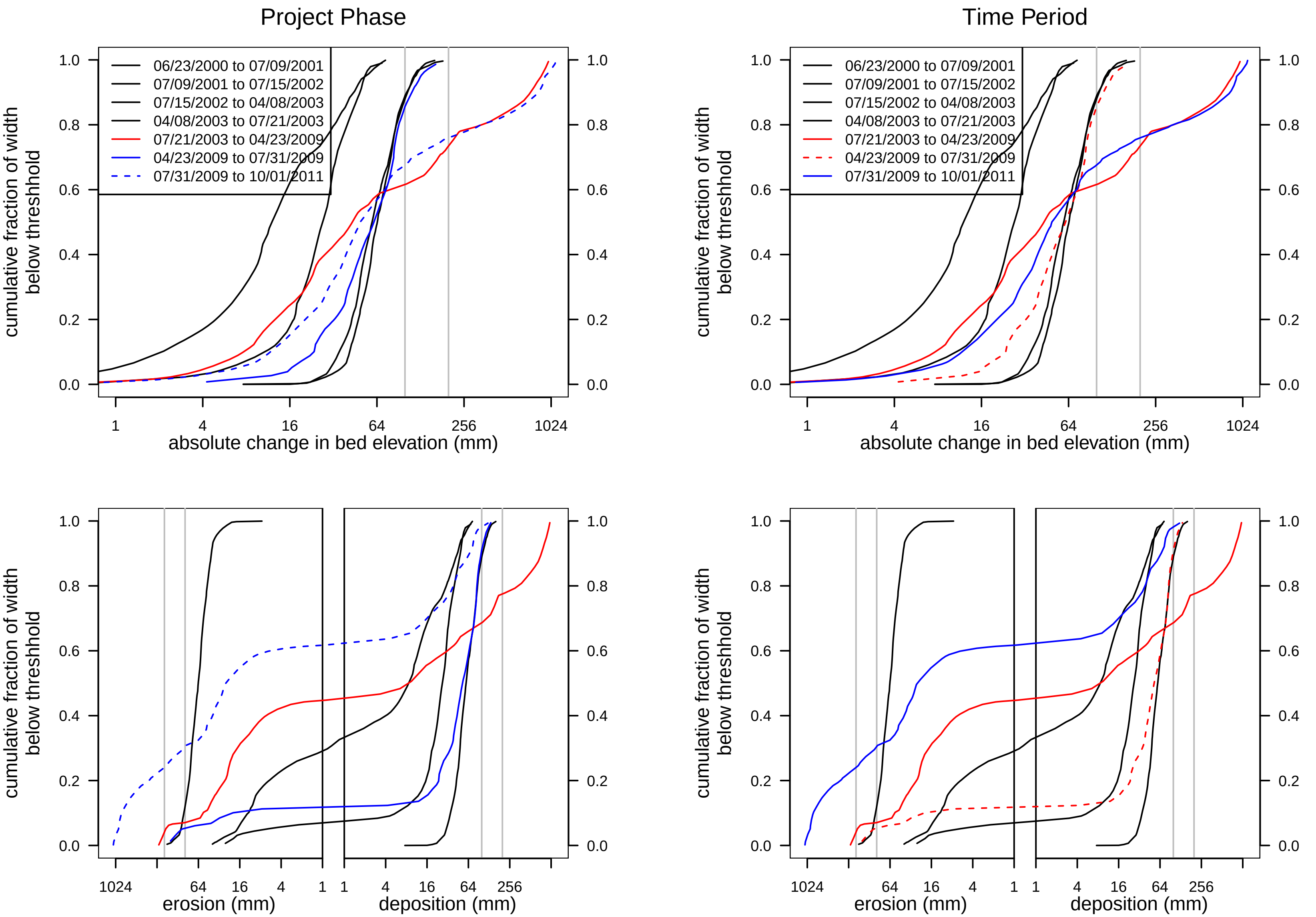
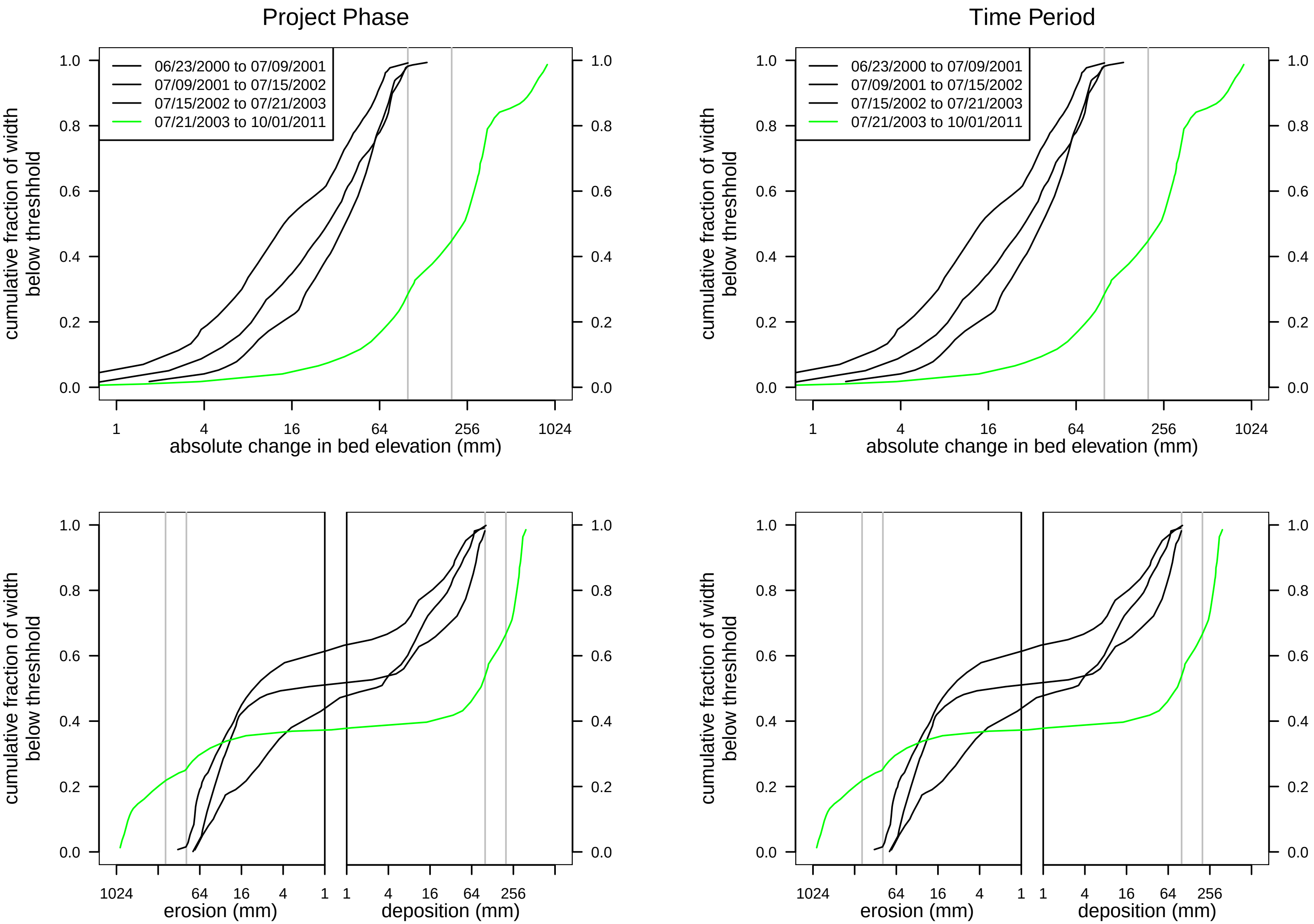


Bucktail
Cross section Station ID 15 (1781+10), KM 170.60



Bucktail
Cross section Station ID 14 (1778+85), KM 170.53



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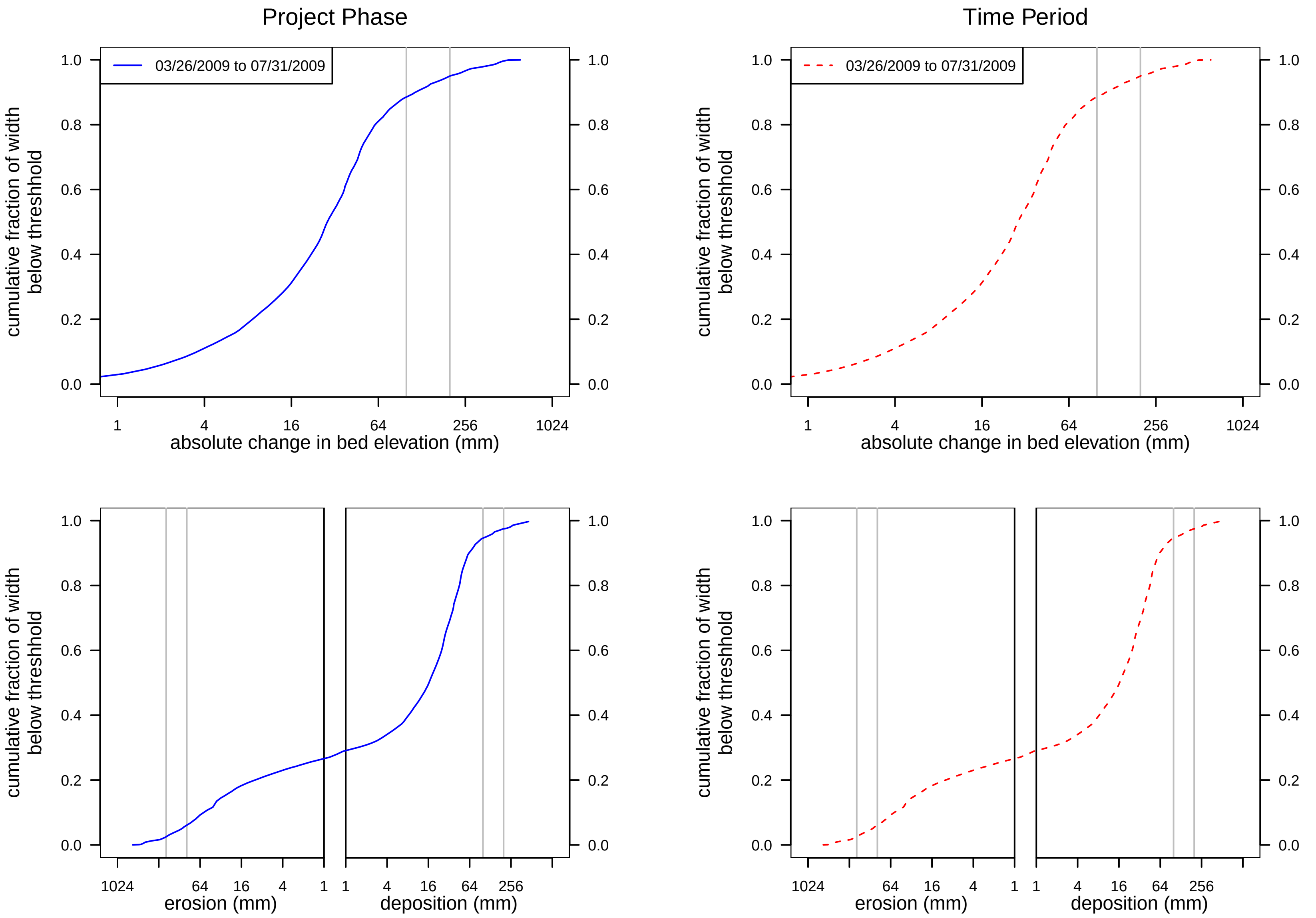
Cross section Station ID 397 (1771+90), KM 170.28



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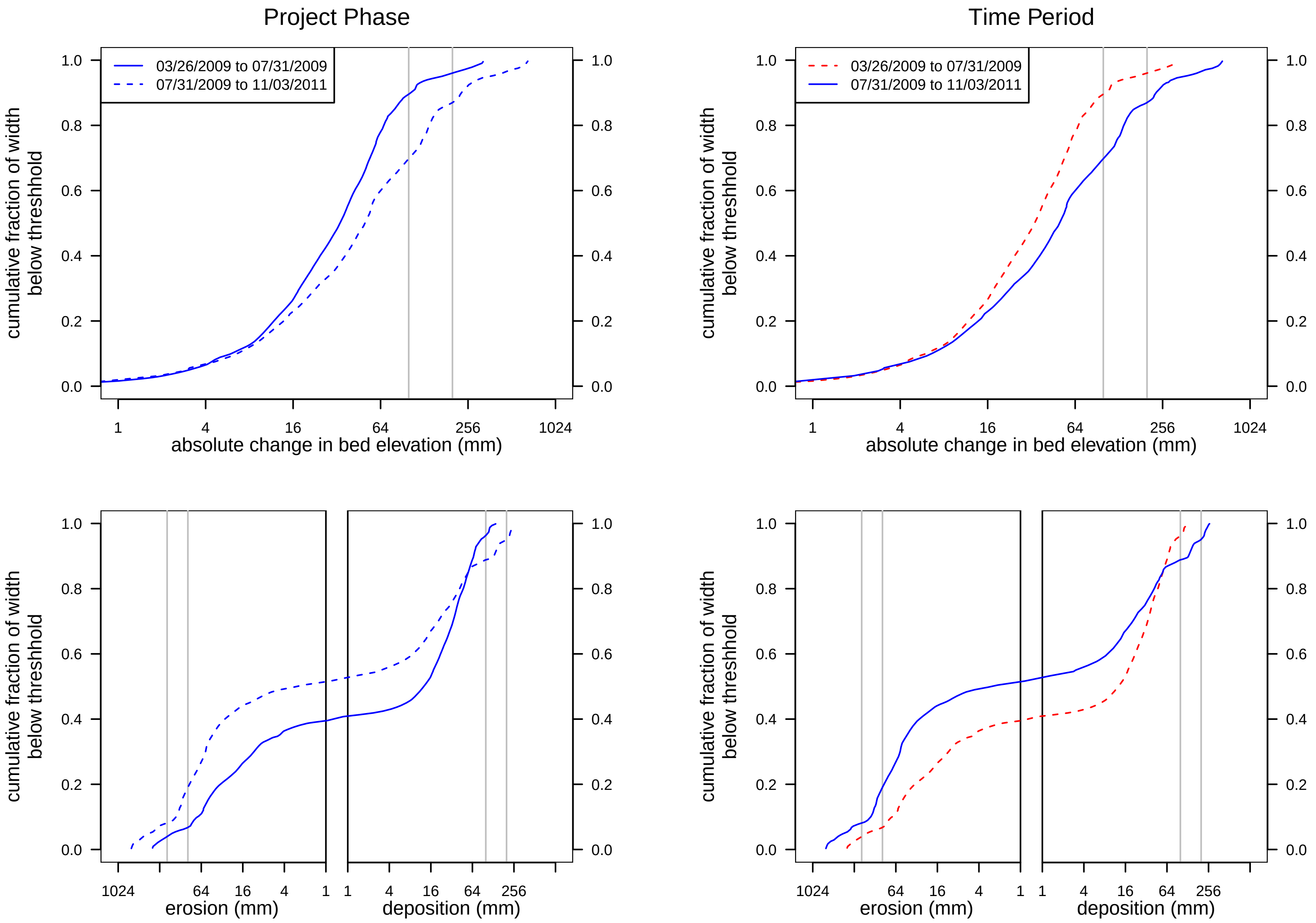
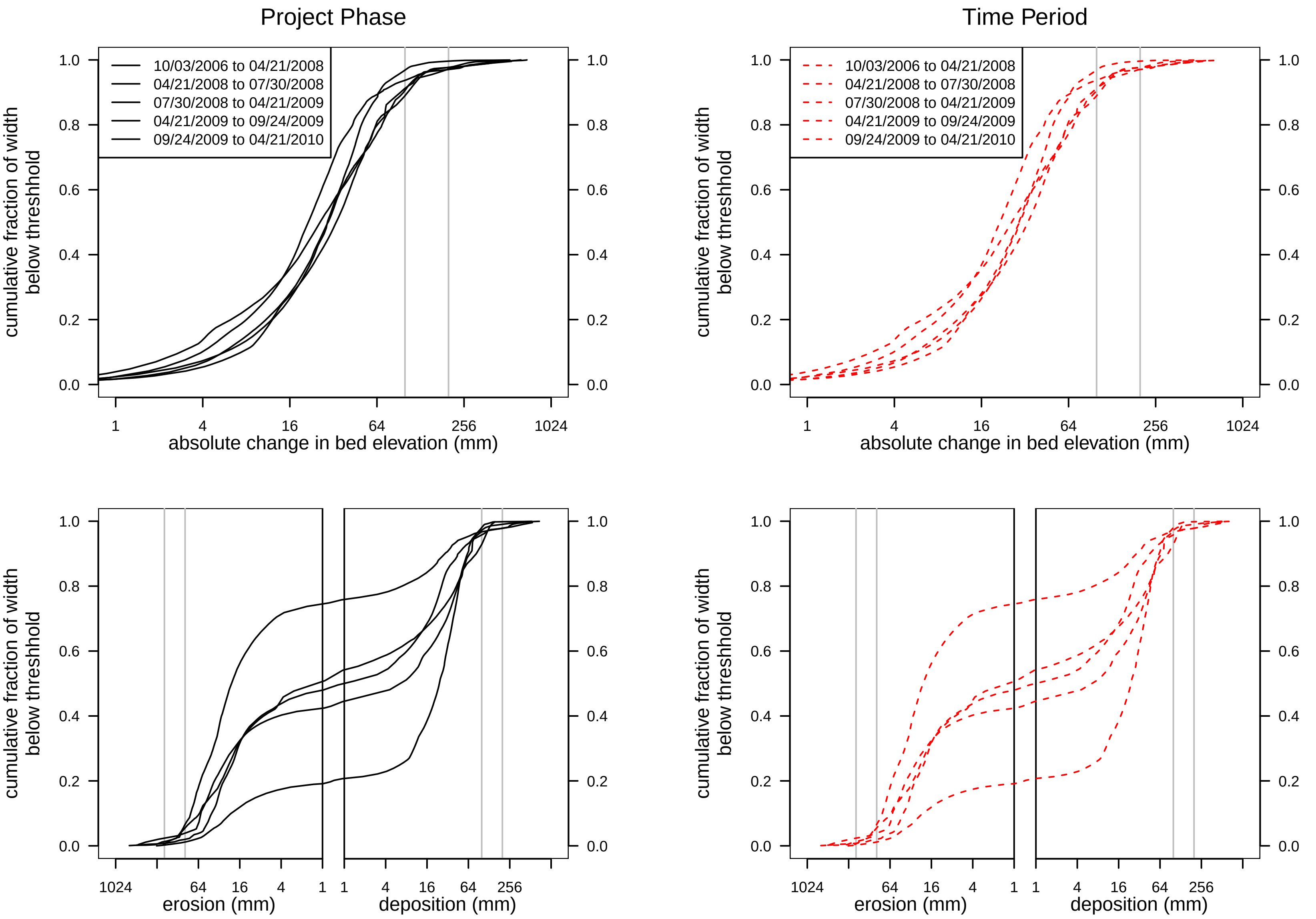
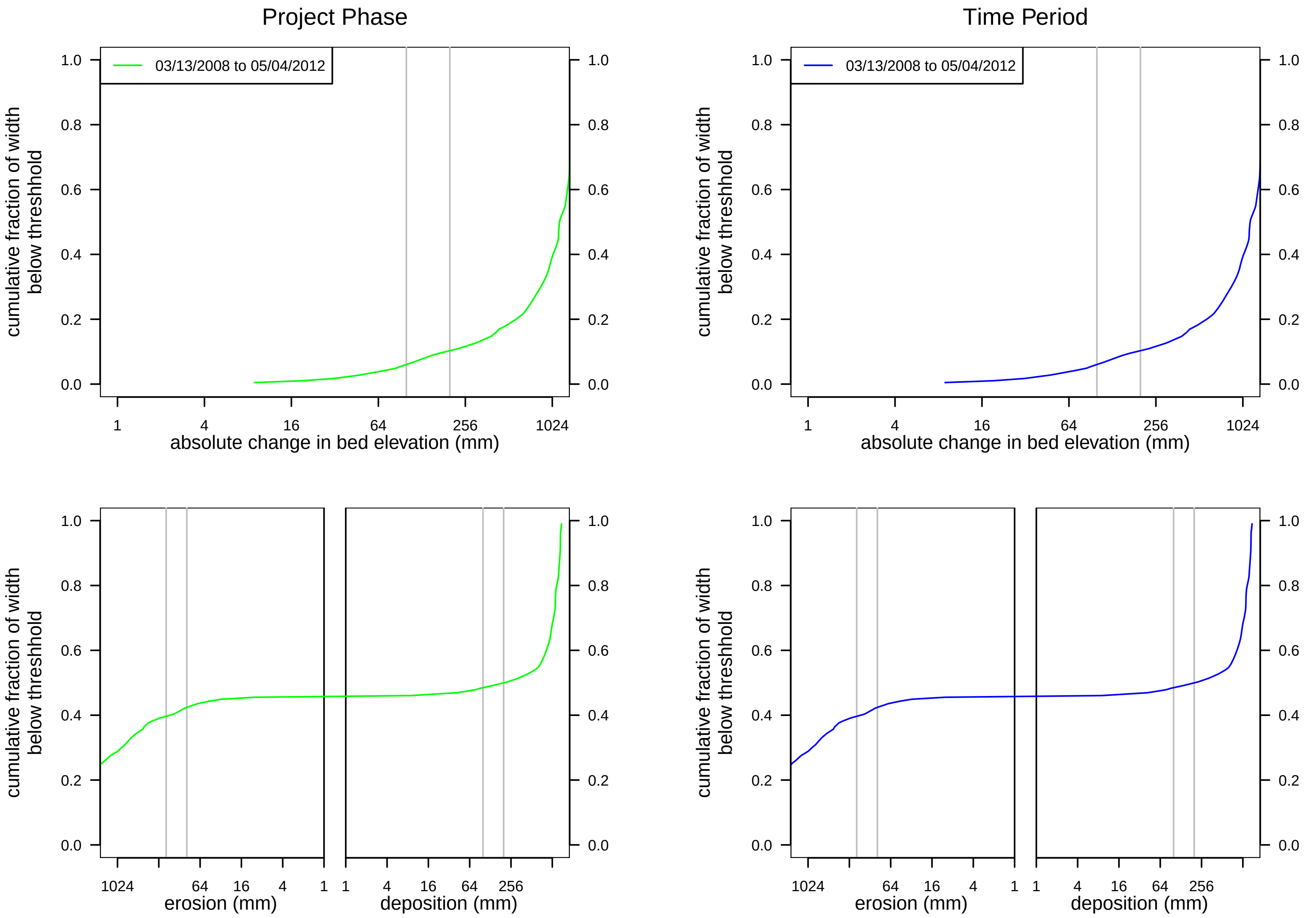
Cross section Station ID 241 (1779+90), KM 169.90



Trinity River above Grass Valley Creek
Cross section Station ID 174 (not specified), KM 168.83



Trinity House Gulch
Cross section Station ID 173 (1695+65), KM 168.02



Trinity House Gulch
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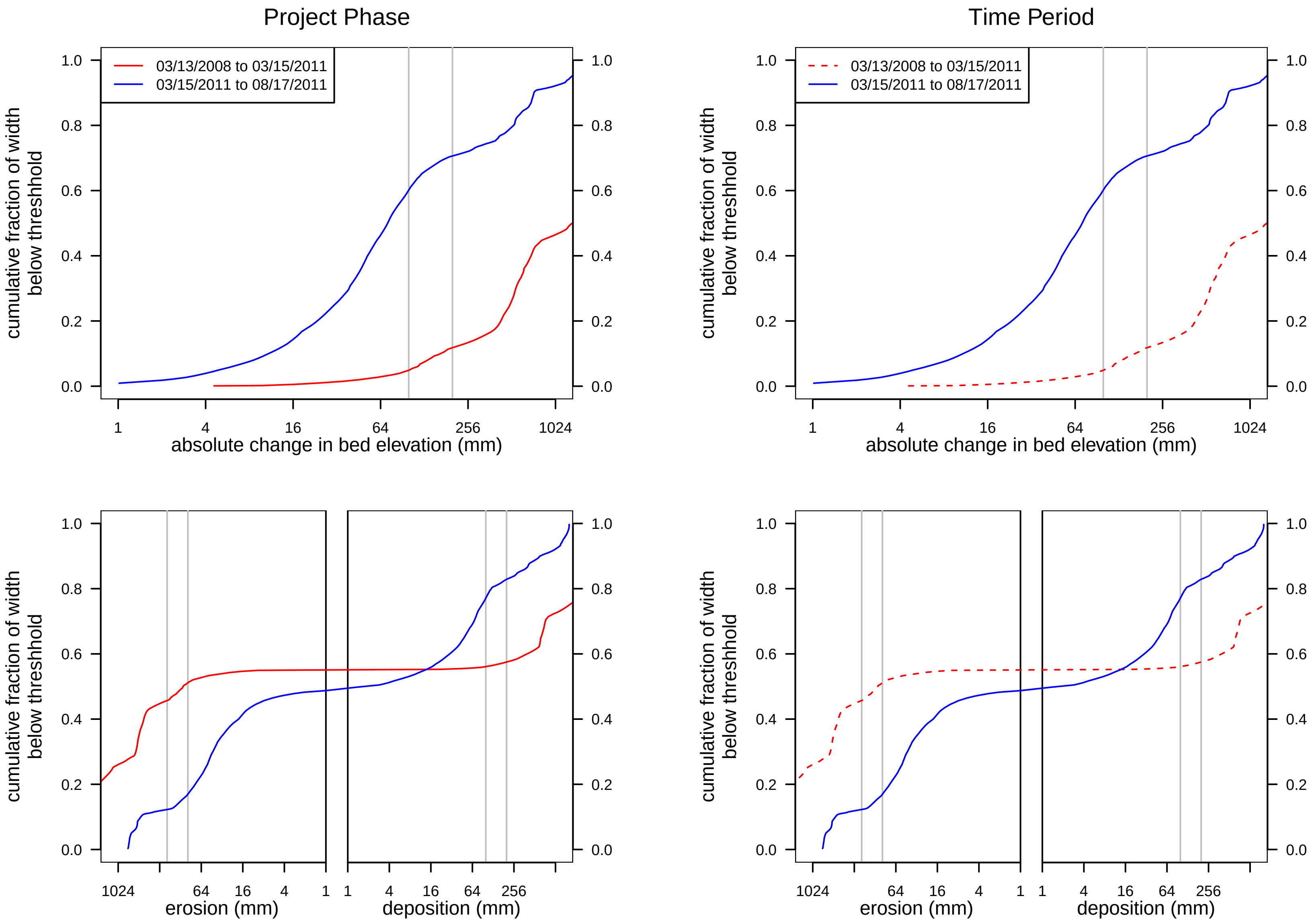
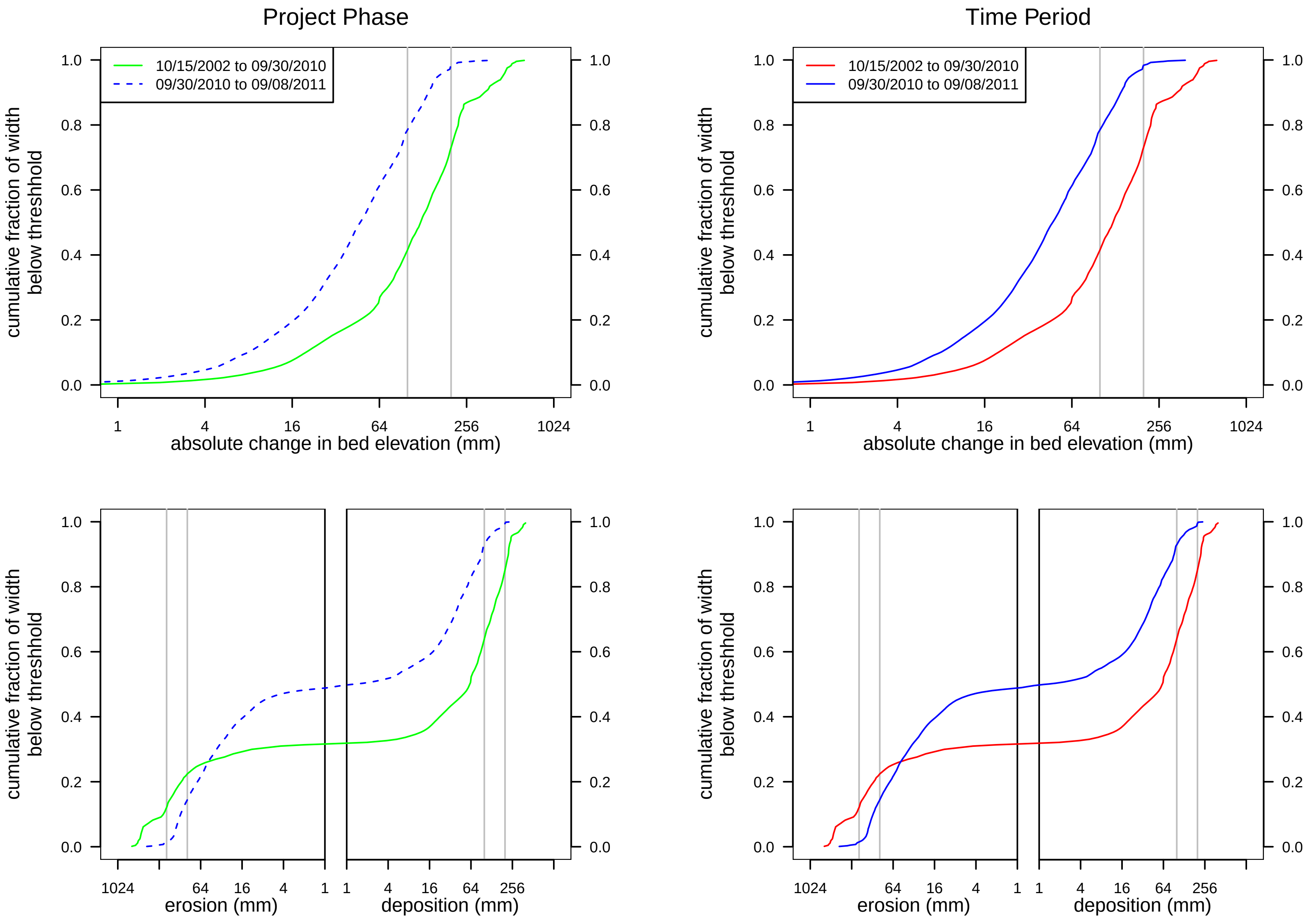


Indian Creek
Cross section Station ID 51 (1247+60), KM 154.30



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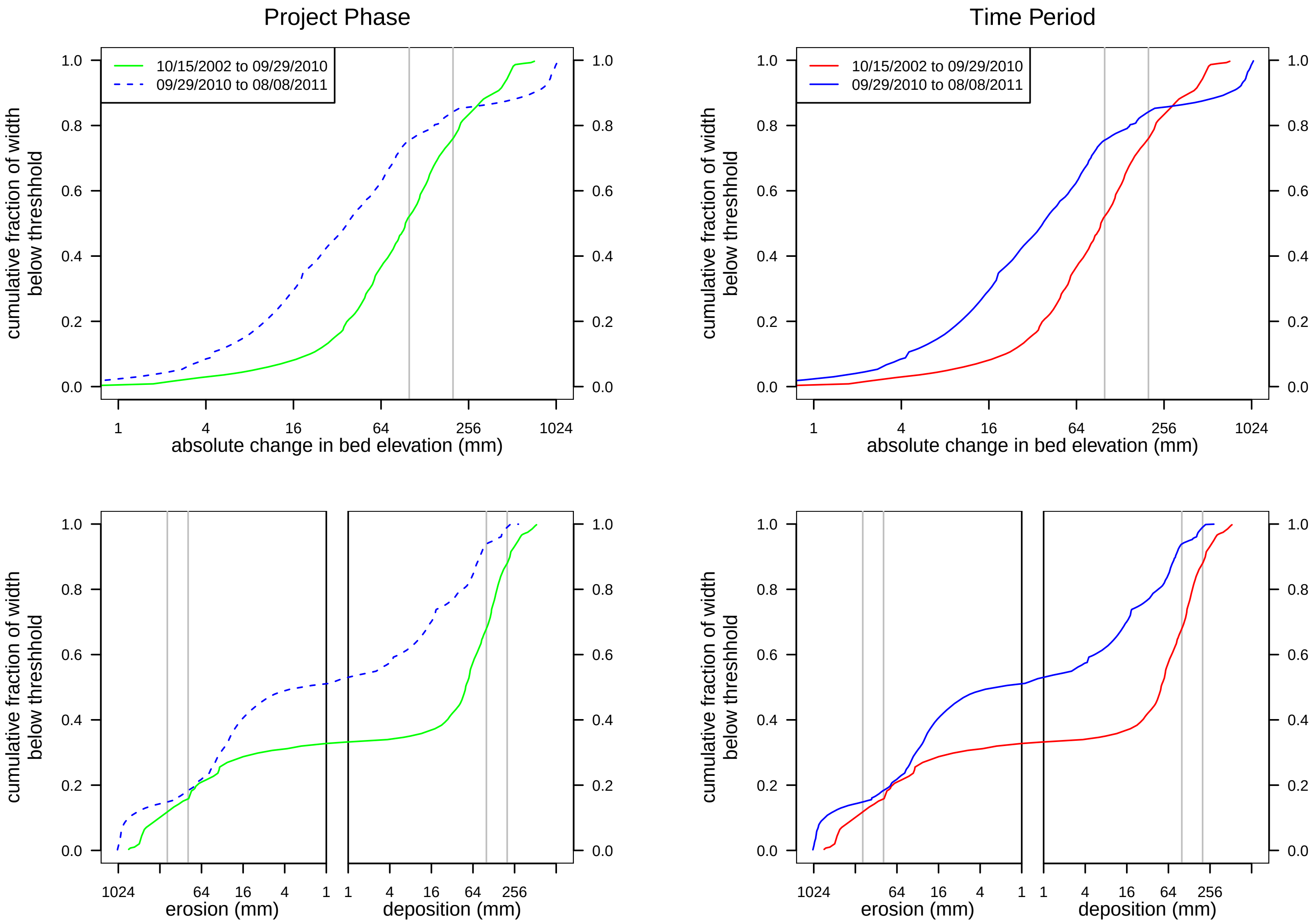

Indian Creek
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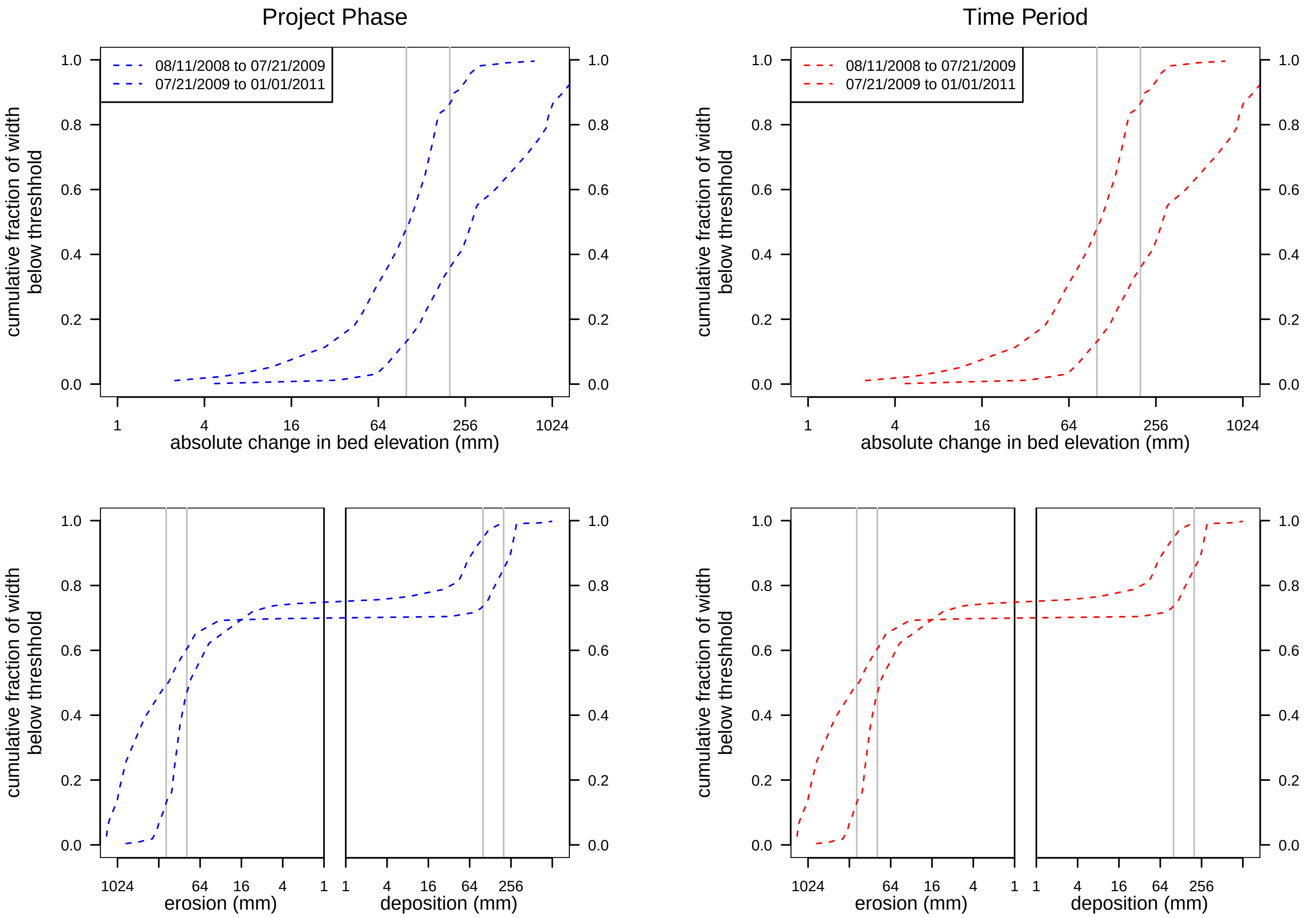

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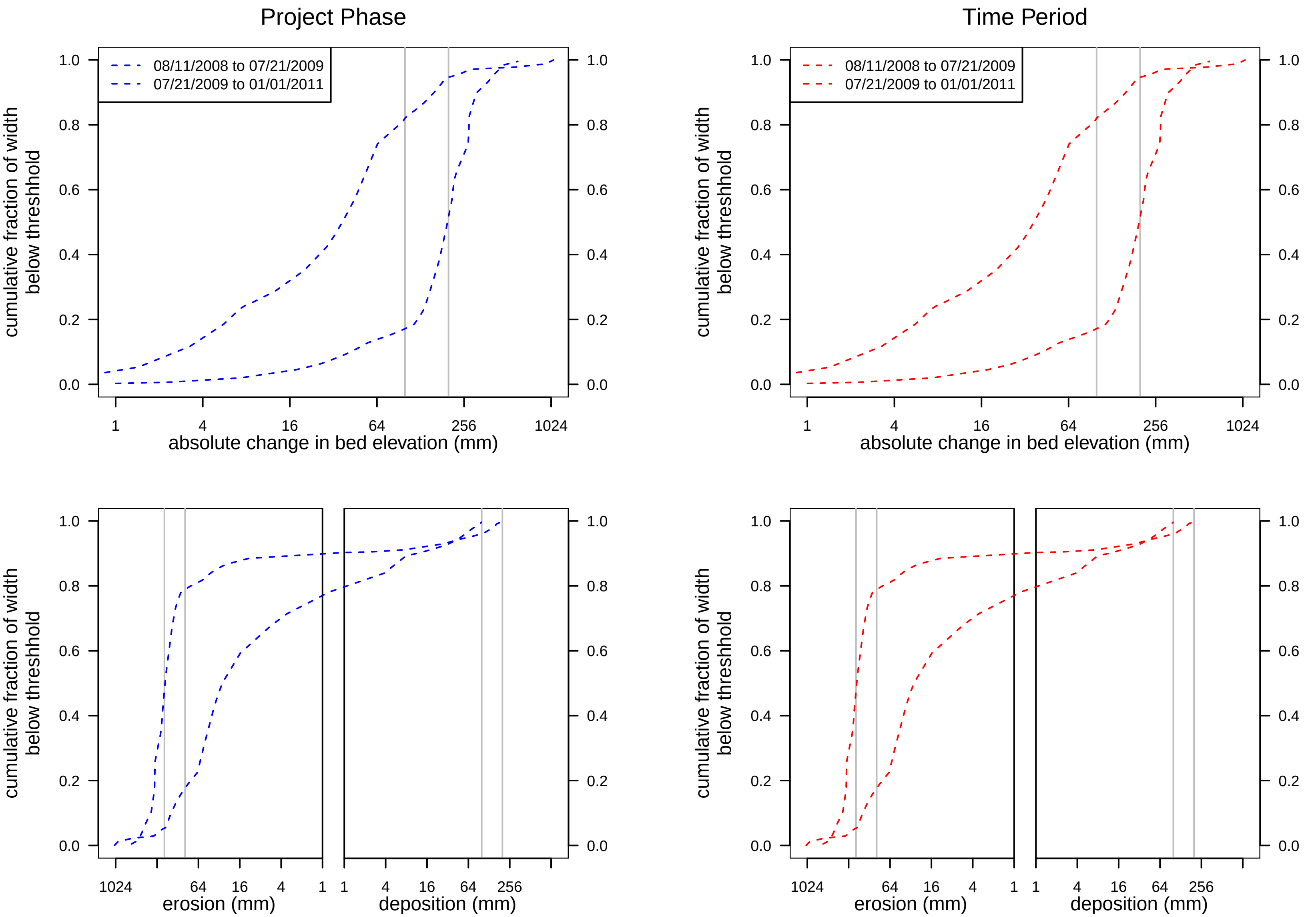
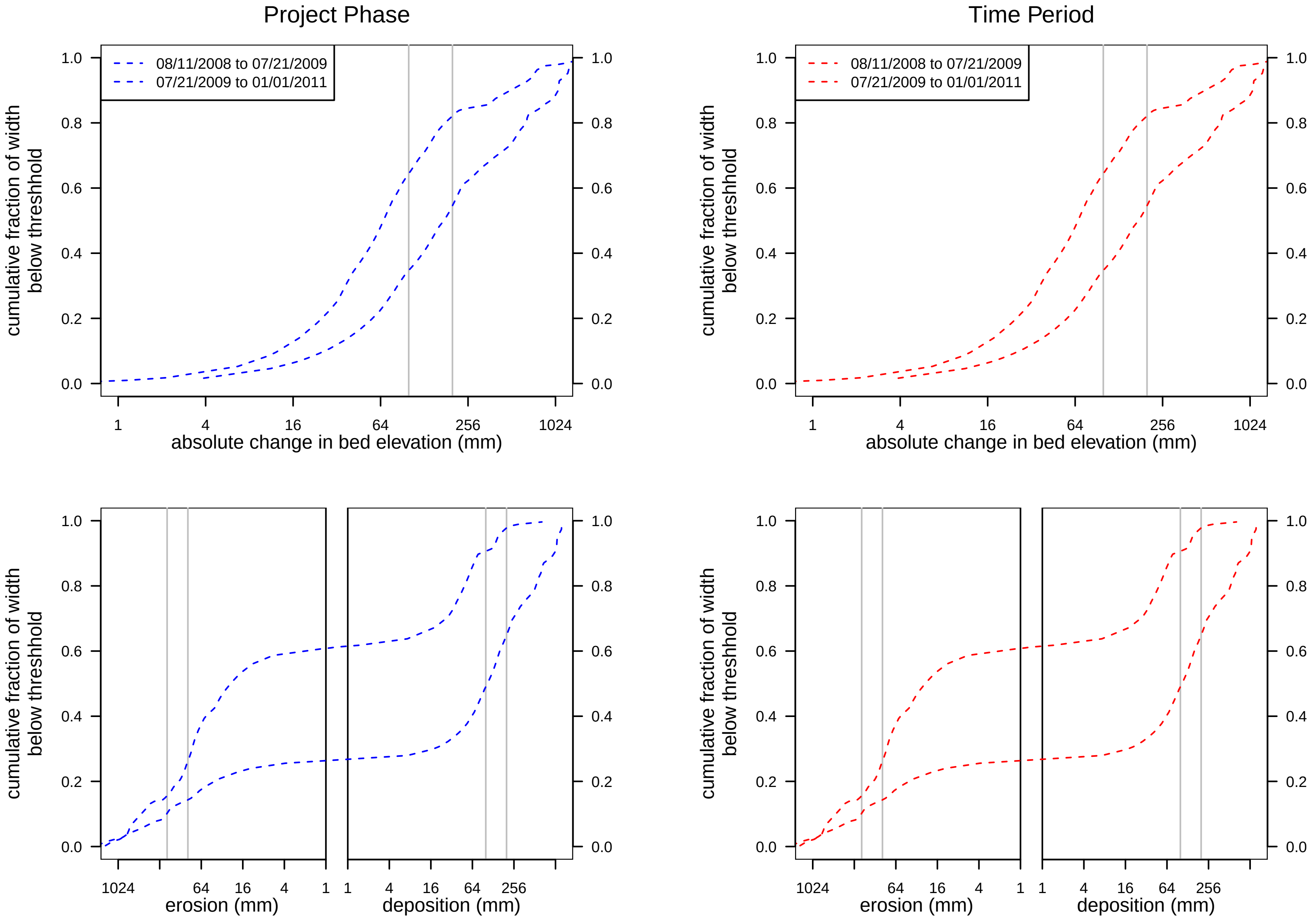


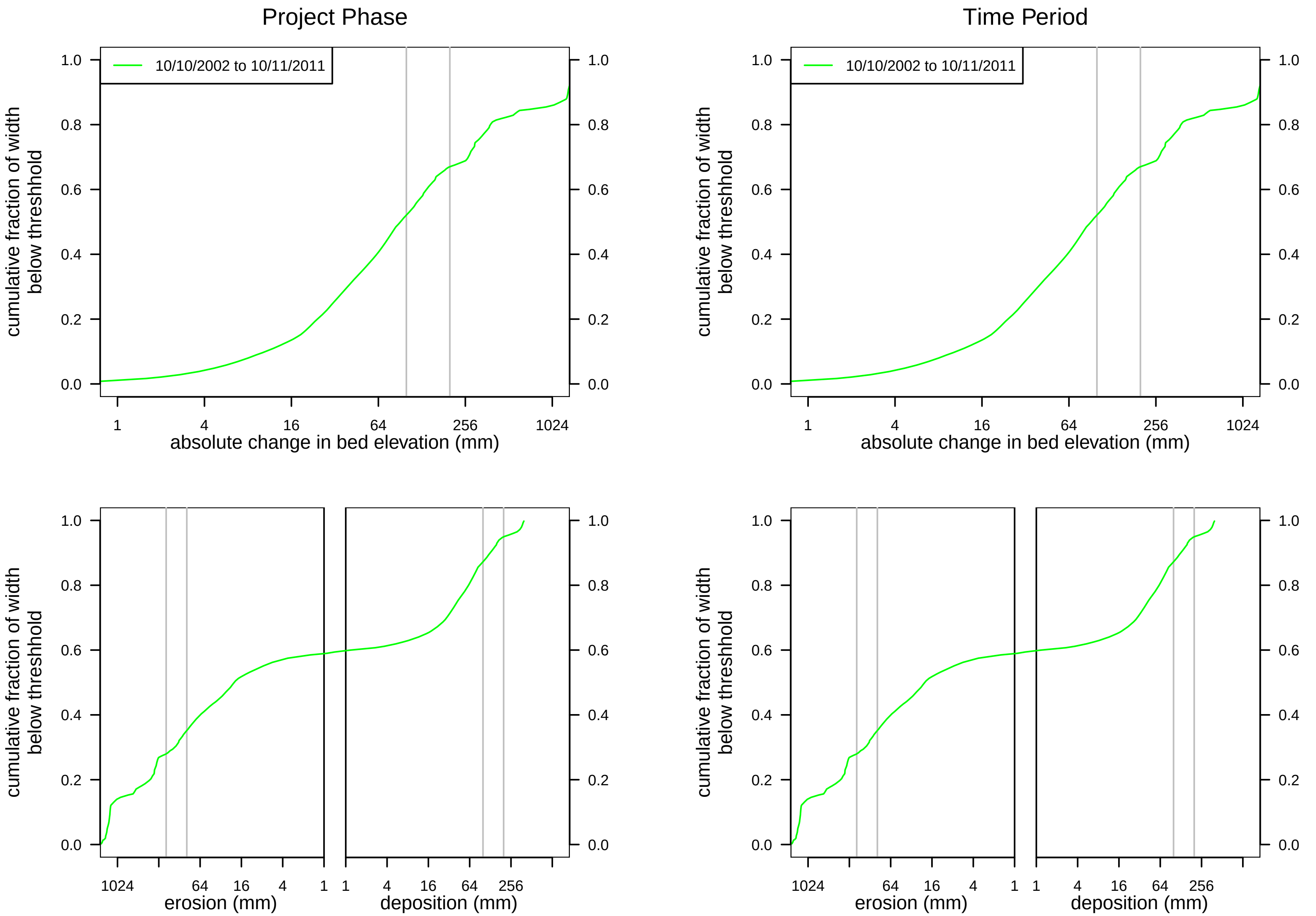
Project Phase

Time Period

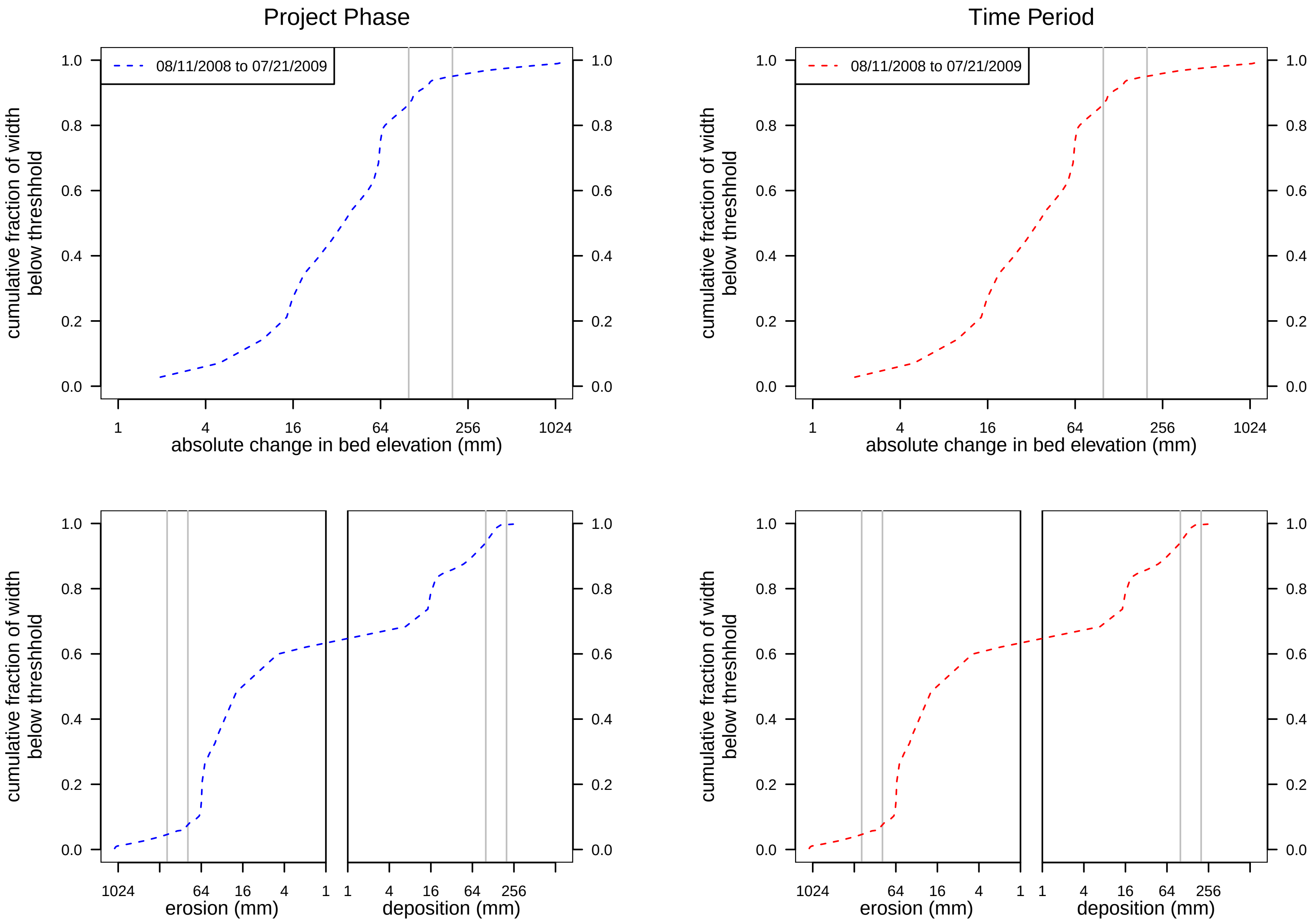
Indian Creek
Cross section Station ID 374 (R3XS3), KM 153.60



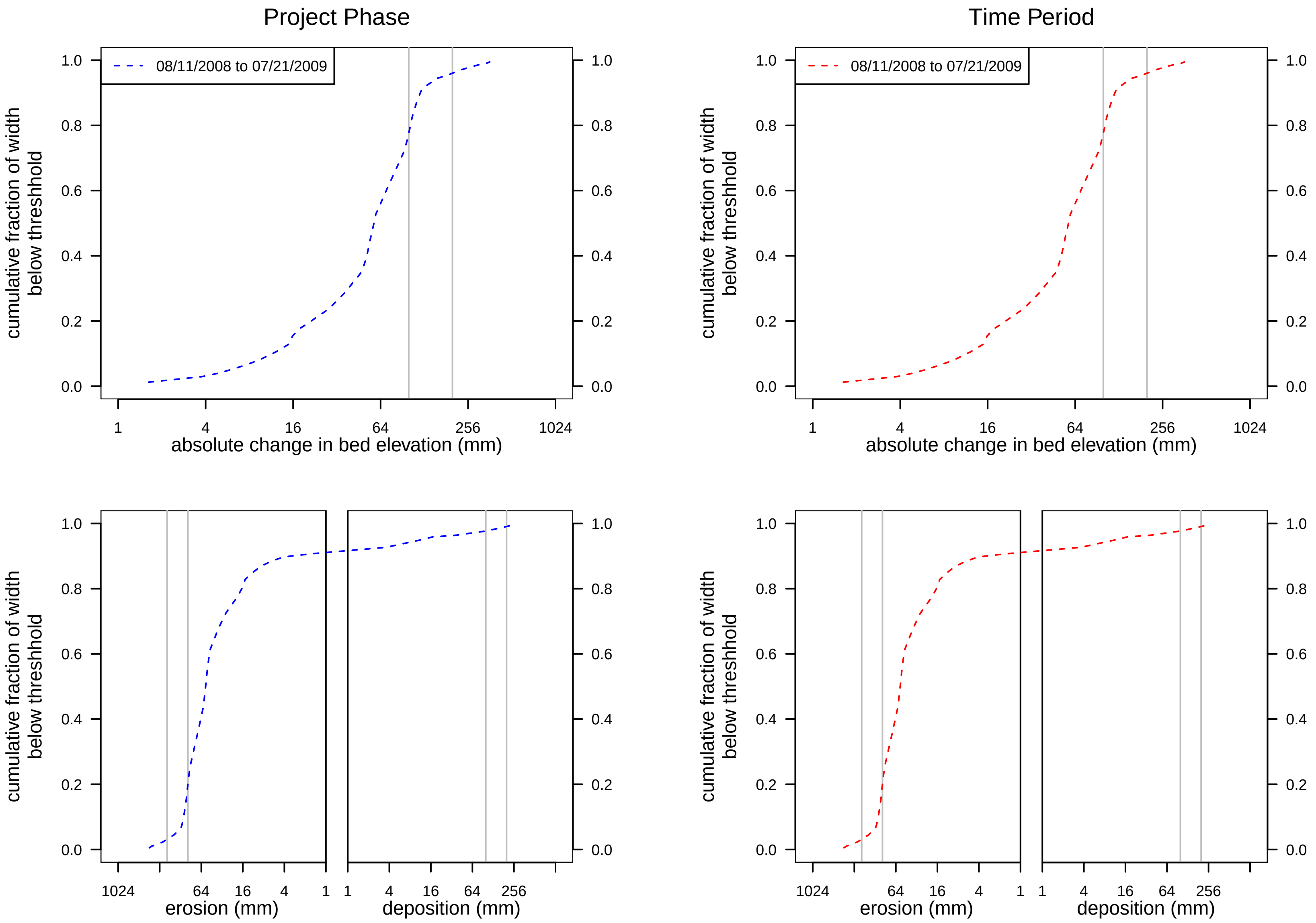
Indian Creek
Cross section Station ID 44 (1220+50), KM 153.47



Indian Creek
Cross section Station ID 377 (RmidXS3), KM 153.04



Indian Creek
Cross section Station ID 378 (RmidXS4), KM 152.47



Indian Creek
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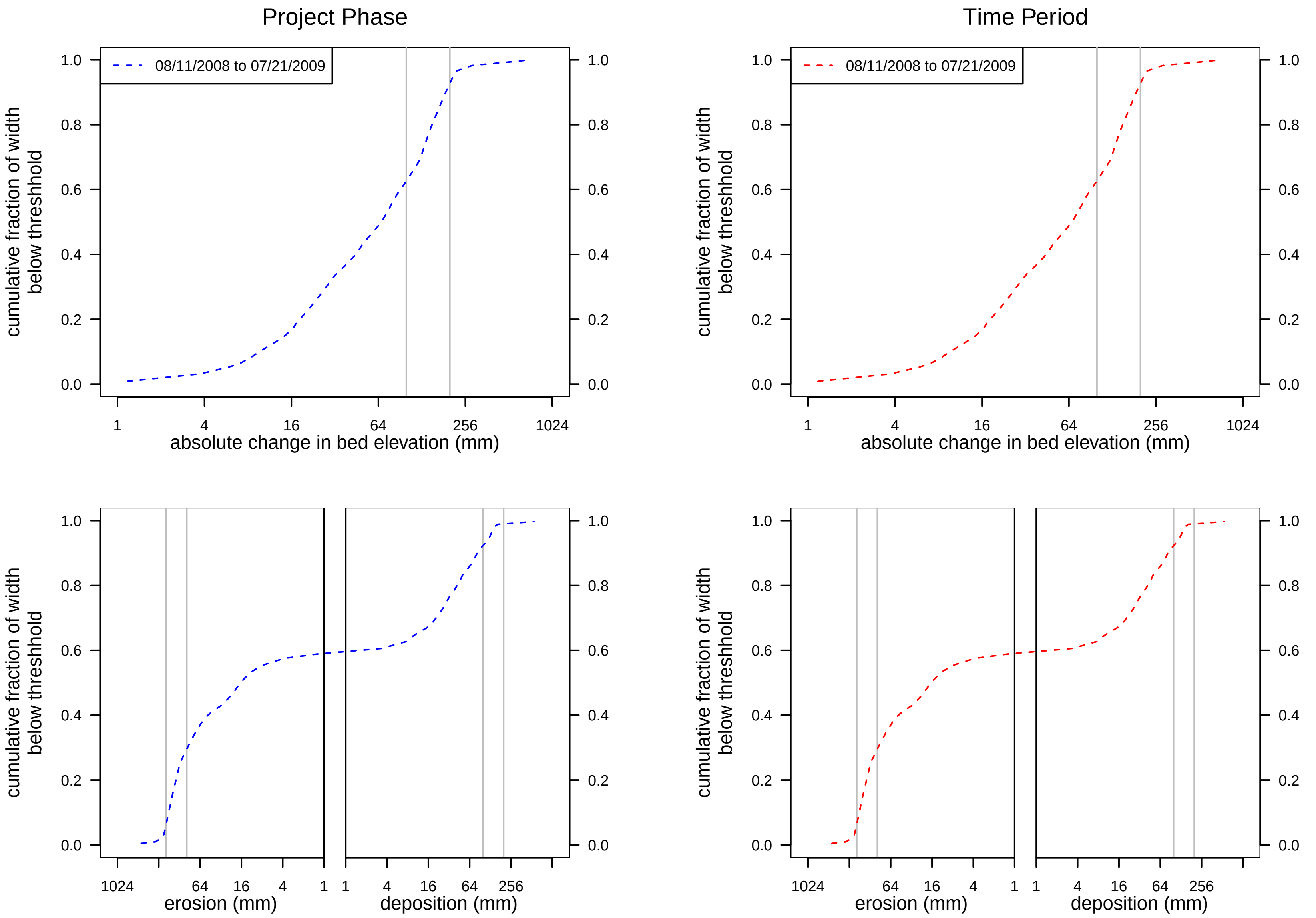
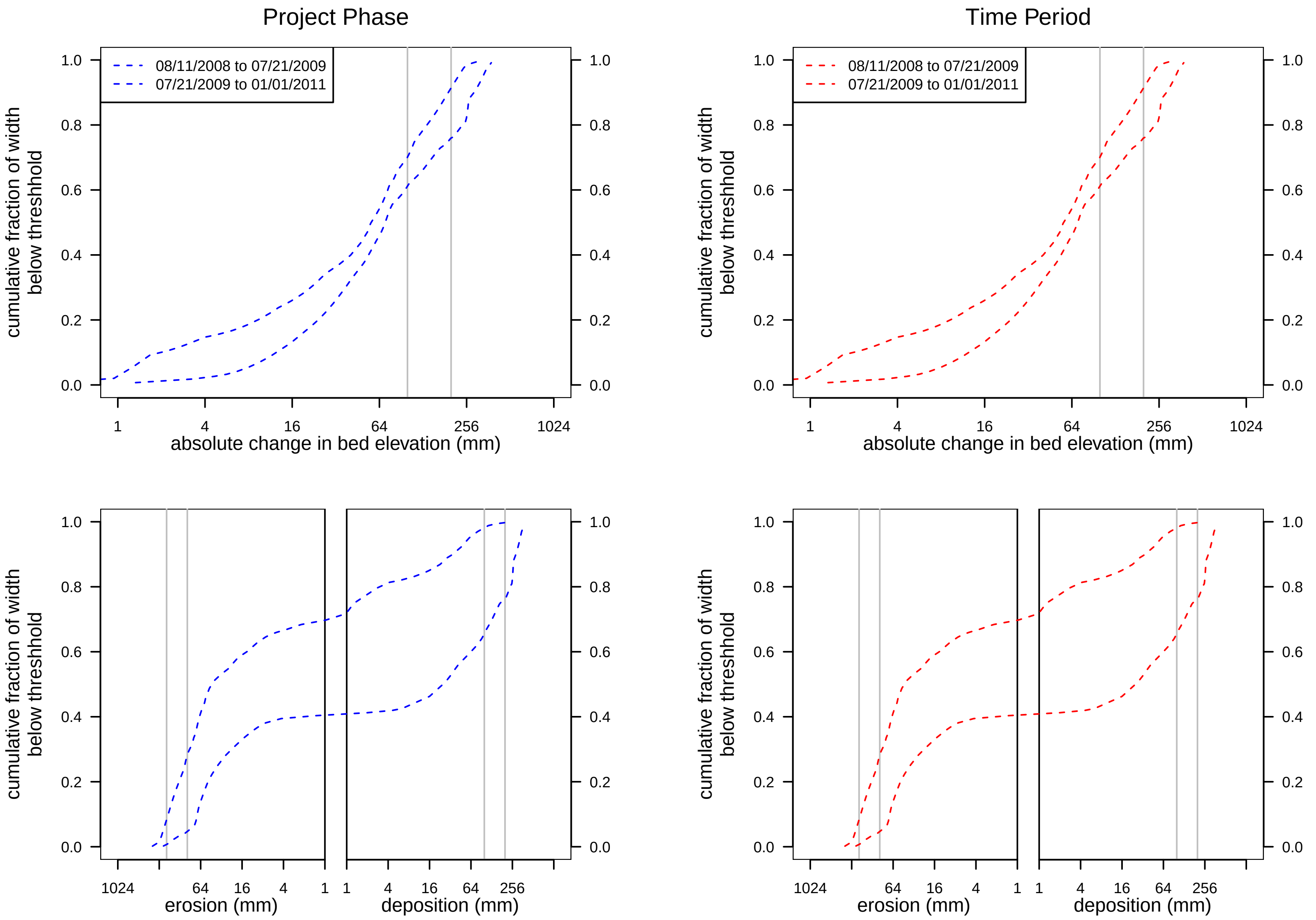


