TRINITY RIVER

MAINTENANCE FLOW STUDY

FINAL REPORT

NOVEMBER 1997

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FINAL REPORT

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PREFACE

Our report summarizes hydrologic, geomorphic, and biological research from 1991 to 1997 and recommends management alternatives for recovering the Trinity River ecosystem below Lewiston Dam. While our initial involvement was coined a “maintenance flow study”, we were obliged to address other equally important issues vital to ecosystem recovery: in-channel sediment management and channel reconstruction. Initial objectives and hypotheses have evolved and expanded, but our basic premise has remained steadfast. A healthy river ecosystem is necessary to restore anadromous salmonid populations. If the alluvial channel morphology prior to the Trinity River Division cannot or will not be restored, we envision little hope for salmon population recovery. Our goal rejects the notion that single species management in regulated rivers can remedy salmon population declines. Instead, a list of alluvial river attributes was developed for coarse bedded alluvial channels as our study’s guidepost. Periodic channelbed mobility, alternate bar formation, bedload routing, and sediment budgeting were pivotal in recommending variable annual flow allocations. Our recommendations, in attempting to accommodate natural alluvial channel processes, should not be construed as final. Rather, an adaptive management program may refine and/or replace them as understanding of the Trinity River ecosystem advances.

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GLOSSARY OF TERMS, NOTATION, AND ACRONYMS

TERM	DEFINITION
Aggradation	Raising of reachwide channel bed elevation due to sediment accumulation.
Alluvial	Bed and banks comprised of sand, gravel, and cobbles, and channel dimensions are adjustable by current fluvial processes.
Alternate bar	An alternating series of point bars, where the low water channel meanders in a sinusoidal pattern between the point bars.
Ascending limb	Component of storm, snowmelt, or dam release hydrograph that is ramping up towards a peak flow magnitude.
Bankfull channel	In alluvial channels, the end of the actively used channel and beginning of floodplain. The bankfull transition is usually correlated to a change in confinement, beginning of fine sediment deposition, and beginning of floodplain riparian species (cottonwoods).
Bankfull discharge	Discharge that just fills the bankfull channel and begins to spill onto the floodplain.
Bar face	Portion of point bar that is downward sloped as one travels from the floodplain towards the low water edge.
Bedload	Coarser component of sediment transported by a stream. During transport, particles are in constant or frequent contact with the stream bottom. Bedload makes up most of the channel bed and banks, but typically represents only 5-15 percent of a streams sediment yield (excluding dissolved component).
Bedload impedance reaches	Reaches of channel where bedload can not be transported through due to human activity (pool dredging) or tributary delta induced backwater.
Boundary shear stress	Force per unit area exerted on the channel bed by a given flow, largely responsible for mobilizing the bed surface and transporting sediment.
Capillary fringe	The zone above a water table where water is drawn into soil pores to a certain height by water surface tension forces (capillarity), and is inversely proportional to a soils pore radius.

Channel morphology	The shape, size, and particle size of a channel created by the interaction of fluvial, biological, and geomorphic processes.
Encroachment	(see Riparian encroachment)
Hydraulic geometry	The relationship of channel morphology to width, depth, velocity, and slope for a given discharge.
Hydrograph	Stream discharge plotted as a function of time. Annual hydrographs use time increments of a day, while flood hydrographs typically use time steps of ½ to 2 hours.
Hysteresis	Difference in sediment transport rates between the ascending limb of a storm hydrograph and the receding limb.
Incipient conditions	Hydraulic/discharge threshold where a given bed particle begins to be mobilized.
Morphology	(see Channel morphology)
Receding limb	Component of storm, snowmelt, or dam release hydrograph that is ramping down from a peak flow magnitude to a lower flow.
Riparian berm	Sand deposited along the edge of the low water channel as a result of riparian vegetation slowing water velocities and inducing deposition of fine sediments transporting either as bedload (coarse sand) or in suspension (fine sand).
Riparian encroachment	The process of riparian initiation establishment maturity progressing toward the low water channel. Reduction in high flow regime reduces natural flood induced riparian mortality, which allows riparian vegetation to initiate and survive in channel locations that would normally be scoured by floods.
Riparian establishment	Begins at the end of the first summer and extends through several growing seasons as the plant increases energy reserves and strengthens roots and shoots.
Riparian initiation	Begins at seed germination and extends through the first summer.

Riparian maturity	When a plant first expends energy on sexual reproduction and continues through its maximum reproductive period.
Sapling	A young tree with a trunk less than 4 inches in diameter at breast height (4.5 feet above the ground surface).
Seedling	A plant shortly after seed germination, includes the first plumuoles.
Subsurface particles	Particles found in the gravel column deeper than one D_{84} diameter below the bed surface.
Surface particles	Particles found in the gravel column from the bed surface to a depth of one D_{84} diameter.
Suspended sediment	The finer sediment component transported by a stream. During transport, particles are suspended in the water column and infrequently come in contact with the bottom. Suspended sediments typically represent 85-95 percent of a stream's sediment yield (excluding dissolved component).
Thalweg	The deepest channel portion.
Water yield	Total volume of runoff generated by a watershed over a water year.

NOTATION	**DEFINITION**
A_d	Debris area.
A_t	Tree area.
C_{Dd}	Debris drag coefficient.
C_{Dt}	Alder drag coefficient.
D	Tree diameter.
d	Average water depth.
d_i	Local water depth.
D_i	Particle size within a substrate distribution, in mm, that represents the *i* th percentile of a cumulative distribution curve. The particle size where *i* percent are finer than that particle size.
D_{sc}	Bed scour depth.
F_c	Critical force of alder failure.
F_d	Water drag force on alder.
F_g	Gravitational force.

g	Gravitational acceleration (9.81 m/s^2).
H	Cable attachment height to alder: distance from cable to rotational failure.
k	von Karman's constant ($\cong$ 0.4)
Mo_c	Critical moment to topple alder.
n	Manning's resistance coefficient.
p	Exceedence probability.
Q, Q_w	Streamflow discharge.
V	Average water velocity.
Q_{bl}	Bedload discharge.
Q_{ss}	Suspended sediment discharge.
r^2	Correlation coefficient.
R^*	Reynold's roughness number.
S	Water surface slope, used as an estimate of energy slope.
U^*	Shear velocity.
U_{ave}	Average water velocity.
W	Channel width.
X	Distance from tractor to the front of alder.
Y	Hydraulic radius.
Y_c	Hydraulic radius at incipient conditions.
ρ_s	Density of sediment (2,650 kg/m^3).
ρ_w	Density of water (1,000 kg/m^3).
θ	Cable angle from tractor to alder.
τ_b	Depth averaged boundary shear stress.
τ^*_{ci}	Critical Shield's parameter for particle of (*i*) size.

ACRONYMS

AF:	Acre-Feet
BM:	Benchmark
BLM:	Bureau of Land Management
BOR:	United States Bureau of Reclamation
CFS:	Cubic Feet per Second
CVP:	Central Valley Project
CDFG:	California State Department of Fish and Game
CRD:	Critical Rooting Depth
DBH:	Tree Breast Height Diameter
DRC:	Root Collar Diameter
DWR:	California State Department of Water Resources
EWI:	Equal Width Increment

HVT:	Hoopa Valley Tribe
NGS:	National Geodetic Survey
NGVD:	National Geodetic Vertical Datum
NRCS:	Natural Resources Conservation Service
RM:	River Mile
SAEX:	*Salix exigua*
SALUL:	*Salix lucida* subspecies *lasiandra*
SWQBC:	State Water Quality Control Board
TRD:	Trinity River Division
TRA:	Trinity Restoration Associates
UCB:	University of California at Berkeley
USBR:	United Stated Bureau of Reclamation
USFWS:	United States Fish and Wildlife Service
USGS:	United States Geologic Survey
XS:	Cross Section
WY:	Water Year

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EXECUTIVE SUMMARY

Background

Completion of the Trinity River Division (TRD) in 1963 dramatically altered the hydrology and geomorphology of the Trinity River mainstem downstream of Lewiston Dam. Pre-TRD peak floods frequently attaining 70,000 cfs conveyed sediment, shaped and maintained the channel, sustained dynamic riparian communities, and provided habitat for salmonids and other wildlife. The TRD reduced peak flood magnitudes to less than 14,000 cfs, eliminated the snowmelt hydrograph, trapped upstream bedload behind Trinity Dam (including gravel comprising salmonid spawning habitat), and removed nearly all flow variability immediately downstream. Changes in channel morphology, and consequently salmonid habitat, were almost immediate. Woody riparian trees germinated, initiated, and matured along the low water channel margin, which was artificially maintained year round at 150 to 300 cfs. This dense vegetation accumulated coarse sands and formed riparian berms along the low water channel margin up to eight feet high. Pre-TRD floodplains were abandoned. Channel morphology simplified into a near rectangular channel geometry entrenched within the riparian berms, reducing the quantity, quality, and diversity of aquatic habitats. The once alluvial channelbed and banks of the pre-TRD mainstem became functionally immobile by riparian encroachment. Only the collective contribution of flow and sediment from major unregulated tributaries salvaged partial alluvial behavior of the mainstem Trinity River downstream of Indian Creek.

Restoration Philosophy and Strategy

The primary goal of the USFWS Trinity River Basin Fish and Wildlife Task Force is “to restore natural salmon and steelhead production in the Trinity River and tributaries downstream from Lewiston Dam.” Recovering dynamic alluvial processes in the mainstem Trinity River ecosystem is the most conservative strategy for improving natural salmon and steelhead populations. We conducted an historical analysis of the Trinity River ecosystem (primarily hydrology, channel morphology, and riparian vegetation) to hypothesize how the Trinity River ecosystem “worked” prior to the TRD. The following set of alluvial river attributes for ecosystem integrity of the mainstem Trinity River was developed:

ATTRIBUTE No. 1. Spatially complex channel morphology.
No single segment of channelbed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities;

ATTRIBUTE No. 2. Flows and water quality are predictably unpredictable.
Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal “predictable unpredictability” is a foundation of river ecosystem integrity;

ATTRIBUTE No. 3. Frequently mobilized channelbed surface.

On average, channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years;

ATTRIBUTE No. 4. Periodic channelbed scour and fill.

The bed surface on alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal;

ATTRIBUTE No. 5. Balanced fine and coarse sediment budgets.

River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be of transported through the river reach;

ATTRIBUTE No. 6. Periodic channel migration.

The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber;

ATTRIBUTE No. 7. A functional floodplain.

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also serve to form the floodplain and low terraces by depositing finer sediment onto the inside banks of meander bends;

ATTRIBUTE No. 8. Infrequent channel resetting floods.

Single large floods (e.g., exceeding 10- to 20-year recurrences) cause channel avulsions, widespread rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods;

ATTRIBUTE No. 9. Self-sustaining diverse riparian plant communities.

Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors;

ATTRIBUTE No. 10. Naturally-fluctuating groundwater table.
Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs, and adjacent wetlands occur similarly to regional unregulated river corridors.

Attainment of these attributes will culminate in a more complex and dynamic channel morphology, providing high quality anadromous fish habitat. These attributes helped us establish quantitative restoration goals downstream from Lewiston Dam, as we tailored our study plan to quantify the fundamental attributes that create and maintain a healthy river ecosystem. These attributes should also help formulate adaptive management monitoring objectives.

Results

We focused on quantifying the primary process-oriented attributes, Attributes 3, 4, 5, 8, and 9. Our historical evaluation of pre-TRD hydrographs (Attribute 2) was used to develop a water year classification (inter-annual variability) and identify distinct hydrograph components (intra-annual variability), while Attributes 3, 4, 5, 8, and 9 determined magnitude and duration of flows. Other attributes (e.g., Attributes 1, 6, 7, and 10) are secondary physical responses to these primary attributes.

Our experimental findings were:

- High flow events immediately after construction of pilot bank rehabilitation sites formed point bars or complete alternate bar sequences, increasing morphological habitat complexity (Attribute No. 1).
- Unregulated flow contribution by tributaries downstream of the TRD cannot mitigate the loss of snowmelt peak and recession hydrograph components eliminated by the TRD (Attribute No. 2).
- Highly mobile in-channel alluvial deposits began mobilizing by flows ≥ 3,000 cfs (Attribute No. 3).
- Point bars and riffles began mobilizing by flows ≥ 6,000 cfs (Attribute No. 3).
- Scour of point bar surfaces, particularly those regions highly susceptible to future riparian encroachment, began to occur by flows ≥ 11,000 cfs (Attribute No. 4).
- The mainstem Trinity River has a deficit sediment budget near Lewiston Dam; coarse sediment supply near Lewiston Dam needs to be augmented, while higher flows are required to mobilize and distribute coarse sediments delivered by downstream tributaries (Attribute No. 5).
- The fine sediment budget is becoming supply-limited due to the sediment control efforts in the Grass Valley Creek watershed and increased dam releases in recent years (Attribute No. 5).
- Channel migration does not occur in reaches with riparian berms firmly anchoring both sides of the channel. Only by mechanically removing selective sections of the riparian berm can channel migration resume (Attribute No. 6).
- At several pilot bank rehabilitation sites where point bars have formed, functional floodplains have initiated (Attribute No. 7).
- First year riparian seedlings could be successfully killed if the bed surface layer was mobilized; 2 and 3 year-old plant required deeper bed scour for significant mortality (Attribute No. 9).

Quantification of these attributes allowed us to develop flow, sediment, and channel morphology management recommendations that would restore fluvial processes.

Recommendations

Flow Recommendations

A water year classification is proposed to accommodate unregulated annual flow variability (Attribute No. 2). Unique annual hydrographs were prescribed for each water year class based on the hydrograph component analyses. On April 1st of each water year, the Bureau of Reclamation projects the total Trinity River Division inflow for the entire water year. We recommend five water year classes, based on their projected annual inflow to Trinity Reservoir, to provide the needed inter-annual flow variability:

WATER YEAR CLASS	EXCEEDENCE PROBABILITY	THRESHOLD RESERVOIR INFLOW FOR WATER YEAR DESIGNATION
Extremely Wet	$p<0.12$	>2,000,000 acre-feet
Wet	$0.12<p<0.40$	1,350,000 to 2,000,000 acre-feet
Normal	$0.40<p<0.60$	1,025,000 to 1,350,000 acre-feet
Dry	$0.60<p<0.88$	650,000 to 1,025,000 acre-feet
Critically Dry	$p>0.88$	<650,000 acre-feet

Recommended annual flow releases at Lewiston Dam were partitioned into hydrograph components identified from pre-TRD annual hydrographs, including: summer baseflow, winter baseflow, rainfall-generated winter floods, snowmelt peak runoff, and snowmelt recession. Historically, certain attributes were satisfied by unique hydrograph components (e.g., Attribute No. 8 channel resetting floods occurred during rain-on-snow winter flood events). Therefore, based on results from quantifying the attributes, the flow magnitude, duration, frequency, and timing for each hydrograph component were described for each water year class. Combining these components resulted in the following annual hydrograph recommendations:

1. EXTREMELY WET ($0.88<p$): Five days at a peak flow of 11,000 cfs in late May, rapidly descending to 6,000 cfs by June 5, holding at 6,000 cfs for five days, then gradually descending to 1,500 cfs by July 13, holding at 1,500 cfs until July 26, then rapidly descending to a 300 cfs summer baseflow by July 31.
2. WET ($0.60<p<0.88$): Five days at a peak flow of 8,500 cfs in during the third week in May, rapidly descending to 6,000 cfs by May 25, holding at 6,000 cfs for five days, then gradually descending to 1,500 cfs by June 27, holding at 1,500 cfs until July 16, then rapidly descending to a 300 cfs summer baseflow by July 19.

3. NORMAL (0.40<p<0.60): Five days at a peak flow of 6,000 cfs in during the second week in May, gradually descending to 1,500 cfs by June 14, holding at 1,500 cfs until July 12, then rapidly descending to a 200 cfs summer baseflow by July 15.
4. DRY (0.12<p<0.40): Five days at a peak flow of 4,500 cfs in during the first week in May, gradually descending to 1,500 cfs by June 4, holding at 1,500 cfs until July 16, then rapidly descending to a 200 cfs summer baseflow by July 19.
5. CRITICALLY DRY (p<0.12): Thirty-three days at a peak flow of 1,500 cfs from May 15 to June 16, then rapidly descending to a 100 cfs baseflow by June 19.

Sediment Management

Duration of peak flows has been set to balance the coarse sediment budget downstream of Rush Creek. Because there is virtually no bedload supply upstream of Rush Creek, bed material introduction will be needed upstream of Rush Creek at roughly the bedload transport rate at the Lewiston gaging station. The particle size of introduced bed material should be greater than 8 mm.

Water Year	Gravel Introduction (tons)
Extremely Wet	23,000 to 53,000
Wet	8,000 to 16,000
Normal	1,600 to 2,250
Dry	175 to 275[1]
Critically Dry	0

[1] functionally zero

Additional recommendations for coarse and fine sediment management are:

- Grass Valley Creek sedimentation ponds should continue to be used as a fine sediment trap, provided the ponds are excavated immediately after large storms.
- Sediment removed from Grass Valley Creek sedimentation ponds should be screened, and bed material greater than 8 mm should be returned to the mainstem for downstream transport.
- Bedload transport continuity should be restored by excavating portions of the deltas of Rush Creek, Grass Valley Creek, and Indian Creek to remove the hydraulic control that prevents coarse bedload from upstream sources from routing through these deltas.
- Reduced fine sediment storage in mainstem pools indicates the fine sediment budget is switching from over-supply to under-supply. Therefore, future pool dredging should be unnecessary, as the recommended high flow regime should continue decreasing fine sediment storage.

Channel restoration

Restoring flow variability, timing, duration, and magnitudes will restore critical dynamic channel processes in the Trinity River. However, restoring dynamic alternate bar morphology will not occur unless the riparian berm is selectively removed in many locations. Removing the riparian berm will reduce confinement and encourage alluvial deposits to form, transport and redeposit. This will correspondingly increase the quantity, quality, and diversity of salmonid habitats. We recommend that future channel rehabilitation projects be designed and built to dimensions corresponding to predicted equilibrium conditions for local site hydrology, coarse sediment supply, and geologic control. Forty-three potential bank and channel rehabilitation sites have been identified between Lewiston Dam and the North Fork Trinity River.

Our approach and recommendations are based on the tenet that conditions preceding construction of the TRD and historical mining activities present a model of a healthy river ecosystem. This study showed that pre-TRD channel morphology and processes can successfully be restored, but not at the scale that existed prior to the Trinity River Division. Barring removal of the dams, the scale of form and process characteristic of the pre-TRD channel cannot be restored. Therefore, restoring a dynamic alluvial river will require a scaled down channel and particle size, coarse sediment supplementation, and more frequent flood events of sufficient magnitude to initiate and sustain important fluvial processes. Bank rehabilitation in key locations, in conjunction with high flows and ample coarse sediment supply, is expected to foster alternate bar formation and enhance habitat complexity for native biota.

CHAPTER 1: INTRODUCTION

Completion of the Trinity River Diversion (TRD) in 1964 initiated dramatic biological and geomorphic changes in the Trinity River below Lewiston Dam. Negative impacts to anadromous fish populations were recognized soon after completion of the project. The TRD blocked access to over 109 miles of anadromous salmonid habitat upstream of the dam site (USFWS 1994). Though spawning and rearing habitat for anadromous salmonids was present downstream of Lewiston prior to the project, many adult salmonids had continued far upstream, utilizing the upper mainstem and tributaries. TRD operations severely degraded anadromous salmonid habitat downstream, forcing the mainstem to assume new ecological roles. By the early-1970s, restoration efforts were underway.

Almost no restoration effort focused on restoring the geomorphic and riparian processes that once created and maintained a healthy river ecosystem. We believe recovery of these processes is the best overall strategy for rehabilitating the anadromous fishery potential for the mainstem channel below Lewiston Dam. As stated in the Trinity River Watershed Analysis (BLM 1995), "…the re-institution of flows adequate for maintenance of dynamic channel morphology and all the ecosystem benefits associated with it is identified as the highest priority restoration needed."

Our study began in 1991 as a "channel maintenance flow" determination. However, we soon realized flow prescriptions alone would not be sufficient for recommending restoration strategies for the

Trinity River ecosystem. Our goal was to determine if mainstem channel dynamics could be rehabilitated, and if so, where and by what means. We first investigated how pre- and post-TRD mainstem processes were related to the annual hydrograph, both physically and biologically. Based on this investigation, we next developed a set of “healthy alluvial river attributes” to identify restoration strategies and to serve as initial hypotheses.

Anadromous salmonids and other native species in the Trinity River ecosystem adapted their life histories to best take advantage of seasonal runoff patterns and an alluvial river morphology. By applying alluvial river attributes as restoration objectives, we assumed that processes and conditions that once supported Trinity River fish populations prior to dam construction should benefit the river ecosystem, and consequently future anadromous salmonid populations. Given flow and sediment regulation will continue (i.e., TRD operation will continue), we then attempted to quantify many of the attributes and recommend annual flow releases, sediment management practices, and channel rehabilitation projects to help recover and maintain a dynamic alluvial channel morphology.

1.1 Geographic setting

The Trinity River, with its headwaters in the Trinity Alps Wilderness Area, drains 2,950 mi^2 before flowing into the Klamath River at Weitchpec in the Hoopa Valley Indian Reservation (Figure 1.1). Altitudes range from over 9,000 ft on Mt. Eddy to less than 500 ft at Weitchpec. The climate is Mediterranean, with streamflow strongly influenced by large rainfall floods (from October through May) and moderate spring snowmelt floods.

Accretion of unregulated flows and sediment from the North Fork Trinity River substantially mitigate geomorphic impacts from TRD operations downstream from its confluence with the mainstem. Given significant impacts from Lewiston Dam down to the North Fork Trinity River, our study focused on this reach. In describing impacts and when making recommendations, we refer to “the mainstem” as the reach from Lewiston Dam (river mile (RM) 112.0) downstream to the confluence with the North Fork Trinity River (RM 72.4).

Streamflow is regulated at Trinity Reservoir having a storage capacity of 2.4 million acre-ft. Immediately downstream of Trinity Dam is Lewiston Reservoir, a relatively small re-regulation reservoir and diversion point for trans-basin water diversion to the Central Valley Project (CVP). Lewiston Dam, which marks the upstream limit of anadromous salmonid access, is 112 miles upstream of the Trinity River-Klamath River confluence. From 1962 to 1979, CVP diversions delivered nearly ninety percent of the Trinity River annual water yield (above Lewiston) into the Sacramento River for urban and agricultural use. After 1979, river releases were increased from 110,000 acre-feet to 340,000 acre-feet, such that the diversion percentage was reduced to roughly seventy percent.

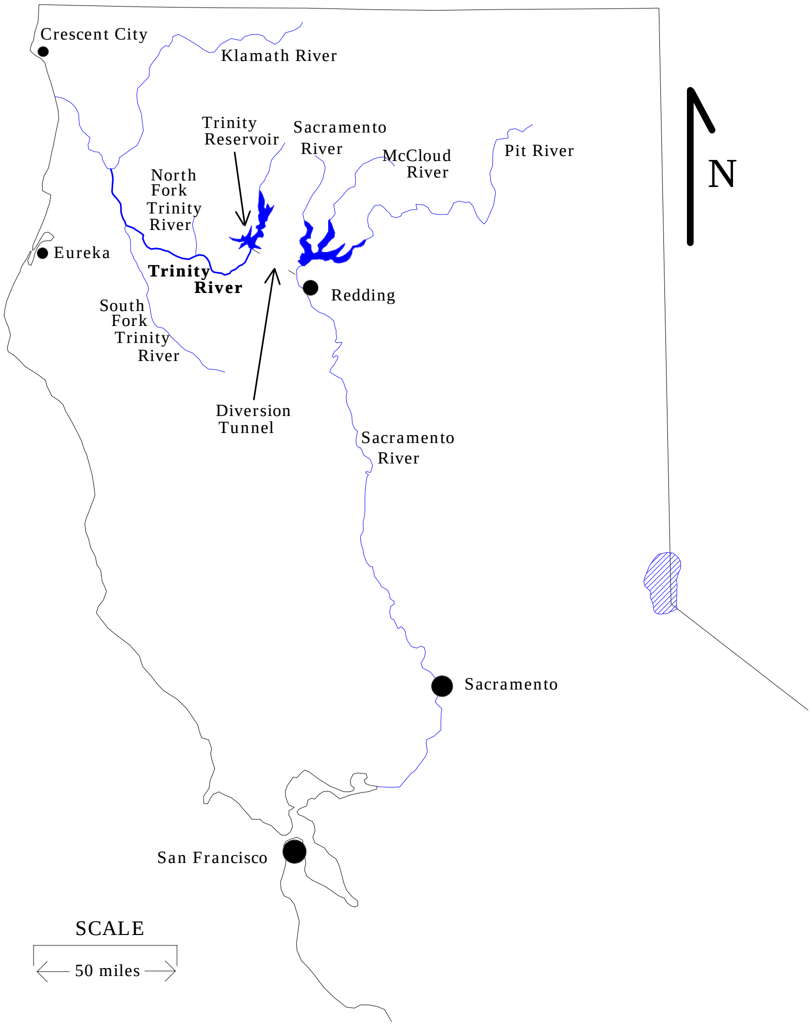

Figure 1.1 The Trinity River in northwestern California.

1.2 Study approach and report organization

1.2.1 Overall study approach

To recommend maintenance flows, we had to quantify threshold flow releases initiating important physical and biological processes identified in the alluvial river attributes. Channel maintenance flows must accommodate threshold flows that mobilize the channelbed and transport coarse bedload. Similarly, to discourage future riparian encroachment we needed to quantify threshold flows that scour riparian seedlings and prevent germination. The impact of the TRD to the Trinity River channel morphology was most pronounced from Lewiston Dam (RM 112) downstream to the North Fork Trinity River (RM 72.4), and we focused our attention on this reach (Plate 1).

Our experimental approach was mostly empirical, though modelling was instrumental in testing some hypotheses and predicting future trends. An empirical emphasis had several advantages: (1) over the five-year effort we were able to develop a quantitative understanding of river processes, (2) our dependence on flume and/or short-term, idealized field investigations to quantify/predict processes was minimized, (3) models could be calibrated with data pertaining directly to the mainstem, (4) constant exposure to the river gave us an appreciation (awe) for the importance of spatial and temporal variability in geomorphic and riparian processes that shape the river ecosystem, (5) we could experiment with methodologies, accepting only those that passed field testing for inclusion in future monitoring, and (6) it was fun.

1.2.2 Report organization

This report progresses from a description of pre-TRD and post-TRD mainstem conditions (Chapter 2), to identification of important alluvial ecosystem traits and processes (Chapter 3), to formulation of a study plan (Chapter 4), to findings for specific investigations (Chapters 5 through 10), to an integration of these findings (Chapter 11), and finally to specific recommendations (Chapter 12). The data collected were considerable; thus individual chapters combine methods, results, and discussions for each specific investigation (Chapters 5 through 10) to facilitate the readers' comprehension, and our own, of this complex ecosystem.

CHAPTER 2: GENERAL CHANGES IN MAINSTEM TRINITY RIVER HYDROLOGY, RIPARIAN VEGETATION, AND CHANNEL MORPHOLOGY

Historic conditions of the mainstem Trinity River are presented as a baseline for evaluating pre-TRD flow and sediment dynamics and identifying characteristics of unregulated annual hydrographs contributing to river ecosystem integrity. Later in this chapter, alterations of the annual flow regime will be qualitatively linked to geomorphic and biological changes in the post-TRD mainstem. Quantitative links will be developed in later chapters before recommending specific maintenance flow releases to rehabilitate the river ecosystem.

General hydrologic impacts of the TRD were analyzed using streamflow records from the USGS gaging stations at Lewiston (RM 110.9), near Burnt Ranch (RM 48.6), and at Hoopa (RM 12.4). Classic analyses included constructing daily and monthly average flow duration curves, annual maximum flood frequency curves, and partial flood frequency curves. We employed these general techniques to simplify comparisons between pre- and post-TRD hydrology, even though they eliminate flow variation as a tradeoff for analytical simplification. For example, a daily average flow duration curve created from a 30-yr record would inaccurately describe daily average flows in most (if not all) of those 30 years. Likewise, monthly flow duration curves eliminate practically all flow characteristics relevant to riverine geomorphic and ecological processes. But in subsequent chapters we evaluated geomorphic and riparian processes dependent on flow magnitude, duration, frequency, and timing using analyses of individual annual hydrographs to capture essential flow variation in our analyses.

Descriptions of the evolution of the riparian community were derived from several sources: reports (e.g., Pelzman, 1973), our qualitative analyses of aerial photographs, vegetation inventories at study sites, and observation of berm cross-sections. Changes in channel morphology were described by comparing pre- and post-TRD cross sections at the USGS gaging station at Lewiston (RM 110.2) and at a cross section in our Steiner Flat study site (RM 91.7).

2.1 Change in streamflow at USGS gaging stations

Major changes in mainstem Trinity River flows by TRD operations required separate analyses of pre-TRD and post-TRD hydrologic regimes. The storage in TRD and diversions into the Sacramento River nearly prevented high flows since 1963. We were interested in this comparative hydrologic analysis for two reasons: (1) to establish a hydrologic baseline from which to quantify cause-and-effect relationships between flow regime and channel morphology, and (2) to quantify the downstream extent of impacts of the TRD to mainstem flows. The objective of this section is to summarize pre- and post-TRD annual water yield, daily average flow duration, and flood magnitude and frequency.

The pre-TRD period was defined as WY1912 to WY1960; the post-TRD period runs from water years WY1961 to WY1995. Three types of hydrologic data were used: (1) instantaneous peak discharges from the USGS (for annual maximum flood frequency analysis), (2) daily average discharges from the USGS (for annual hydrographs, water year designation, and flow duration analysis), and (3) daily average inflow into Trinity Reservoir from the USBR. Data were obtained from the following USGS gaging stations (Table 2.1 and Plate 1):

Station Name	Drainage Area (mi^2)	USGS Station #	Period of Record Used	Number of Years
Clair Engle Reservoir nr Lewiston	692	11-5254	1961-1995	35
Trinity River @ Lewiston	719[b]	11-5255	1912-60 [a], 1961-95 [b]	49, 35
Grass Valley Creek @ Fawn Lodge	30.8	11-5256	1976-1995	20
Trinity River below Limekiln Gulch	812[c]	11-52565	1981-1991 [c]	11
Weaver Creek near Douglas City	48.4	11-5258	1959-1969	11
Trinity River near Douglas City	933	11-5260	1945-1951	7
Browns Creek near Douglas City	71.6	11-5259	1957-1967	11
N.F. Trinity River @ Helena	151	11-5265	1912,1913,1957-80	26
Trinity River near Burnt Ranch	1,438[d]	11-5270	1932-40 [a],1957-60 [a],1961-95 [d]	13,35
Trinity River at Hoopa	2,865 [e]	11-5300	1912,13,17,18,32-60 [a];61- 95 [d]	33,35

[a] Pre-dam

[b] Post-dam, unregulated drainage area = 0.3 mi^2

[c] Post-dam, unregulated drainage area = 93.3 mi^2

[d] Post-dam, unregulated drainage area = 719 mi^2

[e] Post-dam, unregulated drainage area = 2,146 mi^2

Table 2.1 USGS streamflow gaging stations on the mainstem Trinity River and tributaries near the TRD.

2.1.1 Annual water yield at the USGS gaging station at Lewiston

The USGS gaging station on the Trinity River near is the longest continuously operating gaging station on the Trinity River established in 1912. This station, representing the benchmark for Trinity River flows, is located immediately downstream of Lewiston Dam making it ideal for comparing pre- and post-TRD streamflows. Unregulated flows for the entire period of record were derived from gaged flows at Lewiston prior to TRD and Trinity Reservoir inflows following TRD completion. The Trinity River drainage area at the Lewiston gaging station is 719 mi^2.

Average unregulated annual water yield from the Trinity River watershed over the 84 years of record is 1,250,000 acre-ft. Annual values varied from a low of 234,000 acre-ft in WY1977 to a high of 2,893,000 acre-ft in WY1983 (Table 2.2). Under TRD regulation, annual releases (including controlled and uncontrolled releases) below Lewiston ranged from a low of 119,400 acre-ft in WY1977 to a high of 1,291,000 acre-ft in WY1963, and averaged 293,720 acre-ft. From WY1961 to WY1995, an average of 77.4% of the annual runoff of the Trinity River above Lewiston was diverted into the Sacramento River, ranging from a low of 32.8% in WY1994 to a high of 93.2% in WY1983 (Table 2.2).

Pre- and post-TRD annual hydrographs of daily average flows for the Trinity River at Lewiston gaging station (RM 110.0) were plotted from 1912 to 1996. Post-WY1961 annual hydrographs with unregulated daily average flows entering the reservoir were estimated from Trinity Reservoir inflows (based on changes in lake stage) obtained from USBR. The difference in drainage area between the Lewiston gaging station below Lewiston Dam (719 mi^2) and Trinity Dam (692 mi^2) is minimal (27 mi^2). Thus we compared regulated annual hydrographs measured at the Lewiston USGS gage site with estimated unregulated annual hydrographs at Lewiston for post-TRD water years. In Appendix A, annual hydrographs at Lewiston are presented for each water year prior to regulation (WY1961); thereafter, regulated and estimated unregulated hydrographs are presented in the same figure for each water year (WY1962 through WY1996).

The most striking change to the Trinity River at Lewiston annual hydrographs is the near elimination of flow variability. Where flows ranged from summer baseflows of 25 cfs to 50 cfs up to floods of 10,000 cfs to 70,000 cfs within a single water year before regulation, regulated flows were often held to a near constant 150 cfs to 300 cfs over the entire water year (excluding unplanned releases). The large storage capacity of Trinity Reservoir (twice the volume of the basin's average annual water yield) allowed most flood events in the upstream watershed to be captured by the reservoir, such that "safety of dams" releases were infrequent. As a result, peak releases were usually less than 6,000 cfs, and always less than 14,500 cfs (the 1974 flood release). Specific changes to individual components of annual hydrographs, such as summer baseflows and winter floods, are discussed and evaluated in Chapter 5.

Water Year	Lewiston Release (af)	Reservoir Inflow (af)	Percent Released to River
1965	129,078	1,666,739	8%
1966	150,942	1,320,758	11%
1967	238,534	1,638,036	15%
1968	129,324	1,060,936	12%
1969	155,829	1,765,607	9%
1970	213,663	1,585,586	13%
1971	179,887	1,695,234	11%
1972	123,027	1,193,568	10%
1973	132,756	1,413,057	9%
1974	705,586	2,675,848	26%
1975	275,381	1,414,983	19%
1976	126,609	704,766	18%
1977	119,429	233,774	51%
1978	178,106	2,038,834	9%
1979	225,088	867,829	26%
1980	322,604	1,476,849	22%
1981	282,405	884,663	32%
1982	468,101	2,001,994	23%
1983	1,291,339	2,893,314	45%
1984	569,669	1,535,708	37%
1985	250,699	861,152	29%
1986	495,229	1,596,666	31%
1987	309,235	898,852	34%
1988	255,715	977,471	26%
1989	329,885	1,073,967	31%
1990	233,141	732,136	32%
1991	270,754	503,790	54%
1992	354,895	936,448	38%
1993	367,609	1,766,211	21%
1994	355,392	568,231	63%
1995	719,722	2,221,331	32%

Table 2.2 Trinity River post-TRD annual water yields and instream releases.

2.1.2 Flood frequency curves for Trinity River at Lewiston, near Burnt Ranch, and at Hoopa

Annual instantaneous peak discharges at each mainstem Trinity River USGS station were compiled and plotted by return period. The data were then fit to the Log-Pearson Type III distribution and plotted to produce annual maximum flood frequency curves (USGS, 1982). Pre-TRD annual maximum flood flows at Lewiston ranged from a low of 3,060 cfs in WY1920 to a high of 71,600 cfs in WY1956. The fit of Lewiston flood data to a Log-Pearson III distribution predicted 1.5-year to 2.0-year annual maximum floods, often considered channel forming or maintaining floods, of 10,700 cfs and 14,600 cfs, respectively (Figure 2.1).

Impacts to high flow magnitudes are noticeable for much of the river's length. Analyses of pre- and post-TRD flood frequency curves at the Burnt Ranch (RM 48.6) and Hoopa (RM 12.4) gaging stations document the geographic extent of TRD impacts. This comparison shows flood magnitude for a given flood recurrence increasing substantially downstream as unregulated tributaries (e.g., North and South Fork Trinity River, New River) contribute to flooding (Table 2.3, Figures 2.2 and 2.3).

	Lewiston (RM 110.9)	Burnt Ranch (RM 48.6)	Hoopa (RM 12.4)
Pre-TRD 1.5-yr flood (cfs)	10,700	21,200	39,000
Post-TRD 1.5-yr flood (cfs)	1,070	10,700	42,000
Percent of pre-TRD	10%	50%	107%
Pre-TRD 10-yr flood (cfs)	36,700	88,400	118,000
Post-TRD 10-yr flood (cfs)	7,500	40,500	114,000
Percent of pre-TRD	20%	46%	97%

Table 2.3 Comparison of pre- and post-TRD flood magnitudes at mainstem USGS Trinity River gaging stations.

The TRD has had minimal impact on the magnitude of 1.5-yr and 10-yr floods (as annual maxima) at Hoopa, mostly due to the contribution of the South Fork Trinity River and the New River, both entering the Trinity River between the Burnt Ranch and Hoopa gages. The TRD does significantly alter flood magnitudes at the Burnt Ranch gaging site, although the most significant effects are upstream of the North Fork Trinity River confluence.

2.1.3 Flow duration curves for Trinity River at Lewiston, near Burnt Ranch, and at Hoopa

Daily average flow duration curves, for the same three mainstem gaging stations, were constructed by sorting and ranking all daily average flows for the period of interest, computing exceedence probabilities, then plotting discharge by exceedence probability (Dunne and Leopold, 1978). Pre- and post-TRD daily average flows were analyzed separately.

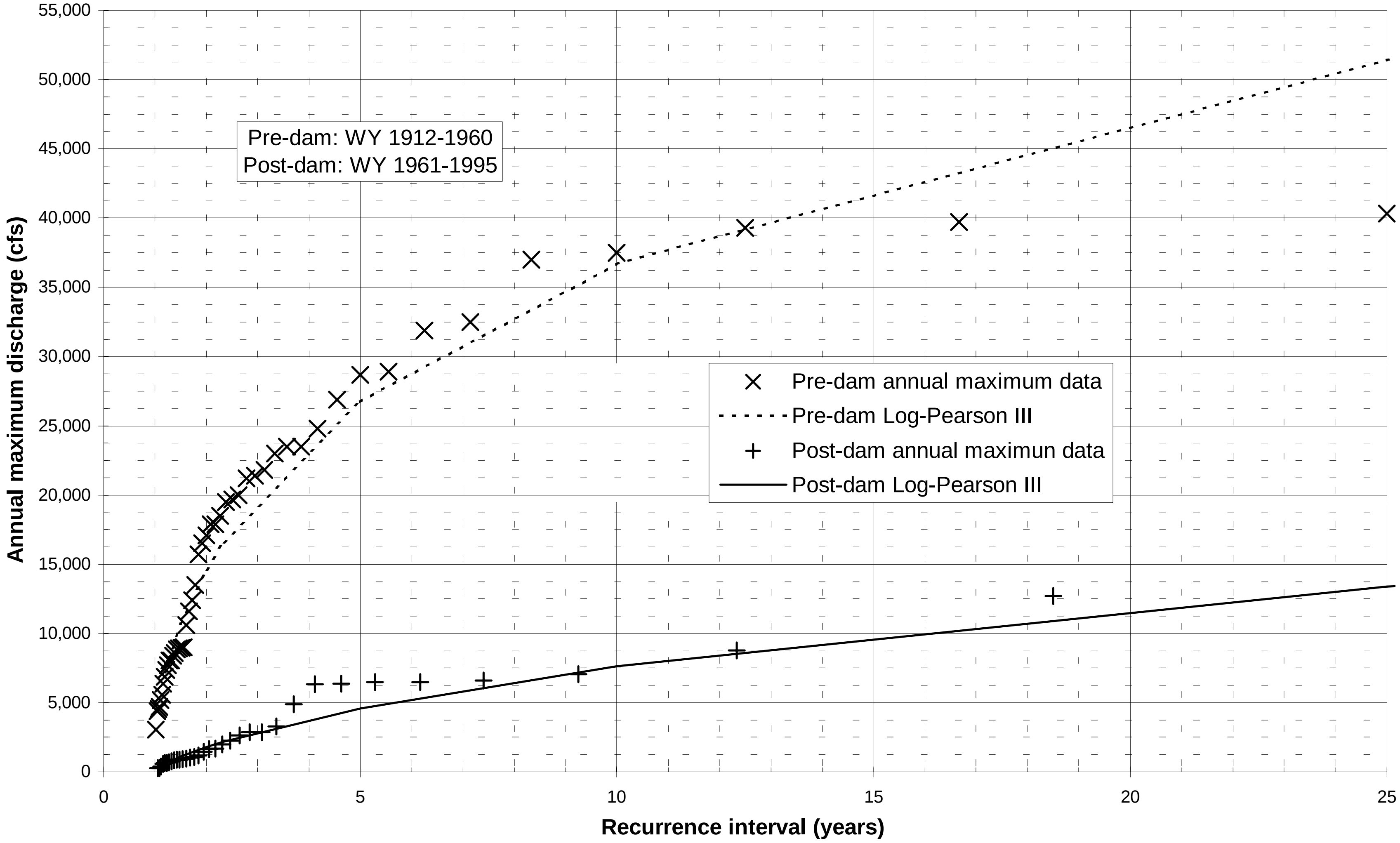

Figure 2.1 Trinity River at Lewiston (11-525500) gaging station pre- and post-TRD annual maximum flood frequency curves.

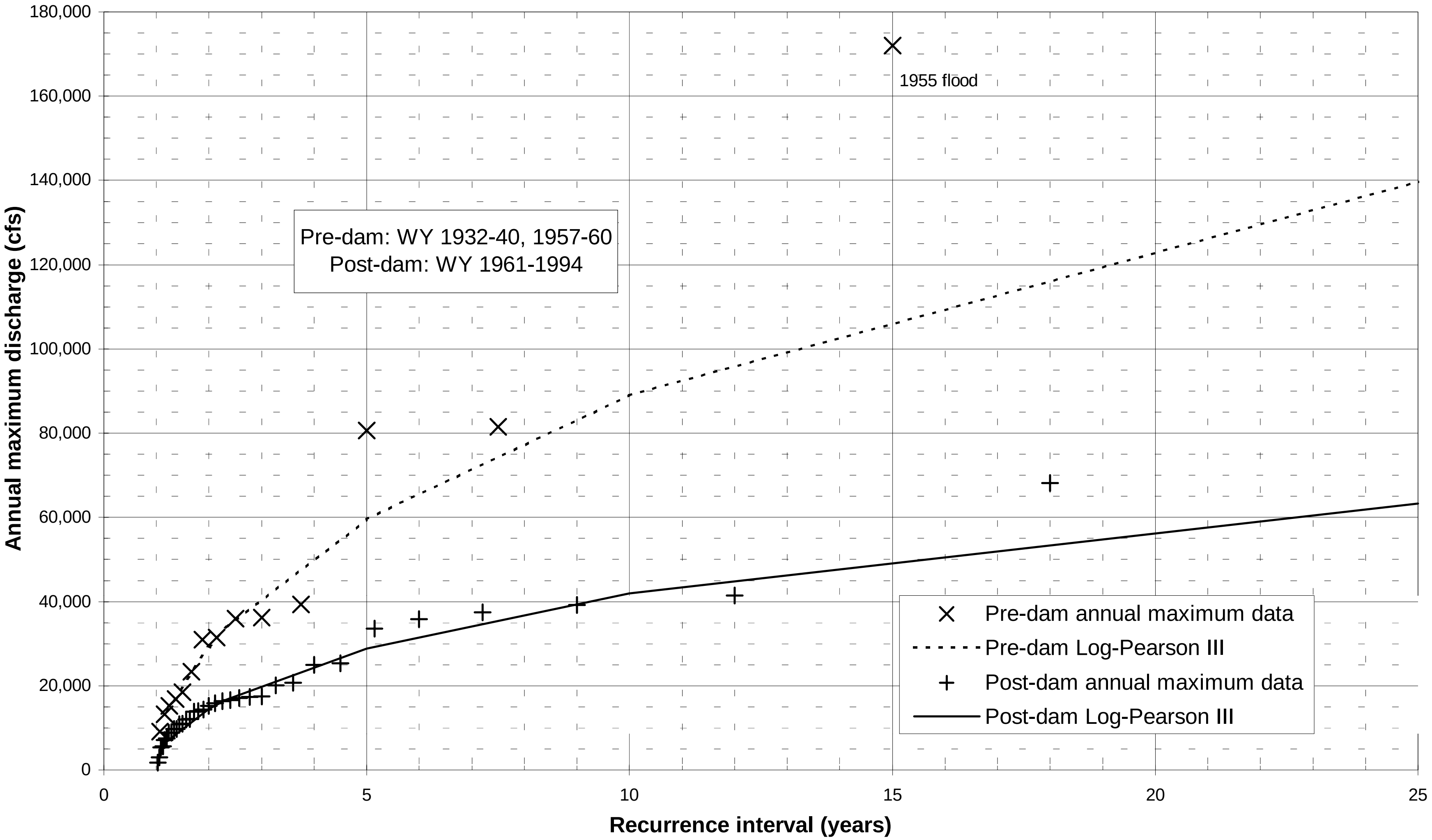

Figure 2.2 Trinity River near Burnt Ranch (11-527000) gaging station pre- and post-TRD annual maximum flood frequency curves.

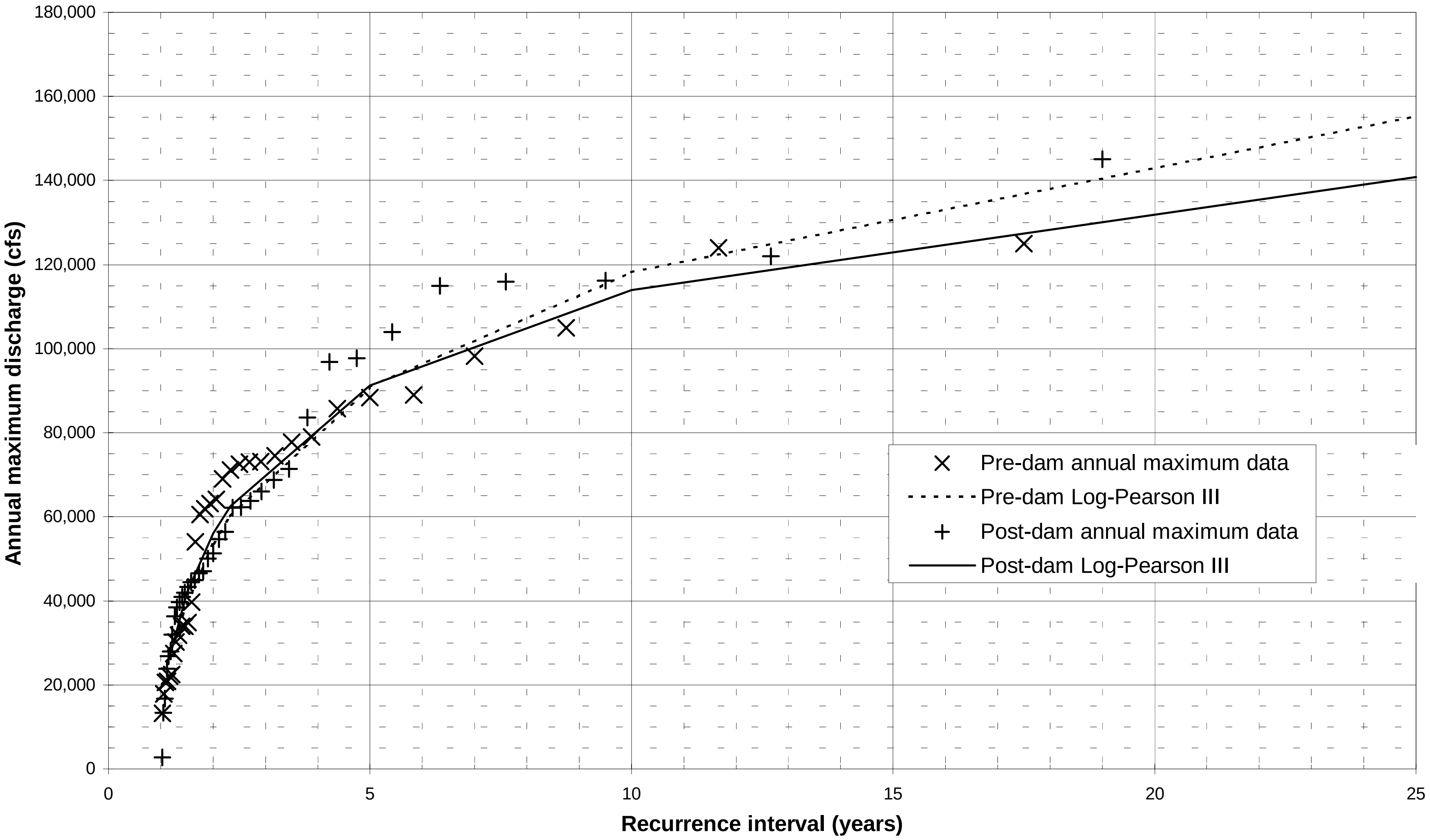

Figure 2.3 Trinity River at Hoopa (11-530000) gaging station pre- and post-TRD annual maximum flood frequency curves.

Consistent with the flood frequency analysis, TRD greatly changed flow duration at Lewiston: close to an order of magnitude reduction in flows at the10 to 30 percent exceedence probabilities (Figure 2.4). Tributary contributions between Lewiston and Burnt Ranch reduce TRD-related changes to Burnt Ranch daily average flows by a factor of two. The impact at Hoopa is lowered to a factor of 1.4 (Figures 2.5 and 2.6).

Consistent trends are observable at all three locations: (1) higher flows, particularly those exceeded less than 50 percent of the year, decreased as a result of TRD operations, and (2) low flows, exceeded over 85 percent of the year, increased (Table 2.4, Figures 2.4 to 2.6). High flow reductions resulted from storage in Trinity Reservoir of most winter flows and snowmelt runoff from the upper watershed. The low flow increase for the 85 to 100 percent exceedences was due to relatively high summer releases from the TRD, particularly after WY1978 when summer baseflow releases were increased to 300 cfs. Lastly, the flattening of the post-TRD flow duration curves signifies reduced annual flow variability.

Gaging Station	River Mile	Unregulated Drainage Area	p= 95%	p=50%	p=10%
Lewiston pre-TRD	110.9	719 mi^2	104 cfs	670 cfs	4,200 cfs
Lewiston post-TRD	110.9	0.3 mi^2	150 cfs	285 cfs	560 cfs
Burnt Ranch pre-TRD	48.6	1,438 mi^2	147 cfs	1,140 cfs	6,550 cfs
Burnt Ranch post-TRD	48.6	719 mi^2	250 cfs	945 cfs	3,300 cfs
Hoopa pre-TRD	12.4	2,865 mi^2	355 cfs	2,950 cfs	12,300 cfs
Hoopa post-TRD	12.4	2,146 mi^2	465 cfs	2,010 cfs	10,300 cfs

Table 2.4 TRD-related changes in daily average flow duration for three mainstem Trinity River gaging stations.

2.2 Change in Riparian Vegetation

2.2.1 Species Composition of the Woody Riparian Community

With the exception of pre-TRD aerial photographs, there were no informational sources available specifically describing historic riparian communities. Therefore, we inferred pre-TRD conditions by combining interpretation of air photos with our observations on regional, unregulated streams (e.g., South Fork Trinity River). The 1960 and 1961 air photos show sparsely vegetated point bars, with patches of annual plants on the bars. Willow patches can be seen interspersed on upper portions of the bars and along margins of dredger tailings. Plants on alternate bar surfaces were annual herbs and grasses, and pioneer woody species such as willows (*Salix spp.*). Other riparian trees, including white

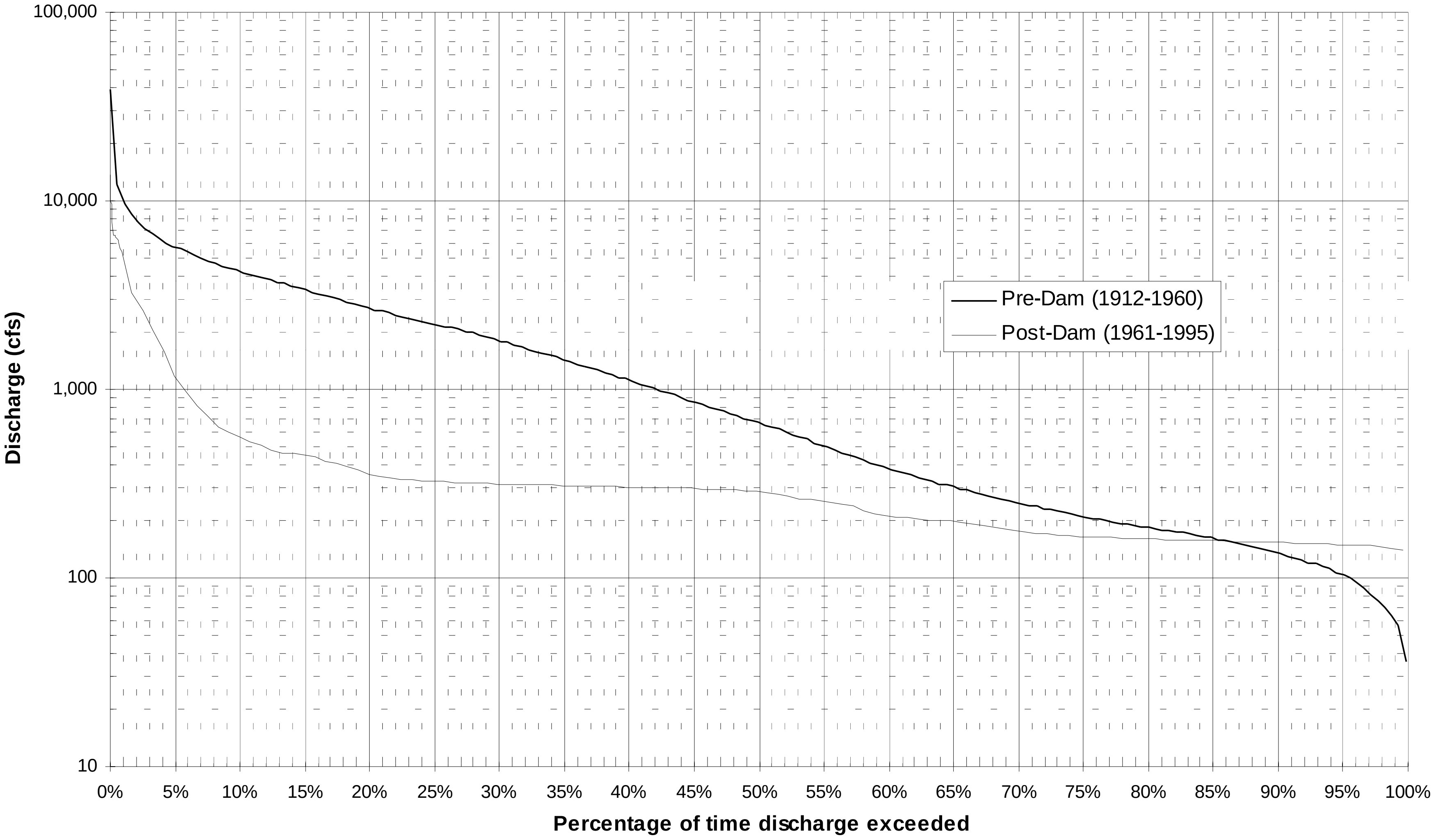

Figure 2.4 Trinity River at Lewiston (11-525500) gaging station pre- and post-TRD daily average flow duration curves.

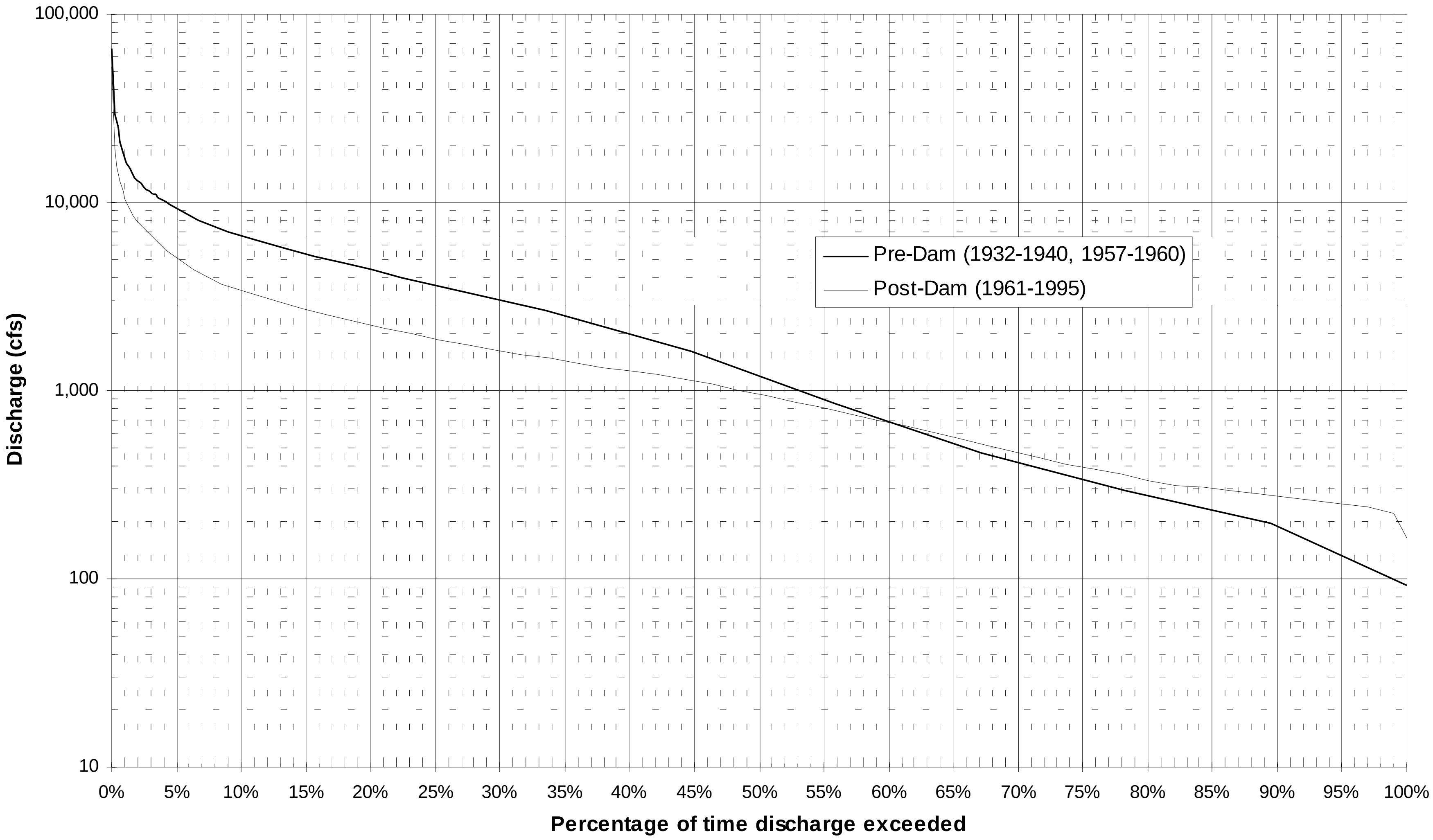

Figure 2.5 Trinity River near Burnt Ranch (11-527000) gaging station pre- and post-TRD daily average flow duration curves.

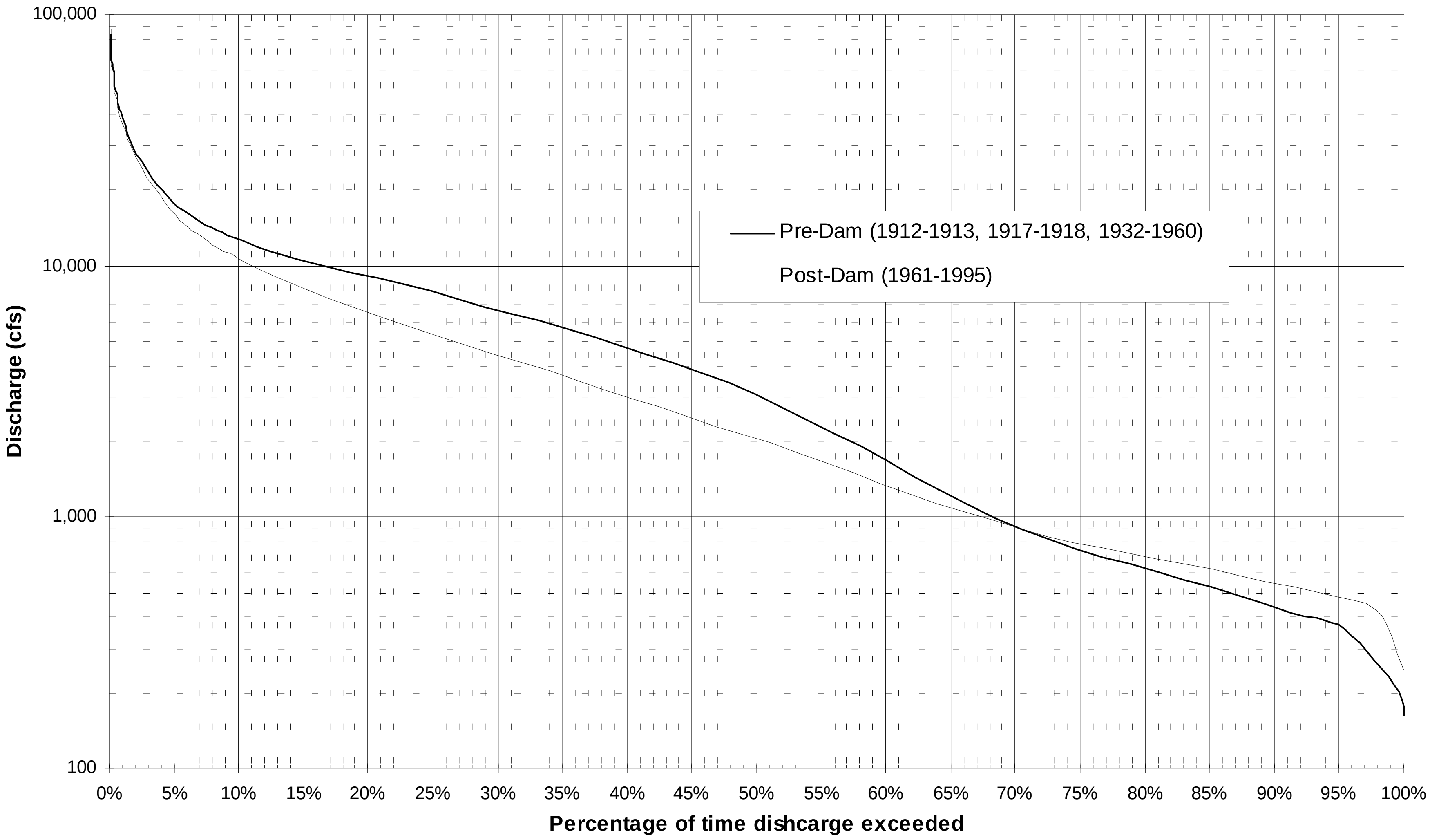

Figure 2.6 Trinity River at Hoopa (11-530000) gaging station pre- and post-TRD daily average flow duration curves.

alder (*Alnus rhombifolia*), black cottonwood (*Populus balsamifera ssp. trichocarpa*), and Fremont cottonwood (*Populus fremontii*) were well established on developing floodplains, low terraces, and old oxbows (historic channel meanders).

Contemporary woody riparian plants were identified using species specific physical characteristics and the Jepson Manual (Hickman 1993) and United States Soil Conservation Service plant identification code conventions (Table 2.5).

Species	Common Name	Code
Salix lucida ssp. lasiandra	Shining willow	SALUL
Salix lasiolepis	Arroyo willow	SALA6
Salix laevigata	Red willow	SALAE
Salix melanopsis	Dusky willow	SAME2
Salix exigua	Narrow-leaf willow	SAEX
Alnus rhombifolia	White alder	ALRH2
Fraxinus latifolia	Oregon ash	FRLA
Populus balsamifera ssp. trichocarpa	Black cottonwood	POBAT
Populus fremontii	Fremont cottonwood	POFR2

Table 2.5 Common woody riparian plant species along the Trinity River mainstem from Lewiston Dam (RM 111.5) downstream to the North Fork Trinity River confluence (RM 72.5).

Discerning woody riparian plant species, especially younger life stages, proved challenging. Morphological characteristics such as leaf shape, presence/absence of glands, and hairs in mature and establishing plants were extremely variable. Distinguishing characteristics for identifying plants older than one year were often inadequate for seedling identification. For example, differences between dusky willow and narrow-leaf willow seedlings, or red willow and shining willow seedlings, were often impossible to discern. In contrast, seedling differences between narrow-leaf willow and red willow or shining willow, basically between tree willows and shrub willows, were apparent. Differences within the groups of shrub willows and tree willows are of taxonomic, if not ecological, importance. For example, some taxonomists in the Pacific Northwest consider dusky willow a subspecies of narrow-leaf willow (Hitchcock, 1969). We decided to continue the struggle with species differentiation.

Four life stages of woody riparian vegetation are referenced in the text:

1. Initiation – beginning at germination and extending through the first summer.
2. Establishment – from the end of the first summer and extending through several growing seasons as the plant increases energy reserves and strengthens roots and shoots.
3. Maturity – when the plant first expends energy on reproduction and continuing through its maximum reproductive period.

4. Old growth - a plant continues to sustain its position in the canopy, but a female tree will no longer reproduce seed at the same high yield as during its mature phase.

2.2.2 Riparian Encroachment and Berm Formation

Riparian communities encountered nearly thirty years of man-made droughts downstream of Lewiston Dam. The TRD diverted up to 92 percent of the annual inflow. This had a dramatic impact on channel morphology and the river ecosystem by permitting seedlings and younger saplings to escape desiccation and scour. Riparian advancement across floodplain surfaces (prior to the TRD) down to the low water channel edge (post-TRD) is termed “riparian encroachment”. The deposition of fine sediment within newly encroached riparian plant stands created levee-like features along the low water’s edge referred to as “riparian berms.”

With only 150 cfs released year-round during the 1960s and 1970s (except occasional higher emergency releases), riparian trees rapidly encroached along this constant low water margin. Riparian encroachment was fastest upstream of Weaver Creek. Ritter (1968) had already observed extensive willow colonization along the low water channel (150 cfs to 200 cfs water surface) by 1965, and significant deposition of fine sediment within this emerging riparian band. This sediment deposition occurred primarily during the December 1964 flood; deposition ranged from almost none near Lewiston Dam to over three feet near the Weaver Creek confluence. Ritter also observed at Rush Creek, a few years following dam closure, “The downstream cross section, which had no earthmoving activity, showed a small amount of aggradation, but the most evident change was the great profusion of young willows which grew along the right bank since the first survey [in 1960].” Four years of optimal growing conditions can easily produce conspicuous six-foot high willows, suggesting seedling survival in WY1964 and WY1965. Riparian berms are today ubiquitous depositional features throughout the mainstem, signaling a change in alluvial behavior riverwide.

Pelzman (1973) concluded that riparian encroachment was prevented prior to the TRD primarily by rapid flow reduction during the summer when seedlings were initiating. He stated that receding flows and associated groundwater watertables caused many seedlings to desiccate. Following dam construction, near constant releases from the TRD eliminated this mortality agent, and greatly increased survival of seedlings. Pelzman (1973) also noted, “Reduced spring flows followed by stabilized flow, exposed considerable areas of the stream channel with moist soil during the period most favorable for germination.” Seedling survival close to Lewiston Dam was almost guaranteed. Even with downstream tributary flow augmentation and occasional floods capable of mobilizing the mainstem’s channelbed surface, rapid plant establishment and berm formation near the 150 cfs water surface elevation reached the North Fork Trinity River confluence. Today berms exceeding seven feet high are extensive below Junction City.

Later, Evans (1980) documented the total change in the surface area of riparian vegetation between

1960 and 1977. He reported that riparian stands of willow and alder increased from 187 acres to 853 acres between Lewiston and the North Fork Trinity River. Evans also described how riparian communities on developing riparian berms evolved. Early on, these communities were dominated by willow overstories. As these communities matured, alders replaced willows in the overstory. He also predicted that broad leaf riparian plants on the berm would be shaded out and ultimately replaced by upland conifer species in approximately 35 years. Wilson (1993) repeated Evan's (1980) surface area census, extending the temporal analysis to include 1989 riparian conditions. Wilson's results were comparable, finding 313 acres in 1960 and 881 acres in 1989 for the same length of mainstem.

Riparian encroachment is well illustrated by a pair of ground photos of the mainstem Trinity River channel looking upstream of the North Fork Trinity River (Figure 2.7), and at Gold Bar (RM 106.3), where a median bar quickly encroached with willow and white alder by 1970 (Figures 2.8 to 2.11). As displayed in a 1975 aerial photograph, the downstream end of the median bar shows mature trees approximately 50 ft tall and over a foot in diameter toppled by the 1974 flood, though most trees on the bar appear unaffected (Figure 2.10). Upstream, approximately 200 ft from the riffle crest, other mature trees along the right bank also were toppled by the 14,500 cfs release, as the flood spilled onto the floodway then returned across the newly formed riparian berm. Large woody debris on the right bank in the pre-TRD photograph (Figure 2.8) is conspicuously absent in later photos, suggesting that flows large enough to deposit large woody debris on these higher bar surfaces no longer occurred.

Riparian berms formed within the historic active channel margin. Low flows released in the late-1960s and early-1970s were well below the flows required to inundate the pre-TRD active channel margin. Willow growth flourished near this low flow waterline, then colonized upslope to the first sharp slope break. This break was at the active channel margin, corresponding to the elevation of pre-TRD high winter baseflows. The varying width of the present-day riparian encroachment band probably reflects, in most locations, pre-TRD active channel dimensions. The progression of riparian colonization on the Gold Bar median bar (Figures 2.8 to 2.11) illustrates this widening of the riparian zone at the riffle crest where the pre-TRD active channel gently sloped up the median bar. Along the steep flank of this active channel, upstream of the riffle crest, riparian encroachment has been restricted to a relatively narrow band.

During berm removal at the Sheridan and Steiner Flat bank rehabilitation sites by bulldozers, mature willow trunks that appeared rooted on the berm tops were actually buried in the berm and rooted on the original pre-project channelbed surface (Figure 2.12). A sharp interface between the original cobblebed surface and recently aggraded coarse sand of the berm revealed the abrupt depositional environment created by maturing saplings along the channel edge. Mature willows had several sets of adventitious roots along their buried trunks with each set presumably correlated to discrete depositional events. The lack of large gravels and cobbles in the berms' stratigraphy also indicated the pronounced role of small to intermediate floods facilitating berm formation. Only one coarse

Figure 2.7 Pre- and post-TRD channel at the confluence with the North Fork Trinity River, showing riparian encroachment and fossilization of alluvial deposits.

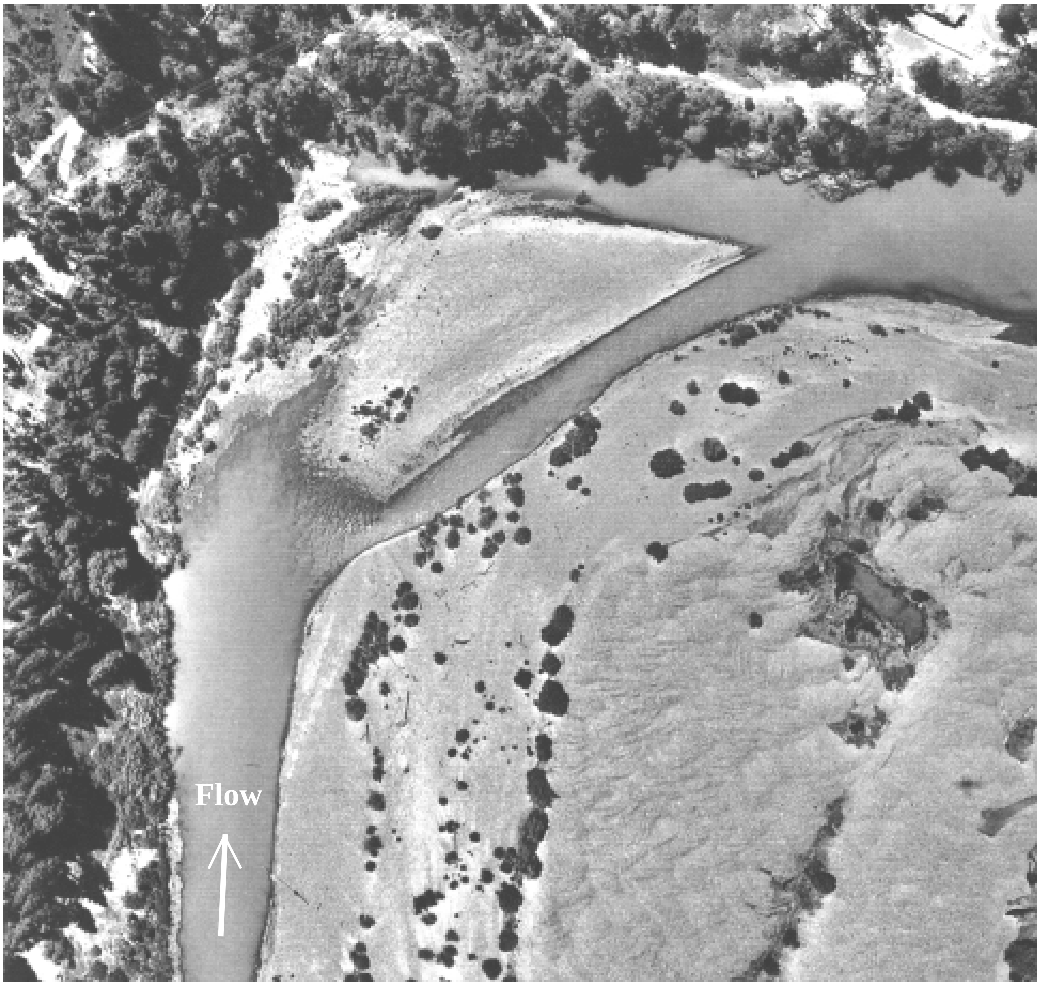

Figure 2.8 Gold Bar (RM 106.3) alluvial deposit in 1961. Note absence of vegetation along the channel edges and scoured dredger tailings along the inside of the bend. Discharge = 192 cfs, scale approximately 1” = 225’.

layer was excavated, presumably corresponding to the WY1974 flood. White alders up to 20 years old were rooted on this layer. Although cobbles were deposited onto the sand berms during this event, the willows had become sufficiently established to resist removal.

Some berms are still aggrading, but at highly variable rates. The 20-year old alders in the Sheridan bank rehabilitation site (mentioned in the previous paragraph) were only buried by 0.8 ft of fine sediment though they were rooted 5 ft high on the berm. In contrast to this slow accretion (at least since the mid-1970s), recent blackberry understories along the left bank of the Gravel Plant monitoring site trapped several feet of sand in one 6,000 cfs dam release in WY1992 (Trinity Restoration Associates (TRA) 1993). Berms can continue aggrading if higher flood elevations are experienced, if the berm vegetation becomes even denser, or if fine sediment supply is increased.

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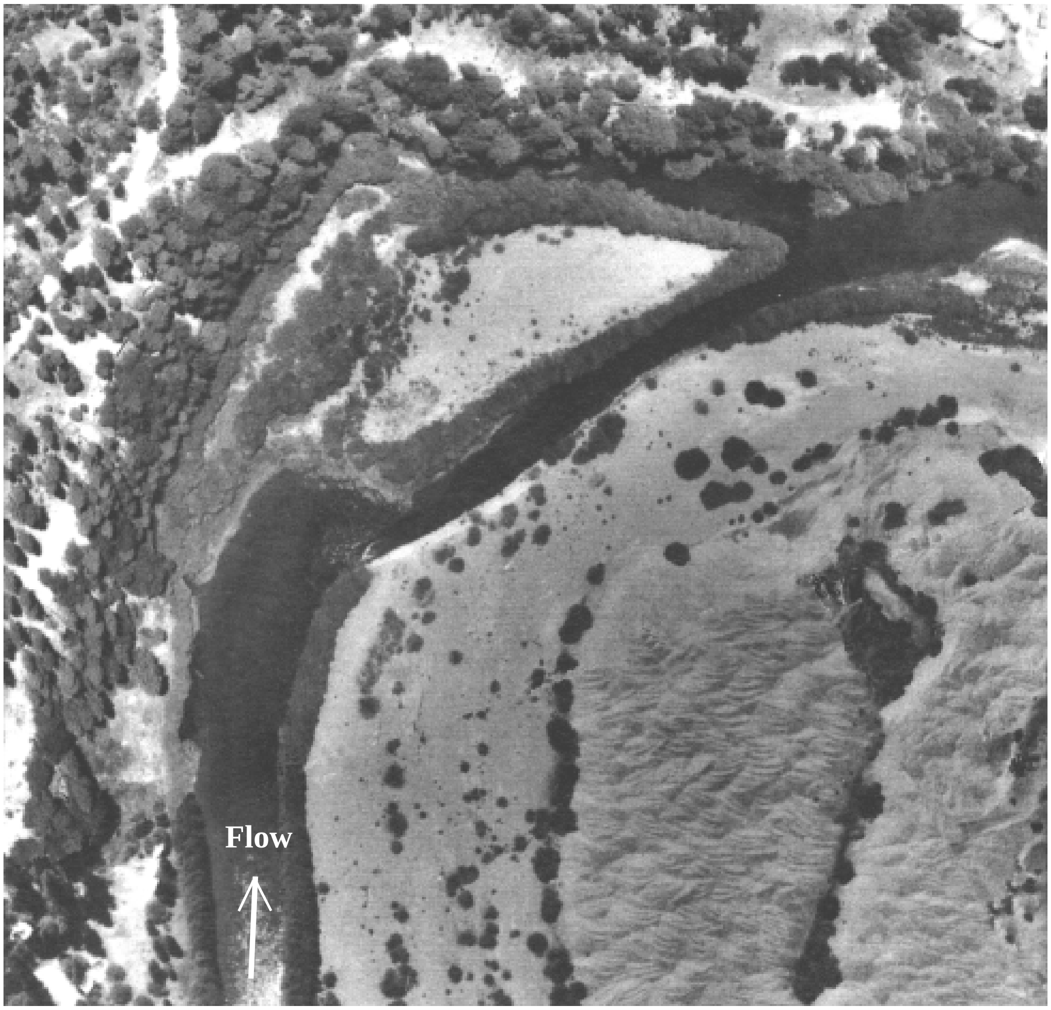

Figure 2.9 Gold Bar (RM 106.3) alluvial deposit in 1970. Note the vegetation established along the channel edges. Discharge = 155 cfs, scale approximately 1” = 225’.

In WY1992 the Upper Sky Ranch site, immediately downstream of the Sheridan bank rehabilitation site, was selected for monitoring because of its right bank point bar (Trinity Restoration Associates 1993). The bar at this time had an exposed cobble surface and was occupied by only early-age classes of willows (cross sections 1097 and 1151). By WY1997 this bar had aggraded with sand such that it is now almost indistinguishable from the berm along the channel bank. Berm formation, therefore, can still be an important local process narrowing mainstem channel width.

2.2.3 Bar Fossilization

During the first few years after completion of the TRD, Lewiston releases allowed riparian plants to establish on formerly mobile alluvial features (Figures 2.8 to 2.11, 2.13). As these established plants grew larger, elevated hydraulic roughness of the plants encouraged fine sediment deposition during tributary-derived high flows, providing seedbeds for additional plants. As the plants grew, their

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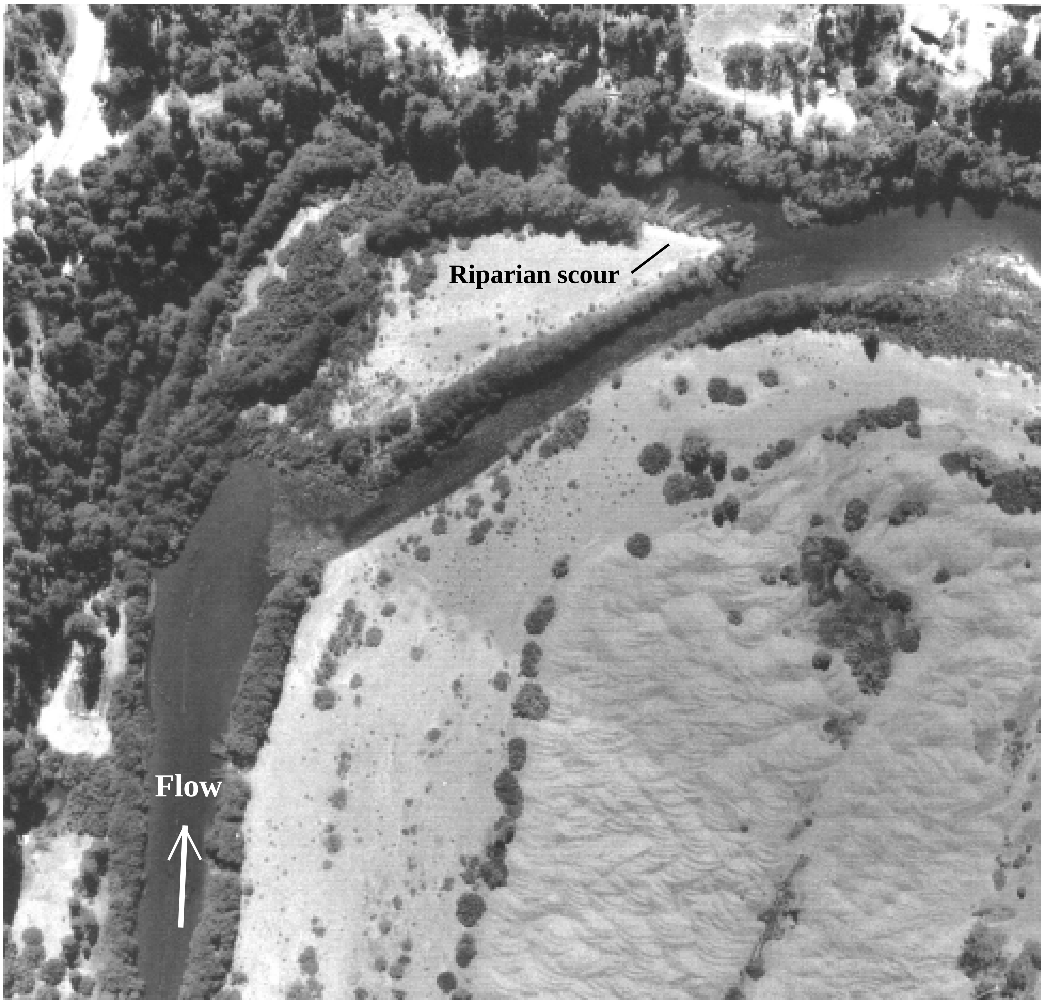

Figure 2.10 Gold Bar (RM 106.3) alluvial deposit in 1975. Note the riparian scour effects of the 1974 flood (14,000 cfs) along the downstream edge of the point bar. Discharge = 213 cfs, scale approximately 1" = 225'.

foothold on previously dynamic alluvial bars became permanent, such that by 1970, Lewiston releases were incapable of scouring them out. The extensive root system of riparian vegetation along the length of the mainstem low water channel "fossilized" the alluvium. In this fossilized state, the alluvium was no longer available for downstream transport.

2.3 Change in Channel Morphology

Mainstem Trinity River channel morphology was influenced by the following periods: (1) pre-European settlement where the morphology was purely a result of natural water-sediment-geology interactions, (2) the 1850's to the late 1800's when terrace and bar deposits were placer mined and off-channel hydraulic mining contributed considerable volumes of sediment to the channel, (3) early 1900's to the early 1950's when large gold dredgers tilled the river channel and floodplain gravel deposits, and (4) post-1960 when completion of the Trinity River Division eliminated upstream

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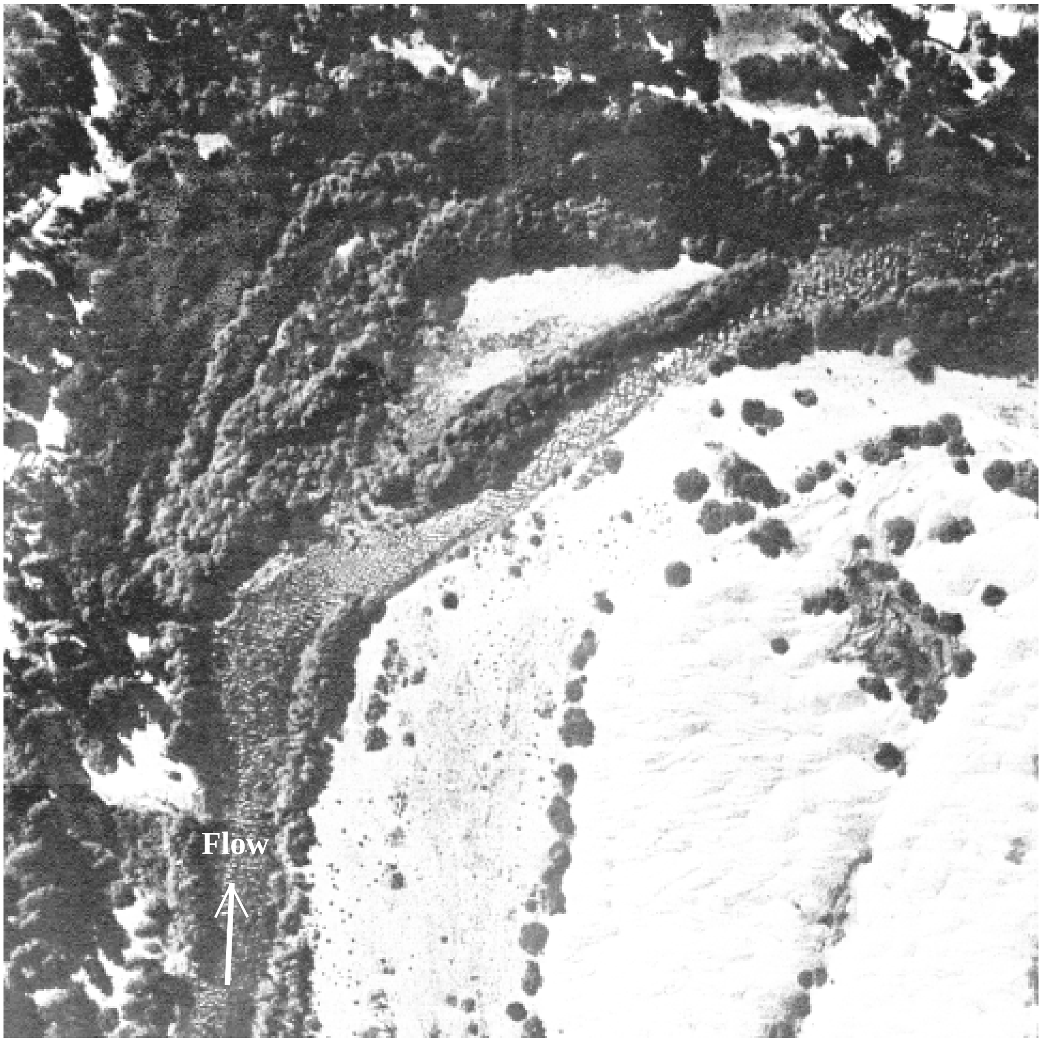

Figure 2.11 Gold Bar (RM 106.3) alluvial deposit in 1989. Note most willow groups on the point bar are observable in the 1961 photo. Discharge = 2,000 cfs, scale approximately 1” = 225’.

coarse sediment supply and greatly reduced the magnitude and volume of flows downstream of Lewiston Dam (RM 112.0). Documentation of morphology prior to the gold dredger era was unavailable. Pre-TRD conditions were inferred from aerial photographs, interpretation of fossilized channel features, and the USGS gaging station cableway cross section at Lewiston (RM 110.2). The following section first discusses how alternate bars responded to TRD operations, then documents changes in channel geometry.

2.3.1 Alternate bar morphology

The fundamental building block of alluvial rivers is the alternate bar unit, composed of an aggradational lobe (depositional feature) and scour hole (the “pool”) (Figure 2.14). The submerged portion of the aggradational lobe is commonly called the “riffle”, whereas the exposed portion is

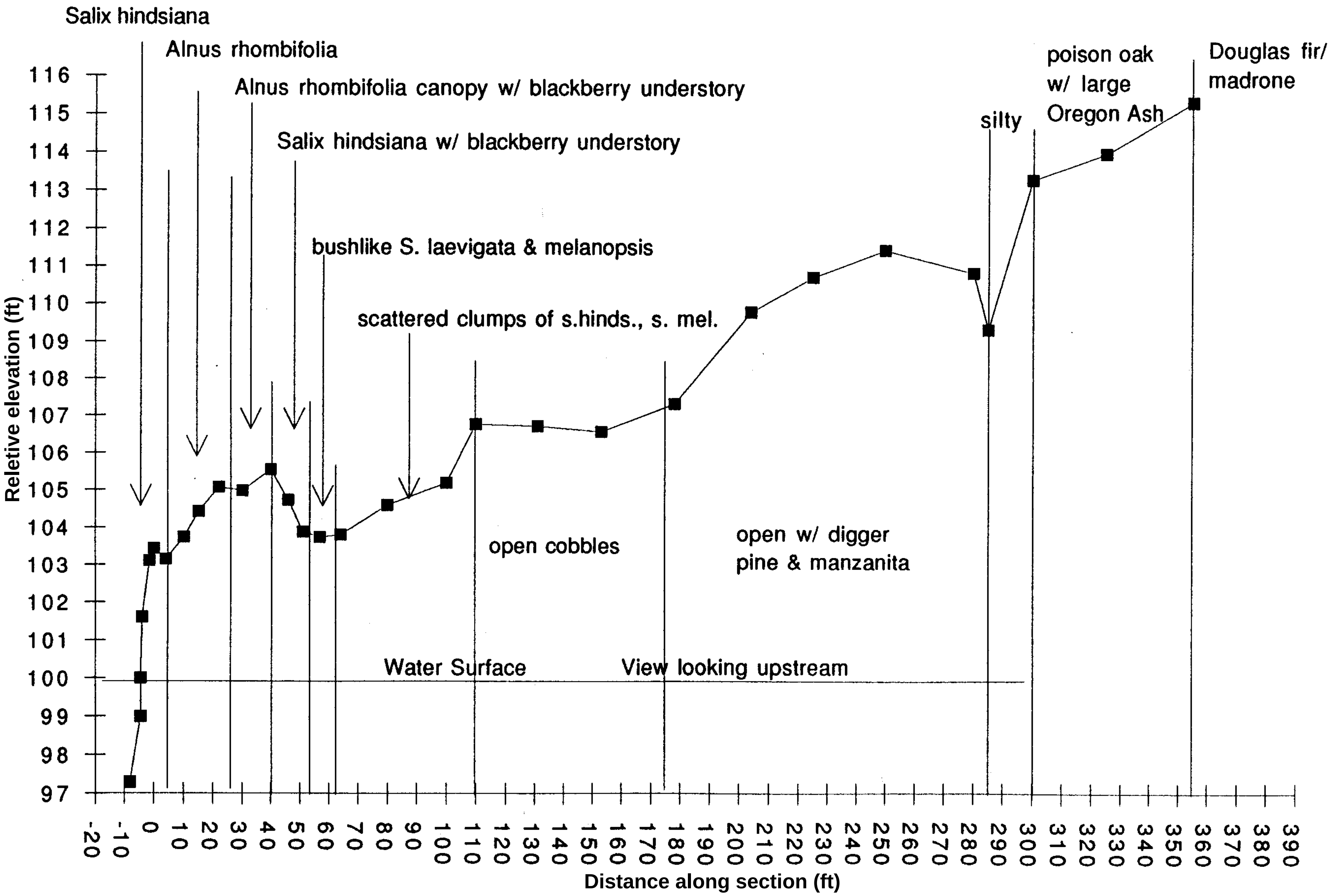

Figure 2.12 Cross section of typical riparian berm on pre-TRD point bar surface near Deep Gulch (RM 81.6).

Figure 2.13 Typical fossilization of a pre-TRD point bar surface near Douglas City (RM 91.8) by encroachment of riparian vegetation.

labeled the “point bar.” With the relatively deep pool opposite the point bar, fisheries biologists call this the riffle-pool sequence. An alternate bar sequence, comprised of two bar units, forms a complete channel meander with a wavelength roughly equaling 9 to 11 bankfull channel widths (Leopold et al. 1964).

Alternate bar sequences are readily apparent in pre-TRD aerial photographs (Figure 2.15), even in reaches confined by bedrock valley walls between Browns Creek and Dutch Creek (Figure 2.16). During low flows, the channel thalweg meanders around the exposed alternating point bars, but during high flows, the bars submerge and the flow pattern straightens. Bedload transport, during high flows, is mostly across the bar face rather than along the thalweg (Figure 2.14).

Prior to flow regulation, the combination of large floods, bedload transport, and attendant channel migration resulted in a dynamic channel morphology and riparian community. Most reaches from Lewiston to the North Fork Trinity River were alluvial, though bedrock outcrops influenced many reaches (Figure 2.16). This dynamic quasi-equilibrium in channel form is characteristic of alluvial rivers (Richards 1982). Pre-TRD bar surfaces had sparse but diverse riparian vegetation. Complex flow fields through alternate bar sequences during high flow events sorted coarse sediments into

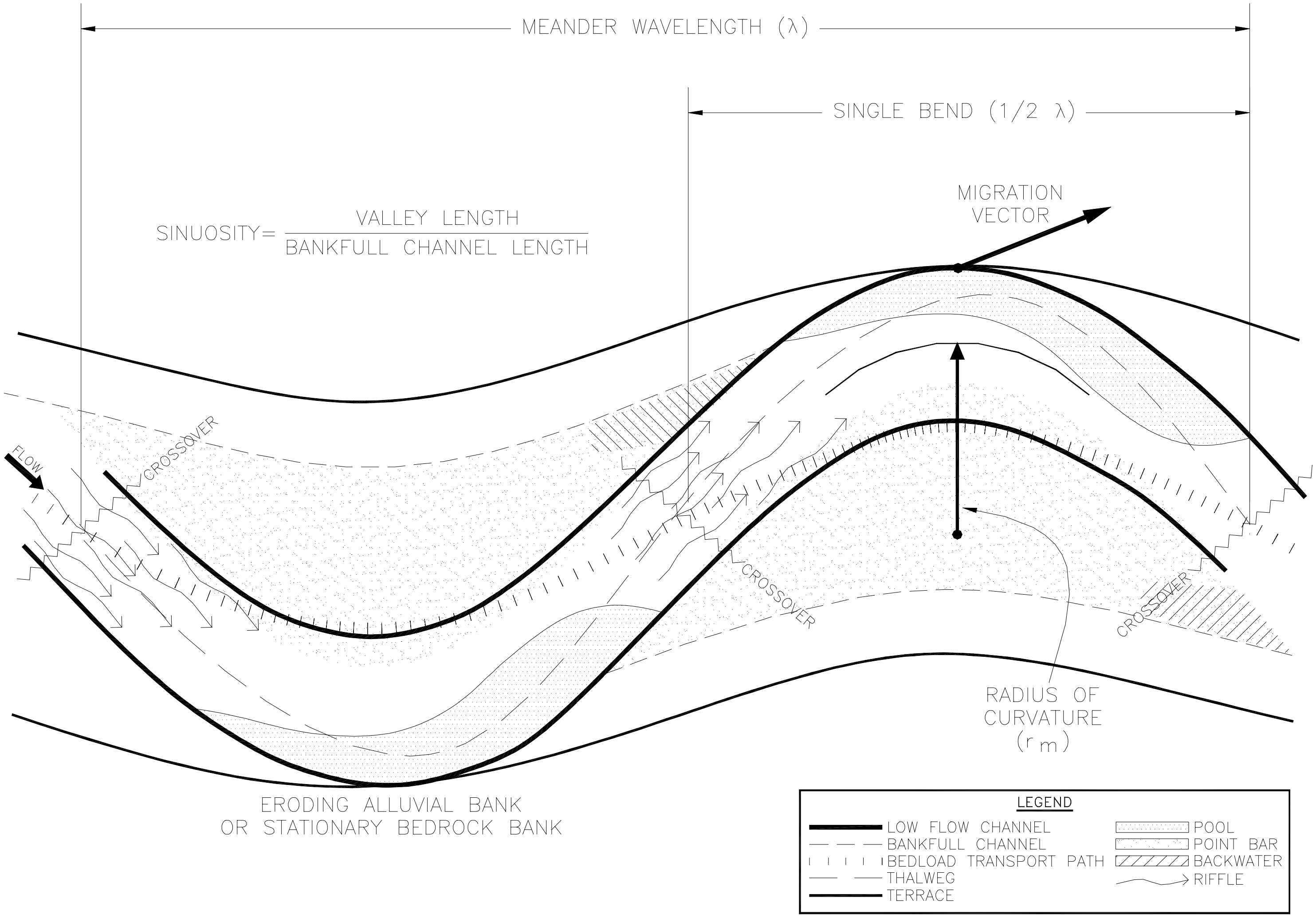

Figure 2.14 Idealized alternate bar unit.

Figure 2.15 Pre-TRD alternate bar unit on the Trinity River near Junction City (RM 80.0), 1961 photograph. Lewiston discharge = 192 cfs, scale approximately 1" = 200'.

distinct locations. In contemporary alluvial rivers (e.g., Trinity River at Hoopa), alternate bar surfaces show signs of frequent, roughly annual mobilization though overall bar shape often appears unchanged between major floods.

Historically, the mainstem had extensive floodplains and a meandering river corridor in its least confined reaches downstream of Dutch Creek (RM 86.1) (Figure 2.17), as well as in partially

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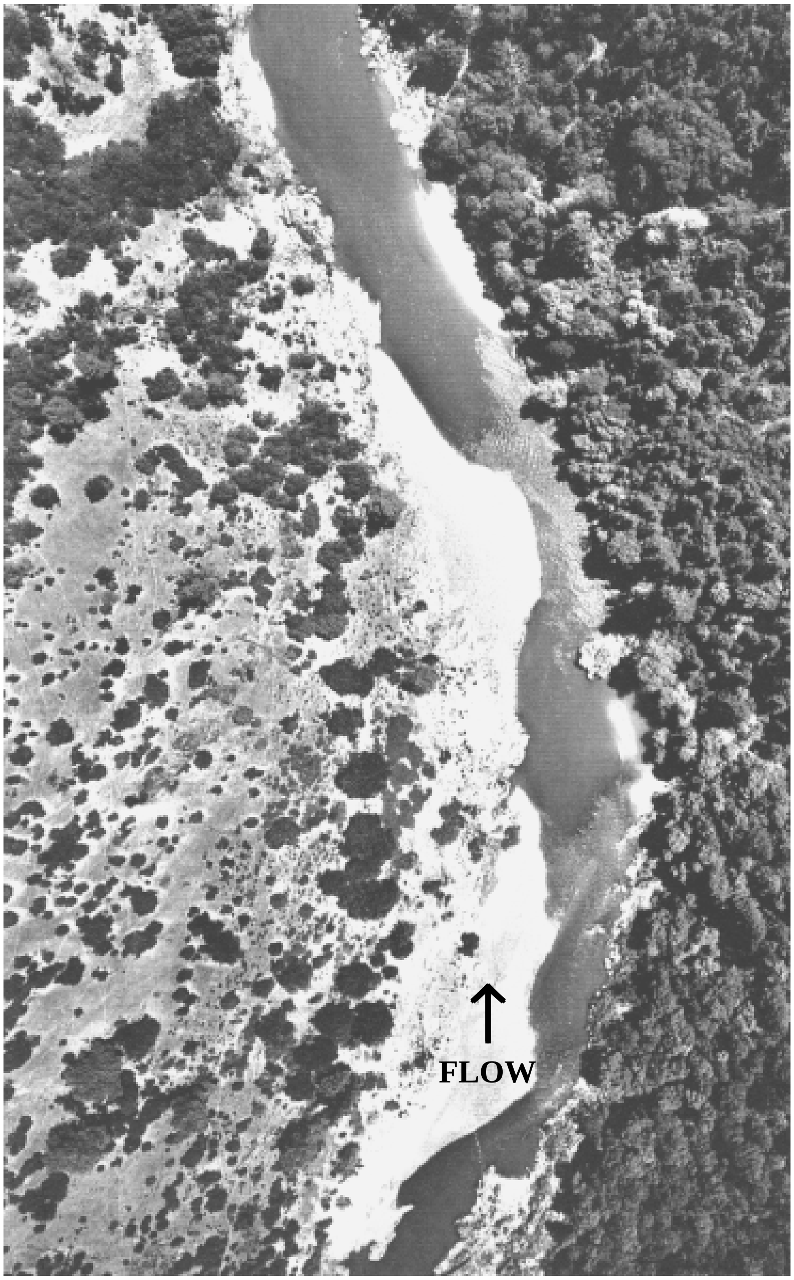

Figure 2.16 Pre-TRD alternate bars in confined canyon downstream of Browns Creek (RM 87.0), 1961 photograph. Lewiston discharge = 192 cfs, scale approximately 1” = 200’.

confined channel reaches closer to Lewiston. Gold dredging since the 1860s, however, had almost eliminated previous floodplain and terrace features, leaving extensive tailings by the mid-1900s. By the 1960s, the power of high flows were demonstrated as many of these tailing deposits were reshaped into a meandering channel with floodplain surfaces and alternate bars (Figure 2.9).

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Figure 2.17 Alternate bar sequences and floodplains near Junction City in 1960. Lewiston discharge = 5,000 cfs, scale approximately 1” = 1,150’.

The present mainstem channel location is almost a snapshot of its location and shape in 1960. But TRD releases have abandoned the former floodplain and compressed the river corridor. Fossilized alternate bars discourage any significant post-TRD morphological adjustment. Once encroached, the bars have remained immobile. An alternating bar morphology is rarely exhibited above the confluence of the North Fork Trinity River (RM 72.3).

Downstream of the Indian Creek confluence (RM 95.1), flow and sediment accretion from tributaries has allowed formation of a few alternate bars. However, no contemporary bar has the size, shape, mobility, and riparian community structure of pre-TRD alternate bars.

2.3.2 Channel geometry

Channel geometry is the cross sectional shape and dimensions of a stream channel. Shapes and dimensions vary spatially through alternate bar sequences within a given reach. Dimensions generally increase downstream as tributary flow and sediment accretion enlarges the channel. Although human activities in the watershed after 1850 disrupted the Trinity River morphology, TRD impacts to flow and sediment regimes have had a greater impact. Generally, the active channel width has decreased and riparian encroachment has promoted a rectangular channel geometry whose bed is infrequently mobilized (Figures 2.18 to 2.20). We hypothesize that this response was caused by two factors. First, the encroaching vegetation immobilized the alluvium beneath and landward from the riparian berms. Coarse sediments in the submerged portions of bars remained available for transport. Second, periodic high flow releases from the TRD and tributary flood contributions to the mainstem Trinity River mobilized coarse sediments in unvegetated submerged bars. However, with the coarse sediment supply from the watershed upstream of Lewiston Dam eliminated, these mobilized sediments were winnowed away and not replaced. The conversion of the asymmetrical channel cross section through these point bars to a rectangular cross section greatly reduced habitat diversity. While no quantitative data are available for pre-TRD particle size distributions, our observations indicated reduced sediment supply, combined with periodic high flows, winnowed finer particles from the bed, removed entire deposits of spawning gravels, and reduced particle size diversity throughout the mainstem.

Data used to describe pre-TRD and post-TRD channel geometry were derived from: (1) a reconstruction of historic floodplain/terrace features at our Steiner Flat study site cross section 5+98 (RM 91.7) and (2) a pre-TRD cross section at the USGS Lewiston gaging station (RM 110.2). At Steiner Flat, a partially confined channel reach that escaped major alteration by gold mining, was selected for our assessment of pre-TRD channel morphology. The USGS Lewiston gaging station had discharge measurements consistently taken at the same cableway location since WY1953 and is the only known location where quantitative pre-TRD cross sections are available. Using depths and water surface elevations measured during high flows, we plotted the cross section in WY1954 and WY1956 (after the 1955 flood). We re-surveyed this cross section in WY1995 for comparison.

2.3.3 Hydraulic geometry

Changes in channel morphology were quantified by the shifts in hydraulic geometry. Hydraulic geometry is the relationship between discharge and width, depth, and velocity at a river cross section (Leopold and Maddock 1953), and can be described as:

$$W = aQ^b \qquad d = cQ^f \qquad V = kQ^m \tag{2.1}$$

Where: Q = discharge in cfs, W = width of the water surface, d = mean depth, and V = mean velocity, and: $Q = W * d * V = aQ^b * cQ^f * kQ^m = 1Q^1$, $a * c * k = 1$, and $b + f + m = 1$.

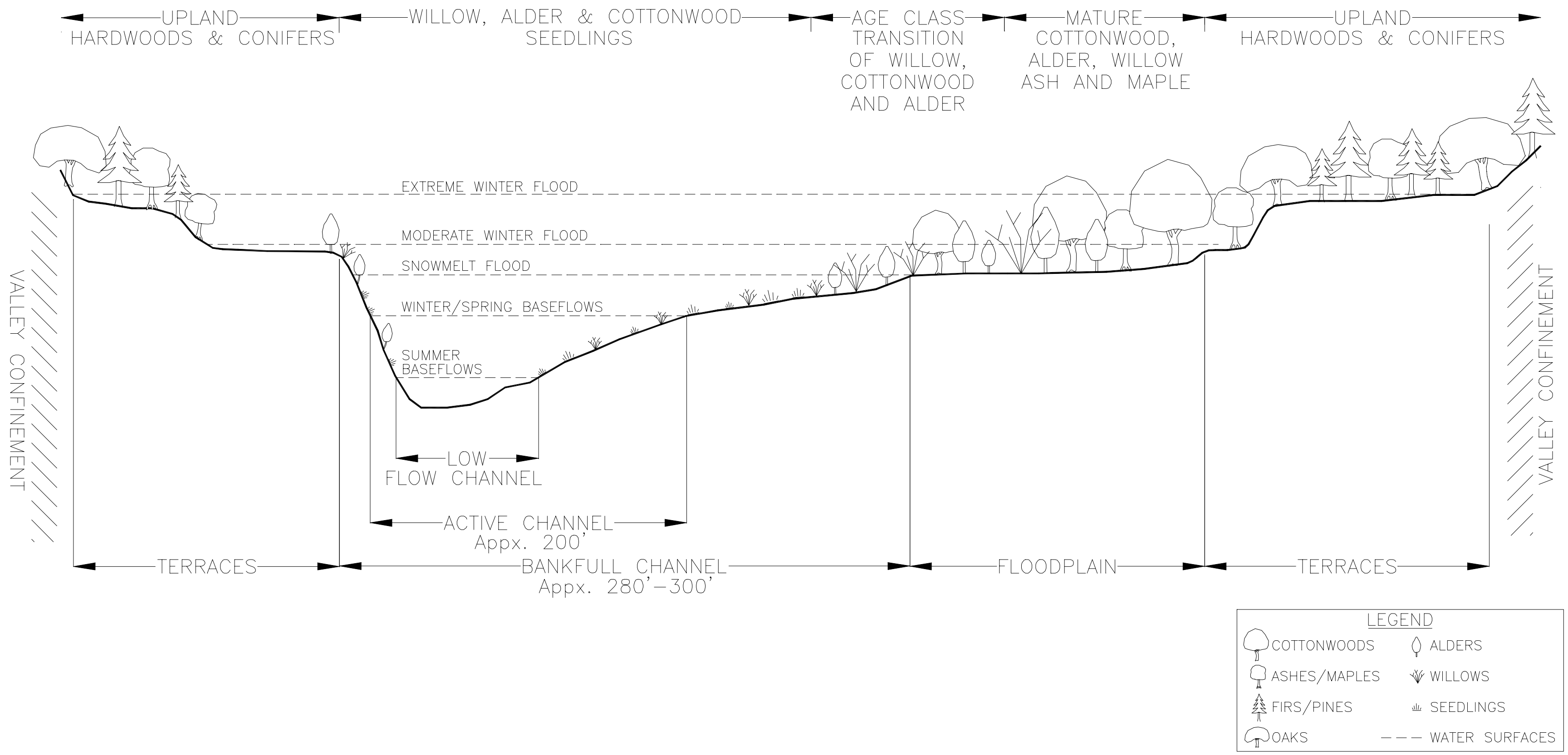

Figure 2.18 Idealized pre-TRD riparian communities, geomorphic surfaces, and annual hydrograph relationships.

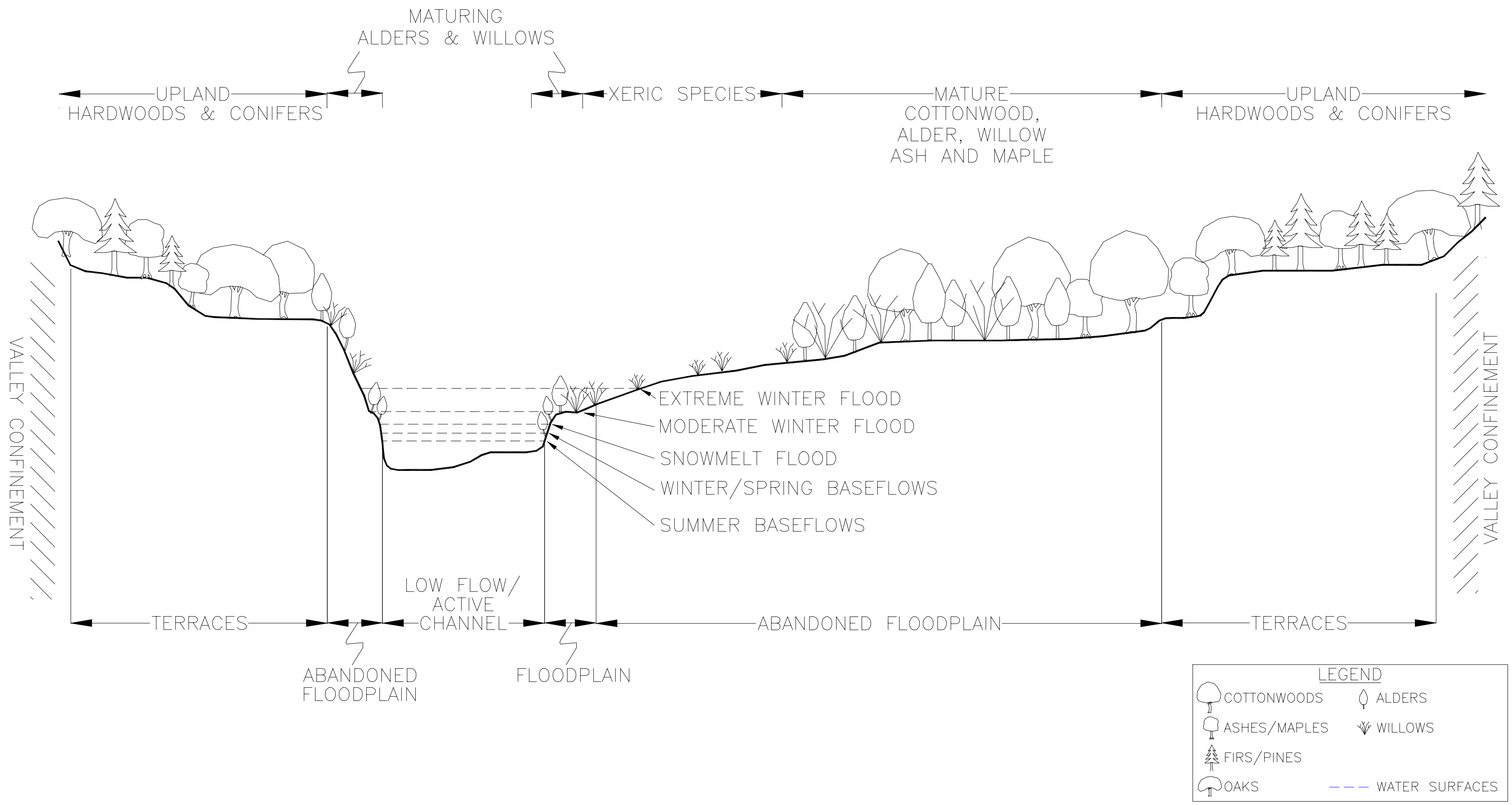

Figure 2.19 Idealized channel morphology adjustment and riparian berm initiation five years after TRD completion.

