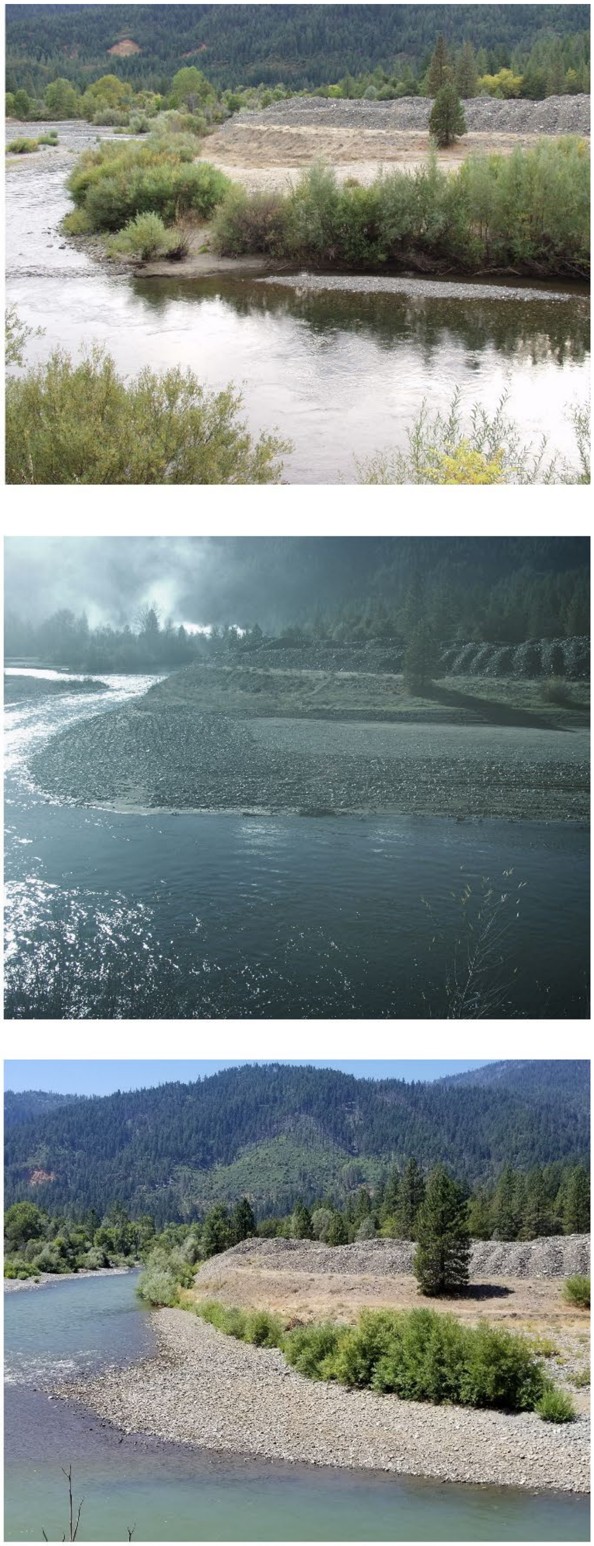
Vegetation Encroachment Synthesis for the Trinity River



Hocker Flat Channel Rehabilitation Site. Top: 2004 Pre-constructio
Middle: 2005 Post-construction; Bottom: 2019 Post-construction

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EXECUTIVE SUMMARY

The Trinity River in northern California once provided numerous resources, including abundant salmon populations. This montane, semi-alluvial river flows through highly constrained bedrock canyons and open valleys, providing diverse instream and riparian habitat depending on the underlying geomorphic feature (i.e., bedrock channel, open gravel bar, partially vegetated floodplain). However, the current channel pattern reflects a long history of resource extraction and exploitation.

The discovery of gold in the mid-1800s led to widespread channel and riparian degradation. The channel bed was completely altered, and hillsides were washed into the river in search of gold, elevating in-channel sediment supply and storage. However, the streamflow regime was unregulated until the early 1960s, allowing for deposition and erosion processes of excess sediment to occur. Portions of the channel margin were vegetated with mature riparian hardwoods such as alders and willows, while other portions were unvegetated mobile features (i.e., gravel bars) that provided habitat for juvenile salmonids and other aquatic fauna when inundated. Local overbank deposition within willows established near the low water edge created linear mounds of fine sediment parallel to flow along channel margins, termed *berms* (Figure E-1). Although degraded, the Trinity River was still capable of reworking the channel bed and banks under the natural flow regime.

Further degradations occurred after World War II, when the Trinity River Division (TRD) of the Central Valley Project was constructed. The TRD includes three dams: Trinity, Lewiston and Whiskeytown dams. Trinity and Lewiston Dams are located on the Trinity River. Trinity Dam is upstream and impounds up to 2.4 million acre-ft of water. Water released from Trinity Dam passes into Lewiston Lake and through Lewiston Dam into the Trinity River. Lewiston Dam regulates Trinity River streamflows.

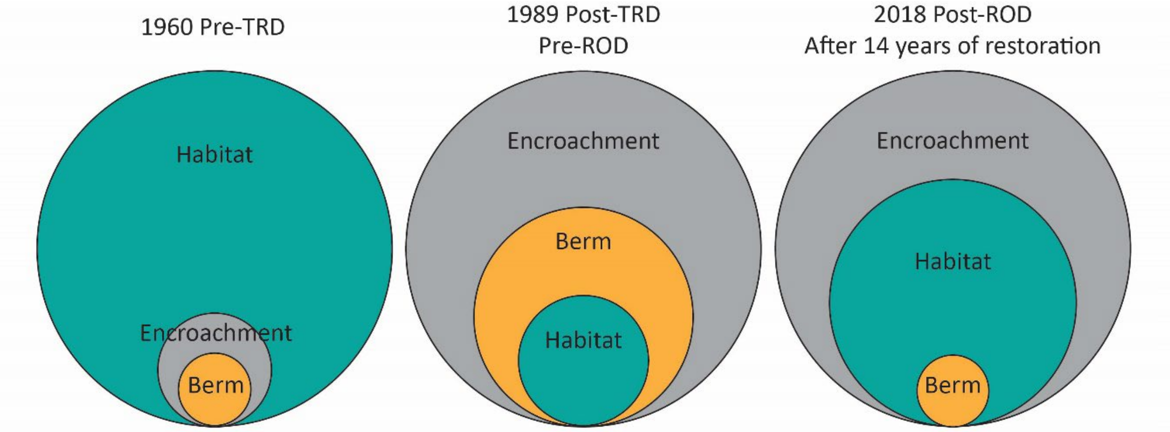

Figure E-1. Conceptual model of the changing relationship between juvenile salmonid habitat, sediment berms, and riparian encroachment in response to the construction of the Trinity River Division (TRD) and implementation of the Record of Decision (ROD). Prior to construction of the TRD, salmonid habitat was abundant, with smaller amounts of vegetation encroachment and sediment berms. Following 20 years of reduced flows from operation of the TRD, riparian vegetation had encroached on the channel, with extensive berms and little salmonid habitat. Contemporary conditions show an increase in salmonid habitat and reduction in the amount of sediment berms following 14 years of restoration; however, encroachment is still a defining feature of much of the channel.

Streamflow changes from operation of the TRD beginning in 1964 resulted in a near-constant flow release of 150 cfs to the Trinity River for almost two decades between 1961–1980. In addition, timber harvest and road building accelerated fine sediment input from downstream tributaries to the Trinity River below the TRD. Riparian vegetation responded to these conditions by growing in a dense band along the low water edge, termed *encroachment.* Encroachment is a natural process that provides cover, stream shading, and habitat complexity; however, when encroachment becomes dense enough to be irremovable by natural stream processes (e.g., vertical or lateral scour, bank failure), it becomes detrimental encroachment. Increased vegetation along the channel margin caused additional fine sediment deposition within the berm, thus increasing the size and extent of riparian berms downstream of the dams. The stream channel morphology became rectangular and greatly reduced habitat for many salmonid life stages (Figure E-1).

In response to declining fish populations, congressional action initiated the *Trinity River Flow Evaluation* (TRFE), which was tasked with providing flow recommendations to improve Trinity River fishery resources. The TRFE hypothesized that the restoration of a variable streamflow regime (including flood peaks for geomorphic work), coarse and fine sediment management, channel rehabilitation, and Adaptive Environmental Assessment and Management (AEAM) could restore a scaled-down, dynamic alluvial river that could rework its channel bed and banks and remedy physical habitat limitations of the rectangular channel that had formed following the TRD. A Secretarial Record of Decision (ROD) in 2000 adopted the recommendations in the TRFE and established the Trinity River Restoration Program (TRRP). The TRRP has been actively implementing restoration actions, including ROD-dictated flows, within a 40-mile reach from Lewiston Dam to the North Fork Trinity River (Restoration Reach) since 2005.

A substantial body of monitoring data has been accrued during the 14 years of restoration, yet much of the information has been reported annually without consideration of results from other years. Additionally, as more is learned through the process and results of restoration design and implementation, there has been interest from Program partners to evaluate whether riparian vegetation encroachment is still a management priority, given the changes in streamflow regime, channel rehabilitation and increased input of coarse material via gravel augmentation.

The goals of this synthesis report are to summarize past and current riparian encroachment trends and to synthesize the relationship between encroachment trends, encroachment inhibiting mechanisms, and management actions in a single document. This synthesis report is inclusive of all Trinity River-related riparian encroachment information so that the full scope of encroachment dynamics and implications for future management can be considered. Detailed analyses can be found in the body of the report. A summary of findings and recommendations that arose from the analyses are provided below.

Since completion of the TRD, vegetation encroached into the late summer low streamflow channel throughout the Restoration Reach. Riparian vegetation mapped on aerial photographs indicated that in 1960, only 300 acres of willow (*Salix* spp.) and white alder (*Alnus rhombifolia*) were growing along the mainstem in the Restoration Reach (Section 4.1); the majority of the areas mapped adjacent to the channel were open and unvegetated boulder and cobble bars and dredger tailings. After 1960, the area of riparian vegetation increased and has remained at over 900 acres since 1980 (Section 4.2). Even the largest post-TRD floods (i.e., 14,000 cfs in 1974) were insufficient to remove mature encroaching vegetation.

Results of riparian band transect and exposed bar monitoring between 2005 and 2017 showed that in most years, 3-year-old or younger riparian hardwoods were scoured from the low water edge by winter storms (tributary-generated floods) and spring ROD releases (prescribed flow releases from Lewiston Dam). Every year, high densities of seedlings initiated regardless of streamflows and substrate availability, but successful establishment was mostly dependent on avoiding channel bed scour the winter following the first growth season. During the 2005 to 2017 period, one cohort

(WY 2006) was documented to have survived to establishment, and therefore beyond the ability of ROD releases to remove via scour (Section 8.1 and 8.2). Although the density of mature plants that established across each site is unknown, willows are highly clonal species that can reproduce vegetatively (i.e., new plants can grow from pieces of stems or roots). Allowing one out of every 14 cohorts to survive to establishment could lead to further encroachment along the low water channel, especially at newly constructed rehabilitation sites.

The sequencing of high flow releases may provide more management flexibility than originally thought in the TRFE. Streamflow management was hypothesized to only be capable of scouring riparian hardwoods up to 3-years-old from the low water edge; older seedlings would not be able to be scoured. The ROD assigned peak release magnitudes to each water year type such that drier water years have lower releases than wetter water years. Several consecutive dry years can lead to riparian establishment along the low flow channel margin and increased encroachment risk. This lends some immediacy to achieving scour thresholds through streamflows 6,000 cfs or higher at least every three years. This scenario occurred following a three-year dry period in 2013–2015, when seedlings that initiated in 2012 were not scoured by dry-year releases (Section 8.3). Although WY 2015 was a Dry year, a portion of the water volume allocated for the year was used to achieve a flood peak associated with a Wet year (> 8,500 cfs) to scour establishing seedlings. The WY 2015 ROD release scoured the 2013 and 2014 cohorts, but the 2012 cohort survived and was theoretically beyond management using streamflows alone. However, WY 2016 was a Wet year, and the ROD release of 9,600 cfs achieved scour of the 2015 cohort and the 2012 cohort, which was four years old at the time. Riparian exposed bar monitoring showed that seedlings that were four years old were capable of being scoured following two consecutive years of releases above 8,500 cfs (Section 8.3).

Riparian encroachment by itself merits management consideration simply because of the long list of potential negative geomorphic effects if encroachment becomes extensive. Based on the history of riparian encroachment in the Trinity River, it makes sense to use every tool available in the ROD to reduce riparian encroachment risk into the active channel. Data suggest that the root length to substrate size hypothesis/management objectives put forth in the TRFE were largely correct. The range of differences in plant densities below 2,000 cfs from one year to the next varies as a result of peak-flow magnitudes achieved during the winter and spring of each water year. In above Normal years, plant densities decreased between sampling. In below Normal years, plant densities sometimes increased. Based on monitoring data through 2016 and the frequency of larger peak flow magnitudes from 2005–2016, the 2006 cohort has been the only cohort that has survived to establishment below 2,000 cfs. All other year cohorts have been scoured.

In addition to encroaching riparian plants, sediment deposition near the low water edge was also documented (Section 5.2.5). Generally, woody plants will encroach the low water edge and may induce berm formation if they establish below the 2,000 cfs water surface elevation and are not scoured within three years of establishment. The formation of a berm limits channel migration and can lead to channel entrenchment, resulting in a rectangular channel morphology that can transport sediment but lacks diversity of substrate and topography that are preferred by most aquatic and riparian biota.

Two hypotheses regarding detrimental riparian encroachment were developed during the Integrated Assessment Plan (IAP). The first encroachment hypothesis (H_1) is from the TRFE and posits that detrimental riparian encroachment is a long-term threat that must be managed because riparian hardwoods can establish along the low-water edge during a series of consecutive dry years, when post-TRD flows and sediment transport are insufficient to scour plants away. The second hypothesis (H_2) came about shortly after ROD streamflows were first implemented in 2005 and arose out of disagreement between some Program participants regarding the underlying mechanisms of riparian encroachment and berm formation, as well as the current state of riparian encroachment within the Restoration Reach. H_2 posits that detrimental riparian encroachment is not a long-term threat because the post-ROD streamflow and sediment regime are sufficient to scour away initiating riparian hardwoods (Section 7). Results of this synthesis report showed that there is insufficient evidence to accept or reject either encroachment hypothesis (Section 9.3). The short post-ROD period, combined with sporadic coarse sediment augmentation and modest changes in the physical system, led to inconclusive results.

Recommendations derived from this riparian encroachment synthesis include:

1. Review, Revise, and Adopt a Reach-based Prediction of Achievable Channel Pattern

Several studies have evaluated the physical constraints of the Trinity River within the Restoration Reach in an attempt to predict the channel form (i.e., single-thread vs. anabranching) in any given reach (Section 3). The TRRP should formally evaluate the reach delineations currently available and adopt a reach designation that makes the most sense from an AEAM context. The predicted channel type, and subsequent expected physical, aquatic habitat, and riparian vegetation outcome, in each reach should be defined. It is likely that the reach delineations adopted by the TRRP will have different goals depending on the channel pattern predicted for that reach.

2. Adopt a Revised Vegetation Encroachment Hypothesis

Currently the frequency and extent of channel bed scour is such that woody plants infrequently establish along the 450 cfs wetted edge, but plants can establish further up the bank where shear stress is insufficient to cause widespread channel bed mobility. Local sediment storage, lateral channel migration and local flow obstructions can alter scour patterns to the extent that established vegetation will be scoured. Two hypotheses were developed as a result of this synthesis. One hypothesis (H_{A1}) was developed to test whether the current trend in flood frequencies is more effective at managing woody seedling establishment and low water encroachment than the frequency and magnitude of floods recommended in the TRFE. The second hypothesis (H_{A2}) was developed to test whether at ROD streamflows may increase the channel width but not eliminate near channel vegetation establishment and berm formation.

3. Evaluate Current Riparian Berm Condition

It is unknown how much area and extent of riparian berm have changed since ROD implementation began in 2005. The SAB estimated that over 85% of the mainstem river shows no change between 2001 and 2011. In the absence of large channel-forming flows (greater than 7,155 cfs), berms can lead to channelization and habitat simplification over time. One ROD success metric could be reduction of the riparian berm in areas of channel confinement. Assessing the current state of the berm could be quantified using an approach similar to how geomorphic changes at channel rehabilitation sites have been evaluated, using topographic differencing of successive terrain models. Channel width and wetted edge length are important indictors of change and reducing the effects of encroachment. The topographic differencing data could be used to address the question of whether the channel has detectably widened and if so, where. Mapped berm locations should be overlaid on the areas with channel length and width changes. The proportion of berm eroded could be estimated as long as the magnitude of change is greater than the amount of error associated with the LiDAR-generated ground surface, which could be affected by dense vegetative cover.

4. Evaluate and Revise Coarse Sediment Augmentation Conceptual Model and Future Augmentation Rates

Coarse sediment augmentation was one of the three management tools proposed in the TRFE, along with ROD streamflows and mechanical rehabilitation. Contemporary coarse sediment augmentation rates are far less than those recommended in the TRFE and over a much smaller reach of river. The second detrimental encroachment-related hypothesis (H_2) hinged on adding smaller-grained coarse sediment to the river at designated locations and intervals to increase the frequency of smaller cobbles and gravels thereby reducing the frequency and abundance of larger cobble and gravel so that that lower magnitude streamflows could more easily achieve channel bed mobility and inhibit woody plant encroachment. H_2 cannot be fully evaluated without a robust coarse sediment augmentation program. The linkage between the desired or anticipated outcome of gravel augmentation and riparian encroachment hypotheses should be re-evaluated and explicitly articulated and monitored.

5. Repeat the Exposed Gravel Bar Census in Normal and Wetter Years

Exposed gravel bar monitoring began in 2013, when band transect monitoring was discontinued. Exposed gravel bar monitoring includes similarities to band transect monitoring but is able to provide better system-wide estimates of vegetation status. The TRRP should continue conducting the annual exposed bar census on an appropriate timeline based on formative flow events (i.e., peak releases greater than 6,000 cfs), but eliminate future band transect encroachment monitoring. Instead, riparian mapping similar to that conducted for systemwide vegetation mapping (M&T 2005, HVT and MA 2015) should be used to monitor the long-term status and trend of riparian vegetation.

6. Annually Estimate Detrimental Riparian Encroachment Risk to Inform Annual Flow Release Planning

Detrimental riparian encroachment risk could be evaluated using late-fall plant density estimates within the 2,000 cfs inundation zone, the detrimental encroachment thresholds, and changes in plant density estimates related to water year classes. Since each water year class has a probability of occurrence, that probability can be used to assess the risk that detrimental encroachment thresholds could be exceeded. For example, if fall field monitoring showed that 3-year-old woody plant density was approaching the detrimental encroachment density threshold, 11,000 cfs (i.e., an Extremely Wet year peak release) would be needed to reduce the densities by scouring plants 3-years old and younger. The current risk of detrimental encroachment would be high (88–100%). As plant densities approach detrimental encroachment thresholds, the reduction in plant density required to prevent encroachment thresholds from being crossed is related to the water year class that can induce scour to depths needed to remove plants of a given age class/root depth. Depending on the outcome of annual encroachment risk evaluations, annual peak streamflows may need to be adjusted to provide the requisite flow magnitude for scouring young seedlings. As part of annual managed ROD streamflow schedule planning, proposed ROD hydrographs can be adjusted to meet scour thresholds if the total allocated volume of flow is not exceeded for a given water-year type.

7. Evaluate Variable Summer Baseflows and Conduct Flow Experiment

Summer baseflows have been 450 cfs at Lewiston since 1991 (Section 4.2) to meet cold water temperature criteria at Douglas City that support adult spring-run Chinook Salmon holding and juvenile salmonid survival and health through the summer. Constant 450 cfs streamflow, regardless of water year type, is a primary contributing factor that leads to encroachment. Summer baseflow variability would promote greater low water fringe complexity, with sparse patchy woody vegetation combined with herbaceous vegetation. It is recommended that TRRP evaluate variable summer baseflows and the temperature effects of having lower flows in dry years and potentially longer recession limbs in wetter years. If variable baseflows could be released in a way that would affect woody plant colonization without negatively affecting fish, the option should be further explored in an AEAM context and flow experiment conducted. Without variable summer and fall baseflows, the TRRP is constrained to using flood peaks alone to inhibit woody plant encroachment.

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1 INTRODUCTION

The Trinity River, from its headwaters to the Klamath River, is over 112 river miles long and drains 2,965 square miles of the geologically complex Klamath Range (Figure 1). The regulated, semi-alluvial portion of the Trinity River watershed from the North Fork Trinity River confluence upstream to Lewiston Dam is approximately 40 river miles long, drains a 560 square-mile area, and is known as the Restoration Reach (Figure 1). Sub-reaches within the overall project area have been defined by various studies (Krause et al. 2010, HVT et al. 2011, Buffington et al. 2014, Gaeuman et al. 2016).

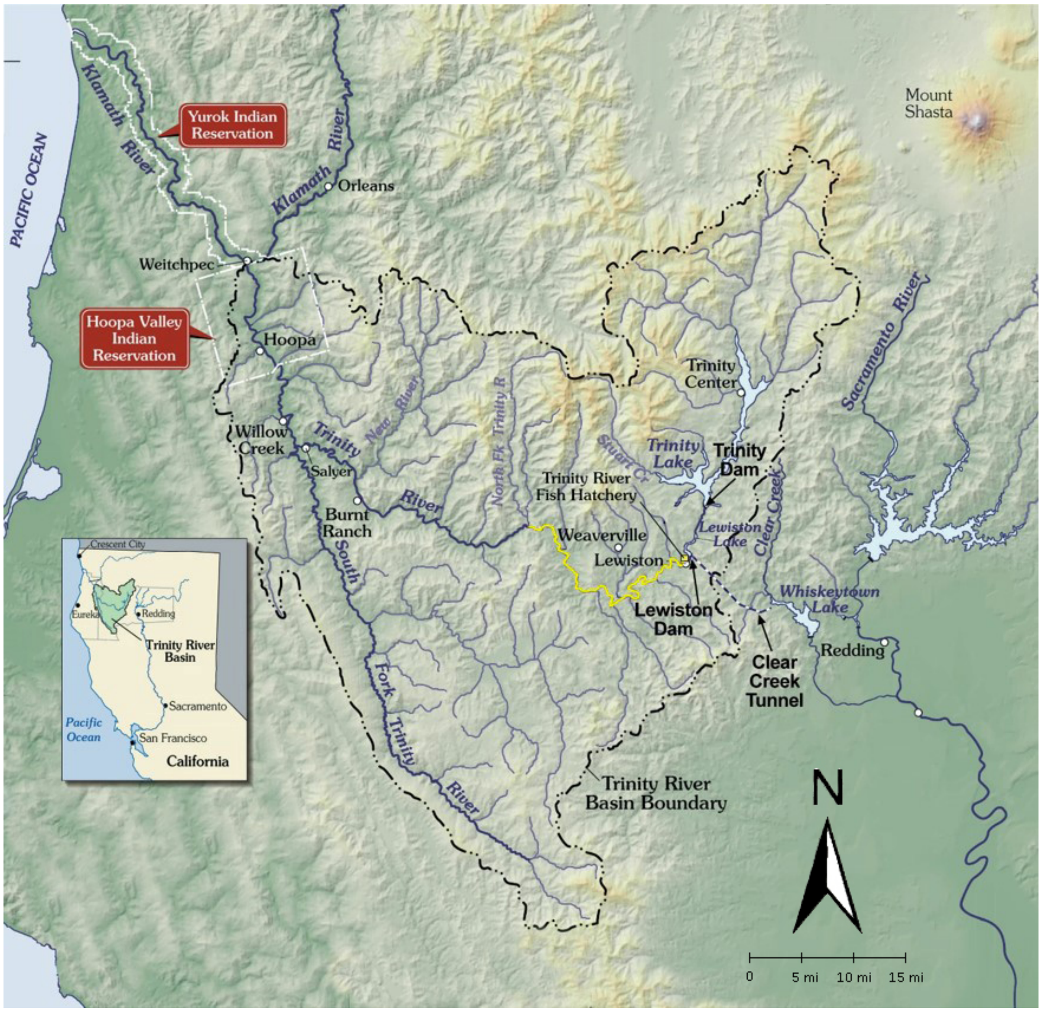


Figure 1. Geographic location of the Trinity River watershed, shown within the black boundary and with the Restoration Reach highlighted in yellow.

Before European settlement, the Trinity River provided numerous resources for generations of Native Americans, including abundant salmon populations. In the mid-1800s, gold was found in the Restoration Reach. Between 1849 and 1964, intensive placer mining for gold using hydraulic cannons and dredge boats occurred in the floodplain and surrounding Trinity River watershed. Placer gold mining transformed the mainstem river and adjacent mountainsides. Forests were logged, streams diverted, canals built, and hillslopes washed into valleys below to be sorted. From the valleys, the sediment moved into the streams and rivers. In the early 1900s, hydraulic and sluice/rocker box mining were replaced with river dredge mining (Bailey 2008, Krause et al. 2010). River dredges worked 24 hours a day for over half a century, turning over the valley sediments, leaving the fine sediments at the bottom and placing coarser sediments on top. These activities severely affected floodplain topography and sediment yields, and changed channel characteristics through the release of large quantities of sediment from the surrounding hillsides into the channel (Bailey 2008, Krause et al. 2010). No quantitative information about the mainstem river morphology or riparian vegetation prior to 1900 exists. Therefore, the geomorphic character and the associated aquatic/riparian habitat prior to European settlement of the Trinity River is unknown. However, it is known that the arrival of miners transformed the watershed, affecting sediment availability, sources, supply, and routing. Photographs from the early 1900s taken upstream of Trinity Dam show conifers intermixed with riparian woody plants on the floodplain and deciduous vegetation along the active channel margin (Fiori and Martin 2011).

After World War II, agricultural needs and growing metropolitan populations increased demand for a reliable source of water and power. The United States Bureau of Reclamation (USBR) conceived and built the Central Valley Project (CVP). The Trinity River Division (TRD) is one component of the CVP and takes advantage of reliable annual snowmelt runoff in the Trinity River watershed. The TRD includes the Trinity Dam and associated Claire Engle Lake, as well as Lewiston Dam, Lewiston Lake, Carr Tunnel, Whiskeytown Dam, Whiskeytown Lake, and the Keswick Reservoir. Trinity River water is diverted into the Sacramento River basin via the Carr Tunnel at Lewiston Dam and ultimately released from Keswick Dam into the Sacramento River. After TRD completion in 1964, about two-thirds of the annual runoff was diverted from Trinity Lake and released into the Sacramento River, reducing the overall volume of water stored and released into the Trinity River below Lewiston Lake.

Construction of the TRD led to decades of reduced streamflow that contributed to further degradation of mainstem Trinity River aquatic and riparian habitats. Riparian vegetation was able to grow along the constant low flow channel margin unchecked by natural winter floods or prolonged snowmelt runoff floods. Sediment from upper portions of the watershed was prevented by the dams from routing downstream, leading to channel incision and narrowing, and loss of salmonid spawning habitat. By 1980, approximately 80–90% of salmonid habitat was lost (USFWS 1980). Moderate flow increases, and congressional actions aimed at improving salmonid habitat, ultimately led to the *Trinity River Flow Evaluation Final Report* (TRFE), which was tasked with providing flow recommendations to the Secretary of the Interior to improve Trinity River fishery resources (USFWS and HVT 1999). The TRFE advocated a multidisciplinary approach and put forth several hypotheses based on the best available science at the time.

A Secretarial Record of Decision (ROD) in 2000 adopted the recommendations in the TRFE and established the Trinity River Restoration Program (TRRP; DOI 2000). The TRRP has been actively implementing restoration actions, including ROD-dictated flows, in the Restoration Reach since 2005. A substantial body of monitoring data has been accrued during the 14 years of restoration, yet much of the information has been reported annually without full consideration of results from other years. Additionally, as more is learned through the process and results of restoration design and implementation, there has been interest from Program partners to evaluate the need for continued TRFE monitoring of vegetation along the river’s edge, given streamflow and annual coarse sediment additions.

2 GOALS AND OBJECTIVES

The goals of this riparian encroachment synthesis report are to summarize past and current riparian encroachment trends and synthesize possible limiting mechanisms in a single document. The intent is to include all Trinity River-related riparian encroachment information so that the full scope of encroachment dynamics and implications for management can be considered. Specific objectives include:

1. Summarize pre- and post-TRD streamflow, and channel and vegetation characteristics, and discuss how pre-TRD conditions inhibited riparian vegetation along the low flow channel margin;
2. Review and summarize riparian vegetation relationships to channel behavior and processes, and identify potential ecological effects associated with vegetation encroachment;
3. Summarize key studies related to riparian vegetation encroachment and channel processes that led to recommendations, management objectives, and actions included in the TRFE;
4. Describe the TRFE restoration strategy, and the Record of Decision (ROD) hydrographs and related objectives;
5. Assess past trends and evaluate the current and future risk of detrimental riparian encroachment;
6. Assess competing encroachment hypotheses and use existing data to identify which hypothesis is supported and which should be rejected; and
7. Develop a recommendation as to whether riparian vegetation encroachment-related objectives should be maintained, revised, or discontinued, thereby identifying future encroachment risk and monitoring requirements based on the outcome of the synthesis.

3 DEFINITIONS

Before delving into the vegetation encroachment synthesis, it is important to define several terms that will be used throughout the report. The definitions in the sections that follow provide context for the underlying hypotheses in the TRFE and highlight areas where there may be scientific disagreement between Program partners.

3.1 Alluvial River and Associated Terms

An alluvial river in the context of this synthesis report is defined as a river that has the potential to rework its channel bed and banks from alluvium transported and deposited by the river under the current flow regime. Alluvial rivers can often arrange themselves in a predictable pattern based on confinement, discharge, slope, sediment supply, and sediment size. In between the broader valleys, the river may pass through reaches where valley walls confine the channel and bedrock provides grade control to the channel; these are semi-alluvial reaches. A semi-alluvial reach is defined as having a limited ability to rework the channel bed and banks, but alluvial features can form within the bedrock constraints.

The Trinity River best fits the definition of a semi-alluvial river. Depositional features are often found as forced bars or occur within the hydraulic shadows of large obstructions. Channel migration and river slope are generally limited by bedrock or the valley walls. In some reaches (i.e., bedrock reaches), bedrock may entirely confine the river and the river cannot rework its channel bed or riverbanks at all. In alluvial portions of the Trinity River, point bars may form at locations of flow separation or on the inside of a bend or curve in the river channel. Helical and divergent flows erode the outside bank and deposit sediment on the inside bank (Dietrich 1987, Nanson and Croke 1992). Flume experiments have shown that formation of point bars is primarily caused by sediment deposition opposite of an eroding bank, allowing the bar to aggrade on the inside edge and causing channel migration (van de Lageweg et al. 2014). Helical flows and point bar formation sort the sediment, creating the deposition pattern of coarser sediments at the head of the bar and finer sediments at the downstream end and along the inside of the bar (van de Lageweg et al. 2014, Chenliang et al. 2016).

Sediment berms (or levees) may naturally form along the margins of unconfined rivers (Russel 1898). When flows spill onto the surrounding floodplain, the coarse fraction of the load is deposited proximal to the channel due to a rapid reduction of velocity that over time builds a mound-like deposit (berm) between the river and its floodplain. Sediment deposited along the channel margin during floods promotes plant establishment as deposits grow deeper and finer. Establishing woody plants create hydraulic roughness, which slows water velocities and induces deposition of fine sediment transported either as bedload (coarse and fine sand) or in suspension (fine sand and silt). Establishing plants may subsequently promote further deposition that forms higher and larger berms over time (Gleason et al. 1979, Sear 1995). Plants that colonize exposed portions of bar surfaces and banks can similarly promote berm formation in those locations, causing channel confinement and narrowing. Even in the absence of plants, sediment deposition can create berms on the downstream edges of meander bends and channel margins (Petts 1984, Bathurst et al. 2002, van de Lageweg et al. 2014). Flume studies have shown that plants can influence channel migration (Tal et al. 2003, Braudrick et al. 2009, Tal and Paola 2010) and have also shown that bank erosion on the outside of meander bends is a primary factor in causing bar formation and additional migration (van de Lageweg et al. 2014). Vegetated or not, berms confine the channel and cause elevated velocities within the central portion of the river and poor salmonid rearing habitat at higher flows (Hampton et al. 1997).

River channel pattern and morphology vary depending on valley confinement and slope, sediment size, and hydrology (Leopold and Wolman 1957, Schumm 1963, Leopold et al. 1964, Schumm 1985, Nanson and Croke 1992, Knighton 1998, Beechie et al. 2006, Eaton et al. 2010, Buffington and Montgomery 2013). The role of establishing vegetation along the channel margin also varies with channel pattern and morphology. For this synthesis report, two broad channel patterns are defined and discussed: multi-thread and single-thread, of which there are several forms within these two broad types (Leopold and Wolman 1957, Knighton 1998, Beechie et al. 2006, HVT et al. 2011, Shea 2013).

The term multi-thread river has been variously applied and here we follow the definitions used by Gaeuman et al. (2016): anabranching has two to four channels and braided has four or more channels. Multi-thread rivers are always alluvial. Multi-thread rivers are the products of high stream power, high sediment supply and highly erodible banks. Typically, braided rivers are not vegetated or are sparsely vegetated and are unstable, continuously changing shape as they migrate over previously built floodplains. Unvegetated braided riverbanks consist of sediments with little or no cohesion.

As vegetation colonizes, establishes, and matures, bank strength increases, and a braided channel pattern may become an anabranching channel pattern with vegetated islands. Anabranching channel patterns are not necessarily the direct evolutionary outcome of a braided channel (Jansen and Nanson 2004). Before human land management activities (e.g., instream wood removal, deforestation, floodplain conversion), many rivers were anabranching (Montgomery et al. 2003, Jansen and Nanson 2004). Large wood obstructions, high sediment loads, vegetation, and sediment deposition on the lee side of in-channel obstructions led to island formation and an anabranching channel pattern. Anabranching channels are vegetated and have more cohesive banks, which are more stable than braided channels. Anabranching channels can transport high sediment volumes while maintaining channel networks and convey sediment more efficiently (faster transport rate per unit stream power) relative to comparable single-threaded channels at near bankfull flow (Jansen and Nanson 2003). Vegetation colonization of the channel margin increases bank strength and can be a positive process that leads to a self-maintaining channel morphology, with islands of mature vegetation around which multiple channels flow (Jansen and Nanson 2003). However, plant roots contribute to bank cohesion, and as they become denser, bank erosion and lateral migration rates decrease (Beeson and Doyle 1995). A higher density of vegetation along the channel margins often leads to a reduction in the number of channels, a deepening of the remaining channels, and steeper streambanks (Gran and Paola 2001). Therefore, in rivers that tend to be anabranching, the growth of moderately dense vegetation along the channel margin could be considered a normal attribute of aquatic habitat. When the width to depth ratio becomes too high, all but one channel are cut off and an anabranching channel becomes a single-thread channel.

An anabranching channel pattern is more likely to become a single-thread channel pattern as slope and/or sediment supply decreases and bank strength increases (Eaton et al. 2010). A single-thread river flows within one flow path (i.e., single channel). It may be straight, meandering, or migrating. Single-thread rivers may or may not be alluvial. Single-thread rivers are common in locations of bedrock or valley wall confinement but also occur in unconfined settings. Vegetation and bank strength in an unconfined alluvial single-thread channel setting can affect channel morphology and the rate of channel change and adjustment.

The influence of vegetation growing along a single-thread river that meanders, avulses, or migrates within one flow path (i.e., channel) is different from a braided or anabranching channel. The more vegetation that establishes on riverbanks, the more stable and less dynamic a river becomes. Vegetation establishing on the inside of a meander bend may be a contributing factor in lateral channel migration (Braudrick et al. 2009). However, migration may be inhibited if woody plant establishment is not restricted to one bank or frequently reduced through flood scour. The influence of establishing vegetation on channel migration and channel morphology may change if naturally occurring river flow fluctuations are reduced significantly. Flow regulation reduces flood disturbance and sediment transport, subsequently causing increases in vegetation abundance and bank strength, and inducing changes in vegetation types and location. A single-thread river that avulses or migrates will be affected by continuous bands of vegetation that cannot be eroded. Vegetation that cannot be eroded may inhibit the ability of the channel to migrate or change. The loss of bank erosion and migration leads to morphological changes to the channel that alter the aquatic and terrestrial habitat functions that were available when the river was able to migrate.

The pre-European geomorphic character and channel pattern of the Trinity River and riparian areas are unknown from historical accounts or early photographs due to the extent of anthropogenic disturbances associated with land use practices before the TRD. Presumably, the channel was single-threaded in many locations with shallow bedrock or valley confinement. However, there were some unconfined locations where the channel was likely anabranching, supported by a high sediment and large wood supply, channel slope and patches of vegetation. The onset of placer gold mining of surface deposits removed vegetation and large wood, rearranged the valley floor, and turned over the valley floor sediment deposits. Any evidence of anabranching channel networks on the Trinity River was erased before photographs or written accounts could describe it.

Beyond the simplified channel meander model presented in the TRFE and the empirical data described in this report, identifying which channel pattern the Trinity River may tend towards based on current sediment-size distribution, slope, confinement, and hydrology provides insight as to how vegetation growing along the channel margin could influence proposed and existing channel patterns (HVT et al. 2011). Design and management goals focus on creating more aquatic habitat, and an increase in the number of wetted channels would equate to more available aquatic habitat. Increasing aquatic habitat is a primary Program goal due to the influence on fish production (Beechie et al. 2012). The creation of anabranching channel networks wherever possible could represent an important opportunity to meet Program goals through an increase of juvenile salmonid habitat. Unfortunately, increases in bank cohesion due to heavily vegetated channels combined with reduced large wood supply, flood peaks, and sediment supply do not support the formation or maintenance of an anabranching channel in all but a few locations downstream of TRD (HVT et al. 2011, Buffington et al. 2014, Gaeuman et al. 2016).

3.1.1 Anticipated Channel Pattern

Anticipated channel pattern analyses have been conducted four times since 2010 (HVT et al. 2011, Beechie et al. 2012, Buffington et al. 2014, Gaeuman et al. 2016). Initial analyses occurred at a broader scale, with the intent to describe the existing physical channel pattern, possible future channel patterns resulting from restoration, and provide guidelines for restoration designs to achieve the desired future channel pattern (HVT et al. 2011). Subsequent analyses attempted to define the channel pattern predictions at a finer scale. Changes to physical rehabilitation designs, which shifted from a focus on restoration of processes to a focus on restoration of form, created the need to reevaluate the probable channel patterns expected to occur within the Restoration Reach. Ultimately, each analysis yielded similar results, despite methodological differences.

The Channel Design Guide (CDG; HVT et al. 2011) predicted channel pattern in the Restoration Reach using physical characteristics, equations, and related channel pattern classifications presented in Eaton et al. (2010). The CDG predicted channel pattern in five physiographic reaches and estimated the dominant discharge and the median channel bed particle size (D_{50}) particle size for each reach. The D_{50} particle sizes used in the analysis ranged from 47 mm to 97 mm, depending on river location (i.e., reach). Riverbank cohesion was estimated two ways: (1) coarse sediment without vegetation and (2) coarse sediment with established tree and shrubs. Under unvegetated conditions, anabranching channels were the predicted channel pattern based on reach-averaged slope in the downstream reach of river between Canyon Creek and the North Fork of the Trinity (i.e., the North Fork Reach in the CDG). A single-thread channel was predicted for the four upstream reaches under unvegetated conditions. When the vegetated bank cohesion is included, a single-thread channel is the predicted channel pattern for all five reaches. The CDG recognized that channel pattern predictions were based on slope averaged for the entire reach, and that localized conditions could support an anabranching pattern in some locations.

In 2012, Beechie et al. predicted channel pattern using physical characteristics of the Trinity River and empirically derived relationships from the Pacific Northwest (Beechie et al. 2012). Using empirically derived relationships, 37 reaches were analyzed and then grouped using cluster analysis. The predicted mainstem channel pattern was found to have predominantly single-thread tendencies, but there were some unconfined reaches where an anabranching channel pattern could develop.

In 2013, Shea discussed multi-thread channels in relation to the Trinity River physiography and post-ROD flow and sediment regimes, specifically in relation to channel rehabilitation designs. He concluded that while the average channel pattern in the Restoration Reach is single-thread, localized exogenous conditions (e.g., bedrock, large wood debris jams, vegetation, or anthropogenic structures) may exist that support formation and persistence of multi-thread channels, specifically anabranching channels. Channel rehabilitation designs should factor in local conditions when selecting a channel pattern for restoration; failure to do so could result in unsuccessful rehabilitation projects that do not maintain design conditions.

The Science Advisory Board (SAB) expanded on the initial analysis conducted in the CDG (Buffington et al. 2014). The expanded analysis compared local channel slopes to threshold values for anabranching under pre- and post-TRD flows. The expanded predictive analysis indicated that there are more locations than identified in the CDG in four of the five physiographic reaches where an anabranching channel pattern could develop and persist. As in the CDG, the North Fork reach was predicted to develop an anabranching channel in this analysis. Other locations where an anabranching channel could develop and persist were identified in the Lewiston, Limekiln, and

Douglas City reaches. The reach from Dutch Creek to Canyon Creek (i.e., the Junction City Reach) was the only reach where an anabranching channel was not likely to develop. The Phase 1 SAB review (Buffington et al. 2014) presented similar findings as Shea (2013).

The River Corridor Management Plan (RCMP) is the most recent effort to predict channel pattern (Gaeuman et al. 2016). The RCMP pointed out the channel pattern analyses are sensitive to discharge and applied a range of dominant discharges that were larger than those considered in previous analyses. The Eaton et al. (2010) equations were applied in the RCMP using a generalized D_{50} size of 50 mm and the 8,500 cfs and 11,000 cfs discharges as the “dominant” discharge, or Q_{bf}. It was also assumed that the banks were unvegetated (which they recognized as being false). The resultant discriminant analysis reinforced previous analyses: the predicted channel pattern in the Restoration Reach is predominantly single-thread channel. When the 11,000 cfs discharge was applied, there were a couple of reaches that might exhibit anabranching characteristics. However, despite using criteria that would most liberally identify physical characteristics leading to an anabranching channel, the predicted channel pattern was still predominantly single-threaded in most reaches. If a larger D_{50} size and bank cohesion were considered, it is possible the analysis would lead to a predominantly single-thread channel in all reaches.

Each time the channel pattern analysis was conducted, the measures to which the equations were sensitive (e.g., slope, particle size, and discharge) were adjusted to ensure that the locations where an anabranching channel might occur would not be underestimated. Restoring a multi-thread channel has great appeal because it immediately increases channel complexity, instream habitat, and colonization surfaces. However, the SAB concluded that, “Of 37 reaches, 31 would maintain a single-thread channel, four would tend to transition from a single-thread channel to island braided during Wet years, and two would already be island braided during Normal water years” (Buffington et al. 2014). The anticipated channel pattern has important implications for how riparian vegetation is viewed, as discussed in Section 3.3.