Indian Creek
Cross section Station ID 380 (R8XS2), KM 152.10



Indian Creek
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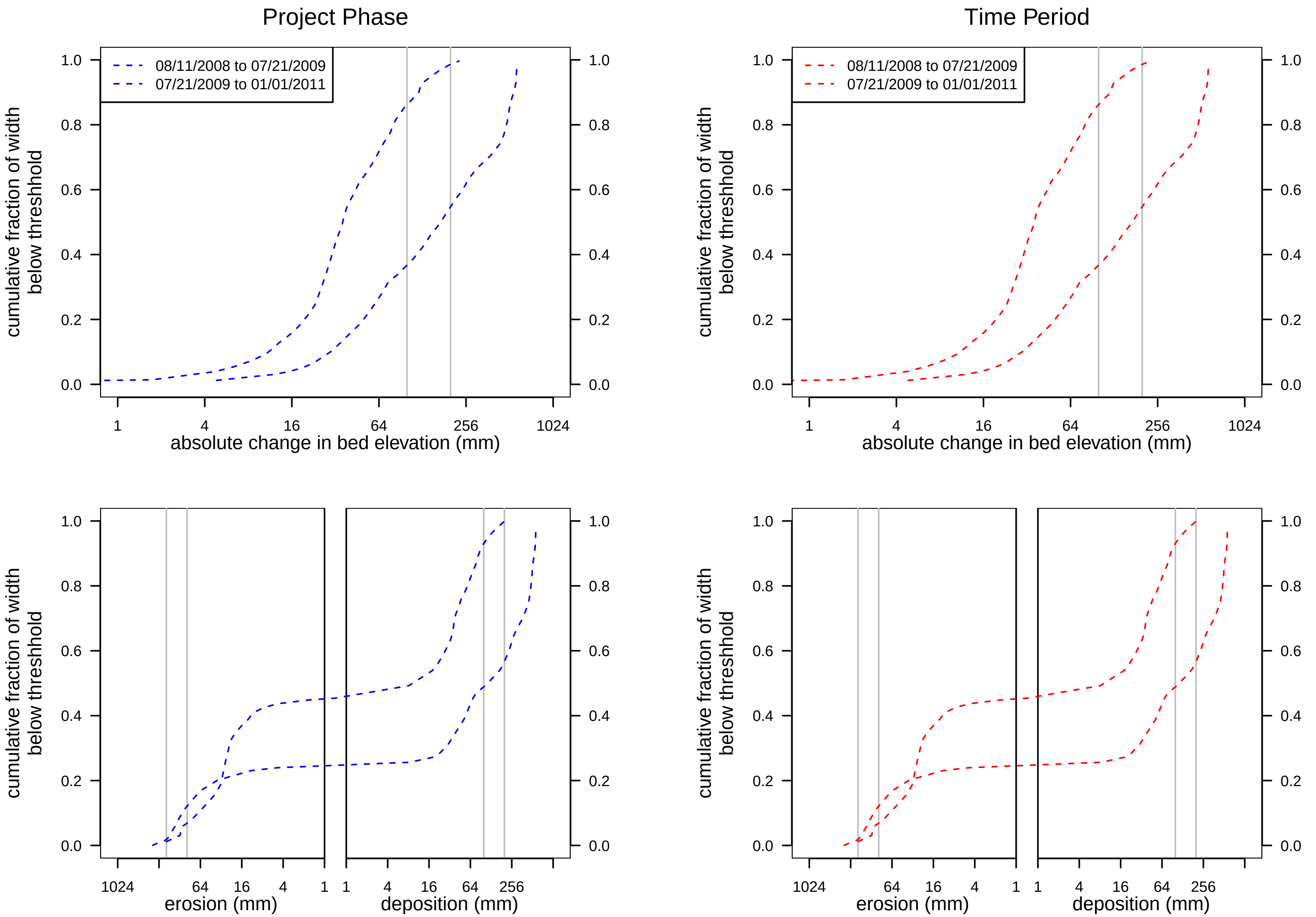

Indian Creek
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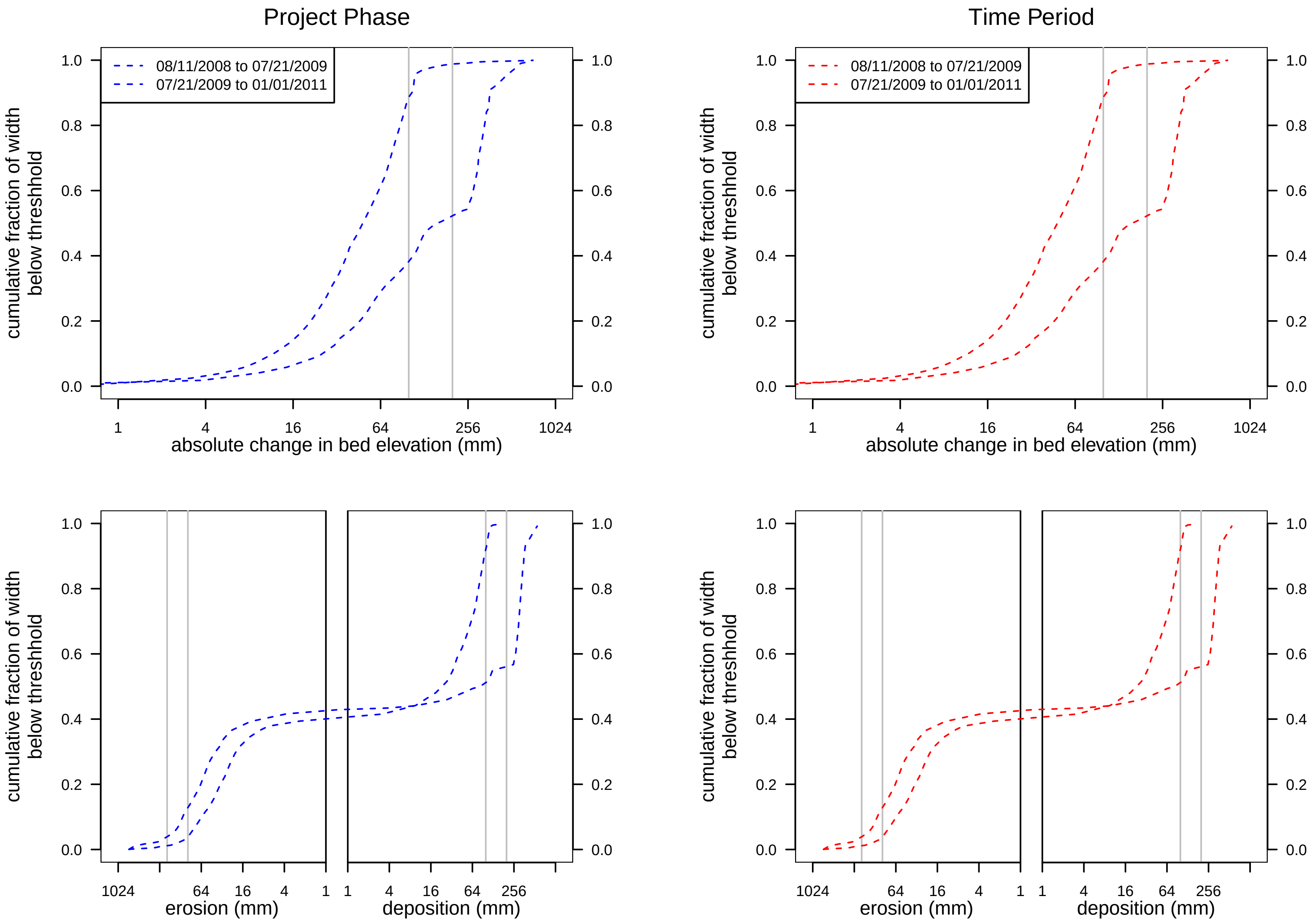

Indian Creek
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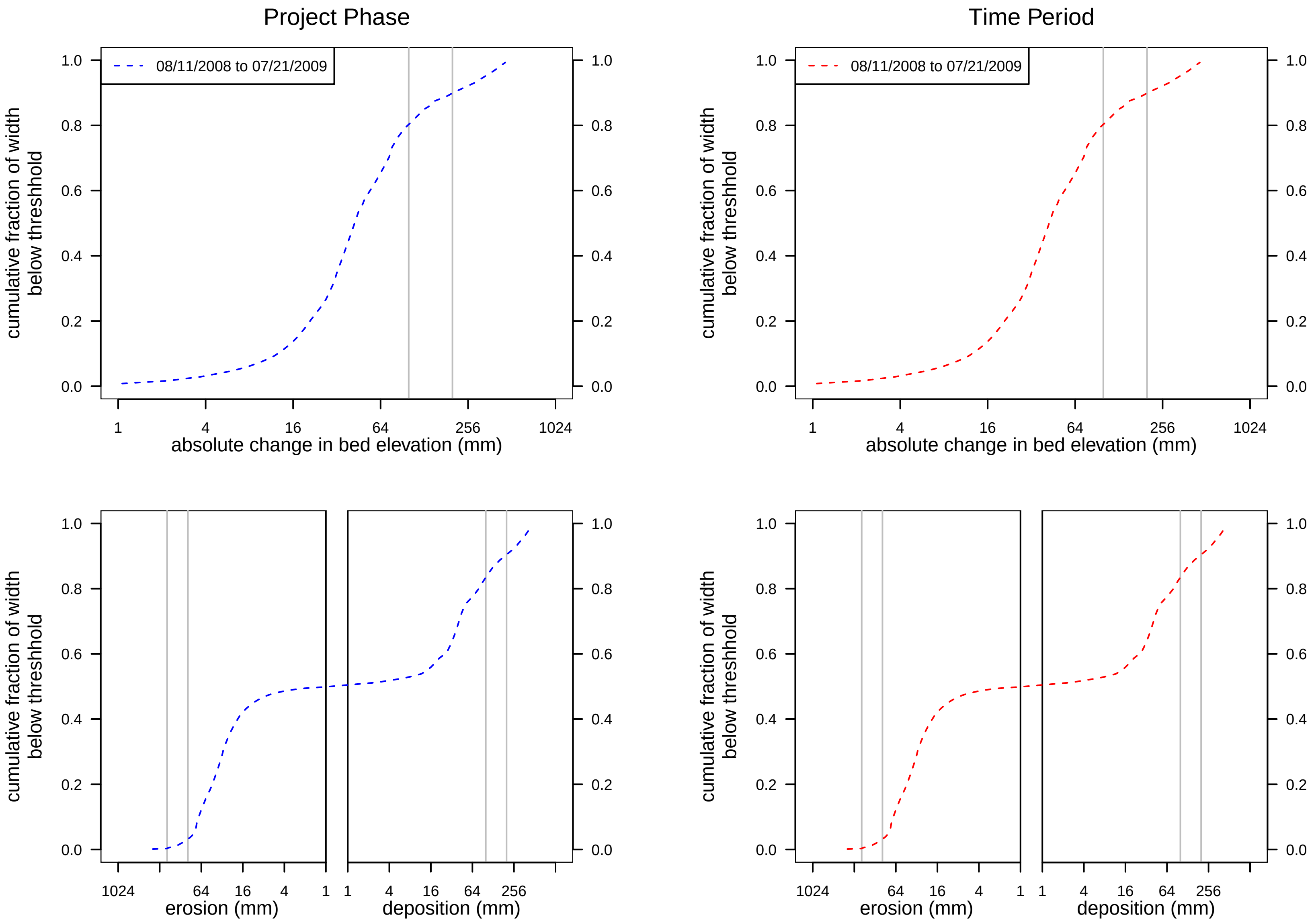

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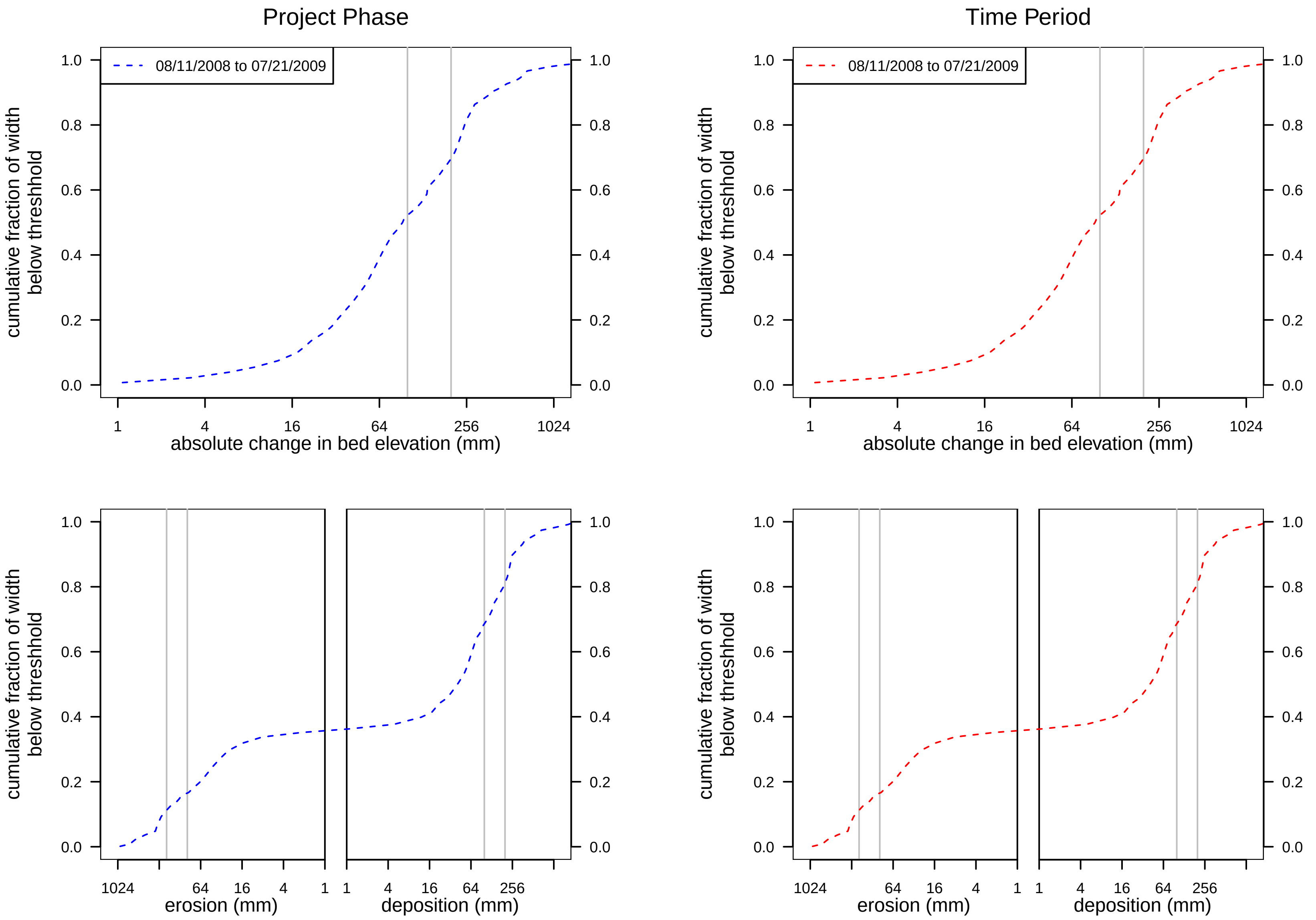

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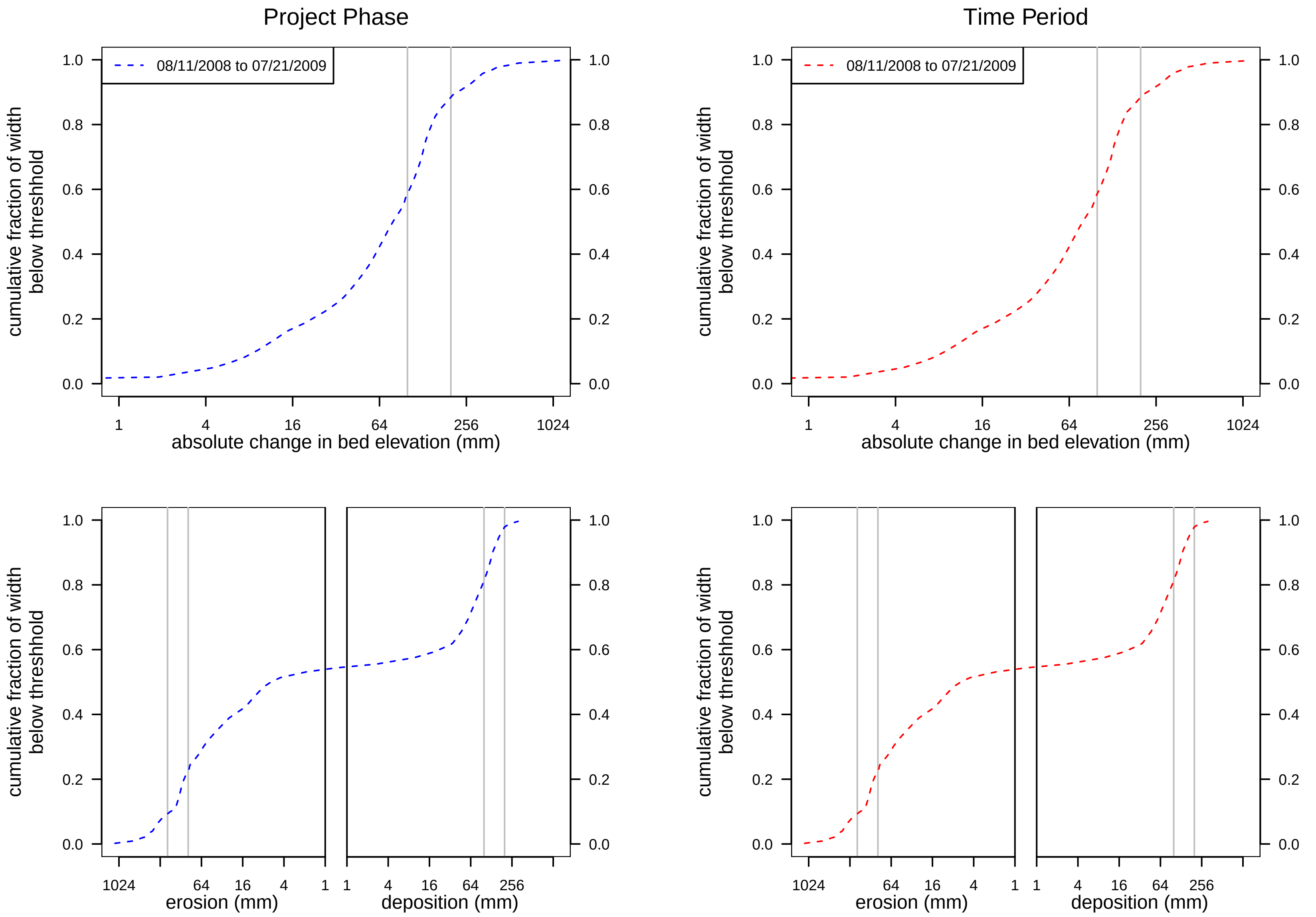
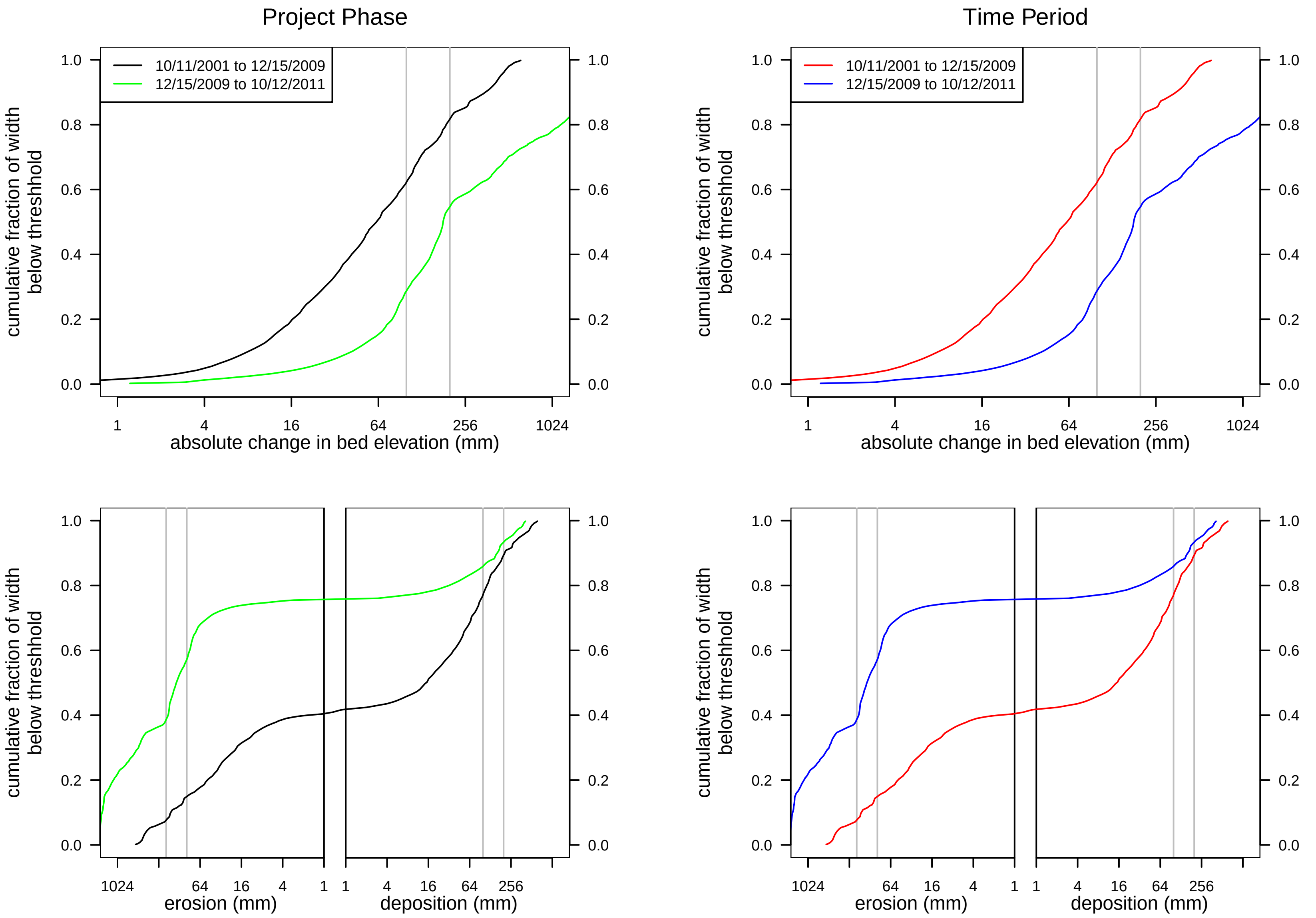


Reading Creek
Cross section Station ID 90 (1096+85), KM 149.71



Reading Creek
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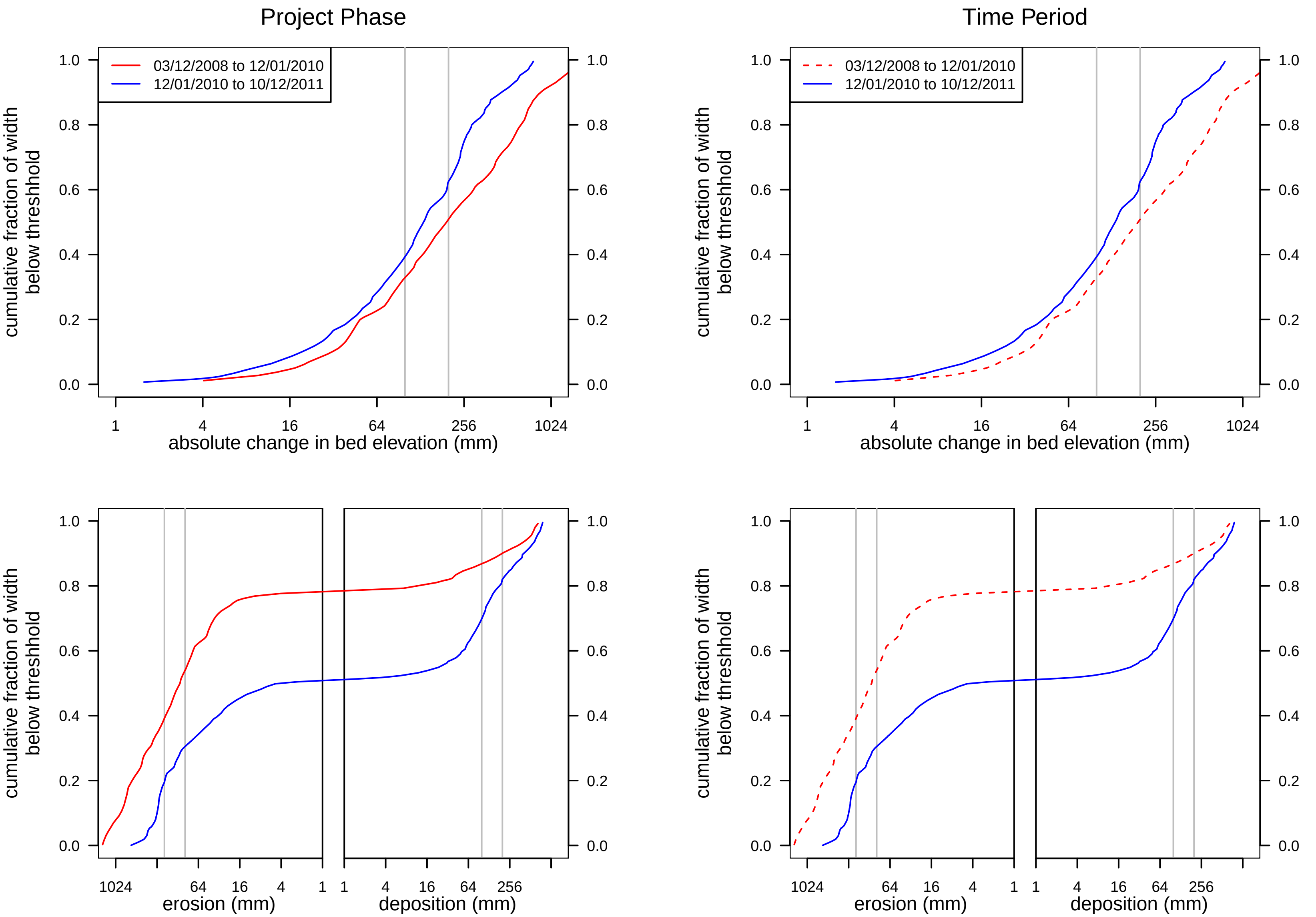

Reading Creek
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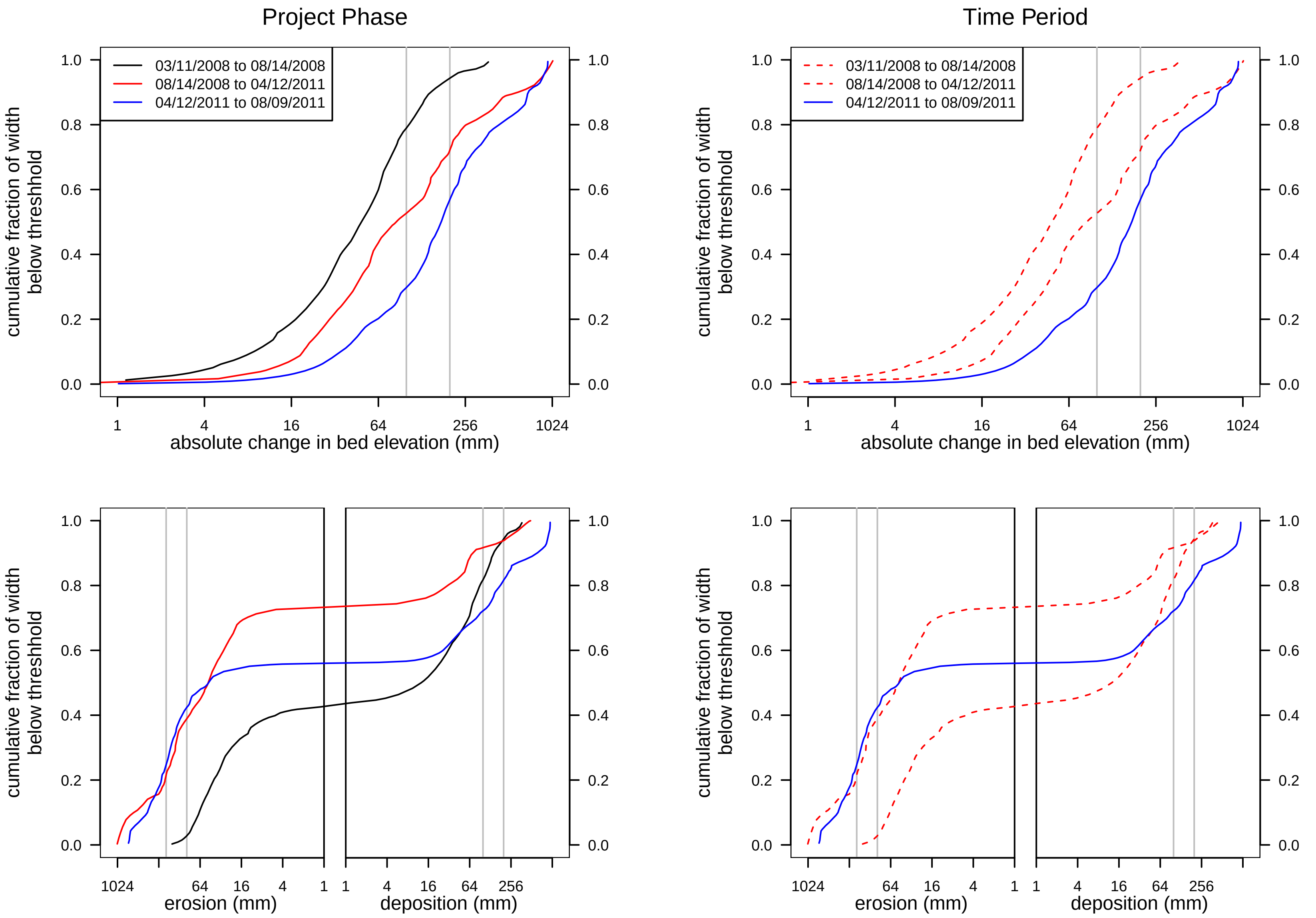
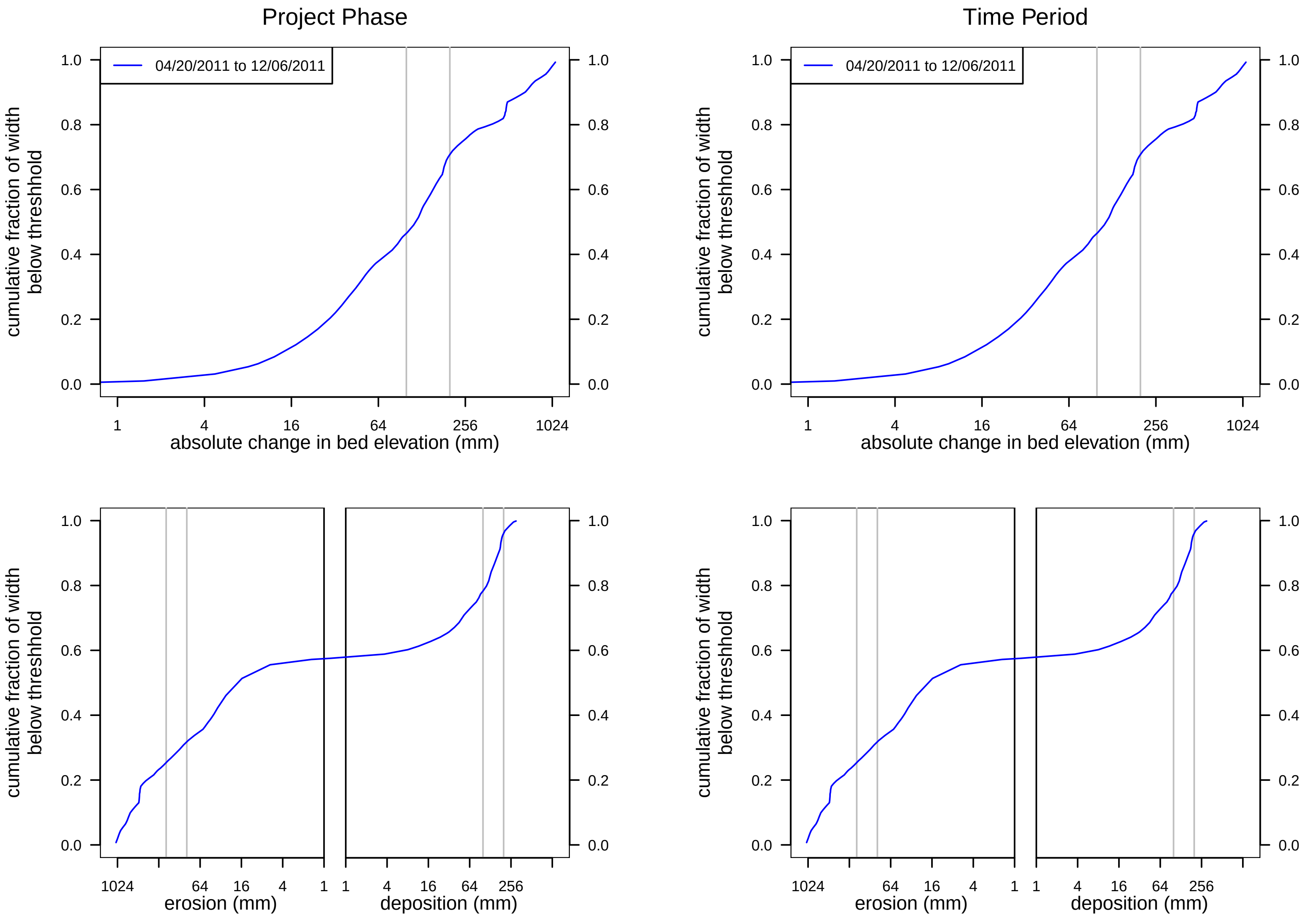


Douglas City Sediment Transport Monitoring Site
Cross section Station ID 457 (SedMon2011), KM 149.20



Douglas City Sediment Transport Monitoring Site
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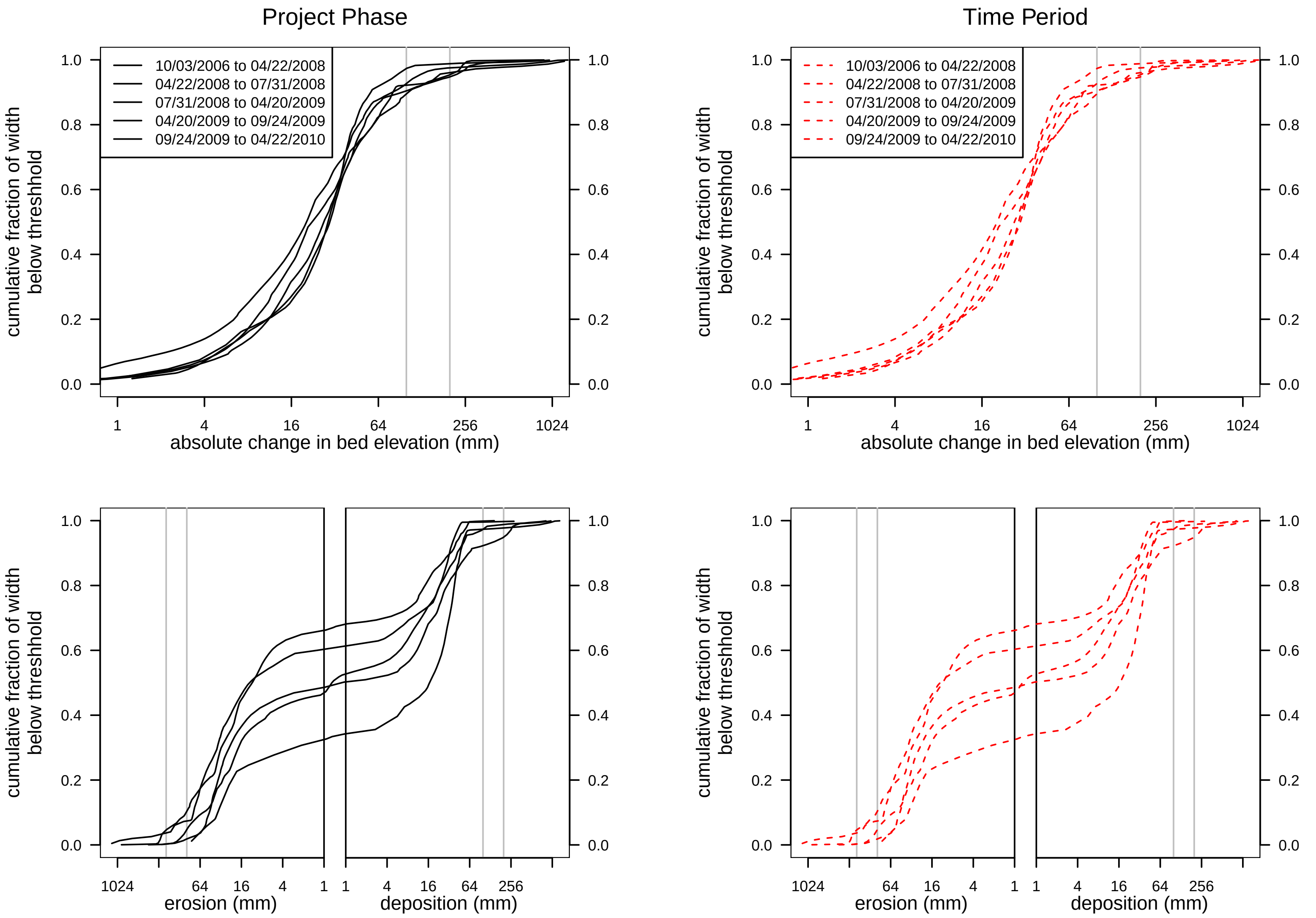

Hocker Flat
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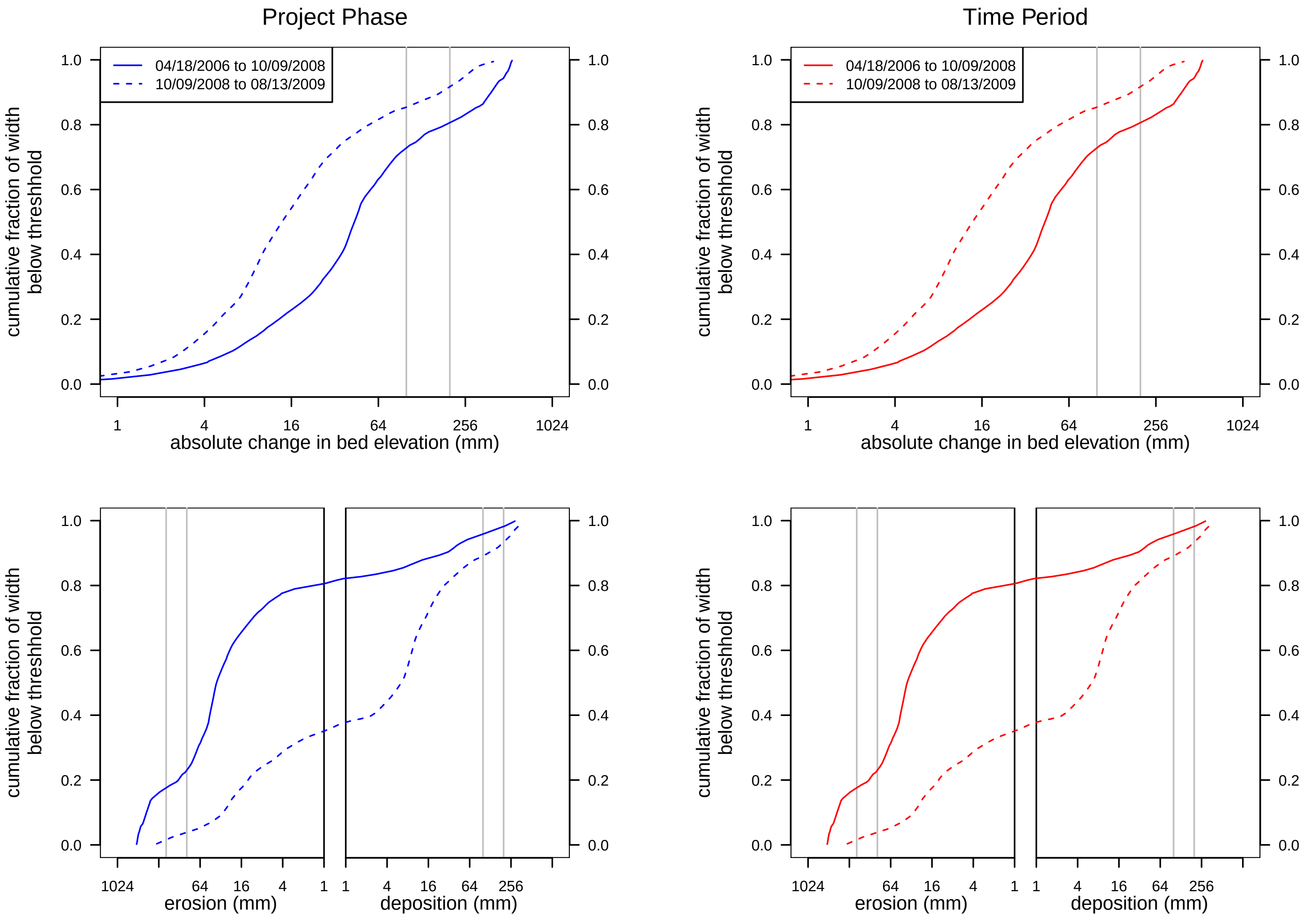

Hocker Flat
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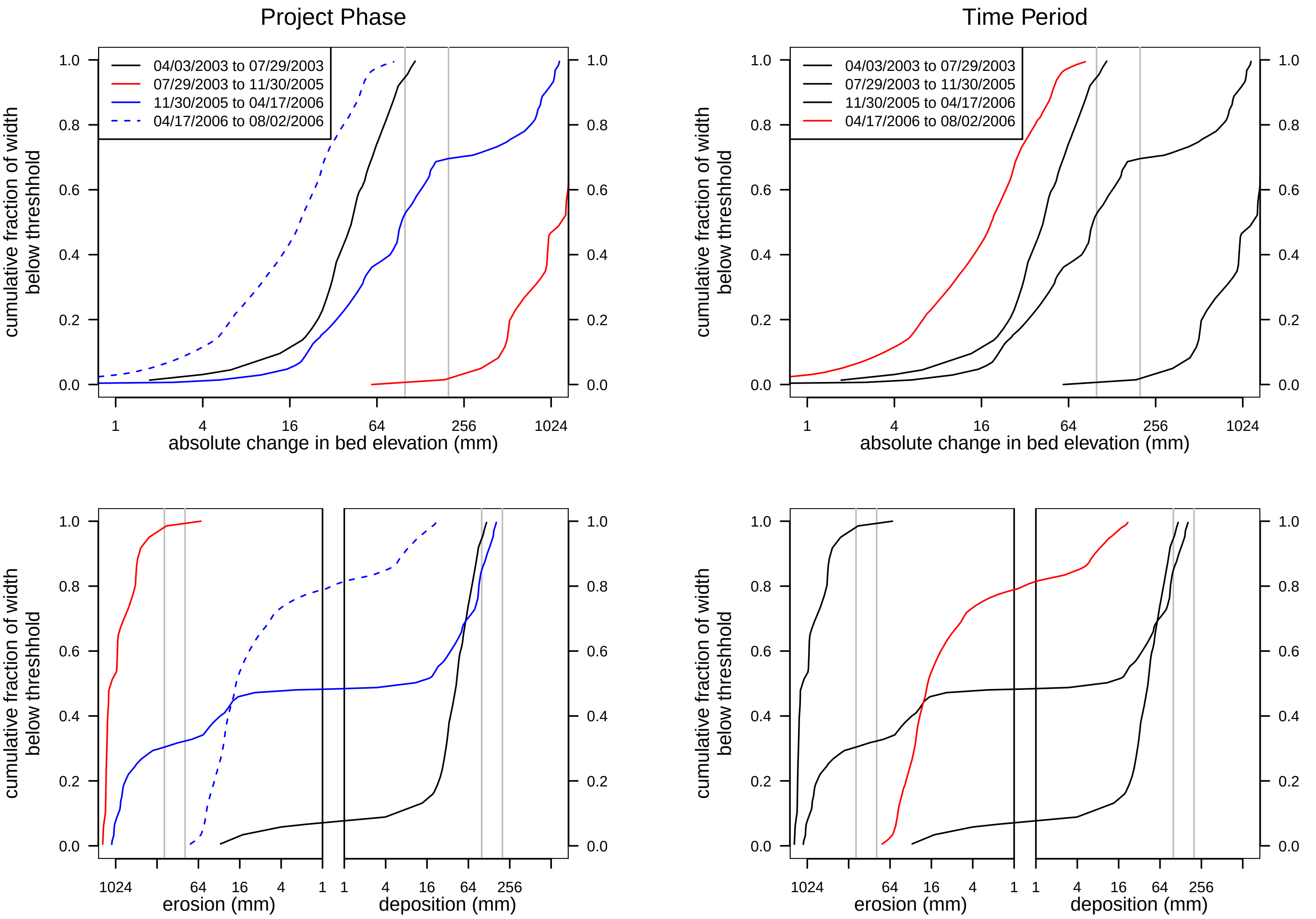

Hocker Flat
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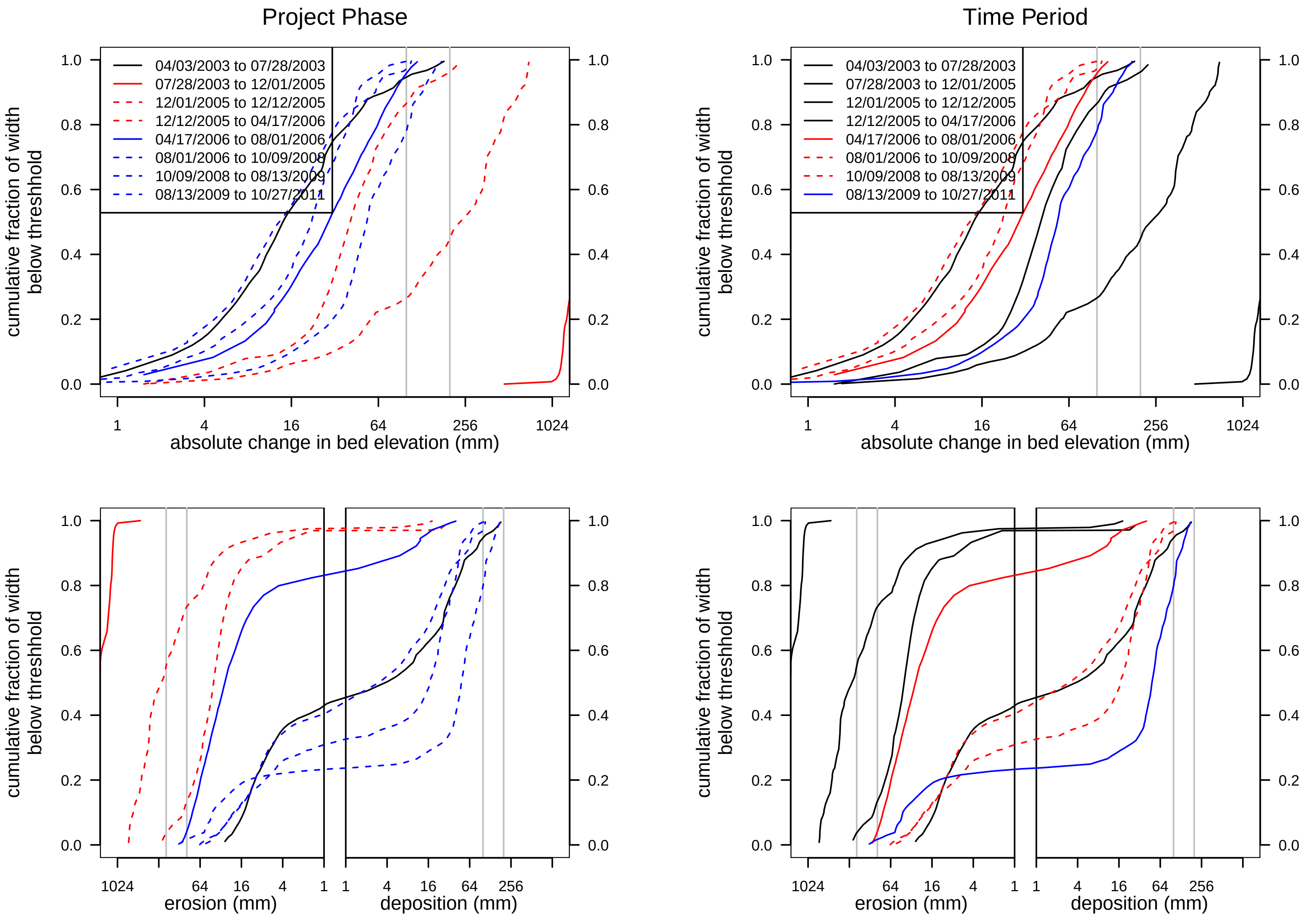

Hocker Flat
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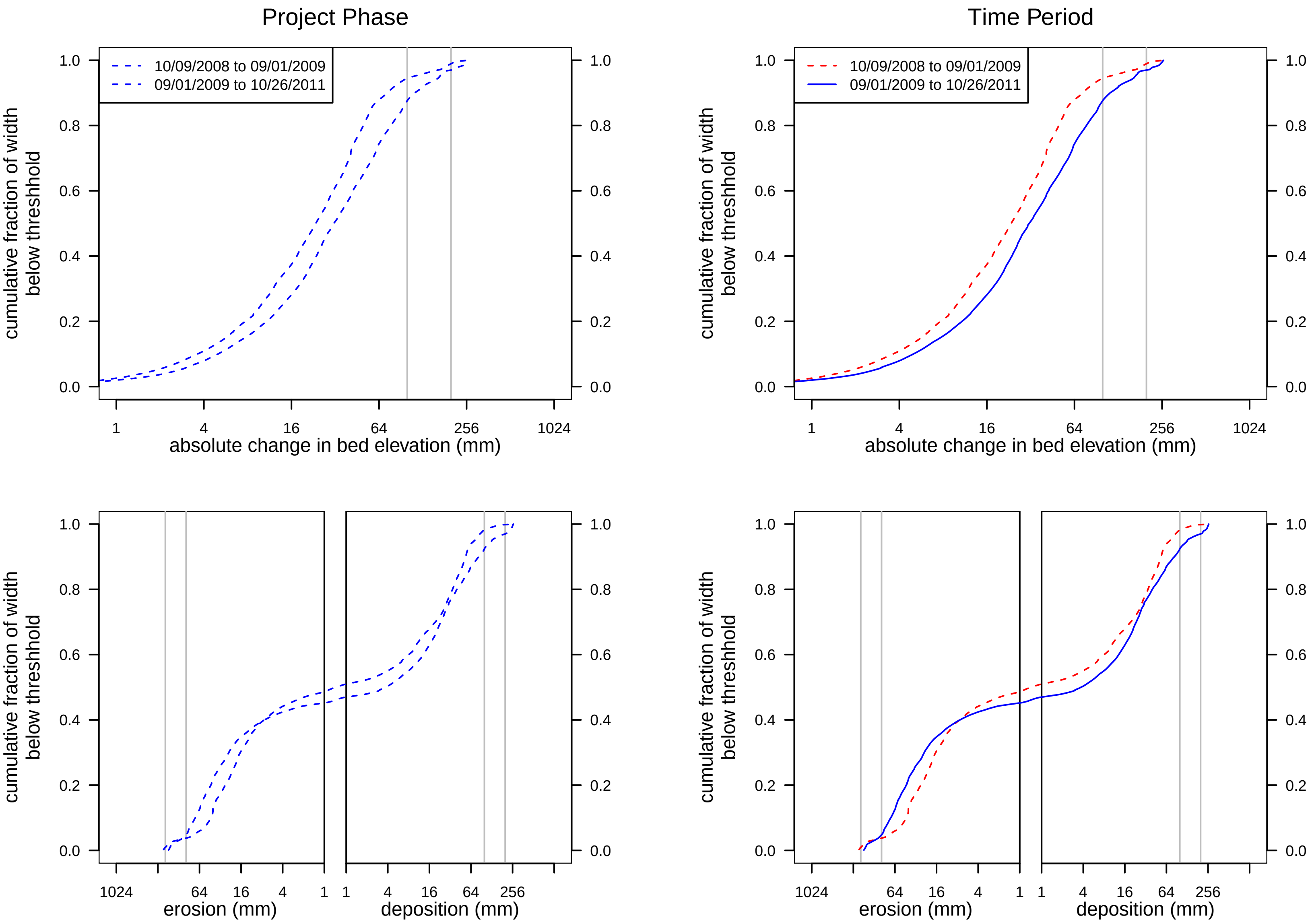

Hocker Flat
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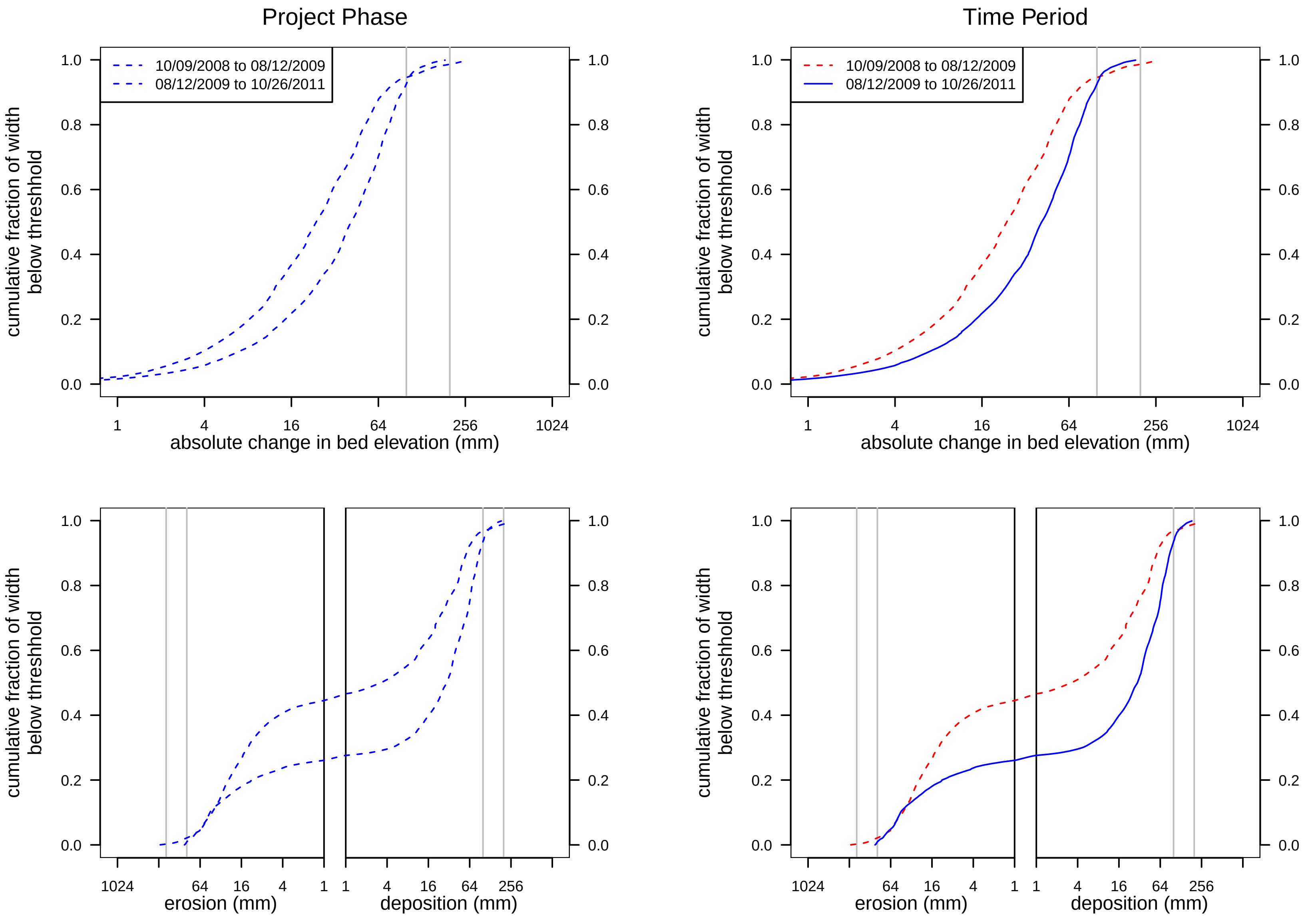

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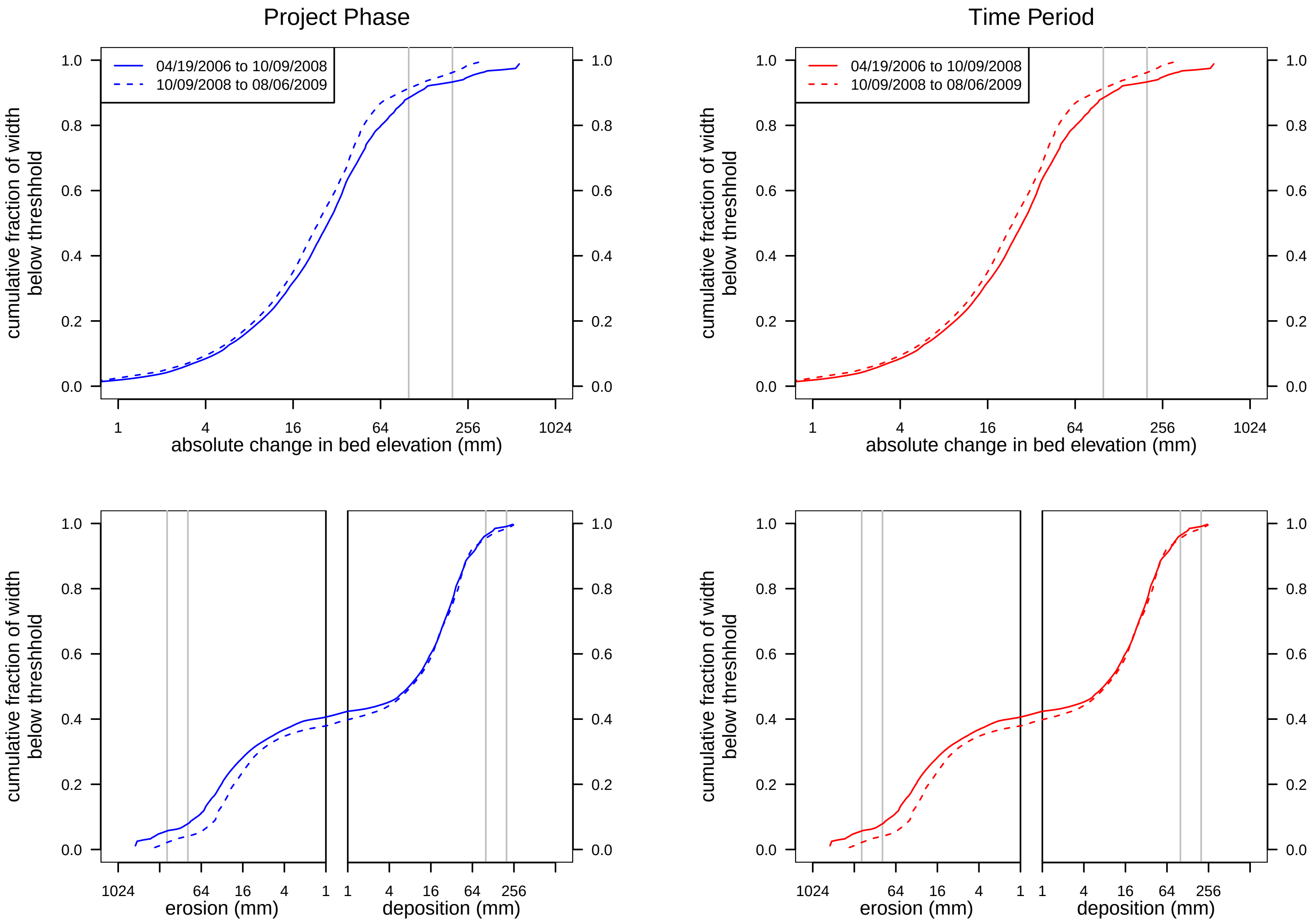
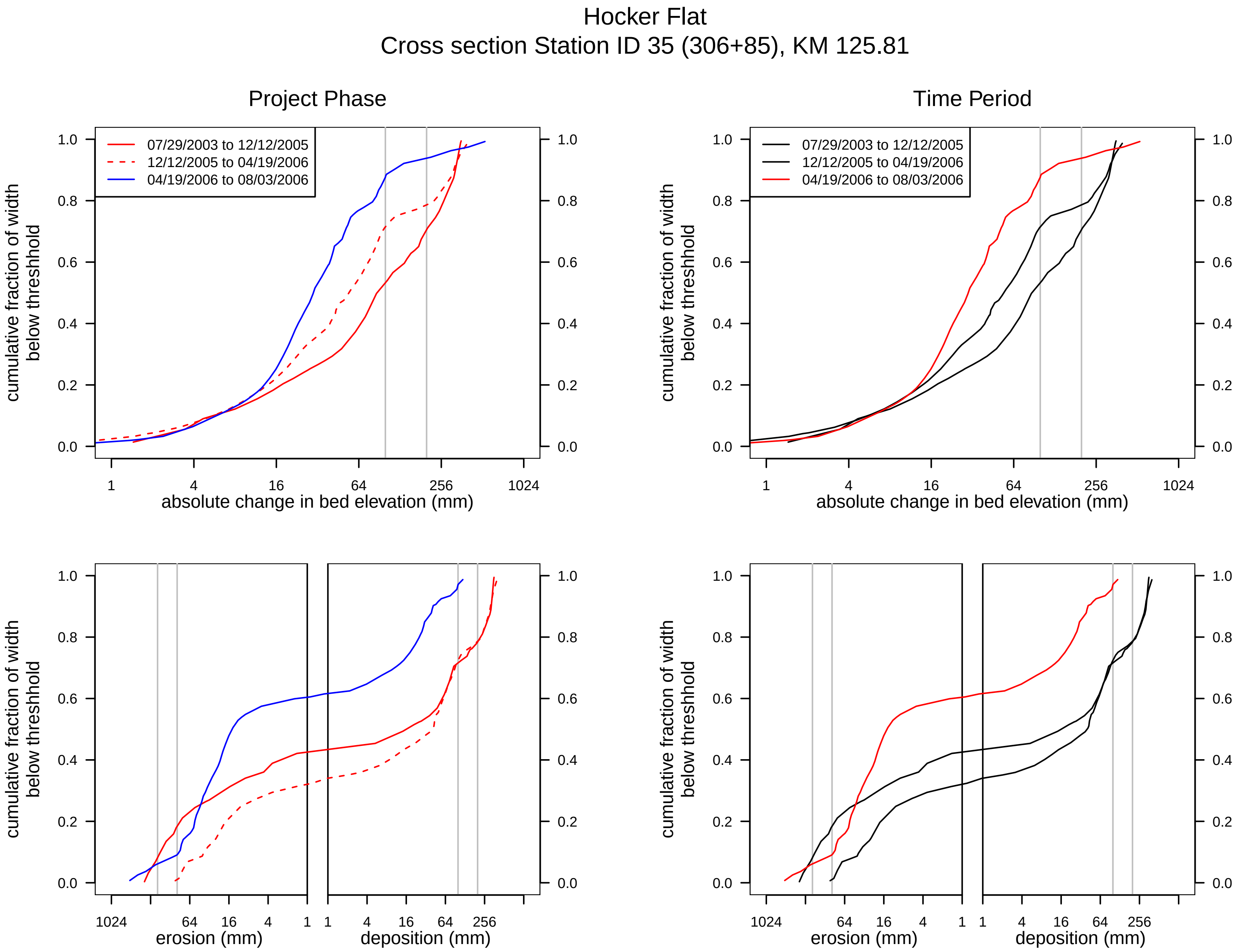
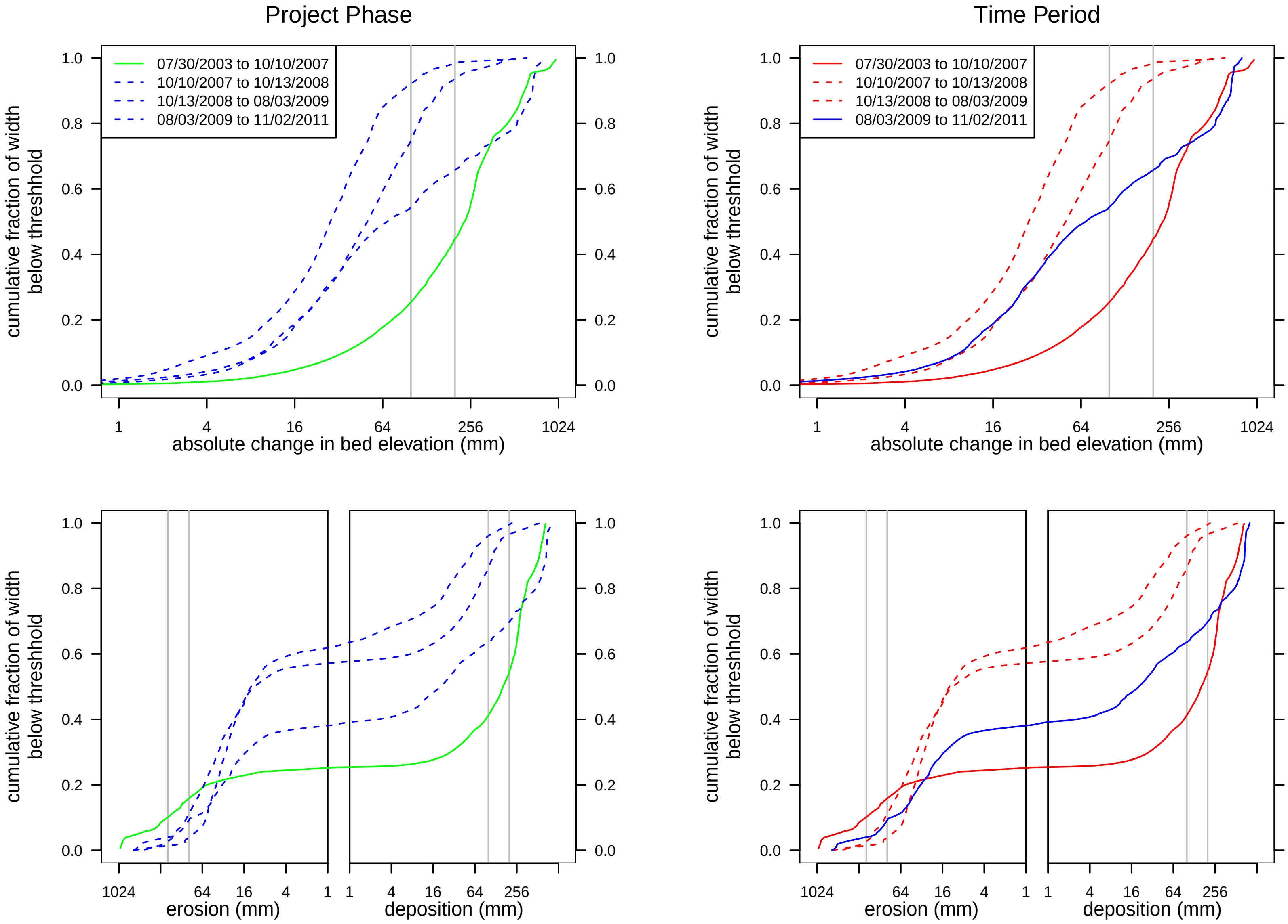