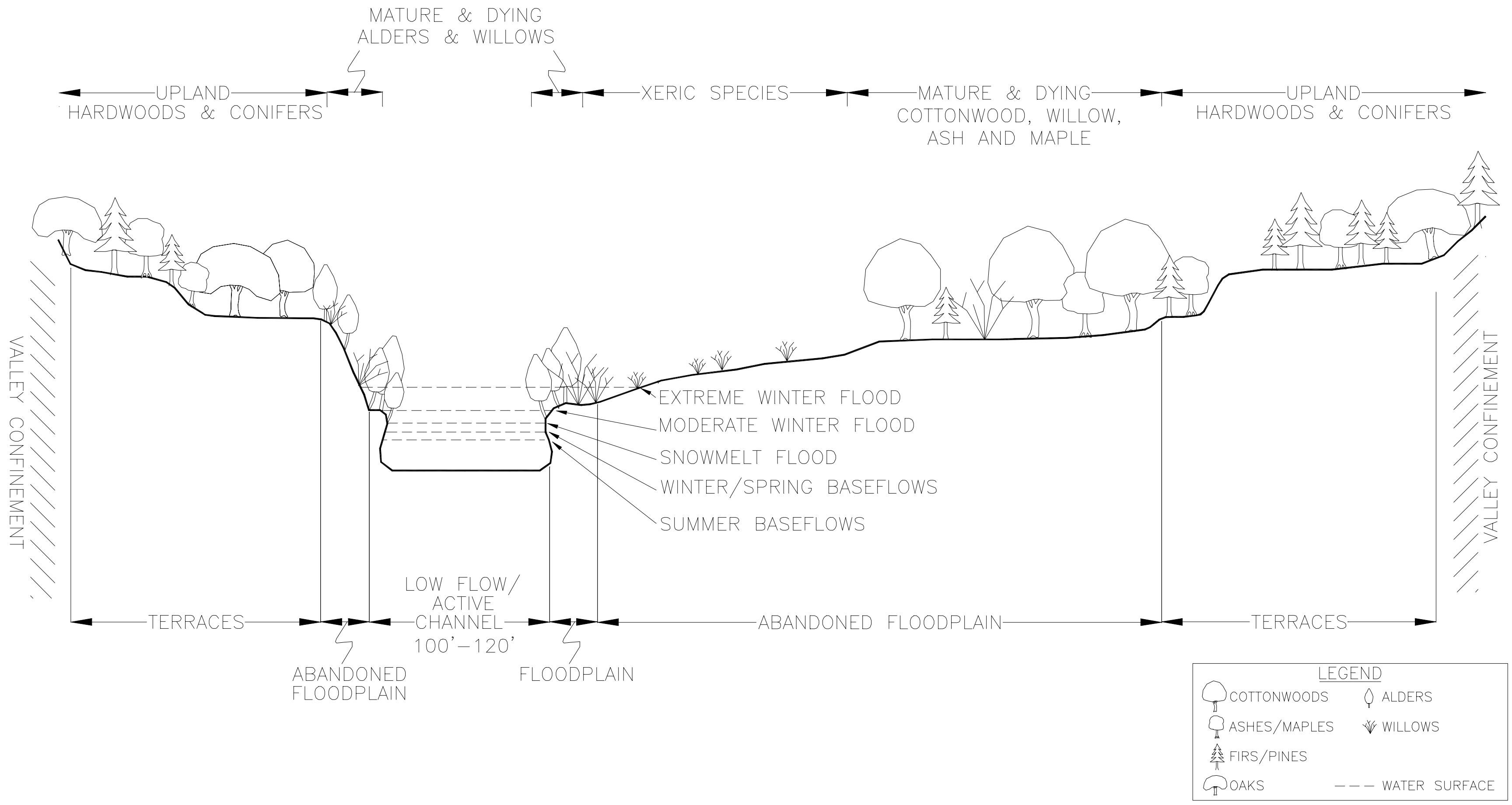

Figure 2.20 Idealized present-day channel and riparian berm morphology and riparian communities.

Our objective at the Lewiston USGS gaging site was to document changes in width, depth, and velocity as the channel adjusted its pre-TRD morphology. USGS 9-207 forms, documenting width, cross sectional area (used to calculate average depth), average cross sectional velocity, and discharge, were used to construct hydraulic geometry from WY1910 to WY1995. Our objectives at the Steiner Flat bank rehabilitation site were to document changes in bankfull width and discharge for the pre-TRD and post-TRD channel.

2.3.3.1 USGS gaging station at Lewiston (RM 110.1)

At this site, the gaging location (wading, bridge, cableway) varied over the years, and some data interpretation was required. From WY1910 to WY1953, high flows were measured from the Old Lewiston Bridge (RM 109.9) while low flow wading measurements were made at varying locations near the bridge. In WY1954, high flow measurements were made from a newly constructed cableway (RM 110.1), while low flow wading measurements again varied in location [the December 1955 flood destroyed the cableway, which was rebuilt in June 1956]. In WY1964 the stage recorder location was moved immediately upstream of Deadwood Creek; however, the discharge measurements continued at the same cableway location.

We adjusted the USGS gaging data as follows: (1) measurements in the 1950’s and early 1960’s were made in a backwater from a small dam 300 ft downstream of the Old Lewiston Bridge, thus widths, depths, and velocities were artificial and not used; (2) wading measurement location varied and resulted in too much data scatter to the point where no conclusions could be confidently made; and (3) bridge-based measurements ended prior to dam construction, therefore, were not used in this analysis. Many scientists working on the mainstem consider depth and velocity have increased, and width has decreased in the low flow channel (Bureau of Land Management, 1995). Elimination of the wading measurements precluded hypothesis testing for flows less than 800 cfs. Fortunately, the cableway measurements from WY1953 to WY1995 were at the same location, thus providing a consistent data set to compare pre- and post-TRD morphological changes for discharges greater than 800 cfs (Figures 2.21 to 2.24).

A large shift in hydraulic geometry occurred during the 2/24/58 flood event (peak discharge was 37,500 cfs), which is notable as this shift was much more dramatic than that caused by the 12/22/55 flood event (peak discharge was 71,000 cfs). The USGS indicated that the cableway location had not changed since installation, but the rapid change between the two periods seems too large to be caused simply by incremental channel adjustment. Therefore, it is more appropriate to compare the WY1958 to WY1961 period to the WY1967 to WY1970 and WY1991 to WY1995 periods, not only for the uncertainty in gaging location, but also due to the lesser variability between measurements (Figures 2.21 to 2.23). The change in low flow width, depth, and velocity were estimated by comparing 1000 cfs discharges. This provided a useful comparison, as flows of 1000 cfs remain confined within the

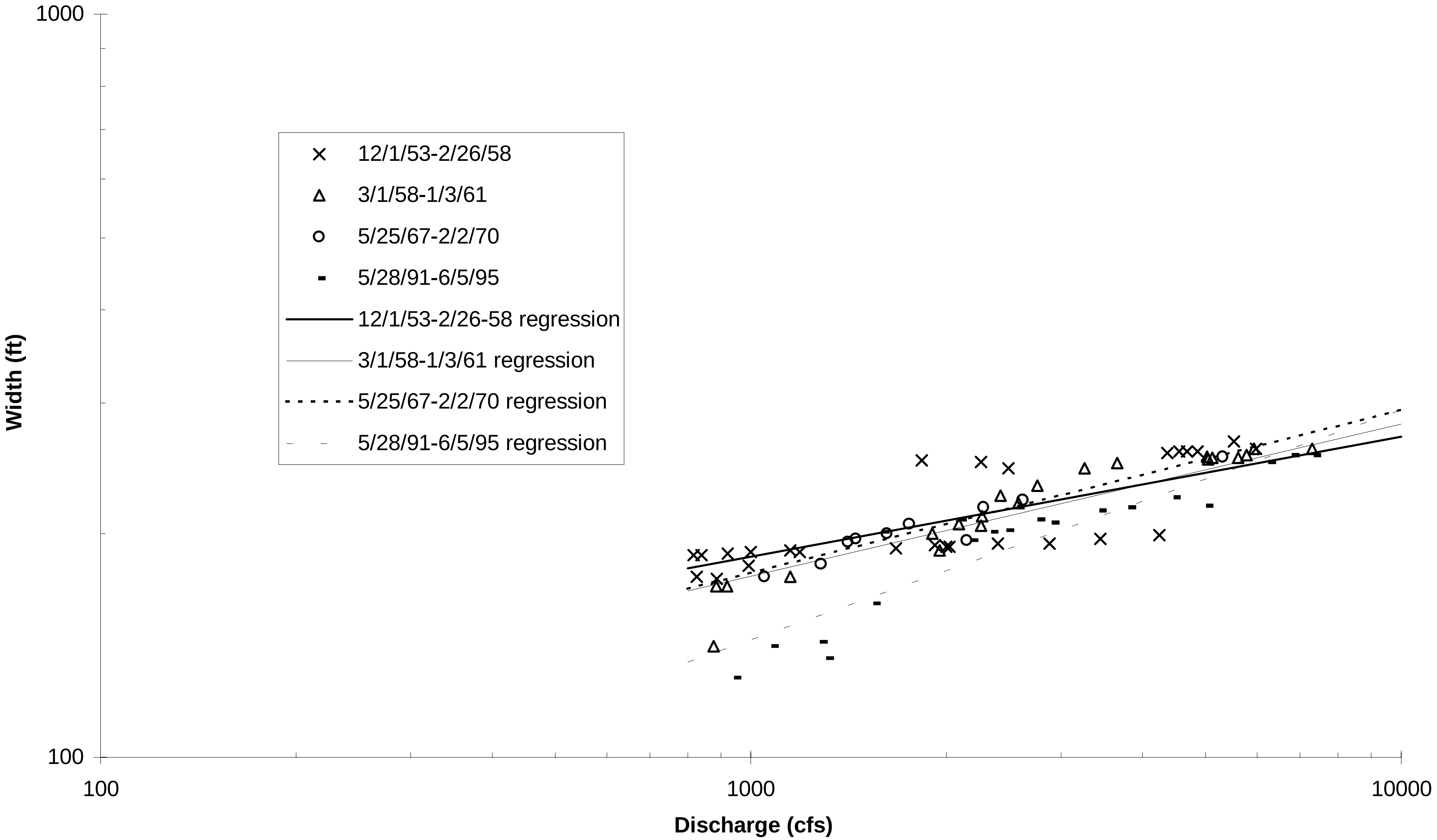

Figure 2.21 Hydraulic geometry evolution at the USGS gaging station at Lewiston: Width as a function of discharge.

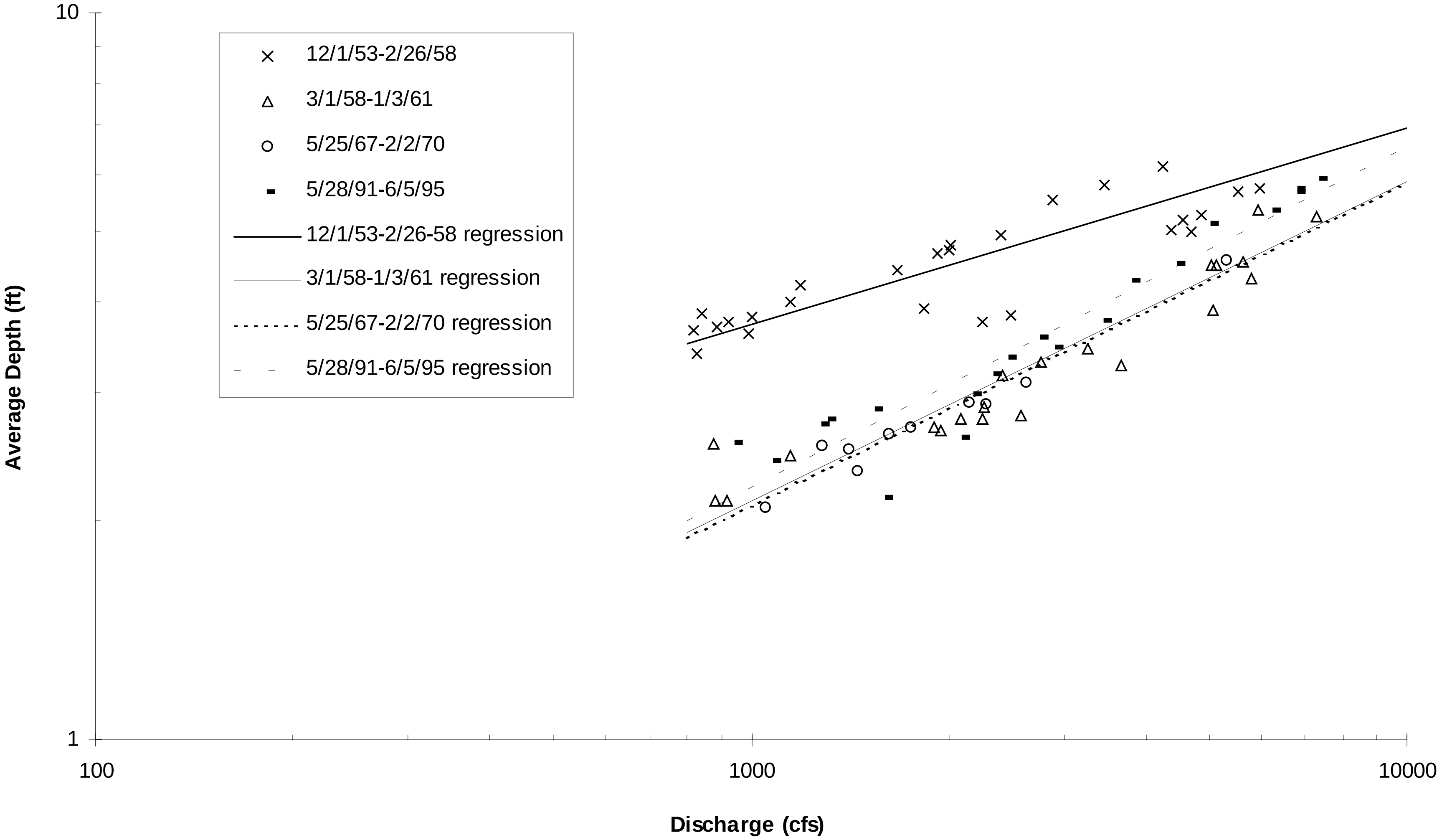

Figure 2.22 Hydraulic geometry evolution at the USGS gaging station at Lewiston: Average depth as a function of discharge.

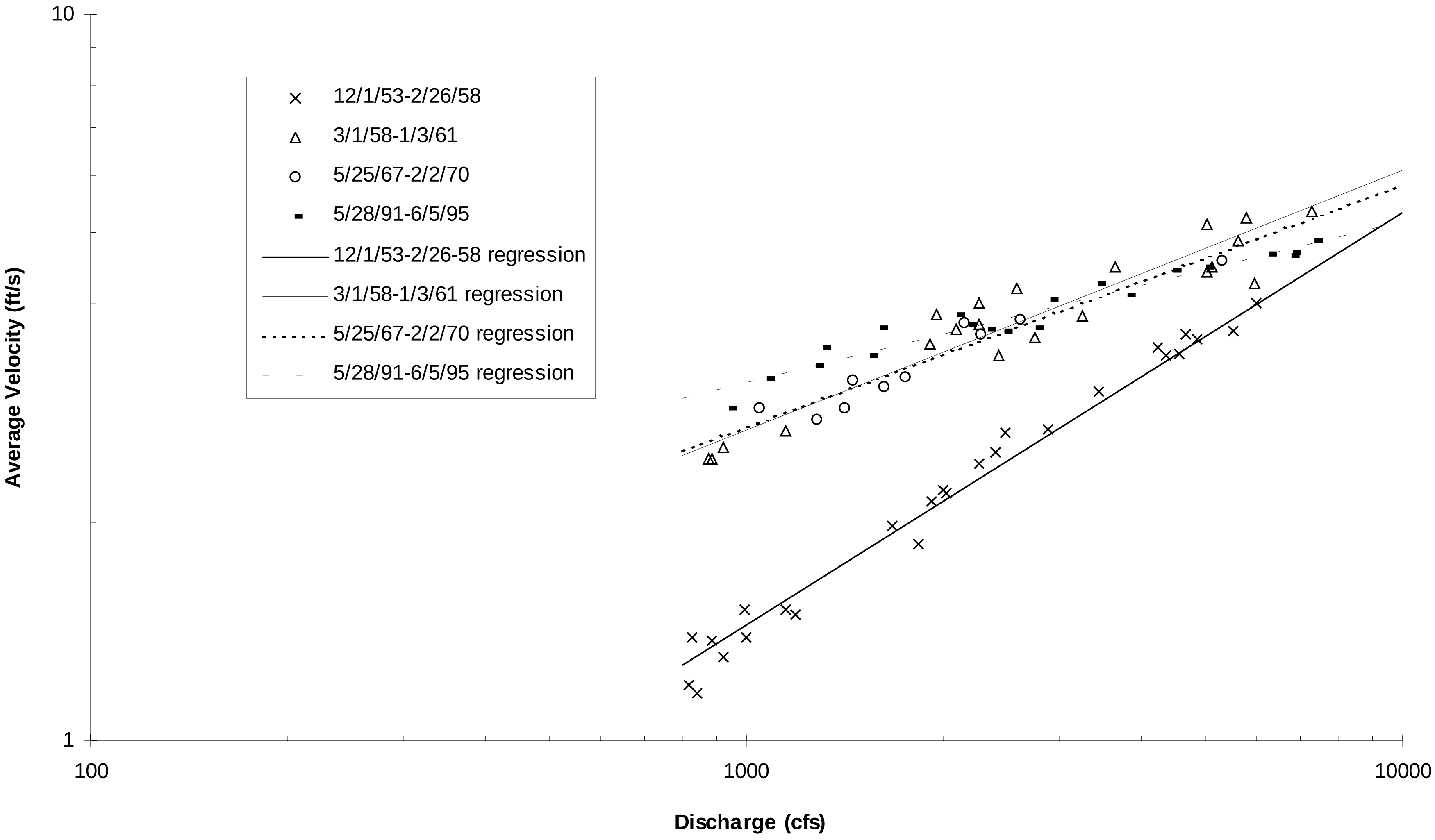

Figure 2.23 Hydraulic geometry evolution at the USGS gaging station at Lewiston: Average velocity as a function of discharge.

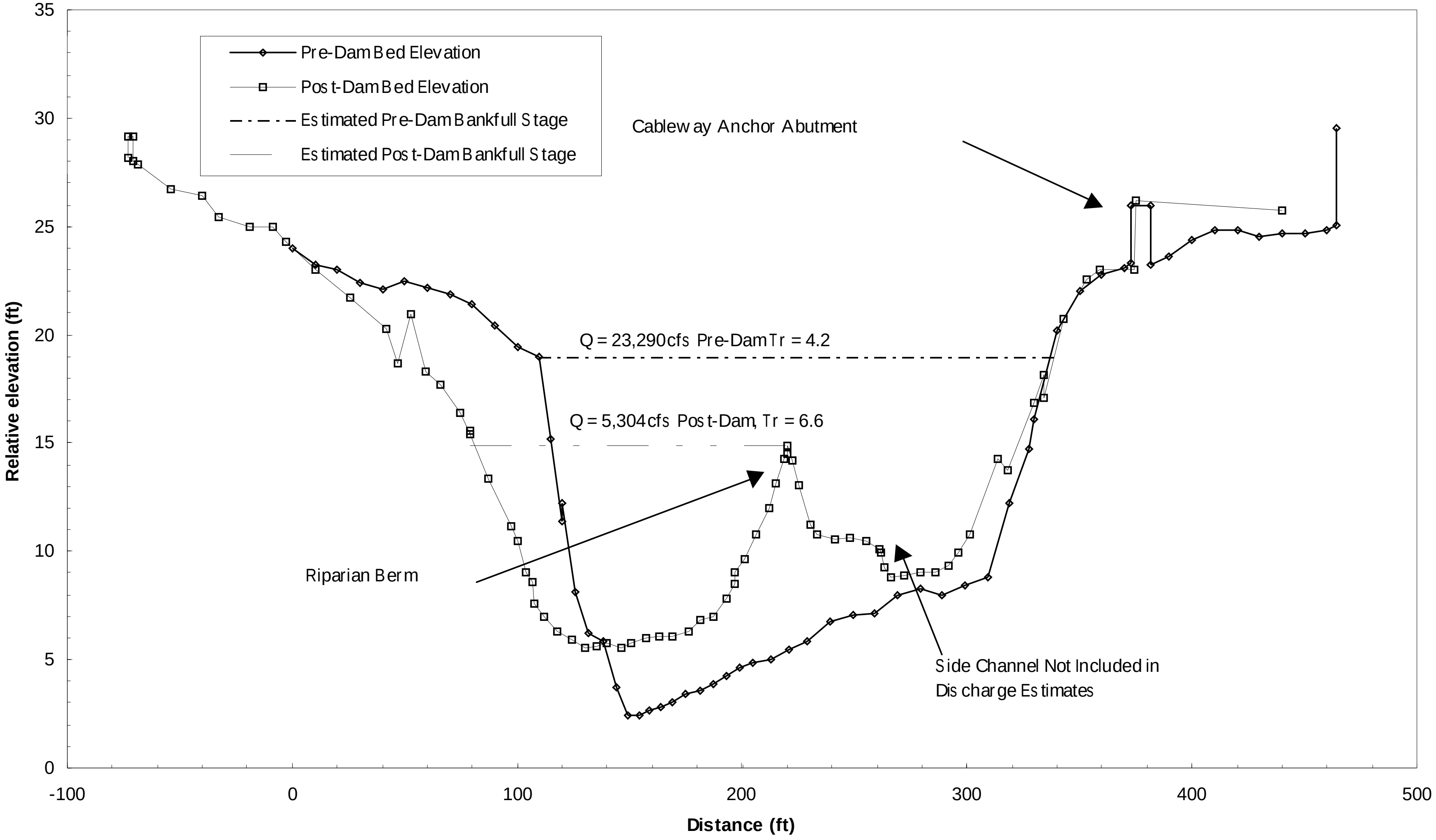

Figure 2.24 Change in Trinity River channel morphology at the USGS gaging station at Lewiston, showing change in estimated “bankfull” discharge and flood recurrence resulting from the TRD. Bankfull indicators are poor quality.

present-day banks (which are confined by riparian berms). We used a representative 1,000 cfs discharge from the 9-207 form rather than the regression equations because the WY1991 to WY1995 values did not plot linearly.

At a discharge of 1,000 cfs, channel width has decreased from approximately 175 ft to near 144 ft; velocity has increased from approximately 2.7 ft/sec to more than 3.1 ft/sec since 1958. Average depth measurements have varied over time, possibly due to changes in gravel storage from Deadwood Creek sediment or being dredged as part of the mid 1970s spawning riffle projects upstream and downstream of the gaging site.

2.3.3.2 Steiner Flat rehabilitation site (RM 91.7)

The pre-TRD and post-TRD channel geometry was reconstructed for cross section 5+98 using data from pre-construction surveys of the bank rehabilitation projects and historic floodplain and terrace features (Figure 2.25). Discharge was estimated, based on the Manning's equation, for pre-TRD and post-TRD bankfull channel indicators. By comparing the discharge estimates to flood frequency curves developed for the site, an inundation frequency was calculated for floodplain features at the site.

Estimates of the pre-TRD channel bed surface were based on distinct changes in particle size along the landward edge of the riparian berm. The surface of the former channelbed was dominated by coarse gravels and boulders; the riparian berms had sands and silts. Pre-TRD floodplain segments were used to identify the approximate bankfull stage, which in turn was used to estimate the hydraulic radius at the cross section. Channel slope through the reach was estimated from a survey of the water surface profile during a 5,080 cfs discharge in WY1996. The channel roughness (Manning's n value) was estimated using the average of five pre-TRD values calculated for the Lewiston site at discharges ranging from 12,600 cfs to 22,700 cfs (Table 2.6).

Date	Discharge (cfs)	Manning's n
2/26/57	22,700	0.0432
2/26/58	12,600	0.0421
1/12/59	21,100	0.036
2/9/60	13,700	0.0355
4/22/63	10,000	0.0396
	Mean n value	0.0394

Table 2.6. Manning's n values back-calculated at Lewiston site for various pre-TRD discharges. A mean value was used for discharge estimates at the Steiner Flat site.

Discharges relative to the pre- and post-TRD channel geometry were calculated using the hydraulic radius, the slope of the channel through the reach, and the estimated roughness of the channel in the

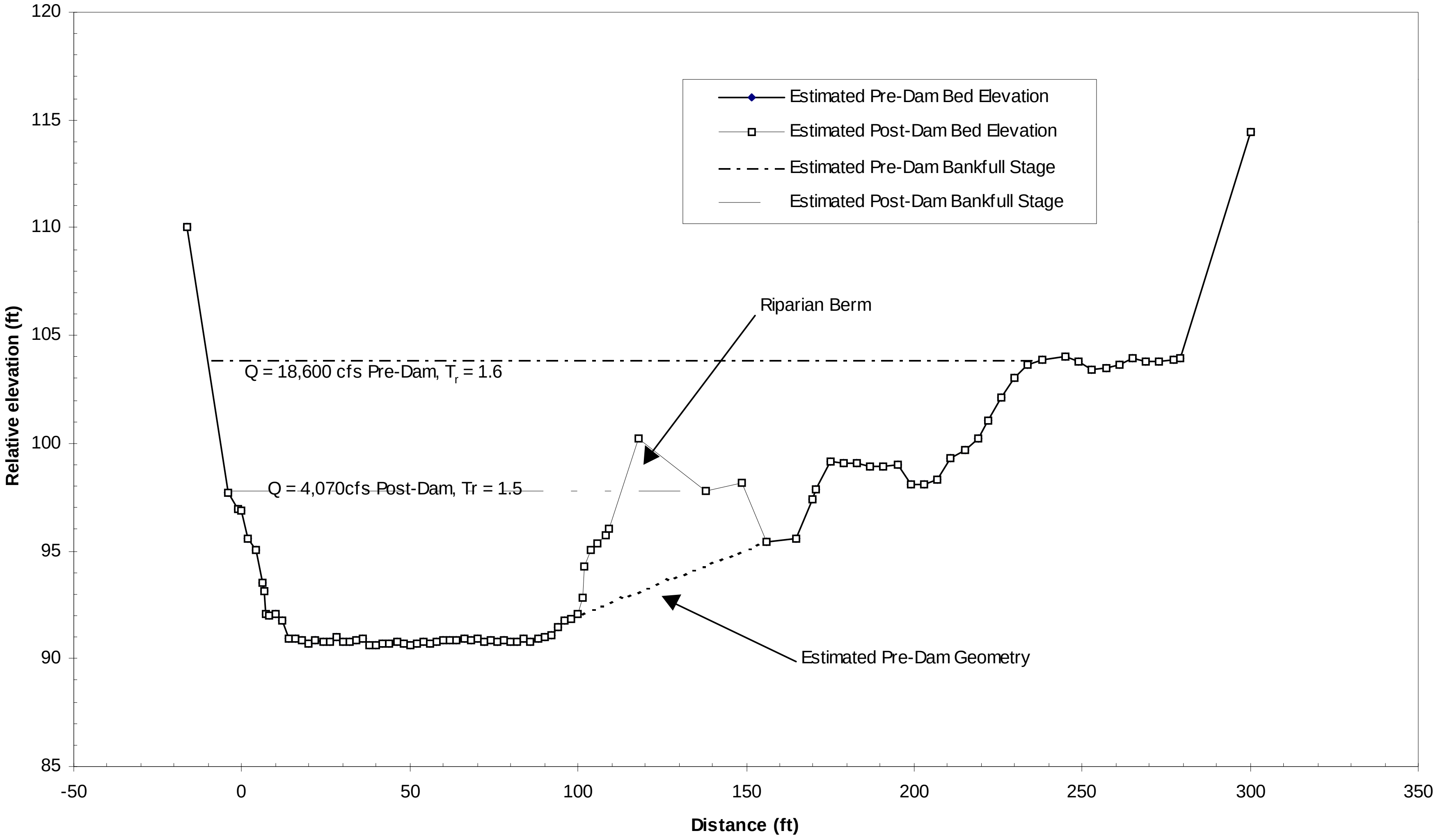

Figure 2.25 Change in Trinity River channel morphology at Steiner Flat (river mile 91.7), showing change in estimated bankfull discharge and flood recurrence resulting from the TRD.

Manning equation. Estimated pre- and post-TRD 1.5-yr discharges at the Steiner Flat site were 16,716 cfs and 3,653 cfs respectively (Figure 2.25). These values represent floods with a 1.6-yr and 1.4-yr return interval.

2.3.4 Planform geometry

Planform geometry is defined by channel shape and dimensions as viewed from above. Interpretation of 1960 and 1961 aerial photographs showed typical pre-dam meander wavelengths ranged from 2,500 ft to 4,000 ft (e.g., Figure 2.15), sinuosity varied between 1.0 and 1.2, and the radius of curvature for meanders varied based on the degree of bedrock influence.

Post-TRD meander wavelength and amplitude have not changed in most reaches upstream of the North Fork Trinity River. This is an artifact of flow regulation and riparian plant encroachment since dam construction. However, many reaches have developed subtle meander patterns within the confines of riparian berms. The wavelength and sinuosity of these newly developed meanders are substantially shorter than those of the pre-TRD channel; as observed at bank rehabilitation sites, these range from 800 ft to 2,700 ft, increasing with distance downstream from Lewiston Dam. Two or more present-day, meanders are confined within one half a meander of the pre-TRD channel (Figure 2.26). Contemporary thalwegs in these reaches are weakly expressed, with their depths only slightly greater (0.5 ft) than the mean channelbed depth. Presence of a meandering thalweg in erodible channelbeds, downstream of the Dutch Creek confluence at RM 86.3, indicates a trend back to a dynamic alternate bar morphology. These reaches have shorter meander wavelengths and amplitudes than their pre-TRD counterparts.

<u>2.4 Change in sediment transport</u>

Sediment was subdivided into fine sediment (e.g., fine sands and silts) and coarse sediment (coarse sand to boulders) classes. After delivery to the mainstem, sediments are carried downstream and deposited as alluvial features within the floodplain. Little information exists on pre-TRD sediment transport between Lewiston and the North Fork Trinity River, with the exception of suspended sediment samples collected from WY1955 to WY1961 by the USGS (Knott 1974). Knott estimates that the average annual suspended sediment discharge from WY1955 to WY1961 was 120,000 tons/year. Assuming a bedload/suspended sediment ratio of 10%, the estimated average annual bedload discharge was 12,000 tons/year.

Completion of the TRD in 1961 eliminated coarse sediment supply from upstream sources. Fine sediment supply was eliminated from the upstream watershed, except during large flood events when suspended sediment was transported through both reservoirs. Sediment derived from tributaries downstream of Lewiston Dam, however, continued to enter the mainstem. In some cases (e.g., Grass Valley Creek), sediment yield to the mainstem increased from intensive land use (primarily road construction and logging). Tributary-derived sediment, in conjunction with limited flow releases from Lewiston, filled pools and reduced spawning gravel quality.

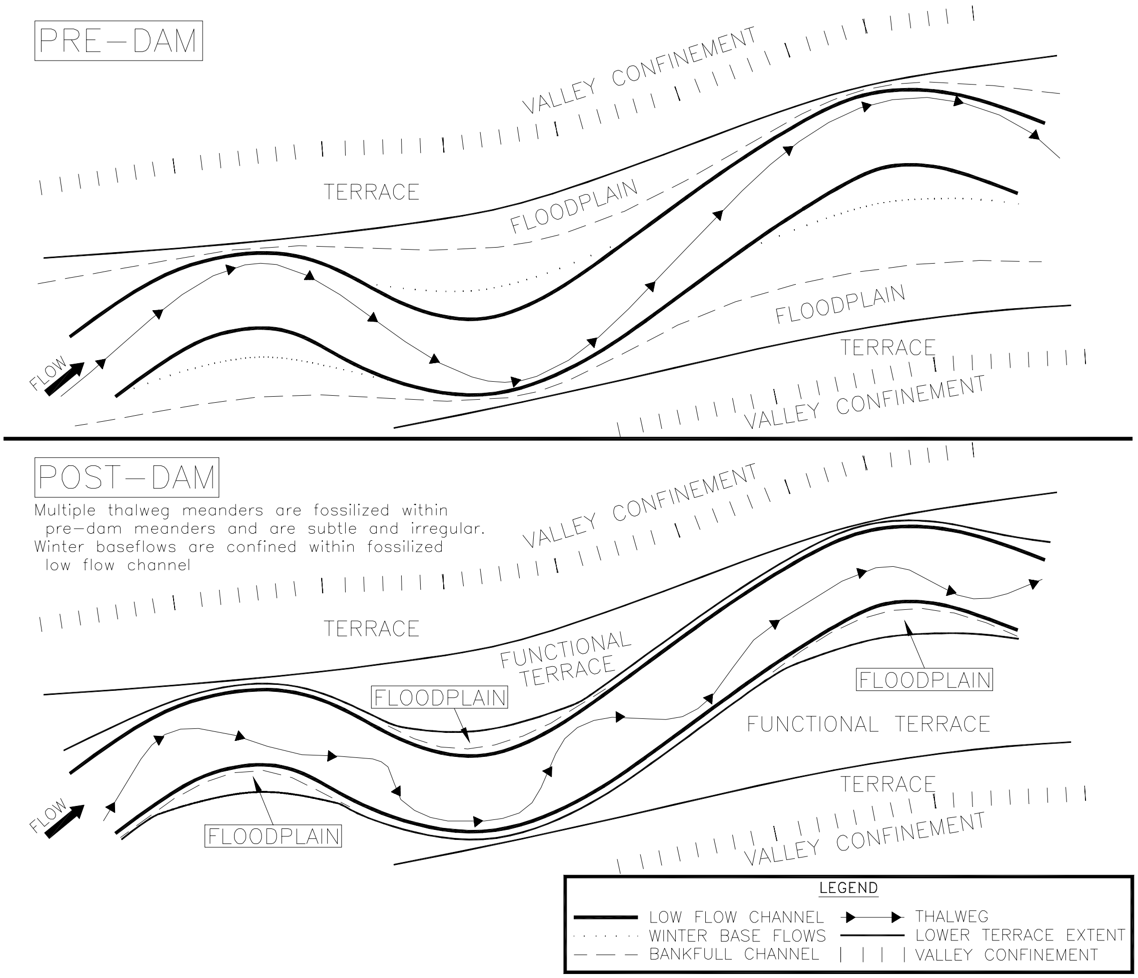

Figure 2.26 Idealized change in planform morphology resulting from the reduced flood flow regime from the TRD.

Flow regulation also has changed sediment transport processes. Without high flows, sediment entering the mainstem between Lewiston and the North Fork Trinity was no longer transported through this reach at rates similar to pre-TRD conditions. Sediment began to aggrade channelbeds and deposit as deltas at the mouths of tributaries. Larger particles commonly transported during pre-dam floods were no longer mobilized. Only fine sediment continued to move. In many reaches, a veneer of sand and gravel blankets cobbles and/or small boulders that are infrequently mobilized.

We estimated post-TRD bedload transport at: (1) the Trinity River near Limekiln Gulch gaging station at RM 98, and (2) Grass Valley Creek near Fawn Lodge gaging station. The Grass Valley Creek watershed is underlain by decomposed granite, yielding large quantities to the mainstem (DWR 1970). The USGS estimates an average annual suspended sediment yield of 27,200 tons/year and an average annual bedload yield of 4,490 tons/year at the Grass Valley Creek gaging station.

Corresponding values at the Trinity River near Limekiln Gulch gaging station are 47,000 tons/year for suspended sediment discharge and 26,275 tons/year for bedload discharge (BLM 1995).

Note the difference between the pre-TRD and post-TRD bedload estimates. We believe the difference is related to increased yield of coarse sand from Grass Valley Creek, which is accounted for as bedload in the post-TRD estimates.

2.5 Summary of changes

The TRD not only blocked access to important salmonid habitat, but also dramatically changed downstream flow and sediment supply. These changes were most dramatic between Lewiston Dam downstream to the North Fork Trinity River confluence. Farther downstream, the cumulative contribution of flows and sediment by tributaries, particularly the North Fork Trinity River, greatly mitigated TRD-related impacts. At Lewiston, where TRD impacts were severe, the following occurred:

- Export of 90% of the average annual water yield into the Sacramento River basin;
- Extremely large floods decreased from 70,000-100,000 cfs to 6,000-14,500 cfs;
- Elimination of common floods greater than 14,500 cfs;
- Near elimination of baseflows exceeding 450 cfs at Lewiston;
- Annual flow variation that once varied from 25 cfs to over 100,000 prior to the TRD was held constant at 150 to 450 cfs;
- Coarse sediment supply from the upper watershed was trapped behind the TRD.

These changes in sediment and water supply caused physical changes to the channel, including:

- Spawning gravels and cobble channel margins used by rearing salmonids were not replenished by upstream sources, decreasing the amount and quality of these habitats;
- Reduced flow volume, magnitude, and duration in the mainstem Trinity River caused tributary-derived sediments to accumulate at their deltas. Coarse bed material remained near the deltas, aggrading Rush Creek, Grass Valley Creek, and Indian Creek deltas. Sand, however, was partially routed downstream, and accumulated in pools, spawning gravels, and along the channel margin deposited as riparian berms;
- Constant flows during the germination period provided ideal environmental conditions, while the lack of high flows prevented seedlings from being scoured away. Therefore, the plants were able to establish and mature along the low water channel margin, becoming even more difficult to remove;
- Establishment and maturation of the riparian community fossilized bar deposits, functionally removing an important source of alluvium in the mainstem Trinity River;
- The riparian berm functionally narrowed the channel width, increased depth, and increased average velocity for flows between 500 cfs and 2,000 to 5,000 cfs (where flows spill over the berm).

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CHAPTER 3: ALLUVIAL RIVER ATTRIBUTES FOR THE MAINSTEM TRINITY RIVER

Fluvial geomorphic processes underpin the structure and function of complex river ecosystems. As interactions between physical and biological components increase geometrically, even simple cause-and-effect relationships are obscured. Regulated rivers must be managed by providing necessary geomorphic and ecological processes within contemporary sediment and flow constraints. The most effective strategy for rehabilitating habitat and fully realizing potential productivity of the anadromous salmonid fishery is to restore river ecosystem integrity to the mainstem Trinity River.

Before attempting to rehabilitate mainstem ecosystem integrity, we needed to establish what defines a healthy river. An effective measure of river health must incorporate the physical processes that create and maintain river morphology, as well as the biological responses to these processes. We chose to characterize river health by measuring geomorphic and riparian processes (as rates), and by documenting direct ecological impacts of interacting fluvial and riparian processes. We defined ten attributes of healthy alluvial river ecosystems to provide working hypotheses and goals for developing a process-oriented rehabilitation strategy. The alluvial attributes integrate variable streamflow, sediment supply, riparian plant life history requirements, and flow-dependent physical processes. Attainment of these attributes will culminate in a more complex and dynamic channel morphology providing high quality anadromous fish habitat.

Given extensive human impact on most rivers, not all attributes may be equally feasible, desirable, or historically quantifiable. Unregulated rivers with morphologies comparable to pristine conditions often no longer exist regionally, making within-basin comparisons between regulated and unregulated river systems flawed or simply impossible. Instead, associating general fluvial geomorphic processes with contemporary annual flow regimes in unregulated river systems outside the region may be necessary. The mainstem Trinity River below Lewiston has no reasonable unregulated counterpart to serve as a model. We depended on historical streamflow records, cross sections, aerial photographs, and local and scientific literature review to develop these attributes. By adopting these attributes, we largely circumvented the common shortcoming of having insufficient pre-regulation data regarding channel morphology and typically no information quantifying pre-regulation channel dynamics.

Basic alluvial processes described in the literature helped predict historical conditions on the Trinity River mainstem. Undisturbed conditions are essentially nonexistent along the Trinity mainstem due to extensive human disturbance to the channel, floodplain, and hillslopes during gold mining, which began in the mid-1800's. Since that time, gold dredgers have excavated much of the natural river channel, often from one valley wall to the other; and placer miners have sluiced entire hillsides onto tributary floodplains, greatly increasing sediment supply. Even with these considerable impacts, the mainstem channel as documented in the 1960 aerial photos still exhibited many features typical of unregulated Northern California alluvial channels (Figure 2.15): a testament to the resiliency of rivers and the influence of high flows in shaping and maintaining channel morphology.

3.1 Attributes of Alluvial River Ecosystem Integrity

The following attributes of ecosystem integrity target specific distinguishing characteristics and physical and biological processes in many coarse gravel-bedded alluvial rivers (defined as rivers capable of shaping their bed and banks). These attributes were used to help establish quantitative goals for ecosystem recovery downstream from Lewiston Dam.

ATTRIBUTE No. 1. Spatially complex channel morphology.
No single segment of channelbed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities;

ATTRIBUTE No. 2. Flows and water quality are predictably variable.
Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is a foundation of river ecosystem integrity;

ATTRIBUTE No. 3. Frequently mobilized channelbed surface.
Channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years;

ATTRIBUTE No. 4. Periodic channelbed scour and fill.

Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal;

ATTRIBUTE No. 5. Balanced fine and coarse sediment budgets.

River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be transported through the river reach;

ATTRIBUTE No. 6. Periodic channel migration.

The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber;

ATTRIBUTE No. 7. A functional floodplain.

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terraces;

ATTRIBUTE No. 8. Infrequent channel resetting floods.

Single large floods (e.g., exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and create off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods;

ATTRIBUTE No. 9. Self-sustaining diverse riparian plant communities.

Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors;

ATTRIBUTE No. 10. Naturally-fluctuating groundwater table.

Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs, and adjacent wetlands occur similarly to regional unregulated river corridors.

Attributes numbered 1, 2, 5, and 10 can help diagnose river ecosystem integrity. Attribute No. 2, central to all physical and ecological processes, is repeatedly addressed in the other attributes. But the need to emphasize annual flow variation warranted a separate attribute. Except Attribute No. 2, the others are direct consequences of fluvial geomorphic processes comprising other attributes. Their usefulness is derived from regional and/or historic expectations of runoff patterns, channel morphology, and riparian community structure in unregulated river ecosystems with minimally disturbed watersheds. All help define a desired condition and quantify channel rehabilitation goals.

Attributes No. 3, 4, 6, 7, 8, and 9 are process-oriented and can be departure points (in most cases, initial hypotheses) for investigating important physical and biological processes. These attributes also served as our restoration goals and lead to adaptive management monitoring objectives. Many attributes are inter-related. For example, maintaining an alternate bar morphology (No. 3 and No. 4) strongly affects channel migration (No. 6), floodplain formation (No. 7), and woody riparian establishment (No. 9).

3.2 Dynamic Alluvial River Equilibrium

Channel maintenance concepts, such as balancing the sediment budget, were not considered in early flow recommendations. Moffett and Smith (1950) did not link their spawning flow recommendations for the mainstem, based on depth and velocity preferences of spawning salmon, with the flows and sediment required to shape and maintain the channelbed providing spawning habitat. The habitat they quantified in the 1940s would not have existed unless the flow-related physical processes that shaped the alluvial channelbed topography and supplied gravel also existed. Their recommended daily average flow release of 150 cfs (Moffett and Smith, 1950) could not accommodate these processes or supply the necessary gravel.

The concept of a dynamic river channel morphology was ignored amid the early-1960s promise that salmon populations would thrive, and possibly improve according to TRD policy, on less flow (Stokely, 1997). Alluvial channel morphology is maintained in “dynamic quasi-equilibrium,” where sediment is transported through the channel at a rate roughly equal to the sediment supplied (Attribute No. 5). Sediment is transported through or stored within the channel (dynamic), but the channel morphology narrowly fluctuates over time (quasi-equilibrium). Knighton (1984) states “no exact equilibrium is implied but rather a quasi-equilibrium manifests in the tendency of many rivers to develop an average behavior.” Changes to sediment supply or flow regime instigate adjustments in channel morphology and the channel’s “average behavior” (Lane, 1955) (Figure 3.1). While a dynamic quasi-equilibrium is not universal among rivers, we believe the concept provides a useful baseline from which to identify and evaluate physical processes (e.g., sufficient flows should be released to export sediment at a rate roughly equal to supply).

3.3 Biological implications

Rivers with dynamic alternate bar sequences are structurally diverse and sustain a wide range of velocities and depths. Associated features such as undercut banks, side channels, and complex velocity shear zones all contribute to a physical mosaic that simultaneously provides habitat for many species. Anadromous fish habitat studies have shown that a physically complex aquatic environment with diverse water depths, velocities, and substrate cover is required for high-quality salmonid habitat (Meehan, 1991). High-quality anadromous salmonid habitat in the pre-TRD mainstem Trinity River depended on two primary physical characteristics: (1) a structurally complex channelbed and floodplain, and (2) a variable flow regime that inundated different segments of this complex channelbed with different frequencies, velocities, and depths.

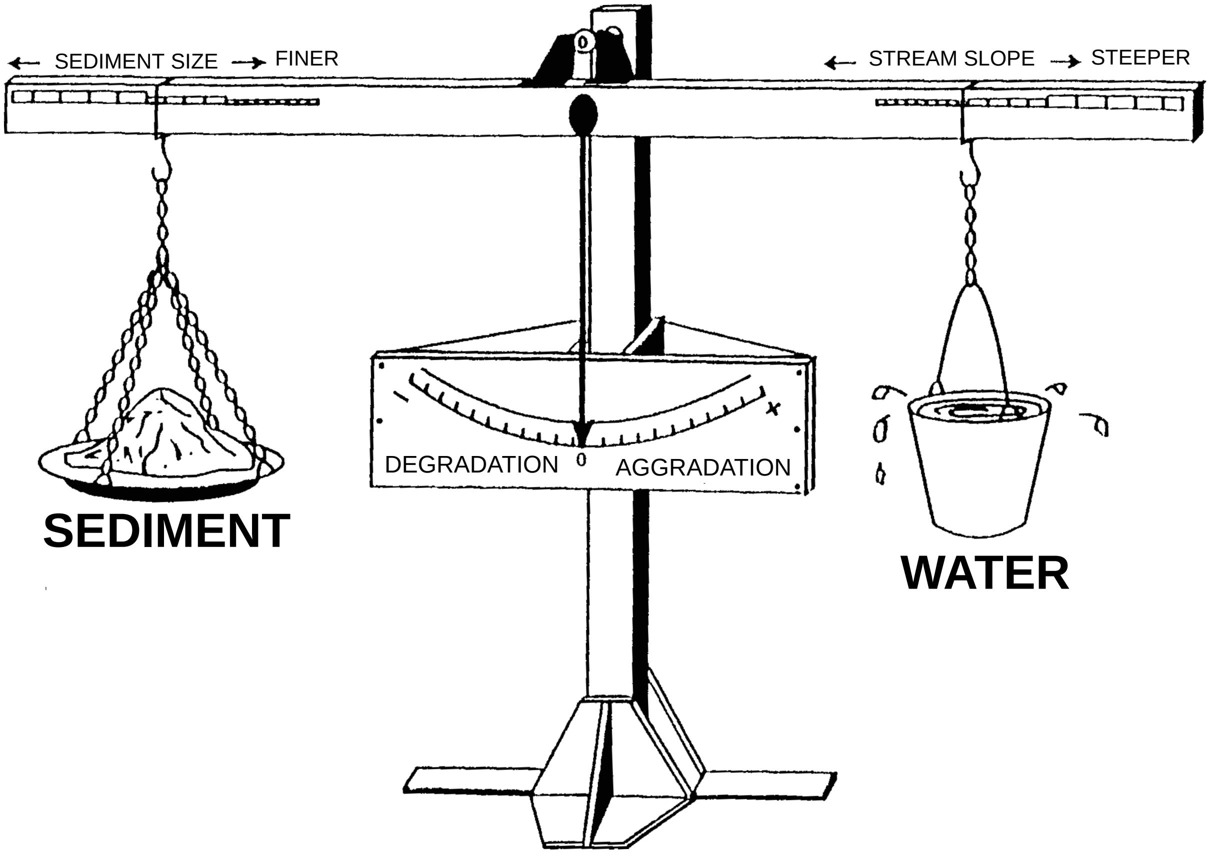


Figure 3.1 Conceptual flow-sediment balance necessary for channel equilibrium, and channel response to disequilibrium (from Lane, 1955).

Without extensive historic physical habitat data, the role of alternate bars creating habitat in contemporary alluvial river ecosystems was a guide to characterizing habitat availability in the pre-TRD mainstem. The topographic diversity of the pre-TRD channelbed surface (and sub-surface) generated diverse anadromous salmonid habitat at any given flow (Figure 3.2). For example, the steep riffle face of alternate bars, at low winter/spring baseflows and summer flows, can provide widely varying water velocities and depths over short distances (a few feet) (Figure 3.3). This hydraulic complexity provides physical habitat for several age classes of juvenile salmonids. At baseflows of approximately 300 cfs, a contemporary alternate bar sequence on the mainstem will provide varying amounts of these salmonid habitats (Figure 3.2):

- adult migration holding area
- preferred spawning substrate and physical microenvironment (depth and velocity)
- early-emergence slack water
- summer rearing for several juvenile age classes
- winter rearing for several juvenile age classes

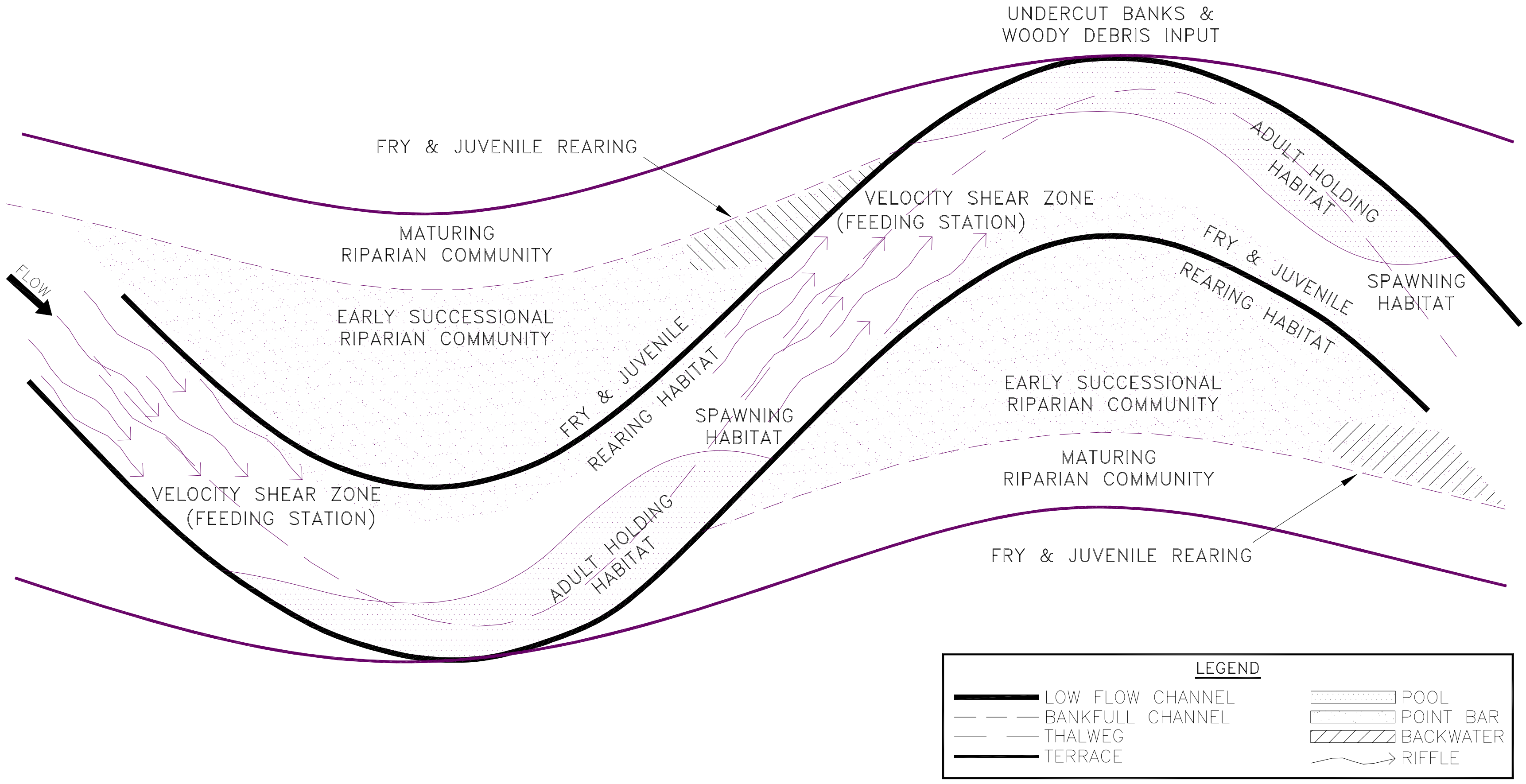


Figure 3.2 Salmonid habitats provided in an idealized alternate bar unit.

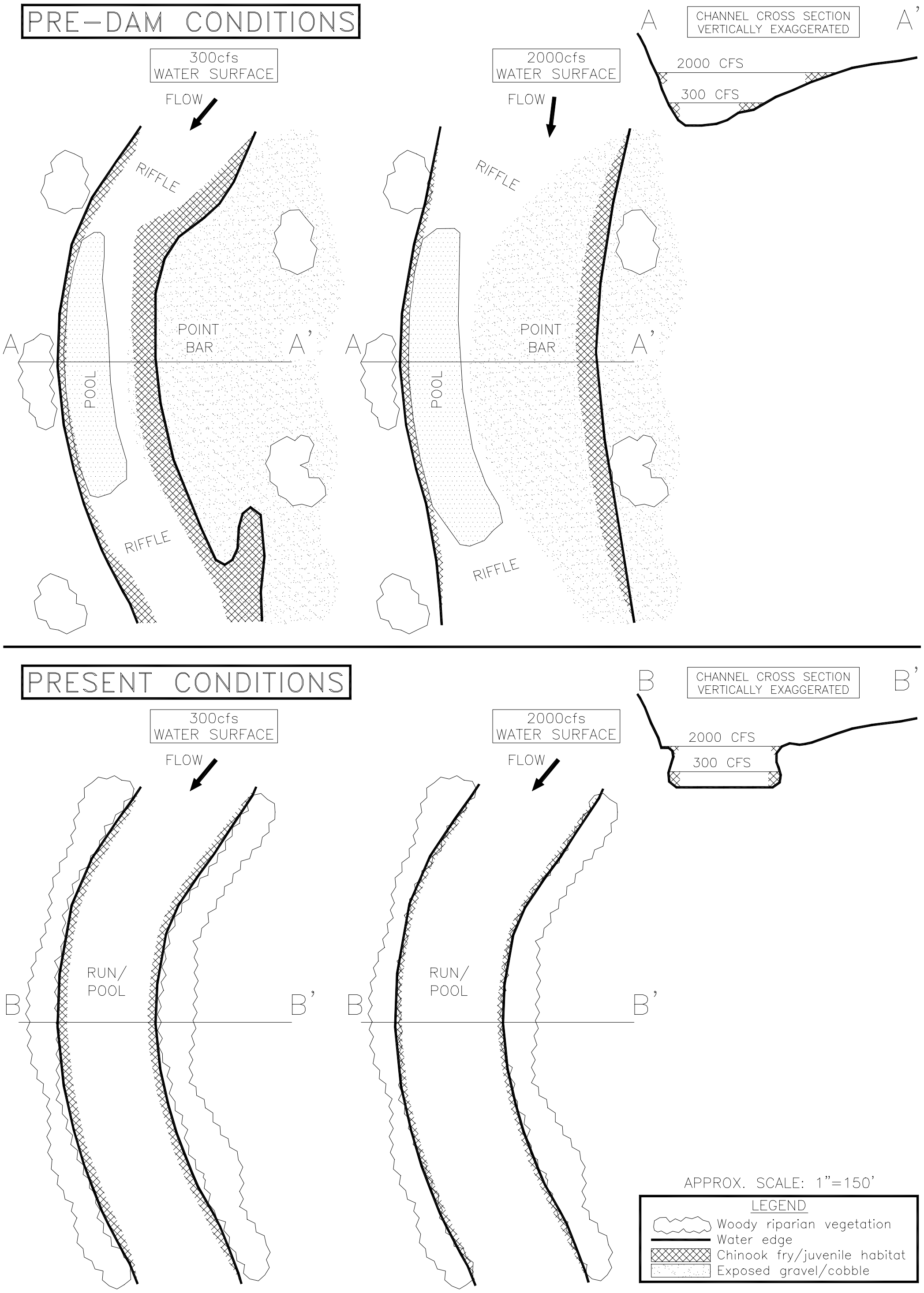


Figure 3.3 Idealized pre-TRD point bar showing relative surface area of fry and juvenile chinook rearing habitat compared to present conditions of riparian encroachment and narrow channel.

At other flows, most if not all these habitats will remain available, though differing in amount and proportion.

With the loss of pre-TRD topographic complexity, today's juvenile salmonid rearing habitat, especially young chinook fry habitat, typically is constrained to narrow ranges of favorable discharge and located immediately adjacent to the channel banks (Figure 3.3). Shallow slackwater habitat preferred by recently-emerged chinook fry nearly disappears in the present channel at intermediate discharges (between 400 and 2,000 cfs), only to reappear at flows greater than 2,000 cfs once the riparian berm has been overtopped (USFWS, 1997). In contrast, contemporary alternate bars evolving at the Steiner Flat bank rehabilitation site (RM 91.8) already provide more diverse habitat over a broader range of flows, from baseflows (300 cfs) up to bankfull flows (approximately 6,000 cfs at this site).

Alternate bar sequences provide additional ecological functions beside supporting anadromous salmonid habitat. A side channel often forms on the landward margin of an alternate bar that flows only during floods. The lower end of side channels is usually deeper (scoured during large floods), providing amphibians refuge from high velocities during flooding and thermal refuge during lower flows. Adult western pond turtles (*Clemmys marmorata*) forage and thermoregulate in and along pool and glide habitats of the main channel, while smaller hatchlings and juveniles prefer backwater pools, shallow river margins, and side channels with vegetation (Reese et al., 1995). These habitats are typically found in, or created by, alternate bar sequences. On the upstream end of alternate bars, a broad shallow area provides slightly warmer and slow-flowing water that attracts amphibians in the winter. Gently sloping exposed flanks of alternate bars provide habitat for foothill yellow-legged frogs *(Rana boylii*) that deposit eggs in shallow, low water velocity areas on cobble bars with sparse vegetation (Lind et al., 1992). The early-successional riparian vegetation on the mid- to upper surface of bars provides habitat for many resident and migratory birds, including the listed willow flycatcher (Figure 3.2).

CHAPTER 4: STUDY PLAN OBJECTIVES

From the inception of the Trinity River Restoration Program through the late 1980's, only one study (Strand, 1981) evaluated fluvial geomorphic processes for restoring the mainstem Trinity River. Our study adopted a process-based approach at rehabilitating the mainstem Trinity River ecosystem, with the fundamental assumption that restoring a healthy river would be the most effective way to restore the anadromous salmonid fishery. Our initial study approach might have been considered a "channel maintenance flow" analysis (Reiser et al., 1989), but it soon evolved into more, incorporating fine and coarse sediment budgets, riparian community dynamics, and channel reconstruction as integral components of our recommendations.

Our flow recommendations required several steps. A critical first step was identifying how pre-TRD annual hydrographs from Lewiston downstream to the North Fork Trinity River confluence had been altered by flow regulation. Changes in flow magnitude, duration, frequency, and timing were considered. This also required re-defining the roles of downstream, unregulated tributaries supplying flow and sediment to the mainstem. The second step was quantifying relationships between the alluvial river attributes and annual hydrographs before and after flow regulation. Attaining river ecosystem integrity largely hinges on exceeding several physical and biological thresholds, preserving natural variation, and balancing the sediment budget. Incipient channelbed mobility (Attribute No.3), alternate bar scour and fill (Attribute No.4), floodplain inundation (Attribute No.7), and riparian seedling scour (Attribute No.9) are not gradual processes but occur as thresholds over narrow flow ranges. Relative importance of each threshold may vary among alluvial river ecosystems (e.g., differences between sand-bedded and gravel bedded alluvial rivers), but each was considered before recommending annual flow regimes for the mainstem Trinity River.

The alluvial river attributes, therefore, are the cornerstone of our study plan. Restoring the attributes to the Trinity River is our objective for rehabilitating the Trinity River. As addressed in Chapter 2, the pre-TRD channel morphology and fluvial processes have not been extensively documented. By establishing that the mainstem morphology was alluvial, we took contemporary knowledge of how alluvial rivers function and applied this understanding to the pre-TRD mainstem Trinity River. The attributes allowed us to offer initial hypotheses relating annual flow regimes to important physical and ecological processes.

Monitoring in WY1991 and WY1992 was documenting fluvial thresholds (Attributes 3, 4, 7, and 9) in a functionally broken channel (Chapter 2) rather than a desired future channel. A fortuitous event occurred when the USBR and USFWS constructed nine pilot bank rehabilitation projects to create more chinook fry habitat (USFWS, 1994). Floods occurring soon after construction created alternate bars at many of these sites, allowing us to monitor and test hypotheses concerning bar mobility and scour, physical processes that cause woody riparian mortality, and floodplain formation. We considered removal of the riparian berm along one bank an opportunity for the river to function alluvially, at least for a short window of time until riparian encroachment returned. We expected alternate bar formation in the longer bank rehabilitation sites to provide better salmonid habitat throughout the project site, not only along the modified banks.

We used the attributes as restoration objectives. Our study plan attempted to quantify minimum thresholds that restored many of the attributes at both restored and unrestored sites. Not all the process-oriented alluvial attributes (3 through 9) were equally examined. Channelbed surface mobility (Attribute No. 3) and bed scour (Attribute No. 4) were addressed extensively, as well as riparian processes (Attribute No. 9) and sediment budgets/bedload routing (Attribute No. 5). Floodplain dynamics (Attribute No. 7) could not be examined because the present-day mainstem lacks them, although rudimentary floodplains may be evolving at pilot bank rehabilitation sites. Groundwater dynamics (Attribute No. 10) were not examined, though the importance of the groundwater water table to off-channel wetlands should not be minimized, especially during snowmelt recession. Channel re-setting floods (Attribute No. 8) were easier to conceptualize than quantify; our analysis focused on predicting relatively large flood flows that remove mature alders.

<u>CHAPTER 5:</u> FLOW VARIATION

Attribute No. 2. FLOWS AND WATER QUALITY ARE PREDICTABLY UNPREDICTABLE. *Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, duration, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is a foundation of river ecosystem integrity*;

Flows in the mainstem varied considerably prior to TRD construction. During rain-on-snow storm events, instantaneous peak flows at Lewiston have exceeded 70,000 cfs, peaking as high as 100,000 cfs. At the other extreme, late-summer flows during drought conditions have dropped below 100 cfs. Much of the natural annual variation in mainstem flows is predictable as general trends (e.g., higher peak flows in wet years, lowest flows in late summer, snowmelt runoff peaks during late spring and early summer). But other flow characteristics, such as the magnitude of peak flows and droughts, are extremely variable annually and cannot be forecasted with precision. Throughout the Pacific Northwest, aquatic and riparian communities, including salmonid populations, have evolved in close association with this predictable unpredictability of seasonal (intra-annual) and year-to-year (inter-annual) streamflow variation.

Inter-annual variability can be expressed as differences in total annual precipitation, instantaneous flood peaks, monthly water yield, the timing of maximum snowmelt, the duration of snowmelt runoff among water years, etc. In contrast, other flow descriptors such as mean annual water yield (a common statistic used to characterize river systems) provide no information regarding inter-annual flow variation. For the mainstem at Lewiston, annual yield since WY1912, while averaging 1.2 million acre-feet, has varied from a low of 227,000 ac-ft to a high of 2,888,000 ac-ft. Fow regimes during these two extremes were strikingly different. Intra-annual variability encompasses shorter time periods (hours to days) and is expressed as changes in intra-annual flow magnitude, duration, timing, and frequency of annual hydrographs. Intra-annual flow variation spans a timescale appropriate for organisms and species cohorts to react to streamflow and interact with channel morphology (e.g., successful germination will be influenced by location on the point bar and transient moisture conditions).

Intra- and inter-annual flow variability is responsible for distinct physical processes fundamental to preserving/returning integrity to the Trinity River ecosystem. This chapter builds on Chapters 2 and 3 by showing how specific aspects of flow variation affect the mainstem ecosystem. A significant first step is adopting a water year classification system that is sensitive to local runoff conditions and promotes variable annual releases.

5.1 Water year classification

Water year classification is used by the US Bureau of Reclamation to assist managers in allocation of CVP water resources from reservoirs across the state. Water year classifications are based on water yield in a selected (but not necessarily representative) basin and are often applied to other regional basins. At present, the water year classification protocol of to operate the TRD is based on annual Shasta Lake (Sacramento River Basin) inflows rather than annual Trinity (Trinity River Basin) Reservoir inflows. In some water years, water supply conditions in the two basins differ, i.e., dry conditions occur in one basin while normal conditions occur in the other. At times, dry-year flow reductions to Trinity River flows have been prescribed when basin runoff conditions warranted normal-year releases. This is not the way to incorporate natural flow variation into annual flow releases for managing the Trinity River ecosystem.

5.1.1 Water year class determination

Annual water yield into the TRD is the total unregulated volume of water entering Clair Engle Reservoir in a water year. For water years prior to TRD construction (WY1912 to WY1960), flow records from the USGS Trinity River at Lewiston gaging station were used to compute annual yield. For regulated water years (WY1961 to WY1995), unregulated inflows to Clair Engle Reservoir were computed by USBR.

To develop water year classifications based on annual water yield, we first established an exceedence probability of annual yields for WY1912 to WY1995. We divided the distribution symmetrically about the median value at annual exceedence probabilities (p) of 0.88, 0.60, 0.40, and 0.12 (Figure 5.1 and Table 5.1). These divisions were used to delineate boundaries between five water year

Figure 5.1 Cumulative plot of ranked annual water yields from the Trinity River upstream of Lewiston for 1912-1995.

WATER YEAR CLASS	EXCEEDEDNCE PROBABILITY	THRESHOLD INFLOW FOR DESIGNATION
Extrememly Wet	p<0.12	2,000,000 acre-feet
Wet	0.12<p<0.40	1,350,000 acre-feet
Normal	0.40<p<0.60	1,025,000 acre-feet
Dry	0.60<p<0.88	650,000 acre-feet
Critically Dry	p>0.88	<650,000 acre-feet

Table 5.1 Proposed Trinity River water year classification.

classes. Until now, TRD operations have been based on three water year designations: “normal or wetter”; “dry”; and, “critically dry”. By adding classifications for “wet” and “extremely wet”, the proposed designations will provide additional flexibility for addressing environmental needs (Attribute No. 2) below Lewiston Dam.

5.2 Annual hydrograph components

Seasonal patterns of daily average flow are identifiable as “hydrograph components” (Figure 5.2). For Pacific Northwest rivers, annual hydrograph components include summer baseflows, winter flood peaks, winter baseflows, snowmelt peak runoff, and snowmelt recession. Each hydrograph component can be characterized by its duration, magnitude, frequency, seasonal timing, and inter-annual variability. Hydrograph components were identified for pre-TRD annual hydrographs using the USGS Lewiston gaging data and USBR Trinity reservoir inflow data.

These hydrograph components can vary considerably with water year class, location in the basin, climatic variation, and TRD releases to the mainstem. For instance, multiple winter floods may occur in Wet water years but be missing in many Dry water years. Snow hydrology, with moderate-magnitude, long-duration peaks and high summer baseflows, is typical of high-elevation tributaries. In contrast, the hydrology of low-elevation tributaries is driven by rainfall events, and characterized by high-magnitude, short-duration peak flows and low summer baseflows. In each case, sub-basin hydrology is linked closely to local physical and biologic processes.

By virtue of its position in the watershed (at a transition point between high-elevation and low-elevation sub-basins), the mainstem near Lewiston exhibits a dual hydrologic personality. In some years, mainstem hydrology is driven by snowmelt mostly originating upstream of Lewiston, with most runoff during a several week period in late spring/early summer. In other years, rainstorms are common above and below Lewiston. Flows will peak many times, but briefly, throughout the winter. We recognized two distinct sources of mainstem floods: snowmelt runoff and rainstorm runoff. Both could occur the same water year. A sub-category of rainstorm events, the rain-on-snow event, is responsible for the largest floods.

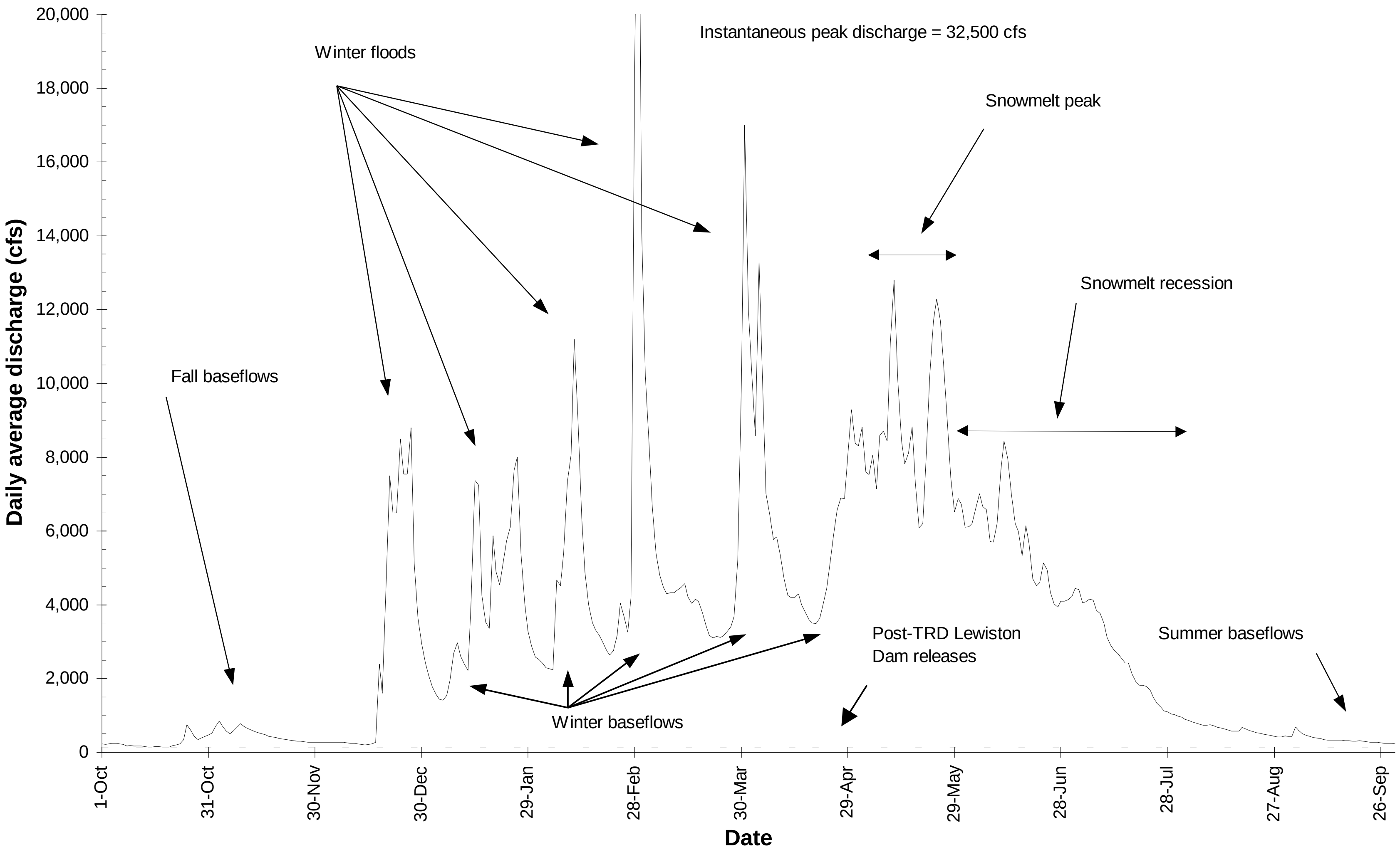


Figure 5.2 1941 Trinity River at Lewiston streamflow hydrograph illustrating hydrograph components typical of a watershed dominated by rainfall and snowmelt runoff (Extremely Wet water year).

Peak snowmelt runoff and high summer baseflows dominate annual hydrographs for sub-basins high in the Trinity River watershed, whereas lower sub-basins (downstream of Lewiston) generate more winter rainfall runoff and relatively low summer baseflows. Therefore, distinct differences in magnitude, duration, frequency, and timing of hydrograph components also should occur with location in the basin. These differences have significant geomorphic and ecological consequences.

We established initial hypotheses relating flow regime, fluvial processes, and ecosystem function from the attributes in Chapter 3. Given significant changes from the pre-TRD flow regime, our analyses could now anticipate (hypothesize) geomorphic and/or ecological consequences, direct where to search for evidence, and suggest flow release adjustments.

Taking a winter flood hydrograph component as an example, we attempted to evaluate the following:

- What geomorphic and biological thresholds are typically reached only during winter floods?
- How do winter floods impact the mainstem sediment budget?
- How do winter floods integrate specific life history requirements, e.g., upstream migration of anadromous salmonids?
- How do winter floods influence channel geometry?
- How do winter floods influence groundwater dynamics and off-channel wetlands?
- How are winter floods different from peak snowmelt runoff events ecologically?

Hypothesizing the ecological roles of hydrologic components in annual flow regimes allowed us to determine how a particular hydrograph component should be analyzed. For winter flooding, we asked the following:

- How many events were there per year?
- What was the peak magnitude of each event in a year?
- What was the timing of each event in a year?
- What was the duration of each event in a year?
- How should we define peak event? (same problem as with partial flood determination)
- How do all the above vary with position in the basin?

Our analytic strategy was to: (1) inspect annual hydrographs throughout the entire record and establish basic hydrograph components, and (2) evaluate each hydrologic component for past and present roles in affecting channel morphology and the river ecosystem. After analyzing historic flow variability, we wanted to isolate processes influencing pre-TRD morphology and dynamics (the alluvial attributes), and then quantify hydrograph components creating these processes. Recommended flow regimes could be assembled from the hydrograph components that might achieve the desired processes.

5.2.1 Annual hydrograph components within water year classes

Hydrograph characteristics (magnitude, duration, timing, and frequency) were obtained by plotting and inspecting annual hydrographs for each water year (Appendix A). Furthermore, annual hydrographs in each water year class were grouped and analyzed independently.

Critical components of pre-TRD flow regimes were identified, quantified, and assigned functional importance with respect to maintaining physical and biological integrity (Table 5.2), and illustrated for Wet, Normal, and Dry annual flow regimes (Figure 5.3).

Differences among and within water year classes have meaningful geomorphic and biological consequences, as discussed further in Chapters 5 through 9. In the following section, annual hydrographs from the Lewiston gaging station will be used as follows:

- Annual hydrographs grouped within the five water year classes were averaged, to produce a single average annual hydrograph for each water class. Averaged annual hydrographs distinguished trends between water year classes, but masked annual flow variability within each water year class (Figures 5.4 to 5.8).
- A single unimpaired annual hydrograph was identified that typified each water year class to show hydrograph components in a given water year class (Figures 5.4 to 5.8). Water years 1938, 1952, 1919, 1933, and 1939 were selected to represent Extremely Wet, Wet, Normal, Dry, and Critically Dry water year classes, respectively.

5.2.1.1 Winter storms

Winter storms (Table 5.2) are rainfall generated runoff events, typically occurring between mid-November and late-March. Large magnitude, short duration events typically occurred from mid-November to late-January, with moderate magnitude events extending through late-March. Peak flows exceeding 70,000 cfs occurred three times since WY1912. The magnitude of peak flows generally correlated with water years (wetter water years producing bigger floods), but there were exceptions. One notable example was the 1964 flood, which peaked at over 100,000 cfs peak discharge, but during a Wet rather than Extremely Wet water year class. The TRD has mostly eliminated all winter storm flows at Lewiston (excluding downstream tributary contribution), with the exception of very wet years when the dam spills. These spill events are always much smaller (<14,500 cfs) than unregulated inflow into Trinity Reservoir.

5.2.1.2 Snowmelt peaks

The magnitude and timing of snowmelt peaks were closely correlated with water year class, because the snowmelt peak was largely a function of snow accumulation the preceding winter. Review of all annual hydrographs available suggests that snowmelt peaks (not associated with rainfall events) ranged from 26,000 cfs during Extremely Wet years to 7,200 cfs during Critically Dry years. However, when all hydrographs are averaged across the five water year classes, snowmelt magnitudes typically range from 8,200 cfs to less than 2,000 cfs for Extremely Wet and Critically Dry water years, respectively (Figure 5.9). Timing of the snowmelt peaks ranged from late-March to

	Description	Geomorphic Function	Riparian Function
Extreme Winter Events	· Extreme magnitude (greater than 40,000 cfs) · Short duration · Unpredictable timing · Low frequency (every 5 to 10 years) · Often, rain-on-snow	· Redistribute deltaic deposits throughout the mainstem · Mobilize large alluvial features including entire alternate bar units · Induce significant channel migration in alluvial meanders · Supply alluvium and colluvium to the mainstem channel from the valley walls by initiating bank erosion and debris slides · Mobilize the largest bed particles (D_{95}) throughout the planform morphology · Move, re-organize, and deposit large woody debris · Realign channel by "jumping channels," with the river re-occupying older main channels or cutting-off sharp channel bends · Significantly scour and/or remove alluvial features formerly anchored by aging riparian vegetation · Deposit fines on terraces and portions of the floodplain.	· Scour all riparian age classes and/or abandon all age classes by channel alignment · Bury younger riparian age classes · Significantly build floodplain and low terraces by fine sediment deposition, particularly on inside channel bends, creating potential seedling germination sites
Winter Storm Events	· High magnitude (15,000 to 40,000 cfs) · Moderate duration · Unpredictable timing · Frequent (1 to 5 years)	· Provide some alternate bar mobilization and migration · Significantly mobilize bed , including recently-introduced tributary delta deposits.	· Scour younger age classes and possibly older trees where minor channel realignment occurs or scour the outside of alluvial bends · Build floodplain by fines deposition, creating potential seedling germination sites
Snowmelt Runoff	· High to moderate magnitude (4,000 to 15,000 cfs) · Long duration · Predictable timing based on water year · Frequent (1-2 years)	· Transport large volumes of finer fraction bedload, but have minor mobilization of alternate bar sequences - Initiate bed surface movement generally, and mobilize many secondary alluvial features in the higher end of flow range · Scour and replace spawning gravel habitat	· Scour yearling age class, particularly within the active channel · Discourage seedling establishment through inundation mortality - Prevent germination by inundation on margins of the active channel
Winter and Spring Baseflows	· Moderate magnitude (2,000 to 4,000 cfs) · Long duration · Annually predictable	· Mobilize limited sand and gravel stored within the active channel · Re-distribute minor volumes of tributary delta deposits down the mainstem	· Promote inundation mortality of seedlings on lower bed surfaces within the active channel · Desicate seedlings established on higher channel surfaces (that germinated during late-spring snowmelt peaks) · Prevent germination on significant portions of the channelbed surface
Summer Baseflows	· Low magnitude (50 to 200 cfs) · Long duration · Annually predictable	· Promote minor sand movement through alternate bar sequences and shifting dune features in pools	· Desicate seedlings established through the late-winter and spring · Provide minor inundation of sensitive sapling species (e.g., cottonwood) during higher low summer flows

Table 5.2 Important geomorphic and riparian functions provided by the pre-TRD annual hydrograph components.

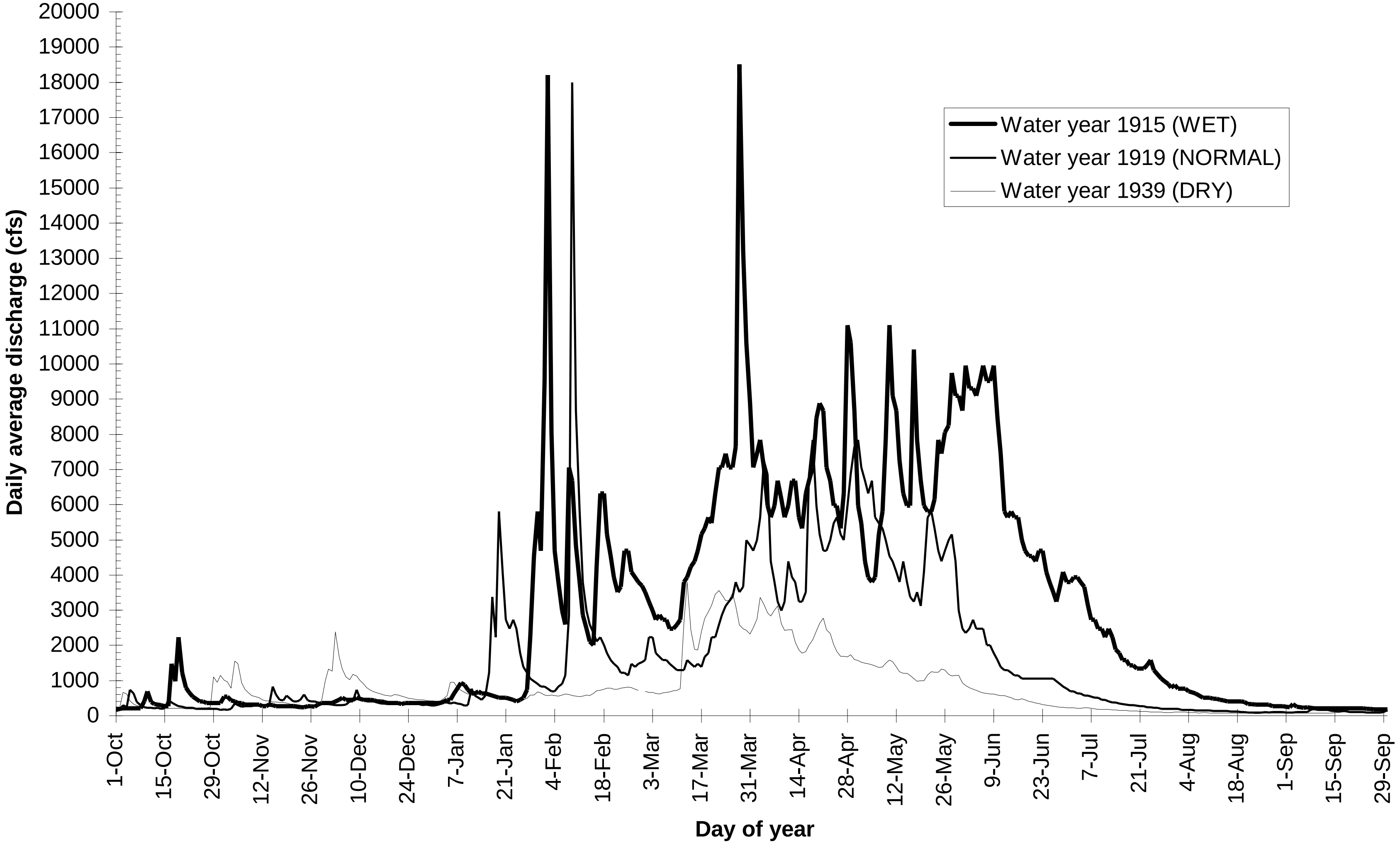


Figure 5.3 Hydrologic components for representative Wet (1915), Normal (1919), and Dry (1939) water years at the USGS gaging station at Lewiston. Note that with drier water years: A) the magnitude of the hydrograph components typically decrease; and B) the timing of the snowmelt peak is earlier in the season.

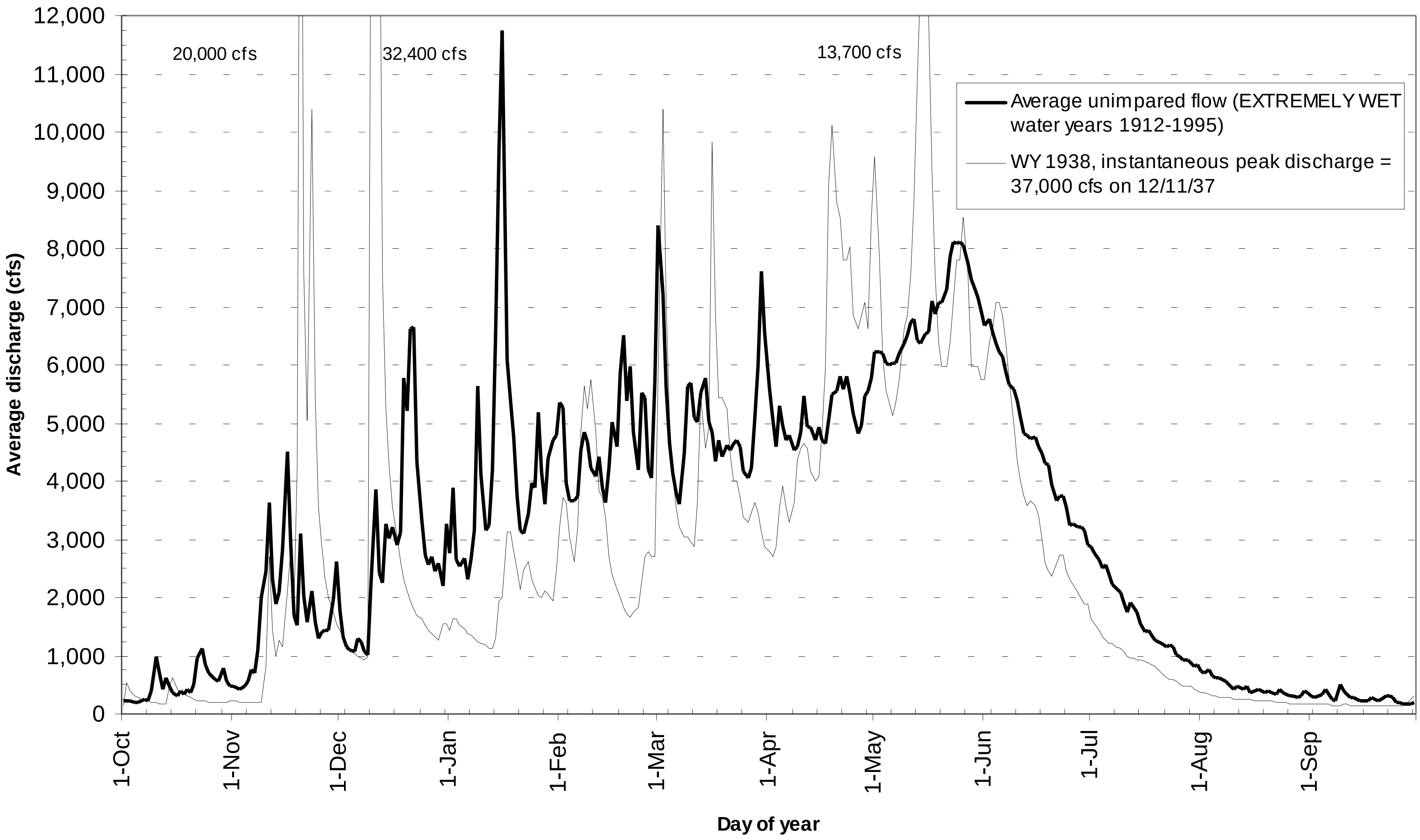


Figure 5.4 Average and representative (1938) EXTREMELY WET water year annual hydrographs at the USGS gaging station at Lewiston.

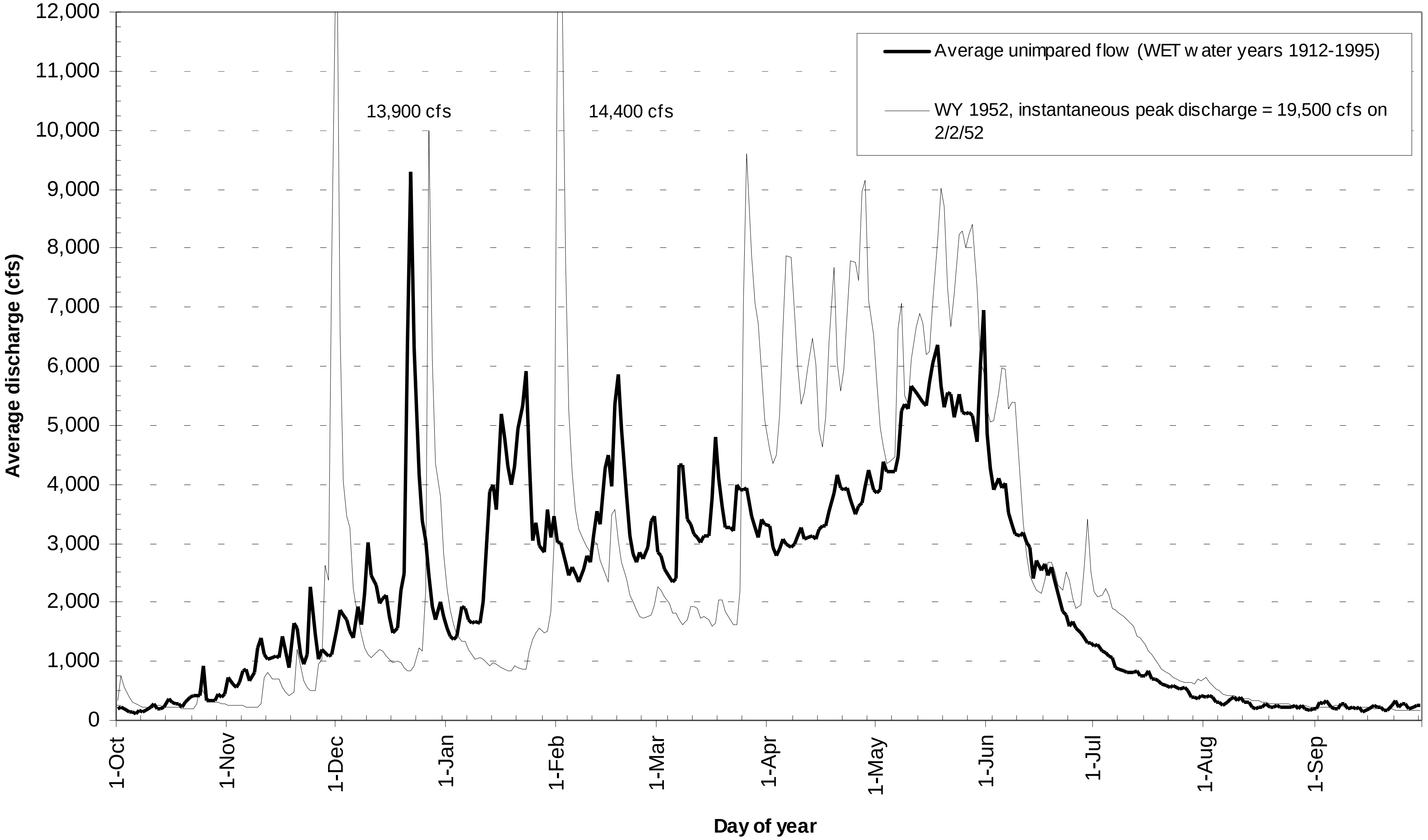


Figure 5.5 Average and representative (1952) WET water year annual hydrographs at the USGS gaging station at Lewiston.

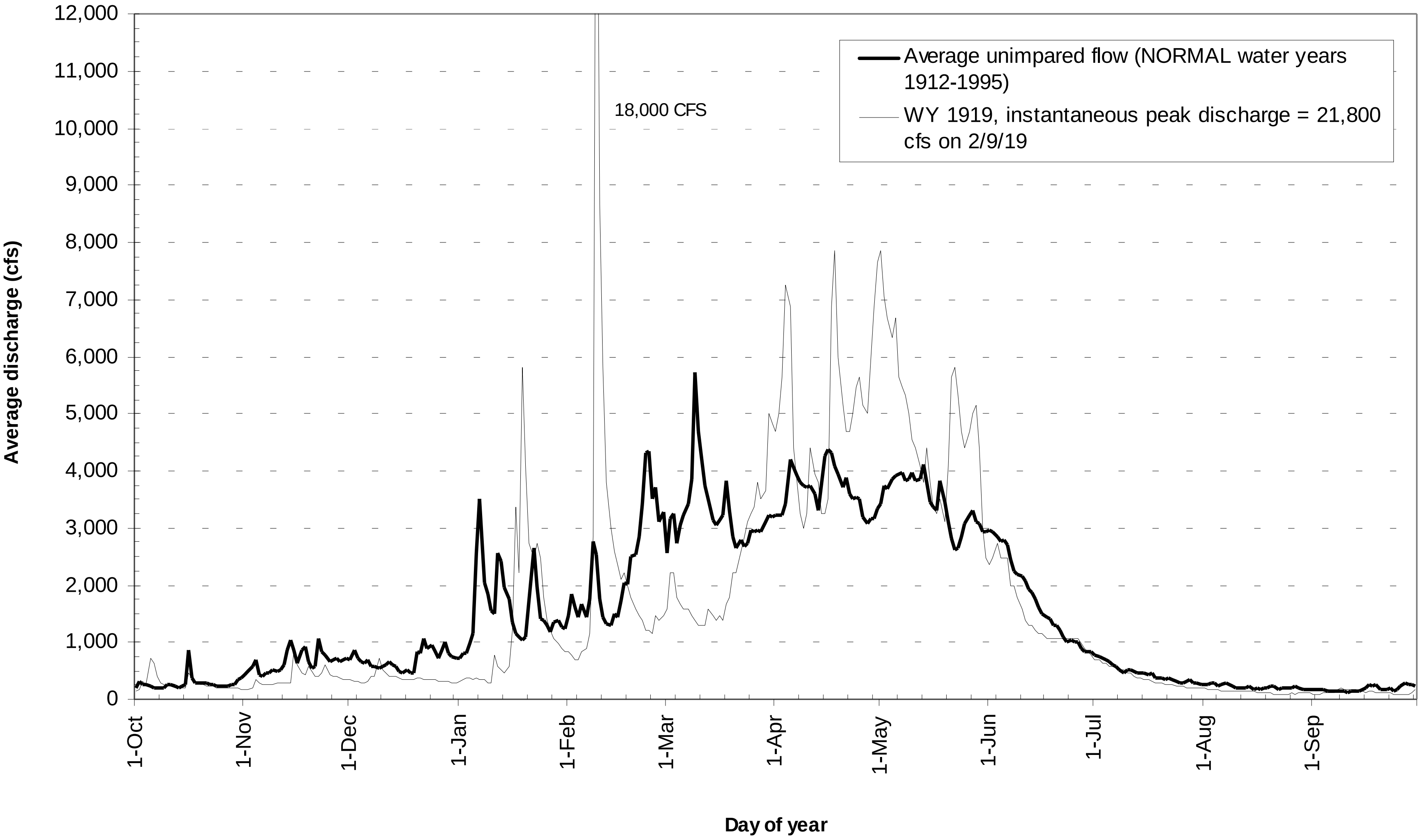


Figure 5.6 Average and representative (1919) NORMAL water year annual hydrographs at the USGS gaging station at Lewiston.

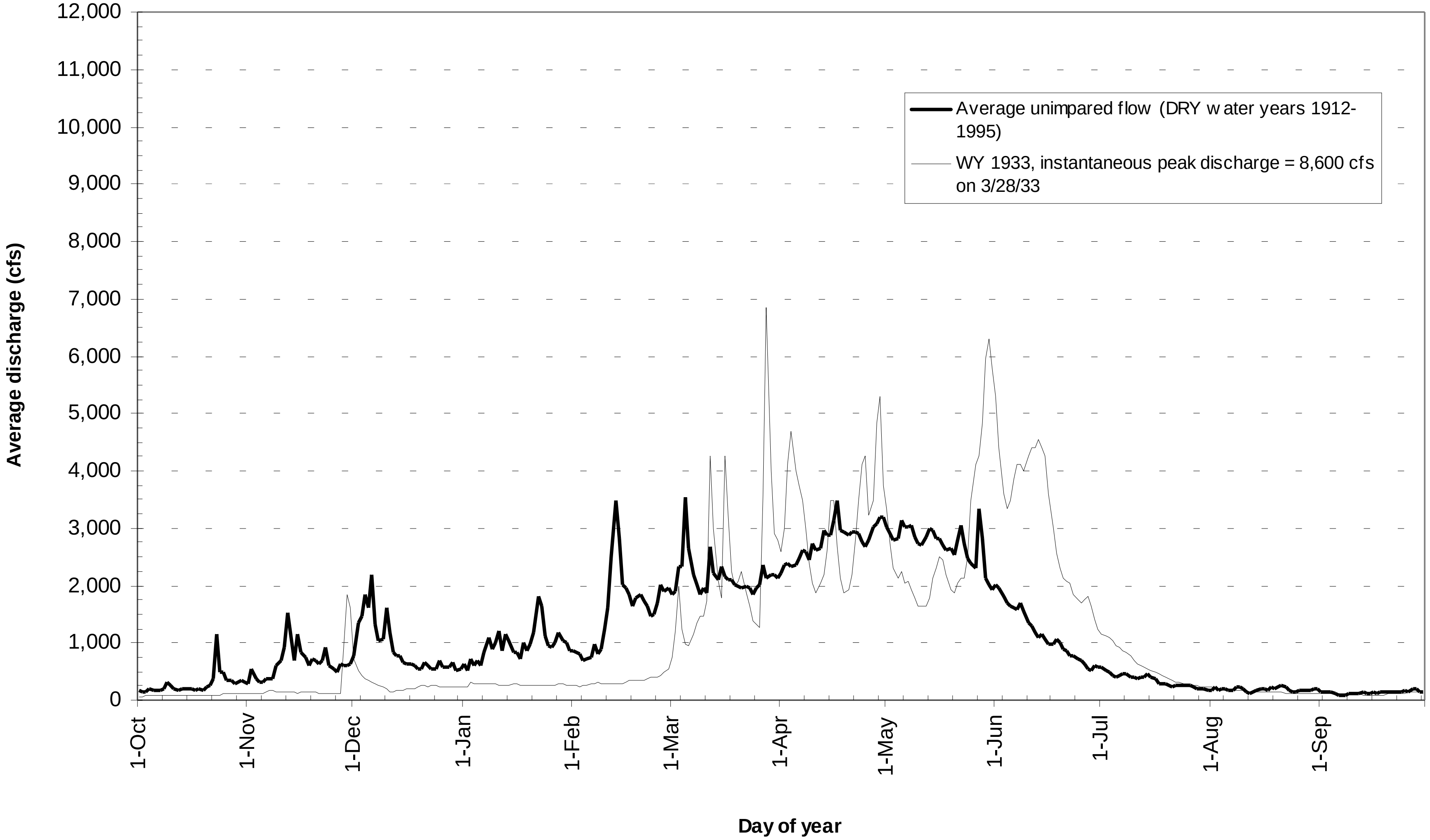


Figure 5.7 Average and representative (1933) DRY water year annual hydrographs at the USGS gaging station at Lewiston.

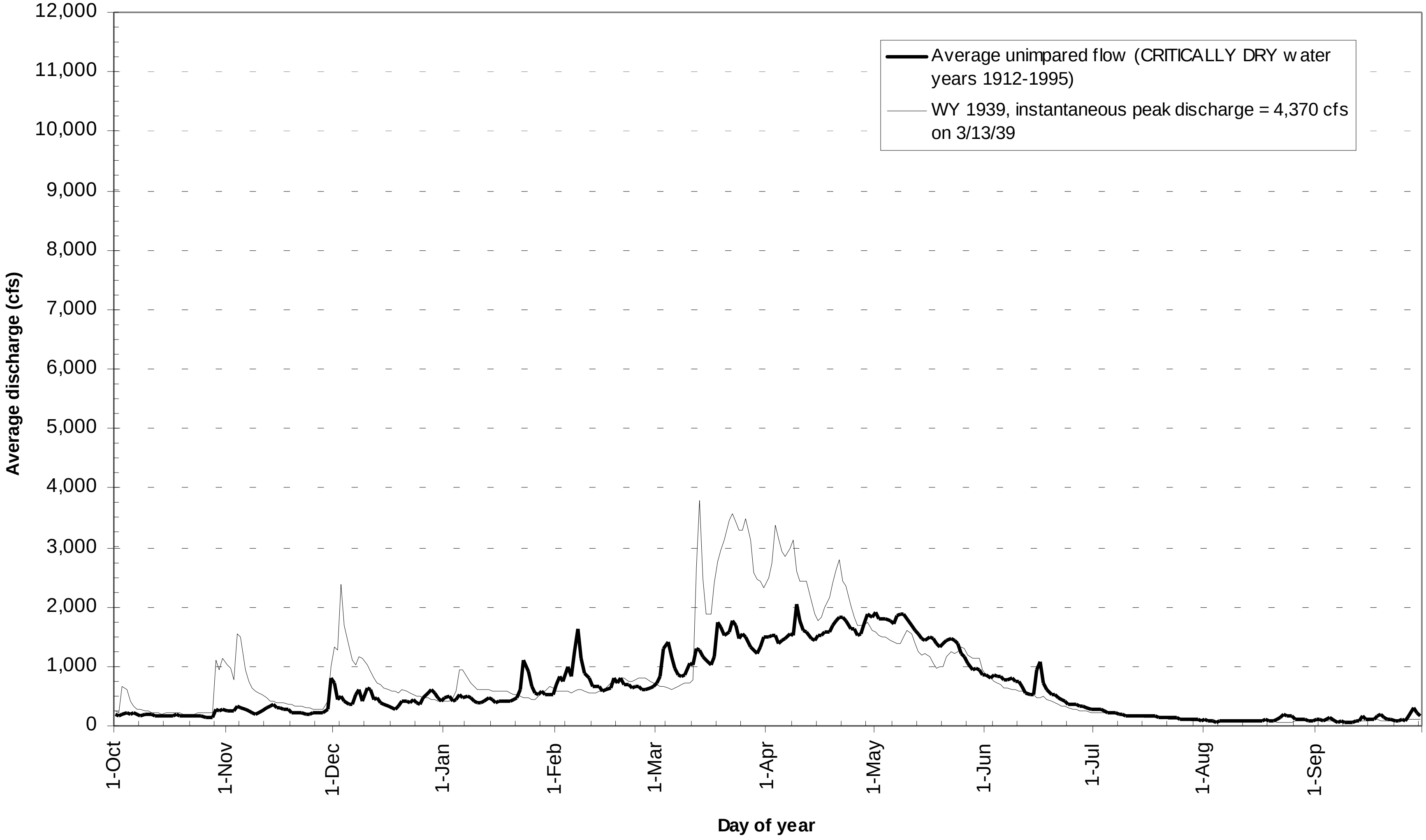


Figure 5.8 Average and representative (1939) CRITICALLY DRY water year annual hydrographs at the USGS gaging station at Lewiston.

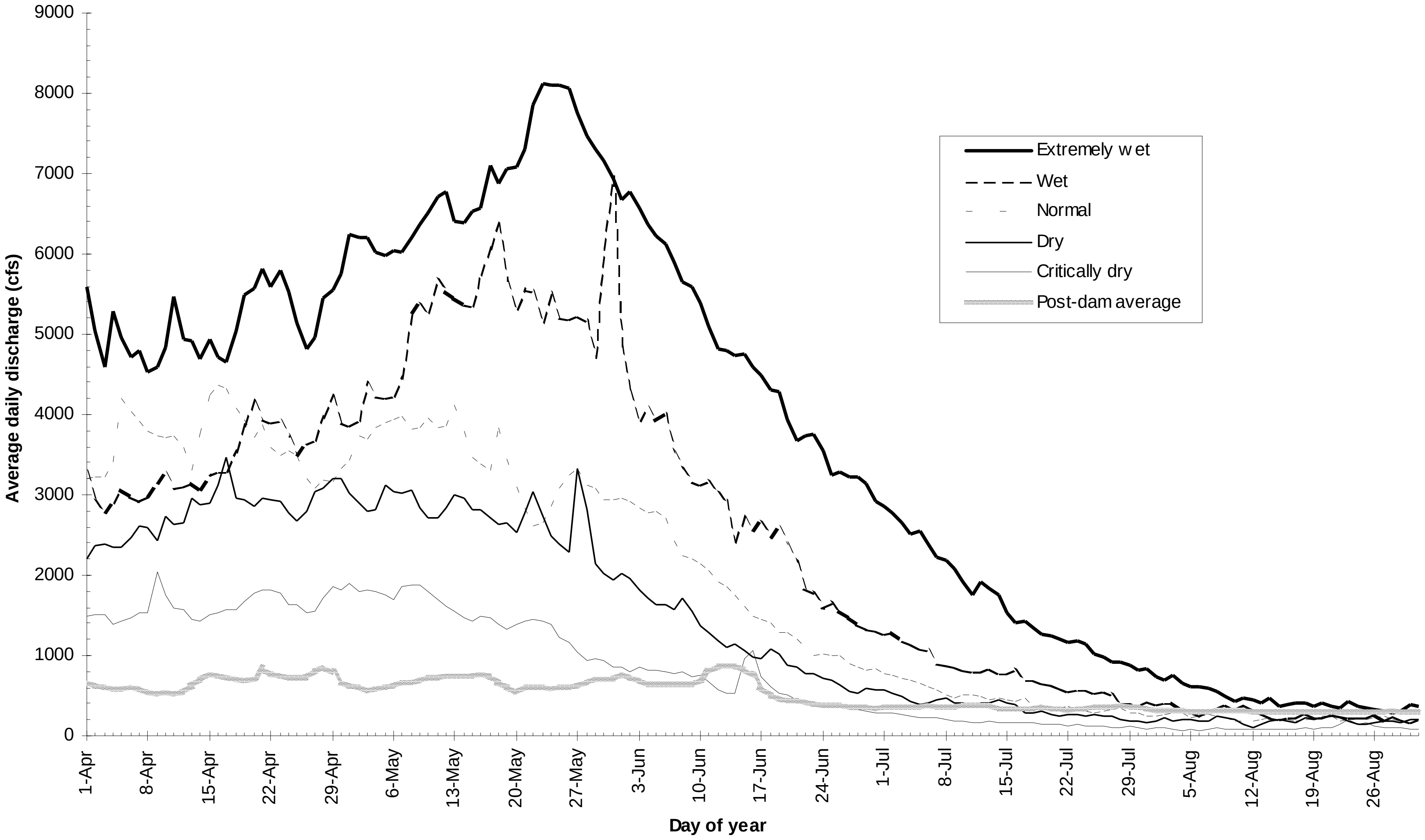


Figure 5.9 Average annual hydrographs of five water year classes during snowmelt runoff period for all water years at the USGS gaging station at Lewiston.

late-May, with peaks during wetter years tending to be slightly later than drier years. Operation of the TRD eliminated distinct peaks in snowmelt runoff downstream (with the exception of occasional tributary snowmelt from Rush and/or Canyon creeks).

5.2.1.3 Snowmelt recession

The snowmelt runoff during Extremely Wet water years usually began in late-March and could recede into late-July (Figure 5.9). In contrast, snowmelt runoff during Critically Dry water years typically ended by mid-May. Operation of the TRD has eliminated a defined snowmelt peak and recession period downstream of the dam (with the exception of minor tributaries downstream of TRD).

5.2.1.4 Summer baseflows

Summer baseflows typically ranged from 300 cfs during wetter years to nearly 100 cfs during Critically Dry water years (Figure 5.10), though summer baseflows went as low as 25 cfs to 50 cfs. Post-TRD summer flows ranged from 150 to 200 cfs prior to WY1979, were held to 300 cfs from WY1979 to WY1990, and have been steady at 450 cfs from WY1991 to the present. Post-WY1979 summer flow releases are significantly higher than pre-dam summer baseflows.

5.2.1.5 Winter baseflows

Winter baseflows are relatively stable flows between individual winter storm events. The receding limbs of storm hydrographs, and high groundwater discharge support these stable flow conditions. Pre-TRD baseflows ranged from 3,000 cfs during wetter years to less than 500 cfs during Critically Dry years (Figures 5.4 to 5.8). Winter baseflows were typically re-established annually by the first major storm event and did not return to summer baseflows. The TRD reduced winter baseflows to 150 cfs prior to WY1979, and 300 cfs following WY1979. Additionally, extended (weeks) spill events during wetter years sometimes functioned as winter baseflows.

5.2.2 Geomorphic and riparian functions by water year class.

Each water year class has the following potential geomorphic and riparian functions in the Trinity River mainstem:

Extremely Wet and Wet Water Year Classes

Dominant geomorphic processes: Substantial bedload transport, alternate bar mobilization, transport of large bedload particles through alternate bar sequences, delta scour, floodplain/terrace deposition, potential planform changes including avulsions, side channel creation, and significant channel migration.

Dominant riparian processes: Woody riparian seeds could only deposit and germinate on upper bar surfaces because extended high snowmelt runoff inundated surfaces of the lower active channel.

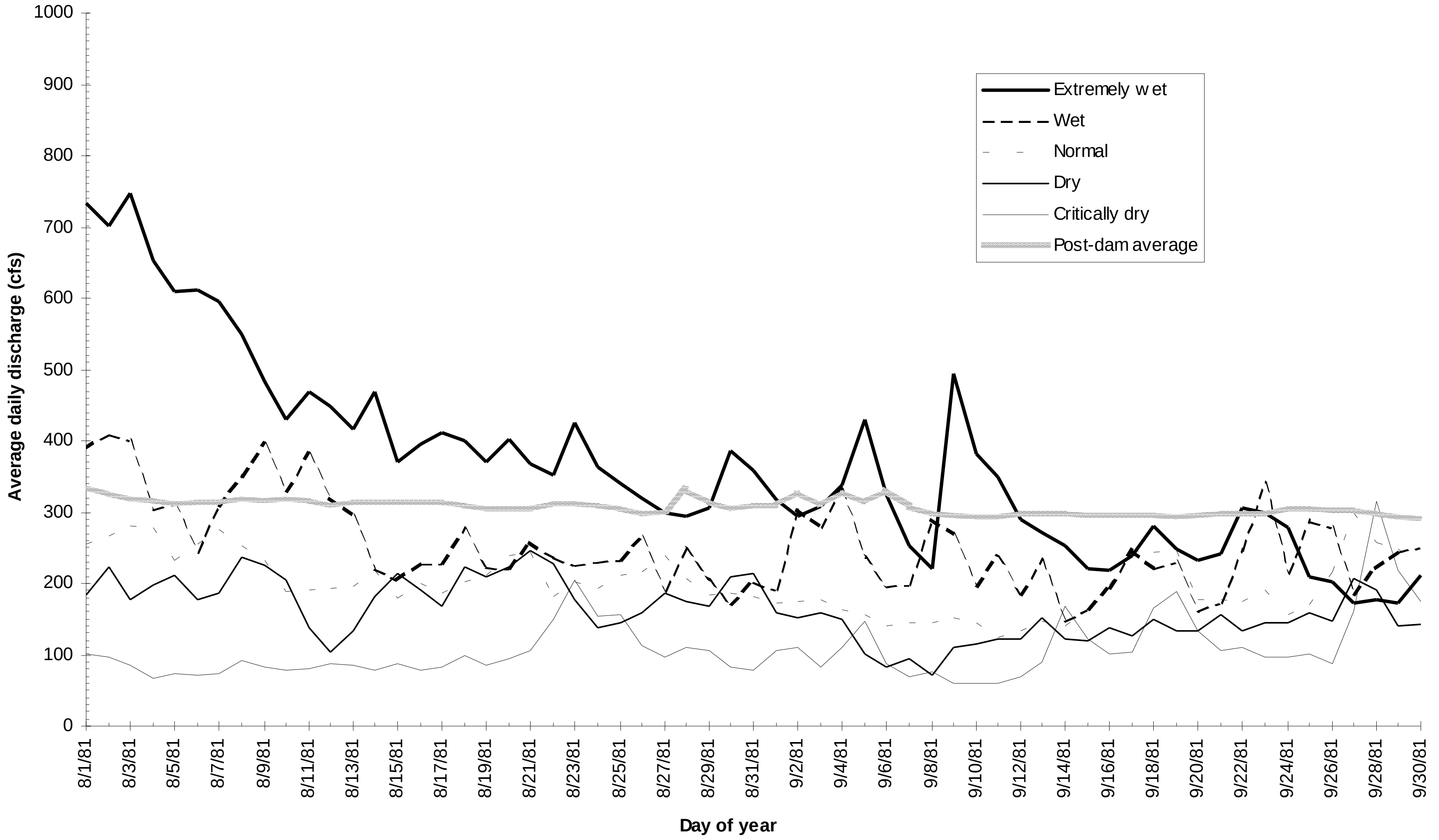


Figure 5.10 Average annual hydrographs of five water year classes during summer baseflow period for all water years at the USGS gaging station at Lewiston.

Consequently, germinating seedlings were especially vulnerable to desiccation by rapidly retreating low summer flow stage. Toppling and scour of mature trees. Scouring of established seedlings and saplings.

Another critical function of winter floods usually associated with Wet and Extremely Wet water years, was to offset riparian encroachment from previous, successive Dry and Critically Dry water years. These drier water years allowed germinating woody species to survive. With each successive Dry year, the seedlings grew larger and therefore more resistant to scour. Eventually, a 10-yr flood or larger would either scour these plants; or cause the channel to migrate, toppling them. These extreme winter flood events were functional “reset buttons” for individual riparian stands, and have maintained conditions favorable to early successional species of the floodplain and riparian community (e.g., herbs, forbs, and pioneer willow species) (Figure 5.11).

Normal Water Year Class

Dominant geomorphic processes: Flows associated with moderate winter floods and snowmelt runoff transport sands and moderate volumes of coarse bedload. Occasional mobilization of alternate bar surfaces, limited turnover of spawning gravel deposits, and modest channel migration.

Dominant riparian processes: Seedlings were scoured from bar surfaces. The particular combination of magnitude, duration, and timing of flows would determine seedling survival at each site, thereby dictating future Wet water year flow requirements for preventing and/or re-setting riparian encroachment for a given year class of seedlings.

Dry and Critically Dry Water Year Classes

Dominant geomorphic processes: Small winter floods and modest snowmelt runoff transport sand in secondary alluvial features and minor coarse bedload. No channel migration.

Dominant riparian processes: Dry water years promoted riparian germination and growth. Unless killed by desiccation from impending low summer flow or by scour the succeeding winter’s high flows (which were common in the pre-TRD flow regime), these newly established seedlings had the potential to encroach into the active channel and along the leading edge of point bars. If seedlings survived desiccation and scour their second and possibly third water years, then only higher magnitude winter storms (scour) or, less probably, extended spring runoffs would kill the saplings (by inundation). If these floods never materialized during the germination-to-sapling life stages, these older trees were much more difficult to remove. Future mortality depended on mobilizing the entire bar/floodplain or re-aligning the channel during extreme rain-on-snow floods. Extremely high flow events, therefore, ultimately removed vegetation when more subtle mechanisms, such as seedling desiccation, failed.