3.2 Riparian Corridor

Riparian areas have been traditionally defined as the zone of direct interaction between the terrestrial and aquatic system(s) or by the dominant plant species present (Warner and Hendrix 1984, Anderson 1987, Gregory et al. 1991, USFWS 1998, BLM 1999, Ilhardt et al. 2000, USFS 2000, Ffolliott et al. 2004, Naiman et al. 2005 2010, USDA-NRCS 2005). Riparian areas are also places where surface and subsurface hydrology connect aquatic areas with adjacent uplands (NRC Brinson et al. 2002, 2002). Riparian areas include wetlands, aquatic support areas, and portions of uplands that significantly influence the conditions or processes of aquatic areas (SWRCB 2012). Riparian areas occur as a corridor along a river or stream and are laterally constrained by valley walls, bedrock, and terraces. The riparian corridor also includes those areas where the channel once occupied and might occupy again in the future, and can be distinguished by gradients in biophysical conditions, ecological processes, and biota. A clearly defined riparian corridor is problematic on the Trinity River due to the degree and extent of anthropogenic disturbance from mining and hydrologic impairment.

3.2.1 Vegetation Effect on Stream Physical Processes

Within the riparian corridor, the environmental factors leading to successful woody plant recruitment are complex and often related (e.g., soil moisture and water surface elevation directly relate to each other). Successful initiation of many riparian woody plants relies on the annual cycle of late spring snowmelt floods and the timing and rate of receding water (Bradley and Smith 1986, Scott et al. 1993). However, after the first year, many related factors can influence successful recruitment, although the degree of influence for each factor may not be well-defined (e.g., bed scour and deposition, substrate quality, and soil moisture availability). The primary factor influencing successful plant initiation is the pattern of streamflow during and after seed dispersal, regardless of the species. Streamflows that recede too quickly can kill a young plant whose roots cannot grow fast enough to keep up with the recession (McBride et al. 1988, Mahoney and Rood 1992, Segelquist et al. 1993). Flows can occur in a pattern that will allow one species to successfully recruit, but not another species, simply because flows are not timed to satisfy the needs of that particular species' seed dispersal period. The relationship between seed dispersal, and flow magnitude and timing is the primary factor that drives vegetation patterns along the mainstem Trinity River, with channel form and substrate quality affecting vegetation to a lesser extent (Bair 1998, 2001b).

Scour and deposition caused by intermittent floods create and destroy the locations where woody riparian species germinate, establish, and mature (McBride and Strahan 1984c, Hupp and Osterkamp 1985, Bradley and Smith 1986, Auble et al. 1994, Kondolf and Wilcock 1996, Scott et al. 1996, Scott et al. 1997, Gordon and Meentemeyer 2006). Flood deposition may create gravel bars and deposit fines on floodplains where plants may germinate and establish. Depending on magnitude, floods may scour gravel bars and floodplains, modifying or eliminating locations of successful woody plant establishment. The right combination of substrate texture, groundwater proximity, inter- and intra-annual flow patterns, and individual woody plant seed dispersal periods are required for a woody plant to establish and grow to maturity. This patchwork of scour and successful establishment results in a structurally diverse and species-rich riparian community.

Large infrequent floods may widen the channel and clear vegetation from portions of the channel margins. In years with lower magnitude floods, vegetation may be able to establish along the channel margin again. Sediment accumulates in the vegetation and the channel narrows. When a large infrequent flood returns, vegetation is scoured, and the channel may widen and/or migrate. It is the push and pull of large infrequent floods and years with moderate floods that create the physical and ecological variability and complexity that is intrinsic to "river health."

In migrating rivers, vegetation along the channel margin plays a key role in facilitating channel migration. Mobile alluvial sediment deposits will be annually colonized with herbaceous and woody plants. Frequent winter and spring flood flows will scour away plants that have grown too far into the low water channel. When flows are insufficient to mobilize the channel margin sediments, vegetation can establish and mature. After plants establish, they may trap sand and small gravel, forming natural sediment levees or berms. Increasing confinement along the channel margins where sediment may be deposited increases shear stress and directs turbulent flow to the opposite bank, causing migration if the opposing bank is high (prone to slumping) or poorly defended by vegetation.

River flow fluctuations (hourly, daily, weekly, monthly, and annually) are the stochastic basis of sediment, water, and vegetation interactions and are a primary source of variability within the river continuum (Junk et al. 1989, Scott et al. 1997, Vesipa et al. 2017, You and Liu 2017). Reductions in flow, either through long-term drought or flow diversion, reduce river flow fluctuations and associated flow timing, magnitude, frequency, duration, and rate of change on multiple times scales (Ligon et al. 1995). Flow regulation reduces river flow fluctuations, which may interrupt sediment routing and transport, and may also reduce overall water yield within the watershed. Regardless of the magnitude of hydrologic impairment on river flow fluctuations, an increase in vegetation is often documented (Ritter 1968, Pelzman 1973, McBride and Strahan 1984a, O'Brien and Currier 1987, Friedman et al. 1996, Scott et al. 1996, Scott et al. 1997, Friedman et al. 1998, Johnson 1998, Merritt and Cooper 2000, Shafroth et al. 2002, Cooper et al. 2003, Birken and Cooper 2006, Gordon and Meentemeyer 2006, DeWine and Cooper 2007, Merritt et al. 2010, Bejarano and Sordo-Ward 2011, Comiti et al. 2011, Casado et al. 2016, Kui et al. 2016).

3.3 Encroachment

Riparian vegetation along the channel margins of a river that migrates or frequently adjusts provides a natural and valuable component to fish habitat. Encroachment refers to vegetation establishment along the edges of the summer and fall low flow stream channel. In unregulated rivers, frequent high magnitude floods and sediment supply and transport mechanically damage or remove establishing vegetation within the low flow channel, or cause the channel to laterally migrate, or locally adjust inhibiting the effect of encroaching vegetation. The vegetation encroachment process often becomes detrimental on regulated rivers because of reduced flood peaks and coarse sediment supply flows (Figure 2, Figure 3). If the species composition, age, density, and continuousness of the riparian band crosses a threshold where the river can no longer erode the channel banks and/or scour established vegetation, the risk of channel simplification, riparian berm formation (Section 3.4), and disconnection of the floodplain from the river is greatly increased, potentially inhibiting the effectiveness of the TRRP restoration strategy (TRFE).

Vegetation encroachment studies are most prevalent in semi-arid or arid climates where human water use and infrastructure may conflict with floodway management or environmental needs (i.e., quality and quantity). Many studies focus on changing land management actions and evaluating and addressing the consequences of vegetation encroachment. Environmental changes related to vegetation encroachment along rivers has been documented on every continent except Antarctica (Casado et al. 2016).

Vegetation encroachment may be caused by flow impairment, land use, and/or climate change. Vegetation encroachment occurs when plant establishment progresses toward the low water channel after flow impairment or during an extended drought period. A reduction in high flows reduces flood scour and inundation-induced riparian mortality, which allows riparian vegetation to initiate and survive in channel locations that would normally be scoured by floods. Once plants establish along a stream or river margin, they become relatively difficult to remove (Rowntree and Dollar 1999, Tal et al. 2003) and the channel loses its dynamic ability to rework its bed and banks, thus becoming static and immutable (Thorne et al. 1996).

Vegetation encroachment can be a negative aspect of hydrologic and sediment impairment, and effects associated with vegetation encroachment include channel narrowing, bank stabilization, reductions in wetted edge length, channel bed coarsening, changes in bed form variation, changes in vegetation life form along the wetted channel margin (i.e., location and abundance in grasses, forbs, shrubs, and trees), and changes in food web structure (McBride and Strahan 1984b, Andrews 1986, O'Brien and Currier 1987, Sherrard and Erskine 1991, Benn and Erskine 1994, Johnson et al. 1995, Friedman et al. 1996, Power et al. 1996, Scott et al. 1996, Thorne et al. 1996, Scott et al. 1997, Friedman et al. 1998, Johnson 2000, Merritt and Cooper 2000, Grams and Schmidt 2002, Shafroth et al. 2002, Cooper et al. 2003, Birken and Cooper 2006, Gordon and Meentemeyer 2006, DeWine and Cooper 2007, Zahar et al. 2008, Magdaleno and Fernandes 2010, Bejarano and Sordo-Ward 2011, Comiti et al. 2011, Pasquale et al. 2014, Casado et al. 2016, Kui et al. 2016, Bohorquez and Del Moral-Erencia 2017b, a, Vesipa et al. 2017). Overall, the environmental changes associated with vegetation encroachment have led to reduced variability in species richness and habitat structure (i.e., functional complexity) where it has been documented (Bejarano et al. 2017, Bejarano et al. 2020). The effects of vegetation encroachment may increase depth and velocity across a range of discharges, reduce flood capacity, and decrease aquatic habitat and riparian area (Andrews 1986, Sherrard and Erskine 1991, Benn and Erskine 1994, Grams and Schmidt 2002, Shafroth et al. 2002, Gordon and Meentemeyer 2006, Zahar et al. 2008, Magdaleno and Fernandes 2010).

Pre-Trinity River Dam (Unregulated)

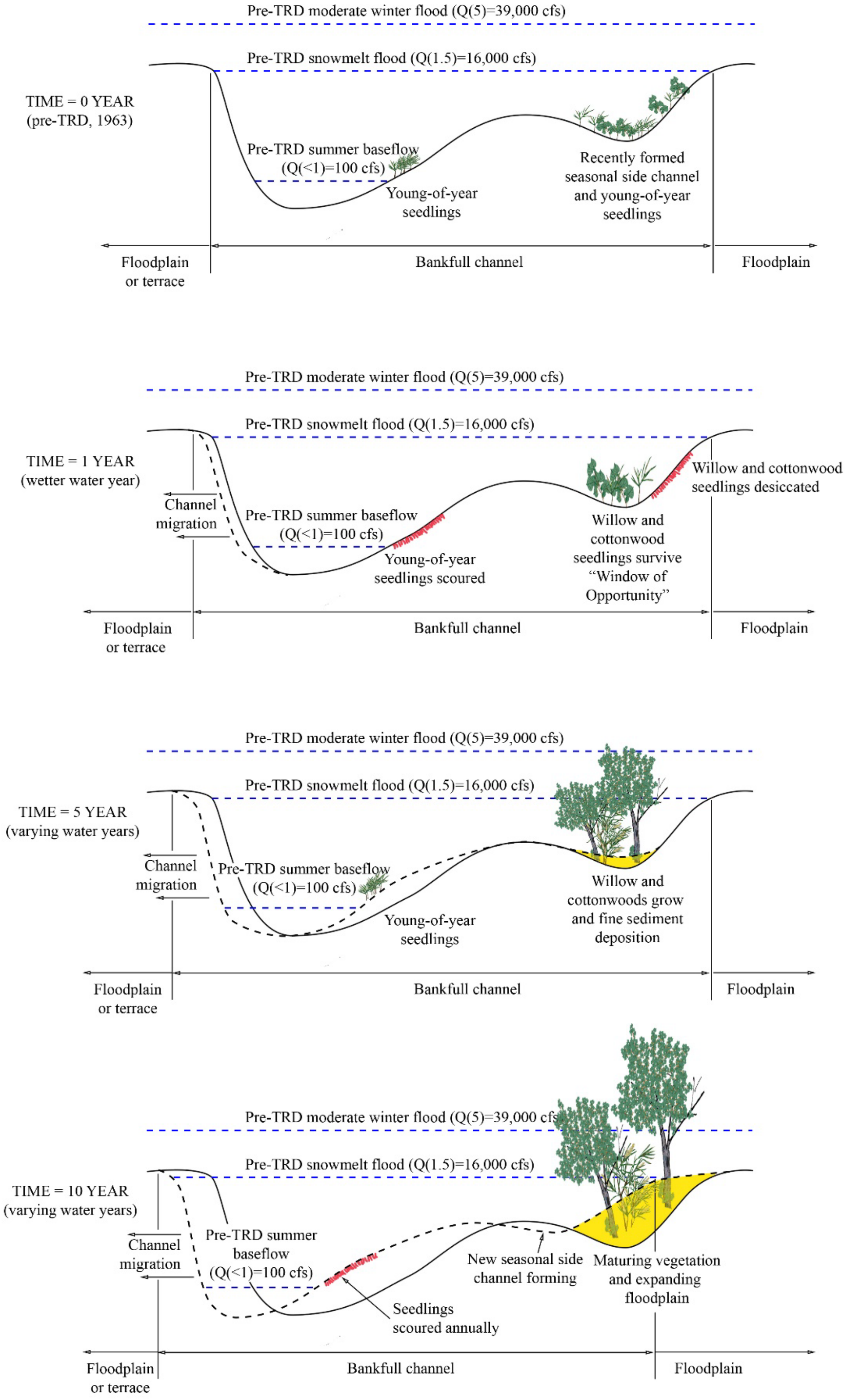


Figure 2. Conceptual model (not to scale) of vegetation dynamics under the unregulated flow regime prior to emplacement of dams and diversions related to the TRD (adapted from Bair 2003).

Post-Trinity River Dam (Regulated)

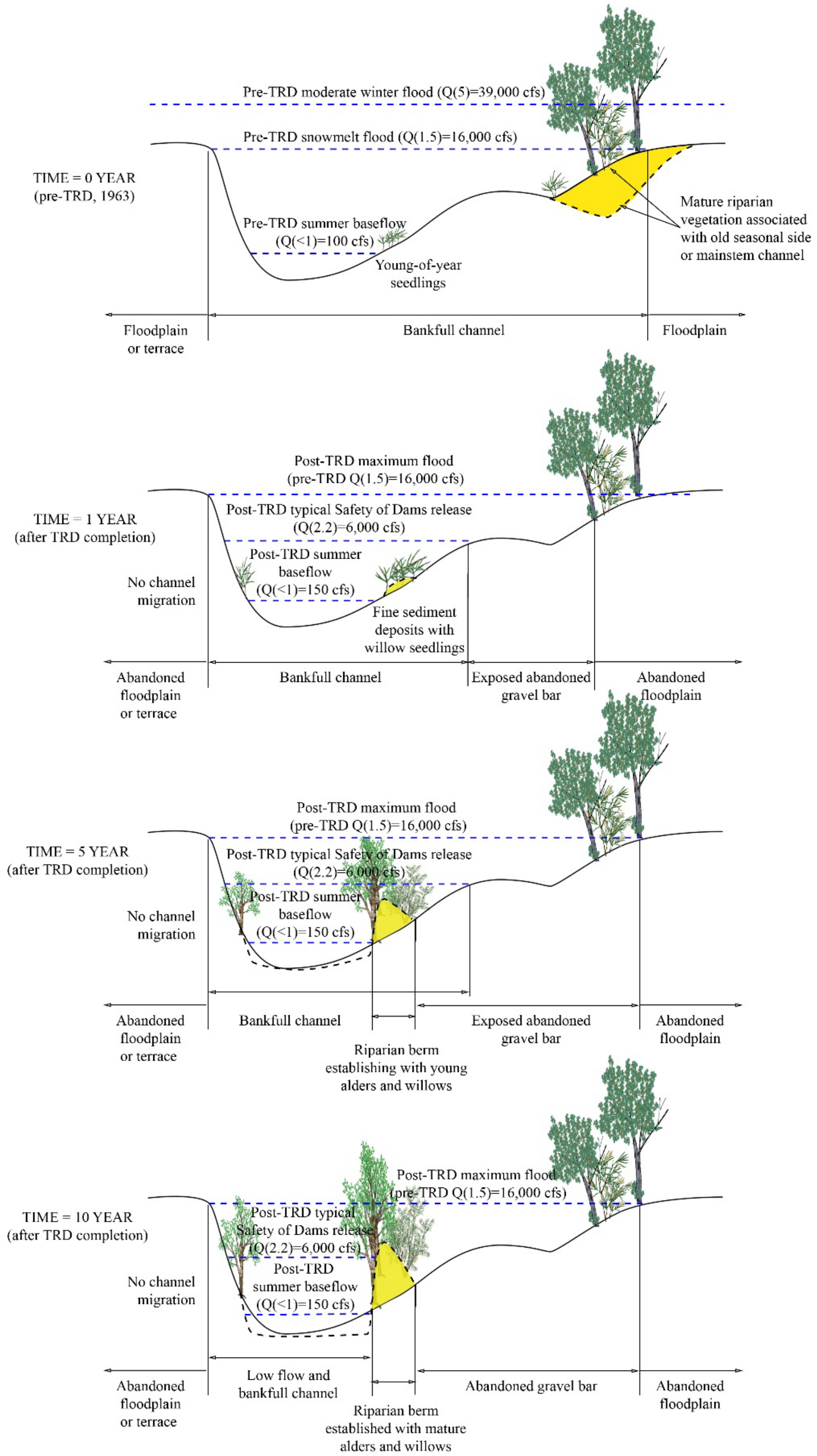


Figure 3. Conceptual model (not to scale) of vegetation encroachment response to reduced flows following emplacement of dams and diversions related to the TRD (adapted from Bair 2003).

Within the Restoration Reach of the Trinity River, vegetation encroachment has been viewed variously as either positive or negative, which has led to significant effort to find a common perspective. The Integrated Assessment Plan (IAP; TRRP and ESSA Technologies 2009) developed and prioritized assessments to guide TRRP restoration actions and improve management uncertainties, including how to address vegetation encroachment. Therefore, a specific definition describing the negative form of vegetation encroachment was developed for the Restoration Reach.

3.3.1 Detrimental Vegetation Encroachment

Detrimental riparian vegetation encroachment occurs on the Trinity River when riparian vegetation, especially clonal willow species (*Salix exigua, Salix melanopsis*), colonize alluvial surfaces (developing bars) within an active channel, and the subsequent pattern of flood flows is incapable of scouring establishing vegetation, causing channel adjustment, avulsion, or migration. If colonizing plants establish, the previously active channel adjusts to be within the bounds of perennial vegetation. Channel adjustments might include channel narrowing and deepening, steeper channel banks, and juvenile salmonid rearing habitat loss. Detrimental encroachment has occurred when establishing vegetation is dense, continuous, and mature enough to:

- Be unable to be physically removed by ROD flow release magnitudes via vertical scour, lateral scour, local scour, toppling, and other mortality mechanisms.
- Initiate a morphologic change to the channel that will eventually be detrimental to fish habitat, including fine sediment deposition and berm building, erosion on the inside edge of the riparian band, simplification of hydraulics in the 450–2,000 cfs inundation zone, and ultimately evolution to a rectangular channel similar to that observed during the post-dam, pre-ROD flow regime (c. 1965–2004). Sediment trapping and berm building within the riparian band reduces depth–velocity combinations that define suitable fish habitat (TRRP and ESSA Technologies 2009).

Encroachment into the active channel is a natural process that can be expected to occur during low-water conditions. However, when encroaching plants like clonal willows are not scoured away by higher flows, they are able to survive and grow larger, with ready access to ample groundwater. Eventually, plants will achieve an age (or size) and density that prevents them from being scoured by higher flows, and this is when encroachment can be detrimental. Once plants have exceeded the size and density encroachment threshold, they are difficult, if not impossible, to remove without channel migration, bank undercutting or mechanical means.

3.4 Riparian Berm

The formation of a dense band of riparian plants along the channel margin has important implications for channel dynamics. Increased hydraulic roughness from vegetation causes fine sediment to deposit within the plants and leads to the formation of a *riparian berm.* This is an extreme form of detrimental riparian encroachment. Not all detrimental encroachment includes a riparian berm. In many location on the Trinity River, riparian berms are a result of flow-induced vegetation encroachment and are geomorphic features that led to changes in location and abundance of grasses, forbs, shrubs, and trees along the wetted channel margin, changes in channel roughness adjacent to the channel, bank stabilization, channel confinement, channel narrowing, reduced bed form variation, reductions in wetted edge length, increases in velocity and depth, and loss of channel side slopes as the channel adjusted into a trapezoidal channel form in a process called channel simplification (Pelzman 1973, Evans 1980, Wilson et al. 1991, M&T 1997, USFWS and HVT 1999, DOI 2000, Young et al. 2006, Curtis and Guerrero 2015, Gaeuman et al. 2016). Once a riparian berm has formed, the channel loses its ability to migrate, causing the channel to become narrower and deeper in cross-sectional shape. The changing channel shape increases sediment transport, causing channel incision and a coarsening of the channel bed. The SAB Phase I review suggested that, in the Restoration Reach, the current flow and sediment regimes are capable of removing a portion of riparian berms in some locations (Buffington et al. 2014); however, the balance of new berms forming in relation to existing berms being scoured is unknown. The acknowledged uncertainties associated with the analysis warrant further study of the effects of restoration flows on riparian berms. Additionally, relationships between riparian berm erosion and the flow magnitude/duration/frequency necessary to cause that erosion are unknown in the Restoration Reach. The mechanical removal of riparian berms during channel rehabilitation is currently the most reliable management tool for these geomorphic features.

4 VEGETATION ENCROACHMENT, CHANNEL SIMPLIFICATION, AND HABITAT LOSS ON THE TRINITY RIVER

Many plants living in the riparian corridor have life history, physiologic, and anatomical adaptations for living in a frequently inundated, high-disturbance environment. Discrete seed dispersal periods, reduced oxygen requirements during dormancy periods, rapid root growth, shallow fibrous roots, the ability to resprout from adventitious buds and fragments, anatomical structures that increase tolerance to prolonged inundation (e.g., aerenchyma in herbaceous plants, and lenticels in woody plants) are examples of riparian plant adaptations. This combination of traits allows riparian plants to quickly respond and adapt to changes in the riparian environment.

Fluvial forces and the landforms that they create drive vegetation patterns in riparian areas (Hupp and Osterkamp 1996, Bendix and Stella 2013). Establishment on higher geomorphic surfaces (e.g., floodplains) is a desired management outcome identified in the TRFE. Establishment near the channel margin can lead to detrimental riparian encroachment in the absence of channel migration and/or scour disturbance. Detrimental riparian encroachment can reduce the ability of the river to rework its banks, leading to channel narrowing and more rectangular channel morphology. Changes in channel morphology and vegetation patterns as a result of the TRD are described in the following sections.

4.1 Hydrology, Channel Pattern, and Vegetation Patterns Prior to the Trinity River Division (TRD)

Before the TRD was completed in 1964, annual streamflows were highly variable throughout the year (Figure 4). Short duration, rainfall-induced, winter storm peaks were coupled with prolonged snowmelt runoff and the associated receding limb. Rainfall freshets could begin in early November. Rain-on-snow events in December typically generated the largest floods on the Trinity River, sometimes more than 70,000 cfs maximum instantaneous flow at Lewiston. Winter baseflows between January and mid-April averaged 2,200 cfs and ranged between 95 cfs up to 34,500 cfs. Snowmelt peaks were smaller than winter rainfall-related peak events, occurring in late April and early May, though timing and peak flow magnitude were variable year to year.

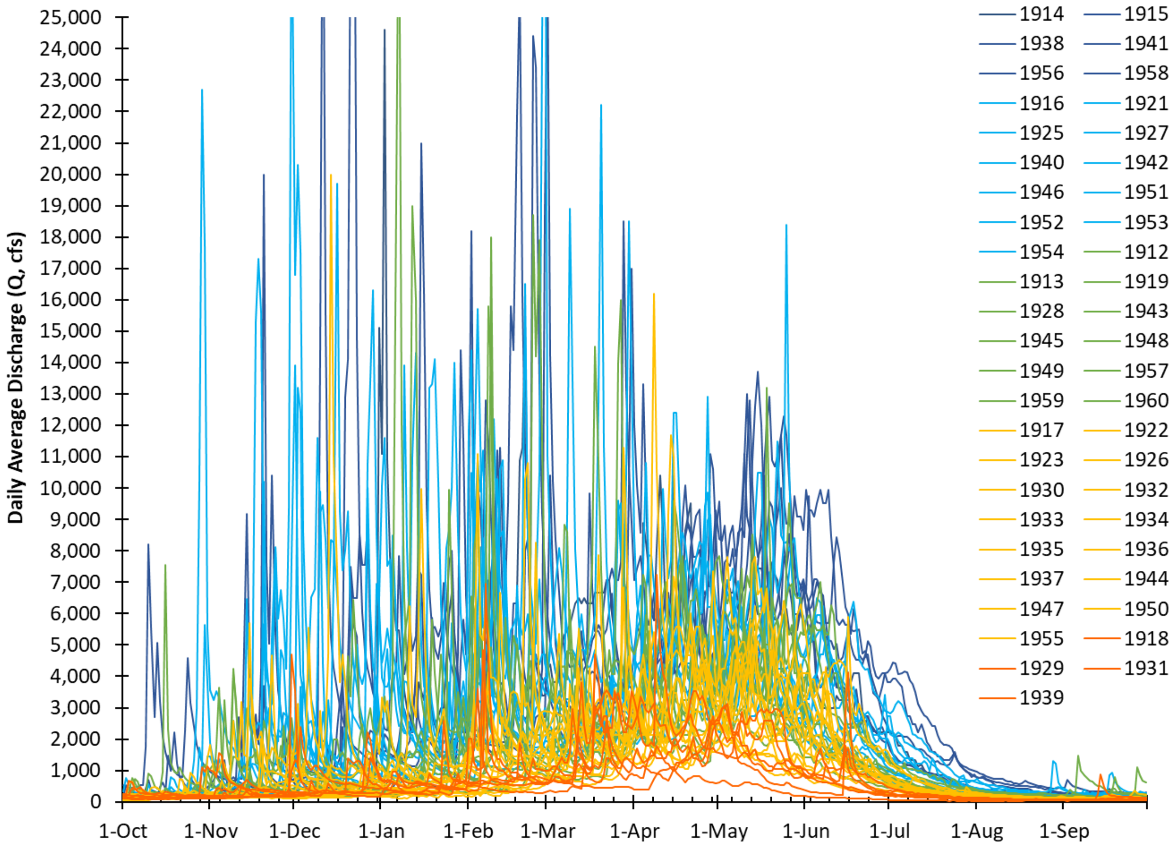


Figure 4. Trinity River at Lewiston unimpaired hydrographs WY 1912–1960. Water years are color coded by type (Extremely Wet = dark blue, Wet = light blue, Normal = green, Dry = Yellow, Critically Dry = Orange).

A prolonged period of streamflow recession followed the annual snowmelt peak (Figure 5). The snowmelt recession could begin in mid-May and could extend through September in wetter years. In drier years, streamflow recession might end in mid-July with summer flows of less than 30 cfs. There were rarely periods of stable flows in any season, and a range of bank elevations were annually inundated for varying lengths of time. In drier years, plants would germinate and establish lower in the channel where they would be more prone to scour, and in wetter years, plants would germinate and establish higher on floodplains, with high-flow scour-induced mortality occurring in the channel.

Trinity River streamflow has been recorded at Lewiston from 1912 to the present. Measured (1912–1960) and computed (1965–1994) unimpaired daily average streamflows were arranged into water years beginning on October 1 and ending September 30 of the following calendar year. An 82-year period of record measured at the USGS Lewiston gage was sorted into water years (WY) and the annual water yield for each water year was calculated by summing the daily average streamflow for the water year. The annual water yield was sorted from largest to smallest volume and plotted as a cumulative distribution curve (Figure 6). Five water year classes were defined at locations where annual water yields decreased or the curve was asymptotic. The annual exceedance probabilities (*p*) of 0.88, 0.60, 0.40, 0.12 defined the upper and lower boundaries for each of the five water year types (M&T 1997, USFWS and HVT 1999). Water year types were Extremely Wet, Wet, Normal, Dry, and Critically Dry years.

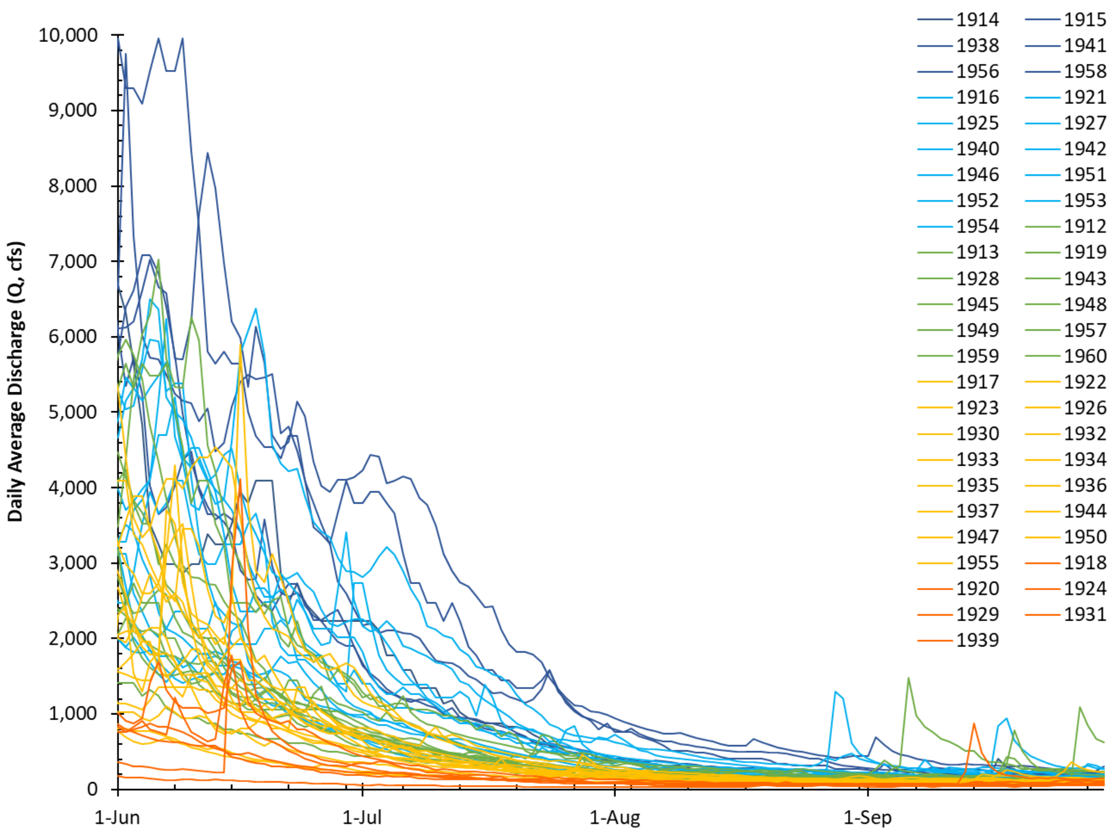


Figure 5. Trinity River at Lewiston unimpaired hydrographs 1912–1960, showing June to September receding limb and summer baseflow period. Water years are color coded by type (Extremely Wet = dark blue, Wet = light blue, Normal = green, Dry = Yellow, Critically Dry = Orange).

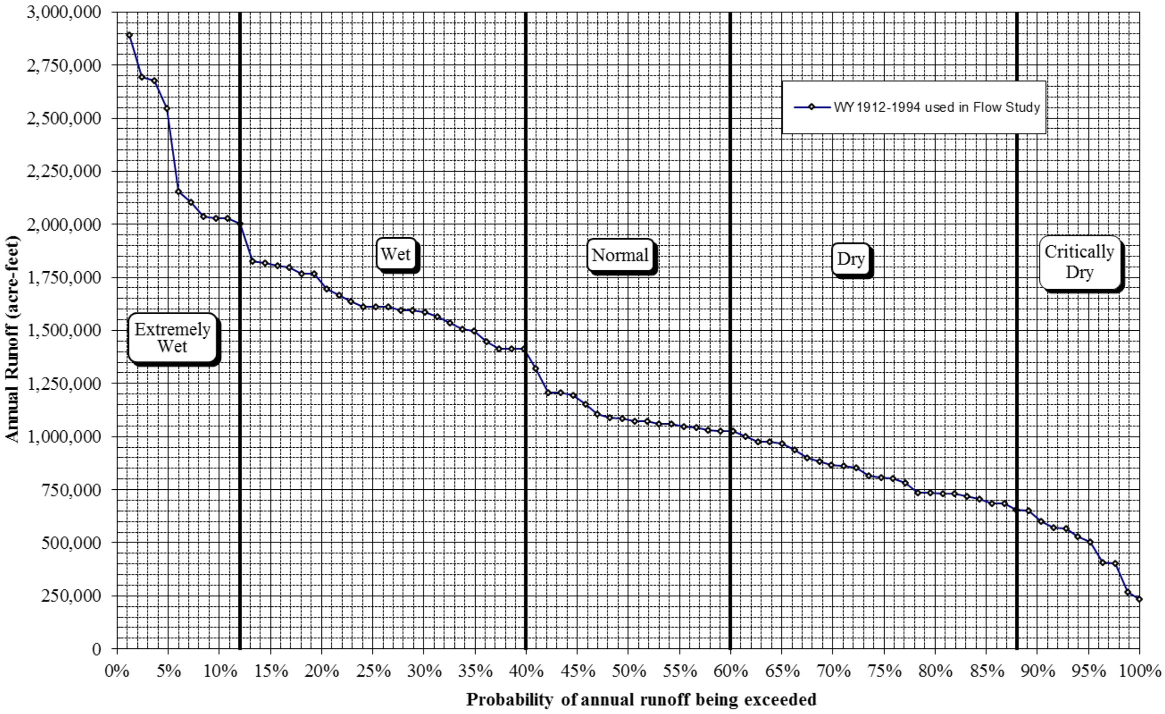


Figure 6. TRFE Water Year Classification based on WY 1912–1994 unimpaired annual runoff (USFWS and HVT 1999).

Climate is a factor in year-to-year water availability and volume, and subsequently streamflow variation. Annual water yields characterize the water volume within each year and vary from year to year because of the relationship between climate, watershed size, and streamflow. Riparian vegetation recruitment typically occurs in wetter years, with drier years typically producing desiccation and plant mortality. In wetter years, summer baseflows were reached later (Figure 5), and water temperatures likely remained lower throughout the summer compared with drier years. Different water year classes can occur in a series of wet years and dry years, a phenomenon known as persistence (Dunne and Leopold 1978). The frequency and persistence of a series of dry and wet years greatly influences the complexity and age class structure within the riparian corridor.

A water year classification based on annual water yields provides a useful framework for evaluating the effects of persistence on plants growing within the riparian corridor. In Normal and wetter years, streamflow patterns promoted channel migration, pushed over mature trees, scoured channel margins during winter floods, facilitated riparian woody plant recruitment on floodplains in the spring, and facilitated riparian woody plant recruitment on lateral and medial gravels in the summer. In drier, below Normal water years, streamflow patterns promoted desiccation mortality of seedlings and young woody plants on floodplains that led to patchy riparian vegetation and facilitated riparian woody plant recruitment on lateral and medial gravels in the summer. Along with flood peaks and annual late season low flows, the natural variability in water year classes was key in inhibiting vegetation encroachment before the TRD was built. Long drought periods were rare, and there are only four occurrences in the period of record where three or more consecutive Dry years occurred (Figure 7). A period of below Normal years would be followed by a period of above Normal years. It was the cycle of wet and dry years (and associated recruitment and mortality agents) that established a sparse variable vegetation along the channel and inhibited the detrimental effects of encroaching plants after a prolonged drought period.

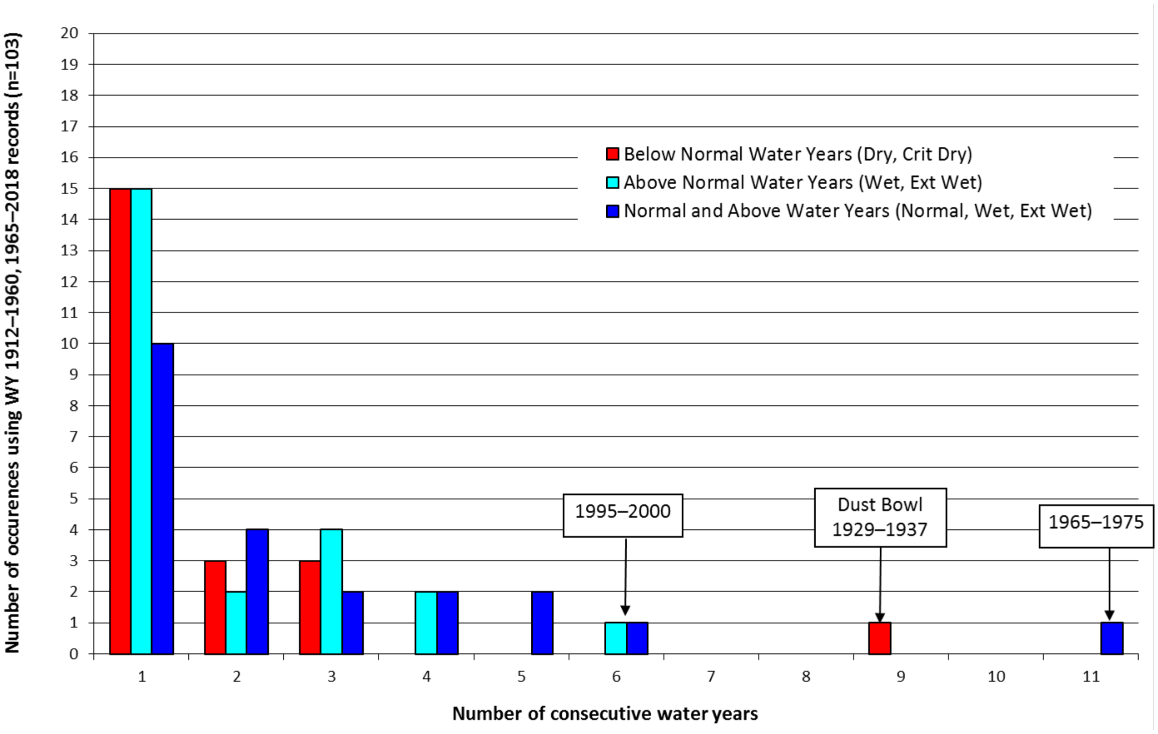


Figure 7. Consecutive water year classes for below Normal, Normal and above, and above Normal water year types from WY 1912–2018.

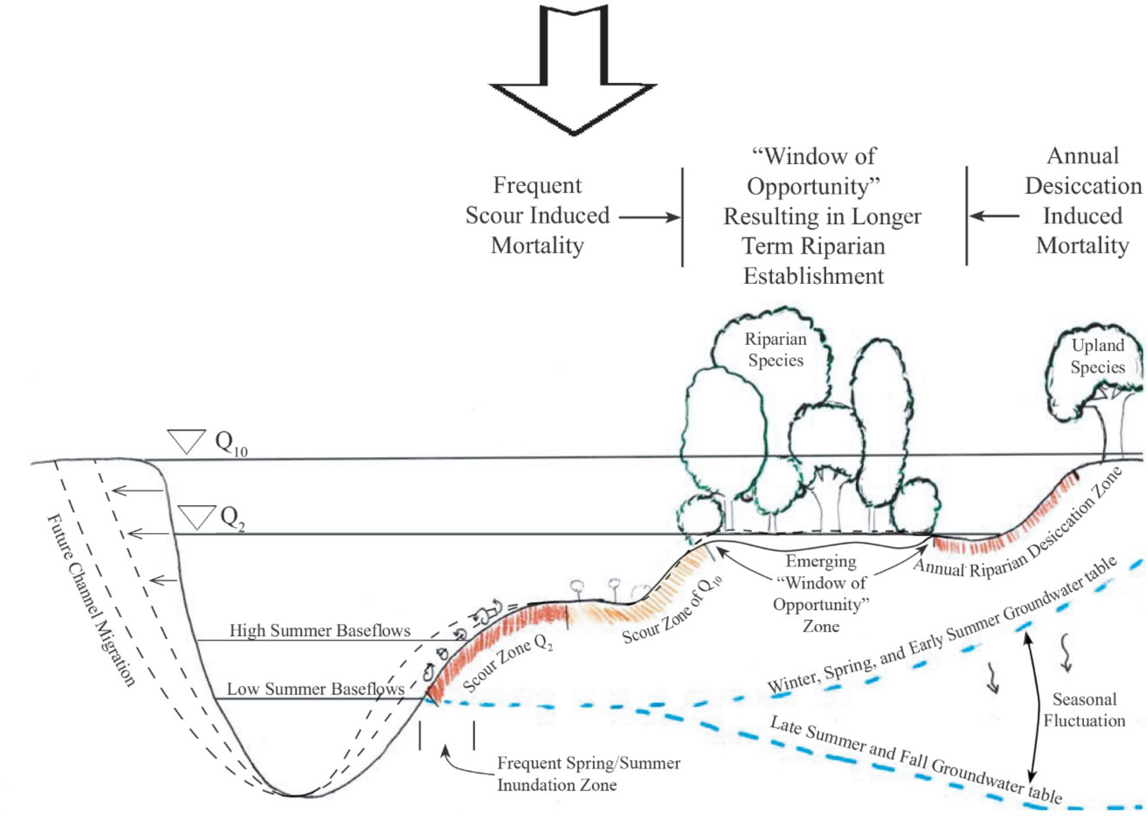
Streamflow variability during a plant's seed dispersal period affects where plant colonization and establishment occur. When a seed falls on a surface, germinates, and begins growth, it is prone to desiccation effects and/or scour depending on where the seed lands relative to the channel and existing soil moisture. There is a balance between annual desiccation, large channel-width-maintaining floods, and those smaller floods that annually scour the channel margin. The upper limit of seedling establishment is a function of desiccation; the lower limit is a function of bed scour (Figure 8) defining a small "window of opportunity" where successful seedling establishment can occur (Kondolf and Wilcock 1996). In the Restoration Reach, a wide range in streamflow magnitudes, variable timing and frequency, duration, and rates of change between peaks and lower flows during the pre-TRD period meant that establishing vegetation could only rarely colonize upper bank positions on floodplains and upper bar surfaces, and that in drier years, the only locations where seeds could germinate and establish were along the low water edge where they would be subsequently vulnerable to future scour mortality. Large channel-width-maintaining floods were important in creating seedbeds on floodplains and seasonally inundated side channels, and in facilitating seedling germination of some woody plant species higher away from the low water edge where they would be less susceptible to bed scour (Figure 8). Seedlings that germinated higher on the bank during these years of channel-width-maintaining floods (i.e., 10-year flood and higher, approximately 7,155 cfs at Lewiston in the Restoration Reach) ran the risk of desiccation on the receding limb of the snowmelt recession during the year they germinated. However, channel-width-maintaining floods occurred infrequently ($> Q_{10}$) during Normal and wetter years, and seedlings annually regenerated within the 10-year flood bank zone. Common floods (i.e., $Q_{1.5}$ to $Q_{2.2}$) would have scoured seedlings growing along the low water margin annually or biannually, cropping the lower limit of seedling establishment.

INITIATION AND ESTABLISHMENT PROCESS

	Early Seeding Plant Box Recruitment Model	Fall Seedling Plant Rafting Recruitment Model
Species:	Cottonwood and Willows	Alder, Ash, Sycamore, Valley Oak
Time of Seed Dispersal:	Spring / Summer	Fall (seeds) / Winter (cones/catkins)

MORTALITY PROCESS

	Scour _____	Desiccation __________	Inundation _________
Process:	Winter storms, snowmelt peaks mobilizing and/or scouring bed surface	Rapid decline of receding limb of snowmelt hydrograph, low summer baseflows after germination	Prolonged receding limb of snowmelt hydrograph, high summer baseflows during seed dispersal / rafting period



- The 2 year flood (Q_2) removes seedlings
- The 10^+ year flood (Q_{10}) removes small trees / shrubs, maintaining channel width

Figure 8. Riparian vegetation "Window of Opportunity" model (modified from Kondolf and Wilcock 1996). Successful initiation requires seedlings to survive scour and inundation from winter storms and spring releases, and desiccation as receding streamflows return to baseflows. The window of opportunity is different for each species depending on the timing of seed dispersal.