Hocker Flat
Cross section Station ID 35 (306+85), KM 125.81
Project Phase
Time Period
07/29/2003 to 12/12/2005
12/12/2005 to 04/19/2006
04/19/2006 to 08/03/2006
cumulative fraction of width below threshold
absolute change in bed elevation (mm)
1
4
16
64
256
1024
0.0
0.2
0.4
0.6
0.8
1.0
erosion (mm)
deposition (mm)

Conner Creek
Cross section Station ID 209 (260+05), KM 124.42



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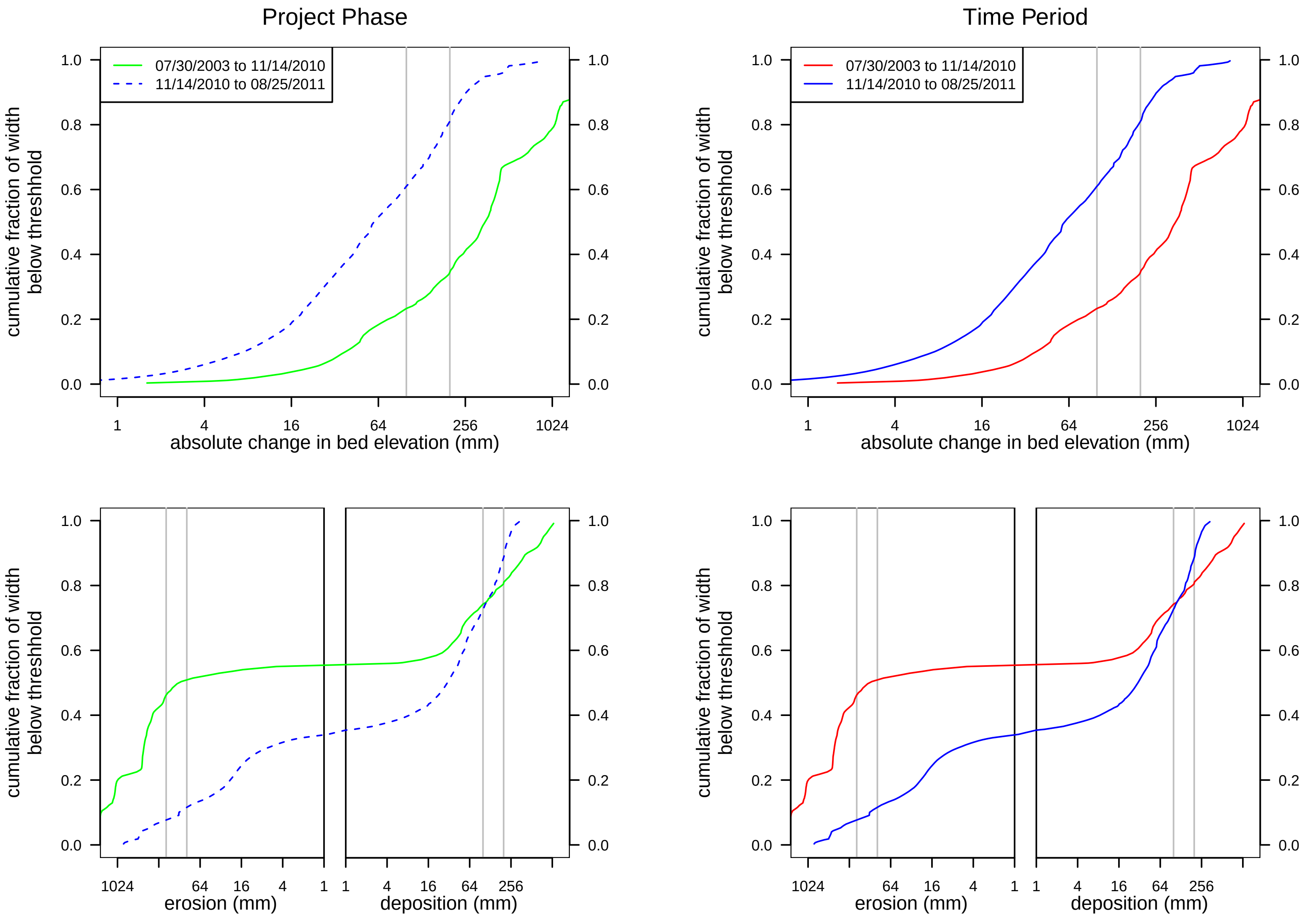

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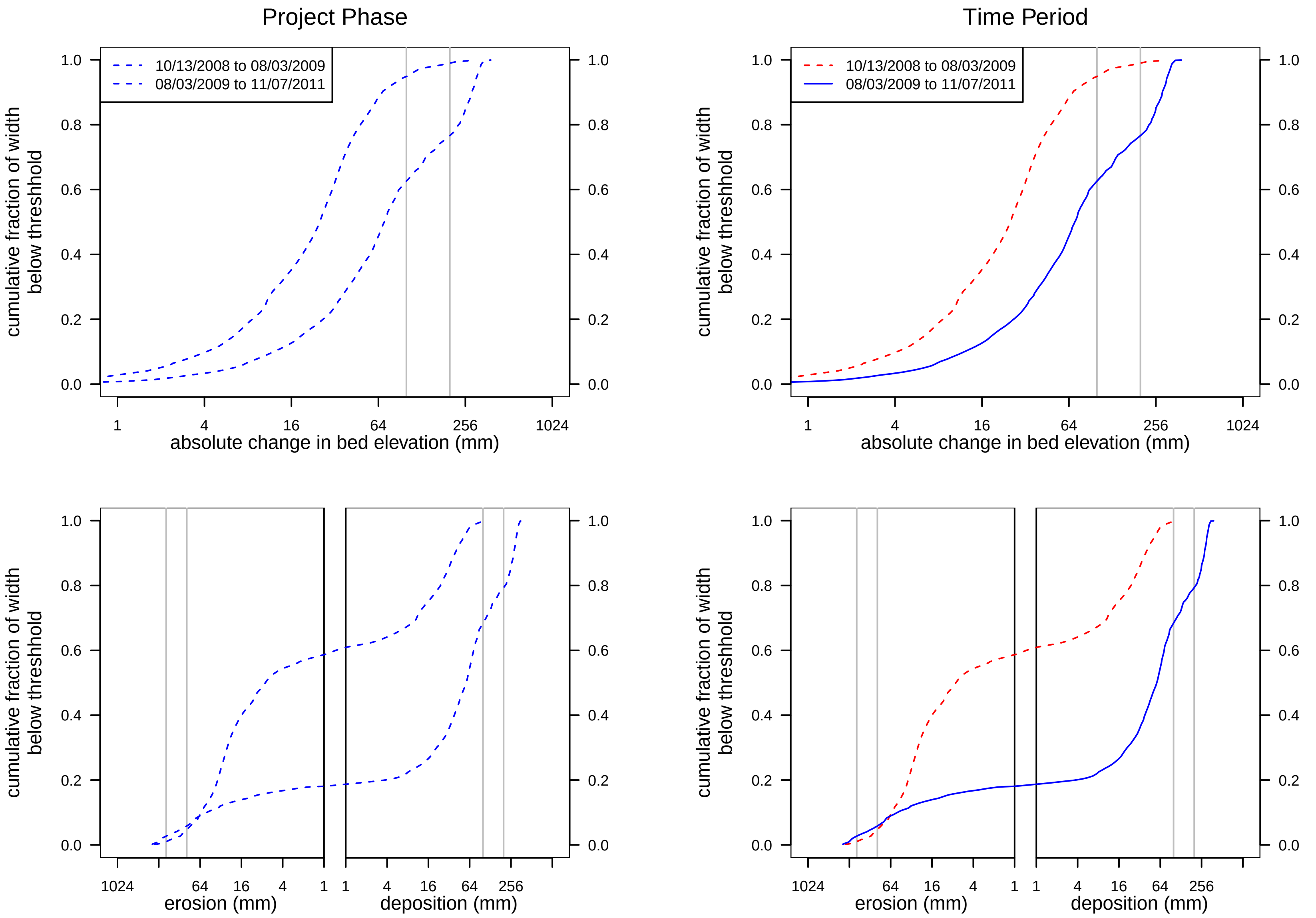

Conner Creek
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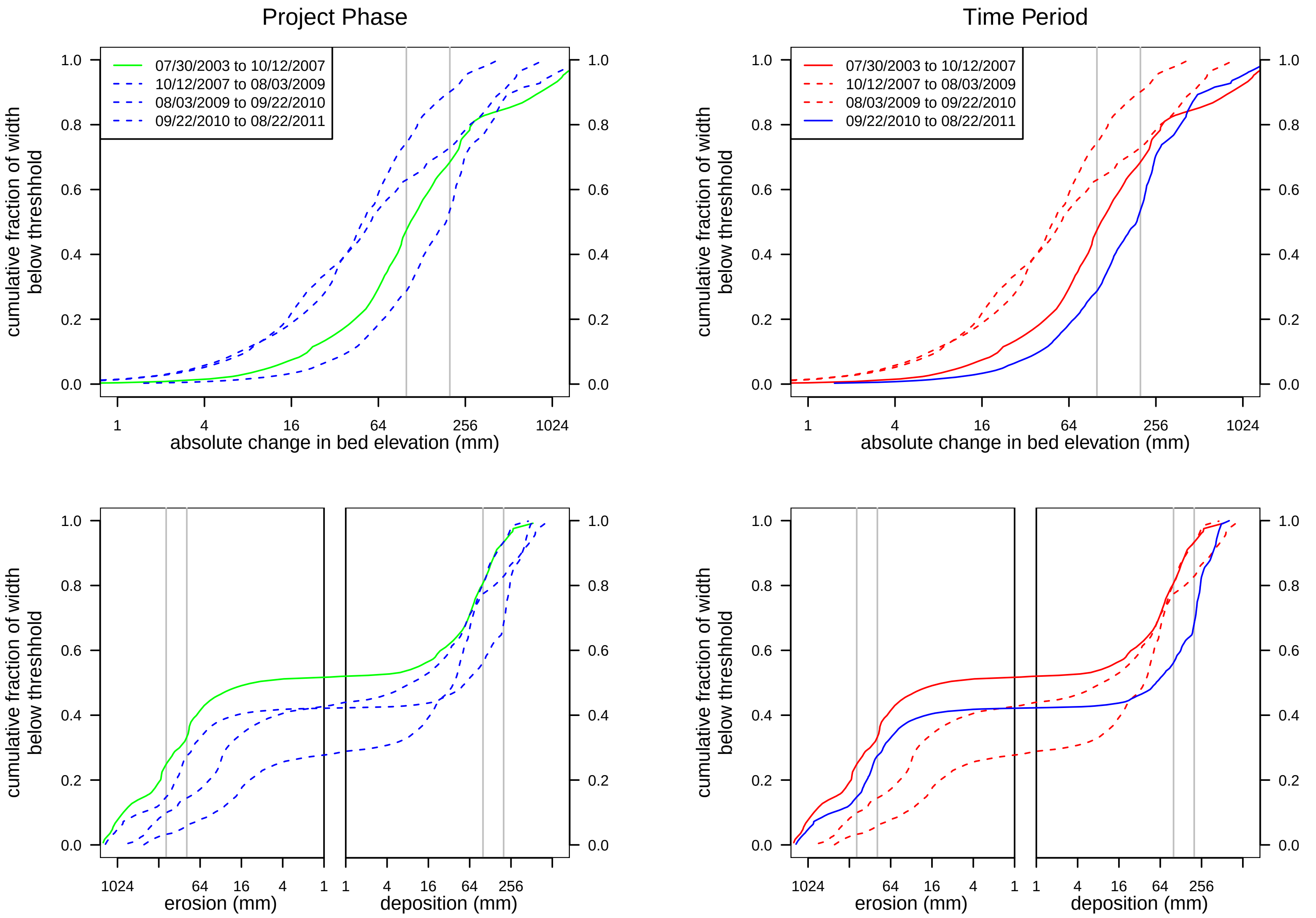

Valdor Gulch
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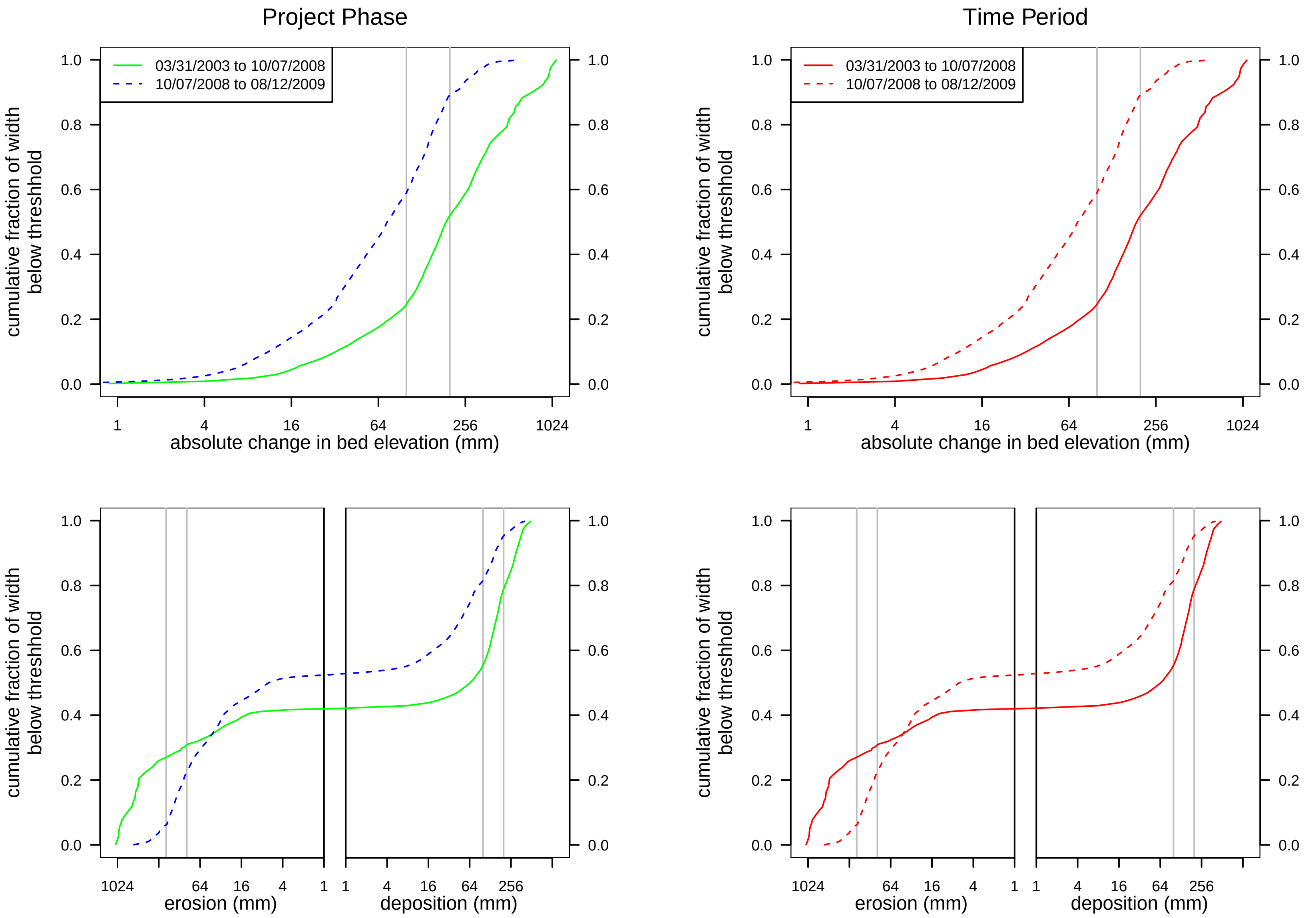

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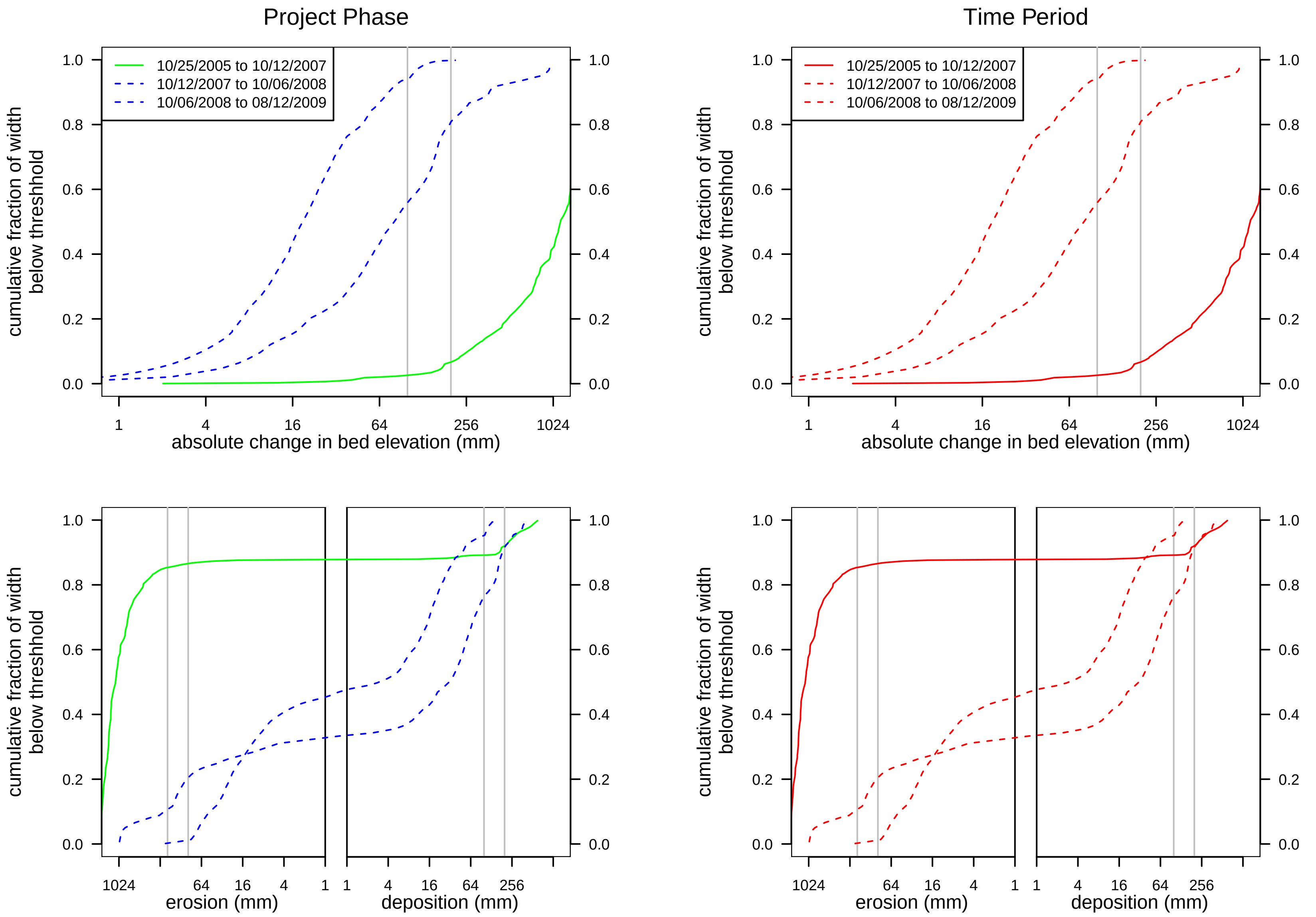

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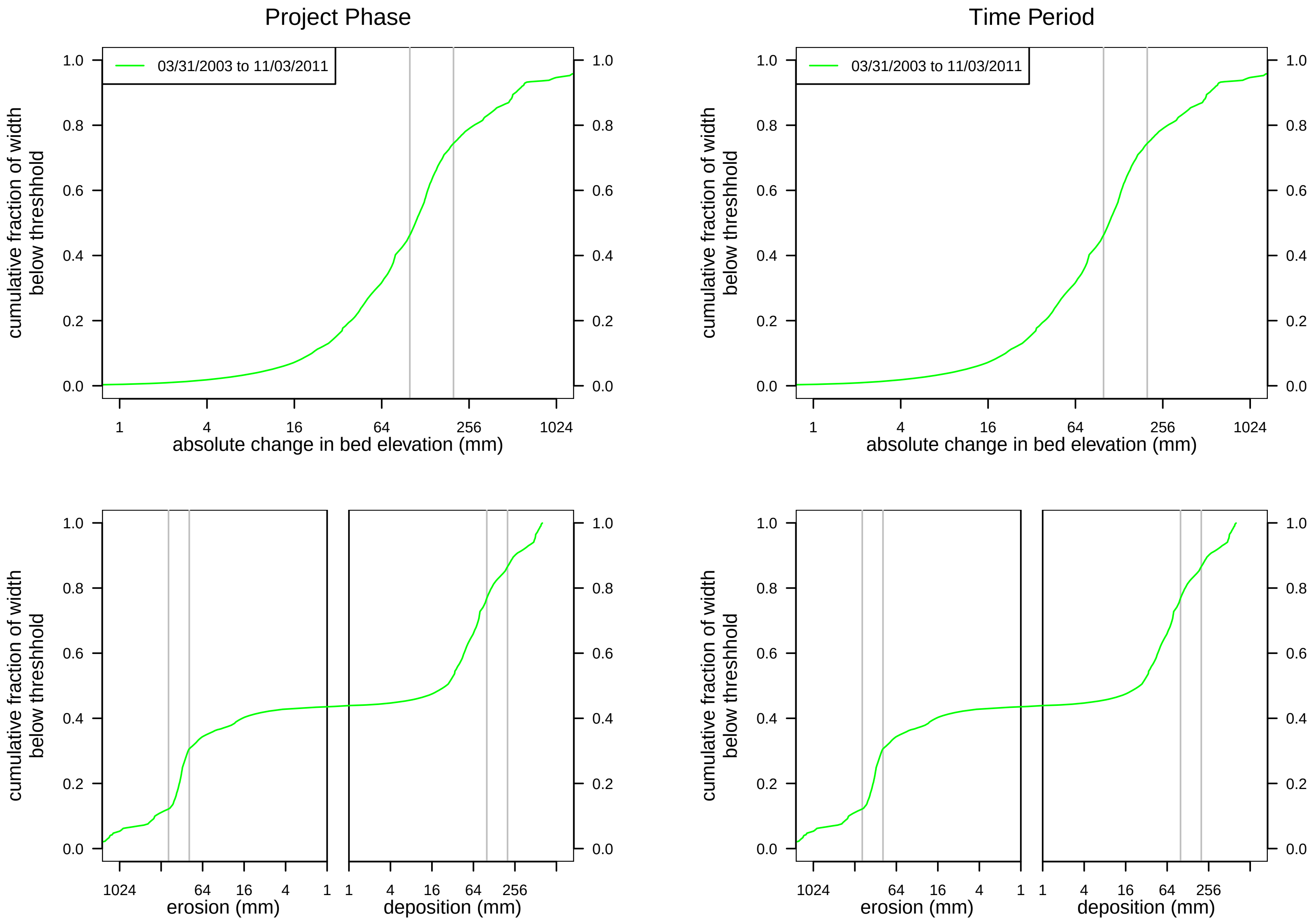

Valdor Gulch
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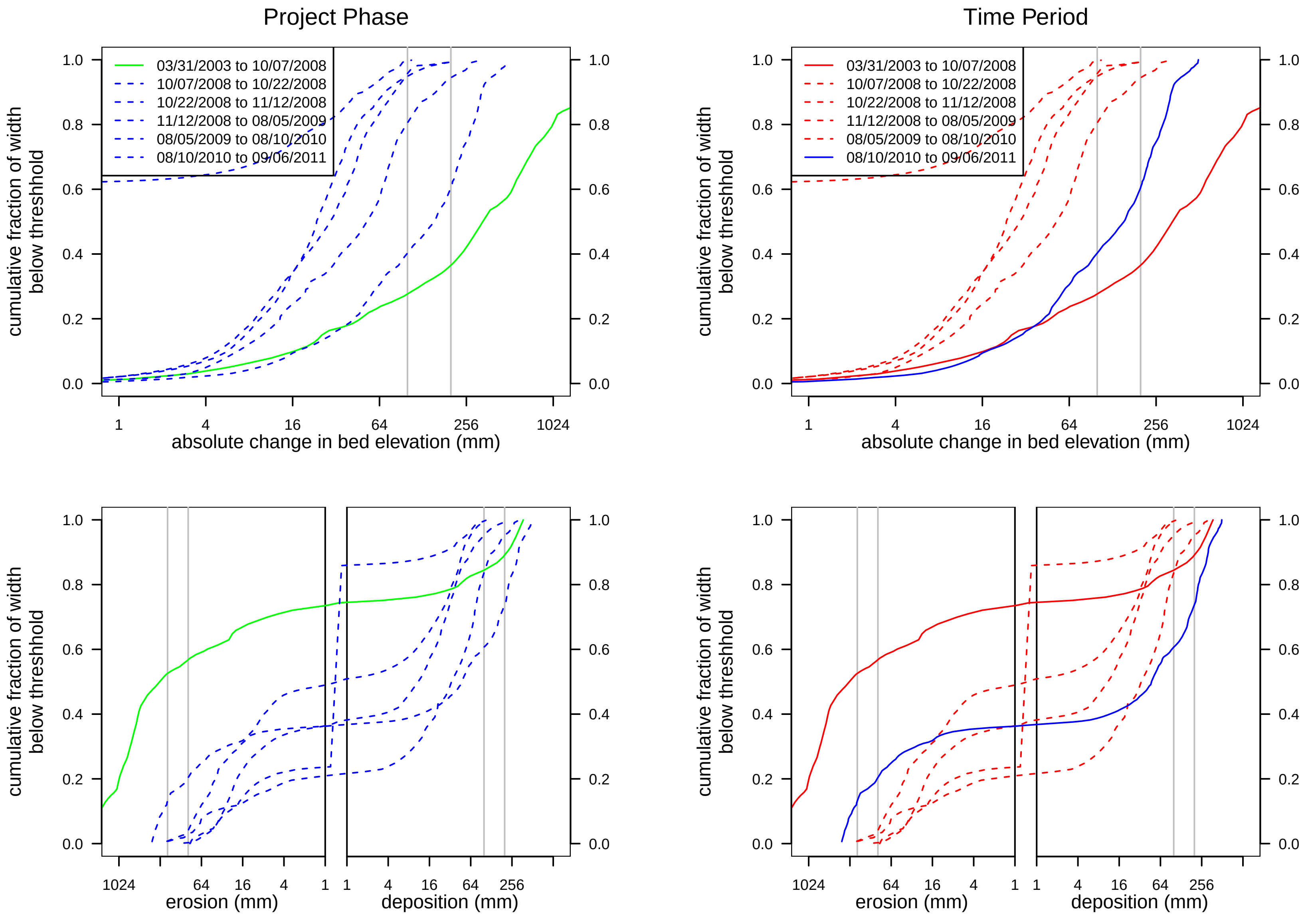

Valdor Gulch
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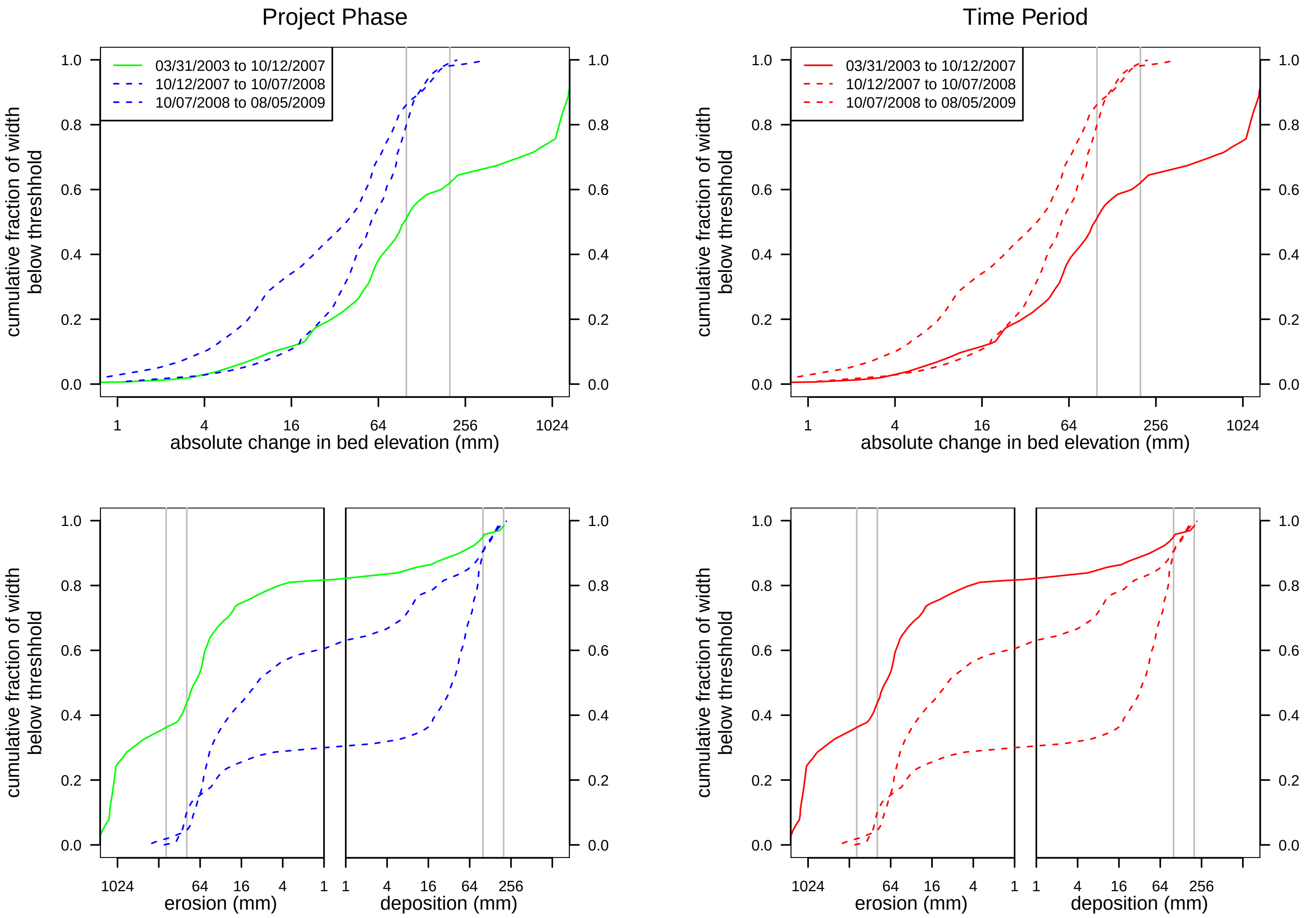

Valdor Gulch
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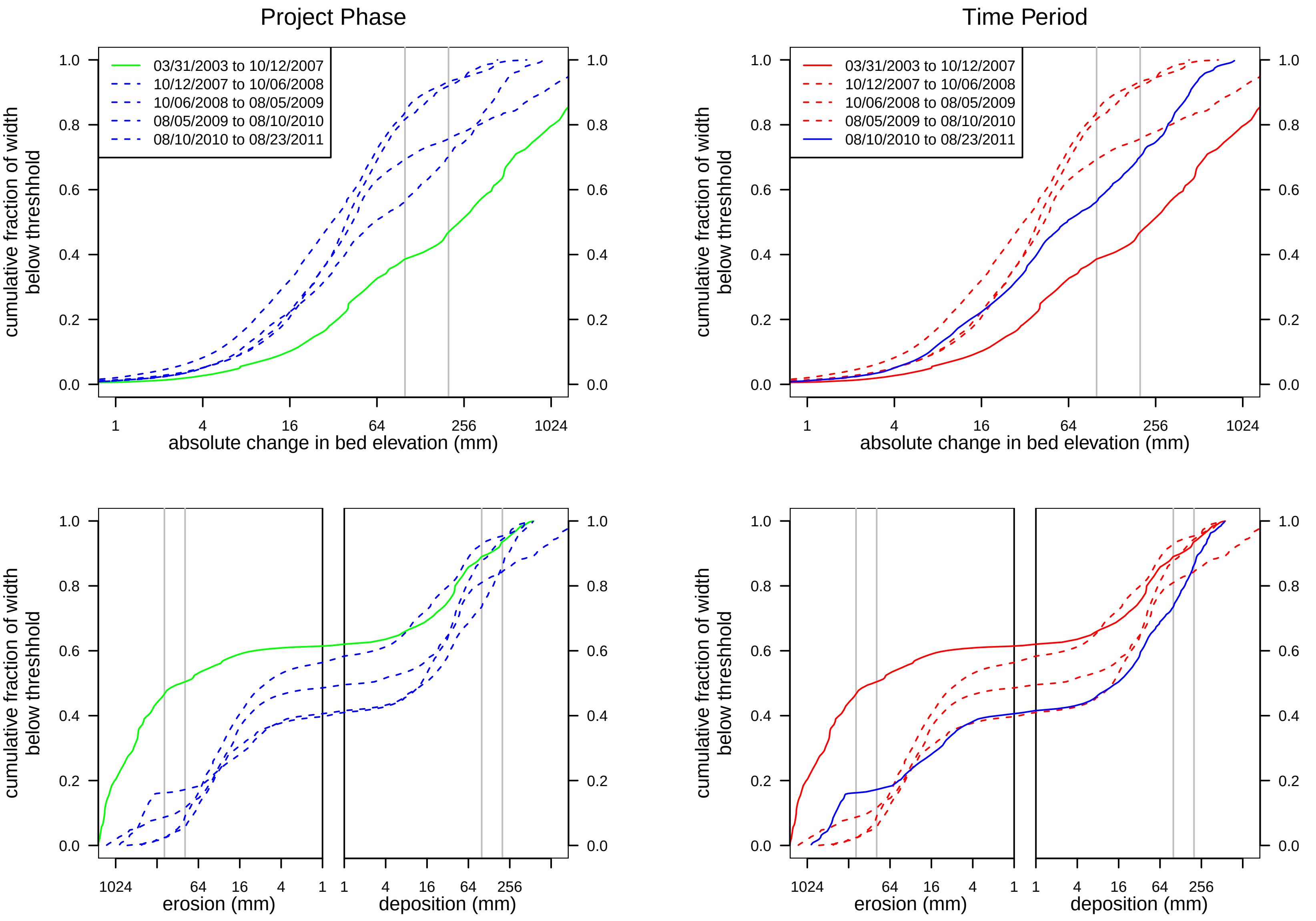

Valdor Gulch
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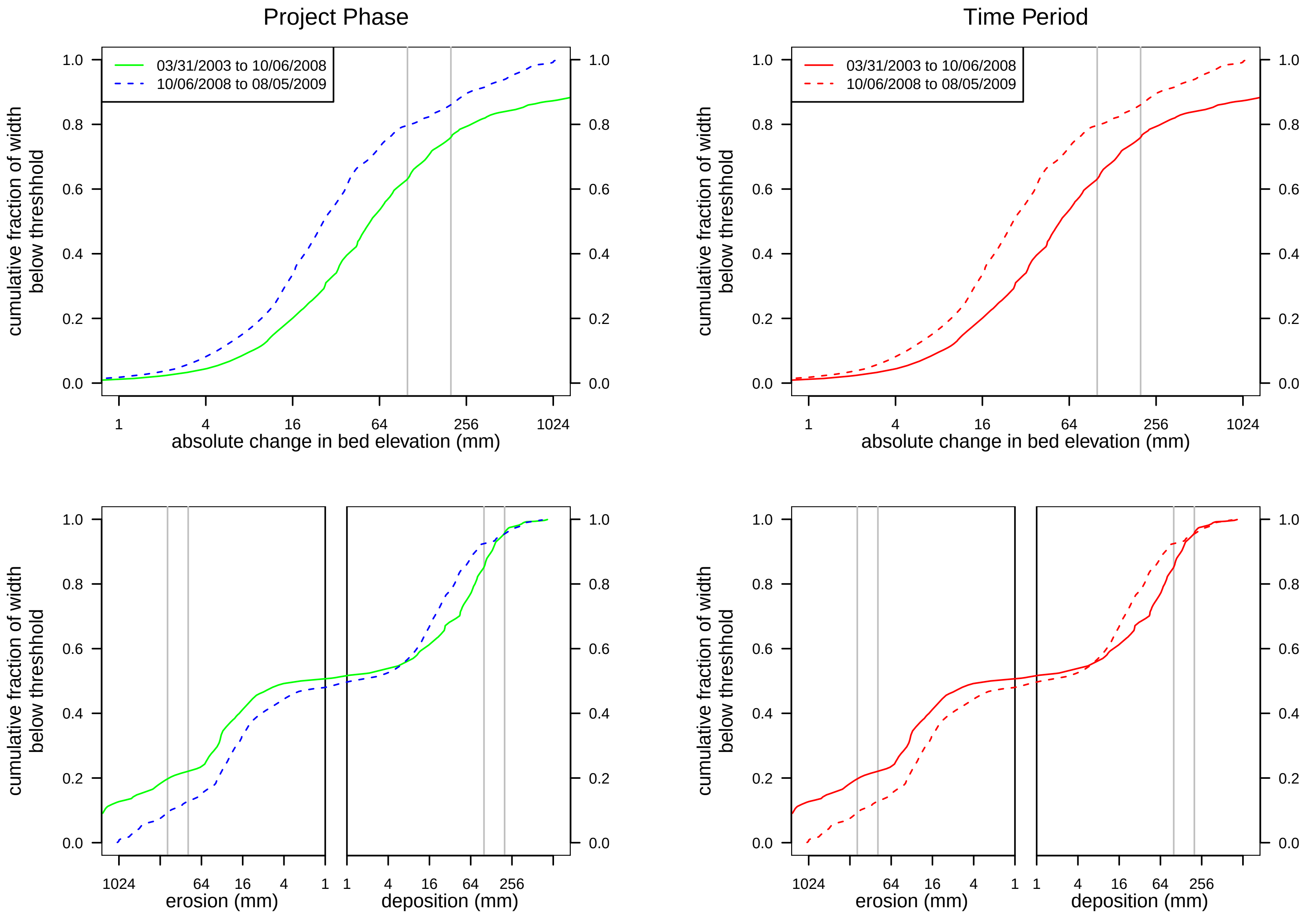
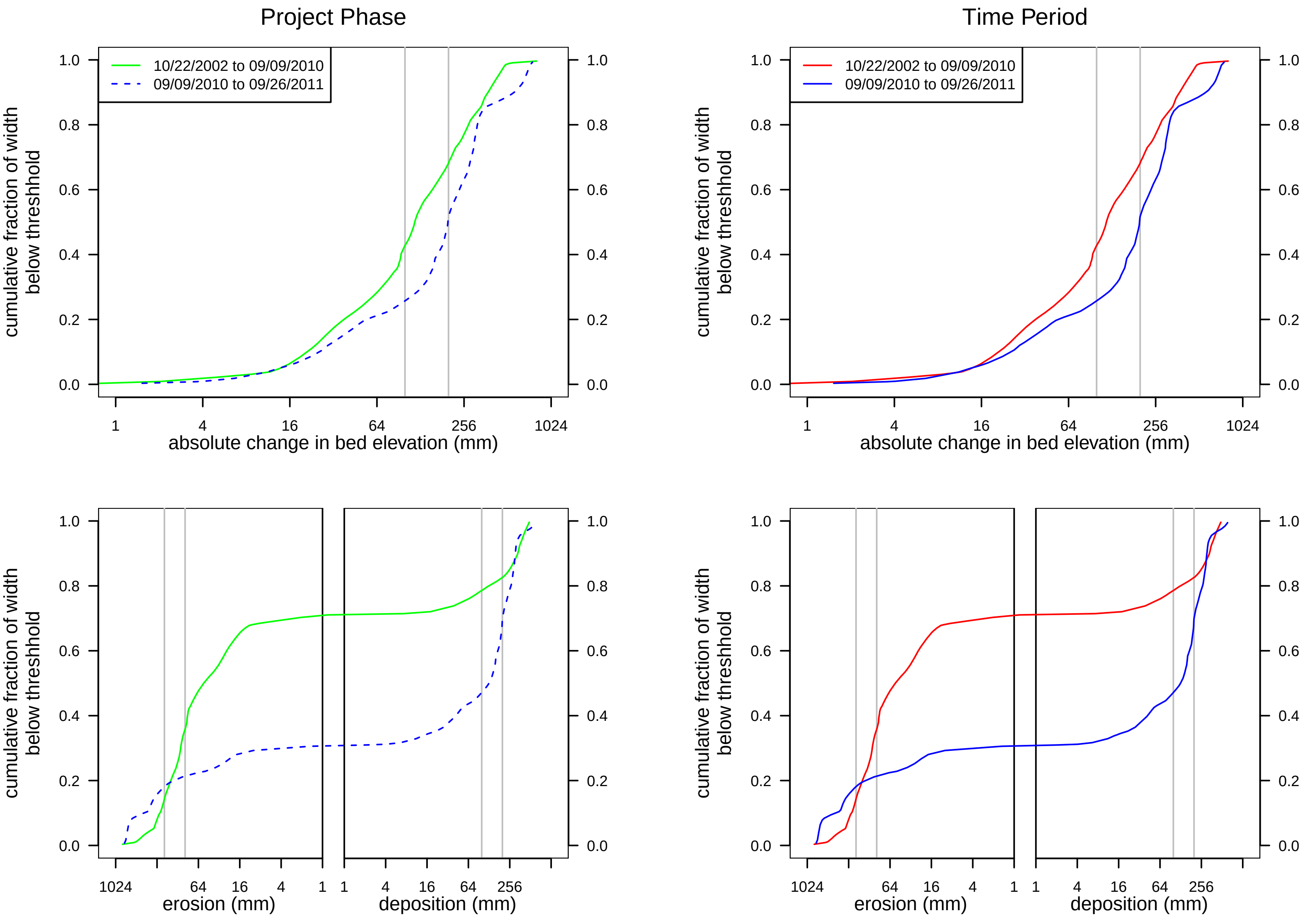


Pear Tree
Cross section Station ID 84 (38+10), KM 117.86



Pear Tree
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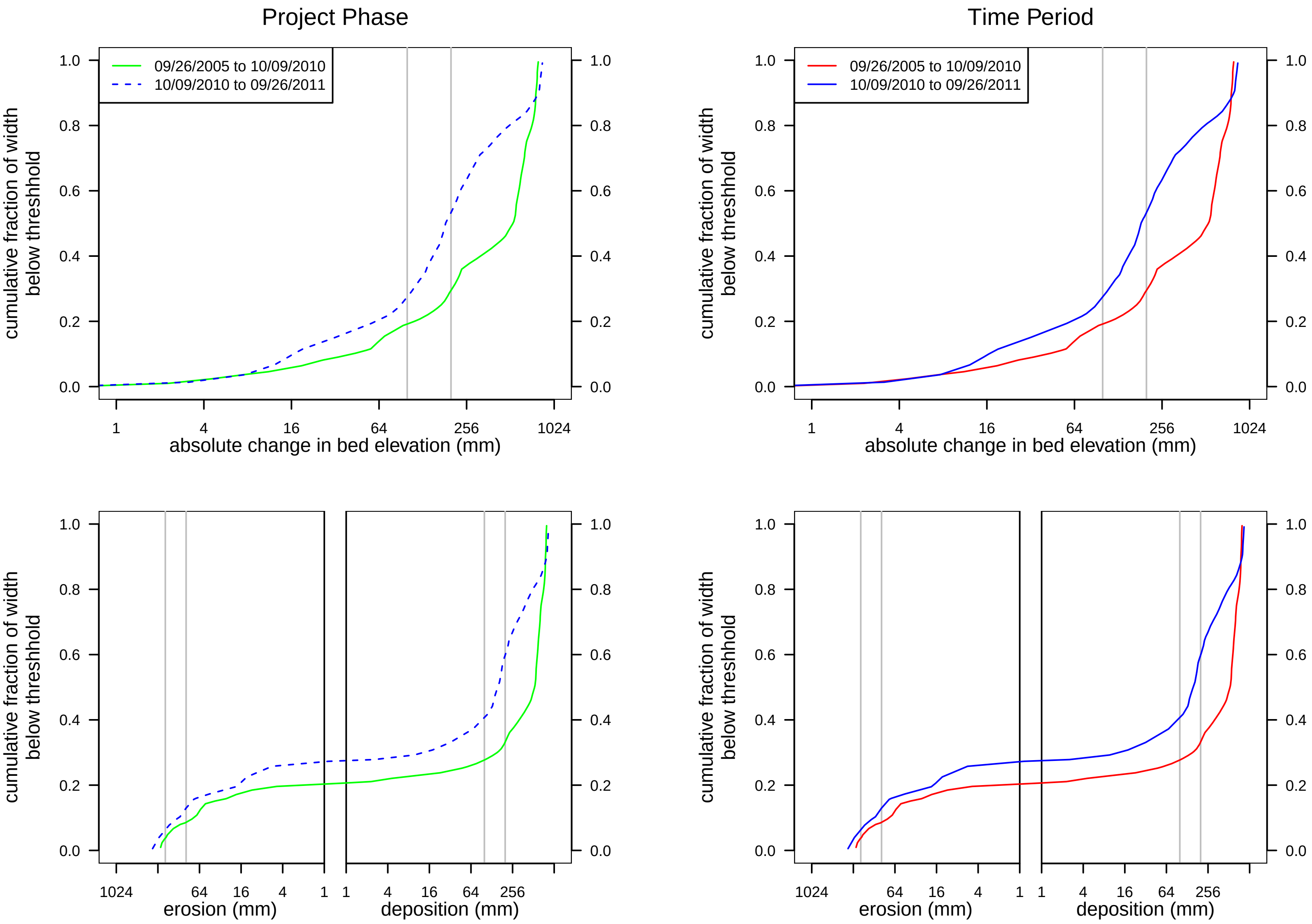

Limekiln
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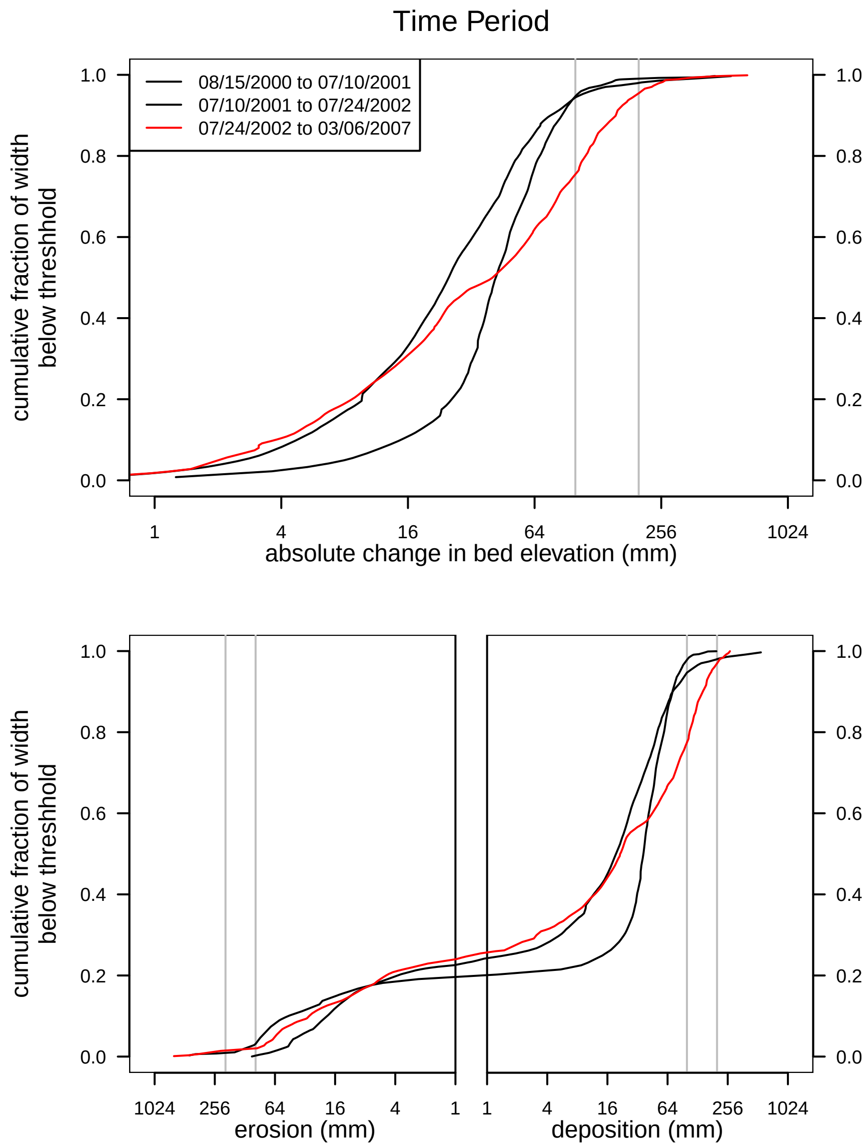

Limekiln
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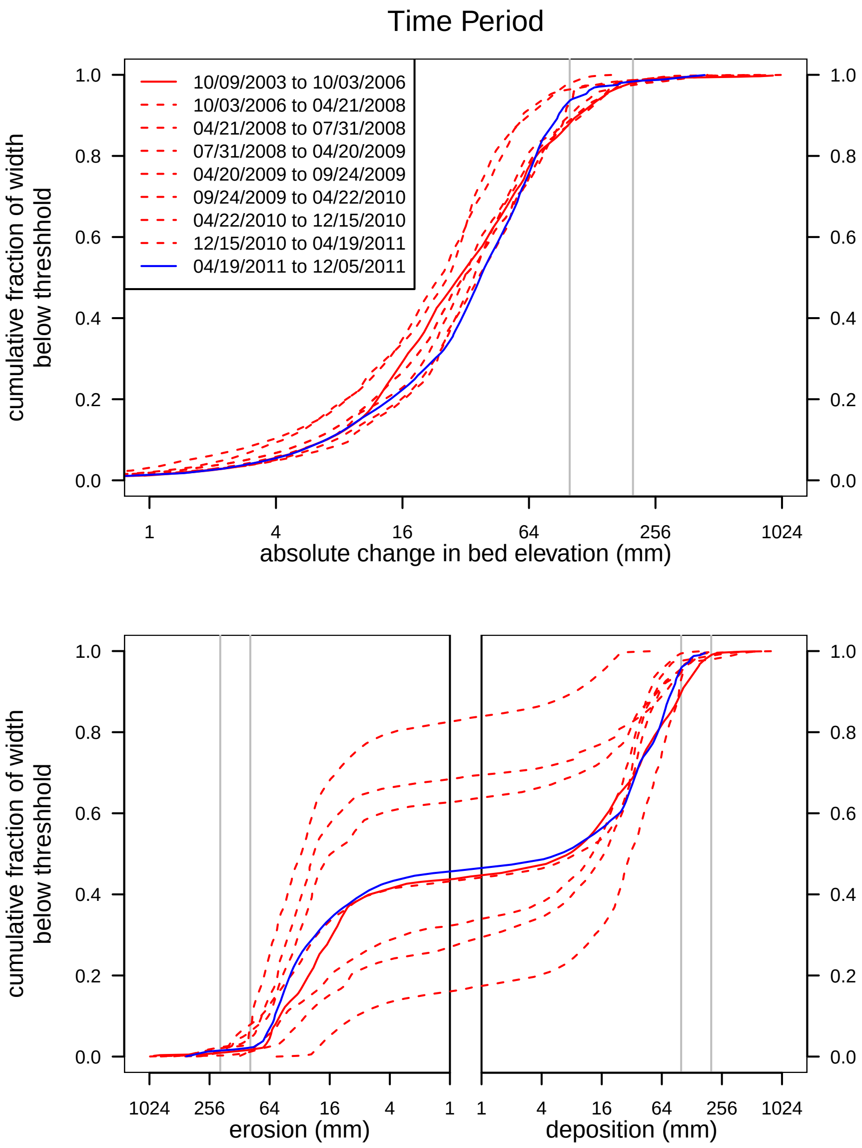
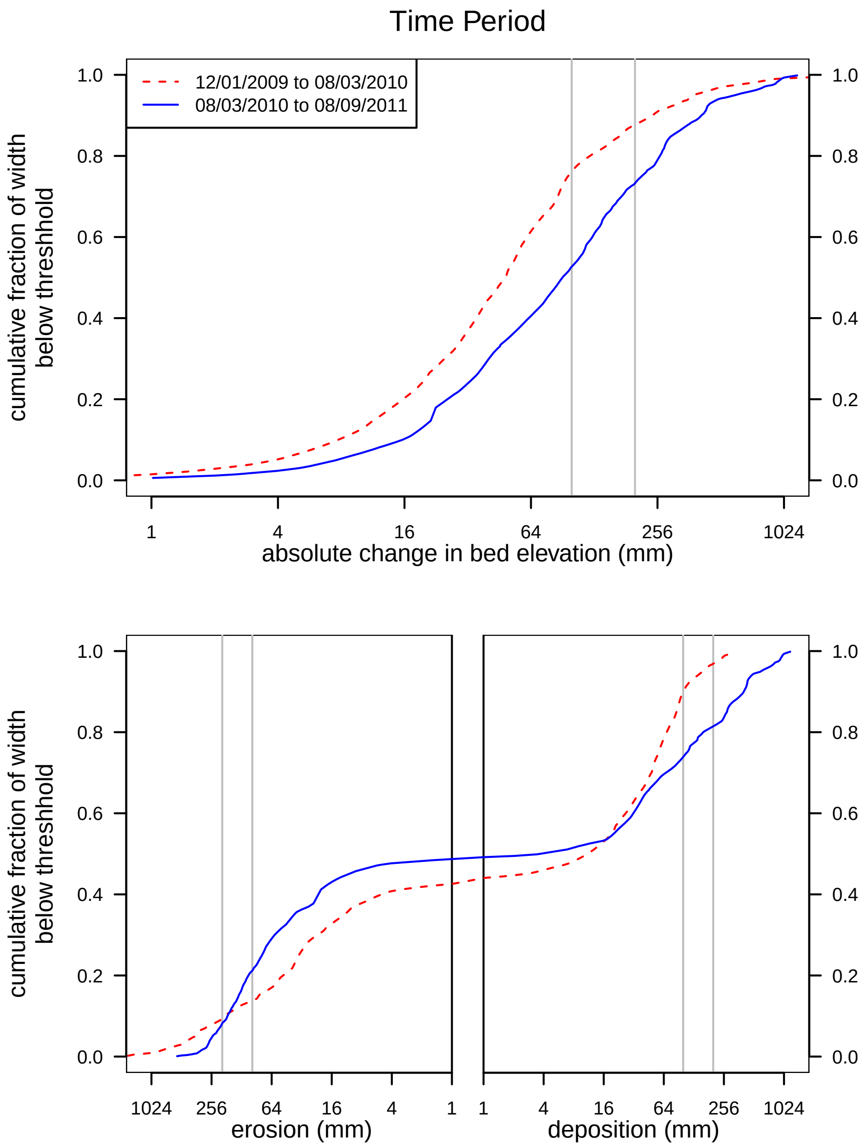
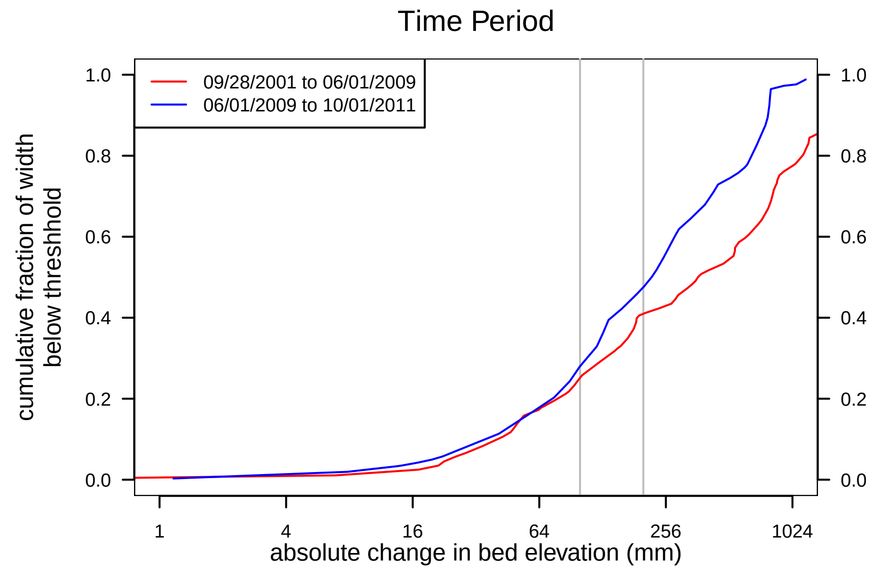
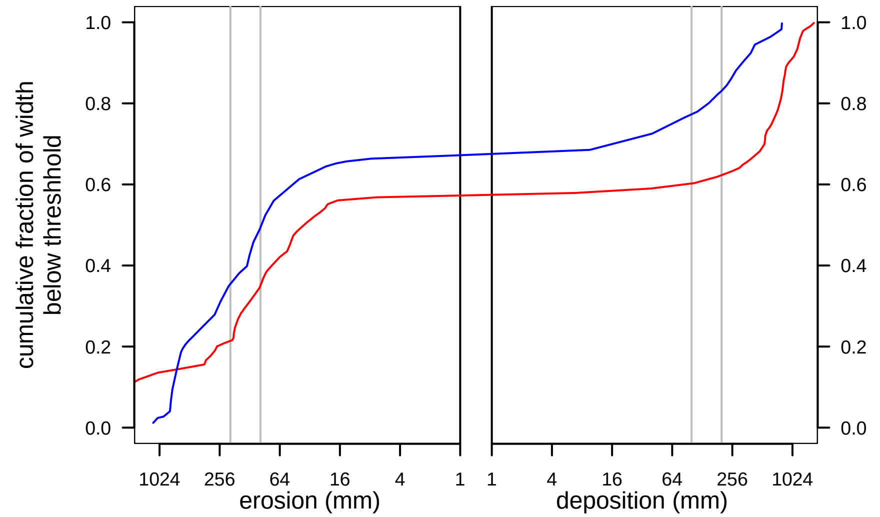


Indian Creek
Cross section Station ID 47 (1224+50), KM 153.60

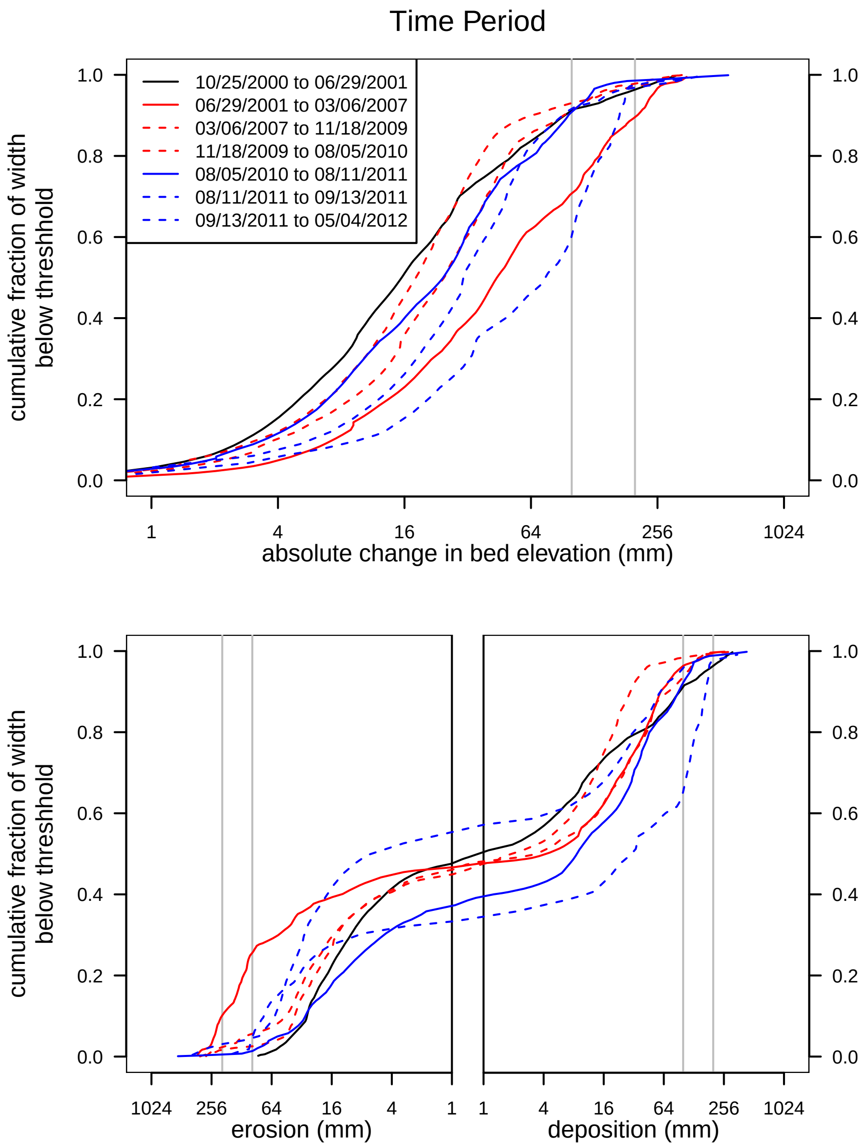


Steiner Flat
Cross section Station ID 154 (11+71), KM 147.96



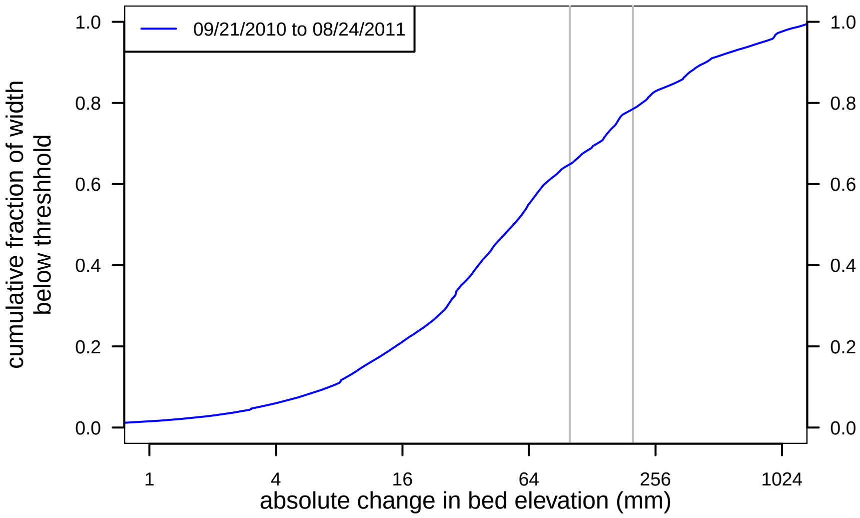


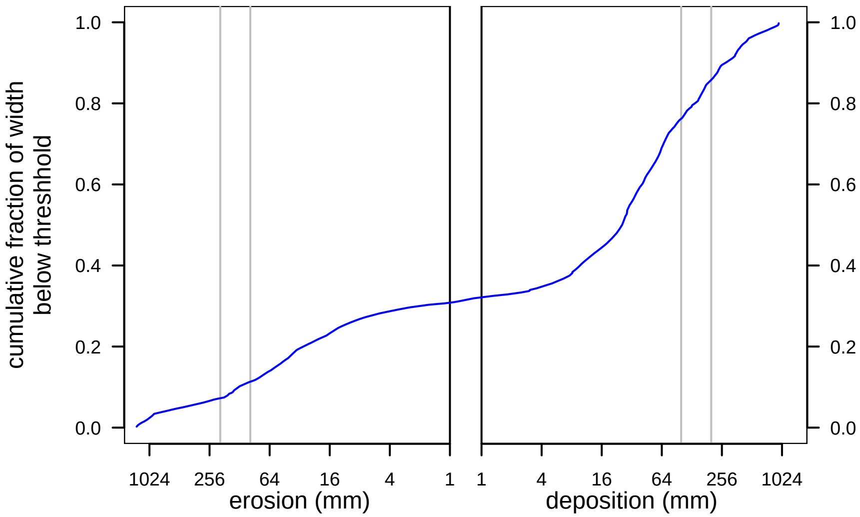
Bell Gulch
Cross section Station ID 2 (11+50), KM 135.89



Conner Creek
Cross section Station ID 200 (241+60), KM 123.86

Time Period





APPENDIX D
METHODOLOGY FOR DATA FRAME DEVELOPMENT

Prepared Under the Direction of
Trinity River Restoration Program's Scientific Advisory Board

With Support from
Stillwater Sciences
850 G Street, Suite K
Arcata, California 95521
And
Anchor QEA, LLC
720 Olive Way, Suite 1900
Seattle, Washington 98101

April 2014

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LIST OF ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
ESL	Environmental Site Limit
GIS	Geographic Information System
GRTS	generalized random tessellation stratified
Program	Trinity River Restoration Program
ROD	Record of Decision
SAB	Scientific Advisory Board
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

1 DEVELOPMENT OF THE SPATIAL DATA FRAME IN A GIS

As part of the Phase 1 review, the support contractors constructed a data frame to support analyses of the effects of Phase 1 actions over space and time. The spatial data frame encompasses the 64-km reach of the Trinity River from Lewiston Dam to the North Fork Trinity River confluence and divides the reach into channel segments that are analogous to sampling units. The initial spatial data frame was based on the existing generalized random tessellation stratified (GRTS) sampling frame used by the Trinity River Restoration Program (Program) and partners for design and analysis of fish habitat and riparian monitoring. The GRTS sampling frame was defined by the Trinity River centerline and divided into 400-meter-long segments. The current sampling frame developed by the support contractors for the Scientific Advisory Board's (SAB's) Phase 1 review utilizes the GRTS sampling frame, but is further subdivided into 200-meter-long segments that are referenced to the existing 400-meter GRTS data frame and to other important breaks (e.g., tributary junctions). Physical and biological data are referenced spatially and temporally by segment, allowing the development of a geodatabase structure that can be used to organize, store and analyze existing and future data. Where possible, the data frame incorporates data for a consistent set of years, including 2001, 2005, 2007, 2009, and 2011. The data frame supports spatial integration of past, present, and future data collection processes, and therefore may form the basis for potential future system-wide analysis and process-based modeling of geomorphic change detection and fish population response. Where available and suitable for spatial analysis, each of the parameters listed below were attributed to each 200-meter segment.