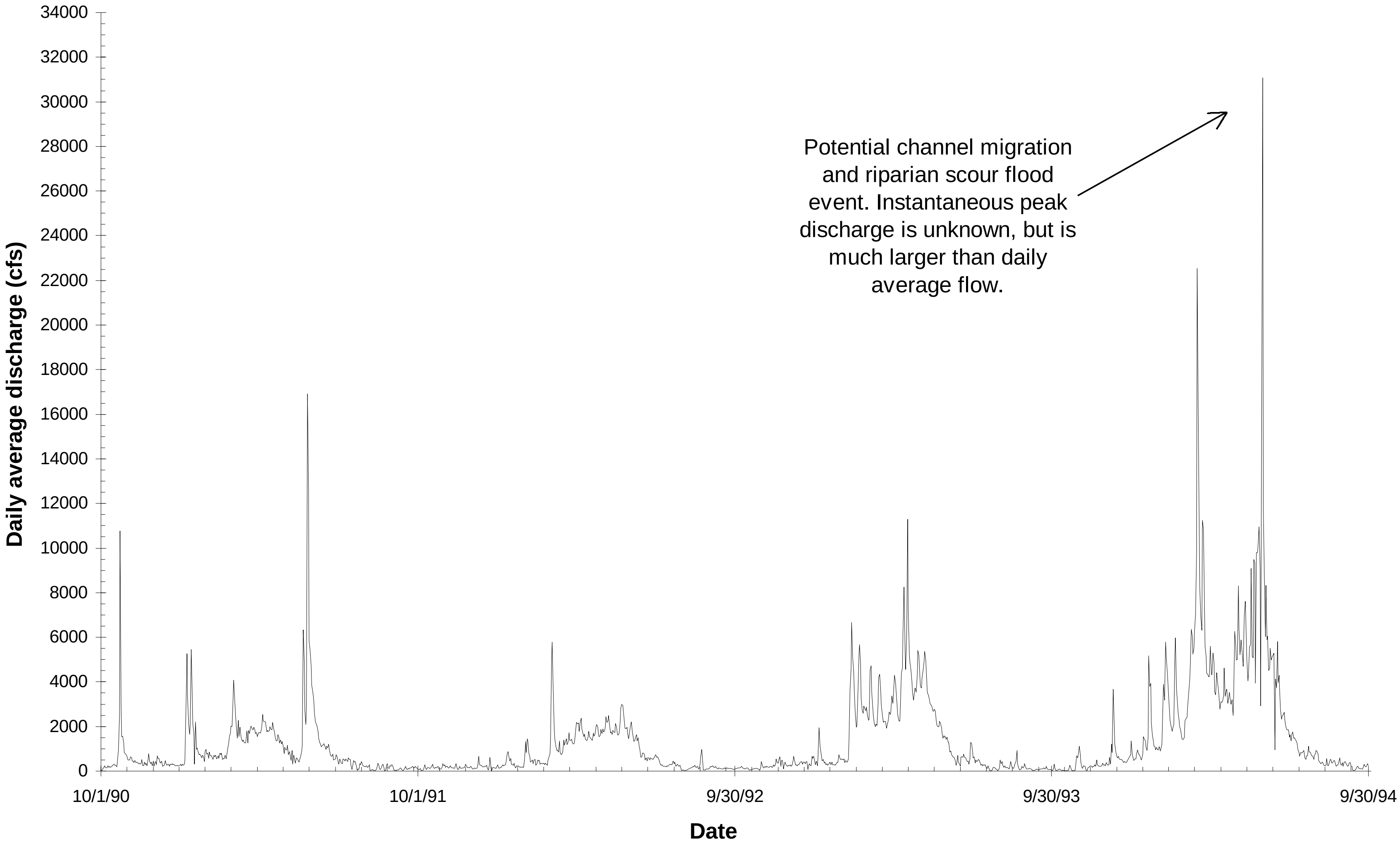


Figure 5.11 Water year 1990 to 1994 sequence of annual hydrographs (Trinity Reservoir inflows) showing the channel "reset button" mechanism following successive drought years.

5.3 Downstream trends in mainstem flood frequency

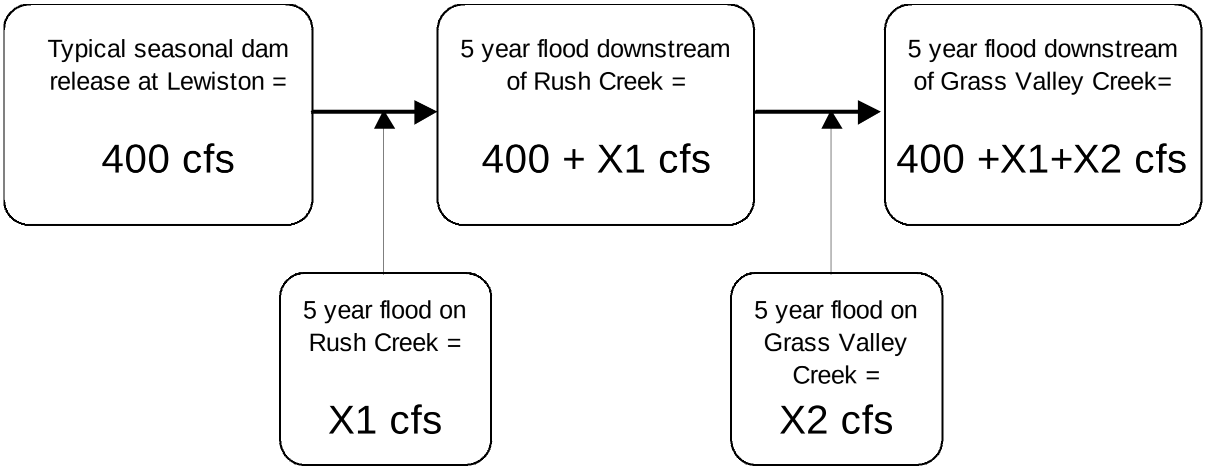
Mainstem floods increase in magnitude downstream as tributaries contribute flood and base flows. Therefore, the mainstem has two flood populations: (1) frequent tributary floods generated by winter storm events, and (2) infrequent mainstem reservoir releases caused by an unusually large snowpack, upstream flood, or full reservoir, which trigger dam safety releases. These releases occur days to weeks after the storm(s), and are not synchronized with tributary flood peaks. As tributary contribution increases downstream, there is a transition down the mainstem where tributary-induced floods are of equal magnitude, then greater magnitude, than dam releases. We attempted to define and locate this transition.

Our objective was to predict mainstem streamflow as a function of distance downstream from Lewiston Dam, using a simple additive model for flood magnitude at common recurrence intervals (Figure 5.12). We developed flood frequency curves at gaged tributaries between Lewiston Dam to the North Fork Trinity River (Grass Valley Creek, Weaver Creek, Browns Creek, and North Fork Trinity River), estimated streamflows of ungaged streams using regional regression equations and unit area adjustments (i.e., flow was assumed proportional to drainage area), and then summed the flow contribution of each tributary to the mainstem Trinity River flow (Figure 5.12).

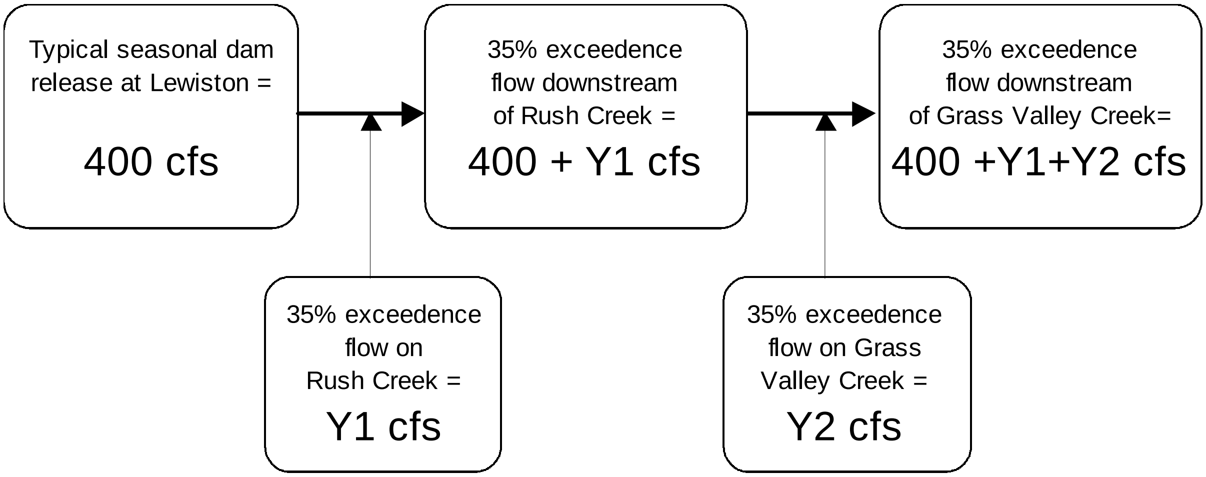
We chose only the major tributaries with watershed areas greater than 20 mi^2 and assumed: (1) flood routing would not be considered (no lag or attenuation between gaging nodes), (2) a flood of a given recurrence occurs on all watersheds during the same storm event (no regional‘differences), (3) small tributaries do not contribute to flood peaks, (4) the gaging stations accurately measure discharge, (5) the period of record used typifies the long-term average, and (6) Lewiston Dam releases control all upper watershed flood events; these releases are assumed to be 400 cfs. Error inherent to assumptions (1) and (3) appeared to be offsetting; we checked this simple model by comparing predicted flood frequency estimates at the Burnt Ranch gaging station with the USGS derived curves. Our simple model predicted discharges for each recurrence interval downstream of the North Fork Trinity River slightly larger than those at the Burnt Ranch gaging station, showing that attenuation of flood peaks did not sufficiently offset the omission of smaller tributaries. A correction factor was applied to the flood magnitudes of each tributary at each recurrence interval to satisfy the constraint that predicted flood magnitude at the Burnt Ranch gage must equal the modeled flood frequency curve. Corrected post-TRD predictions are in Table 5.3, as well as the flood frequency data from the Lewiston gaging station.

Hydrograph component analysis revealed several important downstream hydrologic trends:

- comparing the flood frequency data with the tributary-derived flood frequency data moving downstream shows that the mainstem flood magnitude is surpassed by tributary derived floods near the Indian Creek confluence (RM 95.2). This transition in flood regime influence also correlates with the “alluvial transition zone,” where flow and sediment contributions restore frequent bed mobilization and transport (Ligon et al., 1995).



Downstream flood frequency



Downstream flood frequency

Figure 5.12 Simple additive model for estimating flood frequency and flow duration on the mainstem Trinity River downstream of Lewiston Dam

	1.2 Year Flood			1.5 Year Flood			2.33 Year Flood			5 Year Flood		
River Mile	Pre-dam	Post-dam	Percent of Pre-dam	Pre-dam	Post-dam	Percent of Pre-dam	Pre-dam	Post-dam	Percent of Pre-dam	Pre-dam	Post-dam	Percent of Pre-dam
112	7,171	630 *	9% *	11,813	1,110 *	9% *	14,599	2,160 *	15% *	26,745	4,500 *	17% **
112	7,171	400 **	6% **	11,813	400 **	3% **	14,599	400 **	3% **	26,745	400 **	1% **
107.5	7,478	681 **	9% **	12,376	816 **	7% **	15,315	1,189 **	8% **	28,393	1,826 **	6% **
104	7,616	807 **	11% **	12,752	1,060 **	8% **	15,834	1,760 **	11% **	29,987	3,204 **	11% **
95.4	8,338	1,469 **	18% **	13,951	1,981 **	14% **	17,319	3,398 **	20% **	33,209	5,991 **	18% **
93.8	9,260	2,314 **	25% **	15,309	3,076 **	20% **	18,939	5,182 **	27% **	36,397	8,749 **	24% **
92.8	9,918	2,917 **	29% **	16,402	3,914 **	24% **	20,292	6,673 **	33% **	39,336	11,291 **	29% **
87.8	10,652	3,590 **	34% **	17,520	4,803 **	27% **	21,641	8,159 **	38% **	42,121	13,700 **	33% **
79.2	11,569	4,430 **	38% **	19,073	5,986 **	31% **	23,575	10,290 **	44% **	46,348	17,356 **	37% **
72.5	14,120	6,769 **	48% **	23,648	9,397 **	40% **	29,365	16,670 **	57% **	59,573	28,795 **	48% **

	10 Year Flood			25 Year Flood			50 Year Flood		
River Mile	Pre-dam	Post-dam	Percent of Pre-dam	Pre-dam	Post-dam	Percent of Pre-dam	Pre-dam	Post-dam	Percent of Pre-dam
112	36,700	7,600 *	21% *	51,431	13,400 *	26% *	63,958	17,300 *	27% *
112	36,700	400 **	1% **	51,431	400 **	1% **	63,958	400 **	1% **
107.5	39,392	2,538 **	6% **	55,624	3,385 **	6% **	69,985	4,365 **	6% **
104	42,501	5,008 **	12% **	62,328	8,156 **	13% **	80,882	11,533 **	14% **
95.4	47,602	9,059 **	19% **	70,352	13,867 **	20% **	92,227	18,997 **	21% **
93.8	52,220	12,727 **	24% **	77,580	19,012 **	25% **	101,768	25,273 **	25% **
92.8	56,870	16,421 **	29% **	84,941	24,251 **	29% **	112,160	32,110 **	29% **
87.8	61,067	19,755 **	32% **	91,842	29,163 **	32% **	121,599	38,319 **	32% **
79.2	67,798	25,101 **	37% **	102,908	37,039 **	36% **	137,538	48,805 **	35% **
72.5	88,949	41,901 **	47% **	139,728	63,246 **	45% **	189,598	83,053 **	44% **

NOTE: Tributary floods and high flow releases from the dam do not usually have similar timing, thus the distribution of dam releases are considered different and non-additive to tributary floods (hence, the assumed 400 cfs dam release during tributary floods).

Boxed values illustrate where tributary derived flood frequency regime exceeds dam release flood frequency regime.
* flood frequency estimates are from actual post-dam releases.
** flood frequency estimates assume a 400 cfs release from dam (tributary floods not timed with dam releases, thus not additive).

Table 5.3 Pre- and post-TRD flood magnitudes as a function of recurrence interval and distance downstream from Lewiston Dam.

- floods that occurred every 1 to 2 years at the Lewiston gage prior to the dam now occur every 10 to 15 years.
- the 1.5 year flood, which assumes a significant role in channel size and morphology has been reduced by an order of magnitude from 11,800 cfs to 1,110 cfs
- floods larger than 11,800 cfs, rarely occur upstream of Indian Creek (RM 95.2).
- upstream tributary flood contribution, while significantly increasing post-dam mainstem Trinity River floods, do not adequately compensate the loss of pre-TRD winter floods or pre-TRD snowmelt peak/recession.

5.3.1 Downstream trends in flow duration

To quantify the influence of tributary flows on mainstem daily average flows between Lewiston Dam and the North Fork Trinity River, Frederiksen, Kamine, and Associates (1980) modeled tributary flow duration curves so that mainstem daily average flows could be assigned exceedence probabilities downstream of Lewiston. They used the same type of additive model as shown above, except they added tributary flows for common exceedence probabilities. For example, the flow magnitude for a 50% flow exceedence probability below Rush Creek was simply the 50% mainstem value above Rush Creek added to the 50% value of Rush Creek. We applied this simple model, assuming a constant release of 250 cfs from Lewiston Dam (e.g., assumed no spill events) such that downstream streamflow increases were attributed only to tributary runoff (Figure 5.13). The small difference between the three curves for low flows (>65% exceedence) was primarily due to the minor summer baseflow contribution of these small tributaries to mainstem Trinity River flows. However, the divergence of the three curves for larger flows was due to the more significant tributary contribution during winter storms, winter baseflows, and snowmelt period. This analysis illustrated that tributaries contribute a significant volume of flow during certain portions of the year, such that dam releases during certain winter and spring baseflow periods can be at least tripled within 30 miles downstream of Lewiston Dam.

5.4 Water Year 1991 to 1997 gaging station data below Lewiston Dam

Funding cuts to the USGS gaging program have reduced gaging stations on the Trinity River to the Trinity River at Lewiston (RM 110.9), Grass Valley Creek near Fawn Lodge, and Trinity River near Burnt Ranch (RM 48.6). Constructing a sediment budget, correlating channel response to flood events, and relating flow magnitude and timing to riparian seeding and initiation required installation of four more continuous recording gaging stations. Two mainstem Trinity River gages were installed, one at the Dutch Creek Bridge crossing in Junction City (RM 79.6) and the other at the downstream end of the B.L.M. Douglas City Campground (RM 92.2). Used in conjunction with the USGS gages at Lewiston and Burnt Ranch, these mainstem gages enabled flow duration curves, flood frequency distributions, and flood propagation models to be developed as a function of distance downstream of Lewiston Dam using measured data rather than the simple additive models described above.

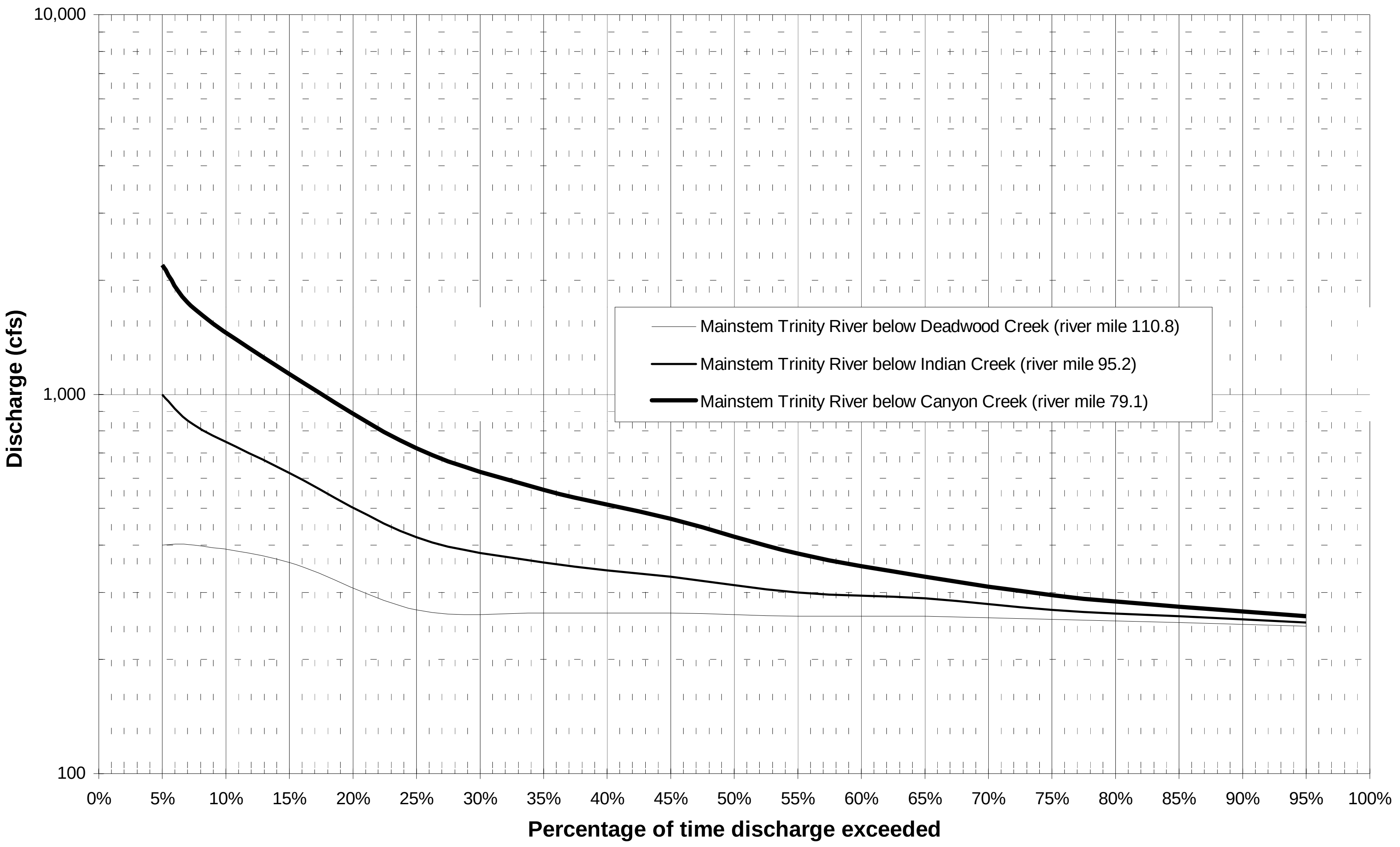


Figure 5.13 Post-TRD mainstem Trinity River flow duration curves showing predicted tributary accretion downstream to Canyon Creek based on Frederiksen, Kamine & Associates (1980).

Three gaging stations were installed on tributaries in WY1997. The Rush Creek and Indian Creek gages are continuous recording stations. The Deadwood Creek gage is currently a staff gage, with a continuous recording gage to be installed in WY1998. In WY1995 to WY1997, staff gages were installed and discharge measured to construct stage-to-discharge rating curves for all stations. These rating curves shifted after the WY1995 and WY1997 floods due to changes in hydraulic control. A continuous record of discharge was computed from these stage-to-discharge relationships and the stage height measurements at the gaging stations.

The following station descriptions summarize gage location, gage operators, period of record, total drainage area, regulated and unregulated drainage area, and peak flows for WY1991 to WY1997. Appendix A summarizes daily average annual hydrographs from WY1991 to WY1997.

5.4.1 Trinity River at Lewiston – RM 110.9

The Lewiston gage is operated by the USGS (USGS 11-525500). The period of record for this gage is August 1911 to present. The total drainage area is 719.3 mi^2, the regulated drainage area is 719 mi^2, and the unregulated drainage area is 0.3 mi^2.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1991	31-May	2,860
1992	13-Jun	6,580
1993	13-Apr	3,270
1994	10-Apr	1,630
1995	25-Mar	7,060
1996	22-Feb	6,370
1997	1-Jan	6,700

Table 5.4 Annual instantaneous maximum floods, Trinity River at Lewiston.

5.4.2 Trinity River at Douglas City – RM 92.2

The Douglas City gage is operated by McBain and Trush. The period of record for this gage is November 1995 to present. The total drainage area is 931 mi^2, the regulated drainage area is 719 mi^2, and the unregulated drainage area is 212 mi^2.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1995	9-Jan	10,800
1996	22-Feb	7,300
1997	1-Jan	24,000

Table 5.5 Annual instantaneous maximum floods, Trinity River near Douglas City.

5.4.3 Trinity River near Junction City – RM 79.6

The Junction City gage was operated by McBain and Trush. The period of record for this gage is June 1995 to December 1996. The gage was destroyed in the January 1997 flood and has not been replaced due to lack of funding. The total drainage area is 1,057 mi^2, the regulated drainage area is 719 mi^2, and the unregulated drainage area is 338 mi^2.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1995	9-Jan	15,800
1996	22-Feb	8,800
1997	1-Jan	30,000

Table 5.6 Annual instantaneous maximum floods, Trinity River at Junction City.

5.4.4 Trinity River near Burnt Ranch – RM 48.6

The Burnt Ranch gage is operated by the USGS (USGS 11-527000). The period of record for this gage is October 1931 to September 1940, and October 1956 to present. The total drainage area is 1439 mi^2, the regulated drainage area is 719 mi^2, and the unregulated drainage area is 720 mi^2.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1991	4-Mar	7,070
1992	17-Apr	8,890
1993	20-Jan	17,400
1994	18-Feb	3,050
1995	9-Jan	35,800
1996	12-Dec	14,700
1997	1-Jan	70,000

Table 5.7 Annual instantaneous maximum floods, Trinity River near Burnt Ranch.

5.4.5 Deadwood Creek near Lewiston

The Deadwood Creek has not been continuously gaged in the past but a stage gage will be installed and operated by McBain and Trush in October 1997. Peak flows were determined by crest stage raft line. The total drainage area is 8.9 mi^2 and is unregulated.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1995	9-Jan	430
1996	--	not gaged
1997	1-Jan	329

Table 5.8 Annual instantaneous maximum floods, Deadwood Creek near Lewiston.

5.4.6 Rush Creek near Lewiston

The Rush Creek gage is operated by McBain and Trush. The period of record for this gage is June 1996 to present. The total drainage area is 22.7 mi^2, and is unregulated.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1995	--	not gaged
1996	--	not gaged
1997	1-Jan	6,000

Table 5.9 Annual instantaneous maximum floods, Rush Creek near Lewiston.

5.4.7 Grass Valley Creek near Fawn Lodge

The Grass Valley Creek gage is operated by the USGS (USGS 11-525600). The period of record for this gage is November 1975 to present. The total drainage area is 38 mi^2, and is unregulated.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1991	4-Mar	76
1992	12-Feb	644
1993	31-May	548
1994	17-Feb	124
1995	9-Jan	2,700
1996	22-Feb	280
1997	1-Jan	2,130

Table 5.10 Annual instantaneous maximum floods, Grass Valley Creek near Fawn Lodge.

5.4.8 Indian Creek near Douglas City

The Indian Creek gage is operated by McBain and Trush. The period of record for this gage is January 1997 to present. The total drainage area is 33.2 mi^2, and is unregulated.

Water Year	Date of Peak Flow	Magnitude of Peak Flow (cfs)
1995	--	not gaged
1996	--	not gaged
1997	1-Jan	2,300

Table 5.11 Annual instantaneous maximum floods, Indian Creek near Douglas City.

CHAPTER 6: CHANNELBED SURFACE MOBILITY AND MOVEMENT

Attribute No. 3. FREQUENTLY MOBILIZED CHANNELBED SURFACE.
Channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which occurs on average every 1 to 2 years

An important geomorphic threshold for restoring and maintaining alluvial river morphology is frequent mobilization of the channelbed surface. Mobilization initiates bedload transport and routing, discourages riparian vegetation from colonizing and fossilizing alluvial features, periodically cleanses spawning gravel deposits, and rejuvenates alluvial features. From WY1991 to WY1993, we documented channelbed surface mobility for a variety of alluvial features from Lewiston to the North Fork Trinity River confluence. Later, we evaluated channelbed surface mobility in the pilot bank rehabilitation sites.

6.1 Initial Hypotheses

6.1.1. Channelbed surface mobility

Particle sizes ranging from boulders to sand are transported by rivers as bedload. Complex flow hydraulics caused by river meandering and geological controls creates alluvial features spanning this particle size range. Some are finer grained (gravels in pool tails), whereas other alluvial features are coarse (cobbles in riffles). This variability in particle size, annual flow magnitude, and associated hydraulic conditions accommodates mobilization of alluvial features over a range of flow magnitudes. While a single bed mobility threshold for the entire channelbed would be convenient, it would be an oversimplification of how gravel bedded rivers function. We evaluated differential surface mobility by documenting tracer rock movement among diverse alluvial features from Lewiston Dam downstream to Junction City, including (Figure 6.1):

- pool tail deposits;
- medial bar surfaces;
- flanks and upstream edges of point bars;
- long straight riffles with uniform cross sections.

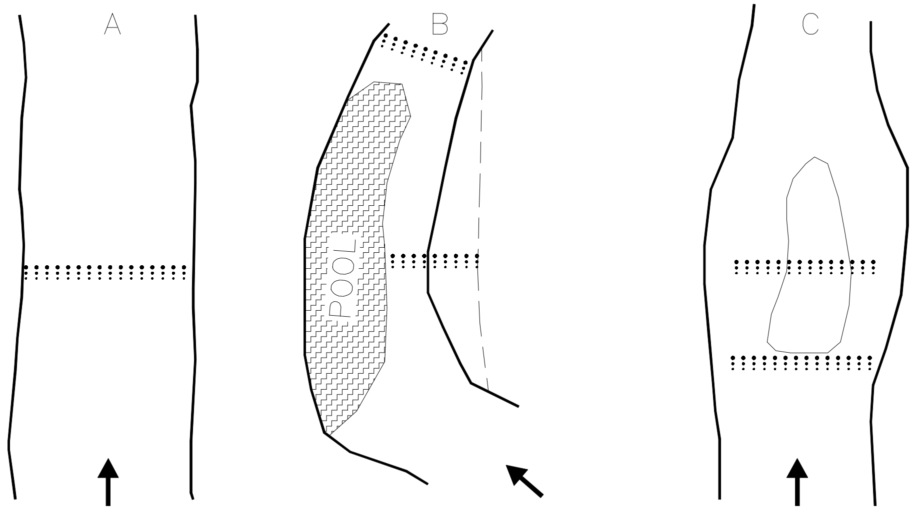


Figure 6.1 Portions of alluvial features targeted for bed mobility experiments between Lewiston Dam and the North Fork Trinity River. Exposed point bars reflect bank rehabilitation sites only since point bars are virtually non-existent in the presently encroached channel.

Channelbed mobility was monitored at all WY1991 and WY1992 monitoring sites (TRA 1993) with established riparian berms, thus representing the post-TRD channel morphology (Plate 1). In WY1996, we monitored channelbed surface mobility on newly formed point bars at the Bucktail and Steiner Flat bank rehabilitation sites.

6.1.2. Coarse bedload movement through major tributary deltas

Attribute No. 5 requires bedload routing of most size classes throughout the mainstem to preserve bedload continuity. We observed aggrading deltas at major tributary confluences (i.e., Rush Creek, Grass Valley Creek, and Indian Creek) were causing a backwater effect in the mainstem that could be preventing mainstem bedload routing. To test this hypothesis, we installed tracer rocks upstream of major tributary deltas to evaluate whether coarse mainstem bedload was being routed.

6.1.3. Coarse bedload movement through selected pools

To satisfy Attribute No. 5 also requires bedload routing of most size classes through alternate bar sequences and deep pools, even though some pools near Lewiston are over 20 ft deep. Based on observed local hydraulics, we hypothesized deeper pools have been gradually filling with coarse bedload since completion of the TRD, and therefore impeding mainstem bedload continuity.

6.1.4. Coarse bedload movement below major tributary deltas

Based on observations of Deadwood Creek and Rush Creek deltas in WY1995, and Indian Creek delta in WY1991 through WY1995, delta removal by mainstem flows began at mainstem flows greater than 3,000 cfs. When the deltas are forming during winter storms, the deltas extend into the mainstem because regulated mainstem flows cannot transport these tributary-derived deposits downstream. This restricts (or “pinches”) the mainstem cross section. When peak mainstem flows greater than 3,000 cfs do occur (almost always out of synchrony with tributary peaks), the deltas are removed and the previous cross section widths reestablished. However, we hypothesized these regulated mainstem floods do not distribute the coarsest tributary bedload beyond the first major depositional area downstream. If so, Attribute No. 5 is not being accomplished in the post-TRD channel.

6.2 Methods

6.2.1. Monitoring and modeling channelbed surface mobility with tracer rocks

Channelbed mobility was monitored in WY1991 to WY1992, comparing differences in mobility between 2,700 cfs and 6,500 cfs for diverse alluvial features longitudinally over the 30-mile study reach. Detailed site descriptions and methods for all channel reaches monitored are provided in Trinity Restoration Associates (1993).

We documented channelbed mobility for a variety of alluvial features, including riffles, exposed point bars, and exposed median bars (Figure 6.1). At each study site, whether in a post-TRD channel morphology site or pilot reconstruction site, surface particle size distributions were sampled using surface pebble counts. If the channelbed surface displayed a mosaic of uniform substrate compositions, a facies map was constructed. Each facies, constituting a uniform patch of channelbed surface, had its own particle size distribution sampled with a pebble count. From these particle size distributions, the D_{84}, D_{50}, and D_{16} particle sizes were selected for tracer rock monitoring. At certain sites, subsurface particle size distributions also were sampled with bulk samples.

Three size classes of tracer rocks were placed along each cross section at two foot intervals, with the D_{84} on the cross section, the D_{50} two feet upstream, and the D_{16} three feet upstream (Figure 6.2). This prevented artificial shielding of smaller tracers by larger tracers. Occasionally, D_{31} and D_{69} tracers were also placed with the D_{84}, D_{50}, and D_{16}.

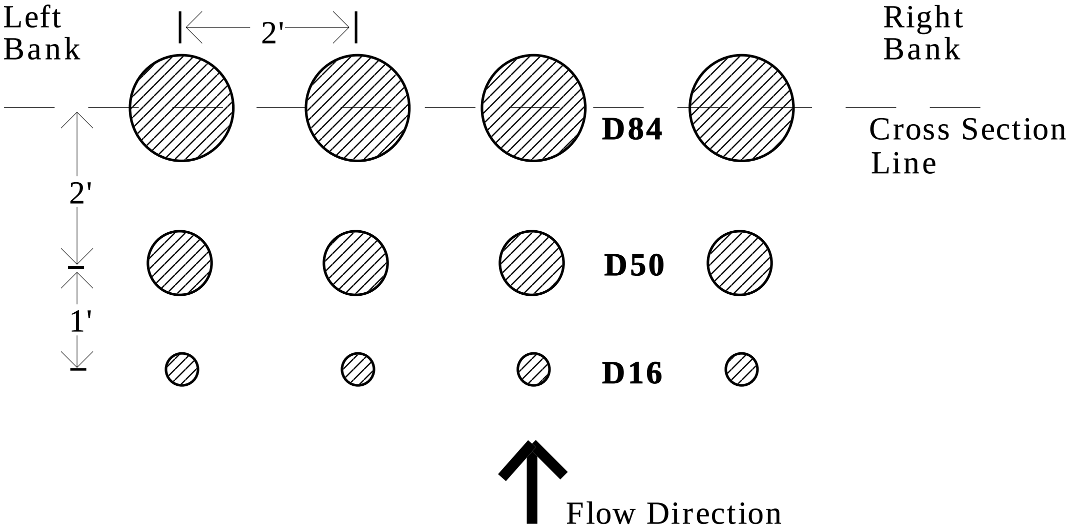


Figure 6.2 Typical tracer gravel placement along cross sections.

Tracer rocks were placed within the active bedload transport width of the cross section, painted florescent orange or another obnoxiously visible color, and numbered so when retrieved, we could determine their origin. Tracer rocks were placed into the channelbed surface by removing a natural rock of similar size and placing the tracer in the rock’s place. This allowed tracer rock placements to reasonably maintain natural bed surface conditions and avoid unnaturally over-exposing or under-exposing the tracers. At some sites, wire basket bed traps were installed to trap larger particles transported by a particular flow (TRA, 1993).

After a high flow release dropped below 500 cfs, tracer rocks were resurveyed. Determining whether each tracer rock had moved was the primary objective. For those rocks that did move, downstream and cross-stream distances each rock traveled were measured from its point of origin. Because we were determining whether incipient conditions had been exceeded for different particle sizes, a definition of “mobilization” was needed to evaluate whether the particle really moved or simply re-adjusted its position slightly downstream due to poor initial placement. Many tracers only moved up to two feet, suggesting that the rock reoriented itself to a more hydraulically stable location rather than being truly mobilized. Therefore, we recorded a tracer as “mobilized” if its travel distance exceeded two feet.

6.2.1.1 Modeling channelbed surface mobility

Bed mobility modeling had two objectives: (1) calibrating an incipient bed mobility model for the Trinity River mainstem by using empirical channelbed mobility results, and (2) forecasting the flow magnitude at incipient mobility in other locations and hydraulic settings. Ideally, for a uniform cross section, tracer rock sets would remain immobile until a stage at which a narrow range of fluctuating boundary shear stresses was sufficient to mobilize particles. This threshold was labeled the “point of incipient motion.”

At a site with approximately steady uniform flow, we measured bed surface particle size distribution, cross section geometry, and water surface elevations during a range of high flow events from WY1991 through WY1996. At each flow, we calculated water surface slope and cross sectional area for each flow. We estimated cross sectionally averaged boundary shear stress from:

$$\tau_b = \rho \, g \, YS \tag{6.1}$$

where: ρ = water density (1,000 kg/m^3), g = gravitational acceleration (9.81 m/s^2), Y = hydraulic radius of entire cross section (area/wetted perimeter), and S = energy slope (approximated by water surface slope assuming uniform flow conditions).

Equation 6.1 is the most common way to estimate boundary shear stress. However, in meandering, gravel bottomed streams, this estimate of boundary shear stress is often inappropriate because steady, uniform flow assumptions cannot be made. Cross-stream and downstream convective acceleration terms have been found to be “zero-order” terms in the force balance equation, such that they cannot be ignored when solving for boundary shear stress (Smith and McLean, 1984; Dietrich and Whiting, 1989). A visual model can be used to appreciate the effect of these forces. Consider water moving down a riffle (large kinetic energy) toward a point bar. The bar surface face increases in elevation in the downstream direction; therefore, some kinetic energy of the fluid is transformed back into potential energy. However, the change in downstream momentum expends energy on the bed surface as well, which adds an additional shear stress term to Equation 6.1. These convective accelerations are topographically induced; therefore, in order to ignore these terms (which we did), one must choose a site that has minimal topographic relief (such as uniform channel geometry and no longitudinal slope changes), making Equation 6.1 a more valid approximation for boundary shear stress. In Chapter 7, vertical velocity profiles, measured during high flows at selected cross sections, were used to calculate local shear stress on developing point bars, rather than a cross sectionally averaged shear stress presented above.

Incipient motion of the bed surface layer is the hydraulic threshold at which channelbed surface particles begin to mobilize, occurring when the drag (F_D) force exceeds the gravitational (F_G) force resisting downstream motion of the particle. Therefore, when the F_D/F_G ratio is larger than unity, movement occurs.

Establishing this F_D/F_G ratio gives:

$$\frac{F_D}{F_G} = \frac{Const * \tau_b * D_i^2}{Const * (\rho_s - \rho_w) * g * D_i^3}$$
$$\frac{\tau_b}{(\rho_s - \rho_w) g D_i} = \frac{\rho_w Y_b S}{(\rho_s - \rho_w) D_i} = Const = \tau *_i \tag{6.2}$$

When used in a straight, uniform reach, the boundary shear stress can be approximated by $\tau_b = \rho g Y S$, where Y is the hydraulic radius (area/wetted perimeter) and S is the local energy slope (usually approximated by the water surface slope for uniform flow conditions). This dimensionless ratio is Shields parameter, which is convenient for quantifying stresses exhibited on the bed surface by the flow field. At incipient (critical) conditions, when $F_D/F_G=1$, Shields parameter is:

$$\tau *_{ci} = \frac{\rho_w Y_c S}{(\rho_s - \rho_w) D_i} = \text{Constant} \tag{6.3}$$

where,

$\tau_c = \tau_b$ at incipient conditions,
Y_c = Hydraulic radius (approximated by average depth at incipient conditions),
S = Slope of energy grade line, estimated by the water surface slope,
D_i = Diameter of particle of interest,
g = Acceleration of gravity - 32.2 ft/s^2 or 9.81 m/s^2
ρ_w, ρ_s = density of water and sediment, respectively.

Shields performed flume experiments to quantify the relationship between τ^*c and the Roughness Reynolds Number (R*) for uniform sediments. Shields determined that τ^*ci was a constant value of 0.06 for Reynolds Numbers greater than 100 (rough flow conditions). However, because uniform sediments were used, the 0.06 value does not consider the effect of grain-to-grain interaction on particle mobility. Empirical values derived from mixed grain sediments are preferable.

The Shields parameter (τ) is specific to particle size (e.g., D_{50}, D_{84}, D_{90}):

$$\tau *_{50} = \frac{\tau_b}{(\rho_s - \rho) g D_{50}} \tag{6.4}$$

where: ρ_s = density of D_{50} particle size (assumed=2,600 kg/m^3). At the Steiner Flat site incipient conditions were observed. Based on hydraulic data collected during the flow, equations 6.1 and 6.4 were solved to estimate the Shields parameter for incipient conditions.

Many sites were monitored in WY1993 to WY1996 over a range of discharges, but had no tracer rock monitoring to identify a flow threshold. With a prediction of the critical Shields parameter, we measured hydraulic conditions at other sites to again solve Equations 6.1 and 6.4. Comparing Shields parameter with the predicted critical Shields parameter provided us a method to estimate whether incipient conditions could be achieved at a given discharge and hydraulic setting (McBain and Trush, 1995).

6.2.2. Tracer rock movement through major tributary deltas

In WY1996, tracer rocks were placed upstream of tributary deltas following the same methodology described above to document bed mobility. Hydraulic conditions (cross sections, water surface elevation, and water surface slope) also were surveyed during the 5,100 cfs dam release at Rush Creek, Grass Valley Creek, and Indian Creek deltas. Tracer rocks (D_{84}) were only placed upstream of the Grass Valley Creek and Indian Creek deltas; tracer rocks were not installed immediately upstream of the Rush Creek delta due to excessive depths and exposed bedrock on the channelbed floor.

6.2.3. Tracer Rock movement through selected pools

To determine whether coarse bedload was being routed through deep pools, the 5,100 cfs release in WY1995 was monitored using tracer rocks (up to 150 mm). As a simple pilot experiment, we threw in 200 tracer rocks (D_{84}) immediately upstream of Sawmill Pool (RM 108.7) and Bucktail Pool (RM 105.0) during the rising limb of the dam release. A similar experiment also was performed in other pools in WY1992 (TRA 1993). Following the release, we searched as far as 0.5 miles downstream to retrieve tracer rocks.

6.2.4. Tracer rock movement below major tributary deltas

These tributary delta deposits are the more mobile of alluvial features in the upper Trinity River. To test whether high mainstem flows transport coarser tributary bed material from the deltas and deposit it downstream, we placed tracer rocks in the tributary deltas and monitored their travel distance during high mainstem flows. Our originally proposed sampling plan was to place magnetically tagged and painted tracer rocks on the portion of the tributary deltas that extended into the mainstem. Distances these particles traveled during the 5,100 cfs release could be a function of flow magnitude and duration. Several questions arose as to how post-TRD bedload is routed downstream. Since TRD completion, how far has bedload derived from the tributaries routed downstream? For a given release, are there differential transport distances for each tributary? How important is flow duration in determining transported distances? Our proposed experiments would have allowed us to monitor tributary bedload routing by measuring the maximum and median distance particles of different size classes moved during a scheduled high flow release. These experiments could be used to determine the dominant post-TRD particle size (e.g., the D_{84}) transported between post-TRD alternate bar sequences.

The budget could not afford magnetic tracking experiments. Using the more traditional tracer rock approach, we were still unable to place tracer rocks in the channelbed prior to the planned release because of an unplanned high flow release preceding the planned release! Instead, we dropped tracer rocks into the mainstem Trinity River at the Deadwood, Rush, Grass Valley, and Indian Creek confluence's during a 6,800 cfs discharge on March 30, 1995 and a 5,100 cfs discharge on May 9, 1995. For the 6,800 cfs release, we dropped-in a set of individually numbered lime green rocks of size classes ranging from 25 mm up to 150 mm in diameter into the confluence's of each of the four tributaries. Of the 250 rocks, 25 rocks were between 100 mm and 150 mm, 50 rocks between 75 mm and 100 mm, 75 rocks between 50 mm and 75 mm, and 100 rocks between 25 mm and 50 mm. Each rock was individually measured and numbered from 1 to 25, 50, 75, or 100, depending on its size class. After each high flows release receded, we located and identified the distance traveled for all recovered rocks. For each monitored date, we plotted distance traveled as a histogram plot. We anticipated a bimodal histogram. The first mode would represent a settling distance (given the tracers were simply dropped into the high flows), while a second mode would reflect downstream transport distance.

6.3 Empirical results

6.3.1. Channelbed surface mobility

Extensive tracer rock observations by Trinity Restoration Associates (1993) documented bed mobility for a 2,700 cfs release in WY1991 and a 6,500 cfs release in WY1992. Although more than two flows are required to identify incipient bed mobility threshold flows empirically, mobility differences between the releases were significant (Trinity Restoration Associates, 1993; Wilcock et al., 1995). A 6,500 cfs release mobilized straight reaches and portions of alternate bar surfaces. The 2,700 cfs flow mobilized finer-grained alluvial deposits and the steeper flanks of alternate bars only. Pathways of recovered tracer rocks placed at the heads of two right bank bars at Steel Bridge illustrate the relative importance of these two flows for channelbed surface mobilization (Figure 6.3). Note on the upstream tracer rock set that many more rocks moved than were identified by path vectors; only those rocks recovered could be assigned vectors.

This pattern of differential mobility was observed at most sites, but the difference in mobility between 2,700 cfs and 6,500 cfs decreased downstream (Table 6.1). Coarse riffles associated with distinct bar features and long straight reaches exhibited marked D_{84} movement exceeding 80 percent at all sites during the 6,500-cfs event, but the percentage of D_{50} moved varied from 30 percent to near 100 percent (Table 6.1). The 2,700-cfs release mobilized secondary alluvial features, particularly sand/gravel deposits overlaying coarser bed surfaces in pool tails. However, bed traps did capture

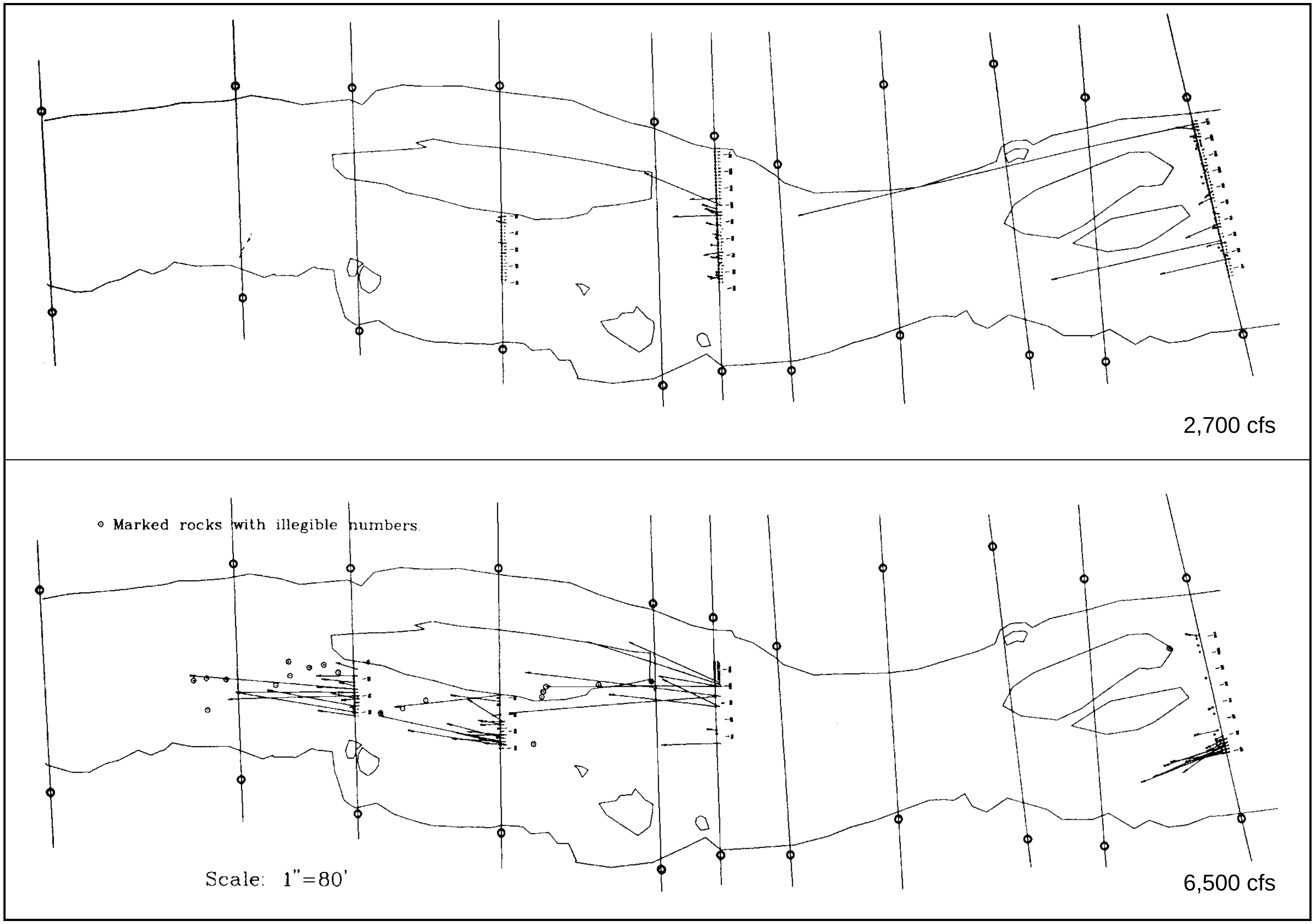


Figure 6.3 Steelbridge study site (RM 99.2) tracer gravel vectors showing increased mobillity from 2,700 cfs to 6,500 cfs (1991 and 1992 releases respectively).

Gravel Plant Study Site RM 105.5

Cross Section/Particle Size	Percentage of Particles Mobilized 2,700cfs (1991)	6,500cfs (1992)
10+00/D50	28	80
10+00/D84	8	96

Steelbridge Study Site RM 99.2

Cross Section/Particle Size	Percentage of Particles Mobilized 2,700cfs (1991)	6,500cfs (1992)
11+75/D50	20	94
11+75/D84	20	100
10+41/D50	43	100
10+41/D84	25	94
07+18/D50	30	100
07+18/D84	34	100

Indian Creek Study Site RM 95.2

Cross Section/Particle Size	Percentage of Particles Mobilized 2,700cfs (1991)	6,500cfs (1992)
11+55/D50	100	100
11+55/D84	97	100
10+00/D50	98	100
10+00/D84	82	100

Steiner Flat Study Site RM 91.7

Cross Section/Particle Size	Percentage of Particles Mobilized 2,700cfs (1991)	6,500cfs (1992)
10+56/D50	100	100
10+56/D84	97	100
00+45/D50	84	100
00+45/D84	76	93

Upper Sky Ranch Study Site RM 81.6

Cross Section/Particle Size	Percentage of Particles Mobilized 2,700cfs (1991)	6,500cfs (1992)
10+00/D50	75	100
10+00/D84	55	80

Table 6.1 D_{50} and D_{84} tracer gravel mobility comparison between 2,700 cfs release (1991) and 6,500 cfs release (1992) at five consistent monitoring sites and cross section stations.

rocks greater than the D_{50} during the 2,700-cfs release along the flanks of median bars and through straight reaches, reflected in the high percentage of D_{50} mobility at Steiner Flat (Table 6.1). Bedload traps caught rocks greater than the surrounding bed's D_{84} at all sites during the 6,500-cfs release (except the trap on cross section 0+45 at Steiner Flat only caught the D_{75}). At most sites, even though bedload transport was occurring, bar morphology remained relatively unchanged after both releases, especially on bars colonized by riparian vegetation more than 2 or 3 years old.

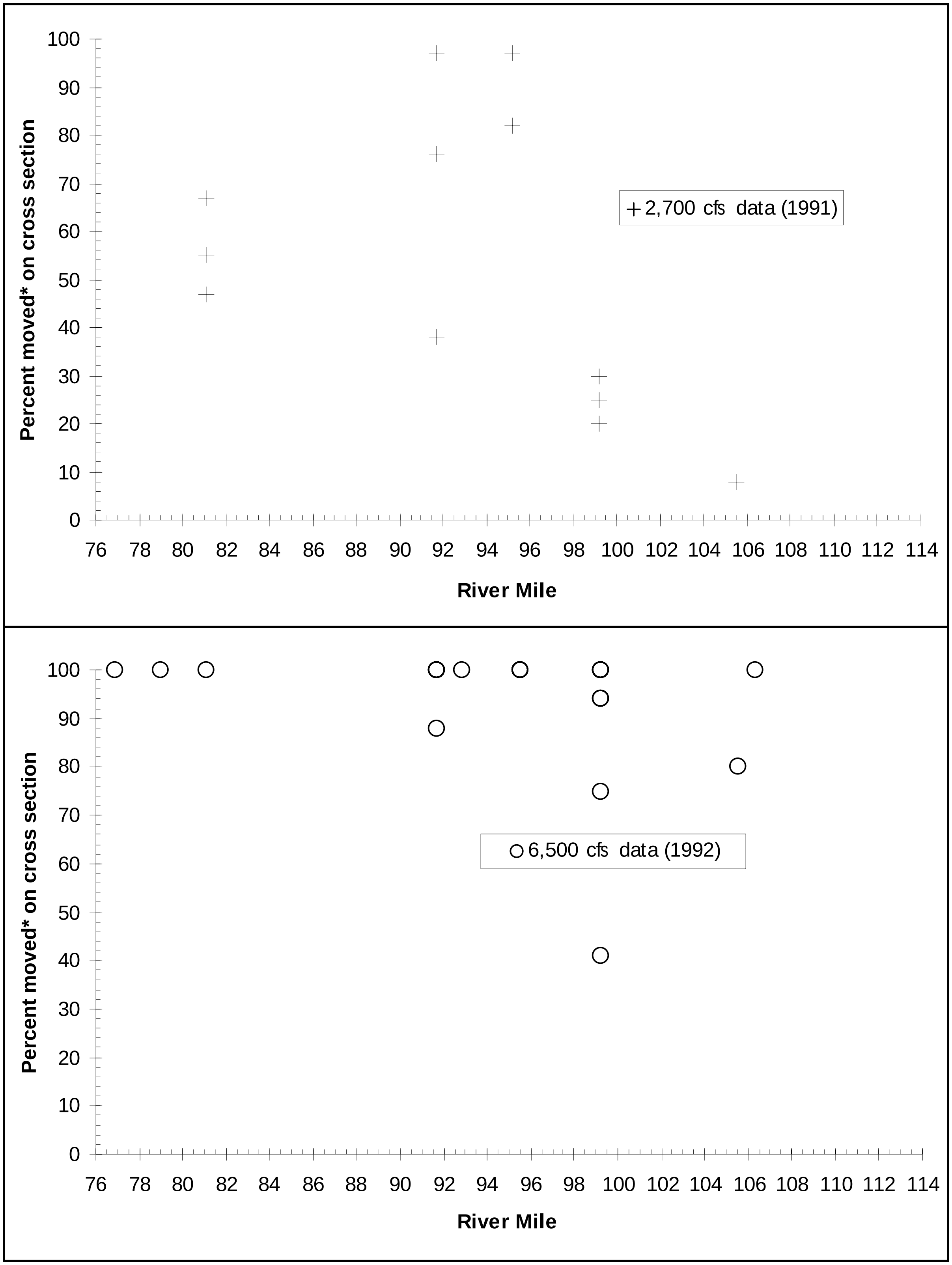
We also compared differences in bed mobility between 2,700 cfs to 6,500 cfs by plotting results of all monitoring sites (Figures 6.4 and 6.5). In all sites except one, at least 80 percent of tracer rocks were mobilized by 6,500 cfs, whereas at 2,700 cfs, the percentage ranged from 8 percent to near 100 percent. The wide range of mobilization was a result of the diverse alluvial features monitored. Direct comparison of identical sites between the two discharges in Table 6.1 provided a better comparison of bed mobility than the broad approach presented in Figures 6.4 and 6.5.

Tracer rocks placed on newly formed point bars on the Bucktail and Steiner Flat bank rehabilitation sites provided insight into thresholds required to mobilize alternate bars that will be constructed in the future. The 5,400 cfs release in WY1996 just began mobilizing the framework of the bed surface (D_{84}) on lower surfaces of the point bars (Figures 6.6 to 6.9). These lower bar surfaces near the 450 cfs water surface elevation are also the zone where riparian initiation is most probable. The 5,400 cfs release just began to mobilize this zone at the Bucktail and Steiner Flat sites. While the smaller size classes of particles mobilized over a wider width of the bar, the D_{84} and larger size classes must be mobilized to scour the riparian seedlings. Therefore, these results showed 5,400 cfs begins to mobilize lower alternate bar surfaces and straight reaches, but higher discharges are needed to mobilize the entire bar surface.

Particle mobility thresholds varied longitudinally, with mobility occurring at lower flows and lower recurrence floods downstream of Indian Creek. This is caused by the cumulative flow and sediment contribution by tributaries downstream of Indian Creek since completion of the TRD, which has allowed the bed surface particle size to adjust to the post-dam flow regime (Trush et al., 1995). Upstream of this “alluvial transition” at Indian Creek, most reaches have not adjusted due to lack of flood flows and coarse sediment supply.

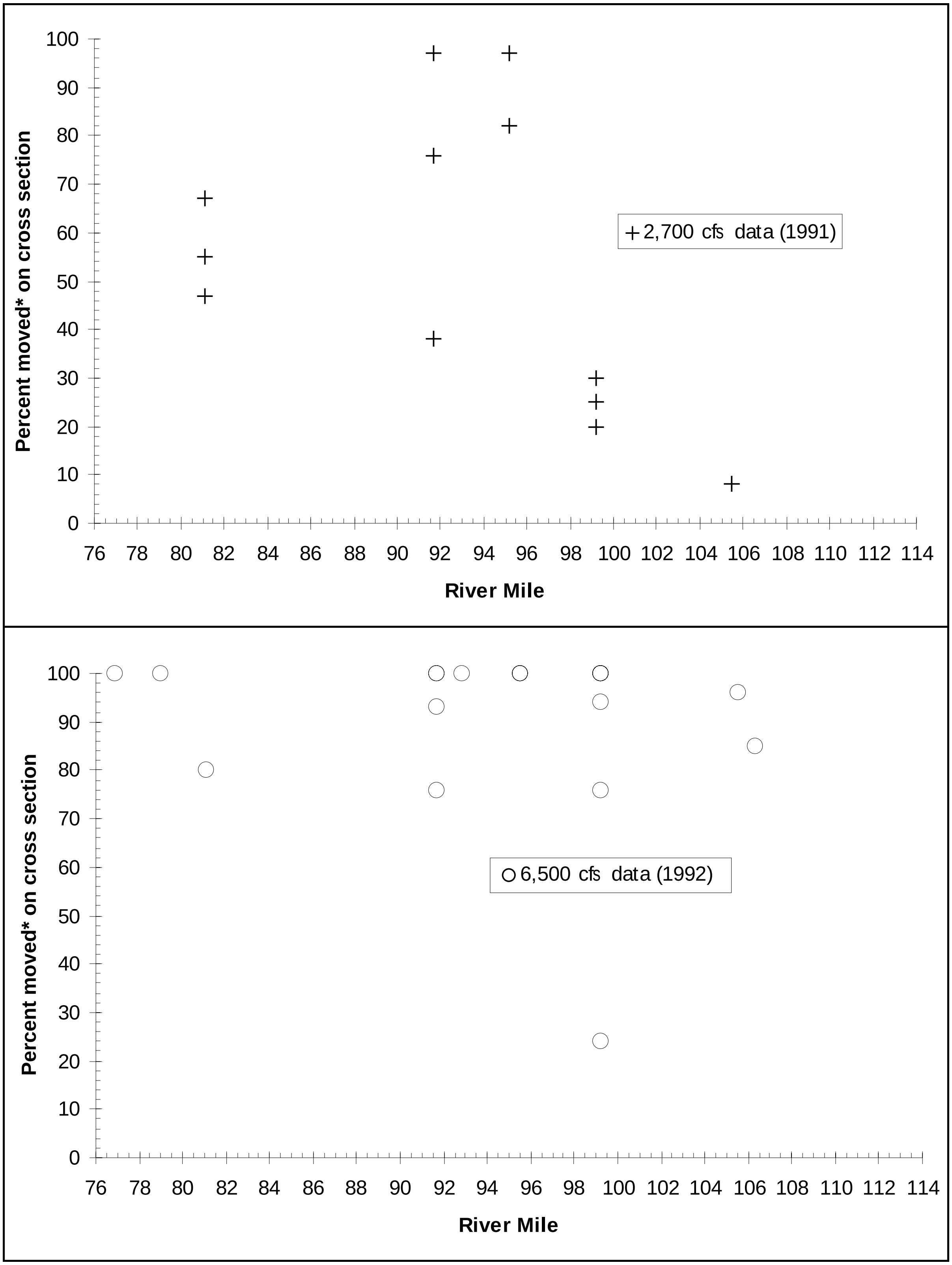
6.3.2. Tracer rock movement through major tributary deltas

Tracer rocks placed upstream of Grass Valley Creek and Indian Creek during the 5,400 cfs release in WY1996 had minimal bed mobilization (Figures 6.10 and 6.11). At Grass Valley Creek, tracer rocks were placed on the riffle crest of the delta, which would be more mobile than 500 ft upstream where the backwater effect would be greater. Even so, only seventeen percent of the D_{84}'s were mobilized. At Indian Creek, the tracer rocks were placed on a depositional lobe over 500 ft upstream of the Indian Creek delta. None of the D_{84}'s and sixteen percent of the D_{50}'s mobilized during the 5,400 cfs release. However, bedload was moving through the cross section because bedload traps placed on the



* Lines represent comparable bed mobility envelope curve.

Figure 6.4 D_{50} tracer gravel comparison between 2,700 cfs release (1991) and 6,500 cfs release (1992) at all monitoring sites.



* Lines represent comparable bed mobility envelope curve.

Figure 6.5 D_{84} tracer gravel comparison between 2,700 cfs release (1991) and 6,500 cfs release (1992) at all monitoring sites.

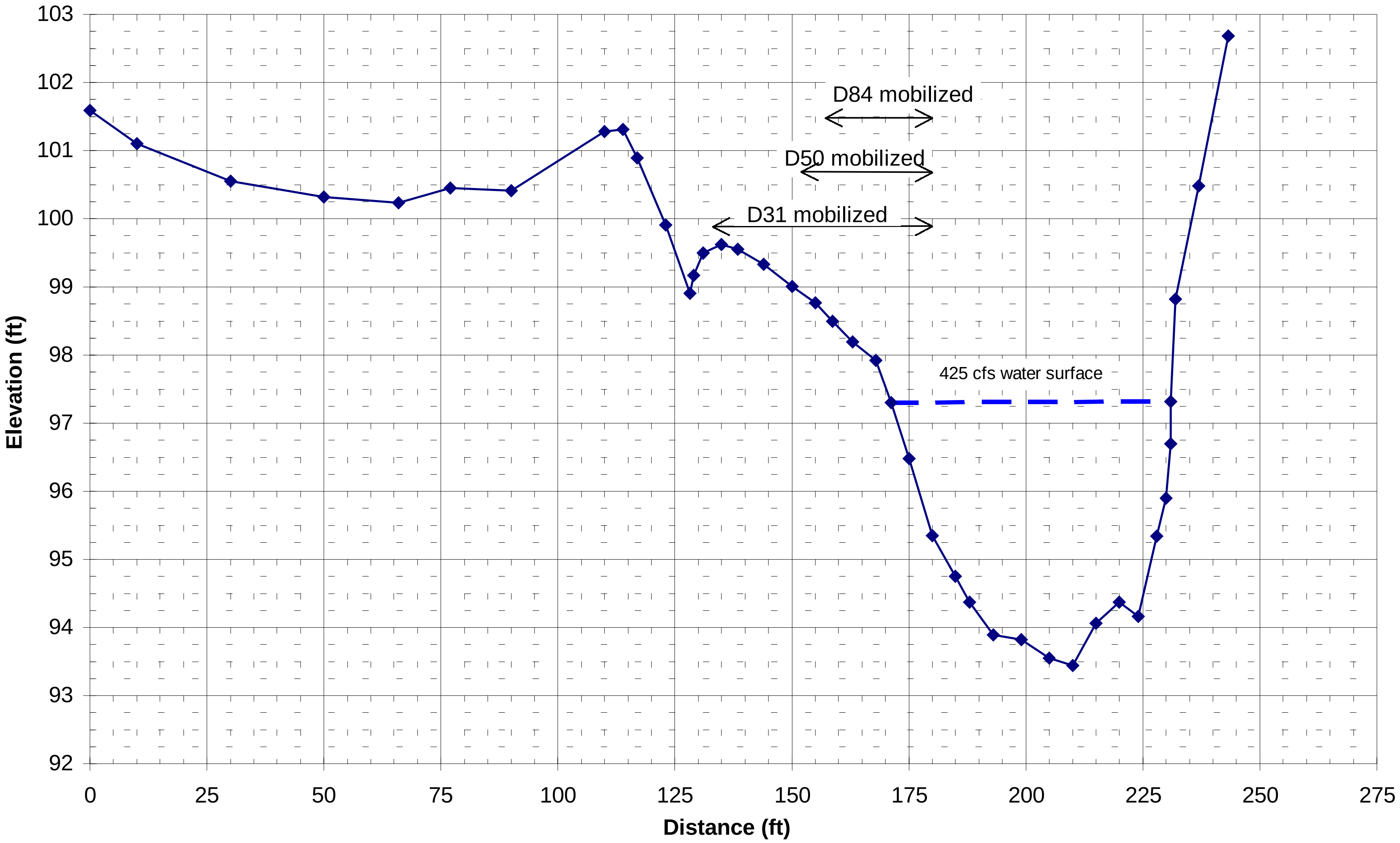


Figure 6.6 Bed mobility pattern at Bucktail bank rehabilitation site, cross section 11+00 during 5,400 cfs release. Rocks placed from station 131-179.

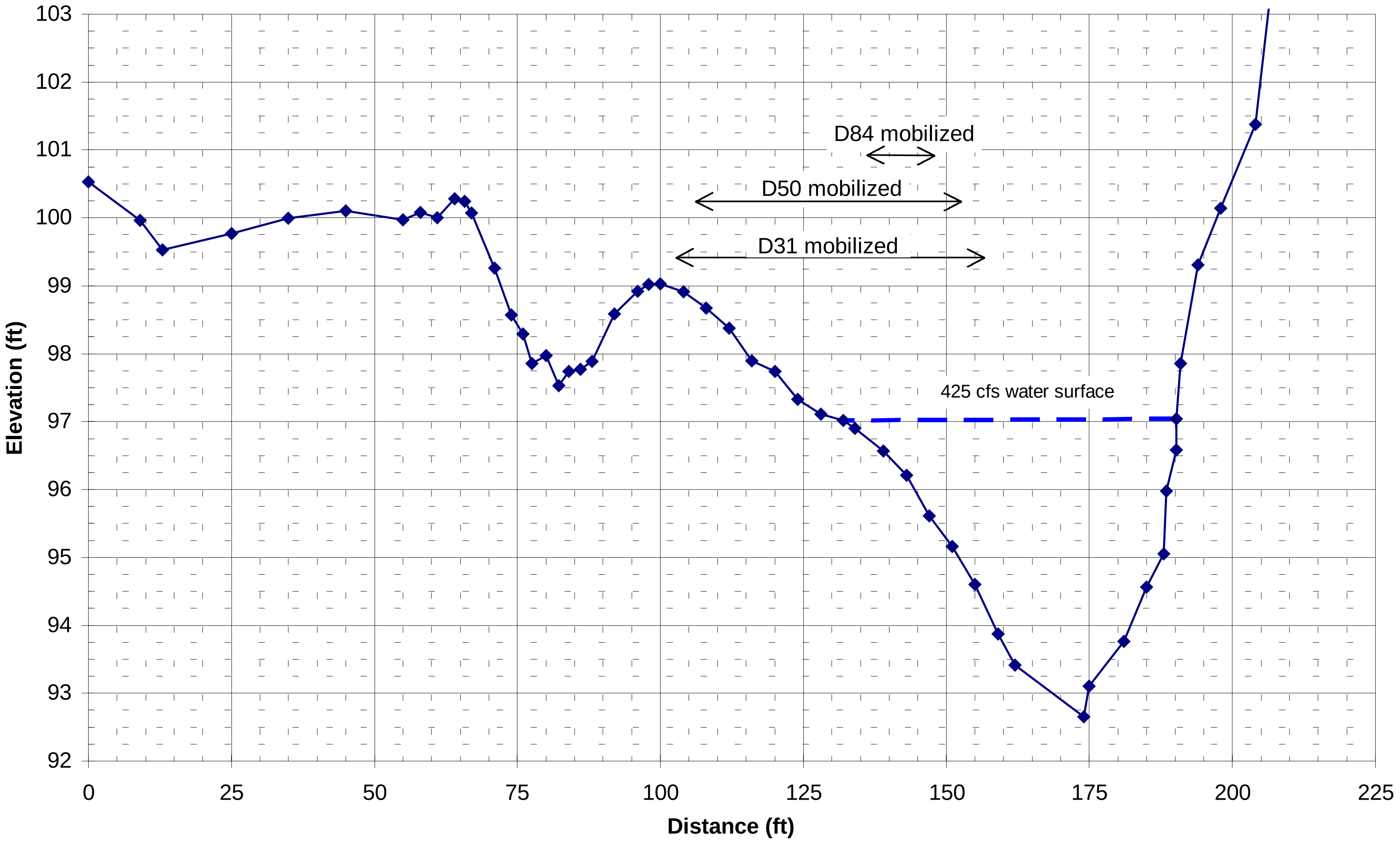


Figure 6.7 Bed mobility pattern at Bucktail bank rehabilitation site, cross section 12+00 during 5,400 cfs release. Rocks placed from station 96-156.

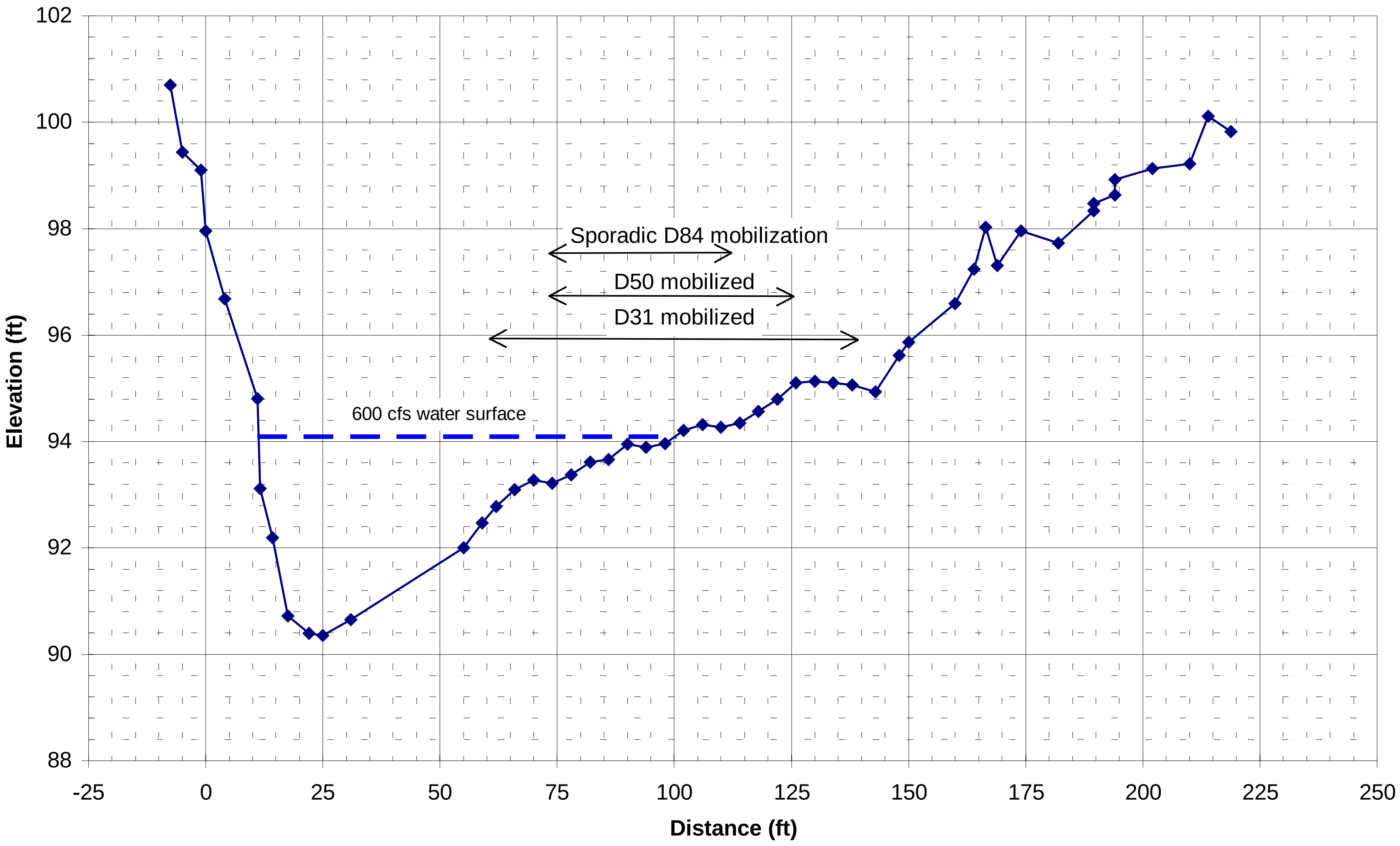


Figure 6.8 Bed mobility pattern at Steiner Flat bank rehabilitation site, cross section 5+02 during 5,400 cfs release. Rocks placed from station 62-138.

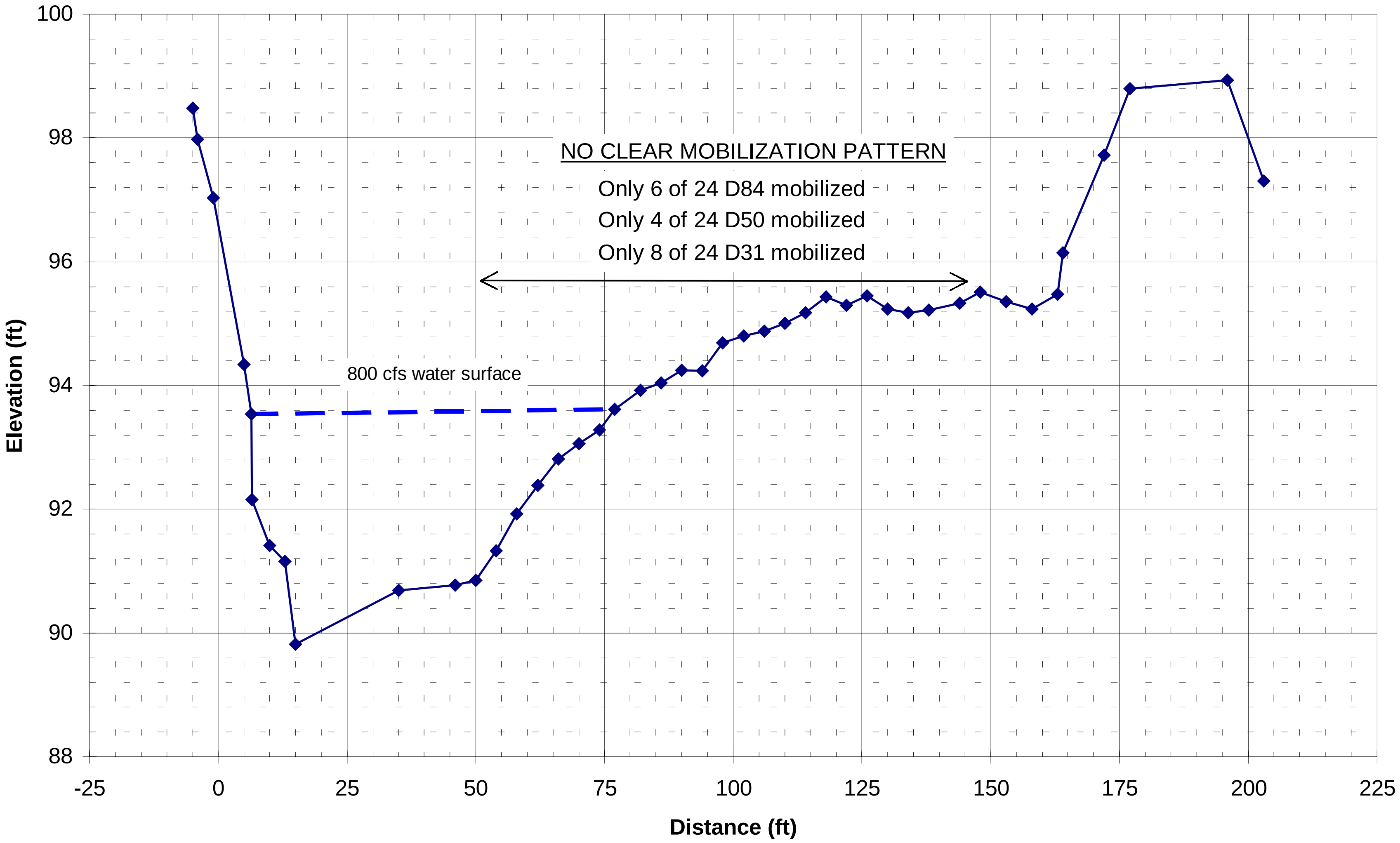


Figure 6.9 Bed mobility pattern at Bucktail bank rehabilitation site, cross section 5+98 during 5,400 cfs release. Rocks placed from station 52-144.

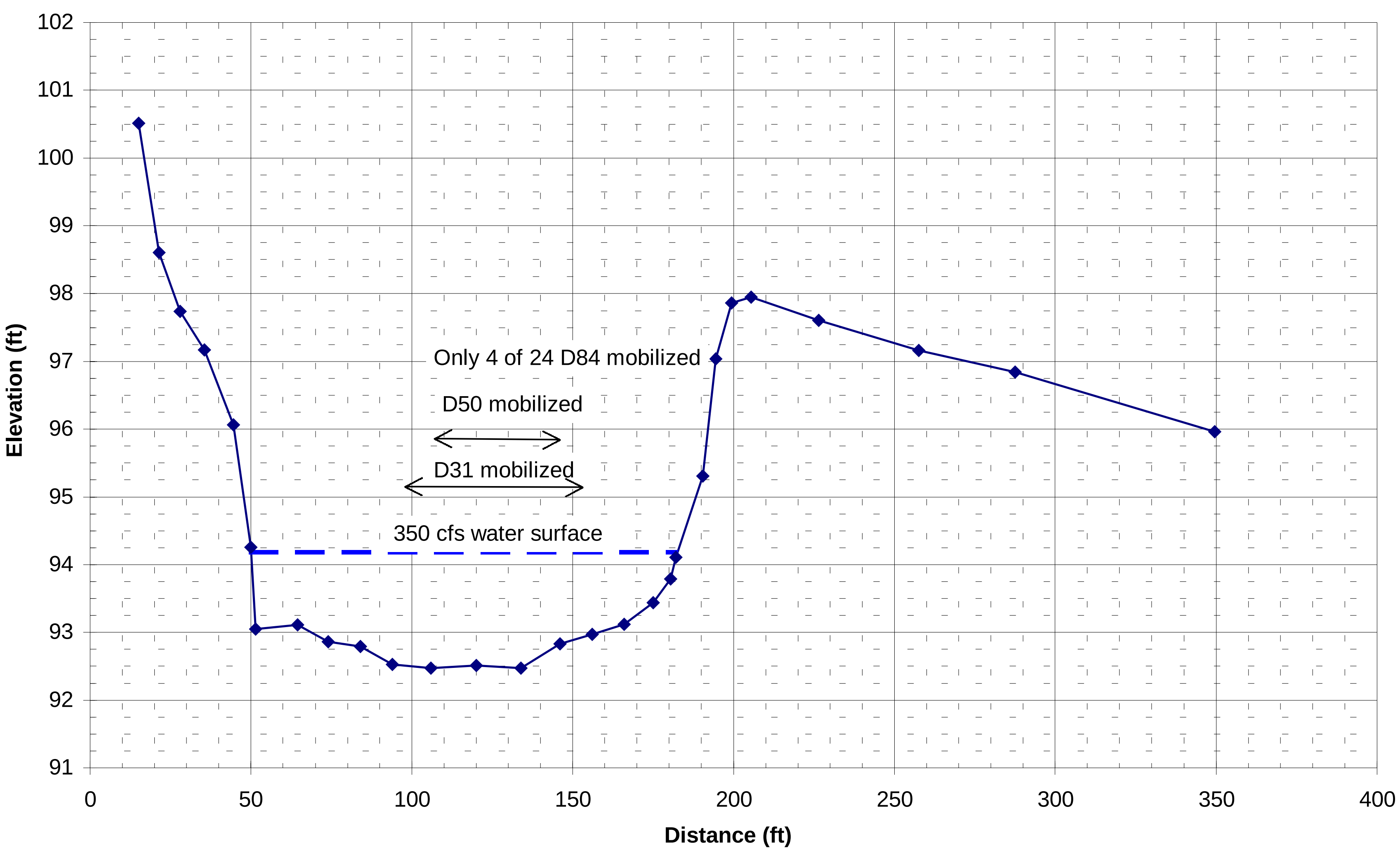


Figure 6.10 Bed mobility pattern at riffle crest immediately upstream of Grass Valley Creek delta during 5,400 cfs release.

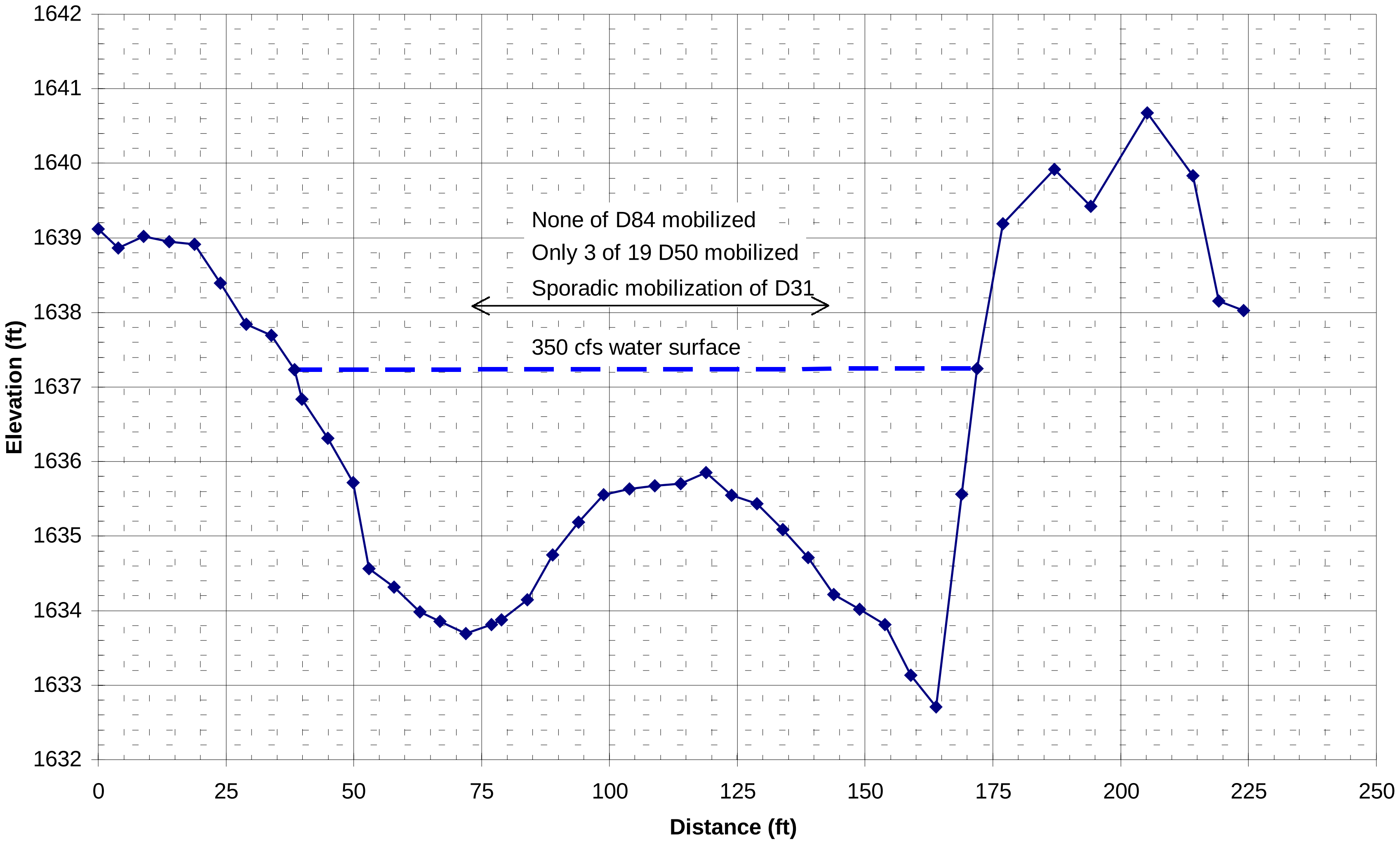


Figure 6.11 Bed mobility pattern immediately upstream of Indian Creek delta during 5,400 cfs release.

cross section captured gravel, while several tracer rocks were slightly buried by new gravel. This gravel was depositing locally (near the head of the backwater reach), causing the depositional lobe to continue growing towards the Indian Creek delta. These results suggest that coarse bedload is not transporting through the Grass Valley Creek and Indian Creek deltas.

Shields parameter for the local D_{84} was predicted at cross sections in the backwater of the Rush Creek, Grass Valley Creek, and Indian Creek deltas, and compared to the incipient Shields parameter observed at Steiner Flat ($\tau^*_{c\ D84}$=0.02). In all cases, the predicted Shields parameter for flows up to 14,000 cfs (not modeled higher) was well below 0.02. For example, at Rush Creek, τ^*_{D84}=0.003. These low Shields parameters were caused by the backwater-induced low slope: Rush Creek = 0.00011, Grass Valley Creek = 0.00063, and Indian Creek = 0.0002; high flow slopes in most mainstem reaches are between 0.001 and 0.002. Therefore, only by increasing slope can shear stress and bedload transport through the tributary deltas be increased. This would best be accomplished by partially excavating the delta, thus lowering the hydraulic control to increase slope.

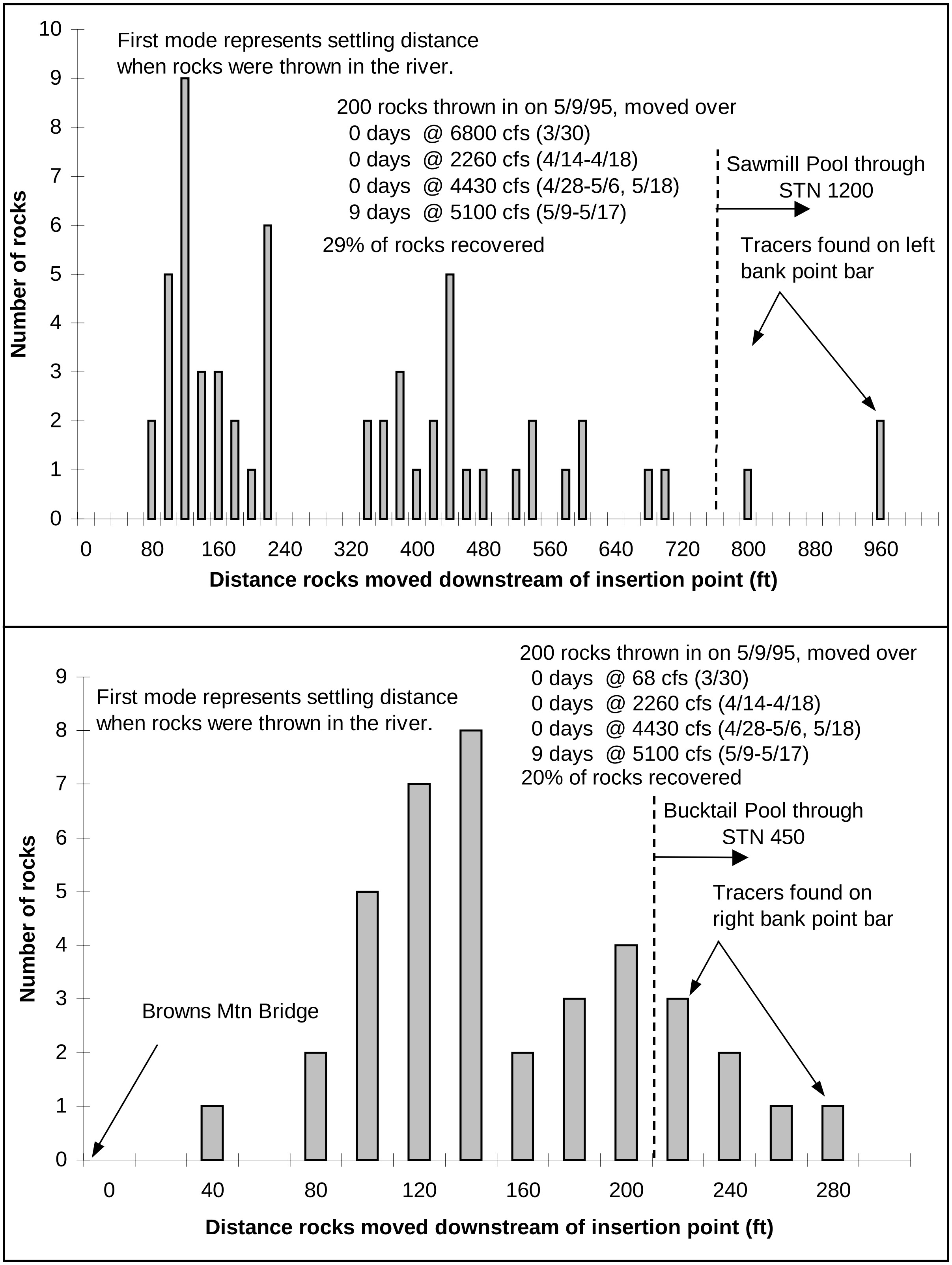
6.3.3. Tracer rock movement through selected pools

In both the Sawmill Pool site and Bucktail Pool site, none of the relocated tracer rocks were found downstream of the pool after nine days of 5,100 cfs; most were found at or near the insertion point (Figure 6.12). Those that traveled into the pool immediately deposited on the subtle point bar on the inside of the pool, and did not actually route through the pool (Figure 6.6). The long travel distance at the Sawmill Pool was a result of the rocks being thrown-in at the middle of a long steep riffle (only available entry point during high flows); tracer rocks had to travel over 650 ft just to enter the pool. The low recovery rate at the Bucktail Pool (20%) was not anticipated (because the travel distance to the pool was considerably shorter than at the Sawmill Pool), but may be attributable to tracer rock burial on the point bar surface. Regardless, tracer rocks were not found beyond the pools, suggesting that most individual rocks do not move long distances during a single event of low magnitude discharge. Some rocks on the adjacent point bar may move to the next downstream riffle-pool sequence during future flows, but the experiment was not repeated in subsequent years.

In WY1992, several tracer rock sets were placed at the head of riffles to determine whether planned releases could initiate movement and transport the D_{50} or D_{84} through the downstream pool. At the Steiner Flat site (RM 91.7) three tracer rocks (a D_{84}, a D_{69}, and a D_{50}) were transported through a 20-foot deep pool and onto the downstream median bar by the 6,500-cfs release (Trinity Restoration Associates, 1993). These two simple experiments suggest that 5,000 to 6,000 cfs is not only near the threshold for general bed mobilization, but also near the threshold for transporting coarse bedload through pool-riffle sequences.

6.3.4. Tracer rock movement below tributary deltas

This first high flow release from Lewiston began on March 18, 1995, starting at 4,000 cfs and increased to 6,800 cfs by March 25, 1995. Unfortunately, mainstem flows began ramping down the


First mode represents settling distance when rocks were thrown in the river.

200 rocks thrown in on 5/9/95, moved over
0 days @ 6800 cfs (3/30)
0 days @ 2260 cfs (4/14-4/18)
0 days @ 4430 cfs (4/28-5/6, 5/18)
9 days @ 5100 cfs (5/9-5/17)

29% of rocks recovered

Sawmill Pool through STN 1200

Tracers found on left bank point bar

First mode represents settling distance when rocks were thrown in the river.

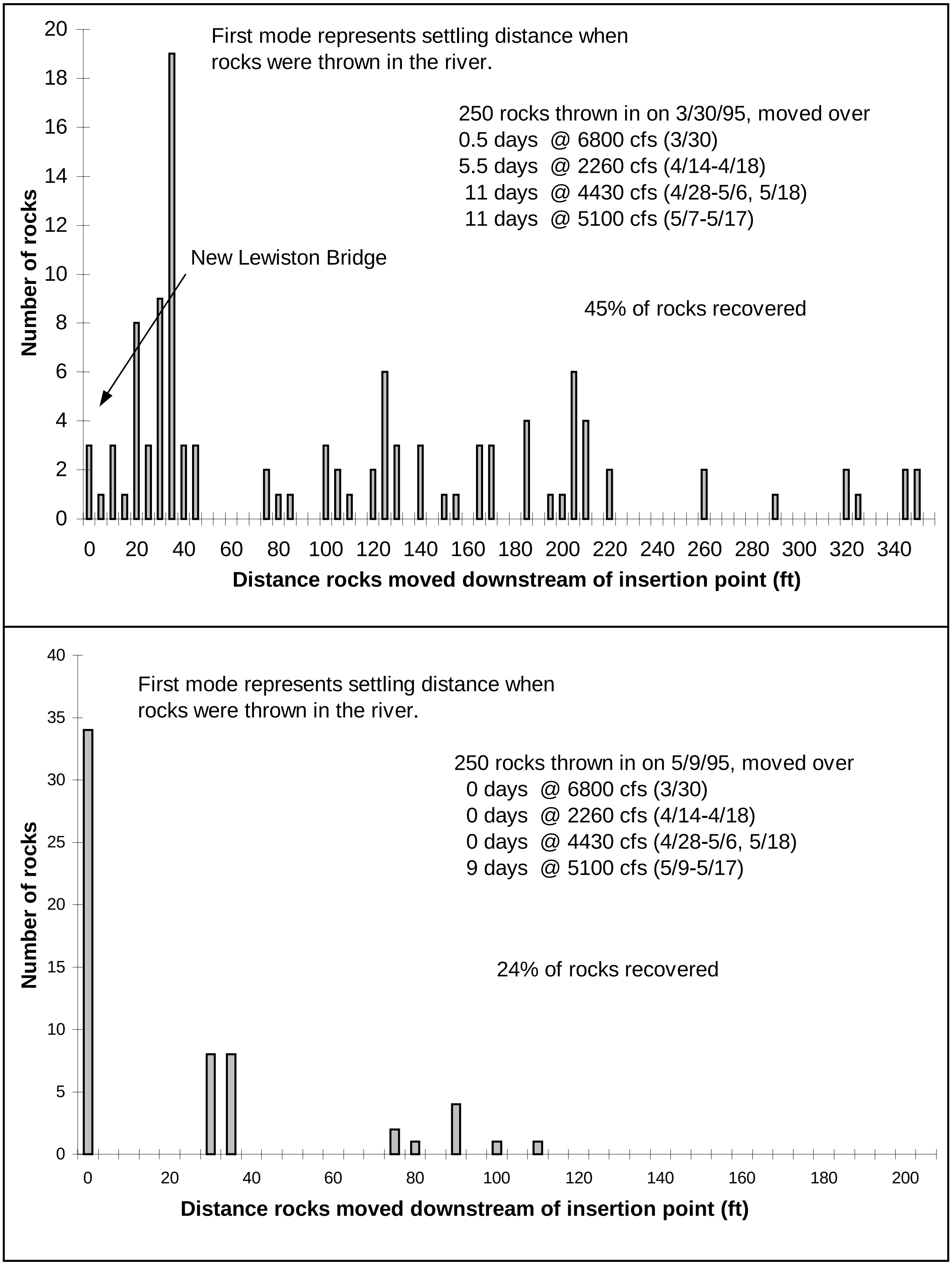
200 rocks thrown in on 5/9/95, moved over
0 days @ 68 cfs (3/30)
0 days @ 2260 cfs (4/14-4/18)
0 days @ 4430 cfs (4/28-5/6, 5/18)
9 days @ 5100 cfs (5/9-5/17)
20% of rocks recovered

Bucktail Pool through STN 450

Tracers found on right bank point bar

Browns Mtn Bridge

Figure 6.12 Tracer gravel movement through Sawmill Pool (RM 109) and Bucktail Pool (RM 105) during WY 1995 high flow releases.



First mode represents settling distance when rocks were thrown in the river.

250 rocks thrown in on 3/30/95, moved over
0.5 days @ 6800 cfs (3/30)
5.5 days @ 2260 cfs (4/14-4/18)
11 days @ 4430 cfs (4/28-5/6, 5/18)
11 days @ 5100 cfs (5/7-5/17)

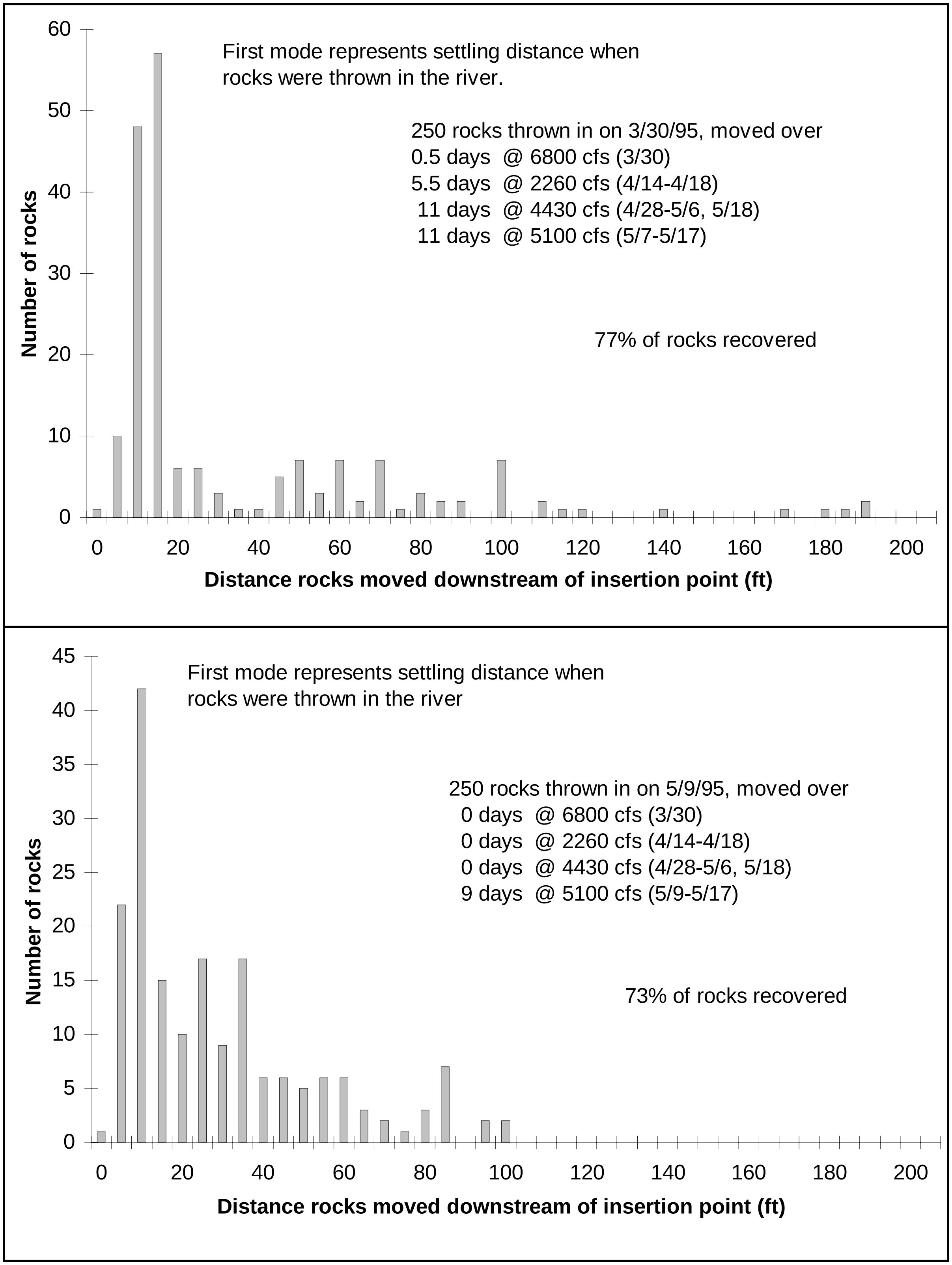
45% of rocks recovered

First mode represents settling distance when rocks were thrown in the river.

250 rocks thrown in on 5/9/95, moved over
0 days @ 6800 cfs (3/30)
0 days @ 2260 cfs (4/14-4/18)
0 days @ 4430 cfs (4/28-5/6, 5/18)
9 days @ 5100 cfs (5/9-5/17)

24% of rocks recovered

Figure 6.13 Tributary tracer gravel movement at Deadwood Creek and Grass Valley Creek during WY 1995 high flow releases.


First mode represents settling distance when
rocks were thrown in the river.

250 rocks thrown in on 3/30/95, moved over
0.5 days @ 6800 cfs (3/30)
5.5 days @ 2260 cfs (4/14-4/18)
11 days @ 4430 cfs (4/28-5/6, 5/18)
11 days @ 5100 cfs (5/7-5/17)

77% of rocks recovered

First mode represents settling distance when
rocks were thrown in the river

250 rocks thrown in on 5/9/95, moved over
0 days @ 6800 cfs (3/30)
0 days @ 2260 cfs (4/14-4/18)
0 days @ 4430 cfs (4/28-5/6, 5/18)
9 days @ 5100 cfs (5/9-5/17)

73% of rocks recovered

Figure 6.14 Tributary tracer gravel movement at Rush Creek during WY 1995 high flow releases.

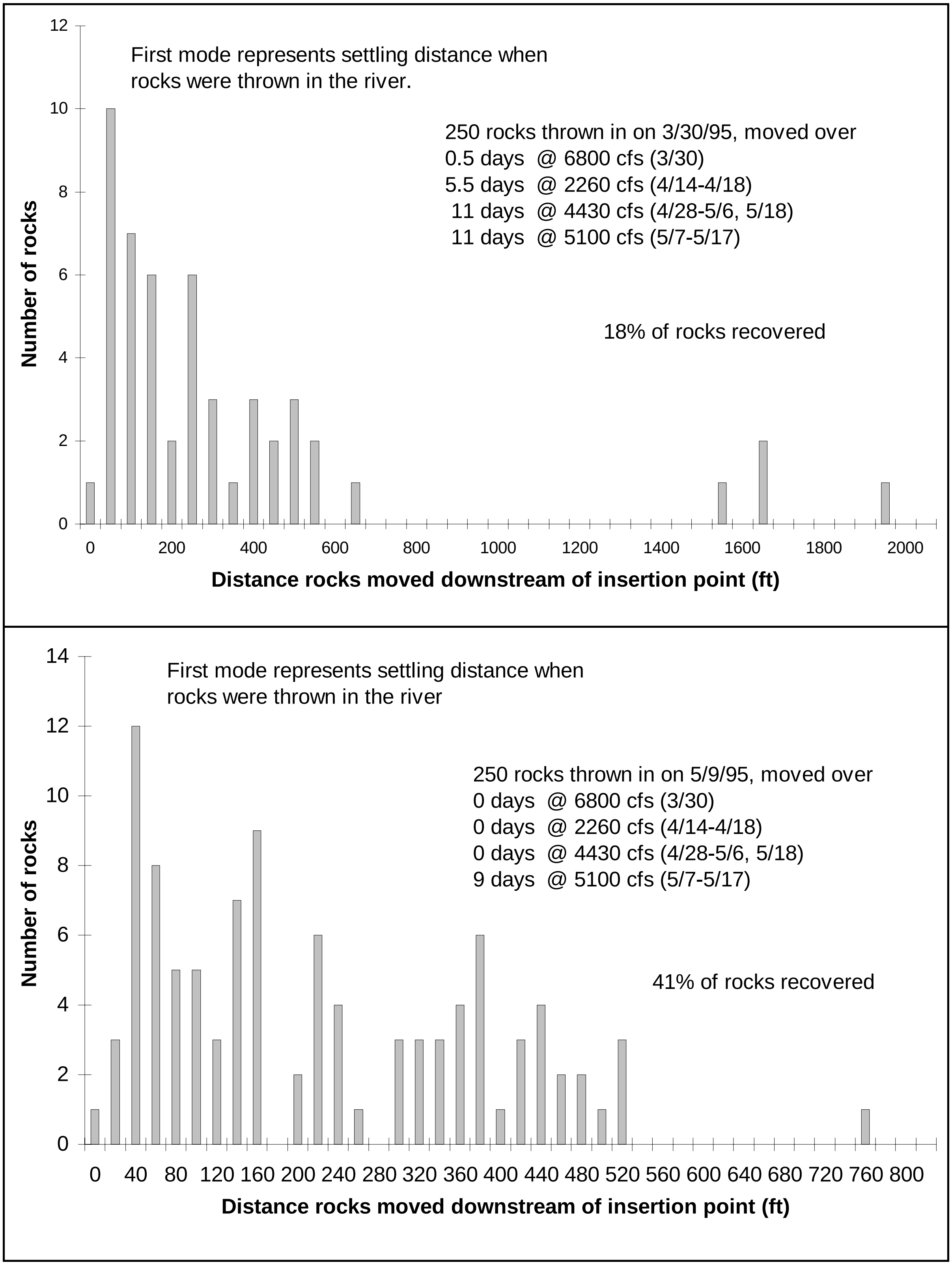


Figure 6.15 Tributary tracer gravel movement at Indian Creek during WY 1995 high flow releases.

following day, to a discharge of 535 cfs by April 7, 1995. The tracer rocks' exposure to this large flow event had only one-half day duration. Additionally, we observed that the delta deposits at Deadwood Creek, Rush Creek, and Indian Creek that had extended out into the river prior to March 18, 1995 had been immediately transported downstream by the mainstem release during the first days of the release. By the time we added our tracer rocks, the mainstem transport capacity had decreased significantly at the tributary deltas. The net effect was that our tracer rocks did not accurately represent a tributary rock in a delta deposit as intended; the travel distance rate was certainly shorter than for the original delta bed material prior to March 18, 1995 (Figure 6.13 to 6.15).

On 4/27/95, Lewiston releases ramped up to 4,500 cfs, and again on May 7, 1995 up to 5,100 cfs. On May 9, 1995 we repeated the tracer rock experiment at each tributary delta using 250 orange rocks. The distance individual rocks traveled, downstream from their insertion points for both dates, was measured July 1995. Unfortunately, the orange dye in the orange rocks faded to yellow (making them difficult to locate and distinguish from the real yellow rocks inserted on March 30, 1995) and many rocks were buried by sand (at the mouth of Grass Valley Creek), so recovery rates were low.

Despite placing no tracer rocks on the delta prior to high mainstem flows and an imperfect recovery method (faded rock colors and poor recovery), information was gained (Figures 6.6 to 6.8): (1) At several of the deltas, most tracer rocks did not move beyond their insertion point; (2) many sites had a bimodal distribution of tracer rock movement, where the first mode occurred near the insertion point (almost no movement) and the second mode coincided with the first downstream depositional area (alluvial feature) below the insertion point; and (3) maximum travel distance for rock tracers at the Rush Creek and Indian Creek deltas increased slightly with a longer flow release.

6.4 Modeling channelbed surface mobility

6.4.1. Critical shields parameter measured on the Trinity River

Based on near-incipient conditions for D_{84} tracer rocks at Steiner Flat (Figure 6.16), the critical Shields' parameter (τ_{*c}) (using depth-averaged shear stress) was estimated to be 0.02 (and 0.035 for D_{50})(McBain and Trush, 1995). This value is consistent with results in the literature when depth-averaged shear stress is used (e.g., Parker et al., 1982; Andrews, 1983) but smaller used when local boundary shear stress was used (e.g., Wiberg and Smith, 1987; Wilcock et al., 1995). The depth-averaged method does not provide local mobility estimates along the cross section, but can be used by simply measuring water surface elevation and slope, cross section geometry, and particle size distribution. The latter methodology is preferable but more difficult to quantify because (at a minimum) water velocities at specific verticals are required (see Chapter 7).

6.4.2. Modeled incipient channelbed surface mobility

By measuring hydraulic conditions at different sites for several flows, we computed 45 values of

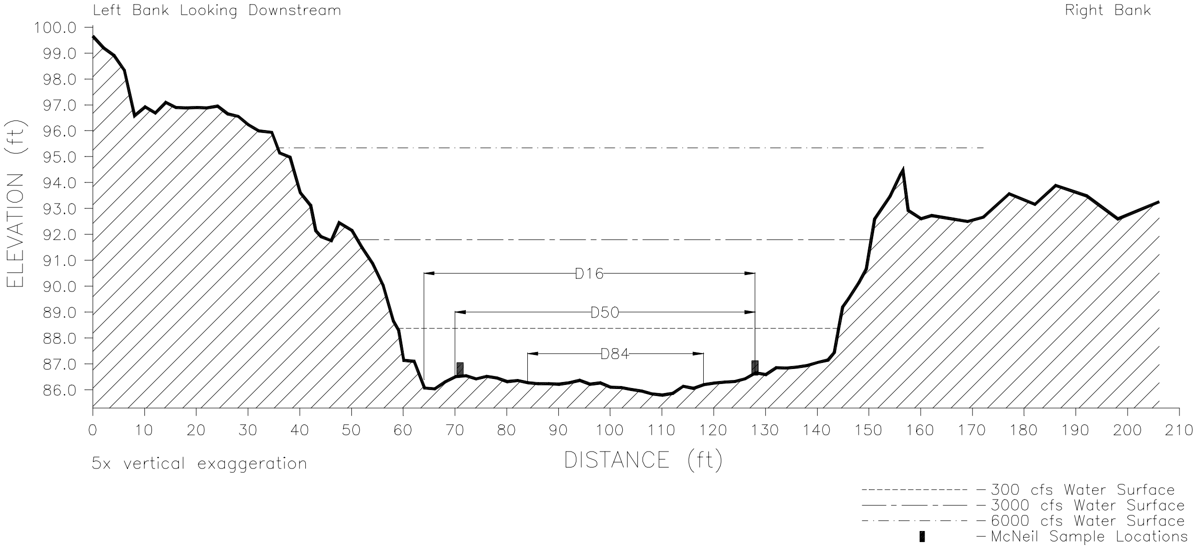


Figure 6.16 2,700 cfs bed mobilization pattern at Steiner Flat cross section 0+45, assumed to be near bed mobility threshold (τ^*_{D84} = 0.02).

Shields parameter. Each value is termed an “instance” in the following text. Shields parameter was computed for both the D_{50} and the D_{84} (Figures 6.17 and 6.18). The horizontal line is the critical Shields parameter observed at the Steiner Flat site, such that instances above this line should theoretically mobilize the bed. Discharges in the 2,700 to 3,000 cfs class only exceeded the D_{84} mobilization threshold in two of twenty instances (Figure 6.18), which we considered insignificant mobilization of the general channelbed surface. Even at discharges of 4,500 to 5,100 cfs, only six of nineteen instances exceeded the predicted bed mobility threshold. Not until discharges exceeded 6,500 cfs did the model predict a significant channelbed mobility threshold, at a uniform cross section in the post-TRD channel influenced by berm formation.

6.5 Summary

- Surfaces of the most mobile alluvial features (steep bar faces, secondary pool tail deposits, eddy deposits) were partially mobilized by 2,700 cfs. The wide range in percent tracer mobilization for the 2,700 WY1991 release (TRA 1993) reflects the relative mobility of diverse alluvial features.
- Wilcock et al. (1995), Trinity Restoration Associates (1993), and ourselves observed that a dam release of 5,000 cfs to 6,000 cfs is the minimum discharge needed to mobilize the general channelbed surface in a uniform channel reach.
- Tracer rock experiments at newly formed point bars documented that 5,400 cfs mobilized the surface layer D_{84} of the bar face near the low water channel, but not the entire bar surface. The WY1997 floods, ranging from 11,000 cfs to 30,000 cfs at our three monitoring sites, caused bed mobilization and scour over the entire bar surface.

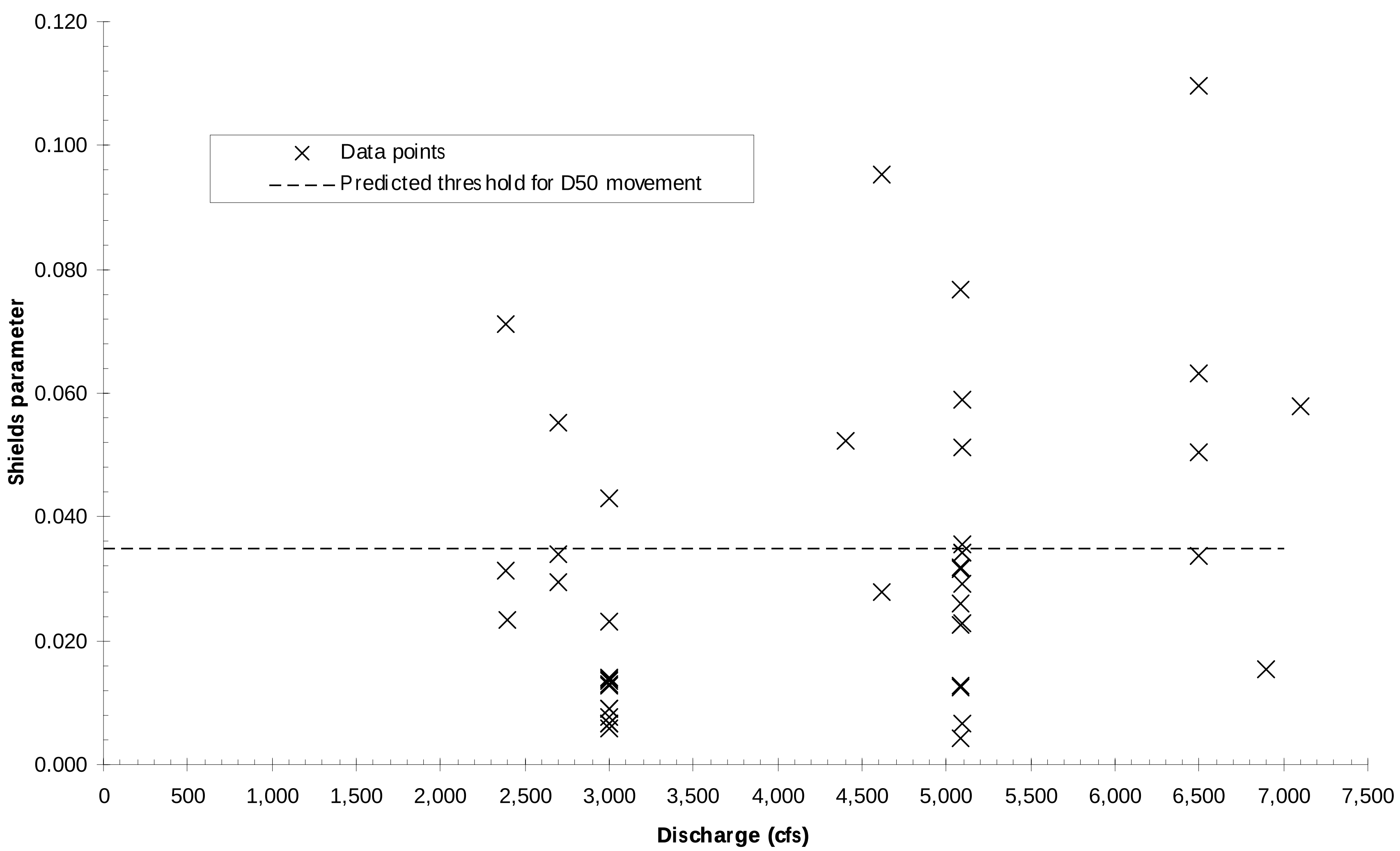


Figure 6.17 Trinity River Depth Averaged Dimensionless Shear Stress Computations for D_{50} Surface Particles.