Integral to riparian woody plant ecology are the different times when ascending limbs, peak streamflows (floods), receding limbs, and baseflows begin and end, and total duration of each flow stage (Figure 9). Successful germination, initiation, and establishment of many riparian woody plants rely on the timing of seed dispersal coincident with these flow periods (Bradley and Smith 1986, Scott et al. 1993, Mahoney and Rood 1998). If seed dispersal occurs during peak streamflows, the seeds will fall on inundated surfaces and wash away. As flows recede, seeds may land on recently exposed moist substrates and germinate. Germination can lead to successful establishment if flows recede gradually enough to provide favorable soil moisture conditions to growing seedling roots. This interaction between the timing of seed dispersal, the availability of suitable moist germination sites on streambanks and floodplains, and gradual flow recession rates that allow growing seedling roots to access retreating groundwater is known as the recruitment box model (Mahoney and Rood 1998). In the Restoration Reach, cottonwood and willow seed dispersal occurs during the receding limb and ends during summer baseflows (Figure 9).

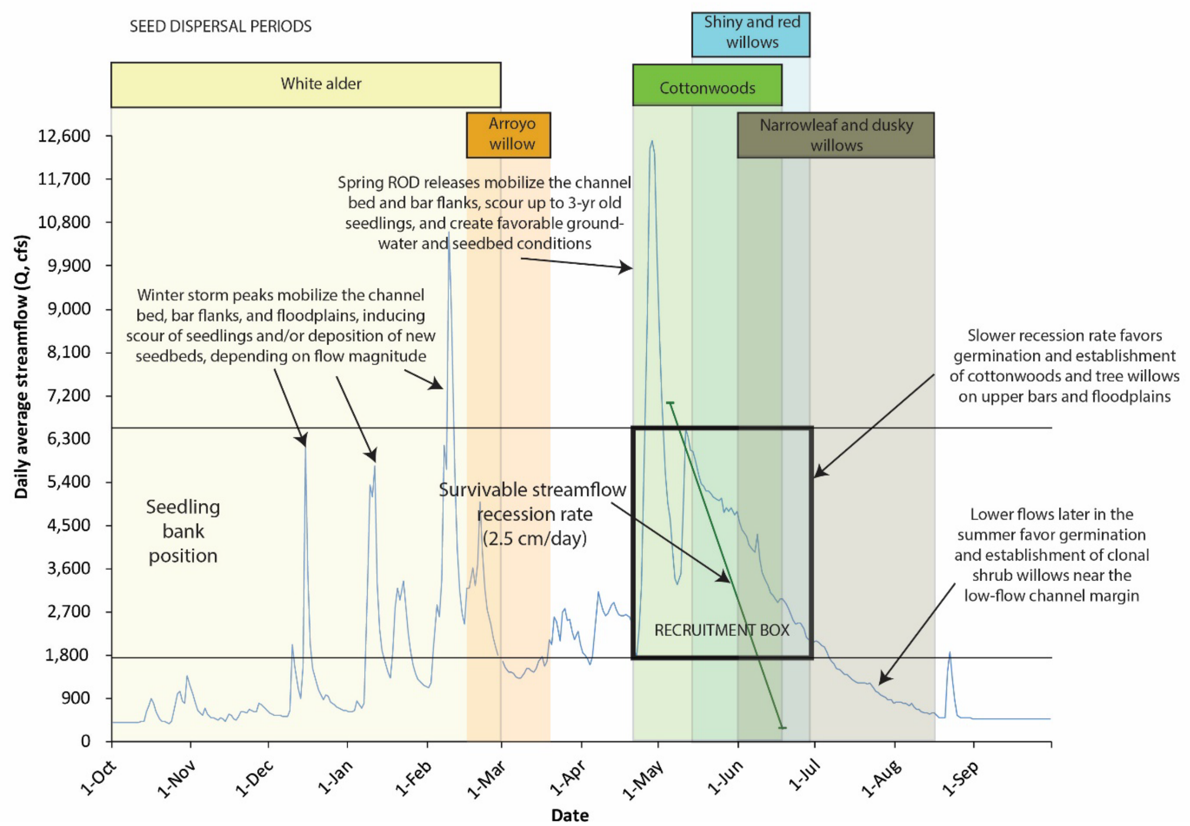


Figure 9. Approximate streamflow release hydrograph from Lewiston for WY 2017, showing hydrograph components that influence survival of riparian hardwoods. While winter storms and spring peak flows may induce both scour and inundation of seedlings, the receding limb of the hydrograph can be used to encourage recruitment. The recruitment box model (Mahoney and Rood 1998) describes favorable conditions for recruitment as the coincidence of seed dispersal onto moist streambank and floodplain positions with gradual flow recession rates. The recruitment box is shown for cottonwoods and tree willows.

Precipitation tapers off rapidly with the progression of spring in the Trinity River watershed and most flood peaks are associated with periods of intense rainfall or rain-on-snow events that lead to streamflows that are rapidly ascending and descending. Rain or rain-on-snow induced floods inundate the highest surfaces along the channel for short periods of time. When rainfall floods happen later in the season, the rapid descending limb can abandon young seedlings on higher surfaces where they may desiccate. During the snowmelt period, regular flood peaks and slow recession annually inundated lower surfaces but, depending on the year and snowpack, flow recession could still be too fast for young seedling roots to keep up and desiccation would occur. In some years it was not until mid-summer when flows became consistent enough to support woody plant seedlings; however, the seedlings that did establish during mid and late summer grew within the channel where annual scour could erode young seedlings. In this situation, annual flow-related desiccation would kill woody plants trying to establish on the bank, and the lower elevation locations where plants were able to establish was so low that annual floods could mobilize the channel bed and erode the seedlings away.

Before flow regulation, the window of opportunity between bed scour and desiccation may have been much higher on the channel margin than post-TRD (Figure 8). It is also possible that prior to the TRD, the zone of desiccation and scour overlapped such that riparian woody plant establishment was rare. With the completion of TRD and nearly constant streamflows, the window of opportunity zone shifted from the pre-TRD floodplain to the low water (e.g., summer) channel margin (Figure 8).

Riparian vegetation is strongly influenced by low- and high-flow characteristics (Pollock et al. 1998, Stromberg et al. 2007, Merritt et al. 2010). Riparian vegetation mapped on aerial photographs indicated that in 1960, only 300 acres of willow (*Salix* spp.) and white alder (*Alnus rhombifolia*) were growing along the mainstem Trinity River between Lewiston Dam and the North Fork Trinity River (Wilson 1993, DOI 2000). The majority of the areas mapped adjacent to the channel were open and unvegetated (Table 1), even when flows were higher (and more of the open gravel bars were inundated). Although we cannot know what unimpaired riparian conditions were like because of extensive historical mining, we can compare the 1960 riparian vegetation estimates with later mapping to examine changes in the amount of riparian vegetation, especially along the channel, resulting from post-TRD conditions. Even though riparian vegetation estimates from 1960, 1977, and 1989 were mapped at different flows, these estimates are telling, since the higher flows would not have been so high as to completely inundate willow, cottonwood, and alder cover types.

Table 1. Summary of pre- and post-TRD cover type acres, based on aerial photo interpretations by Wilson (1993) and Evans (1980).Streamflow releases at the Lewiston gage are shown for the date the aerial photo was taken, when known. The lateral mapping boundary for each study is not known.

Type	**Lifeform**	**1960**		**1977**		**1989**	
		Acres at 5,000 cfs	**Proportion of Area**	**Acres at Unknown Flow**	**Proportion of Area**	**Acres at 2,000 cfs**	**Proportion of Area**
Open gravel bar	Open substrate	752	71%	707	45%	16.4	2%
Willow	Shrub	239	23%	337	22%	326	37%
Willow–alder	Tree	67	6%	446	29%	382	43%
Mature riparian (Cottonwood/ alder)	Tree	3	0%	70	4%	173	20%
Total riparian types mapped	Tree–shrub	309	29%	853	55%	881	98%
Total		**1,061**		**1,560**		**897.4**	

The combination of inter- and intra-annual river flow fluctuations, flood magnitude and frequency, and coarse substrates likely inhibited riparian establishment in most years before TRD completion. Pre-TRD floods would mechanically damage stems in or near the channel, scour plants from the channel bed and banks, and topple mature vegetation through bank undercutting or lateral migration. Plant mortality could result from desiccation (rapid losses in soil moisture or the lack of available soil moisture during the growing season), and/or suffocation from prolonged flood inundation or deposition.

4.2 Post-TRD Hydrology, Channel Pattern, and Vegetation Patterns

The TRD reduced flood peak magnitude, frequency, and overall variability in inter- and intra-annual river flow fluctuations (Figure 10), which increased the ability of riparian vegetation to establish and mature along the late summer/fall water edge. Streamflows were held nearly constant at approximately 150 cfs year-round from 1961–1980 (Figure 11). Modest flow increases occurred in a step-wise manner between 1981 and 1991, when summer baseflows were raised to 450 cfs, with winter baseflows of 300 cfs. Until the Andrus Decision in 1981, peak streamflows below the TRD were infrequent, and of variable magnitude and duration but typically less than 6,000 cfs. Summer baseflows did not vary, except for an increase in flows every other year in August for tribal ceremonial purposes. After 1981, summer baseflows often did not change for 60 consecutive days in wetter years, and 100 or more consecutive days in drier years during the riparian growing season. A woody plant dispersing seeds during the stable summer baseflow period would be very likely to initiate along the low flow channel margin, and in the absence of scouring flows, would establish and mature there.

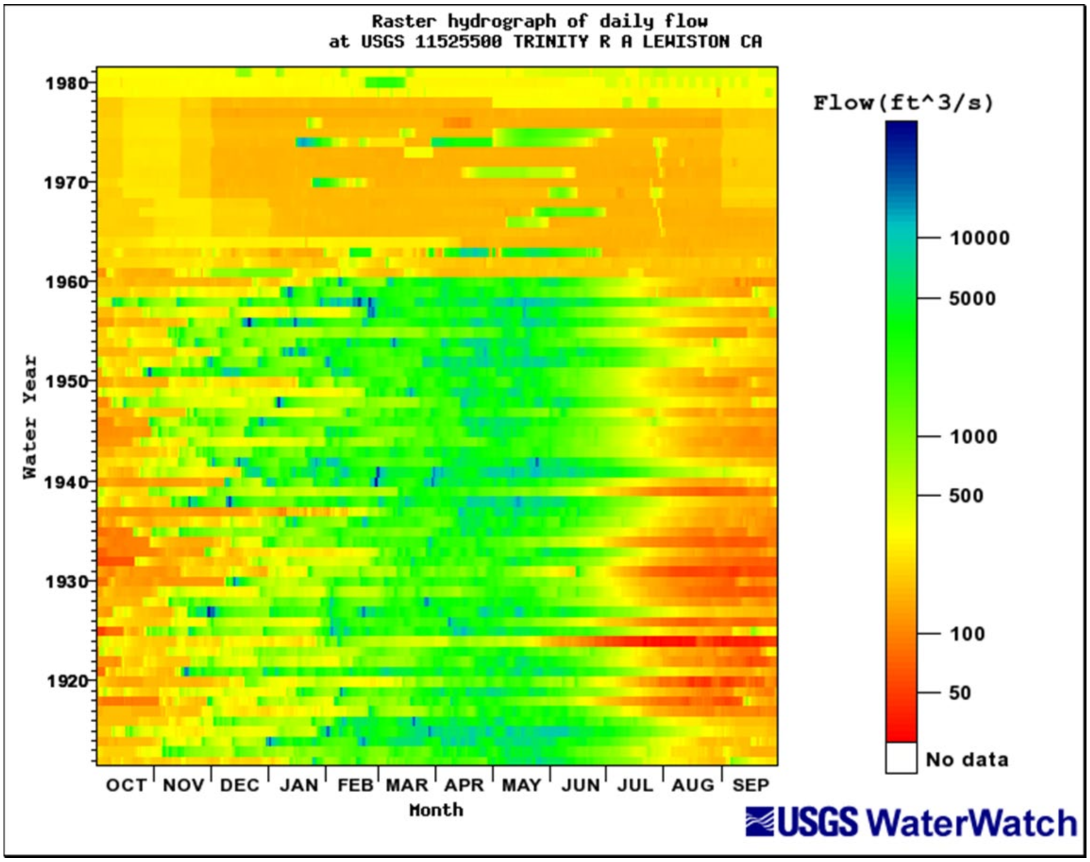


Figure 10. USGS Lewiston gage (11525500) daily average streamflow raster hydrographs (https://waterwatch.usgs.gov/index.php) from WY 1912 to WY 1981. The greater the color variation horizontally and vertically, the greater the variation in river flow fluctuation. Note the reduction in flow variability beginning after 1960 with construction of the TRD.

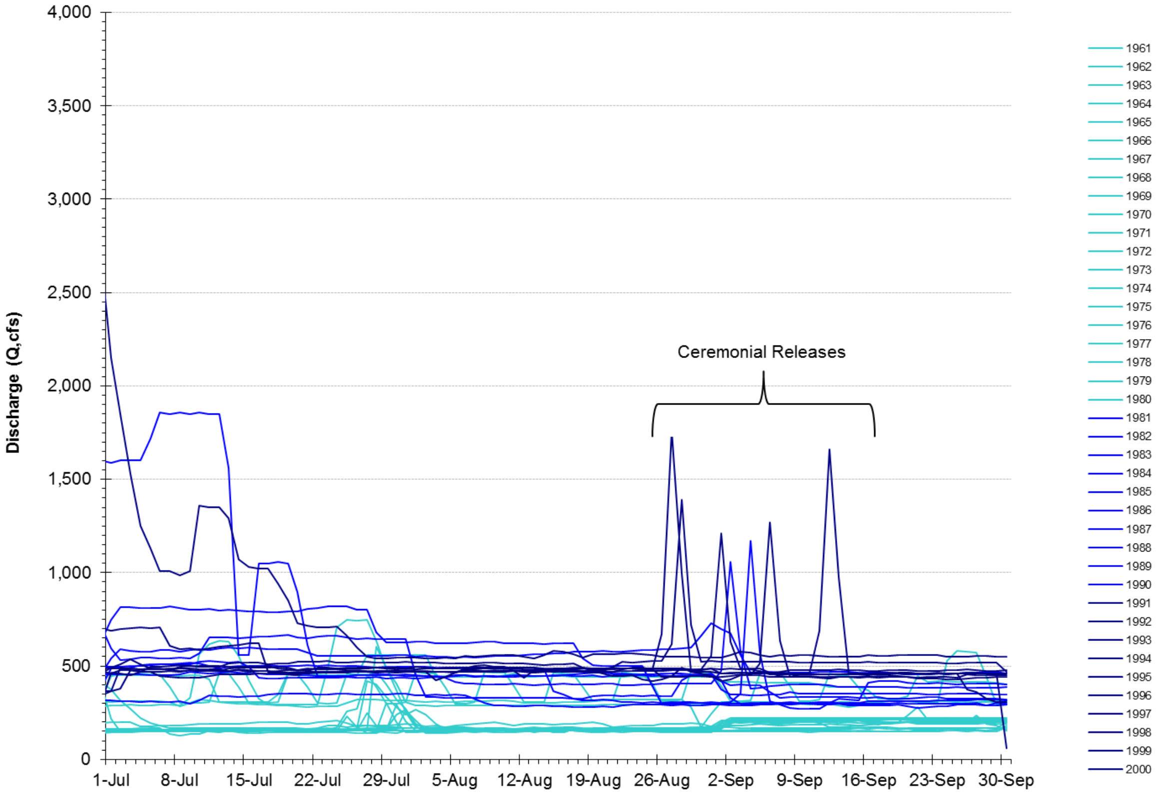


Figure 11. Streamflows during the summer and early fall during the 1961–1980, the 1981–1992, and post-1993 time periods.

The TRD reduced or eliminated many environmental stressors that historically limited plant recruitment along the low flow channel margin. With flow regulation, scouring floods were virtually eliminated and riparian vegetation quickly established next to the 150 cfs water edge along both sides of the channel (Ritter 1968, Evans 1980, DOI 2000). Plant desiccation limited the upper extent of vegetation along the channel, where constant soil moisture was available within the capillary fringe of substrates in contact with the 150 cfs streamflow. Near-constant streamflows of 150 cfs from 1965–1981 created ideal conditions for riparian vegetation encroachment. Established plants would not be toppled, desiccated, mechanically damaged, or suffocated from prolonged inundation because stable streamflows and the near elimination of flood peaks above 6,000 cfs eliminated these modes of mortality. Fine sediment deposition was a potential mortality agent given the magnitude of fine sediment entering the upstream reaches prior to the 1990s. However, the establishment of vegetation adjacent to the channel in areas where large volumes of fine sediment was deposited suggests that deposition was not a limitation to plant survival after TRD was completed, regardless of the fine sediment supply, transport, and deposition.

When establishing riparian vegetation was inundated, by infrequent Safety of Dams releases or tributary-induced high flows, water velocities were slowed and fine sediment deposited within the band of riparian vegetation, causing riparian berm formation (Ritter 1968, M&T 1997, M&T 2000). As the vegetation matured, the riparian berm grew, and bank strength increased. Eventually banks grew high enough to entrench the channel, sometimes for flows exceeding 6,000 cfs (Figure 3). During periods of higher flow (> 450 cfs), berm formation on both channel banks caused the channel to narrow, the area of shallow water depth to decrease, and velocity to increase. Even the largest post-TRD floods were not large enough to remove encroaching vegetation, and a trapezoidal channel developed between two riparian berms that had formed within the encroaching vegetation (Figure 12).

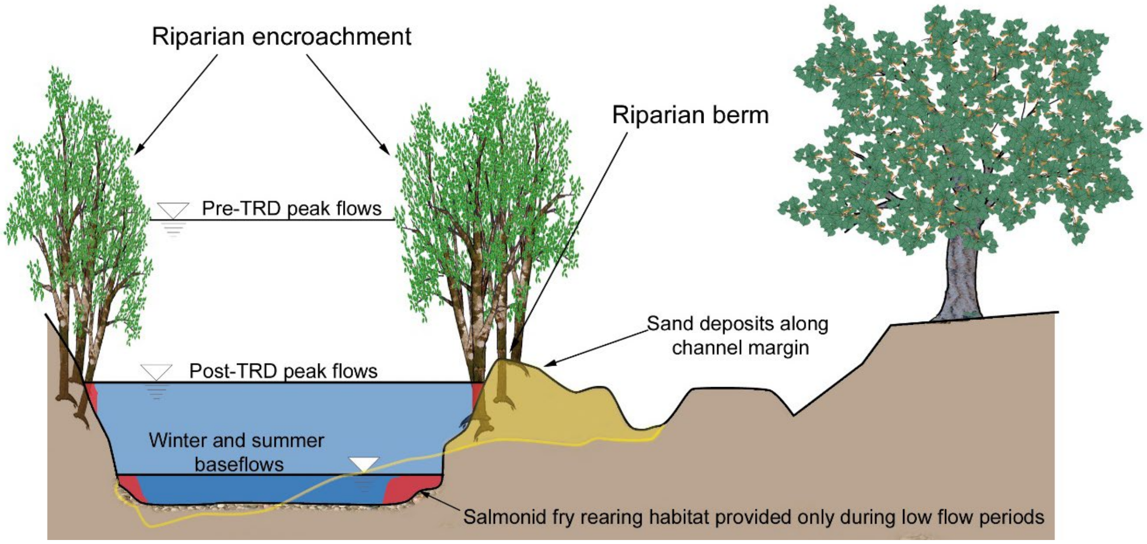


Figure 12. Conceptual model illustrating the effect of vegetation encroachment and riparian berms over a range of winter flows, when fry and juvenile salmonids need aquatic habitat.

The effects of flow regulation on riparian vegetation encroachment are most pronounced upstream near Lewiston where flow magnitudes are exclusively controlled by TRD and there is little to no tributary accretion. Below Weaver Creek, mainstem streamflows often reach annual maximum flood levels in the winter due to cumulative winter tributary accretion. However, peak flows in the portion of the mainstem above Weaver Creek to Lewiston Dam are limited due to the small number of tributaries and associated small unregulated watershed sizes. It is in the reach above Weaver Creek where TRD flood magnitudes must do the bulk of the combined work of berm removal and inhibiting encroachment. The few flood peaks that did occur post-TRD transported the remaining mobile coarse sediment, leaving a trapezoidal channel with an armored cobble bed (TRA 1993, M&T 1997, USFWS and HVT 1999). A post-TRD trapezoidal channel with vegetation encroachment along both banks (Figure 12) provided reduced habitat quality for juvenile anadromous salmonids and was hypothesized to be a primary responsible agent for the decline of anadromous salmonids in the Trinity River within the Restoration Reach (Pelzman 1973, Evans 1980, USFWS and HVT 1999, DOI 2000).

Following the completion of Trinity and Lewiston dams, the area of riparian vegetation increased, and has remained at over 900 acres since 1980 (Ritter 1968, Evans 1980, Wilson 1993, DOI 2000, M&T 2005, NSR 2009). While the post-TRD pattern of riparian vegetation establishment facilitated the development of a diverse avian community of regional importance (Wilson et al. 1991, Riparian Habitat Joint Venture 2004, Miller et al. 2010), it was also associated with the formation and maintenance of sediment berms, channel narrowing and loss of anadromous salmonid habitat within the Restoration Reach (Pelzman 1973, Evans 1980, M&T 1997, USFWS and HVT 1999, DOI 2000, Curtis and Guerrero 2015). By 1989, approximately 92% of the channel margin was vegetated compared to the largely unvegetated channel pre-TRD (M&T 2000).

The 1974 winter flood was a rain-on-snow event and was the largest release from Lewiston Dam since TRD completion in 1964. The 1974 Lewiston release peaked at 14,400 cfs. The 1971 aerial photos show nearly 100% coverage of the channel margins with encroaching white alder stands, and the 1974 post-flood aerial photographs show limited disturbance to the white alder stands resulting from the 14,400 cfs flood (Figure 13). The limited disturbance to vegetation encroachment resulting from the 14,400 cfs Lewiston release was one piece of evidence that suggested that widespread removal of encroaching mature white alder stands would be beyond the capacity of Lewiston releases alone, since the controlled release capacity of the TRD is 13,750 cfs.

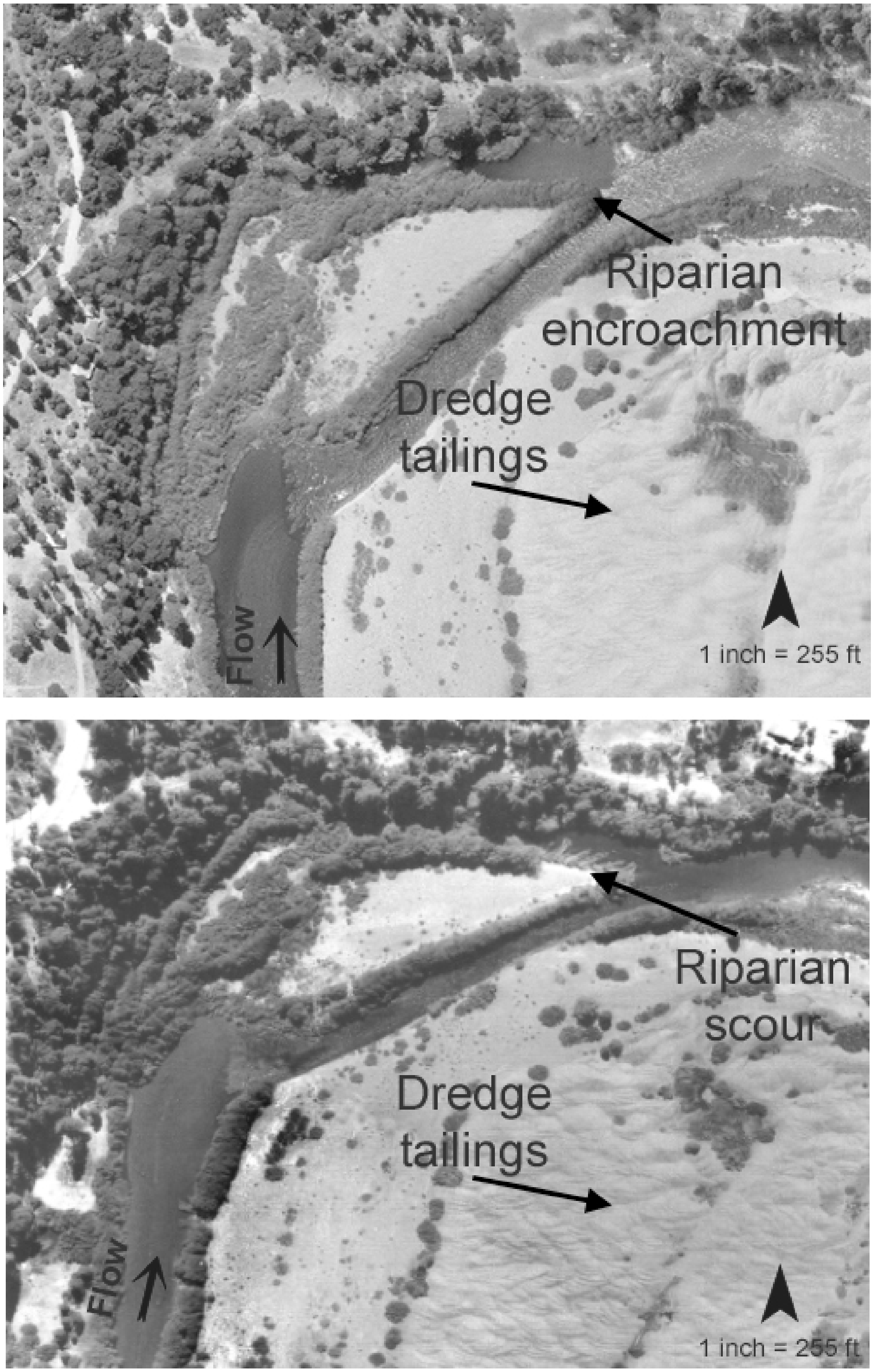


Figure 13. Gold Bar/Dark Gulch (RM 106.3) in 1971 (top) and in 1974 (bottom) after the 14,400 cfs release in January 1974. This was largest disturbance to riparian vegetation encroachment in the reach between Weaver Creek and Lewiston Dam. Gold Bar site is 5 miles downstream of Lewiston Dam and 1 mile downstream of Rush Creek, the first major tributary downstream of Lewiston Dam.

5 EARLY GEOMORPHIC AND RIPARIAN STUDIES ON THE TRINITY RIVER

It was obvious just 10 years after post-TRD flow reductions began that the Trinity River was changing dramatically, which was impacting salmonid populations. In response, resource managers and government agencies began the lengthy process of attempting to modify TRD releases to address or reverse these changes. In 1980, the United States Fish and Wildlife Service (USFWS) proposed channel "maintenance flows" to restore natural channel morphology and thereby improve salmonid habitat in the Trinity River (USFWS 1980). Proposed maintenance flows were initially intended to achieve geomorphic thresholds of bedload transport and channel bed mobilization. In 1981, the Secretary of the Interior Cecil Andrus issued a decision that directed the USFWS to conduct the *Trinity River Flow Evaluation* (TRFE) study (DOI 1981), with the purpose of determining how to restore anadromous fish populations in the Trinity River Basin. The Andrus decision also directed that summer baseflows be increased to reduce water temperatures. From 1981 to 1991, summer and winter streamflows were raised from 150 cfs to 300 cfs (Figure 11). The North Coast Regional Water Quality Control Board completed the basin plan in 1993, which defined maximum allowable water temperature compliance targets and minimum baseflow magnitudes required to meet those temperature targets during the spring and summer. Therefore, summer baseflows were raised in 1993 from 300 cfs to 450 cfs, and winter baseflows remained at 300 cfs (Figure 11).

One component of the 1980 maintenance flow study was to release flows that were large enough to flush fine sediment out of the channel bed and mobilize a significant portion of the channel bed. Later, geomorphic studies expanded the objectives to include maintaining a dynamic alluvial channel with an alternate bar morphology (TRA 1993, M&T 1995, Wilcock 1995). Therefore, flood peak magnitudes were one aspect of the geomorphic studies and, in 1992, a 6,000 cfs peak flow was released. Between 1995 and 1998, additional flow peaks were released (TRA 1993, M&T 1997).

The following sections describe monitoring that occurred during the 1991–1997 geomorphic study period. Geomorphic responses, such as bed mobility, bed scour and deposition, and shear stresses were measured during high flow releases. Various aspects of riparian vegetation ecology, including seed dispersal periods, seedling initiation and establishment, rooting depth, and encroachment dynamics were investigated in relation to all streamflows and integrated with the geomorphic studies. The results were reported in McBain and Trush (1997) and Wilcock (1995) and then synthesized into the TRFE (USFWS and HVT 1999), which is described in more detail in Section 0.

5.1 Geomorphic Studies

Geomorphic studies initially focused on sediment mobility, sediment transport rates, and channel morphology (TRA 1993, Wilcock et al. 1995). Managed floods ranging between 2,700 and 6,000 cfs were released at Lewiston in 1991–1993. At every location where studies were conducted, encroaching vegetation had confined the channel. Study locations were selected where river access was possible, and where limited geomorphic features, such as point bars, had formed under the post-TRD flow and sediment regime.

A channel bed mobility study (TRA 1993) evaluated topographic change, surface and subsurface bed scour, and sediment deposition along cross sections at five locations in the Restoration Reach. The depth of bed scour can be related to the ability of flows to scour initiating riparian hardwood seedlings along the low flow channel, whereas deposition depth and location can be related to the likelihood of either riparian berm formation or seedling suffocation. The channel bed mobility study characterized the surface particle-size distribution using modified Wolman (1954) pebble counts and the subsurface composition with bulk samples taken with a McNeil sampler (TRA 1993). Painted rocks representing the 50th (D_{50}) and 84th percentile (D_{84}) particle sizes were placed

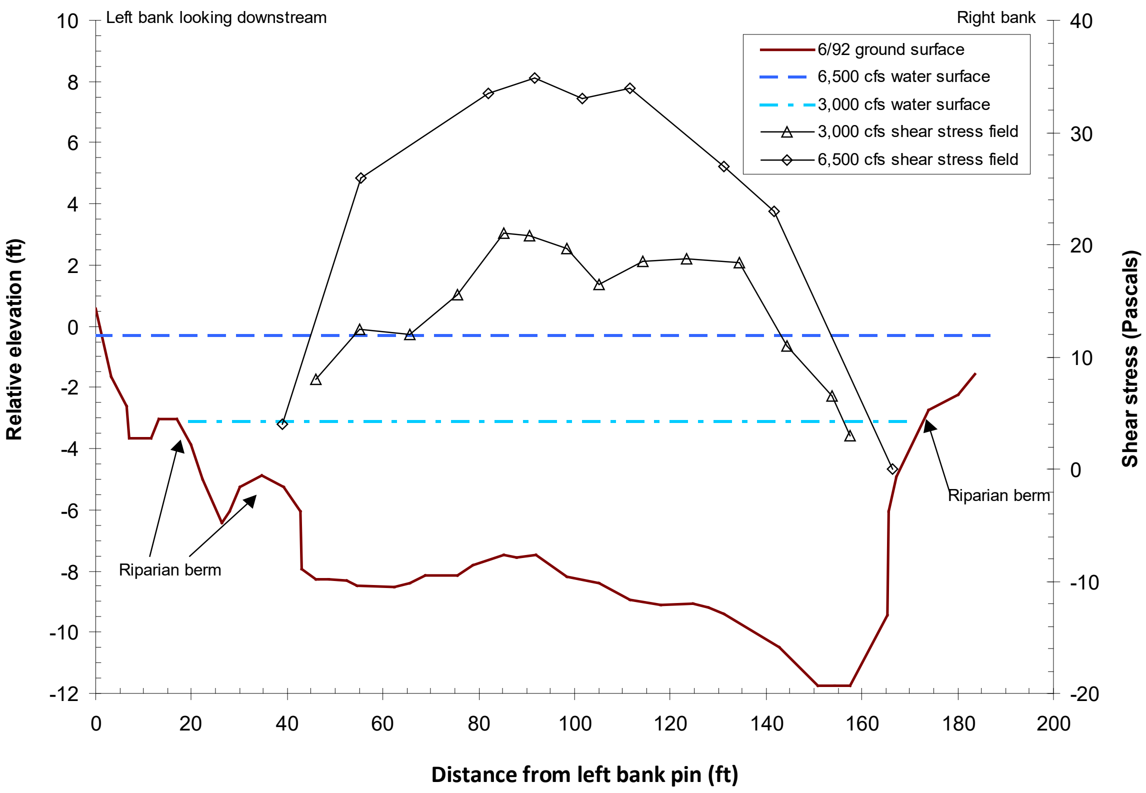


Figure 14. Riparian encroachment at cross section at Poker Bar (RM 102.7) showing computed shear stress fields from Wilcock et al. (1995).

along cross sections on exposed bars and in the wetted channel. Different managed flood peak magnitudes were related to the percent of marked rocks moved. The distance moved downstream was also noted. An important finding of this study was that a 6,000 cfs discharge mobilized the D_{50} and D_{84} on most alluvial post-TRD storage features (TRA 1993, M&T 1997).

A sediment transport study occurred at Poker Bar, where alders grew along both banks and confined the channel (Wilcock et al. 1995). Depth-integrated suspended sediment measurements and Helley–Smith bedload samples were collected, and local boundary shear stress was calculated within each sediment sampling cell along a cross section during each managed high flow release. Boundary shear stress represents the tractive force of a streamflow on the channel bed and can be related to the ability of flows to laterally scour vegetated streambanks. The results from computed shear stress fields within a channel with vegetation encroachment indicated that the largest shear stresses generated during high flow events occur fairly evenly across the center of the channel bed and rapidly drop to near zero along the vegetated channel edge (Figure 14).

Beginning in 1991 and extending through the summer of 1993, the USBR and USFWS constructed nine bank rehabilitation projects as a pilot channel restoration program (also called “feather edge projects”) to increase salmonid fry rearing habitat. At all bank rehabilitation sites, 400–1,000 feet of riparian vegetation and sediment berm were removed along one bank. All woody plants were removed, coarse sands and silts in the berm were moved out of the active channel, and the bank was sloped to create a channel geometry similar to the pre-TRD channel geometry. At many bank rehabilitation sites, clean cobbles were placed on the constructed bank to provide cover for emerging salmonid fry (Hampton and Gilroy 1995). In all cases, when the riparian berm was removed, the low water channel width was increased substantially, in some cases up to 50%. In 1993, geomorphic studies were instigated at the newly constructed bank rehabilitation sites (M&T 1997, USFWS and HVT 1999).

Geomorphic monitoring was conducted at pilot bank rehabilitation sites between 1994 and 2002 (M&T 1997, Bair 1998, USFWS and HVT1999, 2001b, Bair 2003). Cross sections were surveyed using an auto-level before and after maintenance flows or annually. One objective of the high flow releases was to reach channel bed mobilization and scour thresholds. The frequency of channel bed mobility and scour at constructed sites was hypothesized to be a critical link to inhibiting woody plant establishment across active gravel bars, thus preventing riparian encroachment. At each of the pilot bank rehabilitation sites, geomorphic monitoring included:

- Documenting changes in channel morphology via changes in cross section topography and hydraulic geometry,
- Characterizing surface particle size and diversity using facies maps and modified Wolman-style pebble counts (Leopold 1970),
- Characterizing subsurface particles within the active channel using bulk samples taken with a McNeil sampler along cross sections, and
- Documenting bed mobility thresholds, and bed scour and re-deposition depths on exposed point bars and riffles.

At locations where the low water width had been increased by the bank rehabilitation efforts, gravel bars formed at many of the pilot bank rehabilitation sites during a 1995 tributary high flow event. Geomorphic studies were expanded to evaluate whether TRD high flow releases could be used to inhibit vegetation encroachment along the low flow margin of new point bars and maintain these newly formed alluvial features at pilot bank rehabilitation sites. Vegetation response to the pilot bank rehabilitation site construction and subsequent topographic changes associated with vegetation establishment were monitored and coupled with channel bed surface and subsurface scour studies from fall 1994–2002 (M&T 1997, Bair 1998, USFWS and HVT 1999, 2001a, Bair et al. 2003).

Sediment transport rates and velocity profiles were measured during the 6,700 cfs TRD high flow release in spring 1996, and were conducted at the same sites as the channel bed scour and mobility and woody plant demographic studies (M&T 1997). One group of sediment transport measurements was collected at the Steiner Flat pilot bank rehabilitation site (RM 91.9) and another was collected at the Sheridan Creek pilot bank rehabilitation site (RM 82.3). Like the Wilcock et al. (1995) study at the unrehabilitated Poker Flat location, the sediment transport study calculated local boundary shear stress within each sediment sampling cell, in addition to collecting Helley–Smith bedload measurements (n=20 cells). The cross sections where bedload transport was measured bisected gravel bars that had formed at the pilot bank rehabilitation sites since 1995. During the lower TRD releases on the ascending limb, shear stress was largely centered in the thalweg and channel similar to Poker Bar, but as flows increased and peaked, the shear stress field shifted and higher shear stresses were computed along the gravel bars, with a reduction of shear stress within the thalweg and channel (Figure 15). The shift of shear stress onto the bar surface at higher flows contrasted measurements at Poker Flat, where shear stress continued to increase in the center of the channel during the ascending limb and peaks. At both Sheridan Creek and Steiner Flat, the gravel bar affected the location where local shear stress peaked and shifted it from the low water channel bed surface to the channel margin where the gravel bar was located. The results of the bedload sampling, shear stress computations, and bed mobility and scour monitoring suggested that streamflow magnitudes of 6,000 cfs and greater could be used to maintain mobile gravel bars free of seedlings that had formed where rehabilitation had occurred.

However, the study also concluded that individual high flow releases up to 13,750 cfs TRD release capacity would be insufficient to cause significant scour to channel margins with mature alders where rehabilitation had not occurred.

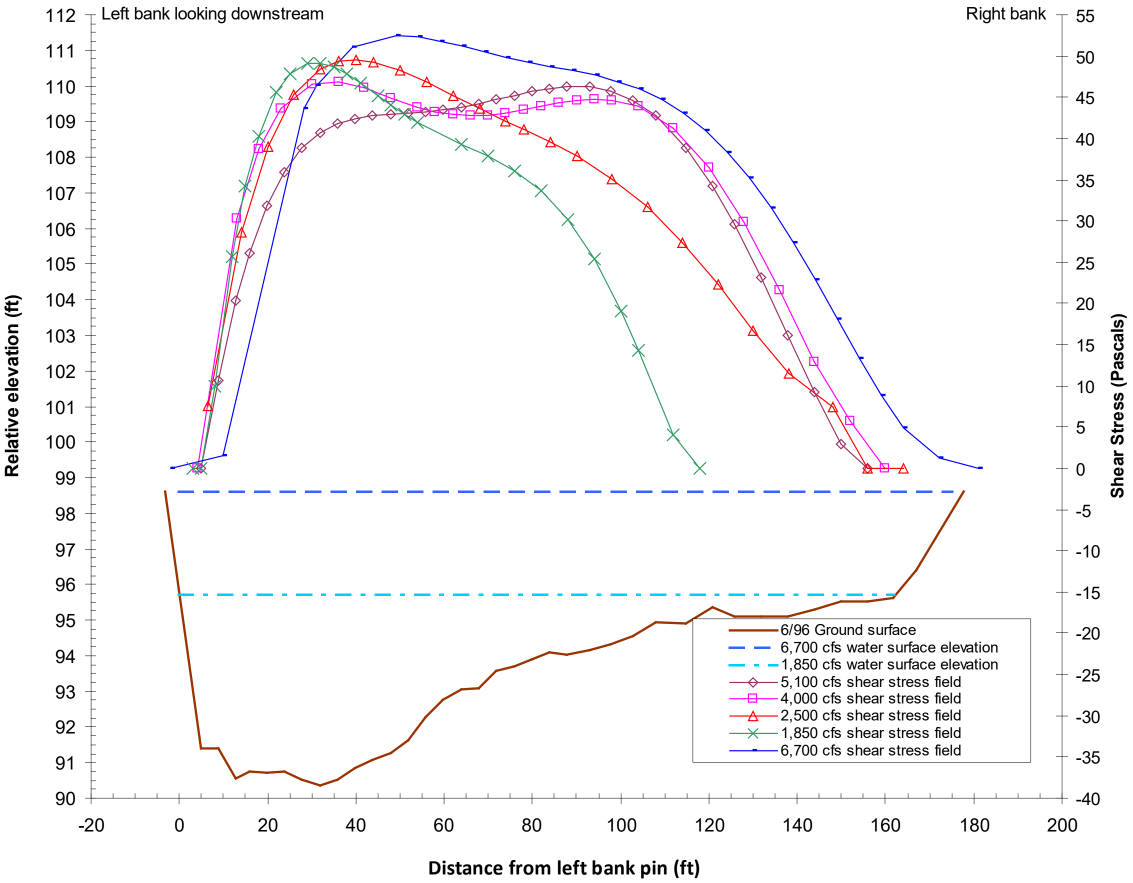


Figure 15. Steiner Flat pilot bank rehabilitation site (RM 91.9) cross section showing shear stress fields for flows ranging from 1,850 cfs to 6,700 cfs.

5.2 Vegetation Encroachment Studies

Beyond mechanical removal using herbicide or heavy equipment, the ability of TRD high flow releases to remove establishing or mature encroaching plants was a critical aspect of rehabilitating channel morphology to be more diverse. Factors that could disturb or remove encroaching vegetation were investigated by McBain & Trush (1997). Plant size and establishment location were hypothesized to be related to a plant's vulnerability to physical and hydrologic factors. Smaller plants growing closer to the summer baseflow water edge would be more prone to the mortality effects of inundation, deposition, and scour than larger plants. Vegetation encroachment studies evaluated potential seedling mortality agents, and disturbance magnitudes and frequencies to assess how or if TRD high flow releases could be used to: (1) reduce the overall amount of mature vegetation encroachment, and (2) inhibit the re-establishment of encroaching plants on transient gravel bars and channel margins where heavy equipment had removed encroaching plants (i.e., pilot bank rehabilitation sites).

5.2.1 Conceptual Life History Model

An initial conceptual woody plant life history model was developed to identify vulnerable life history stages that could possibly be managed to limit detrimental riparian encroachment in the Restoration Reach (Figure 16). To predict successful passage from one life stage to the next, an ecological perspective to life history stages was needed. Four ecologically-based life history stages are: initiation, establishment, maturity, and senescence (M&T 1997, USFWS and HVT 1999, Bair 2001b, TRRP 2004). Initiation occurs when a seed lands on exposed moist substrate, germinates, and survives through the first growing season. The establishment stage begins after the first growing season and continues until maturity, when the plant has enough resources to begin sexual reproduction (i.e., flowering, fruiting, and seed dispersal). Senescence occurs as a plant reaches the end of its life and is characterized by a decrease in growth, reproduction, and increased canopy dieback.

Initiation and establishment are the two periods in a plant’s life history when it is most vulnerable. If a plant can be successfully established, it is likely to live to maturity. When a seed lands on a moist surface, it imbibes water, and the embryo begins to grow. Two cotyledons emerge and a primary root forms, typically within 24–48 hours of landing on the moist surface. The young seedling must grow its primary root to a depth where it can survive streamflow recession, usually over the first 25 days after germination (Noble 1979, Borman and Larson 2002, HVT and M&T 2007, Stella et al. 2010, HVT et al. 2011, Reclamation 2012). If the surface is too hot or dries, the seedling dies. It is only in locations where soil moisture can persist longer during the growing season (March through October) that seedlings can survive to establishment. Post-TRD and pre-ROD, these conditions occurred annually along the 450 cfs water edge and rarely higher on the bank. Seedlings in the initiation phase have been referred to as Young-of-Year (YOY) and are most susceptible to inundation, desiccation, high temperature, and herbivory during the first growing season (Andersen and Cooper 2000, Merritt and Cooper 2000).