The following data frame parameters are relatively invariant over time:

- Distance downstream from Lewiston Dam
- Channel gradient derived from 2009 LiDAR data
- Channel width defined by the 5,000 cubic feet per second (cfs) wetted area
- Valley width defined by the 500-year flood plain extent
- Geomorphic reaches defined in the Channel Rehabilitation Design Guidelines for the Mainstem Trinity River (HVT et al. 2011)
- Distribution of the five reach types defined by Beechie et al. (2012)
- Area of bedrock control within the 100-year flood plain
- Bank length by confinement class (as mapped in 2006 by Dave Gaeuman, Trinity River Restoration Program Office, Weaverville, California)
- Bank length by bank type and material (as mapped in 2006 by Dave Gaeuman, Trinity River Restoration Program Office, Weaverville, California)
- Length and area of riparian berm

The following data frame parameters vary over space and time due to natural river processes and restoration actions:

- Downstream distance from the nearest Phase 1 channel rehabilitation site
- Downstream distance from the nearest gravel augmentation site
- Annual peak flow defined at a set of nodes between Lewiston and the North Fork Trinity River confluence
- Edge of water length (hereafter referred to as bank line length) at the Record of Decision (ROD) summer base flow release in 2001, 2005, 2007, 2009, and 2011
- Summer base flow width and wetted area for the above bank lines
- Fish habitat capacity (areas meeting cover, depth, and velocity criteria)
- Juvenile density (number per square meter by year)
- Redds (number per year)
- Carcasses (number per year)

The following sections describe the development of the spatial data frame in a Geographic Information System (GIS) and development of a data frame database in flatfile and Access formats that is comprised of a subset of spatial data frame attributes most relevant to statistical analysis of Phase 1 project effects. Both forms of the data frame were used by the SAB to support evaluation of the effects of the Program's restoration and management activities on a number of physical and biological response metrics.

1.1 200-meter Channel Segments

The 200-meter data frame shapefile provides the basis for all data frame analysis conducted by the SAB during their review of the Program's Phase 1 channel rehabilitation projects. It consists of channel segments of approximately 200 meters in length, each uniquely identified by a single ID (Figure 1). The data frame shapefile was derived from an existing polyline dataset [1] created for a predecessor analysis based on channel segments 400 meters in length (referred to as 400-meter GRTS). The 200-meter segmentation exactly matches the nodes and line geometry of the 400-meter segmentation.

1.2 200-meter Channel Segment Buffers

In order to attribute data provided by the Program Partners to each unique data frame segment, polygon versions of each data frame segment were created (Figure 1). The polygons were

---

[1] Source file: 400m_grts_segs.shp (located on TRRP spatial database under M\DATA\Utility\)
Source metadata: "400m GRTS segments, received from HVT December 9, 2009."

adapted to encompass the extent of all relevant datasets, including the 11,000 cfs flood plain area and the U.S. Geological Survey (USGS) geomorphic mapping extent. As requested by the SAB, the polygon boundaries were adjusted to match (up to a scale of 1:1) the boundaries of the 'GRTS_Site' [2] corresponding to the Trinity River Habitat Assessment geodatabase provided by the U.S. Fish and Wildlife Service (USFWS; Arcata Office).

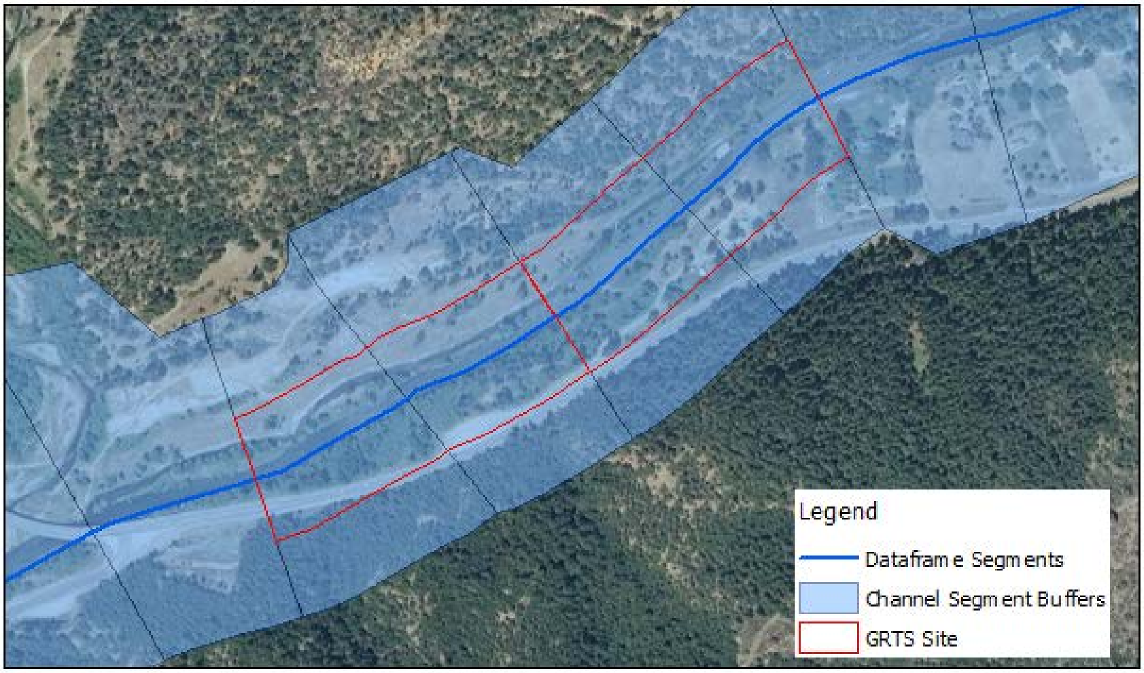


Figure 1

Basic Elements of the Spatial Data Frame

1.3 Evaluation and Attribution of Project-related Datasets

The primary GIS task during development of the spatial data frame was to incorporate numerous existing datasets (i.e., the source data) into the data frame, and provide a summary of their metrics in tabular form for inclusion in a data frame database. Source data were provided by the Program, USFWS, and USGS. For each dataset included in the analysis, the contractors conducted an initial assessment of each dataset relevant to the SAB's Phase 1 review to determine its suitability for incorporation into the data frame. We documented any potential issues with the data and provided feedback to the SAB before moving forward with any analysis.

---

[2] Source file: GRTS_Site (RearingHabitatMappingGDB\Trinity_River_Habitat_Assessment.gdb\GRTS)
Source metadata: "The GRTS_Site feature class contains the bounding polygons for the areas (HabitatArea and Banklines) mapped by the GRTS sampling design. More metadata is available in the actual file.

Below is a summary of the datasets included in the data frame by source data provider, and any potential issues encountered during the initial assessment.

1.3.1 U.S. Fish and Wildlife Service Datasets

The USFWS (via the Program) provided the following data in draft form at the request of the SAB and the Program.

Layer name: GRTS_HabitatArea
Layer type is: Polygon
Layer data source:
\RearingHabitatMappingGDB\Trinity_River_Habitat_Assessment.gdb\GRTS\GRTS_HabitatArea
\-
Layer name: TR_Rehab_Areas
Layer type is: Polygon
Layer data source:
\RearingHabitatMappingGDB\Trinity_River_Habitat_Assessment.gdb\Rehab\TR_Rehab_Areas
\-
Layer name: Trinity_River_Habitat_Assessment - GRTS Banklines
Layer type is: Polyline
Layer data source:
\RearingHabitatMappingGDB\Trinity_River_Habitat_Assessment.gdb\GRTS\GRTS_Banklines
\-
Layer name: RearingHabitatMappingGDB_TR_RehabBanklines
Layer type is: Polyline
Layer data source:
\RearingHabitatMappingGDB\Trinity_River_Habitat_Assessment.gdb\Rehab\TR_Rehab_Banklines
\-
Layer name: Indian_Ck_complex_07_08
Layer type is: Polygon
Layer data source: \RearingHabitatMappingGDB\Indian_Ck_complex_07_08.shp
\-
Layer name: HockerPresmoltHabitatArea2008DVH
Layer type is: Polygon
Layer data source: \RearingHabitatMappingGDB\HockerPresmoltHabitatArea2008DVH.shp
\-

```
Layer name: Carcass_2009
Layer type is: Point
Layer data source: \Carcass_JF\Carcass_2009.shp
--------------------------------------
Layer name: Carcass_2010
Layer type is: Point
Layer data source: \Carcass_JF\Carcass_2010.shp
--------------------------------------
Layer name: Carcass_2011
Layer type is: Point
Layer data source: \Carcass_JF\Carcass_2011.shp
--------------------------------------
Layer name: Redd_2011
Layer type is: Point
Layer data source: \Redds\Redds2011\Redd_2011.shp
--------------------------------------
Layer name: Redd_2010
Layer type is: Point
Layer data source: \Redds\Redds2010\Redd_2010.shp
--------------------------------------
Layer name: Redd_2009
Layer type is: Point
Layer data source: \Redds\Redds2009\Redd_2009.shp
--------------------------------------
Layer name: JuvFishHabitatUse2009
Layer type is: Polygon
Layer data source: \JuvFishHabitatUse2009\JuvFishHabitatUse2009.shp
--------------------------------------
Layer name: JuvFishHabitatUse2008
Layer type is: Polygon
Layer data source:   \JuvFishHabitatUse2009\JuvFishHabitatUse2008.shp
--------------------------------------
Layer name:LWD_Jan2012_TRRP Request
Layer type is: Point
Layer data source: \AnchorQEA\USFWS_LWD\LWD\Shapefiles\LWD_Jan2012_TRRP
Request.shp
```

1.3.2 U.S. Geological Survey – Geomorphic Mapping Datasets

The USGS provided the following data in draft form at the request of the SAB and the Program. The contractor was subsequently notified by the SAB and the Program that these data should not be incorporated into the spatial data frame or any other analysis being conducted as part of the Phase 1 review.

Layer name: Polygon_1980
Layer type is: Polygon
Layer data source: \USGS_draft_geomorph.gdb\Trinity_1980\Polygon_1980

Layer name: Polygon_2001
Layer type is: Polygon
Layer data source: \USGS_draft_geomorph.gdb\Trinity_2001\Polygon_2001

Layer name: Polygon_2011
Layer type is: Polygon
Layer data source: \USGS_draft_geomorph.gdb\Trinity_2011\Polygon_2011

1.3.3 Datasets Provided by the Program

The Program provided 520 gigabytes of data on an external hard drive without documentation describing the contents. Metadata was sparse and non-standardized, and there was no indication of what datasets were relevant for this study. The state of the data included on the hard drive necessitated close communication with the Program to properly select, interpret, and use data in developing the data frame. The SAB requested edits to source data on multiple occasions following initial development of the spatial data frame, prompting several iterations of data frame development. The contractors notified the SAB of several significant uncertainties and potential problems with the low-flow banklines provided by the Program, particularly when used to infer erosion and deposition at the intended spatial scales. The contractors subsequently proceeded with the analysis as requested by the SAB.

The data provided by the Program were as follows:

Layer name: WSE_profile2009
Layer type is: Point
Layer data source:
\M\DATA\Geo\Topography\TerrainModels\2009\ARCGIS_DATA\ARCGIS_GRID_5FT_REACHWIDE

```
---------------------------------------
Layer name: GravelInjectionSites_v2
Layer type is: Point
Layer data source: H:\M\DATA\Rehab_Sites\Augmentation\GravelInjectionSites.shp
---------------------------------------
Layer name: Phase1Sites_UpstreamPoint_atDesignSite
Layer type is: Point
Layer data source: \M\DATA\Rehab_Sites\ESLs\ESL_Rehab_CURRENT.shp
---------------------------------------
Layer name: 2011_LowFlowBanklines
Layer type is: Polyline
Layer data source: \2011_LowFlowBanklines.shp (created by Stillwater Sciences)
---------------------------------------
Layer name: 2009_LowFlowBanklines
Layer type is: Polyline
Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\April2009_LowFlowBanklines\2009_LowFlowBanklines.shp
---------------------------------------
Layer name: 2007_v2_LowFlowBanklines
Layer type is: Polyline
Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\July2007_LowFlowBanklines\July2007_LowFlowBanklines.shp
---------------------------------------
Layer name: 2005_LowFlowBanklines
Layer type is: Polyline
Layer data source: \2005_LowFlowBanklines.shp (created by Stillwater Sciences)
---------------------------------------
Layer name: 2001_LowFlowBanklines
Layer type is: Polyline
Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\Nov2001_LowFlowBanklines\2001_LowFlowBanklines.shp
---------------------------------------
Layer name: Nov2001_LowFlowBanklines
Layer type is: Polygon
```

Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\Nov2001_LowFlowBanklines\Nov2001_LowFlowBanklines_Polygon\Nov2001_LowFlowBanklines_Polygon.shp
----
Layer name: September21_2005_LowFlowBanklines
Layer type is: Polygon
Layer data source: \September21_2005_LowFlowBanklines.shp (created by Stillwater Sciences)

Layer name: July2007_LowFlowBanklines_v2
Layer type is: Polygon
Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\July2007_LowFlowBanklines\July2007_LowFlowBanklines.shp
----
Layer name: April2009_LowFlowBanklines
Layer type is: Polygon
Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\April2009_LowFlowBanklines\April2009_LowFlowBanklines_Polygon.shp
----
Layer name: August2011_LowFlowBanklines
Layer type is: Polygon
Layer data source: \August2011_LowFlowBanklines.shp (created by Stillwater Sciences)

Layer name: 5000cfs_Centerline_Feb2006
Layer type is: Polyline
Layer data source: \M\DATA\Hydro\Rivers\Centerlines\5000cfs_Centerline.shp
----
Layer name: TRbanks2006_07_vSWS
Layer type is: Polyline
Layer data source:
\M\DATA\Geo\Geomorphology\GeomorphicMaps\geomap\bank_erode\banks2006-07\TRbanks2006-07.shp
----
Layer name: Xsections_lines_with_attributes
Layer type is: Polyline
Layer data source: \SourceData\Xsections\XS.gdb\XS\xs_lines_cleaned
----

Layer name: confinement
Layer type is: Polyline
Layer data source:
\M\DATA\Geo\Geomorphology\GeomorphicMaps\geomap\bank_erode\banks2006-07\confinement.shp
----
Layer name: Berms
Layer type is: Polyline
Layer data source:
\M\DATA\Geo\Geomorphology\GeomorphicMaps\Berm_Mapping\bermlength.shp
----
Layer name: StudyReaches
Layer type is: Polyline
Layer data source: \StudyReaches.shp

Layer name: Phase1_Sites_vAll
Layer type is: Polygon
Layer data source: \M\DATA\Rehab_Sites\ESLs\ESL_Rehab_CURRENT.shp
----
Layer name: SAB_modified_ESL_boundaries_v2
Layer type is: Polygon
Layer data source: \SAB_modified_ESL_boundaries_v2.shp

Layer name: Bedrock_v100yrFloodplain
Layer type is: Polygon
Layer data source:
\M\DATA\Geo\Geomorphology\GeomorphicMaps\MT_FloodplainMap2003\03Geo.shp
----
Layer name: 03Geo (Berms, polygons)
Layer type is: Polygon
Layer data source:
\M\DATA\Geo\Geomorphology\GeomorphicMaps\MT_FloodplainMap2003\03Geo.shp
----
Layer name: 6000cfs_ordinary_water_line_vNoIslands
Layer type is: Polygon
Layer data source: \M\DATA\Hydro\Rivers\FlowLines\OrdinaryHighWater_6000cfs.shp
----
Layer name: 11k_plus_100yr_2007

Layer type is: Polygon
Layer data source:
\M\DATA\Hydro\Rivers\FlowLines\11k_plus_100yr_2007\11k_plus_100yr_2007.shp
----
Layer name: DredgeTailings_poly
Layer type is: Polygon
Layer data source:
\M\DATA\Geo\Geology\Mining\DredgeTailingsfromM+T\DredgeTailings_poly.shp
----
Layer name: 500YrFloodplain_vValleyWidth
Layer type is: Polygon
Layer data source: \M\DATA\Hydro\Rivers\FlowLines\500YrFloodplain\500YrFloodplain.shp
----
Layer name: 100YrFloodplain_2007Estimate
Layer type is: Polygon
Layer data source: \M\DATA\Hydro\100YrFloodplain_2007Estimate.shp
----
Layer name: preliminary as_built boundaries
Layer type is: Polygon
Layer data source:
SourceData\Rehab_Sites\Preliminary_Rough_Draft_TRRP_Mainstem_Restoration.shp

1.3.4 Modified Phase 1 Site Boundaries for SAB Analysis

The boundaries for SAB analysis of Phase 1 sites were developed by adapting the Environmental Site Limit (ESL) boundaries developed and provided by the Program. The SAB initially modified the ESL boundaries for each Phase 1 site based on the spatial extent of design features. At the request of the SAB, these boundaries were further modified by the contractor to correspond exactly with the upstream and downstream extents (i.e., cross lines) of each 200-meter data frame channel segment boundary. These adjustments were made according to the rule that if any part of the existing Phase 1 project boundary (as modified by the SAB) extended upstream or downstream into a 200-meter channel segment, all of that 200-meter segment (extending upstream or downstream to the next cross line) was included in the Project area for analysis. This approach is objective, occurs at an appropriate scale, and is effective at uniquely associating channel segments to a particular rehabilitation site. Three of the four Lewiston 4 sites (Deadwood, Lewiston Cableway, and Hoadley Gulch) occur close together. Between each site, the SAB project areas extend into the intervening 200-meter channel segments from opposite directions. To avoid uncertainties regarding which site the intervening segments should be associated with, these three sites were treated as a single rehabilitation project area that extends from channel segment 11 to channel segment 18. There are no other cases in which Phase 1 project areas are close enough to share a channel segment.

1.3.5 As-built Footprints of Design Features at Phase 1 Rehabilitation Sites

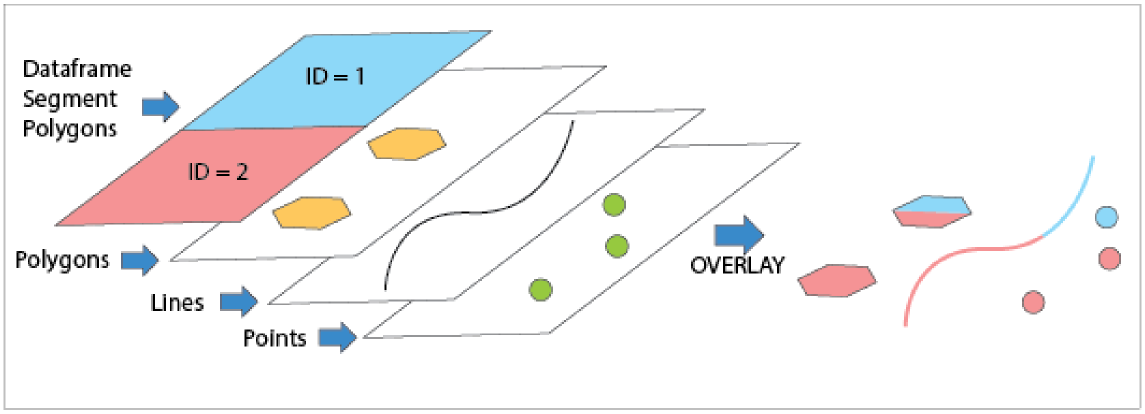
On May 5, 2012, the Program provided the SAB with a preliminary draft version of a GIS layer describing as-built footprints for features constructed within Phase 1 rehabilitation sites. The Program noted at the time that substantial effort was being allocated to building a database of as-built features, but that the final products of that effort would not be available in time for the Phase 1 review. For the purposes of the Phase 1 review, 'Upland Spoils', 'Existing Access Road', and 'Temporary Access Road' were excluded from the spatial data frame.

1.4 Incorporating Project Datasets into the Spatial Data Frame

Data incorporation into the spatial data frame was carried out using three main methods: data overlays, centroid characterization, and proximity analysis. These methods are discussed in Sections 1.4.1 through 1.4.3.

1.4.1 Data Overlays

Overlay operations were used for all datasets that needed to report their metrics (areas, lengths, and counts) by their corresponding data frame segment ID. This type of spatial attribution was applied to polylines, points, and polygon features (Figure 2).



Source: Clarke 1997

Note: Overlay is a GIS operation in which layers with a common, registered map base are joined on the basis of their occupation of space.

Figure 2
Data Overlay

1.4.2 Centroid Characterization

Centroid characterization analysis was needed to assign representative data measurements to a particular segment ID. This was the case for all the different types of bank-to-bank width measurements. First, each data frame segment was converted to a centroid point feature. Based on that centroid, and using a custom python script, we generated lines perpendicular to the data frame segments. The angle at which each width line crosses the centroid was then manually adjusted to accommodate channel meandering. Finally, the lines were adjusted to match the extents of the different flood plain scenarios and overlaid to extract the length measurements of the underlying datasets (Figure 3).

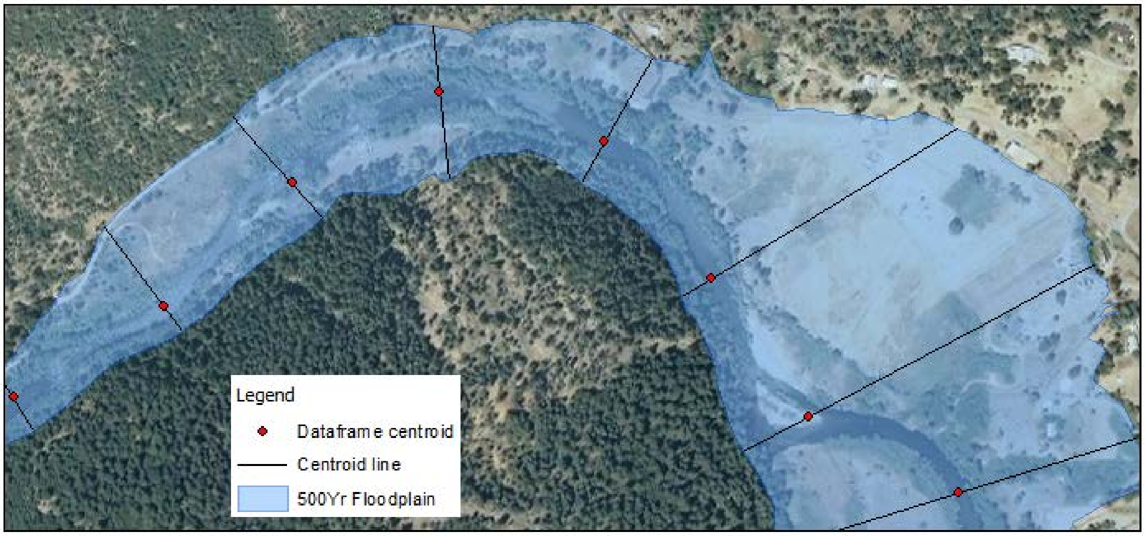


Figure 3

Measurements of 500 Year Flood Plain Width at Data Frame Segment Centroids

1.4.3 Proximity Analysis

There were two instances where a ‘distance to data frame segment mid-point’ was calculated, including calculation of the distance from ‘Phase1 site design’ and the distance from ‘gravel injection point’. In both of these cases, the contractor calculated the upstream distance to the nearest target feature for every data frame segment centroid. In the case of ‘site designs’[3] we created a point feature representing the upstream boundary of each as-built footprint. Distances to each footprint and the gravel injection points were calculated along the data frame centerline using a routing procedure.

---

[3] The following shapefile (\M\DATA\Rehab_Sites\TRRP_RehabSites_AsDesigned\SiteDesigns_CURRENT.shp) was used to represent construction footprints as surrogate for 'as built' boundaries, which were not completed/revised at the time of the proximity analysis (04-12-2012).

2 EXPORTING SPATIAL DATA INTO TABULAR FORM

Each dataset analyzed in the spatial data frame was exported to Excel 2010 format for review and processing into a flatfile database. In most cases, the source data attributed to the spatial data frame contained many ancillary attributes that were not meaningful or useful for inclusion in a flatfile database developed for statistical analysis. An initial review of attribute data exported from the spatial database was therefore conducted to determine the relevance for inclusion in a flatfile database. Parameters with multiple observations within a given data frame channel segment were rolled up into a single value for the data frame channel segment and summarized in pivot tables organized by segment ID. Pivot table summaries were developed to check for obvious data errors, communicate with the SAB and members of the contractor team regarding the content and format of data attributed to the spatial data frame, and ultimately guide development of the flatfile database through prioritization of available data. Pivot tables with suggested roll-up of all parameters requested by the SAB were provided to the SAB for comment prior to developing the first version of data frame database. The contractors modified the roll-up based on SAB feedback and proceeded with database development.

The general procedure for building the data frame database was the same for all layers. Each record of the exported layer consists of a set of attributes of an individual polygon. The processing consisted of assigning each polygon to one of a fixed number of disjoint classes, on the basis of its attributes, and then adding up the values of the basic metric (e.g., area, or intercepted bank-length, or observed carcass numbers) associated with all the polygons of the same class in each channel segment. The result is a data table with one field (column) for each class and one record (row) for each channel segment. In most cases, pivot tables were provided with the exported layers to indicate how the polygons should be classified.

Care was taken to ensure that the classes were always disjoint, and that each cell of the resulting table contained a value if it was meaningful for it to do so. In particular, values of zero appear whenever a category does not occur in a segment. True null values (blanks in Excel, or Null values in Access) were used when no meaningful value could be assigned (for example, in some of the biological data where only portions of the river were surveyed).

The classification and aggregation was performed using an auxiliary Microsoft Access database. A copy of each layer, stripped of header and other extraneous matter, was imported into this database and manipulated into the desired form with one or more SQL queries, then exported back to Excel as a new sheet of the Excel workbook “Trinity_SAB_Dataframe.xls”.

Immediately after each layer was processed and added to “Trinity_SAB_Dataframe.xls”, a block of records was added to the worksheet “Metadata” of the same workbook, providing information about the data columns of the newly added data and specifying the file from which the data were derived.

The sheets of “Trinity_SAB_Dataframe.xls” were imported into tables of the Access database “Trinity_SAB_Dataframe.accdb”, and modified only insofar as strict data typing was enforced (for example, most tables have a “segmentID” field, which was coerced into the type “long integer” and made the table’s native key).

3 REFERENCES

Beechie, T., G. Pess, and H. Imaki, 2012. Estimated changes to Chinook salmon (Oncorhynchus tshawytscha) and steelhead (Oncorhynchus mykiss) habitat carrying capacity from rehabilitation actions for the Trinity River, North Fork Trinity to Lewiston Dam. Contract report to the U.S. Fish and Wildlife Service, Arcata California. 29 pp.

Clarke, K. C., 1997. Getting Started With Geographic Information Systems, Prentice Hall, Upper Saddle River, NJ.

HVT et al. (Hoopa Valley Tribe, McBain & Trush, Inc., and Northern Hydrology and Engineering), 2011. Channel Rehabilitation Design Guidelines for the Mainstem Trinity River. Prepared for the Trinity River Restoration Program, dated January 2011. 161 pp. plus appendices.

APPENDIX E

ANALYSIS OF HABITAT-GEOMORPHIC RELATIONSHIPS USING THE DATA FRAME

This appendix details two approaches for estimating juvenile coho and Chinook salmon rearing habitat at base flow using linear models that relate observed habitat availability to remotely sensed channel features. The analyses are intended to provide examples of how total habitat can be estimated over space and time to examine response to management actions and to provide input for a fish production model as part of implementing a decision support system.

APPENDIX E-1

DATA FRAME ANALYSIS OF HABITAT–GEOMORPHIC RELATIONS FOR JUVENILE CHINOOK AND COHO SALMON, HABITAT TRENDS, AND CHANNEL CHANGE

Prepared for
Trinity River Restoration Program

Prepared by
The Trinity River Restoration Program’s Scientific Advisory Board

April 2014

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1 INTRODUCTION

As part of the Phase 1 review, we were interested in assessing the effects of the Program's management actions (flow release, gravel augmentation, channel rehabilitation) on juvenile rearing habitat availability for coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) within the restoration reach of the Trinity River (upper 64 km). To address this issue, we used a *data frame* (Appendix D) to (1) develop relations between measured rearing habitat availability and remotely-sensed channel characteristics; (2) predict habitat availability across the entire restoration reach from the above relations (i.e., extrapolate into unsampled areas); (3) examine temporal trends in predicted habitat availability; and (4) relate predicted changes in habitat to management actions.

2 METHODS

2.1 Observational Units

The data are a mixture of (1) field measurements of juvenile rearing habitat area determined from habitat surveys conducted by the Program at select locations (e.g., Alvarez et al. 2013), (2) remote-sensed physical characteristics based on aerial photography and low-flow banklines of the entire restoration reach, (3) mapped locations of TRRP actions such as channel re-construction and gravel augmentation, and (4) the daily hydrometric record at the Lewiston gaging station (USGS 11525500). The *data frame* is a GIS data base created for the Program's Science Advisory Board (SAB) that includes many physical and biological features attributed to 200-m segments along the restoration reach (Appendix D). The 200-m segments were split from the Program's 400-m sample segments, commonly referred to as "GRTS" units by Program Partners due to the their sampling design provenance (Goodman et al. 2012)

Habitat measurements made in 200-m segments that were located close together were likely dependent (i.e., spatially autocorrelated), which would preclude the use of simple linear regression models without accounting for such dependencies (Sokal and Rohlf 2012). Thus, we initially fit a global (i.e., model containing all of the predictors) linear regression model that related habitat availability for each life stage to stream channel characteristics. An examination of the residuals ordered by longitudinal position indicated spatial autocorrelation for all four response variables (Figure E1). To account for the spatial dependence, we examined relations using hierarchical linear models. Hierarchical models differ from more familiar regression techniques in that dependence among observations collected within a unit, defined as lower-level units (200-m segments) within upper level units (reaches), is incorporated by including random effects for the lower level intercepts and slopes (Bryk and Raudenbush 2002). All random effects were assumed to be normally distributed with mean of zero and random effect-specific variance (Bryk and Raudenbush 2002). We evaluated the relative fit of two error structures. The first modeled dependence among adjacent 200-m segments and the second modeled dependence among the 5 geomorphic reaches previously classified by the TRRP (Hoopa Valley Tribe et al. 2011). The best error structure was selected using Akaike's Information Criteria (AIC; Akaike 1973) with the small-sample bias adjustment (AICc; Hurvich and Tsai 1989). The error structure with the lowest AICc was used for all model selection, as described below.

2.2 Juvenile Salmonid Habitat Availability and Channel Characteristics

Our four responses were: estimated *total habitat availability* and estimated *optimal habitat availability* for fry and presmolts in the 200-m segments. Total habitat availability for each life stage was estimated using the GRTS data as the sum of three types of habitat: depth, velocity, and cover (DVC); depth and velocity no cover (DVx); and cover only (xxC). Optimal habitat availability was estimated from the DVC category only. We examined the relations between habitat availability and stream channel characteristics derived from aerial photographs taken during low-flow (~ 450 cfs, 12.7 cms) conditions. Channel characteristics included: total bank length of each segment, estimated as the sum of the channel length (left and right bank, the length of which may differ substantially from the 200-m center-line length of each segment); total edge length, estimated as the sum of the length of banks, islands, and bars; average width of the segment, estimated as the wetted area divided by the segment length (200 m); and channel complexity, estimated as:

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

Pearson correlations were run on all pairs of continuous predictor variables prior to analyses. To avoid multicollinearity, predictor variables that were strongly correlated ($|r| < 0.4$) were not used together in the modeling procedure.

Our primary objectives were to identify the stream channel characteristics most strongly related to habitat availability and to the develop the best predicting model for estimating habitat availability in unsampled stream sections using stream channel characteristics derived from aerial photographs. Therefore, we fit all subsets of uncorrelated predictor variables including two-way interactions and quadratic terms. First order interactions and quadratic terms were only included in models that contained the corresponding main effects. To assess the fit of each candidate model, we calculated AICc (defined above). AIC is an entropy-based measure used to compare candidate models (Burnham and Anderson 2002), with the best-approximating candidate model having the smallest AICc. Goodness-of-fit for the global hierarchical models was evaluated by examining residual plots (following Bryk and Raudenbush 2002). All models were fit using the R package lme4 (Bates et al. 2012) and nlme (Pinheiro et al. 2012). Copies of all R scripts used for the analysis can be obtained from J.T. Peterson, USGS Oregon Cooperative Fish and Wildlife Research Unit, Corvallis OR.

One of our objectives was to estimate changes in juvenile salmonid habitat availability through time in the Trinity River. Statistical models, however, should only be applied to conditions similar those under which model-fitting data were collected. The GRTS habitat data and remote sensed channel data were collected during base flows, but they overlap only in 2009 and 2011. To evaluate the similarity between stream conditions during the GRTS survey and the remotely sensed data collection, we created a plot of wetted channel area estimated with the GRTS data and the remotely sensed data and visually examined the relation.

2.3 System-wide Changes in Habitat Availability Through Time

We estimated habitat availability in the Trinity River using remotely-sensed data of stream channel features for the five years 2001, 2005, 2007, 2009, and 2011. Habitat in 200-m segments was estimated using the best approximating models of total and optimal habitat by life-history stage. The habitat data models were fit to natural log-transformed data due to heteroscedastic error (see results below). Therefore, we back transformed the predicted values and prediction variances for each segment and applied the bias adjustment following Soakal and Rolf (2012), producing estimates of *median* habitat availability. The median estimates and prediction variances then were summed across all 200-m segments, by year, to obtain estimates of median habitat availability and variance for the Trinity River. We also calculated 95% confidence limits of the median habitat availability using the prediction variances based on a *t*-statistic with *n*-1 degrees of freedom (Sokal and Rolf 2012).

To quantify average changes in median habitat availability through time, we fit linear regression models. Candidate models of habitat availability included: the year and the discharge that remote sensed data were collected. These predictors were included individually and together and the relative support for each model was estimated calculating AIC and AIC weights following Burnham and Anderson (2002). We focus on reporting delta AIC values and AIC weights because they are the interpretable as evidentiary measures (i.e., AIC is meaningless by itself). All models were fit using R base package (R Core Team 2012). Goodness-of-fit of each model was assessed by examining residual plots.

2.4 Evaluation of System-wide Channel Response to Management Actions

An objective of the Phase I review was to assess whether TRRP actions affected the availability of juvenile salmonid habitats system-wide within the 64 km restoration reach. In the previous analysis, we evaluated changes in median habitat availability through time. Here, we evaluate the relative support for hypotheses relating changes in channel features to TRRP management actions. We focused the analysis on three channel features: bank length, mean channel width, and channel complexity (defined above) because they were strongly related to juvenile salmonid habitat availability (see Results). We estimated the changes in channel features in 200-m segments of the Trinity River as:

$$dx_{i,t} = x_{i,t} - x_{i,t-1}$$

Where:
dx = the change in channel feature
x = the estimated channel feature i at time t and the previous time period t-1.

For example, the change in bank length from 2001 to 2005 ($t = 2005$) was determined as estimated bank length in 2005 minus estimated bank length in 2001.

We used an evidentiary approach (Burnham and Anderson 2001) to evaluate the relative plausibility of hypotheses relating changes in channel features to TRRP management actions. We began by developing models relating hypothesized effects of management actions on changes in the channel features (Table E1). These hypotheses represent four themes: the effects of 1) high flows, 2) gravel augmentation, 3) construction activities, and 4) bank material and channel confinement on system-wide changes in channel features through time. To evaluate the effect of high flows, we estimated the total number of days that flows exceeded one of three thresholds (4000, 6000, and 8000 cfs) in the interval between the dates that remotely sensed data were collected. For example, the number of 4000 cfs exceedence days for $t = 2005$ was the total number of days between the 2001 and 2005 dates of aerial photography that flows exceeded 4000 cfs. We also estimated the effect of gravel augmentation and construction activities by calculating the distance (m) from the midpoint of each 200-m segment to the nearest upstream gravel augmentation and construction activity. For example, if an action took place in an adjacent upstream 200-m segment, the estimated distance from the nearest activity was 100 m. Upstream construction activities were categorized as bank removal, floodplain construction, side channel construction, main channel construction, and wood placement based on classifications in the data frame (Table E2). Streambank material and degree of channel confinement also were categorized for each 200-m segment based on mapping conducted by the Program (Table E2). From these data we estimated the proportion of bank length that consisted of resistant bank material and/or that was laterally confined by features such as hillslopes or relict river terraces. High values of these proportions indicate a restricted channel (confined and/or resistant boundaries), while low values indicate a relatively unrestricted channel (unconfined and/or non-resistant boundaries that would allow more dynamic alluvial responses). We include bank material and channel confinement as factors in our analysis because of their potential role in modulating management actions in this semi-alluvial river (Appendix C), even though they do not in themselves represent a management action.

To evaluate the relative support for hypotheses, we created 3228 candidate models representing all combinations of predictors in the 4 themes described above. Candidate models also included versions with no effect (i.e., null models) for each of the 4 themes. Different flow thresholds (defined above) were not included in the same model because they were strongly correlated. Quadratic terms and interactions only were included in models that included main effects. We fit each candidate model using linear regression and estimated AIC with the small-sample bias adjustment (AICc; Hurvich and Tsai 1989). The relative support for each model was assessed by calculating Akaike weights and the plausibility of each hypothesis was assessed by calculating importance weights as described in Burnham and Anderson (2002). These weights can range from 0 to 1, with the most plausible model and hypotheses having the highest weight. Our primary objective was to evaluate the strength of evidence for whether or not TRRP actions affected the availability of juvenile salmonid habitats system-wide. Therefore, we restricted our interpretations to evaluating the relative evidence for the hypotheses. All models were fit using the R base package (R Core Team 2012). Goodness-of-fit of each global (all predictors) model was assessed by examining residual and normal probability plots. Potential spatial dependence was assessed by examining a plot of residuals ordered by distance from Lewiston Dam.

3 RESULTS

3.1 Juvenile Salmonid Habitat Availability and Channel Characteristics

As expected, total edge and bank length were strongly correlated and were not included together in candidate models for habitat availability. Residual plots of all global habitat availability models indicated heteroscedasticity of variance. Therefore, we natural log-transformed habitat availability responses and refit the models. Examination of the residual plots from models fit to the natural log-transformed data indicated that independence and homogeneity of variance assumptions were met.

The best approximating error structure for all habitat measures was obtained when segments were classified by the 5 geomorphic reaches. The difference in AICc values between the 5-reach classification and the adjacent reach (nearest neighbor) error structures were greater than 10, indicating overwhelming evidence that the former was the best approximating. Plots of the hierarchical model residuals indicated no apparent longitudinal pattern (Figure E1). Therefore the 5-reach classification error structure was used for all model selection.

The best approximating models of habitat availability varied among responses (total available and optimal habitat) and life history stage (fry and presmolts) and contained various combinations of total bank length, average width of segment, channel complexity, and associated quadratic terms and two-way interactions (Table E3). The coefficients of determination indicated that channel characteristics explained 85% of the variability in total habitat availability for both fry and smolt. In contrast, the best approximating models of optimal habitat explained 63-64% of the variability in optimal fry and presmolt habitat (Table E3). The above relations allow system-wide prediction of juvenile rearing habitat across the entire restoration reach (i.e., in unsampled areas) at baseflow conditions (Figure E2).

Examination of a plot of wetted channel area at baseflow estimated with the GRTS data versus the remotely sensed data indicated close correspondence of channel area measures for the overlapping years 2009 and 2011 (Figure E3). Therefore, we assumed that baseflow conditions during all years were sufficiently similar to justify the use of models fit to the GRTS data for estimating habitat availability with the remotely sensed channel measures.

3.2 System-wide Changes in Habitat Availability Through Time

Estimates of changes in total median habitat availability in the Trinity River indicated an increase from 2001- 2011 (Figure E4). Linear regression models indicated strong support that variation in total habitat availability was related to year and discharge during the collection of the remotely sensed data (Table E4). Of these, the ratio of AICc weights for models containing year only were 3 - 68 times greater than models with discharge only, indicating strong evidence that variation in total habitat availability at baseflow was most strongly related to something that varied with time. The best approximating models explained more than 85% of the variation is total median habitat availability (Table E4). We estimate that total habitat at baseflow increased, on average, 1321 m^2/y and 4356 m^2/y for fry and presmolt, respectively. In contrast, the trends for optimal habitat were much weaker with slopes that suggested that optimal habitat increased by 1284 m^2/y and 1304 m^2/y for fry and presmolt, respectively. These values correspond to 1.2 - 1.6% per year increases in habitat availability from 2001 values.

3.3 Evaluation of System-wide Channel Response to Management Actions

Akaike importance weights indicated strong evidence (weights > 0.90) that changes in the channel characteristics related to juvenile habitat were related to the duration of high flows, upstream gravel augmentation, construction activities, and streambank material and channel confinement (Table E5). The ratio of these weights to weights under a null model (i.e., one minus the importance weights) indicated these factors were at least 9 times more likely to be responsible for changes in channel characteristics and associated habitat availability. There also was strong evidence that relations between high flows and changes in average width and channel complexity were non-linear. Evidence that the changes in channel characteristics and associated habitat availability were due to interactions among high flows, upstream gravel augmentation, construction activities, streambank material and channel confinement was mixed (Table E5). There was strong evidence that the effect of gravel placement on mean width changed with high flow duration, but the evidence was weaker for habitat availability. There also was strong evidence that high flows interacted with construction activities to change bank length and channel complexity.

4 CONCLUSIONS

Our analysis outlines an approach that can be used for (1) developing relations between measured habitat availability and remotely-sensed channel characteristics; (2) extrapolating these results to unsampled areas of the river; (3) examining temporal trends in habitat availability; and (4) relating predicted changes in habitat to management actions. Results indicate that juvenile rearing habitat availability has increased since 2001 (albeit slowly, 1.2-1.6% per year) and that management actions are having a positive effect. Data availability limited our analyses of remotely-sensed characteristics to base flow, but ideally the approach would be applied across a range of flows to develop flow/habitat relationships for input to a fish production model. Similarly, channel features were limited to those available to us. Consequently, users may wish to consider additional or alternative features to increase model accuracy; nor is it likely that a single set of features can be used for all species and life stages.

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TABLES

Table E1

Hypothesis and corresponding predictors used to evaluate the relative support for the effect of management actions on system-wide changes in channel features that were related to rearing habitat availability for juvenile coho and Chinook salmon in the Trinity River

Hypothesis	Predictors[1]
Habitat availability correlates increase with the duration of high flows.	Number of days between remote sensed data collection that flows exceeded a threshold. Thresholds evaluated: 4000, 6000, 8000 cfs
Habitat availability correlates increase in areas downstream of gravel augmentation sites, but the effect diminishes with distance.	Nearest upstream gravel augmentation, distance to the action
Habitat availability correlates increase in areas downstream of construction sites, but the effect diminishes with distance.	Nearest upstream construction activity, distance to that activity. Activities included: Bank removal, floodplain construction, side channel construction, main channel construction, wood placement
Habitat availability correlates vary with the characteristics of streambanks	Proportion of stream bank that are resistant, are comprised of resistant material, or confined
Habitat availability correlates increase with the duration of high flows, but the effect diminishes beyond a threshold number of exceedence days	Quadratic term corresponding to flow exceedence in the model
The effect of gravel placement on habitat availability correlates change with high flow duration	Interaction between gravel placement and number of exceedence days
The effect of construction activities on habitat availability correlates change with high flow duration	Interaction between construction activity and number of exceedence days
The effect of high flow duration varies with bank material and channel confinement	Interaction between number of exceedence days, bank material, and channel confinement
The effect of gravel augmentation varies with distance, bank material and channel confinement	Interaction between gravel augmentation, distance from augmentation, bank material, and channel confinement
The effect of construction activities varies with distance, bank material and channel confinement	Interaction between construction activity, distance from activity, bank material, and channel confinement

Note:

[1] Quadratic terms and interactions were only present when main effects were included.

Table E2

Predictors and data source used to evaluate the relative support for hypotheses relating TRRP management actions to system-wide changes in channel features related to rearing habitat availability for juvenile coho and Chinook salmon

Predictor	Source in data frame
Number of days between remote sensed data collection that flows exceeded a threshold	Exceedence (Annual)
Gravel augmentation	Gravel augmentation - island
	Gravel augmentation - point bar
	Gravel augmentation - riffle
	Gravel augmentation - transverse bar
	Gravel augmentation (unspecified)
Streambank material	Resistant: bedrock, boulder, cohesive sediment, riprap
	Non-resistant: gravel, sand
Channel confinement	Confined, extremely confined
	Unconfined, partially confined
Construction activities	
Bank Removal	Bank removal
	Berm removal
	Berm removal (notch)
Floodplain construction	Constructed floodplain (0450 cfs)
	Constructed floodplain (2000 cfs)
	Constructed floodplain (4,000 cfs)
	Constructed floodplain (5,000 to 6,000 cfs) and high flow scour channel
	Constructed floodplain (6,000 cfs) & high flow scour channel
	Constructed floodplain (6000 cfs)
	Constructed floodplain (flow unspecified)
	Constructed floodplain (flow variable)
	Feathered edge & constructed floodplain (6000 cfs)
Side channel construction	Low flow side channel (300 cfs)
	Low flow side channel (300 cfs)
	Low flow side channel (450 cfs)
	Low flow side channel (flow unspecified)
	Side channel
Main channel construction	Main channel realignment - anastomosing
	Main channel realignment - meandering
	Main channel realignment - split flow
Wood placement	Wood placements

Table E3

Parameter estimates, standard errors (SE), and upper and lower 95% confidence limits of best approximating hierarchical linear models for estimating rearing habitat availability for juvenile coho and Chinook salmon in the Trinity River using the GRTS habitat data and channel measurements.

	Estimate[a]	SE	Lower	Upper
Fry total habitat, R^2 = 0.85				
Fixed Effects				
Intercept	0.24610	0.26830	-0.27977	0.77197
Average channel width	0.18190	0.01751	0.14758	0.21622
Average channel width^2	-0.00205	0.00025	-0.00254	-0.00157
Bank length	0.00809	0.00103	0.00607	0.01011
Bank length^2	-0.00001	0.00000	-0.00001	0.00000
Complexity	0.04532	0.01268	0.02047	0.07017
Random effects[b]				
Intercept	0.26908			
Average channel width	0.00034			
Fry optimal habitat, R^2 = 0.63				
Fixed Effects				
Intercept	-0.26260	0.61800	-1.47388	0.94868
Average channel width	0.15860	0.04030	0.07961	0.23759
Average channel width^2	-0.00242	0.00084	-0.00407	-0.00078
Bank length	0.00986	0.00367	0.00266	0.01705
Bank length^2	-0.00001	0.00000	-0.00002	-0.00001
Complexity	-0.36710	0.16550	-0.69148	-0.04272
Complexity^2	0.02229	0.01001	0.00267	0.04191
Average channel width* bank length	0.00013	0.00007	0.00000	0.00026
Random effects				
Intercept	0.21506			
Presmolt total habitat, R^2 = 0.85				
Fixed Effects				
Intercept	0.66970	0.40760	-0.12920	1.46860
Average channel width	0.17980	0.02353	0.13368	0.22592
Average channel width^2	-0.00207	0.00032	-0.00269	-0.00144
Bank length	0.00738	0.00102	0.00538	0.00939
Bank length^2	-0.00001	0.00000	-0.00001	0.00000
Complexity	0.05965	0.01156	0.03699	0.08231

	Estimate[a]	SE	Lower	Upper
Random effects				
Intercept	0.30977			
Average channel width	0.00033			
Presmolt optimal habitat, R^2 = 0.64				
Fixed Effects				
Intercept	-0.54740	0.59140	-1.70654	0.61174
Average channel width	0.14190	0.03714	0.06911	0.21469
Average channel width^2	-0.00124	0.00053	-0.00228	-0.00020
Bank length	0.01424	0.00307	0.00823	0.02025
Bank length^2	-0.00001	0.00000	-0.00002	-0.00001
Complexity	-0.38670	0.16290	-0.70598	-0.06742
Complexity^2	0.02152	0.00985	0.00222	0.04082
Random effects				
Intercept	0.21879			

Notes:

[a] Habitat availability data were natural log-transformed prior to model fitting.

[b] Random effects are variance component estimates.

Table E4

Parameter estimates, standard errors (SE), and upper and lower 95% confidence limits of best approximating linear models for estimating changes in median rearing habitat availability for juvenile coho and Chinook salmon in the Trinity River from 2001 - 2011.

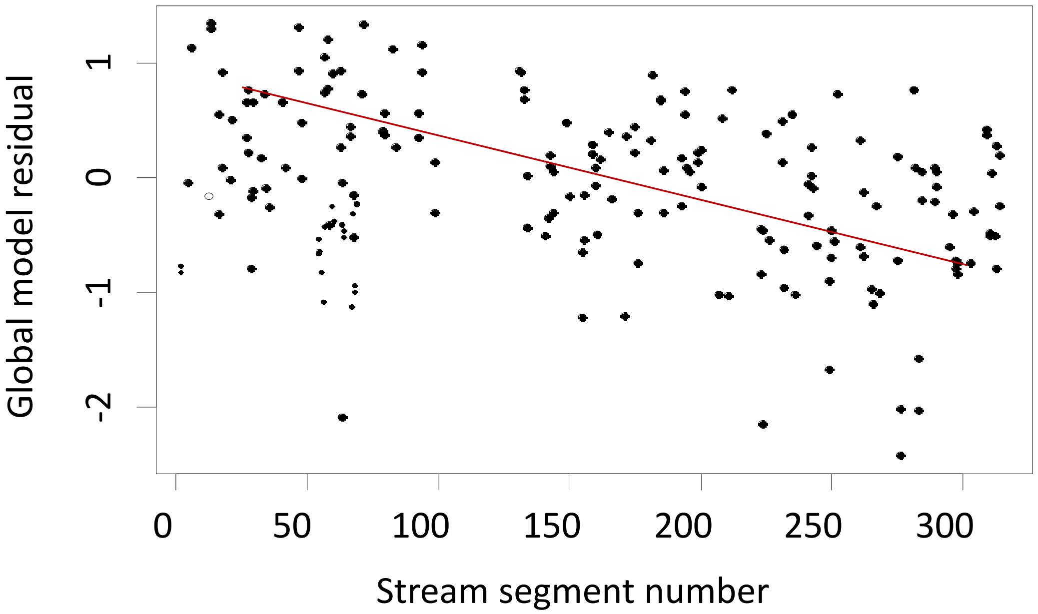
Parameter	Estimate	SE	Lower	Upper
Fry habitat availability R^2 *= 0.897*				
Intercept	-7356000.0	1999000.0	-11274040.0	-3437960.0
Year	3821.0	997.8	3.9	0.1
Discharge (cfs)	48.5	46.8	1.0	0.4
Optimal fry habitat, Multiple R^2 *= 0.948*				
Intercept	-2500000.0	551100.0	-3580156.0	-1419844.0
Year	1284.0	275.1	744.8	1823.2
Discharge (cfs)	38.9	12.9	13.7	64.2
Presmolt habitat availability, R^2 *= 0.856*				
Intercept	-8354795.0	2072734.0	-12417353.6	-4292236.4
Year	4356.0	1033.0	2331.3	6380.7
Presmolt optimal habitat availability, R^2 *= 0.956*				
Intercept	-2523000.0	540900.0	-3583164.0	-1462836.0
Year	1304.0	270.0	774.8	1833.2
Discharge (cfs)	46.7	12.7	21.9	71.6

Table E5

Akaike importance weights for hypotheses relating management actions to system-wide changes in stream channel correlates of rearing habitat availability for juvenile coho and Chinook salmon. Weights can vary from 0-1 with 1 indicating the strongest support.

	Importance weights		
<u>Hypothesis</u>	Bank length	Average width	Channel complexity
Habitat availability correlates increase with the duration of high flows			
4000 cfs exceedence	0.265	0.999	0.017
6000 cfs exceedence	0.193	0.000	0.044
8000 cfs exceedence	0.539	0.000	0.937
None	0.003	0.000	0.002
Habitat availability correlates increase in areas downstream of gravel augmentation sites, but the effect diminishes with distance.			
Yes gravel effect	0.997	1.000	0.998
No gravel effect	0.003	0.000	0.002
Habitat availability increases in areas downstream of construction sites, but the effect diminishes with distance.			
Bank removal	0.000	0.009	0.000
Floodplain construction	0.043	0.094	0.333
Side channel construction	0.015	0.000	0.347
Main channel construction	0.000	0.897	0.000
Wood placement	0.939	0.000	0.318
None	0.003	0.000	0.002
Habitat availability varies with streambank material and channel confinement	0.996	0.999	0.997
Habitat availability increases with the duration of high flows, but the effect diminishes beyond a threshold number of exceedence days	0.679	1.000	0.973
The effect of gravel placement on habitat availability changes with high flow duration	0.232	1.000	0.569
The effect of construction activities on habitat availability changes with high flow duration	0.974	0.378	0.964
The effect of high flow duration varies with streambank material and channel confinement	0.585	0.789	0.748
The effect of gravel augmentation varies with distance, streambank material and channel confinement	0.711	0.501	0.295
The effect of construction activities varies with distance, streambank material and channel confinement	0.412	0.956	0.823

FIGURES



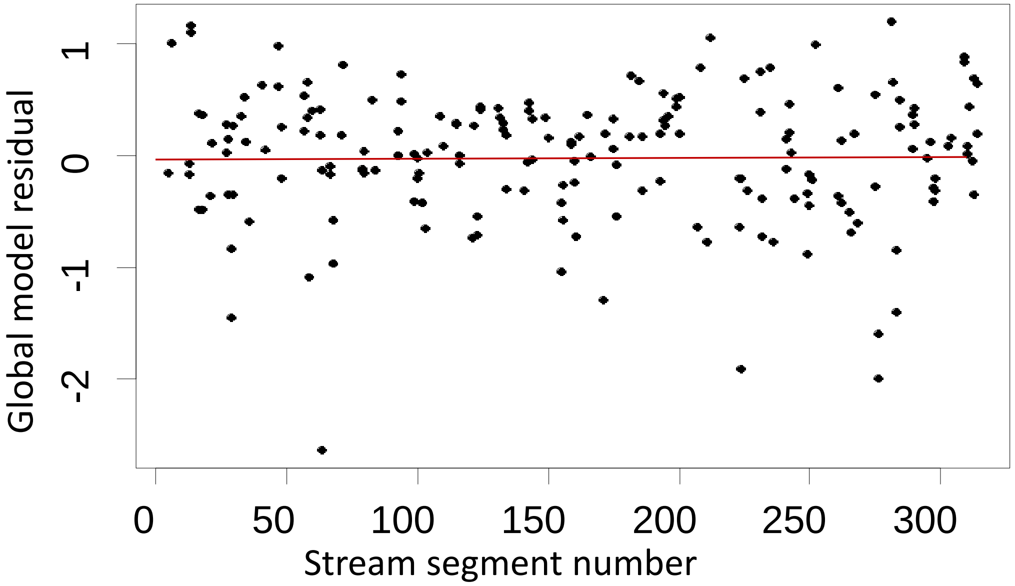


Figure E1

Example of spatial dependence in residuals from the global model of fry habitat availability (top) and elimination of spatial dependence using a hierarchical model that accounts for dependence related to the five geomorphic reaches previously identified by the TRRP (bottom).

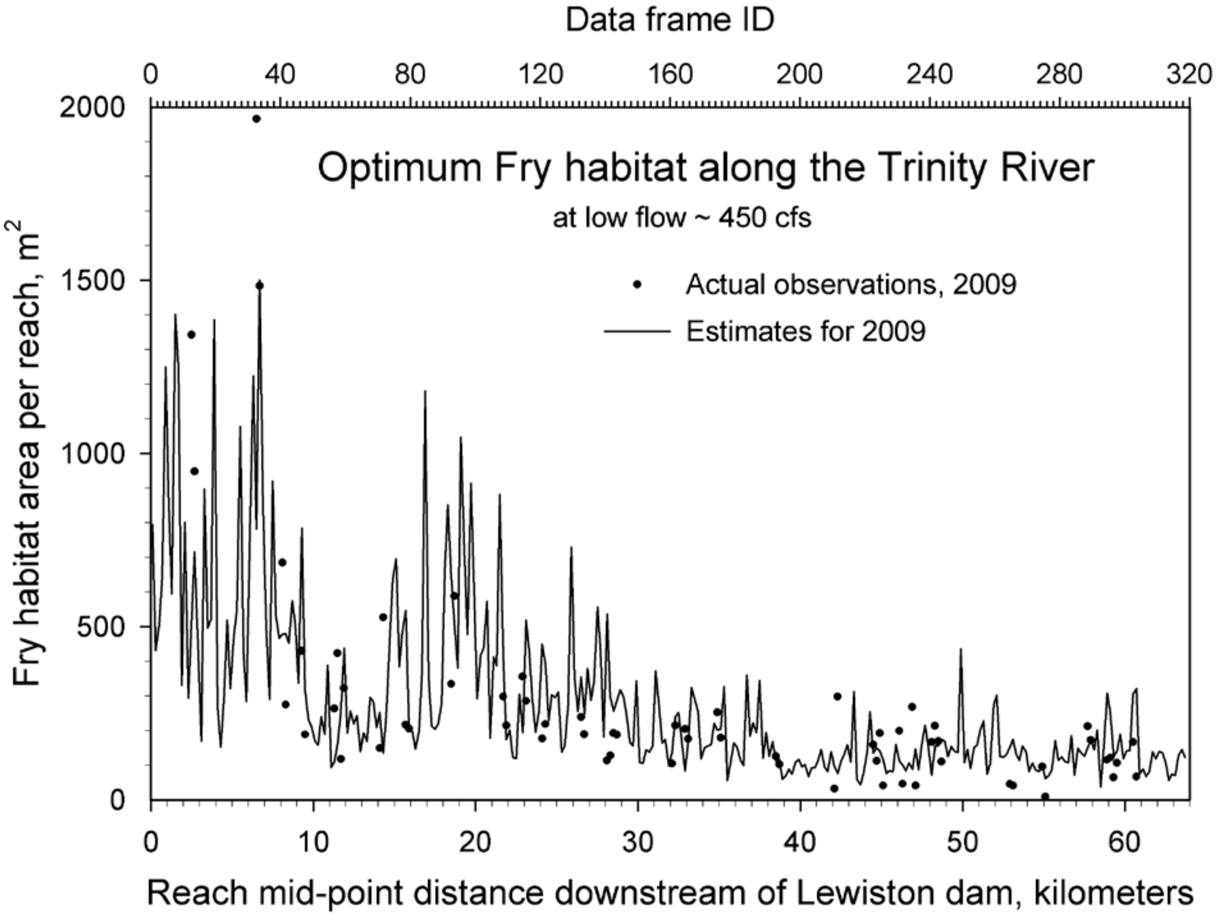


Figure E2

Prediction of optimum fry habitat for Chinook and coho salmon along the restoration reach of the Trinity River. Habitat was estimated using the best approximating models in Table E1 and the stream channel characteristics of 200-m segments from remotely sensed data. Solid circles are observed habitat values from GRTS sampling.

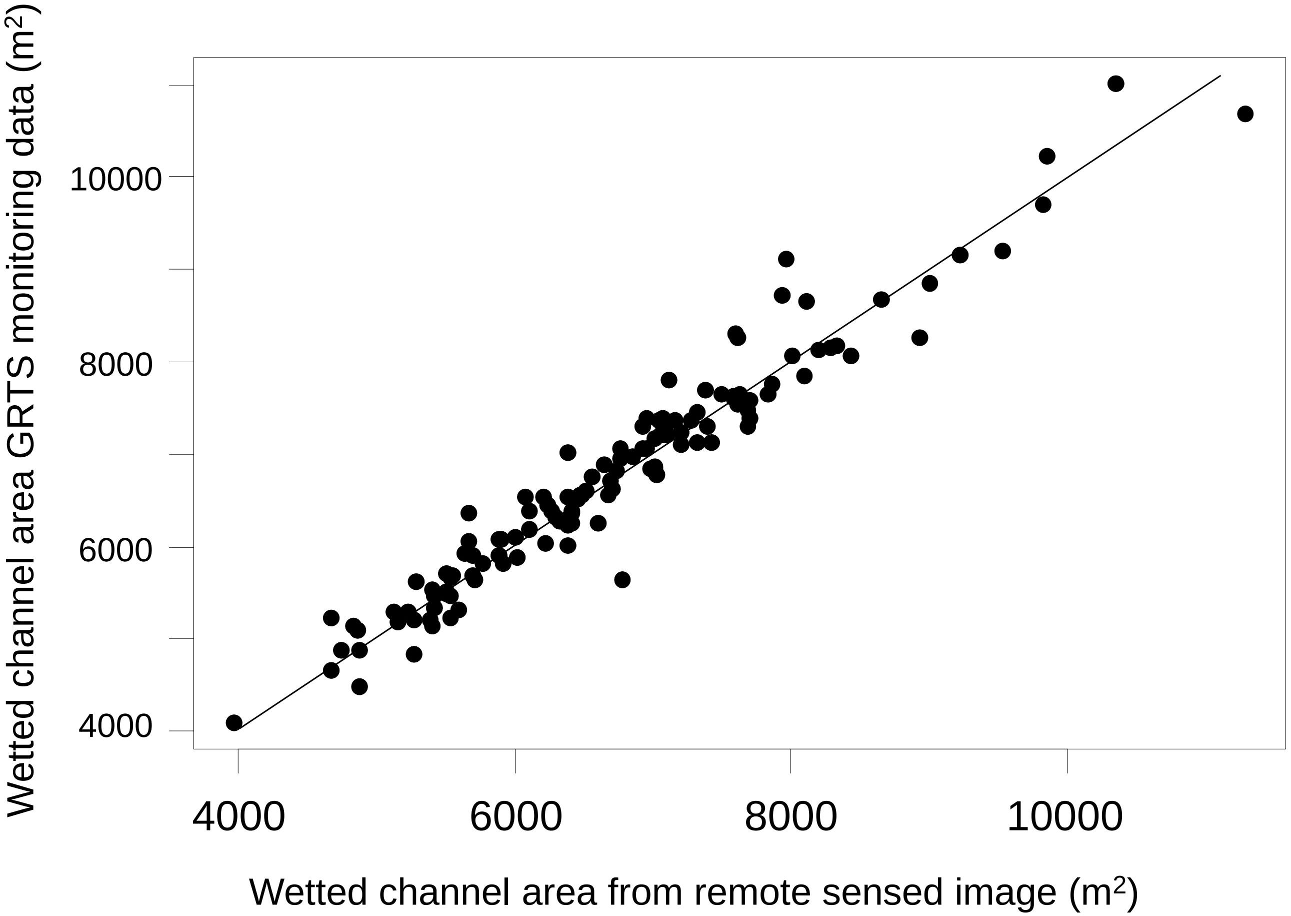


Figure E3

The relation between wetted channel area for 200-m segments on the Trinity River estimated using two different TRRP datasets: the GRITS field measurements and remotely sensed data. Line indicates one-to-one correspondence between measures.