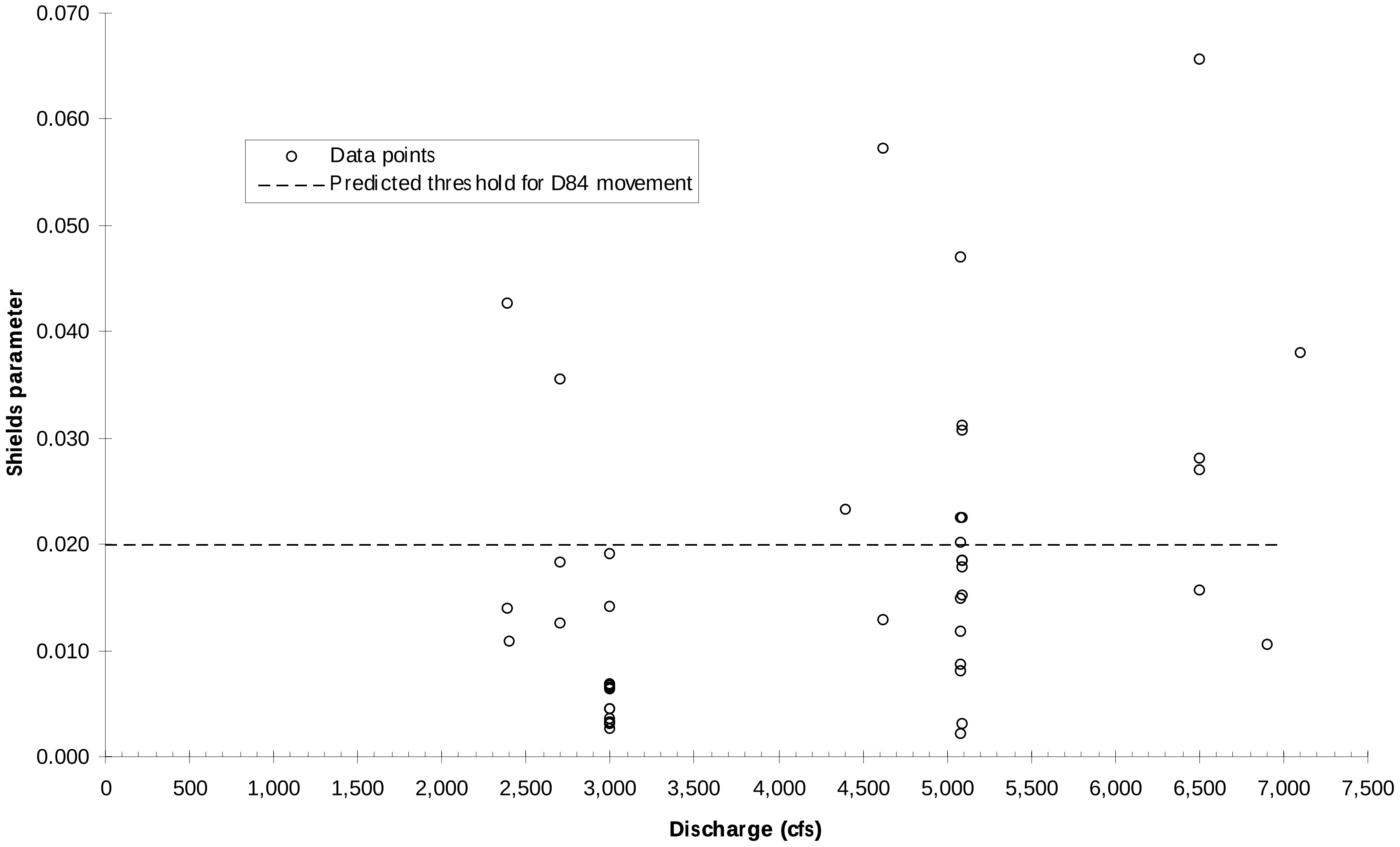


Figure 6.18r Trinity River Depth Averaged Dimensionless Shear Stress Computations for D_{84} Surface Particles.

- Smaller tracer rocks (D_{50}) were slightly more mobile than larger rocks (D_{84}).
- Recently aggraded tributary deltas are extremely mobile. In WY1991, when four years without mainstem high flows allowed the Indian Creek delta to aggrade, pinch, and steepen the slope of the mainstem channel, the 2,700 cfs event caused considerable widening, mobilization, and down-cutting. Tracer rocks on the delta were completely mobilized by this flow.
- Even though the tributary deltas were mobile, travel distances of individual tracers were short even with the 5,100 cfs event lasting over a week. Travel distances downstream of the deltas were typically less than 500 ft, with a maximum distance measured of almost 2,000 ft at the Indian Creek delta.
- Bed mobility modeling and tracer rock monitoring showed coarse bedload is not transported through the Rush Creek, Grass Valley Creek, and Indian Creek deltas by flows at least up to 14,000 cfs due to the backwater effect induced by delta aggradation. Restoring bed mobility and transport through these “bedload impedance reaches” will require delta excavation and redistribution to remove the backwater effect. Once bedload continuity through these bedload impedance reaches is restored, bed mobility and transport should occur at lower discharges (<14,000 cfs) similar to other mainstem reaches.
- For flows under 5,400 cfs, coarse tracer rocks were not transported through two deep pools upstream of the Grass Valley Creek confluence, but several deposited on point bars leading into the pools. Tracer rocks (D_{50} to D_{84}) at the Steiner Flat had transported through a deep pool in WY1992 (TRA, 1993).
- Computation of the Shields parameter for an observed channelbed surface mobility threshold at the Steiner Flat site (McBain and Trush 1995) resulted in a D_{50} (τ^*_{cD50}) of 0.035 and D_{84} of 0.02 using cross sectionally averaged shear stress (Equation 6.1). These values were comparable with predictions provided by Parker et al. (1982) and Andrews (1983) bed mobility models, but were lower than other models using either effective depth or local depth in shear stress computations.
- Bed mobility modeling predicts significant bed mobilization beyond 6,500 cfs (Figures 6.17 and 6.18) at the bank rehabilitation sites.

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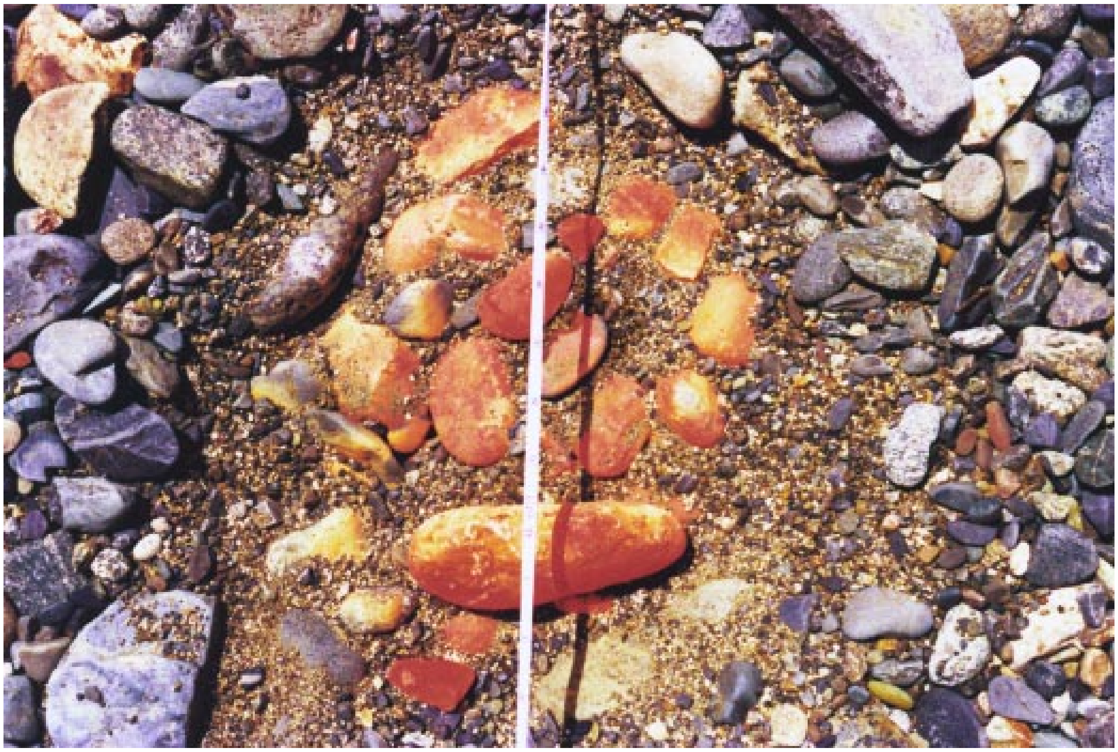


<u>CHAPTER 7:</u> CHANNELBED SCOUR

Attribute No. 4. PERIODIC CHANNELBED SCOUR AND FILL.
Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3-yr to 5-yr annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal;

Discharges in the mainstem fluctuated widely prior to construction of Lewiston and Trinity dams. Flows sufficient to initiate channelbed scour frequently occurred in response to intense rainfall and unusually large snowmelt runoff events. Considerable bed scour and subsequent re-deposition, all within single flood events, maintained a dynamic alternate bar morphology. Bed scour also maintained bar surfaces by scouring seedlings established in prior water years, which discouraged future woody riparian encroachment. Therefore, bed scour is an important management objective of future planned high flow releases.

The primary objective of Attribute No. 4 is that 3-yr to 5-yr floods scour more than the channelbed surface. Depth of the channelbed surface layer was defined as the thickness of the D_{84} particle size of the bed surface. Two questions (objectives) with respect to the function of bed scour on mainstem Trinity River alluvial features were:

1) Do the 3-yr to 5-yr floods provide depths of scour greater than the surface layer? (this question will critically relate to preventing woody riparian encroachment)

2) During a specific high flow release from Lewiston Dam, is the depth of scour (D_{sc}) or relative depth of bed scour (D_{sc}/D_{84}) on mainstem Trinity River alluvial features consistent from Lewiston Dam downstream to the North Fork Trinity River confluence?

The answer to either depended, in part, on whether the channel segment of concern was upstream or downstream from the alluvial transition zone (Trush et al., 1995) near Douglas City (RM 93). Downstream from Douglas City where the channel exhibits considerable alluvial behavior, scour depths were expected to exceed the surface layer for 3-yr to 5-yr floods due to greater sediment supply, less pronounced coarse surface layer, and finer particle size. With a post-TRD high flow regime (Table 5.3), the 6,500 cfs release in WY1992 was approximately a 10-yr recurrence flood upstream from the Indian Creek confluence (RM 95.2), but only a 2-yr flood recurrence downstream from the Browns Creek confluence (RM 93.8) which enters only seven miles downstream from Indian Creek. Given the 6,500 cfs event initiated general channelbed surface mobility at most study sites (Chapter 6), this was a reasonable minimum flow to begin expecting bed scour.

We defined the D_{84} of the coarse channelbed surface layer as the dominant particle size, as it represents the framework of the bed surface. These larger particle sizes are represented in both surface and subsurface particle size distributions (Church et al. 1987), such that the D_{84} of the subsurface is likely of similar size to the surface D_{84}. If the D_{84} particles are mobilized, then the framework particles of the channelbed surface are mobilized and significant bed scour can be achieved.

7.1 Methods

Channelbed scour was documented by: (1) scour chains placed in a wide variety of alluvial deposits (WY1991 to WY1993), and (2) scour cores placed on developing point bars at bank rehabilitation sites (WY1996 to WY1997). For the scour chain observations, the independent variable was discharge rather than a hydraulic variable. The original study plan expected at least six discharges ranging from 3,000 cfs to 8,500 cfs. Only two were released, in WY1992 (6,500 cfs) and WY1993 (3,000 cfs). While both flows provided scour depths for different morphological features, it did not allow extrapolation to other sites or discharges not specifically monitored. We installed scour cores at bank rehabilitation sites in WY1996, and monitored average and local hydraulic conditions at representative cross sections. The data were used to calibrate a model predicting channelbed depth of scour over a wider range of discharges.

7.1.1 WY1991 to WY1993 scour chain observations

Scour chains recorded bed scour and redeposition from the Gold Bar study site (RM 106.3) downstream to J&M Tackle study site (RM 76.9) in WY1991 and WY1992 (Trinity Restoration Associates 1993). The standard scour chain probe described in Lisle and Eads (1991) was used, with scour chain insertion depth ranging from one to three feet depending on channelbed coarseness.

Scour chains were abandoned after 1993 due to breakage and pulling-out. Detailed methodology, selection of study sites, and presentation of raw data are in Trinity Restoration Associates (1993); our report performs additional analyses on their data.

7.1.2 Modeling scour depth with the Shields parameter

A second approach to estimating scour depth as a function of discharge was to model the Shields parameter (Equations 7.1 and 7.2) in uniform straight reaches. We needed to estimate minimum flows scouring the channelbed greater than the depth of 2 D_{50}'s and 2 D_{84}'s.

Cross sectionally averaged boundary shear stress is:

$$\tau_b = \rho \mathrm{YS} \qquad (7.1)$$

where: ρ = water density (1000 kg/m^3), g = gravitational acceleration (9.81 m/s^2), Y = hydraulic radius of entire cross section (area/wetted perimeter), and S = energy slope (approximated by water surface slope assuming uniform flow conditions). The Shields parameter is specific to particle size (e.g., D_{50}, D_{84}, D_{90}):

$$\tau * D_i = \frac{\tau_b}{(\rho_s - \rho) g D_i} \qquad (7.2)$$

where ρ_s = density of D_{50} particle size (assumed to be 2,600 kg/m^3) and i = particle size based on cumulative distribution (percent finer).

Monitoring sites of Wilcock et al. (1995) were in long straight reaches; a range of mobile alluvial deposits, including medial bars and pool tails, were sampled by Trinity Restoration Associates (1993). We expected larger discharges would be needed to scour the bed greater than 2 D_{84}'s deep higher on the flanks and tops of alternate bars, than in uniform straight reaches. Wilcock et al. (1995) developed an empirical relationship between relative scour depth (scour/D_{90}) to the local Shields parameter for the D_{50} ($\tau*_{50}$). Wilcock's relationship predicts that Shields parameter for one D_{90} particle size scour depth is 0.06, and Shields parameter for 1.8 D_{90} scour depth (the end of the curve) is 0.10, an 83 percent increase in Shields parameter (Figure 7.1). We extrapolated from 1.8 D_{90} scour depth up to 2 D_{90} scour depth, assuming that the value of Shields parameter causing channelbed scour greater than 2 D_{90} was twice that needed to mobilize the channelbed surface D_{90}. Therefore, based on Wilcock's relationship, we doubled Shields parameter at incipient motion of the D_{84} as one simple predictive method to estimate Shields parameter causing 2 D_{84} scour depth.

Channelbed surface mobility experiments by Trinity Restoration Associates (1993) at Steiner Flat (RM 91.7) identified critical Shields parameters of 0.02 for the D_{84} and 0.035 for the D_{50} (McBain and Trush 1995), which correlated well with predictions by Andrews (1983) and Parker et al. (1982) using cross sectionally averaged shear stress (Equation 7.1). Doubling each Shields parameter

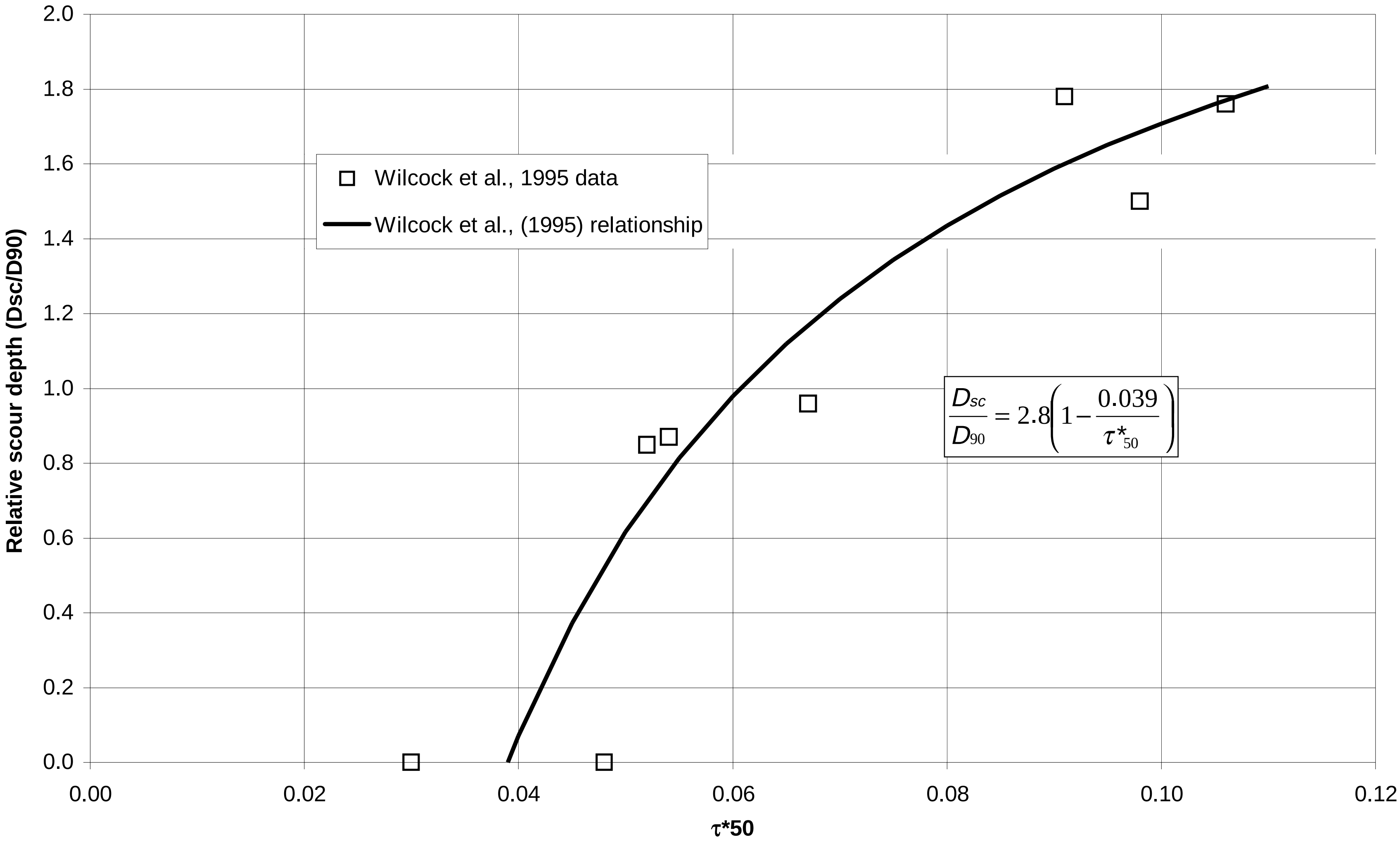


Figure 7.1 Wilcock et al., (1995) relationship between Shield's parameter for the median grain size versus relative scour depth of the D_{90} particle size.

estimate resulted in $\tau^*c_{(2D84)}$ and $\tau^*c_{(2D50)}$ values of 0.040 and 0.070, respectively.

7.1.3 WY1996 to WY1997 scour rock core observations

We hypothesized that if the high flow regime mobilized and scoured alternate bar faces on channel rehabilitation sites, riparian establishment would be minimal, thus preserving the dynamic nature of these evolving alluvial features. Study sites were selected that best satisfied the following criteria:

- straight (not meandering) channel for five to ten bankfull widths
- uniform slope over a range of discharges (no significant slope breaks)
- located near a gaging station so that hydraulic conditions and bed scour response could be correlated to a locally measured discharge
- site had newly-developing point bars
- located at varying distances downstream of Lewiston Dam to document longitudinal trends
- the sites vary in slope and particle size distribution

The first three criteria were selected to simplify equations for the hydraulic analysis. Of nine pilot bank rehabilitation sites, the Bucktail site (RM 105.6), Steiner Flat site (RM 91.7), and Sheridan Creek site (RM 81.6) were selected initially (Plate 1 and Table 7.1). Of these three sites, however, only the Steiner Flat and Sheridan Creek sites were sufficiently long and straight to reasonably conduct hydraulic analyses. In WY1996 and WY1997, scour cores were placed at evenly-spaced locations on each cross section:

Station on Cross Section (distance from LB pin, ft.)	Bucktail Cross Section 11+00	Steiner Flat Cross Section 5+98	Sheridan Creek Cross Section 5+35
Core #1	138.5	73.5	96.0
Core #2	158.6	93.7	126.0
Core #3	170.5	114.0	156.0

Table 7.1 Location of scour core installations at three pilot bank rehabilitation sites.

Scour cores were installed as follows (Figure 7.2):

1) The modified McNeil sampler was used to excavate core 1.0 to 1.5 feet deep;
2) The bottom of the excavated core was surveyed to document maximum measurable scour depth;
3) The core was backfilled with small painted gravels (20 mm to 30 mm) to the top of the surrounding bed surface;
4) The modified McNeil sampler was removed from the bed surface, leaving the painted gravel core in place;
5) The top of painted gravels, which is at the same elevation of the surrounding bed surface, was surveyed to document the pre-flood bed surface elevation ("A" in Figure 7.2).

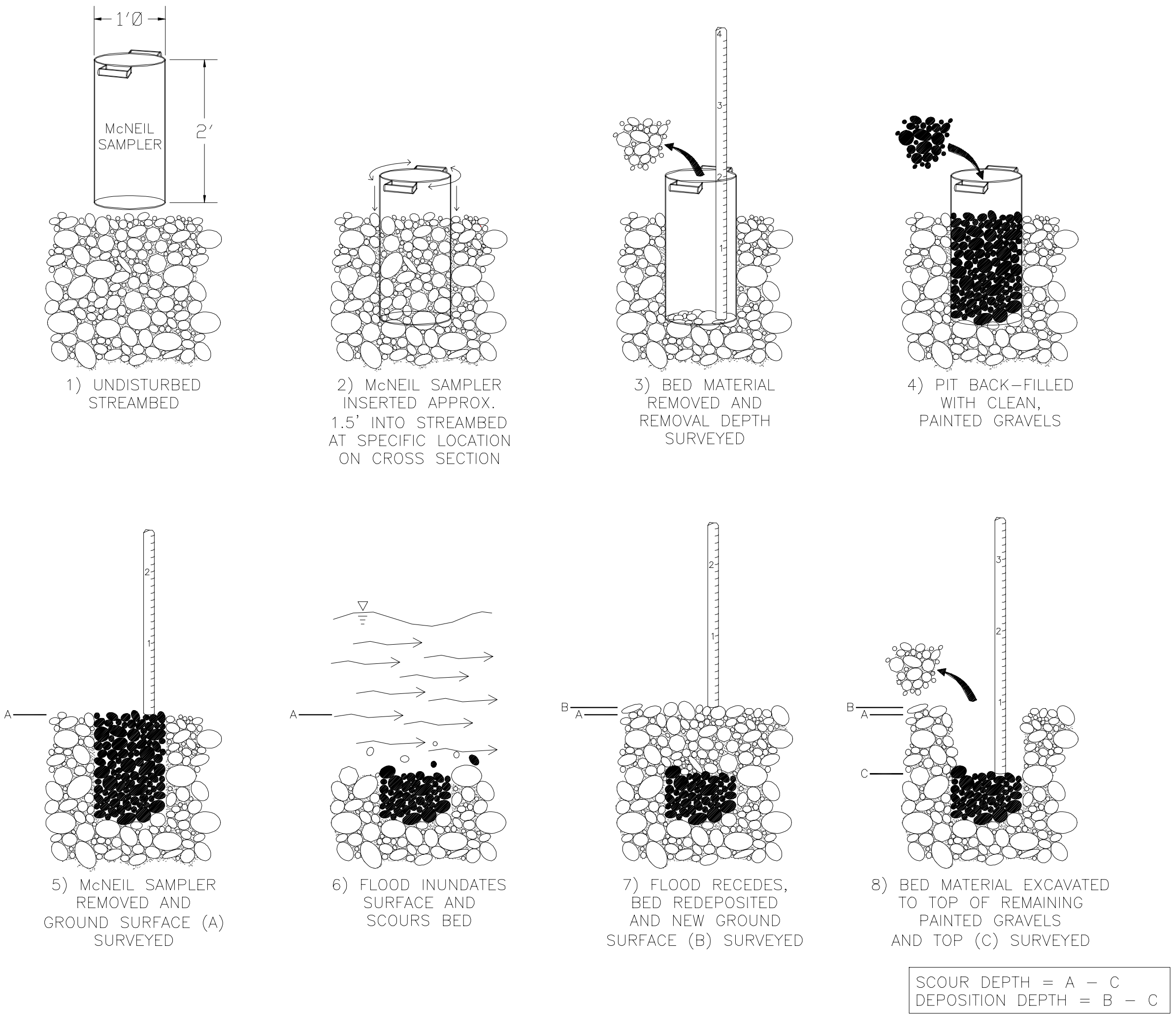


Figure 7.2 Methods for installing scour rock cores, and formulas for computing scour and deposition depth.

The small, painted gravels guaranteed that if the surrounding bed mobilized and scoured to a given depth, the painted gravels in the scour core were scoured to the same depth. After a specific high flow event, scour core monitoring was continued as follows:

6) Scour core location was identified from recorded stationing on the cross section
7) The top of the bed surface at the scour core location was surveyed to document final re-deposition depth ("B" in Figure 7.2)
8) The bed was excavated at the scour core location down to the depth where painted gravels were first uncovered. This elevation was surveyed, representing maximum scour depth during the flood ("C" in Figure 7.2).

Subtracting "C" from "A" computed total scour depth during the flood; subtracting "C" from "B" computed total re-deposition depth. Dividing the total scour depth, D_{sc}, by the D_{90} particle size provided a representative scour depth used by Wilcock et al. (1995).

At each site, one cross section through the apex of the point bar was used to locate the scour cores. Three cores were placed on each representative cross section between the 300 cfs water surface elevation and the bar top (Figures 7.3 to 7.5), where the top of the bar was defined by the transition from gravels to sands and silts.

During high Lewiston releases of WY1996 and WY1997, water surface elevation at each scour core cross section was surveyed. A water surface profile was surveyed through the reach to estimate high flow water surface slope (which was used to approximate energy slope in these long straight reaches). These measurements were used to compute cross sectionally averaged shear stress (τ_b) using Equation 7.1. Data for developing rating curves at adjacent flow gages were used to estimate local shear stress fields above the scour cores. Wilcock et al. (1995) use this technique to develop a relationship between local hydraulic conditions and scour depth, which could be useful for predicting bed scour at high discharges if the curve was reasonably defined.

We made similar measurements to evaluate Wilcock's relationship, and to augment his data set. We measured discharge at the Steiner Flat and Sheridan Creek study sites, avoiding the Bucktail site due to its significant channel curvature, considerable cross channel flow circulation, and lack of anchoring sites on the right bank for the cataraft. At Sheridan Creek, discharge was measured 50 ft upstream of the scour core cross section, and approximately 100 ft upstream of the scour core cross section at Steiner Flat. Rather than using the average shear stress equation in Equation 7.1, we assumed that the vertical velocity profile was logarithmically distributed, and used the logarithmic velocity profile equation ("law of the wall" equation) to quantify local boundary shear stress (Wilcock 1994):

$$\frac{U_{ave}}{U*} = \frac{1}{k} Ln\left(\frac{Z}{Z_o}\right) = \frac{1}{0.4} Ln\left(\frac{0.4d_i}{0.1D_{84}}\right) \qquad (7.3)$$

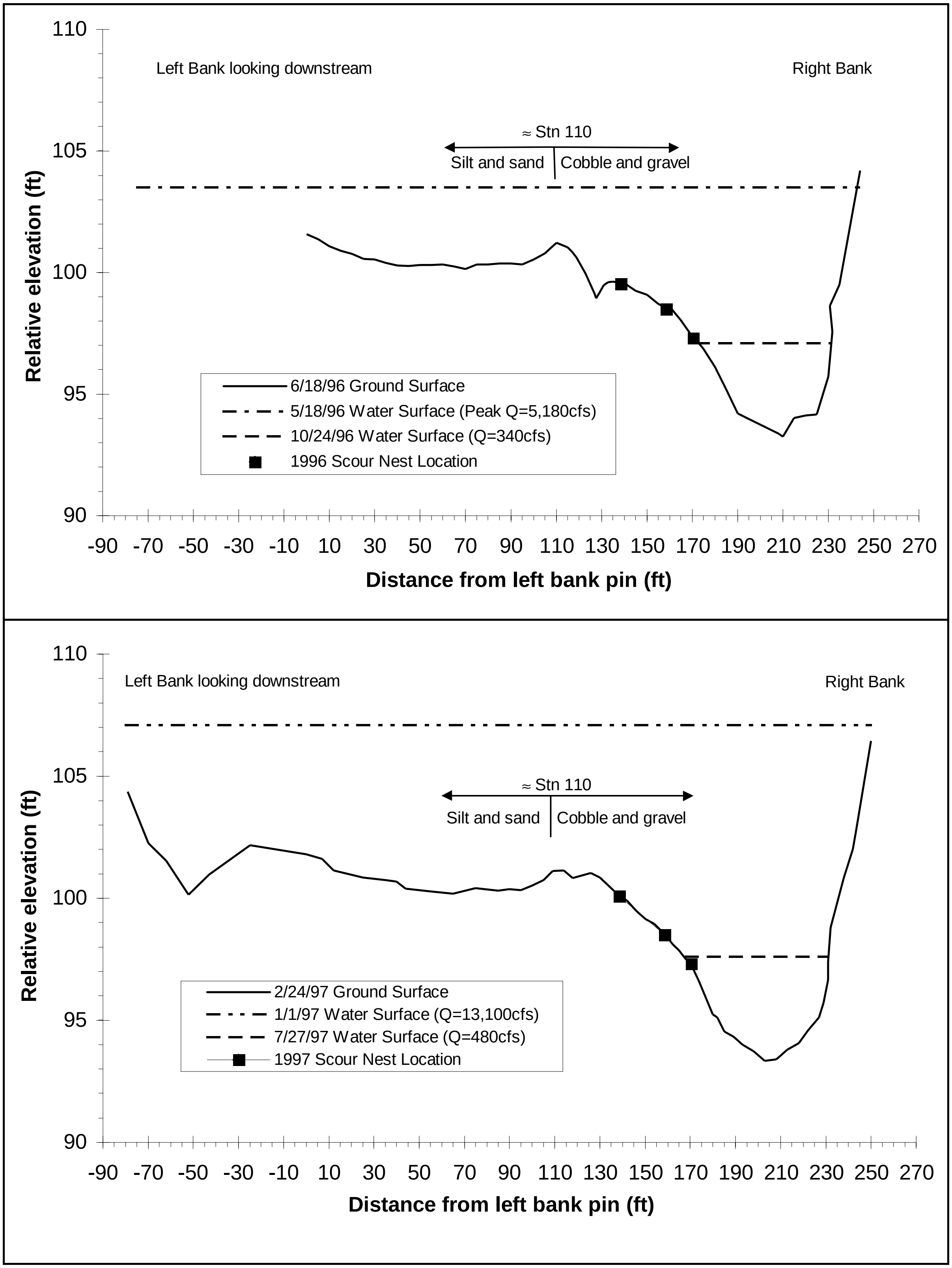


Figure 7.3 Locations of scour rock cores at the Bucktail bank rehabilitation site (RM 105.6) cross section 11+00 for WY 1996 and 1997.

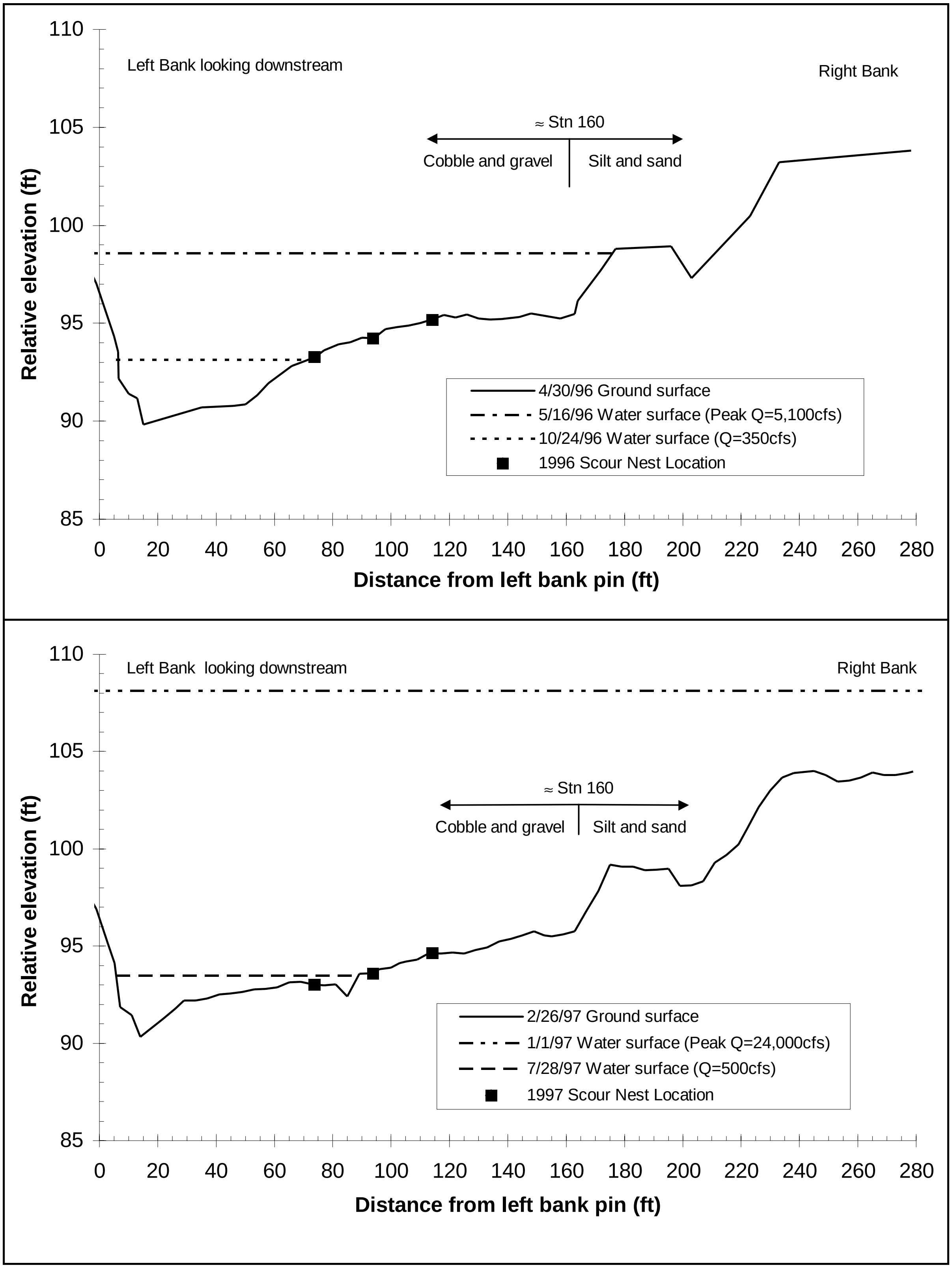


Figure 7.4 Locations of scour rock cores at the Steiner Flat bank rehabilitation site (RM 91.8) cross section 5+98 for WY 1996 and 1997.

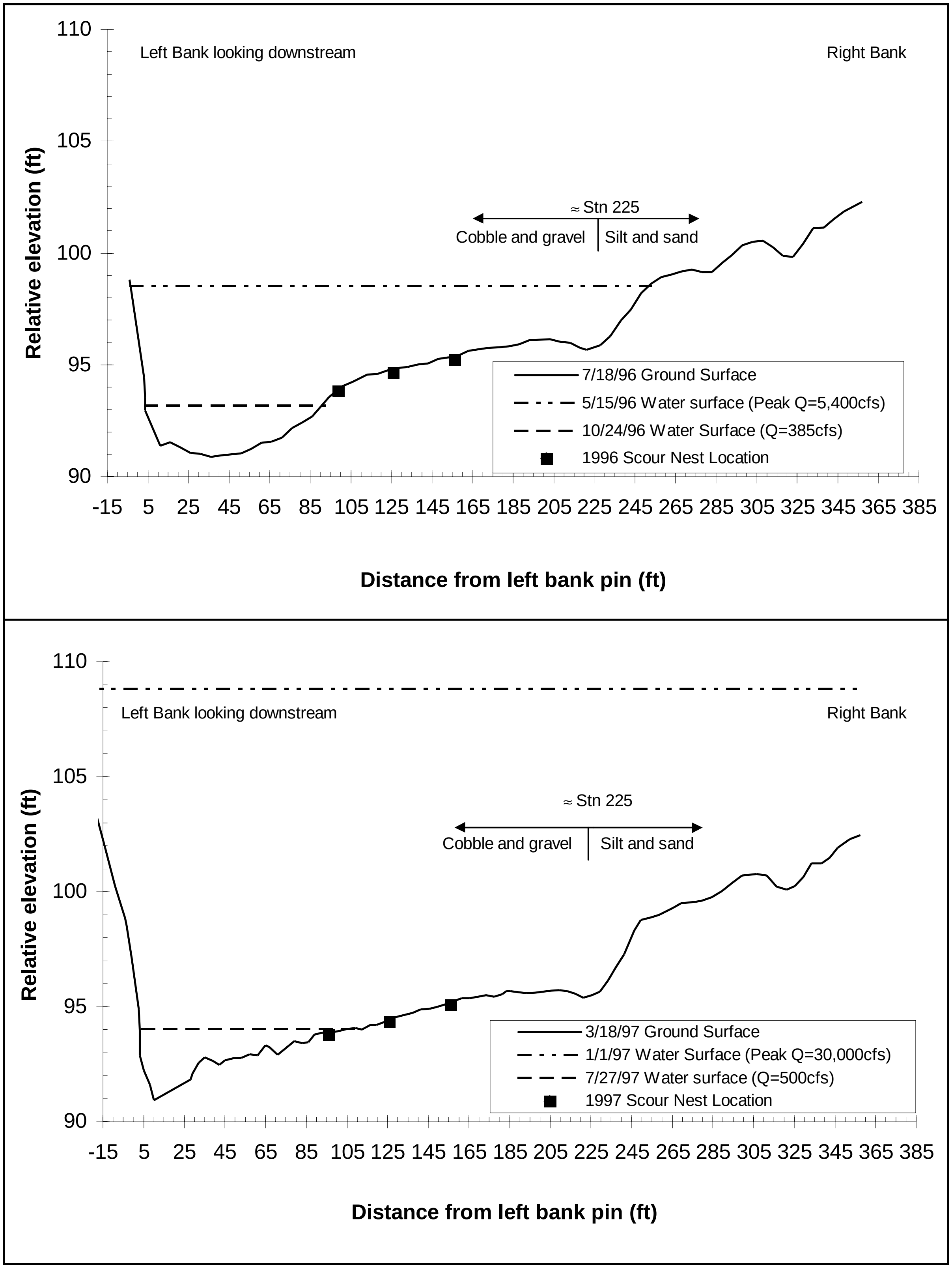


Figure 7.5 Locations of scour rock cores at the Sheridan Creek bank rehabilitation site (RM 81.6) cross section 5+35 for WY 1996 and 1997.

$$U* = \sqrt{\frac{\tau_b}{\rho}} \text{ or } \tau_{bi} = \rho U*^2 \qquad (7.4)$$

where: d_i = depth at each vertical "i" across the cross section, D_{84} = the local particle size of which 84 percent of the bed surface particle size distribution is finer, k = VonKarman's constant, ρ = water density (9.81 m/s^2), and U_{ave} = average water velocity for each vertical "i". Combining Equations 7.3 and 7.4, and solving for boundary shear stress results in:

$$\tau_{bi} = \rho \left(\frac{0.4 U_{ave}}{Ln\left(\frac{0.4 d_i}{0.1 D_{84}} \right)} \right)^2 \qquad (7.5)$$

Mean velocity at each vertical was computed by averaging velocity measurements at 0.2, 0.6, and 0.8 depths. Verticals were measured at 25 to 30 stations for each cross section. At Steiner Flat, local shear stress was estimated for four discharges ranging from 1,800 cfs to 5,100 cfs, and for three discharges ranging from 2,000 cfs to 5,400 cfs at Sheridan Creek. Local shear stress estimates for each vertical in a cross section were plotted, and the shear stress field for the entire cross section was approximated using a 5th order polynomial regression of the raw data. Local boundary shear stress (τ_b) at each scour core was estimated from this shear stress field, and then converted into Shield's parameter for the local D_{50} surface particle size ($t*_{50}$) (Equation 7.2). The Shield's parameter computed from Equation 7.2 was then plotted against representative scour depth (D_{sc}/D_{90}).

Extrapolation of WY1996 scour core results and hydraulic measurements to predict bed scour at higher discharges were problematic because shear stress fields change shape and magnitude with discharge in ways difficult to predict. Depending on discharge, estimates derived by cross-sectional averaging (Equation 7.1) and local shear stress can differ by a factor of two or more. This extrapolation required key assumptions in using the following methodology, including:

1) For each measured local shear stress field, cross sectionally averaged shear stress was also computed from Equation 7.1 using discharge-specific water surface slopes and elevations at the measurement cross section. The ratio of maximum local shear stress (using the velocity distribution) to this average shear stress was related to discharge to predict maximum local shear stress trends at higher discharge.
2) Using rating curves generated from local gaging station discharge measurements and water surface elevations at the scour core cross section, water surface elevations at discharges up to 30,000 cfs were predicted.
3) Cross sectionally averaged shear stress for these extrapolated discharges were computed from Equation 7.1, and the maximum shear stress field was predicted from the relationship developed in Step 1. Shield's parameter was then computed using Equation 7.2.
4) Dimensionless scour depths were estimated based on the bed scour relationship developed with

McBain and Trush data, and Wilcock et al. (1995) data. Multiplying this dimensionless depth by the D_{90} particle size converted it to an absolute scour depth.

7.2 Results

7.2.1 WY1991 to WY1993 scour chains

We used scour chains to measure and compare scour depth during dam releases in 1991 (2,700 cfs) and 1992 (6,000 cfs). Scour chains (see Trinity Restoration Associates [1993] for methodology) were placed in a variety of alluvial features within the low water channel; thus, variable bed scour depths were observed. Only a subset was monitored at consistent locations to directly compare scour between 2,700 and 6,500 cfs (Figure 7.6). The 2,700-cfs event did not provide significant depth of scour, but 6,500 cfs began to exceed the 2 D_{84} scour depth. Because Trinity Restoration Associates (1993) placed these scour chains only in the most mobile alluvial deposits in the low water channel where shear stresses were highest, results are not applicable to alluvial features along the channel margins. Typically, shear stresses along the channel margins are significantly lower than in the center of the channel due to momentum diffusion (Parker 1978), up to a factor of 5 or more (Wilcock et al. 1995). Therefore, 6,000 cfs is the minimum discharge required to scour 2 D_{84}'s deep in straight, uniform reaches.

7.2.2 Shields' parameter modeling

Computations of Shields parameter at a variety of sites suggests that bed scour depth is nearly always less than 2 D_{84} for flows up to 7,000 cfs (Figure 7.7), suggesting that the bed scour objective (Attribute #4) is not satisfied by flows under 7,000 cfs. While there may be some error in assuming that 2 D_{84} scour depth occurs at twice the Shields parameter at incipient motion (Figure 7.1), the trends shown on Figure 7.7 suggests that key bed mobility thresholds are being exceeded at discharges from 5,000 to 6,500 cfs, which matches well with results presented in Chapter 6. Additionally, Figure 7.7 suggests that 2 D_{84} bed scour depth rarely occurs at discharges lower than 7,000 cfs, which corroborates our scour rock data.

7.2.3 WY1996 to WY1997 scour rock core observations and hydraulic modeling

Bed scour and re-deposition differed between WY1996 and WY1997 at the Bucktail, Steiner Flat, and Sheridan Creek bank restoration sites. Scour cores in WY1996 were exposed to a dam release with minor flow augmentation by tributaries (Table 7.2) In contrast, the WY1997 peak was greatly influenced by tributary flow.

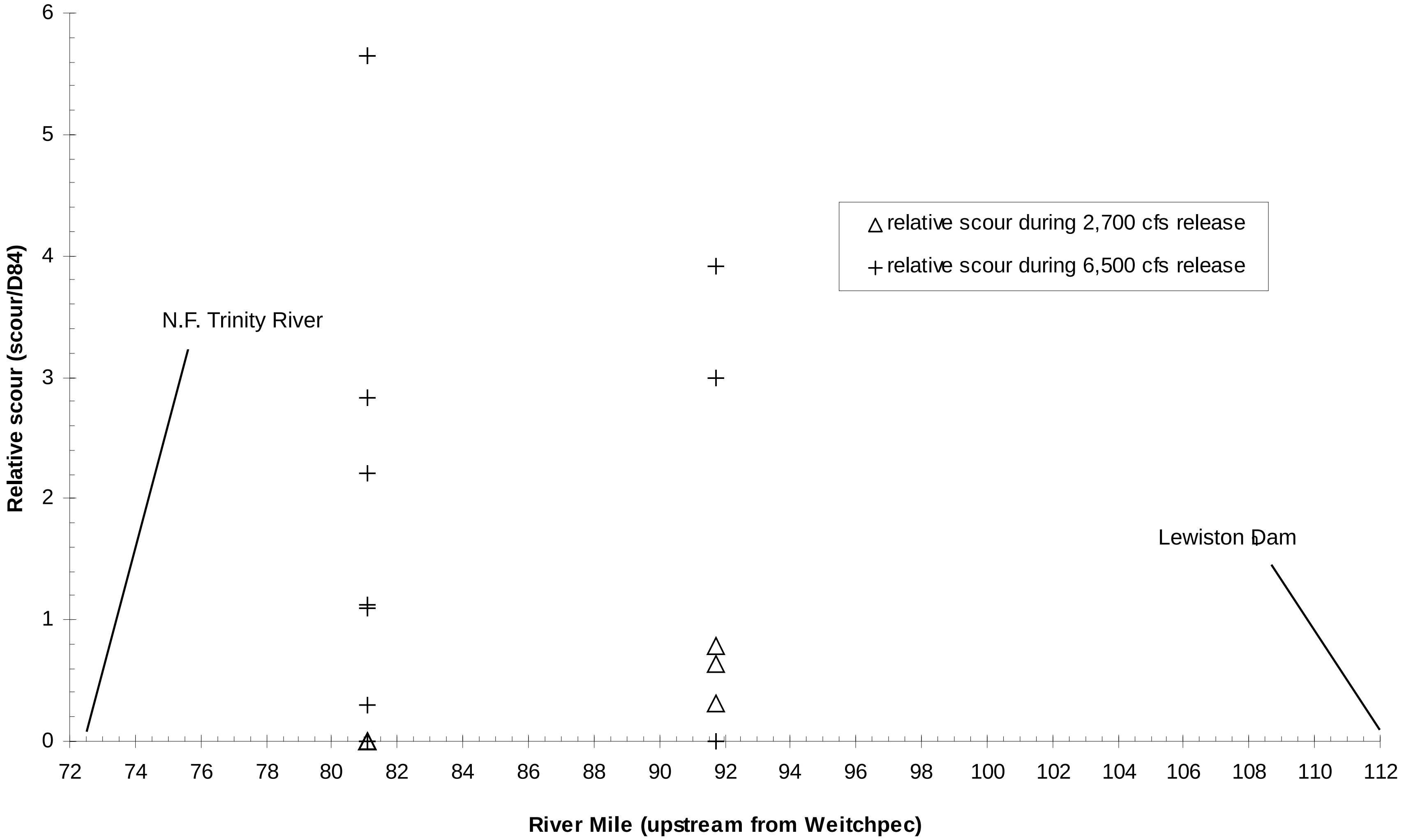


Figure 7.6 Comparison of 2,700 cfs (1991) and 6,500 cfs (1992) induced bed scour at comparable scour chain monitoring locations.

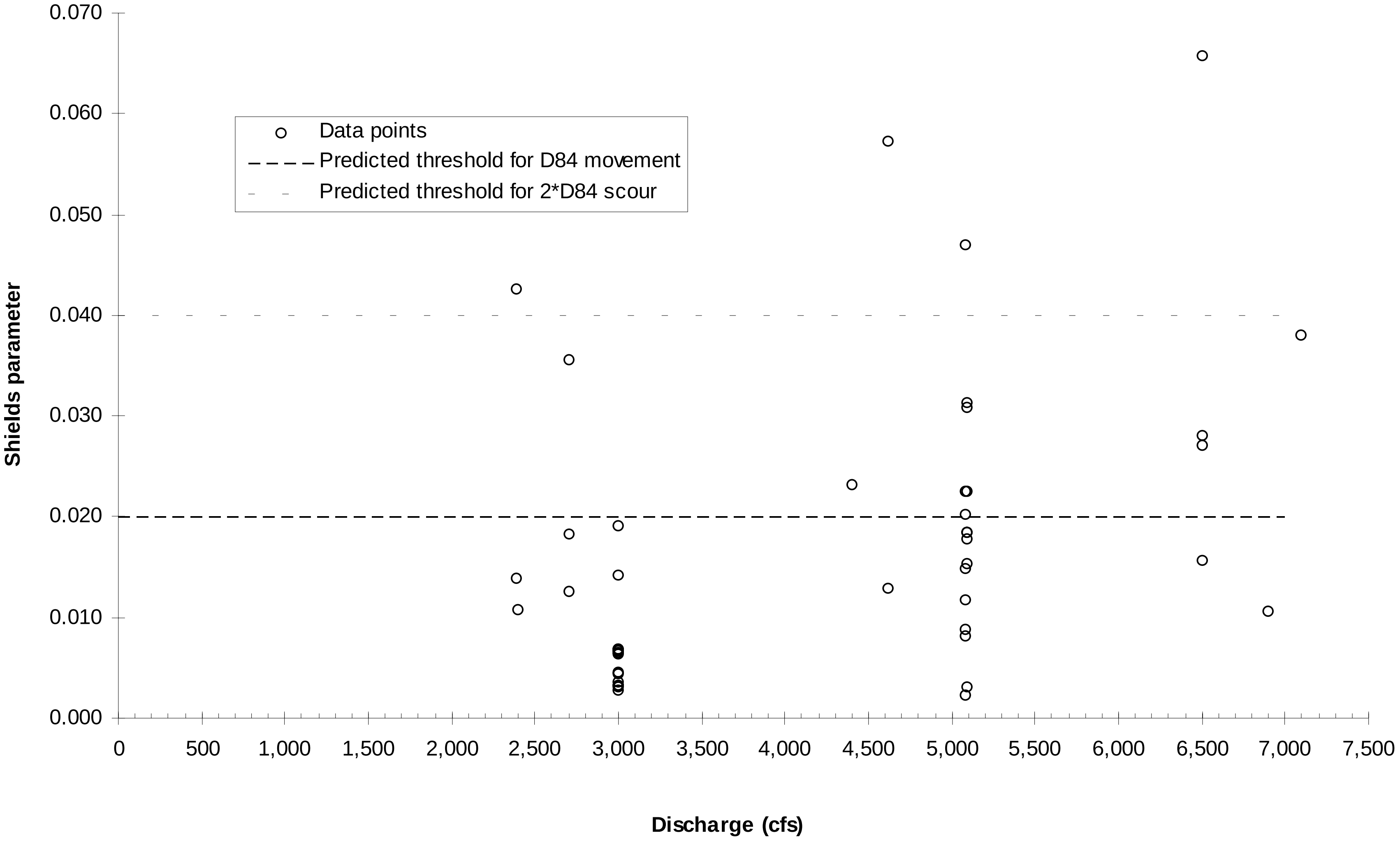


Figure 7.7 Plot of D_{84} Shields parameter for hydraulic monitoring sites at a variety of discharges, comparing whether Shields parameter surpassed predicted bed scour thresholds.

Site	River Mile	Discharge Causing Scour in WY 1996 (cfs)	Discharge Causing Scour in WY 1997 (cfs)
Bucktail	105.6	5,180	11,400
Steiner Flat	91.7	5,400	24,000
Sheridan Creek	81.6	5,600	30,000

Table 7.2 Discharges related to measured scour rock cores at the three bank rehabilitation sites.

The scour cores performed well during the WY1996 dam release, documenting scour depths on point bar surfaces at all three bank rehabilitation sites less than one D_{84} thickness (Table 7.3 and 7.5). A scour depth of less than one D_{84} was winnowing of the bed surface rather than replacement of the surface. Corresponding deposition depth was nearly the same as the scour depth (i.e., resulting in no net cross section change after the high flow). The exception was at the Bucktail and Steiner Flat sites, where areas near the low water channel aggraded approximately 0.5 ft.

Subtle scour and deposition observed during the 5,100 cfs release in WY1996 were not observed during the January 1, 1997 peak flood (Table 7.2). Except for the core highest on the bar at the Bucktail site core (which had a relative scour depth just less than two), all sites scoured deeper than their installation depths (usually greater than 1.5 ft) (Table 7.4 and 7.5). Redeposition varied between sites. At Bucktail, the bar elevation lowered near the low water channel and aggraded towards the top of the bar. The entire bar surface at Steiner Flat lowered by 0.7 ft, while the bar at Sheridan Creek remained essentially unchanged. Substantial bar degradation at Steiner Flat was partially due to the steeper slope (twice that of Sheridan Creek) and increased channel confinement at high flows. An emerging point bar on the left bank (on cross section 0+ 45) also lowered, nearly to where the pre-WY1997 flood point bar morphology was almost gone.

7.2.3.1 Extrapolation of bed scour data to higher discharges

Predicting the discharge threshold required to achieve scour greater than 2 D_{84}'s deep required extrapolation beyond Wilcock's and our measured scour depths. We assumed that the D_{84}, in our computations, was equivalent to using the D_{90} (used by Wilcock et al., 1995). We attempted this extrapolation by: (1) plotting relative scour depth as a function of discharge, and (2) predicting local shear stress on the bars at higher discharges, and using Figure 7.1 to predict relative bed scour (D_{sc}/D_{90}) as a function of Shields parameter for the D_{50} (t^*_{50}).

Documenting scour at the low and high end of the discharge spectrum in WY1996 and WY1997 gave us two important data points for empirically relating discharge to relative scour depth. A linear plot of discharge versus relative scour depth shows discharges between 8,000 and 12,000 cfs begin scouring the flanks of bar surfaces greater than 2 D_{84}'s deep (Figure 7.8). Relative scour depths greater than 2 D_{84}'s deep in Figure 7.8 represent minimum values, as the WY1997 flood scoured deeper than the

BUCKTAIL (RM 105.6) CROSS SECTION 11+00 SCOUR ROCK SUMMARY

Scour inducing discharge (5/18/96) = 5,180 cfs	Water Slope 5/18/96 = -0.0042		
5/17/96 Water Surface Elevation = 103.51ft	1996 D_{50}= 48 mm	1996 D_{84}= 81 mm	1996 D_{90}= 102 mm
	Station 138.5	Station 158.60	Station 170.50
Elevation of top of scour rocks pre-flow	99.55 ft	98.50 ft	97.30 ft
Elevation of top of scour rocks post flow	99.44 ft	98.31 ft	97.06 ft
Scour	-0.11 ft	-0.19 ft	-0.24 ft
Scour	-34 mm	-58 mm	-73 mm
Elevation of top of gravel surface post flow	99.58 ft	98.55 ft	97.42 ft
Deposition	0.14 ft	0.24 ft	0.36 ft
Deposition	43 mm	73 mm	110 mm

STEINER FLAT (RM 91.7) CROSS SECTION 598 SCOUR ROCK SUMMARY

Scour inducing discharge (5/17/96) = 5,409 cfs	Water Slope 5/17/96 = -0.0029		
5/17/96 Water Surface Elevation= 98.12 ft	1996 D_{50}= 51 mm	1996 D_{84}= 99 mm	1996 D_{90}= 108 mm
	Station 73.5	Station 93.7	Station 114
Elevation of top of scour rocks pre-flow	93.28 ft	94.24 ft	95.18 ft
Elevation of top of scour rocks post flow	93.13 ft	94.16 ft	95.12 ft
Scour	-0.15 ft	-0.08 ft	-0.06 ft
Scour	-46 mm	-24 mm	-18 mm
Elevation of top of gravel surface post flow	93.71 ft	94.33 ft	95.17 ft
Deposition	0.58 ft	0.17 ft	0.05 ft
Deposition	177 mm	52 mm	15 mm

SHERIDAN CREEK (RM 81.6) CROSS SECTION 535 SCOUR ROCK SUMMARY

Scour inducing discharge (5/18/96) = 5,632 cfs	Water Slope 5/18/96 = -0.0015		
5/18/96 Water Surface Elevation= 98.51 ft	1996 D_{50}= 34 mm	1996 D_{84}= 60 mm	1996 D_{90}= 66 mm
	Station 96	Station 126	Station 156
Elevation of top of scour rocks pre-flow	93.83 ft	94.64 ft	95.24 ft
Elevation of top of scour rocks post flow	93.69 ft	94.60 ft	95.33 ft
Scour	-0.14 ft	-0.04 ft	0.00 ft
Scour	-43 mm	-12 mm	0 mm
Elevation of top of gravel surface post flow	93.69 ft	94.84 ft	95.33 ft
Deposition	0.00 ft	0.24 ft	0.00 ft
Deposition	0 mm	73 mm	0 mm

Table 7.3 Summary of 1996 scour rock core results at the Bucktail, Steiner Flat, and Sheridan Creek rehabilitation sites.

BUCKTAIL (RM 105.6) CROSS SECTION 11+00 SCOUR ROCK SUMMARY

Scour inducing discharge (1/1/97) = 13,100 cfs Water Slope 1/1/97 = -0.0019

1/1/97 Water Surface Elevation= 105.56 ft 1997 D_{50}= 38.5 mm 1997 D_{84}= 76 mm 1997 D_{90}= 88 mm

	Station 138.5	Station 158.60	Station 170.50	
Elevation of top of scour rocks pre-flow	99.58 ft	98.55 ft	97.42 ft	
Elevation of top of scour rocks post flow	99.19 ft	97.08 ft	96.50 ft	THIS ELEVATION IS THE BOTTOM HOLE TRACER GRAVEL NOT RECOVERD
Scour	-0.39 ft	-1.47 ft	-0.92 ft	
Scour	-119 mm	-448 mm	-280 mm	
Elevation of top of gravel surface post flow	100.11 ft	98.56 ft	97.24 ft	
Deposition	0.92 ft	1.48 ft	0.74 ft	
Deposition	280 mm	451 mm	226 mm	

STEINER FLAT (RM 91.7) CROSS SECTION 598 SCOUR ROCK SUMMARY

Scour inducing discharge (1/1/97) = 24,000 cfs Water Slope 1/1/97 = -0.0014

1/1/97 Water Surface Elevation= 108.02 ft 1997 D_{50}= 58 mm 1997 D_{84}=105 mm 1997 D_{90}= 95 mm

	Station 73.5	Station 93.7	Station 114	
Elevation of top of scour rocks pre-flow	93.71 ft	94.33 ft	95.17 ft	
Elevation of top of scour rocks post flow	91.95 ft	92.62 ft	93.37 ft	THIS ELEVATION IS THE BOTTOM HOLE TRACER GRAVEL NOT RECOVERD
Scour	-1.76 ft	-1.71 ft	-1.80 ft	
Scour	-536 mm	-521 mm	-549 mm	
Elevation of top of gravel surface post flow	93.02 ft	93.60 ft	94.63 ft	
Deposition	1.07 ft	0.98 ft	1.26 ft	
Deposition	326 mm	299 mm	384 mm	

SHERIDAN CREEK (RM 81.6) CROSS SECTION 535 SCOUR ROCK SUMMARY

Scour inducing discharge (1/1/97) = 30,000 cfs Water Slope 1/1/97 = -0.0015

1/1/97 Water Surface Elevation= 108.82 ft 1997 D_{50}=60 mm 1997 D_{84}=105 mm 1997 D_{90}= 110 mm

	Station 96	Station 126	Station 156	
Elevation of top of scour rocks pre-flow	93.69 ft	94.84 ft	95.33 ft	
Elevation of top of scour rocks post flow	92.67 ft	93.12 ft	94.03 ft	THIS ELEVATION IS THE BOTTOM HOLE TRACER GRAVEL NOT RECOVERD
Scour	-1.02 ft	-1.72 ft	-1.30 ft	
Scour	-311 mm	-524 mm	-396 mm	
Elevation of top of gravel surface post flow	93.88 ft	94.58 ft	95.09 ft	
Deposition	1.21 ft	1.46 ft	1.06 ft	
Deposition	369 mm	445 mm	323 mm	

Table 7.4 Summary of 1997 scour rock core results at the Bucktail, Steiner Flat, and Sheridan Creek rehabilitation sites.

Bucktail 1996
D_{50}=48 mm
D_{84}=81 mm
D_{90}=102 mm

Bucktail 1997
D_{50}=39 mm
D_{84}=76 mm
D_{90}=88 mm

Steiner 1996
D_{50}=51 mm
D_{84}=99 mm
D_{90}=108 mm

Steiner 1997
D_{50}=58 mm
D_{84}=105 mm
D_{90}=119 mm

Sheridan Ck 1996
D_{50}=34 mm
D_{84}=60 mm
D_{90}=66 mm

Sheridan Ck 1997
D_{50}=60 mm
D_{84}=105 mm
D_{90}=110 mm

Poker Bar
D50= 22mm
D_{90}=77 mm

Steelbridge
D_{50}=40 mm
D_{90}=140 mm

McBAIN AND TRUSH 1996-1997 DATA

Local Shields Parameter D50	Scour depth (mm)	Relative D90 Scour	Cross section Station (ft)	Discharge (cfs)	Bank rehabilitation site and cross section
N/A	34	0.33	138.5	5,100	Bucktail XS 11+00
N/A	58	0.57	158.6	5,100	Bucktail XS 11+00
N/A	73	0.72	170.5	5,100	Bucktail XS 11+00
N/A	119	1.35	138.5	11,400	Bucktail XS 11+00
N/A	>448	>5.09	158.6	11,400	Bucktail XS 11+00
N/A	>280	>3.18	170.5	11,400	Bucktail XS 11+00
0.054	46	0.43	73.5	5,400	Steiner Flat XS 5+98
0.056	24	0.22	93.7	5,400	Steiner Flat XS 5+98
0.052	18	0.17	114	5,400	Steiner Flat XS 5+98
0.129	>536	>4.50	73.5	24,000	Steiner Flat XS 5+98
0.129	>521	>4.38	93.7	24,000	Steiner Flat XS 5+98
0.129	>549	>4.61	114	24,000	Steiner Flat XS 5+98
0.047	43	0.65	96	5,600	Sheridan Crk XS 5+35
0.039	12	0.18	126	5,600	Sheridan Crk XS 5+35
0.036	0	0.00	156	5,600	Sheridan Crk XS 5+35
0.109	>311	>2.83	96	30,000	Sheridan Crk XS 5+35
0.109	>524	>4.76	126	30,000	Sheridan Crk XS 5+35
0.109	>396	>3.60	156	30,000	Sheridan Crk XS 5+35

WILCOCK et al., 1995 DATA

Local Shields Parameter D50	Scour depth (mm)	Relative D90 Scour	Cross section Station (ft)	Discharge (cfs)	Bank rehabilitation site and cross section
0.106	129	1.77 *	26	6,500	Poker Bar XS 2
0.098	105	1.50 *	30	6,500	Poker Bar XS 2
0.091	119	1.78 *	28.5	6,500	Poker Bar XS 2
0.067	110	0.96 *	11	6,500	Steelbridge XS 3C
0.054	104	0.85 *	12.5	6,500	Steelbridge XS 3C
0.052	88	0.84 *	8.8	6,500	Steelbridge XS 3C
0.048	0	0.00 *	16.5	6,500	Steelbridge XS 3C
0.031	8	0.03 *	14	2,700	Steelbridge XS 3C

* These data taken from Figure 6.3.2 of Wilcock et al., 1995.

Table 7.5 Summary of local shear stress and bed scour at McBain & Trush and Wilcock et.al., study sites.

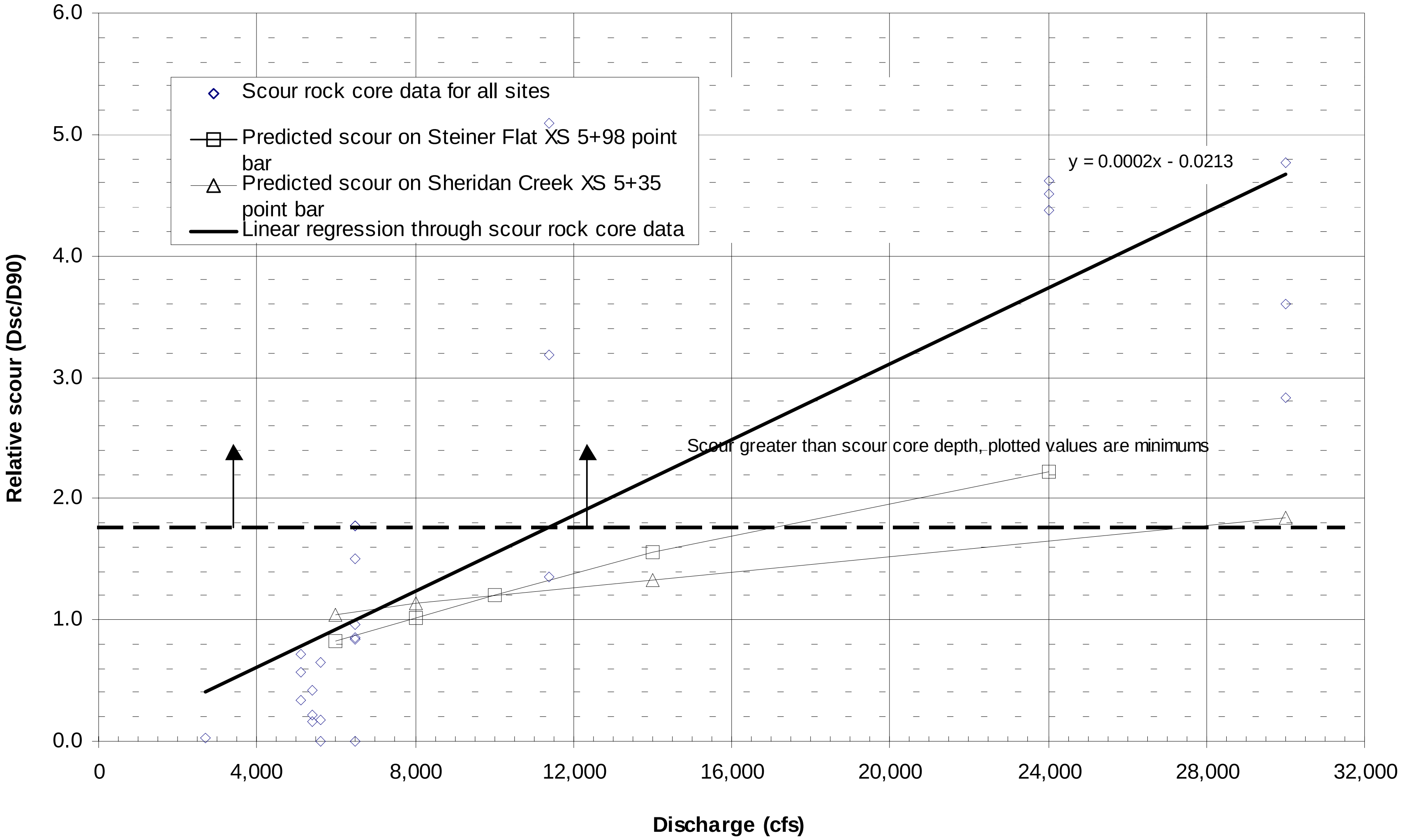


Figure 7.8 Relative scour depth (D_{sc}/D_{90}) as a function of discharge on newly formed point bars at bank rehabilitation sites, including Wilcock et al., (1995) data.

depth of the scour rock cores (usually > 1.5 ft deep). Because the regression was computed with these minimum scour depths, the regressions only provide an approximate discharge range where the 2 D_{84} scour depth would occur. Given this regression was based on minimum scour, the error in our flood peak estimates, and that the core highest on the bar at Bucktail almost scoured 2 D_{84}'s deep at 11,400 cfs, a minimum discharge of 11,000 cfs may satisfy our objective of scouring an entire bar.

We improved scour depth estimates in Figure 7.8 by extrapolating local shear stress fields to higher discharges at the Steiner Flat and Sheridan Creek bank rehabilitation sites. During the WY1996 dam release, the 5,100 cfs release was relatively constant for us to measure water velocity profiles at the Steiner Flat and Sheridan Creek site. We measured 3-point velocity profiles at 25 to 30 verticals near cross section 5+98 at Steiner Flat and near cross section 5+35 at Sheridan Creek. This was done for four flows (1,800 cfs to 5,100 cfs) at Steiner Flat and three flows at Sheridan Creek (2,070 cfs to 5,400 cfs). From these velocity profiles, the local shear stress field was estimated using Equation 7.4 (Figures 7.9 and 7.10), then used to evaluate bed scour depth at specific locations within the cross section for the discharge measured.

We estimated shear stresses on the flanks of point bars estimate flows that can scour initiating riparian seedlings. Local shear stress predicted from velocity profiles was more accurate than local shear stress computed with local depth or cross sectionally averaged depth. On Steiner Flat cross section 5+98, we computed local shear stress from stations 70 ft to 140 ft (Figure 7.9); for Sheridan Creek cross section 4+85, we targeted stations 90 ft to 190 ft (Figure 7.10). For the WY1996 release, our relative scour depth data (Table 7.3) and corresponding D_{50} Shields parameter data were added to Wilcock et al.'s relationship between local τ^*_{D50} and relative scour depth (Figure 7.11). We fit other curves to the data for the WY1997 scour core data (discussed later).

The next step was to extrapolate the shear stress field to higher discharges. One important trend in the shear stress fields for both sites was a shift in the maximum shear stress from the thalweg onto the point bar face. Because flow vectors straighten through a sinuous meanderwith increasing discharge, this shift was expected. However, the decrease in maximum shear stress with a doubling of discharge was not expected (Figures 7.9 and 7.10). Similar shear stress fields in reaches with both riparian berms intact showed no shift in the maximum shear stress zone and a doubling of maximum shear stress with a two-fold increase in discharge (Figure 7.12).

While this shift makes extrapolation to higher discharges extremely difficult, it provided considerable insight into sediment transport, particle sorting, riparian scour, channel stability, and channel design between restored and unrestored reaches of the Trinity River. Nevertheless, we knew that as flows increased and channel confinement from valley walls began to be exerted, shear stresses must increase with discharges larger than those measured (>5,400 cfs). We extrapolated to higher discharges as follows:

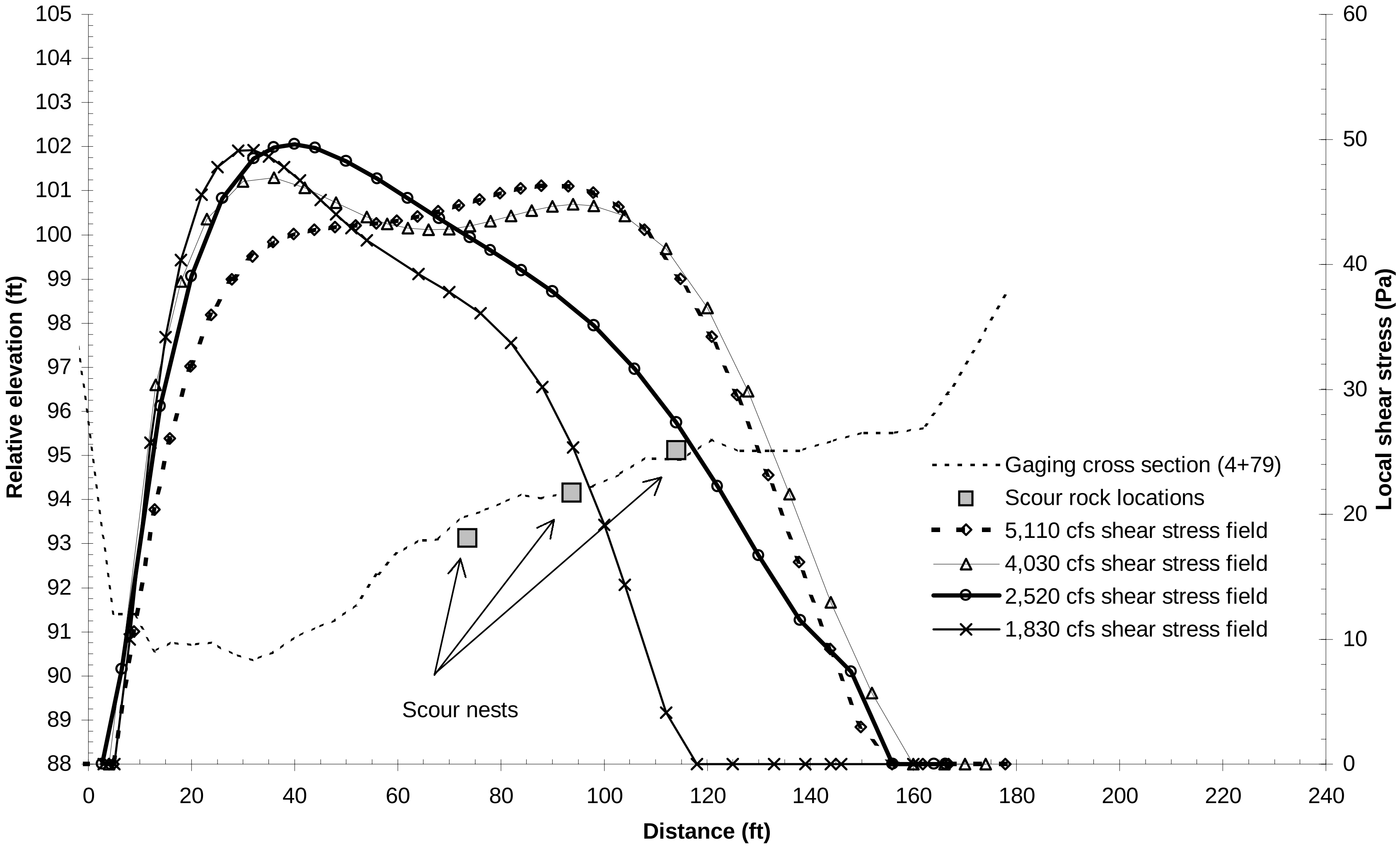


Figure 7.9 1996 shear stress distributions on Steiner Flat cross section 5+98, showing change in magnitude and location with rising discharge.

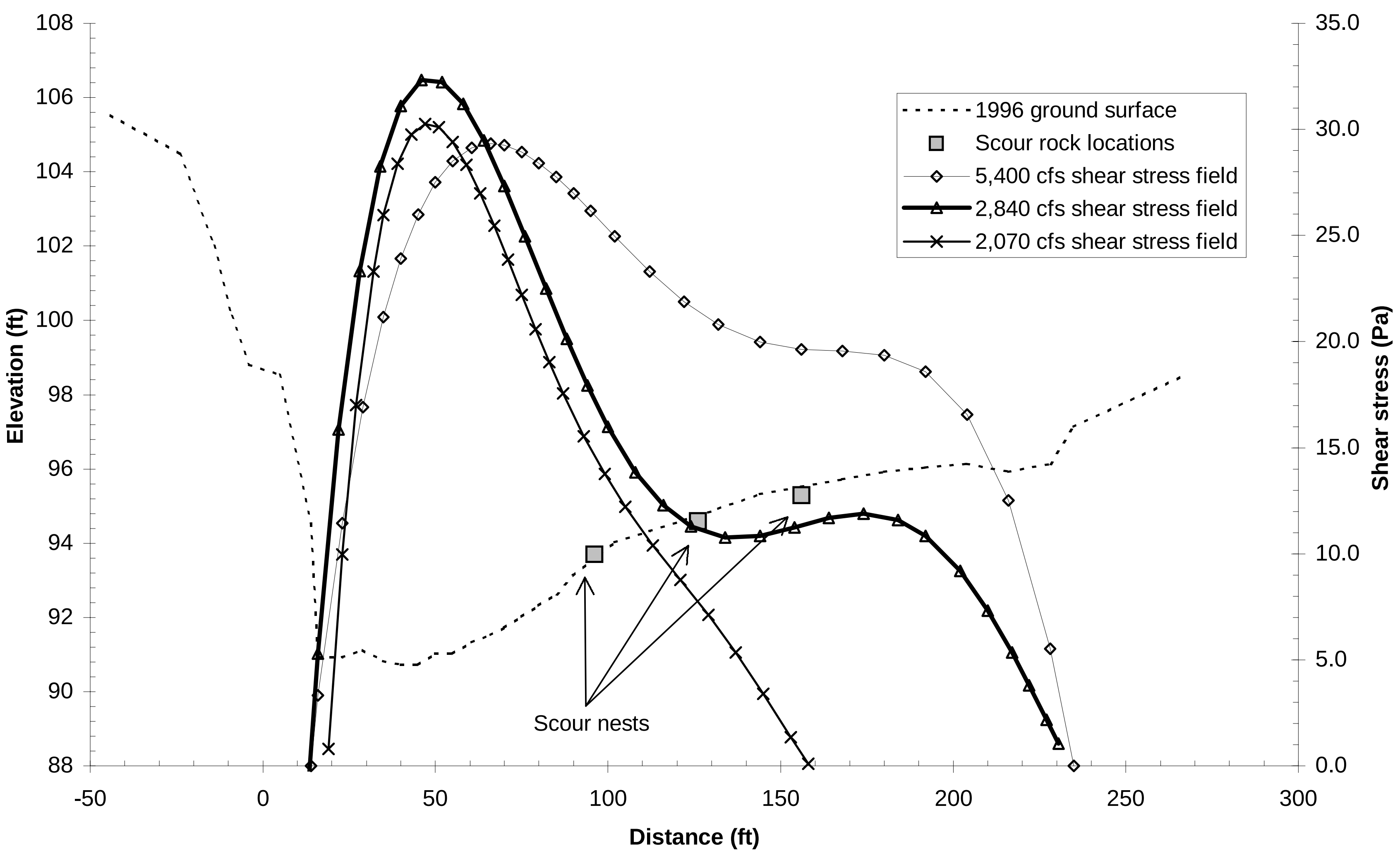


Figure 7.10 1996 shear stress distributions on Sheridan Creek cross section 5+35, showing change in magnitude and location with rising discharge.

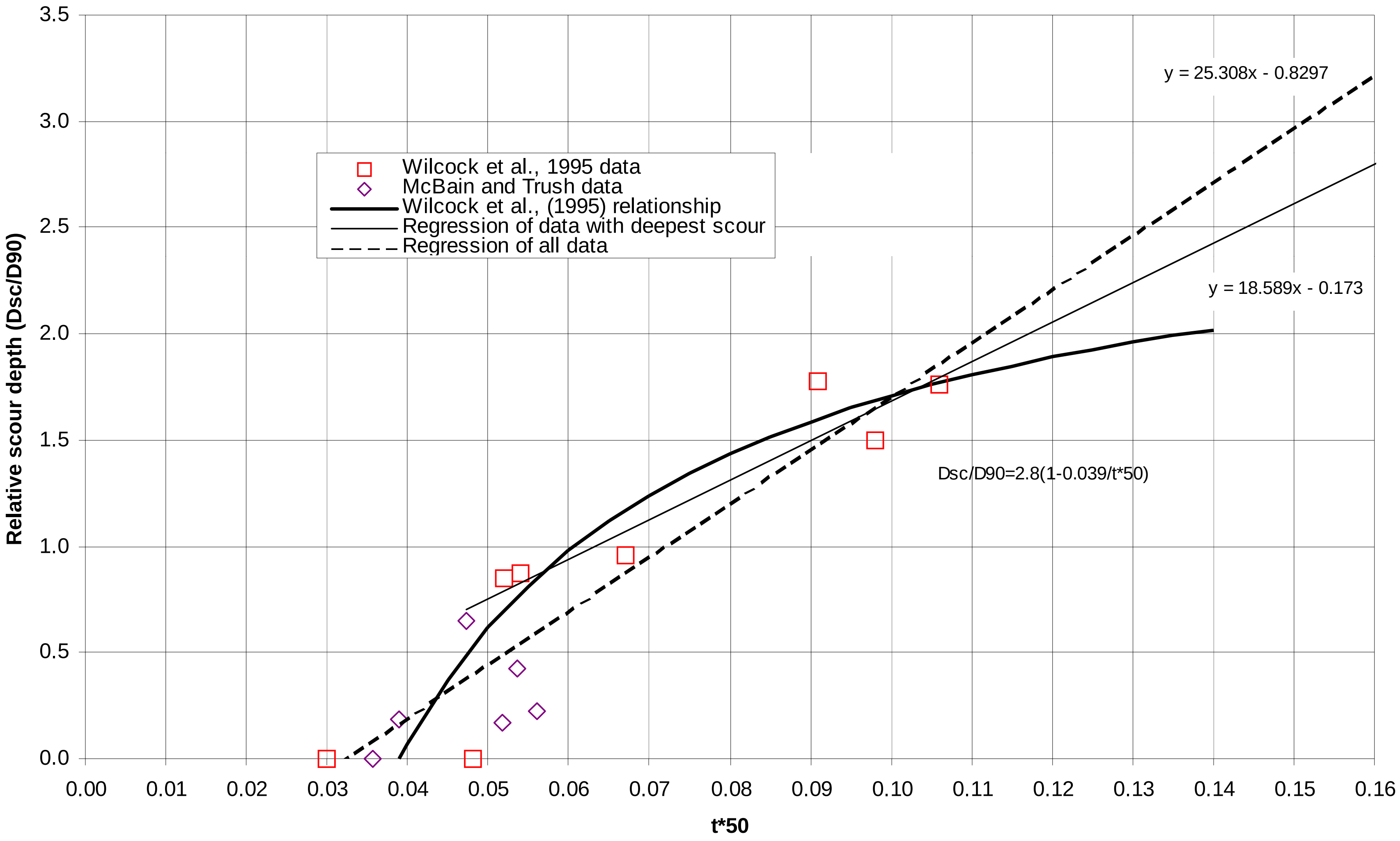


Figure 7.11 Plot of relative scour depth as a function of D_{50} Shields parameter, using 1996 scour rock core data and Wilcock et al., 1995 data.

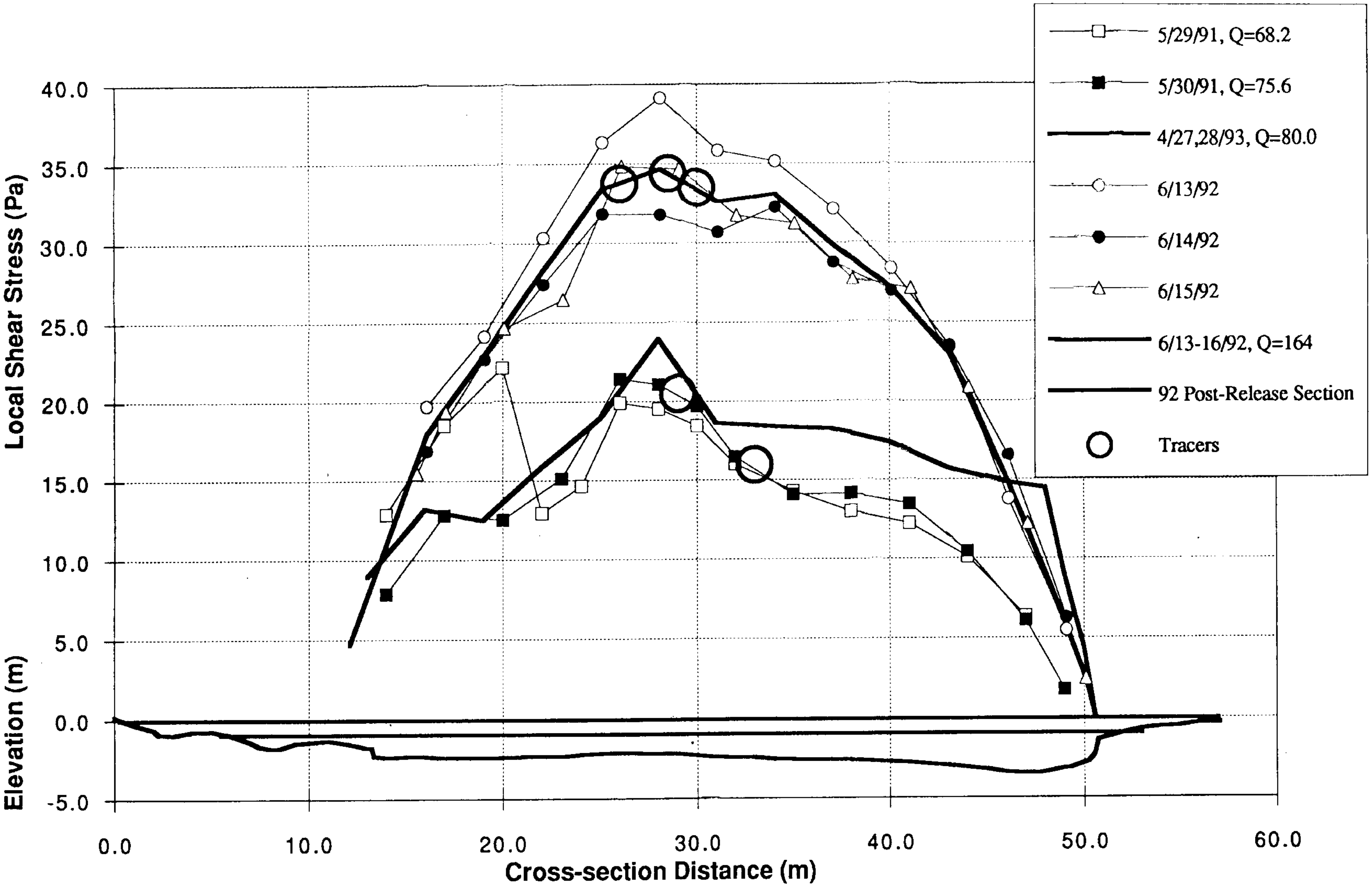


Figure 7.12 From Wilcock et al., (1995). 2,700 cfs and 6,500 cfs shear stress fields at Poker Bar study site, showing rapid increase in peak shear stress and similar shape of distribution. Contrast with Figures 7.9 and 7.10.

1) We computed cross sectionally averaged shear stress from Equation 7.1 for each measured discharge and plotted this average against the maximum local shear stress from Equation 7.5. As flows spread across the point bar and emerging floodplain, the ratio of peak shear stress to average decreased towards 1.0. Due to the trend for each site, we assumed that the ratio was 1.25 for Steiner Flat and 1.5 at Sheridan Creek for higher discharges.

2) For discharges >5,400 cfs, we estimated water surface elevations from rating curves on the cross section, and computed cross sectionally averaged shear stress using the hydraulic radius and measured water surface slopes. We then multiplied this average shear stress by the peak/average shear stress ratio to estimate peak shear stress over the bar surface (the target location of the bed scour objective). Because the local shear stress fields in Figures 7.9 and 7.10 flattened out over the bar surface, we assumed that this flattening trend continued at higher discharges and that peak shear stress could be applied to the entire bar surface.

3) We then computed Shields parameter for the D_{50} from Equation 7.2, using this maximum shear stress estimate (Figures 7.13 and 7.14) and Wilcock's relationship (Figure 7.1), to predict relative scour (D_{sc}/D_{90}).

This approach predicted that discharges in excess of 20,000 cfs would be required to scour the bed surface deeper than 2 D_{90}'s (Figure 7.8), which was unreasonable given our bed scour observations from the WY1997 flood. This poor prediction resulted from: (1) extending Wilcock's curve to higher stresses was inaccurate due to the decreasing slope of the curve, and (2) the Shields parameter may work well for predicting bed mobilization, but the mechanics of bed scour may be more a function of bedload transport rate or coarse surface layer breakdown than the Shields parameter. Re-fitting a curve through ours and Wilcock's data for relative scour greater than 0.6 (Figure 7.11) increased the slope of the curve (thus scour depth), but still greatly under-predicted observed scour depths at higher discharges.

7.3 Summary

Bed scour and re-deposition during large floods are processes usually overlooked as an important restoration objective, but is critical for maintaining point bar surfaces free of vegetation and chronic fine sediment intrusion. However, accurate and predictive approaches are poorly developed. Our predictive needs had to rely mainly on scour chains and scour rock core observations. Results show that:

- Flows from 2,700 cfs to 3,000 cfs were not sufficient to cause significant bed scour in the most mobile of alluvial deposits within the low water channel (pool tails and medial bars).
- Flows over 6,000 cfs begin to provide relative scour depths (D_{sc}/D_{84}) greater than two in these same low water channel alluvial deposits.
- Bed mobilization, but not scour, began at flows greater than 5,000 cfs on newly formed point bar

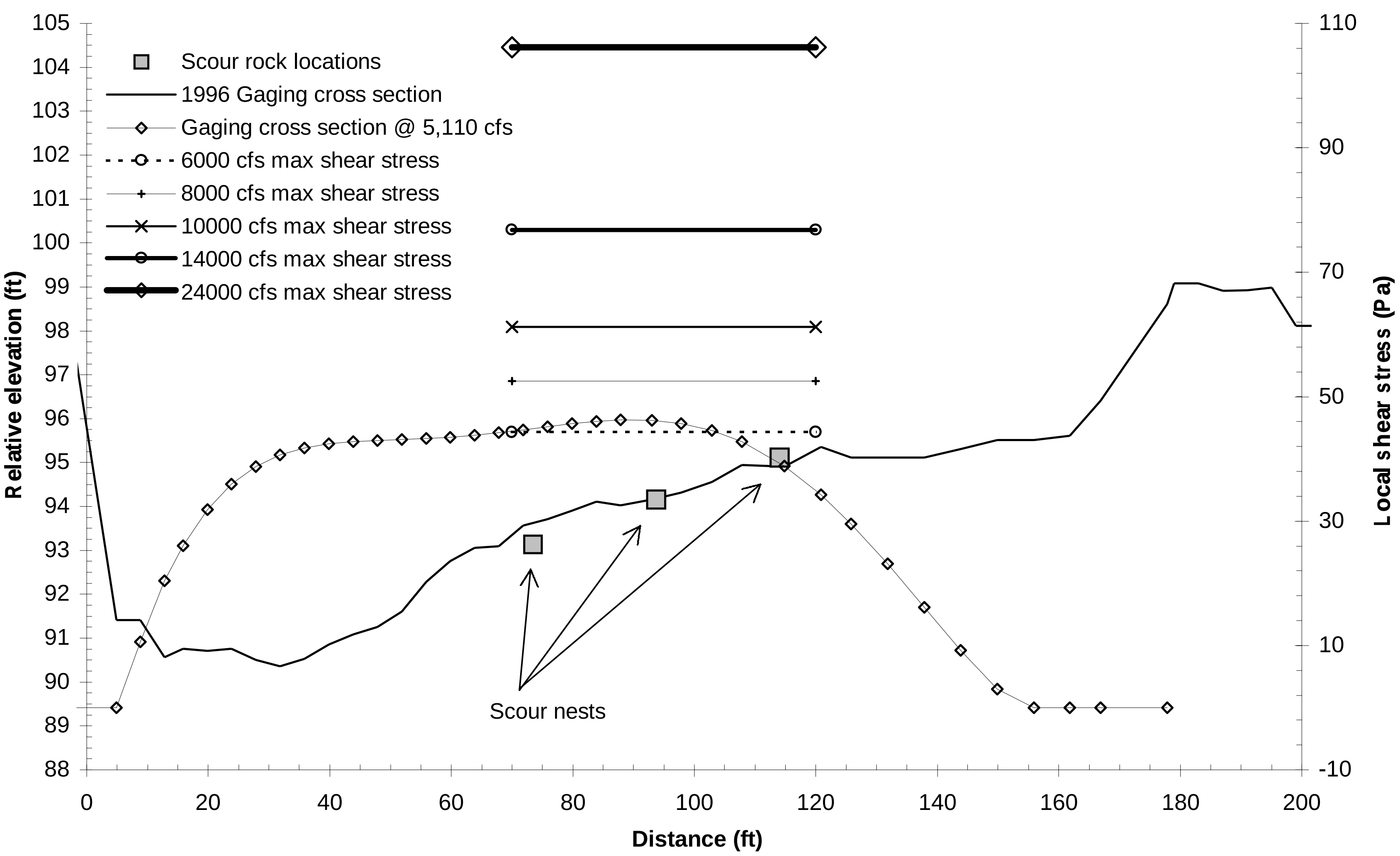


Figure 7.13 Extrapolated local shear stress to larger discharges over Steiner Flat cross section 5+98.

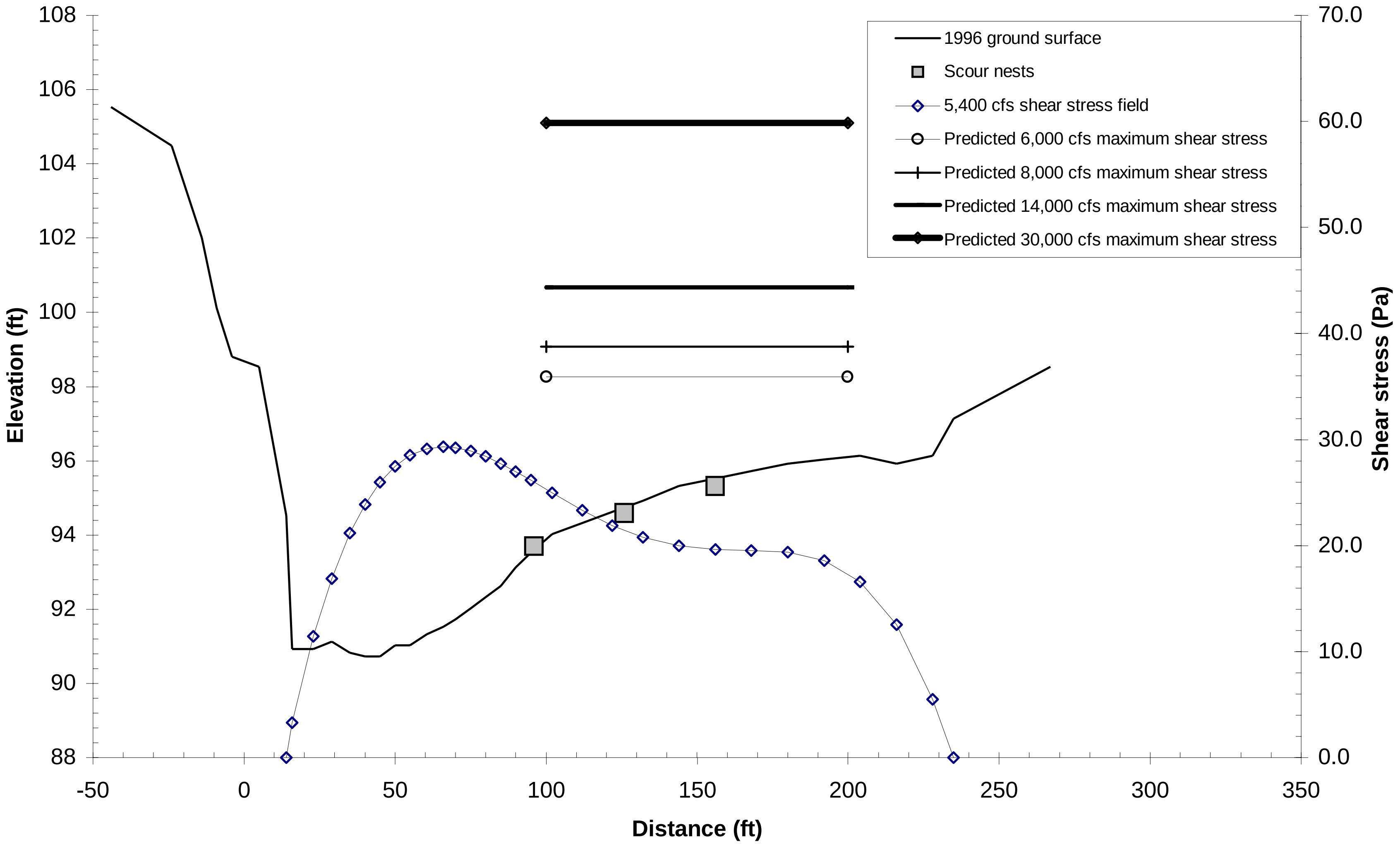


Figure 7.14 Extrapolated local shear stress to larger discharges over Sheridan Creek cross section 5+35.

faces along the channel margin (outside the low water channel).

- Bed scour greater than 2 D_{84}'s deep occurred between 8,000 cfs and 11,400 cfs. A minimum of 11,000 cfs may satisfy our objective of scouring an entire bar. This estimate is a departure point for more channelbed scour monitoring. A range of discharge from 14,000 to 16,000 cfs would be a less risky minimum. Given the importance of channelbed scour in the river ecosystem and the variability of bar morphology, this higher flow range should be the minimum if adaptive management were not prescribed for future refinement of channelbed scour modeling.

Increasing our understanding of bed scour mechanics and increasing the precision of bed scour predictions are top priorities in our WY1998 study plan. Scour rock cores provided superior results when conducted properly. The scour chains often pulled out of the bed (in finer deposits) or broke entirely. When we could not relocate a scour chain after a high flow, we had no idea whether the bed scoured beyond the depth of the scour chain or the chain broke; therefore, the chain provided no data at all. However, as occurred during the WY1997 floods, when we could not locate the scour rock cores, the bed must have scoured beyond the maximum depth of scour rocks placed. While this did not give us an absolute depth of scour, it provided a useful minimum scour depth.

<u>CHAPTER 8:</u> SEDIMENT BUDGET

Attribute No. 5. BALANCED FINE AND COARSE SEDIMENT BUDGETS.
River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be capable of transport through the river reach.

<u>8.1 Introduction</u>

A sediment budget is simply defined by the sediment continuity equation:

$$I - O = \Delta S \qquad (8.1)$$

where: I is volume of sediment Input, O is volume of sediment Output, and ΔS is change in Storage. The spatial scale of a sediment budget can extend from a watershed (Dietrich et al. 1980) to a short reach of channel. Considering the post-TRD mainstem, Input into the reach has been eliminated by the dam (I=0) while Output has been greatly reduced due flow regulation. Therefore, change in Storage must decrease with time. Reduced alluvial storage below dams is well documented (e.g., Williams and Wolman 1984; Kondolf and Matthews 1993).

The sediment budget can be partitioned by particle size class as follows:

1. the coarse sediment budget, represented by particles ranging from coarse sand to small boulders that are transported as bedload (transported particles are in almost continuous contact with the bed surface);
2. the fine sediment budget, represented by particles finer than coarse sand that are transported in suspension (transported particles are suspended in the water column, with infrequent contact with the bed surface).

Subdividing the sediment budget is useful for sampling as well as identifying sediment impacts on ecosystem and salmonid habitat.

In Chapter 2 we described how the TRD changed the sediment supply and sediment transport capacity downstream of Lewiston Dam. The imbalance to the sediment budget has greatly altered channel morphology, alluvial storage, and sediment transport. For an alluvial river to function, alternate bars and other alluvial features (e.g. spawning gravel deposits) must scour and fill. Though most changes to the existing sediment budget are harmful, some can be beneficial. For example, a reduction in fine sediment supply (Input), while maintaining the fine sediment transport capacity (Output), would result in reduced mainstem Storage. This may improve spawning gravel quality and increase pool volume, but disrupting the sediment budget is usually detrimental to instream habitats. Some post-TRD changes on the mainstem have been:

1. Changing land use practices (BLM 1995) has increased fine sediment supply from tributaries since completion of the TRD. Reduced fine sediment transport capacity in the mainstem Trinity River has allowed these fine sediments to deposit in the mainstem rather than routing through or being deposited on functional floodplain surfaces. Fine sediment has filled pools and infiltrated spawning gravels. Riparian berms have formed and interstitial spaces of riffle/run channelbed surfaces have filled (crucial habitat for fry rearing and juvenile salmonid over-wintering).
2. The TRD has eliminated coarse sediment supply from the upper watershed. Since completion of the TRD, a large portion of the remaining mainstem alluvium (pre-TRD bars) was either fossilized by riparian encroachment or scoured away (without replacement) during infrequent mainstem high flow releases. This drastically reduced the quantity of available alluvial deposits for supplying salmonid spawning and rearing habitat.
3. Coarse sediment supply from downstream tributaries continued at an equal or slightly higher rate, while reduced mainstem transport capacity could not remove coarse tributary sediment from depositing at the tributary junctions. Locally, the bed elevation at these tributary junctions aggraded up to eight feet, based on field surveys of channel topography. At Rush Creek, Grass Valley Creek, and Indian Creek, aggraded deltas (compared to pre-TRD deltas) caused major backwaters during high mainstem flows. These backwaters prevented coarse sediments in the mainstem from transporting past the tributary junctions, impeding mainstem coarse sediment routing (Figure 8.1).

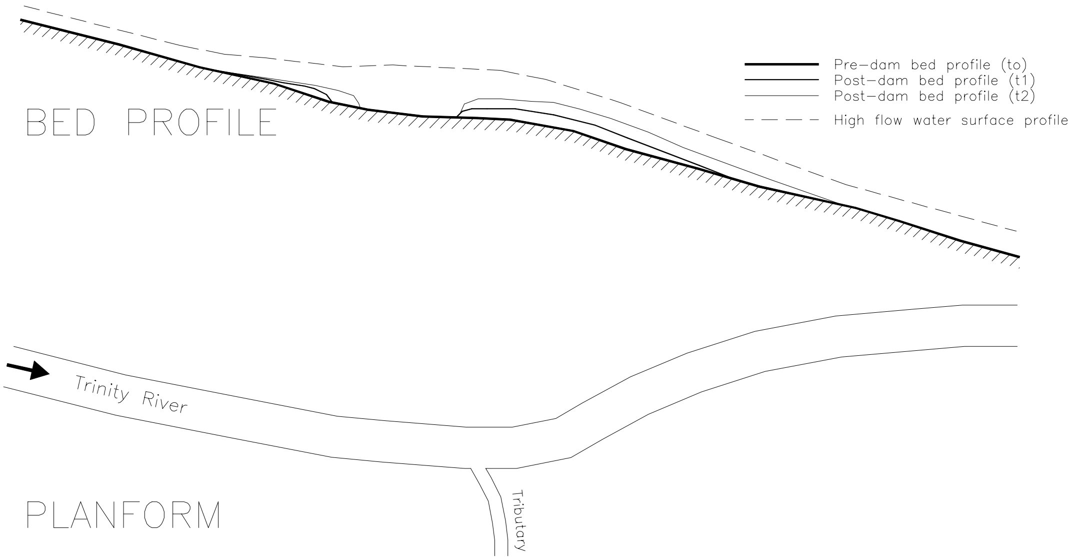


Figure 8.1 Idealized tributary delta evolution resulting from unbalanced coarse sediment budget in mainstem Trinity River from Lewiston Dam (RM 111.9) to Indian Creek (RM 95.2).

Consequences to habitat quality/quantity from sediment budget imbalances have been overlooked; to rehabilitate mainstem morphology and improve the salmonid fishery, the sediment budget must be balanced. This sediment budget was initially started in 1995, with most data collected during numerous winter storms in WY1997. Because the sediment budget on the upper Trinity River is a component of the long-term monitoring program, the budgeting numbers will improve and be refined. Therefore, the reader must remember that the sediment budget computations are preliminary, and represents our best estimate to date based on what is functionally one year's data.

8.1.1. Objectives

We defined our sediment budget study reach as the mainstem from Lewiston Dam (RM 111.9) downstream, past Indian Creek (RM 95.3) and downstream to the mouth of Weaver Creek (RM 93.8) (Plate 1). Below Indian Creek, several closely spaced tributaries rapidly increase sediment supply (Trush et al., 1995). The major bedload producing tributaries progressing downstream from Lewiston Dam are Deadwood Creek (RM 110.8), Rush Creek (RM 107.5), Grass Valley Creek (RM 104.1), Indian Creek (RM 95.2), and Weaver Creek (RM 93.8) (Plate 1). Because the TRD eliminated all upstream bedload supply and stopped bank erosion (due to riparian fossilization of alluvial deposits), these tributaries are the significant source of bedload-sized sediments above Indian Creek. We partitioned the mainstem into five sub-reaches, with each defined by a tributary junction. Contemporary and desired coarse sediment budgeting through the mainstem was conceptualized in Figure 8.2.

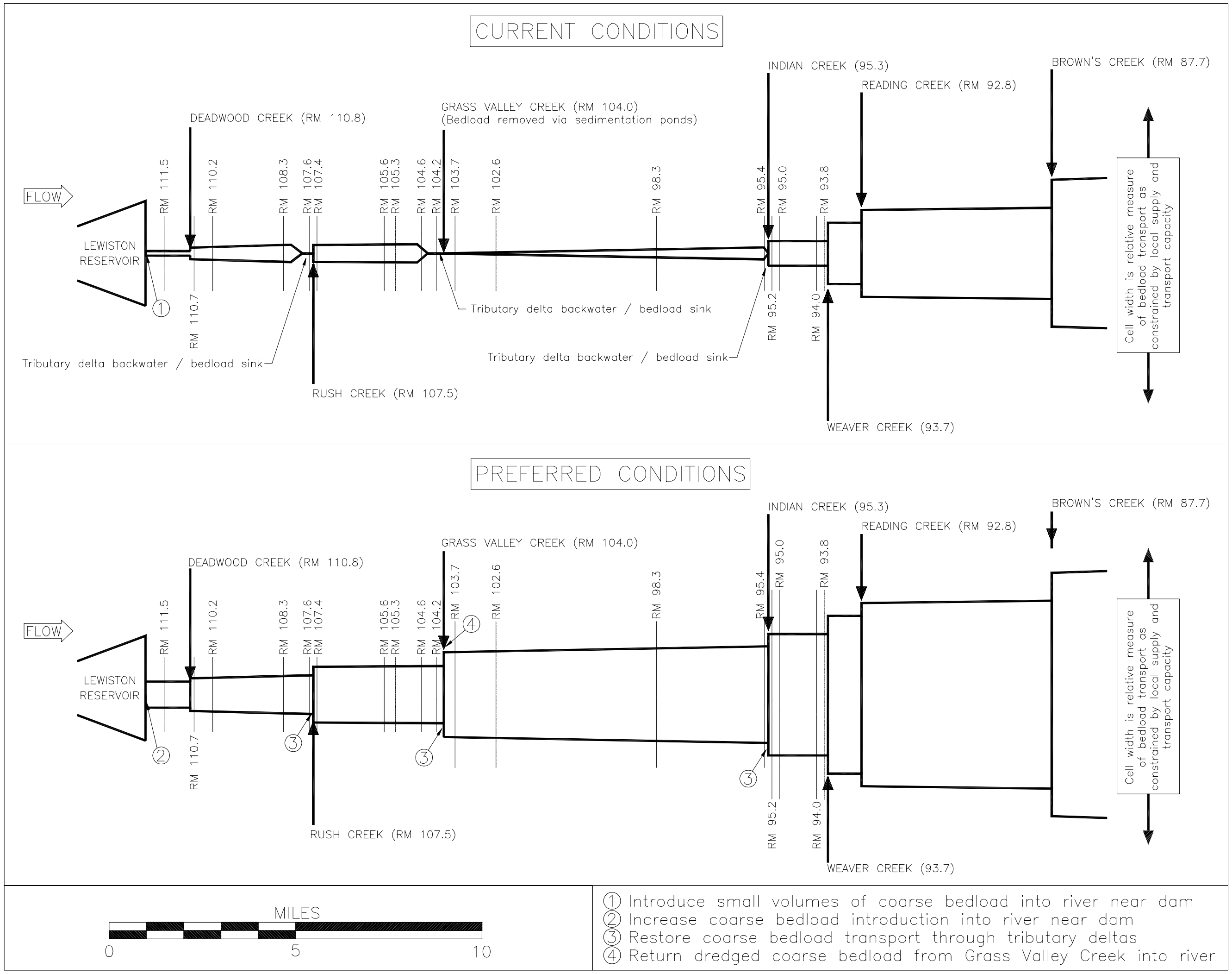


Figure 8.2 Conceptual model for contemporary and desired coarse sediment budgeting through the mainstem Trinity River Downstream of Lewiston Dam. Sediment continuity was evaluated for each sub-reach to identify channel reaches that may require coarse sediment input.

Our objectives for managing the sediment budget were:

1. Quantify the bedload component of tributary sediments contributed to the mainstem Trinity River and determine what magnitude and duration of dam releases would transport these sediments from the deltas and distribute them downstream;
2. Identify reaches on the mainstem Trinity River where bedload supply is limited compared to mainstem transport capacity;
3. Select candidate reaches where local supply should be supplemented with introduced gravels and estimate introduction rates.

In WY1995 and WY1996, we attempted to quantify mainstem and tributary sediment transport rates by combining bedload modeling, bedload traps, and tributary delta volumetric surveys. On the mainstem, these methods provided relative comparisons among sixteen cross section sites, but bedload transport rate estimates were unreliable. The results of bedload modelling for the mainstem are available (McBain and Trush, unpublished).

In WY1997, mainstem and tributary modeling and bedload trapping were abandoned in favor of direct measurement of bedload and suspended sediment. However, to continue documenting tributary bedload input, our WY1995 tributary delta topographic surveys were expanded to other tributaries. These surveys provided reliable bedload input volumes for storm events when the mainstem was kept at low flow.

After modifying our bedload sampling methodology, we expanded the scope of the sediment budget to include the fine sediment component, adding the following additional management objective:

4. Transport fine sediment stored in the mainstem at a rate greater than supply to reduce mainstem fine sediment storage.

To monitor this fourth management objective, we documented changes in fine sediment storage in mainstem pools by comparing WY1993 to WY1997 pool topography. In WY1991 to WY1993, the Johns Hopkins/UC Berkeley study (Wilcock et al. 1995) evaluated sand storage in pools between Grass Valley Creek (RM 104.0) and Steelbridge (RM 99.2). Given that the recently completed Hamilton Ponds and Buckhorn Dam on Grass Valley Creek have reduced sand supply into the mainstem, high mainstem flows from WY1993 to WY1997 would have the capability of transporting a larger volume of fine sediment than supplied. Peak high flows below Grass Valley junction were: 1,500 cfs (WY1994), 6,950 cfs (WY1995), 6,300 cfs (WY1996), and 16,700 cfs (WY1997). We resurveyed these pools in summer, 1997 to determine if the net effect of the last four water years has decreased sand storage. We also compared fine sediment contribution from tributaries to fine sediment transport in the mainstem Trinity River.

8.2 Study sites

8.2.1. Tributary Study Sites

The reach of mainstem Trinity River chosen for quantifying the sediment budget is from Lewiston Dam to Weaver Creek (RM 93.8). This reach was chosen because it is most susceptible to a limited sediment supply and has had few flood events capable of transporting coarse bedload. Downstream of Indian Creek, the combined sediment and flood flow contributions from Indian Creek, Weaver Creek, Reading Creek, Browns Creek, Dutch Creek, Canyon Creek, and North Fork Trinity River has been sufficient to initiate important fluvial processes (see Chapter 2). Therefore, we established bedload and suspended sediment sampling stations on: Deadwood Creek (RM 110.8), Rush Creek (RM 107.5), and Indian Creek (RM 95.2) (Plate 1). The USGS measures bedload and suspended sediment transport (since 1975) at the Grass Valley Creek near Fawn Lodge gaging station (11-525600), which is several miles upstream of its confluence with the Trinity River.

Bedload and suspended sediment sampling sites on each of these three tributaries were 500 to 2,000 ft upstream of the confluence with the mainstem. Tributary delta topography was surveyed from each tributary confluence downstream 1,000 to 1,500 ft. on the mainstem Trinity River. We supplemented USGS monitoring in Grass Valley Creek with topographic surveys in the Hamilton Ponds (0.5 miles upstream from the Trinity River confluence). Decomposed granitic particles contributed by the Grass Valley Creek watershed are strongly bimodal, with modes represented by large gravels/cobbles and 1 mm to 4 mm granitic sands. The large percentage of sand, combined with extremely high erosion rates, has given Grass Valley Creek the dubious distinction as the primary cause of fine sediment oversupply to the mainstem.

8.2.2. Mainstem bedload sampling

Bedload samples were collected at the USGS Lewiston Gage cableway (RM 110.2) and at the former cableway location for the discontinued USGS gage near Steelbridge (Trinity River below Limekiln Gulch, near Douglas City, #11-525655, RM 98.3). Samples were taken during dam releases in January and February of 1997.

8.2.3. Fine sediment storage in mainstem Trinity River pools

In 1993, Johns Hopkins University and UC Berkeley surveyed pool topography in five pools: Ponderosa Pool (RM 103.6), Tom Lang Pool (RM 102.8), Reo Stott Pool (RM 102.0), Society Pool (RM 101.3), and Steelbridge Pool (RM 99.0). All surveyed pools were in a five mile reach below Grass Valley Creek (Figure 8.3) and ranged from 225 ft to 900 ft long (Plates 2 to 6). Four were dredged between 1990 and 1992, as part of the Trinity River Restoration Program, to trap fine sediments. The Steelbridge Pool was the only undredged pool surveyed.