The establishment phase begins at the end of the first growing season when the YOY go dormant. Their physiologic processes slow, and photosynthesis and respiration are reduced. Rapid changes or extreme environmental conditions (e.g., high or low temperatures, dry soil conditions) have less effect once a plant goes dormant. The time when plants go dormant varies year to year depending on climatic conditions in the fall. After the growing season ends, dormant YOY are vulnerable to channel bed scour and deposition during winter and spring high flows. Plant establishment may be directly reduced through floods (Bair 2001b, Bair 2003, Camporeale et al. 2013, Casado et al. 2016, Bankhead et al. 2017, Lightbody et al. 2019). The establishment phase may continue for many years until the plant grows to sexual maturity. A plant is considered recruited when it is sexually mature.

Elevated (compared to unimpaired) stable summer baseflows are currently a management action used to maintain water temperature targets for salmonids (NCRWQCB 2018). Summer baseflows still do not vary, except for an increase in flows every other year in August for tribal ceremonial purposes or supplemental flows released to reduce stress on adult salmon in the lower Klamath River in drier water years. Since summer baseflows were raised from 300 cfs to 450 cfs in 1991, there has been no flexibility in modifying these streamflows to be more variable due to the strict water temperature criteria.

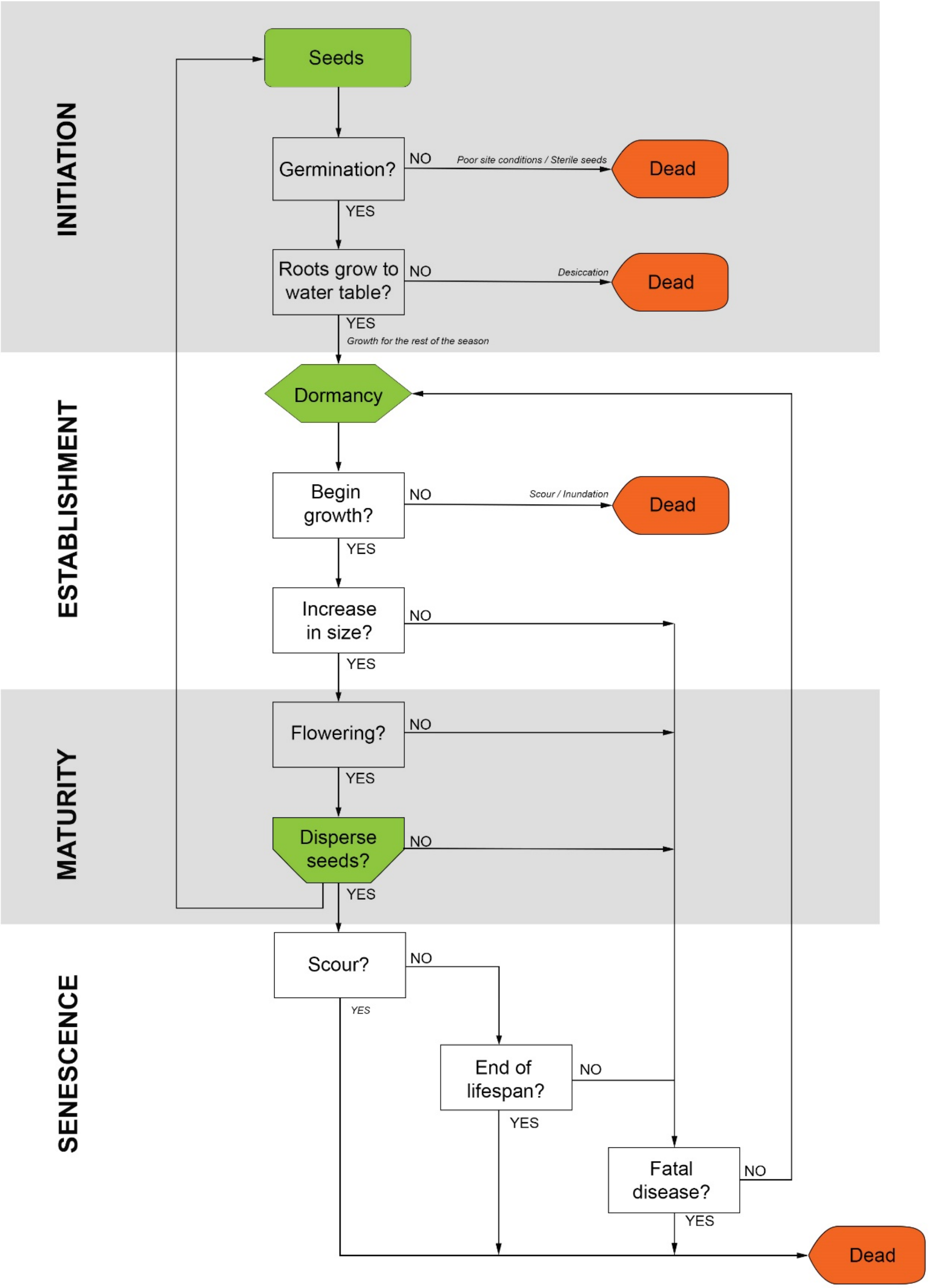


Figure 16. Conceptual woody plant life history (modified from M&T 2000).

5.2.2 Evaluating Mature Riparian Vegetation Disturbance Thresholds

Streamflows that were required to topple and remove mature alders were evaluated by M&T (1997). Natural in-situ tree toppling may have occurred prior to the TRD but decreased with the elimination of floods, channel migration, and extensive bank undercutting. Aerial photographs taken after the 14,400 cfs release in 1974 show small areas of tree toppling (Figure 13), yet most of the trees along the channel margin remained intact. The 1974 release is still the largest TRD release on record. The 1989 aerial photographs show that approximately 92% of the channel margin was a near continuous corridor of mature alders confining the channel (M&T 2000).

Flow magnitudes that induced tree toppling and potential berm disruption were estimated using data collected from mechanical alder toppling in 1995 and field observations of riparian toppling during the 1997 flood (M&T 1997). Before 1996, streambanks downstream of Lewiston had not experienced flood magnitudes much greater than 8,000 cfs, and there was little sign of mature alders being toppled by floods that did occur during this time. In 1996, six mature alders were pulled over to simulate toppling. A tensiometer was attached to the trees and the force required to pull over the trees was measured (M&T 1997, USFWS and HVT 1999). Single tree, small log jam, and large log jam effects on tree toppling were simulated, and flows needed to push over the alders were computed. Results suggested that it could require flows of 16,000–20,000 cfs to topple the most vulnerable mature alders encroaching the channel. The mechanical toppling results suggested that TRD flow releases alone would not be able to achieve the estimated flow magnitudes required to topple trees because the TRD outlet works at Lewiston Dam are limited to 13,750 cfs releases, and private homeowners are greatly impacted at flows greater than 14,000 cfs (DWR 1995).

In late December 1997, a rain-on-snow event generated a large flood (M&T 2000). In downstream reaches, the 1997 flood was the largest post-TRD flood since 1974, although the 1974 release is still the largest release from Lewiston on record. The 1997 flood peak was 6,970 cfs at Lewiston, 24,000 cfs at Douglas City, and 30,000 cfs at Junction City. Near Lewiston, the 1997 flood did not topple or mechanically damage many mature trees; however, downstream of Weaver Creek, the flood crossed a magnitude threshold and there were many areas where mature trees were removed (M&T 2000). The degree and amount of disturbance related to the 1997 flood downstream of Weaver Creek had not occurred before 1997 and has not occurred since. It has been considered unlikely that single TRD releases could be used to topple mature trees and create significant channel bank disturbance except in small areas and locations that were prone to scour because of where they grew (i.e., geomorphic placement or channel locations). However, the evaluation of 1997 flood effects on riparian vegetation disturbance supported the simulated tree toppling results that flows above 16,000 cfs were needed to topple single white alder trees, but that flows of at least 24,000 cfs were needed to topple or snap off grouped trees and remove all silts and sands, leaving only exposed gravel and cobbles for 100 feet or more on one or both sides of the river. The largest and most severe disturbances in 1997 were typically associated with the inside/outside of meander bends, point bar flanks, and straight runs (Table 2). It was concluded based on 1997 flood disturbance results that it would be more feasible to use managed releases to mobilize and scour the channel to inhibit smaller plants from establishing than to reach magnitudes that could remove large areas of encroaching vegetation, since the maximum outlet works capacity is 13,750 cfs and damage to personal property is more severe during flows above 14,000 cfs.

Table 2. WY 1997 channel planform morphology associated with the most severe disturbances downstream of Limekiln Gulch (RM 100.2; M&T 2000).

Channel Planform Location	Percent of Total Severe Disturbances
Point bar head	13%
Point bar flank	10.5%
Point bar tail	4%
Medial bar	9%
Outside of bend	31%
Inside of bend	10.5%
Straight run	12%
High water channel inlet	1%
High water channel outlet	7%
Tributary delta	2%

5.2.3 Woody Plant Seed Dispersal Periods

During the 1990s, seed dispersal periods were evaluated qualitatively to estimate how seed dispersal periods varied between riparian hardwood species in the Restoration Reach (Figure 17). Seed dispersal timing has important implications for riparian encroachment; the appropriate combination of available substrate and soil moisture is necessary for seeds to be able to germinate and establish, but those conditions are irrelevant if they are not present when seeds are actually dispersing. Differences in seed dispersal timing were compared between seven common and abundant riparian species along the mainstem river (Figure 17).

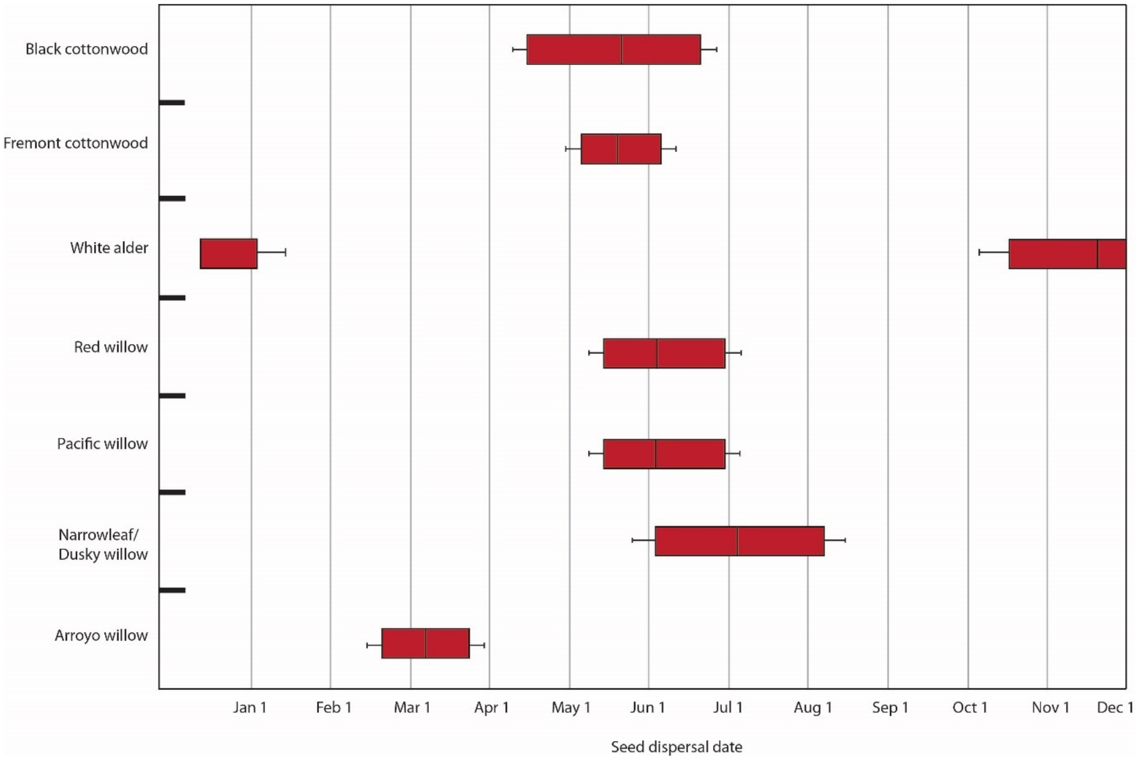


Figure 17. Seed dispersal periods for seven common woody plants established in the Trinity River riparian corridor. Median seed dispersal dates are represented with a vertical line through the box. Whiskers at either end of the box indicate the earliest and latest 5% of seed dispersal (modified from Figure 9.9 in M&T 1997).

Seed rain from different willows and cottonwoods on the Trinity River was found to be nearly continuous from March through August, with each woody species having a fairly discrete window of seed dispersal (Figure 17; Bair 2001b). Observations indicated that white alder disperses seeds in the late fall and across the winter as wind shakes seeds free from the small woody cone-like catkin. Dam releases during the winter are typically a constant 300 cfs, though rainfall-induced floods can occur. Rainfall-induced floods and Safety of Dams releases typically occur during the late winter and early spring. Arroyo willow (*Salix lasiolepis*) is the first to flower and disperse seeds in March. Black cottonwood (*Populus trichocarpa*) begins seed dispersal in April and Fremont cottonwood (*P. fremontii*) follows with seed dispersal in May. Red willow (*S. laevigata*) and Pacific willow (*S. lasiandra*) follow cottonwoods in mid-May. Narrowleaf willow and dusky willow (*S. melanopsis*) begin seed dispersal shortly after red and Pacific willows and peak in mid-June when streamflows are most stable. Narrowleaf and dusky willows belong to a select group of willows that can grow more than one crop of catkins per year; the milder the year, the higher the catkin production. Germination capacity studies showed that 98% of the seeds falling from narrowleaf and dusky willow catkins are viable (Pelzman 1973, Bair 2001b). Narrowleaf and dusky willows disperse seeds the longest, during the stable summer baseflow period, usually until mid-August and in some years, as late as early September.

Differences in seed dispersal periods between the various woody plant species combined with their distribution within the riparian corridor suggested that the location within the channel that plants could germinate and grow through the first year was related to hydrologic conditions when seed dispersal occurs. Before the TRD, many woody species could germinate and establish at a variety of locations beyond the summer low water edge. Seeds that germinated later in the summer grew farther down in the channel where they were more vulnerable to scour and often could not grow large enough to survive winter floods. After the TRD, seeds that germinated in the summer did so at higher elevations within the channel and were not scoured due to the lack of high winter flood events. The dense band of narrowleaf and dusky willow seedlings that established after TRD during the constant 150 cfs streamflow period quickly covered the low water channel margins. After valley-wide dredging and valley bottom urbanization, cottonwood and tree willow distribution was sparse. The few cottonwood, red willow, and Pacific willow trees presumably were unable to disperse seeds into the dense narrowleaf willow thickets and therefore could not germinate or establish in the rapidly growing willow thickets. Alders whose seeds were dispersed in winter via wind and fine sediment deposition, when the willows were dormant and leafless, could germinate and establish in small openings in the willow thickets and were better able to grow within the thickets.

Once the maintenance flow period began in 1981 with the Andrus decision, variable spring flows with rapid recession continued to prevent early spring seeders from being able to germinate and establish. A woody plant species cannot be abundant if its seed dispersal period does not coincide with the hydrologic and environmental conditions it needs for seeds to germinate and grow (e.g., black cottonwood). Conversely, a species may become dominant if its seed dispersal period coincides with widespread available substrate (low flow channel margin) and abundant soil moisture (constant summer baseflows) conditions (e.g., narrowleaf and dusky willow). Stable summer streamflows favored woody species that seeded during the June, July, and August period because the near-constant flow conditions provided near-constant soil moisture. Narrowleaf and dusky willow seeds would have, and likely did, overwhelm the low flow channel margin for the 30 years of near-constant streamflows of 150 cfs during the growing season. Even after moderate flow variation was reintroduced, streamflows have been stable in most years from late June through mid-October, which coincides with the narrowleaf and dusky willow seed dispersal period. Stable summer baseflows combined with long seed dispersal periods have continued to favor the establishment of narrowleaf and dusky willow seedlings along the summer low water edge.

5.2.4 Age and Root Length

Riparian encroachment results from a lack of scour-induced mortality within the low flow channel. The ability of a flood to scour a plant relates to the age of the plant and size of its root system. Woody plant roots will grow to constantly available groundwater but will not grow far into the water table. Roots need to respire, which requires oxygen, and so further growth into saturated soils would limit access to oxygen and result in reduced root growth and potentially suffocation. Older plants will presumably have a greater volume of roots and those growing farther at higher elevations will have deeper roots. Plants with larger root masses and deeper roots are more difficult to remove through flood scour. The length of root growth in the first, second, and third year following seed germination can determine whether a seedling is scoured or not (M&T 1997, USFWS and HVT 1999, Bair 2001b, Bair 2003). If roots grow deeper than 1 D_{84} depth, they may not be able to be scoured by a 6,000 cfs release (USFWS and HVT 1999). Studies conducted to evaluate the effects of controlled 6,000 cfs flood releases and used to support the TRFE evaluated rooting depths of different age riparian hardwood seedlings as a factor that could determine why a three-year-old seedling could survive a flood that scoured a one-year-old seedling in the same location (M&T 1997, Bair 2001b). Seedlings less than one-year-old continue root growth to achieve access to a constant source of available soil moisture (i.e., vertically via the primary root), while older seedlings whose primary root has reached the groundwater table can invest in stabilization (i.e., laterally via a fibrous root system). The ability of a woody plant to withstand winter flood scour is related to the depth and strength of roots that grew during the current and previous growing seasons. Seedlings are vulnerable to winter flood scour in locations where flood scour is greater than an individual plant's rooting depth.

Seedlings were dug up at two different pilot bank rehabilitation sites on the river from a lower bank location that was close to the summer water's edge, and a high bank position that was farther from the summer low water surface (M&T 1997, Bair 2001b). Twenty 1-month-old seedlings were randomly collected within the low and high areas by gently pulling at the root collar while carefully removing substrate. Plant height, length of the root mass, and diameter at root collar (DRC) were recorded. The measured root length was used to define a seedling's rooting depth. The initial sample was increased, and 215 willows seedlings were collected, ranging in age from 1-month to 60-months (Bair 2001b). The sampling focused on expanding the age range to characterize the difference in rooting depths between woody plants of different ages growing in similar bank locations. In 2004, the sample size associated with the initial root length study was further increased with 575 samples, for a total of 790 plants, and the data were summarized using cumulative distributions of rooting depths (Figure 18).

Seedlings establishing higher on the banks had significantly deeper roots than those growing lower on the bank (Bair 2001b). For YOY and 1-year-old seedlings, root length was dependent on whether the seedlings grew low on the bank close to the water edge or higher on the bank. Root length in the first two years of growth presumably reflected how deep a root system needed to grow to reach a stable source of soil moisture. In young seedlings, age may not be nearly as important in determining a seedling's root length as the distance a root needed to grow to reach constant moisture. Once a woody plant reaches constant moisture, it no longer needs to grow deeper and can expend energy on developing a larger network of roots. After the initial depth to constant water is reached, root resources could be used in expanding a plant's access to water (laterally) as the above ground portion of the plant continued to increase in size. Therefore, after the first few years, root volume may be a better indicator than root depth of a plant's ability to withstand scour.

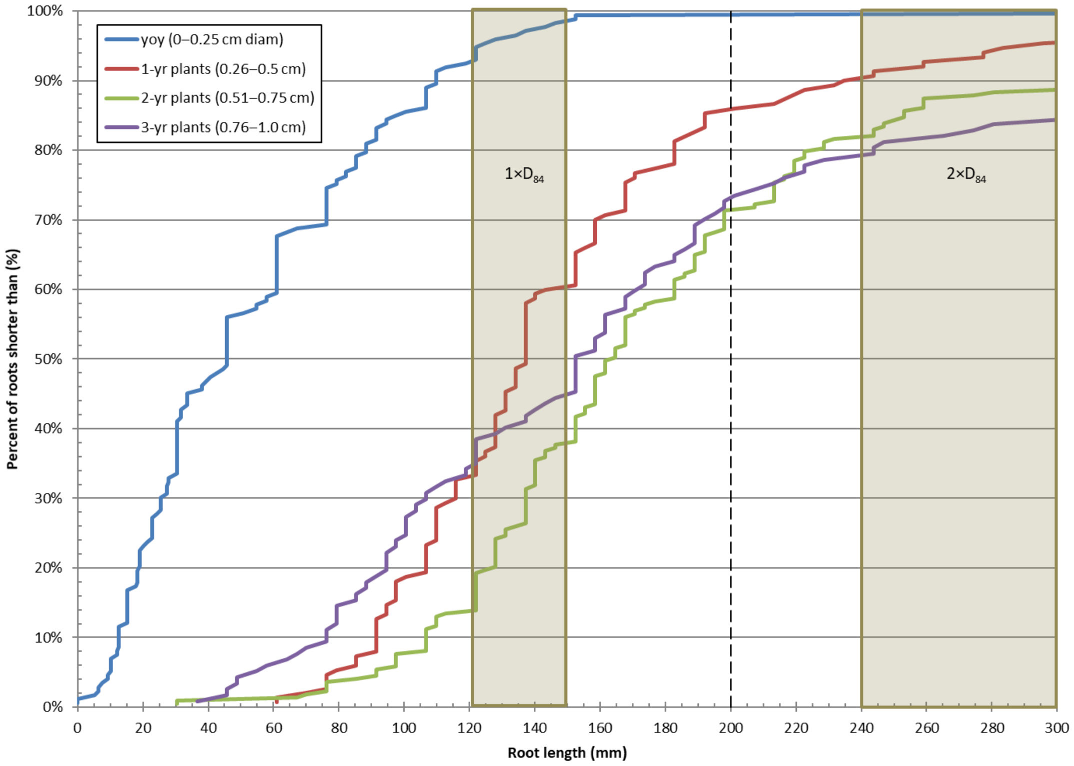


Figure 18. Cumulative root length distributions for YOY, 1-year, 2-year, and 3-year-old seedlings (n=790). Eighty percent of 2- to 3-year-old willow roots are shorter than 240 mm which is at the lower side of 2×D_{84} scour depth. The shaded boxes show the area associated with the 121–149 mm D_{84} range and two times the D_{84} range at the Steiner Flat site. Plants with root lengths equal to or less than the D_{84} would be scoured if that particle size mobilized.

Rooting depths were compared to data summarizing substrate characteristics developed during geomorphic monitoring. Surface substrate characteristics were quantified using facies maps and modified Wolman pebble counts, and subsurface substrate was characterized using bulk samples taken using a McNeil sampler (M&T 1997, Hales 1999, USFWS and HVT 1999). The cumulative distributions of different age willow rooting depths were compared to characteristic particle sizes (i.e., D_{84}, Figure 18) in the locations where the seedlings were sampled. At the Steiner Flat pilot bank rehabilitation site (RM 91.9), the D_{84} ranged from 121–149 mm along the low flow channel margin where encroachment was likely to occur (M&T 1997, USFWS and HVT 1999, Bair 2001b). When compared to the cumulative root distributions, 99% of the YOY seedlings' rooting depths were shorter than 149 mm; 60% of 1-year-old seedlings and roughly 40% of 2-year-old seedlings had roots equal to or shorter than 149 mm (meaning that 40% of 1-year-old seedlings and 60% of 2-year-old seedlings had roots longer than 149 mm).

5.2.5 Woody Plant Demographics and Berm Formation

Nine pilot bank rehabilitation sites were used for evaluating woody plant demographic studies and geomorphic monitoring (e.g., marked rocks, scour chains, cross sections). Pilot bank rehabilitation sites that were occupied during the early geomorphic study period continued to be monitored during the 1998–2004 period, although geomorphic and vegetation monitoring was not conducted at pilot bank rehabilitation sites in 2004. Woody plants were sampled within band transects along one or two cross-sections at each site. Monitoring was conducted during the summer.

Band transects were used to evaluate woody riparian plant demographics and physical mechanisms affecting those demographic trends at pilot bank rehabilitation sites from 1995–2004 (M&T 1997, Bair 2001b, M&T and HVT 2003, HVT and M&T 2004, M&T 2004, HVT and M&T 2006). Band transect sampling designs readily associate water surface elevation and streamflow relationships with riparian vegetation colonization patterns. Band transect data are useful for describing local riparian vegetation conditions that include age and species locations relative to the low water channel. Three transects were sampled at three pilot bank rehabilitation sites between 1994 and 1997. After 1997, one cross section was sampled at each of nine pilot bank rehabilitation sites. Transect data were collected in the spring prior to maintenance flow releases and again in late summer to capture the effect of maintenance flow releases.

Each band transect was installed perpendicular to flow, along a cross section that spanned the channel. Cross section topography and water surface elevation for the maximum, minimum and various other streamflows were surveyed. Data collected at each band transect included species, stem DRC, stem age, stem height, and stem location. If a woody stem was dead, it was noted, and if the mortality agent was known, it was documented.

Marked rocks and scour cores or scour chains were placed adjacent to the band transect so that the results would reflect surface and subsurface mobility trends along the band transect and results could be related to observations of riparian seedling changes. The location of seedling mortality, rock mobilization, and subsurface scour and deposition was documented and related to the largest magnitude flood experienced since the seedlings were last sampled (and when mobility and scour experiments were installed).

The 1995–2004 period included wetter periods and drier periods, and the effects of wet year and dry year persistence on woody plant demographics were measured and evaluated. The 1995–2000 period was unusually wet (Figure 7), with six consecutive water years above Normal (Table 3). Six consecutive wet years had not occurred in the period of record until that time (Figure 7). After WY 1998, TRD releases did not exceed 5,500 cfs until 2002. Flood peaks that did occur during this time period on the mainstem were from winter tributary floods (Figure 19) and were insufficient to cause seedling mortality (Table 4). In 1997 and 1998, late December rain-on-snow events generated large floods and prolonged inundation (Figure 19).

Table 3. Water year classes and peak streamflows for the USGS Trinity River gages at Lewiston, Douglas City, and Junction City during the WY 1995 to WY 2004 period.

Water Year	Water Year Class Based on April 1 Inflow Forecast	Instantaneous Maximum Lewiston (RM 112.1) Streamflow (cfs)	Instantaneous Maximum Douglas City (RM 92.8) Streamflow (cfs)	Instantaneous Maximum Junction City (RM 79.6) Streamflow (cfs)
1993	WET	3,270	No Data	No Data
1994	CRIT DRY	1,630	No Data	No Data
1995	EXT WET	7,060	No Data	15,800
1996	WET	6,390	7,300	8,800
1997	WET	6,970	24,000	30,000
1998	EXT WET	6,190	13,100	17,600
1999	WET	2,000	2,650	3,410
2000	WET	5,430	6,500	7,300
2001	DRY	2,140	4,400	No Data
2002	NORMAL	6,570	5,940	8,590
2003	NORMAL	2,780	6,240	9,170
2004	WET	6,350	9,540	14,900

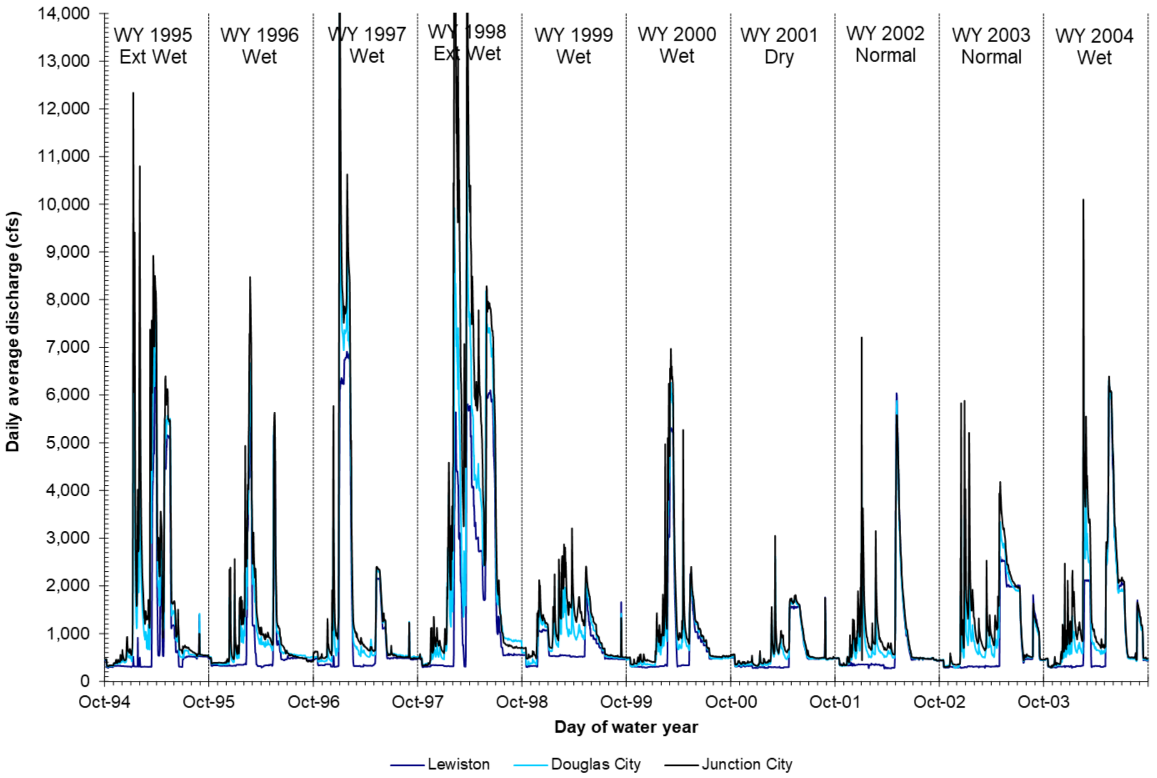


Figure 19. Daily average discharge hydrographs for the USGS Trinity River gages at Lewiston, Douglas City, and Junction City for the WY 1995–2004 period.

Narrowleaf and dusky willows were always the most abundant woody species sampled along band transects and generally initiated within the capillary fringe of the 450 cfs water surface. Red and Pacific willows were the second most abundant, arroyo willows and alders were uncommon, and cottonwoods were rare. Species abundance could be directly related to streamflow conditions during seed dispersal. Alder and arroyo willow seeds were released during the winter baseflow period, when tributary-induced floods with rapid streamflow recession created variable and unpredictable substrate availability, thus contributing to these species' uncommonness. Cottonwoods dispersed seeds during the time-period when flow releases had the greatest rate of change and magnitude (i.e., during TRD high flow releases). Red and Pacific willow seed dispersal occurred in late spring and early summer and often overlapped with the onset of stable summer baseflows. Narrowleaf willow had the longest seed dispersal period, which overlapped with the period of stable summer baseflow and exposed surfaces that were within the capillary fringe of the 450 cfs water surface elevation.

Through 2004, the seedlings that germinated and started growth after June 15 (i.e., YOY) were always the most abundant age class in the summer samples, and the 1-year-old age class was always the most abundant in the spring. Scour and desiccation mortality agents were observed during this period. Inundation mortality was not observed. Desiccation mortality accounted for about 5% of the YOY seedlings in the summer samples, while scour mortality accounted for 87 to 98% of documented mortality. The mortality in age classes between spring and late summer samples indicated that younger plants tended to be more vulnerable to scour than older plants at the same location. Woody plant germination and establishment was limited to the area of the bank below the 2,000 cfs water surface elevation. The upper limit of woody plant establishment was approximately 1.0–1.5 ft above 450 cfs, or the upper capillary fringe limit for fine- and medium-textured sands.

Table 4. Summary of water year classes, peak streamflows and associated cohort survival and mortality during the 1993–2004 period, prior to implementation of ROD streamflows. The "ROD Assigned Magnitude" column shows the annual release magnitude recommended in the ROD for each water year based on the April 1 inflow forecast.

Water Year	Water Year Class Based on April 1 Inflow Forecast	ROD Assigned Magnitude (cfs)	Actual Maximum Daily Average Lewiston Release (cfs)	Instantaneous Maximum Lewiston Streamflow (cfs)	Closest Magnitude ROD WY Class Equivalent	Associated Scour Threshold	Cohorts Scoured	Surviving Cohorts
1993	WET	8,500	3,070	3,270	DRY	No scour mortality	None	1992 cohort
1994	CRIT DRY	1,500	1,610	1,630	CRIT DRY	No scour mortality	None	1992, 1993 cohort
1995	EXT WET	11,000	6,890	7,060	NORMAL	1-year-old and YOY	1994 cohort	1992, 1993 cohort
1996	WET	8,500	6,290	6,390	NORMAL	1-year-old and YOY	1995 cohort	1992, 1993 cohort
1997	WET	8,500	6,910	6,970	NORMAL	1-year-old and YOY	1996 cohort	1992, 1993 cohort
1998	EXT WET	11,000	5,990	6,190	NORMAL	1-year-old and YOY	1997 cohort	1992, 1993 cohort
1999	WET	8,500	1,980	2,000	CRIT DRY	No scour mortality	None	1992, 1993 and 1998 cohort
2000	WET	8,500	5,310	5,430	NORMAL	1-year-old and YOY	1999 cohort	1992, 1993 and 1998 cohort
2001	DRY	4,500	1,678	2,140	CRIT DRY	No scour mortality	None	1992, 1993, 1998, and 2000 cohort
2002	NORMAL	6,000	6,040	6,570	NORMAL	1-year-old and YOY	2001 cohort	1993, 1998, and 2000 cohort
2003	NORMAL	6,000	2,610	2,780	CRIT DRY	No scour mortality	None	1993, 1998, 2000 and 2002 cohort
2004	WET	8,500	6,200	6,350	NORMAL	1-year-old and YOY	2003 cohort	1993, 1998, 2000 and 2002 cohort

Narrowleaf willow seedlings became established during the period of lower flows from 1999–2002. Narrowleaf willow established in high enough densities to re-encroach the channel and plants were large enough to survive scour and mechanical damage when flows exceeded 6,500 cfs in 2002 (Bair 2003). Fine sediment was observed to be preferentially deposited in the establishing willow band and topographic surveys at six of the nine pilot bank rehabilitation sites showed that a fine sediment berm had begun to reform (Figure 20, Figure 21).

It was apparent that that even though floods did not remove 100% of any age seedling, a seedling density threshold existed beyond which floods could not scour enough seedlings away to restrict encroachment. Below a certain seedling density threshold, woody plants did not form a homogenous band of woody plants along the low water edge. Plant establishment during the 1999–2002 period crossed the plant density threshold required to re-instigate encroachment and berm formation.

The lack of flood flows during the 1999–2002 period and measured results at pilot bank rehabilitation sites reinforced the conclusion that seedlings in the first years of life are the most important to manage, because in the absence of flood flows, they were able to grow in just a few years beyond the ability of subsequent modest flood releases to scour them away (i.e., a small window of time was available to manage establishing seedlings).

Riparian woody plant encroachment onto open cobble surfaces during 1998–2000 emphasized the importance of annual scouring floods. Data collected between 1995 and 2004 indicated that seedlings growing close to the summer low water surface are the most prone to scour and pose the highest encroachment threat if not scoured away annually.

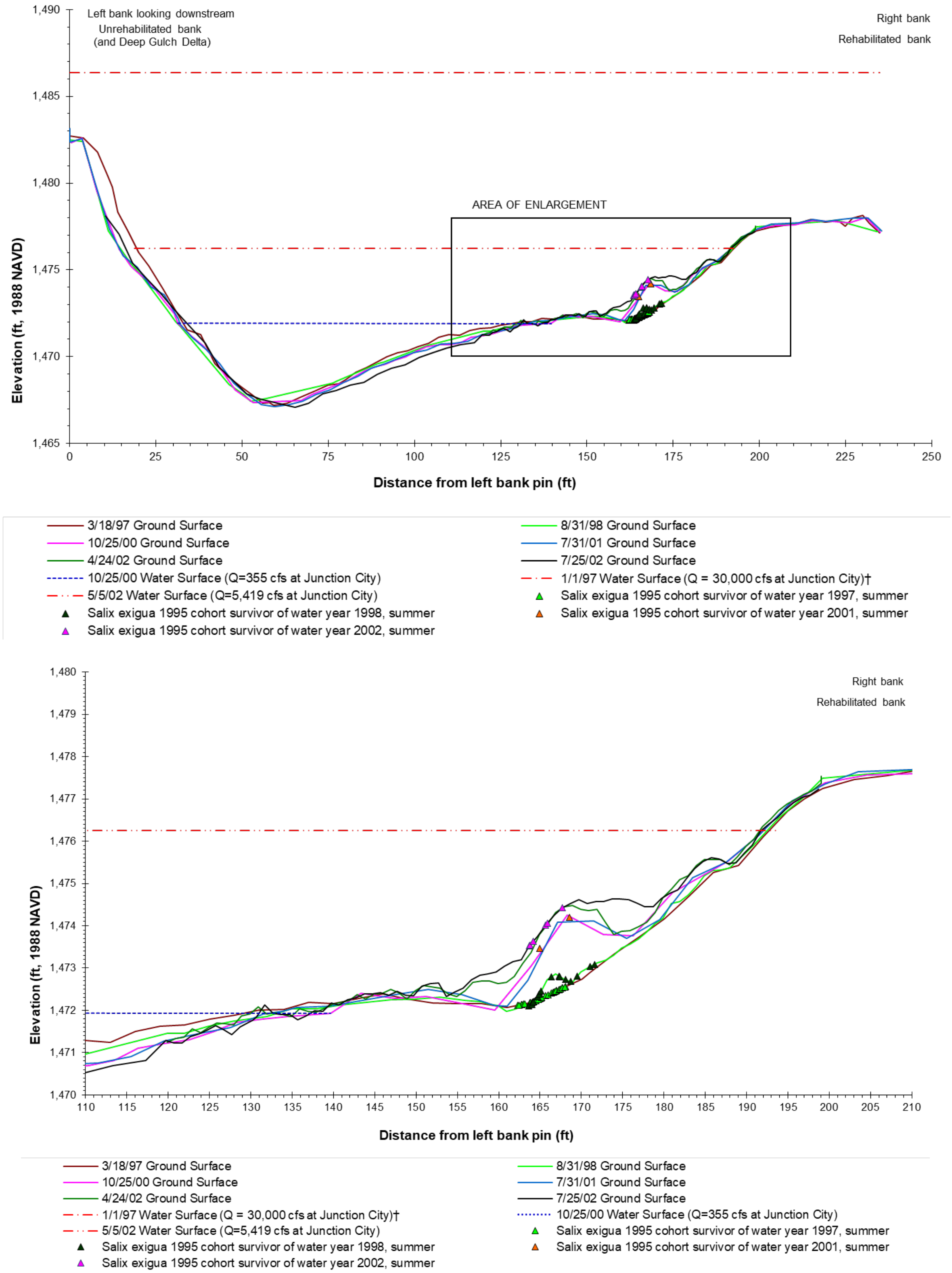


Figure 20. WY 1995 cohort seedling establishment during the 1999–2002 period and incipient berm development at one cross section at the Sheridan Creek pilot bank rehabilitation site. (Top) Entire cross section length. (Bottom) Enlargement of WY 1995 cohort establishment area. Note the developing berm in the WY 2000 ground surface, corresponding to the location of narrowleaf willow seedling initiation in WY 1995.

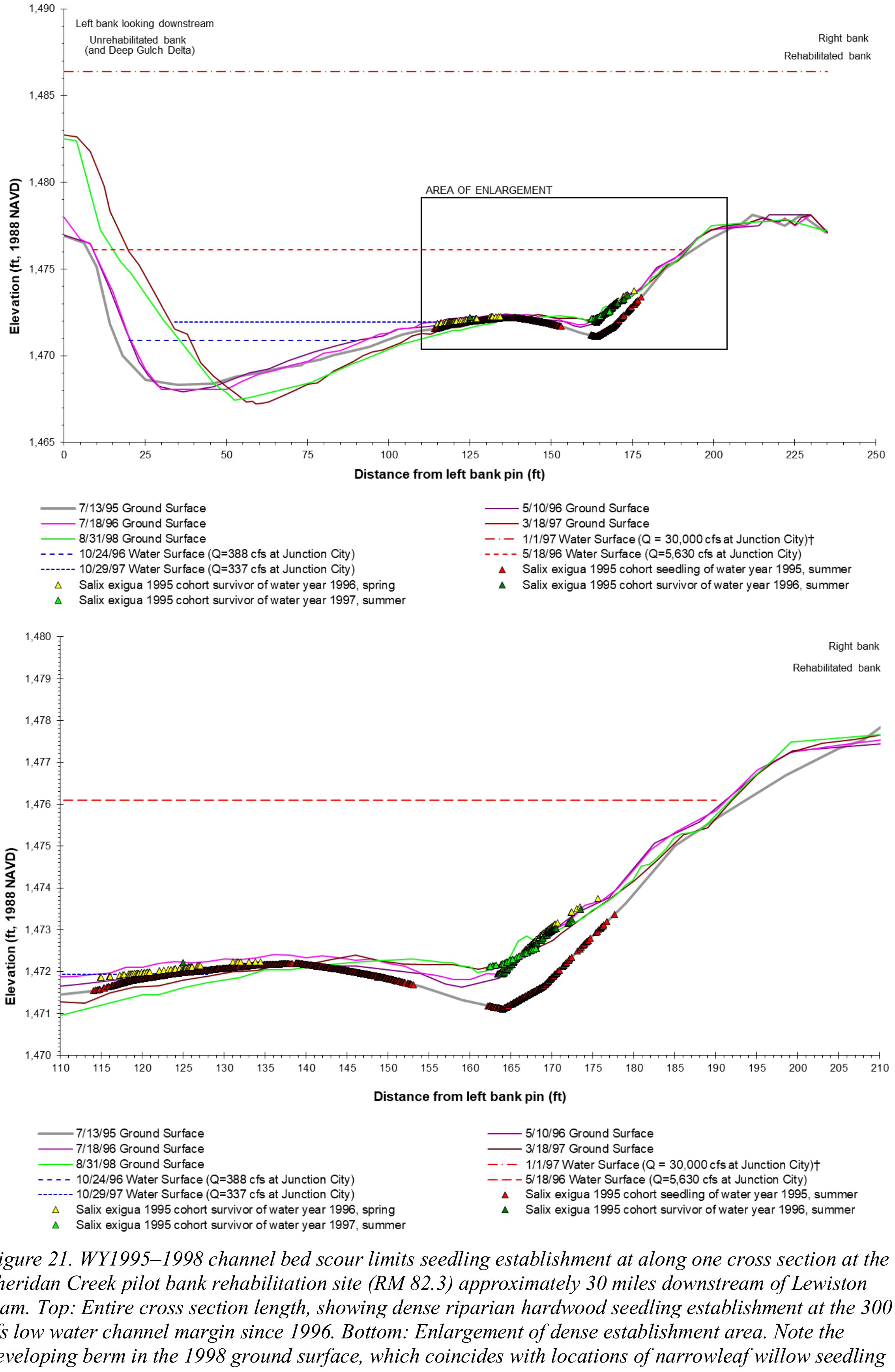


Figure 21. WY1995–1998 channel bed scour limits seedling establishment at along one cross section at the Sheridan Creek pilot bank rehabilitation site (RM 82.3) approximately 30 miles downstream of Lewiston Dam. Top: Entire cross section length, showing dense riparian hardwood seedling establishment at the 300 cfs low water channel margin since 1996. Bottom: Enlargement of dense establishment area. Note the developing berm in the 1998 ground surface, which coincides with locations of narrowleaf willow seedling establishment.