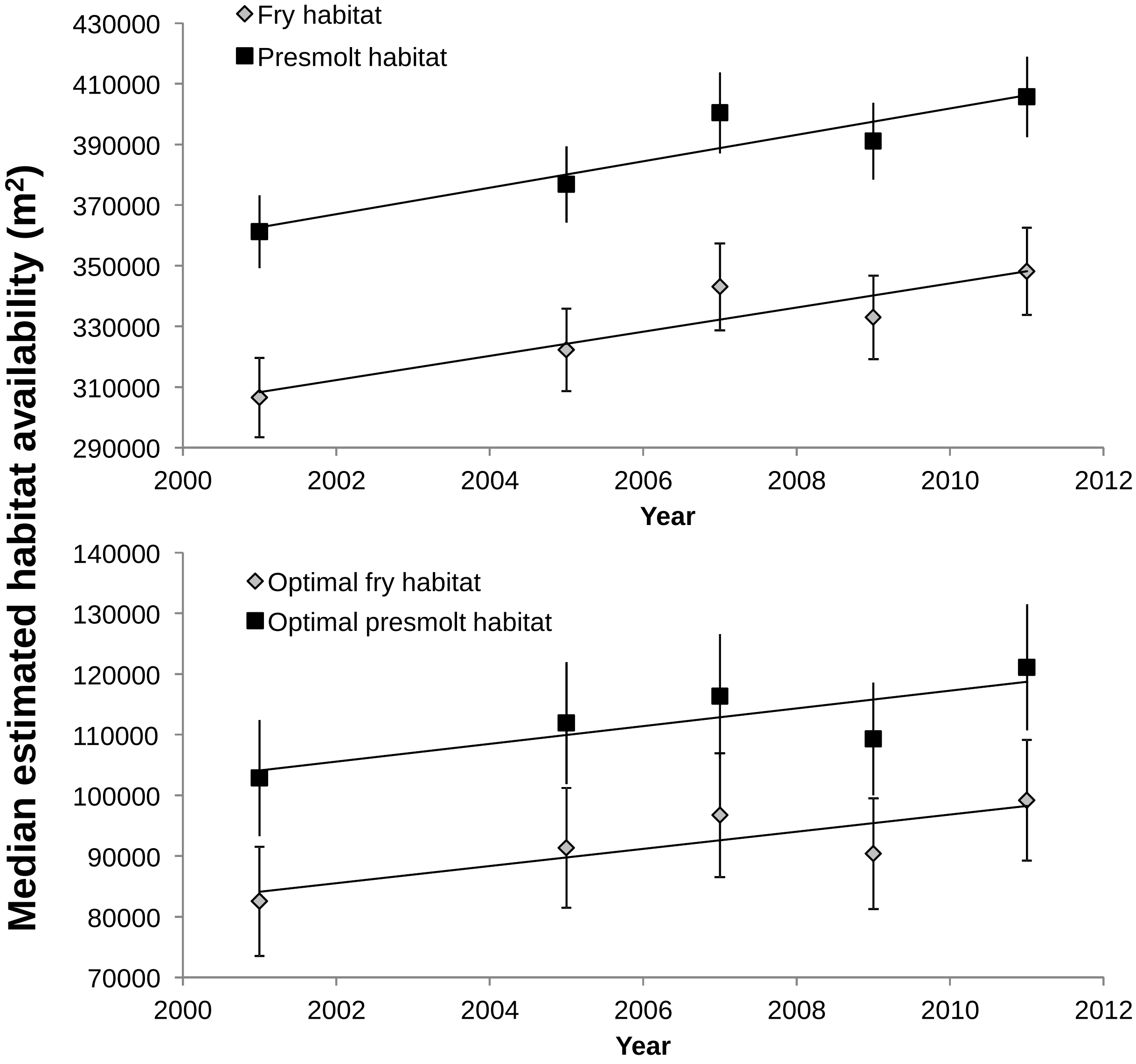


Figure E4

Increase in estimated total (top) and optimal (bottom) base-flow rearing habitat for juvenile Chinook and coho salmon in the Trinity River over the course of the TRRP, by life history stage. Channel rehabilitation projects began in 2005. Habitat was estimated using the best approximating models in Table E1 and the stream channel characteristics of 200-m segments from remotely sensed data. The trend lines were estimated using least-square linear regression. Vertical bars represent 95% confidence limits on estimates.

APPENDIX E-2

ESTIMATING JUVENILE HABITAT WITH STREAM CHANNEL CHARACTERISTICS ALONG THE TRINITY RIVER

Prepared for

Trinity River Restoration Program

Prepared by

Trinity River Restoration Program's Scientific Advisory Board

April 2014

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1 PURPOSE AND RATIONALE

Salmon habitat is an important aspect of the TRRP but is expensive to measure in the field. Estimating habitat at unobserved river locales will provide information on total habitat over time and space for the actual river as well as the virtual one intended for a fish production model such as SALMOD. Furthermore, the analysis that provides the estimation also lends insight to what factors drive habitat. This analysis differs from the previous effort in Appendix E-1 in that it tests different hypotheses with a different combination of data sets. Its main purpose is to demonstrate how channel characteristics obtained from aerial photography, LiDAR, and HEC-RAS can be used to estimate juvenile salmonid habitat that meets depth and velocity crtiteria.

Juvenile salmonids prefer shallow, low velocity water with cover (Thomas and Bovee 1993; Goodman et al. 2010). To predict such habitat for stream segments with no direct habitat measurements, a combination of available stream channel metrics could be potential estimators of juvenile habitat characterized by depth and velocity only. Although cover is important for habitat, cover is not readily available for reaches where habitat was not observed in the field.

Broader patches of shallow, slow water will likely exist in channels with lower-angle bank-margins and gentler water surface slope. Although bank angles or mean depths can be calculated from bathymetry, this is very time consuming, so a faster surrogate would be useful. Two are readily derived from mapped bank lines: surface area and mean width. Segment lengths, which follow the channel centerline at 5,000 cfs, are essentially equal, so surface area and mean width are expected to be strongly collinear.

Bank angle (the channel margin's slope orthogonal to the flow) partly controls how much the mean width or surface area changes with increasing discharge, so these rates of change between selected discharges indicates the mean bank angle for that range of discharge. Flow resistance affects the rate of change for stage and there are complex feed-backs between channel shape and flow resistance, but for a constant flow resistance along a channel, bank angle completely controls the width-change rate at a given locale. Conversely, for a constant bank angle along a channel, the amount of flow resistance controls the stage-to-discharge relation, and in turn, the width-change rate at a given locale. These channel-shape and discharge relations are addressed in Rhodes 1977.

With constant flow resistance along a channel, velocity would vary with water surface slope. Thus, slope was used as a surrogate for velocity. Friction is high near bank margins, and it is conceivable that the shallow, low-velocity areas are concentrated along bank margins, so bank length was used to represent this.

2 DATA SOURCES

Habitat area by life stage (guild) and criteria for juvenile Chinook salmon were extracted from mapped data provided by the TRRP's Fish Working Group; habitat areas for 2009, 2010, and 2011 that were mapped along sampled 400-meter segments during low flow (about 450 cfs at Lewiston) were available. Methods for obtaining these data are in Goodman et al. 2012.

Channel planform characteristics were extracted from HEC-RAS inundation surfaces for the entire project reach. The 2004 bathymetry and 2005 HEC-RAS model were used because newer HEC-RAS models were not available to us. Anchor QEA ran the HEC-RAS model for 450 and 800 cfs discharges, and Stillwater Sciences provided the inundation surface data for these surfaces in the ESRI shape-file format.

Water surface slope by 200-meter segment was extracted by Stillwater Sciences from the 2009 LIDAR-sensed, unobstructed water surface (Woolpert 2010).

We segmented the habitat data and the channel bank line into a standard set of 200-meter segments that split the TRRP's 400-meter segments. The 200-meter segmentation polygons were provided by Stillwater Sciences.

Bank length as a function of ruler length was assessed with 2005 aerial photography (file name 2005_MRSID.sid), where each pixel side is 0.15 meters. The 2004 photography resolution was too coarse (2 meters per side) to allow precise tracing, so the 2005 imagery was used instead.

3 METHODS

The response variables are habitat area (HA), in m^2, meeting the depth and velocity requirements for either fry (HA$_f$) or pre-smolts (HA$_p$). The timing of explanatory variables (2004 to 2005) largely differed from habitat observations (2009 to 2011), and habitat area across years by segment and life stage were highly correlated (Table 1) and with regression slopes near 1, so the average for all years of habitat area by segment was used instead of separating the response by year to simplify the analysis. Because of large changes in channel locations at channel rehabilitation sites, only data from non-constructed (natural) reaches were used, Cases were in downstream order.

Table 1
Pearson Correlation Coefficients Between Mean Habitat Area and Observation Year by Life Stage

	Fry			Pre-smolts		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**
Mean fry habitat for 2009 to 2011	0.992	0.884	0.961	0.918	0.835	0.913
Mean pre-smolts habitat for 2009 to 2011	0.947	0.830	0.880	0.990	0.908	0.968

The correlation between means for life stages for all years was also high (0.938), but life stages remained separate to make this analysis more comparable to others. For simplicity, models are shown with a generic response variable (HA), but separate regressions were run for each life stage (HA_f and HA_p).

The basic explanatory variables were: 1) difference in surface area (SA_δ) as discharge increases from 450 to 800 cfs; 2) water surface slope (s); and 3) bank-margin length at 450 cfs (l). The base unit for SA_δ and l is meters, and slope is m/m. The sample size (n) was 88 for all models, and they were fit using ordinary least squares regression within SYSTAT 8.03 (SPSS 1998).

A starting point is the generic multiple linear regression model:

$$HA = b_0 + b_1 * SA_\delta + b_2 * s + b_3 * l + b_4 * (s * l) + b_5 * (s * SA_\delta) + b_6 * (SA_\delta * l) + E \qquad (1)$$

where b_0 is the amount of habitat when all explanatory variables have a value of zero, and b_1 is a coefficient representing the rate of change for habitat area associated with a unit change in SA_δ given the other explanatory variables in the model. From a rational point of view, the expectation for b_0 is of course zero, but b_0 is retained because the explanatory variables were not observed near zero, and l =zero is not possible given the sampling structure. For models without l, parameter estimation is more complex without b_0. The coefficients b_2 to b_5 have meanings parallel to b_1. The error term E is the difference between observed and estimated HA; E is present in all models, but left out of subsequent descriptions for brevity.

Polynomials can be added to (1) to capture a curved response. Such models can yield more precise estimates, but given the discrepancies in actual and modeled water surfaces, the disparate timing of the channel and habitat data, and no apparent curved response in graphical analysis, quadratic or higher-power terms were not expected to be informative. However, quadratic (squared) terms were used to test for curvature.

As is customary, a sub-model with an interaction term also includes the corresponding lower-order terms so that the sums of squares remain centered without using special corrections. Multi-collinearity was often present in interaction and quadratic terms (Table 2). Mean-centered explanatory variables were used to reduce collinearity (Kleinbaum et al. 1988), and most of it was reduced (Table 2). A mean-centered variable uses the following transformation:

$$\text{Centered variable} = \text{observed variable} - \text{mean of observed variable} \tag{2}$$

Including quadratic terms in (1) adds a substantial number of sub-models to compare if all reasonable permutations are considered, so a smaller set of models with quadratic terms were tried to test whether quadratic terms were informative. These models, which used centered explanatory variables and retained the corresponding lower-order terms, were:

$$HA = b_0 + b_1 * SA_\delta + b_2 * SA_\delta^2 + b_3 * s + b_4 * s^2 + b_5 * l + b_6 * l^2 + b_7 * (s * l) + b_8 * (s * SA_\delta) + b_9 * (SA_\delta * l) \tag{3}$$

$$HA = b_0 + b_1 * SA_\delta + b_2 * SA_\delta^2 + b_3 * s + b_4 * s^2 + b_5 * l + b_6 * l^2 \tag{4}$$

$$HA = b_0 + b_1 * SA_\delta + b_2 * SA_\delta^2 + b_3 * l + b_4 * l^2 \tag{5}$$

$$HA = b_0 + b_1 * SA_\delta + b_2 * SA_\delta^2 + b_3 * s + b_4 * s^2 \tag{6}$$

$$HA = b_0 + b_1 * SA_\delta + b_2 * SA_\delta^2 \tag{7}$$

$$HA = b_0 + b_1 * l + b_2 * l^2 \tag{8}$$

3.1 Bankline Length as a Function of Ruler Length

The measured length of the bankline is sensitive to how finely the true bankline is measured (Mandelbrot 1983). A series of straight lines represents the bankline, and their shorter lengths indicates how closely the true bankline was followed or traced during the measurement process. The shorter the ruler, or the more tightly the true line is followed, the more complex and longer the measured line. The frequency distribution of the measured straight-line lengths are presented to indicate the precision of measurement, and the sensitivity to ruler length was assessed using an unvegetated bankline as depicted on the 2005 aerial photography. The length of this bankline as modeled at 450 cfs was 43.3 meters. The photography was converted to black and white pixels and printed on paper for manual length measurements at the following ruler lengths (ground distance): 0.15, 0.30, 0.60, and 1.20 meters; each pixel on the page was 2.5 mm. Pixel sides were counted directly for the 0.15 increment, while a divider at 5, 10, and 20 mm was used to measure the bank length directly on the printed page. All counts were to the nearest integer. For the 0.15 increment, all angles were either 0 or 90 degrees due to the pixellation. For the divider measures which spanned across pixels, the interior angles varied but were generally between 75 and 135.

The fractal geoemetry of a bankline was assumed to be similar to a coastline, for which the equation is:

$$L_{(\varepsilon)} = F * \varepsilon^{(1-D)}$$

where:
L is the length of the bankline, given ruler length ε, F is a constant, and D is the fractal dimension.

The determination of fractal dimension is explained in great detail in Mandelbrot 1983; for coastlines it is approximately log3/log4, and not sensitive to a wide range of ε. Mandelbrot does not discuss or define F. I found F to be reasonably constant (9350 to 9612) for published lengths of the British coastline for ruler lengths (ε) of 50 to 200 km (Richardson 1961, found in Mandelbrot 1983). For the unvegetated bank, F varied from 32.5 to 36.5 with ε ranging from 0.3 to 1.2 meters. F was much larger, at 47.3, for $\varepsilon = 0.15$. For bank lengths based on the fractal geometry equation, the average of F for all but $\varepsilon = 0.15$ was used.

3.2 Regression Model Comparisons and Selection

The full model (1) and all of its nested sub-models were compared using adjusted R^2, the standard error of the estimate (Sy|x), and Mallows C_p (Mallows 1973, 1995). Models 3 to 8 were compared as a group the same way as (1) and its sub-models. A desirable, selected model would have a higher adjusted R^2, lower Sy|x, and a low C_p with a value near its number of parameters (k), where k equals the number of independent variables (p) plus the constant. Other considerations were not including variables that have low tolerance values (< 0.1) which indicates strong collinearity among at least one other variable in the model (Belsley et al. 1980), and parameter estimates that are statistically greater than zero. This last criterion does not apply to lower order terms that have significant higher-order terms. The selected models were checked to make sure they met the assumptions for linear regression which are independent and normally distributed errors that are homoscedastic, and potentially influential observations were assessed with Cook's distance (Neter et al. 1989). The splitting of the 400-meter sample segments could create spatial auto-correlation, so autocorrelation coefficients and the Wald-Wolfolwitz runs test on the residuals above and below zero were conducted to check for independent residuals.

4 RESULTS

4.1 Bankline Length

The frequency distribution of bankline segment lengths are similar for the modeled 450- and 800-cfs inundation surfaces (Figure 1). The total length of all bankline segments, including the main channel, side channels, and islands, is 203494.467 and 204771.649 for the 450- and 800-cfs surfaces, respectively; other summary statistics are n Figure 1.

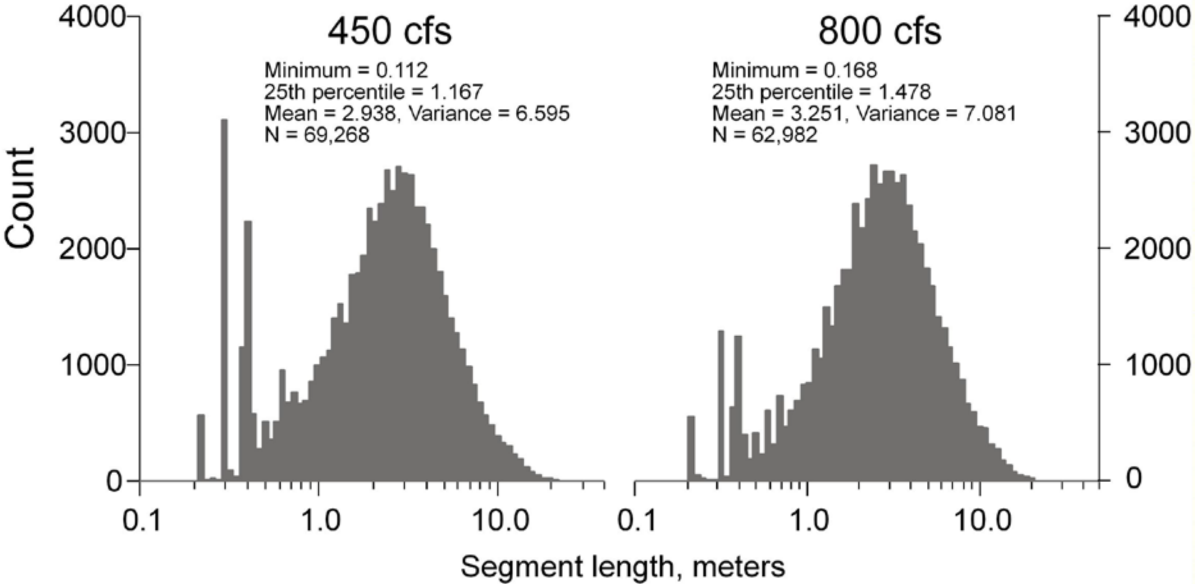


Figure 1

Frequency distribution of bankline segment lengths. These lengths are from the HEC-RAS inundation surfaces overlain on the 2004 bathymetry.

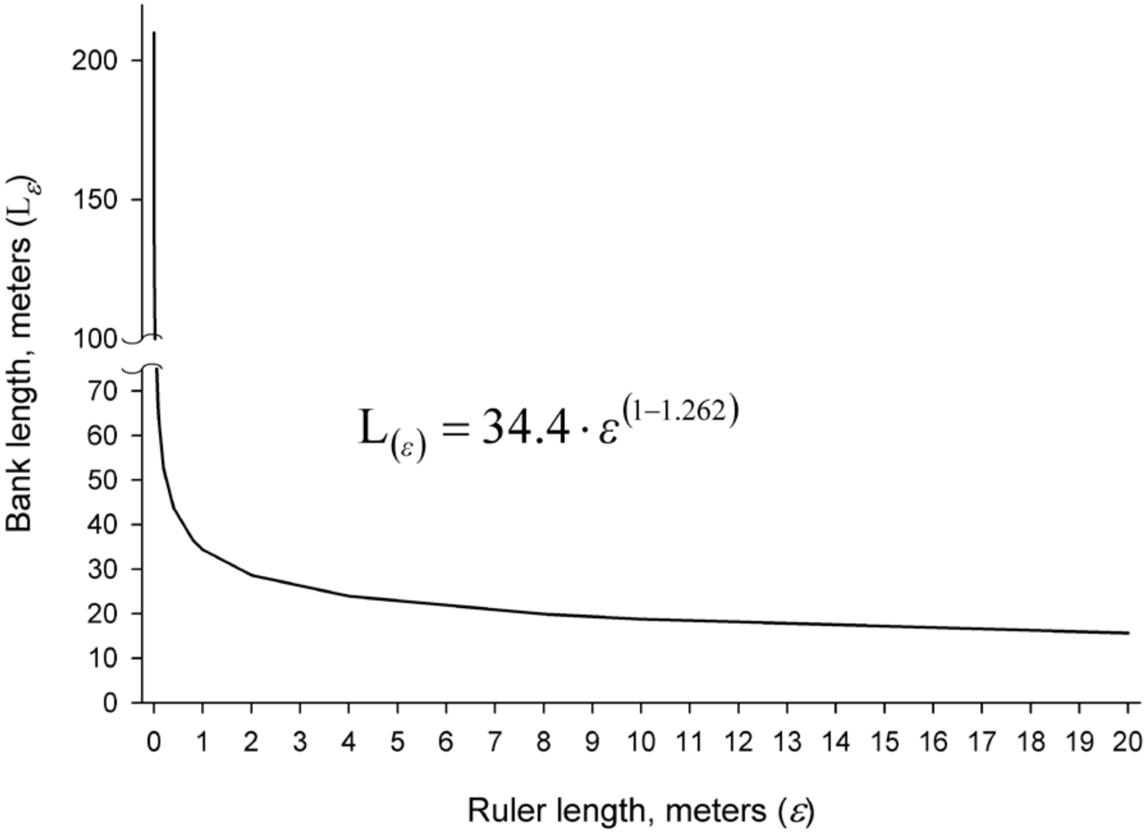


Figure 2
The influence of ruler length on banklength, as determined by the fractal geometry of coastlines. This curve is based on a section of unvegetated bank as photographed in 2005. The HEC-RAS modeled banklength for this same bank section was 43.3 meters.

4.2 Model Comparisons and Selection

Pair-wise combinations of explanatory variables and higher-order terms had varying amounts of collinearity (Table 2). Mean-centering reduced collinearity in most pairs that involved one or more higher-order variables.

Of the two groups, the best non-quadratic model (equation 9, No. 6 listed in Table 3) was a little better than the best of the quadratic group (equation 10, No. 19 in Table 3), although none of the models performed well. The standard error of the estimate (Sy|x) hovered around 200 m^2 for the fry models, and 300 m^2 for the pre-smolt models (Table 3). The respective mean habitat area for fry and pre-smolts within non-constructed reaches was 416.2 and 691.6 $m^{2,}$ so the Sy|x is about half the mean. Adjusted R^2 is also correspondingly low (< 0.24) for all models (Table 3). The best model for each life stage (equations 11 to 14, in section 4.1) had the same variables, but different coefficients.

$$HA = b_0 + b_1 * SA_\delta + b_2 * s + b_3 * l + b_4 * (s * SA_\delta) \tag{9}$$

$$HA = b_0 + b_1 * SA_\delta + b_2 * SA_\delta^2 + b_3 * l + b_4 * l^2 \tag{10}$$

Regarding the Cp criterion, the quadratic models should be evaluated along with the non-quadratic ones by using a common mean squared error, but a full model with interaction and quadratic terms could not be fit because of lingering multi-collinearity that prevented least-squares calculations in SYSTAT. The largest full models that ran are in the Table 3. Recall that the Mallows Cp is compared to the number of parameters (*k*), and unbiased models have a Cp less than or equal to *k*. The Cp is typically plotted against *k* to discern the best model, but in Table 3 it is easy to see that few models are unbiased and these are model numbers 2 and 6 within the non-quadratic group, and number 3 in the quadratic group. These selections hold for fry and pre-smolt model versions, and the ones with the lowest Cp values are denoted with bold text in Table 3. A closer look at model statistics and graphs lends insight into parameter selection, and pertinent statistics and graphs follow.

Table 2

Pairwise Pearson Correlation Coefficients Between Explanatory Variables

Observed Variables

	$SA_{\delta,}$	s	l	$SA_{\delta}*s$	$SA_{\delta}*l$	$s*l$	$SA_{\delta,}^{2}$	s^{2}	l^{2}
$SA_{\delta,}$	1.000								
s	.199	1.000							
l	.567	.279	1.000						
$SA_{\delta}*s$	.684	.737	.553	1.000					
$SA_{\delta}*l$	.797	.230	.874	.676	1.000				
$s*l$	.446	.810	.743	.840	.681	1.000			
$SA_{\delta,}^{2}$	**.957**	.183	.622	.693	.879	.497	1.000		
s^{2}	.218	**.946**	.257	.755	.226	.786	.209	1.000	
l^{2}	.547	.234	**.950**	.548	**.928**	.729	.659	.208	1.000

Centered Variables

	$SA_{\delta,}$	s	l	$SA_{\delta}*s$	$SA_{\delta}*l$	$s*l$	$SA_{\delta,}^{2}$	sl^{2}	l^{2}
$SA_{\delta,}$	1.000								
s	.199	1.000							
l	.568	.279	1.000						
$SA_{\delta}*s$	.182	.239	.288	1.000					
$SA_{\delta}*l$	.426	.135	.727	.446	1.000				
$s*l$	.326	.199	.587	.589	.742	1.000			
$SA_{\delta,}^{2}$	.690	.117	.589	.383	.796	.616	1.000		
s^{2}	.186	.551	.137	.401	.061	.302	.170	1.000	
l^{2}	.454	.151	.771	.400	**.974**	.765	.774	.032	1.000

Note:
Bold = Collinearity > 0.9

Table 3
Regression Model Comparisons Using Centered Variables

No.	Model variables[1]	Fry			Pre-smolts		
		Adjusted R^2	Sy|x	Mallows C_p	Adjusted R^2	Sy|x	Mallows C_p
	Non-quadratic models:						
1	SA_{δ}, s, l, (s *l), (s* SA_{δ}), (SA_{δ}*l)	[2]			[2]		
2	SA_{δ}, s, l, (s *l), (s* SA_{δ})	.234	200.1	6.0[3]	.229	299.4	6.0[3]
3	SA_{δ}, s, l, (s *l), (SA_{δ}*l)	[2]			[2]		
4	SA_{δ}, s, l, (s* SA_{δ}), (SA_{δ}*l)	[2]			[2]		
5	SA_{δ}, s, l, (s*l)	.192	205.4	9.5	.197	305.5	8.4
6	**SA_{δ}, s, l, (s* SA_{δ})**	.239	199.4	4.5	.237	297.9	4.2
7	SA_{δ}, s, l, (SA_{δ}*l)	[2]			2		
8	s, l, (s *l)	.153	210.4	12.9	.156	313.2	11.9
9	SA_{δ}, s, (s* SA_{δ})	.216	202.4	6.0	.208	303.4	6.3
10	SA_{δ}, s, l	.198	204.7	8.0	.200	305.0	7.2
11	SA_{δ}, l	.207	203.5	6.0	.193	306.3	7.0
12	SA_{δ}, s	.157	209.9	12.0	.152	313.9	11.4
13	s, l	.159	209.6	11.0	.160	312.5	10.6
14	SA_{δ}	.165	208.8	9.7	.156	313.2	10.2
15	l	.169	208.4	9.3	.156	313.2	10.1
16	s	.003	228.2	28	.000	342.9	29
	Quadratic models:						
17	SA_{δ}, SA_{δ}^2, s, s^2 l, l^2, (s*l), (s*SA_{δ}), (SA_{δ}*l)	[2]			[2]		
18	SA_{δ}, SA_{δ}^2, s, s^2 l, l^2	[2]			[2]		
19	**SA_{δ}, SA_{δ}^2, l, l^2**	.200	204.4	5.0[3]	.188	307.1	5.0[3]
20	SA_{δ}, SA_{δ}^2, s, s^2	[2]			[2]		
21	SA_{δ}, SA_{δ}^2	.160	209.5	7.3	.149	314.5	7.1
22	l, l^2	.165	208.9	6.8	.152	313.9	6.8

Notes:

1. The constant (y-intercept) was included in all models but is not listed here to save space.
2. Singular matrix prevented calculation.
3. Full model whose mean squared error was used in Mallows Cp. Non-quadratic and quadratic groups treated separately.
4. **Bold** = best models.

4.3 Statistics for the Selected Models

The best non-quadratic model for fry was:

$$HA_f = 108.6 + 0.116SA_\delta - 7228.50s + 0.1912\, l + 55.509(s^* SA_\delta) \tag{11}$$

The best non-quadratic model for pre-smolts was:

$$HA_p = 280.8 + 0.176\, SA_\delta - 37024.67\, s + 0.310\, l + 79.345\, (s^* SA_\delta) \tag{12}$$

The best quadratic model for fry was:

$$HA_f = 199.6 + 0.157\, SA_\delta - 0.000085\, SA_\delta^2 + 0.121l + 0.000194\, l^2 \tag{13}$$

The best quadratic model for pre-smolts was:

$$HA_p = 385.4 + 0.239\, SA_\delta - 0.000143\, SA_\delta^2 + 0.152\, l + 0.000314\, l^2 \tag{14}$$

Model coefficients in 11 to 14 are in the original data space, while those in Table 5 and 6 are based on centered data; the constant parameters (b_0) in Tables 5 and 6 are only ones that required transformation.

Table 5

Regression Statistics for Best Non-quadratic Models Using Centered Data

Effect	Coefficient	Standard Error	Standardized Coefficient	Tolerance	t	p (2-tailed)
Fry						
Constant	407.528	21.158	0.000		18.88	0.000
SA_δ	0.116	0.0508	0.260	0.677	2.28	0.025
s	-7288.500	14461.267	0.050	0.892	-0.50	0.616
l	0.191	0.102	0.222	0.626	1.87	0.064
$s^* SA_\delta$	55.509	23.639	0.233	0.889	2.35	0.021
Pre-smolts						
Constant	679.236	32.234	0.000		21.07	0.000
SA_δ	0.176	0.076	0.264	0.677	2.32	0.023
s	-37024.674	21597.226	-0.170	0.892	-1.71	0.090
l	0.310	0.152	0.241	0.626	2.04	0.045
$s^* SA_\delta$	79.345	35.304	0.223	0.890	2.25	0.027

Notes:
Tolerance is the reciprocal of the variance inflation factor

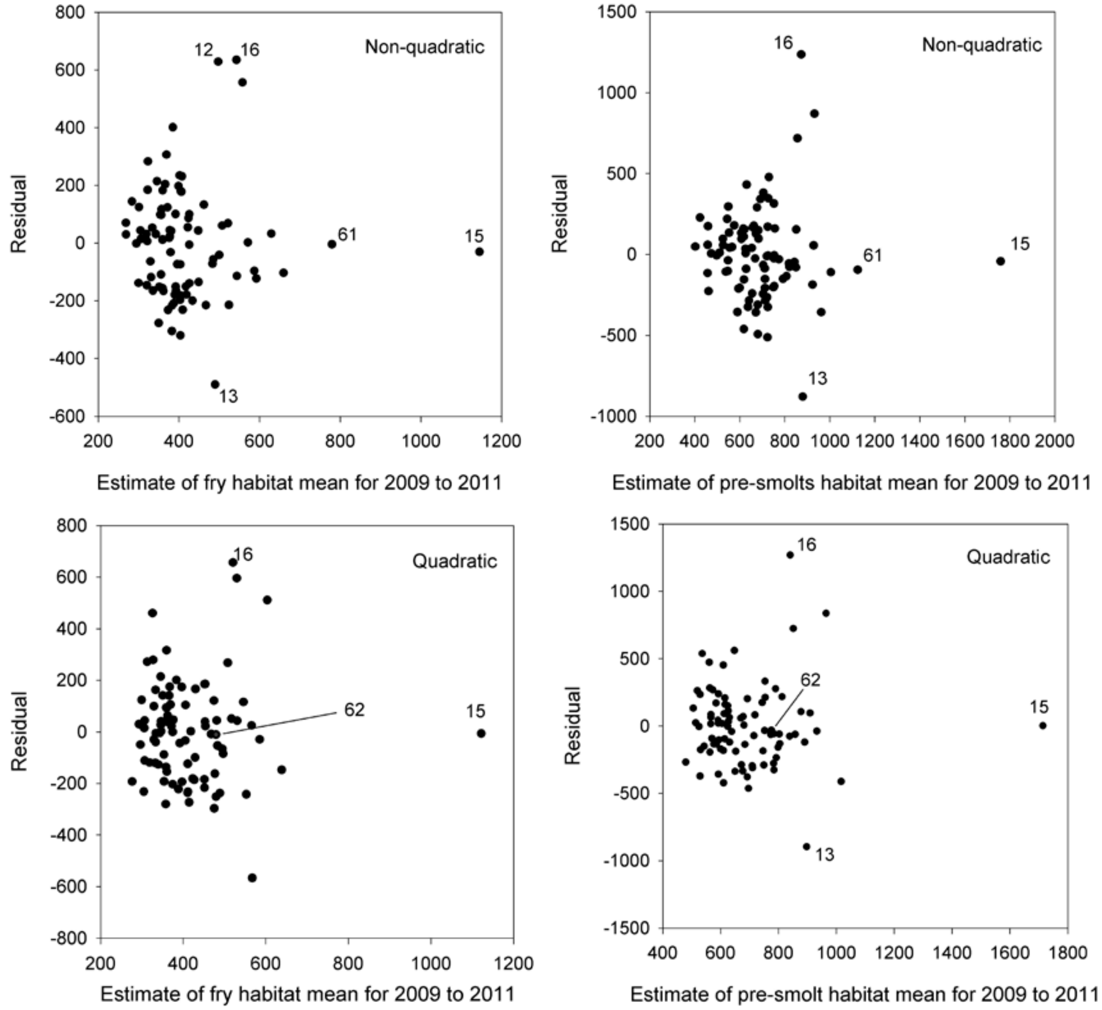
Table 6
Regression Statistics for Best Quadratic Models Using Centered Data

Effect	Coefficient	Standard Error	Standardized Coefficient	Tolerance	t	p (2-tailed)
Fry						
Constant	424.642	28.349	0.000		14.98	0.000
SA_{δ}	0.156804	0.0690	0.351	0.385	2.27	0.026
SA_{δ}^{2}	-0.000085	0.0000954	-0.178	0.227	-0.89	0.378
I	0.121038	0.1491629	0.140	0.307	0.81	0.419
I^{2}	0.000194	0.0001719	0.244	0.198	1.13	0.262
Pre-smolts						
Constant	706.651	42.602	0.000		16.59	0.000
SA_{δ}	0.239155	0.1038	0.359	0.385	2.30	0.024
$SA_{\delta}^{2}s$	-0.000143	0.0001433	-0.202	0.227	-1.00	0.499
I	0.152306	0.2241552	0.118	0.307	0.68	0.045
I^{2}	0.000314	0.0002583	0.265	0.197	1.22	0.277

The pattern of residuals, or error, (observed – estimate) meets the assumptions for making inferences from the least-squares regressions. These assumptions include homoskedacity, (uniformity of variance across the range of the estimates) and normally-distributed and independent errors.

The degree of homoskedacity shows in Figure 3. The general pattern is acceptable but there were some consistent statistical outliers having an extreme studentized residual or high-leverage points that show in Figure 3; these points and two others were flagged in the regression output as such. Cook's distance (Cook 1979) combines the studentized residual and leverage, which measure the deviation about y and x, respectively. Based on Cook's distance (D), point 13, within the non-quadratic model for pre-smolts, was marginally influential (D = 0.616) and the rest were not. No outliers were removed.

In terms of river distance, four of the five outliers (12, 13, 15, and 16) represent the Rush Creek delta area, and the other points (61 and 62) tie to the Reading Creek confluence area.



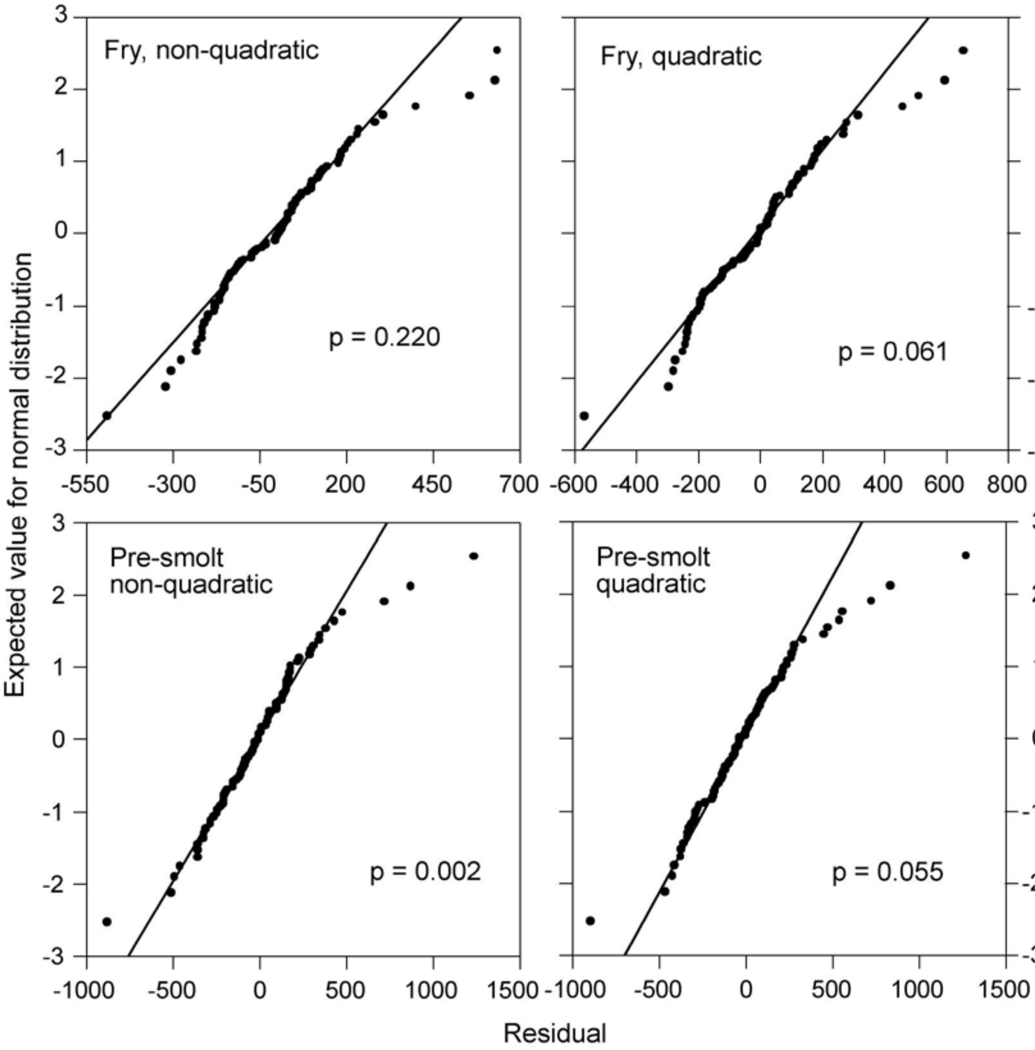
Note: Labeled points are potentially influential and have high studentized residuals or high leverage.

Figure 3

Plots of Residuals Against Estimated Habitat by Life Stage for the Best Model of Each Type

The residuals for each model by life stage had an approximate normal distribution but some of the two-tailed p-values for the Lilliefors test for normality were less than 0.05 (Figure 4). The deviant points in Figure 4 have extreme studentized residuals. No selected model's residuals had an autocorrelation coefficient greater than 0.18, and the lowest p-value for the Wald-Wolfowitz runs test was 0.13, so the residuals are reasonably independent.

The standardized regression coefficients (Tables 5 and 6), in absolute value, were consistently highest for SA_{δ} in all models and for both life stages, while slope had the lowest. Bank length (*l*) and interactions terms with either l or SA_{δ} had standardized coefficients nearly that of SA_{δ}. Thus, SA_{δ} and l had the most influence on estimating habitat area.



Note: The p-values are for the Lilliefors test for normally distributed errors.

Figure 4
Probability Plots of Residuals for Selected Best Models

Of the two models types, the non-quadratic had less inherent collinearity than the quadratic versions, and the adjusted R^2 of the best non-quadratic model was higher than the best quadratic model and all other models too (Table 3). Furthermore, quadratic terms (i.e., SA_{δ}^2, l^2) did not have slope coefficients statistically different than zero. Condition indices for quadratic terms were low (< 6) for all models using centered data, but was high (>30) for l^2 in the best quadratic model when using un-centered (original) data. High condition indices indicate problematic collinearity. Collinear pairs were discovered in data exploration (e.g., Table 2), and the problems that emerged during regression were not surprising.

5 DISCUSSION

Broad patterns in the results emerge despite the inherent problems with the data. The change in surface area with discharge (SA_δ) follows changes in habitat area that meets the depth and velocity criteria, so channels segments with low-angle margins that would harbor more shallow water, tend to have more juvenile salmonid habitat. The amount of habitat area tends to follow bank length (l) as well. Such areas may be narrow stringers along steeper bank margins that SA_δ does not capture as well. Water surface slope (s) was poorly related to habitat area, so local velocity within fish habitat patches is probably not well-correlated with slope as measured between two cross-sections. The 95% accuracy of the LiDAR-derived elevation data was ±0.2054 m (Woolpert 2010). For a 200-meter segment, the 95% elevation error contributes a 0.00103 m/m change in slope. Although not reported, a 66% accuracy for the elevation data would be 0.100 m, which contributes a 0.00005 m/m error. Typical slope values (the central 50%) were between 0.000960 and 0.003139 m/m, so some slopes extracted from the LiDAR points would have substantial errors.

Recall that SA_δ is not only sensitive to bank angle, but also bed-surface complexity. More complex beds would have higher form resistance (Leopold et al. 1960) which probably makes up a large portion (50 to 75%) of total flow resistance (Prestegaard 1983). Complex channel margins would likely create patches of shallow, low velocity water that would be mapped as habitat meeting depth and velocity criteria. Therefore, SA_δ could be an effective surrogate for patch area meeting depth and velocity criteria for young salmonids. Bank topography below 450 cfs using SA_δ would be better characterized by a range of flow less than and up to 450 cfs rather than 450 to 800 cfs. The 2005 HEC-RAS analysis was aimed toward estimating stages at very high flows (CDWR 2007), so extrapolating to low flow stages could be inaccurate if the model is un-calibrated at low flows.

The bankline data used in analyses were derived from a one-dimensional hydraulic model within the HEC-RAS system. Flow resistance (roughness) as quantified by Manning's n is estimated for each reach so that modeled water surface elevations match observed ones at a series of discharge levels at cross-sections. The precision of the modeled water surfaces at any given locale depends on how well the cross-sections represent intervening channel areas. The HEC-RAS inundation surfaces at 450 cfs did not always match the actual water surface as it shows in 2004 aerial photography. In some places, the depth was zero where there should have been water, even in the main channel. The same odd pattern shows in the 800 cfs surface. Although none of the zero-depth locales fell within the 200-m stream segments used in modeling, the zero-depth situation indicates that some error in depth at sample segments is likely.

Bankline segment lengths varied from 0.112 to 43.6 meters, with the vast majority less than 10 (Figure 1). The complexity of the bathymetry likely determines the precision of measurement, or “the length of the ruler”. The influence of ruler length on bankline length increases dramatically when it becomes less than a decimeter (Figure 2). The variable ruler length in the HEC-RAS modeled bankline makes a direct application of fractal geometry (which assumes a fixed length) difficult, but if one assumes that the longer segments are comprised of equal-length rulers along very straight stretches, a ruler length can be estimated from the fractal geometry. The total length of the selected unvegetated bank as modelled by HEC-RAS was 43.3 meters. This total length falls along the fractal geometry curve (Figure 2) at about a 0.4-meter ruler length. Mandelbrot (1983) mentions that coastline lengths vary little when ruler lengths range between 0.2 and 20 meters (and this is approximate); Figure 2 shows this flat part of the curve between 1 and 20 meters. The terrain model used in the 2005 HAC-RAS model apparently yielded a bankline with a modest range of ruler lengths (Figure 1) that mostly fall within this range. The F term in the fractal geometry equation should be constant across a range of ruler lengths for a bankline with fixed endpoints, and F was fairly constant for the divider-measured banklines. The value of F likely increased substantially for the 0.15 meter banklength because of the pixellation. The divider path did not follow the rectangular path provided by the pixels. Hand-drawn or field surveyed banklines are similar to the divider path and are more saw-toothed in outline and the Koch-curve (Mandelbrot 1983) looks more like a bankline; the fractal dimension (D) for a Koch curve is exactly log4/log3 (Mandelbrot 1983), which was used here, but D may vary a little from log4/log3 for a rectangular path, so F was adjusted accordingly for the pixelated path to produce the known total length.

On a practical level, hand-tracing a bankline on aerial photographs with a ruler length less than about 0.5 meters would be time consuming at best and probably impossible along vegetated banks. Similar work with the 2001, 2005, 2007, 2009, and 2011 measured banklines reveal a similar range of bankline segments as reported here. The size distribution of segment lengths for bank reconstruction actions likely influence bank line segment lengths on the order of 1 to 10 meters. Segment lengths due to natural scalloping, small mass-wasting of bank material, and bed particles would be much less than a meter, but segments less than the length of a fish fry (0.01 meters) would not be important for obvious reasons. Therefore, measuring the bankline in segments of about 0.5 to 1 meter should capture the variation in constructed and natural banklines. If desired, the fractal geometry can provide bank lengths for the finer-scale features that are provided naturally and are presumably controlled in a consistent way by flowing water and bank substrate.

The sparseness and age of bankline data (2004) compared to the fish habitat data is the most striking discrepancy. Removing bank rehabilitation areas from the analysis set probably removed the most glaring differences, but channel changes since 2004 in natural reaches have may be large enough in some areas to confound the true relationship between channel characteristics and fish habitat.

A more accurate and updated bathymetry and HEC-RAS model may predict habitat more precisely than the data set used in this analysis. Such a data set exists but was not available for this analysis. Differences between modeled water surface and the bed will yield depths directly rather than using a surrogate such as SA_δ.

Another, perhaps faster way to capture bed topography is with a series of aerial photographs taken at discharge levels that are important to fish habitat. The series of banklines on the photography will trace the bed topography between the stages associated with the discharges, and the approach used here can be applied to the series of discharges. LiDAR returns from the water surface (as used for 2009) is another option for capturing banklines. If SA_δ is a good predictor of fish habitat, the frequent expense of capturing bathymetry and hydraulic modeling to estimate juvenile fish habitat may be avoided.

In light of a primary purpose of this analysis, which was to estimate habitat at unobserved river locales, the models herein (even the “best” ones), should not be used, or used with extreme caution because of the age and low precision of the bankline data. But the broad patterns that emerged and the concepts and process presented in this analysis may serve as a foundation for future analysis with fresher, more precise data.

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APPENDIX F

DISTRIBUTION OF JUVENILE FISH HABITAT ACROSS CHANNEL REHABILITATION DESIGN ELEMENTS

Prepared for
Trinity River Restoration Program

Prepared by
Trinity River Restoration Program's Scientific Advisory Board

April 2014

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1 INTRODUCTION

The Trinity River Restoration Program's (TRRP's) constructed channel rehabilitation projects have a suite of design elements, or features, such as side channels, floodplains, and wood placements, and their comprehensive contribution to juvenile fish habitat has not been examined in detail. As-built features and juvenile fish habitat have been mapped by the TRRP, so an accounting of their relationship is possible and is the purpose of this analysis. The primary metrics are area of juvenile fish habitat, by life-stage. The Trinity River flow evaluation study (USFWS and HVT 1999) noted a constriction in juvenile salmon habitat under modest flows (about 500 to 1,500 cfs), and a goal of channel reconstruction was to reduce this restriction by increasing habitat within this flow range. Flow-to-habitat curves for Phase 1 projects are compared to the unmodified river as observed in the 1980s to assess whether this constriction was reduced or not. The amount of juvenile fish habitat across a range of dam releases for each feature type, as reported here, should guide future channel rehabilitation projects by providing a relative effectiveness of the features in providing juvenile fish habitat.

2 METHODS

2.1 Data Sources

The mapped as-built design elements were in the file "AsBuilt_Features_2013-07-30.*". Wood placements were in a file called "AsBuilt_Wood_2013-07-30.*"; both files were dated July 30, 2013. Project attributes (names, construction dates) were obtained from an earlier as-built file called "Preliminary_Rough_Draft_TRRP_Mainstem_Restoration.*" and dated July 19, 2012. Juvenile fish habitat mapped at selected channel rehabilitation projects before and after construction were in the file "TR_Rehab_Areas.*" dated June 26, 2012. All file sets were in the ESRI shape file format and provided by the TRRP.

Physical habitat, as measured from 1986 to 1993 for the flow evaluation study (USFWS and HVT 1999), was extracted from Figure 5.17 B and 5.17 C therein. These figures reported habitat in square feet by segment. Segment 1A, from Lewiston dam to Dutch Creek, was used for comparison and its length (41.49 km) was used to place habitat on a per river kilometer basis. This is the same segment used for fish production modeling.

Physical habitat for the Phase 1 projects before they were constructed was summed along all project reaches that were habitat mapped at a range of dam releases (300, 450, 700, 1,200, and 2,000 cfs), and reach lengths were measured along the main channel centerline so areas are on a river kilometer basis. Hocker Flat was only mapped at 450 cfs, so it is not included in the pre-construction set, and Dark Gulch was not mapped at 300 cfs, so this level was left out for all projects in the pre-construction set. Total river kilometers for pre-construction was 2.67.

Physical habitat area for constructed Phase 1 features was also placed on a river kilometer basis, but the constructed-length criteria varied by feature type. For main and side channels, the length was simply the centerline of the constructed channel. For features that could occur on either side of a channel, such as a Lowered Bank, all constructed lengths were used. For all features combined, the channel's centerline-length along any feature type, whether on one bank or more, was summed in the same manner as with the pre-constructed reaches. For all features combined along with unconstructed banks within projects, the pre-constructed river length (2.67) was used. Total river kilometers for all features totaled to 2.49. Although Hocker Flat is missing from the pre-construction set, the pre-construction length exceeds the post-construction length because gaps in other project reaches exceed the length within Hocker Flat (0.3 km).

For physical habitat, the flow study method used transects and weighted useable area (WUA), and the habitat suitability criteria included depths greater than those used today for presmolts (called juveniles in the flow report). Although the number of fish observations declined rapidly as depths reached 1 meter, the suitability index remained as 1.0 (full weighting) out to depths of 3 meters (Figure 5.3, USFWS and HVT 1999). Present depth criteria for suitable presmolt habitat is less than 1.0 meter.

The naming and description of fish-habitat design elements varied over time, and to simplify analysis and interpretation, the TRRP consolidated the original 29 classes to 8 during Spring 2013 (Table 1). Design objectives varied, with some elements that were meant to be static while others could change (McBain and Trush and Hoopa Valley Tribe 2012). During such consolidation, the design elements were considered as-built rather than as-evolved during subsequent flow events (Eric Peterson, personal communication May 17, 2013).

The feature types implemented by the Program varied over time, with newer projects tending to have more feature types. Thus, feature types could not be uniformly distributed among the projects (see Table 3).

Table 1

Design Element Classes of Phase 1 Bank Rehabilitation Projects

Design-element class	Description
Alcove	Backwater under 300-450 cfs conditions (no surface-water flow-through).
Aquatic, Non-River	Construction to improve wetlands or small tributary connections.
Gravel Placement	Placed gravel of a size appropriate for spawning. Placement may be in-water or on banks and includes some placed during wood placement.
Fill	Placed material that was not further classified.
Floodplain	Constructed areas with a resulting ground surface greater than approximately 2 feet (vertical) of the river surface under 300 cfs conditions.
Low Banks	Constructed areas with a resulting ground surface within approximately 2 feet (vertical) of the river surface under 300-450 cfs conditions.
Main Channel	An area excavated to accommodate river flow with 20% or greater portion of the river volume under 300-450 cfs conditions.
Side Channel, Ephemeral	Continuous surface flow when river flows are above base conditions (activation flow varies).
Side Channel, Perennial	Continuous surface flow at 300-450 cfs and its flow is less than 20% of river volume.

2.2 Spatial Analysis

The mapped polygons of design elements and wood placements were overlaid with mapped fish habitat using ArcView 3.2a (ESRI 2000). The tabular data set from the overlay was exported to a spreadsheet where feature descriptions were coded to allow hierarchical sorting in SYSTAT 8.03 (SPSS 1998). Details follow.

All 23 channel rehabilitation projects built since 2003 were mapped as-built, but fish habitat mapping occurred on 11 of them and the efforts varied by project. Table 2 summarizes these efforts.

Habitat area for each life stage (fry, pre-smolt) meeting the depth and velocity criteria only (i.e., no cover) was the primary metric for design elements. Such habitat, labeled as DVx, is what is initially built at most features. Cover was expected to vary with time since construction, so it was not included in this analysis to reduce the confounding effects of time since construction during habitat mapping. Most projects had post-construction mapping within a year, while two others (Hocker Flat and Cableway gravel augmentation) had at least three intervening years (Table 2). Also, habitat mapping at Hocker Flat did not include cover, so to be consistent, only habitat meeting the depth and velocity criteria was used. Wood placements were considered as cover during habitat mapping, but mapped wood placements were assessed separately from the patches that met depth and velocity criteria. Methodology on habitat criteria and its mapping are in Chamberlain et al. 2007, Goodman et al. 2010, and Goodman et al. 2012.

Table 2

Juvenile Fish Habitat Mapping Efforts at Channel Rehabilitation Projects

Project	**Year Built**	**Footprint River KM**	**Habitat Mapping Site[1]**	**Mapping River KM**	**Construction-Phase Mapping**	
					Pre-	**Post-**
Lewiston 4/Sven Olbertson	2008	178.9 ~ 179.5	Sven Olbertson	178.9 ~ 179.6	2008	2009
Lewiston 4/ Cableway	2008	177.3 ~ 178.0	*Cableway*	177.4 ~ 177.9	2008	2009
Lewiston Cableway GA[2]	2003	177.6 ~ 177.7	*Cableway*			2009
Lewiston 4/Hoadley Gulch	2008	176.9 ~ 177.2	Hoadley Gulch	176.5 ~ 177.3	2008	2009
Sawmill	2009	175.3 ~ 176.5	Sawmill	175.3 ~ 176.6	2009	2010
Dark Gulch	2008	169.8 ~ 172.1	*Upper Bucktail~Dark Gulch*	171.8 ~ 172.1	2008	2009
			Bucktail~Dark Gulch	169.5 ~ 172.2	2008	2009
			Lower Bucktail~Dark Gulch	170.5 ~ 170.9	2008	2009

Project	Year Built	Footprint River KM	Habitat Mapping Site[1]	Mapping River KM	Construction-Phase Mapping	
					Pre-	Post-
Lowden Ranch	2010	168.0 ~ 169.2	*Lowden Ranch*	168.4 ~ 169.1	2009	2011
Trinity House Gulch	2010	167.5 ~ 167.9	Trinity House Gulch	167.5 ~ 167.9	2011	2011
Indian Creek	2007	151.3 ~ 155.8	Vitzhum Gulch	154.7 ~ 155.8	2008	
			Lower Indian Creek	151.3 ~ 152.4		2009
Reading Creek	2010	148.5 ~ 150.0	*Reading Creek*	148.7 ~ 149.5	2009	2011
Hocker Flat	2005	125.9 ~ 127.5	*Hocker Flat* [3]	125.9 ~ 127.1		2008

Notes:

1. Site names in *italics* were mapped at a range of dam releases, and these sites comprised the habitat data used in this analysis.
2. Lewiston Cableway GA (gravel augmentation) project was mapped along with the newer Cableway project.
3. Hocker Flat was partially mapped, at base flow only, in 2009. Only 2008 data were used in analysis.

Table 3
Area and Number of Design Elements Across Projects that were Habitat-mapped at a Range of Dam Releases

Project	Alcove		Aquatic non-river		Gravel		Fill		Flood plain		Low banks		Channels					
													Main		Side			
															Ephem.		Perenn.	
Cableway GA					19	1												
Cableway					52	4											7	1
Dark Gulch					17	3	0	28	2	4	22	3					52	2
Lowden Ranch	16	2	45	1	9	2			1	3	3	1	28	1	15	1	19	1
Reading Creek					50	4			16	3	14	3	19	3	6	1		
Hocker Flat									2	1	14	1						

Notes:

1. Number pairs under each design element represent the area in hundreds of square meters (left), and the number of features of a given feature type (right), contained within the 2,000-cfs dam release waterline.

The features themselves can change via fluvial impacts after construction, particularly if exposed to large discharges that exceed bed-sediment transport threshold. The partial mobility (greater than 20%) threshold on point bar flanks likely occurs between 2,000 and 4,000 cfs (McBain and Trush and Hoopa Valley Tribe 2012; McBain, personal communication, September 25, 2013). All of the projects were exposed to flows higher than 4,000 cfs after construction and before mapping, with four of them exposed to dam releases above 10,000 cfs (Table 4).

Table 4
Discharge (cfs) and Year of Maximum Dam Release Between Construction- and Habitat-Mapping Periods

Project	Discharge	Date	Project	Discharge	Date
Cableway Gravel Aug.	10400	May 24, 2006	Lowden Ranch	12300	May 4, 2011
Cableway	4630	May 1, 2009	Dark Gulch	4630	May 1, 2009
Hocker Flat	10400	May 24, 2006	Reading Creek	12300	May 4, 2011

The dam releases during Phase 1 habitat mapping were 300, 450, 700, 1,200, and 2,000 cfs. Although no mapped habitat was expected on higher surfaces that were designed to be inundated at flows higher than 2,000 cfs, these features were still included in the analysis because actual flows downstream could exceed 2,000 cfs during mapping, and such features may have included lower surfaces by design, actual construction, or post-construction changes due to high flows.

The projects with post-construction habitat mapped at a range of dam releases (300 to 2,000 cfs) were Cableway, Cableway gravel augmentation, Dark Gulch, Lowden Ranch, Reading Creek, and Hocker Flat. The habitat for the Cableway projects was mapped together at the same time. The fate of the Lewiston Cableway's gravel patch could not be tracked on yearly sequential aerial photography beginning in 2004. The total length of the fish habitat mapping across the range of dam releases was 3.1 river kilometers (rkm), while the total length of the 1 project reaches was 10.2 rkm (Table 2). These lengths represent, respectively, 22% and 5% of the total restoration reach (Lewiston to the North Fork Trinity River, 63.8 rkm).

3 RESULTS

A comparison of the flow-to-habitat curves for the pre-constructed river from Lewiston Dam to Dutch Creek (Segment 1A in the flow study report, USFWS and HVT 1999) and the Phase 1 project reaches before construction, show the dip in habitat area at modest flow levels (Figure 1). The amount of habitat for presmolts as observed during the flow study is much higher, but this is probably due to a generous depth criterion of up to 3 meters compared to the 1 meter used for Phase 1 assessments. In contrast, the flow-to habitat curves for the Phase 1 projects for all in-river features combined are nearly flat for each life stage (Figure 2).

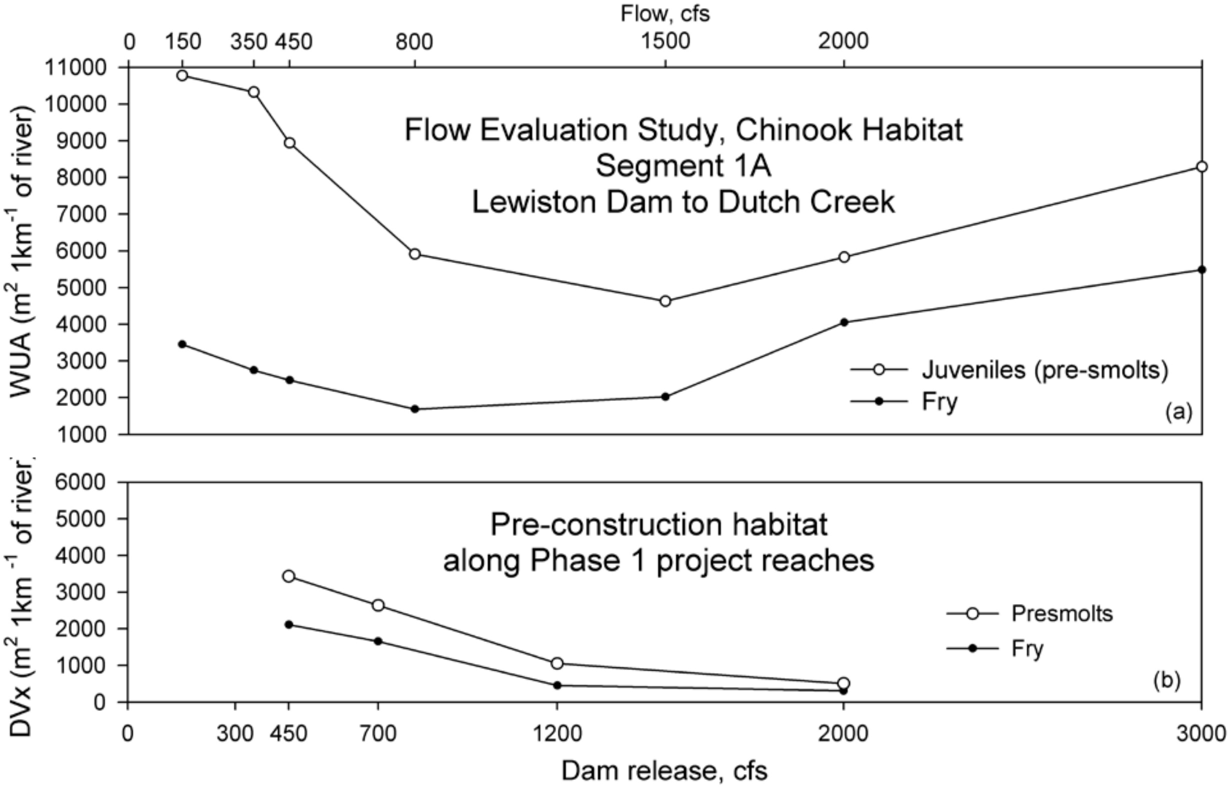

Figure 1
Physical Habitat by Streamflow for Young Salmon Before Construction

The flow study habitat is WUA, and the depth criterion for presmolts was much higher (up to 3 meters) as compared to the present 1 meter. The Phase 1 projects are the same as in Table 3, except for Hocker Flat and Cableway Gravel Augmentation are not included; the former was not habitat-mapped at a range of flows before construction, while the latter had no habitat mapping before construction. The Dark Gulch project was not mapped at the 300-cfs dam release, so this level was left out to simplify analysis. The total river-kilometers for Segment 1A is 41.49, and it is 2.67 for the Phase 1 reaches here as measured along the main channel centerline.

All eight design element types provided fish habitat at all flow levels for both life-forms (Figure 2), and the total habitat along constructed and unconstructed banks is higher (Figure 2a) than the same reaches before construction (Figure 1b).

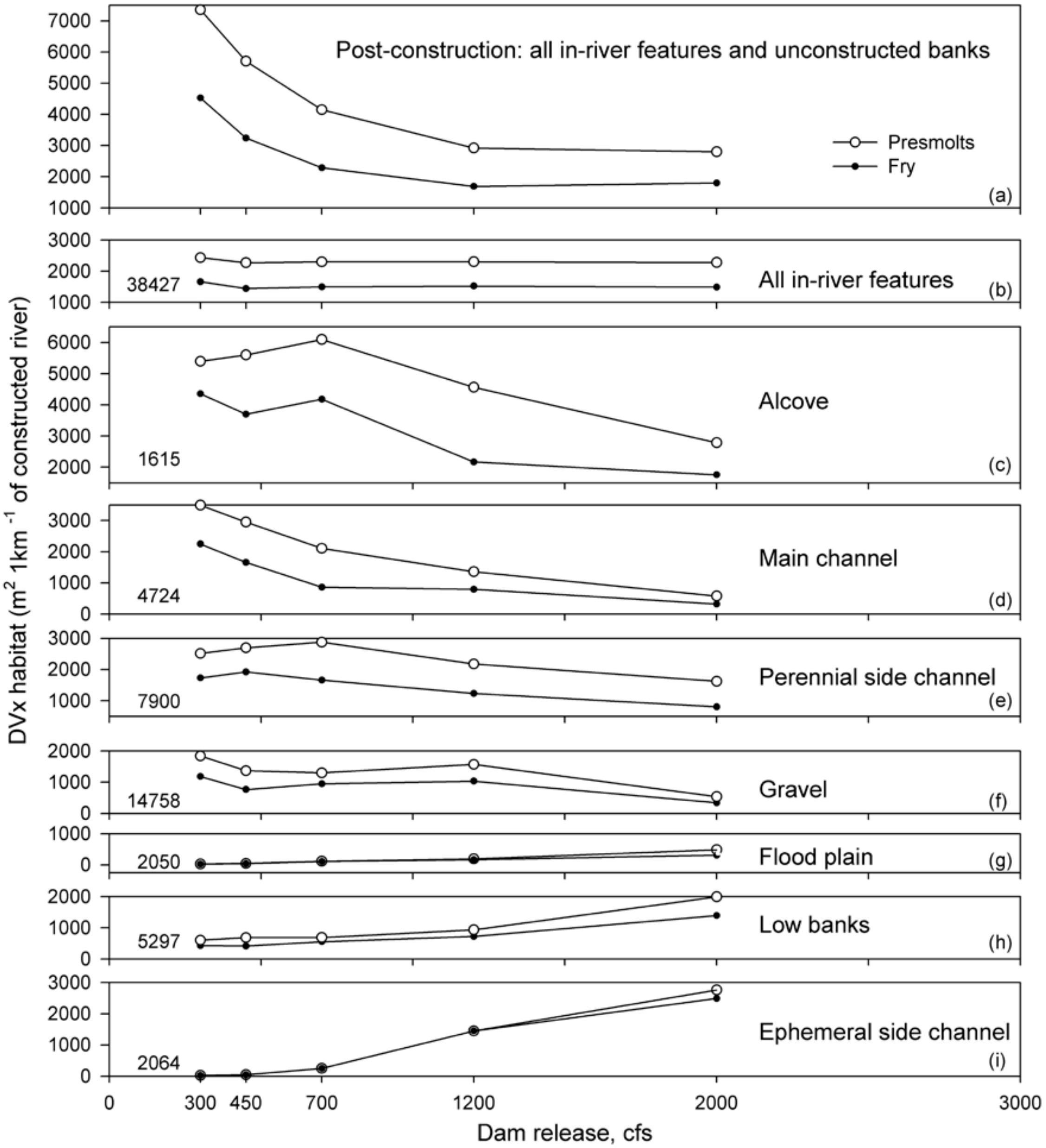

Figure 2

Suitable Habitat Area by Streamflow for Young Salmon after Channel Construction

These graphs correspond to Phase 1 channel rehabilitation projects that were habitat-mapped at a range of flows as listed in Table 3; coho and Chinook habitat was not separated. The "All in-river features" graph (b) combines all feature types except aquatic non-river, and the river length is along the centerline of constructed banks which totaled 2.49. Graphs for separate features (c to i) are based on constructed lengths for the features, which could include both banks. The values within the Phase 1 graphs are total footprint area in m^2; the not-shown Fill feature-type had a 20-m^2 footprint.