8.3 Methods

Tasks necessary to achieve our sediment budget objectives included:

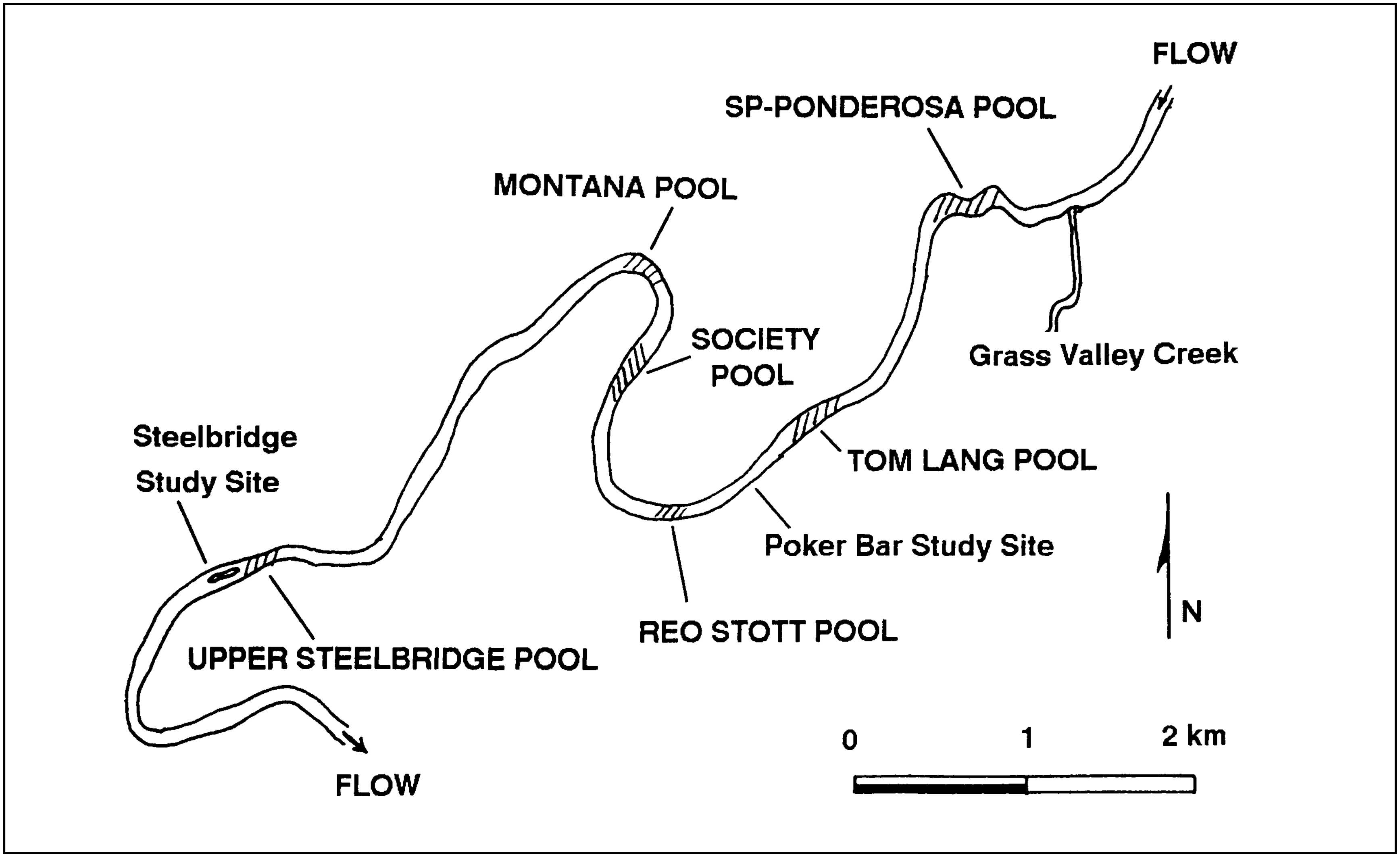


Figure 8.3 Surveyed pool locations from Wilcock et al. (1995). All surveyed pools were in a five mile reach below Grass Valley Creek.

1. Quantify bedload and suspended sediment contribution of tributaries. We constructed bedload and suspended sediment transport rating curves, and by establishing continuous recording gaging stations at the sample site, computed continuous bedload transport flux during high flow events. We relied on USGS bedload and suspended sediment transport data and their computations of bedload transport flux for Grass Valley Creek.
2. Quantify bedload transport rate and capacity on the mainstem Trinity River. Based on mainstem Trinity River transport rates as a function of discharge, differing high flow releases were evaluated to manage the sediment budget. Though we preferred to measure bedload transport relationships in each of the five mainstem sub-reaches, this would require continuous gaging in each reach. Instead, two of the sub-reaches were evaluated: between Deadwood Creek and Rush Creek (Lewiston gaging site), and between Grass Valley Creek and Indian Creek (Limekiln gaging site).

In WY 1995, funding delays and early winter storms prevented us from collecting field data during high flow events. Our attempts to predict transport “after the fact” with forensic hydraulic data (flood debris) and bedload models produced results that were extremely variable and only useful for identifying relative trends (between different sized floods). However, much of the work in WY 1995 to WY 1996, such as establishing cross sections, characterizing particle size, and establishing stream gaging sites, provided the necessary monitoring network needed in WY 1997 for estimating long term sediment transport and bedload routing (Table 8.1).

8.3.1. Bedload and suspended sediment sampling

The difference in flow depths and velocities between the tributaries and the mainstem required completely different sampling techniques. Most tributary flows could be waded, while on the mainstem, flows capable of transporting sediment required a bridge or cataraft to deploy sampling equipment.

8.3.1.1 Tributaries

Suspended sediment was sampled with depth-integrating samplers, using procedures standardized by the USGS (Guy and Norman 1970, Edwards and Glysson 1988). The approach is similar to stream gaging in that the channel cross section is divided into cells, with each cell sampled throughout the vertical at a constant rate. When feasible, we subdivided the channel into 20 cells, which is the standard sampling practice. Since we did not always have discharge data, we used the equal-width increment (EWI) method. On small tributary channels or when the flows were either barely wadeable or unwadeable, alternate methods were employed, with fewer vertical cells. At times, only grab samples could be obtained from a portion or the edge of the channel. The samplers were lowered and raised through the water column at a constant rate in order to integrate the sample over depth. We intended to use two different suspended sediment samplers, differing only in weight and means of deployment, however the largest sampler could not be obtained from the manufacturer until after the high flows. The DH-48 sampler was handheld for wadeable flows. At higher flows, additional handle

Site	1995	1996	1997
Deadwood Creek delta (RM 110.8)	Topographic volumes	No delta formed	Topographic volumes
Rush Creek delta (RM 107.5)			Topographic volumes
Grass Valley Creek sedimentation ponds (RM104.0)	Topographic volumes	Topographic volumes	Topographic volumes
Indian Creek delta (RM 95.2)			Topographic volumes
Deadwood Creek (Trinity Dam Blvd. culvert crossing)			Bedload, suspended sediment
Rush Creek (Bridge crossing 500 ft upstream of Trinity River confluence)			Bedload, suspended sediment
Grass Valley Creek (Fawn Lodge gaging station, 3.2 miles upstream of Trinity River confluence)	USGS bedload, suspended sediment	USGS bedload, suspended sediment	USGS bedload, suspended sediment
Indian Creek (2,500 ft upstream of Trinity River confluence)			Bedload, suspended sediment
Trinity River at Lewiston gaging station cableway (RM 110.2)			Bedload
Trinity River below Limekiln Gulch gaging station cableway (RM 98.3)			Bedload

Table 8.1 Summary of sediment budget data gathered from WY 1995 to WY 1997 by study reach.

extensions were used with the DH-48 to sample at greater depths or from the top of the culvert, such as on Deadwood Creek, when flows were not wadeable. The D-74 sampler is the heaviest (62 lbs) and must be lowered by cable with a sampling crane.

Bedload was sampled using a Helley-Smith pressure-difference sampler, which is the most commonly used bedload sampler (Helley and Smith 1971). We used a hand-held model with a 3-in square orifice and a cable-deployed 6-in model. The 3 in sampler has been calibrated for bedload sizes from sand to small gravel (Emmett 1979; Griffith and Hicks 1980). The modified 6 in model has been used since the early 1980s, and efficiently samples larger grain sizes. Guidelines for the use of the Helley-Smith sampler have been published by Emmett (1981) and updated by Edwards and Glysson (1988), although on smaller channels with high transport rates, it is often necessary to modify these procedures to accommodate field conditions. We typically used a 3 inch wading Helley-Smith sampler for the tributaries, although a 6 inch sampler was used on Rush Creek from a private bridge during peak flows. Unfortunately, without a front stayline, these high flows on the steep, narrow tributary channels (with velocities of over 10 ft per second) could not accurately be sampled even with the 6 inch sampler.

Similar to suspended load, the channel was subdivided into cells for sampling. The sampler was lowered to the streambed and held in position for a fixed and generally uniform time period, typically 30 to 120 seconds depending on how quickly the sampler filled to 40 % full, a generally accepted limit for maintaining sampling efficiency (Edwards and Glysson 1988). The individual cell samples were bagged separately or combined (depending on the bedload transport rate). Information such as the stationing, number of verticals, and duration was recorded, as well as stage observations during sampling.

8.3.1.2 Mainstem Trinity River

Bedload transport on the mainstem Trinity River was sampled using a cataraft and crane arrangement. A typical bedload sampling effort took about four hours per site, with two or three sample replicates collected. These replicate samples integrated potential variability in transport rate as waves of bedload move through the sampling cross section.

Suspended sediment samples were taken to an analytical laboratory. Suspended sediment concentration was determined using standard laboratory techniques. We did not choose to perform any size analysis on suspended sediment samples due to the cost (over $100/sample). We analyzed the bedload samples by drying them in a lab oven, sieving with a standard set of 0.5 phi sieves, and weighing on a 0.5 g accuracy scale. The percentage of individual size fractions was determined and a complete sample size distribution developed for each sample. When collecting numerous replicates, we reduced the number of bedload samples requiring transport, drying and sieving, by wet weighing in the field. This speeded field sampling, allowing more sample collection to better characterize bedload transport variability. At least one replicate of field-weighed samples was saved to characterize grain size distribution, and to determine a correction coefficient for equivalent dry weight. For bedload transport rating curves, both the total sample weight (all bedload sizes) and the gravel component (bedload > 8mm) were plotted.

After lab analysis of the sediment samples, the transport rate calculated from each sample was computed using standard procedures and formulas (Edwards and Glysson 1988). The bedload or suspended load summary table for each site shows the computed transport values. The associated streamflow at the time of each sediment measurement was determined from staff gage observations and the rating table for each gage. These data pairs were then plotted to develop a bedload or suspended sediment discharge rating curve.

8.3.1.3 Streamflow gaging

To develop continuous records of sediment transport, a continuous record of streamflow was desirable. This was a primary justification for installing continuous recording gaging stations on Rush Creek (June 18, 1996) and Indian Creek (January 1, 1997), and eventually Deadwood Creek this October 1997 (see Chapter 5). Discharge was computed by determining stage-discharge relationships or “rating curves.” A datalogger was installed on Rush Creek in WY 1996. However, shipping delays and the January 1997 floods prevented us from installing the Indian Creek gaging station until late-January 1997. Where continuous records of WY 1997 flood events were unavailable, sufficient records of stage either from crest stage records and/or high water surveys were used to estimate storm peaks.

8.3.2. Delta volume surveys

Beginning in WY 1995, we initiated a tributary delta monitoring program to determine whether gravel contributions from Deadwood Creek, Rush Creek, Grass Valley Creek, and Indian Creek could be estimated accurately. Typically, when tributaries are flooding due to a storm event, flows on the mainstem Trinity River have remained between 150 cfs and 300 cfs, allowing tributary derived sediments to accumulate as deltas in the mainstem. Mainstem transport of these deltas at 300 cfs is negligible. Therefore, measuring change in delta topography by storm event measures the cumulative tributary sediment yield for a complete tributary storm event.

Infrequent high flow releases from Lewiston Dam (typically less than 6,000 cfs) in subsequent months or years then distribute some of these coarse sediments a short distance downstream. Several hundred feet downstream of each of these tributary mouths, complex depositional features have developed, which include various sized islands and a complex of channels. Our monitoring program topographically mapped these features before and after significant storm events to determine the coarse sediment input volume and depositional patterns in the mainstem. This technique was used on Deadwood Creek, Rush Creek, and Indian Creek. Sediment deposition in the sedimentation ponds constructed by DWR on Grass Valley Creek were topographically monitored because they trap nearly all bedload that would normally be delivered to the Trinity River. These ponds are dredged each spring to remove sediments that accumulate during the winter. These ponds were re-surveyed after being dredged.

The topographical monitoring techniques used on the tributaries were developed by Trinity Restoration Associates (TRA 1993). A Sokkia Set 5 Total Station with a Sokkia SDR-33 Data Collector was used to survey three-dimensional coordinate points of the delta and mainstem surfaces. A minimum of two control points with known and consistent horizontal (X and Y) and elevational (Z) coordinates were established to provide long-term survey control for each site. The resulting points were then downloaded into AutoCAD and SoftDesk Civil Engineering Digital Terrain Model (DTM) software to create surface topography models, produce contour maps, and calculate volumetric changes of the delta deposit.

On the river, points were surveyed in a rough grid fashion with an approximate point density 10 ft apart, but actual point locations were chosen by topographic breaks rather than a set distance apart. The more topographically complex a section of delta, the more points were required to accurately document topography. Beyond topographic grid points, we also identified significant slope breaks and water surface edges/elevations; at Grass Valley Creek the transition from gravel to sand in the sedimentation ponds was delineated.

8.3.3. Fine sediment storage in mainstem Trinity River pools

The objective of the pool surveys was to measure changes in pool topography, and if possible, relate this change to fine sediment storage trends. As in WY 1993, the 450 cfs water surface served as the elevational datum upon which pool topography could be determined from water depth. Because the longitudinal water surface slope through the pool was essentially zero, using the 450 cfs water surface over the entire length of the pool as a datum was reasonable. Each of the five pools was surveyed using a network of cross sections extending to pins along the water edge along each bank. Fiberglass tapes were extended across each cross section, and depth measurements were recorded at stations along the tape. A two person crew in an inflatable kayak used a 25 ft expandable fiberglass stadia rod to measure water depth to the nearest tenth of a foot. These depths were converted to a relative elevation by subtraction from the 100 ft arbitrary datum assigned the 450 cfs water surface. The water surface elevation was surveyed into various benchmarks to confirm that the stage was similar for both surveys.

The cross sectional and depth data were transformed into three dimensional points measurements based on the Wilcock et al. (1995) 1993 pin coordinates. These data were imported into topographical modeling software to generate digital terrain models and contour maps for WY 1993 and WY 1997; differences in digital terrain models computed the net changes in volume. However, this net volume change included coarse sediment aggradation as well as fine sediment (the original objective of this evaluation).

To strictly evaluate changes in fine sediment storage, the underlying coarse alluvium must not change topography, and coarse sediment must not be deposited. The January 1997 tributary flood augmented the 5,500 cfs release from Lewiston, such that coarse sediment transport in the mainstem was large. Many of the dredged pools partially filled with gravel rather than sand. We attempted to document which areas had filled with sand in order to estimate 1997 sand storage, but visual observations could not be made due to turbid flow releases from the Trinity River Division all summer. Therefore, we had to rely on the feel of the stadia rod on bottom sediments to estimate local surface particle composition.

8.4 Results

8.4.1. Bedload and suspended sediment sampling

Because most sediment transport occurred during infrequent high flow events, we collected sediment transport data only during storm events. During WY 1997, samples were collected during the December 4 to 5, December 8 to 9, December 28 to January 1, and January 25 to February 1 storm periods on tributaries (Table 8.2). On the mainstem, samples were collected during the prolonged

Study Site	No. of Discharge Measurements	No. of Bedload Measurements	No. of Suspended Sediment Measurements
Deadwood Creek	7	9	7
Rush Creek	8	10	12
Indian Creek	10	8	6
Trinity River at Lewiston	USGS gaging station	3	0
Trinity River below Limekiln Gulch	Discontinued USGS gaging station	2	0
Trinity River near Douglas City	5	0	0
Trinity River at Junction City	3	0	0

Table 8.2 Summary of flow and sediment measurements in water year 1997

high flow releases from the TRD, extending throughout January and into February following the large January 1 flood peak.

Streamflows were measured during these same storm periods and in intervening periods to define stage-discharge relationships. The January 1 flood event was sufficiently large to cause significant channel changes in most of the tributary channels. As a result, large shifts in the stage-discharge rating curves occurred; additional post-flood measurements were needed to define new rating curves. Peak discharges using the slope-area method were estimated at each site following the January 1 flood. The slope-area method required surveying cross sections and peak water surface profiles.

Data collected during the 1997 sampling period are in Appendix B, with the following information for each sediment sampling site:

1. Periodic staff plate observations, date and time of various streamflow and sediment transport measurements, and brief notes of conditions at the time of observation or sample.
2. Summary tables of sediment transport measurements
3. Summary tables of discharge measurements (equivalent to USGS 9-207 forms)
4. Summary tables of mean daily streamflow
5. Summary tables of daily sediment discharge

8.4.2. Delta volume surveys

8.4.2.1 Deadwood Creek Site (RM110.8)

In WY 1997, we established a concrete benchmark on the left bank of the Trinity River approximately 100 ft downstream of the New Lewiston Bridge, with relative horizontal coordinates N 10,000 ft, E 10,000 ft, and elevation 1,815.51 ft (1929 NGVD). The site extends from the top of the pool under the New Lewiston Bridge downstream about 1,300 ft to the downstream end of a complex of vegetated islands. We mapped the site in August 1996 to establish pre-flood topography. In March 1997, we mapped the upstream portion of the site to document Deadwood Creek coarse sediment deposition during the January 1, 1997 storm (Plate 7). Comparing this surface with the August 1996 topographic survey revealed a small deposit near the mouth of Deadwood Creek and scour in the deepest spot of the confluence pool, but minor overall change in the pool tail (Table 8.3). We did not extend the March 1997 survey to the downstream end of the site. Because we did not measure an appreciable change in the Deadwood Creek delta, either the high flow releases from the TRD transported the sediment out of the site or there was minor bedload contributed by Deadwood Creek. The low bedload transport estimate for WY 1997 (see Section 8.5.1.2) suggested that the small change in tributary delta volume was a function of low tributary sediment contribution over the year rather than the mainstem high flows transporting delta material from the reach.

Site	Subsite	Flood Event	SURFACE 1 (Survey Date)	SURFACE 2 (Survey Date)	CUT (yd^3)	FILL (yd^3)	NET CHANGE (yd^3)
DEADWOOD		1/1/97	Jul-96	Feb-97	376	265	111 (CUT)
RUSH		12/5, 12/9/96	Aug-96	Dec-96	22	724	702 (FILL)
RUSH		1/1/97	Dec-96	Mar-97	2,525	7,640	5,115 (FILL)
GVP	Upper Pond	2/5, 2/20/96	Oct-95	Aug-96	274	2,777	2,503 (FILL)
GVP	Lower Pond	2/5, 2/20/96	Oct-95	Aug-96	1681	739	941 (CUT)
GVP	Upper pond	12/5, 12/9/96	Aug-96	Dec-96	80	480	400 (FILL)
GVP	Upper pond	1/1/97	Dec-96	Jan-97	495	7,875	7,380 (FILL)
GVP	Lower pond	1/1/97	Dec-96	Jan-97	0	2,199	2,199 (FILL)
GVP	Upper pond	Pond Excavated	Jan-97	May-97	12,982	N/A	12,982 (CUT)
GVP	Lower pond	Pond Excavated	Jan-97	May-97	1,027	N/A	1,027(CUT)
INDIAN	Trinity River	Mainstem floods only	Jul-95	Jul-96	1,948	582	1,365 (CUT)
INDIAN	Trinity River	12/5, 12/9/96, 1/1/97	Jul-96	Mar-97	3,359	1,914	1,444 (CUT)
INDIAN	Indian Creek	1/1/97	Jul-96	Mar-97	30	949	920 (FILL)

Table 8.3. Trinity River tributary delta mapping dates and total volumetric changes.

8.4.2.2 Rush Creek Site (RM107.6)

In August 1996, a concrete benchmark was established high on the right bank of the Trinity River with arbitrary coordinates of N 10,000 ft, E 10,000 ft, and relative elevation of 100.0 ft. The site was mapped from just upstream of the mouth of Rush Creek downstream approximately 1,600 feet. On December 13, 1996, we re-mapped the upper 300 ft section near the Rush Creek mouth, measuring 700 yd^3 deposited by the December 5 and 9, 1996 storm events (Table 8.3). The entire complex of islands and multiple channels was again mapped in March 1997. We measured over 7,500 yd^3 of newly deposited sediment along the right side of the channel just downstream of the Rush Creek mouth and 2,500 yd^3 of scour along the left bank and the adjacent fast, deep main channel at the upper left edge of the site (Plate 8). Because we were interested in the sediment delivery by Rush Creek, we did not subtract the 2,500 yd^3 of scour that occurred on the left bank (opposite the tributary delta) from the total fill. We estimated that the minimum bedload contribution from Rush Creek in WY 1997 was 7,600 yd^3. High mainstem flows during and after the January 1, 1997 flood likely transported a substantial portion of bedload contributed by Rush Creek, so the WY 1997 estimate should be considered a minimum estimate.

8.4.2.3 Grass Valley Creek Sedimentation Ponds (RM 104.0)

The large supply of coarse decomposed granitic sands, transported by flows as low as 50 cfs, usually is transported as bedload. Bedload sediment yields computed by USGS were dominated by this sand fraction. Bulk samples of sediments deposited in Hamilton Ponds (near the mouth of Grass Valley Creek) showed that 70% is finer than 8 mm (Table 8.4).

Water year	Peak Discharge (cfs)	Bedload Yield (tons)	Estimated Bedload Yield >8mm (tons)	Hamilton Ponds Sediment Yield (tons)
1976	115	330	100	
1977	38	0	0	
1978	2,080	N/A	N/A	
1979	394	2,287	691	
1980	1,030	7,546	2,280	
1981	610	277	84	
1982	1,030	2,592	783	
1983	4,670	37,359	11,286	
1984	982	7,472	2,257	
1985	495	793	240	
1986	2,500	6,703	2,025	
1987	570	443	134	
1988	441	85	26	
1989	536	1,391	420	5,375[1]
1990	332	548	166	
1991	76	403	122	
1992	644	1,817	549	
1993	548	928	280	
1994	124	2	1	
1995	2,700	39,083	11,807	43,125[1]
1996	256	159	48	3,125
1997	2,130	3,071*	928*	12,500

*USGS data not available, estimated by 1989, 1995, 1996 correlation with Hamilton Ponds

[1] Data from Roberts (1996). 1995 data adjusted based on Borchard pers. comm.

Table 8.4 USGS bedload sediment yields at Grass Valley Creek near Fawn Lodge gaging station.

We evaluated the USGS bedload yield values by topographically surveying the Hamilton Pond delta. Benchmarks installed by the U.S. Bureau of Reclamation (USBR) provided several control points with relative X, Y, and Z coordinates, which we re-occupied and used in our surveys. These ponds were mapped by USBR and NRCS in October 1995 (Roberts 1996). In August 1996, we re-mapped both ponds to determine the volume of new sediment deposited during winter and spring 1995-96, and establish a new baseline for winter WY 1996 to WY 1997. The dominant change was the deposition of a 2,500 yd^3 lobe at the inlet of the upper pond along the right bank (Plate 9). A December 13, 1996 survey measured about 400 yd^3 of new sediment deposited on the downstream end of this lobe during an early December storm. The large January 1, 1997 flood practically filled the upper pond with almost 7,400 yd^3 of sediment (Plate 9). Another 2,200 yd^3 of new sediment (mostly sand) was transported into the lower pond, where it formed a delta downstream of the spillway between the ponds. The most recent survey in May 1997 established a new baseline after NRCS dredged both ponds in preparation for WY 1998 (Plate 9). Almost 13,000 yd^3 of sediment from the upper pond and 1,000 yd^3 from the lower pond was removed. A comparison between the October 1995 and the May 1997 surveys (not shown) suggested that 2,000+ yd^3 more material was excavated from the left edge of the upper pond than in WY 1995, yielding more retention capacity.

We evaluated the USGS bedload estimates by comparing the volume of WY 1989, WY 1995 and WY 1996 sediments deposited into Hamilton Ponds with that predicted/measured by USGS (Table 8.4). Roberts (1996) suggested that the entire 42,000 yd^3 capacity of the ponds was filled by WY 1995 floods, with approximately 7,500 yd^3 in the ponds prior to the floods (S. Borchard, pers. com.). Therefore, an estimated 34,500 yd^3 (43,125 tons) was deposited during WY 1995.

USGS bedload yields were consistently lower than those measured in the Hamilton Ponds, which is partially explained by a slightly larger drainage area at the ponds, but may also be a function of the rating curve not adequately defining higher discharges and the analyses not accounting for transport differences between rising and falling limbs of storm hydrographs. We consider the pond volume estimates superior to USGS estimates because the ponds integrate all transport events and transport rate fluctuations, and they are located at the watershed outlet.

8.4.2.4 Indian Creek Site (RM95)

The Indian Creek site was first mapped in WY 1992 as part of the channel morphology monitoring component of the Channel Maintenance Flow Study (TRA, 1993). A concrete benchmark was established mid-way through the site on the left bank with arbitrary coordinates of Northing 10,000’; Easting 10,000’; and Elevation 100.0’ (TRA, 1993). A baseline was established with magnetic north as 0 degrees and a backsight spike set in an oak tree high on the right bank. In WY 1995, the benchmark was surveyed to NGS BM S77 on the Highway 299 bridge over Indian Creek, and our concrete benchmark was adjusted from a relative 100.0 ft elevation to the NGVD 1929 elevation of 1,638.90 ft.

Mapping from WY 1992 through WY 1995 was limited to the mainstem Trinity River from the mouth of Indian Creek downstream about 1,500 ft. Although not included in Table 8.3, the mainstem near the Indian Creek mouth experienced significant changes, such as delta and left bank bar deposition during the winter and spring flows followed by scour and downstream sediment movement when the mainstem flow releases occurred. The July 1996 mapping was extended to include the 1,000 ft of Indian Creek between the Highway 299 crossing and the mouth. We determined the volumetric change for lower Indian Creek between July 1996 and July 1997 separately from changes in the Trinity River section of the site (Table 8.3). The resultant changes showed about 900 yd^3 of net deposition in the lower section of Indian Creek, while the mainstem Trinity River exhibited almost 3,400 yd^3 of scour, mostly from the upper section of the site. Approximately 1,900 yd^3 of that material deposited on the right bank side downstream island (Plate 10). Mainstem flows in this reach were extremely large in January (over 12,000 cfs), and considerable export of Indian Creek sediments occurred. Therefore, the 1,900 yd^3 estimate is only a small component of what was actually contributed by Indian Creek, and shows that the tributary delta monitoring method is only useful when mainstem flows remain small.

8.4.2.5 Particle size distribution and bulk density

One objective of the sediment budget was to estimate tributary sediment delivery rates near the dam for coarse sediment greater than 8 mm. Therefore, particle size distribution was measured at each tributary delta by collecting bulk samples and at our gaging sites by collecting bedload transport samples. Bulk density of the deposited sediments was measured from these bulk samples (Table 8.5).

Sampling location	Bedload % >8 mm	Delta % >8 mm	Bulk density of delta material (tons/yd3)
Tributaries			
Deadwood Creek	Not sieved	79	1.60
Rush Creek	31 - 98	72	1.90
Grass Valley Creek	1[1]	30	1.25[2]
Indian Creek	30 - 54	58	1.84
Mainstem			
Lewiston cableway	7-8	N/A	N/A
Limekiln cableway	30-33	N/A	N/A

[1] 1996 USGS data, low discharge measurements so only sand was transported as bedload
[2] from Roberts (1996)

Table 8.5. Percent of bedload sample particle sizes greater than 8 mm and bulk density of tributary deltas.

Much of the bedload yield from a given watershed is sand. Because sand transport is strongly a function of a changing watershed sand supply, the rating curve frequently adjusts for the finer grain sizes. Using only particles larger than 8 mm may help reduce some of the variability between samples over time. The sediment rating curve for the greater than 8 mm fraction was not based on a correction to the total sediment rating curve. Instead, a rating curve for each was developed; one for the greater than 8 mm fraction, and one for less than 8 mm, based on the weighed fraction of the bedload sample.

This provided two curves for particle size distribution of the sediment in transport over a range of discharges.

Bulk density was measured for each delta sediment sample to account for variations in the lithology among the sub-basins. This enabled us to convert cubic yards of sediment in tributary deltas to tons, which was comparable to published USGS sediment data on Grass Valley Creek.

8.4.3. Fine sediment storage in mainstem Trinity River pools

8.4.3.1 Ponderosa Pool (RM 103.6)

Between WY 1993 and WY 1997, there was 5,600 yd^3 of fill and 1,550 yd^3 cut from the pool, for a net fill of 4,050 yd^3. The deposited bedload formed gravel bars at the upstream end of the pool, while most scour occurred at the downstream end of the pool. The downstream end of the pool was the only location where sand deposition was evident (Plate 2), suggesting scour at the downstream end of the pool was in a sand deposit. Some of this sand deposit was caused by the undercutting of the riparian berm and toppling of mature alders into the channel, which deposited sand from the riparian berm into the channel margin.

8.4.3.2 Tom Lang Pool (RM 102.8)

This pool was dredged before the 1992 release to a depth of 8 ft to13 ft; most of the fill was gravel in the dredged area of the main channel. There was 3,830 yd^3 of fill and 560 yd^3 cut from the pool, for a net fill of 3,270 yd^3, between WY 1993 and WY 1997. Sand deposition and storage occurred on the right bank (Plate 3). Gravel deposition was so extensive that gravel was routing through the pool, evidenced by the transverse bar midway through the pool and emergence of a gravel bar at the downstream end of the pool. Sections of the left bank were undercut, toppling mature alders into the channel and causing several feet of channel widening where the alders toppled. Small gravel bars formed downstream of the toppled alders as scour and lee deposits resulting from the alders.

8.4.3.3 Reo Stott Pool (RM 102.0)

This pool has extensive bedrock control, resulting in a forced meander bend that induces deposition on the inside of the bend rather than in the pool (Plate 4). Pool depth has been reduced due to gravel deposition to the point where gravel is likely routing through the pool again (evidence of a transverse gravel bar through the middle of the site). Between WY 1993 and WY 1997 there was 1,140 yd^3 of fill and 470 yd^3 cut from the pool, for a net fill of 670 yd^3. Some bank erosion occurred upstream of the sand/gravel bar on the right bank, resulting in mature alders leaning into the channel. A medial bar forming at the downstream end of the pool was also composed of small cobble and gravel, but the left bank point bar at the end of the pool was entirely sand.

8.4.3.4 Society Pool (RM101.3)

Between WY 1993 and WY 1997 there was 495 yd^3 of fill and 1,110 yd^3 cut from the pool, for a net cut of 615 yd^3. The bed surface was predominately gravel/cobble, with a small amount of sand storage on the left bank margin (Plate 5). In WY 1990, approximately 10,800 yd^3 of sediment was dredged from the pool. The present pool topography suggested that the post-dredging topography has not filled with gravel and equilibrated, and will function as a future coarse sediment trap.

8.4.3.5 Upper Steelbridge Pool (RM 99.0)

Between 1993 and 1997 there was 1,140 yd^3 of fill and 470 yd^3 cut from the pool, for a net fill of over 670 yd^3. This is the only undredged pool of the five evaluated, and appeared that its proportion of sand storage was largest among the five pools. The surveyed area covered only the lower two thirds of the pool, in what was functionally the pool tail deposit (Plate 6). Major areas of fill were located at the upstream end near the left bank. The pool tail was aggrading with gravel, causing the riffle crest to extend upstream with time.

8.5 Analyses

8.5.1. Bedload and suspended sediment transport rating curves

8.5.1.1 Introduction

Sediment transport is complex, characterized by significant point, inter-, and intra-storm variability. Each variation was observed while sampling in WY 1997. These effects add substantially to the difficulty in computing continuous records of streamflow and sediment transport. In addition, the large WY 1997 flood event of December 31 and January 1, altered the streambed in the vicinity of our gaging stations and produced dramatic shifts in the streamflow and sediment transport rating curves.

8.5.1.2 Tributaries

All supporting data are found in the appropriate location (by tributary) in Appendix B, unless specifically assigned a figure number in this chapter.

Deadwood Creek:
Deadwood Creek did not have the unusually large flows experienced by the north-side tributaries (Rush Creek, Weaver Creek, and Canyon Creek) during the January 1997 flood event. Peak flow estimates for the January 1, 1997 flow were 330 cfs, considerably smaller than the WY 1995 peak discharge estimate of 430 cfs. These two peak flows were estimated using indirect discharge techniques for culverts. As a result of the lower storm flows, relatively little sediment was transported by Deadwood Creek in WY 1997. The highest suspended sediment concentration was sampled on the first large storm of the year, December 4 and 5, 1996.

Suspended sediment concentration and load measurements were plotted against discharge. There was considerable scatter and no definite relationships. However, when the same data were analyzed for storm sequence and for the relative position on the storm hydrograph (rising versus falling limb), an improved relationship was apparent. The first large storm of the season had much higher suspended sediment concentrations than subsequent storm events for a given discharge. The suspended sediment data following this “first flush” event have well-defined relationships with reasonable correlation coefficients.

Bedload data were analyzed collectively and for rising/falling limb position (Figure 8.4). Rising limb data had significantly greater transport rates than similar flows on the falling limb, the opposite of what is commonly found in alluvial channels where bedload transport often peaks on the falling limb. The large culvert under the road to the Lewiston Hatchery amplified an audible correlation with transport rates in that bedload could be clearly heard bouncing through the culvert.

Rush Creek:

Rush Creek experienced unusually high flows during the December 31 and January 1 flood. This was apparently related to the percent of watershed in the rain-on-snow zone (4,000 to 6,000 ft elevation). Peak flows were estimated at 6,000 cfs during that event, a unit discharge over 250 cfs/mi^2. Significant erosion occurred in the watershed, with numerous road closures from slides and culvert failures from debris flows. In the alluvial portions of Rush Creek, channel changes were observed just upstream of the sampling station at a private bridge near the confluence. As a result of this channel change, a new channel was created which forces the main flow path directly into the left bridge abutment, presenting poor flow conditions for sampling and poor stage records due to an almost continual surging of flow. We determined that this site was no longer suitable for gaging, and a new permanent gage site about 300 yards upstream has been selected in a reach that remained stable during the flood.

The discharge rating curve for Rush Creek shifted substantially due to channel aggradation after the flood and the channel shift upstream. The stage shift was almost 1.5 ft at flows of 100 cfs, indicating a major fill cycle of the streambed. The indirect discharge measurement after the peak flow only yielded a discharge estimate of 4,400 cfs. When the channel fill is taken into account, the peak estimate of 6,000 cfs appeared more reasonable. The rating shift was also evident in the stage hydrograph for the water year, as winter base flows changed from a stage of 4.0 ft to 4.3 ft as seen in December 1996, to a stage of 5.7 ft after the flood. After the small storm at the end of January, there was minor streamflow change in Rush Creek and even the peak snowmelt runoff on April 20 only reached a maximum of 150 cfs.

Twelve suspended sediment measurements were made on Rush Creek during WY 1997, with concentrations ranging from 22 to 1,400 mg/l, and their respective sediment loads of 13 to 8,000 tons/day. The largest sample was collected at 2,100 cfs. Given the channel was not wadeable and collected

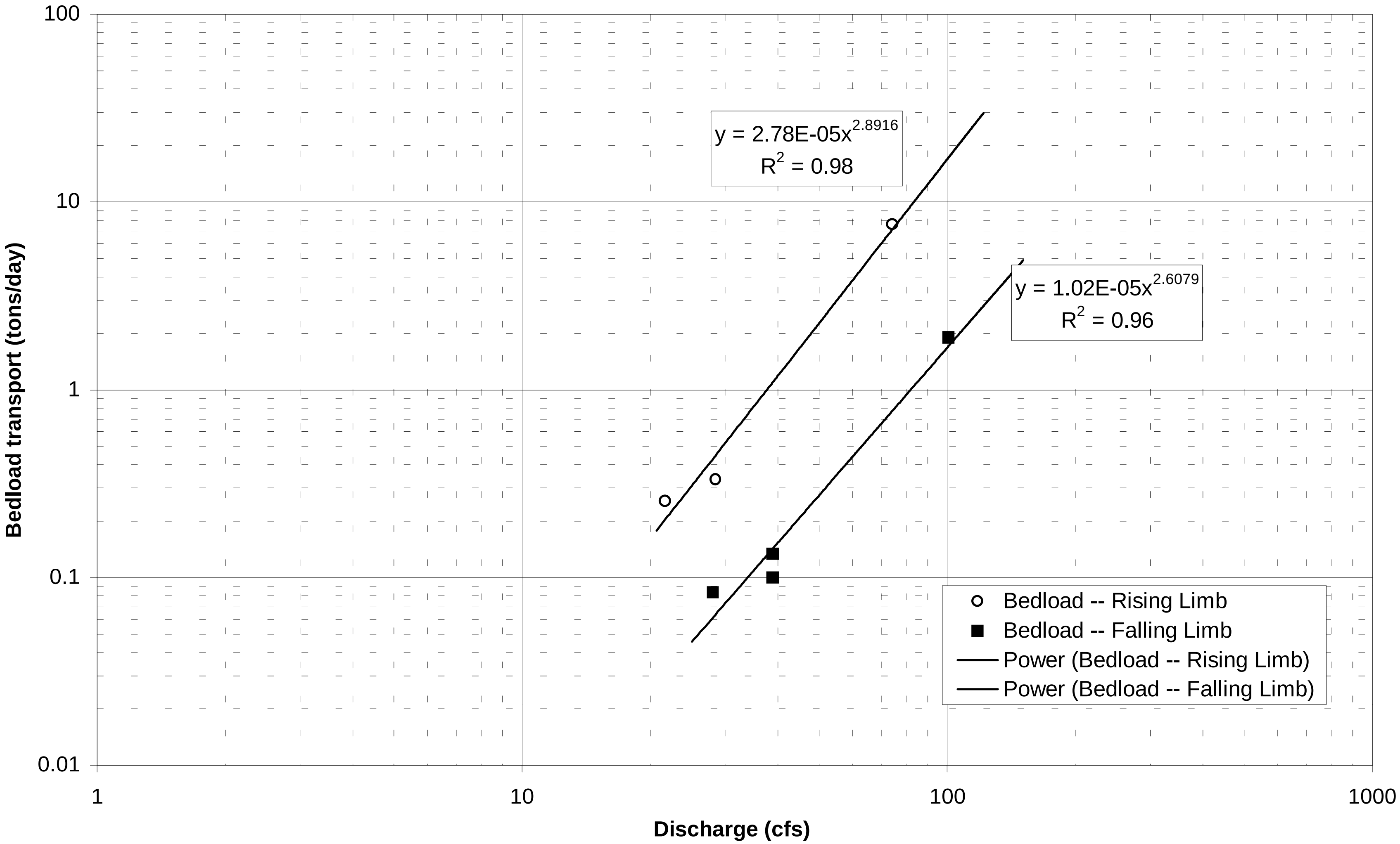


Figure 8.4 Deadwood Creek near Lewiston, bedload transport analysis for rising and falling position on the hydrograph.

by a grab sample, this concentration was probably lower than actual if a depth-integrated sample over the entire channel could have been made. The suspended sediment transport data were plotted to develop a rating curve. Even without considering the rising and falling limbs of the storm hydrograph, a good relationship between discharge and suspended sediment load was observed (r^2 = 0.90). Segregation into rising/falling limb categories improved the correlation slightly (r^2 = 0.94). The hysteresis effect can be clearly seen in sediment concentration over a storm event (Appendix B). This relationship, with much higher concentrations and loads on the rising limb of the storm hydrograph, is characteristic of suspended sediment transport on other streams.

Bedload transport measurements exhibited more scatter than suspended sediment (Figure 8.5). No improvement in the bedload rating curve was observed when the data were analyzed for rising/falling status, although each was greatly affected by one outlier. If the outliers were removed, the regression lines would show significantly greater bedload transport rates on the falling limb.

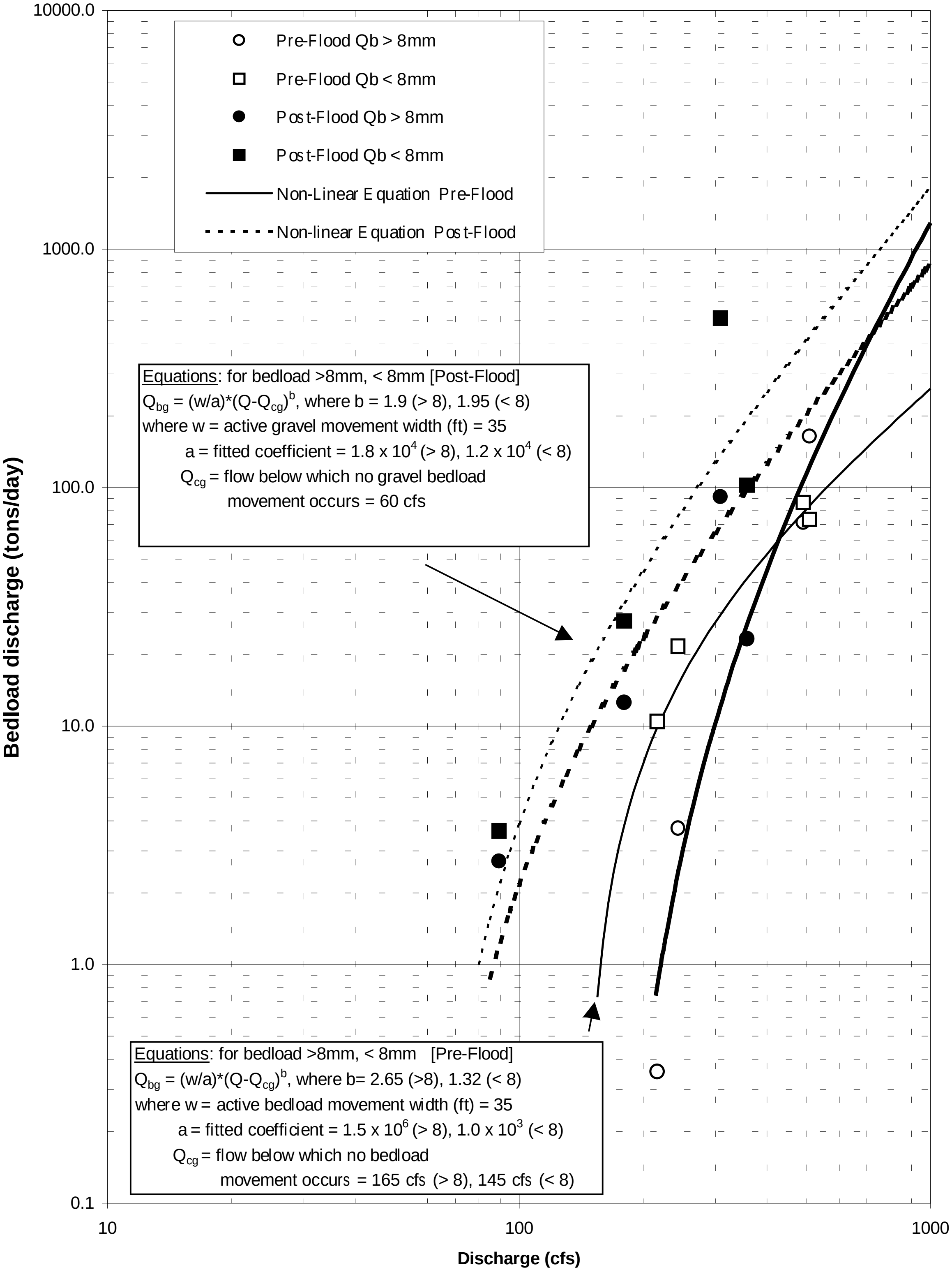
Indian Creek:

In contrast to Rush Creek, peak flows in WY 1997 on Indian Creek were not unusually large and apparently were smaller than in WY 1995. Although flows were not unusual, a major landslide/debris flow occurred in the upper Indian Creek watershed during the January 1, 1997 storm, delivering tremendous amounts of sediment to the channel. Much of this sediment moved downstream into alluvial reaches, where channel aggradation occurred through a reach that had just been reconstructed by the BLM.

In a similar fashion to Rush Creek, a significant shift in the discharge rating curve occurred after the channel aggraded during the storm. An indirect discharge measurement for the flood peak (1,800 cfs) was adjusted upward to compensate for the general channel fill.

Eight suspended sediment measurements were made during WY 1997 on Indian Creek, with concentrations between 33 and 1,200 mg/l. Suspended sediment rating curves for load and concentration yielded a fair correlation for load (r^2 = 0.79). Segregation of the data by storm showed much higher concentrations and loads after the major flood event, compared to rising limb data before the flood. The hysteresis effect was again evident during the samples collected in the storm of January 26 to 28, with rising limb loads 3 to 5 times greater than for the same flow on the falling limb, reflecting a depletion in the supply of fine sediment available for transport over the course of the storm.

As on the Deadwood Creek and Rush Creek bedload transport rating curves, there was considerable scatter (Figure 8.6). We attempted to reduce this scatter as at the other stations by evaluating pre- and post- flood data, as well as ascending and receding hydrograph limb data. Our measurements before and after the January 1, 1997 storm event showed over an order of magnitude increase in bedload transport, so not surprisingly, the pre- and post-flood curve segregation best reduced variability in the



Equations: for bedload >8mm, < 8mm [Post-Flood]
$Q_{bg} = (w/a)^*(Q-Q_{cg})^b$, where b = 1.9 (> 8), 1.95 (< 8)
where w = active gravel movement width (ft) = 35
a = fitted coefficient = 1.8×10^4 (> 8), 1.2×10^4 (< 8)
Q_{cg} = flow below which no gravel bedload movement occurs = 60 cfs

Equations: for bedload >8mm, < 8mm [Pre-Flood]
$Q_{bg} = (w/a)^*(Q-Q_{cg})^b$, where b= 2.65 (>8), 1.32 (< 8)
where w = active bedload movement width (ft) = 35
a = fitted coefficient = 1.5×10^6 (> 8), 1.0×10^3 (< 8)
Q_{cg} = flow below which no bedload movement occurs = 165 cfs (> 8), 145 cfs (< 8)

Figure 8.5 Rush Creek near Lewiston, pre- and post-flood bedload discharge rating curves for >8mm and <8mm particles.

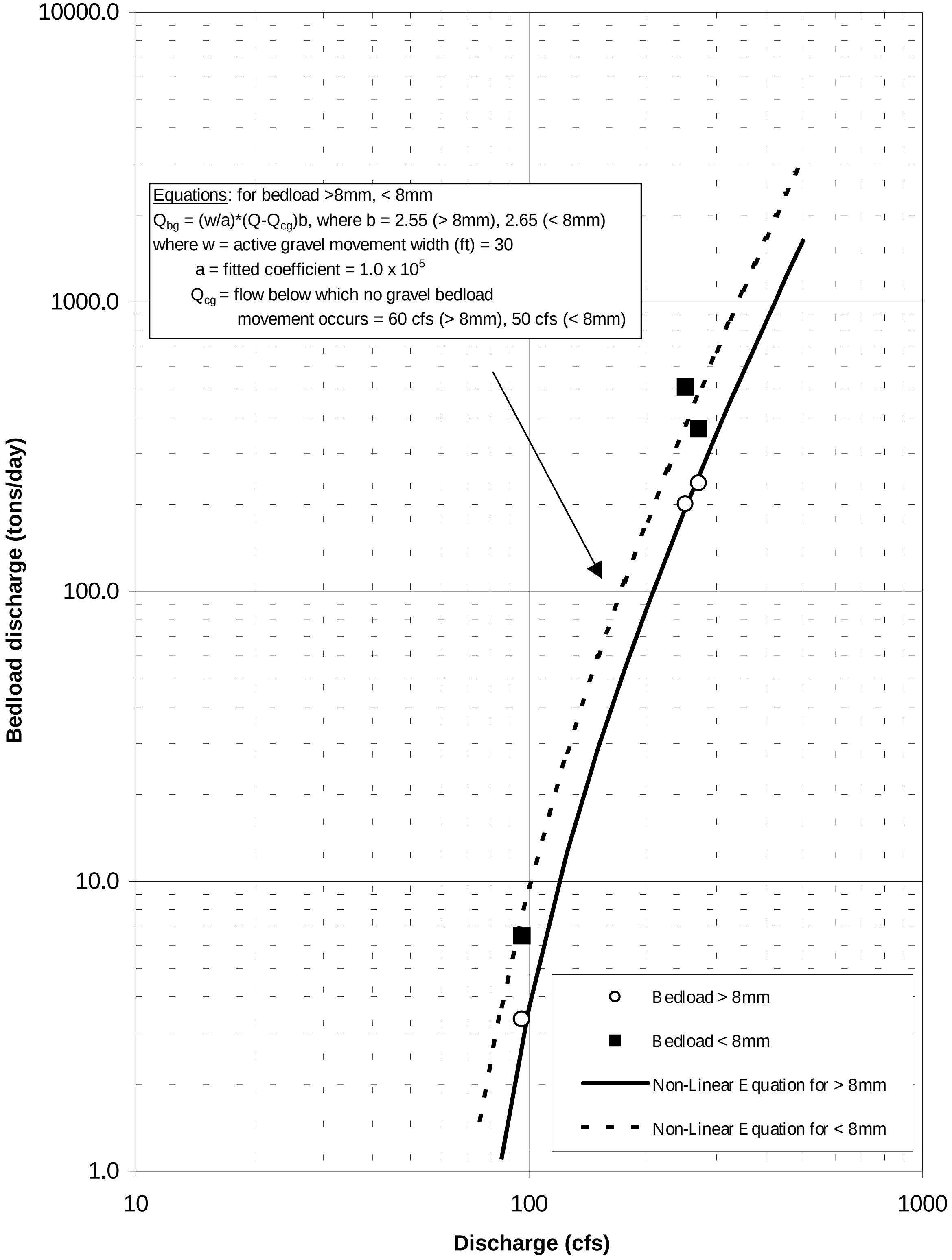


Figure 8.6 Indian Creek near Douglas City, bedload discharge rating curves for >8mm and <8mm particles.

bedload rating curve relationships (Figure 8.6).

8.5.1.3 Mainstem Trinity River

Trinity River at Lewiston:
Three bedload measurements were made at the USGS cableway in Lewiston during the high flow releases following the January 1 flood. The measurements define a steep bedload transport relationship (Figure 8.7). Caution must be used in the interpretation, however, as over 60% of the mass of the samples collected on February 6, 1997, for example, was in the three largest size classes and represented a relatively small number of grains. The sampler could have been "scooping" these large grains as it was retracted from the streambed. However, the consistency of the samples (made with averages of 2 or 3 consecutive replicates at each station) indicated that coarse sediment transport was occurring. While we expected small transport rates for fine sediment at the Lewiston gaging site due to small upstream watershed supply, we were surprised that there was virtually no fine sediment in our bedload samples. In all samples, there was no more than 10% of the sample weight finer than 8 mm.

Trinity River below Limekiln Gulch:
Only two bedload measurements were collected at this former USGS gaging site in WY 1997. These measurements closely agree with the best-fit line for USGS data from WY 1989 to WY 1991 (Figure 8.8). Earlier USGS bedload data (WY 1981 to WY 1986) show much greater transport rates at low flows, presumably indicative of greater sand supply in the early- to mid-1980s.

8.5.2. Computation of sediment transport records.

Computation of continuous records of sediment transport requires continuous records of streamflow and sufficient records of sediment transport to define shifts in the discharge-sediment load relationship during and between storm events. We have used the previously described sediment samples to construct preliminary sediment discharge rating curves for the various tributaries and the two mainstem sites for both suspended load and bedload. Our first efforts involved fitting simple power functions ($Q_s = aQ^b$, where "a" is a coefficient and "b" is the exponent describing the slope of the best-fit line), to the observed data. Improved fit was obtained by subdividing into pre- and post-January 1, 1997 flood periods, and or rising/falling limb data sets to account for storm hysteresis. The equations in our first computation of sediment records are listed below (Table 8.6) and identified on the various figures or in the appendices. The relative lack of data, particularly in cases with 5 or fewer data points, results in misleadingly high correlation coeffcients (r^2).

Surprisingly, if all tributary suspended sediment measurements were combined (Figure 8.9)(except the first storm on Deadwood Creek), a good correlation was obtained ($r^2 = 0.94$). Although for individual storm events and, in particular, rising vs. falling limb differentiation, improved results were obtained by using the individual tributary (Table 8.7) or storm relationships. Comparison of WY

Site	Bedload Equation	(r^2)	No. of Data Points	Period Used
Deadwood Creek	$Q_b = (0.00003)Q^{2.89}$	0.98	3	Pre-flood
Deadwood Creek	$Q_b = (0.00001)Q^{2.61}$	0.96	4	Post-flood
Rush Creek	$Q_b = (0.000002)Q^{2.94}$	0.93	6	Pre-flood
Rush Creek	$Q_b = (0.00009)Q^{2.50}$	0.77	6	Post-flood
Grass Valley Creek	$Q_b = (0.0941)Q^{1.04}$	0.39	28	All
Indian Creek	$Q_b = (0.000002)Q^{3.08}$	1.00	2	Pre-flood
Indian Creek	$Q_b = (0.0000005)Q^{3.75}$	0.92	9	Post-flood
Trinity @ Lewiston	$Q_b = (2 \times 10^{-31})Q^{8.88}$	0.99	3	All
Trinity @ Limekiln	$Q_b = (1 \times 10^{-13})Q^{4.12}$	0.94	11	All

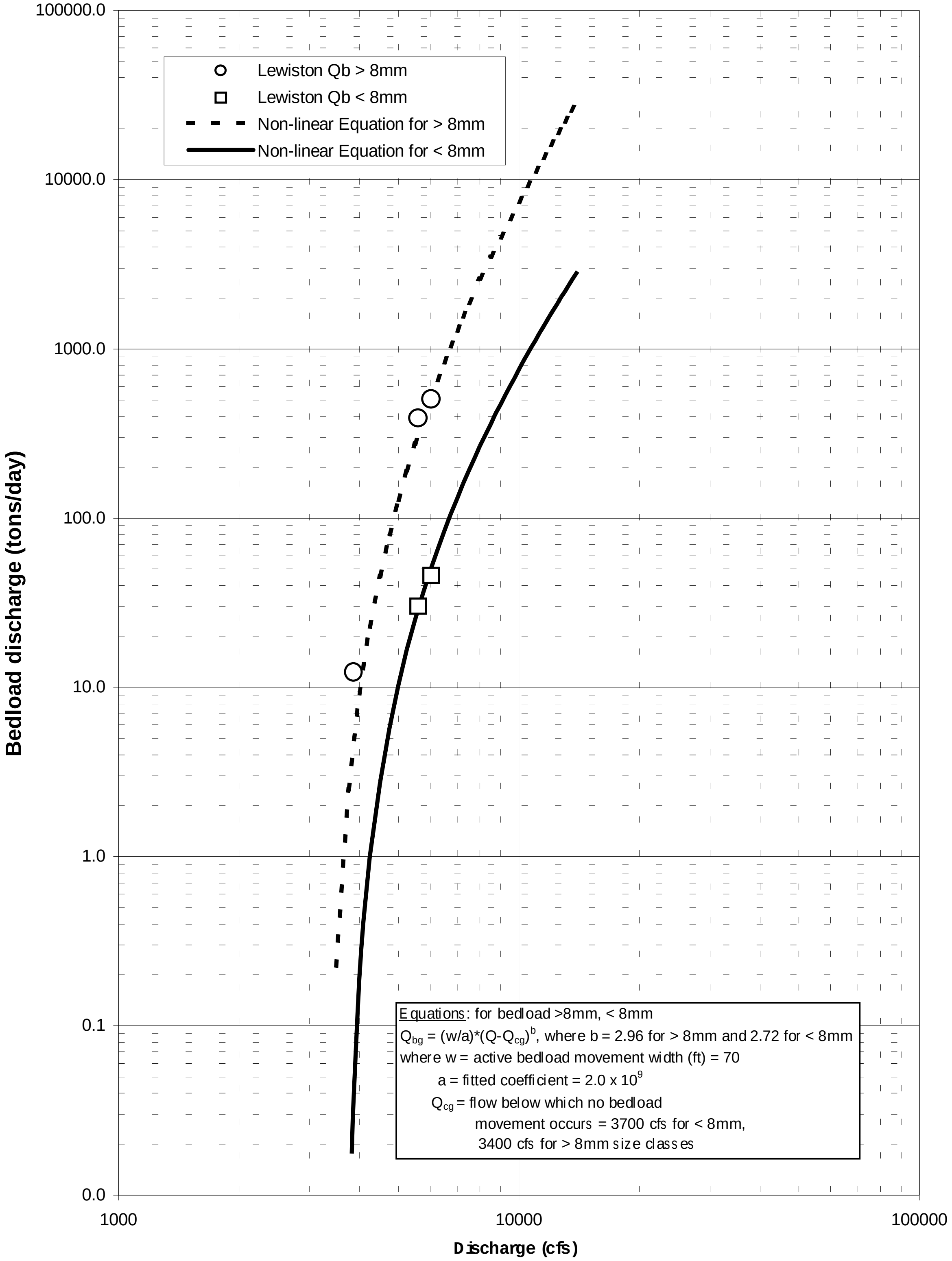
Table 8.6 Tributary and mainstem bedload sediment transport relationships.

Site	Suspended Load Equation	(r^2)	Number of Data Points	Period Used
Deadwood Creek	$Q_s = (0.00003)Q^{2.72}$	0.93	4	After 12/5/96
Rush Creek	$Q_s = (0.00006)Q^{2.46}$	0.95	8	Pre-flood
Rush Creek	$Q_s = (0.0003)Q^{2.26}$	0.79	3	Post-Flood
Grass Valley Creek	$Q_s = (.00028)Q^{2.38}$	0.79	70	All
Indian Creek	$Q_s = (3\times10^{-8})Q^{3.68}$	0.99	3	Pre-flood
Indian Creek	$Q_s = (1\times10^{-8})Q^{4.13}$	0.83	5	Post-flood
All Tributaries Combined	$Q_s = (0.0001)Q^{2.36}$	0.94	22	-na-

Table 8.7. Tributary suspended sediment transport relationships.

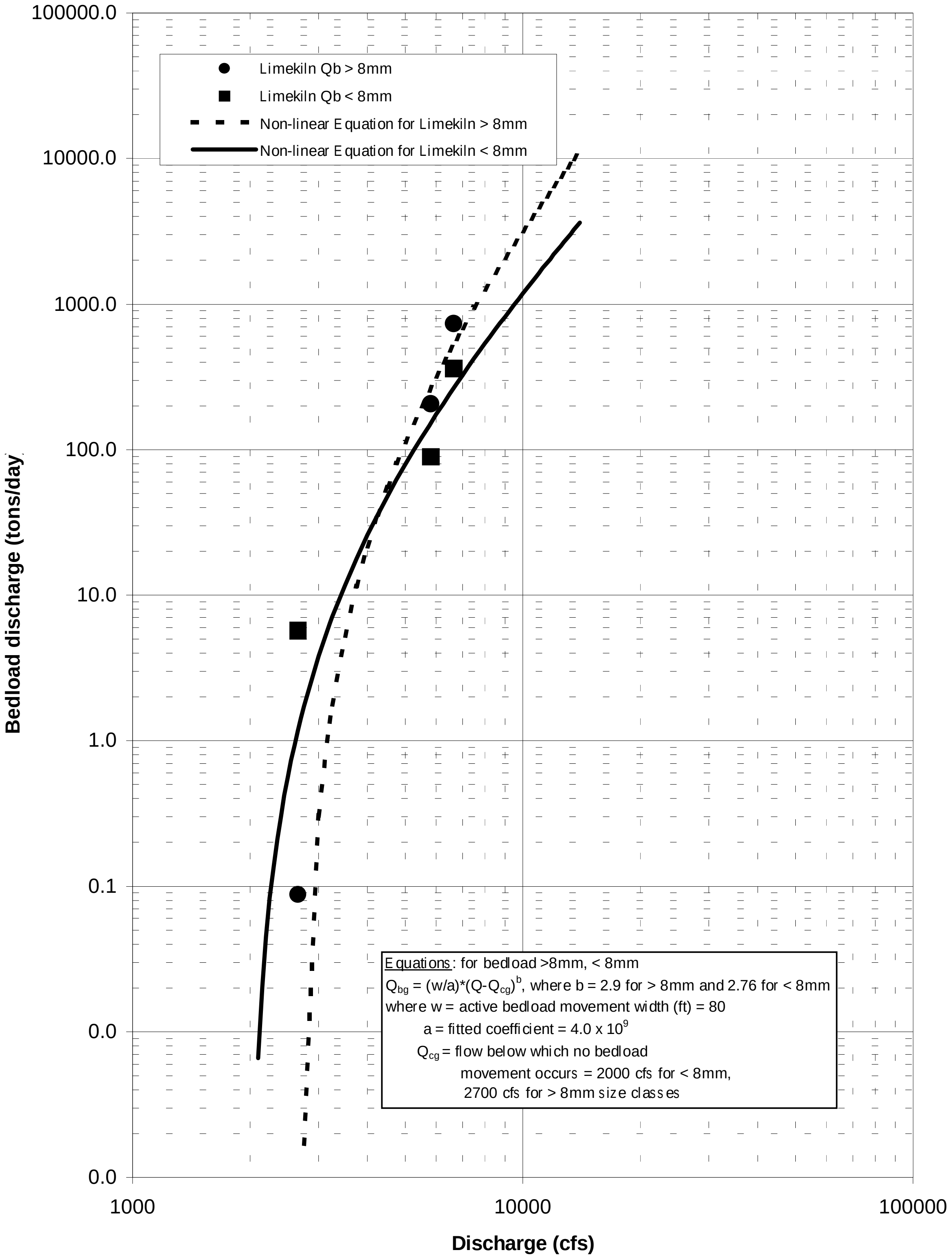
1997 suspended sediment data with previous (WY 1989 to WY 1995) suspended sediment data from Grass Valley Creek showed a similar relationship with identical regression equations. This suggests that these tributaries produce and transport fine sediments at generally consistent rates, despite differences in soils and land use.

Using these equations, initial computations of sediment transport records were made by applying the appropriate equation (pre-flood, post-flood, rising limb vs. falling limb, first storm of season, etc.) to the appropriate period of continuous streamflow records. Where continuous streamflow records did not exist, such as for December storms on Indian Creek, or the entire water year on Deadwood Creek, hydrographs were estimated based on our storm-stage observations and the shape of the nearest basin with continuous records (Rush Creek for Deadwood Creek, and Grass Valley Creek for Indian Creek). The hydrographs were then split into 15-minute, 30-minute, or 60-minute intervals based on available data. Sediment transport equations were applied to each interval and then summed to determine the total transport by type for each day. Results of these computations were included in two



Equations: for bedload >8mm, < 8mm
$Q_{bg} = (w/a)*(Q-Q_{cg})^b$, where b = 2.96 for > 8mm and 2.72 for < 8mm
where w = active bedload movement width (ft) = 70
a = fitted coefficient = 2.0×10^9
Q_{cg} = flow below which no bedload
movement occurs = 3700 cfs for < 8mm,
3400 cfs for > 8mm size classes

Figure 8.7 Trinity River at Lewiston mainstem bedload transport for > 8mm and < 8mm size classes.



Equations: for bedload >8mm, < 8mm

$Q_{bg} = (w/a)*(Q-Q_{cg})^b$, where b = 2.9 for > 8mm and 2.76 for < 8mm

where w = active bedload movement width (ft) = 80

a = fitted coefficient = 4.0×10^9

Q_{cg} = flow below which no bedload movement occurs = 2000 cfs for < 8mm, 2700 cfs for > 8mm size classes

Figure 8.8 Trinity River below Limekiln Gulch near Douglas City bedload transport for > 8mm and < 8mm size classes.

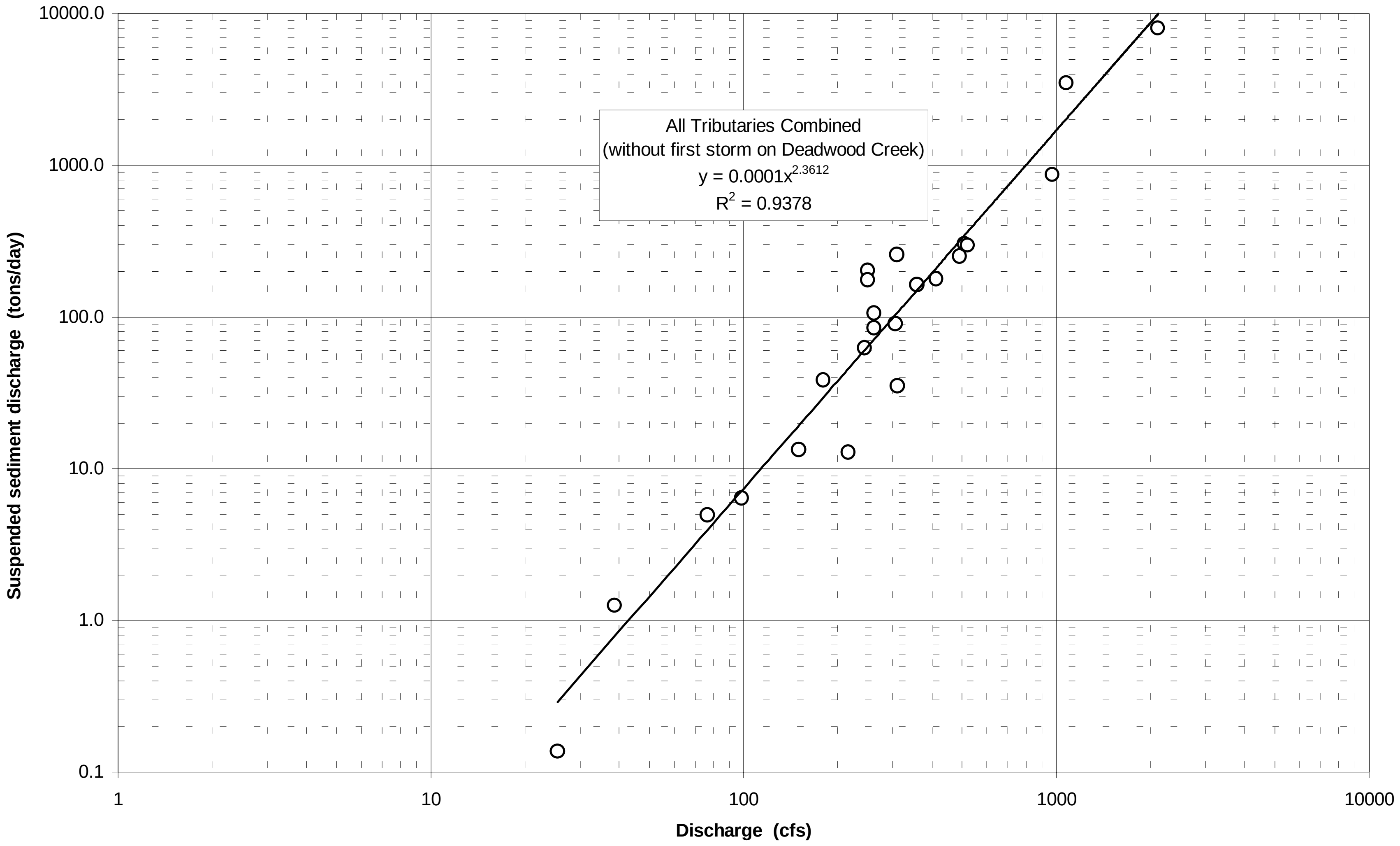


Figure 8.9 Suspended sediment rating curve using pooled 1997 data from Deadwood, Rush, and Indian Creeks.

tables in the appropriate section of Appendix B, with a record for suspended load and bedload at each station.

Table 8.8 contains the annual sediment load calculations using the best-fit power equations. Bedload computations appear much larger than would be reasonable when compared to suspended load. Almost all of the computed bedload was transported in two days with the highest flows (12/31/96-1/1/97), which were periods where there were no field observations of transport. In a few cases, we have independent estimates of bedload transport based on volumetric surveys at deltas. In particular, the storm of December 8 to 10 on Rush Creek produced a volumetric change at the delta of 702 yd^3 (1,338 tons based on a bulk density sample of 1.9 tons/yd^3). Computed bedload sediment transport for this storm period was 975 tons, which provided reasonable agreement. The results appear reasonable because that storm did not greatly exceed the range of measured flows, and there was no evidence of a rating shift or significant channel and/or watershed changes. The delta surveys at other locations were generally affected by the long duration of high flow reservoir releases that probably transported much of the tributary-derived sediments from the survey reach.

Tributary	Suspended Load (tons)	Bedload (tons)	Total Load (tons)	Drainage Area (mi^2)	Sediment Yield (tons/mi^2)
Deadwood Creek[1]	90	180	270	9	29
Rush Creek[1]	30,500	34,700	65,200	22	2,900
Grass Valley Creek[2]	13,400	700	14,100	37	380
Indian Creek[1]	8,100	36,500	44,600	34	1,300

Notes: [1] Sediment loads for Deadwood, Rush, and Indian Creeks based on flow records and measurements of sediment transport.
[2] Sediment loads for Grass Valley Creek based on historical measurements of sediment transport by the USGS, and provisional flow records for the Grass Valley Creek at Fawn Lodge gage operated by the USGS.

Table 8.8 Trinity River tributary sediment budget: summary of WY 1997 transport computations.

For Grass Valley Creek, we used published measurements of sediment transport by the USGS from recent years (WY 1989 to WY 1995) to establish transport equations. Without detailed flow data, we were unable to differentiate pre-flood, post-flood, and rising vs. falling limb relationships which may have improved the fit of the equations. The Hamilton Ponds provided an independent estimate of bedload transport from the Grass Valley Creek watershed. Unfortunately, the surveyed accumulations in the ponds for WY 1997, 9,580 cubic yards or 12,000 tons (using a bulk density factor of 1.25), does not agree with the bedload transport of 710 tons predicted by the power function regression through pre-1997 data. The exponent of the power function regression equation for Grass Valley Creek at Fawn Lodge is far too small.

As noted above, one significant problem with using a power relationship lies in the need to extrapolate the equation beyond the observed data. Frequently, this may occur because high storm flows could not be sampled due to excessive velocities and/or debris, or that the peak flows occurred during darkness. In these cases, straight-line extension of the log-linear relationship (power function) to these unmeasured flows may yield erroneously large transport values. Many transport functions in the literature are based on equations that have a non log-linear form, although within small data ranges, a log-linear fit may relatively closely approximate the function. In an effort to improve the extrapolation of the transport data to high flows, we fitted equations of the form:

$$Q_b = (w/a)*(Q-Q_c)^b, \qquad (8.2)$$

Where: Q_b is the fraction of bedload transport (tons/day), either > 8mm or < 8mm
w is the width of the active bed in feet during transport,
a is a fitted coefficient (typically in the range of $1x10^5$ to $1x10^8$,
Q is the discharge (cfs)
Q_c is the discharge at which no bedload transport occurs, and
b is a fitted exponent typically between 2 and 3

These equations approximate the Parker (1979) transport formula for gravel-bed channels, and produce non log-linear relationships which are very steep at the lower ends, but less steep than simple power equations at high discharges. We developed these for selected stations, again which were based on only a few data points. These functions are presented in Table 8.9 and shown in Figures 8.5 through 8.8. They were used to estimate bedload yield (either > 8mm or < 8mm) from the Indian and Rush Creek watersheds, and bedload transport at the Lewiston and Limekiln stations.

Site	Bedload Equation > 8mm	Bedload Equation < 8mm	Period Used
Rush Creek	$Q_{bg} = (35/1.5 \text{ x } 10^6)(Q-165)^{2.65}$	$Q_{bs} = (35/1000)(Q-145)^{1.32}$	Pre-Flood
Rush Creek	$Q_{bg} = (35/1800)(Q-60)^{1.90}$	$Q_{bs} = (35/1200)(Q-60)^{1.95}$	Post-Flood
Indian Creek	$Q_{bg} = (30/1.0 \text{ x } 10^5)(Q-60)^{2.55}$	$Q_{bs} = (30/1.0 \text{ x } 10^5)(Q-50)^{2.65}$	Post-Flood
Trinity River at Lewiston	$Q_{bg} = (70/2.0 \text{ x } 10^9)(Q-3400)^{2.96}$	$Q_{bg} = (70/2.0 \text{ x } 10^9)(Q-3700)^{2.72}$	All
Trinity River below Limekiln Gulch	$Q_{bg} = (80/4.0 \text{ x } 10^9)(Q-2700)^{2.90}$	$Q_{bg} = (80/4.0 \text{ x } 10^9)(Q-2000)^{2.76}$	All

Table 8.9 Non-linear transport equations for various tributary and mainstem stations.

Table 8.10 compares the computed annual bedload sediment estimates from Rush and Indian Creeks using the power equations and the non-linear modified-Parker equation. Yields are considerable lower when computed by the non-linear equation, indicating that the power function appears to have over estimated yields at the highest discharges. We anticipate confirming and/or improving these relationships with additional sampling in WY 1998.

Site	Annual Bedload Computed Using Log-linear (power) Equations (tons)	Annual Bedload Computed Using Non-linear Equations (tons)
Rush Creek	60,504	34,728
Indian Creek	55,183	36,484

Table 8.10 Comparison of Annual Bedload Yield from selected tributaries computed by two methods.

8.5.3. Coarse sediment routing

We developed a coarse sediment budget for the mainstem to evaluate routing of coarse sediment through the system. This knowledge is vital in assessing availability of coarse channel substrate transported by proposed flow regimes. Higher flows that are intended to initiate and maintain dynamic channel features, or to maintain channel rehabilitation sites, will by their nature and purpose transport gravels through the system. If this transport exceeds that delivered by tributaries, we expect channel morphology, substrate, and salmon habitat to be negatively impacted. One primary objective of this sediment budget evaluation was to determine whether gravel introduction below Lewiston Dam would be needed, and if so at what rates. This approach is similar to others being implemented on a number of other rivers below reservoirs (Kondolf and Matthews 1993).

To assess coarse sediment delivery from tributaries, we used our grain size analyses to determine the percentage of bedload less than and greater than 8 mm. These percentages were applied to the measured transport rates (for all size classes) to determine individual transport rates for the two size classes (Table 8.11-8.13). For Rush Creek, with the significant post-flood shift in bedload transport, separate curves were developed for pre-and post-flood conditions (Figure 8.5). We did not have size distribution data for Indian Creek pre-flood, and were unable to accurately predict its size distribution, although from the shift in the bedload rating curve, most of the sediment must have been transported after the flood peak. We also did not have size distribution data for our bedload samples from Deadwood Creek, and instead used the percentages determined from our delta bulk sample.

These sediment yields can be evaluated by comparing them with predicted bedload transport in the mainstem Trinity River using bedload transport equations developed for the Lewiston (RM110.2) and Limekiln Gulch (RM 98.3) gaging sites. Using the Lewiston gaging station daily average discharge for WY 1997 gave a sediment transport rate of 25,000 tons for sediment greater than 8 mm, and only 2,475 tons for sediment less than 8 mm. Similarly for the Limekiln Gulch site, where daily average discharges were estimated by combining Lewiston, Rush Creek, Deadwood Creek, and Grass Valley Creek flows, transport of sediment greater than 8 mm was computed as 20,430 tons and 12,600 tons for sediment < 8mm. Comparing this with the sediment yield of the tributaries (Table 8.11) shows mainstem aggradation would most likely continue at Rush Creek, Grass Valley Creek (if the sediments were not trapped by Hamilton Ponds), and Indian Creek. Conversely, because there is very

Date	Deadwood Creek		Rush Creek		Grass Valley Creek at Hamilton Ponds		Indian Creek	
	Peak Q (cfs	Bedload > 8mm (tons)	Peak Q (cfs)	Bedload > 8mm (tons)	Peak Q (cfs)	Bedload > 8mm (tons)	Peak Q (cfs)	Bedload > 8mm (tons)
1/9/95	430	3,200			2,700	13,000		
12/4/96	30	0.08	438	124	included in 12/9/96 estimate		80	0.24
12/9/96	37	1	946	732	37	120	512	118
1/1/97	329	140	6,000	15,070	329	3,600	2310	11,296
1/28/97	54	2.6	510	223	included in 1/1/97 estimate		277	775
1997 total		143		16,089		3,720		12,190

Table 8.11 Trinity River tributary sediment yields >8 mm by WY 1997 storm event.

Date	Total Bedload	> 8mm	< 8mm
12/4/96	31.2	12.4	18.8
12/9/96	1025	732	293
1/1/97	32853	15070	17783
1/28/97	660	223	437
Annual Total	34,728	16,089	18,639

Table 8.12 Rush Creek coarse sediment yields

Date	Total Bedload	> 8mm	< 8mm
12/4/96	0.72	0.24	0.48
12/9/96	356	118	238
1/1/97	33807	11296	22511
1/28/97	2321	776	1545
Annual Total	36,484	12,190	24,294

Table 8.13 Indian Creek coarse sediment yields

limited supply from Deadwood Creek, approximately 25,000 tons of gravel would need to be introduced below Lewiston Dam to prevent further gravel loss, channel downcutting, and bed coarsening.

8.5.4. Extrapolation of coarse sediment budget for long-term averages

One objective of this analysis was to predict the coarse sediment budget for the upper mainstem Trinity River, so that we could modify the magnitude and duration of high flows to most efficiently transport coarse sediments derived from the upper tributaries. For example, what is the coarse sediment yield from each tributary for a Wet year or Normal year? Can we then evaluate whether the high flow regime recommendation for that particular water year would be sufficient to transport this volume of tributary-derived coarse sediments? We originally planned on using the Grass Valley Creek sediment yield from WY 1976 to WY 1996 as a scalar for the other tributaries. However, there were problems with this approach:

- To extrapolate Grass Valley Creek data back in time to other tributaries, we must assume that the sediment supply remained the same for all tributaries. Completion of Buckhorn Dam in 1990 and watershed restoration efforts on Grass Valley Creek have reduced sediment yield from Grass Valley Creek the past few years. We observed a large shift in the bedload rating curves corroborating this, but due to the huge scatter in the USGS bedload measurements, removal of one of their points could substantially move the bedload rating curve. Regardless, if we used the ratio of WY 1997 tributary data to Grass Valley Creek data as a proportion to go back in time (and the unit sediment yield from Grass Valley Creek is much lower in WY 1997 than the other years), the extrapolation would greatly over-predict sediment yield for the tributaries.
- Most USGS measurements were taken at flows that were not moving particles greater than 8 mm, and the bedload measurements were usually measuring sand transport at low flows (“throughput load” as per Parker et al., 1982). We attempted to fix this by correcting the transport rates with the %coarser than 8 mm with bulk samples from deposits in Hamilton Ponds.
- Grass Valley Creek is not a watershed that would be considered “representative” due to the probable change in sediment yield with time, and the difference in lithology.
- Storm runoff and sediment yields vary between watersheds for any given storm event due to snow level, differences in storm cell intensity, and antecedent watershed conditions. For example as happened in WY 1997, the peak flow and sediment yield on Grass Valley Creek were moderate (typical of a Wet water year), but peak flows and sediment yield on Indian Creek and Rush Creek were much larger, and more representative of Extremely Wet water years.

Since there are no long-term discharge records on any of the tributaries except Grass Valley Creek, we were forced to extrapolate our 1997 data using historic peak discharges from Grass Valley Creek. We considered two methods to extrapolate Grass Valley Creek data: extrapolate based on Grass Valley Creek sediment yield data, or extrapolate based on peak discharge on Grass Valley Creek. After doing both, we felt that extrapolation based on peak flow data provided better sediment yield estimates.

The extrapolation based on peak flows was performed as follows. For all storms in WY 1997, we plotted the >8 mm sediment yield on each tributary, but as a function of peak discharge on Grass Valley Creek rather than peak discharge on each tributary (Figure 8.10). Then we went back to the Grass Valley Creek annual peaks from WY 1976 to the present, predicted sediment yield for each year and classified the sediment yield to the corresponding water year designation of that year. The annual maximum peak discharges were sorted, ranked, and an exceedence probability computed. The five water year classes were then established at the same exceedence intervals as on the mainstem, from Critically Dry to Extremely Wet. This analysis assumed that the annual peak discharge dominates sediment yield from the watershed, and that peak discharge on Grass Valley Creek does not change with time as sediment yield has. This analysis should provide reasonable sediment yield predictions for all water years except Extremely Wet years. The power function regressions in Figure 8.10 yield extremely large sediment yield predictions for Rush and Indian Creeks during Extremely Wet years (over 100,000 tons of > 8mm bedload on Indian Creek). This is caused by extrapolating the curve in Figure 8.10 beyond the range of data collected, and this extrapolation most likely over-estimates sediment yields for Extremely Wet years. The Extremely Wet year predictions shown in Table 8.14 should not be relied upon for Indian Creek, and treated with considerable caution for Rush Creek. We envision future monitoring to abandon this type of analysis, and river managers to monitor the volume of sediment delivered to the Trinity River each year, and recommend the proper combination of flow magnitude and duration to transport this sediment downstream. The extrapolation exercise performed here is meant only to provide rough estimates of flow duration during peak dam releases, to be updated on a yearly basis as monitoring data improves sediment yield estimates.

ESTIMATED COARSE SEDIMENT YIELDS (tons)				
WATER YEAR	Deadwood Creek	Rush Creek	Grass Valley Creek at Mouth	Indian Creek
Extremely Wet average:	280 tons	48,600 tons[1]	12,800 tons	164,000 tons[1]
Wet average:	50 tons	9,000 tons	3,050 tons	14,300 tons
Normal average:	4 tons	800 tons	1,300 tons	340 tons
Dry average:	2 tons	390 tons	1,150 tons	85 tons
Critically Dry average:	0 tons	0 tons	700 tons	0 tons
Average	50 tons	8,600 tons	3,050 tons	23,800 tons

[1] WY 1997 sediment yield values used as average coarse sediment yield instead of extrapolated

Table 8.14 Results of Option 1 tributary coarse sediment yield extrapolation.

8.6 SUMMARY

Satisfying the objective of providing gravel introduction rate predictions based on a long-term average sediment yield from upstream tributaries was difficult with one season of preliminary sediment yield estimates upon which to extrapolate. However, because the sediment yields for Rush and Indian Creeks were so large, they can be considered some of the maximum rates of coarse sediment transport for an Extremely Wet water year. By applying recommended flow regimes to the mainstem bedload transport rating curves (in Chapter 11), we will evaluate if tributary sediment

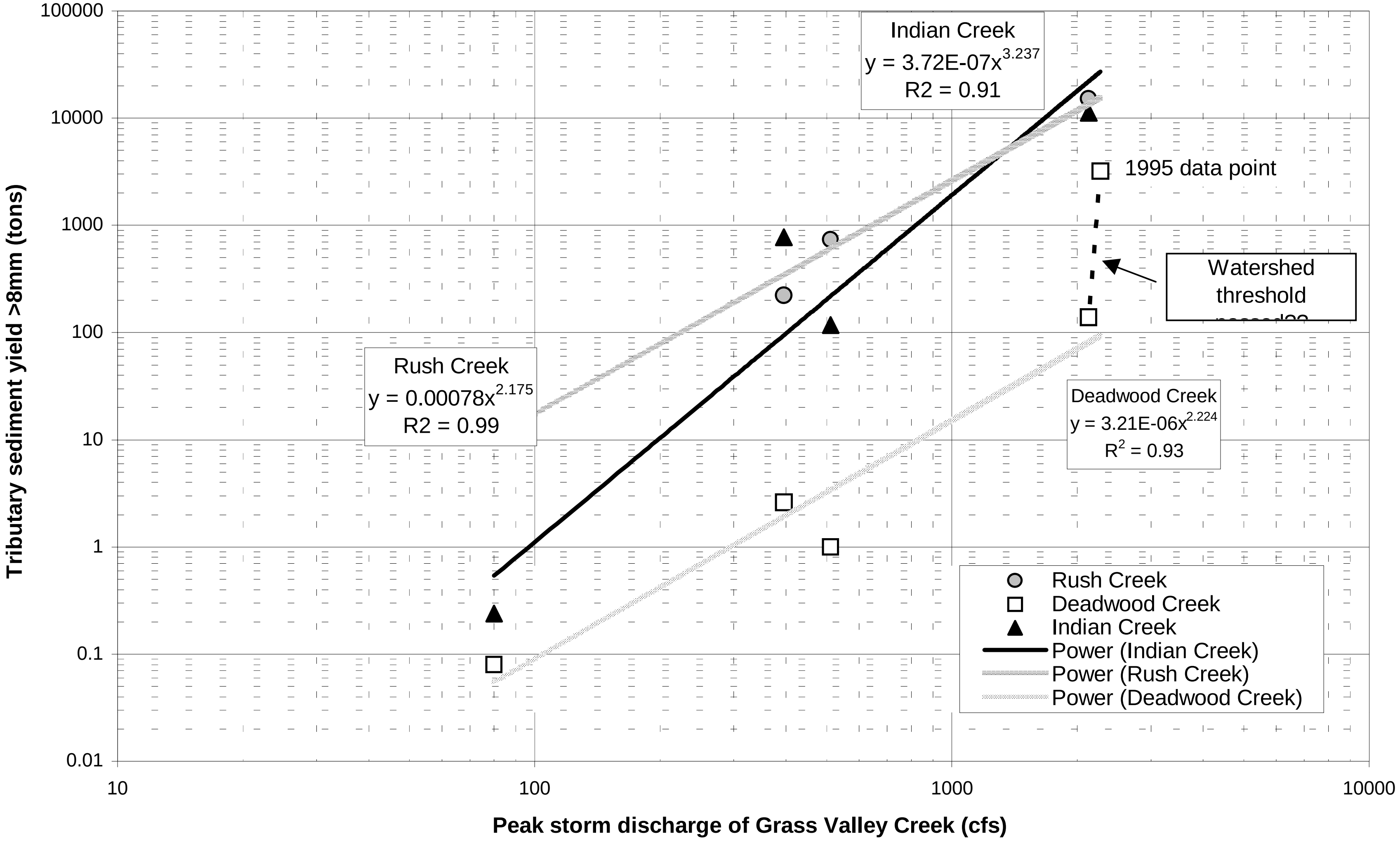


Figure 8.10 Predicted tributary coarse sediment yield (> 8mm) as a function of Grass Valley Creek peak discharge.

inputs to the mainstem are adequate (Figure 8.2), and evaluate how much gravel would need to be introduced in reaches where mainstem transport capacity exceeds supply.

Four sediment budget management objectives were identified:

1. Transport the bedload component of tributary sediments contributed to the mainstem Trinity River from the deltas and distribute them downstream;
2. Identify reaches on the mainstem Trinity River where bedload supply is limited compared to mainstem transport capacity;
3. Select candidate reaches where local supply should be supplemented with introduced gravels and estimate introduction rates;
4. Transport fine sediment stored in the mainstem at a rate greater than supply to reduce mainstem fine sediment storage.

Management considerations resulting from our sediment budget investigation include:

- Mainstem bedload transport rate estimates using modelling and bedload traps were unreliable. Bedload traps often overfilled for larger flows where the data were needed most. The volume of gravel that “escaped” could not be estimated. Additionally, the process of bedload trap filling altered the local shear stress field, interfering with bedload transport into the traps. Bedload modeling produced highly variable results due to natural variability between cross sections, inaccuracies in estimating energy slope (to which the model was extremely sensitive), and our site-selection for representative cross sections. More detailed sediment routing modeling should be conducted in conjunction with additional field measurements of bedload transport for the tributaries and mainstem.
- Releasing mainstem flows out-of-phase with tributary floods guarantees an unbalanced future coarse sediment budget because there is no corresponding increase in transport with cumulative tributary sediment supply.
- Tributary sediment yield is not linear with wetter water year classes (Table 8.14). Sediment yield is strongly correlated with specific upstream watershed failures, and there are storm intensity thresholds that cause rapid and extremely large increases in sediment yield. This is best illustrated by the WY 1997 flood on Indian Creek. Bedload transport rates at 300 cfs were 75 tons/day prior to the flood, but after the flood peak, transport rates at 250 cfs were over 600 tons/day. Several hillslope failures supplied sand and gravel that continued to route through the watershed for over a month.
- Deadwood Creek contributes very minor bedload until a discharge threshold of 300 cfs is surpassed, after which sediment yield increases rapidly. Flows greater than 300 cfs are rare, only occurring during WET or EXTREMELY WET water years.
- Substantial gravel introduction will be needed upstream of Rush Creek to maintain/improve existing habitat (see Chapter 11 for estimates based on proposed flow regimes). This reach is the most heavily used mainstem spawning reach; therefore maintaining an adequate spawning gravel supply will be an important management strategy.

- Deadwood Creek suspended sediment yield is very low, nearly the same as bedload. We rarely observed significant turbidity in Deadwood Creek, even during higher flows when we could hear (and measure) significant bedload transport in the culvert. While this roughly equal suspended to bedload sediment yield is unusual (Richards, 1982), it was supported by our mainstem Trinity River bedload samples at the Lewiston cableway having functionally no fine sediment.
- There are types of impedance reaches and both are man-made: aggraded tributary junctions and dredged pools. Both trap coarse bedload and disrupt bedload continuity.
- Pool enlargement to facilitate fine sediment deposition, and subsequent dredging, is not recommended in the future. While some of our objections are philosophical (e.g., Is suction dredging really an ecosystem restoration approach?), many are related to the effect of dredging on local coarse sediment budgets. Pool dredging in WY 1991 to WY 1992 enlarged their volumes. Subsequent measurement of net changes in pool volume in WY 1997 documents that they have not trapped appreciable quantities of fine sediment.
- Dredged pools have been extremely efficient in trapping coarse bedload, including spawning gravels that should be routed downstream. Some pools now show evidence of gravel routing through (e.g., Reo Stott Pool), but others do not (e.g., Society Pool). As the pools trap gravel and fill, reaches immediately downstream are starved of coarse sediment, causing channel downcutting, reduced bar features, and bed coarsening (all of which are detrimental to salmonid habitat). Continued and timely maintenance of the Hamilton Ponds is extremely effective at removing the largest source of fine sediment to the Trinity River, and future high flows on the mainstem Trinity River should greatly decrease fine sediment storage.
- Tributary delta measurements are the most accurate and precise methods for estimating sediment yield from tributaries, and provide an excellent check on the bedload transport rating curves prepared from Helley-Smith samples. Unfortunately, wet years in WY 1995 and WY 1997 resulted in safety of dams high flow releases, which transported much of the tributary deltas downstream before we could measure the volume contributed by each tributary storm. We recommend continuing the tributary delta surveys, but only surveying the mainstem reach from the tributary confluence downstream 500 ft (and only surveying the delta if mainstem releases have not removed any of the delta). Not knowing the delta volume transported by the mainstem releases only provided a minimum sediment yield from the tributaries.
- Predicted fine sediment transport (< 8mm) at Limekiln Gulch in 1997 was less than that contributed by Rush Creek such that in-channel & berm storage of fine sediment likely increased.

CHAPTER 9: RIPARIAN DYNAMICS

Attribute No. 9. SELF-SUSTAINING DIVERSE RIPARIAN PLANT COMMUNITIES

Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors.

Our study identified several mortality agents for woody riparian species that are dependent on flow. In this section, we first present probable relationships between these mortality agents (e.g., desiccation and scour), the annual hydrograph, and river channel dynamics. Then in subsequent sections, specific hypotheses were formulated and evaluated, substantiating these relationships and linking pre- and post-TRD annual hydrograph components to explain how woody riparian encroachment and riparian berm formation can be prevented in the future.

Our hypothesis that riparian vegetation is significantly influenced by flows, has support from the literature. Bradley and Smith (1986) showed that desiccation (killing seedlings high on a point bar) and scour (killing seedlings low on the bar) allowed only occasional cottonwood cohorts to survive. Our analysis of hydrograph components, for identifying flow-related physical processes affecting riparian communities, is not unique. Scott, Wondzell, and Auble (1993), in relating specific components of the annual hydrograph to riparian life history dynamics, note, "Aside from the rising limb, all aspects of the hydrograph play a vital role in the germination, establishment, and long-term survival of many riparian species."

9.1 Pre-TRD Woody Riparian Vegetation Dynamics: Hypotheses

Preventing germination precludes channel encroachment. Historically, this was accomplished by inundating potential germination surfaces when seeds were available and viable. In most Extremely Wet and Wet water years, flows during the snowmelt recession limb continued into July, inundating alternate bar surfaces throughout most of the seed-release period. But in drier years, early receding snowmelt exposed bar surfaces to successful germination. The natural sequence of annual snowmelt hydrographs could not prevent germination in all water years.

Newly germinated seedlings are vulnerable to scour by the next winter's high flows. Mobilization of the channelbed surface layer should have scoured out and/or winnowed young seedlings rooted as deep, or slightly deeper, than the surface layer thickness. However, the entire channelbed surface is not uniformly susceptible to mobilization by a single flood magnitude. Surfaces higher on an alternate bar require greater magnitude floods for bed mobilization. Attribute No. 3, alluvial rivers typically mobilize the surface layer of the channelbed annually, is an over simplification of expected channelbed dynamics. A range of threshold flow magnitudes would have been necessary to prevent seedling survival throughout alternate bar sequences. These threshold flow magnitudes would have been generated by winter floods and the larger snowmelt peaks in Extremely Wet, Wet, most Normal, and occasional Dry water years. Therefore, mainstem flows capable of mobilizing at least a portion of the entire channelbed surface layer were common.

But a small percentage of young seedlings often escaped scour for two years or longer, at which time they became securely rooted deeper than the surface layer (unless close to the summer baseflow elevation where groundwater would keep rooting depths very shallow). Occasionally, seedling establishment was widespread. If two or three drier years occurred sequentially, germination was favored and bed mobilization was minor. Mobilization of the bed surface, though probably highly effective at removing young seedlings, would not have been sufficient to prevent bar encroachment.

Larger, but less frequent floods could scour deeply rooted seedlings (Attribute No. 4). Flood peaks occurring every 3 to 5 years had the capability of scouring depositional features, such as alternate bar sequences, deeper than the surface layer. The critical rooting depth (the depth of scour at which the roots can no longer anchor the plant) relative to the surface layer thickness would be a major factor determining the potential of higher flood magnitudes for killing older plants.

Maturing trees tend to become established in stands. As a stand matures, hydraulic forces of flood flows are modified. Flood flows generating bed shear stresses capable of scouring a single tree isolated on a bar are often incapable of scouring the same tree in a stand. The vertical velocity field in the stand becomes highly modified, even during very large, infrequent flows such as the January 1997 flood. Often, hydraulic modification of the velocity field is so complete that the surface beneath a stand experiences aggradation rather than scour. Individual mature trees along the edge of stands may still be susceptible to scour.

A stand can be undercut by lateral bank migration (Attribute No. 6) or isolated from mainstem low flow channels by bank avulsion (Attribute No. 8). We could not estimate the recurrence of flood flows initiating meander migration, as we observed no substantial migration during our study. However, we are aware that unregulated alluvial rivers typically migrate during bankfull discharges and higher. Bank avulsion also was not observed, but does occur in unregulated alluvial channels during infrequent large floods.

9.2 Assessing Riparian Plant Mortality

Germination prevention, scour, lateral undercutting, and stand isolation can be associated with specific components of the unregulated hydrograph. Of great significance is the snowmelt hydrograph with its extended receding limb. Snowmelt flows inundate bars throughout much of the period when seeds are released, thus preventing germination on lower bar surfaces. Also, these flows often mobilize the channelbed surface, curtailing plant establishment, occasionally scouring alluvial features to remove older established saplings, and initiating bank migration to undermine mature/old growth stands. The snowmelt hydrograph is missing from post-TRD annual flow regimes. The role of the summer baseflow hydrograph component in preventing and/or encouraging seedling initiation may be the most difficult to assess.

We examined the following hypotheses:

(1) Critical rooting depth is a function of age.
(2) Mobilization of the channelbed surface in the winter (Attribute No. 3) would remove seedlings established the previous spring and summer, and possibly remove seedlings established the summer before;
(3) Channelbed scour (Attribute No. 4) would remove one and two year old seedlings, and possibly three to four year old seedlings;
(4) The exposed capillary fringe, during the period of seed release, is the principal medium for germination. The band (range of elevations on a particular alternate bar) of this exposed capillary fringe is a function of the magnitude and duration of snowmelt recession, as well as bar morphology and bar composition. The band of successful germination and initiation would be significantly affected by the magnitude, duration, and timing of snowmelt recession (Attribute No. 2).
(5) Subsurface moisture in alternate bars can be limiting successful seedling initiation.
(6) Large floods (Attribute No. 8) would remove older seedlings and mature trees;

9.3 Inventorying Woody Riparian Initiation and Establishment

Woody plant initiation and establishment was monitored at selected bank rehabilitation project sites. In WY1995, Sheridan Creek, Steiner Flat, and Bucktail were monitored as representative of the nine rehabilitation sites. A geomorphically homogenous 400 ft reach was selected from each site. Starting at the upstream end of each reach, five cross sections were established at 100 ft intervals, adding these to cross sections established previously.

Transects were inventoried using belt transects (Kent and Coker, 1992; Bonham, 1989). Plants initiating and establishing during spring and summer 1995 were included. Belt transects were four feet wide and extended across the entire bar surface perpendicular to the channel. Plants were inventoried within 4 ft by 2 ft quadrats, each subdivided into a grid of 0.10 ft by 0.10 ft cells. A coordinate system was established to relocate each plant within a cell. We centered the quadrat on a measuring tape to sample two feet upstream and downstream of the channel cross section line. Quadrat elevation and changing water surface elevations were recorded.

We encountered problems with springtime inventorying; plants supposedly killed by flooding (shoots broken away by high water, but with roots remaining) would reappear in the summer inventory. Springtime plant inventorying occurred early in the growing season when some plants had not yet broken dormancy, a stage at which species identification was difficult. The summer inventory avoided both problems and should be considered more consistent between years.

Initiating seedlings were fragile; handling these plants would often disturb their roots and risk sampling mortality. Therefore we evaluated initiation by counting, not handling, seedlings less than 1.5 inches high. If a plant was greater than 1.5 inches high we measured height and root collar diameter for each plant, or only for the longest stem if more than one stem was present. We sorted the seedlings into annual cohorts for each woody species on each belt transect.

In 1995, we initially planned to inventory five transects at three selected bank rehabilitation sites. Plant initiation varied greatly between sites with several cross sections at Bucktail and Steiner Flat having no initiating or establishing plants and all five cross sections at Sheridan Creek having thousands on each. As a result, only transects with initiating or establishing plants at Bucktail and Steiner Flat were inventoried (three and four transects, respectively); only two cross sections were inventoried at Sheridan Creek.

Monitoring was expanded to all bank rehabilitation sites in WY1996 to sample a wider range of channel morphologies. We repeated the inventory protocol of the previous year, but included only one representative cross section at each site instead of five. Transect selection in WY1996 was based on proximity to newly formed depositional features. Belt transects sampled in WY1996 were inventoried again in spring and summer of 1997. During spring of 1997, we included two new belt transects at the Jim Smith bank rehabilitation site.

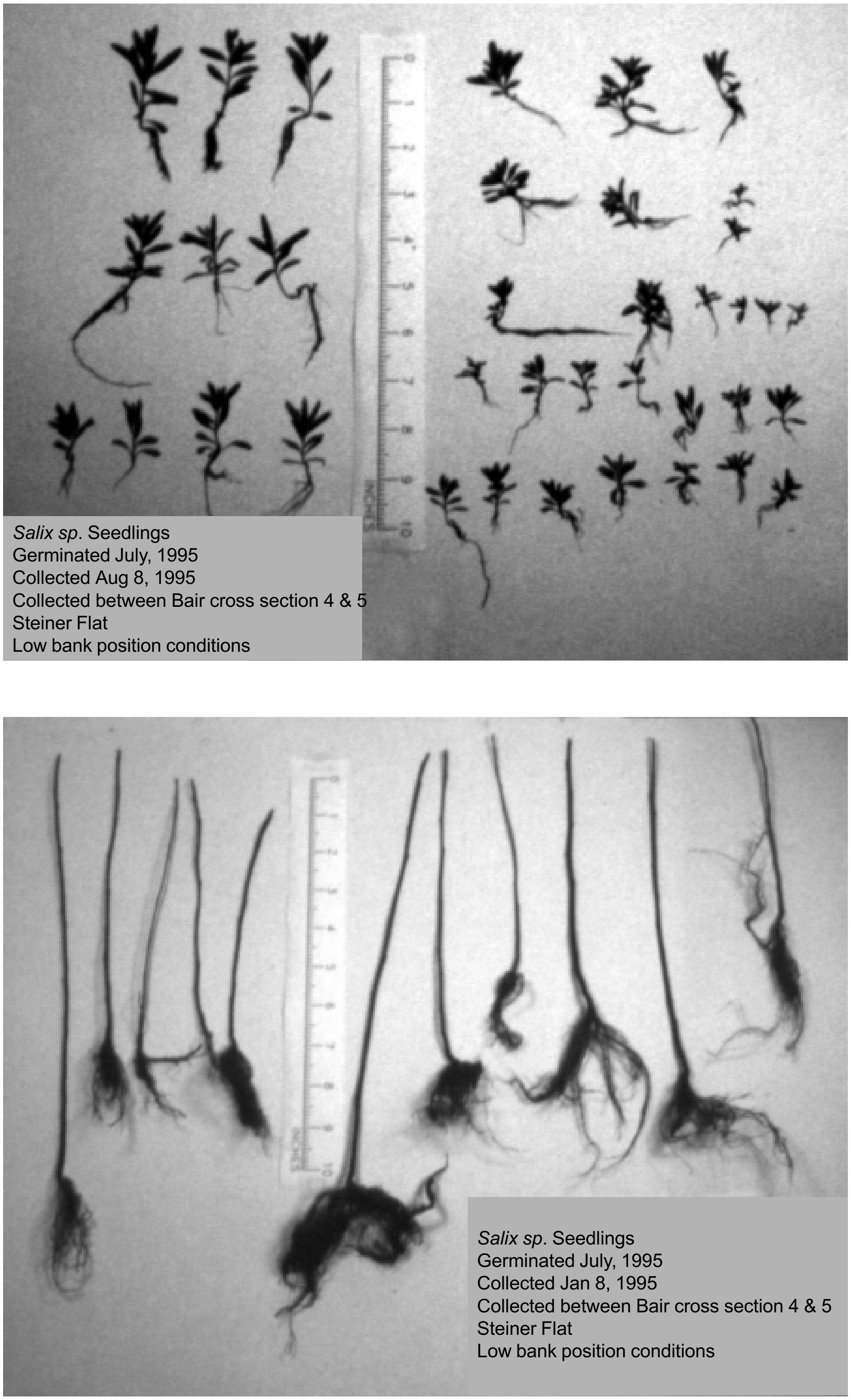
Not all woody riparian plants were removed from the bank rehabilitation sites during construction. Willow root material re-sprouted and quickly grew back. Because our interest was in woody plants initiating, not re-sprouting after bank excavation, criteria were developed to exclude plants that had not initiated on the newly constructed surfaces. We defined a pre-construction plant as having multiple stems greater than three feet high or a root collar diameter (DRC) greater than 76 mm (approximately 3 in). The first criterion eliminated established willows; the second eliminated established alder, ash, and cottonwood.

9.4 Critical Rooting Depth

Critical rooting depth (CRD) is the root depth just capable of anchoring the plant in the face of shear stress. Critical rooting depth was first hypothesized to be a function of age. A second determinant of rooting depth could be proximity of the water table and/or the capillary fringe (a wetted zone above the water table elevation). A plant's root system extends no deeper than the water table, but instead spreads laterally above this elevation. In sum, we hypothesized that plant age, groundwater proximity, and possibly substrate composition could impact CRD.

Willow CRDs were examined, as these were most pervasive among the encroaching woody plants (i.e., the best initial colonizers of open bar surfaces). We sampled CRDs for a 60-month range of willows initiating and establishing on exposed flanks of excavated channelbed surfaces of the Steiner Flat and Sheridan Creek bank rehabilitation sites. We excavated the surrounding matrix while gently pulling on the plant stem until root strength failed. While this method was not subject to rigorous control, the shallow rooting pattern made this approach plausible. Plants rooting close to the water table, such as narrow-leaf willow *(Salix exigua)* at the Sheridan site, have their roots spread more laterally, than extended vertically (Figures 9.1 to 9.3). The depth to which we excavated in removing almost the entire root structure was surprisingly shallow. Following excavation, there was very little root remaining in the channelbed, generally only the fine root hairs extending deeper. Following major floods that scoured other bars, we once observed established willows anchored to the channelbed even though 80% to 90% of their root masses were exposed. For plants situated higher on the bar, a larger portion of the root remained in the ground, though generally 85% or more of the total root depth was still included in the critical root depth.

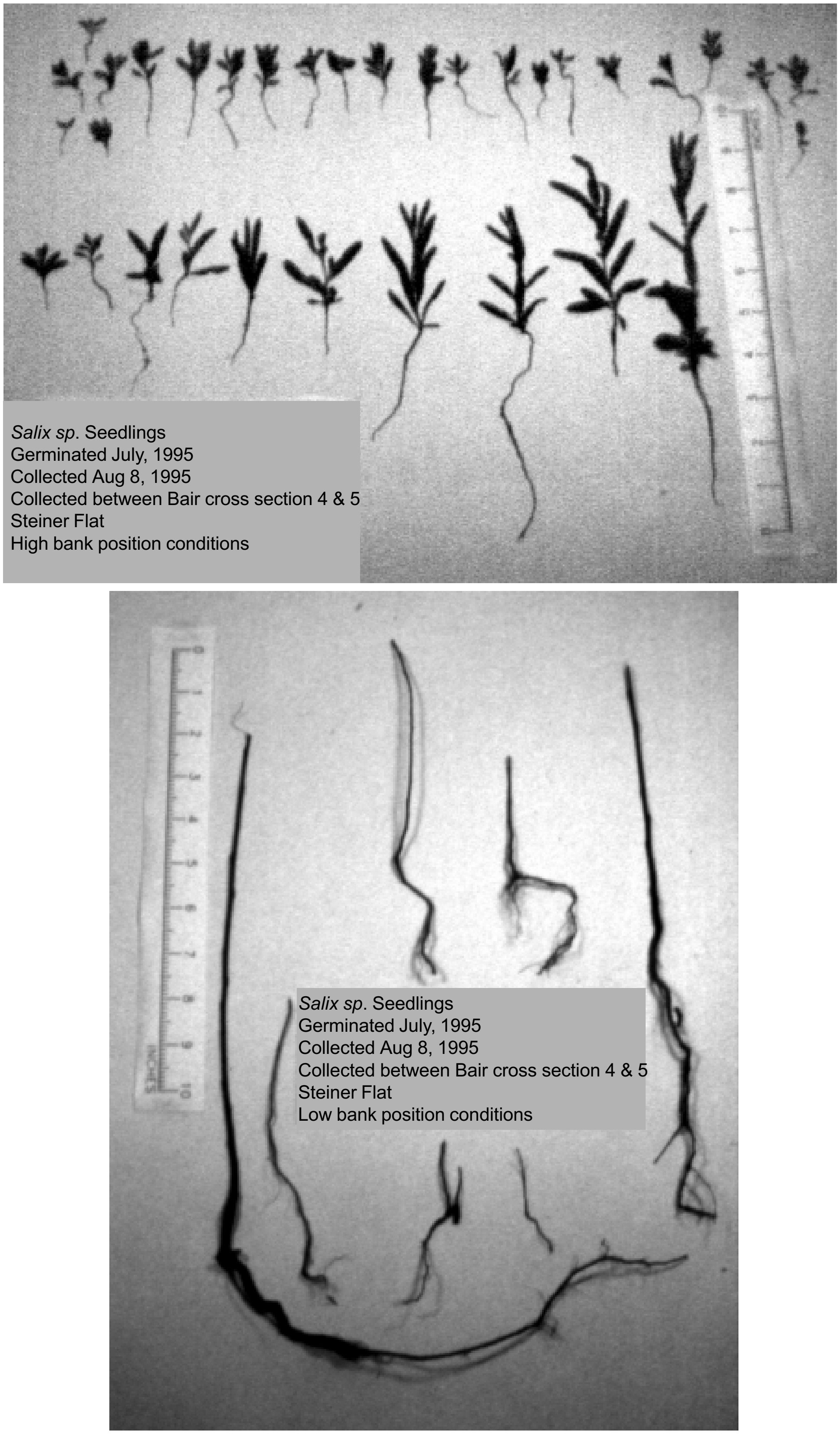
CRDs varied within a given age class (Table 9.1 and Figure 9.4). This variation was quantified by sketching a median and maximum limit of critical rooting depth. Our original hypothesis of CRD being age-dependent clearly was challenged. Although one-month old seedlings had shallower critical rooting depths than six-month old seedlings (Figure 9.4), older seedlings exhibited only a small increase in CRD with age. Median CRD for 8-month old seedlings and 38-month old plants were similar. A conservative estimate for the 8-month CRD was 130 mm; the 38-month CRD was 170 mm. Even 60-month old plants, considering the small sample size, had shallow CRDs similar to the 38-month old plants (Figure 9.4).



Salix sp. Seedlings
Germinated July, 1995
Collected Aug 8, 1995
Collected between Bair cross section 4 & 5
Steiner Flat
Low bank position conditions

Salix sp. Seedlings
Germinated July, 1995
Collected Jan 8, 1995
Collected between Bair cross section 4 & 5
Steiner Flat
Low bank position conditions

Figure 9.1 *Salix exigua* rooting and growth patterns for individuals rooted near low water surface. Each plant has numerous shallow lateral roots, and no single dominant taproot.



Salix sp. Seedlings
Germinated July, 1995
Collected Aug 8, 1995
Collected between Bair cross section 4 & 5
Steiner Flat
High bank position conditions

Salix sp. Seedlings
Germinated July, 1995
Collected Aug 8, 1995
Collected between Bair cross section 4 & 5
Steiner Flat
Low bank position conditions

Figure 9.2 *Salix exigua* rooting and growth patterns for individuals rooted higher on the bank, above low water surface. Each plant has a taproot and few lateral roots.

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Salix sp. Seedlings
Germinated July 1995
Collected Jan 8, 1996
Growing all over new bar
Sheridan Creek
Open bar conditions

Figure 9.3 Top: *Salix exigua* rooting and growth patterns for individuals rooted on open bar conditions. Bottom: Salix exigua rooting and growth pattern of mature individual in riparian berm. Note adventitious lateral root growth on stem (not a taproot) due to several feet of deposition on riparian berm.

Descriptive Statistics for Willows Growing on Open bars	1 Month	6 Month	8 Month	36 Month	38 Month	60 Month
Sample size (n)	39	26	28	3	42	6
Mean Critical Rooting Depth (mm)	19.5	51.5	99.1	132.0	91.7	165.2
Median Critical Rooting Depth (mm)	18.3	45.7	99.1	121.9	94.5	144.8
Critical Rooting Depth Standard Deviation	11.0	23.8	25.9	46.6	29.0	69.8
Minimum Critical Rooting Depth (mm)	6.1	15.2	30.5	91.4	36.6	121.9
Maximum Critical Rooting Depth (mm)	51.8	106.7	146.3	182.9	158.5	304.8
Mean Height (mm)	17.7	139.9	44.2	436.8	192.9	1130.2
Median Height (mm)	15.2	137.2	42.7	426.7	187.5	1082.0
Height Standard Deviation	9.8	72.2	18.1	107.0	96.3	324.9
Minimum Height (mm)	3.0	39.6	12.2	335.3	39.6	792.5
Maximum Height (mm)	39.6	289.6	100.6	548.6	402.3	1615.4
Mean Root Collar Diameter (mm)	1.0	2.6	2.0	7.1	3.0	12.3
Median Root Collar Diameter (mm)	0.9	2.6	1.8	7.3	2.7	12.0
Root Collar Diameter Standard Deviation	0.4	0.8	0.7	0.6	0.8	4.0
Minimum Root Collar Diameter (mm)	0.6	1.2	1.2	6.4	1.8	7.6
Maximum Root Collar Diameter (mm)	2.1	4.6	4.6	7.6	4.9	17.7

Table 9.1 Height, root collar diameter and critical rooting depth characteristics for willow seedlings and saplings sampled on open bar surfaces during water year 1995 and 1996.

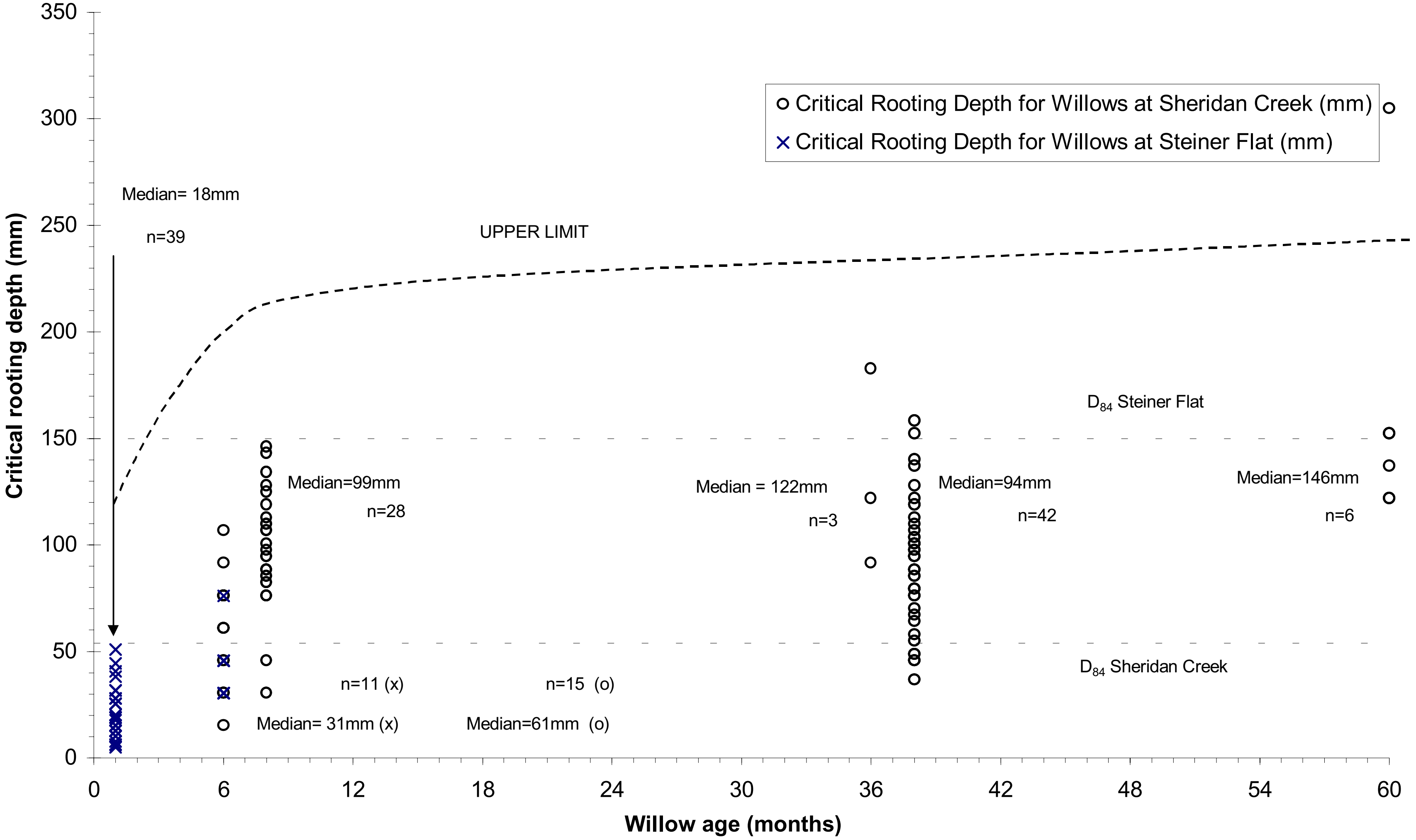

Figure 9.4 Critical rooting depth for willows of various ages, collected on exposed, active channel bed surfaces in the summer of 1995 and winter/spring 1996. Median values from each group sampled are given in millimeters. Two bank restoration sites were sampled: Steiner Flat at (RM 91.7), and Sheridan Creek (RM 81.6). Sample size is indicated above each age by site.