5.3 Synthesis of Early Studies (1991–2004)

The results of the sediment transport, geomorphic, and woody plant demographic studies were integrated. Seeds need fine sediment to germinate and grow (Karrenberg et al. 2015). If the substrate is too coarse, a seed cannot germinate. Finer-sized materials have higher capillarity and support first-year germination and growth better than coarser materials such as sand (Reid et al. 1987). Woody plant demographic studies conducted at pilot bank rehabilitation sites in the 1990s found that over 90% of willow seedlings occurred on coarse to fine sands (i.e., more than 15% of the particle size distribution was smaller than 2 mm (Bair 2001b). Therefore, an abundance of fine sediment creates more nursery areas where narrowleaf and dusky willows could colonize and become established. Reducing the fine sediment supply could provide a way to reduce initiation and establishment of willows near the low flow channel margin.

Younger establishing plants with root lengths approximately the depth of the channel bed surface layer (i.e., depth of D_{84}) were especially prone to mortality when the channel bed was mobilized. Marked rock studies combined with woody plant and topographic changes indicated that a flow of 6,000 cfs began to mobilize exposed point bar surfaces, and when mobilized, 60–90% of 1-year-old and younger plants were removed (M&T 1997, Bair 1998, Bair 2003). After the first growing season, root lengths continued to increase in subsequent years but not as substantially as root volume did. When mortality was documented in older age classes, it was always associated with deeper scour. Managed flow releases of 6,000 cfs could mobilize the channel bed but did little to scour the subsurface. Measured scour depths and topographic changes indicated that flows above 8,500 cfs measured downstream at Junction City caused subsurface scour, but that that flows between 11,000 cfs and 14,000 cfs were required to cause scour and redeposition beyond 300 mm (or approximately the depth of two D_{84}'s). Roughly 70% of 3-year-old plants have roots that are less than 204 mm (Figure 18). While there were no measured 3-year-old plants in 1996 when the first flows greater than 8,500 cfs were measured at Sheridan Creek (RM 82.3), it was inferred that the measured scour would have been sufficient to remove 3-year-old plants. The geomorphic data collected during the 1995–2000 period indicates that there is a lateral limit of scour where the shear stress tapers off and the channel bed is not mobilized. The lateral limit of seedling scour coincided with peak shear stress locations measured during the bedload transport measurement (Figure 15). This result suggests that there will always be a location at the lateral limit of shear stress where vegetation may be able to establish. Peak flows in WY 1997 and 1998 verified that gravel bar scour and redeposition at pilot bank rehabilitation sites could scour establishing seedlings (Table 4; M&T 1997, Bair 1998, Bair et al. 2003).

6 TRINITY RIVER FLOW EVALUATION REPORT AND THE RECORD OF DECISION

Managed high flow releases and field studies conducted after the 1981 Andrus decision (summarized in Section 5) were compiled and analyzed in the TRFE (USFWS and HVT 1999). The TRFE was completed in 1999 and recommended streamflow, sediment, and mechanical management actions, and AEAM to expedite the recovery of shallow, slow-velocity juvenile anadromous habitat (USFWS and HVT 1999). In 2000, Secretary of the Interior Bruce Babbitt signed a Record of Decision (ROD) that adopted TRFE recommendations and directed the formation of the TRRP (DOI 2000). The TRRP was tasked with implementing the ROD to restore the Trinity River and its populations of salmon, steelhead, and other fish and wildlife. Hypotheses and strategies for achieving the envisioned dynamic alluvial river (scaled to the new ROD flow regime) are detailed in the TRFE, which is summarized in the following sections. Specific hypotheses in the TRFE related to riparian vegetation and its effects on river morphology and channel dynamism are the focus of this discussion.

6.1 TRFE Restoration Strategy

The TRFE strategy focuses on restoring a scaled-down, dynamic, and complex channel morphology on the Trinity River as a foundation for fisheries restoration. The TRFE placed considerable value on mobile gravel bars, sloping banks, and channel migration. The process of bar building and channel migration was thought to have the greatest potential for increasing and maintaining Chinook Salmon (*Oncorhynchus tshawytscha*) fry and juvenile habitat. The TRFE also identified the portion of exposed gravel bars and channel margins between 450 and 2,000 cfs as the most vulnerable to the effects of detrimental riparian encroachment (Figure 22). Measuring the cause-and-effect mechanisms that instigate or inhibit vegetation encroachment and whether the identified thresholds were creating and maintaining juvenile salmonid habitat was considered fundamental to evaluating management action effectiveness and conducting riparian vegetation-related adaptive management. The TRFE identified that the narrow rectangular channel that had formed within the channel margin with vegetation encroachment was the reason for decreased juvenile anadromous fish habitat availability between 450 and 2,000 cfs (Figure 12; USFWS and HVT 1999). The TRFE presented results that showed how post-TRD riparian vegetation had influenced channel morphology and inhibited fluvial processes that would have historically maintained channel complexity. The TRFE included specific management actions that would reduce and inhibit dense, homogenous, continuous, encroaching vegetation. Removing and inhibiting encroaching vegetation was seen as a means of recovering a less uniform channel morphology than existed post-TRD. Discouraging riparian establishment along the low water channel margin to prevent riparian encroachment was one ROD objective.

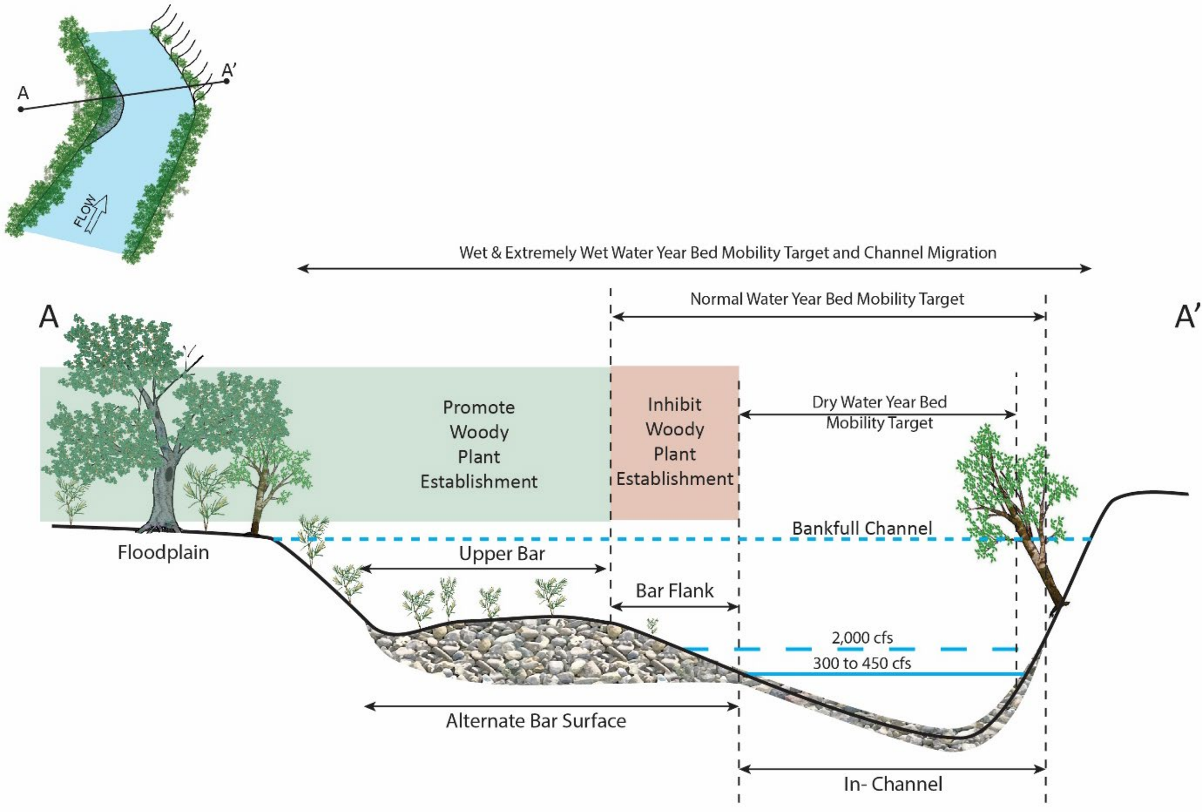


Figure 22. Bank zones where TRFE actions intended to inhibit or promote woody plant establishment. The bankfull channel is approximated by the $Q_{1.67}$ flood, which varies depending on location within the Restoration Reach.

The TRFE characterized the Trinity River as a single-thread, meandering river, and utilized an alternating bar sequence as a conceptual physical framework to illustrate desirable outcomes and benefits of rehabilitating the attributes of an alluvial river (USFWS and HVT 1999, Trush et al. 2000, DOI 2000). It was hypothesized that the restoration of a variable streamflow regime (including flood peaks for geomorphic work), coarse and fine sediment management, and channel rehabilitation could restore key river processes that could rework the channel bed and banks. An alluvial river that was smaller in scale than the pre-TRD river would be self-maintaining after active rehabilitation activities (i.e., mechanical channel manipulation) ceased.

The TRFE recognized that constraints from urbanization, infrastructure, sediment supply, and water and power needs would likely preclude restoration of a system of similar scale to the pre-TRD Trinity River mainstem. Contemporary peak flows (approximately 13,750 cfs) are limited by the Trinity Dam outlet works, which is about an order of magnitude less than historic peak flows. In addition, summer baseflows are held constant (450 cfs) for at least half of the riparian plant growing season and are substantially larger than historic summer baseflow magnitudes (100 to 300 cfs).

Reducing woody plant establishment along the low water margin and thereby avoiding riparian encroachment and berm re-formation, was initially identified in the TRFE and further detailed in the Environmental Impact Statement/Report (CH2MHill 1999, U.S. Fish and Wildlife Service and Hoopa Valley Tribe 1999). The TRFE restoration strategy recognized that riparian vegetation was an important habitat component for fishes and wildlife, but that vegetation growing along the summer baseflow channel could also potentially have a detrimental effect on rehabilitated areas, and that riparian encroachment that could not be removed through TRD releases alone already affected much of the river. Inhibiting future riparian encroachment was thought to be a crucial part of maintaining gradual sloping banks and gravel bars (an indicator of a complex channel morphology) once they were created. Riparian encroachment was identified as a process that could potentially have a deleterious effect on the Programmatic goal of restoring juvenile salmonid habitat.

The TRFE identified and the ROD adopted three broad management actions: channel rehabilitation, sediment augmentation, and managed spring streamflows, to create a future river that is scaled to a new regulated flow and sediment regime, with many of the attributes associated with an alluvial river. It was hypothesized that increasing juvenile anadromous fish habitat area and availability via the rehabilitation of a smaller-scale alluvial river would boost anadromous fish production (USFWS and HVT 1999, DOI 2000). Improved flow releases, coupled with physical channel rehabilitation and sediment management, were to act together to restore many alluvial river attributes to the mainstem that would improve the quantity and quality of juvenile fish habitat in the river bank region below 2,000 cfs (USFWS and HVT 1999, Trush et al. 2000, DOI 2000).

The restoration strategy outlined in the TRFE relied on a one-time mechanical alteration of the channel banks that would be maintained through variable streamflows and sediment management. Channel rehabilitation was considered a viable means of creating juvenile Chinook Salmon rearing habitat following the evolution of nine pilot bank rehabilitation sites after construction and monitoring results of high flows from 1993–1998 (Section 5). Strategic riparian vegetation removal and riverbank recontouring to pre-TRD morphology, but with smaller dimensions scaled to the new ROD flow regime, were the primary mechanical rehabilitation actions described in the TRFE to alter the riverbank slope and create more fry and juvenile rearing habitat.

6.2 Streamflow Management

Streamflow restoration was a primary management action described in the TRFE and adopted in the ROD. The ROD flow releases are an important control on riparian vegetation patterns and processes. Streamflow can be used as a mortality agent, inducing scour of smaller plants to prevent or limit encroachment. It can also be used to promote germination and establishment of desirable plant species by providing geomorphically suitable germination sites and adequate soil moisture to support growing plants. Several aspects of streamflow contribute to its versatility as a management tool and can be manipulated to achieve desired riparian outcomes, such as reduced detrimental encroachment and increased establishment on higher geomorphic surfaces. Inter-annual (i.e., year-to-year) variability often dictates flow magnitude of ROD releases, which can in turn be fine-tuned to promote or discourage riparian plant growth. Intra-annual (i.e., within-year hydrograph components) variability often dictates flow timing of ROD releases and can be used strategically to meet various salmonid, wildlife, and riparian vegetation management objectives.

6.2.1 Inter-annual Variability

The TRFE used water year variability and associated variable flood peaks as an important part of creating and maintaining a complex channel. Peak streamflow magnitude varied by year, and the water year classification was used to characterize inter-annual variability. Five water year types were defined using annual runoff volumes (Figure 6). Flood peaks associated with each water year class had the same probability of occurrence (i.e., would occur at the same frequency) as the water type with which they were associated. An Extremely Wet year and Critically Dry year could occur 12 times every 100 years, while a Normal year could occur 20 times in 100 years. The frequency of flood peaks that could scour young riparian seedlings was dependent on the future sequencing of water year types. For example, if a few drier water years occurred and flood peak magnitudes did not reach scour thresholds, it was hypothesized that detrimental riparian encroachment thresholds would be surpassed.

6.2.2 Intra-annual Variability

Five hydrographs were developed based on water year class (Figure 23). Water year classes were intended to capture the variability in annual runoff and used to assign riparian objectives to different water years. Proposed hydrographs could potentially expand the riparian corridor relative to pre-ROD conditions, but the post-ROD riparian corridor would still be narrower than pre-TRD. However, a richer and more expansive riparian vegetation was possible with streamflow restoration than historically existed pre-TRD, or as a result of 30 years of highly regulated pre-ROD streamflows.

The TRFE and ROD provided considerable flexibility in scheduling and planning annual flow releases. The TRFE acknowledged that in many years, winter floods often exceeded geomorphic thresholds and acted as the primary encroachment-limiting factor. However, the TRFE also recognized that tributary accretion was largely the cause of winter floods downstream of TRD, and that upstream of Weaver Creek, winter tributary accretion was often insufficient to surpass geomorphic thresholds at the desired frequency.

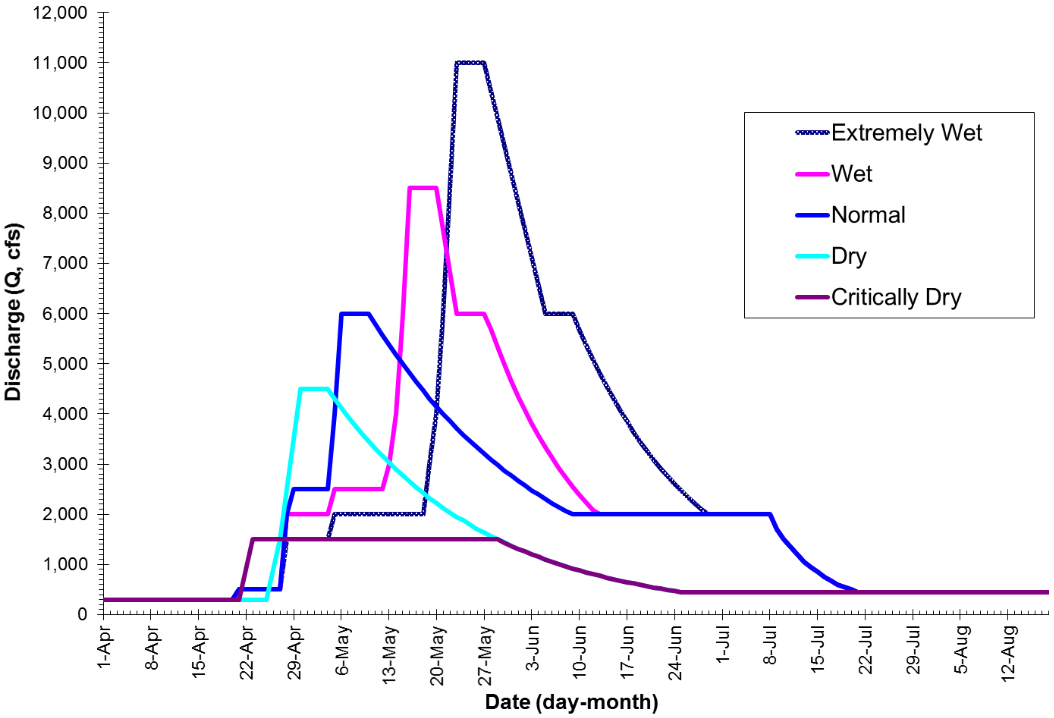


Figure 23. Five water year-specific hydrographs developed in the TFRER (USFWS and HVT 1999) and adopted in the ROD (DOI 2000).

Rather than rely solely on winter flood peaks to do the geomorphic work, the TRFE relied on managed flood releases to consistently and frequently cross geomorphic thresholds and do the majority of the physical work throughout the entire Restoration Reach. The ROD allowed for flood peaks to be greater than those recommended for a given water year type as long as the managed ROD release did not exceed the overall water volume assigned to that water year class.

One source of inter-annual variability that could be used to manage riparian vegetation encroachment is variable summer baseflows. Post-TRD summer baseflows are considerably higher than before the TRD was built. McBain & Trush (1997) recommended in the *Trinity River Maintenance Flow Study Report* that managed summer baseflows should follow a pre-TRD pattern, with flows reaching as low as 50 cfs in drier years and increasing overall variability to promote scour of seedlings, namely narrowleaf willow, establishing in the low water channel. However, this recommendation was not adopted by the TRFE or the ROD due to RWQCB water quality regulations (i.e., maximum allowable temperature targets). Therefore, summer baseflows within the Restoration Reach are currently managed at a constant 450 cfs or higher to maintain cold water temperatures that benefit salmonids. A reconsideration of variable summer streamflows could improve the Program's ability to manage riparian vegetation encroachment in below Normal water years.

6.2.3 Water Year-specific Objectives

The TRFE included annual flow hydrographs that were semi-reflective of pre-TRD snowmelt hydrographs, rescaled to the type of water year (Figure 23). Normal and wetter year objectives focused on increasing woody plant species and age class diversity on upper bars and floodplains and discouraging riparian vegetation initiation along the low channel margins. Objectives in drier years focused on inundating lower geomorphic surfaces for longer periods to prevent seeds from landing on them and germinating (Table 5).

Table 5. Bed mobility, bed scour, riparian seedling scour, and riparian seedling initiation and establishment objectives from TRFE Table 8.2 (primary fluvial geomorphic and riparian management objectives for the Trinity River by water year class) and TRFE Tables 8.5 through 8.9 (recommended releases from Lewiston Dam with management targets, purpose, and benefits during Extremely Wet through Critically Dry water years).

Objective	**Critically Dry**	**Dry**	**Normal**	**Wet**	**Extremely Wet**
	(Q_{peak} = 1,500 cfs)	**(Q_{peak} = 4,500 cfs)**	**(Q_{peak} = 6,000 cfs)**	**(Q_{peak} = 8,000 cfs)**	**(Q_{peak} = 11,000 cfs)**
Bar Flank Bed Mobility	(None)	Mobilize the surface of in-channel alluvial features (e.g., spawning gravel deposits).	Mobilize D_{84} particles on general channel bed surface and along flanks of alternate bar surfaces.	Mobilize D_{84} particles on alternate bar surfaces.	Mobilize D_{84} particles on flanks of alternate bar surfaces.
Bar Flank Bed Scour	(None)	(None)	Channel bed scour and redeposition of gravels.	Channel bed scour greater than 1× D_{84} depth and redeposition of gravels.	Channel bed scour greater than 2× D_{84} depth and redeposition of gravels on face of alternate bars.
Bar Flank Riparian Seedling Scour	Discourage germination of riparian plants on lower bar surfaces for the early portion of the seed release period.	Discourage germination of riparian plants on bar flank for the early portion of the seed release period.	Woody riparian vegetation mortality up to 1-yr old along bar flank of alternate bar surfaces.	Woody riparian vegetation mortality up to 2-yr old along bar flank of alternate bar surfaces.	Woody riparian vegetation mortality along low water edge of alternate bar surfaces; scour up to 3-yr old woody riparian vegetation along channel margins and scour younger plants higher on bar flanks.
Upper Bar and Floodplain Riparian Establishment	(None)	(None)	Woody riparian regeneration on upper bar surfaces.	Woody riparian regeneration on upper alternate bar surfaces and floodplains.	Woody riparian regeneration on upper alternate bar surfaces and floodplains.
Large Wood Storage	(None)	(None)	(None)	Increase riparian vegetation and future large wood recruitment.	Increase riparian vegetation and future large wood recruitment.
Promote Riparian Germination Lower in the Channel via Lower Summer Baseflows	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria

6.3 Channel Rehabilitation Site Design

Construction of the nine pilot bank rehabilitation sites removed entire plants, including roots, and placed a surface layer of cobbles to recreate habitat for emergent salmonid fry. Willows were not observed to be re-sprouting from any root masses that remained after construction. The initial responses measured at pilot bank rehabilitation sites suggested that mechanical rehabilitation could be used to accelerate river recovery and reduce the effects of vegetation encroachment.

Mechanical rehabilitation that removed encroaching vegetation and constructed gently sloping banks was one of three primary management actions described in the TRFE and adopted in the ROD. The TRFE identified 44 locations where mechanical rehabilitation via vegetation clearing and bank recontouring would remove vegetation encroachment and construct sloping channel margins to facilitate rescaling of the channel dimensions to the ROD flow regime. A one-time rehabilitation approach, similar to that used at the nine pilot bank rehabilitation sites, was intended to remove encroaching vegetation on one side of the river or the other in small areas. ROD high flows would then further remove encroaching vegetation upstream and downstream of the initial mechanical removal and increase the area of channel without encroachment. The mechanical rehabilitation visualized in the TRFE was to occur rapidly (i.e., within five years).

When the first channel rehabilitation sites were designed, instream rehabilitation activities were not included. Hocker Flat was the first channel rehabilitation site constructed (2005), and designs included gently sloping channel margins (i.e., feather edges) and constructed “benches” that were inundated 1 ft deep at 5,000 cfs (i.e., floodplains). In 2007, instream rehabilitation activities were added to designs, including gravel bars, constructed meanders, and side channels. The net result after construction was a low flow channel that was narrower, and a bankfull channel that was wider than before construction.

6.4 Sediment Management

Sediment management is also a principal management action intended to rescale, reform and sustain the post-ROD alluvial river. The combination of streamflow and sediment management could affect the mainstem physical form and function systemwide. Fine sediment reduction and coarse sediment augmentation would be used to rehabilitate gravel bar size and frequency, aid in floodplain formation and evolution, and construct nursery and rearing sites for fish, plants, and animals.

6.4.1 Fine Sediment Management

Decades of land management activities and forest management practices on highly erodible decomposed granite accelerated erosion and sediment supply to the Trinity River mainstem in several tributary watersheds downstream of TRD. In 1992, the U.S. Environmental Protection Agency (EPA) listed the Trinity River as a 303(c) impaired water body due to the excessive volume of sand in the mainstem. A threshold for the total mean daily load of fine sediment was defined for the mainstem Trinity River (EPA 2001).

In the absence of high flows after the TRD was completed, fine sediment from tributaries deposited in the Trinity River and was infrequently transported. Thirty years of near-constant streamflows were incapable of transporting the total volume of fine sediment contributed by tributaries, which resulted in fine sediment storage increasing in the channel bed and the areas immediately adjacent to the channel. Establishing willows and other woody plants roughened the channel margins and slowed the water sufficiently to promote deposition and sediment berm formation. Sand filled formerly deep pools in the mainstem.

During the 1990s, specific management actions were directed at reducing tributary fine sediment contribution. Highly erodible decomposing granite slopes were planted, and roads were rehabilitated in many watersheds. Grass Valley Creek is the largest tributary watershed whose lithology is predominantly decomposed granite. The Buckhorn Sediment Dam was built in the upper Grass Valley Creek watershed to retain fine sediment and reduce delivery to the Trinity River. Two additional in-channel ponds (i.e., the Hamilton Ponds) were built near the Grass Valley Creek confluence with the mainstem to retain fine sediment. Fine sediment was regularly removed from Hamilton Ponds and stockpiled nearby through the early 2000s.

Measures to reduce fine sediment supply have been very effective and fine sediment has been reduced in the Restoration Reach (Gaeuman and Krause 2013). Between the mid-1970s through 1991, fine sediment was dredged from pools in the Trinity River; reductions in upslope supply have resulted in the cessation of fine sediment management within the Trinity River mainstem channel (Krause et al. 2010). Although fine sediment supply has been reduced in tributaries, fire or land management that could eliminate or reduce vegetation ground cover or canopy interception in a watershed with decomposed granite could increase fine sediment supply until a watershed is revegetated. Given the recent Carr Fire, fine sediment delivery from adjacent hillsides may increase in the next few years; therefore, it should not be assumed that fine sediment is no longer a management issue.

Fine sediment within the mainstem is stored on floodplains, riparian berms, and within the surface matrix of gravel, and can be easily transported at low rates by modest flows (1,000 cfs). It is also easily deposited, especially in areas of increased roughness. For example, the roughness associated with younger seedlings has been observed to influence fine sediment deposition on the receding limb of flood flows (Bair 2003). It is hypothesized that lower magnitude floods that do not mobilize coarse sediment but do mobilize fine sediment cause the greatest volume of fine sediment to deposit within establishing plants (i.e., berm formation).

6.4.1 Coarse Sediment Management

The TRFE identified that the coarse sediment supply from the watershed above the TRD was being retained behind the dams, and that downstream of Lewiston Dam, infrequent Safety of Dams releases had mobilized the smaller size fractions (gravels), resulting in an overly coarse, immobile, armored channel bed. A Coarse Sediment Management Plan was developed in 2007 to refine the volumes, augmentation rates, and locations developed in the TRFE. The reach from Lewiston Dam to Indian Creek was identified in the TRFE as having the lowest coarse sediment storage, and it was therefore identified as a priority reach for coarse sediment augmentation. A scaled-down coarse sediment augmentation size range (⅜–5-inch diameter) was developed to be mobile by ROD high flow releases in Normal and wetter water years. Coarse sediment augmentation rates were developed to increase the amount of sediment available for transport and storage. Minimum augmentation volumes ranged from 22,630 tons in Extremely Wet years to zero in Critically Dry water years (Table 6). Coarse sediment augmentation was intended to provide sufficient supply to increase coarse sediment storage over time and decrease the overall active channel particle size distribution. In addition to increasing storage (i.e., gravel bars), decreasing the active channel particle size distribution would allow ROD high flow releases to mobilize the channel bed, with the additional benefit of inhibiting riparian seedling establishment and encroachment through more frequent mobilization.

Although coarse sediment retained by TRD is a primary component of the reduced coarse sediment supply in the upstream reaches near TRD, overall coarse sediment supply was increased by mining activities. Placer mining between 1848 and the late 1940s contributed orders of magnitudes more fine and coarse sediment than would have been delivered naturally (Krause et al. 2010). The amount of sediment delivered to the mainstem in a little over 100 years was the equivalent yield of about 1,400 years of naturally-derived sediment. Aggradation raised the channel bed by an estimated 16 ft between Oregon Gulch and the North Fork Trinity River (Krause et al. 2010). Two primary and several smaller sediment wedges were identified in a detrended longitudinal profile. The largest upstream sediment wedge is located between Indian Creek and Weaver Creek. The distribution of the riffle crests associated with the sediment wedges suggests that alluvial channel patterns may have developed in locations that otherwise would have been bedrock or less alluvial overall (Buffington et al. 2014). Although TRFE did not specifically include the sediment yield associated with the mining legacy nor its effects on the longitudinal profile of the river, the TRFE did identify the mainstem between Lewiston and Indian Creek as having the lowest coarse sediment storage.

Table 6. Recommended and actual coarse sediment augmentation volumes since 1998 (from Krause 2012, Gaeuman 2020).

Water Year	Water Year Class Based on April 1 Inflow Forecast	TRFE Minimum Recommendation (U.S. Tons)	Actual Total Augmentation (U.S. Tons)	Difference (U.S. Tons)
2000	WET	13,700	2,781	–10,919
2001	DRY	206	0	–206
2002	NORMAL	2,466	0	–2,466
2003	NORMAL	13,700	2,740	–10,960
2004	WET	13,700	0	–13,700
2005	WET	13,700	0	–13,700
2006	EXT WET	42,470	2,302	–40,168
2007	DRY	206	6,138	5,932
2008	NORMAL	2,466	17,002	14,536
2009	DRY	206	11,179	10,974
2010	NORMAL	2,466	22,454	19,988
2011	WET	13,700	7,288	–6,412
2012	NORMAL	2,466	0	–2,466
2013	DRY	206	2,329	2,124
2014	CRIT DRY	0	0	0
2015	DRY	206	3,781	3,576
2016	WET	13,700	4,932	–11,398
2017	EXT WET	42,470	7,672	–34,798
2018	CRIT DRY	0	0	0
2019	WET	13,700	4,795	–8,905
2020	CRIT DRY	0	0	0

The amount of gravel that has actually been augmented is substantially less than recommended. Gravel augmentation was recommended in reaches primarily above Indian Creek, particularly near the USGS gage and the USGS cableway in Lewiston. Gravel augmentation currently occurs near the USGS gage and at a location farther downstream at Lowden Meadows. The augmentation locations were identified for areas upstream of the sediment deposition attributed to legacy mining. Gravel augmentation was intended to restore sediment transport continuity that was interrupted by Lewiston Dam, large dredger-created pools, or deltaic deposits. The augmented gravel size class distribution was to be sized such that it would be frequently mobilized with ROD flood peaks and could reduce the D_{84} particle size in locations where augmentation occurred. Sediment augmentation could also increase local gravel storage (i.e., bar formation) within the low water channel, potentially confining the low water channel to the extent that channel bed scour would occur more frequently and over a broader area along the low water channel margin. A smaller D_{84} would lead to more frequent bed and bar scour and redeposition that in turn would reduce detrimental encroachment risk and improve the quantity and quality of Chinook Salmon and steelhead spawning habitat.

7 DETRIMENTAL ENCROACHMENT HYPOTHESES

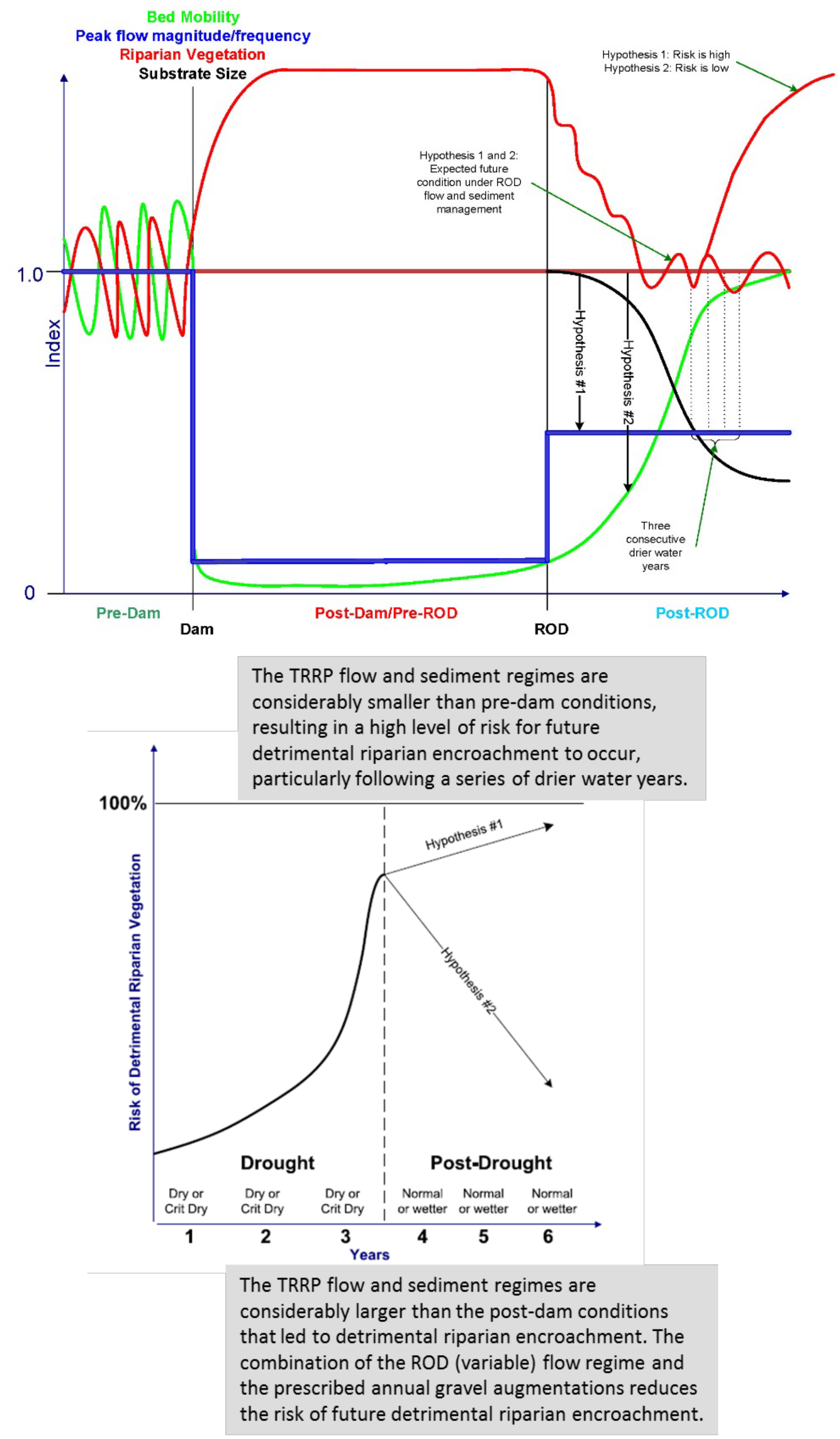
Five years of ROD streamflows did not lead to widespread removal of riparian berms and riparian vegetation encroachment as envisioned in the TRFE. This led to uncertainty regarding whether TRRP management activities (ROD flows, coarse sediment additions, and mechanical actions) will exceed fluvial (magnitude, duration, and frequency) and riparian (initiation, scour, desiccation) process thresholds frequently enough to inhibit detrimental riparian encroachment from influencing the topographic and structural complexity of the channel. There is also uncertainty, depending on the anticipated channel pattern, regarding the degree of risk associated with encroaching woody plants. Ideally the outcome of the TRFE management actions would be increased high-quality fish habitat that is maintained through time.

Two hypotheses regarding riparian encroachment risk were developed during IAP preparation (Figure 24; Appendix M of TRRP and ESSA Technologies 2009). Encroachment risk-related hypotheses were linked to the physical sub-objective of increasing physical habitat, since the quality and availability of aquatic habitat is assumed to be directly related to geomorphic complexity, among other factors (e.g., water temperature, food sources, flow; TRRP and ESSA Technologies 2009).

The first hypothesis is an outcome of monitoring and analyses that occurred during the early geomorphic and riparian studies and at pilot bank rehabilitation sites (Section 5). It assumes that the predominant anticipated channel pattern in the Restoration Reach is a single-thread channel. This hypothesis is integral to the TRFE, and many monitoring studies have been designed to test it. The first hypothesis states:

- Hypothesis (H_1): The post-ROD flow and sediment regimes are considerably less than pre-dam conditions, such that there are sequences of years where the risk of detrimental riparian encroachment over the long term is substantial.

Regime models such as those described in Millar (2005) suggest that channel width and depth adjust quickly to changes in water and sediment supply. Using theoretical regime equations (Millar 2005), it was expected that the low flow channel would widen where it is unconfined geologically or by infrastructure in response to the increase in annual water volumes released to the river below TRD when compared to pre-ROD conditions. However, increases in low flow channel width do not necessarily translate into high quality fish habitat (i.e., a wider deeper channel with no shallow margins persists). With increased width, channel confinement and fine sediment deposition may still form a berm when plants older than three years can establish in densities sufficient to instigate channel simplification, albeit further up the bank than under pre-ROD hydrology. The net result will be a wider deeper channel than existed pre-ROD. The effect of increased ROD flows may be to shift woody plant establishment slightly higher up the bank to ~1,000 cfs instead of at 450 cfs, where it occurred prior to the ROD. Since regime equations are sensitive to coarse sediment supply and bank strength, increasing coarse sediment supply could be one way to decrease the risk of detrimental encroachment.



The TRRP flow and sediment regimes are considerably smaller than pre-dam conditions, resulting in a high level of risk for future detrimental riparian encroachment to occur, particularly following a series of drier water years.

The TRRP flow and sediment regimes are considerably larger than the post-dam conditions that led to detrimental riparian encroachment. The combination of the ROD (variable) flow regime and the prescribed annual gravel augmentations reduces the risk of future detrimental riparian encroachment.

Figure 24. Competing detrimental encroachment hypotheses from the IAP (TRRP and ESSA Technologies 2009).

If the first hypothesis is borne out, then the risk of future encroachment exists, and management effort and resources will be required to inhibit the effects of woody plants establishing along the low water edge. For example, local scour could be promoted to create gaps in the dense band of colonizing vegetation, thereby keeping the vegetation from crossing detrimental encroachment thresholds and maintaining high quality fish habitat. Management actions directed at inhibiting detrimental encroachment will need to be followed up with semi-annual effectiveness monitoring.

The second hypothesis came about shortly after ROD flows were first implemented in 2005. There was disagreement between Program partners regarding the underlying mechanisms of berm formation and riparian encroachment, as well as the current state of encroachment within the Restoration Reach. The anticipated channel pattern associated with the second hypothesis was not explicitly stated. The second hypothesis was developed to counterbalance the perspective of the TRFE. To date, no studies have been developed to test the second hypothesis, which states:

- Alternative Hypothesis (H_2): The TRRP flow and sediment regimes are considerably more than the post-dam conditions that led to detrimental riparian encroachment and therefore will prevent detrimental riparian encroachment from occurring in the future.

From the perspective of hypothesis 2, where not confined geologically or by infrastructure, the bankfull channel has been widening compared to pre-ROD conditions in response to the ROD flow regime. The rate of widening is a function of the magnitude and frequency of streamflows above incipient erosion thresholds. Continued gravel augmentation at the recommended rates will likely result in enhanced modes of riparian vegetation mortality, a decrease in the median particle size, and an increase in the mobility of the bed, which in combination will result in greater topographic, particularly vertical, variability, a more sinuous low flow (< 1,000 cfs) channel, and greater frequency and magnitude of repeated geomorphic units. Fine sediment storage in the mainstem has been decreasing in response to the ROD flow regime and upslope fine sediment reduction. Although recent fires in the watershed could contribute additional upslope fine sediment as barren slopes erode, overall reduced fine sediment inputs are expected to continue into the future. In the medium- to long-term, the combination of the ROD flow regime and the prescribed annual gravel augmentations should reduce the risk of detrimental riparian encroachment, while enhancing geomorphic complexity.

If the second hypothesis is correct, then heterogeneous (patchy) riparian plant density will occur, reducing the risk of exceeding the riparian encroachment threshold and subsequent channel simplification. In other words, ROD hydrology, channel rehabilitation site construction, and gravel augmentation will create gaps in the dense band of colonizing vegetation and spatially lower densities; encroachment can be prevented, and high-quality fish habitat maintained. If the second hypothesis is borne out, then the risk of future encroachment is low and management effort and resources can be redirected elsewhere with little future monitoring.

8 IMPLEMENTATION OF THE ROD AND EVALUATION OF MANAGEMENT ACTION INFLUENCE ON ENCROACHMENT FROM 2005 TO 2017

Each hypothesis and a combination of management actions were evaluated in an AEAM context. However, in most instances, all streamflow management, sediment management, and channel rehabilitation activities occur simultaneously within a year. The ability to detect the effectiveness of one management action over another was confounded by the limitations of developing a sufficient number of replicate samples and contrasting the results. Management actions vary with water year type and long-term outcomes of each discrete year's actions could be affected by the persistence of wetter or drier years before and after.

Detecting the effect of one management action over another within the context of currently available data was difficult because not all management actions were implemented with the same frequency. In the discussion that follows, streamflow magnitude is the prevalent management action acting on encroaching plants outside of channel rehabilitation sites. Coarse sediment augmentation has not been implemented according to the schedule or in the quantities recommended in the TRFE; infrequent sediment augmentation prevented any comparisons between pre-and post-augmentation riparian encroachment, namely because the introduced sediment was not well transported by ROD flows. Mechanical rehabilitation has certainly affected riparian vegetation along the channel margin. To the extent possible, the effects of physical rehabilitation and response of riparian vegetation were also examined using currently available data. However, streamflows are considered as the primary management action to control encroachment.

Available monitoring data were reviewed and evaluated for four time periods: 1998–2004 (as described in Section 5.2), 2005–2009, 2010–2012, and 2013–2017. Survivorship of riparian hardwood cohorts and changes in cross section topography (when available) were compared to annual streamflow releases during the four time periods. The streamflow restoration component prescribed under the ROD was deferred for the first five years after the ROD due to litigation. In 2005, the first managed spring hydrograph using ROD water was released. The following sections describe the monitoring methods and results used during each time period and show the methodological changes that were made over time as part of the adaptive management process.

8.1 2005 to 2009

8.1.1 Sampling Design

Until 2004, all geomorphic and riparian monitoring had been conducted at pilot bank rehabilitation sites. In 2005, the first channel rehabilitation site was constructed at Hocker Flat. Between 2005 and 2009, geomorphic and riparian encroachment monitoring was conducted at channel rehabilitation sites before and after construction. Due to funding constraints and monitoring limitations imposed until a TRRP science framework was completed, riparian and geomorphic monitoring were not conducted in 2007 (a Dry year) or 2008 (a Normal year). Geomorphic and riparian monitoring sites were selected based on the number and type of design elements constructed (e.g., alcoves, side channels, feather edges, berm notches, gravel bars, floodplains) suitable to assesses changes in cohort abundance and distribution in areas where encroachment posed the greatest threat (e.g., cleared edges along the mainstem).

8.1.2 Method Revisions

During the 2005 to 2009 period, individual woody plants were sampled within band transects placed along the portion of the cross section that intersected cleared channel margins and/or gravel bars. Data collection and analysis methods remained similar to those used during the maintenance flow study period (1991–1995). Revisions were made to the analysis of seedling densities to allow for a better comparison of systemic trends between sites.

8.1.2.1 Seedling Density Within Index Flow Bins

At each band transect, woody plant location data collected along transects were translated into a cross section station and ground surface elevation (i.e., the coordinate system used in establishing the cross sections) using cross section data collected during geomorphic monitoring to create the topographic sequence (M&T and HVT 2004). Seedlings were overlaid on the cross section and seedling density and frequency for plant species computed (Bonham 1989, Kent and Coker 1992). Plant density (plants per sq ft, sq m, or hectare) was calculated within inundation bins defined by index flows.