Presmolt habitat area tends to be about 50% higher than fry habitat (Figure 2a), and although their number of mapped polygons is a little less than for fry (984 versus 1013), the difference is not surprising given the deeper depth criterion allowed for presmolt habitat.

The efficiency of a given feature type in providing habitat is indicated by the ratio of total habitat area at a given dam release to its footprint area within the 2,000-cfs dam release wetted channel (Figure 3). For example, alcoves have the highest efficiency at low flows, while flood plains have the highest at high flows. Aquatic non-river has the lowest efficiency at all flow levels. There were negligible amounts for ephemeral side channels at the two lowest flow levels, and essentially no habitat at fill features at all flow levels; fill-associated habitat is not shown in the figures. Perennial side channels and gravel placements provided the most habitat at a wider range of flows than all other features. The relative contributions to juvenile habitat are similar for the two life-stages.

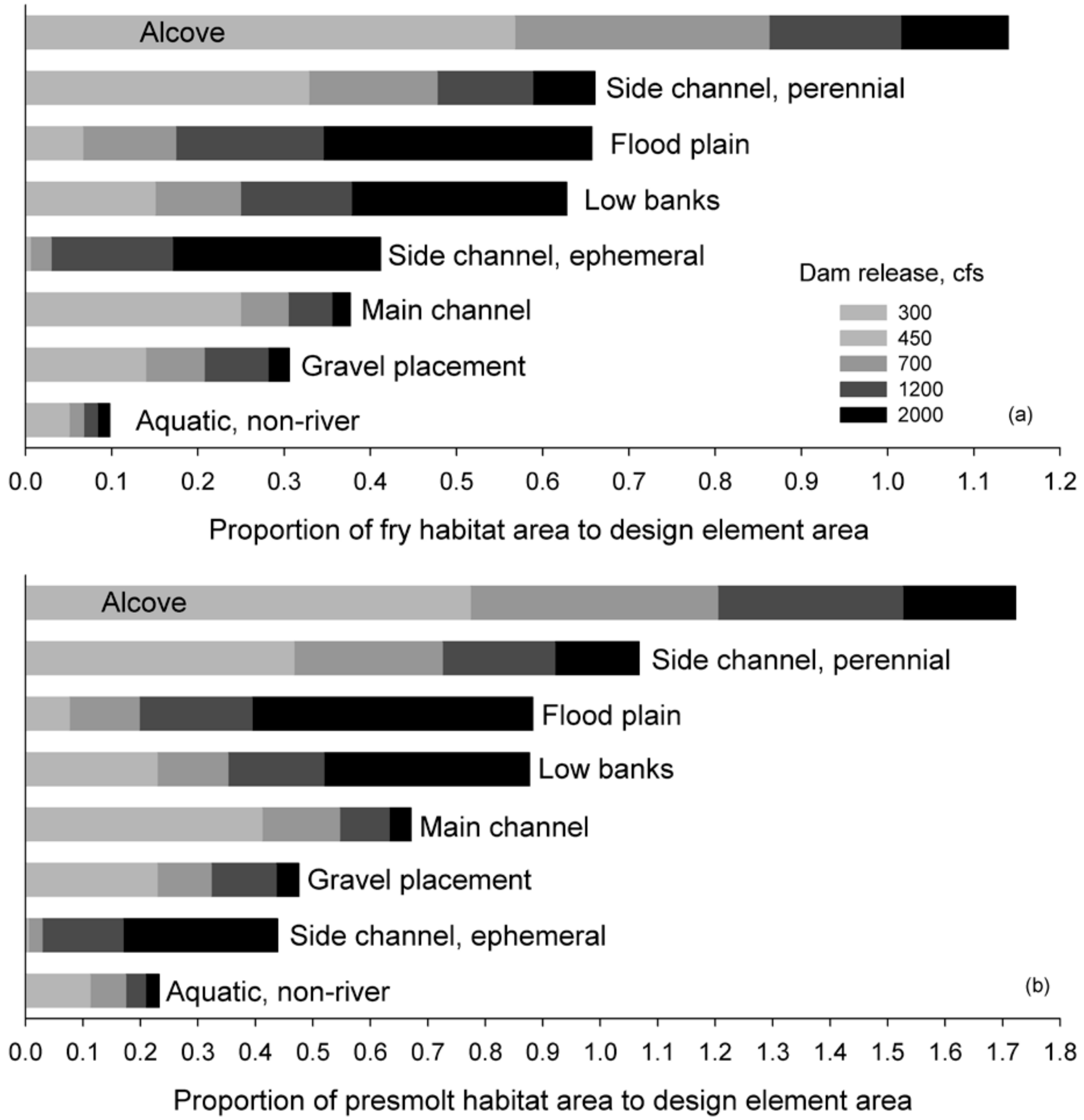

Figure 3

Areal Efficiency of Channel Rehabilitation Features in Providing Suitable Fry (a) and Presmolt (b) Habitat Area Meeting Depth and Velocity Criteria

There is considerable overlap in patch boundaries across stages associated with the dam releases, so the flow-wise areas are not additive, but areas at a given flow release can be directly compared. The legend applies to both graphs.

Constructed floodplains are designed to become inundated at flows of around 2,000 cfs and above, so habitat on floodplain features is unexpected. Of all the built floodplain that provided habitat at all flows and for both life stages, 83% of it was at the Reading Creek project. Much of this percentage was concentrated in features previously classed as "Constructed Floodplain & High Flow Scour Channel" before being aggregated in the more inclusive "Floodplain" class. The Reading Creek Project was built in 2010, and the post-construction habitat mapping occurred after the large 2011 flow (12,300 cfs), so there may have been some changes to as-built features before habitat mapping occurred. Some channel erosion is clearly visible below and near the constructed floodplain, but any elevational changes on surfaces are difficult to see on sequential aerial photography.

Within a project reach, as defined by the up-and down-stream extents of the construction footprints, design elements provided about 48% of the total DVx fry habitat at all flows, and similarly, 44% of the presmolt habitat.

Wood was considered as cover in habitat mapping, and depth and velocity was also measured within and near wood placements. As expected, the total area for wood placements is similar to area of habitat meeting cover criteria, or depth, velocity, and cover criteria, at or near wood placements. A small amount (less than 4%) of habitat meeting depth and velocity but not cover (DVx) was captured in the overlay process. Table 5 summarizes the distribution of habitat by life stage at wood placements. Total area of wood placements was 3881 m^2. Total area for a given habitat category (e.g., DVC, xxC) exceeds the total area of wood placements because of overlapping boundaries at different flow levels.

Table 5

Distribution of Habitat Area (m^2) at Wood Placements at a Range of Flows

	Dam release, cfs					
	300	**450**	**700**	**1,200**	**2,000**	**Total**
Fry						
xxC	441	617	766	964	1,526	4,316
DVC	587	578	776	1,026	495	3,462
DVx	80	82	76	37	22	297
Presmolts						
xxC	111	246	534	789	943	2,623
DVC	917	949	1,011	1,201	1,078	5,156
DVx	150	111	114	80	40	494

4 DISCUSSION

The flow evaluation study (USFWS and HVT 1999) found a constriction in WUA for fry and juvenile (presmolt) Chinook rearing habitat as flow increased above about 300 cfs, followed by a slow recovery above 2,000 cfs (Figure 1a). The Phase 1 features, when considered together, present a less-constricted (i.e., no dip at mid-flows) flow-to-habitat curve (Figure 2b), which is a goal of channel rehabilitation. Several feature types contribute to reducing the dip of the curve in Figure 2b; side channels (both types), low banks, and gravel placements contributed the most because they have high amounts of habitat in the flow range that was inherently restricted in habitat. Along a project reach, which includes constructed features and unconstructed (intact) banks, total habitat for both life forms increased after project implementation (Figure 1b and 2a), but the dip in habitat at modest flows remains when unconstructed banks are included (Figure 2a). Project reach-lengths for all Phase 1 projects total to 17.1 kilometers, or 27% of the project reach (Lewiston Dam to the North Fork), so there is a considerable amount of channel that likely has the habitat constriction.

The design elements are prone to post-construction changes due to flowing water and sediment, so interpretations about as-built features should consider such potential changes. The higher features such as floodplains are less-prone then lower ones such as gravel placement, and as mentioned earlier, their planned elevations are too high to provide much expected habitat at the observed flows. Gravel placements are often meant to change with flow and may be the most ephemeral of all, so the habitat amounts shown here may not reflect as-built or future conditions. Moreover, gravel can move to another location and provide habitat there and not be counted as “constructed” habitat because it is not in its as-built location. This is especially so for the Lewiston Cableway Gravel Augmentation project that was built in 2003, and not mapped until 2009. However, this project was comprised of only one bar, so the results are not very sensitive to it.

Although habitat mapping across the flow range (300 to 2,000 cfs) occurred on only 6 out of the 23 projects, the 26% coverage on a project level is fairly large from a sampling perspective, and the percentage on a built-length basis is about the same (22.6%). The 6 projects capture the temporal range of activity reasonably well (Table 2), but most of the projects were in the upstream third of the project reach, so fluvial settings were not as well-represented. When project age and location are considered together, the representation is poorer. For example, no newer projects far-downstream were sampled.

Wood placements varied in size and style over time, but this analysis did not consider such differences. The small amount of area (less than 4%) of mapped wood placements extending into mapped fish habitat without cover (Table 5, DVx) indicates the accuracy of wood placement footprints mapping. The influence of wood on velocity likely extends a short distance away into the channel, but only the mapped boundaries were used in this analysis. Adding a 3-meter-wide buffer of influence around a typical wood placement would more than double its influence as considered here.

A comparison between the present, un-constructed reaches with the constructed reaches at a range of flows would lend insight into how effective flow and gravel management on a systemic scale compares to construction efforts, but the data for the channel outside of projects are not available. Obtaining these data presents logistical and labor challenges because the higher flows do not occur long enough to allow measuring much high-flow habitat. The PHABSIM efforts for the flow study required measurements spaced over several years, and such efforts were hampered by even rarer and less-predictable high flows than under the Record of Decision flow regime. The Phase 1 mapping efforts associated with the range of dam releases required 38 days to measure habitat along the pre-constructed channel, and 89 days along the more complex constructed channel. Although total channel lengths may seem modest, mapped edges total to 224 and 359 kilometers, respectively, for the pre- and post-construction reaches covered in this analysis.

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6 ACKNOWLEDGMENTS

The Trinity River Restoration Program staff and partners collected and provided the data. This report stems from an earlier draft (January 2013) using 2012 features data. Several members of the design team, Eric Peterson and David Bandrowski improved the mapped-feature boundaries, and members of the fish working group, including Justin Alverez, Damon Goodman, and Aaron Martin provided insight on the fish habitat mapping. This report was improved by comments on the first draft by Joe Polos and those already named here. John Buffington also provided comments.

APPENDIX G

CHANGES TO THE CHANNEL REHABILITATION PROJECT DESIGN PROCESS DURING PHASE 1

Prepared Under the Direction of
Trinity River Restoration Program's Scientific Advisory Board

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LIST OF ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
GRTS	generalized random tessellation stratified
HVT	Hoopa Valley Tribe
km	kilometer
m^3/s	cubic meters per second
NOAA	National Oceanic and Atmospheric Administration
Program	Trinity River Restoration Program
RM	river mile
ROD	Record of Decision
TMC	Trinity Management Council
TRFEFR	Trinity River Flow Evaluation Final Report
WY	water year
YT	Yurok Tribe

1 INTRODUCTION

The *Trinity River Flow Evaluation Final Report* (TRFEFR; USFWS and HVT 1999) and *Record of Decision Trinity River Mainstem Fishery Restoration, Final Environmental Impact Statement/Environmental Impact Report* (ROD; DOI 2000) outline the channel rehabilitation strategy for the Trinity River. The goal of the strategy is to produce a scaled-down, dynamic, alluvial channel that the ROD's flow and sediment augmentation actions can maintain over time and that will continue to form new rearing and spawning habitat for fish through time.

The strategy relies on the mechanical rehabilitation of channel sites to complement a flow and gravel augmentation regime. The TRFEFR identified 44 potential main-channel and three potential side-channel construction sites. These sites were incorporated into the ROD. The sites were located where coarse sediment was available, meander bends existed, and in long, straight reaches where channel rehabilitation could result in substantial changes in channel complexity and salmonid habitat formation. It was recognized that entrances to many of the side channels constructed in the 1980s and 1990s had filled with debris. Therefore, sites were initially sought that could be maintained (i.e., would remain open) with ROD flows and without the need for active maintenance.

The TRFEFR and ROD also recommended that the channel rehabilitation strategy focus on encouraging channel dynamics via planform and bankfull channel dimensions. Channel rehabilitation projects, coarse sediment augmentation, and high flows were expected to maintain these dynamics into the future. Consistent with this approach, there were no recommendations in the TRFEFR to manipulate the river within the low flow channel by modifying pools, riffles, or other features.

However, most water years (WYs) since the ROD was signed have been categorized as dry, normal, or wet, and only one year was classified as being extremely wet. Furthermore, the volume of material located in existing flood plain terraces was not fully recognized when the ROD was developed. Because of the these constraints, the Trinity River Restoration Program (Program) placed an emphasis in Phase 1 on using mechanical channel rehabilitation to reduce the response time for geomorphic change and fish habitat development.

The TRFEFR acknowledged that the design strategy and project dimensions would vary among the different geomorphic reaches within the 64-kilometer (km) restoration reach based on the variety of underlying geology, sediment supply, hydrology, and bed grain size. However, the TRFEFR and ROD provided few details on how specific design elements were to be used to achieve the ROD's goals, or the design criteria for these elements. Potential design elements included side channels, flood plain topography, alcoves, high-flow scour channels, and large wood.

Therefore, throughout Phase 1, the Program Partners have modified the process used to design channel rehabilitation sites by adapting it based on information on the success of various design elements as the information was developed.

For example, initially there was one large design team. Starting in 2010, four separate design groups were formed. Each design group develops a design for an individual rehabilitation site that reflects the group's views on how to create fish rearing habitat at the site and maintain it over time. Forming multiple design groups increased the diversity of design perspectives incorporated into the site design process. The four design groups are: 1) federal; 2) Hoopa Valley Tribe (HVT); 3) Yurok Tribe (YT); and 4) state. Each design group is composed of a multidisciplinary team of engineers and scientists. Integration across the design groups occurs through the larger design team, which is a formally recognized Program work group. The design team is also an interdisciplinary and multi-agency panel. Core members include representatives from the HVT, YT, federal agencies (U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, U.S. Bureau of Land Management, and National Oceanic and Atmospheric Administration [NOAA] Fisheries), and state agencies (California Department of Water Resources and California Department of Fish and Game).

The design groups and the design team conduct their work through consensus-based decision making. Alternative positions are documented and policy issues that arise are referred to the Trinity Management Council (TMC) for resolution. The Program has several work groups (physical, fish, wildlife/riparian, temperature, flow scheduling, watershed, data, interdisciplinary, and public relations) that interact with and support the design team and design groups.

In January 2011, the *Channel Rehabilitation Design Guidelines for the Mainstem Trinity River* (Guidelines; HVT et al. 2011) were issued so that the four design groups could use a common and consistent suite of design criteria. The Guidelines document used empirical relationships and data from reference reaches to develop design methods and features at reach and site scales. These included: 1) planform design dimensions that accommodated wavelength and radius of curvature dimensions that were appropriate for the ROD's high-flow regime; 2) bankfull channel dimensions that resulted in recommended ranges for bankfull channel width and depth; 3) low-flow channel dimensions that resulted in recommended ranges for low-flow channel width; 4) guidelines for constructed bars; 5) guidelines for secondary channels; 6) flood plain design dimensions and guidelines for flood plain inundation for geomorphic purposes; 7) riparian vegetation design criteria; 8) large wood placement guidelines; and 9) other considerations such as incorporating bedrock into a design.

The *Guidelines* document also described a detailed hydrologic analysis for design groups to use when developing reach-specific estimates of summer and winter baseflow magnitudes and durations. In addition, reach-specific flood frequency estimates were re-analyzed for winter floods and ROD flow releases during springtime to inform decisions about individual design elements that depend on bankfull discharge. These elements include flood plains, side channels, and high flow channels, for example.

In 2011, the individual design groups compiled fact sheets on each of the 15 channel rehabilitation sites constructed under Phase 1 to document the design objectives for each site and establish a common framework for the practices employed among projects. These fact sheets specifically addressed how the design group expected the site would physically change over time and form juvenile salmonid rearing habitat.

To further adapt the design process for upcoming Phase 2 design activities, the U.S. Bureau of Reclamation hired a contractor to review the Program's Phase 1 design process (CH2MHill and Entrix 2010). CH2MHill and Entrix (2010) recommended that the Phase 2 design process: 1) place more emphasis on the geomorphic potential of a site and describe trends in horizontal and lateral bed stability; 2) describe how each site is expected to change over time based on the rehabilitation design; 3) continue standardizing the design approach; 4) immediately create as much of the target habitat as possible; 5) design projects that are self-sustaining and trigger future changes that further restore the system; 6) engage the public in the process; and 7) revisit early projects constructed from 2005 to 2007 to see where additional habitat benefits can be achieved. Their report also provides general recommendations regarding defining successful criteria, integrating monitoring results into future designs, and identifying opportunities that could benefit the system at a watershed scale.

In summary, during Phase 1 the design team structure and design processes were adapted to new information based on the success of various design elements. Greater emphasis was placed on documenting the basis for each aspect of a project's design as Phase 1 designs were developed and implemented. Sections 2 through 4 of this report describe how the design approach and specific design elements changed during three discrete periods within Phase 1.

2 EARLY YEARS (2005 TO 2006)

Project designs implemented in 2005 and 2006 used simple features and selected sites located in the lower portion of the 64-km restoration reach. The mechanical work was conducted mostly above the summer low flow water line in the flood plain, and was designed primarily to allow the river to do the work of evolving the channel. Vegetation along the bank and in the flood plain was removed, feathered edges based on a 10:1 slope were formed along the channel margins, and flood plain terraces were lowered so they would be inundated to a depth of 0.305 m (1 foot) at a flood frequency of approximately 1.5 years and at a flow of 170 cubic meters per second (m^3/s; 6,000 cubic feet per second [cfs]).

For example, the Hocker Flat project involved extensive vegetation removal and flood plain re-contouring, with no large wood installations and little structural complexity built into the flood plain. It consisted primarily of terraces with few riparian berms, and a significant amount of earthwork was undertaken to lower the terrace and reconfigure it into a functional flood plain. The extent of the earthwork required to achieve its design goals surprised many who were expecting simple berm breaching and feathered-edge projects. This was based on the TRFEFR (USFWS and HVT 1999), which did not adequately describe the extent of the material located in terraces along the river. The flood plains at Hocker Flat were excavated to elevations below the 170 m^3s^{-1} level to accommodate up to 1 foot of uncertainty in the flood stage as modeled using HEC-RAS. HEC-RAS is the River Analysis System computer program developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center to model the hydraulics of water flow through rivers.

Even during these early years, the design process was adapting to new information. A more broad set of design hypotheses was used to increase the diversity and amount of habitat being developed. For example, while the Hocker Flat design included lowering the flood plain to inundate at a flow of 170 m^3/s (6,000 cfs), the Conner Creek design in 2006 also included an area that flooded at 13 m^3/s (450 cfs). At Valdor Gulch in 2006, it was hypothesized that as high flows began to work in conjunction with the constructed right bank (when looking downstream), existing bars upstream of the project area would expand. This was expected to cause scour along the right bank at the upstream end of the project, bar development along the right bank at the downstream end of the project, and increased channel sinuosity and complexity at the site. Lowering a remnant bar feature to an elevation inundated by 1.5-year recurrence flows of 170 to 187 m^3/s (6,000 to 6,600 cfs) was included to support riparian revegetation and promote natural riparian recruitment, thereby increasing riparian zone structure and diversity. Because fish monitoring of Hocker Flat in 2006 showed little utilization by adults or juveniles (Goodman et al. 2010), additional wood elements were incorporated into the Valdor Gulch, Elkhorn, and Connor Creek designs to increase topographical diversity and habitat complexity.

In terms of adapting the design process to new information, a key event occurred in 2006. A storm event resulted in the rehabilitated Hocker Flat site being exposed to a flow of 567 m^3/s (20,000 cfs). Little habitat appeared to have been formed by this event and Goodman et al. (2010) observed that fish utilization rates at the site were low following the event. Therefore, the lack of a physical response to this extreme flow event caused designers to adopt more aggressive construction techniques and move activities directly into the wetted channel to reduce the response time for geomorphic change and habitat development.

The design of riparian elements at rehabilitation sites has also evolved over time, based in part on post-construction monitoring. In 2005 at Hocker Flat, the riparian vegetation within the lowered flood plain and feathered banks was grubbed and removed. No large wood cover type was designed or implemented at the site; however, removing some mature trees during construction was avoided.

In 2006, the four sites located downstream of Hocker Flat used a similar design process with respect to riparian vegetation. Pre-construction surveys identified existing cover types. Then, specific riparian vegetation management design elements were identified, including berm, stump, and root stock removals. Large wood placement was used for the first time at Conner Creek, where imported root wads were placed individually at the toe of the constructed flood plain. At Elkhorn in 2006, design elevations near large trees were modified to save the trees and leave remnant islands of pine, ash, and alder in the feathered edge. Also, large wood was added to certain features and tree trunks were buried in the riverbank.

3 MIDDLE PERIOD (2007)

In 2007, the design team used notches at Indian Creek to facilitate the natural erosion of berms under high flows. Consistent with the Program's original vision of using a minimal amount of mechanical effort to manipulate riparian berms, it was hypothesized that excavation of notches in one area would cause the remaining berm on the right bank of the river to erode. However, there was significant disagreement within the Program regarding the potential for that to occur. It was also hypothesized that excavation in another area would induce the channel to migrate and some of the narrow islands created by side channel construction to eventually erode. The design also included a series of notches in another area that were expected to result in selective berm removal. Notches were chosen as the design element for this area because of a lack of space for spoiling excavated materials on the right bank of the river and poor access for hauling spoils away from the location.

Another objective of the project was to improve the hydraulic connectivity between the channel and the flood plain area behind the berm and increase the availability of off-channel habitat to fish at flows greater than 57 m^3/s (2,000 cfs). The improved connectivity was expected to increase the potential for ROD flows to erode the remaining sections of berm. The design concept was based on Program documents that emphasized the removal of riparian vegetation and berm deposits, but the approach was modified to include the excavation of a side channel when test data suggested that no topographic berm was present in one area.

During this period, Program staff supervised the placement of a small amount of large woody debris at various locations within the project during construction. This included the extensive application of individual logs along the toe of the main channel, side channels, flood plain, and in a constructed wetland feature. However, much of the wood at this site is only partially functional, in that it provides limited hydraulic control and cover because it consists primarily of single trees and not complex accumulations such as logjams that can create pools and sustain side-channel features.

The site design incorporated more riparian design elements than previous projects. Pre-construction surveys of cover types were conducted over much of the site. During construction, disturbance of large areas of existing vegetation was avoided to support the natural regeneration of favorable mature trees. Further, many of the design elements (island retention, mature tree retention, and notching) have the potential over the short-term and possibly long-term to contribute large woody debris to the immediate site and areas downstream.

4 RECENT YEARS (2008 TO 2010)

Projects constructed from 2008 to 2010 also focused on modifying flood plains so they would become inundated at lower flow levels (e.g., 4,500 cfs) and be under 1 foot of water at the design flow level (e.g., 6,000 cfs). However, more complex features were incorporated into the designs and the amount of in-channel work conducted at each site increased. In 2008, five projects were completed between river miles (RMs) 105 and 112. The design objectives of these projects specifically attempted to increase the availability, quantity, and quality of fish habitat between specific flow ranges and the amount and structural complexity of fry rearing habitat. Flow targeted in these designs was low, typically ranging from 8 to 57 m^3/s (300 to 2,000 cfs). Side channels were constructed, wood was placed in low-flow channels, and coarse sediment storage and supply was added through the construction of alternating bars.

In 2009 and 2010, project designs were implemented at Sawmill, Lowden Ranch, Trinity House Gulch, and Reading Creek from RMs 92 to 110. Most of these projects were located farther downstream than those constructed in 2008. The projects constructed in 2009 and 2010 were generally larger in scope, and had more features and higher costs compared to previous projects. In particular, the complexity of the features was significantly expanded compared to earlier projects. Small sections of the channel were designed to force a meander in the main channel using constructed bars (e.g., Sawmill) to introduce local channel complexity and trigger processes that encouraged further meander development.

The Lowden Ranch design included the use of multiple design elements to create a branching and more sinuous channel. These included flood plain benches, side channels, medial bars, anabranching channels, and vegetated islands. At both low and bankfull flow, an anabranching river form has multiple channels separated by vegetated islands (Schumm 1985). This channel form contrasts with braided channels that are characterized by open gravel bars, multiple low flow channels, and typically just one wide, shallow channel at bankfull flow. Creating an island can more than double the extent of edge habitat for fish at all flows over the length of the island, increase flow complexity, and trigger additional scour and erosion associated with flow bifurcation around the island, especially if large wood structures are constructed at the upstream ends of the island (CH2MHill and Entrix 2010). Increasing the number of islands constructed at a site results in more hydraulic and physical complexity; increased substrate and bedform variability and overhanging riparian vegetation; and improved wood debris retention (CH2MHill and Entrix 2010).

While Dark Gulch in 2008 included a wood habitat development reach where single root wads were placed along the toe of the main channel and buried in gravel, projects such as Sawmill in

2009 and Sven Olbertson in 2008 included placement of multiple, unanchored large logs on top of the flood plain. Also, Sawmill was the first site to incorporate a substantial number of log structures (14) into the design to increase pool depth and promote bank scour. The design also included a stated objective to maintain riparian vegetation, an intact canopy for the benefit of wildlife, and a large wetland to benefit wildlife and increase riparian habitat diversity.

The Program's design process for wood materials initially emphasized making placement decisions (i.e., number, size, and orientation of pieces) in the field during construction (e.g., Sawmill in 2009 and Lower Reading Creek and Trinity House Gulch in 2010). These project designs relied heavily on "design-build" field placements, making it difficult to assess how the design performed when conducting post-construction monitoring of wood volumes and stability. Furthermore, the wood-material designs were not explicit about how the structures were expected to alter flow conditions and create habitat. More recently, the design and installation of wood structures have become integrated into the site design drawings, which include stamped wood placement plans. Also, design reports now address how the wood elements are expected to affect the potential for hydraulic and sediment transport effects to occur (e.g., Lowden Ranch).

Another component of the Program that has been adaptively managed has been the use of flow to enhance geomorphic work. WY 2011 was classified as a wet WY. Program flows typically would have been released that year according to the schedule in the ROD (DOI 2000). However, a higher peak release was desired and the Program's Flow Work Group designed a release of 312 m^3/s (11,000 cfs) for a period of 3 days, compared to the standard release of 241 m^3/s (8,500 cfs) over 5 days identified in the ROD. Results of studies designed to evaluate the effects of the higher peak flow are underway and will be used to make future adjustments in flow duration and timing.

5 SUMMARY

Throughout the Phase 1 implementation period, channel rehabilitation project designs were adapted to new information and increasingly include more features than originally envisioned in the TRFEFR (USFWS and HVT 1999) and ROD (DOI 2000). The Program used design features that increasingly manipulated the bankfull channel and flood plains. Recent designs encourage lateral channel migration by excavating dredge tailings or terraces on the outside of meander bends, and reconfigure the mainstem channel into a more sinuous pattern through the construction of mid-channel islands. Constructed side channels and the placement of large wood in restoration sites (mainstem, alcoves, side channels, and flood plain sites) were used to immediately create juvenile salmonid rearing habitat. Designs moved away from leaving a manicured site after construction, toward an as-built condition that contained more roughness, patchiness (including riparian vegetation), and topographic diversity to encourage local hydraulic interaction, scour, and deposition. Some of this was accomplished as part of the site design—such as leaving patches of mature riparian vegetation and the use of variable flood plain elevations—and some was accomplished by directing work in the field during construction.

The first rehabilitation sites (Hocker Flat, Pear Tree, Conner Creek, Valdor Gulch, and Elkhorn) were located downstream of Canyon Creek to allow for the greatest accretion of tributary flow to affect geomorphic change. This was during a period when ROD flows were reduced because of court-ordered water allocation restrictions that were in place from 2001 to 2004. Full ROD water allocations began in 2005 after a lawsuit was resolved. Subsequent projects were located farther upstream, which placed newly created habitat near the main salmon spawning areas located immediately below Lewiston Dam and where juvenile fish were produced.

Changes in the design approach undertaken during Phase 1 appear to be aiding the Program's goal of achieving the ROD's fish habitat objectives. Alvarez et al. (2011) found a positive correlation between total pre-smolt rearing habitat area, side channel length, and bank length, and a significant negative correlation with distance from Lewiston Dam. Alvarez et al. (2011) sampled thirty-two 400-m-long river units in 2009 using a generalized random tessellation stratified (GRTS) sample unit selection protocol. When the site-specific variables were assessed against optimal habitat area, the only significant finding was a negative correlation with distance from Lewiston Dam. However, they found a positive trend in the amount of habitat formed by construction activities completed after the ROD, as compared to pre-ROD and no action conditions. Alvarez et al. additionally found that the highest densities of juvenile Chinook and coho salmon were in slow, shallow areas within close proximity to cover and at sites located farther upstream.

Riparian habitats within the 64-km treatment reach vary due to past land use, historic flows, historic geomorphology, and the natural recruitment of vegetation. Mapping of riparian habitats and cover types was initially conducted at a system scale (McBain and Trush 2005) and more recently at individual rehabilitation sites (Alvarez et al. 2011). The mapping is used during project design development to both target and avoid certain riparian vegetation cover types. Riparian actions implemented earlier in the Program at sites lower in the treatment reach were more aggressive (i.e., riparian vegetation was removed) than those implemented more recently and located farther upstream. Riparian cover types and habitats within the restoration reach are in different stages of stabilization as a result of the construction activities, ongoing sediment loads, and flow and gravel augmentation. Similar to the in-water channel, it is assumed that riparian vegetation will continue to change over time as different design elements interact with flow and the morphology of the river channel responds to Program actions.

Importantly, the lessons learned from Phase 1 are already being incorporated into the Phase 2 design process. The design process now commonly uses hydraulic model studies of the final design to quantitatively estimate the potential ecological benefits associated with the design, along with the expected impacts on near-term hydraulic and sediment transport conditions associated with the rehabilitation elements. For example, the Lower Steiner Flat project reach was modeled under both existing and final design conditions for three flow scenarios: seasonal low flow (520 cfs), seasonal high flow (6,215 cfs), and the 100-year flood flow (38,500 cfs). The primary objective of the seasonal low flow scenario was to evaluate rearing habitat quality for fry and juvenile salmonids. The primary purpose for the seasonal high flow scenario was to evaluate impacts related to sediment transport and the associated near-term geomorphic response. Results from the 100-year flood scenario provided an understanding of the high flow effects of rehabilitation elements and spoils areas. Although evaluating the potential ecological benefits associated with a selected design is an important component of the design process, the logical next step is to conduct similar assessments of alternative designs as they are being developed by a design group working on a specific site. That way, information on fish habitat formation could be included in the alternative selection process and used during design discussions regarding the tradeoffs associated with each alternative, rather than using fish habitat formation estimates for the selected alternative only.

In 2011, the design groups compiled fact sheets on each of the 15 channel rehabilitation sites constructed under Phase 1. These included a brief statement of how the design group hypothesized the site would evolve over time. This expectation was developed after the fact in many cases and frequently consisted of a short, generic statement. For example, the Hocker Flat Design Summary Fact Sheet stated that the hypothesized design evolution at the reach scale was "channel migration and subsequent bar building, increased sinuosity, natural riparian regeneration on constructed floodplains." In contrast, the site design reports developed for Phase 2 sites commonly include more explicit descriptions of how the individual site elements are expected to change over time. For example, the *Trinity River Oregon Gulch Conceptual Design Report* describes the long-term anticipated evolution of each of nine project activity areas (HVT and McBain and Trush 2010). These descriptions are a result of the Program Partners' collaborative efforts to describe how past designs were expected to change and whether the sites performed as expected after construction and exposure to Program flows. The descriptions showcase the continued "adaptive" nature of the channel rehabilitation site design process and the Program.

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APPENDIX H
DECISION SUPPORT SYSTEM FRAMEWORK

Prepared for

Trinity River Restoration Program

Prepared by

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LIST OF ACRONYMS AND ABBREVIATIONS

1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
AEAM	Adaptive Environmental Assessment and Management Program
ARM	Adaptive Resource Management
CDWR	California Department of Water Resources
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
DSS	Decision Support System
DTM	digital terrain model
FaSTMECH	Flow and Sediment Transport Morphological Evolution of Channels
FL	fork length
GRTS	generalized random tessellation stratified
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HVT	Hoopa Valley Tribe
IHAP	Integrated Habitat Assessment Project
LiDAR	Light Detection and Ranging
m^2	square meter
MD-SWMS	Multi-dimensional Surface Water Modeling System
NRC	National Research Council
Program	Trinity River Restoration Program
Reclamation	U.S. Bureau of Reclamation
ROD	Record of Decision
RRS	relative reproductive success
SAB	Scientific Advisory Board
SDM	structured decision-making
SNTEMP	Stream Network Temperature Model
TMC	Trinity Management Council
TRFEFR	Trinity River Flow Evaluation Final Report
USDOI	U.S. Department of the Interior
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WRIMS	Water Resource Integrated Modeling System

1 INTRODUCTION

1.1 Background

The goal of the Trinity River Restoration Program (Program) is to restore and maintain the anadromous fishery resources of the Trinity River (USDOI 2000). Program components to achieve this goal include: 1) annual water year allocation to design hydrographs that provide variable flows to accomplish geomorphic and ecological objectives; 2) fine and coarse sediment management; and 3) mainstem channel rehabilitation (USFWS and HVT 1999).

Seven years of restoration activities have been performed, along with an extensive monitoring program. The Program must now decide what future activities to perform, how to accomplish them within the designated rehabilitation sites, and how to monitor them. These decisions will be based upon the existing monitoring data and modeling results to achieve the objectives identified in the Record of Decision (ROD; USDOI 2000). Currently, these decisions are qualitative and based on professional judgment. Despite the accumulation of a substantial amount of data and information by the Program, currently there is no centralized, transparent, and comprehensive approach for incorporating a variety of stakeholder objectives into the Program and evaluating and communicating the effects of alternative Program management decisions on fish populations and stakeholder objectives.

Furthermore, there is no overarching quantitative framework that permits the Program to quantify the benefits of specific activities in a transparent manner and estimate how these activities may have contributed to river system response within and outside the boundaries of specific project sites. Such analyses are complicated by multiple, interacting factors operating at different spatial and temporal scales within the 64-km (40-mile) restoration reach of the Trinity River from Lewiston Dam to the North Fork Trinity River and through the entire Trinity River to Weitchpec at the confluence of the Klamath and Trinity rivers where water temperature objectives for outmigrants extend (e.g., variability of water years, channel scour and deposition, water temperature regimes, and fish population processes). Integrating monitoring programs and modeling results is needed to address these interacting factors and changes in dynamic processes over time, which requires a quantitative framework. For example, monitoring data can indicate that an increase in habitat was achieved at various locations after Program activities, but this is insufficient information to design effective future actions. To improve future designs that are cost effective, one needs to know to what extent the improvement in habitat was due to flow modification, gravel augmentation, and channel modification, and how much that improvement is likely to influence system-wide responses leading to increased in-river salmon production. Moreover, physical and biological responses to management actions may be slow and revealed only after long periods of monitoring (on the order of years to decades; e.g., Buffington 2012).

In the meantime, an integrated modeling program is needed to more rapidly assess the potential benefits of different management actions and to make defensible decisions. In particular, a crucial modeling element currently missing from Program efforts is a fish production model.

Quantitative modeling and evaluation of simulated management scenarios can help fill the above information gap and should become an important component of the Program, both to judge the success and cost-effectiveness of activities to date and to plan subsequent phases of restoration and monitoring. Such analyses and evaluations were envisioned by the ROD, which identified "an Adaptive Environmental Assessment and Management Program (AEAM) consisting of a Technical Modeling and Analysis Group and a Rehabilitation Implementation Group" (USDOI 2000).

Platt (1964) argued that "certain systematic methods of scientific thinking may produce much more rapid progress than others." Platt's argument was that science proceeds much faster in a framework of hypothesis testing, and in particular where experiments can be defined that definitively allow us to select among competing hypotheses, that is, "strong inference." Nichols and Williams (2006) reiterated this plea within the context of conservation science and management. They argued that "monitoring should not be viewed as a stand-alone activity, but instead as a component of a larger process of either conservation-oriented science or management." They contrasted "targeted monitoring" with "omnibus surveillance monitoring." Their conclusion, following Platt (1964), was that targeted monitoring (i.e., monitoring within a hypothesis-testing framework) provides for much faster learning than surveillance monitoring (i.e., untargeted): "monitoring should be evaluated in the same manner as for any other scientific process, the only distinction being the nature of the hypotheses…under consideration" (Nichols and Williams 2006). That is, monitoring is most effective when designed and conducted in such a way as to test competing hypotheses, and ideally, to exclude one or more hypothesis.

This issue illustrates the need for a structured decision-making (SDM) system for the Program. The Program has promoted, and continues to promote, the development of physical and biological models for the system. There is a need to link these modeling frameworks into a coherent system of quantitative tools to support future assessments of the Program's effectiveness as well as decisions on how to manage the Program as new information becomes available. Such an analytical framework, guided by a hypothesis-testing approach, is what we refer to as the Decision Support System (DSS).

The DSS refers to an overall process and structure for integrating the disparate pieces of a large program to support effective decision-making. It is a structure insofar as it includes goals, objectives, conceptual models, and hypotheses that are tied to system processes that are important to management decisions, relevant monitoring, and quantitative models. In the context of the Program, the DSS would contain a linked set of quantitative models (hydrologic, morphodynamics, temperature, fish habitat, and fish population dynamics) that provide the connection between management actions and their potential ecological effects, that is, between specific actions and measurable system objectives, thus permitting a more accurate evaluation of management actions and better decision-making regarding future actions. The DSS is also a process, insofar as its components specify a series of actions: identification of objectives and alternatives; modeling, which includes not only the development, application, and testing of models but the interpretation and communication of their results; comparison of choices and projected outcomes; objective-driven monitoring; planning; and, as appropriate, modification of objectives and models.

While the primary “engine” of the DSS is the set of linked quantitative models listed above, the full DSS is a much larger construct, including additional scientific issues such as interactions with other species (e.g., with brown trout and wildlife), the full range of stakeholder needs (e.g., public safety during flow releases, sewage disposal, potable water supplies, and infrastructure protection), and a framework for communicating the alternatives and the results to a wide range of constituents and stakeholder groups. A primary recommendation of the Scientific Advisory Board (SAB) is that a comprehensive DSS be developed as an explicit component of the Program, with the primary goals of clarifying and integrating the range of stakeholder goals, translating these into specific “fundamental” objectives, and quantifying these with a set of linked models so that future planning and evaluation of alternatives is performed in a coherent, complete manner. A similar recommendation was recently made during peer review of the Program’s 2013 science work plan (Atkins 2012).

1.2 What is a Model?

In this context, a model is a quantitative representation of a set of environmental processes in a specific location. “Modeling framework” refers to the actual equations and their solutions embedded in computer code that performs the calculations. “Model application” refers to the modeling framework along with the site-specific details that are used as inputs to the modeling framework, including the following:

- Initial conditions, for example the current bathymetry and sediment composition of the river
- Inputs to the model (also termed boundary conditions), for example the flows released from Lewiston Dam that enter the restoration reach

- Parameters, for example the settling speeds of sediment particles of various sizes in the water column, or the relationship between flow and habitat suitability for salmon fry and pre-smolts

Key attributes of models are their spatial and temporal scales. Spatial scales refer to both the domain of the model (the size of the modeled river reach) and its resolution (how finely resolved the predictions are, e.g., 1 m, 10 m, 50 m). In the ecological literature, these have been defined as the grain (resolution) and extent (domain) (Wiens 1989). Temporal scales refer to both the domain of the model (the period of time simulated in the model, e.g., 1 year, 50 years, also termed the model "extent") and the smallest interval at which the model performs those calculations (i.e., the time step, e.g., 1 second, 1 hour, 1 day, also termed "resolution" or "grain"). There is a trade-off when designing a model: models that are finely resolved with large spatial and temporal domains are often considered ideal but may be computationally impossible (it takes too long to run the models). Thus, modeling projects may involve a suite of models designed to operate at a range of scales, to permit both finely resolved predictions as well as system-wide calculations. Achieving the right balance of scales is a critical component of the design of a quantitative decision support framework for the Program.

Another key attribute is model dimensionality. In the present context, 1-D models contain a single chain of longitudinal model segments, each of which represents a portion of the river. Two-dimensional models contain a horizontal grid of segments, with more than one segment in the cross-river direction as well as the longitudinal direction. Three-dimensional (3-D) models also include more than one segment in the vertical direction.

The DSS proposed for the Program consists of a framework of interacting models with varying scales and dimensionality. The framework presented below is provided as an example of one approach the Program could adopt. The Program Partners should use the framework outlined in this appendix as a guide to develop a DSS that meets the Program's needs, given their more intimate knowledge of the available data and models.

1.3 Objectives

The primary objective of this appendix is to introduce the need for a DSS, describe its components that build on existing modeling efforts by the Program, and discuss its application in the Program. In particular, this appendix:

1. Emphasizes the role of the DSS in decision-making for the Program

2. Describes models that have already been developed for the Trinity River, discusses modeling frameworks that are available for application to the Trinity River, and provides recommendations regarding model frameworks for the Program
3. Provides an overview of the types of data needed for a core set of DSS models to better understand and predict effects from Program restoration actions
4. Suggests next steps in the consideration and development of a more comprehensive DSS

In Section 2, we describe the role of the DSS in decision-making. In Section 3, we describe the structure of a core DSS, that is, the model components. Section 4 contains a general description of the data required for these core models, a description of the types of data currently being collected by the Program, and ways to address any potential data gaps. In Section 5, we discuss model uncertainty and adaptation, and the application of the model in the Program. Section 6 contains a discussion of next steps. We emphasize here that structured decision making is an objectives-driven approach. That is, the specific approach taken to solve the problem and the models used are primarily determined by the objectives of the decision makers and stakeholders. Therefore, no single example or case study will adequately represent all of the factors or considerations that are relevant to the Program because the objectives and constraints of each case study are unique. In what follows, we describe the structured decision making process and the steps required to develop an integrated DSS. This process was followed by all of the case studies described and more recently, has been used by the Central Valley Project Improvement Act Fisheries Program to prioritize restoration actions for anadromous fishes. We also identify key elements that should be considered when developing a DSS for the Program (e.g., the integration with existing work in the Klamath Basin) and suggest models that are *potentially* useful. The suggested models, however, should not be treated as strict prescriptions. Rather, we suggest that project personnel consider multiple approaches (models) and, based on their familiarity with the system and Program objectives, choose those that best meet their needs.

2 DECISION-MAKING AND THE DECISION SUPPORT SYSTEM

2.1 Adaptive Management

Adaptive management is a systematic approach for improving resource management by learning and adapting from management outcomes through partnerships of managers, scientists, and other stakeholders who learn together how to create and maintain sustainable resource systems (Sexton et al. 1999). Three elements are necessary for a program to follow the U.S. Department of the Interior (USDOI) adaptive management protocol (Williams et al. 2009). First, decisions must be recurrent to allow opportunities for learning to influence future decision-making. Second, decisions must be based on predictions that incorporate structural uncertainty. Often this will be represented by two or more alternative models or hypotheses about system functionality. Third, there must be an objective-driven monitoring program. Programs that do not contain these essential elements are not, and properly should not be called, “adaptive management.”

Adaptive Resource Management (ARM) as defined by the USDOI (Williams et al. 2009) involves the use of quantitative models to help decision-making where outcomes following decisions are uncertain. The uncertainty is incorporated through the use of alternative models representing hypotheses of physical and population dynamics and statistical distributions representing error in model parameters and environmental uncertainty. Each model (hypothesis) is assigned a level of plausibility defined as a model weight. These weights can take values from zero to one with the sum of weights for all models equaling one. The values can be assigned to each model empirically using Akaike weights, Bayesian posterior model probabilities, or similar methods. Alternatively, weights can be subjectively assigned to each model based on expert judgment of a consensus of stakeholders. The optimal decision is selected based on the current system state (e.g., rearing habitat availability) and a prediction of the expected future state following a management decision, taking into account various sources of uncertainty. After monitoring data are collected, model structure, parameter values, and model weights are updated by comparing model predictions with observed conditions. The adjusted model and model weights can then be used to predict future conditions and choose the optimal decision. This adaptive feedback provides for learning through time and, ideally, the resolution of competing hypotheses with monitoring data. Because of its great potential for integrating monitoring programs into decision-making, ARM has now been formally adopted by the USDOI for managing federal resources (Williams et al. 2009).

In ARM, monitoring serves two purposes. First, monitoring provides an estimate of the current state of the system before a decision is made. For example, the SAB has emphasized the need for establishing baseline habitat conditions and estimating annual in-river fish production over the 64 km of river above the North Fork. To date, the only pre-rehabilitation baseline habitat information is from the upper 42 river km (26 river miles) used as input in the Trinity River Flow Evaluation Final Report (TRFEFR; USFWS and HVT 1999). Second, after a management alternative is implemented, monitoring provides information on what changes, if any, occurred to the system. More importantly, monitoring also should provide information on the system dynamics that should reduce uncertainty in the model (by testing and/or comparing alternative models). Monitoring and models are tightly linked in ARM. The model structure and parameter values are updated by comparing predictions to observed outcomes. Thus, predicted and measured responses should be on the same unit scale and in the same units. For example, if models estimate fry density, then monitoring should estimate the number of fry per unit area rather than estimating an index of population size, such as relative abundance. Likewise, if models estimate growth and movement of juvenile fish, monitoring fish numbers and lengths at one location is not sufficient. This means that model predictions must be measurable through monitoring.

Another important feature of ARM is that the models are used to determine monitoring priorities (i.e., what, when, and how much to measure). This is accomplished using sensitivity analysis to identify the components that have the greatest effect on the expected outcome of the decision and more importantly, the components that have the greatest effect on what decision alternative (e.g., approach to increasing fry habitat) is estimated to be best. Sensitivity analysis provides stakeholders with a means to identify those components that largely drive the decision and those that could be improved through an ARM process. During sensitivity analysis, the Program can estimate the value of collecting information (monitoring) for specific processes or features and focus on optimizing monitoring efforts aimed directly at improving decision-making. ARM also can be useful for resolving potential conflicts among stakeholders. If stakeholders agree on the objectives, but have different ideas about how the system works, the differing ideas can be incorporated into the decision model as alternative models. For example, the SAB has learned that Program Partners may disagree about the best approach for meeting project objectives. If these disagreements are about the system dynamics, an ARM process can be used to assess which ideas about system dynamics are most consistent with observed system response. Likewise, if stakeholders disagree on how to construct specific models that would generate similar outcomes, this process can be used to assess which model is most consistent with monitored responses.

These fundamental and conceptual modeling and simulation approaches are integral to adaptive management as first developed at the Institute of Resource Ecology, University of British Columbia in collaboration with scientists from throughout the world (including the U.S. Fish and Wildlife Service [USFWS]) and described as Adaptive Environmental Assessment and Management (AEAM; Holling 1978), a special case of ARM. ARM is designed to move beyond qualitative assessments of ecosystem change, more accurately determine the extent to which efforts to affect ecosystems are working, and diagnose why some actions succeed while others do not. ARM is a structured, iterative process of optimal decision making in the face of uncertainty. The goal of ARM is to reduce ambiguity via systematic monitoring that accumulates data required to improve future management decisions and improve management outcomes over time.

When the TRFEFR was written and adopted in the ROD, the AEAM approach to management based on “good supporting science” was specifically described in the Implementation Plan for the Preferred Alternative for the Trinity River (USFWS 2000). This need was re-emphasized in the 2004 Trinity Management Council (TMC) Subcommittee Report: “Restaff….with qualifications aligned with Implementation Plan to develop in-house expertise for modeling and assessment needs of the Program” (TMC Subcommittee 2004). The emphasis of AEAM was on modeling and assessment of model predictions, not simply continued monitoring as usual. Monitoring data was to provide the opportunity to assess and invalidate (or support) alternative models, thus increasing the understanding of system processes and the degree of belief in investigations conducted to date. As with all ecological models, the models used in adaptive assessment processes are approximations of reality and are not intended to predict exactly what will happen. Rather, models are to be used to investigate the relative effects or benefits of alternative management actions, and future investigations are improved when monitoring and retrospective analyses are used to contribute to developing a common understanding of how an ecological system functions. Although they are recognized in Program documents (e.g., TRRP and ESSA 2009), the use of integrated models has yet to be fully implemented. Therefore, the SAB feels strongly that a central, integrated modeling component within the Program is essential for developing measurable objectives, evaluating predictions, and reporting progress toward quantitative habitat and in-river salmonid fish production goals.

2.2 Stakeholder Objectives

Stakeholder objectives are the most important component of a DSS. Objectives are defined here as quantifiable factors that reflect the values of decision-makers and stakeholders and relate directly to the management decisions or actions. Failure to explicitly identify objectives will lead to conflict among decision-makers and stakeholders.

The fundamental objective of the Program is to restore the wild salmon fishery as stated in the ROD (USDOI 2000). However, other stakeholder objectives must also be considered and they must be quantifiable. Including all stakeholder objectives in the decision-making process increases transparency and fosters goodwill among all parties. Failure to explicitly incorporate stakeholder objectives into the DSS will limit its usefulness.

The Program's Integrated Assessment Plan (TRRP and ESSA 2009) identifies a series of objectives for implementing the ROD and addressing the fundamental objective of restoring and maintaining fish production. These objectives, however, are primarily *means objectives*. That is, they are objectives that, if achieved, will presumably result in attainment of the Program's fundamental objective(s) related to the ROD (TRRP and ESSA 2009). Fundamental objectives are the most important objectives that represent the core values of stakeholders and decision-makers. It is crucial to make the distinction between fundamental and means objectives. Means objectives *sometimes* help realize the fundamental objectives, and they primarily reflect stakeholder and decision-maker beliefs and ideas of how the system works. In other words, they are often *hypotheses* about system dynamics. A useful DSS must recognize the differences between fundamental and means objectives and treat means objectives as potential ways to achieve fundamental objectives. For example, fishery biologists may believe that reestablishing natural geomorphic processes will result in a stream channel that can support a self-sustaining salmonid population. This means that the true fundamental objective is "a self-sustaining salmonid population." However, there may be several alternative means for achieving a self-sustaining salmonid population that may or may not involve reestablishing natural geomorphic processes.

Emphasis should be placed on incorporating fundamental objectives into a future DSS for three reasons. Fundamental objectives are those things that matter most to decision-makers and will be the basis for judging the expected success of proposed management and identifying the course of action that is expected to best achieve the objectives. Changes in the fundamental objectives or their quantifiable attributes following implementation of a management action will be used to determine the success of the management action. For example, fishery managers in Georgia identified bass angler satisfaction as their fundamental objective (Peterson and Evans 2003). The quantifiable attributes of the bass fishery that anglers cared most about were: 1) catching large fish; 2) catching large numbers of legal-size fish; and 3) year-to-year consistency in fish populations. Thus, the DSS was used to estimate changes in these attributes in response to alternative management regulations. After implementing the management decision, creel and angler opinion surveys were used to determine if the changes in the three attributes and the fundamental objective (angler satisfaction) were consistent with the model predictions. Finally, adaptive management involves the elimination of alternative ideas (models) of system dynamics that are no longer supported by (monitoring) data. This means that stakeholders must be prepared to eliminate means models that are no longer supported by data.

2.3 Example of a DSS

Model frameworks that integrate hydrology, geographic context, and fish meta-population processes are increasingly used to inform management decisions (e.g., Freeman et al. 2012). They enable the effects of changes in river flow and habitat on fish population dynamics to be simulated across river reaches that comprise interconnected habitat segments. Below we describe the DSS that has been developed to assist in managing water resources in the southeastern United States (Freeman et al. 2012).

The interconnection between human development and the use of water resources presents one of the most significant problems facing natural resource managers world-wide. One key aspect of this problem is the negative impact of increasing demands for water on resident aquatic fauna. This pattern is evident in the southeastern United States, which has among the highest proportion of imperiled aquatic species in the Northern Hemisphere (Warren et al. 2000; Williams et al. 2008). However, there remains substantial uncertainty regarding the specific mechanisms regulating these at-risk fauna. Thus, natural resource managers in the area are faced with making water resource decisions that meet the needs of growing human populations and at-risk fauna, while taking into account significant uncertainty. Therefore, in 2005, the U.S. Geological Survey (USGS) initiated a program to develop a structured, transparent approach to managing water for meeting the needs of society and aquatic ecosystems. In the following sections, we briefly describe this SDM process and the outcomes to date. Technical details of the models can be found in Freeman et al. (2012).

To develop a decision model framework for managing water resources, the Flint River basin was chosen as the initial focus basin. The Flint River basin, located in southwest Georgia, is typical of the region. It contains five federally listed aquatic species, and land use ranges from high density urban (Atlanta) in the upper portion of the basin to high density irrigated agricultural lands in the lower portion. The mainstem Flint River is also a valued recreation resource that provides numerous boating and fishing opportunities.

Water management decisions have the potential to affect multiple stakeholders throughout the Flint River basin. Stakeholders included three state agencies, the Georgia Department of Natural Resources, Wildlife Resources and Environmental Protection Divisions, and the Georgia Farm Bureau; two non-governmental agencies, the Nature Conservancy and the Instream Flow Council; and two federal agencies, USFWS and the U.S. Department of Agriculture. In addition, three of the stakeholders were water decision-makers with the authority to manage the resources within the basin: the Environmental Protection Division, Wildlife Resources Division, and USFWS.

Representatives of each stakeholder agency were contacted and invited to participate in the SDM process. These representatives, primarily managers and administrators with the respective organizations, met in a series of 2- or 3-day workshops to identify the problem, identify and structure their objectives, and identify decision alternatives. The fundamental objective was identified as maximizing citizen satisfaction. The stakeholders then identified a set of means objectives based on user groups: the satisfaction of non-consumptive users and the satisfaction of consumptive users. Six means objectives were identified for achieving the satisfaction of consumptive and non-consumptive users: the number of boatable days of the river, the aesthetic value of the river (since dropped), water quality, water availability for human use, and the status or health of the native aquatic biota. The stakeholder group also identified three management decision alternatives based on agency authority and mandates: reservoir siting and construction, water withdrawal and use, and the implementation of land use regulations.

A prototype decision model was developed and refined during the initial stakeholder meetings. Technical experts then were invited to the process and asked to refine and parameterize the prototype model. The model went through a series of revisions starting with a large, complicated prototype model created by the stakeholders. The final decision model, detailed in Freeman et al. (2012), tracked the presence of multiple fish and mussel species in individual stream segments. The model operated on an annual time step and simulated the dynamics of each species in individual segments in response to streamflows, water quality, stream channel characteristics, and stream isolation. Streamflows were estimated using a physical model: a spatially distributed, deterministic, physically based hydrologic model and a statistical model calibrated using existing stream gage data. Stream channel characteristics and dynamics were estimated using long term bed elevation models, digital elevation data, geologic and soils data, and land cover data. The water resource decision model included multiple uncertainties including environmental and statistical uncertainty, which were incorporated using statistical distributions. Structural uncertainty was incorporated using eight models, each representing alternative hypotheses of system dynamics.

The decision model was examined using sensitivity analysis and was found to be most sensitive to assumptions about the fish and mussel meta-population dynamics, the flow model, and stream channel dynamics. These findings prompted members of the technical advisory team to pursue additional studies and develop a monitoring program targeted at reducing these key uncertainties and improving the understanding of fish and mussel meta-population dynamics, hydrology, and stream channel dynamics. The decision models have since been expanded to evaluate strategies for minimizing the effects of climate change and human population growth on aquatic ecosystems.

In conclusion, this is an example of an integrated suite of quantitative models that was developed to support decision-making by linking biological responses to river processes and management actions. While the specific components of the Flint River example differ from those that would constitute a Trinity River DSS, this example nonetheless represents the type of quantitative model system the SAB is proposing for the TRRP.

3 STRUCTURE OF THE TRINITY RIVER DECISION SUPPORT SYSTEM

3.1 Overall Structure

A DSS consists of four components: stakeholder fundamental objectives and any supporting means objectives, management alternatives, an integrated suite of models, and objective-driven monitoring (Figure 1). The DSS integrates physical and biological process models to estimate the extent to which alternative management actions have met, or might meet, stakeholder fundamental objectives. The DSS allows stakeholders and decision-makers to work interactively to identify preferred management actions, evaluate the effect of Program assumptions and uncertainty on estimated outcomes, identify key components for targeted monitoring, and use monitoring data to revise or improve the understanding of the system dynamics and address uncertainty, and thus, improve decision-making.

The assessment of changes in physical habitat available for juvenile fish rearing and adult spawning is central to fish production and the overarching goals of the Program. The example DSS described here integrates physical and biological models to estimate changes in physical habitat and salmonid production over time (Figure 2). The principal factors that control the availability of suitable physical habitat are the streamflow and temperature regimes (timing, magnitude, duration), instream and riparian vegetation that provides cover and shade, and the morphodynamics of the river channel (coupled interactions between hydraulics, sediment transport, and channel morphology). Insofar as restoration actions are primarily aimed at addressing these variables (means objectives), the DSS attempts to represent these changes mechanistically. Coupling of mechanistic models assumes that a complex system can be understood by examining the workings of key individual parts and the manner in which they are linked. Where available resources may not allow the Program to develop sophisticated mechanistic representations of the interactions between physical processes and biological responses, the DSS must also allow for empirical or qualitative representations and assessments.

The interconnections between models are illustrated in Figure 2. Figure 2 also indicates how the DSS provides a model framework that connects management actions (flow releases, channel modifications, and gravel augmentation) as inputs with the outputs needed for decision-making (e.g., smolt success, habitat suitability, population response). The model components are discussed, in turn, in the following sections.

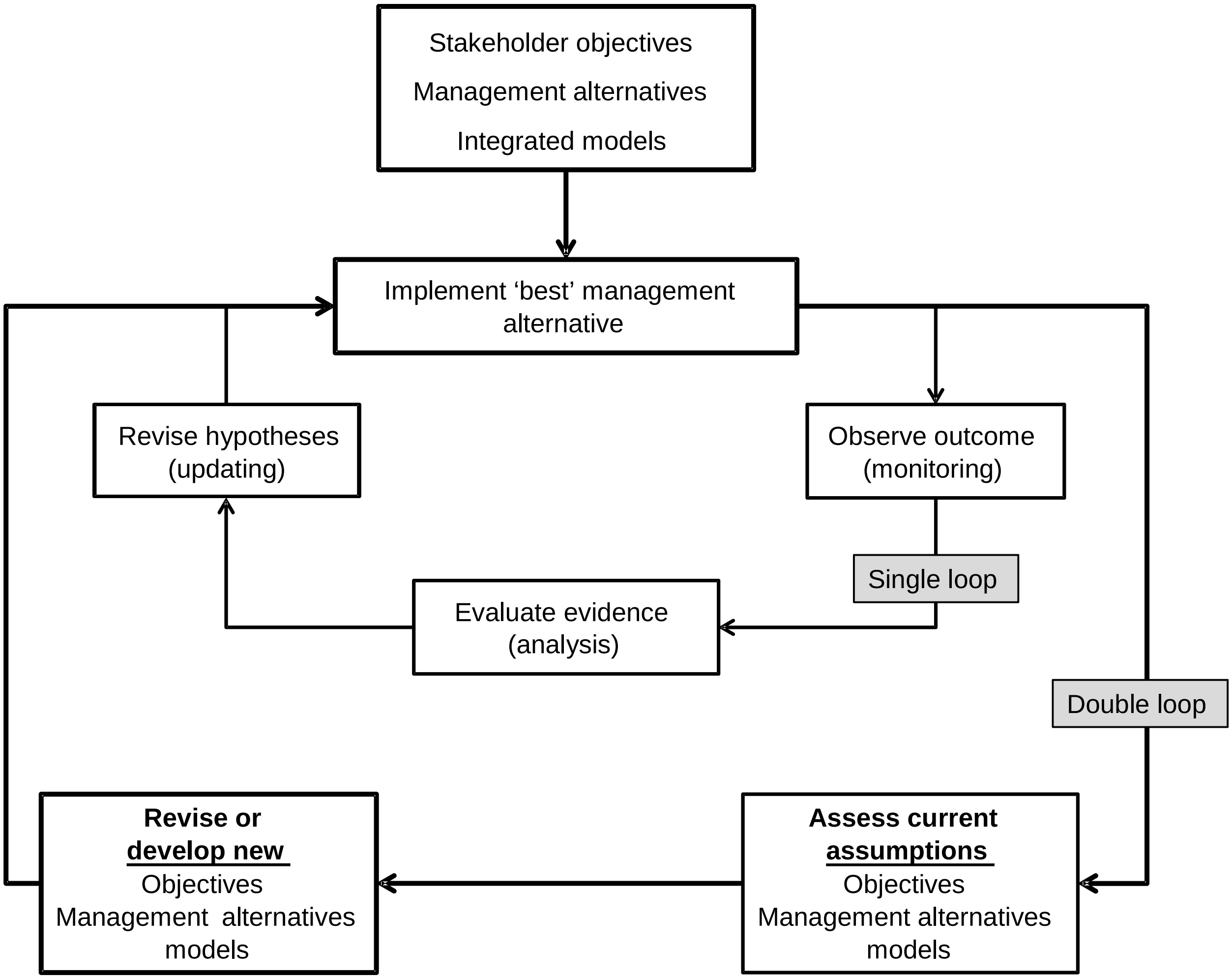


Figure 1

Schematic of Decision Support System Framework that Includes Single and Double-Loop Learning

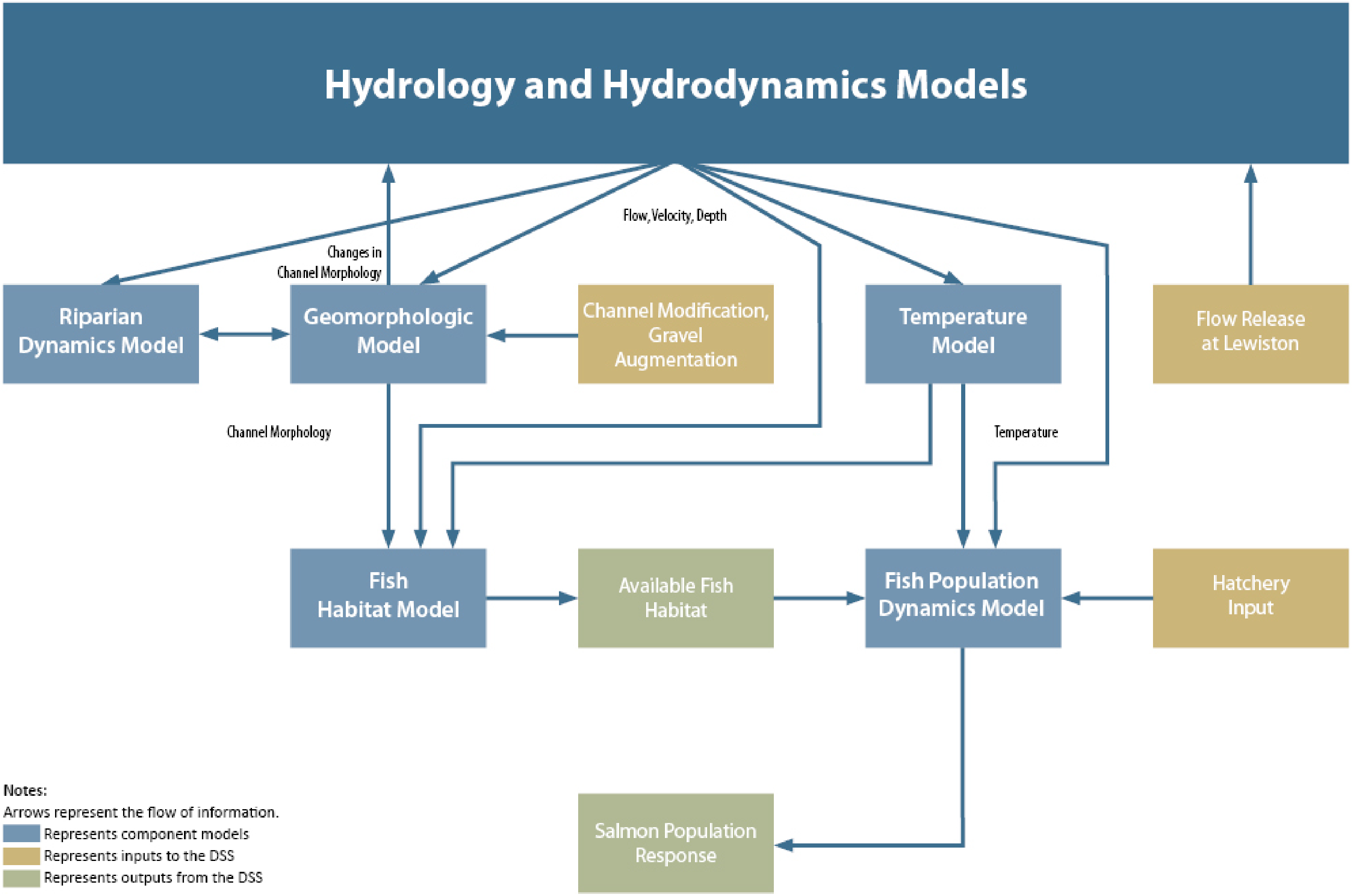


Figure 2

Model Components of a Program Decision Support System

3.2 Guidance for Developing a DSS Suite of Models

The selection of specific models is an important part of the DSS process, as discussed above. This is because models must be selected to meet the specific goals of the TRRP, that is, to provide the information needed to make management decisions. While Figure 2 shows the general linkage between management actions (flow, gravel augmentation, and channel rehabilitation) and population response, the Partners need to evaluate very specific actions such as adjustments to hydrograph shape and the use of rehabilitation design elements, such as side channels, wood, and mid-channel bars. Therefore, in selecting models, the spatial and temporal scales of the models are key considerations: they must provide the resolution needed to address the management decisions. Thus, a coarse 1-D hydrologic model will not provide the information needed to design a specific rehabilitation element in a specific location. A finely resolved 2-D model will provide the information, although such models have their own limitations, in particular, extensive data needs and long model run-times. These considerations are critical to the design of the overall DSS system of models, which must involve models on a range of spatial and temporal scales, to both provide the detailed local information necessary for design decisions as well as the river-wide information necessary for addressing the overarching goals of the project. To date, the Program has focused largely on the design element and site scales, but must also consider the reach and system scales, as well as interactions between rehabilitation projects at these scales.