To assess whether channelbed mobilization (Attribute No. 3) could prevent plant establishment, CRD was evaluated relative to the depth of the channelbed surface layer (defined by the diameter of the D_{84}). The CRD for six-month-old plants approximated the depth of the channelbed surface layer at the Sheridan site (54 mm) and less than that of the Steiner Flat site (150 mm). The first major scouring events encountered by successfully initiated plants generally occur between 6 and 12 months. One-year old plants have a median CRD near 100 mm and an upper CRD of approximately 140 mm. CRD exceeds the Sheridan Creek channelbed surface layer and approximates the Steiner Flat channelbed surface layer. Based on our simple model, initiated seedlings should be highly susceptible to their first season of channelbed surface mobilization at Steiner Flat but might survive at Sheridan Creek.

A simplifying assumption underlying our model was that scour to depths less than the CRD would not impair survival. What we observed on the bars was not as straightforward. On January 8, 1996, we inspected the Sheridan Creek site following a 3,400 cfs peak flow in late December 1995. Willow seedlings of the WY1995 cohort were stressed, with roughly half their roots freshly exposed where the sand had been scoured from interstitial areas among larger particles. The channelbed had not reached a mobility threshold, though smaller rocks (up to 30 mm) had moved. This event demonstrated that seedlings under age one could be killed or weakened by flows which fail to mobilize the entire surface layer of bars. A slightly higher discharge would presumably increase scour of the sand matrix as well as larger surface particles.

Lacking extensive laboratory experimentation, we were unable to quantify impacts of partial scour and/or burial, flood-caused abrasion of dormant stems, and stem breakage. As an alternative, we associated annual channelbed dynamics with narrow-leaf willow seedling initiation/establishment in WY1995 and WY1996 on three bank rehabilitation sites. All woody species were monitored. We needed to know whether a flood capable of mobilizing the channelbed surface, but not significantly scouring deeper, could kill the previous summer's willow cohort. For the three sites, few narrow-leaf willow individuals of the WY1995 and WY1996 cohorts survived into the summer of 1997 (Table 9.2). To interpret channelbed dynamics over these water years, the following annual hydrographs were referenced: for Bucktail we used the Lewiston gage site (Figure 9.5), for Steiner Flat we used the Douglas City gage (Figure 9.6), and for Sheridan Creek we used the Junction City Gage (Figure 9.7).

The Sheridan Creek rehabilitation site has a broad gently sloping right bank that annually supports abundant narrow-leaf willow initiation. Without benefit of snowmelt flows inundating most of the bar surface during seed dispersal, willows germinated on the exposed bar surface down to low water surface in WY1995, WY1996, and WY1997. For example, the upper portions of the recently formed bar surfaces were exposed in mid-June during narrow-leaf willow seed dispersal, allowing widespread germination (Figure 9.8).

Had the bar had been inundated through seed dispersal, germination would have been prevented. The WY1995 cohort experienced channelbed mobilization its first winter (Figure 9.8). The discharge peak near 8,500 cfs probably mobilized at least the surface layer and portions of the subsurface (consult Attributes No. 3 and No. 4). By May 1996 (the next inventory), most had died (Table 9.2). Unfortunately the Junction City gage did not survive the January 1, 1997 flood and records were lost. The peak was approximately 30,000 cfs (determined by slope-area method), well above the threshold for major subsurface scour. No willows from earlier cohorts survived on the open bar (Table 9.2). Although census data for summer 1997 have not been finalized, we observed that the bar was widely occupied by initiating narrow-leaf willow seedlings as in previous water years.

A.	Narrow-leaf Willow (*Salix exigua)* Cohort Abundance					
	1995 Sample		1996 Sample		1997 Sample	
Annual Cohort	Spring	Summer 8/15/95	Spring 5/14/96	Summer 7/28/96	Spring 5/1/97	Summer
WY 1993	NA	5	13	19	0	NA
WY 1995	NA	5,207	192	114	0	NA
WY 1996	NA	NA	0	914	0	NA
WY 1997	NA	NA	NA	NA	0	NA

B.	Narrow-leaf Willow (*Salix exigua)* Cohort Abundance					
	1995 Sample		1996 Sample		1997 Sample	
Annual Cohort	Spring	Summer 8/8/95	Spring 5/4/96	Summer 7/26/96	Spring 4/30/97	Summer
WY 1993	NA	0	0	1	2	NA
WY 1995	NA	994	76	129	9	NA
WY 1996	NA	NA	11	100	0	NA
WY 1997	NA	NA	NA	NA	0	NA

C.	Narrow-leaf Willow (*Salix exigua)* Cohort Abundance					
	1995 Sample		1996 Sample		1997 Sample	
Annual Cohort	Spring	Summer 7/25/95	Spring 5/4/96	Summer 7/25/96	Spring 4/30/97	Summer
WY 1993	NA	27	0	7	0	NA
WY 1995	NA	1,444	57	19	0	NA
WY 1996	NA	NA	1	1	0	NA
WY 1997	NA	NA	NA	NA	0	NA

Table 9.2 Narrow-leaf Willow (Salix exigua) abundance at: A) Sheridan Creek (RM 81.6) cross section 2+35; B) Steiner Flat (RM 91.7) cross section 4+31; and C) Bucktail (RM 106.5) cross section 12+00.

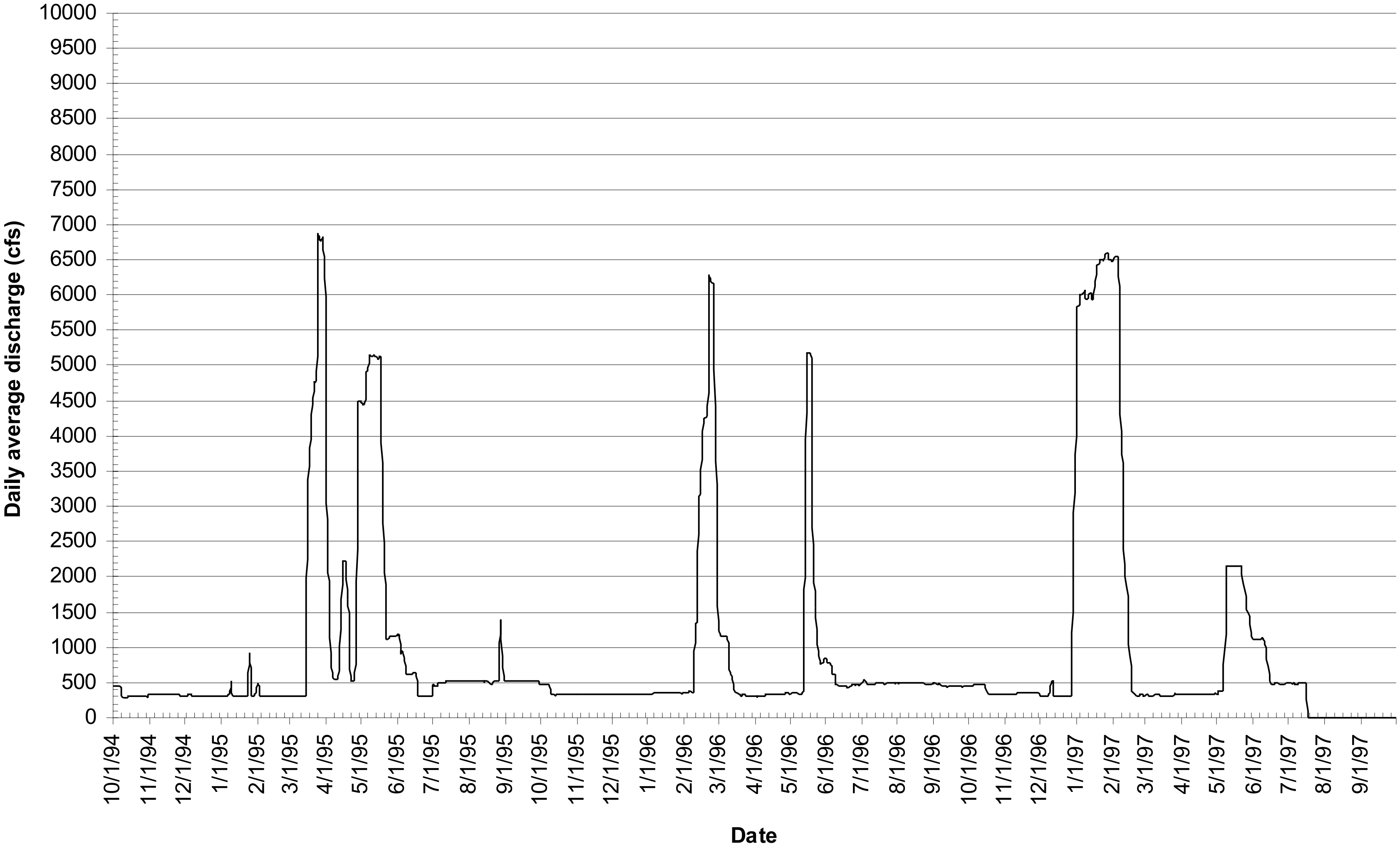

Figure 9.5 Trinity River at Lewiston (RM 110.9) daily average discharge for WY 1995-1997.

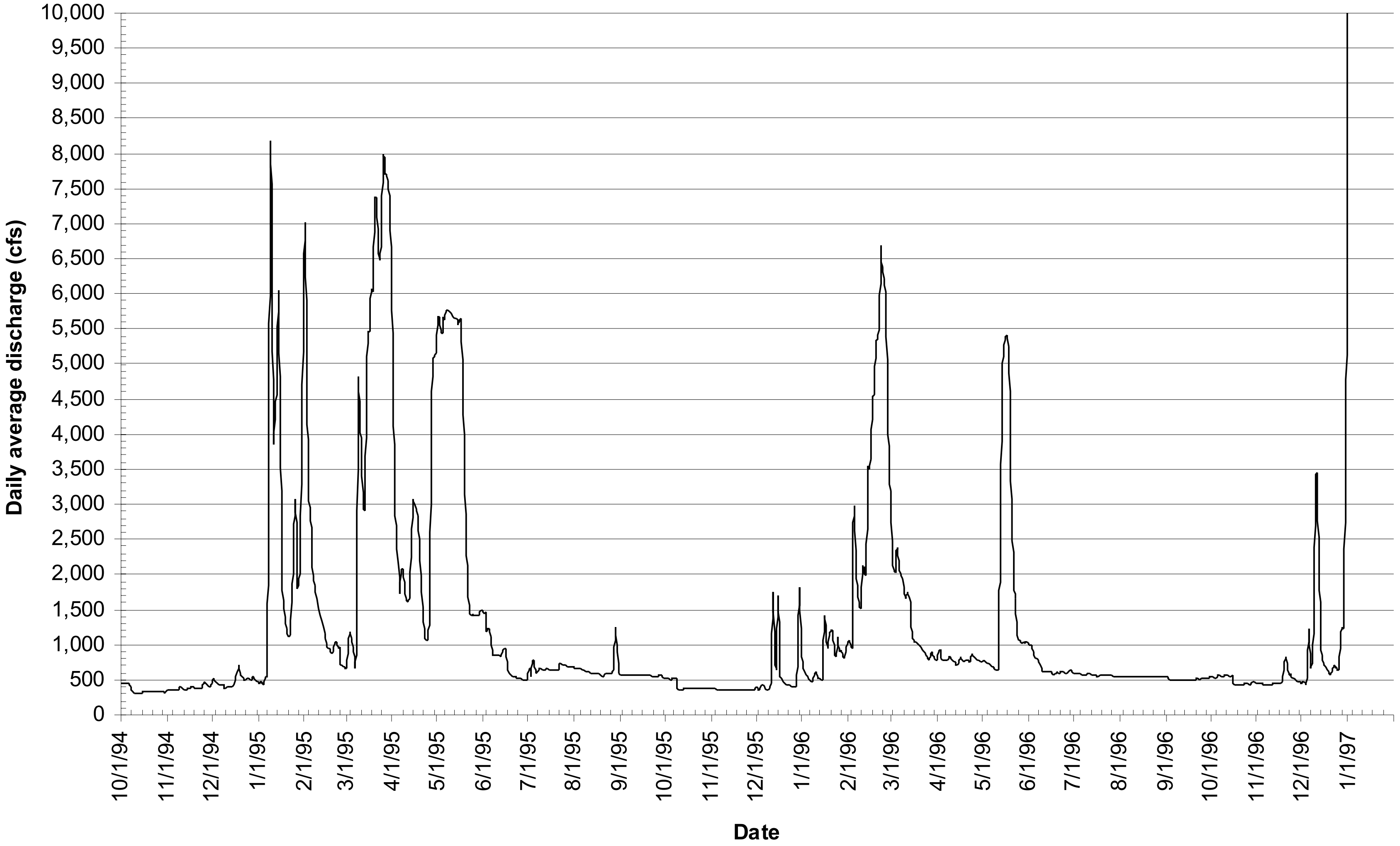

Figure 9.6 Trinity River Near Douglas City (RM 92.2) daily average discharge for WY 1995-1997.

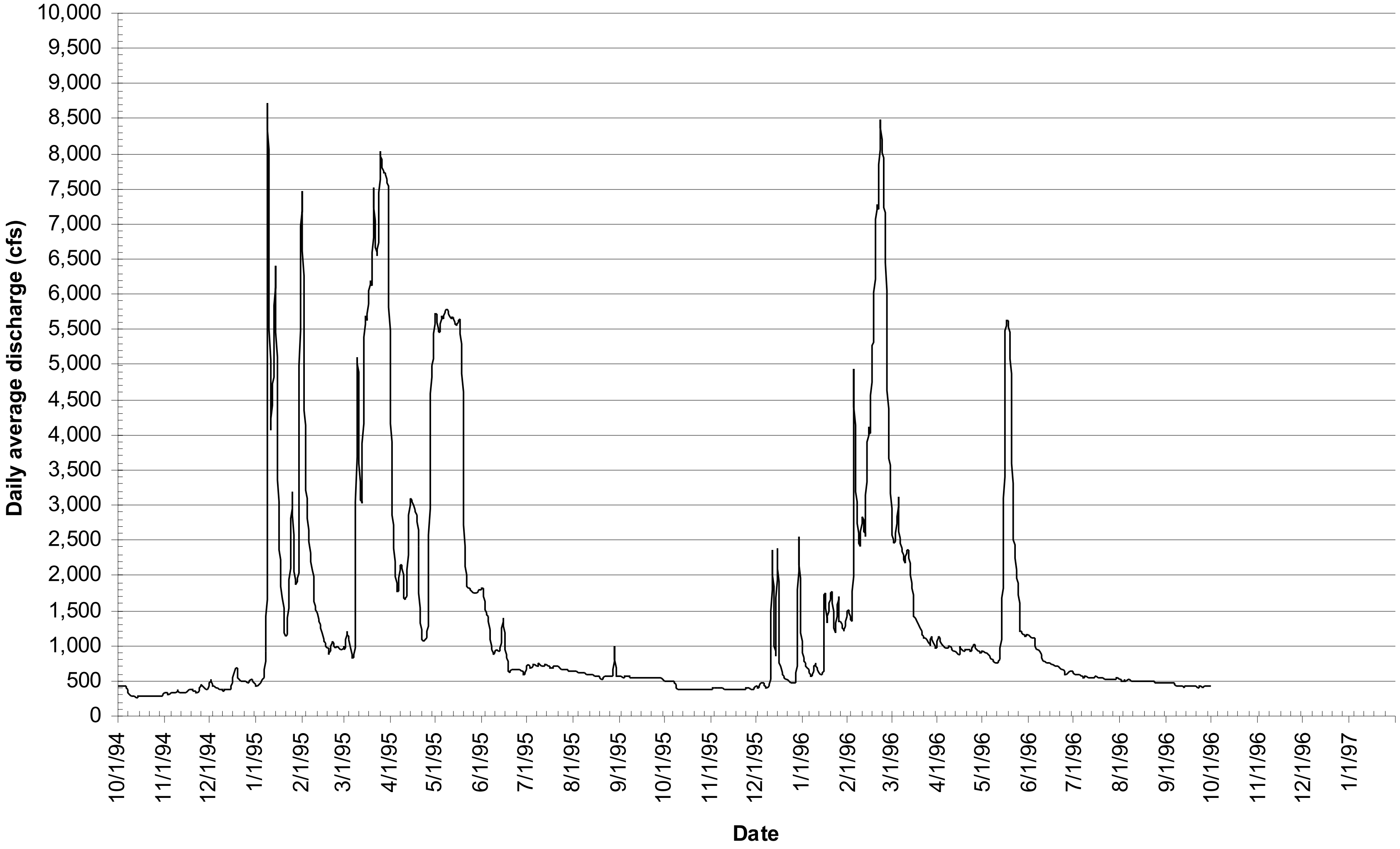

Figure 9.7 Trinity River at Junction City (RM 79.6) daily average discharge for WY 1995-1996.

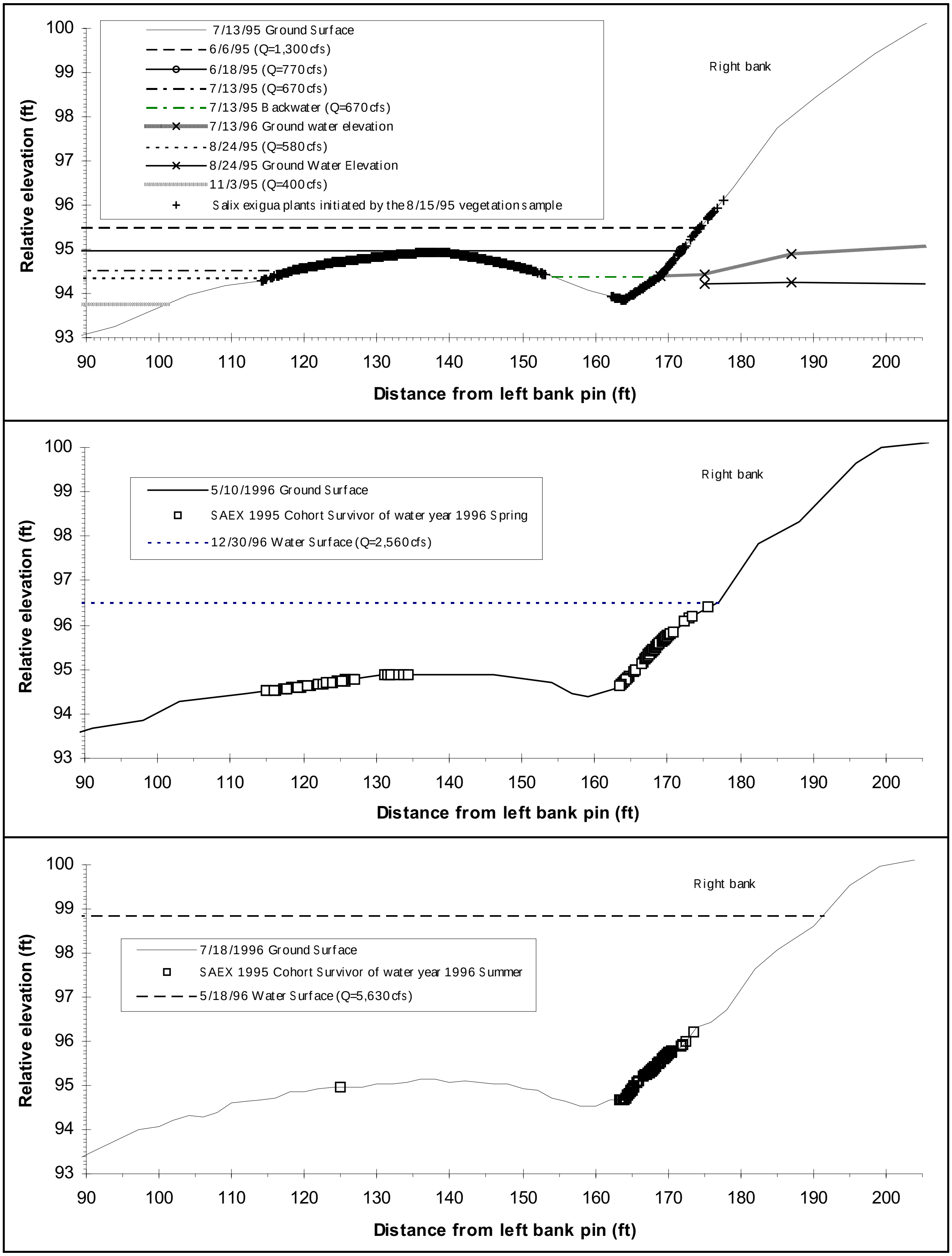

Figure 9.8 Sheridan Creek Bank Rehabilitation Site - RM 81.6, cross section 02+35, *Salix exigua* distribution, top: 1995 cohort, August 8, 1995 vegetation sampling. middle: 1995 cohort, May 14, 1996 vegetation sampling. bottom: 1995 cohort, July 28,1996 vegetation sampling.

A similar series of events can be described for willow cohorts at Steiner Flat. At the Bucktail site, seedlings were killed by bar deposition. The poor WY1996 cohort initiation at Bucktail may have been due to a poor seed crop from lack of rain in May/June (Table 9.2). At the other rehabilitation sites, we began plant censusing in summer 1996. The January 1, 1997 flood almost eliminated the WY1996 cohort establishing on these sites (McBain and Trush unpubl.).

The winter peak floods in WY1996 caused widespread channelbed surface mobilization and local subsurface scour. Much of the 1995 cohort died, but a few survived (Table 9.2). Our assumption of no seedling mortality unless scour exceeds the critical rooting depth is therefore conservative.

9.5 Life History Schedules

Life history data for common woody riparian species were collected between Lewiston Dam (RM111.5) and the North Fork Trinity River (RM 72.4) from WY1995 through WY1997. Each observed life history transition was recorded in matrix format (Plate 11). Time of bud swelling in spring, flowering duration, time for fruit development, seed dispersal period, leaf abscission timing, and dormancy period were recorded. Beginning WY1995, a date for each observed life history transition was recorded in the life history matrix. For example, if arroyo willow (*Salix lasiolepis*) seed dispersal was observed on April 9, 1995, then the box for April and arroyo willow had that date recorded. After WY1995, additional observations filled gaps, or further supported documented plant life history transitions.

We were specifically interested in seed dispersal timing. A box whisker chart showing specific seed dispersal ranges was developed from the life history matrix (Figure 9.9). The data reflect only the starting and finishing times of seed dispersal for six species and the median dispersal date. The period of seed dispersal was variable; exact dates were sometimes unknown. In these cases, we used values derived from the literature (Young and Young, 1992; Burns and Honkala, 1990; Roe, 1958) or other local sources (Pelzman, 1973; Trinity Journal, 1994).

9.6 Snowmelt Recession and Summer Flows: Seedling Initiation or Mortality?

Successful germination requires a moist surface. A moist exposed capillary fringe extending above the water surface provides favorable germinating conditions, particularly as conditions higher on the bar surface (above this fringe) become increasingly hostile as summer progresses. Elevational range of the exposed capillary fringe at the channelbed surface was measured from the upper margin of moist substrate down to the water line. Maximum elevation change in fine sand at Steiner Flat was 2.5 ft; the minimum was 2.0 ft. Measurements in sand were taken in the morning before the sun had warmed the soil and while relative humidity was high; this may have resulted in a slightly higher elevation estimate. On gravel/cobble surfaces, the exposed capillary fringe height was narrower; In summer 1995, the fringe at Bucktail (12+00) on July 26 was 0.6 ft, at Steiner Flat (04+31) on August 8 it was 0.5 ft, and at Sheridan Creek (02+35) on August 15 the fringe was 0.4 feet.

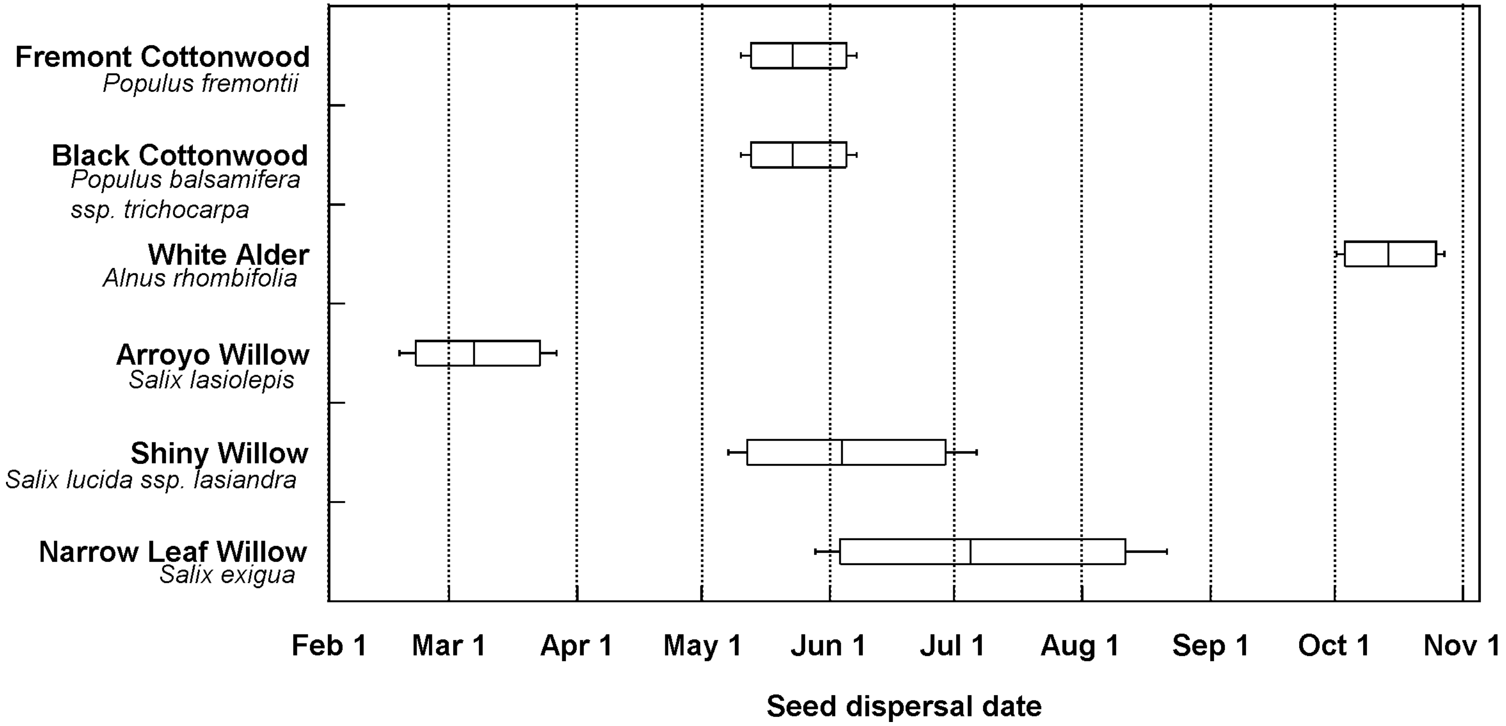

Figure 9.9 Woody riparian seed dispersal timing for six common species, each box displays the length of time by which 90% of all seeds are dispersed. Median dispersal dates are represented with a vertical line through the box. Whiskers at either end of the box indicate the earliest and latest 5% of seed dispersal. White alder continues to drop seeds retained in the woody cone throughout winter and early spring, although >80% of the seeds are dropped during the initial seed dispersal period when female cones open.

This exposed fringe follows the receding flow elevation. As snowmelt, then summer baseflows, decline toward autumn, recently germinating seeds deposited on the bar above this fringe have a considerably higher risk of desiccation. Species releasing seeds in late-spring and summer would be at greatest risk, even though many riparian species can develop extensive root systems quickly (Segelquist et al., 1993). From mid-June to mid-August, this exposed capillary fringe has been the preferred location for narrow-leaf willow seeds to successfully germinate.

To associate physical conditions with seedling initiation, we documented where seedling initiation occurred using the belt transects. Date and discharge for water surface elevations throughout spring and summer were plotted on the same cross section to show where initiation was associated with the exposed capillary fringe, or was limited by timing of seed release.

Once seeds germinated on the moist surface of the exposed capillary fringe and began to establish roots, the seedlings could utilize subsurface moisture (reference next section). Thereafter, the exposed fringe could continue migrating down the bar surface (following receding summer flows) without harming the seedlings. By summer's end, the migrating exposed fringe had created a broad band of favorable germination substrate. Seedlings higher on the bar were weeks older.

As expected, inventoried seedlings at the summer's end were associated with this exposed capillary fringe, but over a wider elevational range than the fringe's elevational range of 0.4 to 0.5 ft. At the Pear Tree Gulch bank rehabilitation site, initiating narrow-leaf willow and shining willow (*Salix lucida*) seedlings ranged up to 1.5 ft above the low summer flow stage (Figures 9.10 and 9.11). At Limekiln Gulch bank rehabilitation site, narrow-leaf willow ranged up to 1 ft above the low summer flow surface (Figure 9.12). At Deep Gulch bank rehabilitation site (RM 82.0*),* narrow-leaf willow and shining willow seedling initiation ranged 1.8 ft (Figures 9.13 and 9.14).

Unregulated tributary flows modify downstream rates of water stage decline. When Lewiston is releasing a constant flow of 300 cfs in early summer, flows below Junction City can be fluctuating at 600 cfs or greater. Later in the summer, flows would remain at 300 cfs near the dam, but downstream flows will gradually recede toward 300 cfs as tributary contributions diminish. Therefore close to the dam, the exposed capillary fringe remains at the 300 cfs stage height; most seedlings would be expected to establish within a narrow elevational band of approximately 0.5 ft above the 300 cfs elevation. But below Junction City, the exposed capillary fringe would migrate through the summer (tracking the declining water stage), creating favorable germinating conditions over a broader band. Therefore in wetter years, when tributary contributions to baseflows are substantial, a low flow dam release to limit woody riparian germination will not be effective at confining germination to a narrow band below Indian Creek. In dry years, when tributary contributions are very low, a 300 cfs dam release could confine germination to a narrow band below Indian Creek (that could be scoured out by next winter's high flows).

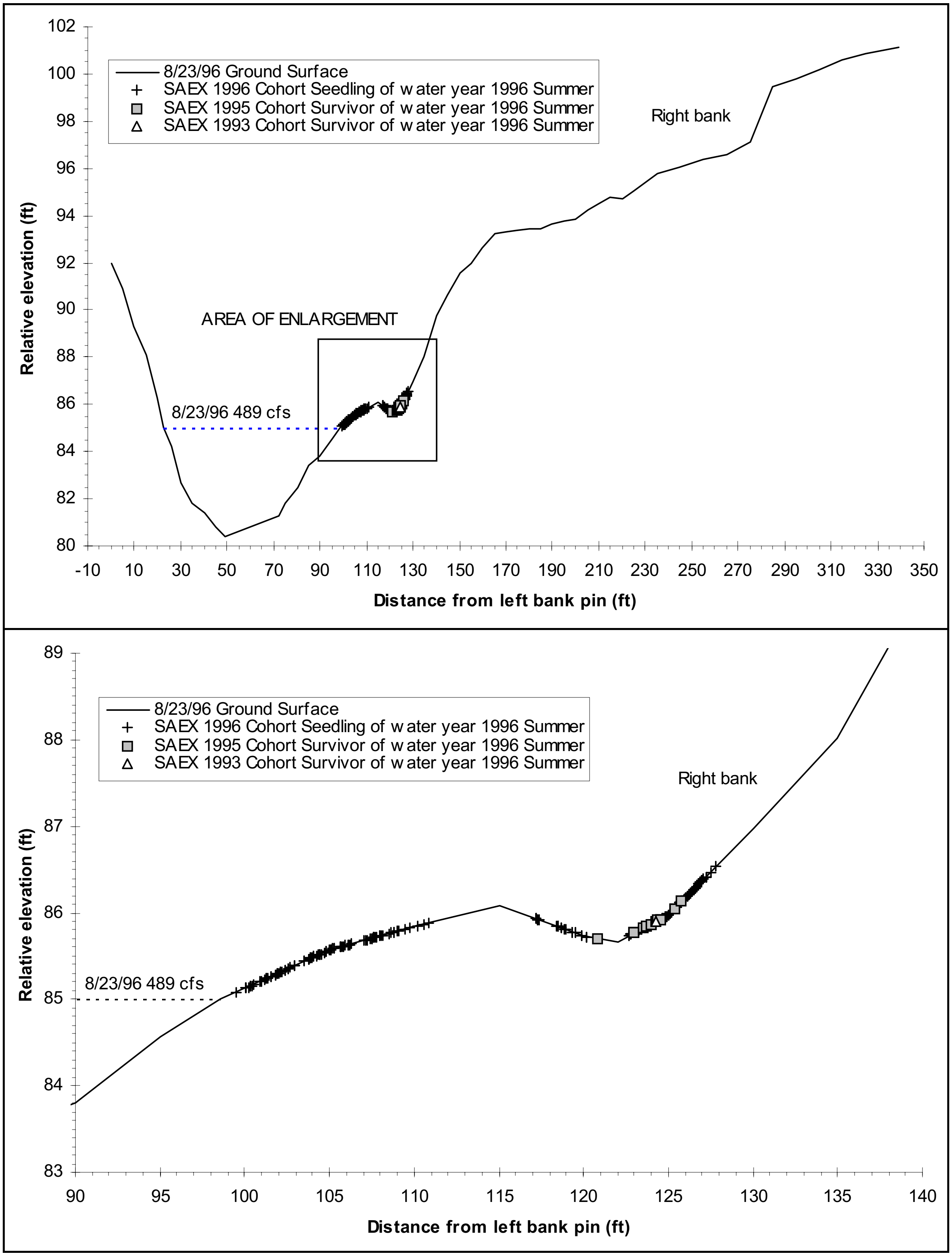

Figure 9.10 Pear Tree Gulch bank rehabilitation site (RM 73.1) cross section 15+00, *Salix exigua*, all cohorts, WY 1996 summer.

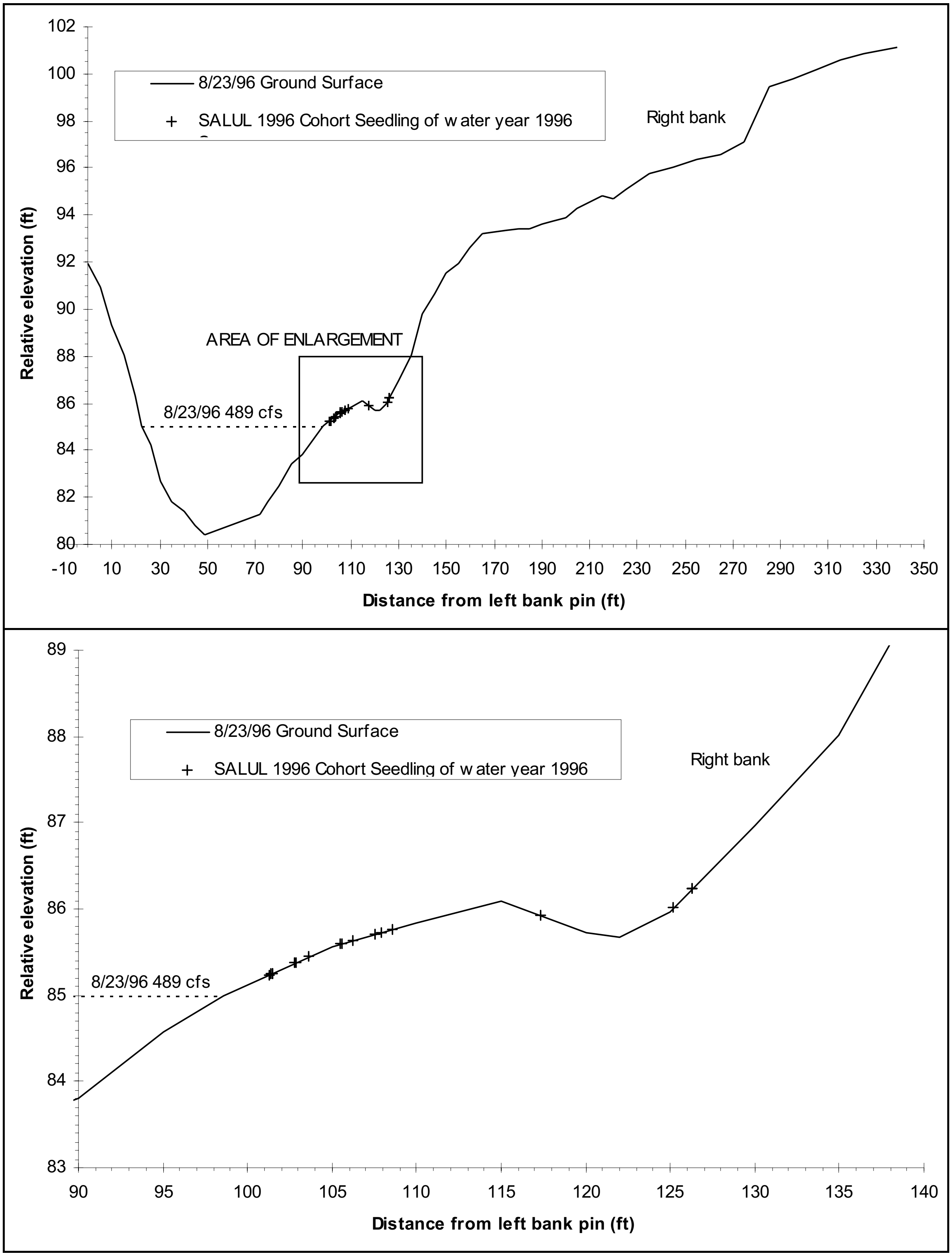

Figure 9.11 Pear Tree Gulch bank rehabilitation site (RM 73.1) cross section 15+00, *Salix lucida* ssp. *lasiandra*, 1996 cohort, WY 1996 summer.

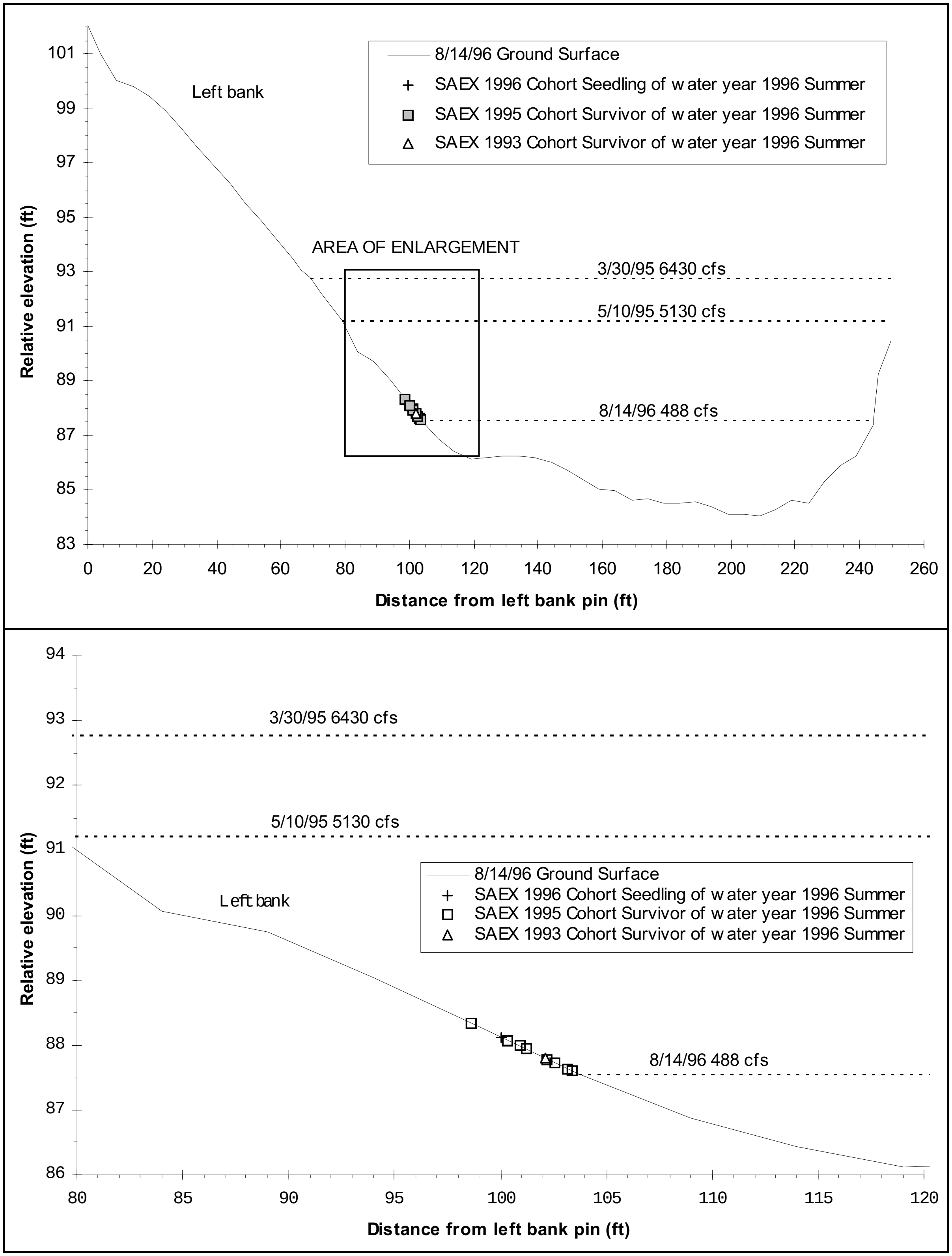

Figure 9.12 Lime Kiln Gulch bank rehabilitation site (RM 100.2) cross section 11+86, *Salix exigua*, all cohorts, WY 1996 summer.

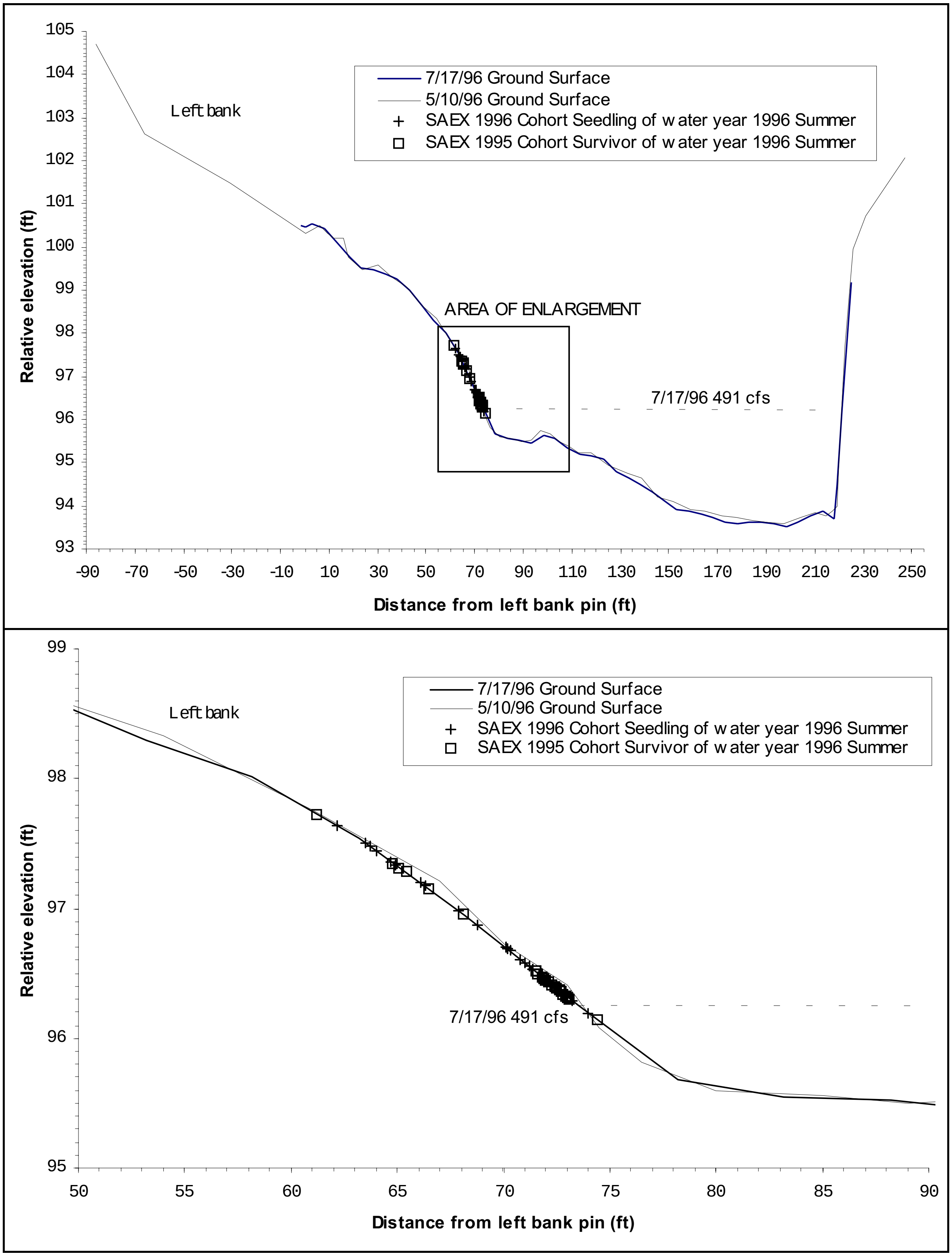

Figure 9.13 Deep Gulch Bank Rehabilitation Site - RM 82.0, cross section 13+90, *Salix exigua*, all cohorts, WY1996 summer.

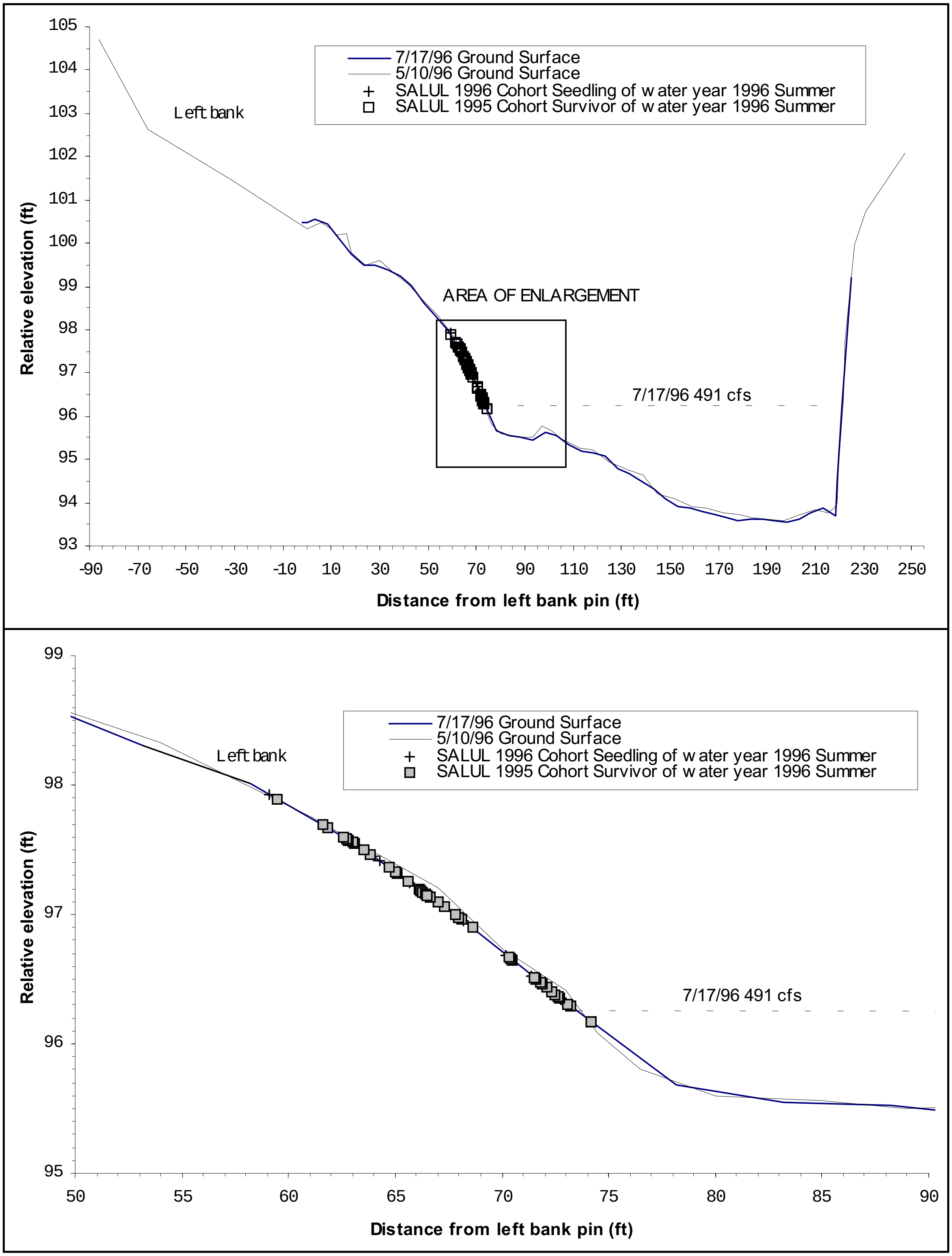

Figure 9.14 Deep Gulch Bank Rehabilitation Site - RM 82.0, cross section 13+90, *Salix lucida* ssp. *lasiandra*, 1996 cohort, WY1996 summer.

At Pear Tree Gulch, declining tributary inflows from June 1, 1996 through July 1, 1996 significantly modified bar inundation by Lewiston Dam releases. Though dam releases dropped from 800 cfs the first week to approximately 500 cfs the last three weeks Pear Tree Gulch cross section 15+00 was experiencing gradually declining flows from 1200 cfs to 600 cfs (Figure 9.10). On cross section 15+00, the top of the bar was just inundated the first week of June. As flow gradually declined, the slow migration of the exposed capillary fringe zone provided a favorable environment for germination at stations 99 through 128. Without tributary influence, a steady flow of 500 cfs with a 0.5 ft exposed capillary fringe would create the same favorable environment from station 99 ft to 106 ft (Figure 9.10). Closer to the dam, fixed low flow releases and lesser tributary flow contributions produced a narrower range of exposed capillary fringe over the same time period.

The Sheridan Creek site presented a unique setting. The low gradient of the reconstructed bar surface allowed the exposed capillary fringe to occupy most of the bar surface throughout the summer. Seedlings germinating on the bar top, as the bar just became exposed, and were never far from the exposed capillary fringe throughout the summer. Narrow-leaf willow seedlings blanketed the bar surface by late-summer in WY1995, WY1996, and WY1997. We anticipate that the Sheridan Creek alternate bars will continue to aggrade (Chapter 10).

9.7 Subsurface Moisture

Once germination at the surface had occurred, we needed to determine whether subsurface moisture levels were adequate for seedling establishment. Subsurface moisture levels were measured throughout late spring and summer 1997. Three sets of soil moisture sensors (two electrodes embedded in a 0.50 x 0.75 inch gypsum block) were placed near belt transects at Bucktail, Steiner Flat, and Sheridan Creek bank rehabilitation sites. The first soil moisture sensor was installed down to the lowest expected late-summer water surface (450 cfs) in late-May. The second and third sensors were installed at one-foot intervals higher than the first. Changing substrate moisture levels along the cross sections also were related to changing water surface elevations. Subsurface moisture readings were converted to soil moisture tension (centibars), and presented as a percentage of field capacity.

The rehabilitation sites had subsurface moistures approaching field capacity (100%) just below the bar surfaces. On the Bucktail site, soil moisture remained high close to the bar surface into August (Figure 9.15). The subsurface capillary fringe extended more than two feet above the groundwater table.

9.8 Alder Removal by Re-Setting Floods

9.8.1 Objectives

Although several individuals have speculated on the magnitude of flows required to remove mainstem riparian berms, to date no predictions have been offered. However, aerial photographs before, during, and after the 1974 flood (14,000 cfs released from Lewiston Dam) show only minor

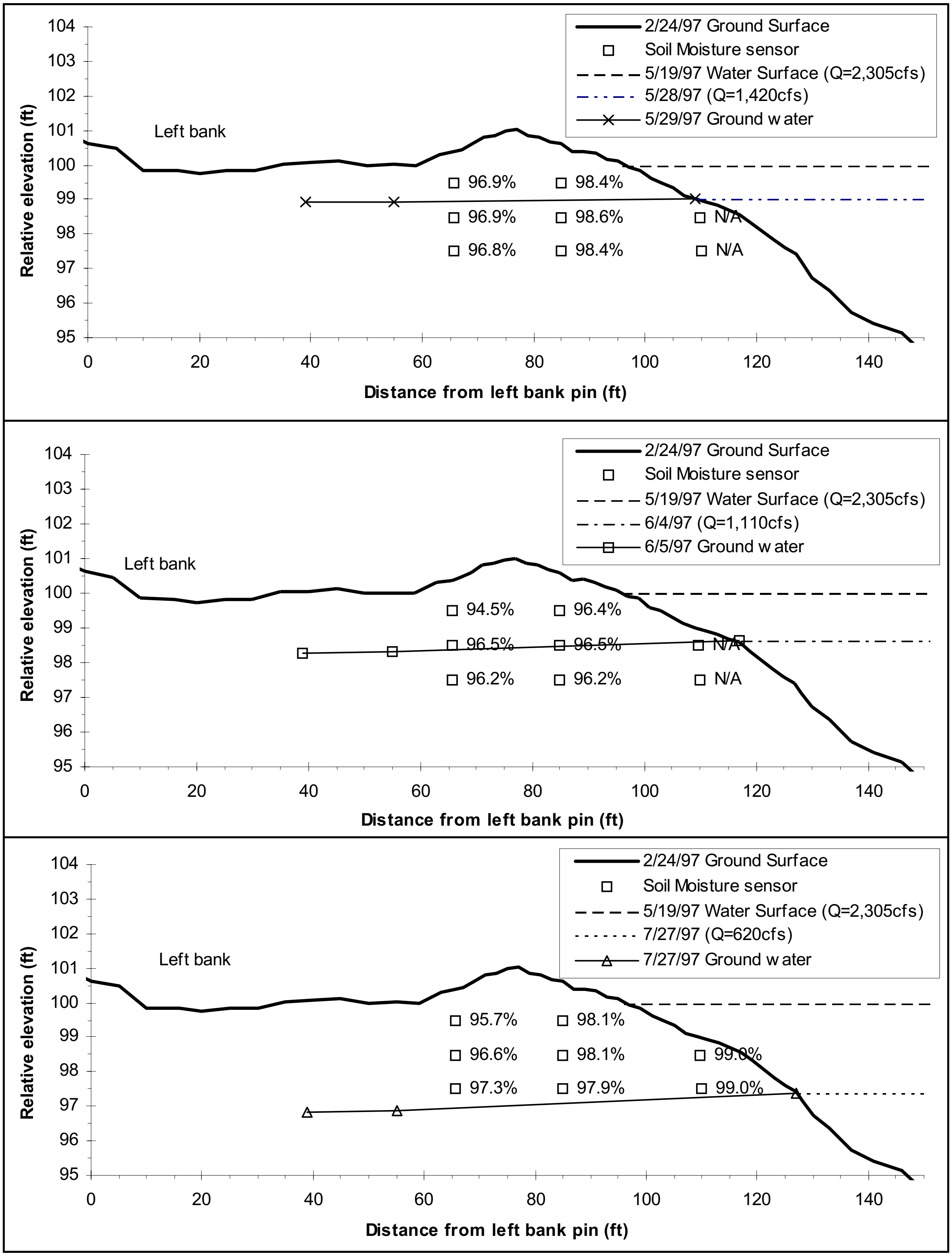

Figure 9.15 Bucktail bank rehabilitation site (RM 105.6) ground water and soil moisture (as a percentage of field capacity) values, top: 5/28/97, middle: 6/5/97, bottom: 7/27/97.

disturbance to the riparian berm (Figures 2.8 to 2.11). The WY1997 flood below Rush Creek (approximately 11,000 cfs) also scoured and undercut mature trees in the riparian berm, though again this effect was minor.

We provided an estimate of this threshold by computing the "critical moment" required to topple a mature alder rooted in a riparian berm. The critical moment is synonymous to a critical torque, which is the product of a force acting on an object and the distance from the force to the point of rotational failure (in our case, the root mass). We measured critical moment while pulling over alders (slated for removal by the bank restoration project) with a D7 Caterpillar bulldozer.

9.8.2 Methodology

We chose six mature alders (1.0 to 1.5 ft dbh) at the downstream end of the Steiner Flat bank restoration site (RM 91.7). The alders were rooted 10 ft to 20 ft from the water's edge and were approximately 5.5 ft above the 450 cfs water surface elevation. One day was required for site preparation, pulling over the trees, and taking supportive field measurements.

The complexity of fluid forces on trees located within differing planform locations during a hypothetical flood required simplifying assumptions before attempting this analysis. Trees within the riparian berm are sheltered from fluid forces by other trees, and also by obstructions in the channel (e.g., bedrock). Actual removal of the riparian berm would be episodic; as discharge increased, an increasing number of trees would be removed until there would be sufficient woody debris in the river to essentially push the remaining trees over like dominos. Predicting when this would occur was extremely difficult, so we targeted the minimum flow needed to begin toppling exposed trees. This required the following simplifying assumptions:

1. a force balance will be computed on a single alder exposed to the full force of the flow (no hiding effects from other trees),
2. the cross sectional area of the tree will include debris piled on the front of the tree, and the elevation of this debris mass rises with the water surface elevation
3. the trees sampled are representative of trees on other mainstem berms.

Our methods were as follows: (1) we saturated soil near the base of the tree for 12 hours prior to the experiment to simulate soil conditions during a flood event, (2) we pulled trees over, measuring the failure force with a tensiometer and computing the critical moment of failure, and (3) we applied a logarithmic velocity profile at each tree location to predict water force (and moment) as a function of depth. When the predicted critical moment from (3) equals the measured critical moment of (2), then the discharge at the depth determined in step (3) was computed.

9.8.3 Measuring critical moment of tree failure

Critical force of tree failure (F_c) was measured by attaching a choker cable 10 ft to 11 ft high in each tree, attaching an in-line 30,000 lb capacity tensiometer to the choker, attaching the winch cable of a

D7 Caterpillar bulldozer, and pulling the tree over with the winch (Figure 9.16). The tensiometer had a needle measuring the maximum force applied, however, this maximum value was often caused by the winch placing the initial tension on the tree (by jerking the cable). Rather than rely on this maximum value, we oriented the tensiometer so that the force could be observed at the time of tree failure.

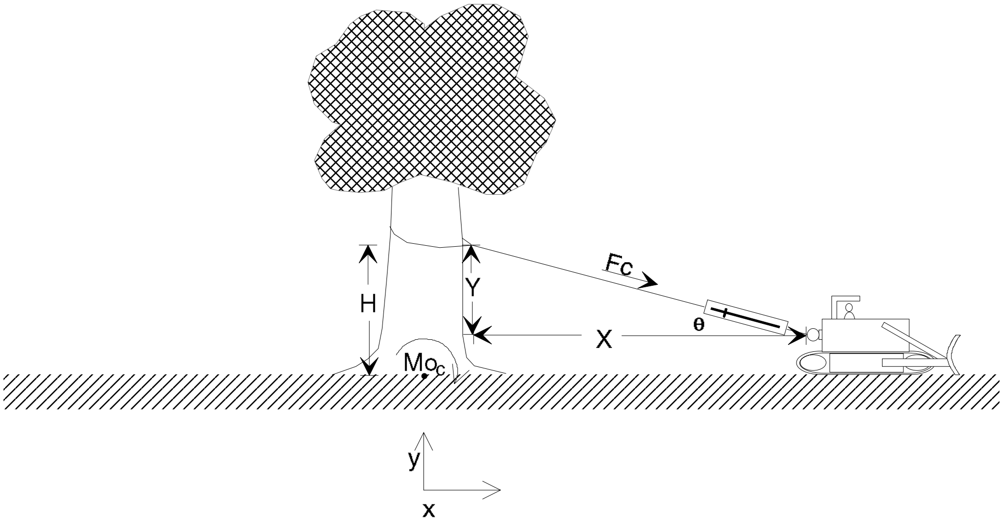

Figure 9.16 Force diagram of mature alder toppling experiment, illustrating forces to pull over alder with tractor.

The critical moment was then computed by:

$$Mo_c = Fc_x H \tag{9.1}$$

where: Fc_x = critical force in the *x* direction;

H = height of the cable attachment from the point of rotational failure.

The tensiometer measured Fc, so we solved for the sum of moments in the x direction to solve the critical moment (Mo_c):

$$Mo_c = \sum Mo_x = F_c \cos(\theta) H \tag{9.2}$$

where: $\theta = \mathrm{Tan}^{-1}(Y/X)$;

Y = height of cable above tractor winch (ft);

X = distance from front of tree to tractor winch (ft);

H = distance from cable to point of rotational failure (ft);

Mo_x = moment caused by force in X direction.

Force of water on tree

Determining the river stage height or flow velocity to push a tree over required the drag force on the tree to be calculated. The drag force (F_D) is defined as follows:

$$F_{Dt} = \frac{1}{2} C_{Dt} \rho V^2 A_t$$
$$F_{Dd} = \frac{1}{2} C_{Dd} \rho V^2 A_d \qquad 9.3$$

where: C_{Dt}, C_{Dd} = Coefficient of drag on the tree and debris, respectively, estimated from tables of measured values in fluid mechanics textbooks;
ρ = density of water;
V = water velocity (ft/sec);
A_t, A_d = cross sectional area of the tree and debris jam (ft^2), respectively.
F_{Dt}, F_{Dd} = drag force on the tree and debris, respectively

The drag force caused by the flowing water would act at the midpoint of the submerged part of the tree if the force of the water acted uniformly over the entire submerged portion (Figure 9.17). Because the water velocity in a vertical profile increases approximately logarithmically with depth, the force exerted on the tree is not uniform. Therefore the location of the resultant force will be near 40% of the depth (the location of the average velocity in the vertical velocity profile).

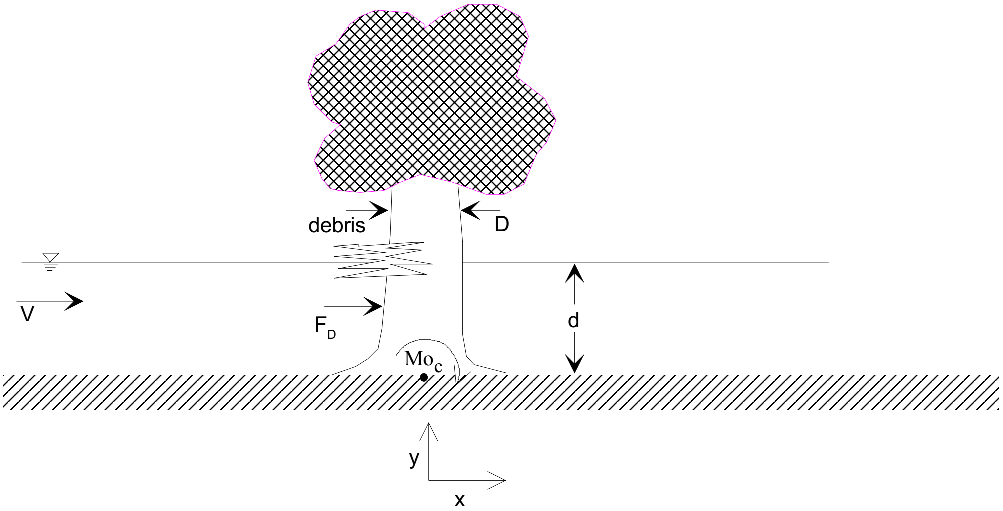

Figure 9.17 Force diagram of mature alder showing forces for high flow to push alder over.

The product of the drag force of the water (F_D) and distance of the resultant force from the rotational centerline (f(d)) is the critical moment (Mo_c):

$$Mo_c = F_{Dt}(0.4d) + F_{Dd}(d) \qquad (9.4)$$

where: d = river depth at tree (ft) (Figure 9.17).

Substituting equation 9.3 into 9.4:

$$M_o = 0.2(C_{Dt})(\rho)(A_t)(d)(V^2) + 0.5(C_{Dd})(\rho)(d)(V^2)(A_d), \text{ or}$$
$$M_o = 0.2(C_{Dt})(\rho)(D)(d^2)V^2) + 0.5(C_{Dd})(\rho)(d)(V^2)(A_d) \qquad (9.5)$$

where: A_t = cross sectional area of tree trunk, approximated by the product of diameter (D) and stem length exposed to flow (d);

d = river depth;

A_d = cross sectional area of debris jam, obtained from a typical WY1995 debris jam on the mainstem.

At the critical moment, equation 9.2 and 9.5 would be equal:

$$F_C\cos(\theta)(H) = (0.2)(C_{Dt})(\rho)(D)(d^2)(V^2)+(0.5)(C_{Dd})(\rho)(d)(V^2)(A_d) \qquad (9.6)$$

Equation 6 cannot be solved because both “d” and “V” are unknowns. However, applying the logarithmic velocity distribution equation for flow on a given vertical provides the second equation needed to solve equation 9.6:

$$V = \frac{\sqrt{gdS}}{k}\ln\left(\frac{0.40d}{0.1D_{84}}\right) \qquad (9.7)$$

where: g = gravitational acceleration;

k = Von Karman’s constant = 0.4;

S = energy slope at high flows, which we measured from the >7,000 cfs WY1995 discharge;

D_{84} = the particle size upon which 84 percent of the particle size distribution is smaller. This measure was used for bottom roughness, which was approximately 100 mm in the main channel.

We then solved for d and V, computed the water surface elevation at depth = d, and applied Manning's equation at that water surface elevation to estimate discharge.

9.8.4 Results

Of the six trees toppled, four provided acceptable data for this analysis. Equipment failure impaired the other two. The critical moments of failure for the four trees were: 54,000 ft-lbs (diam=0.80 ft), 97,600 ft-lbs (diam=1.0 ft), 100,000 ft-lbs (diam=1.1 ft), and 96,600 ft-lbs (diam=1.2 ft). The consistency of failure moments, particularly of the latter three trees, gave us reasonable confidence in the force required to push the trees over.

The estimated critical discharge for tree failure was primarily dependent on the size of debris pile lodged against the tree, because the debris has a large surface area (larger coefficient of drag) and acts on the tree at the maximum distance from the rotation point (increased moment). Debris pile dimensions were classified as follows: large debris (15 ft X 7.5 ft), small debris (10 ft X 5 ft), and a single log (8 ft X 2 ft). The range of predicted critical discharges is listed in Table 9.3. The small debris jam class best approximates typical debris jams on the mainstem, suggesting flows in the 16,000 to 20,000 cfs range are necessary to topple most exposed mature alders. Larger, undetermined flows would be required to push over enough trees and trigger a domino effect throughout the riparian berm.

Debris Jam Classification	Debris Dimension	Alder #2 (D=0.8 ft) Discharge (cfs)	Alder #4 (D=1.0 ft) Discharge (cfs)	Alder #5 (D=1.1 ft) Discharge (cfs)	Alder #6 (D=1.2 ft) Discharge (cfs)
Large jam	15 ft X 7.5 ft	10,100	10,800	9,250	11,800
Small jam	10 ft X 5 ft	15,900	18,300	16,200	19,400
Single log	8 ft X 2 ft	31,800	41,000	37,000	42,100

Table 9.3. Critical discharges needed to push over mature alders in a riparian berm as a function of debris size.

9.9 Summary of Riparian Dynamics

We centered much of this chapter's discussion on factors limiting plant survival, and the importance of these factors to restoring the mainstem river ecosystem. Variable flows, ranging from high, scouring floods to summer baseflows were required to prevent riparian encroachment. In their natural state, woody plant occupation of alternate bar faces was characterized by relatively sparse stands of mature willows and alders, and large areas of open gravel bar dominated by annuals or young plants soon to be eliminated by floods. Without flow variability and large magnitude floods to periodically eliminate vegetation near the water's edge, rehabilitation sites along the mainstem can be expected to revert quickly to encroached conditions. Recommendations intended to restore mainstem dynamic alluvial features and their associated riparian vegetation must incorporate the following findings:

- Narrow-leaf willow is the most pervasive woody riparian plant species responsible for post-TRD bar encroachment.
- Narrow-leaf willow had the broadest seed release time, extending past the snowmelt recession period even in wet years.
- Critical root depth was only partially related to the age of willow seedlings/saplings; plants older than 6 to 8 months and up to three years had similar, shallow critical rooting depths.
- Winter floods which mobilized the channelbed surface and portions of the subsurface were not completely effective at removing the previous water year's initiating willow cohort and earlier established cohorts.
- Initiated and established plants were removed by the January 1, 1997 flood, but most mature trees in the berms were unharmed.
- Successful germination and initiation occurred within the moist surface of the exposed capillary fringe during summer baseflows.
- Plants less than three years old could be removed by flows scouring the channelbed, but if managers miss this "window of opportunity", older plants will develop into saplings and be extremely difficult to remove by bed scour.
- Undercutting by channel migration and toppling by accumulated flood debris floods are probably more important mortality agents than channelbed scour for mature trees. Recent TRD releases have not provided these agents.
- Subsurface moisture throughout bars was sufficient for plant establishment even during low flows in late summer.
- Single floods with a minimum peak discharge of 14,000 cfs (based on modeling and observation) can impact mature tree survival given an ideal set of conditions: the tree is fully exposed to the flow and prone to woody debris accumulation. A peak flow range of 16,000 to 20,000 cfs is a more realistic threshold.

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CHAPTER 10: PILOT BANK REHABILITATION PROJECTS EVALUATION

10.1 General Project History of Pilot Bank Modification Sites, WY 1993 to WY 1997

From WY1991 to WY1993, the U.S. Bureau of Reclamation (USBR) and U.S. Fish and Wildlife Service (USFWS) constructed nine bank modification projects (originally labeled "feather edges") as part of their pilot channel rehabilitation program to increase salmonid fry rearing habitat (Table 10.1, locations on Plate 1). Depending on the site, 400 ft to 1,000 ft of the riparian berm along one bank was excavated down to the original pre-TRD channelbed surface (Figures 10.1 and 10.2). In some sites, clean cobbles were placed on the excavated bank to provide cover for salmonid fry. Following construction, each site received varying levels of monitoring with the largest sites receiving the most (e.g., Steiner Flat and Sheridan/Deep Gulch sites).

10.2 Original and Contemporary Channel Rehabilitation Objectives

The original objective for pilot channel reconstruction was to increase slow and shallow habitat for emerging chinook and coho salmon. The encroached post-TRD channel bracketed by riparian berms provided mostly deep and fast homogeneous habitat, unlike its alluvial predecessor. Excavated banks were to provide a gently sloping channelbed with a range in depth and velocity preferred by young salmonids.

Bank Rehabilitation Site	Rive Mile	Date Constructed	Years Monitored	Constructed Low Water Channel Width (ft)	Number of Cross Sections
Bucktail	105.6	1993	1994-97	90	5
Limekiln	100.2	1993	1996-97	140	3
Steel Bridge	98.9	1993	1996-97	135	4
Steiner Flat	91.7	1991, 92, 93	1991-97	110	9
Bell Gulch	84.4	1993	1996-97	110	3
Deep Gulch	82.0	1993	1996-97	130	5
Sheridan Creek	81.1	1993	1991-97	170	6
Jim Smith	78.5	1993	1996-97	160	4
Pear Tree Gulch	73.1	1992	1996-97	65	7

Table 10.1 Bank rehabilitation project sites on the mainstem Trinity River.

But the pilot sites should provide more; berm removal could encourage the mainstem Trinity River to function as an alluvial channel again. Removal of one non-erodible bank and initial widening of the channel should create a depositional environment. Alternate bar formation would provide a much greater opportunity for improving salmonid habitat throughout the pilot channel site than originally expected of only the excavated bank. Channelbed particle size diversification, bank scour, floodplain formation, and possibly channel migration would all contribute to greater spatial and temporal channel complexity (Attributes No. 1 and No. 2) for plant and animal communities.

We also anticipated that a post-TRD alluvial response would create a channel morphology be different from the pre-TRD alluvial channel morphology. Alternate bars would be smaller than pre-TRD bars. The channel would begin to meander, but with considerably shorter wavelengths and amplitudes than pre-TRD meanders (Figure 2.26). By removing the berm and initially widening the channel, we also expected an overall fining of the channelbed surface, though steep, oblique riffles within evolving alternate bar sequences would retain a large particle size (Figure 10.3).

We did not forecast these new cross section and planform dimensions. Rather, the pilot reconstruction sites, especially the longer ones, provided a blank, oversized palette to document the channel's self-adjustment over several years of experimental dam releases and natural tributary flows. Although we did not have the desired control over flow regimes (especially downstream of Douglas City) or authority over the number and location of pilot sites, pilot channel responses were monitored to quantify these alluvial processes and to document trends toward attaining an alluvial channel morphology.

Project site monitoring also allowed us to apply our proposed alluvial attributes toward establishing the geomorphic and ecological roles of each annual hydrograph component. Our ultimate goal was to

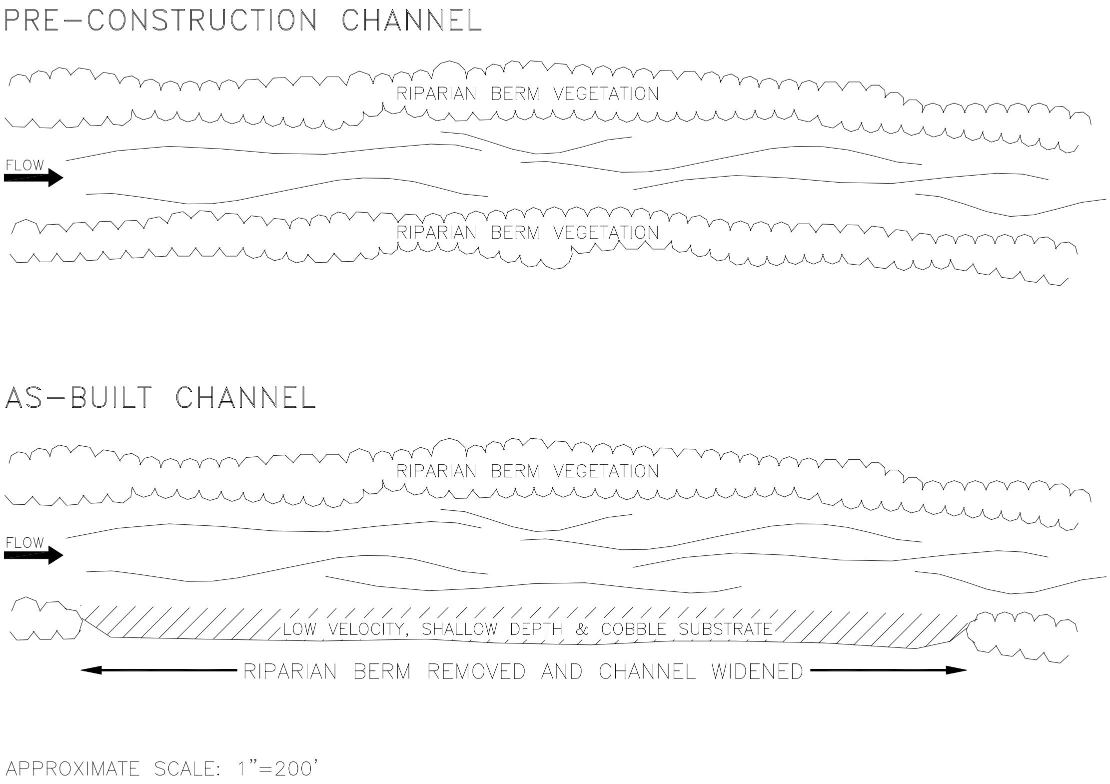

Figure 10.1 Idealized planform of bank rehabilitation work showing the position of the riparian berm and original bank construction.

recommend variable, annual flow releases at Lewiston capable of sustaining (or aiding) alluvial evolution in the present-day pilot and future channel reconstruction sites downstream to the North Fork Trinity River confluence. The pilot sites also were ideal for quantifying flow-related mechanisms governing riparian encroachment (addressed and summarized in Chapter 9). In earlier studies (Trinity Restoration Associates 1993), only the few remaining dynamic alternate bars could serve as study sites. The broad uniform surfaces of the excavated banks, as well as surfaces on the newly-forming alternate bars, allowed us to focus on specific physical mechanisms preventing germination and/or killing seedlings.

Our monitoring protocol was based on the alluvial attributes serving as initial hypotheses for pilot channel responses. Several have already been addressed: Is the channelbed mobilized on average once annually (Attribute #3)? Does deeper scour occur less frequently (Attribute #4)? Other attributes have not been addressed specific to the pilot bank reconstruction sites: Are alternate bars forming in the longer pilot project sites (Attribute #2)? Is a floodplain forming (Attribute #7)? Can a dynamic early-successional riparian community be sustained (Attribute #9)? Can woody riparian encroachment be prevented (Attribute #9)? Site-specific descriptions, in the following section, document morphological trends and probable future trends and responses.

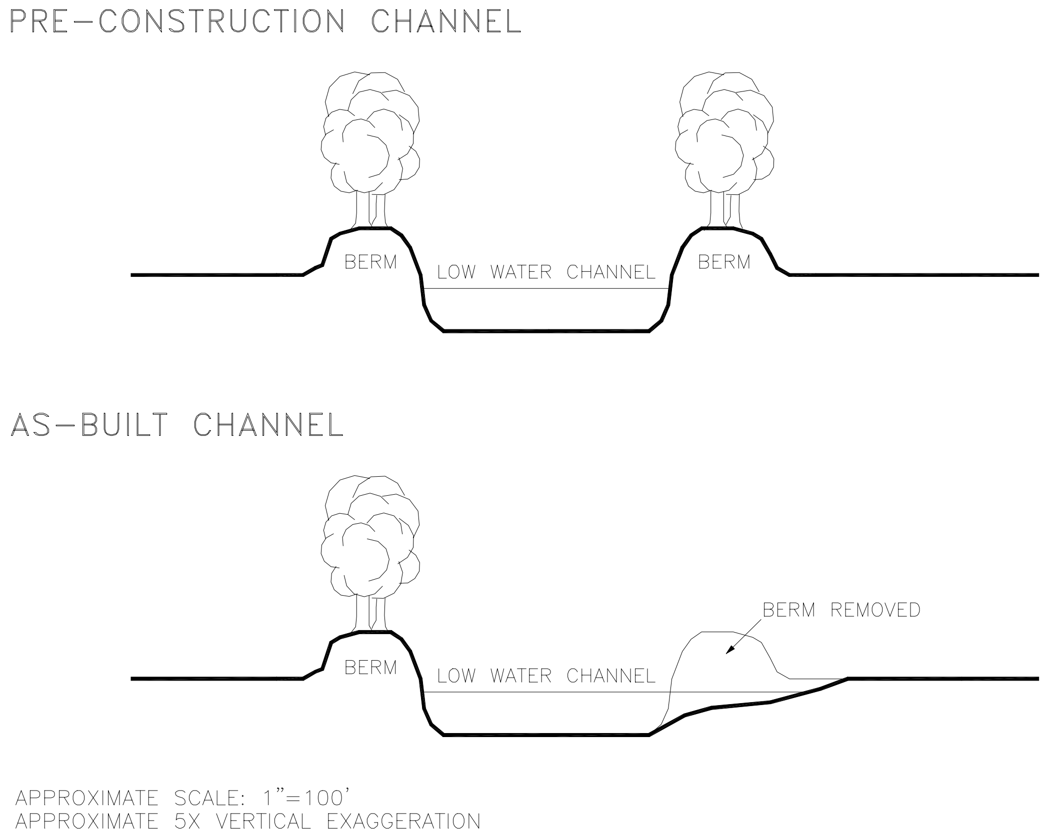

Figure 10.2 Idealized cross section of bank rehabilitation showing the profile of the channel before and after bank construction.

10.3 Monitoring Methodologies

10.3.1 Development of an Alluvial Channel Morphology

Our three primary project monitoring sites were apportioned down the mainstem. The uppermost project site was Bucktail (RM 105.6). Although it had a short constructed length, it was located within the upper non-alluvial zone, only 6.4 mi downstream of Lewiston Dam. Steiner Flat (RM 91.7) was the senior pilot project. Trinity Restoration Associates (1993) had been monitoring this channel reach before its selection as a bank reconstruction project site. This site is located within the alluvial transition zone downstream of several major tributaries. The Sheridan Creek site, situated in the alluvial zone, also had been monitored by Trinity Restoration Associates (1993) prior to bank reconstruction. The other sites received variable monitoring intensities (Table 10.1).

The following dependent morphological variables were examined for each pilot bank construction site:

1. channel width
2. cross section shape

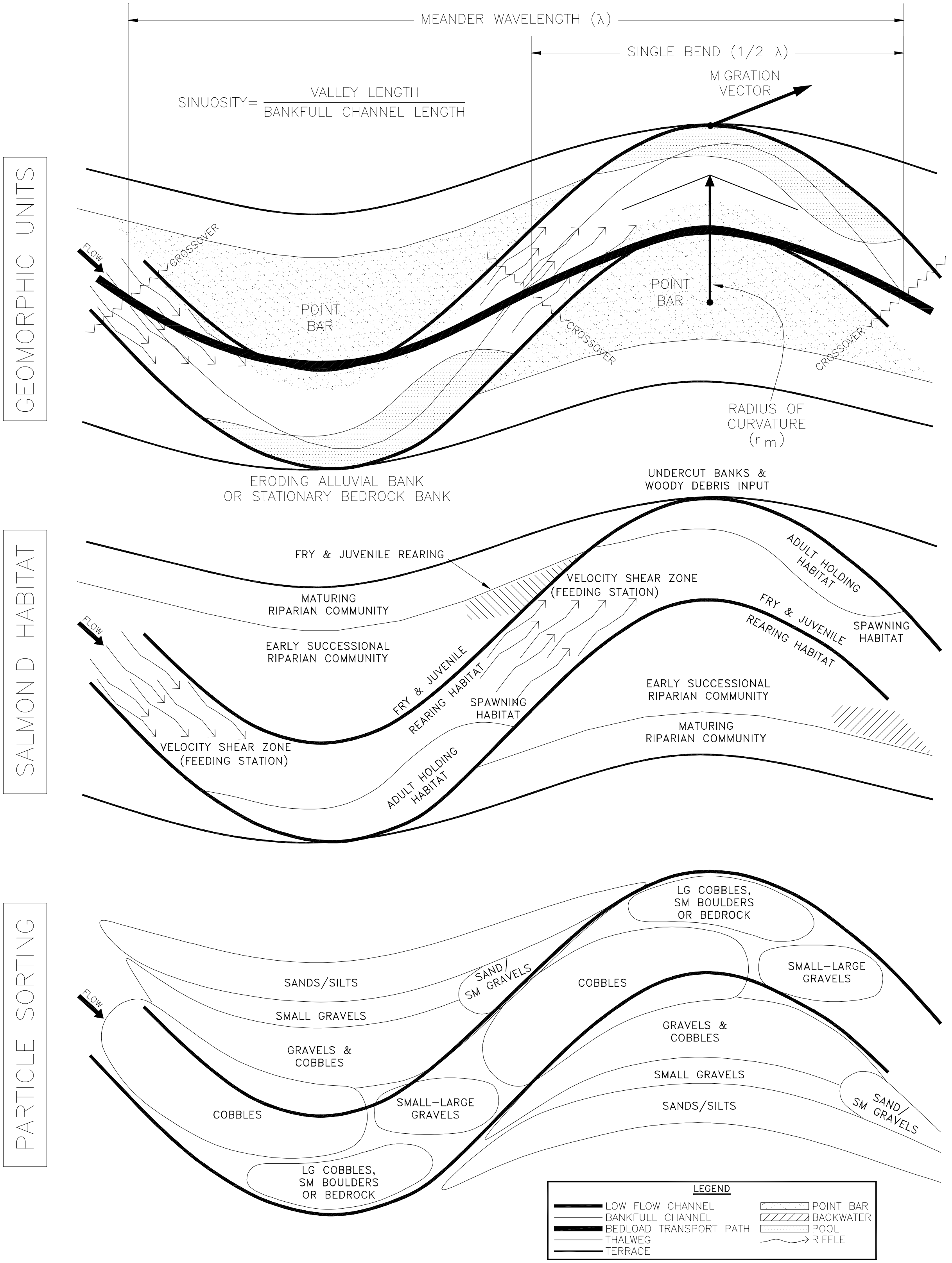

Figure 10.3 Idealized geomorphology, habitat and facies diagram of developing rehabilitation site.

3. cross section hydraulic geometry
4. substrate particle size distribution
5. thalweg development and meandering
6. channelbed topography indicating alternate bar development

Independent variables were peak discharge and time.

All previous cross sections and several new cross sections were surveyed in WY1995. We continued to re-survey established cross sections at Steiner Flat and Sheridan Creek bank rehabilitation sites. We also established new cross sections at Bucktail, Steiner Flat and Sheridan Creek sites. Trinity Restoration Associates (1993) had established cross sections at other non-construction sites; these were also monitored in WY1995 as comparisons. During WY1996, the remaining six bank rehabilitation sites were surveyed using previously established USBR and USFWS cross sections. After the WY1997 January peak flood, cross section surveys at Bucktail, Steiner Flat, Bell Gulch, Deep Gulch, Sheridan Creek, and Jim Smith bank rehabilitation sites were extended higher onto the banks for slope-area estimation of peak discharge. Nine bank rehabilitation sites consisting of forty-six cross sections in WY1996 were re-surveyed in WY1997.

Distances between cross sections varied within and among sites; no fewer than three cross sections were placed within a single bank rehabilitation site. All cross sections were labeled by distance from one cross section designated as 10+00. All cross sections were surveyed to the nearest 0.01 ft with an auto level. The cross section plots for WY1994 and WY 1995 were derived from topographic surveys and may not precisely reflect the actual channel shape since points used to define the topography were not on the cross section. These plots are used only to identify trends at the cross section relative to the WY 1996 and WY 1997 surveys.

Permanent benchmarks were installed at all bank rehabilitation study sites above the 10,000 cfs water surface elevation. Each permanent benchmark consisted of a concrete pad and imbedded carriage bolt/aluminum benchmark defining our datum. Our benchmarks were placed near original USBR benchmarks and/or witness trees wherever possible. Unless elevation above mean sea level was known, our datums were assigned an arbitrary elevation of 100 ft. All nearby federal, county, or state benchmarks were referenced to our datums. Fixed rebar pins defining cross section endpoints were referenced to permanent datums. Benchmarks at Steiner Flat and Jim Smith sites were replaced following the WY1997 floods.

During WY1995 and WY1996, substrate composition was described along selected cross sections using Wolman pebble counts (n=100). Gravel and cobble deposited in WY1996 were well-sorted by size into distinct areas (facies) of the channelbed surface. In summer 1996 and 1997 we delineated each substrate facies boundary on a total station site map; these were subsequently digitized. Substrate facies monitoring began at Bucktail (RM105.6), Steiner Flat (RM91.7) and Sheridan

Creek (RM 81.1) bank rehabilitation sites in WY1996. Substrate facies at the six remaining bank rehabilitation sites were monitored in WY1997. Wolman pebble counts were taken within each facies delineation to document changes in surface particle size distributions.

Upstream of Indian Creek, annual maximum flood frequencies are primarily influenced by discharges from the dam. Downstream of Indian Creek however, dam releases are smaller than unregulated tributary floods. This transition, from dam influence to tributary influence, required development of another annual maximum flood frequency curve specific to the mainstem downstream of Indian Creek.

10.3.2 Hydraulic Geometry of Alternate Bars

Hydraulic geometry of evolving alternate bar surfaces also was monitored. Specific flow elevations were surveyed on selected cross sections in the Steiner Flat and Sheridan Creek channel rehabilitation sites using hourly flow records from the Junction City and Douglas City gaging stations. Water surface slopes were surveyed, and roughness coefficients back-calculated, to predict other flow elevations. Because of rapid bar development in several sites, hydraulic geometry had to be calculated annually at many cross sections.

10.4 Results

10.4.1 Site-Specific Morphological Responses

10.4.1.1 Bucktail rehabilitation site (RM 105.6)

The Bucktail bank rehabilitation site was constructed in 1993 by removing the riparian berm along the left bank downstream of an old gabion weir (Figure 10.4). USBR surveyed the site topography in fall 1994 and again in 1996. An additional survey in February 1997 documented changes in channel geometry following the January flood (Table 10.2).

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
24-Mar	1995	6,970	9.0
22-Feb	1996	6,450	8.1
1-Jan	1997	11,400	19.8

Table 10.2. Peak flows for WY1995 to WY1997 at the Bucktail rehabilitation site.

A point bar, originally formed during the 1995 release (6,400 cfs) continued to aggrade and extend downstream during flows greater than 5,000 cfs (Figures 10.5 and 10.6). Bar formation increased thalweg sinuosity and increased asymmetry in the channel cross section. A flat surface beyond the original constructed edge is now covered with silt, sand, and appears to be a developing floodplain

Figure 10.4 Bucktail rehabilitation site post-construction. Note boulder in the channel, left of center. Cobbles along constructed edge were placed as work was completed.

Figure 10.5 Bucktail rehabilitation site after 1995 flood. Note original placed cobbles being buried by developing bar (frame right). The boulder in the foreground is the same one shown in Figure 10.4.

Figure 10.6 Bucktail rehabilitation site after the 1997 flood. The bar continued to extend downstream burying the boulder shown in figures 10.4 and 10.5. Note the lack of turbidity in the backwater (foreground), compared to the main channel. This is suitable habitat for organisms that are not well adapted for turbid conditions.

(Figure 10.7). Consistent low water channel widths throughout the reach indicate the channel was establishing a new hydraulic geometry following construction (Figure C-1). There is bedrock control along the right bank through this reach.

Since 1994, cross section 10+00 showed only minor (<0.5 ft) degradation along the left edge of the low water channel (Figure C-2). A 10 ft wide section of the right bank scoured 2.5 ft during the WY1995 flood. No bar development has been observed at this cross section.

Point bar development was evident at cross section 11+00 with 3 ft of aggradation along the left bank during the WY1995 flood (Figure C-3). This narrowed the low water channel by 35 ft and widened the floodplain by 20 ft. During the WY1997 flood an additional 2 ft of aggradation occurred along the top of the bar. No adjustments in the low water channel width occurred as a result of the WY1996 or WY1997 floods.

At cross section 12+00, aggradation was similar to cross section 11+00 with 2 ft of aggradation during each WY high flow (Figure C-4). The aggradation continued along the left bank as the bar extended downstream. The low water channel width had been reduced from 100 ft to less than 60 ft.

At cross section 13+00, bar aggradation and low water channel narrowing were similar to cross section 12+00 (Figure C-5). Here, 1.5 ft of aggradation occurred during the WY1995 flood with an

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Figure 10.7 Photograph showing the substrate transition on an emerging floodplain at the Bucktail rehabilitation site. Fine sand and silt are common substrate components along developed floodplains in alluvial rivers.

additional 0.5 ft deposited during the WY1996 high flows. In WY1997, a deep deposit aggraded along the left bank and the channel narrowed from 100 ft to 60 ft.

Aggradation at cross section 14+00 was less than in the middle cross sections for earlier years but did occur along the left bank of the low water channel in WY1997 (Figure C-6). This trend was similar to downstream cross sections at other sites where aggradation increased with each high flow as the bar extended downstream. Low water channel width was 60 ft. Following a WY1996 February flood (6,290 cfs), the point bar aggraded 1.5 ft. Three months later, only 0.10 ft to 0.25 ft of surface scour and 0.5 ft of deposition were documented on the same point bar from a 5,180 cfs maintenance release

The channel bed surface has become finer since bank rehabilitation. The face and head of the bar have continued to grow finer since the point bar deposited during the WY1995 floods (Table 10.3).

The middle section of the bar became finer between WY1995 and WY1996, but the trend did not continue after the winter 1996 peak.

Particle Facies	July 26,1995		April 30,1996		July 26,1996		March 4, 1997	
Values	D_{50}	D_{84}	D_{50}	D_{84}	D_{50}	D_{84}	D_{50}	D_{84}
Facies 1	66	167	45	126	49	73	38.5	76
Facies 2	51	84	38	65	48	81	40.5	63
Facies 3	30	53	26	44	17	34	45	76
Facies 4	33	55	N/A	N/A	N/A	N/A	17	44
Facies 5	N/A	N/A	N/A	N/A	N/A	N/A	17	27

Table 10.3 Summary of Bucktail bank rehabilitation site changes in particle size distribution from WY1995 to WY1997.

The gabion weir upstream of the bank rehabilitation site greatly affected water surface slopes. Below 2,500 cfs (Figure C-8), the weir created a steep water surface slope (0.0094 to 0.0042) between the first two cross sections. The last three cross sections were low gradient at all flows (0.0004 to 0.0001). Flows above 2,500 cfs were not affected by the weir and began to even out at 7,000 cfs (0.0006 to 0.0001). Water surface slopes for discharges above 7,000 cfs increased gradient considerably (0.0019).

The alternate bar is still developing. Downstream extension of the bar along the left bank will continue to decrease width and increase sinuosity and asymmetry. The most significant geomorphic change will likely occur at cross section 14+00 as the bar extends through this section. Low water width at the cross section should reach the same width as the upstream cross sections (60 ft). The emerging floodplain should continue to aggrade with sand and silt. The particle size distribution of the channelbed surface should become more spatially complex with greater alternate bar development.

10.4.1.2 Limekiln bank rehabilitation site (RM100.2)

A point bar has been developing along the left bank resulting from the WY1997 flood peak (Table 10.4). Bar development was most noticeable in two upstream cross sections (Figure C-9). Only minor deposition was noted in the most downstream section. The thalweg typically degraded less than 1 ft. Our February 1997 survey showed that the top of the bar was just below the low water surface at the most upstream cross section. This bar probably will emerge during late summer low flows (450 cfs), narrowing the low flow channel by approximately 25 ft. Bar aggradation also increased asymmetry in the channel cross section. In addition, sediment deposited by the WY1997 flood increased sinuosity.

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
24-Mar	1995	6,940	8.9
22-Feb	1996	6,420	8.1
1-Jan	1997	16,700	46

Table 10.4 Annual peak flows for WY1995 to WY1997 at the Limekiln rehabilitation site.

Cross section 10+00 deepened by an average of 1 ft, while the right bank retreated approximately 5.0 ft between WY1994 and WY1996 (Figure C-10). In 1997, the bar face scoured 1.5 ft, but the top of the point bar aggraded 2 ft. This steepened the bar face, narrowed the low water channel, and increased channel asymmetry. Point bar deposition extended from cross section 10+00 to 11+86, but no scouring occurred along the bar face at the lower cross section.

Cross section 11+86 degraded along the right bank between WY1994 and WY1996 resulting in a deeper more asymmetrical channel (Figure C-11). In 1997, a point bar 50 ft wide and 2 ft deep was deposited along the right bank decreasing the width-to-depth ratio and further increasing cross section asymmetry.

There was no significant bar development at cross section 14+85 between WY1994 and WY1997 where the aggradation was 30 ft wide, but less than 1 ft deep (Figure C-12). Because bar development has not yet extended into this reach, there has been no narrowing of the low water channel.

Four particle facies were mapped at the Limekiln Site in WY1997 (Table 10.5). Gravel and cobbles were deposited along the left bank during the WY1997 flood, extending from the site’s upstream end as two lobes and coarsening downstream (Figure C-9). Facies 1 and 2 represented the surface of an emerging point bar that has a long narrow lobe grading from finer facies 1 to coarser facies 2 sediments. Facies 3 and 4 were essentially the same, representing finer deposition along the left bank.

Particle Facies	D_{50} (mm)	D_{84} (mm)
Facies 1	52	85
Facies 2	62	104
Facies 3	50	89
Facies 4	49	89

Table 10.5 Particle size distributions for WY1997 at the Limekiln bank rehabilitation site (July 28,1997).

Water surface slope increased as flow increased (Figure C-13). There were no significant gradient controls upstream, within, or downstream of the reach. At low discharges less than 1,000 cfs, the slopes ranged from 0.0014 to 0.0017. As flows increased, the slope became steeper approaching 0.0020.

The point bar along the left bank should continue to aggrade and extend downstream. As this occurs, more of the bar will emerge during low flows, narrowing the channel, increasing sinuosity, and adding complexity to the reach. As the point bar develops, surface particle size distributions along the bar will coarsen.

10.4.1.3 Steelbridge bank rehabilitation site (RM 98.8)

By comparing channel morphology from WY1994 to WY1997 topographic surveys, we assessed channel response resulting from the intervening winter floods (Table 10.6). Since 1993, the Steel Bridge rehabilitation site has responded similarly to the Bucktail site by episodic aggradation and reshaping of a point bar along the left bank (Figure C-14). Some deepening of the thalweg also occurred. We documented reduction in the width of the low water channel (450 cfs) of 75 ft, narrowing to approximately 65 ft. Bar formation has increased asymmetry in the channel cross section and increased sinuosity. Bar development is greatest in the middle of the project reach where aggradation has exceeded 3 ft. Along the upper reach, the bar face degraded as the outer edge of the bar aggraded. On the downstream end of the project, aggradation was less than 1 ft but similar channel geometry was developing as the point bar continued to extend downstream. Bedrock control prevented channel migration and significant thalweg shifting.

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
24-Mar	1995	6,940	8.9
22-Feb	1996	6,420	8.1
1-Jan	1997	16,700	46

Table 10.6 Annual peak flows for WY1995 to WY1997 at the Steel Bridge rehabilitation site.

At the cross section 10+00, a point bar was deposited along the left bank WY1995 and the low water channel was degraded by up to 2 ft (Figure C-15). The bar was reshaped in 1997 during high flows (Table 10.6) as it aggraded 1 ft along the left bank and degraded 0.5 ft along the bar face. The depth of the low water channel also increased as the bed degraded approximately 1 ft. The channel width remained at approximately 135 ft, because the point bar had not sufficiently aggraded to emerge above low flows.

Point bar development continued downstream through cross section 11+10 (Figure C-16). Between WY1994 and WY1996, the bar aggraded approximately 1.5 ft as the low water channel degraded more than 2 ft. In WY1997, the bar aggraded an additional 1.5 ft with minor (<0.5 ft) degradation in the low water channel. The low water channel remained approximately 150 ft wide, but the point bar aggraded to within 0.5 ft of the low water surface. When the bar emerges it will reduce the low water channel width from 150 ft to 65 ft.

At cross section 12+10, the thalweg degraded 1.5 ft as the point bar aggraded 1 ft between WY1994 and WY1996 (Figure C-17). Prior to the WY1997 flood, point bar development was not well defined, however the 1997 survey showed significant point bar aggradation. An additional 2.5 ft of aggradation occurred along the bar, lowering the width-to-depth ratio of the low flow channel. Emergence of this bar reduced low flow width from 145 ft to 65 ft.

Cross section 13+10 changed least during between WY1994 and WY1997 (Figure C-18). A thin cobble veneer, presumably a continuation of the upstream deposits, blanketed the left bank. The deposit was 35 ft wide and 0.5 ft deep and may be the leading edge of the bar as it continues to extend downstream.

In 1997, we documented particle size sorting in both a downstream direction as well as across the channel. However, overall variability of the point bar's particle size distribution was much lower than at other sites (Table 10.7 and Figure C-14). We mapped four facies below the low water surface. The upstream end of the site, above cross section 12+10, was slightly finer than the downstream end. The D_{50} was similar between all facies, with a range of 17 mm between the largest and smallest D_{50} (Table 10.7).

Particle Facies	D_{50} (mm)	D_{84} (mm)
Facies 1	67mm	121mm
Facies 2	84mm	136mm
Facies 3	76mm	125mm
Facies 4	75mm	140mm
Facies 5	67mm	115mm
Facies 6	78mm	108mm

Table 10.7 Summary of Steel Bridge bank rehabilitation site surface particle size distribution, WY1997.

As discharge increased, water surface slopes during WY1997 decreased from 0.0027 to 0.0018. The profile flattened towards 0.0018 (Q=16,700) as the water surface was less influenced by local grade control (Figure C-19).

As expected, the channel was responding to post-construction widening by developing a lower width-to-depth ratio. Future high flows that adequately mobilize the bed will likely initiate additional aggradation as well as bar extension downstream along the left bank. A large pool immediately downstream may influence the rate and downstream extent of this developing bar. Bedrock control of the deepest section of the channel will inhibit lateral migration and farther degradation of the thalweg.

10.4.1.4 Steiner Flat bank rehabilitation site (RM 91.7)

The post-TRD Steiner Flat site was a straight, flume-like reach before riparian encroachment was removed by bank rehabilitation (Figure 10.8). Its channel cross section was rectangular. No lateral channel migration or point bar formation was evident during WY1991 to WY1993 monitoring. We monitored in-channel topography for pre- and post-rehabilitation changes (Table 10.1), and documented the evolution of an alternate bar sequence.

Channel migration coupled with medial bar and point bar development produced an alternate bar sequence (Figure 10.9). Channel response varied throughout the project reach indicating a transition from a straight, wide channel to a more sinuous and deeper low water channel (450 cfs). During the WY1997 flood (Table 10.8), the channel continued to migrate toward the left bank at the upstream end of Steiner Flat as the thalweg deepened and shifted to the left. Lateral migration removed four mature alders. Downstream, at cross section 03+31, the channel scoured 10 ft into the right bank. Aggradation along the right bank in the upstream reach produced a point bar and narrowed the low water channel. Degradation of the medial bar along the middle reach increased the average depth of the channel. At the downstream end of the project site, aggradation produced a greater asymmetry in the low water channel as a bar began to develop along the right bank. The net effect of deposition and scour through this reach was an increase in channel complexity and sinuosity by development of an alternate bar morphology (Figure C-20).

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
9-Jan	1995	10,800	4.7
22-Feb	1996	6,670	2.3
1-Jan	1997	24,000	24.5

Table 10.8 Annual peak flows for WY1995 to WY1997 at the Steiner Flat rehabilitation site.

During the January 1997 flood, the channel aggraded up to 6 ft along the right bank and created a shallow point bar along the bank at cross section -0+69 (Figure C-21). The thalweg degraded over 4 ft and shifted 20 ft to the left. This narrowed the low water channel from 135 ft to 90 ft.

At cross section 0+45, a medial bar aggraded following construction (Figure C-22). The bar continued to aggrade throughout two water years until the bar was 4 ft deep and 13 ft wide by spring

Figure 10.8 Post-construction bank at Steiner Flat. The riparian berm can be seen end-on behind the person in the photo. The cobbles that line the bank were artificially placed during construction.

Figure 10.9 Steiner Flat rehabilitation site after the 1997 flood. Note the point bar emerging along the right bank and the bedrock exposed along the opposite bank beyond. Debris transported downstream can be seen caught up in the trees along the upstream end of the riparian berm.

1996. This split the channel and reduced width of the low water surface by approximately 20 ft. Following the WY1997 flood however, the medial bar degraded to within 2 ft of the post-construction right bank surface, and the low water channel was restored to its post-construction width. Although the medial bar was removed, the deposit that remained along the right bank increased asymmetry of the channel cross section.

Cross section 1+45 evolved similar to 0+45 (Figure C-23). A medial bar 2 ft deep developed and split the channel by WY1995. The bar degraded during the WY1997 flood while the channelbed aggraded 1.5 ft along the right bank.

Cross section 2+31 did not change between WY1995 and WY1996. The medial bar was not emergent in 1996 as in upstream cross sections but responded the same way to the WY1997 flood (Figure C-24) by degrading approximately 1 ft while aggrading the thalweg 4 ft. The low water channel width was not changed by the flood event.

At Cross section 3+31 no significant change in channel geometry was observed between WY1995 and WY1996. (Figure C-25). In contrast to upstream cross sections, this cross section aggraded 3 ft in the middle of the channel and up to 1 ft along the right bank during the WY1997 flood. Additional modification of the channel occurred along the right bank, where the bank receded approximately 10 ft, widening the low water channel.

Cross section 4+31 showed no significant change in channel geometry between WY1995 and WY1996, however, we documented a similar response to the 1997 flood compared to upstream cross sections (Figure C-26). Over 2 ft of aggradation occurred toward the center of the channel with less aggradation (<0.5 ft) along the right bank. The width of the low water channel did not change. Approximately 1.5 ft degraded along the floodplain at the same station as cross section 3+31. Deep scour at cross sections 3+31 and 4+31 were a result of the January 1997 flood, not the extended 6,000 cfs release in March 1997. We documented scour along the constructed edge above the low water surface since WY1994. A large scour hole continued to develop above the low water surface in what was being used as an access road at the downstream end of the site. Prior to the WY1997 flood, the scour hole was 1 ft deep and 5 ft wide, after the flood the hole had grown to 4 ft deep and 10 ft wide.

Bar development did occur at cross section 5+02 as the channel aggraded along the right bank (Figure C-27). However, the 3 ft of aggradation increased elevation of the low water level, leaving the channel width unchanged.

At cross section 5+98, post-construction aggradation built a point bar 3 ft deep along the right bank (Figure C-28). This reduced the low water channel width from 115 ft to 65 ft. During the WY1997 flood, the uppermost part of the bar was degraded approximately 1.5 ft while much of the former low water channel aggraded (>2 ft). The low water channel width has widened to approximately 95 ft.

We documented no change to the particle size distribution resulting from WY1991 and WY1992 maintenance flows. In 1992, we sampled two ranges of particle sizes along cross section 0+45. There were coarse and fine components at the cross section, both samples quantified channel substrate the year phase two was constructed. Surface particle size distributions were documented the year following the second phase of construction at cross section 0+45 (Table 10.9). A coarse component on cross section 0+45 was not sampled again until after WY1995 floods (Figure C-29). The coarse component sampled in 1995 was finer than the coarse in 1992 (Table 10.9). The finer particle size distribution has not changed since WY1992, only planform channel location changed. By WY1996, the fine component D_{50} grew smaller by 10 mm and the D_{84} remained constant after the initial fining immediately following construction.

Cross Section 00+45			
Date	Cross Section Station	D_{50} (mm)	D_{84} (mm)
5/22/91	Mid-channel	50	96
5/15/92	27-45	50	98
6/26/92	28-50	45	75
6/26/92	54-72	47	185
4/8/93	30-86	46	73
10/4/93	97-134	43	71
8/31/94	43-80	46	75
7/26/95	70-138	58	115
8/2/95	138-174	65	150
7/26/96	50-75	40	77
7/26/96	75-100	46	89
7/26/96	100-140	77	118
7/26/96	140-170	85	146

Table 10.9. Summary of Steiner Flat cross section 0+45 surface particle size distributions from WY1991 to WY1996.

The channel surface fined after the third phase of construction (Table 10.10). After the WY1995 floods, three particle size ranges were sampled. However we did not find sufficient differences between two of the samples and combined them (Table 10.10). The coarse and fine components were well defined on the point bar deposited as a result of WY1995 floods. There have been no changes to the D_{50} or D_{84} in the coarse and fine components since their initial deposition in 1995. The pebble counts at cross section 05+98 in spring 1996 indicated that WY1995 an WY1996 winter flows coarsened the bar (Figure C-29). However, the spring 1996 maintenance release (5,180 cfs) deposited a lobe of finer material over the bar. The sediment lobe, deposited by the maintenance release, decreased the particle size distribution on the bar face of the lower point bar.

Cross Section 05+98			
Date	Cross Section Station	D_{50} (mm)	D_{84} (mm)
Mid-channel			
10/4/93	45-85	77	200
8/31/94	50-80	60	170
8/1/95	50-80	60	110
4/30/96	60-110	74	119
7/26/96	50-130	51	99
3/3/97	50-110	58	105
Bar Surface			
8/1/95	80-110	61	105
8/1/95	50-110 (combined)	60.5	105.5
8/1/95	110-130	40	70
4/30/96	110-130	50	92
3/3/97	110-130	37	86

Table 10.10 Summary of Steiner Flat cross section 05+98 surface particle size distributions from WY1991 to WY1996.

Morphologically, Steiner Flat bank rehabilitation site changed significantly since the final phase of construction in 1993. Spatial sorting increased since rehabilitation. Gravel facies were highly mobile, and facies location on the planform has shifted (Figure C-29).

After the WY1997 flood, more facies were mapped than observed in WY1996. These facies changes were on channel features that were scoured and redeposited. Overall, the upstream, right bank, and point bar D_{50} decreased, whereas the D_{84} increased from WY1995 to WY1997. Although the upper point bar was completely re-worked during the WY1997 floods, there was no change in particle size distribution compared to WY1996. The medial bar that formed along the left bank in WY1995 has coarsened.

Since January 1995, water surface elevations or raft lines were surveyed at every cross section over a wide range of discharges (318 cfs to 30,000 cfs) to determine water surface slope along the right bank (Figure C-30). Low water slope gradient was 0.0036, while the high water slope decreased toward 0.0014. Generally, water surface slope gradually decreased as flow increased.

The post-construction geomorphic response was encouraging. Reestablishment of alluvial behavior was evident throughout. Alternate bar development, lateral shifts of the thalweg, and development of a deeper, narrower low water channel occurred. There was evidence of a developing floodplain, defined by a substrate transition form coarse gravel to sand and silt.

This site will continue to develop an alternate bar morphology. The floodplain emerging at this site will continue to develop and aggrade with fine sediment.

In contrast to upstream sites, the discharges necessary to cause bed scour and reshaping of the alternate bar morphology were more frequent here (Table 10.8). Flows exceeding 6,600 cfs, capable of mobilizing the channelbed, have a return period of 2.3 years compared to the Bucktail site where the recurrence interval is 8.1 years for a discharge of 6,450 cfs.

10.4.1.5 Bell Gulch bank rehabilitation site (RM 84.4)

A medial bar developed most notably in the two upstream cross sections during WY1995 floods (Table 10.11). No bar development was noted in the most downstream section, although the low water channel (450 cfs) aggraded over 2 ft (Figure C-31). Aggradation of the thalweg has been continuous but was typically less than 1 ft for each flood. Our February 1997 survey showed that the top of the bar was just below the low water surface at the most upstream cross section. This bar should emerge during late summer low flows of WY1997, splitting and narrowing the low flow channel by approximately 15 ft.

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
9-Jan	1995	15,800	6.7
22-Feb	1996	7,670	2.2
1-Jan	1997	30,000	27.3

Table 10.11. Annual peak flows for WY1995 to WY1997 at the Bell Gulch rehabilitation site.

During the WY1995 flood (Table 10.11), the medial bar that formed created a backwater and narrowed the low water channel at cross section 10+00 (Figure C-32). After the WY1997 flood, the bar aggraded 1 ft, shifted closer to the right bank, and aggraded the thalweg 1.5 ft.

Downstream at cross section 11+50, the low water channel aggraded 2 ft along the left bank resulting in a point bar that narrowed the low water channel by 25 ft (Figure C-33). The thalweg aggraded less than 1 ft but shifted 10 ft to the right. Two ft of degradation occurred along the right bank The WY1997 flood scoured the channel along the left bank removing the medial bar crest. The medial bar deposit does not extend downstream as far as cross section 13+05. The thalweg aggraded 1 ft, but did not shift laterally.

In WY1995, cross section 13+05 was deepened and narrowed as the thalweg degraded 1 ft and shifted 20 ft to the right. In addition, 1 ft of sediment was deposited along the left bank (Figure C-34). Sediment was deposited during the WY1997 flood, transported downstream from the medial bar crest at cross section 11+50. As a result, the channel bottom aggraded 3 ft, flattening the bottom of the low water channel, and increasing the width-to-depth ratio.

Bell Gulch exhibited diverse surface particle size distributions (Table 10.12 and Figure C-31). The main channel substrate below the low water surface (facies 6 and 7) was similar, consisting of very coarse gravel and medium cobbles. A lee deposit composed of facies 8 and 9 on the downstream right bank was coarsest. The backwater portion of the lee deposit (facies 8) consisted of coarse and very coarse gravel. The channel face on the lee deposit had large cobbles and very coarse gravel.

Particle Facies	D_{50} (mm)	D_{84} (mm)
Facies 1	56	101
Facies 2	29.5	55
Facies 3	N/A	N/A
Facies 4	32	73
Facies 5	49	80
Facies 6	59	100
Facies 7	55	97
Facies 8	77	121
Facies 9	23	42

Table 10.12 Surface particle size distributions for WY1997 at the Bell Gulch bank rehabilitation site (March 5,1997).

Above the low water channel margin the WY1997 floods deposited a wide range of particle sizes. Particle sizes decreased downstream with localized sand deposits indicating local eddy currents during the 1997 floods.

Water slope decreased as discharge increased when local variations in the bed surface no longer affected the water surface slope (Figure C-35). The gradient through the restored reach was 0.0060 at low water and decreased to 0.0011 as flow increased. At the peak discharge during the WY1997 flood, the water surface slope was 0.0019.

The point bar along the left bank will continue to aggrade and extend downstream. As this occurs, more of the bar will emerge during low flows narrowing the channel, increasing sinuosity, and adding structural complexity. During high discharges the bar will be scoured and the low water channel will widen and aggrade.

10.4.1.6 Deep Gulch bank rehabilitation site (RM 82.0)

Monitoring during WY1996 and WY1997 showed no development of an alternate bar during high flows for either year (Table 10.13). Minor degradation, typically less than 1 ft occurred in the upstream reach with only deposition noted in the most downstream sections (Figure C-36). Cross sectional shape of the low water channel (450 cfs) remained unchanged.

At cross section 10+00, the cross section deepened by an average of 1 ft and the right bank aggraded approximately 1 ft during the WY1997 flood (Figure C-37). The thalweg degraded approximately 1.5 ft but did not shift laterally. Above the low water surface, the WY1997 flood flows degraded a 20 ft section of the left bank.