Inundation bins were developed for each cross section using water surface elevation estimates developed from HEC-RAS modeling. The index flows used to define the upper and lower boundaries of inundation bins were 450, 2,000, 4,500, 6,000, 8,500, and 11,000 cfs. Analyzing woody plant establishment trends occurred in the following sequence:

1. The woody plant data were sorted into cohorts using field-estimated age;
2. Sampled woody plants were plotted onto the cross sections by cohort;
3. The location, age, and species were sorted into inundation categories (i.e., < 450, 450–2,000, 2,000–4,500, 4,500–6,000, 6,000–8,500, 8,500–11,000, and >11,000 cfs, respectively);
4. Woody plant densities within each inundation category were calculated for the transect using band transect area within each inundation bin (Bonham 1989, Kent and Coker 1992); and
5. Changes in woody plant densities for different ages between the fall of one year and following fall were quantified, and the physical causal mechanisms were assessed (i.e., channel bed mobility, and bed scour and deposition that caused the changes in cohort distribution).

8.1.3 Relationship of Biologic and Physical Data Trends to Management Actions

Monitoring was conducted in three out of five years during the 2005–2009 period. Water year 2006 was an Extremely Wet year (Table 7). Although infrastructure improvements to allow an 11,000 cfs TRD release were not completed in 2006, peak flow releases exceeded 10,000 cfs at Lewiston (Table 7). The WY 2006 flood peak was the largest magnitude event during the 2005 to 2009 period. Peak flows during 2007 did not exceed 5,000 cfs and peak flows in 2009 did not exceed 6,500 cfs (Table 7).

Table 7. Water year classes and peak streamflows for the USGS Trinity River gages at Lewiston, Douglas City, and Junction City during the WY 2005–WY 2009 period.

Water Year	Water Year Class Based on April 1 Inflow Forecast	ROD Assigned Magnitude (cfs)	Instantaneous Maximum Lewiston Streamflow (cfs)	Instantaneous Maximum Douglas City Streamflow (cfs)	Instantaneous Maximum Junction City Streamflow (cfs)
2005	WET	8,500	7,640	7,980	8,540
2006	EXT WET	11,000	10,400	12,500	16,700
2007	DRY	4,500	4,810	4,810	4,490
2008	NORMAL	6,000	6,890	7,510	7,210
2009	DRY	4,500	4,630	6,090	6,500

Thirteen channel rehabilitation sites were constructed between 2006 and 2009 (Table 8). The Hocker Flat channel rehabilitation site was constructed in fall 2005, making it the first rehabilitation site constructed post-ROD (Table 8). The first seed dispersal following construction was thought to be the most likely to colonize cleared surfaces and most likely to establish if channel bed mobility or deep scour thresholds (> $2 \times D_{84}$ in depth) were not achieved with the frequency prescribed in the TRFE. Seedling demographics were monitored at Hocker Flat in WY 2005 prior to construction and WY 2006 following construction (M&T and HVT 2004, HVT and M&T 2006). Monitoring was expanded to include eight other sites constructed by WY 2009 (Alvarez et al. 2015). Below we present a subset of results that are typical of the sites monitored during this period.

Table 8. Channel rehabilitation sites constructed during the WY 2005 to WY 2009 period.

Site	Year Constructed	First Cohort that Could Colonize the Surface
Hocker Flat	2005	2006 cohort
Lewiston Hatchery Coarse Sediment Augmentation	2006	2007 cohort
Lower Conner Creek	2006	2007 cohort
Elkhorn	2006	2007 cohort
Pear Tree Gulch	2006	2007 cohort
Valdor Gulch	2006	2007 cohort
Indian Creek	2007	2008 cohort
Dark Gulch	2008	2009 cohort
Lewiston 4 (Sven Olbertson, Deadwood Creek, Cableway, and Hoadley Gulch)	2008	2009 cohort
Sawmill	2009	2010 cohort

Berm formation was not documented at cross sections during the 2005–2009 period, though narrowleaf willow encroachment was documented. Narrowleaf willow seedlings germinated and established between the 450 and 2000 cfs water surface elevations (Figure 25). The 2006 peak flow scoured the unvegetated channel margins and managed releases in the spring focused on promoting cottonwood germination following the 10,000 cfs flood peak. WY 2007 was a Dry year. Narrowleaf willow seedlings that germinated in summer 2006 would not have been scoured during 2007; flood peaks during 2007 were insufficient to induce channel bed scour (Table 9). WY 2008 was a Normal water year class and flood peaks did not exceed 7,000 cfs. While 7,000 cfs was capable of scouring the 2007 cohort, it was not capable of scouring the 2006 cohort. A Dry year followed in 2009. Peak flows did not exceed 5,000 cfs at Lewiston, though reached 6,500 at Junction City. Peak flows of 6,000 cfs would have been able to scour the 2008 cohort, but not the 2006 cohort. The result of water year sequencing and associated flood peaks between 2005 and 2009 was that the 2006 narrowleaf and dusky willow cohort was able to survive past three years old and establish in the 450 to 2000 cfs bank region (Table 9). Hocker Flat was the only constructed channel rehabilitation site in 2006 and as such was the only location where mechanically cleared channel margins would have been susceptible to seedling establishment and re-encroachment. Flows exceeded 6,000 cfs at Douglas City in 2009. One-year-old seedlings would have been scoured at channel rehabilitation sites downstream of Weaver Creek, where tributary inputs would have increased flow magnitude, but survived upstream (e.g., the Indian Creek channel rehabilitation site; Alvarez et al. 2015).

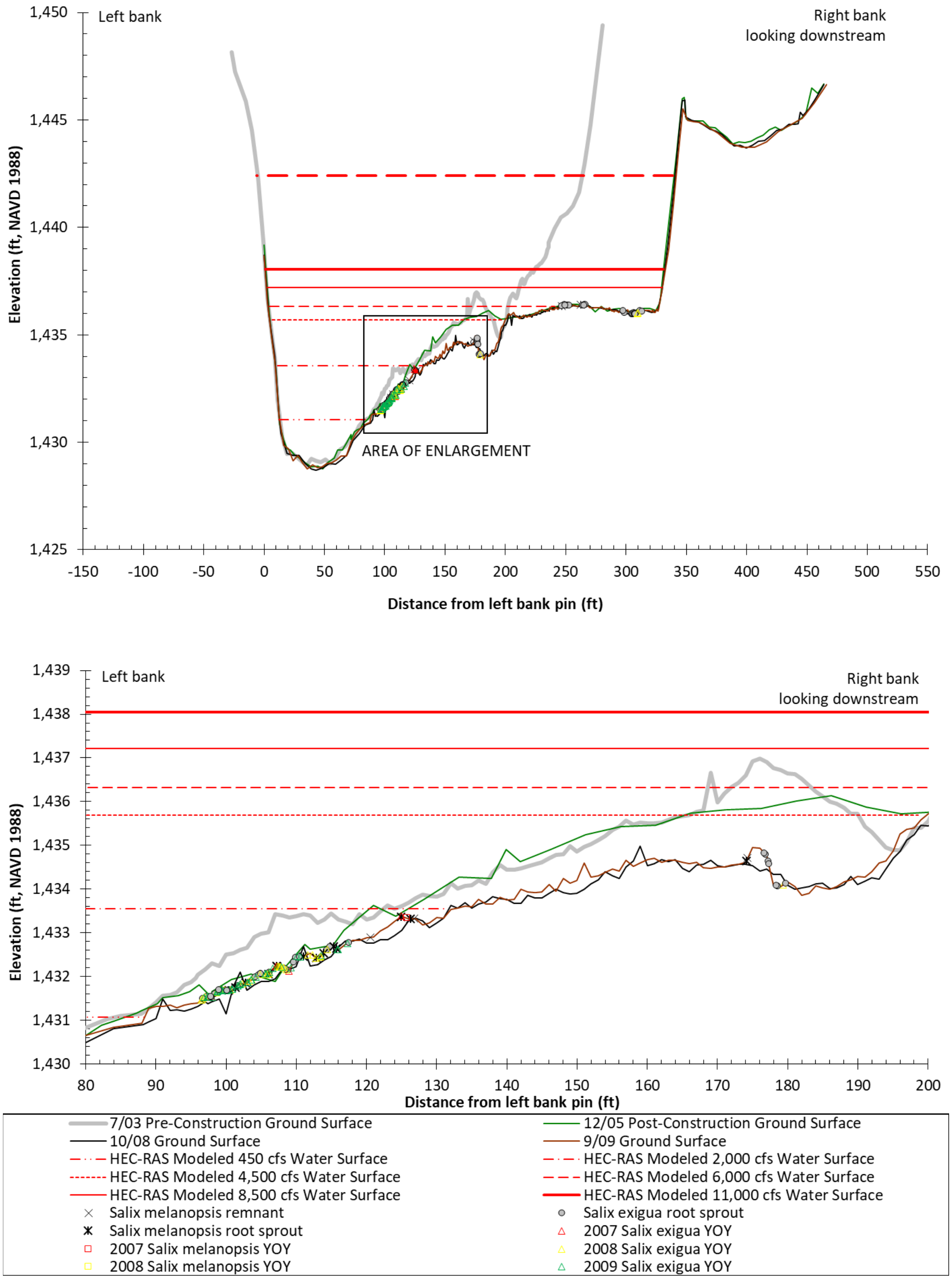


Figure 25. WY 2007–WY 2009 seedling establishment at Hocker Flat cross section 326+90 (Jim Smith pilot bank rehabilitation site cross section 12+00). (Top) Entire cross section length, showing pre-construction ground surface, post-construction ground surface, and location of seedling establishment. (Bottom) Enlarged portion of Hocker Flat channel rehabilitation site cross section 326+90 showing WY 2007–WY 2009 seedling establishment on bank locations between 450 and 2,000 cfs.

Table 9. Summary of water year classes, peak streamflows, and associated cohort survival and mortality during the 2005–2009 period.

Water Year	Instantaneous Maximum Lewiston Streamflow (cfs)	Cohorts Scoured	Surviving Cohorts	Persisting Cohorts
2005	7,640	2004 cohort	None	1993, 1998, 2000 and 2002 cohort
2006	10,400	2003, 2004, and 2005 cohorts	None	1993, 1998, 2000 and 2002 cohort
2007	4,810	None	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort
2008	6,890	2007 cohort	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort
2009	4,630	None	2006 and 2008 cohort	1993, 1998, 2000, 2002, 2006 and 2008 cohort

The five years of monitoring at channel rehabilitation sites indicated that narrowleaf willow shoots regrowing from roots that remained after construction (i.e., resprouts) were larger and grew faster than willow seedlings of a similar age. At all sites constructed between 2005 and 2009, vegetation clearing and grubbing was surficial and did not remove all of the roots associated with encroaching willows at constructed channel rehabilitation sites. Narrowleaf willow was observed to be resprouting from remaining roots. Resprouting willows grew in the same bank location and often grew to a similar size as before construction in under three years (Figure 26). Willow regrowth was therefore more of an encroachment problem than seedling establishment at the early channel rehabilitation sites. TRFE streamflow magnitudes may be capable of removing seedlings with shorter root lengths and volumes but could not be expected to remove willows regrowing from much older and sizable root systems that remained after construction.

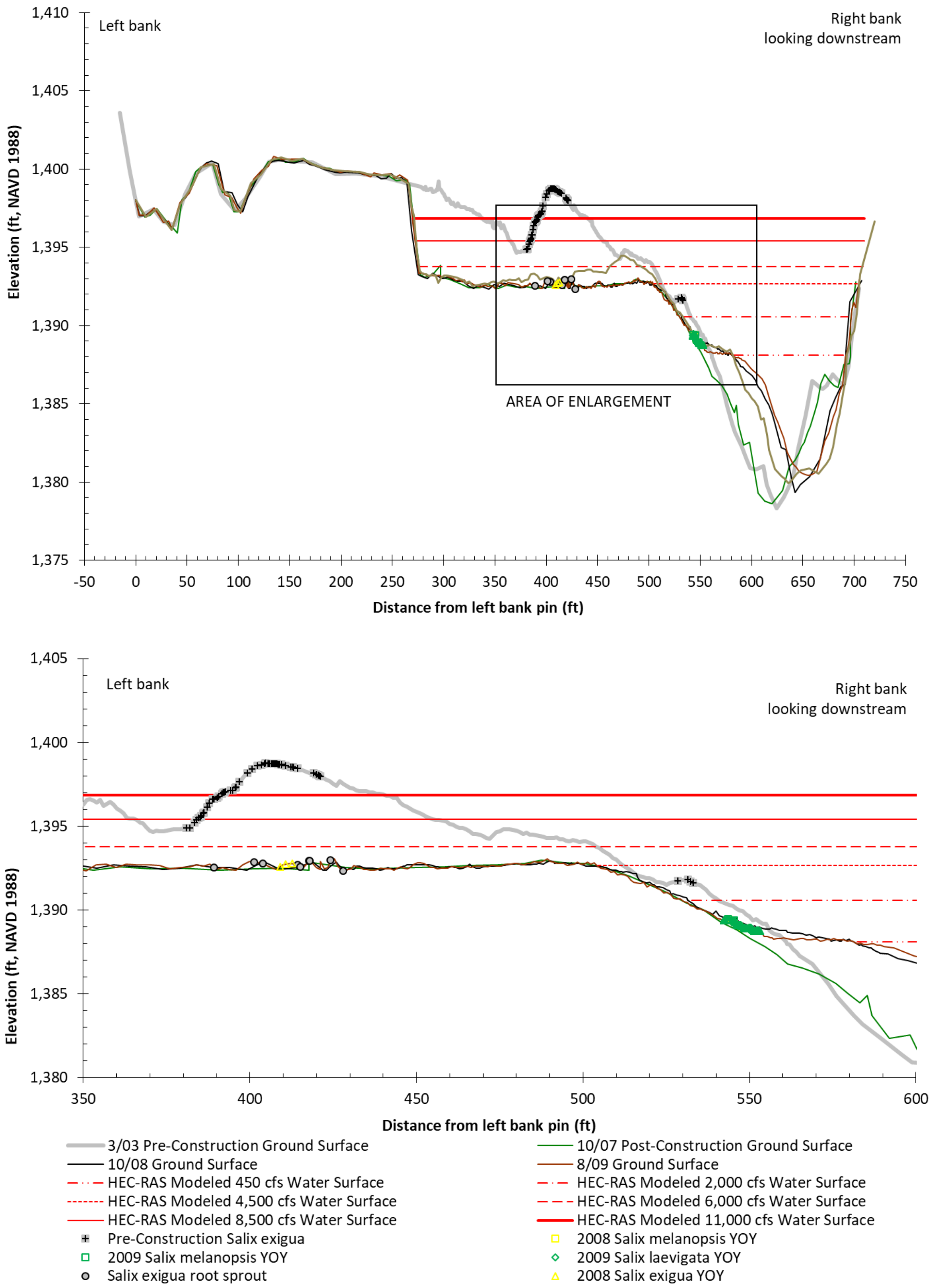


Figure 26. WY 2008–WY 2009 seedling establishment and root regrowth locations at Valdor Gulch cross section 141+20. (Top) Entire cross section length, showing pre-construction ground surface and plant locations, post-construction ground surface, and locations of seedling establishment. (Bottom) Enlarged portion of Valdor Gulch channel rehabilitation site cross section 141+20 showing WY 2008–WY 2009 seedling establishment and root regrowth locations relative to the pre-construction narrowleaf willow established shrub locations.

In 2007, the first perennially flowing side channel that was longer than half a meander wavelength was constructed at Indian Creek. Several entrances and exits were included in the side channel, in case one was to plug. In addition to the side channel, floodplain benches were constructed. The Indian Creek channel rehabilitation site was a departure of the mechanical rehabilitation envisioned in the TRFE. The design left encroaching plants in place and did not widen the mainstem channel; instead, the mainstem channel margins remained vegetated and woody plant establishment on exposed side channel margins and constructed floodplain benches was seen as a benefit.

8.2 2010 to 2012

The IAP was completed in 2009. Objectives specific to riparian vegetation were derived from the TRFE during the development of the IAP (TRRP and ESSA Technologies 2009), the guiding technical document for applying AEAM within the TRRP. IAP riparian objectives are linked to fish production, fish habitat, and wildlife habitat objectives; and also encompass the primary riparian regulatory requirement of replacing an equal amount of vegetation removed during channel rehabilitation projects. Channel rehabilitation site-specific monitoring used prior to 2010 was abandoned for a sample design that was spatially balanced and allowed evaluation of systemic trends.

8.2.1 Sampling Design

From 2010 to 2012, the sampling strategy and framework described in Chapter 4 of the IAP were followed to select study sites for riparian encroachment monitoring (TRRP and ESSA Technologies 2009). The sampling strategy was used for evaluating systemic changes within the Restoration Reach. Both geomorphic and riparian monitoring were completed under the systemic sampling strategy.

Systemic sampling between 2010 and 2012 employed the generalized random tessellation stratified (GRTS) sampling design to address status and trends within the upper Restoration Reach, building on efforts that were recommended in the IAP (TRRP and ESSA Technologies 2009) and initiated in WY 2009 (Alvarez et al. 2015). The sampling universe was defined as the Trinity River from Lewiston Dam to the confluence with the North Fork Trinity River, which contained five panels (Panel 1 through Panel 5) consisting of 16 individual GRTS segments 400 m long, all spaced uniformly within the Restoration Reach (Table 10). Monitoring was conducted at two cross sections selected within the limits of each GRTS site. Sites were selected using a rotating panel revisit design, which was initiated in 2009 for fish habitat studies only and adopted in 2010 for geomorphic and riparian studies. The rotating panel design was intended to sample two panels within each year; in the following year of sampling, one of the panels was repeated and one new panel was added until all five panels were sampled. The process was then repeated as the first panel was sampled again and the pattern continued. Six segments within each panel were monitored for a total of twelve segments annually.

Table 10. The GRTS rotating panel design was adopted in 2010 for geomorphic process and riparian studies. The ellipsis after 2018 indicates the pattern of sampling continues through time.

GRTS Panel	Water Year										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	…
1	X	X			X	X				X	
2		X	X			X	X				
3			X				X	X			
4			X	X				X	X		
5				X	X				X	X	
….											…

8.2.2 Method Revisions

During the 2010 to 2012 period, individual woody plants were sampled within band transects placed along the portion of the cross section that intersected open exposed channel margins and/or gravel bars within each GRTS segment. Data collection methods remained similar to past years. However, rather than utilize a field determined age for a stem, the age of the stem was assigned based on a size class to address the size differences between a 1-year-old seedling and a 1-year-old willow resprout. The analyses were also revised from portraying demographic changes along cross sections to a tabular seedling density summary in inundation categories (<450, 450–2,000, 2,000–4,500, 4,500–6,000, 6,000–8,500, 8,500–11,000, and >11,000 cfs) to allow for comparisons between sites and comparing year-to-year differences.

8.2.2.1 Root Collar Diameter Size Relationship to Seedling Age

The TRFE flood peaks were targeted at seedlings and not resprouting stems. Scouring a resprouting willow requires a considerably larger streamflow than a willow seedling of a similar age. During the 1995–2009 period, stem age was used to describe the structural composition of riparian vegetation along the band transect, especially at the low water edge. Field estimation of stem age was a problematic metric for evaluating encroachment risk, especially at channel rehabilitation sites where vegetation was removed from the channel edge and willows resprouted. For instance, a 1-year-old willow seedling is almost always smaller than a 1-year-old willow stem growing from a pre-existing root structure (i.e., a “root-sprout”); the seedling must create its own new root system from scant resources available in a seed the size of a pepper fleck, whereas a root-sprout has a well-developed root system to draw from. An analysis based on age alone could potentially mischaracterize the encroachment risk from 1-year-old plants, since true seedlings may be scoured by flows that are incapable of scouring the 1-year root sprouts. At sites where channel rehabilitation has not occurred, this is less of a problem. However, since the GRTS sample universe may include channel rehabilitation sites, riparian woody plant demographic trends became based on diameter at root collar (DRC) rather than stem age. Since 2010, riparian woody plant demographic trends were analyzed using the measured DRC for woody plants sampled within band transects. Fortunately, DRC is strongly correlated with stem age ($R^2 = 0.72$, $p<<0.001$; Figure 27) and thus, size classes based on DRC are roughly equivalent to age classes (Table 11). Diameter at root collar better represents the stem size to be scoured and is a highly repeatable measurement. (HVT and MA 2012)

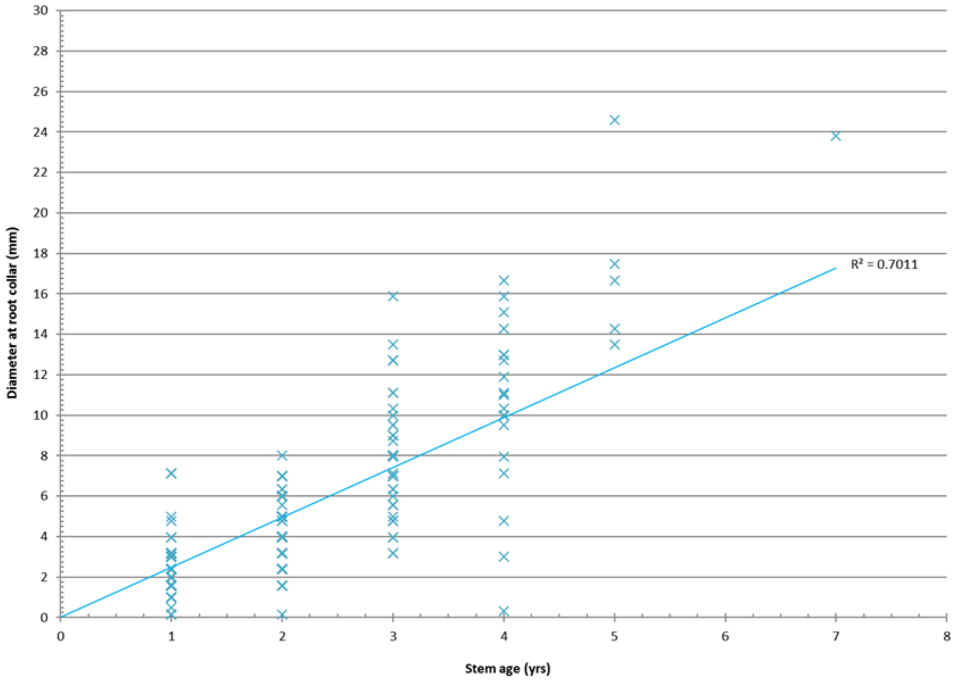


Figure 27. Relationship between stem age and stem diameter at the root collar (DRC).

Table 11. Size classes and associated dominant plant age of hardwoods measured at GRTS panel sites.

Size Class (cm)	Dominant Plant Age	Q to Remove	WY Type to Remove	Risk Code	Risk Description
0.0–0.25	Young-of-Year	6,000 cfs	Normal and wetter	Green	Moderate risk, these hardwoods should be watched to evaluate if they get to the 2-yr old stage; no modification of the hydrograph needed
0.26–0.50	1-year-old	6,000 cfs	Normal and wetter	Green	Moderate risk, these hardwoods should be watched to evaluate if they get to the 2-yr old stage; no modification of the hydrograph needed
0.51–0.75	2-year-old	8,500 cfs	Wet and wetter	Yellow	High risk, 8,500 cfs suggested for that year; may recommend subtle adjustments to hydrograph release for that given water year
0.76–1.0	3-year-old	11,000 cfs	Extremely Wet	Red	Extreme Risk, 11,000 cfs suggested that year; may need to modify hydrograph release for that given water year
1.01–1.50	4-year-old	Unlikely to remove with flows alone	N/A	Grey	Beyond what ROD streamflows are expected to remove
1.51–2.0	5-year-old	Unlikely to remove with flows alone	N/A	Grey	Beyond what ROD streamflows are expected to remove

The root collar is the location along a stem where the above-ground portion of the stem transitions into the roots and is characterized in most plants as a welt or slightly raised portion between the stem above ground and the roots. Internally, the stem vascular morphology changes as well. In an environment where there is frequent scour and deposition, the root collar may become exposed or buried and adventitious roots may arise. When the root collar cannot be easily found along a stem, some excavation is conducted around the stem to find the root collar without disturbing surrounding plants or growing roots. The substrate is replaced after the root collar is measured. If no root collar can be identified, the stem is measured at the soil–air interface. Most shrubs were easily identified as individuals by a single trunk-like stem or centralized point from which multiple stems arose. Stems emerging from the ground singly could represent individual plants or sprouts from an underground horizontally oriented root (i.e., root sprouts). Individual stems were distinguished from root sprouts using a pull test: the stem was gently tugged near the root collar; tugging on a root sprout caused other stems growing from the same root to move in response, while individual stems did not cause other stems to move. While the pull test is generally reliable at determining an individual stem from a root sprout, misclassifications sometimes occurred.

The age of individual riparian woody plant stems was estimated during root collar measurement. Riparian woody plant stems were classified into YOY, 1-year-old, 2-year-old, 3-year-old, and older than 3 years. To be considered YOY woody plants, cotyledons or cotyledon scars had to be present and stems usually did not exceed 0.25 cm DRC. One-year-old woody plants (in the second growing season) may have had a broken stem if mechanically damaged by flows, or a terminal bud scar, and/or stem discoloration. Usually 1-year-old woody plants are small and do not exceed 0.50 cm DRC. Two-year-old woody plants (in the third growing season) may have had multiple broken stems if mechanically damaged by flows, or two terminal bud scars, and/or stem discoloration between each year’s growth. Two-year-old woody plants usually do not exceed 0.75 cm DRC. Three-year-old woody plants (in the fourth growing season) may have multiple broken stems if mechanically damaged by flows, or three terminal bud scars, and/or stem discoloration between each year’s growths. Three-year-old woody plants usually do not exceed 1.0 cm DRC. Woody plants older than three years (stems in the fifth growing season) may have had multiple broken stems if mechanically damaged by flows, or four terminal bud scars, and/or stem discoloration between each year’s growth. Woody plants older than three years usually exceed 1.0 cm DRC. The change in the stem density between age classes relies on DRC as the primary variable to estimate an age class. The field-estimated age was used as a secondary estimate.

Analyzing woody plant establishment trends occurred in the following sequence:

1. The woody plant data were sorted into size classes using DRC (Table 11);
2. Sampled woody plants were plotted onto the cross sections by DRC size classes;
3. The location, DRC size class, and species of successful initiating woody plants was sorted into inundation categories (i.e., < 450, 450–2,000, 2,000–4,500, 4,500–6,000, 6,000–8,500, 8,500–11,000, and > 11,000 cfs, respectively);
4. Woody plant densities within each inundation category were calculated for the transect (Bonham 1989, Kent and Coker 1992);
5. Changes in woody plant densities for different DRC size classes between the fall of one year and following fall were quantified and the physical mechanisms that caused the changes in DRC size class distribution were assessed; and
6. Encroachment risk was evaluated using the density of seedlings of each DRC size class within inundation categories along the low flow channel.

8.2.2.2 Evaluating Encroachment Risk

Woody plants establishing on lower bars between 450 cfs and 2,000 cfs were identified in the TRFE as posing the greatest encroachment risk, whereas woody plants growing on upper bars and floodplains contributed to desirable floodplain vegetation. Generally, woody plants will encroach the low water edge and may induce berm formation if they establish below the 2,000 cfs water surface elevation (Bair 2003). Woody plant demographic studies continued to indicate that woody plants in the 3-year-old size class (e.g., those plants with DRCs falling between 0.76 and 1.0 cm DRC) were the woody plant size class that posed the greatest threat of becoming permanently established below 2,000 cfs. If a 3-year-old woody plant survived to the fourth year, it would become established. Extremely Wet water year flood peaks (e.g., streamflows near or exceeding 11,000 cfs) achieving deep subsurface scour could totally or partially remove the 3-year-old size class. Extremely Wet year classes occurred during the period of record at a frequency of about once every 12 years.

Encroachment risk was assessed at GRTS panel sites using a “red-yellow-green” evaluation for different size classes of woody plants growing above 300 cfs between WY 2010 and 2012. Using size classes and associated dominant plant age of hardwoods measured at GRTS panel sites, each size class was assigned a risk color code as part of the red-yellow-green evaluation (Table 11). Woody plants in the 3-year-old size class were coded red to indicate that they had the highest risk of becoming established between 450 and 2,000 cfs. Woody plants belonging to the 2-year-old size class (e.g., 0.51–0.75 cm DRC) were coded yellow, because they may induce encroachment but are still vulnerable to channel bed surface scour caused by ROD streamflows of 8,500 cfs or greater. Woody plants belonging to the YOY and 1-year-old size classes, ranging from 0–0.50 cm DRC, were coded green, because they are highly susceptible to channel bed surface scour induced by flows of 6,000 cfs or greater. Woody plants belonging to size classes larger than 1.0 cm DRC growing below 2,000 cfs were coded grey, as they had passed beyond the threshold of scour that can be induced by managed streamflow releases alone. Woody plants greater than 4-years old are expected to grow to maturity, unless local physical and hydraulic conditions exist to create deeper scour or mechanical damage, leading to death. Although woody plants greater than 1.0 cm DRC may not be considered vulnerable to vertical scour, it was important to include them in the analysis to understand whether other factors (e.g., lateral scour) that were originally considered in the TRFE or management actions could induce mortality to larger size woody plants. The streamflow required to reduce detrimental riparian encroachment was estimated in addition to a color code assignment. Woody plants growing above 2,000 cfs were always coded green because the establishment of riparian woody plants on upper bars and floodplain surfaces was considered to be beneficial.

One drawback to using a red-yellow-green type of analysis is that it focuses on the presence or absence of an age class without context of density. Patchy woody plant establishment along the low water margin is desirable, yet the presence of a given age class (i.e., 3-year-old) made the encroachment threat high regardless of how many individuals were present. A few establishing woody plants were not capable of encroachment and channel narrowing; however, many woody plants establishing could encroach and narrow the low water channel.

A second method was developed to evaluate the risk of detrimental riparian encroachment at monitoring sites. It was hypothesized that if establishing plant densities could be kept below the 1999–2003 establishing densities, then encroachment could be effectively inhibited, as described below. Woody plant density at GRTS sites was compared to plant densities that crossed preliminary encroachment thresholds calculated from data collected in the 1998–2003 period at the Sheridan Creek pilot bank rehabilitation site cross section 497+50 (i.e., XS02+35; Table 12). Sheridan Creek was constructed in 1993 and consisted of riparian berm removal. Band transect and topographic monitoring between 1995 and 2003 showed the riparian berm had reformed by WY 2002 as a result of riparian woody plant initiation and establishment that began in WY 1995.

Preliminary encroachment thresholds were based on plant densities calculated for all plants measured below 2,000 cfs as described above. This analysis was limited by sample size (n = 1 site); however, it provided a preliminary range of known stem densities that led to detrimental riparian encroachment and subsequent berm formation at a site within the Restoration Reach.

Table 12. Plant densities measured at Sheridan Creek pilot channel rehabilitation site (XS 02+35) in 1997, the year before detrimental riparian encroachment occurred. These plant densities represent preliminary detrimental riparian encroachment thresholds.

Plant Size (DRC, cm)	Plant Age	Plant Density Encroachment Threshold (plants/ft^2)	Plant Density Encroachment Threshold (plants/m^2)
0–0.25	Young-of-Year (YOY)	16	172
0.26–0.50	1-year		
0.51–0.75	2-year	0.65	7
0.76–1.0	3-year	0.15	2
> 1.0	> 3-year	0.11	1

8.2.3 Relationship of Biologic and Physical Data Trends to Annual Hydrology

Monitoring was conducted in all three years during the 2010–2012 period using the rotating GRTS panel sample design. 2010 to 2012 were Normal and wetter water years (Table 7). Infrastructure improvements to allow an 11,000 cfs TRD release were completed in 2011. Water year 2011 was a Wet year and an 8,500 cfs release would have been the flood peak prescribed in the TRFE; however, because a release greater than 10,000 cfs had not been made in the 10 years since the ROD had been signed, the Streamflow and Temperature Working Group recommended that an 11,000 cfs peak be released in spring 2011. The 11,000 cfs release was intended to induce disturbance beyond what had been previously attained systemwide, but in particular in the reach upstream of Weaver Creek. In 2011, peak flow releases exceeded 11,000 cfs at Lewiston for the first time since the ROD was signed in 2000 (Table 13). The WY 2011 flood peak was the largest magnitude release from TRD since 1974. Water year 2010 and 2012 were both Normal years and peak flows exceeded 6,000 cfs in both years (Table 13).

Table 13. Water year classes and peak streamflows for the USGS Trinity River gages at Lewiston, Douglas City, and Junction City during the WY 2010 to WY 2012 period.

Water Year	Water Year Class Based on April 1 Inflow Forecast	ROD Assigned Magnitude (cfs)	Instantaneous Maximum Lewiston Streamflow (cfs)	Instantaneous Maximum Douglas City Streamflow (cfs)	Instantaneous Maximum Junction City Streamflow (cfs)
2010	NORMAL	6,000	7,480	7,450	7,660
2011	WET	8,500	12,300	12,900	13,700
2012	NORMAL	6,000	6,180	6,480	6,290

Fifteen channel rehabilitation sites had been constructed by 2010 and another three were completed by 2012 (Table 14). Channel rehabilitation site designs were rapidly evolving by 2010. Channel rehabilitation designs included forced meanders, medial bars that split flows, side channels, off-channel wetland ponds, large wood structures and wood placement, as well as constructed benches that become inundated at a wide streamflow range. Multiple channel designs mimicked anabranching channels, while others forced the river from its pre-construction channel and replaced it with a meander. Some channel rehabilitation sites did not remove encroaching vegetation along the mainstem and instead built off-channel wetlands and side channels. Overall, channel rehabilitation site designs grew more aggressive than was initially described in the TRFE.

Post-construction vegetation encroachment was a concern at sites where channel migration and gravel bar formation were primary objectives and where the channel had been widened and vegetation cleared. With the evolution of channel rehabilitation site designs, encroachment was not a concern where rehabilitation designs did not remove encroaching vegetation, and the maintenance of constructed fish habitat at those sites was intended to be less reliant on floods and sediment storage. Therefore, seedling demographics were no longer monitored at channel rehabilitation sites unless a GRTS panel segment overlapped with one, in which case efforts were made to reoccupy historically monitored cross sections if the cross section still intersected a gravel bar (HVT and MA 2012, HVT and MA 2013).

Table 14. Channel rehabilitation sites constructed during the WY 2010 to WY 2012 period.

Site	Year Constructed	First Cohort that Could Colonize the Surface
Lowden Ranch	2010	2011 cohort
Reading Creek	2010	2011 cohort
Trinity House Gulch	2010	2011 cohort
Wheel Gulch	2011	2012 cohort
Lower Steiner Flat	2012	2013 cohort
Upper Junction City	2012	2013 cohort

The 2010–2012 peak flows scoured channel margins and reduced the number of narrowleaf willow seedlings within the 1-, 2- and 3-year-old size classes. WY 2010 was a Normal year and flows exceeded 7,000 cfs at Lewiston. Approximately 79% of the 2009 cohort that germinated in summer 2009 was scoured by the 2010 spring ROD release (Table 15; HVT and MA 2012). WY 2011 was an Extremely Wet water year class and flood peaks exceeded 11,000 cfs. The WY 2011 peak scoured the 2010, 2009, and 2008 cohorts (HVT and MA 2013) but was not able to scour the surviving 2006 cohort. WY 2012 was a Normal year and peak flows exceeded 6,000 cfs. The 2012 spring ROD release scoured 95% of the 2011 cohort on average between sites. The result of water year sequencing and associated flood peaks between 2010 and 2012 was that 1-, 2-, and 3-year-old narrowleaf and dusky willow cohorts were not able to establish at densities that could encroach within the 450–2000 cfs bank region (Table 15). Cross section data were not evaluated for berm formation during the 2010–2012 period.

Table 15. Summary of water year classes, peak streamflows, and associated cohort survival and mortality during the 2010 to 2012 period.

Water Year	Instantaneous Maximum Lewiston Streamflow (cfs)	Cohorts Scoured	Surviving Cohorts	Persisting Cohorts
2010	7,480	2009 cohort	2006 and 2008 cohort	1993, 1998, 2000, 2002, 2006 and 2008 cohort
2011	12,300	2008, 2009, and 2010 cohorts	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort
2012	6,180	2011 cohort	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort

Three years of using the GRTS rotating panel suggested that the TRFE prescribed flow thresholds intended to induce narrowleaf willow mortality were working. The 2008 cohort of willow seedlings had a high risk (red color) in the spring of 2011. Had the 2011 water year peak release followed the ROD prescription, flow magnitudes would have been 8,500 instead of 11,000 cfs (Table 13). The 11,000 cfs was successful in managing the 2008 cohort, but it is possible that if flows had only been 8,5000 in 2011, the 2008 cohort would have been able to survive and become established.

8.3 2013 to 2017

8.3.1 Sampling Design

The 400-m segment sampling frame used between 2010 and 2012 performed well for some studies (fish habitat, large wood, and riparian vegetation mapping), but has sampling limitations (biases) when used to focus on geomorphic objectives, such as the relationship of channel bed mobility and scour to mobile alluvial bars. When the GRTS-selected 400-m segments were used for assessing geomorphic and riparian vegetation response, there were few locations (i.e., gravel bars) within a selected segment where observations could be made to estimate the broader systemic response to management actions. After three years of using the GRTS rotating panel design for geomorphic and riparian band transect monitoring, it was found that the 400-m segments that defined a monitoring site did not always contain gravel bars that are exposed at 450 cfs.

The sampling design for encroachment risk, channel bed mobility, and channel bed scour (TRRP and ESSA Technologies 2009) assumes that experiments will be located on mobile surfaces (i.e., bars). Bars are aquatic features that provide or represent many attributes that the TRRP wishes to promote (fish habitat, a frequently mobilized channel bed, a sufficient coarse sediment supply, sufficient flow to distribute coarse sediment along the Restoration Reach) and their abundance and condition are directly affected by TRRP management actions. However, they are relatively scarce throughout the system, and the normal GRTS-selection routine typically provided a sample of segments with only a few bars on which to locate experiments. This sample selection process caused experiments to be located on geomorphic features (i.e., immobilized, densely vegetated streambanks) that were not representative of the actual features of interest (i.e., mobile, open bars). The resulting inconsistent geomorphic placement of experiments increased the variability of the experiments, making interpretations difficult.

Riparian and geomorphic monitoring used a variation of the GRTS systemic sampling design to best suit encroachment-related monitoring objectives. An alternative was implemented during 2013 to focus on exposed mobile point bars and mid-channel bars rather than GRTS selected 400-m segments.

A census of "exposed bars" was taken in the Restoration Reach using the most recently available aerial photographs. Exposed bars were defined as all point bars and medial bars > 1,500 ft^2 that are exposed at 450 cfs, and visible on WY 2012 aerial photographs. Exposed bars had to have sufficient surface area to install a cross section and at least 10 bed mobility experiments, which was estimated to be approximately 1,500 ft^2. Additional attributes included:

1. Sparse vegetation cover (bars were "open," meaning they had less than 2% total cover by any plant species),
2. Location (bars located in the mainstem only; bars in side channels were excluded, as were tributary deltas), and
3. Particle size (minimum particle size was greater than 50 mm (very coarse gravel), as visible on aerial photographs).

Bars meeting these criteria were identified on aerial photographs and then measured in the field to confirm their elevation exceeded the 2,000 cfs stage, such that monitoring could be conducted across the 450–2,000 cfs zone. The bar census was performed in summer of 2012 to define sampling units for WY 2013. The exposed bar census was repeated in the summer of 2013, 2015, and 2016. In 2012, 69 mapped bars met the criteria; in 2013, 68 met the criteria; in 2015, 68 met the criteria; and in 2016, 88 met the criteria (Figure 28, Table 16).

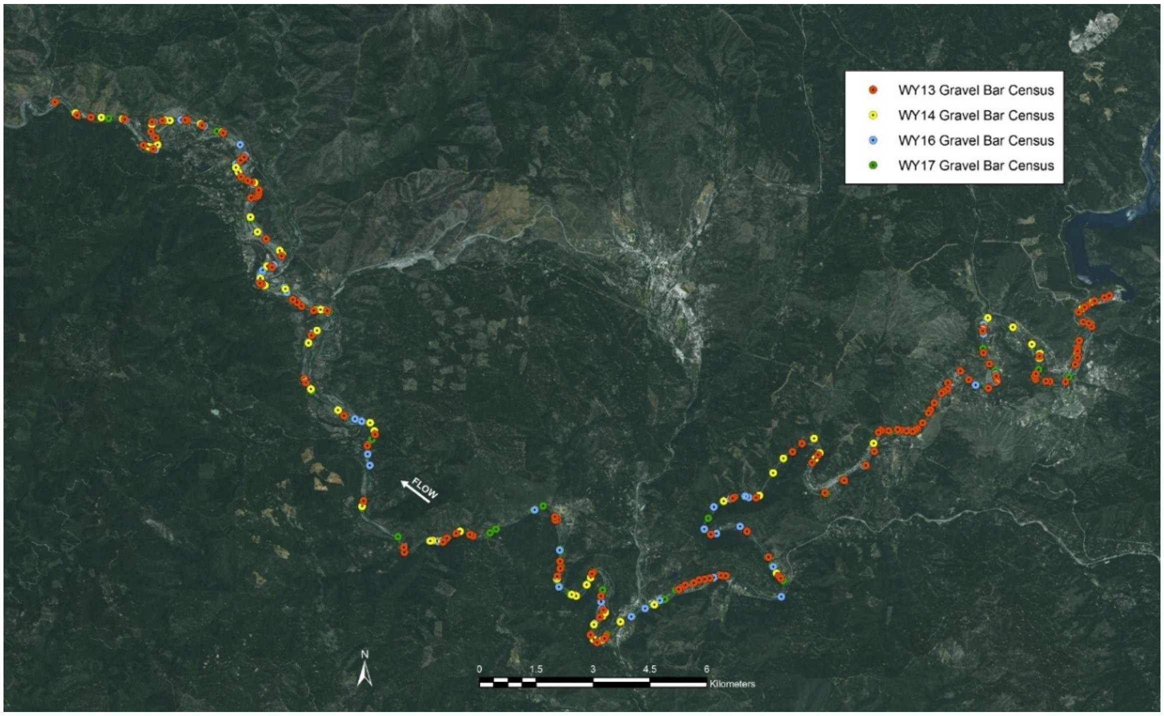


Figure 28. Censused exposed gravel bar locations between Lewiston Dam and the North Fork Trinity River used for developing field sampling locations in 2012 through 2016.

Table 16. Count of exposed gravel bars between Lewiston Dam and the Trinity River that met or did not meet the exposed bar criteria in 2012–2016. A bar census was conducted after flows receded in 2016 but no field sampling of exposed bars occurred in WY 2017.

Type of Bar	**2012**	**2013**	**2015**	**2016**
Bars totally inundated at less than 2,000 cfs	69	125	126	103
Bars totally inundated at more than 2,000 cfs	69	68	68	88
Total	138	193	194	191

Each year, the GRTS selection routine was applied to the annual count of exposed bars that met the criteria. The selection routine yielded a spatially-balanced, repeatable sample of exposed bars (Pickard 2012). The selection of mobile gravel bars that were unvegetated and exposed between 450 and 2,000 cfs reduced sampling design-related variability to more clearly evaluate TRFE bed mobility and riparian encroachment objectives (USFWS and HVT 1999), which were further refined in the IAP (TRRP and ESSA Technologies 2009). In the fall of 2012, 24 bars were selected for sampling in WY 2013; in the fall of 2014 through 2016, 16 exposed bar locations were selected. No field sampling of exposed bars occurred in 2017. The total number of exposed bars in the Restoration Reach has not changed much since 2013; however, the number of bars that are totally inundated at or below 2,000 cfs has gone down and the number of bars that require more than 2,000 cfs to be totally inundated has increased (Table 16), suggesting that bars have generally increased in elevation systemwide.