Many of the models that can form parts of a DSS for the Program exist or are under development, and the SAB strongly supports the use of existing models whenever possible. In addition, the SAB supports the recommendation of the National Research Council (NRC) that the modeling frameworks for the Trinity and Klamath rivers be as integrated as possible (NRC 2008):

> *Integration of these two efforts is essential... To fully integrate these two programs, the same models (such as flow, temperature, habitat, and fish-population dynamics) with the same level of detail, time step, and linkage among models should be used on both sub-systems. With similar integrated modeling and data management, alternative management scenarios (involving reservoir releases, sediment augmentation, and so forth), using an assumed water supply, climate conditions, and salmon stock returns, could be quickly evaluated. Such linkage of models could greatly facilitate communication among various stakeholders and managers and lead to better adaptive-management approaches.*

In this appendix, we discuss models developed specifically for the Trinity River that are compatible with ongoing efforts on the Klamath River. The SAB recommends that the

Program's DSS be developed in coordination with modeling efforts on the Klamath River to ensure consistency in the approaches developed and applied to both river systems. A joint technical working group for the Klamath and Trinity rivers would enhance system-wide learning and should be considered.

In developing a DSS, we considered several attributes as essential. The DSS should:

- Explicitly and quantitatively link management decisions or actions to stakeholder fundamental objectives
- Facilitate the communication of complex scientific information in a manner that is understandable and meaningful to stakeholders
- Incorporate and quantify the key uncertainties associated with management actions and system dynamics
- Provide the means to evaluate and compare the relative benefit of management actions on stakeholder objectives
- Inform the channel rehabilitation design process to ensure that future project designs help meet Program objectives
- Provide the means for incorporating or modifying objective-driven monitoring data to improve the understanding of system dynamics and increase the value of future management actions
- Be consistent with decision-making tools being developed for the Klamath River, as the Trinity River is its largest tributary

Examples of the types of specific questions that quantitative models should address are:

- If the water releases from the Lewiston Dam are modified, how might juvenile fish growth and survival be affected, and what are the ultimate population responses?
- With limited funds, what locations should be selected for gravel augmentation and channel modification to have the greatest impact on system response and smolt success?
- What monitoring data are needed in order to improve our ability to make these projections?
- How much spawning and rearing habitat is needed to achieve the Program's goals?
- How may channel response and habitat evolution alter fish population limiting factors?
- How will proposed actions affect adult holding habitat in the near and far term?

The remainder of this section provides descriptions of each of a suite of models that may be used to build an initial integrated core for the Program's DSS. Improved or new models and additional components would be added as appropriate in the future. The models discussed include those currently used or available to the Program in the spirit of capitalizing on existing efforts, but this is not meant to be an exhaustive list and specific model selection is left to the users.

3.3 Water Management Models

3.3.1 Background

Water management models are designed to support flow allocation decision-making in complex river and reservoir systems. They specify flows at multiple points in a system that are subject to a series of constraints, such as minimum and maximum flow requirements and specific stakeholder needs. Model outputs (computed flow levels) can be used as input to hydrologic and hydrodynamic models, which in turn are used to compute water velocities and depths at various locations as input to other models.

3.3.2 Current Activities

Flow releases from Lewiston Dam to the Trinity River are developed by the Flow Work Group through a collaborative process, including public input (e.g., Krause 2012). The ROD provides recommended daily release schedules for five water year types ranging from critically dry to extremely wet. The annual runoff forecast for Trinity inflow is jointly developed by the National Weather Service and the California Department of Water Resources (CDWR) for the entire state of California, including the Trinity River.

Additional predictive models are under consideration. The flow routing model MODSIM was developed for the Klamath basin (Hanna and Campbell 2000) to support the development of basin-wide strategies for short-term water management, long-term operational planning, drought contingency planning, and water rights analysis (Labadie 2006).

In addition, the Water Resource Integrated Modeling System (WRIMS) model, a generalized water resources modeling system for evaluating operational alternatives of large, complex river basins, was developed jointly by the U.S. Bureau of Reclamation (Reclamation) and CDWR and has been applied by Reclamation to the Klamath River (Beighley and Killgore 2011).

3.3.3 Recommendations

The development of a water management model using the WRIMS framework for the Trinity River would have the benefit of providing consistency throughout the Klamath/Trinity Basin, with a daily time step. A WRIMS framework has already been developed for the Klamath River with 15 nodes and 4 flow demands (Beighley and Killgore 2011). As identified above and consistent with the recommendations of the NRC (see Section 3.2), one of the goals of the DSS is to support the linkages to the model frameworks developed for the Klamath River with those developed for the Trinity River. For this reason, the SAB recommends the development of a WRIMS model for the Trinity River. It is suggested that Reclamation's Technical Center in Denver, Colorado, be contacted to determine the time and effort needed to incorporate the WRIMS model as part of a Trinity River's decision-making system. However, we understand that use of the WRIMS model requires potentially complicated coordination with Central Valley flow scheduling, which may make other approaches more appealing.

3.4 Hydrologic and Hydrodynamic Models

3.4.1 Background

The hydrologic and hydrodynamic models are the foundation of the DSS, providing information that is critical for all of the other models (Figure 2). These models provide the quantitative link between management actions, in particular flow releases, and river response (morphodynamics and hydraulic aspects of fish habitat as necessary inputs to fish population dynamics models), given different water year conditions (wet, normal, dry, etc.). With these models, one can simulate flow release alternatives and evaluate how the river throughout the restoration reach may respond over time. This can be done using either 1-D or 2-D models, with associated trade-offs between the resolution of predicted values and the required model inputs and run-time, as discussed above.

3.4.2 Current Activities

Large-scale, Low-resolution Models

The CDWR implemented a HEC-RAS model for the upper 64-km reach of the Trinity River from Lewiston Dam to the North Fork Trinity River. HEC-RAS is a computer program developed by the U.S. Army Corps of Engineers (Corps) to model the hydraulics of water flow through river channels. The CDWR model was developed in 2006 based on topographic data collected in 2001 and 2004. The 2006 model contained varying segment lengths that averaged approximately 100 m over the entire 64-km reach. In 2011, the CDWR implemented a newer version of HEC-RAS for the Trinity River based on topographic data collected in 2009. The CDWR and Program Partners are using the HEC-RAS models to develop flood designations below Lewiston Dam for different Program flow releases. HEC-RAS modeling is also used in assessing compliance with Federal Emergency Management Agency requirements related to changes in water surface elevation during channel rehabilitation design development.

In addition, Watercourse Engineering implemented a 1-D hydrodynamic model covering the entire Trinity River downstream of Lewiston Dam and portions of the Klamath River

(Watercourse Engineering 2007). They used the RMA2 model (King 2001), which solves the fully dynamic momentum and continuity equations (shallow water equations) using the finite element method. It produces time series of velocities, water levels, and discharges through a continuous system of computational elements approximating the actual geometry of a river. The RMA2 model can be run as a 1-D or 2-D model and provides a mechanistic representation of flow on a sub-daily scale. For the 64-km restoration reach, this model employed cross sections similar to those used in the HEC-RAS model with a similar spatial resolution of approximately 100 m.

Fine-scale, High-resolution Models

Fine-scale, high-resolution hydrodynamic models can be used to support fish habitat assessment, in conjunction with fish habitat mapping. Extensive fish habitat mapping performed by the Program has allowed current conditions and the effects of channel rehabilitation, gravel augmentation, and flow augmentation actions to be assessed based on pre- and post-construction mapping under base flow conditions. Mapping has also been performed under a range of flow conditions at some locations and provides support for estimating the potential effects of future Program flow regimes on fish habitat availability. Figure 3 shows an example depicting the change in various fish rearing habitat categories at four locations as river flow increased.

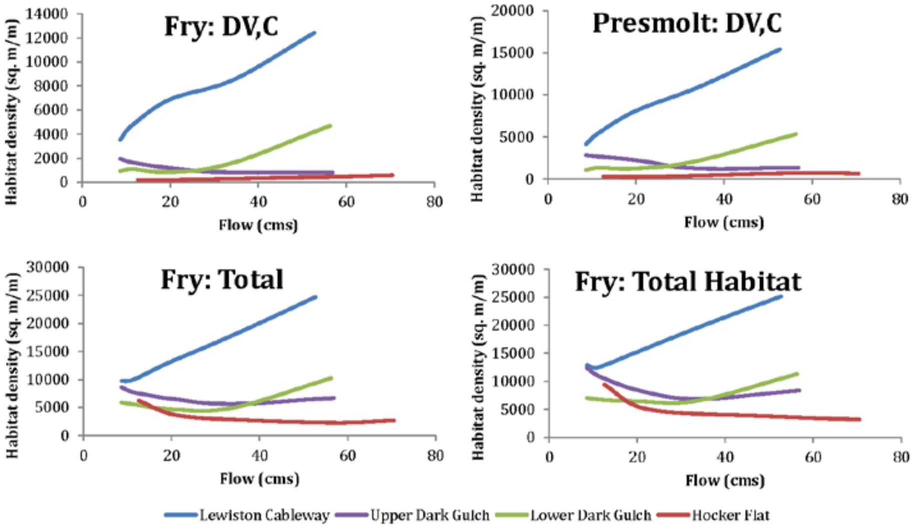


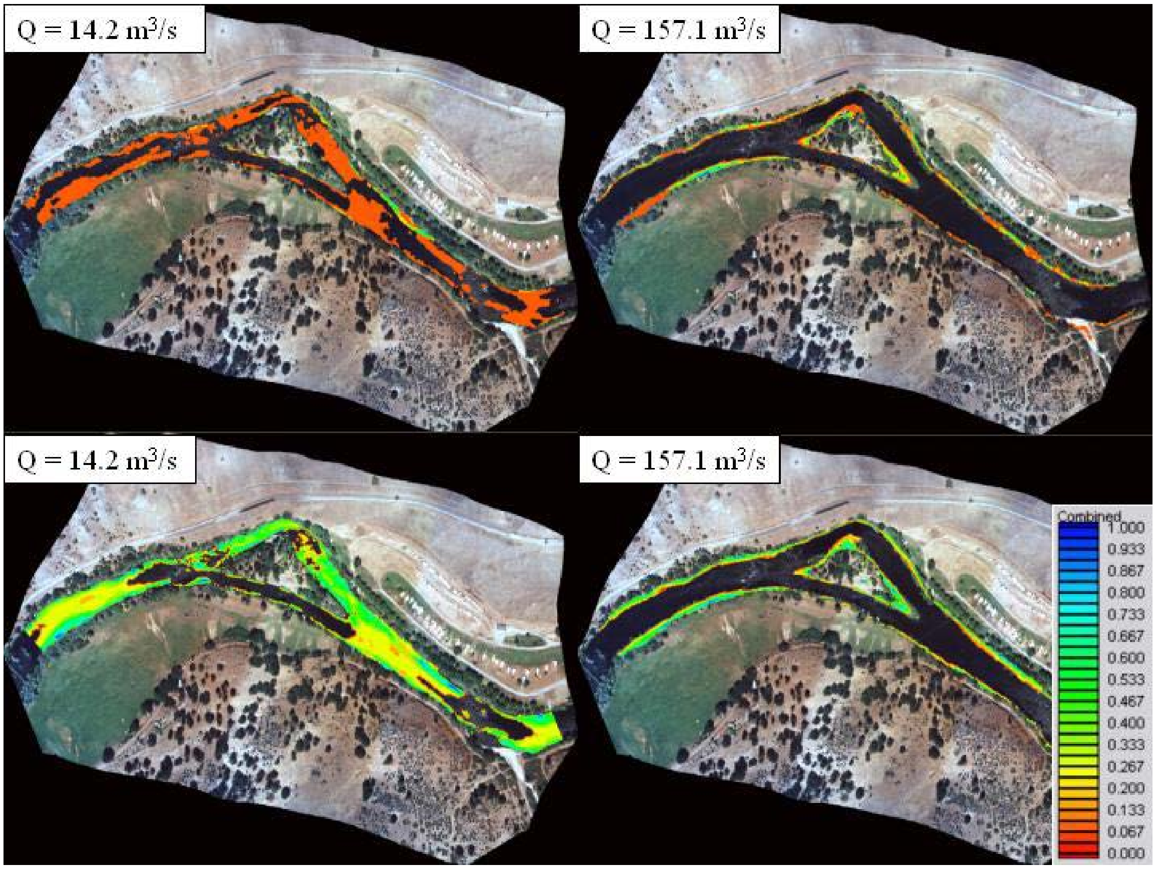
Figure 4-20. Post-construction rearing habitat density across streamflow (Flow) at multiple channel rehabilitation sites. DV,C indicates high quality Chinook salmon and coho salmon presmolt rearing habitat and total habitat indicates all qualities of rearing habitat. Streamflow was measured at each site for this analysis. Hocker Flat was evaluated in summer 2008 all other surveys were conducted in summer and fall 2009. The fry life stage indicates fish > 50 mm FL and presmolt 50 to 200 mm FL.

Source: Alvarez et al. 2011, Figure 4-20

Figure 3

Example of Habitat Mapping under Various Flow Conditions

A key component of adaptive management is the ability to predict the potential changes that are expected to result from alternative restoration activities (e.g., channel modification, gravel augmentation, or modification of the flow regime) as well as increased riparian and wildlife habitat. To some extent, this can be performed using data shown above relating suitable fish habitat density to flow. However, fine scale, high-resolution 2-D hydraulic/habitat models can be used to extrapolate this mapping data to provide flow/habit relations as input to fish population models. For example, Hardy et al. (2006) developed a 2-D hydraulic/habitat model that produced flow/habitat relations at sampled locations on the Klamath River (Figure 4). Results from this 2-D hydraulic/habitat model were also integrated with substrate and vegetation information in a GIS framework to produce estimates of functional cover and escape cover parameters throughout the river reach (Hendrix et al. 2011). Curves that describe the relationship between each of these parameters and habitat suitability were developed. Finally, these relationships were combined with the finely resolved hydrodynamic and habitat mapping to estimate the suitability of each model grid element. This model was found to provide a more realistic representation of habitat suitability for Chinook salmon fry in the Klamath River than simpler models (Hardy et al. 2006). These results were then scaled to the reach level, producing estimates of suitable area, or the area of habitat/length of river for each study reach as a function of streamflow.



Predicted spatial distribution and quality of available habitat at the R-Ranch study site. The top row contains results from the behavior-based habitat model at 14.2 (left) and 157.1 (right) m3 /s. The bottom row shows results for these same discharges based on the simple depth, velocity, and substrate-based habitat model for these same flow rates.

Source: Hardy et al. 2006, Figure 7

Figure 4

Example of Results of Simulated Habitat Modeling Using A Behavior-based Habitat Model (top row) Versus a More Simplistic Model Based on Depth, Velocity and Substrate Criteria (bottom row)

High-resolution 2-D hydrodynamic models were developed for two sections within the 64-km restoration reach of the Trinity River to support detailed assessment of instream habitat (Alvarez et al. 2011). The models were developed to demonstrate the capabilities of the modeling techniques to assess and improve restoration designs. The modeled sections were located at Reading Creek and Lowden Meadows. The study employed the Flow and Sediment Transport Morphological Evolution of Channels [FaSTMECH] model that is provided with USGS's Multi-Dimensional Surface Water Modeling System (MD-SWMS) software (McDonald et al. in press).

The model was developed at a grid-resolution of 1 m^2 and covered approximately 0.6 km of the Trinity River at each section.

As summarized by Alvarez et al. (2011), "although trends were similar between model predictions and mapping estimates of habitat parameters (depth/velocity, inundated cover and wetted perimeter), differences were apparent." Thus, while the modeling requires refinement, it shows promise. We recommend that habitat mapping and 2-D hydraulic models be further combined to simulate physical habitat conditions over the entire range of flows for each water year. To be acceptable for such a wide range of flows, the model must be tested against empirical measurement at flow levels different from levels used to construct the models. Furthermore, there are two critical fish habitat model components that each must be tested by comparison with empirical data: 1) the hydraulic sub-model component, which simulates the distribution of velocities and depths throughout the sampled reach at a range of unmeasured flows; and 2) the habitat suitability sub-model, which simulates the potential distribution of selected life stages of fish throughout the sampled reach also at a range of unmeasured flows. Proper application would calibrate both sub-models to empirical measurements in order to obtain reasonable agreement with both depth/velocity and presence/absence observations of fish. After calibration, both sub-models are then tested against additional measures of depth/velocities and fish presence/absence to ensure reasonable agreement, assuming fish availability is not a limiting factor (i.e., no cases of suitable, but unoccupied, habitat).

Currently, the Program is applying FaSTMECH at 11 locations covering a total of approximately 6 km of the 64-km restoration reach (CDFG et al. 2010). The FaSTMECH 2-D model developed for select reaches of this system provides hydrodynamic information at a fine lateral and longitudinal resolution (1 m^2; but is still vertically averaged), thereby enabling a much more accurate assessment of the available habitat. Since the spatial coverage of the 2-D model is presently limited to the 11 river sections, its results must be extrapolated to cover the rest of the river. Some options for performing this extrapolation are provided in Section 3.7.

The Program has also begun to incorporate 2-D hydraulic modeling of design alternatives into the channel rehabilitation design process used for Phase 2 sites. The Sedimentation and River Hydraulics 2-D model (SRH-2D), developed by Reclamation (USFWS et al. 2012), was used during development of the Upper Junction City rehabilitation site to evaluate the civil design, the potential for management activities to fill holding pools, and potential change in salmonid rearing habitat associated with design alternatives. Depth and mean column velocity outputs from SRH-2D model runs were used to characterize habitat for Chinook salmon fry and juveniles based on suitability criteria developed by Hampton (1997). Model outputs were in the form of polygons quantifying habitat areas within suitability classes for each rearing life history stage (fry and juvenile) for site discharges of 20, 76, and 212 $m^3 \cdot s^{-1}$ (700, 2,700, and 7,500 cubic feet per second [cfs]). Model results indicated the design alternatives increased habitat area from 70 to 500% depending on the life history stage and flow. The results allowed designers to recognize that the largest gains in habitat were associated with side channel and alcove design elements. The Program also used SRH-2D to evaluate the potential effects of the 2011 high flow injection at Lowden Ranch, including whether the gravel injection would promote gravel deposition on bars and transport through pools (Gaeuman in review).

For the Lower Steiner Flat project, a more complex approach for modeling changes in juvenile rearing habitat than the one employed at Upper Junction City was developed. A 2-D hydraulic model of the Lower Steiner Flat reach was developed to evaluate the potential influence of the concept design on hydraulic and fish habitat characteristics (CH2MHill 2011). Model results were evaluated by defining a set of benefit indices that could be quantitatively measured and mapped, and comparing these benefits with costs associated with the various alternatives evaluated under various flows. The approach incorporated the quantitative habitat suitability indices for the Trinity River outlined by others (e.g., Goodman et al. 2010), and measures to capture benefits from other considerations such as complexity and cover. The results for each alternative were screened qualitatively to assess risk to infrastructure and other identified channel features. The approach produced a semi-quantitative evaluation of benefits and costs that incorporated many important project objectives to help identify a preferred alternative. Results of model studies indicated that various proposed project elements were likely to create different habitat benefits for the fish life stages at different flows, and supported the need for these types of model studies. The process of evaluating alternatives required the simultaneous optimization of many variables and allowed designers to visualize changes in channel conditions and habitat area associated with various design alternatives.

3.4.3 Recommendations

Ideally, a 2-D hydrodynamic model would be constructed for the entire 64-km study reach. However, such a model would have large input requirements and a very long run-time. Therefore, the recommended DSS consists of a 1-D hydrologic model, supplemented by a 2-D hydrodynamic model at selected sites. Working together, these models provide the flow information needed for the DSS in a cost-effective manner. The hydrologic model provides the flows that act as the upstream boundary conditions (inputs) for the hydrodynamic models, which are developed for selected sub-reaches of the river that are of particular interest (e.g., rehabilitation sites or critical habitat data inputs identified for population models).

In addition to the TRRP's current use of hydraulic modeling in site design (e.g., setting invert and floodplain elevations, specifying discharges carried in side channels or split flows), this approach will provide flow/habitat relations for each sampled segment (both constructed and non-constructed) under various management options . When projecting future conditions, the HEC-RAS model can be used to model system-wide changes in flows and water surface elevations for different flow release scenarios. This information can then be fed to the finely resolved FaSTMECH model at each habitat sample site to compute changes in local velocity and depth, which can be applied using habitat suitability criteria as developed by TRRP or the equations of Hardy et al. (2006).

The SAB recommends that the Program continue the development of predictive habitat models, including the integration of habitat mapping and 2-D hydrodynamic model predictions discussed in Alvarez et al. (2011) and model testing with independent observations of fish distribution at modeled flows, as discussed above. In addition to calibration and testing of velocity distribution outputs from the hydraulic sub-model, the SAB recommends that the habitat suitability sub-model also be tested by considering three suitability classes: optimal, marginal, and unsuitable. Presence or absence of observed fish distributions at these habitat classes resulting from model-simulated flow levels can be tested against fish presence or absence observations as described by Thomas and Bovee (1993); see also Hardy et al. (2006). Careful calibration and validation of both sub-models are necessary to establish scientific credibility of the habitat model outputs (Annear et al. 2004) that are essential as inputs to fish population models. Because fine-resolution model results may only be available for the 11 river segments, a means of extrapolation is required to characterize conditions throughout the rest of the river using more easily obtained channel geometry information as described in Section 3.7. This system-wide habitat data, in turn, provides necessary inputs for a fish population model (a critical missing component of current Program efforts). Eventually, augmenting the identified 11 sites for better coverage of the system should be considered.

3.5 Temperature Models

3.5.1 Background

Water temperature models are generally tightly linked to hydrology or hydrodynamic models and operate on the scales and dimensions of those models (daily or hourly, 1-D or 2-D). For example, the Stream Network Temperature (SNTEMP) model is a mechanistic, 1-D heat transport model that simulates the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux. The model was developed in the early 1980s for the U.S. Department of Interior, Fish and Wildlife Service (Theurer et al. 1984) and has since been used in studies to analyze the effects of reservoir discharge timing, release temperature, and release volume (or some combination of all three) on downstream water temperatures (Bartholow 2000). Also, depending on the scale of the analysis (inter-year or intra-year), a water balance model may also be necessary.

3.5.2 Current Activities

A SNTEMP model was implemented that covers the entire Trinity River downstream of Lewiston Dam and also the lower sections of the Klamath River (Zedonis 1996). Since then, the Stream Temp model has been developed, which uses SNTEMP as the calculation engine but has a Windows-based user interface shell with added data input and output capabilities. The model uses 7-day time step inputs, but provides section-wide average daily temperature outputs at selected locations (nodes) placed at integer distances of 24-hour water travel. Thus, the present Stream Temp (SNTEMP) model uses a 24-hour thermal budget cell, where it tracks all water within a 24-hour travel time distance and applies heating and cooling to that body of water. The model was extensively calibrated and validated to a long period of record for the Lewiston Dam to Weitchpec reach. It is used by Reclamation to manage water releases from Lewiston Dam to meet temperature requirements in the Trinity River.

Improvements to a daily time step are necessary for consistency across the Klamath/Trinity Basin and for use in fish habitat and fish population modeling. In this regard, the RMA11 (King 2002) model was implemented for the Program and used in conjunction with the 1-D RMA2 hydraulic model to provide estimates of temperature at sub-daily time steps (Watercourse Engineering 2007). It was calibrated to existing Trinity River temperature data for the 2000 to 2005 period, covers the Lewiston Dam to Weitchpec reach of the Trinity River and the Orleans to Weitchpec reach of the Klamath River. It has been used by Reclamation on a very limited basis to evaluate water release scenarios and water temperature management options for the Trinity River. It is important to note that whichever temperature model is used to provide linkages within the DSS, the model will need to include predictions of water temperatures associated with releases from Lewiston Dam on the temporal scale needed for fish habitat and population modeling.

In addition to the models above, the HEC-RAS model also has the capability to simulate stream temperature. However, a stream temperature modeling effort using HEC-RAS has not been undertaken by the Program to date for meeting temperature targets.

3.5.3 Recommendations

Two modeling frameworks might be appropriate to the Trinity River that integrate temperature and hydrodynamic models to meet fish habitat modeling requirements for sub-daily temperatures at multiple locations along the river. Their use is recommended because they have already been developed for the Trinity River and they use similar numerical frameworks, which reduces the effort required to develop an integrated model framework.

The first framework combines HEC-RAS with Stream Temp (SNTEMP). The HEC-RAS model has its own temperature module, but unlike Stream Temp it has not been applied to the Trinity River. However, depending on how Stream Temp is currently configured, modifications to achieve the required outputs (daily or sub-daily time step) may be required.

The second framework is RMA2 combined with RMA11. The RMA11 model has the benefit of a daily or sub-daily time step. Furthermore, it is our understanding that Reclamation currently uses a combination of WRIMS with RMA11 for the Klamath River. Thus, the use of RMA2 and RMA11 on the Trinity River would have the benefit of being consistent with the Klamath River modeling, which would facilitate basin-wide analyses and water management by Reclamation. The combination of RMA2 and RMA11 has the added benefit of finer spatial resolution, if desired. However, the combination of RMA2 and RMA11 has some limitations. Depending on time of year, tributary inflows are poorly represented in the model. Also, while hydrodynamic parameters in the model for the reach downstream of the North Fork Trinity River have been calibrated, additional sampling should be conducted to replace estimated cross sections with actual measurements.

3.6 Morphodynamic Models

3.6.1 Background

Morphodynamic, or geomorphic, models simulate the movement of sediment and the consequent changes in the form of a river channel due to erosion and deposition. They help in evaluating the extent to which constructed habitat features will provide suitable fish habitat and how those features may evolve over time. In addition, in alluvial reaches, these models can aid in evaluating the potential for management activities to allow river flows to drive a desired channel change that is intended to create more complex channel geometry and associated increases in fish habitat suitability and, ultimately, fish production. This could include evaluating the effects of gravel augmentation on bar formation, the volume of gravel needed to achieve a desired effect on channel complexity, how flow guidance structures affect erosion on one or both banks, and the effect of flow augmentation on berm erosion in a specific area. Finally, changes in morphology feed back to the 1-D and 2-D models of hydrology, hydrodynamics, and temperature: flows change river shape and substrate size which, in turn, affect flow depth, velocity, and stream temperature; these, in turn, control habitat suitability and fish production (Figure 2).

There are several categories of numerical morphodynamic models that can potentially be used in the DSS to predict the dynamic evolution of a riverbed and other parameters relevant to fish habitat. This could include changes in channel aggradation or degradation, grain-size distributions of bed surface and subsurface material, suspended sediment concentration, and flow parameters. Morphodynamic models, also known as sediment transport models or mobile boundary models, may be 1-D, 2-D, or 3-D. These models can produce results relatively quickly, predict the outcome of multiple scenarios, and test the sensitivity of outcomes to variation in processes and conditions. As with all numerical models, morphodynamic models require targeted data collection programs for calibration and validation.

A morphodynamic model is typically composed of a hydrodynamic sub-model that is coupled with sediment transport equations and Exner equations of sediment continuity. The dimension of the hydrodynamic sub-model (1-D, 2-D, or 3-D) determines the geomorphic model's dimension. The most widely used models predict channel scour and fill within a defined channel boundary. Local water depth, flow velocity, and shear stress are used to calculate local transport capacity, which is used to predict channel scour or fill from imbalances in sediment transport (input minus output). Bank stability and toe erosion models predict bank stability under different hydraulic and geotechnical conditions (e.g., Simon et al. 2011), while river meander models predict long-term trends in the movement of a river centerline based on predicted differences in shear stresses or velocities between banks (e.g., Johannesson and Parker 1985).

One-dimensional models that predict sediment transport dynamics and channel scour and fill on a cross-section averaged and reach-averaged basis (e.g., Cui et al. 2011) are relatively simple to set up and are more widely used than 2- and 3-D morphodynamic models (e.g., Greimann and Huang 2009; Cui et al. 2011). One-dimensional morphodynamic models can be set up for a long river reach for long-term simulations, but because of their cross-section averaged and reach-averaged nature, they do not have the resolution to predict habitat-scale variations needed as inputs to biological response models or fish production models.

Two- and 3-D morphodynamic models theoretically provide predictions of morphodynamic changes at fish habitat scales. However, the following factors may limit the accuracy and precision of 2- and 3-D morphodynamic model predictions at fish habitat scales (Biron et al. 2011; Cui et al. 2011):

1. Two- and 3-D morphodynamic transport models generally apply the same set of sediment transport equations as 1-D models. The equations are derived by correlating the downstream flux of sediment with the average shear stress or other flow parameters (such as velocity and depth) through a cross section. This gross approximation becomes less accurate when dealing with lateral sediment movement. The simple linkage between

sediment transport and shear stress may ignore some of the key mechanisms responsible for complex sediment transport dynamics. While 2- and 3-D models can predict the general location and relative direction of channel change (i.e., aggradation or degradation), these models are less reliable at predicting the magnitude of change and the topographic complexity observed in the field.

2. Two- and 3-D models require large amounts of input data that are often either too expensive or infeasible to collect for an ideal modeling exercise. Two- and 3-D morphodynamic models are also restricted by a lack of model calibration and validation data (Biron et al. 2011).
3. Two- and 3-D models require a large amount of data storage and computer resources, restricting the length of river reach that can be modeled.
4. Some aspects of the modeling results are dependent on how the boundary conditions and model grid are defined.

Despite these limitations, 2- and 3-D morphodynamic models can predict critical features that 1-D models cannot, provided that model limitations are fully understood and their results are not over-interpreted. For example, development of topography associated with planform curvature, and scour associated with an in-river structure, are often critical processes in river restoration that are generally predictable at a coarse resolution with 2- or 3-D morphodynamic models.

Theoretically, an integrated approach could enable predictions of the effects of structural manipulations, sediment trapping and augmentation, and flow management on physical habitat anywhere in the restoration reach of the Trinity River, given an unlimited capability to collect field data, run models, and analyze results. However, several key questions must be addressed in developing such an integrated modeling approach. First, what limits the potential to produce these outputs? Second, how could these outputs be utilized in fish-habitat models? Third, what must be done to optimize this potential?

Each rehabilitation project site represents unique and complex conditions inherent in a natural river, which limits the transfer of results from one site to another. However, it is not feasible to perform coupled geomorphic-habitat modeling at all sites. Therefore, the potential application of geomorphic models in river restoration projects is better suited for use on a project-by-project basis. The models could be run on selected sites that represent a restoration practice (e.g., engineered log jams, bar construction, or side channel construction), and the results could then be coupled with professional experience to select and design similar treatments elsewhere.

Substantial advances in geomorphic modeling were made in the last decade, and the state of the art is rapidly evolving. Examples of 1-D models include HEC-6 and HEC-RAS developed by the Corps, SRH-1D by Reclamation, DREAM by Cui et al. (2006), TUGS by Cui (2007), and other models based on virtually the same set of principles applied to different conditions.

3.6.2 Current Activities

Geomorphologic models for the Trinity River are not as developed as the hydrologic and hydrodynamic models. Examples of potentially useful 2- and 3-D models include: 1) the IRIC package developed by International River Interface Cooperative (http://i-ric.org/en/index.html) as demonstrated in Shimizu (2003), Lisle et al. (2000), Takebayashi and Okabe (2006), and Logan et al. (2010, 2011); 2) Delft3D by Delft University; 3) R2DM by University of British Columbia (Kwan 2009); and 4) SRH-2D developed by Reclamation. All of these models contain applications that link local hydraulics to sediment transport. They are in various stages of development, testing, and documentation, and their application to real problems is generally not routine. The SRH-2D and IRIC packages can assign non-erodibility to areas of the channel boundary; thus, both are applicable to alluvial and semi-alluvial reaches (those having some degree of resistant boundaries, such as bedrock). Outputs of local hydraulics (velocity and depth) at the meter scale provide an interface for habitat models at that scale.

The Program used SRH-2D to predict geomorphic response to gravel injection at the Lowden Ranch rehabilitation site during a high-flow release in 2010. Gravel injected during the event was intended to expand an existing incipient mid-channel bar. The model was used to evaluate potential changes in channel form and grain size under varying injection volumes. This is an example of the Program effectively using morphodynamic models to achieve its goals; in this case, determining the appropriate quantity of gravel injection to support a “dynamic construction” approach to channel modification and fish habitat formation.

A meander model previously applied to rehabilitation sites in the Trinity River (Young et al. 2006; Larsen et al. 2002; Golet et al. 2006) predicts meander migration in alluvial channels with floodplains and was applied to such reaches of the Trinity River (Young et al. 2006). However, it has limited applicability to many reaches of the Trinity due to the frequent occurrence of semi-alluvial conditions, which include bedrock outcrops and other non-erodible boundaries. Adaptations were made by Young et al. (2006) using local variations in erodibility and wavelength-scale average erodibility, but the model does not handle features such as isolated outcrops in a bend. Model results indicate slow meander migration in alluvial reaches for the post-ROD flow regime. The model could be useful for further investigations of meander migration in alluvial reaches of the Trinity River. Furthermore, availability and utility to users other than the model designers (U.C. Davis Department of Environmental Design) are uncertain, and routines in SRH-2D also model bank erosion. Based on discussions with the author of the meander migration model used on the Trinity River, their model is not publicly available, but will be sometime in the future (Larsen, pers. comm. 2012).

3.6.3 Recommendations

More than one geomorphic modeling framework may be appropriate for the Program, because of the range of spatial scales of interest. Program elements such as flow releases that are designed to reinitiate geomorphic functions typically result in reach-scale impacts (e.g., on the order of 10 channel widths). At these scales, a 1-D geomorphic model may be applicable. On the other hand, for the site-specific channel rehabilitation projects that are constructed for immediate habitat improvement at local site scales, a 2-D hydrodynamic model is more applicable, combined with a 2-D or 3-D morphodynamic model. However, integrating the cumulative geomorphic effects of rehabilitation projects across the 64-km restoration reach will likely require 1-D modeling due to the large scale of such analyses.

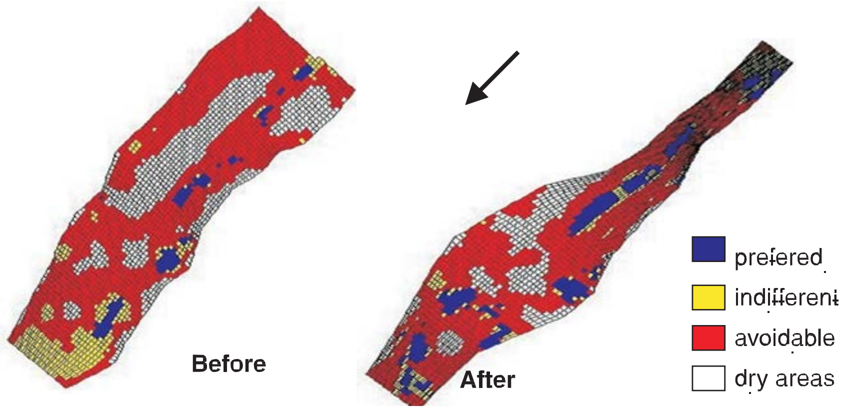
Many of the available 1-D and 2-D morphodynamic models are suitable for applications in the Trinity River to predict channel response to flow, sediment supply, and structural changes. However, the success of the application may depend more on how, rather than which, models are used. As a result, the modeler's experience and familiarity with the models and the availability of user support likely determines which models should be chosen for the project. One possible 1-D model is SRH-1D, which was developed by Reclamation's Technical Service in Denver. Utilizing the SHR-1D model is likely advantageous because the modeler will likely have access to necessary technical support from Reclamation staff, although other 1-D morphodynamic models are also suitable. Two 2-D morphodynamic models (IRIC and SRH-2D) are advantageous because of Program staff familiarity with the models and potential easy access to technical support. Both IRIC and SRH-2D model local 2-D hydraulic conditions that can interface with distributed habitat models, and both apply to semi-alluvial and alluvial reaches. The choice involves an investment by the user to build on his/her experience with updates on new developments. Since there is no strong advantage between IRIC and SRH-2D, and more developments are forthcoming, we recommend that the choice of models be left to the discretion of the users.

3.7 Virtual Fish Habitat Models

3.7.1 Background

Mechanistic habitat models link hydrodynamics and river bathymetry with key qualities of the habitat, which in the case of salmon are depth, velocity, temperature, substrate composition, and distance to cover. Such models can be 1-D or 2-D, and can be developed with a range of spatial domains and resolution. These models describe current or future conditions and therefore do not have a time component.

For example, using a habitat analysis program (HABITAT) in combination with 2- and 3-D hydraulic models, Alfredsen et al. (2004) developed a tool for predicting how hydraulic parameters and biological criteria changed under various habitat design alternatives and allowed different designs to be evaluated from hydraulic and biological perspectives prior to habitat construction. Results of hydraulic studies that simulate discharges, calibrate the model, and run the model using various design alternatives and flow regimes are linked with aquatic species habitat suitability criteria to produce an index to habitat suitability in relation to flow, commonly called weighted usable area or relative suitability index. This index can be used to develop maps of useable habitat under the flow conditions analyzed and evaluate the impact of alternative flow regimes and habitat features on aquatic resources. The spatial distribution of habitat and hydrological data (discharge time series) can then be analyzed to identify the amount and periods of time that preferred habitat is available to fish. The model can be applied to a variety of restoration objectives including increasing rearing, spawning, and migration habitat, and restoring side channels (Alfredsen et al. 2004). Also, visualization of how conditions change under various design alternatives allows stakeholder groups to become involved in the designs and aid their refinement. An example of model output from one such model is shown in Figure 5.



Source: Alfredsen et al. 2004, Figure 4-20

Figure 5

Change in Habitat From Original (left) to Modified (right) After Simulated Modifications to Increase Pool Habitat and Areas of More Suitable Velocities in the Dalåa River, Norway

Two-dimensional fish habitat models are finely resolved (on the scale of 1 m^2) in order to describe and test the details of fish distribution and avoidance behavior (e.g., Hardy et al. 2006).

Because such a fine-scale habitat model would require long run times, one cannot be developed for the entire 64-km reach of the Trinity River. For this reason, the DSS is likely to include finely resolved models for selected study areas, as is current practice (in particular, the 11 areas of the Trinity River where extensive, detailed geomorphological data have been collected by the Program Partners). The finely resolved 2-D hydrodynamic model and the detailed habitat model work together to produce fine-scale, flow–habitat relations at selected sites that provide input to habitat time series and finally input to fish population models projecting response to management actions. The results of these fine-scale models at sample sites must be extrapolated to the entire 64-km restoration reach to provide the needed input to a fish population model such as SALMOD, or the Stream Salmonid Simulator (SSS) model that is currently being developed for the Klamath River. The SALMOD manual (Bartholow et al. 2000) calls this series of reaches "computational units"; we refer to the entire collection of computational units as the "virtual fish habitat model" and when combined with other models simulating information at these computational units (such as water temperature and water routing) they are collectively termed the "virtual river." The only difference from the Klamath River SSS application is that we recommend using the GRTS sample segments to define the computational units, rather than basing them on mesohabitat units (Section 3.8.1). Once the flow-to-habitat relations for the computational units are developed for the 64-km restoration reach, as well as from the North Fork confluence to Weitchpec, the linkage of the Trinity River fish production model can be made to the Klamath River model, and evaluations can be made of the effects of spring flows and temperature management actions on spawning success and outmigrating salmonids.

3.7.2 Current Activities

For practical reasons, the Program collects juvenile salmon habitat data at predominantly low flow at select sample sites. To implement a fish production model such as SSS, it is necessary to expand these efforts in two ways: 1) develop flow–habitat relations across the full range of flows that occur in the river; and 2) extrapolate flow–habitat relations developed for individual sites to the entire 64-km restoration reach. The Program has begun to address the first item by using 2D hydrodynamic models to predict habitat as a function of discharge (Alvarez et al. 2011), but the second item remains to be addressed. One approach for spatially extrapolating the flow–habitat relations is to map the physical environment of the entire river, followed by a matching-up exercise, in which the river would first be divided into geomorphic and hydrologic segments, segments further sub-divided into reaches that become the basis for computational units, and then all un-sampled reaches within a sub-segment of the river would be matched with the site(s) where flow–habitat relations have been developed from habitat sampling and 2D hydrodynamic modeling. This river segmentation and extrapolation or matching exercise is based upon geomorphology, hydrology, and a set of physical characteristics that could be developed from sources such as aerial and field photographs, field surveys, and cross section and bathymetry data.

Alternatively, statistical models can be used for spatially extrapolating the flow–habitat relations across the 64-km restoration reach by relating physical river features that are correlated with habitat availability and quality. Such features may include channel characteristics (e.g., slope, width, or bed surface grain size), geomorphic features (e.g., channel planform types or bar features) and/or stream discharge. For example, Appendix E details two statistical approaches for estimating juvenile habitat at base flow using linear models that relate observed habitat availability at GRTS sites to remotely sensed channel features. Data availability limited our analyses to base flow in these examples, but ideally the approach would be applied across a range of flows to develop flow–habitat relationships for input to a fish production model. Similarly, channel features were limited to those available to us. Consequently, users may wish to consider additional or alternative features to increase model accuracy; nor is it likely that a single set of features can be used for all species and life stages. Unlike the habitat simulation approach, the statistical approach produces continuous functions of predicted habitat along the length of the 64-km study reach and does not require a priori identification of geomorphic strata. As such, it may be more flexible and adaptable than the matching-up approach that is based on a nominal variable such as reach type. Reach types and their boundaries are expected to change over time in response to management actions, requiring periodic channel/habitat measurements for updating the simulation models. A combination of both approaches may be useful for facilitating communication among technical groups when comparing alternative management actions (flow schedules, gravel augmentation, scouring vegetation, reservoir temperature releases, etc.) and with the stakeholders to document Program progress through the years. The DSS should incorporate various models and approaches for adaptive management and communication with the public.

When developing a fish population model, a key aspect to keep in mind is the need to eventually account for the effects of flow augmentation and temperature management on habitat availability down to the confluence with the Klamath River, since fish must rear/migrate through this section of the river and this is one of the Program’s management actions.

3.7.3 Recommendations

As discussed above, we recommend the development of a virtual habitat model as input for a fish population model, which includes determining flow–habitat relations across a range of flows at select sites and extrapolating that information across the 64-km restoration reach for simulating fish production. Toward this end, we recommend that the Program continue the development and testing of 2D hydrodynamic models for predicting flow–habitat relations (e.g., Alvarez et al. 2011). Existing data from habitat sampling should be used to test and calibrate predicted values of depth, velocity, and associated habitat suitability determined from the 2D hydrodynamic models (Section 5.1). Full calibration and testing will also require collection of habitat data at stages beyond base flow at numerous sample sites.

We also recommend the more expedient statistical approach for spatially extrapolating measured and modeled flow–habitat relations. Two examples of the statistical approach are found in Appendix E. When there is disagreement among Program Partners as to the best approach for extrapolating the habitat models from sample sites to the total restoration reach, then models that estimate habitat could be compared by validating each model's estimate to observed habitat that was not included in the model, using a cross-validation procedure. Ultimately, the model most in agreement with the objective-driven monitoring data would be selected.

Moreover, we recommend that the Program review and extend the GRTS sampling as appropriate, with the objective of developing the virtual habitat model prior to the next phase of field work in order to provide river-wide estimates of fish habitat that can be compared with results of field sampling in the future (post-construction monitoring and GRTS sampling).

3.8 Fish Population and Production Models

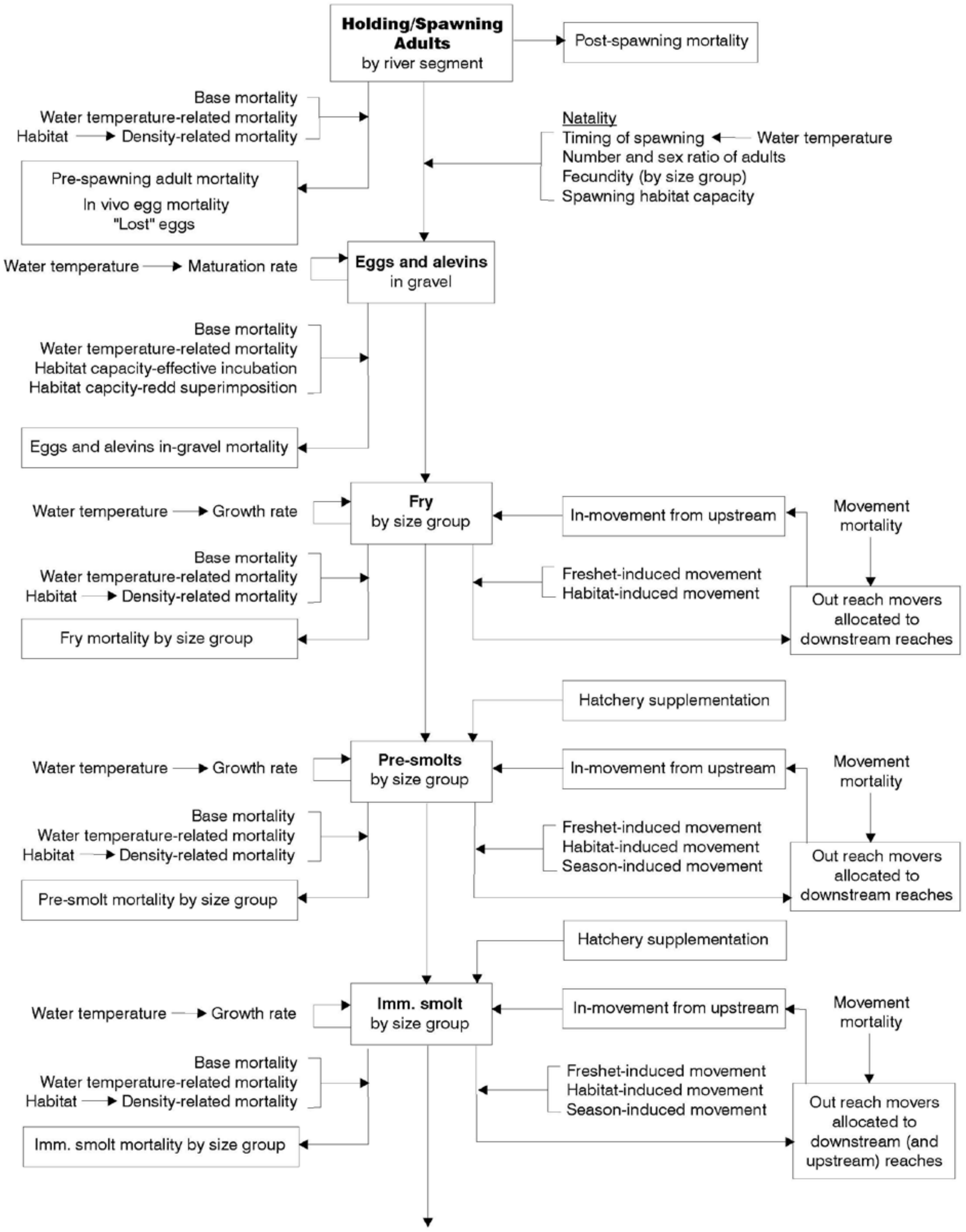
3.8.1 Background

Models that couple the internal dynamics of a fish population and its possible response (e.g., the growth, movement, and total number of pre-smolts exiting the restoration reach) to changing habitat conditions (e.g., flow, depth, temperature, channel and vegetation characteristics) are being developed to estimate how fish populations respond to specific habitat management actions and how this influences population productivity. For example, a trout population dynamics model named MODYPOP was used to identify how the temporal variability of environmental parameters, particularly temperature, discharge, and weighted useable area, influenced the structure of trout populations in three different rivers in France (Gourad et al. 2004). In the Pacific Northwest, Scheuerell et al. (2006) evaluated how proposed actions to improve physical habitat throughout a river basin translated into projected improvements in four salmon population attributes considered important for recovering the populations: abundance, productivity, spatial structure, and life-history diversity. For spring-run Chinook salmon, Jorgensen et al. (2009) evaluated the effect of habitat actions on rearing habitat quality at the landscape scale and Honea et al. (2009) evaluated the effect on population status. In the Trinity and Klamath rivers, SALMOD was developed to evaluate how fish population productivity responded to changes in physical habitat (flow and temperature) (Williamson et al. 1993;

Bartholow and Henriksen 2006). More recently, steps are underway to update and convert the SALMOD model into SSS for use on the Klamath River (Perry, pers. comm. 2012).

While there are many fish population models that can, in principle, be applied to the Trinity River, for consistency the SAB considers the SALMOD model appropriate for the DSS using the improved version (SSS) as applied to the Klamath River, as discussed below.

A diagram of the original SALMOD model applied to the Trinity River is shown in Figure 6. It is not a full life cycle model, but begins at the adult stage and ends at the exiting immature smolt stage, capturing in-river production, a stated fundamental objective of the Program’s management actions. The life stages included in the model are holding/spawning adults, eggs and alevins, fry (34 to 50 mm fork length [FL]), pre-smolts (50 to 80 mm FL), and immature smolts (80 to 110 mm FL) (Table 1). The primary processes modeled are mortality at all stages, spawning, incubation of eggs and alevins in gravels, and the growth rate and movement of fry, pre-smolts, and immature smolts. The primary physical drivers for the biological functions contained in SALMOD are the discharge-dependent hydraulics and water temperature for each channel segment. The number of pre-smolts and immature smolts is assumed to be influenced not only by natural production, but also by hatchery supplementation. Movement is freshet-induced, habitat-induced, and season-induced.



Source: Bartholow et al. 2003

Figure 6

Overview of Original SALMOD Model

Table 1
Examples of Life Stage and Class Structure Definition of an Anadromous Salmonid Population along with SALMOD's Order of Calculation

Life Stage Name	Calculation Order	Class	Class Definition
Spawner	2 4	sf sm	Spawning Female Non-Spawners
Adult	1 3	af am	Female Male
Egg/Alevin	5	1 2 3	0.0% to 33.3% 33.3% to 66.6% 66.7% to 100.0%
Fry	6	f1 f2	34 mm to 38 mm 38 mm to 50 mm
Pre-smolt	7	p1 p2 p3	50 mm to 60 mm 60 mm to 70 mm 70 mm to 80 mm
Immature-smolt	8	i1 i2	80 mm to 90 mm 90 mm to 110 mm

Notes:
Classes are defined by percent development (deposition to emergence) for egg stage and by fork length (in millimeters) for all other life stages
Source: Bartholow et al. 2003

The original SALMOD employs a weekly time step, which typically starts with the first week of spawning. Rate functions, such as growth and mortality, are weekly values. Physical drivers are represented by weekly averages. The spatial resolution uses a mesohabitat inventory approach in which the study area is classified and mapped as discrete mesohabitat types that tend to behave similarly in response to discharge fluctuations. Classification is based mainly on channel structure and slope, modified by the general distribution of microhabitat, including cover. These mesohabitat units are the model's computational units. However, the computational units are flexible and can be user-defined. For example, it might be most expedient for the Program to define computational units based on the existing GRTS habitat sampling segments that are extrapolated across the restoration reach using approaches similar to those described in Section 3.7 and Appendix E. The only requirement for the computational units is that one is able to define life-stage specific flow–habitat relations for each type of unit.

Streamflow, water temperature, and flow–habitat relations (i.e., discharge-dependent suitable habitat area) produced for each computational unit are the physical state variables included in this model. The restoration reach is divided into computational units (i.e., user-defined channel segment lengths) wherein simulated flows and temperatures are considered roughly homogeneous at a given location. Flow and temperature data are organized by river segments and by time step, and habitat quality is defined by a flow–habitat relationship for each computational unit. The original SALMOD was applied to the upper 42 river km (26 river miles) and assumes a linear stream structure with no tributary or branch fish production input.

The biological resolution in SALMOD is fairly standard, in the sense that it employs a typical categorization of fish life history related to physical morphology, behavior, and reproductive potential (Figure 6). Fish are tracked by cohorts within computational units. Each cohort is classified by life stages and class within life stages (Table 1). As a cohort grows, its life stage and size class attributes are modified when it matures to the next size class or life stage.

Biological rate parameters such as growth and mortality can depend on life stage and class. Non-adult cohorts are tracked individually within a computational unit. Many variables are tracked for each cohort, including:

- Number of eggs or fish
- Average weight and length of fish
- Percent egg development (deposition to emergence)
- Number of redds composing an egg cohort
- Number of in vivo eggs per gravid spawning female
- Life stage and class of the cohort
- Effective incubation area

3.8.2 Current Activities

SSS is currently under development in the Klamath River and has not yet been formally adapted to the Trinity River. However, because salmon production models used in the Trinity and Klamath rivers must be integrated at some level, USFWS is proposing to adapt SSS to the Trinity River. The SAB supports the application of SSS to the Trinity River. Therefore, we reviewed ongoing efforts to develop a fish production model (SSS) for the Klamath River to support fall Chinook salmon management decisions (Hendrix 2011). We discussed the ongoing development of SSS with Russell Perry of USGS (Cook, Washington). This included SSS’s data input requirements, time step, spatial scale, how the model tracks fish populations, whether critical subroutines in the model are updated (fish growth, movement, mortality, and disease), and how SSS will treat density-dependent mortality. The input data requirements for applying

SSS to the Trinity River are similar to those described in the SALMOD User Manual (Bartholow et al. 2003). However, given that SALMOD was last developed for the Trinity River nearly 20 years ago (Williamson et al. 1993), updating the flow, temperature, and habitat inputs would be required.

In addition, analysts using SALMOD on the Klamath River considered it out-of-date and embarked on an extensive revision of the model, which they named SSS. Most of the planned changes to SALMOD to develop it into SSS focus on improvements in the driving functions, including the following:

- *Temporal scale*. SALMOD ran on a weekly time step. SSS will run on a daily time step.
- *Spatial scale*. Mesohabitat units (e.g., run, riffle, pool) are used in both SALMOD and SSS. However, the spatial scale is flexible and user-defined, as discussed above. The most important aspect of each spatial unit is a life-stage-specific flow–habitat relationship.
- *Sub-populations*. SALMOD did not track different source populations (e.g., tributary populations entering the mainstem). SSS will track source populations.
- *Growth*. SALMOD modeled growth of fall Chinook salmon based on lab studies of sockeye salmon (*O. nerka*). For SSS, a new growth model is being developed based on data from fall Chinook salmon. Also, SSS for the Klamath River will incorporate density-dependent growth.
- *Movement*. SALMOD's movement model failed to adequately emulate the dispersion typically observed in migrating populations. For SSS, a movement model that captures the tendency for migrating populations to both move downstream and spread out over time is being developed. In SSS, movement rates will be size- and density-dependent. A possible modeling strategy will be to use Brownian motion with drift to model stochastic downstream movement of fish cohorts, which was applied to juvenile Chinook salmon (Zabel 2002). In this two-parameter model, fish move according to a Gaussian distribution that spreads as it travels downstream. The drift parameter describes the mean velocity of a cohort and can be related to covariates, including flow or temperature.
- *Mortality*. There will be little change between SALMOD and SSS in modeling thermal tolerance. However, SALMOD lacked an adequate disease mortality model. A new disease sub-model for SSS in the Klamath River is being developed. It will include infection and mortality dynamics of juvenile salmon caused by a lethal parasite, *Ceratomyxa shasta*. In addition, SALMOD allowed for a user-defined, density-dependent mortality. SSS will explicitly define how mortality is related to fish density via available habitat. A future direction for such modeling would be to incorporate a Shiraz model approach into SSS where abundance, productivity, spatial structure, and life

history diversity are all related to physical habitat (Scheuerell et al. 2006). In this approach, the number of fish surviving to their next life-history stage is the number alive at the end of the current life stage. Survival and capacity parameters are described in a multistage Beverton-Holt model (Moussalli and Hilborn 1986):

$$N_{s+1} = \frac{N_s}{\frac{1}{p_{s\rightarrow s+1}} + \frac{1}{c_{s+1}} N_s} \tag{1-1}$$

where:

N_{s+1} = the number of fish surviving to their next life-history stage

N_s = the number of fish currently alive

$p_{s\rightarrow s+1}$ = survival or productivity to the next stage

c_{s+1} = capacity of the environment to support the fish

Another potential improvement that is unplanned, but that could be performed, is to include the relative reproductive success (RRS) of hatchery-origin spawners. SALMOD currently does not distinguish between hatchery- and wild-origin spawners. The goal of this potential component of SSS is to characterize the RRS of hatchery-origin vs. wild-origin spawners. Hatchery-origin spawner proportions as low as 0.25 can substantially reduce the productivity of wild-origin spawners (Chilcote et al. 2011). SSS developers may incorporate a RRS success parameter and hatchery vs. wild spawner inputs into the model.

Also, analyses of spawner-recruitment relationships are being conducted on the Klamath River using a Ricker Model (Ricker 1954) to evaluate how salmon population productivity changes over time and varies among tributaries.

3.8.3 Recommendations

As stated above, the SAB supports the development and application of SSS to the Trinity River and its use as a key component of the DSS. The expected outcome of the SSS modeling effort is to demonstrate how management actions and rehabilitation projects throughout the restoration reach and the reach from the Trinity River confluence with the North Fork Trinity River to Weitchpec translate into projected improvements in juvenile salmon growth, abundance, productivity, capacity, and distribution. The SSS modeling effort is also needed to link the Trinity River model to the Klamath River fish production model.

The USFWS is involved in the development of SSS for application to the Klamath River and is discussing the need to initiate the development of SSS on the Trinity River. The SAB encourages the USFWS to continue this work, and recommends that the Program support the development of SSS on the Trinity River. SSS is a critical component of the DSS, and thus, is needed to support future assessments of the Program's effectiveness and decisions on how to manage the Program as new information becomes available.

The SAB also recommends that analyses of spawner-recruitment relationships be considered for the Trinity River when assessing the effects of Program actions on salmon populations. This modeling approach could serve two key purposes. First, it would allow the entire suite of actions implemented during Phase 1 to be assessed in terms of whether changes to the inherent productivity of salmon populations following Program actions can be detected. Positive trends in spawner-recruit ratios could indicate a strong signal in response to Program restoration activities. Similarly, differences in spawner-recruitment relationships between rivers that benefitted from Program actions and those that did not would be highly informative. Second, the results of spawner-recruitment analyses can be used to verify predictions based on SSS modeling. Verification is an important aspect of any model development project.

Finally, the Program should also consider incorporating life-cycle models being developed for the Klamath River into the Program, either as a formal component of the DSS or an independent analytical tool that can be used to address key programmatic questions. Development of a life-cycle model for the entire Klamath Basin would allow for differences in freshwater rearing and migration conditions to be compared between the Klamath and Trinity rivers because fish outmigrating from both systems are exposed to similar environmental and fishery pressures in the lower river and ocean. Outputs from SSS would be inputs to the life-cycle model, and outputs from the life-cycle model (adult escapement) could be used to inform the broader programmatic questions, such as estimating the amount of rearing habitat needed to achieve adult escapement targets developed in the Integrated Assessment Plan (TRRP and ESSA 2009).

To facilitate understanding of model integration, the SAB recommends that the DSS be implemented in phases, starting with integration via linkages among existing models, followed by refinement as knowledge is gained. For example, one could link existing models and data inputs to SALMOD as it exists. This would facilitate partner and stakeholder understanding of how monitoring drives model output. Through this exercise, one would identify where ongoing model development or experimental data collection efforts would replace or update the first phase of DSS development. A phased process of DSS development would reinforce the notion that no single model is necessarily the "best," but is expected to be improved or replaced over time as objective-targeted monitoring dictates.

3.9 Riparian Dynamics Models

3.9.1 Background

There are several key components of the life cycle of riparian vegetation: germination, seedling survival, and growth to sexual maturity. In particular, the annual pattern of stream flow, or annual hydrograph, is associated with specific stages of the emergence and growth of seedlings of key riparian canopy species such as cottonwoods (*Populus* spp.). These include flood flows that precede seed dispersal and form suitable germination sites for seedlings, flow recessions following peak flows that expose germination sites and promote seedling root elongation as flows recede, and base streamflow that supplies soil moisture to meet seedling water requirements throughout the year (Mahoney and Rood 1998). The combination of root growth and capillary fringe defines the successful recruitment band for seedling establishment.

Models of riparian species recruitment processes have been developed. For example, Mahoney and Rood (1998) describe the “recruitment box,” which is an integrative model that defines the stream stage patterns needed for successful cottonwood seedling establishment. These types of models address two fundamental processes: 1) riparian initiation, the process of plant seedling germination and initial growth and development as a function of flow magnitude, duration and timing, and bed material; and 2) riparian scour, the process of flow-induced seedling mortality based on flow magnitude, channel geometry, and the location of individual plants within the channel geometry. The integration of riparian initiation and scour determines riparian recruitment success and patterns of establishment over time.

3.9.2 Current Activities

The Program’s actions are designed to achieve two riparian ecosystem management goals: 1) restrict riparian establishment on exposed alternate bar sequences; and 2) promote riparian establishment on floodplains and high-flow scour channels. The Program’s specific riparian management objectives are to: 1) increase species and age class diversity within riparian vegetation (on upper bars and floodplains); 2) discourage riparian vegetation initiation along the low channel margins; 3) increase riparian vegetation and future large wood debris recruitment; and 4) revegetate reconstructed sites with native riparian species (emphasizing black and Fremont cottonwoods to increase seed source for natural regeneration) (USFWS and HVT 1999).

The Program Partners are developing a model for predicting how riparian vegetation establishment will proceed in response to various management actions, called the Tool for Achieving Riparian Germination and Establishment of Target Species, or TARGETS. It focuses on three key riparian species of trees that dominate the riparian ecosystem of the Trinity River:

narrowleaf willow, black cottonwood, and white alder. TARGETS is based on the concept that a riparian plant becomes “recruited” when it becomes sexually mature. Recruitment processes in the TARGETS model are organized into two phases: initiation and recruitment. Changes in physical, hydrologic, and biologic variables during these two phases are used to predict where target species will be recruited using a cross-section based approach.

An effort to validate the TARGETS model has been initiated. Using the 1998 water year hydrograph, monitoring of riparian initiation at the Sheridan Creek pilot bank rehabilitation site was compared to TARGETS results. Results of the validation studies suggest that the TARGETS model predicted narrowleaf willow initiation most accurately when a capillarity depth of 0.3 m (0.98 feet) and no drought tolerance was used in the model. Also, there was no significant difference ($p>0.05$) between the predicted and observed narrowleaf willow initiation zones. For black cottonwood initiation, TARGETS predicted that black cottonwood initiation would occur, even when the most conservative environmental scenario of 0 m capillarity and no drought tolerance were used. However, no initiation of cottonwoods was observed at the site in 1998.