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
9-Jan	1995	15,800	6.7
22-Feb	1996	7,670	2.2
1-Jan	1997	30,000	27.3

Table 10.13 Annual peak flows for WY1995 to WY1997 for the Deep Gulch rehabilitation site.

Cross section 11+95 degraded 1 ft along the left bank (Figure C-38). Minor aggradation (<0.5 ft) occurred along a 10 ft section of the right bank at the bottom of the low water channel. The low water channel width did not change between WY1996 and WY1997.

At cross section 13+90, less than 0.5 ft aggraded along several segments of the channel (Figure C-39), with no adjustment in channel width.

At cross section 16+00, a 40 ft section of the low water channel (Figure C-40) aggraded 1 ft. The aggradation filled the thalweg causing it to shift 135 ft to the right. There was no narrowing of the low water channel at this cross section.

Cross section 17+80 showed approximately 1 ft of aggradation along the left side of the low water channel, similar to cross section 16+00. The thalweg aggraded, causing it to shift 135 ft to the right (Figure C-41). A small section of the left bank, below the low water surface, degraded approximately 1 ft. There has been no narrowing of the low water channel at this cross section.

We sampled three facies at Deep Gulch during the summer of WY1997 (Table 10.14). The fine gravels of facies 1 were deposited in a small lobe along the left bank in the upstream reach during the 1997 flood (Figure C-42). Facies 3 and 2 represent the surface of the low flow channel forming a long narrow lobe grading from a finer facies (3) to coarser facies (2).

Water surface slope at this site was constant as flow increased (Figure C-43) There were no significant gradient controls upstream, within, or downstream of the reach.

Development of alluvial features at this site has not yet occurred. The channel cross section remains essentially rectangular with minor aggradation and degradation shifting the topography of the channel bottom.

Particle Facies	D_{50} (mm)	D_{84} (mm)
Facies 1	16	35
Facies 2	64	124
Facies 3	23	90

Table 10.14 Surface particle size distributions for WY1997 at the Deep Gulch bank rehabilitation site (July 29,1997).

10.4.1.7 Sheridan Creek bank rehabilitation site (RM 81.6)

The post-TRD Sheridan Creek site was a straight, flume-like reach similar to the Steiner Flat site before riparian encroachment was removed by bank rehabilitation (Figure 10.10). The channel cross sectional morphology was rectangular. No lateral channel migration or point bar formation was evident from WY1991 to WY1993. Since then, we have been monitoring channel topography for pre- and post-rehabilitation changes (Table 10.1), and documenting an evolving alternate bar sequence.

Channel migration and point bar development produced an alternate bar sequence and a meandering planform at this site (Figure 10.11). Channel response varied throughout the project reach indicating a transition from a straight, wide channel to a more sinuous, and deeper low water channel (450 cfs). During the WY1995 flood (Table 10.15), point bar development along the right bank narrowed the low water channel and increased its asymmetry. This feature was not significantly altered by WY1996 high flows, i.e., the February tributary flood or the May 5th 180 cfs maintenance flows. During the WY1997 flood (Table 10.15), the channel continued migrating toward the left bank at the upstream end of the Sheridan Creek site as the thalweg deepened and shifted to the left. Farther downstream, the channel aggraded along the left bank, shifting the low water channel 25 ft to the right. Point bar aggradation along the left bank increased the sinuosity of the channel as a meander developed through the middle of the reach. At the downstream end of the project site, aggradation produced greater asymmetry in the low water channel as a bar developed along the right bank. The net effect of deposition and scour through this reach has been increased channel complexity and sinuosity (Figure C-36).

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
9-Jan	1995	15,800	6.7
22-Feb	1996	7,670	2.2
1-Jan	1997	30,000	27.3

Table 10.15 Annual peak flows for WY1995 to WY1997 for the Sheridan Creek rehabilitation site.

Figure 10.10 Sheridan Creek rehabilitation site. The long berm extending down the channel was a fine sediment retention berm used during construction and left intact after work was completed. The bank rehabilitation work can be seen along the upper right of the photo.

Figure 10.11 Sheridan Creek site after the 1995 flood. Note the large bar that developed along the constructed bank and the bar along the opposite bank. Some remnants of the original cobbles can be seen along the right edge of the photo. The grass growing from the bar (left of center) was grass that had established itself on the sediment retention berm shown in figure 10.52.

At cross section 0+65 comparison of WY1996 and WY1997 surveys showed minor change (Figure C-44): approximately 0.5 ft of aggradation along the bottom of the low water channel and left bank above the low water surface. Minor (<0.25 ft) degradation occurred along the right bank, but point bar formation and channel narrowing were not documented.

Cross section 1+35 was first surveyed in 1995, and then annually through 1997 (Figure C-45). Channel changes were minimal during the WY1996 high flow with approximately 1 ft of aggradation along the right bank above the low water surface. In 1997, more pronounced change occurred as the thalweg degraded 1.5 ft and shifted more than 10 ft to the left. Left bank retreat of up to 10 ft also balanced the width reduction resulting from a deepening thalweg. Approximately 1 ft of sediment was deposited just above the low water surface along the right bank.

At cross section 2+35, changes during the WY1996 high flows were minimal, with less than 0.5 ft of degradation in the thalweg and approximately 0.5 ft of aggradation along the right bank (Figure C-46). Also, some aggradation (1.5 ft) occurred along the left bank. In WY1997, channel change was more pronounced as the left bank aggraded 4.5 ft and the right bank degraded 2 ft. The thalweg degraded approximately 1.0 ft and shifted 25 ft to the right, resulting in a narrower low water channel.

Cross section 3+35 showed degradation of the thalweg (1 ft) and aggradation of the right bank (<1 ft) during the WY1996 high flows (Figure C-47). In WY1997, approximately 5 ft of sediment was deposited as a point bar along the left bank. The right bank has degraded up to 1.5 ft resulting in a shift of the low water channel approximately 20 ft to the right. The thalweg has also shifted to the right by about 25 ft.

Degradation of 1.5 ft at the thalweg was the most notable change in the channel cross section 4+35 during the 1996 high flows (Figure C-48). This was accompanied by 0.5 ft of aggradation along the right bank, effectively reducing the width-to-depth ratio. In WY1997, aggradation of the left bank did not continue through this cross section but degradation of the right bank was similar to upstream cross sections. Significant aggradation (3 ft) of the former low water channel occurred with incipient point bar features appearing along the left bank channel.

Cross section 5+35 was surveyed prior to, and immediately following, bank construction (Figure C-49). This allowed assessment of changes from the flood of WY1995 in addition to WY1996 and WY1997 changes. During the WY1995 flood, the right bank aggraded 3 ft, reducing the low water channel width from 180 ft to 95 ft. This same response was observed throughout the project reach where significant aggradation along the right bank resulted in a point bar. High flows in WY1996 caused approximately 1 ft of degradation along the right bank below the low water level. The WY1997 flood aggraded the right bank below the low water surface by more than 2 ft. Higher on the bar, the flood degraded the bar by 0.5 ft to 1 ft.

Before the right bank construction, there was not a wide range of surface particle size distributions or spatial sorting. As expected following rehabilitation, particle size grew finer from WY1992 to WY1996, and there was greater spatial sorting (Table 10.16 and Figure C-42). But as bars developed and the channel narrowed in WY1997, particle size coarsened.

	Particle Size	
Date	D_{50}mm	D_{84}mm
26-May 1991	21	50
9-Jun 1991	27	56
30-Apr 1992	25	54
2-Jul 1992	28	73
28-Jul 1996	34	60
5-Mar 1997	60	105

Table 10.16 Sheridan Creek bank rehabilitation site cross section 5+35 surface particle size trends from WY1991 to WY1997.

Since 1996, water surface elevations or raft lines were surveyed at established cross sections, to determine water surface slope along the right bank for discharges ranging from 380 cfs to 30,000 cfs (Figure C-50). The low water gradient through the Sheridan Creek bank rehabilitation site steepened at cross section 5+35, reflecting variability of the channel bed topography. The low water slope upstream of 5+35 ranged from 0.0008 to 0.0019. Downstream of 5+35, the slope increased to 0.0049. At higher discharges the water surface slope was more uniform throughout the reach and decreased toward 0.0014. Generally, water surface slope and complexity gradually decreased as flow increased.

Alternate bar development, lateral channel migration, and development of a deeper and narrower low water channel were strong indicators of alluvial channel dynamics, Future alluvial adjustments, including more narrowing and more alternate bar development, are expected.

10.4.1.8 Jim Smith bank rehabilitation site (RM 78.5)

Post-construction channel changes at the Jim Smith site were similar to other project site changes, particularly the Bucktail site. Since bank excavation in WY1994, the low water channel (450 cfs) narrowed at all cross sections (Figure C-51). Cross sections aggraded along the right bank, becoming increasingly asymmetrical. Channel evolution was most dramatic following floods in WY1995 and WY1997 (Table 10.17). An alternate bar was shaped along the right bank and the thalweg slightly aggraded. Most sediment deposited at, or slightly above, the low water surface elevation became part of this emerging point bar. Bar formation increased channel complexity by creating a secondary channel with a backwater to the right of the bar. The side channel survived the high flows of WY1996, only to be buried during the WY1997 flood. A remnant is still visible in the WY1997 survey.

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
9-Jan	1995	19,300	6.3
22-Feb	1996	8,770	2.0
1-Jan	1997	41,000	33.4

Table 10.17. Annual peak flows for WY1995 to WY1997 for the Jim Smith rehabilitation site.

At cross section 10+00, aggradation along the right bank below the low water channel was less than 0.5 ft, while the alternate bar above the low water surface aggraded approximately 3 ft (Figure C-52). The depth of the thalweg remained constant, however 2 ft of bank erosion along the left bank shifted the thalweg position approximately 10 ft to the left.

At cross section 11+10, aggradation during the WY1995 flood resulted in a bar 4 ft deep and a secondary channel along the right bank (Figure C-53). One foot of aggradation also occurred along the right bank below the low water surface and up to 2 ft of bank eroded along the left. The thalweg aggraded less than 1 ft and shifted approximately 10 ft to the left. In WY1997, an additional 1 ft of aggradation occurred along the right bank, ranging from 1 ft below the low water level to 2.5 ft in the secondary channel originally formed in WY1995.

Cross section 12+10 responded to the WY1995 flood as did cross section 11+10. A bar 4 ft deep and secondary channel developed along the right bank (Figure C-54). One and a half feet aggraded along the right bank below the low water surface but the bank did not erode. The thalweg aggraded approximately 1.5 ft and shifted approximately 30 ft to the left. In WY1997,additional aggradation along the right bank ranged from 1 ft below the low water level to 3.5 ft in the secondary channel.

This aggradational trend continued at cross section 13+00 (Figure C-55). In WY1995, a bar 3 ft deep and secondary channel developed along the right bank. One and a half feet aggraded along the right bank below the low water surface. The left bank did not erode. The thalweg aggraded approximately 2 ft and shifted approximately 20 ft to the left. In WY1997. An additional 1 ft aggraded along the right bank and thalweg, with 3 ft deposited in the secondary channel.

Surface particle sorting along this reach was expressed as three roughly parallel bands that extended through the reach (Figure C-51). Cobbles and boulders graded from finer (D_{84} = 44 mm, D_{50} = 26 mm) along the right edge of the bar to coarser (D_{84} = 140 mm, D_{50} = 102 mm) adjacent to the low flow channel (Table 10.18). This distribution probably was the result of lateral variations in shear stress across the channel. No pre-construction particle size distributions were available to determine if the entire channel bed surface has become finer and/or more variable. An elevated flat surface covered with fine sediments, a common indicator of developed floodplains, was not observed.

Particle Facies	D_{50} (mm)	D_{84} (mm)
Facies 1	26	44
Facies 2	55	86
Facies 3	102	140

Table 10.18 Surface particle size distributions for WY1997 in the Jim Smith bank rehabilitation site (March 5, 1997).

Water surface profiles surveyed in WY1997 became steeper, from 0.0021 to 0.0033 as discharge increased. At higher flows, the profile flattened toward 0.0014 (Figure C-56). Changing water surface profiles with increasing discharge are indicative of a complex channel morphology. Earlier profiles were not available for comparison.

Future trends can be inferred from recent alluvial adjustments following bank excavation. The low water channel width steadily narrowed as the right bank continued to aggrade. Accompanying this aggradation has been continued development of a point bar above the low water channel elevation. The floodplain emerging at this site will continue to develop and aggrade with fine sediment. We expect continued narrowing, more point bar growth, increased sinuosity of the thalweg, and greater complexity in water surface profiles at low flows.

10.4.1.9 Pear Tree bank rehabilitation site (RM 73.1)

Monitoring in WY1996 showed development of point bar along the right bank and degradation of the left bank, resulting from WY1995 flood peaks (Table 10.19). Deposition by the 1995 flood has built a point bar with a steep bar face. Bar development was greatest in the middle three cross sections and showed less aggradation along the upstream and downstream reaches (Figure C-57). Thalweg degradation throughout the reach was approximately 1 ft; lateral shifts were less than 10 ft. Our May 1997 survey showed that the top of floodplain degraded in the middle reach. High flows at the time did not permit surveying the main channel.

Date	Water Year	Estimated Peak Discharge (cfs)	Post-Dam Recurrence Interval (yrs)
9-Jan	1995	19,300	6.3
22-Feb	1996	8,770	2.0
1-Jan	1997	41,000	33.4

Table 10.19 Annual peak flows for WY1995 to WY1997 at the Pear Tree rehabilitation site.

At cross section 10+00 no significant change along the right channel bank was noted (Figure C-58), however 2 ft of degradation did occur along the left bank, slightly widening the low water channel (450 cfs) approximately 5 ft.

Point bar deposition was apparent at cross section 11+86 as deposits built out toward the channel along a steep bar face (Figure C-59). The deposit at cross section 11+86 was 30 ft wide and up to 3 ft deep. More than 1 ft of aggradation along the right bank below the water surface has steepened the bar face more.

At cross section 12+72 a bar was deposited during the WY1995 flood (Figure C-60). The low water channel and left bank also degraded by 1.5 ft during the flood. The WY1995 bar deposits were partly degraded along the bar face in 1997. The WY1997 survey also showed up to 2 ft of degradation on the floodplain.

Cross section 14+10 showed a similar evolution to cross section 12+72, with 4 ft of bar aggradation and 1.5 ft of low water channel degradation in WY1995 (Figure C-61). This was followed in WY1997 by 3.5 ft of degradation along the bar face and 1.5 ft of aggradation along the top of the bar. The most notable change at cross section 15+00 was 2.5 ft of degradation in the low water channel (Figure C-62). No noticeable bar building occurred at this cross section or at cross section 16+00, although at 16+00 the floodplain aggraded up to 2 ft (Figure C-63).

Gravel and cobbles were deposited along the right bank during the WY1997 floods extending from the site's upstream end as two lobes, coarsening downstream (Figure C-57). Four facies were sampled at Limekiln during the summer 1997(Table 10.20). Facies 1 and 2 represented the surface of the emerging point bar and formed a long narrow lobe grading from finer facies (1) to coarser facies (2).

Water surface slope at this site increased as flow increased (Figure C-64). There were no significant gradient controls upstream, within, or downstream of the reach. At low discharges less than 1,000 cfs the slopes ranged from 0.0014 to 0.0017. As flows increased, the slope steepened to 0.0020.

We expect the point bar along the right bank to continue aggrading and extending downstream. As this occurs more of the bar will emerge during low flows, narrowing the low water channel, increasing sinuosity, and adding complexity to the reach.

Particle Facies	D_{50} (mm)	D_{84} (mm)
Facies 1	52	85
Facies 2	62	104
Facies 3	50	89
Facies 4	49	89

Table 10.20 Surface particle size distributions for WY1997 in the Pear Tree bank rehabilitation site (March 5,1997).

10.4.2 Channel Dimension Changes at Evolving Alternate Bars

The hydraulic geometry of the bank rehabilitation sites changed following construction as the river adjusted its channel to the post-dam flow regime. The channel response to widening varied, but generally was marked by narrowing and deepening of the channel for a given discharge. This trend was best illustrated at Steiner flat (cross section 5+98) and Sheridan Creek (cross section 5+35). At Steiner Flat we measured discharge and channel geometry at cross section 0+45 prior to construction in 1992 and then again following the WY 1995 flood and the WY 1997 flood (Figure 10.12). At Sheridan Creek we made similar measurements at cross section 5+35 prior to construction in 1993 and again after the WY 1995 and WY 1997 floods (Figure 10.13).

Following construction, bar development at Steiner flat did not reduce channel width since a medial bar formed following the WY 1995 floods and was not emergent during channel measurements (Figure C-22). The hydraulic geometry did change however, with decreased average depth and increased average velocity. Following the WY 1997 flood, the hydraulic geometry changed again reversing its earlier trend. Width remained relatively constant as average depth increased and average velocity slowed. The medial bar was primarily responsible for the shift in the hydraulic geometry. As the bar aggraded in the WY 1995 flood, its cross section became shallower without affecting channel width. This increased average velocity through the cross section. During the WY1997 flood the medial bar was degraded, deepening the channel and reducing average velocity.

Cross section 5+98 at Steiner Flat responded differently from cross section 0+45 and is more analogous to cross section 5+35 at Sheridan Creek. Both sites narrowed and deepened as point bars developed along their right bank. At Sheridan Creek, the hydraulic geometry responded in a similar way to the Steiner Flat cross section 5+98 during the WY1995 and WY1996 floods. The width and depth relative to the pre-construction channel decreased and the average velocity increased. This trend continued in WY1997.

<u>10.5 Bar Inundation</u>

Discharges required to inundate developed bar surfaces (Table 10.21) were derived from channel cross sections and rating curves. At the Pear Tree site, the discharge estimate was based on Manning's equation because no rating curve had been developed. The water surface elevation used in the estimates inundated the bar tops by 0.5 ft.

Discharges inundating the bars varied by site and had no longitudinal trend downstream (Table 10.21).

<u>10.6 Habitat evolution at bank rehabilitation sites</u>

Alternate bar development has created diverse aquatic and riparian vertebrate habitat. Plates 23 and 24 were sketched from early topographic surveys in 1992 and 1995 to illustrate qualitative ecological

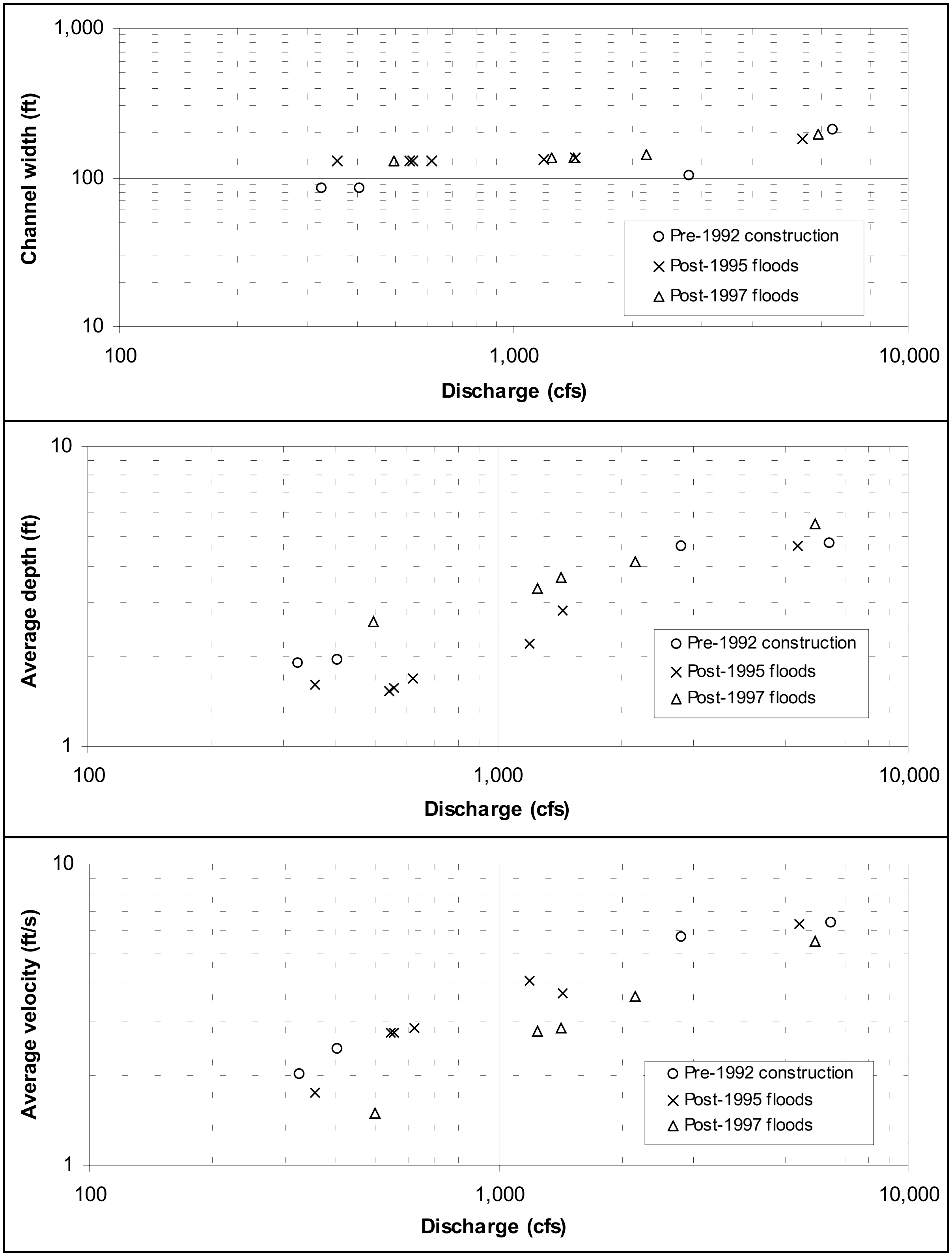


Figure 10.12 Hydraulic geometry of cross section 0+45 at Steiner Flat. Notice the reversed trend in average channel depth and average velocity at this cross section. This is primarily due to the development and subsequent degradation of the medial bar during the 1995 and 1997 floods.

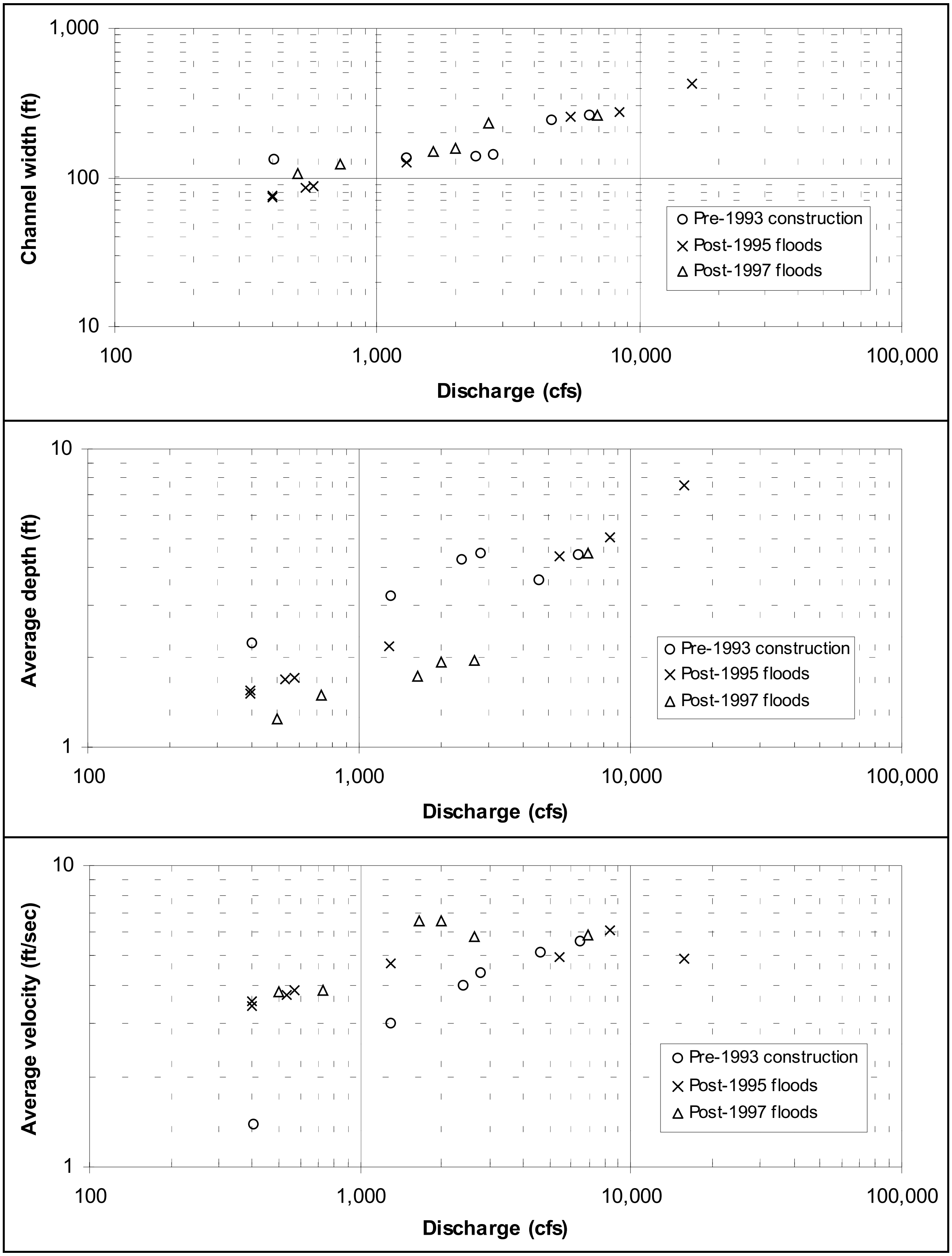


Figure 10.13 Hydraulic geometry of cross section 5+35 at Sheridan Creek. Note the continued decrease in average depth and the increase in average velocity following construction.

Site (RM)	Cross Section	Discharge to Inundate Bars (cfs)
Bucktail (105.6)	12+00	3,300[2]
Limekiln (100.2)	11+86	bar developing
Steel Bridge (98.8)	12+10[1]	bar developing
Steiner Flat (91.7)	05+98	1,300[2]
Bell Gulch (84.0)	11+50	bar developing
Deep Gulch (82.0)	10+00[1]	bar developing
Sheridan Creek (81.6)	05+35	1,900[2]
Jim Smith (78.5)	12+10	2,851[3]
Pear Tree (73.1)	15+00	1,300[3]

[1] cross section passes through pool.
[2] estimated from rating curve.
[3] estimated from Manning's equation.

Table 10.21 Discharges required to inundate the tops of developed alternate bars (by 0.5 ft) at the bank rehabilitation sites.

effects of pilot bank rehabilitation. Although only the right bank was reconstructed at Steiner Flat, habitat has improved throughout the project reach. The evolving alternate bars have diversified water depth and velocity over a wide range of flows (350 to 4000 cfs). As bar development continues and meandering occurs, habitat quantity, quality, and diversity should improve.

As originally envisioned by USFWS, the reconstructed bank (i.e., with the riparian berm scraped down to the pre-TRD channelbed surface) would provide slow-water habitat for chinook fry. Steiner Flat in 1995 provided anadromous salmonid habitat for all salmonid species and age classes, not just chinook fry. Amphibians also were major habitat beneficiaries of the pilot projects. Post-TRD riparian berms have almost eliminated slow, shallow water habitat most utilized by western pond turtles (Plate 23). The alternate bars create local slow water eddies in their lee, and local backwaters upstream, providing shallow depth and slow velocity habitat somewhere in the site over 350 to 4000 cfs (Plate 24).

10.7 Summary and Conclusions

Developing alluvial channel morphology was evident at all but one bank rehabilitation site (Table 10.22). Riparian berm removal has allowed the mainstem channel to reestablish alluvial behavior throughout the treated reach. Removal of one riparian bank and consequent widening of the channel have created a depositional environment where alternate bar formation, bank scour, floodplain formation, and particle size diversification have contributed to greater spatial and temporal complexity (Attributes #1 and #2).

Site (RM)	Cross Section	Width (ft)				Average Depth (ft)	
		Pre-construction Low Water	As-built Low Water	Present Low Water	Substrate Transition	Low Water	Substrate Transition
Bucktail (105.6)	12+00	602	90	60	130	3.7	7.3
Limekiln (100.2)	11+86	902	140	1403	none	3.7	None
Steel Bridge (98.8)	12+101	1002	135	77	none	5.3	None
Steiner Flat (91.7)	05+98	95	110	80	160	2.8	5.0
Bell Gulch (84.0)	11+50	902	110	1253	none	3.0	None
Deep Gulch (82.0)	10+001	1052	130	1104	none	5.0	None
Sheridan Creek (81.6)	05+35	130	170	95	220	2.9	4.5
Jim Smith (78.5)	12+10	1002	160	90	205	3.3	8.0
Pear Tree (73.1)	14+10	no data	65	755	none	3.0	None

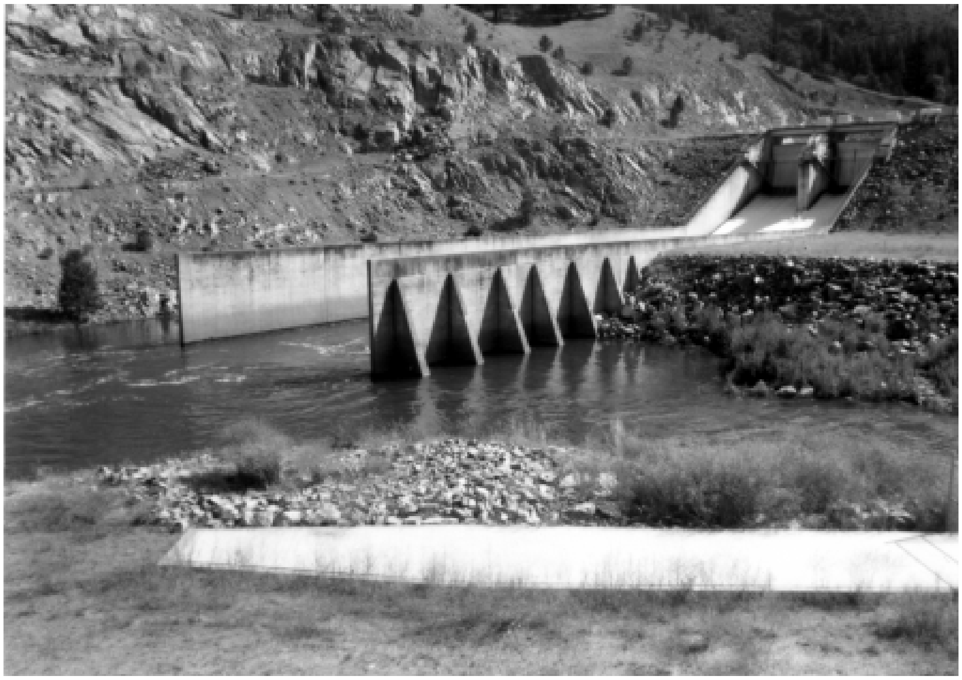
[1] cross section passes through pool.
[2] taken from pre-construction air photos
[3] point bar has not emerged from low water channel.
[4] no post-construction bar development at this site.
[5] dimensions taken from 1996 data.

Table 10.22 Summary of channel response at developing point bar cross sections (where applicable).

Sites such as Steiner Flat and Sheridan Creek have developed alluvial features such as medial and point bars that have recently emerged above the low water surface. These sites also experienced significant scour and reshaping of bar surfaces during the WY1997 flood. At Sheridan Creek, scour eroded the opposite bank and shifted the thalweg, thereby increasing sinuosity through the project reach. Most remaining sites have shown varying alluvial development. Typically, aggradation along the constructed bank has initiated point bars that, in turn, have narrowed the channel and decreased the low flow width-to-depth ratio.

Varying development of alternate bar morphology at the rehabilitation sites reflected differences in the influence of bedrock control, channel configuration, presence of riparian berms upstream and downstream, and post-construction channel length. Bedrock influenced sites, where induced secondary circulation was strong, consistently showed the greatest bar development. Bars typically aggraded along the opposite bank upstream of the outcrop and downstream on the lee side of the exposure. Bucktail, Steel Bridge, Steiner Flat, Sheridan Creek and Pear Tree are influenced by bedrock. At Limekiln, Bell Gulch, and Jim Smith the post-construction response was primarily influenced by lack of channel curvature and short construction length. The limited length of these sites prevented development of complete alternate bar sequences.

Deep Gulch was the only site that did not change. Yet immediately downstream, the Sheridan Creek site was the most alluvial monitored. Clearly, sediment was being transported through the Deep Gulch site but was not deposited. This was probably due to the post-construction configuration of the reach. Secondary circulation, capable of delivering bedload onto the left bank, is lacking.



CHAPTER 11: DEVELOPMENT OF RECOMMENDATIONS

Since the 1970s, anadromous salmonid populations have been a primary focus of restoration efforts on the mainstem Trinity River. As with other organisms native to the Trinity River, these fish evolved to the physical conditions and processes that persisted over thousands of years. Aquatic and riparian habitats along the river corridor were in large part created and maintained by flows. Floods, droughts and seasonal variation in water quality were at times stressful to individual organisms. However, these very phenomena were also responsible, over the long term, for maintaining highly productive habitat for locally adapted species.

Following construction of the TRD, mainstem habitats were substantially impacted, and both physical and biological responses were soon detected. The primary physical changes in the mainstem between Lewiston Dam and the North Fork Trinity River result from the disruption of physical processes dependent on the downstream flow of sediment and water. Alluvial processes, such as bar formation and channel migration, were nearly eliminated. In addition, sediment originating in areas above Lewiston was no longer transported beyond Trinity and Lewiston dams.

Our recommendations are based on the tenet that conditions existing over the decades preceding construction of the TRD present a model of a healthy river ecosystem. Our observations show that pre-TRD channel morphology and processes can be restored, but not at the scale that existed prior to the Trinity River Division. Our vision of a restored Trinity River is one that has attributes of the pre-TRD dynamic alternate bars, maintained by both tributary floods and TRD flow releases, but at a smaller scale (channel dimensions and particle size). We expect that the physical processes required by native aquatic and riparian species can be restored, to a sufficient degree, by combining the recommended Lewiston Dam releases with sediment management and channel restoration projects.

11.1 Summary and Findings of Alluvial River Attributes

Alluvial river attributes target specific distinguishing characteristics and physical/riparian processes contributing to river ecosystem integrity. Physical processes, desired physical responses, and their ecological significance are summarized for each attribute when appropriate. Specific findings from our study are also summarized.

11.1.1. Attribute No. 1. SPATIALLY COMPLEX CHANNEL MORPHOLOGY.

No single segment of channelbed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities.

Objectives for Physical Processes:

- Accommodate the process-oriented alluvial attributes (No. 3 through 9)

Desired Physical Responses:

- An alternate bar morphology extending upstream from the present alluvial transition zone near Indian Creek
- Development of a functional floodplain, now missing from the post-TRD channel morphology
- Asymmetrical cross sections in a meandering channel with a sinuous thalweg pattern

Ecological Significance:

- Riparian community with all stages of successional development
- No loss of riparian habitat with channel migration
- Diverse salmonid habitat availability for all life stages over wide ranging flows, flood and baseflow

FINDINGS

⇒ High flows in WY1995 to WY1997 have satisfied many of the attributes. At pilot channel rehabilitation projects, alternate bar development already has provided greater channel complexity.

⇒ Single flood events up to 30,000 cfs (as experienced in WY1997 at Junction City) have not removed the riparian berm. Multiple flood events from 14,000 cfs to 30,000 cfs could eventually achieve removal (progressively undercutting the banks), but we cannot predict when or if the fish can wait. To restore an alternate bar morphology, portions of the berm must be removed mechanically.

⇒ Alternate bars require scour and replenishment. Without bedload continuity to provide replenishment, alternate bars will eventually disappear as local in-channel storage dwindles away. Downstream of Indian Creek, bedload continuity is achieved and supply by tributaries can maintain a few bars. Upstream of Indian Creek, where bedload continuity is interrupted at several locations, coarse tributary bedload is not being routed downstream.

11.1.2. Attribute No. 2. FLOWS AND WATER QUALITY ARE PREDICTABLY UNPREDICTABLE.

Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is a foundation of river ecosystem integrity.

Objectives for Physical Processes:

- Inundate lower alternate bar features during dispersion of riparian plant seeds
- Provide variable water depths and velocities over spawning gravels during salmonid spawning to spatially distribute redds
- Inundate broader margins of alternate bars, including backside scour channels, to create shallow slack areas between late-winter and snowmelt periods for early life stages of salmonids and amphibians
- Provide favorable range of baseflows for maintaining high quality juvenile salmonid rearing and macroinvertebrate habitat within an alternate bar morphology
- Provide late-spring outmigrant stimulus flows
- Rapid post-snowmelt recession drop in stage to strand/desiccate seedlings initiating/establishing on alternate bar surfaces

Desired Physical Responses:

- Restore physical/riparian processes associated with a snowmelt hydrograph component below Lewiston Dam
- Optimize physical anadromous salmonid habitat availability for all seasons
- Restore periodic inundation of the floodplain and groundwater dynamics

Ecological Significance (if all annual hydrograph components provided):

- Discourage riparian plant germination on alternate bars by inundation during seed dispersion
- Distribute redds to minimize superimposition and reduce vulnerability of redd population to scour by high releases
- Increase anadromous salmonid egg survival by minimizing redd interpositioning
- Match natural seasonal timing of hydrograph components to benefit other non-salmonids

FINDINGS

⇒ Water year classification provides variation of annual hydrograph components between years. Recommending variable flows by water year insures fluvial and riparian processes also are variable. For example, tributaries deliver more sediment to the mainstem in wetter water years, therefore larger mainstem flows are necessary to route this bed material input

⇒ Recommended flows within water year classes attempt to accommodate the process-oriented attributes by assigning flow characteristics to each hydrograph component

11.1.3. Attribute No. 3. FREQUENTLY MOBILIZED CHANNELBED SURFACE.

Channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years.

Objectives (every 2 of 3 years as an annual maximum):

- Achieve incipient condition for most of channelbed surface
- Surpass threshold for transporting sand through most pools
- Scour 1-yr to 2-yr old seedlings on alternate and medial bars
- Provide effective turnover of spawning gravel deposits

Desired/Diagnostic Physical Responses:

- Mobilize surface tracer rocks (D_{84}), particularly in the zone of riparian plant initiation along a given cross section
- Maintain alluvial surface-to-subsurface particle size ratio as close to dam as possible
- Reduce substrate embeddedness in riffle/run habitats and reduce sand storage in pools
- Create local scour depressions around large roughness elements
- Mobilize spawning gravel deposits several surface layers deep

Ecological Significance (if physical processes achieved):

- Higher survival of eggs and emerging alevins by reducing fines and embeddedness
- Greater substrate complexity in riffle and run habitat for improved macroinvertebrate production
- Lower rates of riparian encroachment by scouring shallow-rooted 1 to 2-year old seedlings
- More habitat complexity (micro-habitat features)
- Deeper pool depths/volumes for adult fish cover and holding

FINDINGS

⇒ Upstream of Indian Creek, 6,000 cfs mobilizes the bed surface in post-TRD reaches (all features are under the low flow water surface), but at emerging bars, only mobilizes along low water channel margin (i.e., does not mobilize higher up bar surface, therefore, requiring larger flows to mobilize the entire bar surface)

- ⇒ Downstream of Indian Creek, the channelbed mobilization threshold is lower due to increased gravel supply, smaller surface particle size distribution (related to supply), and channel self adjustment. The threshold is less than 6000 cfs in straight channel sections, but again higher for developing point bars
- ⇒ Deltas must be excavated and maintained to route mainstem gravel and cobble
- ⇒ Greater coarse sediment supply would decrease the threshold flow for bed surface mobilization by reducing bed particle size
- ⇒ Wilcock's scour core data corroborate the tracer rock data, showing $1D_{84}$ scour (i.e., bed surface layer mobilization) occurs near 6,000 cfs in straight post-TRD channel segments

11.1.4. Attribute No. 4. PERIODIC CHANNELBED SCOUR AND FILL.

Alternate bars are scoured deeper than the coarse surface layer by floods exceeding 3 to 5 year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following these scouring floods usually is minimal.

Objectives for Physical Processes:

- Rejuvenate spawning gravel deposits
- Kill 2-yr to 4-year old seedlings establishing on alternate bar surfaces
- Deposit fine substrate onto upper alternate bar and floodplain surfaces

Desired Physical Responses:

- Close to dam, reduction in surface-to-subsurface D_{50} and D_{84} particle size ratios
- Deep scouring (several surface layers deep) of most alluvial features, including steeper riffles
- Facilitate alternate bar formation upstream of Indian Creek
- More alternate bars and developing bar sequences downstream of Douglas City.
- Increased diversity of surface particle size distributions
- Greater topographic complexity of side channels associated with alternate bars, especially distal portions

Ecological Significance (if physical processes achieved):

- Improved channelwide habitat complexity (micro- and macro-habitat features) for anadromous salmonid spawning and rearing habitat
- Increased pool depths for adult fish cover and holding
- Re-establishment of dynamic riparian plant stands in various stages of succession on higher elevations of alternate bars
- Mortality of 3-yr to 4-yr old saplings on alternate bar surfaces to discourage riparian plant encroachment and berm formation

- Habitat rehabilitation for riparian-dependent amphibian, bird, and mammal species

FINDINGS

⇒ Based on scour core monitoring and bed scour modeling for newly formed (-ing) point bar surfaces, a minimum of 10,000 to 12,000 cfs provided scour depths greater than $2D_{84}$'s thickness. A higher range of 14,000 to 16,000 cfs would be advised if adaptive management were not implemented

⇒ Initial bed scour on lower bar flanks was at 8,500 cfs using scour data at the Bucktail site

11.1.5. Attribute No. 5. BALANCED FINE AND COARSE SEDIMENT BUDGETS.

River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be transported through the river reach.

Objectives for Physical Processes:

- Reduce fine sediment storage in the mainstem
- Maintain coarse sediment storage in the mainstem
- Route mobilized D_{84} through alternate bar sequence
- Prevent mainstem accumulation of tributary bed material
- Eliminate bedload impedance reaches

Desired Physical Responses:

- D_{84} tracer rocks should negotiate alternate bar sequences every 1 to 2 years on average, i.e., larger particles from upstream riffles should not accumulate in downstream pools
- Reduced storage of fine sediment in riparian berms
- Eliminate aggradation, and encourage slight degradation of bed elevation at tributary deltas (smooth-out longitudinal profile through these reaches)

Ecological Significance:

- Improve and maintain spawning habitat quality without reducing quantity
- Increase pool depths for adult salmonid cover and holding
- Reduce riparian berm bar fossilization to improve channel dynamics and salmonid habitat
- Maintain physical complexity by sustaining alternate bar morphology

FINDINGS

⇒ The reach between Lewiston Dam to Rush Creek is sediment starved; large volumes of bed material will need to be introduced. Having an adequate gravel supply in this reach is the most important of all reaches due to the high intensity use by spawning and rearing salmonids. The exact quantities of gravel introduction will depend on the magnitude, duration, and frequency of high flow recommendations (Chapter 11).

⇒ Grass Valley Creek bedload trapped by the Hamilton Ponds greater than 8 mm need reintroduction to the mainstem.

⇒ Bedload supply from Rush Creek, Grass Valley Creek, and Indian Creek is sufficient to balance mainstem transport, but is not being adequately distributed downstream.

⇒ Physical elimination of bedload impedance reaches is needed to restore bedload transport continuity (allow gravels to route past tributary deltas); flows above 14,000 cfs are needed to route coarse mainstem bedload upstream of Indian Creek if contemporary delta morphology remains.

⇒ The fine sediment budget must maximize the ratio of mainstem transport to tributary contribution. Fine sediment reduction in Grass Valley Creek has reduced coarse sand input into the mainstem (and increased the mainstem to tributary ratio).

11.1.6. Attribute No. 6. PERIODIC CHANNEL MIGRATION.

The channel migrates at variable rates and establishes wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber.

Objectives for Physical Processes:

- Promote ‘typical’ bank erosion rate in alluvial reaches
- Floodplain deposition every 3 to 5 years
- Create channel avulsions every 10 years on average
- Encourage meander wavelengths 8 to 10 bankfull widths long
- Stored sediment in the floodplain is slowly released downstream

Desired Physical Responses:

- Maintain channel width while channel migrates
- Create sloughs through infrequent channel avulsions
- Create side channels through frequent alternate bar reshaping
- Increase meander amplitude and expression of the thalweg
- Create water temperature variability within alternate bar sequences
- Increase input of large woody debris along channel margins

Ecological Significance (if all physical objectives achieved):

- Diverse age class structure in stands of cottonwood and other species dependent on channel migration.
- Full range of seral stages in riparian plant communities

- Increased habitat quality and quantity for native vertebrate species dependent on early successional riparian forests
- High flow refuge and summer thermal refugia for amphibians and juvenile fish provided in rejuvenated scour channels
- Increased habitat complexity by input of large woody debris from eroding banks

FINDINGS

⇒ Channel migration (with the exception of Coopers Bar at RM 74.0) does not occur upstream of the North Fork Trinity River due to the armoring effect of the riparian berm. Until the riparian berm is removed, channel migration cannot occur. Our objective is to reinitiate channel migration where practical, and this will require selective removal of the riparian berm. Of all the pilot bank rehabilitation sites, the only site with sufficient length to permit a full alternate bar sequence to initiate has shown slow but measurable rates of channel migration (Steiner Flat). Other than documenting that channel migration can be restored with selective berm removal, no other attempts were made to predict migration rates or direction.

11.1.7. Attribute No. 7. A FUNCTIONAL FLOODPLAIN.

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terraces.

Objectives for Physical Processes:

- Inundate the floodplain on average once annually
- Encourage local floodplain surface deposition and/or scour by less frequent, but higher floods
- Have floodplain construction keep pace with floodplain loss as channel migrates across the river corridor
- Provides sufficient channel confinement to maintain hydraulic processes (Attributes No. 3 and 4)

Desired Physical Responses:

- Maintain channel width as river migrates
- Increase hydraulic roughness and greater flow storage during high magnitude floods

Ecological Significance:

- Increase in woody riparian overstory and understory species diversity, compensating for woody riparian stands lost along outside banks of eroding meander bends
- Keep physical processes conducive for maintaining early-successional riparian dependent species, especially for birds and amphibians

FINDINGS

⇒ The berm surface, while periodically inundated by high flows, is not considered a functional floodplain because its formation is a result of riparian vegetation roughness rather than channel migration and floodplain building. The riparian community dictates where the present non-functional floodplain is, rather than flow and sediment transport.

⇒ Functional floodplains are regions where fine sediments can be removed from the inner channel and deposited.

⇒ At several of the bank rehabilitation projects where alternate bars have initiated, the river has sorted particles ranging from gravels and cobbles on lower point bar surfaces to sand and silt on upper point bar surfaces. This transition in particle size is abrupt, and the areas of sand and silt deposition are beginning to form flat surfaces resembling floodplain surfaces. Again, removal of the berm has allowed the river to begin forming these functional floodplains.

11.1.8. Attribute No. 8. INFREQUENT CHANNEL RESETTING FLOODS.

Single large floods (e.g., exceeding 10- to 20-year recurrences) cause channel avulsions, widespread rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods.

Objectives for Physical Processes:

- Form/Reshape alternate bar surfaces every 10 to 20 years, on average
- Improve bedload routing by minimizing impedance of bedload transport past tributary deltas.
- Eliminate or minimize extent mature riparian vegetation stands on alternate bar surfaces and floodplains every 10 to 20 years
- Deposit fine substrate on lower terrace surfaces once every 10 to 20 years
- Provide infrequent deep scour high on alternate bars and on the floodplain
- Construct and maintain (rejuvenate) natural side channels
- Scour and redeposit entire alternate bar sequences every 10 to 20 years

Desired Physical Responses:

- Deep scour (several D_{84} surface layers deep) in most alluvial features, including steeper riffles
- Significant channel migration and infrequent channel avulsion.
- Alternate bar scour and redeposition
- Extensive removal of saplings and mature trees in riparian stands
- Increase complexity of natural side channels

Ecological Significance (if physical processes achieved):

- Improve channel-wide habitat complexity (micro- and macro-habitat features) for anadromous salmonid spawning and rearing habitat

- Create greater pool depths for adult fish cover and holding
- Create dynamic riparian stands in various stages of succession on higher elevation of alternate bars
- Control populations of 3- to 4-year old saplings on alternate bar surfaces close to channel center, and scour stands of mature riparian vegetation.
- Convert mature, less productive riparian habitats to highly productive, early successional stages

FINDINGS

⇒ Flows necessary to reset current channel features is in excess of 30,000 cfs

⇒ Flows beginning at 11,000 and approaching 16,000 cfs should begin to cause significant bed scour and reinitiate channel migration in the absence of berms in selective locations, but would probably not cause channel avulsions or significant mortality to mature riparian vegetation.

⇒ Mature trees can be toppled by a minimum of 14,000 cfs under ideal conditions; higher peak flows, from 16,000 to 20,000 cfs, are more conservative.

11.1.9. Attribute No. 9. SELF-SUSTAINING DIVERSE RIPARIAN PLANT COMMUNITIES.

Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors.

Objectives for Riparian Processes:

- Prevent riparian plant encroachment
- Maintain early-successional woody riparian communities
- Remove mature riparian trees established in the riparian berms
- Eliminate widespread presence of riparian berms
- Rehabilitate off-channel wetland communities

Desired Physical Processes to Meet Objectives:

- Floods periodically scour seedlings and saplings
- Channel migration creates new seedbeds, initiating new riparian cohorts
- Channel avulsion creates oxbows and off-channel wetland habitats, initiating patches of riparian stands

Ecological Significance (if all physical objectives achieved):

- Increase woody riparian overstory and understory species diversity
- Increase woody riparian age diversity

- Increase patchwork of riparian stands
- Promote rehabilitation of channel dynamics (migration, formation of alternate bars)
- Increase availability of habitat for wildlife dependent on early seral stage riparian plant communities

FINDINGS

⇒ *Salix exigua* is the pioneer species that encroaches bar surfaces and initiates riparian berm formation

⇒ Inundation does not kill *Salix exigua*

⇒ Preventing *Salix exigua* from establishing requires either regular scour mortality or germination prevention

⇒ Rapid root development by *Salix exigua* results in a "window of opportunity" for scour mortality for plants 1-yr to 3-yr old. Once a plant escapes to three years old, then larger floods (Attribute No. 8) are required to scour the plant or cause the channel to migrate through the rooting location

⇒ Riparian initiation and establishment on exposed alluvial bar features is best prevented by inundating the bars during the *Salix exigua* seeding period. The pre-dam snowmelt runoff period, which typically extended into mid- to late-July, inundated many of the bar surfaces during the seeding period. Reestablishing the snowmelt hydrograph is needed to restore this preventative process.

11.1.10. Attribute No.10. NATURALLY-FLUCTUATING GROUNDWATER TABLE.

Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs, and adjacent wetlands occur similarly to regional unregulated river corridors.

Objectives for Physical Processes:

- Naturally fluctuating seasonal groundwater elevation

Desired Physical Responses:

- Maintenance of off-channel habitats, including overflow channels, oxbow channels, and floodplain wetlands

Ecological Significance:

- High diversity of habitat types within the entire river corridor

FINDINGS

⇒ Subsurface moisture in alternate bars on pilot bank rehabilitation sites is at field capacity through the summer

11.2 Flow recommendations

11.2.1. Frequency and Occurrence of Annual Hydrograph Components, and the ecological roles of water year classification

Our proposed water year classification (Table 11.1) accommodates inter-annual variability (Attribute No. 2) by triggering the release of unique annual hydrographs in association with each water year class. As a result, Lewiston releases will vary as a function of naturally occurring water supply conditions.

Water Year Class	Annual Exceedence Probability	Threshold Reservoir Inflow for Water Year Class Designation
Extremely Wet	$p<0.12$	>2,000,000 acre-feet
Wet	$0.12<p<0.40$	1,350,000 to 2,000,000 acre-feet
Normal	$0.40<p<0.60$	1,025,000 to 1,350,000 acre-feet
Dry	$0.60<p<0.88$	650,000 to 1,025,000 acre-feet
Critically Dry	$p>0.88$	<650,000 acre-feet

Table 11.1 Recommended Trinity River water year classes.

We expected the following objectives (in the process-oriented attributes) from recommended annual hydrographs assigned each water year class:

EXTREMELY WET

-Mobilization of most alluvial features (Attribute No. 3)
-Bed scour > two D_{84}'s depth (Attribute No. 4)
-Sediment transport and bedload routing (Attribute No. 5)
-Periodic channel migration (Attribute No. 6)
-Floodplain creation and inundation (Attribute No. 7)
-Channel avulsion and migration (Attribute No. 8)
-Substantial mortality of channel-encroaching plants (Attribute No. 9)

WET

-Bed mobilization of most alluvial features (Attribute No. 3)
-Bed scour > one D_{84} depth (Attribute No. 4)
-Sediment transport and bedload routing (Attribute No. 5)
-Periodic channel migration (Attribute No. 6)

-Floodplain creation and inundation (Attribute No. 7)
-Substantial mortality of channel-encroaching plants and prevention of germination (Attribute No. 9)

NORMAL

-Bed mobilization of most alluvial features (Attribute No. 3)
-Sand transport (Attribute No. 5)
-Floodplain inundation (Attribute No. 7)
-Riparian seedling mortality and germination prevention (Attribute No. 9)

DRY

-Bed mobilization of inchannel alluvial features (Attribute No. 3)
-Limited sand transport (Attribute No. 5)
-Riparian seedling mortality and germination prevention (Attribute No. 9)

CRITICALLY DRY

-Preventing woody riparian germination for only part of the seed release period in May and early-June (Attribute No. 9)

11.2.2. Recommended Annual Hydrograph Components by Water Year Class

We are recommending flows by incorporating alluvial attributes, flow characteristics, and hydrograph components from the unregulated flow regime to help assemble annual hydrographs for each water year class (Figure 11.1). The basic hydrograph components were: summer and winter baseflows, winter floods, snowmelt peak runoff, snowmelt recession flows, and ramping flows (Chapter 4). For each hydrograph component, we reviewed historic magnitudes, durations, frequencies, and timing as appropriate. We relied on the pre-TRD unregulated annual flow regime to identify the frequency and timing for each hydrograph component. Identification of the magnitude and duration for each component was less straightforward.

The presence of the TRD, and our assumption that it would continue to operate, imposed one fundamental constraint that had direct bearing on our recommendations regarding flow magnitudes and durations: elimination of upstream bedload supply, which shifted the primary source for mainstem bedload from the upper watershed to tributaries downstream of Lewiston Dam. Floods with pre-TRD magnitude and durations, with their large bedload transport capacities, would now be damaging to the coarse sediment budget rather than beneficial.

Instead of arbitrarily recommending reduced pre-TRD flood magnitudes and durations, we identified the effects of changing magnitude and duration on the function of hydrograph components in pre-TRD annual hydrographs. Given restricted sediment supply and smaller dimension of the post-TRD

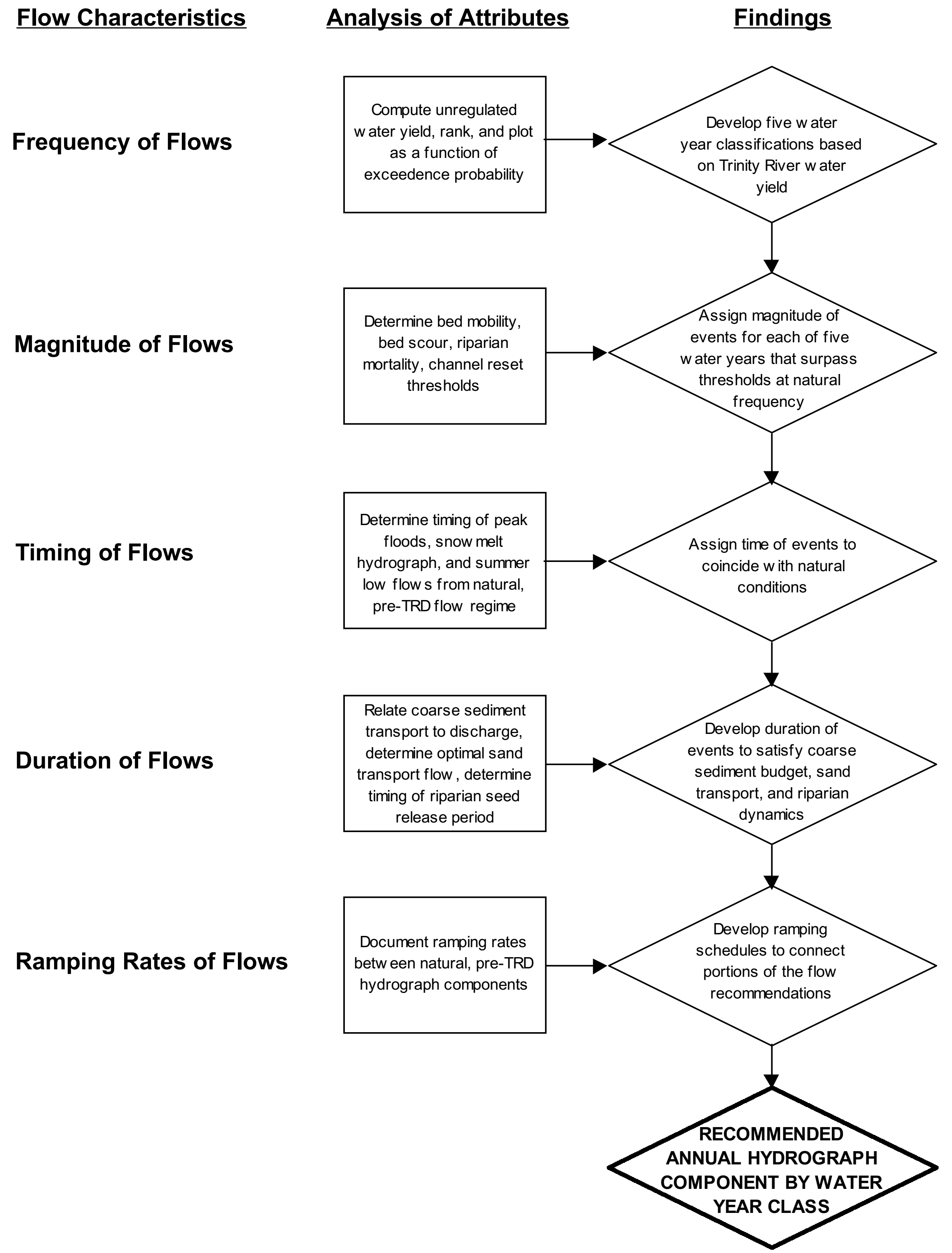


Figure 11.1 Trinity River flow recommendation decision making process for each hydrograph component (e.g., this flowchart would be appropriate for a spring snowmelt peak flood). After we use this process to determine each hydrograph component, we assemble the components, generating annual hydrograph recommendations for each water year class.

channel, we hypothesized that lesser flood magnitudes and shorter durations are adequate to restore necessary physical processes in the mainstem, though not all at historic frequencies (e.g., Attribute No. 8). The tradeoff would be acceptance of a smaller alluvial river. Attributes No. 3 through 9 served as our hypotheses.

Earlier chapters describe ecological functions of the attributes, and relate these to annual hydrograph components. In Figure 11.1, flow characteristics are described for each hydrograph component, which in turn are described by respective functions. We will present our recommendation by assigning flows to each annual hydrograph component among all water year classes.

11.2.2.1 Winter Baseflow Component

Prior to TRD construction, winter baseflows in the mainstem varied within and among water year classes. The primary geomorphic process provided by pre-TRD winter baseflows was sand transport. However, given the large water volume of baseflows, and the decreasing sand supply from the watershed, we chose to rely on biologically-based flow recommendations provided by USFWS: 300 cfs from October (starting date could be variable depending on water temperature criteria) until the onset of the snowmelt flood in May, regardless of water year class. In the future, two baseflow scheduling issues should be considered: (1) baseflows should vary by water year class to promote inter-annual variability, and (2) flows throughout a single salmonid spawning season could be fluctuated to discourage redd interpositioning and encourage intra-annual variability.

11.2.2.2 Snowmelt Flood Component

Snowmelt Flood Magnitude

Historically, spring flows in the mainstem were largely generated from snowmelt runoff in high-altitude areas above Lewiston. Pre-TRD snowmelt-derived peaks ranged from 26,000 cfs to less than 2,000 cfs depending on water year, and extended over a period of weeks. Since the TRD was completed, these flows have for the most part been stored and diverted into the Sacramento River basin. Tributaries entering the Trinity River between Lewiston and the North Fork Trinity River are either small and contribute small snowmelt peaks, or are low-elevation watersheds lacking substantial snowpacks. Downstream tributaries still provide important winter storms on the mainstem Trinity River (though much smaller than pre-TRD), which help to surpass key geomorphic thresholds (Attributes No. 3, 4, 7 and possibly No. 8) but cannot provide adequate snowmelt runoff. A critical choice had to be made for future annual flow regimes: recommending TRD releases to restore winter storm peaks, snowmelt floods, or both.

A choice existed because of flow and sediment accretions increase significantly below Rush, Grass Valley, and Indian creeks. Winter storm generated peak flows in the Trinity River below Indian Creek are substantial even today. For example, a 10-yr recurrence interval tributary derived flood below Indian Creek is approximately 9,000 cfs. If TRD peak releases are limited to 11,000 cfs by the outlet works capacity, significantly increasing the magnitude and frequency of flooding in this reach can only occur if releases are timed to coincide with tributary flooding (piggybacking) or the outlet works are re-engineered.

Upstream of Indian Creek, Lewiston releases can significantly affect flood frequencies. However, with discharges of 6,000 cfs and larger, bedload transport rates increase rapidly. With upstream coarse sediment supply eliminated by the TRD, the coarse sediment budget is already in deficit upstream of Rush Creek, and TRD releases sufficient to significantly augment flood peaks below Indian Creek will increase the sediment budget deficit. Upstream of Rush Creek, contemporary flood frequencies are almost entirely controlled by Lewiston releases. Sediment supply and flow accretion in this reach are extremely limited, as all tributaries are small (Chapters 4 and 8).

We found that flows required to mobilize the channelbed surface (Attribute No.3) in this reach were lower than anticipated. The smaller particle size of tributary inputs from Indian Creek downstream (relative to pre-TRD mainstem particle size) requires a lower flow threshold for achieving Attribute No. 3 than we originally anticipated. Peaks in the range of 6,000 cfs mobilize channelbed surfaces in the active channel and along lower flanks of alternate bars developing at bank rehabilitation sites.

Our recommended Lewiston releases target objectives related to ecological functions of snowmelt flooding, and accommodate geomorphic objectives of both snowmelt floods and winter storm floods. Because the tributaries are rainfall dominated, the snowmelt hydrograph has almost disappeared for the mainstem (Chapter 2). As described in previous chapters, the snowmelt hydrograph and recession limb had significant geomorphic and riparian functions. The magnitude of a snowmelt hydrograph adapted to the present-day constraints of tributary sediment supply and flows is within the operational and societal constraints of the TRD. The mainstem ecosystem cannot be managed without restoring the functions derived from the snowmelt hydrograph.

We chose to restore snowmelt floods with variable flood peaks among the water year classes (Table 11.2), thus simplifying the Lewiston annual hydrograph with a single flood peak. Closer to the dam, this release would serve the functions of the snowmelt component (Table 11.2) but not all functions of the winter flood component (e.g., Attribute No.8). Restoring the snowmelt hydrograph benefits the entire mainstem, unlike dam releases intended to augment winter floods that would only positively affect a portion of the mainstem.

We recommend four peak discharges: (1) 4,500 cfs in Dry water years to mobilize very dynamic alluvial deposits within the low water channel (e.g., spawning gravel deposits), (2) 6,000 cfs in Normal water years to mobilize a wide range of alluvial deposits and entrain sand into the flow column, (3) 8,500 cfs in Wet water years to significantly mobilize alluvial deposits, scour lower flanks of alternate bars, undercut banks, scour woody riparian seedlings, deepen pools, subtly reshape

Water Year Class	Peak Flow Magnitude	Riparian Function	Geomorphic Function
Extremely Wet	11,000 cfs	Seedling and sapling scour, lateral bank undercutting, and limited mature plant breakage	Bed mobility, bed scour, minimal channel resetting and migration, sand flushing and transport
Wet	8,500 cfs	Seedling and sapling scour, limited bank undercutting	Bed mobility, limited bed scour, sand flushing and transport
Normal	6,000 cfs	Seedling scour	Bed mobility, sand transport
Dry	4,500 cfs	Limited seedling scour	Limited bed mobility, sand transport
Critically Dry	1,500 cfs	Prevent initiation on bars by inundation	Limited sand transport

Table 11.2 Recommended snowmelt peak magnitudes by water year class with riparian and geomorphic functions/ thresholds satisfied.

point bars, and redistribute tributary bedload throughout the mainstem, and (4) a minimum peak of 11,000 cfs in Extremely Wet water years, as a departure point for future adaptive management, to scour alluvial deposits to depths exceeding two D_{84}'s, re-arrange alternate bars, accelerate channel migration, deepen pools, and prevent delta aggradation. We strongly recommend that the USBR upgrade the outlet works capacity of Trinity Dam to provide flow releases greater than 11,000 cfs if adaptive management finds it necessary. This would not only provide river managers with added flexibility and the opportunity to release flows larger than 11,000 cfs, but also provide more usable storage in the TRD, improve safety of dams operations, and allow power generation during high flow releases. The 1,500 cfs peak in Critically Dry water years does not transport coarse sediment; its primary purpose is to inundate exposed point bars during riparian seed release, discouraging germination on these surfaces.

Immediately following peak releases for Extremely Wet and Wet water years, we recommend incorporating sand transport flows as recommended by Wilcock et al. (1995): five days at 6,000 cfs. The objective of the 6,000 cfs release is to efficiently transport sand exposed by 11,000 cfs and 8,500 cfs bed scouring flows through the project reach and eventually past the North Fork Trinity River confluence.

Snowmelt Flood Frequency

The recommended Lewiston releases approximate peak flow frequencies associated with the healthy river attributes. Annual snowmelt flood peaks that mobilize the channelbed surface (Attribute No.3) during Normal water years and wetter attain an annual exceedence probability of 60 percent (Table

11.1), or annual recurrence interval of 1.7 years. Bed scour deeper than the surface layer (Attribute No. 4) is projected to occur less frequently. Peak flows sufficient to scour alternate bars will occur during Wet and Extremely Wet water years, which equates to an annual exceedence probability of 40 percent, or an annual recurrence interval of 2.5 years. The largest of the recommended peak flows (Attribute No. 8) would have an annual exceedence probability of 12 percent, or an annual recurrence interval of 8.3 years.

Snowmelt Flood Timing

Timing of the average snowmelt peak runoff prior to the TRD was staggered between water years, and we chose to follow this timing trend in our recommended flows (Table 11.3). During wetter year types, peak flows should be released soon after tributaries contribute their sediment load to the mainstem, which will: (1) keep riparian vegetation from encroaching and stabilizing deltas, (2) scour delta deposits to re-distribute sediments throughout the mainstem, and (3) prevent build-up of delta deposits that impede bedload transport.

Water Year	Range of Natural Snowmelt Peak Timing	Recommended Timing of Peak Flow
Extremely Wet	Last week of March to last week in May	Last week of May
Wet	Third week of March to last week in May	Third week of May
Normal	First week of March to last week in May	Second week of May
Dry	First week of March to last week in May	First week of May
Critically Dry	Second week of March to second week of May	Second week of May

Table 11.3 Recommended timing of peak flows by water year.

Snowmelt Flood Duration

Duration of the snowmelt flood peak was determined by balancing tributary supply of coarse bedload (> 8 mm) with mainstem bedload transport capacity (Attribute No. 5, Chapter 8). Bedload transport in the mainstem is a function of the magnitude and duration of flows surpassing transport thresholds. Based on our measurements, bedload transport occurs at discharges above 3,000 cfs, but is not significant until flow exceeds 5,000 cfs (100 tons/day for particles > 8 mm). We generated bedload transport relationships for particles greater than 8 mm and less than 8 mm at both the Lewiston and Limekiln Gulch gaging stations (Figures 8.7 and 8.8). Sediment sizes > 8mm is generally considered beneficial to salmonid spawning and rearing habitat, while the particles smaller than 8 mm are usually considered detrimental.

We estimated average annual tributary coarse sediment yield >8mm to the mainstem for each water year type. Our estimates were extrapolated from data collected during WY1995 and WY1997 on Deadwood Creek, Rush Creek, Grass Valley Creek, and Indian Creek (Table 11.4). We recognize that simplifying assumptions integral to our method of extrapolation likely reduce the accuracy of the estimates (Chapter 8). We believe, however, that trends shown by our data are useful: Normal, Wet, and Extremely Wet water years dominate long-term coarse sediment yield from tributaries, while yield in drier years is insignificant. We extrapolated WY1995 and WY1997 bedload data to a long-term average annual yield for each water year class by developing a relationship between annual peak discharge on Grass Valley Creek and tributary coarse sediment yield (Table 11.4). We chose to not to extrapolate based on Grass Valley Creek coarse sediment yield because sediment control efforts on Grass Valley Creek have significantly reduced sediment yield from Grass Valley Creek over the past seven years (Roberts, 1996), and because this sediment yield changed with time, the historic sediment data would skew estimates.

Water Year	Deadwood Creek	Rush Creek	Grass Valley Creek at Mouth	Indian Creek
Extremely Wet average:	280 tons	48,600 tons	12,800 tons	164,000 tons
Wet average:	50 tons	9,000 tons	3,050 tons	14,300 tons
Normal average:	4 tons	800 tons	1,300 tons	340 tons
Dry average:	2 tons	290 tons	1,150 tons	85 tons
Critically Dry average:	0 tons	0 tons	700 tons	0 tons

Table 11.4 Estimated coarse sediment yields (>8mm) from upper tributaries, extrapolated to 1976-1997, and averaged by water year classification.

Based on our bedload transport measurements at the Lewiston and Limekiln Gulch gaging station cableways during flows up to 6,000 cfs, we generated bedload transport curves for particles > 8 mm. Because the maximum discharge where bedload was sampled was 6,000 cfs, we had to extrapolate the transport curve to predict transport at flows up to 14,000 cfs. Small error in our extrapolation of bedload rating curves, because they are plotted on log-scale, can result in large error in bedload predictions at higher discharges. Thus, the predicted transport for flows greater than 8,500 cfs should be treated with caution (Table 11.5). The duration of recommended peak releases was then adjusted to balance the sediment budget downstream of each tributary. We used the same technique to generate a transport curve for the mainstem near Limekiln Gulch gaging station, and used both stations to estimate duration of flow releases needed to transport tributary contributed bedload. Presently, backwater areas above deltas at the mouths of Rush Creek, Grass Valley Creek, and Indian Creek

Discharge	1 days	2 days	3 days	5 days	7 days	10 days
	Lewiston					
14,000 (cfs)[1]	29,000	57,500	86,000	144,000	200,000	287,000
11,000 (cfs)	11,000	21,000	32,000	53,000	75,000	107,000
8,500 (cfs)	3,300	6,600	9,900	16,500	23,000	33,000
6,000 (cfs)	450	900	1,350	2,250	3,150	4,500
4,500 (cfs)	35	70	105	175	250	350
2,000 (cfs)	0	0	0	0	0	0
	Limekiln					
14,000 (cfs)[2]	11,350	22,700	34,000	57,00	79,000	113,000
11,000 (cfs)	4,600	9,300	14,000	23,200	32,500	46,000
8,500 (cfs)	1,650	3,300	4,900	8,200	11,500	16,500
6,000 (cfs)	320	640	960	1,600	2,240	3,200
4,500 (cfs)	55	110	165	275	385	550
2,000 (cfs)	0	0	0	0	0	0

[1] 14,000 was included for consideration in the event 11,000 cfs does not provide adequate bed scour.

Table 11.5 Total mainstem bedload transport (>8 mm) at the Trinity River Lewiston gaging station cableway (RM 110.2) and the Trinity River Limekiln Gulch gaging station cableway (RM 98.3) as a function of release duration, in tons.

impede the transport of coarse sediment. We recommend that these delta deposits be removed to restore bedload transport continuity through these reaches; meanwhile, we did not consider supply cumulative in the downstream direction.

The following snowmelt flood duration recommendations are based on the assumption that, for now, coarse bedload cannot be routed past tributary deltas.

EXTREMELY WET YEARS

Based on the Lewiston bedload transport rating curve, a five day release of 11,000 cfs transports approximately 53,000 tons of sediment > 8mm, and the five day release of 6,000 cfs transports 2,250 tons, for a total of approximately 55,250 tons for the year. The same combination using the Limekiln Gulch data produces 25,000 tons for the year. When comparing the Lewiston data to the estimated supply of 48,600 tons from Rush Creek, a slight deficit results. A two day release of 14,000 cfs would result in the same bedload transport as five days at 11,000 cfs, and conserve 50,000 acre-ft of water. We recommend a five day duration of 11,000 cfs based on the Lewiston transport data, but recognize that TRD upgrades allowing a release peak of 14,000 cfs should be considered, as this would conserve water. A 14,000 cfs release would also improve the channel resetting function of Extremely Wet years (Attribute #8) and be a more conservative flow for causing alternate bar mobilization (Attribute #4).

WET YEARS

Using the Lewiston bedload transport rating curve, a three day release of 8,500 cfs transports approximately 9,900 tons of sediment > 8mm, and the five day release of 6,000 cfs transports 2,500 tons, for a total of approximately 12,500 tons for the year. A five day release of 8,500 cfs and the five day release of 6,000 cfs using the Limekiln curve results in 9,800 tons for the year. We recommend a five day duration of 8,500 cfs to roughly balance the expected annual coarse sediment yield from Rush Creek (9,000 tons).

NORMAL YEARS

Using the Lewiston bedload transport rating curve, a five day release of 6,000 cfs transports approximately 2,250 tons of gravel, and compared to the estimated supply of 800 tons from Rush Creek, this results in a bedload deficit of over 1,000 tons downstream of Rush Creek. A five day release of 6,000 cfs using the Limekiln curve results in 1,600 tons for the year, which is still larger than the estimated supply from Rush Creek. We recommend a five day release of 6,000 cfs.

DRY YEARS

Using the Lewiston bedload transport rating curve, a five day release of 4,500 transports approximately 275 tons of gravel, which compared to the estimated supply of 290 tons from Rush Creek, which roughly balances the bedload sediment budget downstream of Rush Creek.

CRITICALLY DRY YEARS

Tributaries contribute virtually no bedload under these conditions. Therefore, releases to the mainstem are not required to transport bedload. Peak releases in May are intended to: limit encroachment of riparian vegetation by inundating low-elevation bar surfaces; assist migration of smolts; and provide appropriate water temperatures in downstream reaches.

We anticipate that the recommended releases will result in continued losses of coarse sediment from the channel above Rush Creek (Table 11.4 and Table 11.5). Additional coarse sediment will therefore need to be introduced to the reach below Lewiston Dam if spawning habitat for anadromous salmonids is to be optimized.

11.2.2.3 Ascending and Descending Limbs of Snowmelt Flood

Annual hydrographs for the Trinity River between WY1912 and WY1995 showed a distinct asymmetry in the pattern of snowmelt runoff. Representative transitions from winter baseflows to snowmelt flood peaks were analyzed for trends by water year type and peak snowmelt magnitude (Figure 11.2). Ascending limbs were typically steep, with large individual stormflow spikes superimposed on an increasing snowmelt baseflow. In contrast, descending limbs were more gradual and show smaller stormflow spikes superimposed on steadily decreasing baseflows. We found no correlation between the average slope, shape, or duration of the ascending limb and the water year type.

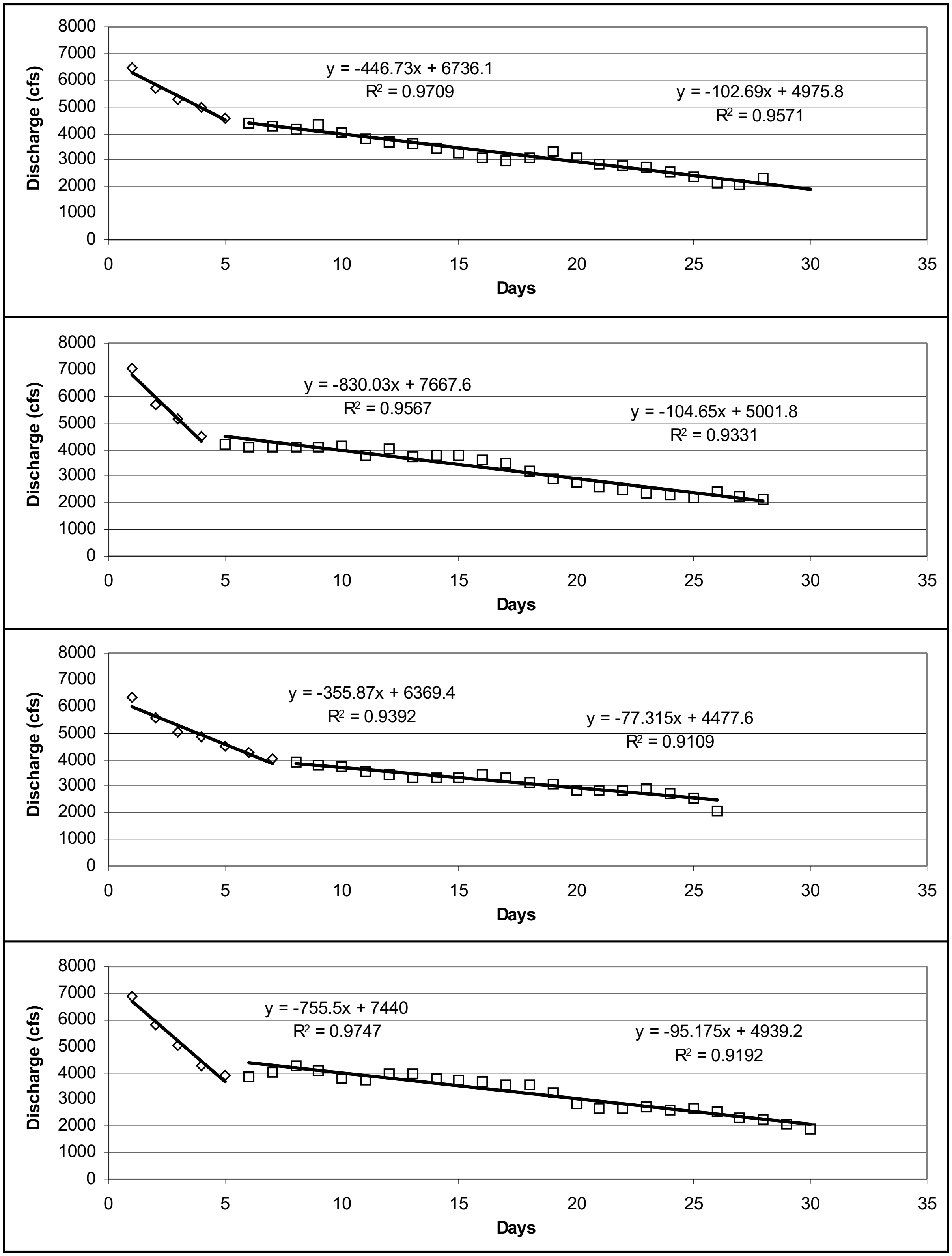


Figure 11.2 Average descending limb and snowmelt recession of the snowmelt hydrographs for (from top to bottom) Extremely Wet, Wet, Normal, and Dry years (6,000 to 2,000 cfs).

Descending limbs of the snowmelt hydrographs having peaks between 6,000 cfs and 1,500 cfs were more consistent in slope and duration than the associated ascending limbs. In addition, individual storm spikes superimposed on the limb were smaller and less common. Segments of the descending snowmelt limbs were selected and averaged by water year type. The shape of the descending limb was noticeably bimodal, with a steep upper segment followed by a lower sloped segment (Figure 11.2). The steeper segment, hereafter referred to as the descending limb, typically lasted 4 to 7 days, and receded at an average rate of 650 cfs/day. The flatter segment, labeled the snowmelt recession, occurred when flows were less than 4,500 cfs, spanned approximately 24 days, and receded at an average rate of 100 cfs/day. Snowmelt recession was considered a distinct hydrograph component. Slopes of the declining daily average flows for the different water years (Figure 11.2) were averaged to produce the recommended daily release reductions.

Recommendations for ascending limb ramping rates were based on the typical storm spike characteristics of the snowmelt hydrograph. A rapid increase in discharge associated with winter rain-on-snow events was the pattern used to define the rate of increasing discharge. The descending limb defined by flows between the snowmelt peak and 4,500 cfs, mimics rapid flow reduction observed immediately following the pre-TRD snowmelt peak. Recommended releases intended to mimic ascending and descending limbs of snowmelt floods by water year class are:

For Extremely Wet years we recommend increased releases beginning on 17 May. The first day, discharge should be increased by 700 cfs to 1,000 cfs. During the following five days, discharge should be increased by 1,000 cfs per day to 4,000 cfs. On the fifth, sixth, and seventh days discharge should be increased by 2,000 cfs, 2,500 cfs, and 2,500 cfs respectively until a discharge of 11,000 cfs is reached. The discharge should then be held at 11,000 cfs for five days. The descending limb should begin after the fifth day of peak flow. A rapid drop of 650 cfs per day for seven days should reduce the discharge to 6,000 cfs. After five days at 6,000 cfs, the discharge should be reduced by 650 cfs/day down to 4,500 cfs, than by 100 cfs/day down to 1,500 cfs.

For Wet years we recommend an increase in discharge beginning on 11 May. The first day discharge should be increased by 700 cfs to 1,000 cfs. During the following three days, discharge should be increased by 1,000 cfs per day to 4,000 cfs. On the fifth and sixth days discharge should be increased by 2,000 cfs, and 2,500 cfs respectively until a discharge of 8,500 cfs is reached. The discharge should then be held at 8,500 cfs for five days. The descending limb should begin after the seventh day of peak flow. A rapid drop of 650 cfs per day for four days should reduce the discharge to 6,000 cfs. After five days at 6,000 cfs, the discharge should be reduced by 650 cfs/day down to 4,500 cfs, than by 100 cfs/day down to 1,500 cfs.

For Normal years we recommend an increase in discharge beginning on 2 May. The first day discharge should be increased by 700 cfs to 1,000 cfs. During the following 3 days, discharge should be increased by 1,000 cfs per day to 4,000 cfs. On the fifth day, discharge should be increased by 2,000 cfs until a discharge of 6,000 cfs is reached. The discharge should then be held at 6,000 cfs for 5 days. The descending limb should begin after the fifth day of peak flow, and be reduced by 650 cfs/day down to 4,500 cfs, than by 100 cfs/day down to 1,500 cfs.

For Dry years we recommend an increase in discharge beginning 26 April. On the first day, the discharge should be increased by 200 cfs to 500 cfs. During the following 4 days discharge should be increased by 1,000 cfs per day until a discharge of 4,500 cfs is reached. The discharge should then be held at 4,500 cfs for 5 days. The recession period limb should begin after the fifth day of peak flow, and recede by 100 cfs/day to 1,500 cfs.

For Critically Dry years we recommend an increase in discharge beginning on 6 May. During the first 9 days, the discharge should be increased by 100 cfs per day to 1,000 cfs. The tenth day discharge should be increased by 500 cfs until a discharge of 1,500 cfs is reached. The discharge should be held at 1,500 cfs for 33 days until 16 June (to prevent riparian germination), after which the discharge should be reduced to 100 cfs over a three-day period.

11.2.2.4. Snowmelt Recession Hydrograph Component

Duration and Magnitude

Historically, the snowmelt recession period was accompanied by a gradual reduction in discharge related to a diminishing snowpack. We found pre-TRD snowmelt recession periods were a function of water year class (Table 11.6).

Water Year	Average Ending Date of Snowmelt Recession Period	Recommended Timing of End of Snowmelt Runoff
Extremely Wet	First week of August	Through July 28
Wet	Last week of July	Through July 19
Normal	Second week of July	Through July 15
Dry	First week of July	Through June 19
Critically Dry	First week of July	Through June 19

Table 11.6 Timing of snowmelt recession period by water year class.

The pre-TRD descending limbs and recession periods appeared consistent in slope and duration. Therefore, discharge ramping rates for the snowmelt recession period (flows < 4,500 cfs) were averaged, resulting in a recommend recessional ramping rate of 100 cfs/day for all water year classes (Figure 11.2). The receding limb following the 1,500 cfs bench is artificially made more rapid (500 cfs per day) to reduce the period the bar surface is wetted (to reduce riparian initiation on the bar).

Peak springtime releases of slightly longer duration (i.e., extending the declining limb of the spring snowmelt flood hydrograph into the summer compared to natural runoff timing) will be required to discourage/prevent germination of channel-encroaching vegetation. This could serve to: (1) offset the impacts of failing to provide releases which mimic the largest of pre-TRD flood flows, those which caused channel avulsions and rapid band erosion, and (2) offset the impacts of high summer baseflow (temperature control) releases, which will tend to increase survival of riparian vegetation colonizing along river bars.

The proverb of “an ounce of prevention is worth a pound of cure” applies to the riparian encroachment problem on the Trinity River. The best way to discourage riparian encroachment is to prevent annual germination on bar surfaces through extended inundation, and/or to increase plant mortality by rapidly reducing releases once plants germinate (desiccation). Bar-inundating releases of 1,500 cfs from early-May to mid-June coincide with the seed release period for the several willow species found along the mainstem Trinity River, and if the bars are under water during this period, plants physically cannot initiate on them.

Recommendations for the snowmelt recession period as a function of water year class are as follows:

EXTREMELY WET
100 cfs/day for 32 days until a discharge of 1,500 cfs is reached. A discharge of 1,500 cfs should be maintained until 28 July, after which the discharge should be reduced to 300 cfs over a 3-day period.

WET
100 cfs/day for 26 days until a discharge of 1,500 cfs is reached. A discharge of 1,500 cfs should be maintained until 19 July, after which the discharge should be reduced to 300 cfs over a three-day period.

NORMAL
100 cfs/day per day decrease in discharge for 32 days until a discharge of 1,500 cfs is reached. A discharge of 1,500 cfs should be maintained until 15 July, after which the discharge should be reduced to 200 cfs over a three-day period.

DRY
100 cfs/day per day for 30 days should reduce the discharge to 1,500 cfs. A discharge of 1,500 cfs should be maintained until 19 June, after which the discharge should be reduced to 200 cfs over a three-day period.

CRITICALLY DRY
No snowmelt recession period.

11.2.2.5 Summer Baseflow Hydrograph Component

Magnitude

We recommend summer and early-fall baseflow releases with magnitudes similar to pre-TRD flows at Lewiston. These range, from 100 cfs for Critically Dry water years to 300 cfs for Extremely Wet water years (Table11.7). Maintaining artificially low summer water temperatures through unseasonably high TRD baseflow releases provide no geomorphic benefit, and likely increases the risk of channel encroachment by woody riparian plants. Seedlings initiating on bar surfaces near the low baseflow waterline and capillary zone will be more prone to scour by subsequent high flows. We recognize that concerns over water temperatures may override geomorphic considerations when setting summer releases.

Water Year	Average Unregulated (and recommended) Summer Baseflows	Minimum Summer Baseflows (SWQCB)
Extremely Wet	300 cfs	450 cfs
Wet	300 cfs	450 cfs
Normal	200 cfs	450 cfs
Dry	200 cfs	450 cfs
Critically Dry	100 cfs	450 cfs

Table 11.7 Recommended summer baseflow magnitudes by water year class.

Duration

Summer baseflows would extend from the end of snowmelt recession until the first increase in tributary discharge, designated as October 1 for computing annual water volume by water year class.

11.2.3. Recommended Annual Hydrographs by Water Year Class

Taking the above recommendations, hydrograph components were assembled into annual hydrographs for each water year type (Figures 11.3 to 11.7). The uniform recommended releases from Lewiston Dam lack variability expected from an unregulated river. With significant tributary contributions downstream, this sterile-appearing flow regime increases in variability. We used the discontinued USGS gaging station at Douglas City for water years 1946 to 1951 to illustrate how the recommended annual hydrographs would appear downstream. Subtracting the daily average flows at Lewiston from the Douglas City daily average flows represents cumulative tributary flows between the two gaging stations. This accretion, when added to our recommended annual hydrographs, shows that the tributaries restore variability during the winter storm period, but do not appreciably

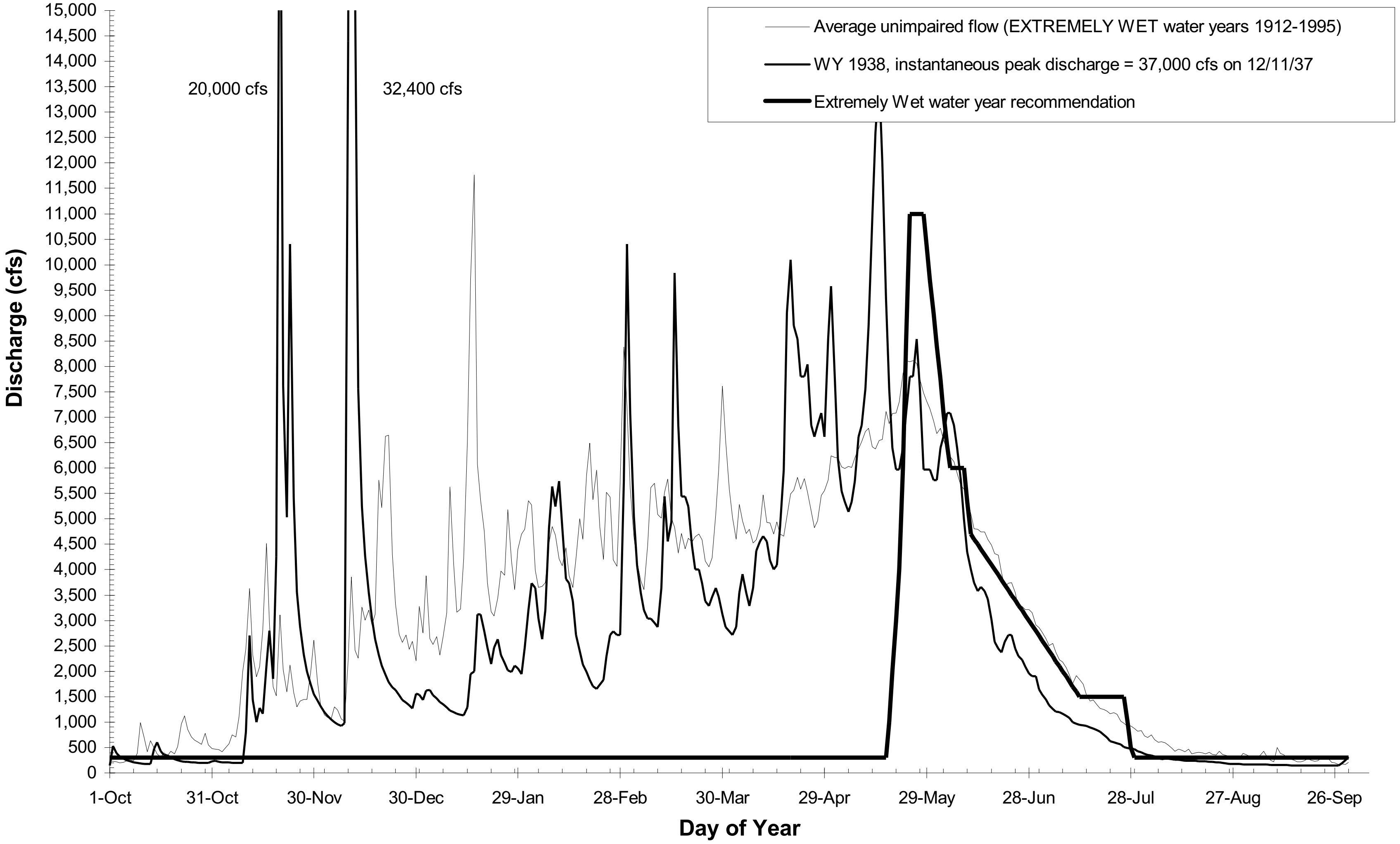


Figure 11.3 Lewiston flow release recommendation for Extremely Wet water years, with average and representative Extremely Wet water year

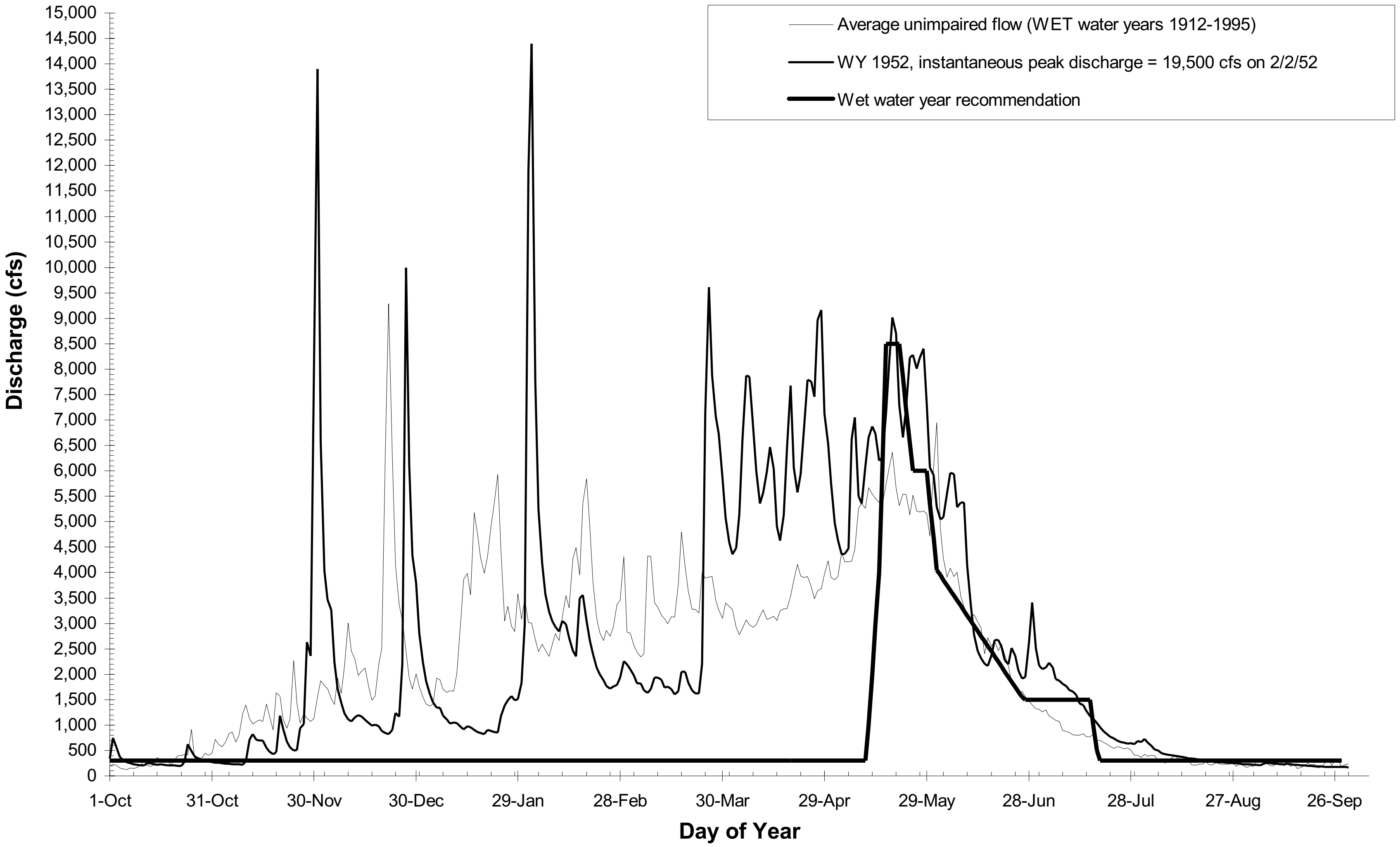


Figure 11.4 Lewiston flow release recommendation for Wet water years, with average and representative Wet water year

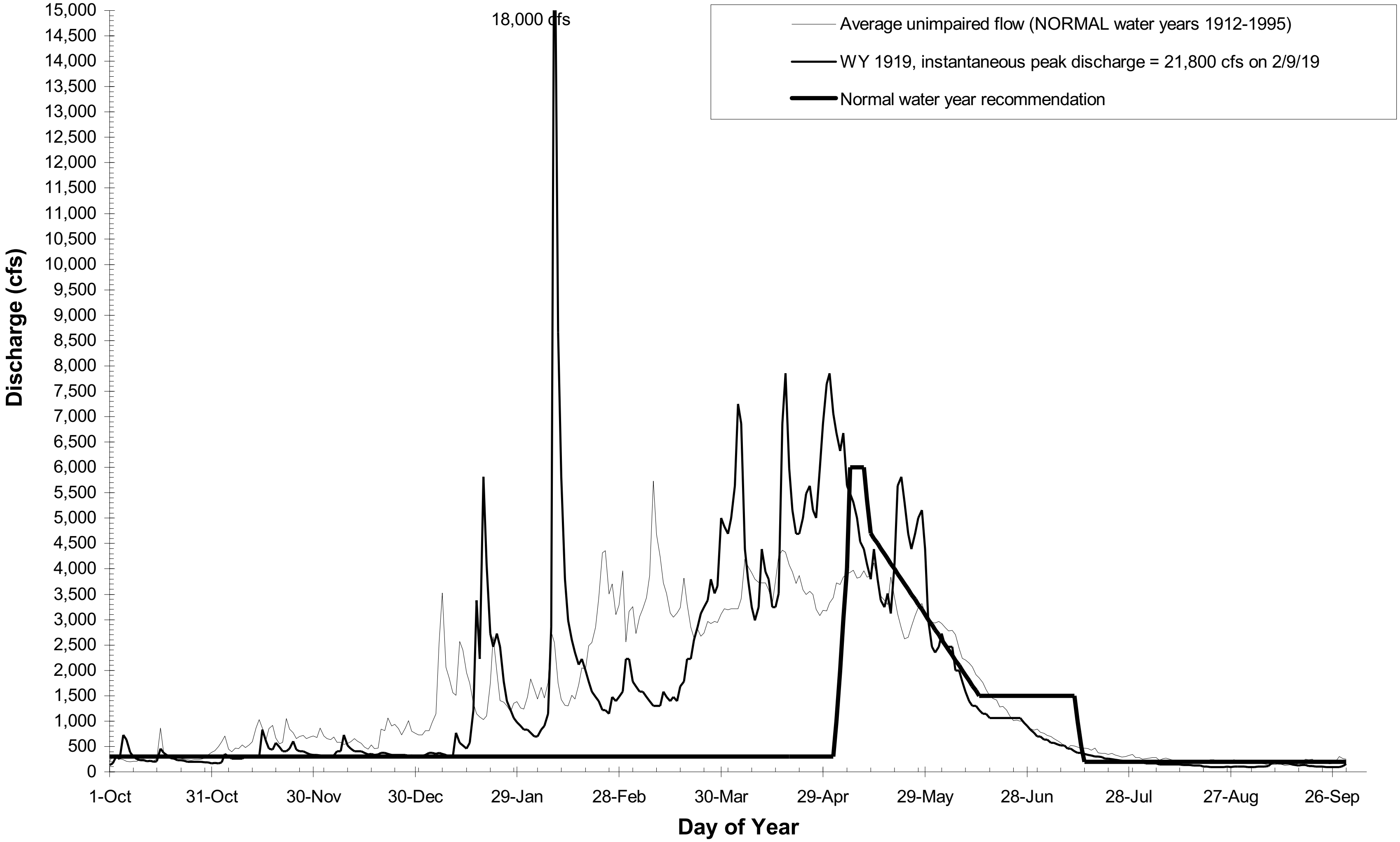


Figure 11.5 Lewiston flow release recommendation for Normal water years, with average and representative Normal water year

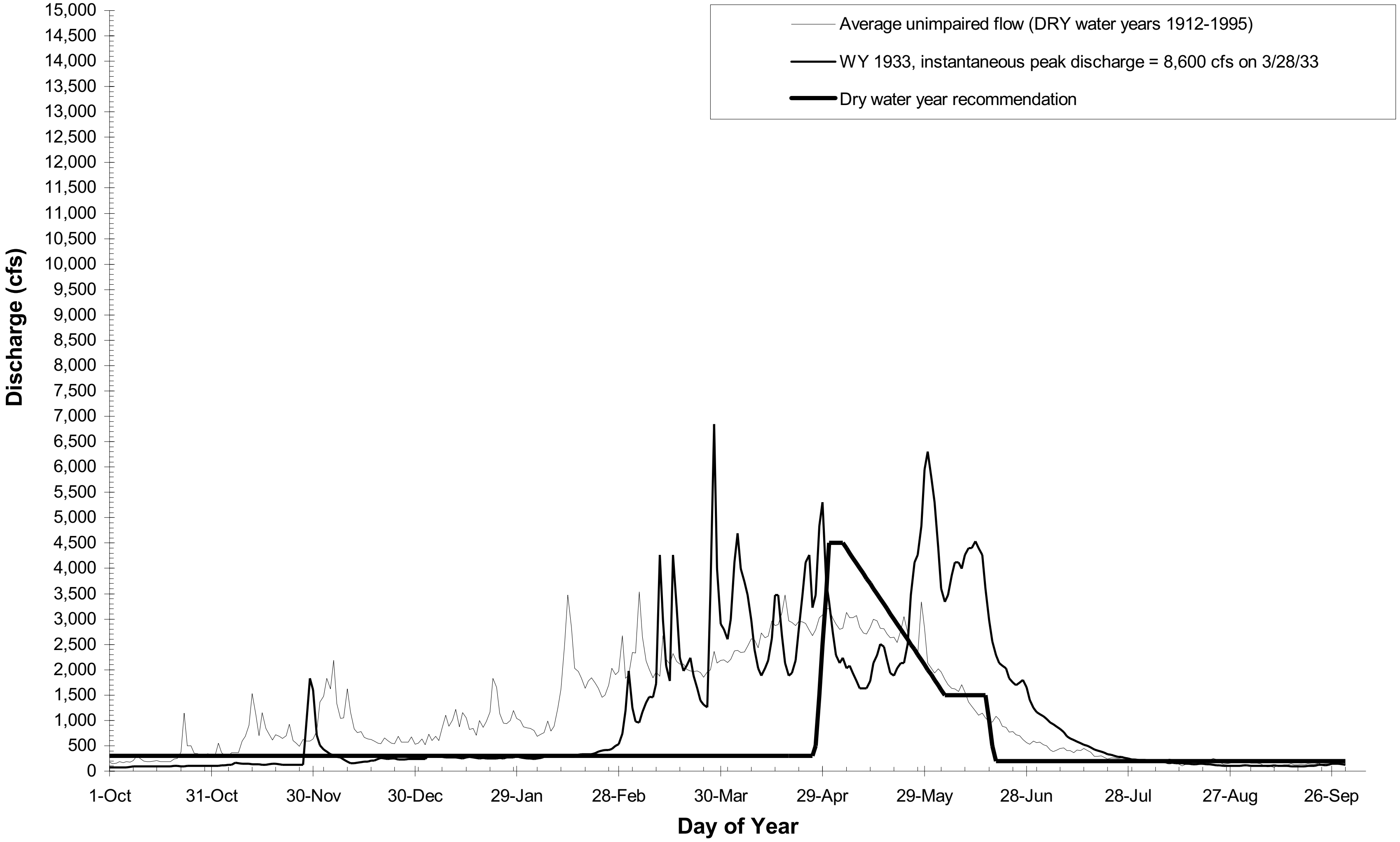


Figure 11.6 Lewiston flow release recommendation for Dry water years, with average and representative Dry water year

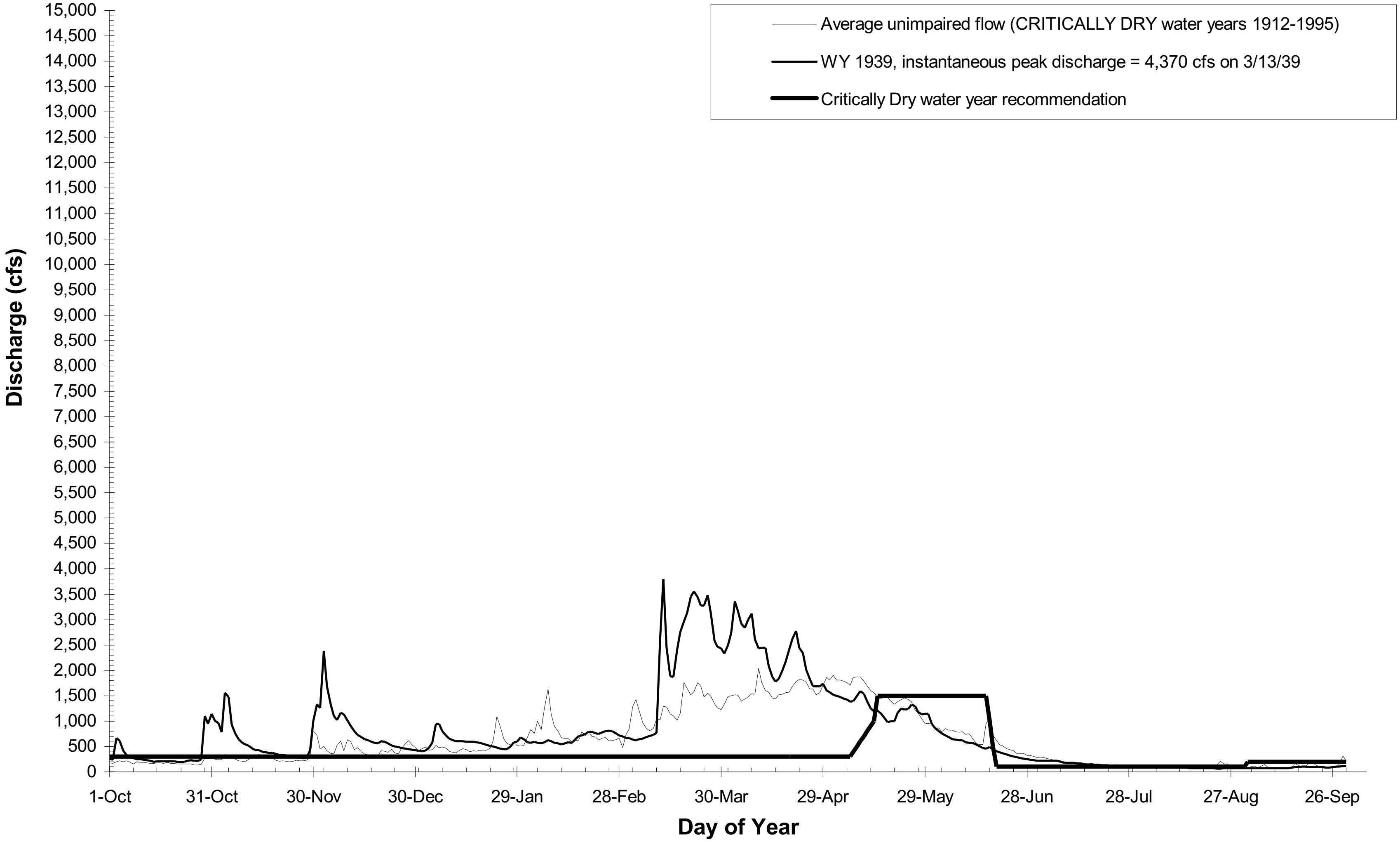


Figure 11.7 Lewiston flow release recommendation for Critically Dry water years, with average and representative Critically Dry water year

contribute to the snowmelt period (Figures 11.8 to 11.13). Targeting TRD releases to the snowmelt period best restores flow variability to annual hydrographs downstream.

11.3 Sediment management recommendations

11.3.1. An Alluvial Transition

The mainstem is still geomorphically adjusting to its imposed flow and sediment regimes. Flow and sediment contributions by downstream tributaries cumulatively provide the opportunity for a more dynamic alluvial river downstream. The same maintenance flow regime will serve different geomorphic and riparian functions depending on location below Lewiston Dam, because the mainstem is transforming from a relatively immobile channel to a more alluvial channel.

Significant mobility of the bed surface (the D_{50} and/or D_{84}), with a 1.5-yr to 2.0-yr recurrence, is an attribute of many alluvial rivers (Attribute No. 3). To help identify where this alluvial transformation is occurring, we assessed longitudinal trends in bed mobility to locate a transition from infrequent bed mobility to frequent bed mobility expected of a healthy alluvial channel. The flow and sediment regime just downstream of this transition, generated almost entirely by cumulative tributary inputs, was considered adequate for expecting an alluvial channel behavior.

Using potential channelbed surface mobility at the 1.5 to 2.0 year annual maximum flood as our principal criterion for alluvial behavior, we determined the transition occurs near Douglas City (RM 93.0). For more detail on methods and analyses, refer to *Assessing Downstream Variation of Fluvial Processes for Recommending Maintenance Flows in Regulated Rivers* (Ligon et al., 1995). These results suggested that evaluating the sediment budget (an expensive endeavor) was less important downstream of Indian Creek, because the tributaries provide an ample supply of coarse sediment and hydraulic forces are capable of frequently mobilizing this supply.

11.3.2. Coarse sediment management

As is the case with all rivers, tributary sediment contribution cumulative increases sediment load in mainstem rivers in the downstream direction. However, tributary delta aggradation on the upper Trinity River has removed this bedload continuity, such that supply is dependent on the nearest upstream tributary rather than the cumulative supply of all upstream tributaries. In natural systems, storm runoff events in tributaries tend to be timed with storm runoff in mainstem rivers, such that the transport of the cumulative sediment supply is accommodated by a corresponding increase in flood flow in the downstream direction. In other words, natural piggybacking of tributary flood flows increased the sediment transport capacity of mainstem rivers, which helped balanced the sediment budget downstream.

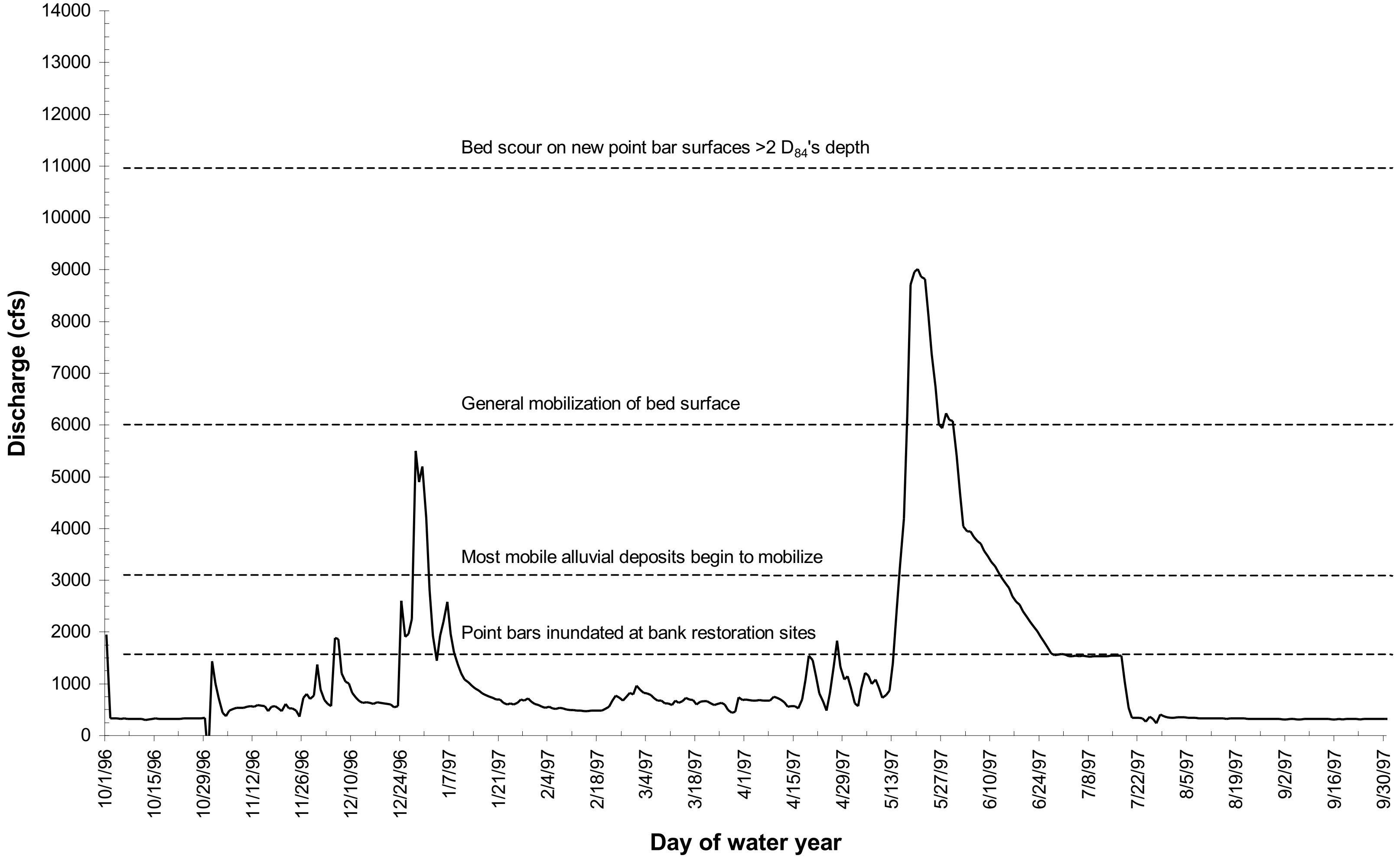


Figure 11.8 Hypothetical water year 1946 annual hydrograph at the discontinued USGS gaging station near Douglas City with recommended Lewiston Dam releases and downstream tributary accretion. Wet water year.