8.3.2 Relationship of Biologic and Physical Data Trends to Annual Hydrology

Seedling sampling, combined with cross section surveys, and channel bed mobility and scour monitoring, was conducted across open bars (e.g., point bars, mid-channel bars) in order to evaluate the risk of detrimental riparian encroachment. Monitoring was conducted in 2013–2016 at the exposed bars selected using the GRTS routine. The 2013 to 2017 period was a drier period, with three consecutive dry years from 2013–2015 (Table 17). The occurrence of three consecutive dry years was a critical part of the first detrimental encroachment hypothesis (Section 7). If seedlings were allowed to grow past the age of 3-years (or greater than 1 cm DRC), it was hypothesized that they would reach a size density threshold that would lead to detrimental encroachment. Flows during 2013 did not exceed 5,000 cfs and in 2014 did not exceed 3,500 cfs. The peak flow in 2014 occurred in the fall and was not a result of springtime managed flow releases associated with the ROD. Water year 2015 was a Dry Year; however, the Streamflow and Temperature Working Group used the water volume allocated to a Dry year and reached a peak flow greater than 8,500 cfs in order to scour establishing seedlings (Table 17). WY 2016 was a Wet year and the flood peak exceeded 9,500 cfs at Lewiston. The second-largest magnitude release since 1974 was released in the spring of 2017, when peak flows reached 12,000 cfs at Lewiston during the managed spring releases (Table 17). Effectively, three wet years (2015–2017) followed two dry years (2013–2014) due to managed peak flows being greater than what was prescribed for that year's water year class in the TRFE (Table 17).

Table 17. Water year classes and peak streamflows for the USGS Trinity River gages at Lewiston, Douglas City, and Junction City during the WY 2013 to WY 2018 period.

Water Year	**Water Year Class Based on April 1 Inflow Forecast**	**ROD Assigned Magnitude (cfs)**	**Instantaneous Maximum Lewiston Streamflow (cfs)**	**Instantaneous Maximum Douglas City Streamflow (cfs)**	**Instantaneous Maximum Junction City Streamflow (cfs)**
2013	DRY	4,500	4,590	4,760	6,340
2014	CRIT DRY	1,500	3,460*	3,280	3,480
2015	DRY	4,500	8,830	9,100	9,690
2016	WET	8,500	9,600	11,100	11,200
2017	EXT WET	11,000	12,300	13,400	13,800
2018	CRIT DRY	1,500	2,040	3,630	4,500

*The peak discharge of 2014 was not associated with spring ROD flows; rather it occurred on September 22, 2013, and was associated with Lower Klamath temperature and health flows.

Six additional channel rehabilitation sites were completed by 2016 (Table 18). Two of the channel rehabilitation sites, Upper Douglas City (Douglas City 2015) and Bucktail, were reconfigurations of sites that had not performed as expected. Channel rehabilitation designs continued to be aggressive and included forced meanders, medial bars that split flows to mimic anabranching channels, new side channels, off-channel wetland ponds, large wood structures, and large wood augmentation. During the 2013 to 2016 period, channel rehabilitation focused less on constructed benches that are inundated at a wide streamflow range.

Table 18. Channel rehabilitation sites constructed during the WY 2013 to WY 2016 period.

Site	Constructed	First Cohort that Could Colonize the Surface
Douglas City 2013	2013	2014 cohort
Lorenz Gulch	2013	2014 cohort
Lower Junction City	2014	2015 cohort
Douglas City 2015	2015	2016 cohort
Limekiln Gulch	2015	2016 cohort
Bucktail	2016	2017 cohort

Post-construction vegetation encroachment was not much of a concern at sites where channel migration and variable wetted widths and areas were not primary objectives. One site, Limekiln Gulch, was built in a confined canyon with shallow bedrock. Alluvial channel morphology was not targeted, and encroachment was not a concern. Where encroaching vegetation was not removed, the designs typically emphasized off-channel wetland ponds and side channels. The maintenance of constructed off-channel fish habitat was not reliant on floods and sediment storage and has been negatively affected by undesirable flood-induced sediment deposition. The creation of off-channel habitat at the expense of allowing encroaching vegetation was not envisioned in the TRFE or CDG.

Peak flows during the 2013 and 2014 dry years were incapable of scouring channel margins and exposed bars, and the number of narrowleaf willow seedlings within the 1- to 2-year-old size classes was not reduced in 2013 and 2014 (Table 19). One objective of increasing flows to 8,500 cfs in 2015, a Dry year, was to reduce the encroachment risk from cohorts not scoured in 2013 or 2014. However, streamflows able to scour the 3-year-old seedlings from the 2012 cohort (e.g., 11,000 cfs) were not achievable under the dry year conditions. The effect of the 8,500 cfs release in 2015 on cohort demographics was that the 2014 and 2013 cohorts were scoured, but the 3-year-old seedlings from the 2012 cohort were not (Table 18; HVT and MA 2016). In fall 2015, 264 young-of-year, three 1-year, one 2-year, one 3-year, and nine greater than 3-year-old plants were sampled at 16 exposed bars, for a total of 278 plants. In fall 2016, zero plants were sampled at 16 exposed bars. In the absence of field monitoring, it is better to assume that if a larger flow threshold is not achieved, the larger size/older age class of plant is not scoured. The 2016 result was not predicted. It is possible that some greater than 3-year-old plants survived because flows did not exceed 11,000 cfs; however it is also possible that two consecutive years of peak flows greater than 8,500 cfs were capable of scouring away older classes that were previously thought to only be scourable by an 11,000 cfs peak. The result of water year sequencing and associated flood peaks between 2013 and 2016 was that no narrowleaf and dusky willow cohorts were able to establish within the 450 to 2,000 cfs bank region (Table 18). Cross section data were not evaluated for berm formation during the 2013–2016 period.

Regardless of the sampling frame and methods used to evaluate encroachment, results continue to suggest that the TRFE prescribed flow thresholds intended to induce narrowleaf willow mortality were capable of maintaining a variable low water fringe if seedlings were scoured within three years to inhibit the establishment of 3-year-old and older woody plants. If the seedling management window is surpassed as it was for the 2006 cohort, TRFE prescribed streamflow peaks alone are unlikely to inhibit encroachment.

Table 19. Summary of water year classes, peak ROD-release streamflows, and associated cohort survival and mortality during the 2013–2016 period.

Water Year	**Instantaneous Maximum Lewiston Streamflow (cfs)**	**Cohorts Scoured**	**Surviving Cohorts**	**Persisting Cohorts**
2013	4,590	None	2006 and 2012 cohort	1993, 1998, 2000, 2002, 2006 and 2012 cohort
2014	3,460*	None	2006, 2012, and 2013 cohort	1993, 1998, 2000, 2002, 2006, 2012, and 2013 cohort
2015	8,830	2013 and 2014 cohorts	2006 and 2012 cohort	1993, 1998, 2000, 2002, 2006 and 2012 cohort
2016	9,600	2012 and 2015 cohorts	2006 cohort	1993, 1998, 2000, 2002, and 2006 cohort

*The peak discharge of 2014 was not associated with spring ROD flows, rather it occurred on September 22, 2013, and was associated with Lower Klamath River water temperature and fish health flows.

9 SYNTHESIS AND DISCUSSION

Studies that led to the TRFE and the ROD found that higher flows combined with coarse sediment augmentation and channel rehabilitation could restore alluvial processes that inhibited detrimental riparian encroachment. Streamflow variability and large peak releases were a keystone to the restoration success. The ROD adopted a management strategy that relied on streamflow variability as a restorative agent. Restoration actions were to be tailored via the AEAM process to specific Program needs within a water year.

Meandering, migrating, and avulsing rivers are most prone to the detrimental effects of vegetation encroachment. Encroaching vegetation inhibits the development of local sediment storage (i.e., bar formation), which in turn inhibits the ability of the river to resize the channel bed particle size distribution as gravel is replenished with smaller fractions of gravel. As vegetative roughness increases or is maintained along the channel margins, sediment transport will be maintained or increased, and the sediment routed through the site to an area where there is available storage. The Phase 1 SAB review identified little variation in width with increasing streamflow even after ROD implementation in 2005 (Buffington et al. 2014), and the RCMP (River Corridor Management Plan) identified reaches in unconfined valleys where sediment was routed through rather than being stored (Gaeuman et al. 2016). One explanation for this is the rectangular channel morphology that encroaching vegetation has created. The lack of changing wetted width with increased streamflow may be a direct result of persistent encroachment.

Detrimental encroachment is a physical response with a biologic source. The woody plants that are responsible for encroachment are well-adapted to take advantage of the high disturbance frequency found in unimpaired rivers. When Trinity River streamflows were diverted post-TRD, the environmental stressors that limited plant establishment were removed.

The TRFE relied on plant anatomy and life history characteristics to develop management strategies that would inhibit encroachment and subsequently the influence of establishing willows on the physical system (channel morphology and confinement). The TRFE identified three main management actions that in combination could be applied to reduce the effect of established encroaching vegetation and limit future woody plant establishment along the channel margin to elicit a beneficial physical response.

One ROD objective was to increase the amount of juvenile Chinook Salmon habitat. The TRFE used shallow slow-water habitat as representative of aquatic habitat that had been lost post-TRD and that could be recovered using the management actions directed in the ROD (restoration streamflows, sediment augmentation, and mechanical rehabilitation). Sparsely vegetated gravel bars with gently sloping margins were seen as a means of creating and sustaining shallow slow-velocity habitat over a wide range of streamflows (i.e., suitable habitat). Habitat with the right depth and velocity combination is usable habitat, but the same habitat with cover is optimal habitat, and areas with cover alone were found to be preferentially used by juvenile fish (USFWS and HVT 1999).

Juvenile fish habitat is more complex than just barren channel margins or unvegetated gravel bars with the right depth–velocity combinations. The TRFE never envisioned that restricting encroaching woody plants would prevent all plant establishment along the low flow channel margin. Woody plant demographic data collected during the maintenance flow period indicated that 60–95% of establishing narrowleaf willow could be removed through channel bed scour alone. Some proportion of every cohort could potentially establish every year. The establishment of patchy woody plants along the channel margin should be viewed as an important habitat component.

Sediment berms and encroaching vegetation were common features along the Trinity River and identified early on as limiting salmonid rearing habitat. A major justification for restoration was the need to remove berms and prevent their reformation. The post-ROD flow and sediment regime are hypothesized to prevent berm reformation. Another strategy included in the ROD was to construct short sections into the existing berm and remove vegetation, then let high flows erode the remaining vegetation. It has been shown that maximum managed flood peaks are insufficient to cause the large-scale removal of mature riparian vegetation and associated sediment berms adjacent to areas where the berm has been removed and vegetation cleared.

9.1 Reflections on the TRFE Restoration Strategy and Implications to Riparian Encroachment

The TRFE oversimplified the academic, social, bureaucratic, and temporal obstacles to developing a smaller-scale alluvial river. The physical changes embodied in the TRFE were to be large, obvious, and occur in a short time (i.e., years). Without the gravel augmentation component, the full TRFE strategy has yet to be implemented. However, considering the partial gravel augmentation combined with restoration streamflows, it is apparent that without mechanical restoration, the envisioned changes are minor and may take decades, if they occur at all.

The TRFE and the ROD described and adopted a restoration strategy that was threshold-based and did not necessarily require defining ecologically desired outcomes resulting from management actions (USFWS and HVT 1999, DOI 2000). Therefore, no quantitative measures of desired riparian ecological outcomes were defined for the Trinity River. While many TRFE management objectives (targets) are streamflow thresholds that directly relate to specific physical outcomes, there is little discussion about the recovery rate from channel encroachment to a smaller-scale alluvial river, or recovery trends.

The TRFE strategy relied on a simple meander wavelength to serve as a template for the future channel condition. While seeming simple in its form 30 years later, the basis of Chinook Salmon population recovery was centered on juvenile habitat recovery which was, and still is, founded on the future channel pattern. The defined strategy was to be a first step that would be modified through a structured AEAM program. Vegetation establishment along the water's edge plays a crucial role in what is interpreted as a successful restoration program outcome. Vegetation encroachment poses different risks in a single-thread channel than in an anabranching system. Encroachment in an anabranching channel could lead to reductions in channel width and increases in depth over time, leading to the reduction in channel number. The quantity of aquatic habitat would be reduced; however, the diversity and quality could be potentially maintained. Encroachment along a single-thread channel could lead to reduction in width and increases in depth, with reduction in quantity, quality, and diversity of habitats. Without sufficient flows or sediment supply, the channel may become moribund. An anabranching channel with vegetation encroachment could provide more habitat to a range of salmonid life stages than similarly encroached single-thread rivers; however, managing encroachment should be a high priority regardless of the channel type.

Selecting to restore a channel pattern that cannot be maintained after construction using the management tools available can lead to rapid channel encroachment, which would restrict the ability of the Program to meet juvenile salmonid habitat recovery targets. This is especially true at sites where an anabranching planform has been constructed with high quantities of habitat in the as-built condition (e.g., Wheel Gulch). As the planform adjusts to the actual physical constraints and potentially develops vegetation encroachment, the amount of constructed juvenile habitat may be diminished over time and the ability of the mainstem channel to adjust may also be reduced (i.e., lost opportunity).

While it is important to define what the future channel pattern might be, the role of mature and establishing encroaching vegetation is a contributing factor (positive or negative) to the sustainability of a given channel planform. An anabranching channel pattern provides the greatest juvenile fish habitat increases in combination with rehabilitation, large wood augmentation, and high streamflows. Unfortunately, there seems to be an apparent conflict between the channel that is desirable for creating the greatest juvenile habitat capacity and the channel that is possible using the management strategies available within the limitations of urbanization (i.e., upper limits of flow releases), current particle size distribution, and flood frequency.

Currently channel bed scour, lateral migration, and lateral channel expansion are the predominant mortality mechanisms that are inhibiting encroachment. Inundation, deposition, and undercutting may currently be mortality mechanisms, but overall the effect of these mechanisms is so little as to not be captured in monitoring or mapping. The observed and documented mortality mechanisms continue to be similar to those discussed in the TRFE (Figure 16).

Over time, successful restoration of the processes emphasized in the TRFE and ROD could be expected to lead to a more diverse vegetation pattern. Riparian woody plants, particularly black cottonwood and white alder, should become established on floodplain surfaces where they are less vulnerable to scour-induced mortality and can mature into forest. Riparian vegetation, particularly narrowleaf willow, will continue to establish on upper bar surfaces disturbed by frequent floods, which will prevent the formation of extensive, linear bands of vegetation. Narrowleaf willow will regularly initiate on bar flanks, where it will be removed by managed streamflows on a semi-annual basis and survivors are few. On the outside of meander bends, lateral scour may locally remove mature vegetation and recruit large wood. Establishment of vegetation on upper bar surfaces can increase roughness and accelerate sediment deposition, which leads to floodplain development and an increase in the patch size, number of age classes, and possibly species richness, and a decrease in the edge:area ratio of the patch. In migrating cross sections, this would be counteracted by lateral erosion on the opposite side of the river. The desired conditions of an increasing canopy cover and understory that is increasing in species richness and a nonexistent pattern of riparian encroachment into the low water channel (TRRP 2004) would be achieved. In long straight reaches with relatively static cross sections, vegetation establishment on bars may lead to woody plant encroachment and bar stabilization within the active channel, unless periodic high flows deeply scour both the upper bar surface and bar flank.

9.1.1 Reflections on Streamflow Management

The TRRP has evolved its management objectives to reach the maximum allowable peak streamflow release as frequently as possible in Normal and wetter years. The reason for increasing the frequency of maximum flood peaks has been to maximize the amount of geomorphic work and sediment transport, under the assumption that increasing the rate of physical change would restore the river more rapidly. Since the beginning of ROD flows in 2005, an Extremely Wet year has occurred twice: in 2006 and 2017 (Figure 30). In 2006, infrastructure limited the TRD release to 10,400 cfs, and in 2017, the release was 12,000 cfs at Lewiston. Using the flood frequency analysis in the TRFE, the 11,000 cfs event at Lewiston had a recurrence interval of about 10 years. The actual flood peak frequency based on ROD streamflows since 2005 has been increased for larger floods, so that the 11,000 cfs flood is now about a 7-year recurrence event, an increase of 7% in frequency of Extremely Wet year peaks (Figure 31). The shift in flood peak magnitude frequency could be a result of the short (15 year) period of record, and as the ROD streamflows are implemented over more years the discrepancy may not be as great. However, if the current trend of releasing bigger peaks more frequently than was recommended by the ROD continues, the shift in flood frequency could be realized. At a practical level, the sequencing of actual flood peaks has been relatively effective at managing encroachment in alluvial portions of the Restoration Reach. The TRRP has used the flexibility in developing streamflow schedules annually to effectively address management concerns, such as encroachment, within a given year without exceeding the water allocated based on water year class. Flood frequency and magnitude have inhibited detrimental encroachment, with only the WY 2006 cohort establishing below 2,000 cfs since 2005 (Table 18).

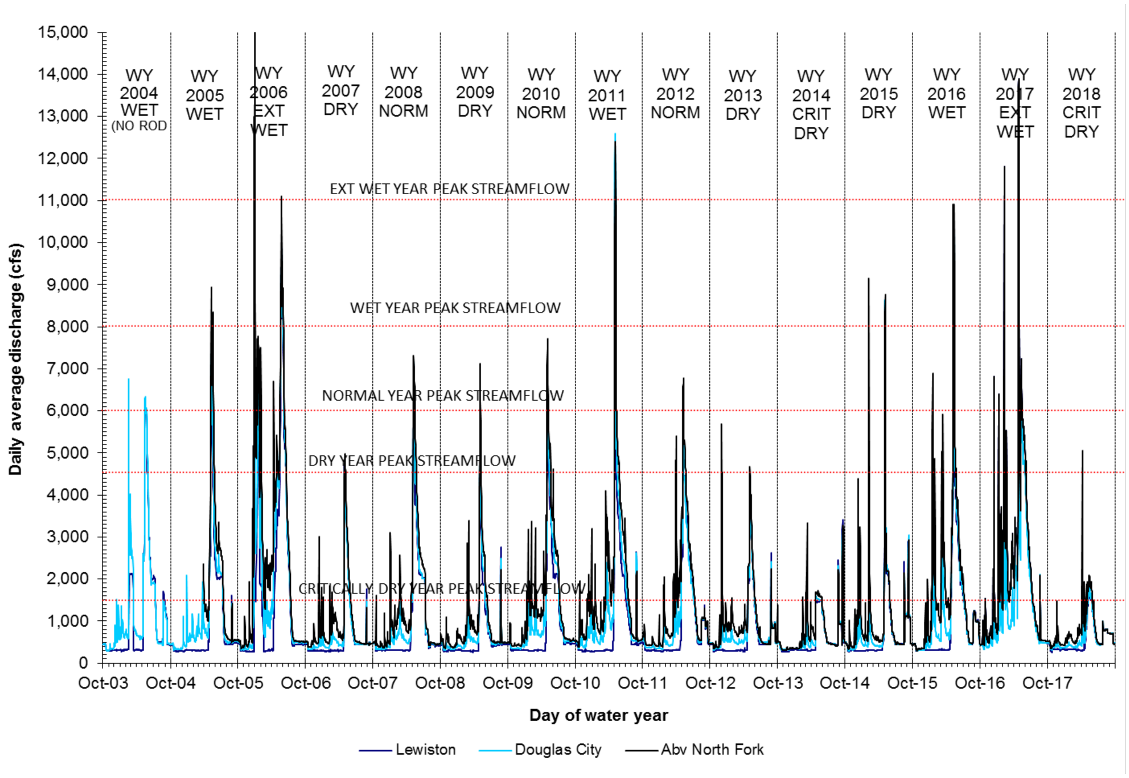


Figure 29. Water years 2004–2018 daily average streamflow hydrographs for USGS gaging locations Lewiston, Douglas City, and the mainstem above the Trinity River North Fork.

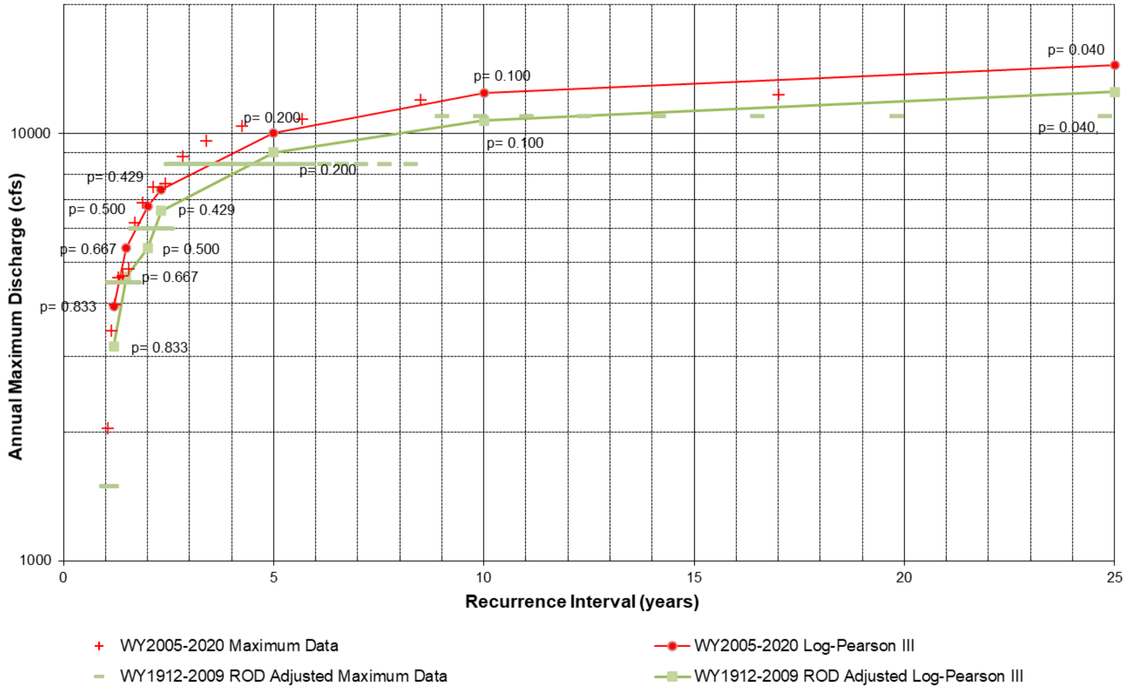


Figure 30. 1912 to 2009 flood peaks scaled down to ROD flood peaks based on water year class (green) vs actual (red) WY 2005–WY 2020 flood frequency at USGS gage at Lewiston.

The RCMP pointed out the channel pattern analyses are sensitive to streamflow and applied a range of dominant streamflows larger than those considered in previous analyses (Gaeuman et al. 2016). The RCMP used an increased frequency of the 8,500 cfs and 11,000 cfs flood flows. Currently the 8,500 cfs flood has not increased in frequency but the 11,000 cfs flood has, and the current increase is higher than was anticipated in the RCMP. Increased flood magnitude frequency could be one way to help the river achieve an anabranching channel form in locations unconstrained by bedrock or valley walls. Increased flood frequency for Wet and Extremely Wet year flood peaks inhibits encroachment and could be helpful in facilitating the channel evolution towards an anabranching type in those reaches that could possibly support it.

9.1.2 Reflections on Channel Rehabilitation Site Design

The regrowth of willow shrubs from roots that were not completely removed during site construction was a problem not anticipated in the TRFE. Regrowth is the sprouting and growth of woody riparian plants intentionally removed during channel rehabilitation site construction and represents a lost opportunity to remove riparian vegetation encroachment via mechanical means. During the 2005–2009 period, regrowth from roots caused many of the early sites to be re-encroached and quickly return to a condition similar to that which existed before construction. If the intent of vegetation clearing is to remove encroaching vegetation and portions of the root mass are left behind, the project will not meet the intended objective of removing encroaching vegetation.

Currently riparian vegetation grows along the river where suitable substrates and soil moisture exist within semi-alluvial and alluvial channel forms (e.g., bars, semi-vegetated bars, islands, split flow channels. While vegetation structure and patterns adjacent to the channel may vary with channel form, areas of multi-aged, species-rich riparian vegetation are a valuable ecosystem component of straight, meandering, or anabranching channel forms.

Forced meanders, multi-thread channels, and split flows will likely continue to be included in future channel rehabilitation site designs. Channel-forcing features, split flows, and other design elements characteristic of multi-thread channels do not rely on gently sloping channel margins to create and maintain juvenile fish habitat. Instead, ground lowering adjacent to flowing channels is combined with selected channel patterns to create a variable wetted edge across a wide range of streamflows. Lowering ground surfaces next to wetted channels will decrease the distance that establishing plant roots need to grow to access shallow groundwater, thereby increasing the overall amount of riparian hardwood initiation at rehabilitated sites. One trade off that each design team will need to consider is the increase in width next to the wetted channel and the reduced ability of the channel to convey sediment (i.e., scour seedlings to prevent encroachment).

Medial and lateral gravel bars have been included in designs and are locations where terrestrial habitat interfaces with aquatic habitat in dry months. Lateral bars may accrete on the streamward side of the channel with commensurate channel migration on the opposite bank (Figure 31). Depending on flood frequency and local coarse sediment supply, gravel bars may be prone to detrimental riparian vegetation encroachment throughout the mainstem. Constructed gravel bars included in future designs increase local coarse sediment storage and provide new locations for riparian hardwood initiation. Future designs could specify that coarse sediment without sand be used to construct the design feature to reduce the suitability of the gravel bars for seed germination. Eliminating the fine sediment fraction in design features to inhibit woody plant establishment could be used to manage detrimental encroachment in the short term.

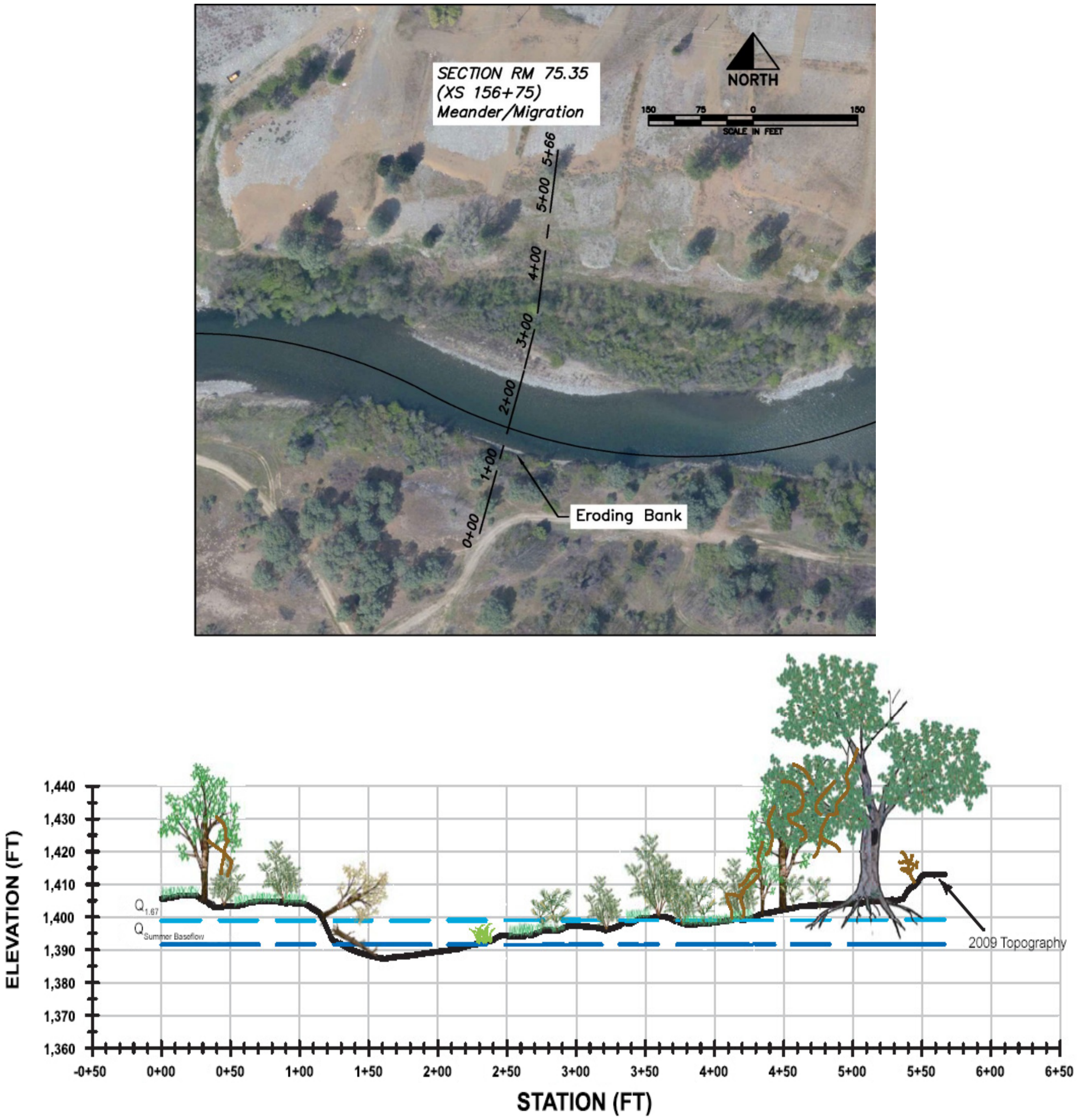


Figure 31. (Top) Planform location of developing alternate bar and cross section at Valdor Gulch (RM75.35), showing riparian vegetation patterns relative to the developing geomorphic surfaces and channel migration. (Bottom) patch age and vertical structure along a representative cross section with respect to a developing alternate bar, floodplains, and subsequent channel migration.

Vegetated bars and island bars are gravel bars that form in locations where sediment deposits form a bar within the channel (Figure 32). Initially the bar may be unvegetated. Gravel may aggrade around the outside edge of constructed medial bars, increasing the amount of sloping edge habitat. As mid-channel bars continue to develop through deposition, herbs, trees, and shrubs will colonize the bar and channel margins (Figure 32). Gravel bars tend to form whether large wood structures have been constructed or not (e.g., Lorenz Gulch, Wheel Gulch, Upper Junction City). Vegetated bars inundated at 2,000 cfs and lower streamflows often provide optimal juvenile rearing habitat conditions.

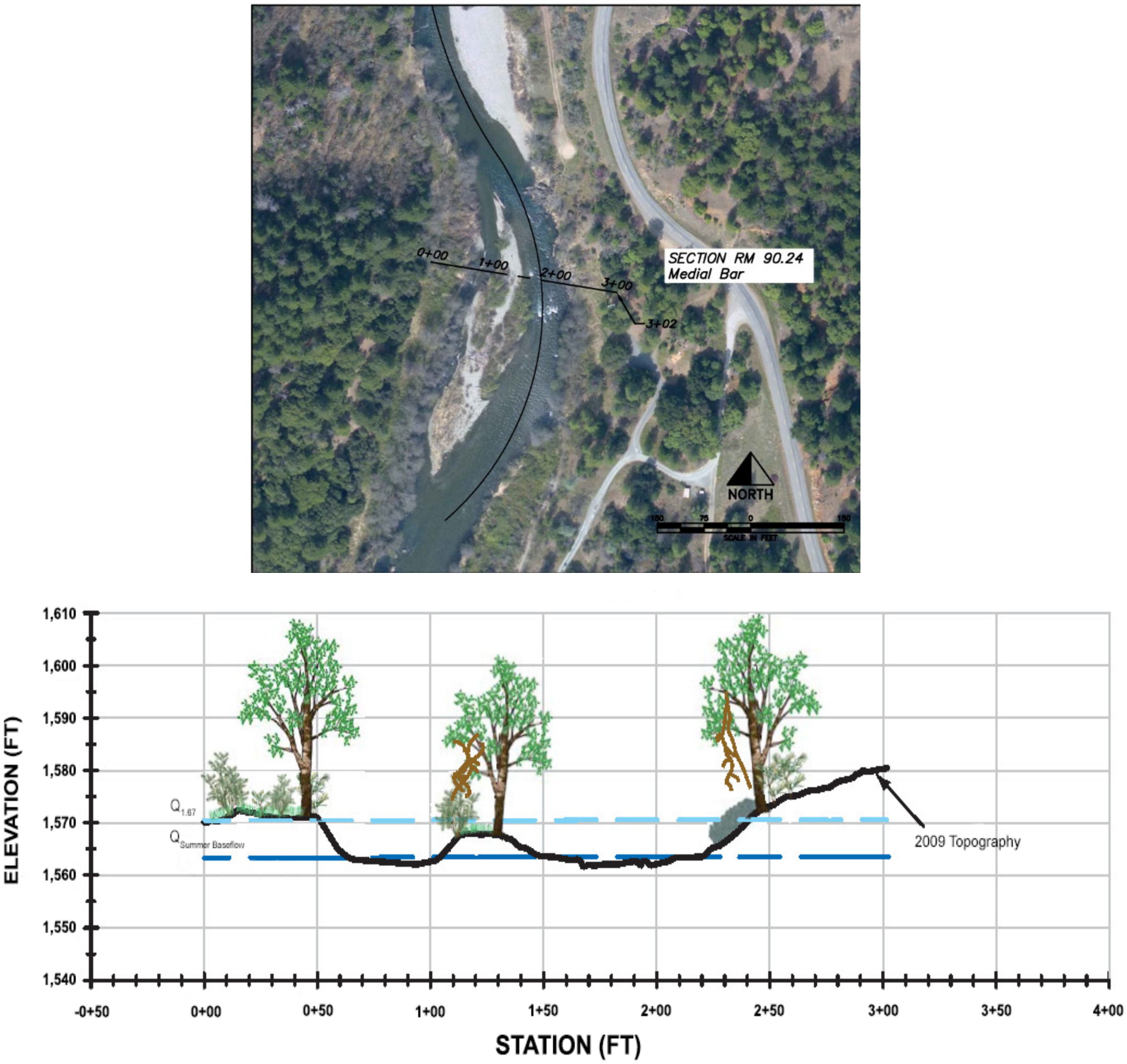


Figure 32. (Top) Planform location of a mid-channel bar and cross section upstream of Lorenz Gulch (RM 90.24), showing mainstem and side channel-related riparian vegetation patterns. (Bottom) Mainstem and side channel patch age and vertical structure along a representative cross section.

Floodplains are often included in channel rehabilitation site designs (Figure 31). Lowered floodplain ground surfaces adjacent to the wetted channel could be designed to mimic early floodplain formation where fine sediment can accrete over a period of years. When a floodplain is just developing, often woody plants may colonize the surface and enhance conditions that would promote deposition. At some channel rehabilitation sites, the steeper active channel longitudinal slope transitions into a lower sloped plain at the bankfull transition between the active channel and the floodplain (HVT et al. 2011). Currently naturally formed floodplains on the mainstem within the Restoration Reach are relatively uncommon due to anthropogenic disturbance prior to TRD and the effects of sediment and streamflow regulation post-TRD (M&T 2005, Krause et al. 2010, Gaeuman et al. 2016).

Seasonal channels are locations that are periodically inundated. Fine sediment may deposit in seasonal channels and riparian hardwood seedlings can easily establish. Seedlings establishing in seasonal channels are less susceptible to rapid streamflow recession and scour associated with managed spring releases because seasonal channels are typically farther from the mainstem channel and flood force and are lower in elevation than floodplains, thus being closer to perennial groundwater (Figure 33). A combination of floodplains interlaced with seasonal channels occur at forced bends and areas of high riparian vegetation complexity and area. The combination of floodplains and seasonal channels offers locations where woody plant establishment and frequent disturbance contribute both structural and age class diversity to rehabilitation efforts and added value to aquatic habitat value (Figure 33).

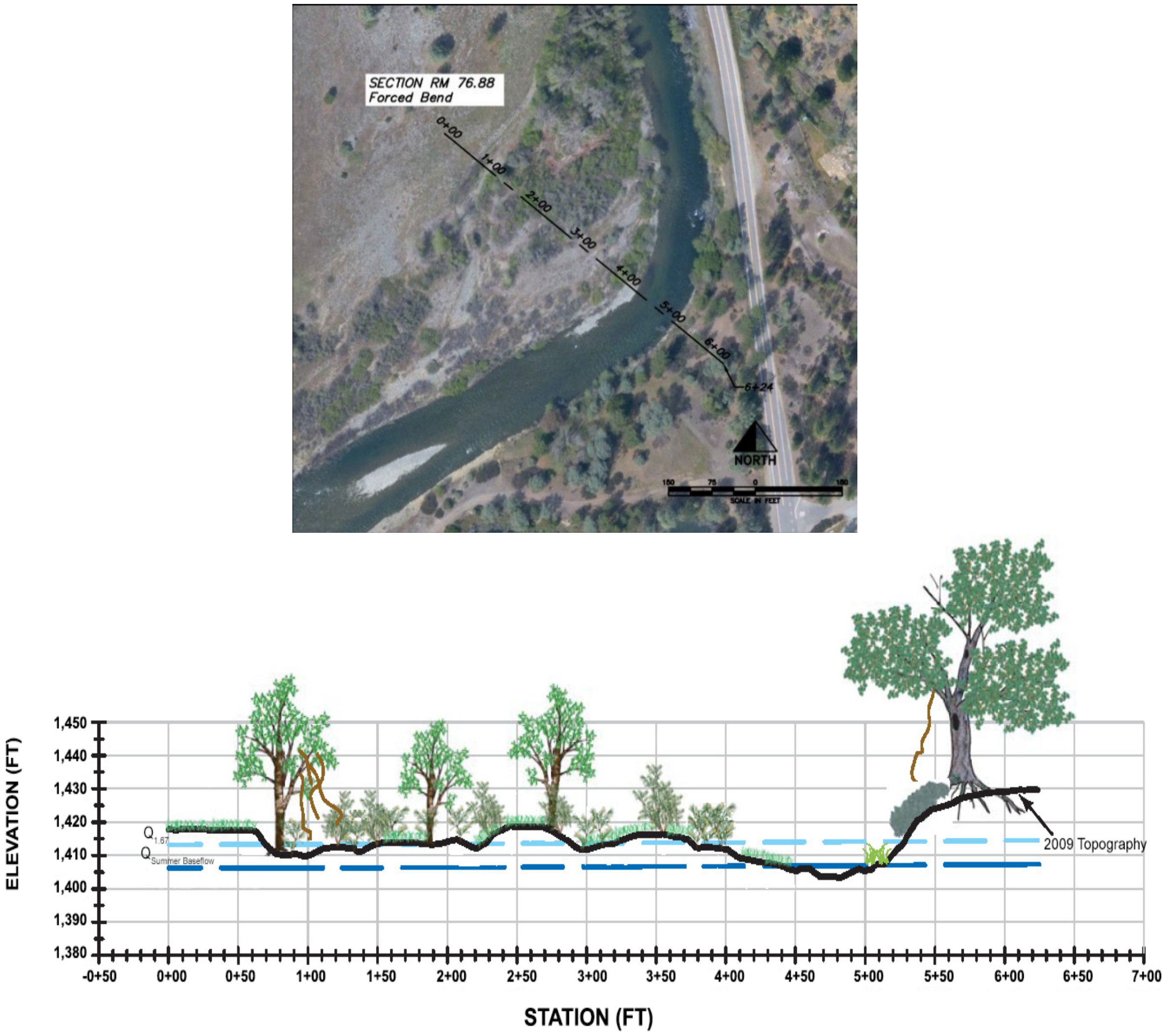


Figure 33. (Top) Planform location of forced bend and cross section near J&M Tackle (RM76.88), showing mainstem and seasonal flow channel-related riparian vegetation patterns. (Bottom) Mainstem and side channel patch age and vertical structure along a representative cross section.

Effectiveness monitoring should be used in the future to evaluate project success and whether encroachment is an issue for specific design elements. Constructed channel rehabilitation site design performance could also be evaluated to assess whether anabranching channels are sustainable in the contemporary Trinity River system. Wheel Gulch is a channel rehabilitation site that was built in the North Fork Reach where an anabranching channel has been consistently predicted when banks are unvegetated. Wheel Gulch was designed to be a split flow, multi-thread, anabranching channel with large wood habitat structures and engineered log jams. Coarse sediment deposition at Wheel Gulch following the insertion of exogenous materials (i.e., engineered log jams), along with the construction of split flow channels, has repeatedly been used to show that the particle size distribution can be reduced and bed-load quantities in the North Fork Reach are of sufficient size and volume to achieve a different channel morphology. However, the ability of the river to maintain the anabranching configuration that was constructed at Wheel Gulch is debatable. Casual observation suggests that gravel plugs have formed in the constructed split flow channels, potentially cutting them off from the mainstem. Furthermore, there is no quantitative evidence that the particle size at Wheel Gulch has grown smaller since the ROD; the D_{50} particle size was already small before the project was built (the CDG used a D_{50} of 47 mm for this reach). The river seems to be filling the constructed anabranching channel with sediment at that location, and Wheel Gulch is a good example of a rapidly evolving site.

The channel evolution away from anabranching at Wheel Gulch does not mean an anabranching channel is not possible in the North Fork Reach. As the D_{50} is reduced river wide, large wood storage increases, and vegetation encroachment is removed mechanically or through flood scour, it is possible that the predicted channel pattern could realistically be anabranching. Unfortunately, the current physical structure conditions, and current coarse sediment and large wood management, preclude this pattern from persisting or forming without mechanical assistance.

9.1.3 Reflections on Sediment Management

Sediment is an important component of the process-based restoration envisioned in the TRFE and ROD. Historical activities in the Trinity River watershed led to extreme sediment imbalances that have been slowly remediated over time through various restoration activities. However, the sediment imbalance contributed greatly to riparian encroachment throughout the Restoration Reach. Improvements in sediment management are still needed if restoration of geomorphic processes is to be achieved.

9.1.3.1 Fine Sediment

In the 1960s and 70s, the fine sediment supply from tributaries was orders of magnitudes greater than it is today (GMA 2001). The increase in fine sediment related to land management and the limited range of flows from TRD provided the material and the hydrologic setting to build sediment berms in establishing vegetation. With watershed rehabilitation including erosion control, planting, and sediment ponds, fine sediment input has been greatly reduced (Fine Sediment Synthesis report, in preparation).

One way to reduce encroachment potential is to reduce the amount of fine sediment that is stored in the matrix of coarser gravel bars. Fine sediment is an important part of floodplain evolution and overall vegetation growth. Most plants cannot grow without some fine sediment to provide capillarity for soil moisture. Gravel bars without fines could inhibit germination because there are less fines in the matrix upon which to germinate. A reduced fine sediment supply could mean a reduction in future berm building and inhibited plant establishment along the summer water edge. The variable range of post-ROD flows, along with the reduction of fine sediment, could mean less material delivered to higher elevations and available to build floodplains. Fine sediment is a key ingredient to making sediment berms; however, the lack of berm formation is more likely a reflection of reduced fine sediment supply, and woody plant encroachment can still be detrimental in the absence of a berm.

Fire in a highly erodible watershed, such as the Carr Fire in the Trinity River watershed, could increase fine sediment supply depending on the burn intensity and extent. Future management actions may need to be directed to recovering burned watersheds to reduce erosion and fine sediment supply. Fine sediment supply, transport, and storage should continue to be managed in an AEAM context with respect to floodplain evolution, encroachment risk, and berm formation.