The TARGETS model was then applied to Hocker Flat where the post-construction topography from cross sections surveyed in late 2005, various wet water year options, and ranges in capillary conditions on cross sections and drought tolerances were modeled. Using the model at this site showed that black cottonwood and narrowleaf willow initiation was most accurately predicted by assuming zero drought tolerance and a 0 and 0.3 m capillarity, respectfully.

The establishment component of the TARGETS model is under development. Several key uncertainties exist with the TARGETS model. For the initiation phase, these include whether the capillary fringe provides a "buffer" to rapid changes in streamflow elevation, whether the development of riparian vegetation at rehabilitation sites will be greater in area and structural complexity than current conditions, and whether high flows will remain at an elevation sufficient to create moist seed beds at desirable bank locations (i.e., floodplains). For the establishment phase, the uncertainties include whether scour that is deeper than or equal to root depth is sufficient to kill the hardwood, whether the window of scour vulnerability is within 3 years, whether planform location enhances or hinders channel bed scour influence on hardwood mortality, and whether a small number of establishing survivors (less than 5%) along the low water margin lead to encroachment (Bair, pers. comm. 2012).

3.9.3 Recommendations

Although the TARGETS model would benefit from more development, it appears to be a useful guide for shaping Program annual flow releases and developing and refining hypotheses about riparian ecosystem recruitment processes in the Trinity River. In this regard, the TARGETS model is a useful and important component of the DSS, and the SAB recommends that the Program Partners continue using the model to better understand the system. Although the model itself may need refining, the inputs to the model (particularly soil texture and water availability) are difficult to measure, yet important to plant establishment. Consequently, focusing on model inputs is more important than focusing on model structure at this point in the development of TARGETS. As model development proceeds, consider how predictions could inform the distance-to-vegetation aspect of the fish habitat modeling efforts.

4 DATA NEEDS AS INDICATED BY THE DECISION SUPPORT MODELS

The Program collects a large amount of information through various ongoing studies. However, at present, these efforts are primarily "surveillance monitoring," rather than monitoring that is directly informing adaptive management through a formal DSS. In this section we provide an overview of the information needed for developing and applying the component models in the DSS framework recommended in Section 3, the data currently collected by the Program that are applicable to the models, and any data gaps if the available data are insufficient to support the recommendations. This review was not exhaustive, but was intended to provide an overview for the reader and a starting point for the Partners as they evaluate DSS data requirements.

4.1 Hydrologic and Hydrodynamic Models

Hydrodynamic models use information on upstream and tributary inflows, groundwater recharge and direct drainage, and bathymetry to develop cross sections and channel slopes. Characteristics of the streambed, such as sediment size and the presence or absence of aquatic vegetation, are needed for establishing friction parameters (hydraulic resistance). In the absence of other information, the friction parameters are typically calibrated to match observed water-surface elevations, velocities, and flows. The level of detail required in the input data depends on the grid resolution adopted for the hydrodynamic model, which differs for the 1-D and 2-D models, the modeling objectives, and the management questions addressed. Calibration of the hydrodynamic model will require information on water surface elevations, velocities, and flows.

Table 2 summarizes the hydrodynamic and temperature data being collected by the Program. The information is based on reports by Watercourse Engineering (2007) and Alvarez et al. (2011) that discuss existing data sources for the upper 64-km restoration reach. The bathymetry of the river has been well characterized. The Program has also collected sediment data on several restorations sites as part of fish habitat characterizations. Additional sites are currently being studied, which will add to the existing database. Existing USGS gage data provide information on flow and water-surface elevation on the mainstem and major tributaries. Due to the regulatory requirements for maintaining temperature in the river, several continuous temperature probes in the mainstem and on major tributaries are maintained by the Program Partners and provide temperature data at the needed resolution.

Table 2

Existing Sources of Hydrodynamic and Water Temperature Data

Data	Source	Coverage	Resolution
Bathymetry	USGS DEM1 (http://seamless.usgs.gov/ned13.php)	Entire River	10 m[d]
	LiDAR Bathymetry Survey (2004 [USBR 2005], 2009 [Watershed Sciences 2009])	Upper 64-km restoration reach[c]	6 feet (1.8 m)[d]
	Various Bathymetry Surveys (e.g., Woolpert 2010; GMA 2012)	Upper 64-km restoration reach[c]	Reachwide at 5 feet (1.5 m); specific map tiles at 1 foot (0.3 m)
	IHAP study – focused topographic surveys (Alvarez et al. 2011)[b]	Surveys conducted on specific sections of the 64-km restoration reach	0.15 m[d]
Streamflow	USGS Streamflow Network	Five mainstem stations in the upper 64-km restoration reach[a]	Daily (some at hourly); coverage history varies
River Stage	USGS Stremflow Network	Subset of locations where flow information is available	Instantaneous stage is translated into daily average discharge; instantaneous values are recorded every 15 minutes; coverage history varies
Groundwater	HVT and McBain & Trush (2006, 2007)	Correlations between groundwater and surface water elevations were studied at Valdor Gulch and Pear Tree sites for water year 2005, and at Lewiston, Bucktail, and Hocker Flat in water year 2006	
	TRRP collects data from well tubes, some of which have data loggers	Various	
Meteorology	Lewiston/Trinity Camp	Upper 64-km restoration reach[c]	Hourly air temperature, relative humidity, wind speed, and shortwave radiation
	Lewiston Fish Hatchery	Upper 64-km restoration reach[c]	Hourly air temperature, relative humidity, wind speed, and shortwave radiation
	Hoopa Valley, CA	Below North Fork confluence	Hourly air temperature, relative humidity, wind speed and shortwave radiation
	Lowden, CA (BLM)	Upper 64 km	Hourly air temperature, relative humidity, and wind speed

Data	Source	Coverage	Resolution
Mainstem and Tributary Temperature[e]	USGS Streamflow Network		Some telemetry stations have continuous data for recent years over summer; other locations have year-round measurements
	CDEC		
	USFWS and USFS		
Shading[f]	HVT and McBain & Trush (2006, 2007)	Baseline conditions survey at four restoration sites in the 64-km restoration reach	Results are provided on a relative cover basis for various riparian vegetation categories at each restoration reach surveyed
	IHAP Study (Alvarez et al. 2011)	Pre- and post-rehabilitation data at several restoration sites provided in IHAP report	Results are provided on a relative cover basis for various riparian vegetation categories at each restoration reach surveyed
	LiDAR Photogrammetric Surveys		

Notes:
a = USGS data currently used in HEC-RAS and RAM2 models
b = The IHAP study (Alvarez et al. 2011) also provides bed mobility information needed for sediment transport evaluations, albeit limited to sections where focused surveys were conducted
c = Upper 64-km reach of Trinity River from below Lewiston Dam to North Fork confluence
d = Fine resolution FaSTMECH model will require LiDAR Data; RMA2 and HEC-RAS models can be developed at a finer resolution using LiDAR data
e = See discussions by Watercourse Engineering (2007) and Zedonis (1996)
f = Aerial imagery can be used to qualitatively supplement the extent of riparian vegetation in sections where vegetation surveys have not been conducted; LiDAR surveys conducted in 2009 and 2011 cover the 64-km restoration reach and offer the best data source for modeling shading
CDEC = California Data Exchange Center
HVT = Hoopa Valley Tribe
IHAP = Integrated Habitat Assessment Project
LiDAR = Light Detection and Ranging
USFS = U.S. Forest Service
USFWS = U.S. Fish and Wildlife Service
USGS = U.S. Geological Survey

Table 3 provides a summary of the adequacy of existing data. Existing bathymetry data, particularly the most recent surveys, provide information at a fine scale. Information at a finer resolution may be needed for focused hydrodynamic modeling of restoration sections as part of the habitat studies, but for a reach-wide model (over the upper 64 km), the available data are adequate.

Table 3
Data Gaps for Modeling Hydrodynamics and Water Temperature in the Upper 64-km Restoration Reach

Modeling Data Needs	HEC-RAS	RMA2/RMA11	FaSTMECH	SNTEMP
Bathymetry	Adequate	Adequate	Adequate	Adequate
River Bed Characteristics	Limited	Limited	Limited	N/A
River Flow	Adequate	Adequate	Limited	Adequate
Water Surface Elevation	Adequate	Adequate	Limited	Adequate
Velocity	Limited	Limited	Limited	Limited
Groundwater Inflow	Limited	Limited	N/A	Limited
Meteorological	Limited	Limited	N/A	Limited
Water Temperature	Adequate	Adequate	N/A	Adequate
Vegetative Shading	Limited	Limited	N/A	Limited

Notes:
Tributary inflows and temperature information is generally limited, but is available at a sufficient resolution to not preclude mechanistic modeling
FaSTMECH = Flow and Sediment Transport Morphological Evolution of Channels
HEC-RAS = Hydrologic Engineering Center – River Analysis System
N/A = not applicable
SNTEMP = Stream Network Temperature Model

Because velocity information is critical in determining habitat suitability (Hardy et al. 2006), it is imperative that any hydrodynamic modeling framework be calibrated to velocity data. The Integrated Habitat Assessment Project (IHAP; Alvarez et al. 2011) included the collection of velocity profiles using handheld current meters at restoration sites. If fine-resolution hydrodynamic models are developed as part of the DSS, then collection of depth and velocity profile data sets at additional calibration flows in appropriate sample segments throughout the river using current meters, acoustic Doppler current profilers, or other techniques will be required. Also, calibration of the 2-D hydraulic mesh at a range of flow conditions at each sample site will be necessary.

In sum, much of the data to support hydrologic and hydrodynamic modeling have been collected by the Program, although supplemental data may be needed, depending on which models are used in the DSS.

4.2 Temperature Models

In addition to the parameters necessary for hydrology, the simulation of water temperature requires meteorological information including cloud cover, wind speed and direction, air temperature, relative humidity, and incident solar radiation. Depending on the temporal and spatial resolution, this information could be required at sub-daily to weekly intervals from one or more meteorological stations. The heat budget calculations will also require information on topographic and vegetative shading, water temperature of tributaries, and groundwater inflows. Existing data are described in Table 2.

Data to support temperature modeling have been collected and are planned for future collections in the Trinity River. A more in-depth review of the data should be conducted to ensure that the available data satisfy the requirements of the model recommended in Section 3.5.3 (daily and sub-daily time step).

Groundwater inflows could be important in influencing stream temperature, particularly during summer low flow conditions. We noted substantial inputs from unknown sources when estimating flow exposure histories for the 15 channel rehabilitation project sites for water years 2003 to 2011. We assumed the source of the temperature increase was due to groundwater input. Recent studies initiated by the Program have attempted to characterize the correlation between river stage and groundwater levels (HVT and McBain & Trush 2006, 2007). These studies concluded that groundwater levels are strongly correlated with river stage, but that contributions in the restoration sites are likely to be minor. However, they also note that significant uncertainties exist with these studies. While this suggests that groundwater contributions are likely to be unimportant for much of the year, we recommend that the results from these studies be further evaluated to characterize base flow estimates from groundwater sources and provide a definitive determination of their impacts.

Riparian vegetation is important from both a habitat and water temperature standpoint. Changes in riparian vegetation before and after restoration activities have been characterized (HVT and McBain & Trush 2006, 2007). While this provides information at a fine resolution at the restoration sites, we recommend that the results of these studies be supplemented with existing aerial photogrammetry surveys (Woolpert 2010) to determine the amount of shading throughout the restoration reach.

4.3 Morphodynamic Models

TRRP is increasing its expertise in using morphodynamic models for predicting site-scale geomorphic responses to planned coarse sediment injection and mechanical channel rehabilitation. For example, modeled channel evolution in response to mechanical treatments and gravel injection in the Lowden Ranch rehabilitation reach provided valuable predictions of magnitudes and locations of erosion and deposition, but changes in some areas were not predicted accurately (Gaeuman 2012a, in review).

Morphodynamic modeling of river channels is analogous to weather prediction in that model predictions are typically more accurate at shorter temporal and spatial scales. As in weather prediction, initial changes can evolve in unpredictable trajectories that can grow to affect large areas. Rather than being uniformly and routinely applied, morphodynamic modeling is most effective when tailored for specific problems, with an understanding of the limitations imposed by the accuracy of the predictions. Implementing morphodynamic models requires time and resources that must be balanced against those of other aspects of rehabilitation, and it may not be practical or cost-effective to use 2-D morphodynamic modeling in all projects or at large scales (e.g., the entire management reach).

Different morphodynamic models may require different data input, but most 2-D morphodynamic models require the following information:

1. Detailed digital terrain models (DTMs) of channel topography over reach lengths equal to at least 10 channel-widths, with a mesh resolution appropriate to address the questions of interest
2. Particle-size distributions of bed load and the bed surface (including associated physical parameters)
3. Time series of measured water surface elevations and discharges over the range of model flows

Models inputs may also include information about the spatial distribution of particle size and the physical characteristics of sediment by patch or layer, roughness elements, critical shear stress (sometimes defined separately for erosion vs. deposition), bank erosion inputs, and vegetation (type, characteristics, and growing season).

Bed material particle size is essential in evaluating bed mobility and, thus, is a key parameter in morphodynamic modeling. Depending on the unique modeling situation, particle-size distributions can be assumed to be uniform or non-uniform vertically and/or aerially. Armoring is common in gravel-bed channels so that a coarser surface layer overlies a finer subsurface layer. Conventionally and by necessity, the subsurface layer is bulk-sampled and sieved at a few locations and an average particle-size distribution is applied over the entire reach. Areas of contrasting surface sizes (patches) can be more easily recognized and measured with pebble counts (e.g., Buffington and Montgomery 1999). Where surface sizes are non-uniform enough to warrant modeling, a zeroing approach can be applied by inputting a coarse-scale designation of surface patches and a uniform subsurface, running the model without imposing rehabilitation treatments, and allowing the model to evolve the spatial distribution of surface particle sizes (Gaeuman, pers. comm. 2013). The output then serves as the initial conditions for modeling channel evolution following rehabilitation treatments. The cost-effectiveness of incorporating degrees of non-uniformity in bed material particle size depends on the variability that exists and the requirements for modeling at a particular site. These are best evaluated by an experienced user and can be expected to vary from site to site.

DTMs of Trinity River channel topography were annually developed throughout the management reach from 2009 through 2012 (Woolpert 2010; GMA 2012) from a combination of repeat LiDAR, bathymetry, and topographic survey data. The Program anticipates that DTMs will be updated based on repeat surveys before and after future high flow releases, and by as-built topography following future implementation of channel rehabilitation projects. Detailed information about the particle size distribution of bed load in the Trinity River is collected at four sites in the management reach during annual sediment transport monitoring (GMA 2001, 2002, 2006a, 2006b, 2007, 2008, 2009, 2010a, 2011). Information about the particle size distribution of the bed surface and subsurface in the Trinity River has been described at select locations and transects through pebble counts and bulk sampling (GMA 2003, 2010b; Alverez et al. 2011; HVT and McBain & Trush 2012a, 2012b). Water-surface elevation and discharge are measured at five USGS gaging stations on the mainstem Trinity River between Lewiston and the North Fork Trinity River.

These existing data, and similar future data collected as part of the same study programs, will need to be supplemented with additional site-specific information within the model domain. Morphodynamic modeling for the purpose of predicting site-scale channel response to coarse sediment additions and mechanical rehabilitation would likely require additional site-specific monitoring of water-surface elevations at the upstream and downstream model boundaries; characterization of the bed surface and subsurface through bulk samples, pebble counts, and facies mapping; mapping of bed roughness elements; and measurements of velocity distribution for model calibration. Side-scan sonar surveys or other similar techniques may be a useful approach for broadly classifying the bed surface into fine and coarse sediment patches. The current state of morphodynamic modeling and associated uncertainties presently limit their use in predicting large, system-scale geomorphic response to management activities.

4.4 Fish Habitat Models

The Program Partners have collected a variety of fisheries and habitat data within the 64-km restoration reach. The Program has conducted pre- and post-rehabilitation juvenile rearing habitat mapping for Chinook and coho salmon fry and pre-smolt life stages within most of the individual rehabilitation sites constructed between 2005 and 2011. Rearing habitat was mapped based on three criteria for each fish developmental stage: depth, velocity, and distance to cover. Habitat was considered optimal for fish if it met both the depth/velocity and distance to cover criteria, and was considered suitable if it met either the depth/velocity criteria or distance to cover criteria.

The same juvenile rearing habitat mapping has also occurred at the restoration reach scale to identify changes in the quantity and quality of rearing habitat area at 12.7 $m^3 \cdot s^{-1}$ (450 cfs) streamflow. This reach-level habitat mapping uses a rotating panel revisit design and GRTS sample unit selection protocol. By applying this study design annually, the synergistic effects of restoration actions are documented. To date, data were collected in 2009, 2010, and 2011 and can be compared across years. However, the rotating panel design encompasses a 5-year time period and more years of data will be needed to fully interpret the results of GRTS sampling. Currently, the GRTS design is being evaluated to determine whether it is working as intended and to determine ways to improve it in the future, if necessary (Pickard 2011). Requirements of the virtual habitat model that will provide input to the fish population model (SSS) should be included in discussions of future GRTS design adjustments and improvements.

Habitat validation studies occurred within three of the rehabilitation sites: Hoadley Gulch (Goodman et al. 2010), Lewiston Cableway (Goodman et al. 2010), and Lowden Meadows (Alverez et al. 2011). These studies were conducted to evaluate whether biological use was consistent with predicted habitat areas based on the optimal and suitable habitat criteria. These habitat validation studies evaluated fish density differences among the mapped habitat categories and identified conditions juvenile fish chose when occupying rearing habitat (Goodman et al. 2010). The results of the habitat validation studies concluded that juvenile Chinook and coho salmon densities were significantly different among habitat categories and matched predictions of habitat quality, where the highest densities of fish were observed within areas identified as high quality habitat for juveniles (Goodman et al. 2010).

To summarize, a large amount of habitat mapping information exists among the various data collection programs (pre- and post-construction evaluations, GRTS, and habitat validation studies). However, to develop the flow–habitat relations as output from a virtual habitat model (Section 3.7), information is needed to estimate depth and velocity (and distance to cover when possible) over a broader range of spatial scales and flow (including those over the floodplain and constructed high-flow benches) and for specific seasonal hydrograph components.

4.5 Fish Population and Production Models

We reviewed the habitat and fish population input parameters and drivers (flow and temperature) needed to implement SSS on the Trinity River based on Bartholow et al. (2000). The units of data used in the original SALMOD are in Table 4. An alphabetical list of SALMOD processes as specified in the CONTROL.DAT file, their applicable optional switches, and defaults are in Table 5. Data files and descriptions of their contents are in Table 6. Some of the input requirements may change as SSS is further developed.

Table 4

Data and Units Used in SALMOD

Value	Unit
Flow	cfs
Usable Area	ft^2/ft
Length of fish	millimeters
Weight	grams
Growth (juvenile)	% wet weight/day
Growth (egg/alevin)	% of development to emergence
Temperature	°C
Density	$grams/m^2$, or number of $fish/m^2$
Area	m^2
Distance (stream lengths)	meters

Source: Bartholow et al. 2003

Table 5

Alphabetical List of SALMOD Processes as Specified in the CONTROL File, their Applicable Optional Switches, and Defaults

Process Name	Description	Switches	Defaults
BIOMASS	Computes biomass in each computational unit in order to calculate capacity limits.	None allowed	None
CARRY	Determines when females carry eggs for calculation of in vivo egg mortality.	/TIME	All
CATASTROPHE	Allows for mortality due to any catastrophic event.	/DATE (mm/dd/yyyy) /RATE (percent)	Required Input 100%
COLLAPSE	Collapses cohorts of like stage/class to reduce the overall number of cohorts. Only necessary if computation time is a problem.	/TIME	All
DETAILS	Prints details for the process immediately following the details line.	/TIME /CU /STAGE /CLASS	All All All All
FRESHET MOVEMENT	Performs fish movement due to freshet events.	/TIME /STAGE /CLASS /CU /OPTION	All All All All 2xPorA (see below)
GRADUATE	Updates stage/class of fish based on their length.	/TIME /STAGE /CLASS /CU /EMERGE /INITDEV	All All All All -99.0 0
GROWTH	Calculates growth as a function of water temperature.	/TIME /STAGE /CLASS /CU	All All All All
HABITAT MOVEMENT	Performs movement based on habitat constraints.	/TIME /STAGE /CLASS /CU /MOVE /ORDER	All All All All Down100 1
IMMIGRATION	Moves fish from the "virtual stream@ back into the stream. This is a mechanical, rather than biological, process.	None allowed	None
MATURE	Allows juvenile fish to mature into adults.	/TIME /STAGE /CLASS /CU	Time step 52 All All All
MORTALITY	Performs mortality based on mortality functions specified in RELATION.DAT.	/INVIVO	none

Process Name	Description	Switches	Defaults
SEASONAL MOVEMENT	Performs movement based on time of year.	/TIME /STAGE /CLASS /MOVE	All All All Down100
SPAWN	Performs spawning based on the parameters in SPAWN.DAT. (Must precede MORTALITY)	/SI /TIME [a]	Random All
SUMMARIZE	Creates a report of summary population statistics in the output file.	/TIME /CU	All All
SUPPLEMENT	Adds returning spawners or hatchery fish to the stream based on the parameters in SUPLMENT.DAT.	/Time /Time=0 [b]	All

Notes:

The /SPECIES switch may be used for ALL processes if necessary.

[a] TIME may be used for these processes; however, as the time steps are defined in the data files, specifying the time in the process is largely redundant.

[b] Special case to seed the stream prior to any process.

Table 6
Data Input Needs for SALMOD

File	Data Type	Description
FILES.DAT	N/A	Lists other input files.
CONTROL.DAT		Specifies simulation and data parameters.
	CAPACITY	The CAPACITY format indicated, either Numbers or Biomass, must correspond with the habitat capacity data provided in RELATION.DAT. The system default is Biomass.
	DATE	DATE specifies a beginning date (mm/dd/yyyy) for the simulation and associates a specific calendar date with the time steps. The system uses the beginning date to determine weekly dates for the output tables. DATE must be specified or a runtime error will occur.
	POPULATION	The POPULATION option determines whether the current fish population remains in the river at the end of the year. When POPULATION = Anadromous each year in a multi-year run will begin with a new stock of spawners, and spawners die after spawning. When POPULATION = Resident, spawners do not die after spawning and the MATURE process should be included to allow juveniles to mature into adults. POPULATION = Multiyear is similar to Anadromous, but only adult fish will die at the end of the year, so that immature fish will remain in the system.
	SUMMARIZE	The SUMMARIZE option creates a report of summary population statistics in the output file. If SUMMARIZE=Time, the population status, mortality, and movement statistics during each time step and cumulative statistics at each time step are reported. If SUMMARIZE=Units, the same information is provided for each computational unit at each time step. This option can use the /Time= switch (see discussion of switches below) to limit the time steps in which the summary will be printed. Note that this option will produce a large output file if allowed to run for all time steps. Compared with the DETAILS process switch (described below), the SUMMARIZE option is much easier to read.
	TIMESTEP	The TIMESTEP option allows the user to specify the length of the simulation run in weeks. This option must be specified, or the system will default to zero and nothing will happen.
	CARRY	The CARRY process determines when adult females carry eggs. This process calculates the number of eggs for females in a cohort based on their weight and then tracks the number of eggs with them to estimate the in vivo egg mortality due to the exposure temperature of the adult female environment. CARRY may span a biological year boundary.

File	Data Type	Description
	Biological and computation processes	See Table 5.
FLOW.DAT		Daily stream flow data for each and river segment.
RELATION.DAT		Movement, mortality, and growth relationships.
	Seasonal Movement	Seasonal Movement parameters include the time-step when seasonal movement occurs, the distance moved, the proportion moved, and the associated mortality rate. Seasonal Movement parameters are required for each juvenile life stage in the Anadromous model, and all life stages in the Resident model, by size class.
	Temperature vs. Growth	A Temperature vs. Growth relationship is required for every non-adult life stage and provides the weekly growth factor for specific temperature values. These values are also required for adult life stages in the Resident model.
	Base Mortality Rate	The Base Mortality Rate indicates the proportion of the population dying each week from causes other than movement or temperature. A base mortality rate is required for every life stage.
	Temperature-induced Mortality Rate	A Temperature-induced Mortality Rate is also required for every life stage. This relationship indicates the proportion of the population dying each week at various temperatures.
	Temperature-induced in vivo Egg Mortality Rate	The Temperature-induced in vivo Egg Mortality Rate indicates the proportion of eggs dying each week at various temperatures. This relationship is required for each species.
	Weight vs. Length	A Weight vs. Length relationship is also required for each species.
	Habitat-induced Movement Mortality Rate	The Habitat-induced Movement Mortality Rate indicates the proportion of the population that dies from moving a certain distance. The last distance provided in this distance versus mortality rate relationship is the maximum distance that a fish can move in one time step. Any fish required to move beyond this maximum distance dies. This relationship is required for each juvenile stage in the Anadromous model, and all life stages in the Resident model, by size class.
	Density-induced Mortality Rate	The Density-induced Mortality Rate is required for each life stage. This relationship is expressed in density as number of fish in number/m^2 (or biomass in gm/m^2, depending on **Capacity** designation in CONTROL.DAT) per unit area versus the weekly mortality rate. The density levels provided are significant even if the mortality rate does not vary. The upper density limit provided is the habitat carrying capacity that triggers habitat-induced movement. This parameter is obviously a key to SALMOD dynamics. Note that we are assuming that the upper density limit per unit habitat is fixed for

File	Data Type	Description
		each lifestage and does not vary across mesohabitat types or throughout the period of food availability. Both of these assumptions must be considered in applying SALMOD and considering how the habitat qualities are measured and how finely to divide the lifestage descriptors.
	Female Weight vs. Numbers of Eggs	A Female Weight vs. Number of Eggs relationship for each species is the final relationship contained in this file.
SPAWN.DAT		Spawning parameters and timing.
	Species name	Name of species
	Average Area Per Redd Pocket	Average Area Per Redd Pocket
	Minimum spawning temperature	Minimum temperature above which spawning occurs.
	Maximum spawning temperature	Maximum spawning temperature below which spawning occurs
	Ave. weight of fry upon emergence	Average weight of fry upon emergence from gravel.
	Proportion spawning in time step b, b+1,…,b+n	Distribution of spawning over time.
SPECIES.DAT		Names species, lifestages, and classes, and gives their length limits (in mm).
	Number of Life Stages	(Maximum of 12)
	Life Stage Name	Life stage name
	Number Of Species	Number of species
	Species Name	Name of species
	Number Of Classes	Number of classes
	Class Name	Class name
	Class Lower Limit*	Class lower limit. Percent developed or size class lower limit.
	Class Upper Limit*	Class upper limit. Percent developed or size class upper limit.
STREAM.DAT		Defines the stream computational units, defines flow and temperature segmentation, and controls tally of outmigrants.

File	Data Type	Description
	Number of computation Units (n)	To be determined
	Computational unit lengths	Computation unit lengths for each of the n computation units.
	Mesohabitat type code	A code giving mesohabitat type of computational unit.
	Number of flow segments (m)	To be determined
	Beginnings and ends of each flow segment	To be determined
	Number of temperature segments (q)	To be determined
	Beginnings and ends of each temperature segment	To be determined
	Gate ID and Gate Type	Directions that movements are allowed at upper and lower extents of study area.
SUPLMENT.DAT		Timing and location of fish to be added to the stream.
	Adult inputs	Time Step, Species Name, Upstream Comp Unit # or Distance, Downstream Comp Unit # or Distance, # adults, Sex ratio (F:M), weight for males, weight for females
	Juvenile inputs	For Juveniles: Time Step, Species Name, Upstream Comp Unit # or Distance, Downstream Comp Unit # or Distance, # juveniles, weight.
TEMP.DAT		Stream temperature data by time step and river segment.
	Temperature (in degree C)	Matrix of temperatures indexed by time step (row) and temperature segment (column). Temperatures contained in the file should be representative of those encountered by the lifestage(s) present at the appropriate time of year.
WUA.DAT		Table lookup of low vs. (weighted) usable area functions for all lifestages and mesohabitat types. This data file contains the detailed (weighted) usable area versus flow data for each mesohabitat type, species, and life stage. Flow is in cubic feet per second and usable area in square feet per foot of stream. There is a limit of 30 flow versus usable area pairs per lifestage. The indentation shown is

File	Data Type	Description
		simply for readability and is not required. Information on more mesohabitat types than required can be included in this file.
	Flows that define flow-UA relationship.	Flows in cubic feet per second Flow is in cubic feet per second
	Usable area	The usable area in square feet per foot of stream.

Source: Bartholow et al. 2003

The Program is collecting a substantial amount of information that can potentially be used as inputs to SSS. For adult salmon, this includes run-size estimates and scale analysis to determine the age-specific run size for fish sampled from tribal and recreational fisheries and at weirs, in the broodstock at Trinity River Hatchery, and on the natural spawning grounds. Also, the California Department of Fish and Wildlife has been collecting data from coded wire tag and other mark-recapture studies to estimate the escapement of naturally and hatchery produced fall and spring Chinook salmon grilse and adults, coho salmon and steelhead; sport harvest above the Willow Creek weir; smolt-to-adult return rates for fish released from the Trinity River Hatchery; pre-spawn mortality; sport catch in the lower Klamath River; and salmonid distributions in tributaries. The Program is also maintaining a cohort reconstruction model for Trinity River natural-origin fall run Chinook salmon, and conducting annual salmon redd and carcass surveys to identify temporal and spatial responses in mainstem spawning to restoration actions over time.

The Hoopa Valley Tribe (HVT) surveys tribal harvest of Trinity River fall and spring Chinook salmon, coho salmon, and steelhead. This effort is used to determine total harvest and the contribution of Trinity River hatchery fish. In addition, the Program and Partners: 1) conduct creel census of sport harvest to estimate the harvest of salmonids in sport fisheries between the Willow Creek weir and the confluence of the Trinity River with the Klamath River; 2) monitor the fishery upstream of the Willow Creek weir through a tagging and tag recovery project associated with the weir operations; 3) support monitoring of tribal and recreational fisheries in the lower Klamath River below the confluence of the Trinity River with the Klamath River; and 4) estimate the run-size of hatchery and naturally produced Chinook salmon, coho salmon, and fall-run steelhead.

For juvenile salmon, this includes recently initiated efforts to monitor juvenile salmonid density in the restoration reach during the primary rearing period to evaluate long-term changes in the spatial and temporal distribution of juvenile salmonids in the restoration reach, and provide linkages between the distribution and availability of salmonid rearing habitats and juvenile salmonid rearing abundance and distribution. The abundance, run timing, condition, and health of juvenile salmonids is being monitored through the Trinity River juvenile salmonid outmigrant monitoring program. Finally, the seasonal and inter-annual variation in the incidence and severity of disease in juvenile Chinook salmon in the Trinity River and lower Klamath River are being monitored.

The first step in the process of developing SSS for application to the Trinity River is to compare data inputs required by SSS with the existing monitoring data collected to identify any information gaps. The Program Partners who collect the monitoring data should conduct this comparison. For data gaps that are identified, monitoring plans to collect the information necessary to develop SSS and implement the DSS in the Trinity River can then be incorporated into monitoring plans.

4.6 Riparian Dynamics Models

Input parameter data needed for the TARGETS model to predict how riparian ecosystems will respond to Program flows include: 1) seed dispersal periods for black cottonwood and narrowleaf willow; 2) species drought tolerances; 3) the location of successful seedling germination (initiation); 4) root growth rates; 5) capillary fringe estimates; 6) the channel cross section and surface particle size distribution across the cross section; 7) river stage versus discharge rating curves; and 8) the hydrograph.

5 APPLICATION OF THE DECISION SUPPORT SYSTEM IN THE PROGRAM

5.1 Model Testing and Verification

The process of developing and applying models to ecosystem management is thoroughly discussed in the 2008 NRC report with specific attention to river system habitats and fish populations. They suggest that there are five important steps in such applications (adapted from EPA 2003):

1. Problem and purpose definition
2. Model development
3. Calibration and testing
4. Sensitivity analysis
5. Results interpretation and communication

The validity of any quantitative model must be tested against data. For each model, the key output variables are selected for calibration as follows:

- Hydrologic and hydrodynamic models are calibrated against water surface, velocity, and depth data. Some degree of calibration of the existing models has already been performed, as mentioned in Section 3.
- Temperature models are calibrated against water temperature data. Some degree of calibration of the existing models has already been performed, as mentioned in Section 3.
- Morphodynamic models can be calibrated against field geomorphology data (i.e., records of scour and aggradation that occur in response to flow changes).
- 2-D hydraulic/fish habitat models can be calibrated and tested against field-measured physical habitat (depth, velocity, substrate, and distance to vegetation) and fish observation (suitable, marginal, unsuitable area) data. For example, model/data comparisons have been performed by the Program for the 2-D hydrodynamic model (Alvarez et al. 2011). The results are illustrated in Figure 7. Once fully calibrated and tested, 2-D hydraulic/fish habitat suitability models can be statistically tested by comparing observed presence and absence of fish with areas predicted as optimal, marginal or unsuitable. Regardless of the density of fish present, there should be more fish in the predicted optimal habitat areas than in the marginal habitat areas and no fish observed in the unsuitable areas.
- The virtual habitat model will be developed as described in Section 3.7. Predicted fish habitat at river segments can potentially be tested by comparison with data collected at other rehabilitation sites within geomorphic segments, GRTS sampling sites, or newly measured “test” sites.
- Fish population models can be tested against field population data.

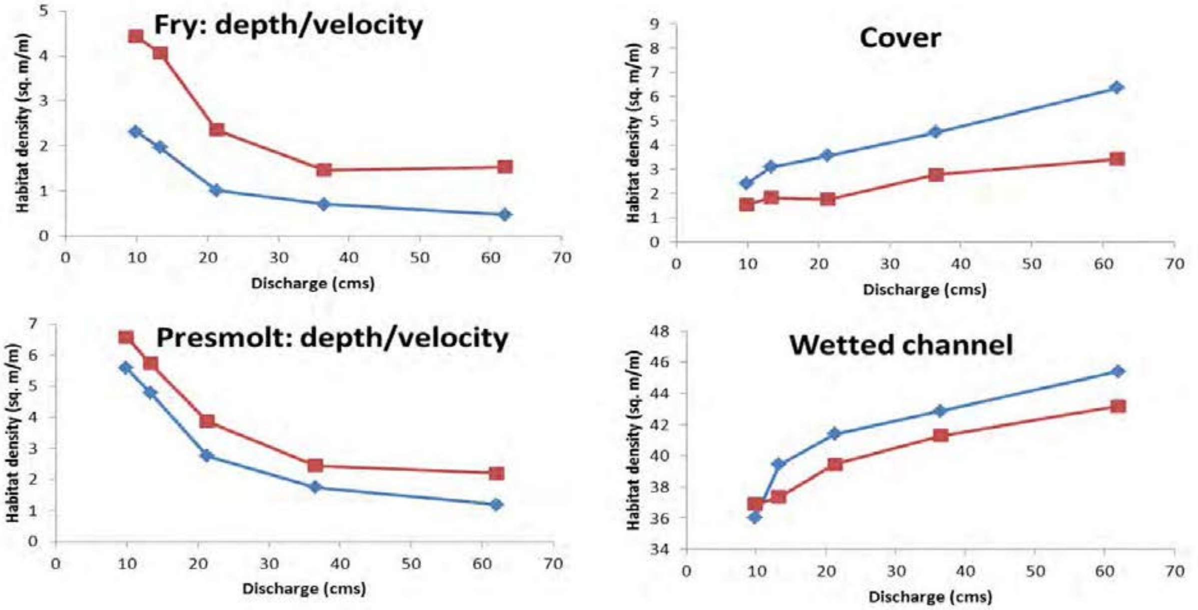


Figure 9-1. Rearing habitat variables estimated by a two-dimensional hydraulic model (blue) and habitat mapping (red) surveys at Reading Creek bank rehabilitation site before construction. Comparisons were made for estimates of areas within depth/velocity criteria for fry and presmolt life stages, area of inundated in-water escape cover (cover) and the area of wetted channel.

Source: Alvarez et al. 2011

Figure 7

Example of Model/Data Comparison for a Fish Habitat Model

Ideally, calibration and validation is a two-step process. Models are first calibrated, which involves adjusting a few key parameter values to improve model fit to the measured data. During calibration, all parameter values must remain within the uncertainty bounds for those parameters. That is, parameters are not “knobs” that can be turned arbitrarily. The selection of parameters to adjust is an important process and must be done carefully; the model must be sensitive to the parameter within its range of uncertainty as determined by independent data. Furthermore, the value of that parameter must be constrained such that it is useful for prediction. For example, if the value of a parameter is adjusted independently for each individual calibration data value, a model can lose its predictive power; it becomes so site-specific that the value of the parameter for new model applications (e.g., different parts of the river, or different flow regimes) cannot be determined.

The second step is validation, which from a scientific viewpoint requires testing model output, without further parameter adjustment, against a different data set collected under different conditions. The model is considered validated if its results are consistent with data without adjustment. If adjustments are necessary, this is considered another calibration and further testing is needed.

In reality, for some types of models, there is often enough data only for calibration. Furthermore, even in cases where there are two independent data sets for calibration and validation, mismatches during validation can sometimes be addressed by adjusting parameter values to make the model consistent with both the calibration and validation data sets. Cases where this cannot be done can provide significant insights into limitations in the structure of the model.

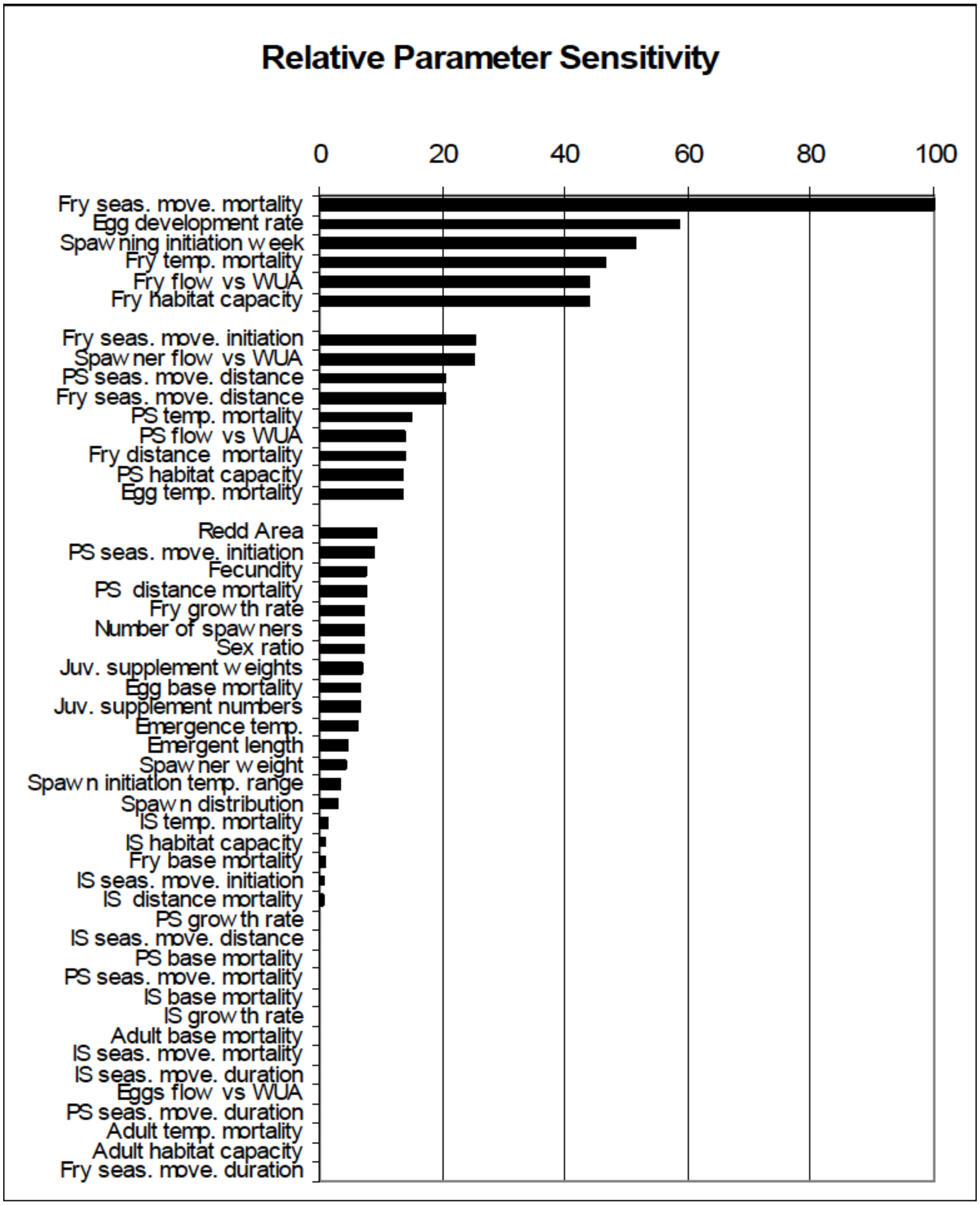
Model/data testing should be as robust as possible. For example, for the fish habitat model, the hydraulic component should be tested against depth and velocity data collected at a variety of flow rates. The biological component requires testing against observed fish distributions at model simulated flows independent from flows used to calibrate the hydraulic component (Thomas and Bovee 1993). For the channel morphodynamic model, it should be tested against data collected in a variety of geomorphically different areas. The temperature model should be tested under different flow rates, depths, and seasons.

Finally, the standards that are applied when testing and calibrating a model should be appropriate to the questions at hand. For example, predicting temperature to the tenths of a degree is probably not necessary for the purposes of the Program. Inappropriate testing may result in a considerable unnecessary level of effort, and sometimes may result in the rejection of a model that is sufficient for the purposes at hand.

5.2 Sensitivity Analysis

A critical component of any modeling project is sensitivity analysis. In a sensitivity analysis, values of individual model parameters are adjusted, and the responses of key model outputs are observed. The results presented in Figure 8 provide an example of a sensitivity analysis, where model sensitivity is assessed relative to an input, namely, discharge. For a factor of two change in discharge (from about 10 to 20 $m^3 \cdot s^{-1}$), habitat areas that are within depth/velocity criteria for fry decline by about a factor of two (from densities of about 2 to 1 $m^2 \cdot m^{-1}$), while cover increases by only approximately 50% (from about 2.5 to 3.5). That is, depth/velocity criteria predicted by the model are more sensitive to variation in discharge than cover. Sensitivity analysis is used to identify the factors that have the greatest effect on the predicted changes that occur after a decision is made. For example, sensitivity analysis could be used to identify the model components that have the greatest effect on predicted increase in juvenile salmonid habitat after high-flow events. Sensitivity analysis also is used to identify the factors that have the greatest effect on which decision alternative is estimated to be the best for achieving management objectives. Equally important, sensitivity analysis provides decision-makers with a means to identify those factors (i.e., key uncertainties) that largely drive the decision and that could be improved with additional study or through an adaptive management process.

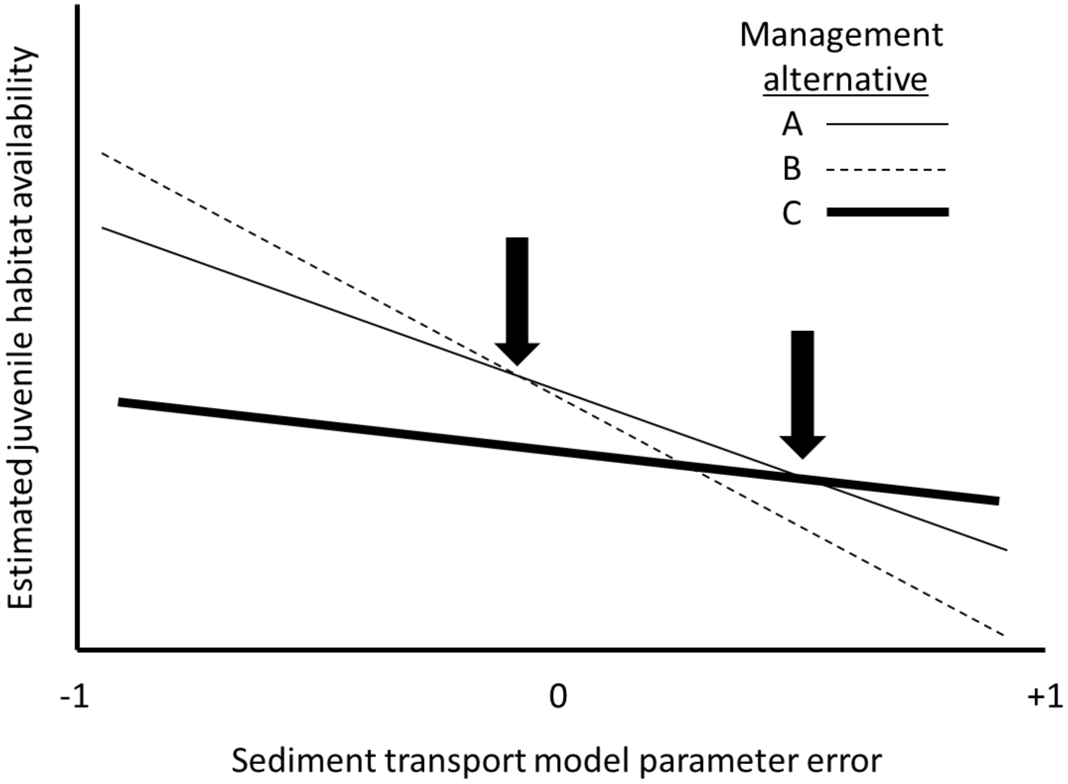
There are many approaches to sensitivity analysis, and no single type is best. The three types of sensitivity analysis that are most often used in natural resource decision modeling are one-way sensitivity analysis, two-way sensitivity analysis, and response profile sensitivity analysis. One-way sensitivity analysis is the most common. Here, the value of an individual model component or model inputs (e.g., high-flow events) is varied from its minimum to its maximum to evaluate how it affects the predicted change in management objectives (e.g., juvenile habitat) resulting from a decision. These changes are often rescaled or normalized to allow comparisons among components on very different measurement scales (Figure 8). In a two-way sensitivity analysis, two model components or model inputs are varied to evaluate the sensitivity to the interaction between them. These are generally displayed in a contour plot. A response profile sensitivity analysis is used to evaluate how the best decision changes when one or two model components are varied. It is used to answer the following question: Does uncertainty (e.g., error) in this component affect what decision is estimated to be best? For example, consider a situation where decision-makers need to choose one of three management alternatives that are intended to increase juvenile salmonid habitat (i.e., the management objective). To evaluate the effect of statistical error in a model parameter, a response profile sensitivity analysis would include estimating the expected change in juvenile habitat across the range of values for the parameter (Figure 9). In this example, the best alternative (i.e., the decision that results in the greatest juvenile habitat) changes three times across the range of parameter values. This suggests that the parameter error is a key uncertainty because it significantly influences the decision that is estimated to be best. Each type of sensitivity analysis provides a different look into the behavior of the model; therefore, all decision models should be examined with more than one technique.



Source: Bartholow and Henricksen 2006, Appendix D

Figure 8

Example of Results of Sensitivity Analysis For SALMOD Model Outputs of Fall Chinook Salmon Production in the Klamath River



Note: Hypothetical example of response profile sensitivity analysis of three decision alternatives, A, B, and C. Lines represent estimated juvenile habitat availability for each decision from +/- 1 standard deviation of a sediment transport model parameter. Arrows represent value of parameter error where the best decision to maximize estimated juvenile habitat availability changes from one alternative to another.

Figure 9

Hypothetical Example of Response Profile Sensitivity Analysis

5.3 Uncertainty and Adapting the DSS to New Information

Significant uncertainties are associated with management decisions and are likely substantial in a complex system such as the Trinity River. These uncertainties stem from three basic sources (following Williams et al. 2002): 1) environmental uncertainty, which is composed of environmental and demographic variation and has both spatial and temporal components; 2) statistical uncertainty, due to the use of sample data to estimate model parameters; and 3) structural (or ecological) uncertainty, due to an inability to accurately determine the processes or models that best represent system dynamics (e.g., the relationship between geomorphology, streamflow, fluvial dynamics, and fish population demographics). In this appendix, special attention is devoted to structural uncertainty, because it probably represents the main source of uncertainty associated with the Program. Because the structure and function of aquatic systems are so complex, there are often several plausible hypotheses to explain observed ecological patterns and processes. Structural uncertainty can be incorporated in the DSS using alternative models to represent different hypotheses of system dynamics. Evaluating these hypotheses and identifying those that are best supported by objective-specific monitoring can reduce structural uncertainty and improve decision-making.

Several methods are available for reducing structural uncertainty. The gold standard is experimentation, which involves replication, randomization, and treatments. Conducting experiments, however, is labor intensive, which precludes application at the large spatial scales and long time frames that are often necessary in fish management. In contrast to experiments, observational studies use statistical control to describe patterns among data that may be collected across broad spatial or temporal extents. These types of studies often provide the basis for constructing integrated models. The third complimentary approach, ARM (Walters 1986), is a technique that is well-suited to reducing structural uncertainty and improving decision-making in management.

As discussed earlier, ARM is about learning while managing. Management decisions are made and feedback, in the form of monitoring data, are used to reduce uncertainty about system dynamics. This iterative process has been defined as single loop learning (Figure 1). Single loop learning in the context of ARM begins after the initial DSS is completed. That is, objectives and decision alternatives have been identified and the integrated models have been built. Learning within the single loop occurs with respect to the given (fixed) set of objectives, alternatives, and models and learning occurs relatively frequently (e.g., annually). Through time, decision-makers may find that the DSS needs to be changed (i.e., the current set of models is inadequate or management objectives or decision alternatives are insufficient). In double loop learning, the management objectives, decision alternatives, and models are reassessed and potentially revised to reflect changes in scientific knowledge and management objectives and alternatives (Figure 1). Learning in the outer loop occurs at a much slower rate and with slower frequency compared to single loop learning. There is no rule regarding the best time to initiate the reassessment, as it will vary from program to program and largely depends on the decision-makers, stakeholders, and technical experts. The completion of the Phase 1 review, however, may be an excellent opportunity for a reassessment.

Learning is, at its most basic, the detection and correction of errors; when an outcome occurs that isn’t as expected, learners will find an alternative strategy to move forward. If the alternative strategy is within the governing variables, values, plans, and rules, it is single-loop learning. Alternatively, if the response is to reflect on the governing variables themselves, the learning is double-loop (Argyris and Schön 1974). Double-loop learning results from confronting underlying assumptions and processes and may lead to a change in the way in which strategies and consequences are framed and operationalized. Single-loop learning is the common mode of learning when objectives and strategies are rote; the emphasis of the learning cycle is on refining a process to be more efficient (Usher and Bryant 1989). Double-loop learning requires a deeper level of reflection and questioning, examining the structure of the learning system that supports the objectives and strategies. In the former case, the learning routine follows an established process, so while embracing change, it does afford control and manageable risk for the participants. In the latter case, the underlying assumptions of the learning system itself are confronted and publicly tested, which can be threatening to individuals and organizations. However, double-loop learning is required for informed, adaptive decision-making in rapidly changing and highly uncertain environments (Argyris 1990).

For example, if water-surface elevations are recorded at specific high- or low-flow conditions, then the chosen flow model can be re-evaluated for those conditions to verify whether it is able to reproduce the observed flows. This will improve the credibility of the models and contribute to reducing any uncertainty associated with management decisions. Similarly, if it is determined that a component model in the framework is unable or inadequate to describe observed phenomenon, the model(s) will need to be recalibrated and refined. If such efforts are not successful in improving model performance, then alternative models will need to be considered. When the same data can be used to construct alternate models (stakeholders may disagree on the model but agree on the needed inputs and potential outputs), testing with monitoring data may better support one model over another and provide for acceptance of the supported model.

Component models should also be used diagnostically to guide data collection. If model simulations exhibit substantial uncertainty, then data gaps will need to be identified and additional data collection efforts initiated. Once new data become available, then the component models in the framework must be refined and management decisions re-evaluated. The goal of using DSS is to identify areas of uncertainty through model simulations and focus data collection needs to produce cost savings to the Program and improve the level of confidence associated with its management decisions.

In decision-making, the terms “Bayesian inference” or “Bayesian updating” are used to describe the process by which information is gathered and used to improve scientific understanding and thus decision-making. In a Bayesian updating process, one essentially starts with prior information and then updates that information using data, producing “posterior” probabilities or information. The process of model updating discussed here is inherently a Bayesian process, insofar as monitoring data are used as evidence to adjust prior information (i.e., the previous models), producing the posterior information (i.e., modified model structure or parameter values).

Bayesian updating can be performed in a variety of ways, ranging from qualitative to quantitative or statistical. For example, model parameter values may be adjusted as needed to bring the model into agreement with new data, while maintaining agreement with the old. This is an effective approach that results in a model of increasing robustness, or, if parameter adjustment is insufficient to match new data, in significant learning regarding the structure of the model. Statistical techniques are available for application as well.

The approaches to model updating should be developed as the DSS is constructed, as it will depend on the specifics of the component models and the data used for calibration and validation.

5.4 Integration of the DSS into the Program

A DSS should be developed by and for decision-makers and stakeholders. The technical work of developing and calibrating the models is only part of the overall process of developing a DSS. Stakeholders must initially understand and buy into the process and into the DSS as a useful tool for comparing alternatives, informing management decisions, and assessing progress toward achieving Program goals. Thereafter, the first step in developing the DSS is the identification of the Program's fundamental and means objectives, both of which must be developed quantified by stakeholders.

Following the identification and structuring of objectives, the decision alternatives need to be identified and explicitly defined. The next step is to decide upon what types of models (in this case, linkages among hydrology/hydrodynamics, morphodynamics, fish habitat, and fish population dynamics) are needed to connect the specific decision alternatives to fundamental management objectives. Specific frameworks, or codes, must be selected (these are discussed in this appendix). Finally, the models are developed and calibrated. While these are all technical tasks, it is critical that the stakeholders be involved throughout the process: understanding and accepting the uses and limitations of computer models is a difficult task for non-modelers and takes time and familiarity. In the SAB's experience, stakeholders are naturally wary of computer models; trust is gained only over time, as stakeholders gain expertise. A major mistake is presenting only one alternative and the projected modeled results to stakeholders followed by arguing that the model components represent the state of the art and therefore should be accepted. By projecting alternative outcomes and the monitoring that will be needed for comparison, stakeholders become more involved.

Most of the components of the recommended core DSS modeling framework have either been developed or are under development and will be available to aid in the design of the next phase of restoration activities. The lack of a comprehensive DSS at this stage in the Program does not mean that the initial DSS process will not be helpful in the short term. This is because one of the benefits of a DSS is inherent in the process of its development: a stakeholder group that buys into the development of a DSS will benefit from the system-wide integrative thinking that is integral to a DSS.

Thus, the integration of the DSS into the Program should be considered a process that has benefits every step of the way. The earlier the process is started, the greater the benefits. Once the process is started, it can be linked more directly with upcoming stages and decisions of the project. Therefore, the SAB recommends that the process of developing a DSS begin as soon as possible. A logical first step would be to apply the DSS framework to an aspect of the Program that is already well developed. At the recent Program Science Symposium conducted in January 2013, the suggestion was made to apply the DSS framework to the development of the 2013 flow allocation schedule. Since the processes and models for allocating annual and daily flow are well developed and need no further refinement for use in a DSS, this was an excellent suggestion. The DSS framework could be used to help the Partners learn how to use a DSS and arrive at recommendation for distributing the available 2013 water allocation among various time steps to achieve multiple stakeholder objectives. These objectives would include geomorphic work, riparian establishment and nourishment, protection of infrastructures and property, effects on adult holding habitat, etc. This would enable stakeholders and Partners to become familiar with the DSS framework that incorporates various stakeholder (means) objectives into the flow allocation process, without having to develop the concomitant models and model structure needed to support the development of flow management recommendations.

Another initial step recently taken by the Program was the use of the Stream Project decision model (Baker and Wilcock 2012) to evaluate design options for rehabilitation projects, quantify public input, and convey options to the public. While valuable, the approach has been limited to site-scale analyses (individual rehabilitation projects) and does not represent a full DSS as described here (Figure 2).

5.5 Stakeholder Communication

5.5.1 Framework for Communication

Because stakeholder involvement is key to the successful use of a DSS in the Program, effective stakeholder communication is essential. Communication is likely to be primarily with the TMC and the Trinity Adaptive Management Working Group (TAMWG), and through them to other stakeholders. The first step in developing a communication framework is the designation of a DSS leader to guide and manage the process. A technical work group is also required. This group should include the likely developers of the component models and stakeholders with technical expertise, and outside experts should be considered as well to provide additional perspectives.

Developing the DSS requires ongoing communication among the TMC, TAMWG, and technical staff. Communications regarding the DSS should be verbal, through conference calls and joint meetings, to the extent possible because the DSS is a complex technical tool and its utility will depend on non-technical stakeholders gaining familiarity and buy-in. Communication by a series of short technical memoranda can also be effective: brief technical documents are more likely to be read, and repeated communications engender familiarity.

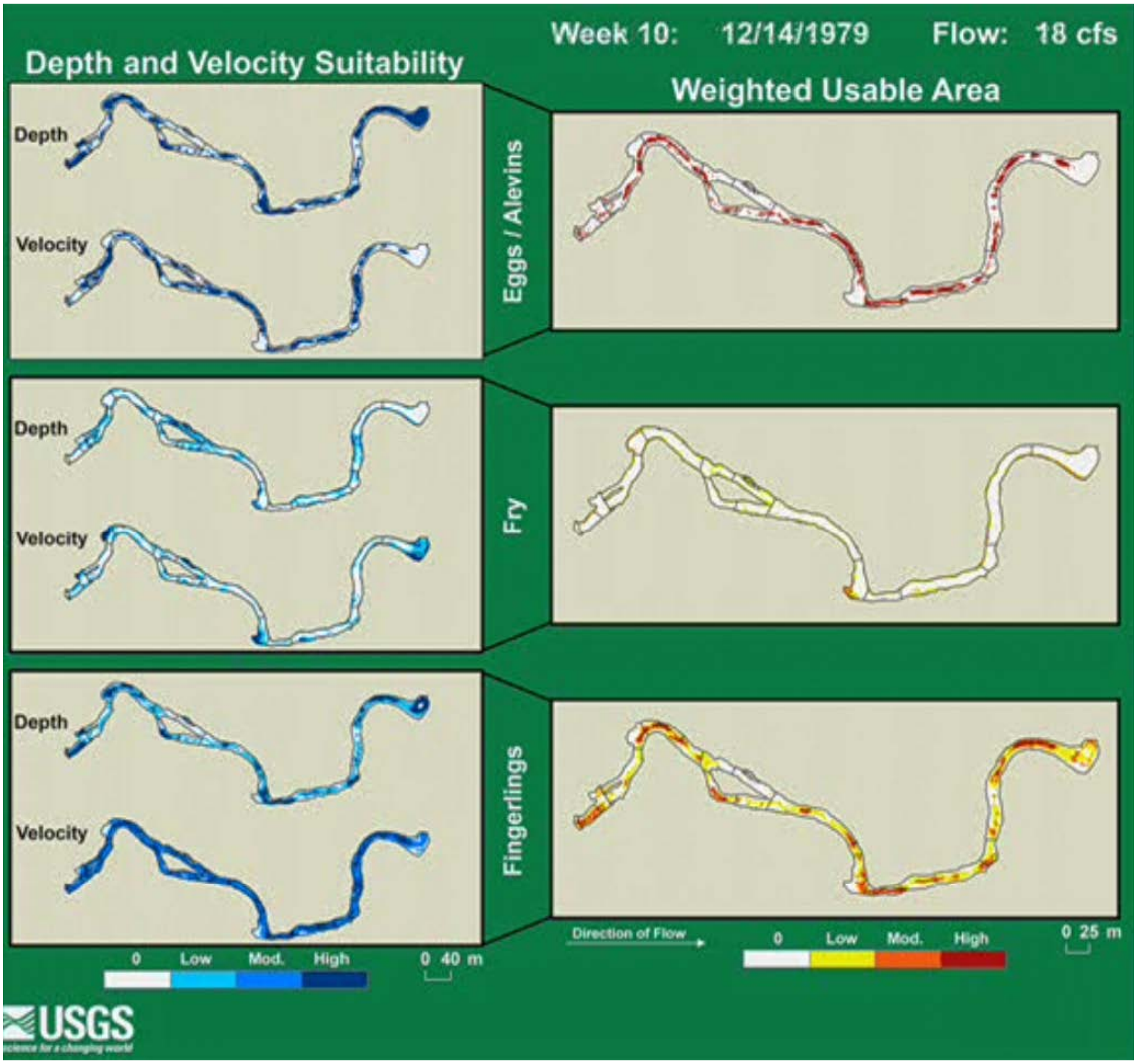
Timely summation of data collections and delivery for model input is essential. All partners and data gathering groups must place highest priority to data summary and expedient delivery of data reports to other Program groups as needed for collective analyses and input to the DSS. Individual group publication is encouraged and protection of data is essential. At the Program level, a common database is needed for joint partner use and stimulation of collaborative learning and multiple authored publication of accomplishments, important findings, and progress toward restoration goals. For successful implementation of a DSS as described above, all data must be considered as protected property of the investigators and the collective Program. Trust in collaborative investigation and reporting is essential.

As the DSS is developed, consideration can also be given to instituting an external peer review. Such peer reviews are common in other environmental fields and can improve the DSS and increase the level of comfort stakeholders have with the tool. A peer review process that involves interim reviews and discussions throughout the development of the DSS is likely to be more effective than waiting to review the end product. Usually the technical staff that develop models are in a good position to design a peer review process based on previous experience.

5.5.2 Visualization and Presentation of Model Outcomes

A data visualization method is an essential component of the DSS, and one that illustrates results of complex model studies in formats that are easy to visualize and understand for stakeholders and decision-makers. We reviewed a GIS-based data visualization tool recently developed for the Program by the USGS that links habitat changes to salmonid life stages. This tool is called “SmartRiverGIS” and it translates 2-D hydrodynamic habitat model outputs (velocity, flow, water depth, and distance to cover), as well as other relevant habitat parameters such as substrate or vegetation into spatial representations of useable habitat area for each fish species and life stage of interest. Figure 10 shows a sample graphic developed using this tool. The tool is also capable of importing SALMOD model outputs into the GIS framework and displaying maps that link available habitat with fish population data, such as redd locations and juvenile fish densities.

In addition, other geo-spatial maps may need to be developed to fully understand the system under current conditions and future management scenarios. This may include, for example, showing those sections of the river prone to scour or aggradation. If computational times are manageable, statistical evaluations can be designed to quantify the uncertainty in model outputs, such as salmonid population responses associated with uncertainty in the model inputs (e.g., changes in precipitation or temperature). This would allow decision-makers to weigh the cost and risk associated with a proposed action against any benefits accrued from the actions.



Adapted from: http://www.fort.usgs.gov/smartrivergis/2DwLegend.asp

Figure 10

Sample Graphics Showing SmartRiverGIS Capability

6 NEXT STEPS

This appendix provides a conceptual plan for the quantitative models that would be one part of the DSS, with specific suggestions for the modeling frameworks and a preliminary discussion of data that the models indicate are important for integrating the monitoring data into decision-making. Recommended next steps are described below. The need for, and specific actions to be taken during each step, depends on the results of the previous step, as follows:

- A decision by stakeholders as to whether to proceed with, and fund accordingly, a quantitative DSS
- Identification of a DSS lead to guide and manage the process, as well as a technical group to support the process
- Determination of a communication process
- Development of key stakeholder fundamental objectives that can be addressed by a DSS
- Development of an implementation plan, or work plan, for the DSS, with schedule, budget and task leaders identified
- Selection of model frameworks to be included in the DSS:
  - This should be done in conjunction with other groups within the Program that are evaluating and discussing modeling options, for example the Flow, Physical, Fish, and Temperature Work Groups, and the Design Team
  - This should also be done in communication with, and if possible in collaboration with, model development efforts for the Klamath Basin, with the goal of developing an integrated framework for the entire basin
  - The SAB thinks that for the most part, models that have already been developed or are under construction are the appropriate tools for the DSS, but that these need to be supplemented. In particular, a fish production model will require: 1) expansion of flow–habitat relations to the full range of managed flows at all habitat measurement sites; and 2) development of a Virtual Habitat Model (Section 3.7 and Appendix E) that extrapolates the site-scale flow–habitat relations in order to estimate the longitudinal distribution of fish habitat down the full length of the Trinity River restoration reach
  - Eventually the DSS models may be extended to the Klamath River
- A detailed review of input data that the DSS models indicate are critical, a comparison of those data needs with the current monitoring program, and development of recommendations for modification of the monitoring program as appropriate
  - This would involve categorization of all ongoing monitoring and data collection activities as either: 1) necessary input for models addressing fundamental management objectives; 2) input needed for models providing supporting means

  objectives; or 3) experimental, with the first two items being given priority support by the Program to facilitate DSS development
  - It would additionally involve identification of all data needs for fundamental and means objective models that are not being collected at present, and modification of ongoing work plans as needed to address identified data gaps
- Development and integration of the DSS models
- Development of a GIS-based framework for visual and tabular presentation of DSS model outputs via the TRRP Online Data Portal (http://odp.trrp.net)

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