9.1.3.2 Coarse Sediment

Coarse sediment augmentation has not influenced river rescaling as hypothesized in the TRFE and the Coarse Sediment Management Plan (CSMP; M&T 2003). One objective of gravel augmentation was to reduce the particle size of the channel bed. An anticipated outcome of gravel augmentation was that woody plant encroachment would be easier to manage, as it would take lower streamflows to mobilize the smaller-diameter channel bed substrate. Repeated surface and subsurface particle size sampling conducted in 2001, 2009, 2014, and 2018 do not show a clear trend of particle sizes becoming smaller with time either in the surface or subsurface layers between years. However, four of seven sites sampled in 2018 had a smaller median particle size (D_{50}) than in 2001 (GMA Hydrology 2020). At four gravel augmentation sites between 2006 and 2017, there was a weak trend in decreasing size for the D_{90}, and no apparent trend for the D_{50} with the exception of one site at Limekiln Gulch, where a slight decrease was evident (Gaeuman and Stewart 2017). There may be no statistically significant trends as to whether the channel bed is coarsening or fining; however, current trends suggest that particle sizes may grow smaller if gravel augmentation continues.

Another objective of coarse sediment augmentation was to increase local coarse sediment storage, which presumably would mean an increase in gravel bars within the active channel. There has been an increase in local coarse sediment storage due to increased streamflow magnitude and frequency in locations where coarse sediment augmentation has occurred and at tributary deltas (Gaeuman and Stewart 2017). However, coarse sediment has only been added 10 times, and in lower volumes than prescribed since the ROD was implemented, leading to ambiguous storage results beyond the location where coarse sediment augmentation occurred. The bar census conducted between 2012 and 2016 suggests that although bar size has increased, only minor changes in number, frequency, and location of gravel bars has occurred (Table 16, Figure 28). Increases in transient storage (i.e., gravel bars) increase the areas where woody plants could establish, possibly leading to detrimental encroachment, channel simplification, and poor instream habitat. It is also possible that as woody plants establish and mature on the gravel bars, the decrease in cross-section area increases channel shear stress along the channel margins and forces the preexisting channel morphology to adjust to increased local storage, thus creating a positive geomorphic outcome, and maintaining juvenile habitat.

9.2 Management Strategies Not Specifically Included in the ROD

The TRFE focused on vertical scour processes to inhibit riparian encroachment. However, vertical scour is not the only mortality mechanism that can inhibit detrimental riparian encroachment. New approaches could add management flexibility to reduce future encroachment risk. For instance, lateral and local scour, channel migration, prolonged inundation, and increased large wood loading likely already contribute to riparian vegetation initiation and mortality and channel dynamics in the Restoration Reach. Including these elements as part of future management strategies could improve riparian encroachment outcomes.

9.2.1 Large Wood

It is possible that with continued large wood addition and large wood structure construction, bank failure and local scour dynamics around wood pieces and wood jams could encourage further bank erosion and inhibit local woody plant encroachment. Large wood supply, storage, and transport will be an important part of maintaining future channel morphology, whether it is a single-threaded or anabranching channel.

Exogenous factors are able to create and support anabranching channels (Shea 2013). Large wood is an exogenous component that could assist in creating an anabranching channel. For large wood to be functionally successful at maintaining an anabranching channel, the riparian and upland forests would need to continue the supply of wood in sizes and volume needed to support an anabranching channel after constructed wood elements have ceased to provide function. The estimates of the wood size classes and volumes needed to support a multi-channel system were 10 to 20 pieces of wood greater than 20 cm diameter and 2 m long per bankfull width (Cardno Entrix and CH2MHill 2011). The initial wood loading estimates were derived from Pacific Northwest (PNW) interior forests dominated by ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*P. contorta*). Above TRD, forested slopes and medial bar islands may be covered with Douglas-fir (*Pseudotsuga menziesii*), sugar pine (*P. lambertiana*), incense cedar (*Calocedrus decurrens*), and other large conifers similar to the species used in the PNW estimates. Closer to the water, white alder and cottonwood are more common, which may represent different wood loading rates than the PNW estimates. The average rainfall and average temperature at Weaverville indicate that the Trinity River watershed below TRD is a Mediterranean climate that provides conditions to support deciduous woody forests (Whittaker 1975). Given current and future climatic conditions and potential forest types, it is unlikely that large wood of the appropriate size and volume will be sustainable in the Restoration Reach without continued active wood augmentation.

9.2.2 Bank Failure

Diurnal fluctuations (i.e., diel patterns) are one source of streamflow variability. Incorporating diurnal fluctuations into spring ROD releases could be used to encourage bank failure. During the diurnal peak, the soil pores fill with water and during the diurnal low, the pores drain. If daily streamflow fluctuations of 1 to 2 ft were possible at the peak release and then gradually decreased as the recession continued, similar to patterns on unimpaired streams regionally, the diurnal fluctuation could create rapid drops in the substrate pore pressure to the extent that the bank may fail. Multiple studies have shown that when water surface levels in a stream channel decline more rapidly than subsurface water levels in the adjacent streambank, the resulting pore-water pressures in the streambank substrates can induce instability and mass failure (Micheli and Kirchner 2002a, b). Over many years, bank failure related to changing pore pressure could be significant. While operationally possible, there are constraints on how fast streamflows may ascend and descend during managed ROD flows. There may also be safety issues depending at what magnitude bank failure inducing flow fluctuations are started, and landowners adjacent to the river could lose property or riverside improvements to caving banks. While bank failure may be one way the TRRP could increase the rate of channel morphologic change without mechanical assistance, it must be considered within Program constraints and factor in public safety.

9.2.3 Consecutive Flood Peaks

The effect of multiple successive flood peaks as a means of inhibiting encroachment was not evaluated during the TRFE. A single flow of 11,000 cfs may not be the only way to kill 3-year-old establishing woody plants. The WY 1995–1998 period had three consecutive wet years. Peak TRD releases during the 1995–1998 period ranged from 6,000 to 7,000 cfs. Seedlings from the 1995 cohort were not completely scoured and were able to grow to maturity. The seedling data collected during this time did not indicate the potential of using multiple flood peaks as a means of managing establishing seedlings. The data collected nearly 20 years later in 2016 indicates that seedlings greater than 3-years old were removed by the WY 2016 managed flood peak. The 9,600 cfs WY 2016 flood peak followed the WY 2015 8,830 cfs flood peak. Two consecutive years at or above 8,500 achieved the scour of 3-year-old seedlings in WY 2016, where two consecutive years of 6,390 cfs and 6,970 cfs in 1996 and 1997 did not.

It may be simpler to manage seedlings with one peak flow that meets the scour mortality threshold associated with a 1-, 2-, or 3-year-old woody plant. Reaching two flood peaks of similar or greater peak magnitude in consecutive years may use a prohibitive amount of annual allocated water volumes. However, in periods of prolonged droughts of three years or greater, it may be more economic water-wise to have an 8,500 cfs flood peak in year three, and another 8,500 cfs in year four to achieve the same goal as one 11,000 cfs event. The approach is risky, though there is a higher probability that in year four a Normal or wetter year would occur that would allow larger flood peak magnitudes to be more easily achieved.

9.2.4 Inundation Mortality

With sufficient inundation, woody plants will die. One qualitative piece of evidence for inundation mortality in the Restoration Reach occurred in 1993 when summer baseflows were raised from 300 cfs to 450 cfs. Mature alders that had established along the wetted channel began to show signs of leaf yellowing and increased disease; many of these trees perished and were standing dead before 2005. The summer baseflow period before the ROD lasted over 90 continuous days; therefore, it is possible that mature trees could be killed if inundated for an entire growing season and seedlings for two or more weeks (Amlin and Rood 2002, Auchincloss et al. 2012). The late summer Klamath River fish health streamflows provide a second piece of evidence that inundation mortality could be a useful management tool. Narrowleaf willow YOY seedling mortality occurred during years when streamflows were raised from 450 cfs to 1,500 cfs or greater for over 45 days for fish health flows. There are no monitoring data to quantify the effect of inundation mortality directly; however, it could be a potentially effective mortality agent if streamflow duration and magnitude were managed to target the long-term inundation of mature alder trees, or YOY seedlings in years when ROD releases are insufficient to scour them (i.e., flows below 6,000 cfs).

9.2.5 Desiccation Mortality

With rapidly receding flows and/or no rainfall, coarse substrates may dry quickly and plants that establish where there once was available soil moisture may desiccate and die. Seedling desiccation and related plant mortality was documented during the TRFE. Desiccation mortality accounted for about 5% of the YOY seedlings in summer samples. Desiccation mortality that was documented occurred at the upper elevation limits of establishing seedlings and not at lower elevations and was usually associated with cobble and coarse sand substrates. Desiccation mortality was not observed in older seedlings or established or mature woody riparian plants. The low quantities of desiccation mortality in YOY seedings and no other age class did not appear to be a viable way of limiting seedlings, since the summer baseflow magnitude was fixed and there would always be a place lower on the bank where seedlings could germinate and survive with ample access to water.

9.3 Evaluation of Riparian Encroachment-related Hypotheses

Two hypotheses relating to riparian encroachment have been developed for the Restoration Reach of the Trinity River. Hypothesis #1 (H_1) states that the current flow and sediment regimes are smaller than the pre-TRD regimes and therefore the future risk of detrimental riparian encroachment is high following a series of drier years. Hypothesis #2 (H_2) states that the current flow and sediment regimes are larger than the (post-TRD) pre-ROD regimes that led to encroachment in the first place, and therefore the future risk of detrimental riparian encroachment is low. The first hypothesis was developed following early geomorphic and riparian studies and was adopted in the TRFE and ROD as the working hypothesis for riparian encroachment. The second hypothesis was developed during preparation of the Integrated Assessment Plan in 2009, following the first four years of ROD implementation.

At the time the ROD was signed, uncertainty existed around whether managed flood magnitudes could prevent a dense band of riparian vegetation from growing along the low flow channel at a density where channel simplification begins (detrimental riparian encroachment hypothesis; Section 7). To date, inhibiting encroachment has been dependent on the magnitude, frequency, and sequencing of flood peaks to sufficiently mobilize and scour the channel bed frequently enough to prevent most riparian hardwoods from exceeding three years of age along the low flow channel (TRRP and ESSA Technologies 2009). After woody plants exceed a size (or age or density) threshold, monitoring data showed that peak ROD flows alone cannot scour them away (Section

5.3 and 8.1). The 2006 cohort was the one cohort that survived to establishment due to the sequence of three consecutive years of streamflows that were unable to scour them away (Table 18).

As woody plant size and density begin to influence local hydraulics, it becomes increasingly harder to remove plants with floods alone. Fine sediment (sand) deposition and the berm-building process were not monitored and therefore not documented between 2005 and 2016, but woody plant encroachment was. The lack of fine sediment supply in the mainstem and discontinuation of band transect monitoring are the mostly likely reasons that fine sediment deposition and berm formation have not been documented since 2005. Once the size/age/density threshold has been exceeded, other mortality mechanisms must be relied on to reduce the influence of encroaching plants on channel narrowing, increased water velocities, and a rectangular channel morphology.

Detrimental encroachment hypotheses could not be rigorously evaluated. There are only 13 years of post-ROD streamflow and channel rehabilitation data available. Within those years, there has not been an even distribution of water year types, and riparian monitoring was not conducted during all years. Sporadic and questionably successful coarse sediment augmentation has effectively rendered this management strategy as ineffective during the post-ROD monitoring period. Additionally, the Trinity River system has not responded as rapidly as anticipated, so that changes between monitoring years have been small. Further, very little consideration or planning/monitoring has gone into the alternative detrimental encroachment hypothesis (#2) after it was first proposed, and therefore data have not been collected to specifically test it. Collectively, these limitations prevent any conclusive analysis of the hypotheses regarding the threat posed by detrimental riparian encroachment. However, we consider the available data in the context of each hypothesis and make qualitative assessments of detrimental riparian encroachment threat in the following discussion.

H_1, as stated in the TRFE, posits that detrimental riparian encroachment is a long-term threat that must be managed because riparian hardwoods can establish along the low-water edge during a series of consecutive dry years, when post-TRD flows and sediment transport are insufficient to scour plants away. Pre-TRD, the sediment and streamflow regimes, combined with a Mediterranean climate, were the primary factors controlling plant establishment and inhibiting encroachment. Large magnitude winter peaks and variable summer baseflows, with streamflows reaching as low as 30 cfs in Critically Dry years, meant that the plant species associated with woody plant encroachment would colonize far into the active channel where they would be more susceptible to mortality caused by high winter flood flows. The lack of late spring and summer precipitation created drought years with sparse colonization beyond the edge of the low water channel. Hypothesis #1 could be successfully rejected if there were consecutive periods of below Normal water years where plants did not colonize the low water edge and survive beyond their ability to be scoured. Two periods of consecutive dry years followed 2006 and 2012 (Table 7, Table 17). During the dry period following 2006, flows did not exceed 8,500 cfs until managed ROD releases in 2011, when streamflow peaks exceeded 11,000 cfs. Seedlings that initiated in 2006 had five years of growth before the 11,000 cfs release and were beyond the predicted scour thresholds. The 2006 cohort and willow resprouts established and detrimentally encroached the channel at Hocker Flat. During the dry period following 2012, flows did not exceed 6,000 cfs until the 8,830 cfs release in 2015. Seedlings that initiated in 2012 were not scoured by the WY 2015 release and were expected to be beyond the ability of flows to scour. However, the 2016 release was 9,500 cfs, and the 2017 release was 12,000 cfs, the second largest on record since the 1974 flood. Monitoring showed that two consecutive years of flows greater than 8,500 cfs were capable of scouring seedlings older than 3 years, including the 2012 cohort, which was 5-years-old when it was scoured. While 3-year-old plants were unable to be scoured by the single flow of 8,500 cfs, they were able to be scoured by two or more consecutive years of peak releases above 8,500 cfs. The effects of vegetation encroachment are contextual; however, woody plants will establish along the low water if a period of drier years persists and flood peak magnitudes are insufficient to cause widespread mortality in the oldest establishing cohort of woody plants. These observations provide strong evidence in support of H_1.

H_2 from the IAP posits that detrimental riparian encroachment is not a long-term threat because the post-ROD streamflow and sediment regime are sufficient to scour away initiating riparian hardwoods. Flow releases of 6,000 cfs do cause bed mobilization within the 450–2,000 cfs bank zone. Assuming that the year-to-year peak release pattern will continue to be adjusted with an emphasis on higher, more frequent peaks (Figure 30), it is possible that over the long-term, the observed combination of bed mobility and scour will be sufficient to cause scour mortality to riparian plants along the low flow channel and inhibit encroachment. During the 13 years of post-ROD monitoring, only one riparian hardwood cohort (2006) survived beyond the ability to be scoured. Such a pattern could lead to patchy riparian vegetation establishment, which is the presumed pre-TRD condition. The planform density of the surviving cohorts has not been measured and should not necessarily be assumed to have formed a dense band along the channel margin. However, it is important to consider the species that are establishing along the low water edge: narrowleaf and dusky willows are highly clonal and well-adapted to form thickets along the channel margin. Establishment of these species could lead to detrimental riparian encroachment, even if only one or two cohorts survive every decade. The effects of coarse sediment augmentation, a requirement for success of H_2, were not clear. The effects of gravel augmentation are localized, and augmentation volumes are tailored to maintain sediment transport rates near the dam similar to those at measured downstream locations (Gaeuman 2014, Gaeuman and Stewart 2017). There was no clear trend between 2001 and 2018 in channel bed coarsening or fining at channel bed sampling locations where gravel augmentation did not occur (GMA Hydrology 2020). However, at four gravel augmentation sites between 2006 and 2017, there was a weak trend in decreasing size for the D_{90}, and no apparent trend for the median particle size (D_{50}), with the exception of one site at Limekiln Gulch where a slight decrease was evident (Gaeuman and Stewart 2017). It is possible that with continued gravel augmentation, H_2 could be accepted as true; however, it is improbable in the near term. Reductions in channel bed particle size have not been sufficient to lower the discharge thresholds needed to mobilize the channel bed. There is no way to reject H_2 with the current data and flood peak frequency. To reject H_1 or H_2, there needs to be sufficient contrast. The risk of encroachment is problematic, because if H_1 is true and the three-year threshold is exceeded, the resulting detrimental riparian encroachment would be counter-productive to Program goals and would be resource-intensive and time consuming to correct through the AEAM framework.

10 RECOMMENDATIONS

Whether encroaching vegetation is a benefit or problem is contextual. In reaches where there is shallow bedrock control or where valley walls confine the river, vegetation cannot encroach the low water channel. In alluvial reaches, heavily vegetated channel margins associated with encroachment are valuable cover and fish habitat when inundated. Encroachment becomes a problem when it inhibits bank erosion and confines the channel. The available information suggests that encroachment is and will continue to be a management consideration for the TRRP in alluvial reaches where channel adjustment and/or migration create and maintain juvenile rearing habitat. The following recommendations have been developed to address uncertainties and data gaps identified throughout this report.

10.1 Review, Revise, and Adopt a Reach-based Prediction of Achievable Channel Pattern

The TRRP must rectify the obvious disconnect between current channel prediction analyses and current conditions along the river (Section 3.1.1). The current Eaton et al. (2010) model does not predict an anabranching channel for the Trinity River without unvegetated banks and increased peak flow magnitude Unvegetated banks are unrealistic if vegetation establishment occurs along the current channel margin. Furthermore, it does not appear that an anabranching channel form can naturally construct itself in areas with encroaching vegetation. Consequently, less vegetation, higher flows, and a smaller D_{50} particle size would be needed to maintain a migrating or anabranching channel in the presence of vegetated banks.

The desired future condition must fit within the physical constraints of the existing system. The current particle-size distribution and flood frequency may not be able to achieve anabranching channels quickly, or at all. The Channel Design Guide (HVT et al. 2011) evaluated channel patterns in large sections of the river; however, the TRRP should conduct similar analysis at a local site level to inform channel design and temper management expectations. Site or segment level analysis should use realistic cohesion estimates and local channel bed particle sizes and channel slope.

The TRRP should formally evaluate the reach delineations currently available and adopt a reach designation that makes the most sense from an AEAM context; additional attempts to redefine reaches are not necessary because they would not provide much more information to the Program. Consistent reach definitions would be useful across disciplines and would make monitoring results from riparian vegetation, fish habitat, bird, herpetology, and physical studies more easily comparable. The reach delineations based on the mining legacy sediment wedge or hydraulic controls would likely make the most sense (Krause et al. 2010, Buffington et al. 2014, Gaeuman et al. 2016). Once a reach delineation is adopted, the predicted channel pattern and expected physical, aquatic habitat, and riparian vegetation outcome in each reach should be defined in shorter segments, potentially using the 200 m data frame developed as part of the Phase 1 review (Buffington et al. 2014). Past, present, and future channel rehabilitation sites in each reach and sub-segment would be identified. The encroachment threat for each reach and sub segment could be defined and evaluated. This exercise would build on opportunities and constraints identified in the RCMP.

After a physical model and a reach delineation are selected and adopted (agreed upon), the TRRP should evaluate the trade-offs of detrimental riparian encroachment in some locations compared to habitat quality and quantity increases associated with locations where an anabranching channel may be possible. The habitat gains maintained from inhibiting encroachment in single-thread reaches may be relatively minor compared to the habitat gains in anabranching locations. Having a Program-defined goal that specifies the priority of reducing encroachment on a single-thread channel vs. creating salmonid habitat through construction of anabranching channels, would simplify future restoration efforts on the Trinity River by providing guidance to Program partners during the rehabilitation site design and monitoring processes. It is likely that the reach delineations adopted by the TRRP will have different goals depending on the physical model (i.e., channel pattern) predicted for a reach or sub-segment.

10.2 Develop and Adopt a Revised Vegetation Encroachment Hypothesis

The current riparian vegetation encroachment hypotheses make assumptions about the causal factors leading to detrimental riparian encroachment (i.e., current conditions are worse than pre-TRD conditions in H_1, current conditions are better than post-TRD and pre-ROD conditions in H_2; Section 7) that are difficult to assess quantitatively. Both causal factors are likely true (Section 9.3). Monitoring has focused on the annual establishment of riparian hardwood seedlings along the low water edge at specific sites, the results of which are then extrapolated to the entire Restoration Reach. However, local conditions at each site are unique and systemwide estimates are problematic, since the planform extent of establishing riparian vegetation is not tracked annually. Surviving cohorts may occur in discrete patches or in dense, continuous bands. Frequent disturbance to near channel vegetation is more likely to inhibit the formation of dense continuous bands, reducing bank cohesion and creating and maintain juvenile salmonid habitat.

The TRFE and ROD assumed the Trinity River was a meandering, semi-alluvial, single channel river. With continued implementation of the ROD, the distribution of vegetation from the low water edge to upland habitats was assumed to follow a predictable pattern. Herbs should dominate along the low flow water edge and then gradually transition into shrubs and then trees up the riverbank, as distance and elevation increase from the wetted channel. The formation of floodplains relies on the ability of the channel to migrate and deposit sediment that accretes to form floodplains, or disturbance magnitudes with a frequency that changes the current channel configuration. One objective of managing woody plant establishment along the low water edge was to maintain juvenile salmonid habitat once the post-TRD channel configuration adjusted to sediment augmentation and the ROD flow regime.

Two additional hypotheses were developed as a result of this synthesis. One hypothesis was developed to test whether the current trend in flood frequencies is more effective at managing woody seedling establishment and low water encroachment than the frequency and magnitude of floods recommended in the TRFE. The second hypothesis was developed to test whether ROD streamflows may increase the channel width but not eliminate near channel vegetation establishment and berm formation.

Currently, the frequency and extent of channel bed scour is such that woody plants infrequently establish along the 450 cfs wetted edge, but plants can establish further up the bank where shear stress is insufficient to cause widespread channel bed mobility. Local sediment storage, lateral channel migration, and local flow obstructions can alter scour patterns to the extent that established vegetation will be scoured.

> H_{01}: *The 6,000, 8,500, and 11,000 cfs flood events occurring at the frequency of Normal and wetter years cannot inhibit near channel woody seedling establishment and the formation of a dense band of vegetation after a period of three consecutive dry years.*

Expected outcomes:

- Dense vegetation band near the low flow channel,
- Increased local bank cohesion,
- Deepening channel, and
- Reduced juvenile salmonid habitat quantity and quality.

If the null hypothesis is true and sediment supply and transport are in equilibrium, it is possible that as woody plant establish, salmonid rearing habitat will be lost. Encroaching vegetation inhibits episodic channel adjustments or migration and leads to channel deepening, which decreases seasonally available juvenile salmonid habitat quantity and quality. Existing rearing habitat may convert to perennial vegetation or become too deep and fast to be useable habitat.

> H_{A1}: *The 6,000, 8,500, and 11,000 cfs flood events occurring more frequently than Normal and wetter years and during dry periods can inhibit near channel woody seedling establishment and disrupt the formation of a dense band of vegetation even after a three-year dry period.*

Expected outcomes:

- Patchy near channel vegetation,
- Decreased local bank cohesion,
- Episodic channel adjustments or migration, and
- Increased and maintained juvenile salmonid habitat quantity and quality.

If the alternate hypothesis is true and sediment supply and transport are in equilibrium, it is possible that as perennial vegetation is scoured away to create new salmonid rearing habitat, existing rearing habitat may convert to perennial vegetation, and the balance of disturbance, vegetation scour, rearing habitat area, and vegetation remain the same at a decadal scale.

Viewing encroachment from a broader landscape perspective over a longer time frame may be more appropriate to a river system with variable flows. Some years may be characterized by large floods with a sediment deficit, resulting in widespread erosion, and other years may be characterized by a sediment surplus, resulting in deposition. Erosion will remove vegetation at the low water edge and along floodplains. Subsequent sediment deposition will create new juvenile salmonid habitat. Older juvenile habitat becomes a location of riparian hardwood colonization. Portions of the channel may be heavily vegetated while other portions provide juvenile salmonid rearing habitat. The location of vegetated and open channel margin may or may not change annually depending on water year sequences and local sediment supply.

There is a limit to the extent that annual flows can alter the channel configuration and inhibit encroachment. During a flood peak, there is a lateral threshold beyond which shear stress is unable to mobilize the channel bed surface and remove establishing woody plants. Higher shear stress values are required to scour out plants as they grow older. Vegetation may establish beyond where flood flows may mobilize the channel bed. One concern is that seedlings will establish slightly higher on the bank and lead to similar channel conditions as those documented during the TRFE.

> *H_{02}: If a dense vegetation band establishes further up the bank beyond the limits of scour, bank cohesion will be high and the channel may get deeper and reduce the ability of the channel to migrate, similar to the pre-ROD encroached channel but wider.*
>
> Expected outcomes:
>
> - Uniform channel widths, depths, and steep channel margins,
> - No channel adjustment, bar formation, or migration, and
> - Reduced juvenile salmonid habitat quantity.

If the null hypothesis is correct, then establishing woody plants will encroach the channel slightly higher on the bank. Encroaching vegetation will continue to inhibit episodic channel adjustments and lead to channel deepening, which decreases seasonally available juvenile salmonid habitat quantity and quality. Existing rearing habitat may become too deep and fast to be useable habitat.

> *H_{A2}: If a dense vegetation band establishes further up the bank beyond the limits of scour, the channel may still be dynamic within the limits of established vegetation.*
>
> Expected outcomes:
>
> - Variable channel widths, depths, and shallow channel margins,
> - Episodic channel adjustments, bar formation, or migration, and
> - Increased and maintained juvenile salmonid habitat quantity and quality.

If the alternative hypothesis is correct, then establishing plants will not confine the channel and the channel could adjust and seasonally available juvenile salmonid habitat quantity and quality would be increased and maintained.

While evaluating equilibrium may be useful at a decadal scale, encroachment management must occur in shorter periods and should be considered annually. Based on the data collected between 1995 and 2016, water year classification and managed flood peak magnitude can be used to assume annual seedling mortality patterns. Recruitment monitoring could be used to verify assumptions and identify the presence/absence of seedlings in different bank locations. Encroachment risk should be considered as part of annual flow release planning.

10.3 Evaluate Current Berm Condition

Studies in the Restoration Reach dating back to the 1990s have shown that streamflows greater than 16,000 cfs are needed to remove single mature alder trees from the streambank edge, and even greater flows are needed to remove groups of alders (Section 5.2.2). Riparian berms are therefore unable to be managed (i.e., removed) in the Restoration Reach using streamflows alone. There is current disagreement among Program partners regarding the extent of riparian berms in the Restoration Reach. As a result, there is uncertainty regarding the need to consider riparian berm removal during channel rehabilitation design and effectiveness monitoring. It is unknown how much the area and extent of riparian berms have changed since the ROD. The SAB estimated that over 85% of the mainstem river shows no change in the periods evaluated (i.e., 2001–2005, 2005–2007, 2007–2009, 2010–2011). Establishing and mature vegetation influences the location and size of deposited sediment. Coarse and fine sediment deposited during overbank flows create both berms and floodplains, and there is not a clear way to distinguish an incipient floodplain from an incipient berm. In the absence of large channel-forming flows, berms associated with vegetation encroachment can confine the channel, leading to channel narrowing and deepening, and a rearing habitat reduction over time. One ROD success metric could be reduction of the riparian berm associated with encroaching vegetation and habitat loss.

The current state of the berms should be assessed similarly to how geomorphic changes at channel rehabilitation sites have been evaluated (HVT and MA 2014). Topographic changes are computed using a differencing method applied to two terrain models. The terrain models are typically created from topographic datasets, commonly including topographic and bathymetric surveys (circa 2009 and circa 2016). Topographic differencing can be performed using ArcGIS and Geomorphic Change Detection (GCD) software (Wheaton 2008). The GCD software applies a combination of user-defined filters to account for data source (i.e., survey method) error and statistical evaluations to create a Digital Elevation Model (DEM) of difference (DoD). At a study site, DoD results are used to create isopach maps, which are displayed as a range of colors corresponding to the magnitude of change between surveys (e.g., net scour and net aggradation).

There are limits to a GIS exercise and how much we can learn relative to the errors inherent in the data and magnitude of changes we might be seeing. When evaluating changes in berm condition, it is worth noting there are problems using this method in areas of dense vegetation when the surface data are from LiDAR, because LiDAR error is compounded in areas with dense riparian vegetation due to the limited ability of the LiDAR to penetrate vegetation and accurately record ground-surface elevation.

Channel width and wetted edge length are important indictors of change and reducing the effects of encroachment. The DoD data could be used to address the question of whether the channel has detectably widened and if so, where. The cause of the width change could be evaluated relative to large wood, berm removal, channel rehabilitation site construction, or channel migration. The 2003 geomorphic mapping which specifically mapped berms as a geomorphic unit identified about 22–25% of the Restoration Reach as having berms. Part of the exercise would be to place mapped berm locations on the areas with channel length and width changes. The proportion of berm eroded could be estimated as long as the magnitude of change is greater than the amount of error associated with the data. The 200 m GRTS data frame from the Phase 1 review or the hydraulic unit approach in the RCMP would be a good way to tally the data.

10.4 Evaluate and Revise the Conceptual Model for Coarse Sediment Augmentation and Update the Coarse Sediment Management Plan

The riverwide reduction of the coarse sediment particle-size distribution was an initial component of the CSMP. The numeric model and the results of sediment transport monitoring as applied by Viparelli et al. (2011) suggest that it is possible to reduce the channel bed particle-size distribution with gravel augmentation and current measured sediment transport rates. It is possible that coarse sediment volume augmentation estimates may have reduced the size of the coarser channel bed component. In the four model runs conducted by Viparelli et al. (2011), the reach averaged median diameter became smaller with both lower and higher augmentation volumes (i.e., 10,021 and 14,689 US Tons/year, respectively). The D_{90} became smaller only when higher volumes of coarse sediment were augmented. The augmentation rates recommended in the TRFE and CSMP were considerably more that have been currently implemented (Table 6). It is unclear whether the current coarse sediment augmentation rates of 3,000 to 8,000 US Tons are capable of achieving the intended reduction in particle sizes, or if that is even a current objective of coarse sediment augmentation. Obviously, a smaller coarse sediment particle-size distribution would make managing encroaching woody plants easier. What is less clear is whether the particle-size distribution can feasibly be made small enough to significantly influence sediment transport and storage and whether it should be a TRRP priority. The second detrimental encroachment-related hypothesis (H_2) hinged on a reduction of the D_{84} to more easily achieve channel bed mobility and inhibit woody plant encroachment (Section 7). H_2 cannot be fully evaluated without a robust coarse sediment augmentation program. The linkage between the desired or anticipated outcome of gravel augmentation and riparian encroachment hypotheses should be reevaluated and explicitly articulated and monitored.

10.5 Repeat the Exposed Gravel Bar Census in Normal and Wetter Years

The band transect monitoring protocol was developed over 15 years ago to evaluate specific questions relating to TRFE hypotheses. Band transect monitoring is cross section-based and provides an extremely detailed dataset, allowing us to track individual plants from germination to either mortality or establishment; however, it is a resource-intensive method (i.e., it takes a lot of time and money to obtain the data) and it only tells us about a single cross section of the river. Results of band transect monitoring have shown that woody riparian plant encroachment has been inhibited on active bars along the 450 cfs wetted edge. Based on increased knowledge since the band transect protocol was developed and subsequent changes to band transect monitoring methodology, the band transect monitoring was discontinued in 2013 and replaced by exposed bar monitoring, which includes similarities to band transect monitoring, but is able to provide better systemwide estimates of vegetation status. The Program should continue conducting the annual exposed bar census on an appropriate timeline based on formative flow events (i.e., peak releases greater than 6,000 cfs), but eliminate future band transect encroachment monitoring and rely on riparian mapping similar to that conducted for systemwide vegetation mapping (M&T 2005, HVT and MA 2015) instead to monitor the long-term status and trend of riparian vegetation.

10.6 Annually Estimate Detrimental Encroachment Risk to Inform Annual Flow Release Planning

Encroachment by itself merits management simply because of the long list of negative geomorphic effects caused by vegetation encroachment (Casado et al. 2016). Detrimental encroachment risk can be visualized as the probability of crossing a plant density threshold where encroachment is no longer manageable, which leads to channel narrowing, deepening, and reduced fish habitat. Based on the history of vegetation encroachment in the Trinity River, it makes sense to use every tool available to reduce vegetation encroachment into the active channel. This could be further supported with a simple cost–benefit analysis. Regardless of how imperfect the definition of detrimental encroachment risk is, it makes sense to continue to monitor the bank position of depositional zones and surviving seedlings and compare them to the pre-ROD pattern.

Data suggest that the root length to substrate size hypothesis/management objectives put forth in the TRFE were largely correct (Section 9.1). The range of differences in plant densities below 2,000 cfs from one fall to the next varies as a result of peak-flow magnitudes achieved during each water year. In above Normal years, plant densities decreased between sampling. In below Normal years, plant densities often increased. As plant densities approach detrimental encroachment thresholds, the reduction in density required to prevent encroachment thresholds from being crossed is related to the water year class that can induce scour to depths needed to remove plants of a given age class/root depth. Based on monitoring data through 2016 and the frequency of larger peak flow magnitudes from 2005–2016, the 2006 cohort has been the only cohort to have survived to establishment below 2,000 cfs. All other year cohorts were scoured.

Detrimental encroachment risk could be evaluated using fall plant density estimates within various size classes in the < 2,000 cfs inundation zone, the detrimental encroachment density thresholds (Table 12), and changes in plant density estimates related to water year classes. Since each water year class has a probability of occurrence, that probability can be used to assess the risk that detrimental encroachment thresholds could be exceeded:

$$p_e = 1-(p)_{wy} \qquad \text{Eq. 1}$$

where $(p)_{wy}$ is the exceedance probability of the water year type that causes the change in desired plant density and p_e is the probability of encroachment.

For example, if fall field monitoring showed that 3-year-old woody plant density was approaching the density threshold, a flow greater than 11,000 cfs (i.e., an Extremely Wet year peak release) would be needed to reduce the densities below the density threshold; the current risk would be high (88–100%; color red). In this example, the detrimental encroachment risk associated with an Extremely Wet year would be: $p_e = (1-0.12) = 0.88$, or a greater than 88% chance of encroachment if the managed flow magnitude is not met or exceeded that year. The assessment steps could be:

1. Estimate annual plant density in the bank zone < 2,000 cfs (YOY, 1-year, 2-year, 3-year, > 3-year-old, and total).
2. Calculate the difference between annual plant densities and the detrimental encroachment threshold values (Table 11) to estimate the change in plant density needed to prevent densities from crossing the threshold values.
3. Select the flow required to remove the oldest age class approaching the detrimental encroachment threshold and calculate the risk of detrimental encroachment (Table 19).
4. During the development of the annual ROD streamflow release, make recommendations to reach peak flows that would most likely inhibit plant densities from crossing detrimental encroachment thresholds.
5. Systemically monitor the efficacy of spring peak releases on changing plant density and inhibiting detrimental riparian encroachment.

Table 20. Estimated risk of detrimental encroachment for each riparian hardwood size class based on the probability of occurrence of the water year type needed to remove the size class.

Size Class	Dominant Plant Age	Q to Remove	WY Type to Remove	Risk Code	Risk of Detrimental Encroachment
0.0–0.25 cm	Young-of-Year	≤ 6,000 cfs	Normal and wetter	Green	None
0.26–0.50 cm	1-year-old	≤ 6,000 cfs	Normal and wetter	Green	Low
0.51–0.75 cm	2-year-old	≤ 8,500 cfs	Wet and wetter	Yellow	Moderate
0.76–1.0 cm	3-year-old	≥ 11,000 cfs	Extremely Wet	Red	High
1.01–1.50	4-year-old	Unlikely to remove with flows alone	N/A	Grey	Encroached, unless two consecutive years of > 8,500 cfs releases are possible
1.51–2.0 cm	5-year-old	Unlikely to remove with flows alone	N/A	Grey	Encroached, unless two consecutive years of > 8,500 cfs releases are possible

10.7 Evaluate Variable Summer Baseflows and Conduct Flow Experiment

Annual summer baseflows have been 450 cfs since 1991 (Section 4.2). Streamflows are held at a near constant 450 cfs at Lewiston to maintain cold water temperatures farther downstream that support incoming adult salmonid survival and health. In many years, this is more than 90 consecutive days at the same streamflow for over half the riparian hardwood growing season and solely within the narrowleaf and dusky willow seed dispersal periods. The streamflow stability combined with the longest seed dispersal period of any willow species along the Trinity River mainstem in the Restoration Reach is a continued recipe for narrowleaf–dusky willow encroachment wherever there are exposed unvegetated edges at 450 cfs. If plants could establish lower in the channel in drier years, it would be much easier to scour them away in future years. In wetter years, a prolonged recession limb would inundate lower surfaces throughout the summer, promoting woody plant colonization farther up the bank (Figure 5). Summer baseflow variability would promote greater low water fringe complexity, with sparse patchy woody vegetation combined with herbaceous vegetation. Without variable summer and fall baseflows, the TRRP is constrained to using flood peaks to inhibit woody plant encroachment.

It is recommended that TRRP evaluate variable summer baseflows and the temperature effects of having lower flows in dry years and potentially longer recession limbs in wetter years. It would be valuable to understand what flexibility, if any, is available for reducing or increasing summer baseflows. The evaluation would need to include the effects that variable baseflows would have on Chinook Salmon, steelhead, Coho Salmon (how many hours can a fish undergo thermal stress before it is significant), and foothill yellow-legged frog. One hypothesis is that dropping flows earlier and lower in drier years would create thermal triggers to promote fish migration out of the Trinity River and through the lower Klamath before conditions become unsuitable. If variable baseflows could be released in a way that would affect woody plant colonization without negatively affecting fish, the option should be further explored in an AEAM context and flow experiments conducted.

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APPENDIX A: PROPOSED RIPARIAN ENCROACHMENT SYNTHESIS REPORT OUTLINE

The following outline was included in the FY 2018 Riparian Encroachment Synthesis Report Proposal.

Proposed Riparian Encroachment Synthesis Report Outline

I. Introduction

- Purpose and Need
    - Conceptual life history model and limiting factors
    - Streamflows timing, frequency, magnitude, duration, and rate of change interactions with willow life history
    - ROD hydrograph components that could promote encroachment (i.e., summer baseflows)
    - Historic patterns of water year persistence (1, 2 and 3 yrs of drought years in the hydrologic period of record at Lewiston)
    - Detrimental encroachment defined
    - Encroachment process, channel simplification and habitat loss
    - TRFE Objectives
    - Encroachment hypothesis (H1 and H2 from the workshop/PITA/IAP)

II. Goals and Objectives

- Goal to summarize and synthesize riparian encroachment trends and possible limiting mechanisms to provide a single synthesis of all the riparian information so that the full scope of encroachment dynamics and implications for management can be considered.

III. Identify and discuss management actions directed at inhibiting encroachment

- Annual Hydrographs
    - ROD Hydrograph components with encroachment-related objectives
        - Inundation and channel bed scour and mobility
        - Cause and effect mechanisms related to specific hydrograph component
    - Winter peak flows magnitude and frequency and spring peak flows magnitude and frequency
    - TRFE-predicted flood frequency related to water year classes
    - Time series hydrographs and water year class sequencing
    - Actual flood frequency relative to water year classes
- Channel rehabilitation site design
    - Initial design features/topography (feather edges, bank scallops, mass grading)
    - Current designs features

- How has the design evolution changed relevance of encroachment to successful restoration outcome?

- Fine sediment management
    - Berm formation
    - Historic and current trends (from Fine Sediment Transport and Storage Synthesis Report, if funded)
- Klamath late summer streamflows for fish health
    - Past flow schedules overlaid on life history to identify hypothesized effects
- Discussion of combined management action effects on encroachment and the ability to detect the effect of one management action over another within the context of currently available data and collection frequency

IV. Existing Physical and Biologic Data Evaluation and Summary

- Periods of record and methods
- Cross section topographic change
- Channel bed scour and surface mobility
- Band transects
- Linkage of biologic and physical data trends to annual hydrology

V. Synthesis and Discussion

- Peak flow magnitude and frequency efficacy at restricting encroachment
- Encroachment risk during 1, 2, 3 year and greater drought cycles
    - Effect of 2015 high flow after x years of drought (this topic might not be included in final assessment)
- Mechanisms that restrict encroachment
    - Identify predominant mortality mechanisms from the physical, hydrologic and biologic data
    - How do current encroachment trends reflect hypothesized mortality mechanisms discussed in the TRFE and what are the differences?
- Define the current risk of encroachment
    - Do the data suggest that one encroachment hypothesis is more likely to be true than another?
    - Current trend in channel rehabilitation site design
    - Current trend in streamflow peak magnitude and frequency
    - Channel bed scour and mobility frequency
    - Fine sediment availability
    - Stable mainstem summer baseflows for temperature and variable summer baseflows for fish health

VI. Recommendations

APPENDIX B: FINAL RIPARIAN ENCROACHMENT SYNTHESIS REPORT OUTLINE

The following outline represents changes to the proposed outline as recommended by Program partners. Comments on the proposed outline were provided by the Yurok Tribe, the U.S. Bureau of Reclamation, and the U.S. Forest Service. The final report outline changed during creation of the report to accommodate and better organize pertinent information.

1 Introduction
2 Goals and Objectives
3 Alluvial River Definition and Anticipated Channel Types
  3.1 Anticipated Channel Pattern
4 Riparian Vegetation Effect on Stream Physical Processes
5 Vegetation Encroachment Channel Simplification and Habitat Loss on the Trinity River
  5.1 Pre-TRD Hydrology, Channel Type, and Vegetation Patterns
  5.2 Post-TRD Hydrology, Channel Type, and Vegetation Patterns
6 1980 Andrus Decision and Maintenance Flow Period
  6.1 Geomorphic Studies
  6.2 Vegetation Encroachment Studies
    6.2.1 Conceptual Life History Model
    6.2.2 Evaluating Mature Riparian Vegetation Disturbance Thresholds
    6.2.3 Woody Plant Seed Dispersal Periods
    6.2.4 Age and Root Length
    6.2.5 Woody Plant Demographics and Berm Formation
7 Trinity River Flow Evaluation Report and the Record of Decision
  7.1 TRFE Restoration Strategy
  7.2 Streamflow Management
    7.2.1 Water Year Classes and Flood Frequency
    7.2.2 Water Year Hydrographs
    7.2.3 Water Year Specific Objectives
  7.3 Channel Rehabilitation Site Design
  7.4 Sediment Management
    7.4.1 Fine Sediment Management
    7.4.1 Coarse Sediment Management
8 Detrimental Encroachment
  8.1 Detrimental Encroachment Hypotheses
9 Evaluation of Management Action Influence on Encroachment From 1998 to 2004
  9.1 Study Design
  9.2 Relationship of Biologic and Physical Data Trends to Management Actions
10 Evaluation of Management Action Influence on Encroachment From 2005 to 2009
  10.1 Sampling Design
  10.2 Method Revisions
    10.2.1 Seedling Density Within Index Flow Bins
  10.3 Relationship of Biologic and Physical Data Trends to Management Actions
11 Evaluation of Management Action Influence on Encroachment From 2010 to 2012
  11.1 Sampling Design
  11.2 Method Revisions
    11.2.1 Root Collar Diameter Size Relationship to Seedling Age
    11.2.2 Evaluating Encroachment Risk
  11.3 Relationship of Biologic and Physical Data Trends to Annual Hydrology
12 Evaluation of Management Action Influence on Encroachment From 2013 to 2016
  12.1 Sampling Design
  12.2 Method Revisions