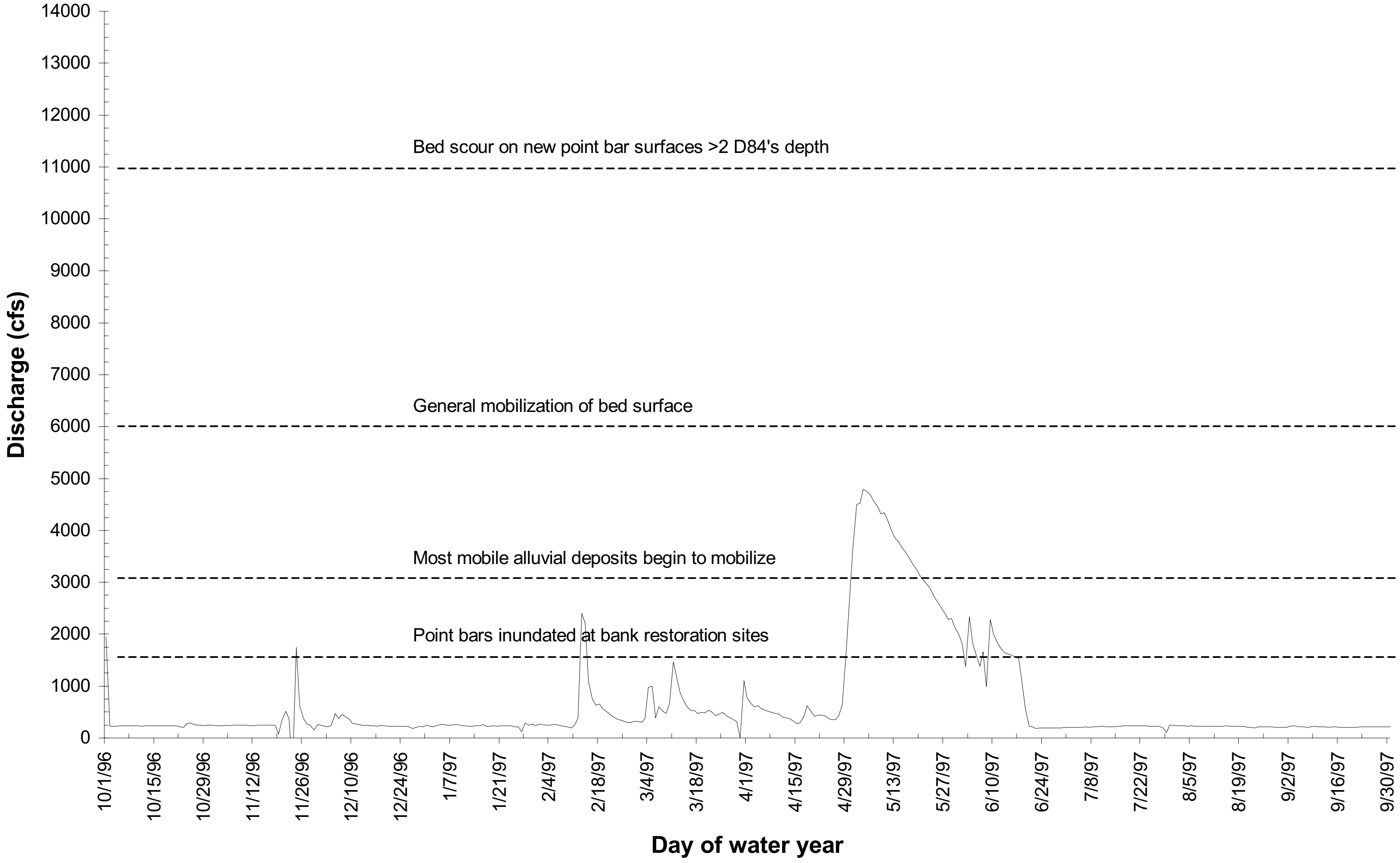


Figure 11.9 Hypothetical water year 1947 annual hydrograph at the discontinued USGS gaging station near Douglas City with recommended Lewiston Dam releases and downstream tributary accretion. Dry water year.

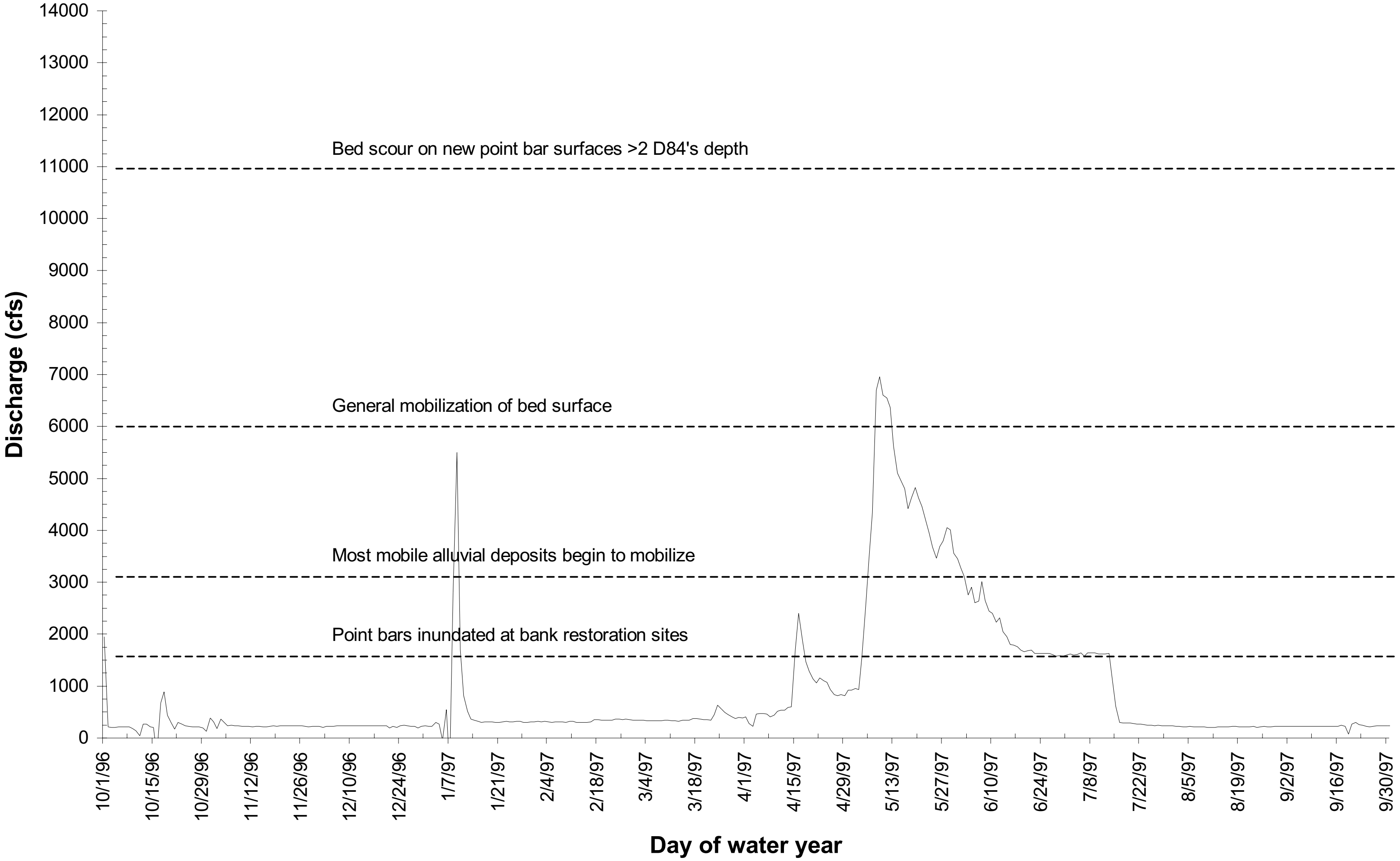


Figure 11.10 Hypothetical water year 1948 annual hydrograph at the discontinued USGS gaging station near Douglas City with recommended Lewiston Dam releases and downstream tributary accretion. Normal water year.

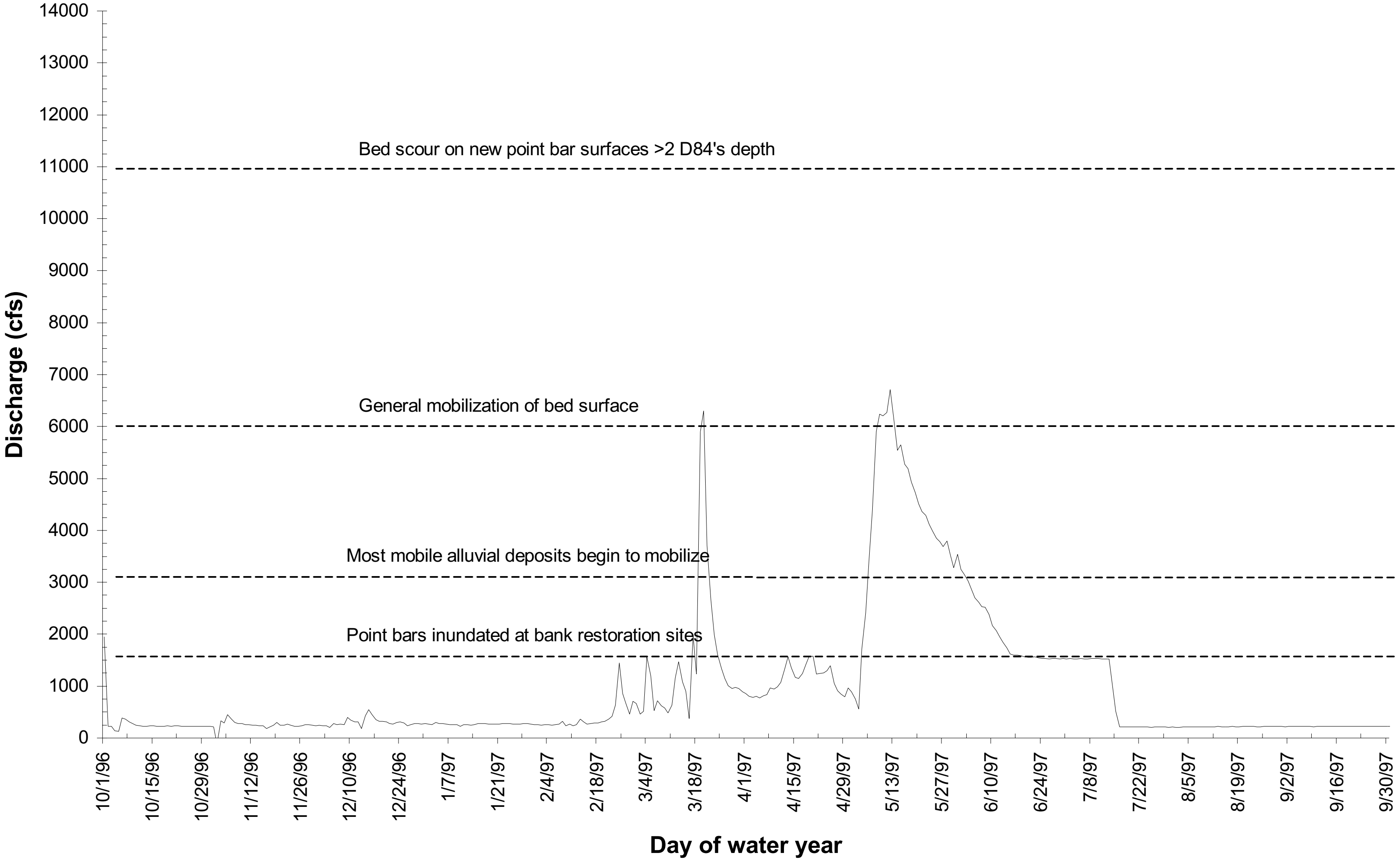


Figure 11.11 Hypothetical water year 1949 annual hydrograph at the discontinued USGS gaging station near Douglas City with recommended Lewiston Dam releases and downstream tributary accretion. NORMAL water year.

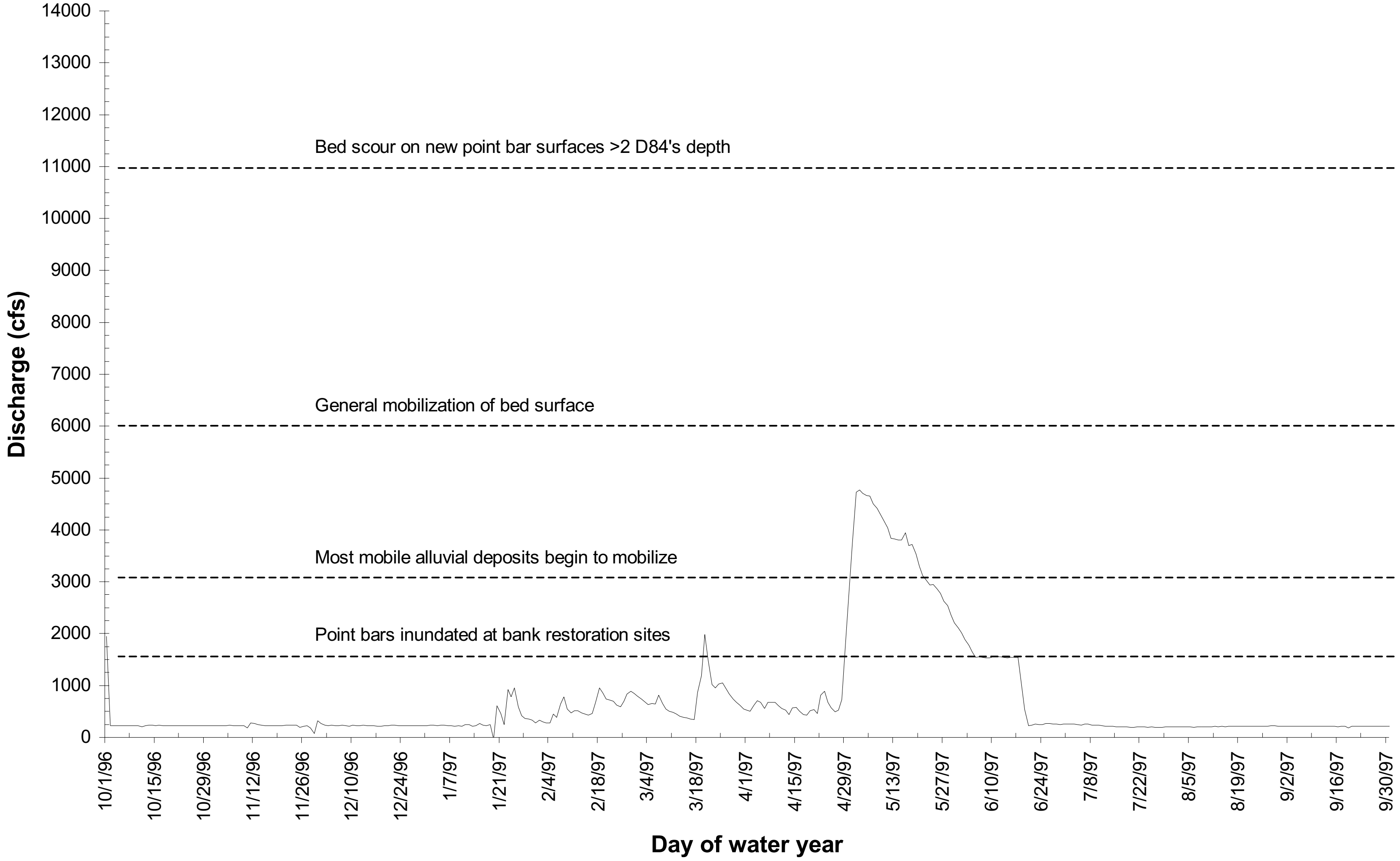


Figure 11.12 Hypothetical water year 1950 annual hydrograph at the discontinued USGS gaging station near Douglas City with recommended Lewiston Dam releases and downstream tributary accretion. DRY water year.

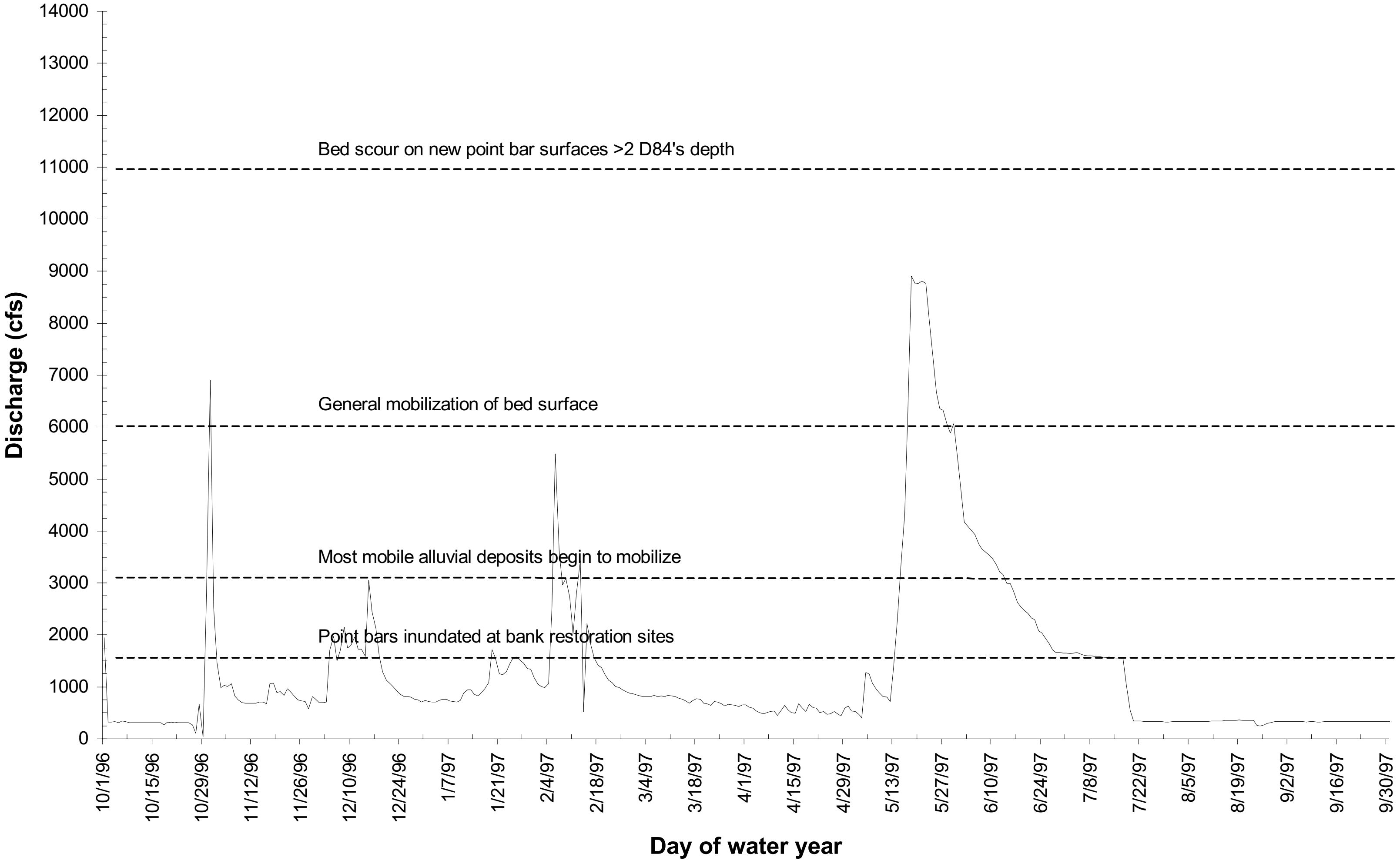


Figure 11.13 Hypothetical water year 1951 annual hydrograph at the discontinued USGS gaging station near Douglas City with recommended Lewiston Dam releases and downstream tributary accretion. WET water year.

This sediment budget function is a strong argument for piggybacking; however, as discussed above, our flow recommendations incorporate this sediment transport function into the snowmelt peak hydrograph component. Because tributary flows are relatively small when the mainstem high flows are released, mainstem transport capacity remains relatively constant downstream. Currently, the sediment supply in each mainstem reach is governed by the nearest upstream tributary due to the bedload impedance reaches upstream of the Rush Creek, Grass Valley Creek, and Indian Creek deltas. We recommend restoring bedload transport through these reaches by excavating portions of these deltas. Recommended mainstem flows balance the sediment budget downstream of the Rush Creek and Indian Creek deltas, with a slight under-supply downstream of Grass Valley Creek. By releasing flows of sufficient magnitude and duration to balance the coarse sediment budget downstream of Rush Creek, the sediment budget between Lewiston Dam and Rush Creek suffers. Transport capacity always will be relatively high compared to a supply rate that is almost zero. Therefore, gravel introduction will be required immediately downstream of Lewiston Dam at a rate that balances the coarse sediment budget from Lewiston Dam downstream to Rush Creek (Table 11.8).

Water Year	Gravel Introduction (tons)
Extremely Wet	23,000 to 53,000
Wet	8,000 to 16,000
Normal	1,600 to 2,250
Dry	175 to 275[1]
Critically Dry	0

[1] functionally zero

Table 11.8 Gravel introduction needs in reach between Lewiston Dam and Rush Creek by water year class.

Other recommendations include:

- Coarse tributary bedload sediment has historically (e.g., Deadwood, Rush, and Indian creeks) and is currently (e.g., Grass Valley Creek) removed from the mainstem Trinity River. As water is the life-blood of the Trinity River, gravel and cobbles are the building blocks of a healthy Trinity River channel morphology. This coarse sediment forms point bars and other alluvial features. It provides salmonid spawning and rearing salmonid habitat, and macroinvertebrate habitat. Future coarse sediment must not be removed. We recommend that sediment larger than 8 mm be removed from the Hamilton Ponds on Grass Valley Creek, separated, and returned to the Trinity River.
- Tributary delta/sediment budget monitoring is crucial for yearly flow recommendations. A “flow management team,” part of the adaptive management plan, would depend on this information to recommend a flow schedule that will transport and distribute annual sediment below tributary junctions. Our sediment budget study represents too short of a monitoring period to reliably

calibrate bedload modeling. Our successes and failures in methodology have shown that the preferred monitoring protocol would include: (1) bedload and suspended sediment sampling on these tributaries to estimate sediment contribution to the mainstem Trinity River, (2) detailed total station surveys on the four tributary deltas to verify yearly tributary bedload contribution estimates, (3) cross section surveys at various reaches downstream of the deltas to monitor channel degradation or aggradation, and 4) tracer gravels to monitor travel distance downstream of the tributaries. The first monitoring protocol would develop empirically derived curves between "volume of tributary sediments" and "mainstem flow magnitude and duration necessary to route sediment." These data would provide quantitative sediment transport requirements of yearly maintenance flows, preventing coarse bed material accumulation at tributary junctions.

- Introducing potential bedload with a significant component of fine sediment defeats the purpose of improving salmonid spawning and rearing habitat. Introduced bed material should be larger than 8 mm.
- Reserving dredger tailings for future sediment management and river restoration should be a top priority. These reserves represent the most economical and readily available source of bed material.
- Gravel introduction should target the reach immediately downstream of Lewiston Dam (RM 111.9 to RM 111.2), in the spawning riffles upstream of the USGS cableway in Lewiston, and downstream of the Old Lewiston Bridge (RM 110.0).
- Bed material introduction should also resume downstream of Grass Valley Creek to mitigate the effect of Hamilton Ponds removing the coarse sediment contribution from Grass Valley Creek. Hamilton Ponds have removed not only the finer component of Grass Valley Creek bedload, but also the needed coarser component. Substrate mainstem reaches immediately below the Grass Valley Creek confluence have a large cobble matrix (probably a remnant feature of the pre-TRD channelbed) embedded with coarse granitic sands. Increased supply of gravels and small cobbles should improve salmonid habitat downstream.

11.3.3. Fine sediment management

A common misperception is that fine sediment is always detrimental for the river ecosystem, but this is not always the case. For example, fine sediments deposit on the inside of migrating meander bends and encourage riparian regeneration. However, chronic fine sediment loading, as has occurred on the Trinity River after completion of the Trinity River Division, has greatly increased instream fine sediment storage rather than on floodplains, which has severely impacted salmonid habitats. Efforts to reduce fine sediment supply from Grass Valley Creek (historically the largest source of fine sediment), and reduced fine sediment storage in the mainstem Trinity River through pool dredging and high flows from WY1991 to WY1997, has greatly reduced the fine sediment supply in the mainstem Trinity River. However, the berm stores a tremendous volume of sand. A conservative estimate computed from the 80 miles of bank from Lewiston downstream to the North Fork Trinity River, assuming 3 ft berm height and 20 ft berm width, gives nearly 1 million yd^3 of sand storage.

Future channel and bank rehabilitation projects will help remove some storage from the mainstem. Other tributaries do not contribute the chronically high loads of fine sediment that Grass Valley Creek contributes. Our measurements (Appendix B) of suspended sediment yield from Deadwood Creek, Rush Creek, and Indian Creek show low concentrations and loads of fine sediment, even during the large floods of WY1997. Typical ratios of bedload to suspended sediment yield were 5 to 10 percent. Our WY1997 estimates ranged from near equal load (100 percent) on Deadwood Creek to approximately 50 percent on Rush Creek. These low fine sediment yields were corroborated in delta bulk samples, which show that the percentage of fine sediment finer than 2 mm is less than 12 percent. This was not the case for Grass Valley Creek. Continued operation of Buckhorn Dam and Hamilton Ponds is crucial for reducing fine sediment load in the mainstem Trinity River.

11.4 Channel restoration recommendations

11.4.1. General design considerations

Engineers cannot design, nor can bulldozers create and maintain, mainstem channel morphology and habitat better than Nature. By planning to remove riparian berms, as done on the pilot bank rehabilitation projects (Chapter 10), we are removing the "handcuffs" from the river, and providing the river an opportunity for self-adjustment. Accompanied by the recommended annual flow regimes, future restoration projects can facilitate this self-adjustment and maintenance by approximating equilibrium channel dimensions and encouraging channel sinuosity in their construction.

Two processes have been responsible for creating alternate bar morphology based on pilot site monitoring (Chapter 10): (1) forced meanders, and (2) inherent tendencies for stream meandering. Forced meanders, where the river encounters an obstruction at an angle greater than 10 degrees, forces secondary circulation and point bar formation. Additionally, the pools formed are typically deeper, the bar has more diverse particle size, and the flows are hydraulically more diverse. These sites can produce point bars over short distances (e.g., the Bucktail and upper portion of Steiner Flat bank rehabilitation sites). To produce alternate bars in straight reaches, sufficient length is required for meandering to initiate and develop. Many pilot restoration sites in straighter reaches were shorter than a post-TRD meander wavelength; alternate bars have not or are only slowly developing (e.g., Limekiln, Bell Gulch, and Deep Gulch bank rehabilitation sites). Future channel restoration projects should take advantage of forced meander opportunities and encourage greater sinuosity in straighter reaches.

We predicted the boundary shear stress field for a variety of discharges in WY1996 at the Steiner Flat and Sheridan Creek bank rehabilitation sites (Chapters 6 and 7). The location and magnitude of maximum shear stress through newly formed alternate bars was variable. The location of maximum shear stress moved from the thalweg onto the point bar faces at higher flows. In contrast, the shape of the shear stress field and location of maximum shear stress does not appreciably change with increasing discharge at unrestored sites, but the magnitude rapidly increased with flow (Wilcock et al. 1995). This observation may be one of the most convincing arguments for restoring and maintaining dynamic alternate bar sequences because:

- the shifting shear stress field causes particles to sort laterally and longitudinally in the channel, providing a variety of particle size dependent habitats critical to salmonids,
- the shifting shear stress field as a function of discharge will encourage slightly different particle sorting for each discharge, such that particle size will be variable from year to year,
- the slight decrease in maximum shear stress with increasing discharge is the response to lack of confinement on one bank, and should reduce bedload transport rate through the middle of the channel and increase residence time of alluvium (short term depositional features)
- the lack of shear stress increase with discharge (up to 5,400 cfs) will eventually increase at unknown higher discharges, but should maintain an overall smaller particle size (gravels to small cobbles) in the channel that are more conducive to salmonid habitat.

Strategically removing portions of the riparian berm also sets the stage for restoring channel migration processes. Channel migration and adjustment is a critical component of the success of this vision. Channel adjustment in the years after construction (Chapter 10) will be a necessary step the river must take in the rehabilitation process.

11.4.2. Potential bank rehabilitation projects

In consultation with USFWS, we identified potential channel restoration sites between Lewiston Dam and the North Fork Trinity River (Plate 25) from aerial photographs and selected site visits (approximately half were field inspected). Some mainstem planform types are inappropriate for mechanical rehabilitation, such as straight reaches with bedrock banks, tributary deltas, low gradient reaches with hard downstream grade control, and those with potential liability of damaging human structures. We considered only the following criteria (excluding county zoning or landowner willingness) for site selection in this initial screening:

- alluvial bank(s) present
- sufficient channel width and length available
- no human structures would be threatened
- no functioning, self-sustaining riparian communities would be physically disturbed
- access reasonably available
- location relative to mainstem’s alluvial transition
- acceptable planform morphology type (see below)

Considering the rationale and design potentials for mechanically altering different mainstem planform types, we identified the following planform types as acceptable for proposed channel restoration project sites:

The following categories identify mainstem channel planforms suitable for proposed bank rehabilitation projects. A short rationale and general design strategies are provided.

STRAIGHT, PARTIALLY ALLUVIAL HISTORIC REACH

Rationale: Dredger mining throughout the valley corridor brought major changes to the channel's planform. The mining may have pushed channels to one side of the valley, forcing flow to parallel non-erodible valley walls (only one bank is potentially erodible following berm removal). Two good examples are: downstream of the Browns Mountain Bridge (RM 104.5), and downstream of the Douglas City Bridge (RM 93.1), and at RM 75.4 (Plate 25). Both exhibit indistinct thalwegs and trapezoidal cross sections.

Design: The post-TRD thalweg is beginning to meander within the pre-TRD channel (Chapter 2). One rehabilitation strategy is to accentuate these smaller, contemporary meander wavelengths, with the expectation that a more diverse alluvial morphology will evolve and maintain itself. To encourage alternate bar formation, sections of the berm along the potentially erodible bank can be removed to direct thalweg migration. On the outside bend of anticipated meanders, unaltered portions of the riparian berm would provide the needed resistance for establishing pools and re-directing the meander downstream to the opposite bank. No extensive floodplain reconstruction was considered for these straight channel reaches.

WIDE RADIUS, ALLUVIAL HISTORIC BEND

Rationale: These gently arcing pre-TRD meander bends with long radius of curvatures (greater than 2,000 ft) now appear straight, accentuated by the narrow border of encroached riparian vegetation along both potentially-erodible channel banks. Berm removal along the upper, inside bank (i.e., in half a pre-dam channel bend, or one-fourth meander wavelength) should significantly reduce confinement and encourage alternate bar formation.

Design: To encourage alternate bar formation, riparian berms on both banks can be alternately removed to direct thalweg migration. This strategy would have a better chance for success than a similar strategy applied to only one bank (e.g., the straight post-TRD planform with only one erodible bank). On the outside bend of anticipated meanders, unaltered portions of the riparian berm would provide the needed resistance for establishing pools and re-directing the meander downstream to the opposite bank.

INTERMEDIATE RADIUS, PARTIALLY-ALLUVIAL HISTORIC BEND

Rationale: These sites have the least potential for improving anadromous fish habitat, compared to project sites with the possibility for large-scale alternate bar formation. However, much of the middle and upper mainstem reaches have this planform type, so an attempt to induce deposition and limited bar formation will significantly improve salmonid habitat availability and quality.

Design: Removal of the narrow riparian berm will improve deposition, creating limited edgewater habitat, but may not be sufficient to initiate alternate bar formation unless project site extends longer than a post-TRD meander wavelength.

SHORT RADIUS FORCED HISTORIC BEND

Rationale: With the loss of higher floods and upstream bedload sources, dimensions of the pre-TRD morphology became “over-sized” for transporting contemporary flows and sediment inputs. On shorter radius of curvature bends, especially those with extensive tailings, the original channelbed surface can be lowered to flood with a similar frequency and depth before regulation. These are especially important planforms for establishing riparian forests that require periodic inundation, scour, and deposition, and important for creating off-channel and scour channel habitat.

Design: Cut-off channels (or “overflow channels”) are common on these pre-TRD bars, providing habitat during high flows and possibly alcove formation at the downstream edges. Some side channel projects are positioned along the backside of short channel bends, in effect simulating overflow channels. Side channel development has not been successful, as designed, where the channel behaves alluvially, e.g., at the J&M Tackle site (RM 76.9). Three major design problems encountered have been: (1) fish biologists want perennial flow, even though most natural overflow channels flow only seasonally, and then only during high flows. For perennial flow the side channel entrance must be designed to prevent even minor aggradation. In alluvial reaches with significant bedload being transported frequently, aggradation has been commonplace. Keeping flows perennial will be an ongoing maintenance project, (2) the temptation that bigger and/or longer side channels are better may not be prudent. As side channel length increased (e.g., upstream of Junction City) overall slope decreased, making bedload transport more difficult. If the slope drops too much, bedload will accumulate within the side channel and further decrease upstream slope within the side channel and, (3) the simple geometry of some lower mainstem side channels did not provide sufficient physical complexity for juvenile salmonid rearing habitat.

We can encourage natural formation and maintenance of overflow channels at project sites farther downstream. Overflow channels can be shaped, with the intent that future flooding will maintain their function. They would not flow throughout the year, as constructed side-channels were originally designed to do, but would provide high flow habitat refuge. Such a strategy would create two design approaches riverwide: (1) maintain classic side channels close to Lewiston Dam and, (2) favor overflow channels on reconstructed bars as the mainstem becomes more dynamic downstream. This would avoid two of the design problems encountered.

Areas scoured by high flows in the most downstream portion of an overflow channel can provide excellent aquatic vertebrate habitat at all flows. We call perennially scoured areas ‘alcoves’, defined as scour areas created and maintained by an alternate bar but removed from the main channel thalweg, but with its low flow stage continuous with that of main channel flow. These were common on moderately sharp alluvial bends and on the downstream margins of mid-channel bars where flow along one side is disproportionately high. They provide slackwater juvenile salmonid habitat at high flows usually have good to excellent cover from accumulated woody debris and/or overhanging vegetation, and are connected to the main channel so that no fish are stranded during receding spring flows.

One contemporary alcove (and many other similar examples can be found) associated with a mid-channel bar has been maintained since dam closure by bar fossilization. At RM 108.6 the mid-channel bar created an alcove in its lee prior to regulation. This alcove was preserved, as riparian encroachment gradually attenuated most flow toward the left bank. Alcoves could be initially shaped on the downstream end of back channels, with the intent that high flows will continue to keep these dynamic features functioning as aquatic vertebrate habitat. Designing alcoves on sharply curving bends would best be started in the middle and upper mainstem reaches, i.e., taking advantage of the least dynamic mainstem segment to develop design and re-construction techniques. These alcove areas could become depositional unless backwater through-flows are maintained during the flood hydrograph.

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CHAPTER 12: RECOMMENDATIONS

This chapter provides a summary of recommendations developed in Chapter 11. Chapter 11 provides the rationale of these recommendations, and links recommendations to specific components of this and other studies.

12.1 Water year designation

On April 1st of each water year, Bureau of Reclamation projects the total Trinity River Division inflow for the entire water year. Based on the projected total inflow, the water year type should be designated by the inflow criteria in Table 12.1, and the flow release schedule for that water type be commenced.

WATER YEAR CLASS	EXCEEDENCE PROBABILITY	THRESHOLD RESERVOIR INFLOW FOR WATER YEAR DESIGNATION
Extremely Wet	p<0.12	>2,000,000 acre-feet
Wet	0.12<p<0.40	1,350,000 to 2,000,000 acre-feet
Normal	0.40<p<0.60	1,025,000 to 1,350,000 acre-feet
Dry	0.60<p<0.88	650,000 to 1,025,000 acre-feet
Critically Dry	p>0.88	<650,000 acre-feet

Table 12.1 Recommended Trinity River water year classification criteria.

12.2 Annual flow regimes

We recommend the following Lewiston flow releases for each of the five water year designations (Table 12.2):

1. EXTREMELY WET (0.88<p): Five days at a peak flow of 11,000 cfs in late May, rapidly descending to 6,000 cfs by June 5, holding at 6,000 cfs for five days, then gradually descending to 1,500 cfs by July 13, holding at 1,500 cfs until July 26, then rapidly descending to a 300 cfs summer baseflow by July 31 (Figure 11.3).
2. WET (0.60<p<0.88): Five days at a peak flow of 8,500 cfs in during the third week in May, rapidly descending to 6,000 cfs by May 25, holding at 6,000 cfs for five days, then gradually descending to 1,500 cfs by June 27, holding at 1,500 cfs until July 16, then rapidly descending to a 300 cfs summer baseflow by July 19 (Figure 11.4).
3. NORMAL (0.40<p<0.60): Five days at a peak flow of 6,000 cfs during the second week in May, gradually descending to 1,500 cfs by June 14, holding at 1,500 cfs until July 12, then rapidly descending to a 200 cfs summer baseflow by July 15 (Figure 11.5).
4. DRY (0.12<p<0.40): Five days at a peak flow of 4,500 cfs in during the first week in May, gradually descending to 1,500 cfs by June 4, holding at 1,500 cfs until July 16, then rapidly descending to a 200 cfs summer baseflow by July 19 (Figure 11.6).
5. CRITICALLY DRY (p<0.12): Thirty-three days at a peak flow of 1,500 cfs from May 15 to June 16, then rapidly descending to a 100 cfs baseflow by June 19 (Figure 11.7).

12.3 Sediment maintenance

The duration of peak high flow events has been set to balance the coarse sediment budget downstream of Rush Creek, which unbalances the coarse sediment budget upstream of Rush Creek. Therefore, gravel introduction will need to occur, at roughly the bedload transport rates at the Lewiston gaging station (Table 12.3). The particle size of introduced gravels should be between 8 mm and 128 mm to coincide with gravel sizes preferred by spawning salmonids.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
1-Oct	300	300	300	300	300
2-Oct	300	300	300	300	300
3-Oct	300	300	300	300	300
4-Oct	300	300	300	300	300
5-Oct	300	300	300	300	300
6-Oct	300	300	300	300	300
7-Oct	300	300	300	300	300
8-Oct	300	300	300	300	300
9-Oct	300	300	300	300	300
10-Oct	300	300	300	300	300
11-Oct	300	300	300	300	300
12-Oct	300	300	300	300	300
13-Oct	300	300	300	300	300
14-Oct	300	300	300	300	300
15-Oct	300	300	300	300	300
16-Oct	300	300	300	300	300
17-Oct	300	300	300	300	300
18-Oct	300	300	300	300	300
19-Oct	300	300	300	300	300
20-Oct	300	300	300	300	300
21-Oct	300	300	300	300	300
22-Oct	300	300	300	300	300
23-Oct	300	300	300	300	300
24-Oct	300	300	300	300	300
25-Oct	300	300	300	300	300
26-Oct	300	300	300	300	300
27-Oct	300	300	300	300	300
28-Oct	300	300	300	300	300
29-Oct	300	300	300	300	300
30-Oct	300	300	300	300	300
31-Oct	300	300	300	300	300
1-Nov	300	300	300	300	300
2-Nov	300	300	300	300	300
3-Nov	300	300	300	300	300
4-Nov	300	300	300	300	300
5-Nov	300	300	300	300	300
6-Nov	300	300	300	300	300
7-Nov	300	300	300	300	300
8-Nov	300	300	300	300	300
9-Nov	300	300	300	300	300
10-Nov	300	300	300	300	300
11-Nov	300	300	300	300	300
12-Nov	300	300	300	300	300
13-Nov	300	300	300	300	300
14-Nov	300	300	300	300	300
15-Nov	300	300	300	300	300
16-Nov	300	300	300	300	300

Table 12.2 Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
17-Nov	300	300	300	300	300
18-Nov	300	300	300	300	300
19-Nov	300	300	300	300	300
20-Nov	300	300	300	300	300
21-Nov	300	300	300	300	300
22-Nov	300	300	300	300	300
23-Nov	300	300	300	300	300
24-Nov	300	300	300	300	300
25-Nov	300	300	300	300	300
26-Nov	300	300	300	300	300
27-Nov	300	300	300	300	300
28-Nov	300	300	300	300	300
29-Nov	300	300	300	300	300
30-Nov	300	300	300	300	300
1-Dec	300	300	300	300	300
2-Dec	300	300	300	300	300
3-Dec	300	300	300	300	300
4-Dec	300	300	300	300	300
5-Dec	300	300	300	300	300
6-Dec	300	300	300	300	300
7-Dec	300	300	300	300	300
8-Dec	300	300	300	300	300
9-Dec	300	300	300	300	300
10-Dec	300	300	300	300	300
11-Dec	300	300	300	300	300
12-Dec	300	300	300	300	300
13-Dec	300	300	300	300	300
14-Dec	300	300	300	300	300
15-Dec	300	300	300	300	300
16-Dec	300	300	300	300	300
17-Dec	300	300	300	300	300
18-Dec	300	300	300	300	300
19-Dec	300	300	300	300	300
20-Dec	300	300	300	300	300
21-Dec	300	300	300	300	300
22-Dec	300	300	300	300	300
23-Dec	300	300	300	300	300
24-Dec	300	300	300	300	300
25-Dec	300	300	300	300	300
26-Dec	300	300	300	300	300
27-Dec	300	300	300	300	300
28-Dec	300	300	300	300	300
29-Dec	300	300	300	300	300
30-Dec	300	300	300	300	300
31-Dec	300	300	300	300	300
1-Jan	300	300	300	300	300
2-Jan	300	300	300	300	300

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
3-Jan	300	300	300	300	300
4-Jan	300	300	300	300	300
5-Jan	300	300	300	300	300
6-Jan	300	300	300	300	300
7-Jan	300	300	300	300	300
8-Jan	300	300	300	300	300
9-Jan	300	300	300	300	300
10-Jan	300	300	300	300	300
11-Jan	300	300	300	300	300
12-Jan	300	300	300	300	300
13-Jan	300	300	300	300	300
14-Jan	300	300	300	300	300
15-Jan	300	300	300	300	300
16-Jan	300	300	300	300	300
17-Jan	300	300	300	300	300
18-Jan	300	300	300	300	300
19-Jan	300	300	300	300	300
20-Jan	300	300	300	300	300
21-Jan	300	300	300	300	300
22-Jan	300	300	300	300	300
23-Jan	300	300	300	300	300
24-Jan	300	300	300	300	300
25-Jan	300	300	300	300	300
26-Jan	300	300	300	300	300
27-Jan	300	300	300	300	300
28-Jan	300	300	300	300	300
29-Jan	300	300	300	300	300
30-Jan	300	300	300	300	300
31-Jan	300	300	300	300	300
1-Feb	300	300	300	300	300
2-Feb	300	300	300	300	300
3-Feb	300	300	300	300	300
4-Feb	300	300	300	300	300
5-Feb	300	300	300	300	300
6-Feb	300	300	300	300	300
7-Feb	300	300	300	300	300
8-Feb	300	300	300	300	300
9-Feb	300	300	300	300	300
10-Feb	300	300	300	300	300
11-Feb	300	300	300	300	300
12-Feb	300	300	300	300	300
13-Feb	300	300	300	300	300
14-Feb	300	300	300	300	300
15-Feb	300	300	300	300	300
16-Feb	300	300	300	300	300
17-Feb	300	300	300	300	300
18-Feb	300	300	300	300	300

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
19-Feb	300	300	300	300	300
20-Feb	300	300	300	300	300
21-Feb	300	300	300	300	300
22-Feb	300	300	300	300	300
23-Feb	300	300	300	300	300
24-Feb	300	300	300	300	300
25-Feb	300	300	300	300	300
26-Feb	300	300	300	300	300
27-Feb	300	300	300	300	300
28-Feb	300	300	300	300	300
1-Mar	300	300	300	300	300
2-Mar	300	300	300	300	300
3-Mar	300	300	300	300	300
4-Mar	300	300	300	300	300
5-Mar	300	300	300	300	300
6-Mar	300	300	300	300	300
7-Mar	300	300	300	300	300
8-Mar	300	300	300	300	300
9-Mar	300	300	300	300	300
10-Mar	300	300	300	300	300
11-Mar	300	300	300	300	300
12-Mar	300	300	300	300	300
13-Mar	300	300	300	300	300
14-Mar	300	300	300	300	300
15-Mar	300	300	300	300	300
16-Mar	300	300	300	300	300
17-Mar	300	300	300	300	300
18-Mar	300	300	300	300	300
19-Mar	300	300	300	300	300
20-Mar	300	300	300	300	300
21-Mar	300	300	300	300	300
22-Mar	300	300	300	300	300
23-Mar	300	300	300	300	300
24-Mar	300	300	300	300	300
25-Mar	300	300	300	300	300
26-Mar	300	300	300	300	300
27-Mar	300	300	300	300	300
28-Mar	300	300	300	300	300
29-Mar	300	300	300	300	300
30-Mar	300	300	300	300	300
31-Mar	300	300	300	300	300
1-Apr	300	300	300	300	300
2-Apr	300	300	300	300	300
3-Apr	300	300	300	300	300
4-Apr	300	300	300	300	300
5-Apr	300	300	300	300	300
6-Apr	300	300	300	300	300

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
7-Apr	300	300	300	300	300
8-Apr	300	300	300	300	300
9-Apr	300	300	300	300	300
10-Apr	300	300	300	300	300
11-Apr	300	300	300	300	300
12-Apr	300	300	300	300	300
13-Apr	300	300	300	300	300
14-Apr	300	300	300	300	300
15-Apr	300	300	300	300	300
16-Apr	300	300	300	300	300
17-Apr	300	300	300	300	300
18-Apr	300	300	300	300	300
19-Apr	300	300	300	300	300
20-Apr	300	300	300	300	300
21-Apr	300	300	300	300	300
22-Apr	300	300	300	300	300
23-Apr	300	300	300	300	300
24-Apr	300	300	300	300	300
25-Apr	300	300	300	300	300
26-Apr	300	300	300	300	300
27-Apr	300	300	300	500	300
28-Apr	300	300	300	1500	300
29-Apr	300	300	300	2500	300
30-Apr	300	300	300	3500	300
1-May	300	300	300	4500	300
2-May	300	300	300	4500	300
3-May	300	300	1000	4500	300
4-May	300	300	2000	4500	300
5-May	300	300	3000	4500	300
6-May	300	300	4000	4400	300
7-May	300	300	6000	4300	300
8-May	300	300	6000	4200	400
9-May	300	300	6000	4100	500
10-May	300	300	6000	4000	600
11-May	300	300	6000	3900	700
12-May	300	1000	5350	3800	800
13-May	300	2000	4700	3700	900
14-May	300	3000	4600	3600	1000
15-May	300	4000	4500	3500	1500
16-May	300	6000	4400	3400	1500
17-May	300	8500	4300	3300	1500
18-May	1000	8500	4200	3200	1500
19-May	2000	8500	4100	3100	1500
20-May	3000	8500	4000	3000	1500
21-May	4000	8500	3900	2900	1500
22-May	6000	7850	3800	2800	1500
23-May	8500	7200	3700	2700	1500

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
24-May	11000	6550	3600	2600	1500
25-May	11000	6000	3500	2500	1500
26-May	11000	6000	3400	2400	1500
27-May	11000	6000	3300	2300	1500
28-May	11000	6000	3200	2200	1500
29-May	10350	6000	3100	2100	1500
30-May	9700	5350	3000	2000	1500
31-May	9050	4700	2900	1900	1500
1-Jun	8400	4050	2800	1800	1500
2-Jun	7750	3950	2700	1700	1500
3-Jun	7100	3850	2600	1600	1500
4-Jun	6450	3750	2500	1500	1500
5-Jun	6000	3650	2400	1500	1500
6-Jun	6000	3550	2300	1500	1500
7-Jun	6000	3450	2200	1500	1500
8-Jun	6000	3350	2100	1500	1500
9-Jun	6000	3250	2000	1500	1500
10-Jun	5350	3150	1900	1500	1500
11-Jun	4700	3050	1800	1500	1500
12-Jun	4600	2950	1700	1500	1500
13-Jun	4500	2850	1600	1500	1500
14-Jun	4400	2750	1500	1500	1500
15-Jun	4300	2650	1500	1500	1500
16-Jun	4200	2550	1500	1500	1500
17-Jun	4100	2450	1500	1000	1000
18-Jun	4000	2350	1500	500	500
19-Jun	3900	2250	1500	200	100
20-Jun	3800	2150	1500	200	100
21-Jun	3700	2050	1500	200	100
22-Jun	3600	1950	1500	200	100
23-Jun	3500	1850	1500	200	100
24-Jun	3400	1750	1500	200	100
25-Jun	3300	1650	1500	200	100
26-Jun	3200	1550	1500	200	100
27-Jun	3100	1500	1500	200	100
28-Jun	3000	1500	1500	200	100
29-Jun	2900	1500	1500	200	100
30-Jun	2800	1500	1500	200	100
1-Jul	2700	1500	1500	200	100
2-Jul	2600	1500	1500	200	100
3-Jul	2500	1500	1500	200	100
4-Jul	2400	1500	1500	200	100
5-Jul	2300	1500	1500	200	100
6-Jul	2200	1500	1500	200	100
7-Jul	2100	1500	1500	200	100
8-Jul	2000	1500	1500	200	100
9-Jul	1900	1500	1500	200	100

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
10-Jul	1800	1500	1500	200	100
11-Jul	1700	1500	1500	200	100
12-Jul	1600	1500	1500	200	100
13-Jul	1500	1500	1000	200	100
14-Jul	1500	1500	500	200	100
15-Jul	1500	1500	200	200	100
16-Jul	1500	1500	200	200	100
17-Jul	1500	1000	200	200	100
18-Jul	1500	500	200	200	100
19-Jul	1500	300	200	200	100
20-Jul	1500	300	200	200	100
21-Jul	1500	300	200	200	100
22-Jul	1500	300	200	200	100
23-Jul	1500	300	200	200	100
24-Jul	1500	300	200	200	100
25-Jul	1500	300	200	200	100
26-Jul	1500	300	200	200	100
27-Jul	1000	300	200	200	100
28-Jul	500	300	200	200	100
29-Jul	300	300	200	200	100
30-Jul	300	300	200	200	100
31-Jul	300	300	200	200	100
1-Aug	300	300	200	200	100
2-Aug	300	300	200	200	100
3-Aug	300	300	200	200	100
4-Aug	300	300	200	200	100
5-Aug	300	300	200	200	100
6-Aug	300	300	200	200	100
7-Aug	300	300	200	200	100
8-Aug	300	300	200	200	100
9-Aug	300	300	200	200	100
10-Aug	300	300	200	200	100
11-Aug	300	300	200	200	100
12-Aug	300	300	200	200	100
13-Aug	300	300	200	200	100
14-Aug	300	300	200	200	100
15-Aug	300	300	200	200	100
16-Aug	300	300	200	200	100
17-Aug	300	300	200	200	100
18-Aug	300	300	200	200	100
19-Aug	300	300	200	200	100
20-Aug	300	300	200	200	100
21-Aug	300	300	200	200	100
22-Aug	300	300	200	200	100
23-Aug	300	300	200	200	100
24-Aug	300	300	200	200	100
25-Aug	300	300	200	200	100

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Date	Extremely Wet (cfs)	Wet (cfs)	Normal (cfs)	Dry (cfs)	Critically Dry (cfs)
26-Aug	300	300	200	200	100
27-Aug	300	300	200	200	100
28-Aug	300	300	200	200	100
29-Aug	300	300	200	200	100
30-Aug	300	300	200	200	100
31-Aug	300	300	200	200	100
1-Sep	300	300	200	200	200
2-Sep	300	300	200	200	200
3-Sep	300	300	200	200	200
4-Sep	300	300	200	200	200
5-Sep	300	300	200	200	200
6-Sep	300	300	200	200	200
7-Sep	300	300	200	200	200
8-Sep	300	300	200	200	200
9-Sep	300	300	200	200	200
10-Sep	300	300	200	200	200
11-Sep	300	300	200	200	200
12-Sep	300	300	200	200	200
13-Sep	300	300	200	200	200
14-Sep	300	300	200	200	200
15-Sep	300	300	200	200	200
16-Sep	300	300	200	200	200
17-Sep	300	300	200	200	200
18-Sep	300	300	200	200	200
19-Sep	300	300	200	200	200
20-Sep	300	300	200	200	200
21-Sep	300	300	200	200	200
22-Sep	300	300	200	200	200
23-Sep	300	300	200	200	200
24-Sep	300	300	200	200	200
25-Sep	300	300	200	200	200
26-Sep	300	300	200	200	200
27-Sep	300	300	200	200	200
28-Sep	300	300	200	200	200
29-Sep	300	300	200	200	200
30-Sep	300	300	200	200	200
TOTAL ACRE-FT:	763,339	621,917	537,421	439,736	267,769

Table 12.2 (continued) Daily flow recommendations for all water year classifications.

Additional recommendations for coarse and fine sediment management include:

- Sediment removed from Hamilton Ponds should be screened, and particles between 8 mm and 128 mm should be returned to the mainstem for downstream transport.
- Restore bedload continuity by excavating portions of the deltas of Rush Creek, Grass Valley Creek, and Indian Creek to remove the hydraulic control that prevents coarse bedload from upstream sources from routing through these deltas.

Water Year	Gravel Introduction (tons)
Extremely Wet	23,000 to 53,000
Wet	8,000 to 16,000
Normal	1,600 to 2,250
Dry	175 to 275[1]
Critically Dry	0

[1] functionally zero

Table 12.3 Gravel introduction recommendations in reach between Lewiston Dam and Rush Creek by water year.

- Hamilton Ponds should continue to be used as a fine sediment trap, as they are very effective in preventing coarse sand from entering the mainstem, provided that the ponds are excavated immediately after large storm events.
- Reduced fine sediment storage in mainstem pools suggests that the fine sediment budget is transitioning from over-supply to under-supply. Therefore, we do not believe future pool dredging is necessary, as the high flow regime should be adequate to continue decreasing fine sediment storage.

12.4 Channel restoration

Bank rehabilitation in key locations, in conjunction with high flows and ample coarse sediment supply, are expected to foster alternate bar formation and enhance habitat complexity for native biota. We recommend that future bank rehabilitation projects be designed and built to dimensions corresponding to predicted equilibrium conditions for local site hydrology, coarse sediment supply, and geologic control. Forty-three potential bank and channel rehabilitation sites, identified with USFWS personnel, are shown on Plate 25.

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APPENDIX A

ANNUAL HYDROGRAPHS FOR THE TRINTY RIVER AT LEWISTON USGS GAGING STATION FOR 1912 TO 1997

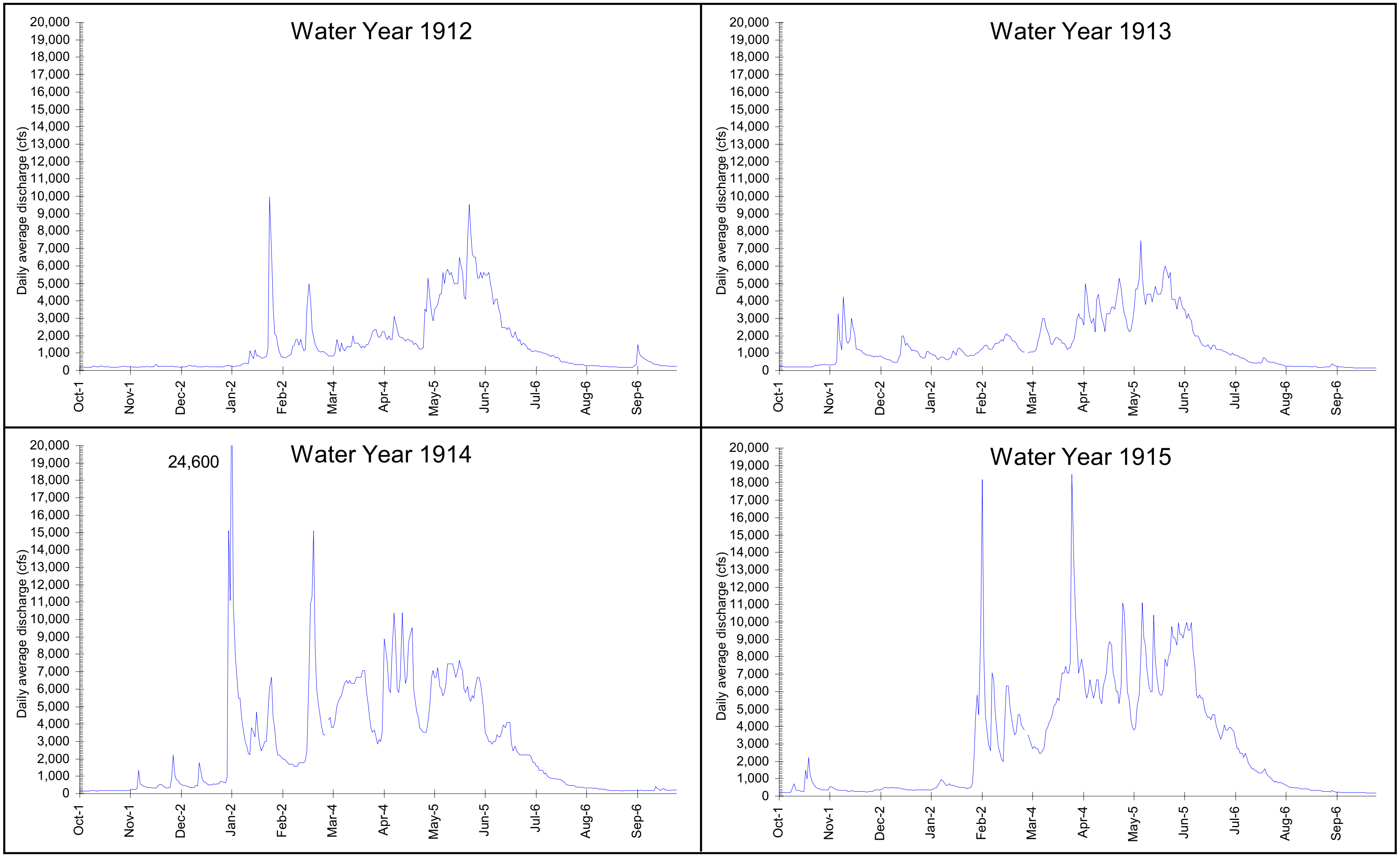


Figure A-1 Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

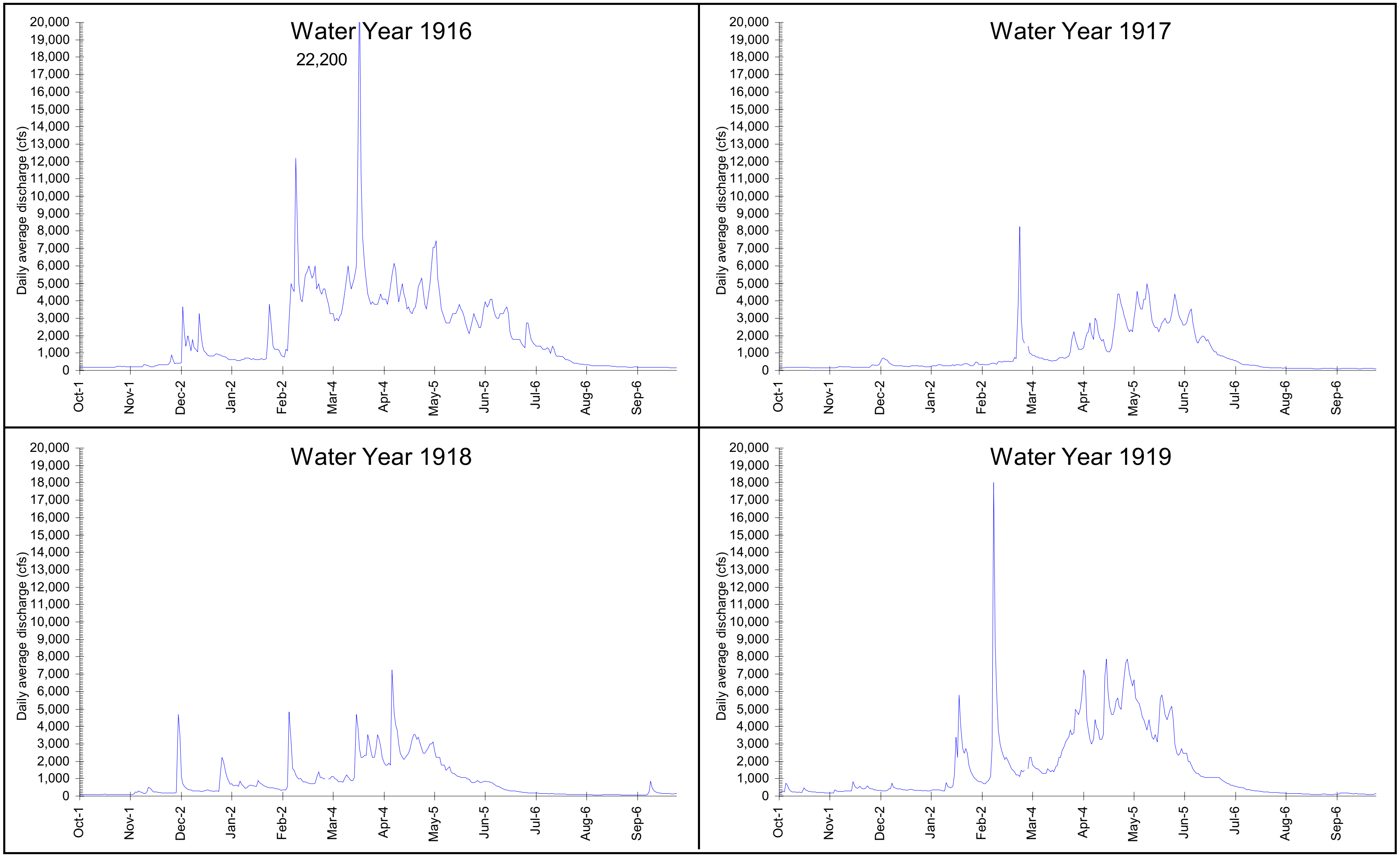


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

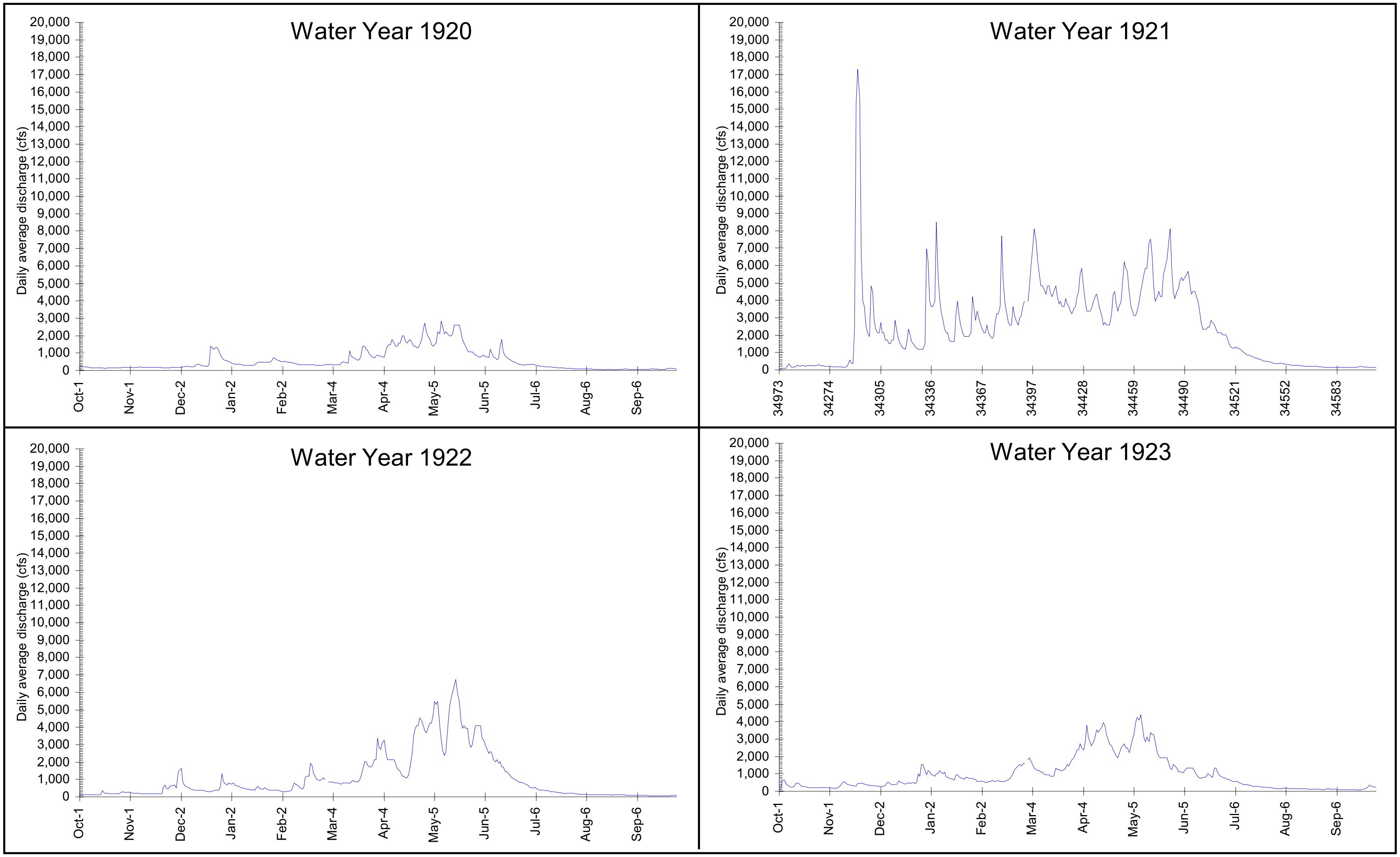


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

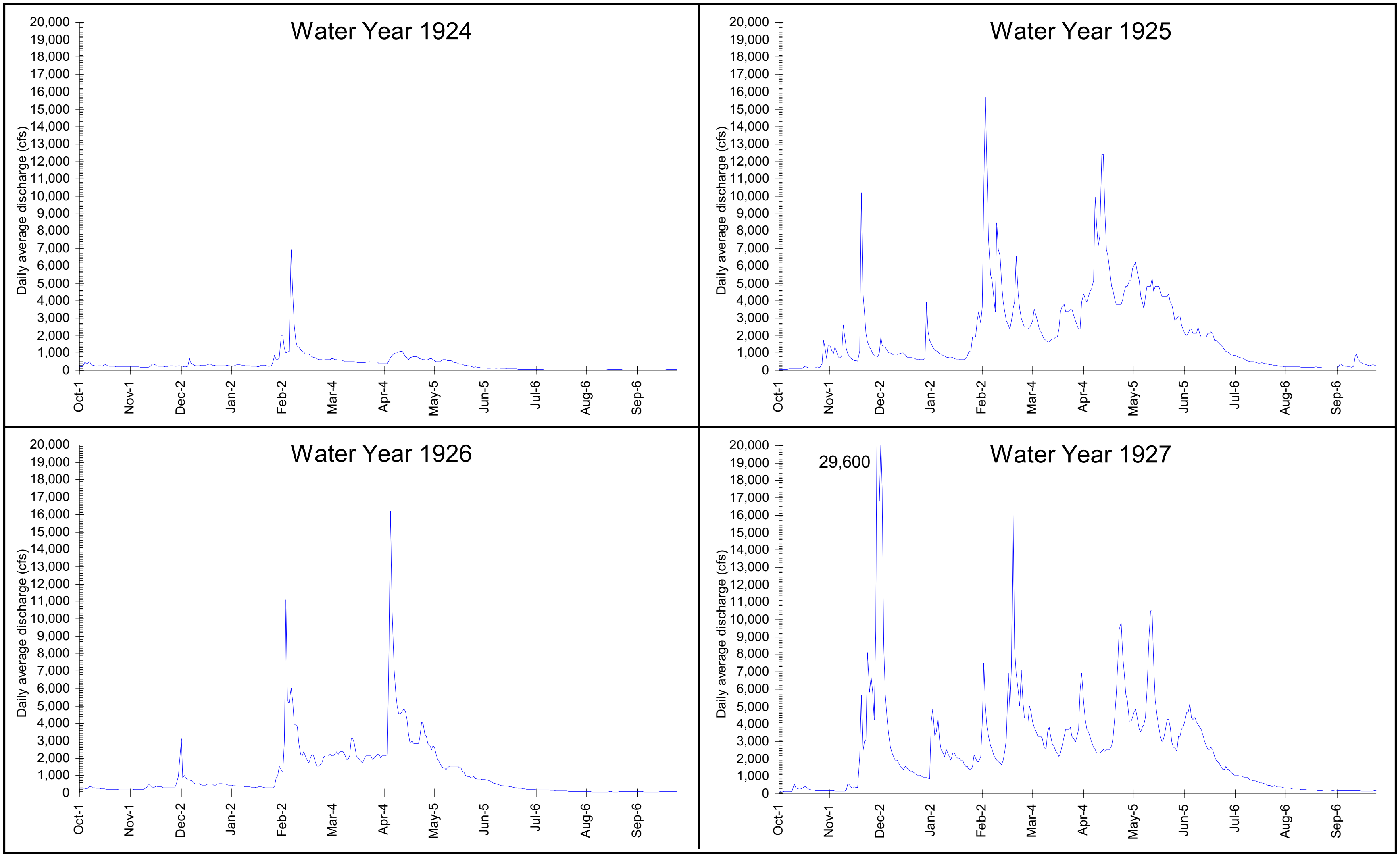


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

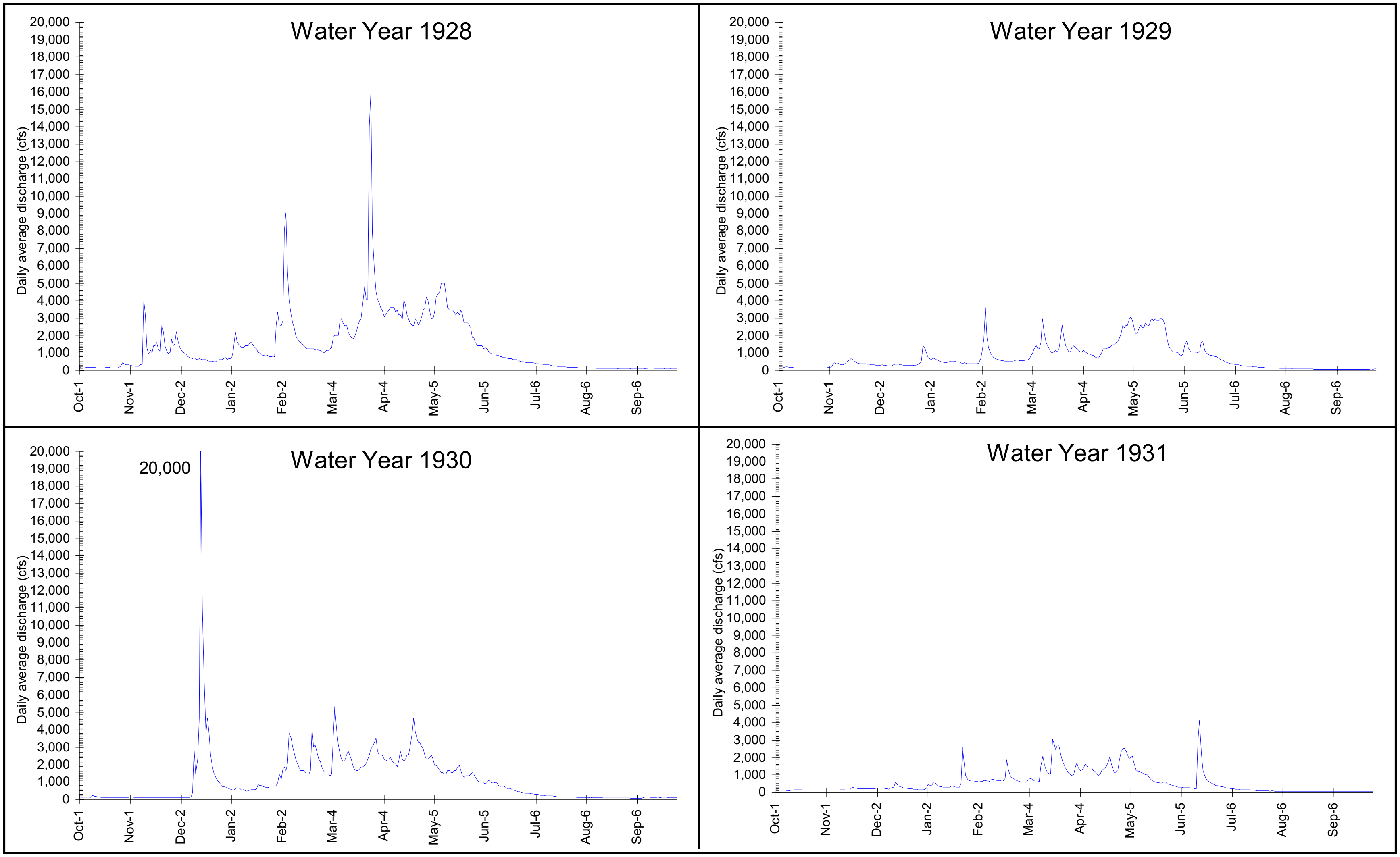


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

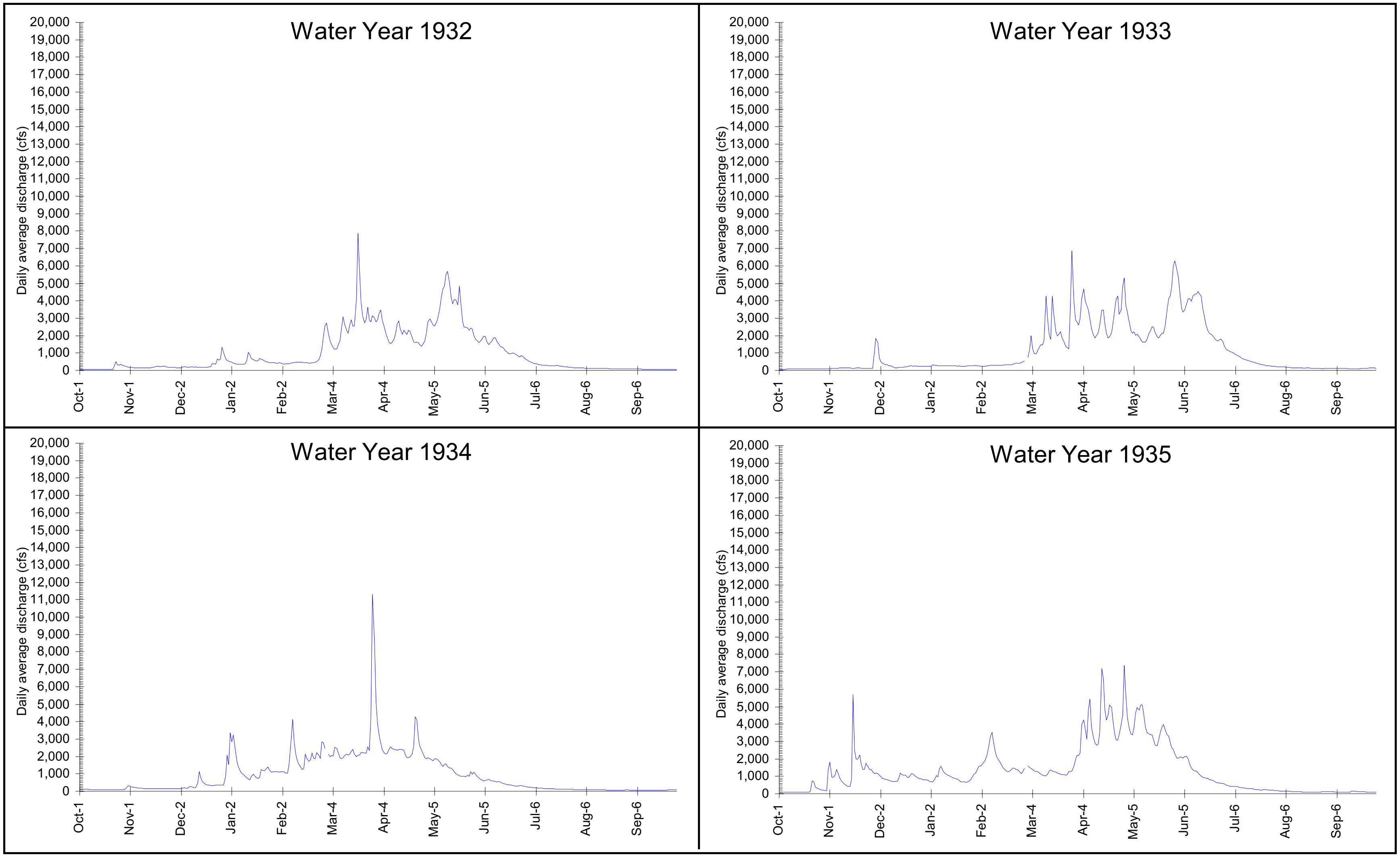


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

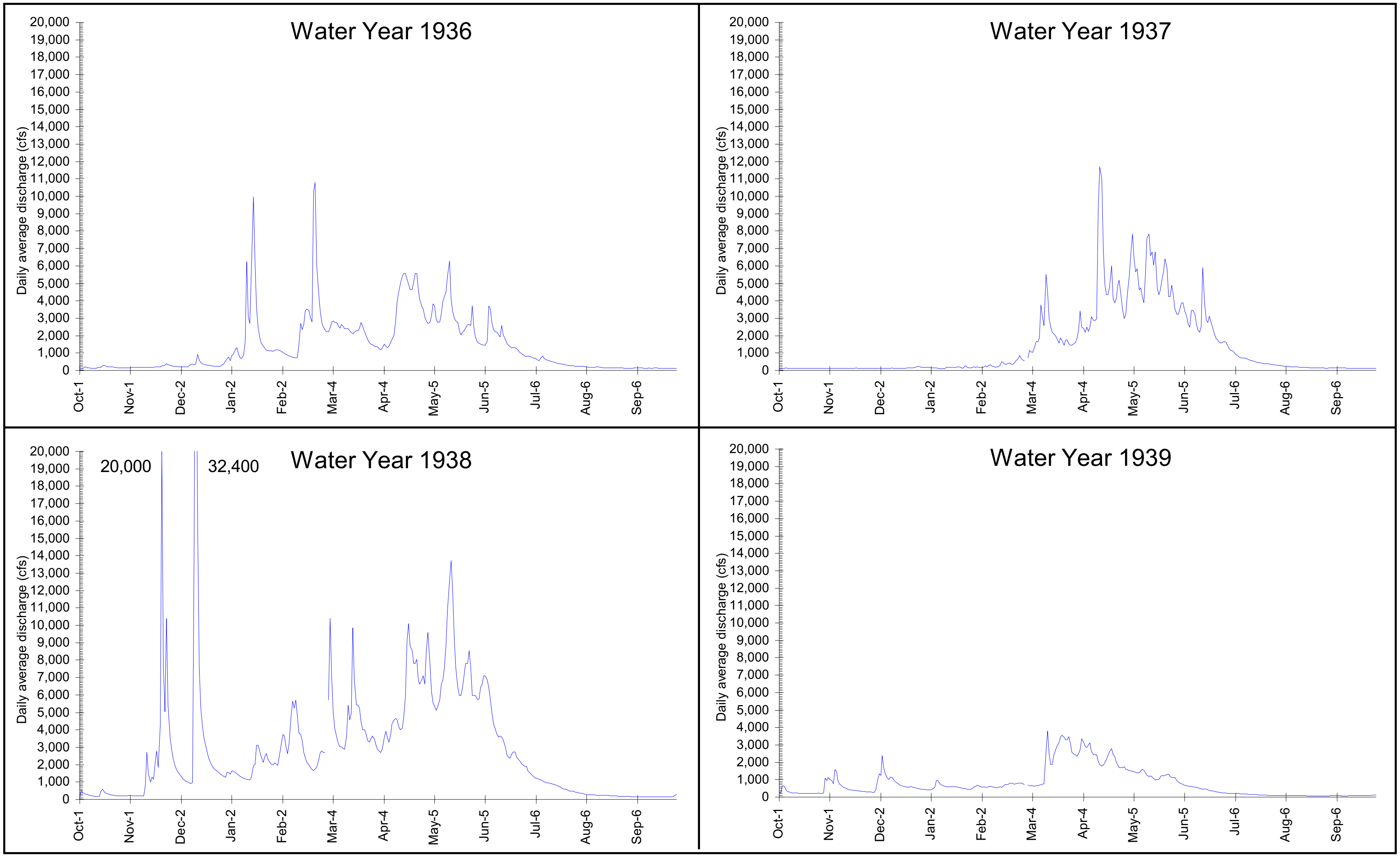


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

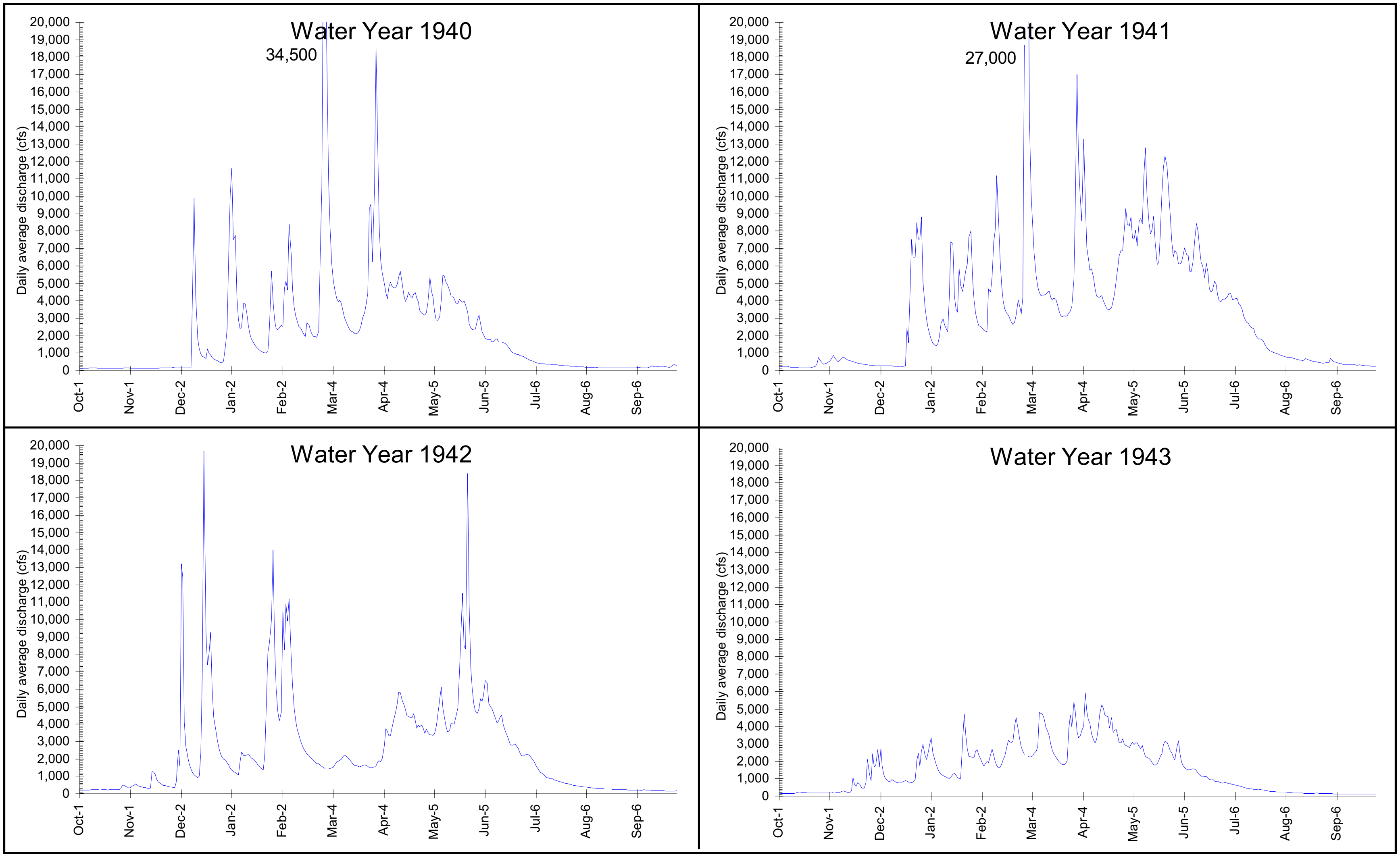


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

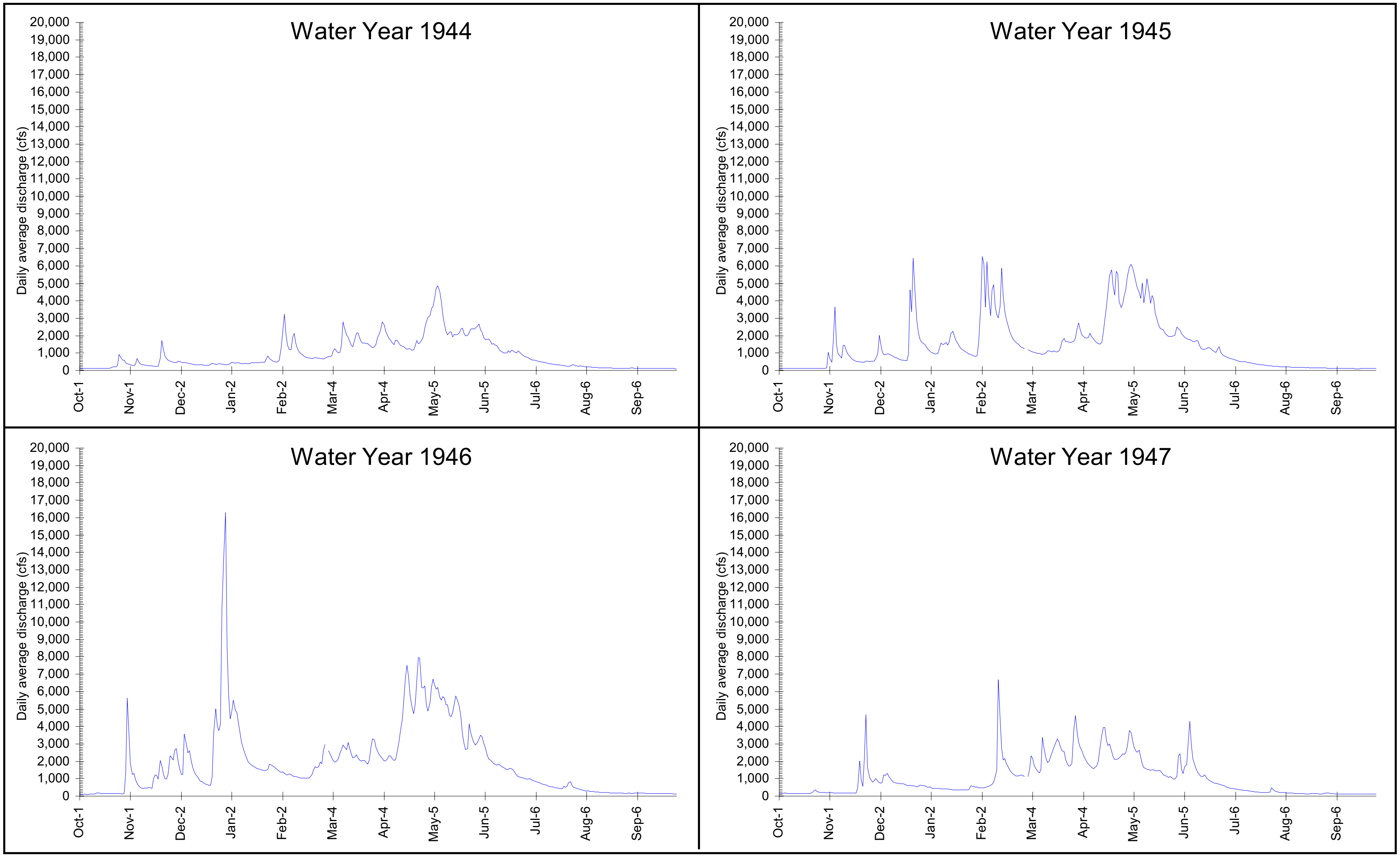


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

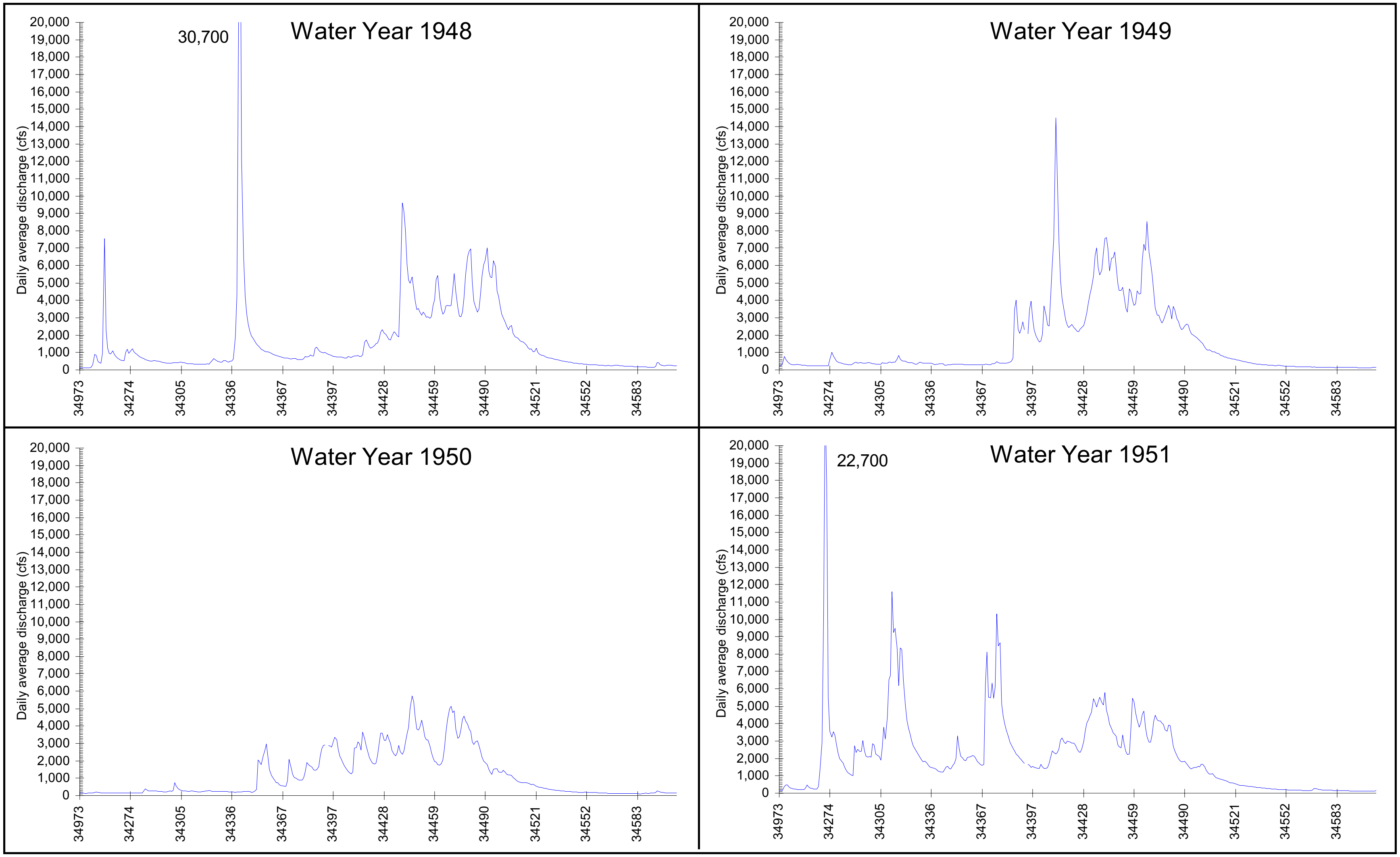


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

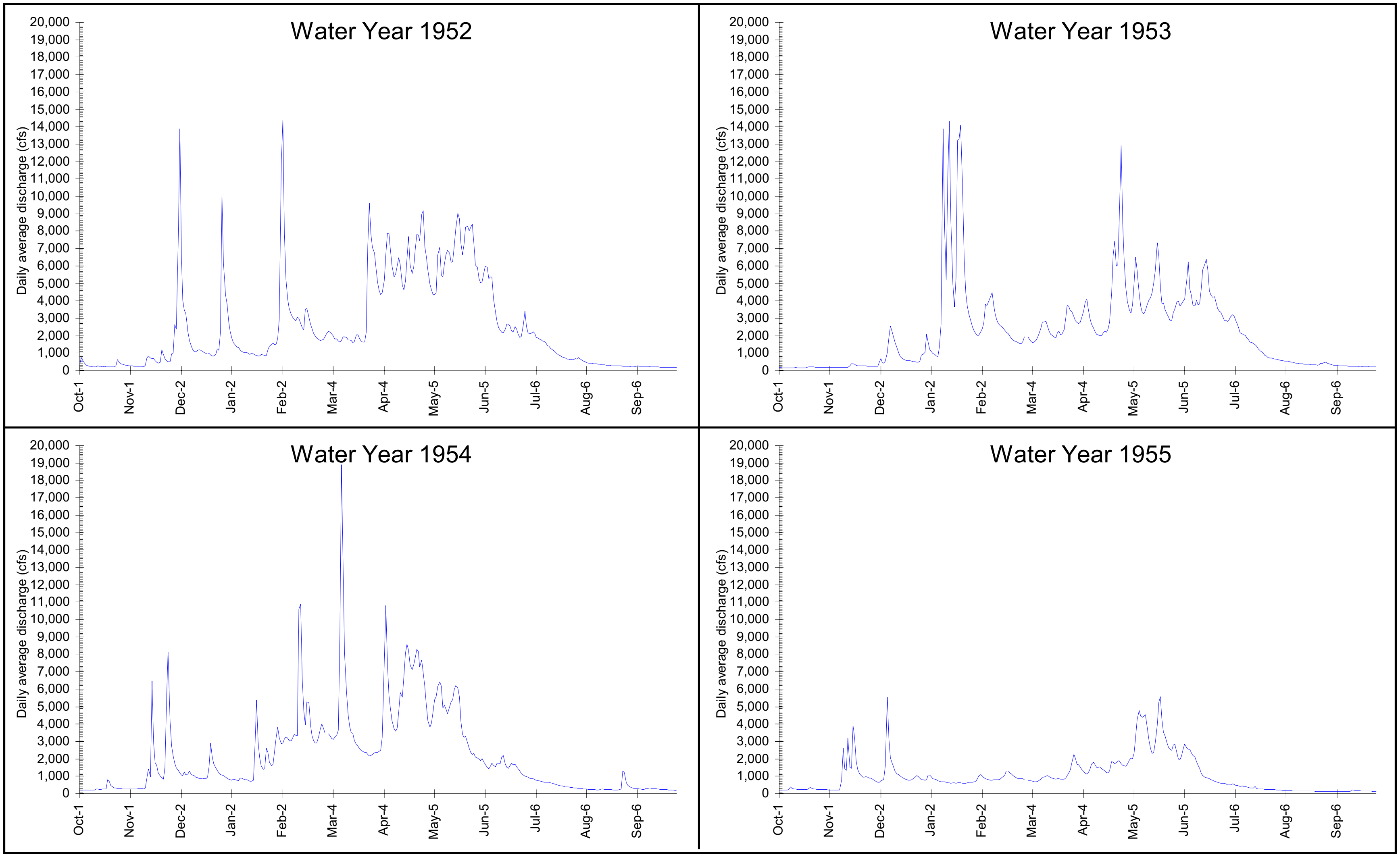


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

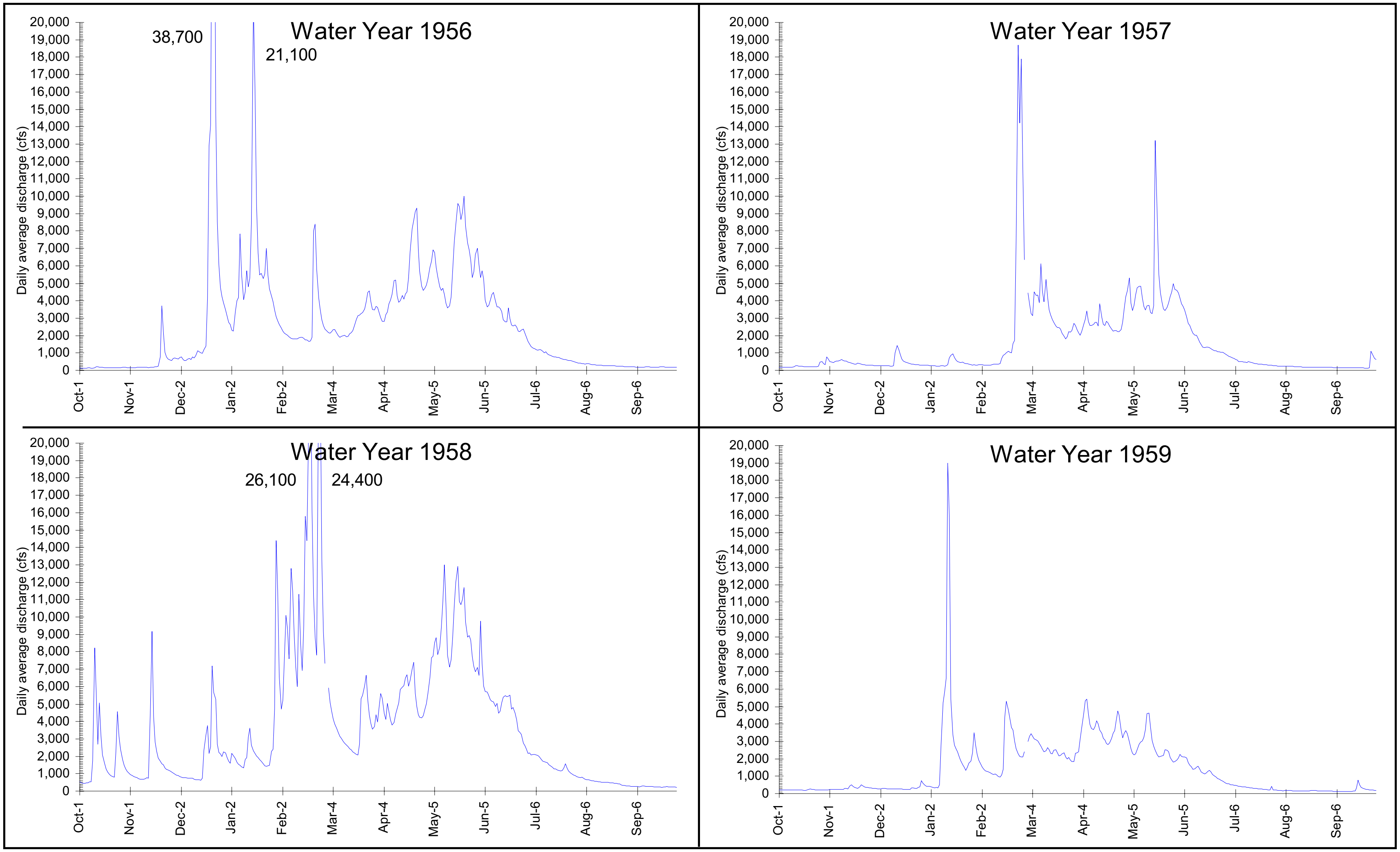
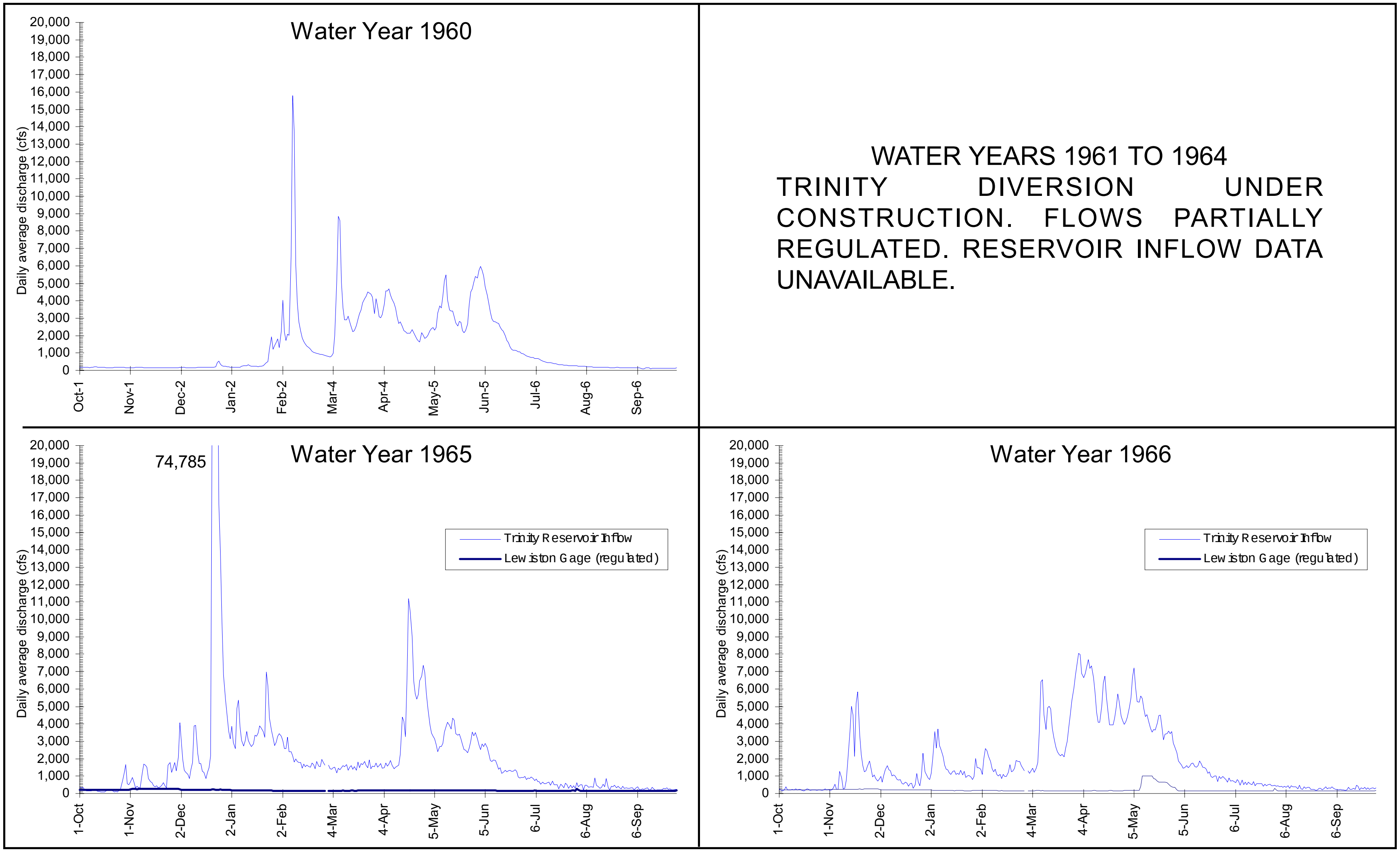


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.



WATER YEARS 1961 TO 1964
TRINITY DIVERSION UNDER CONSTRUCTION. FLOWS PARTIALLY REGULATED. RESERVOIR INFLOW DATA UNAVAILABLE.

Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

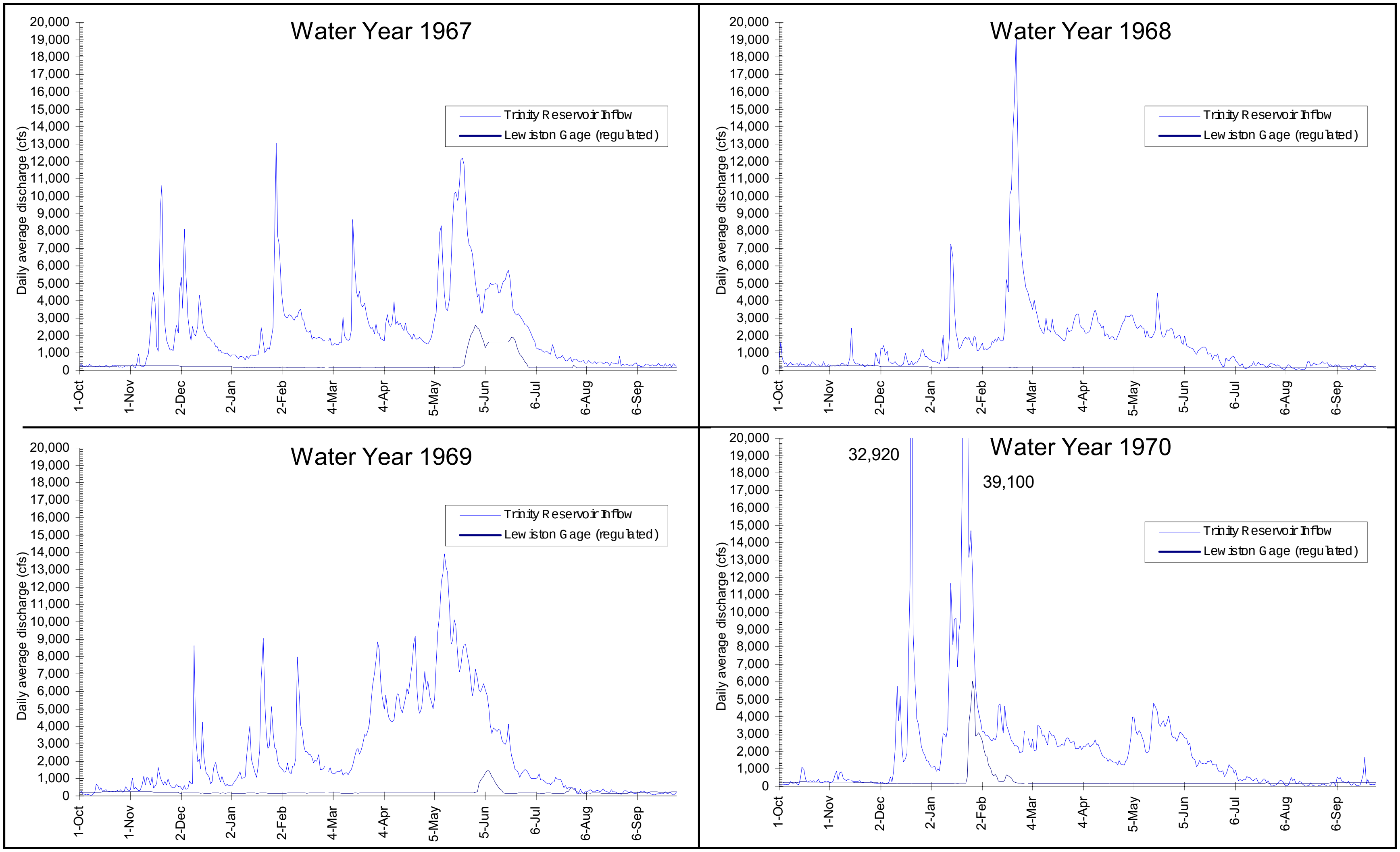


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

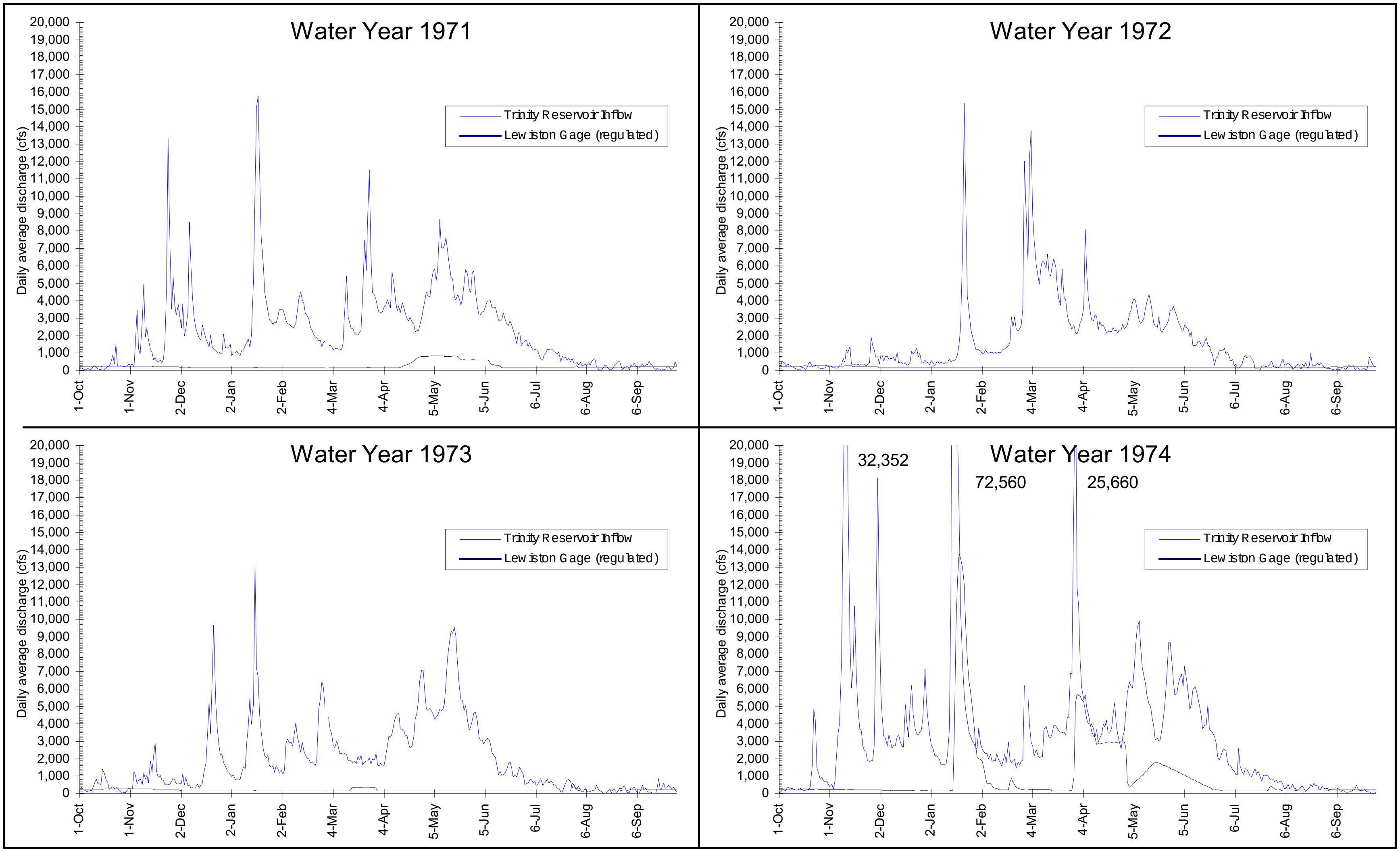


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

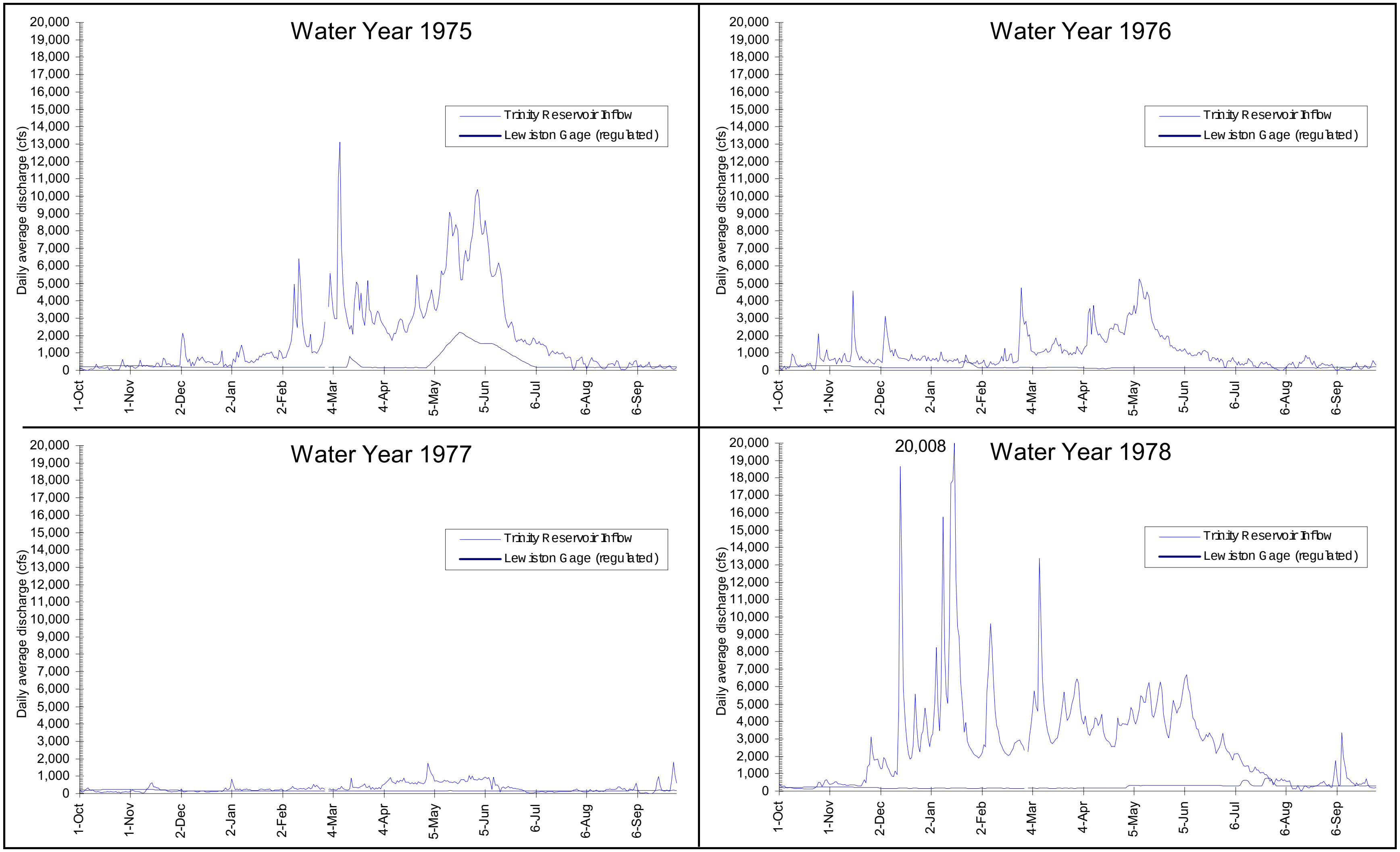


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

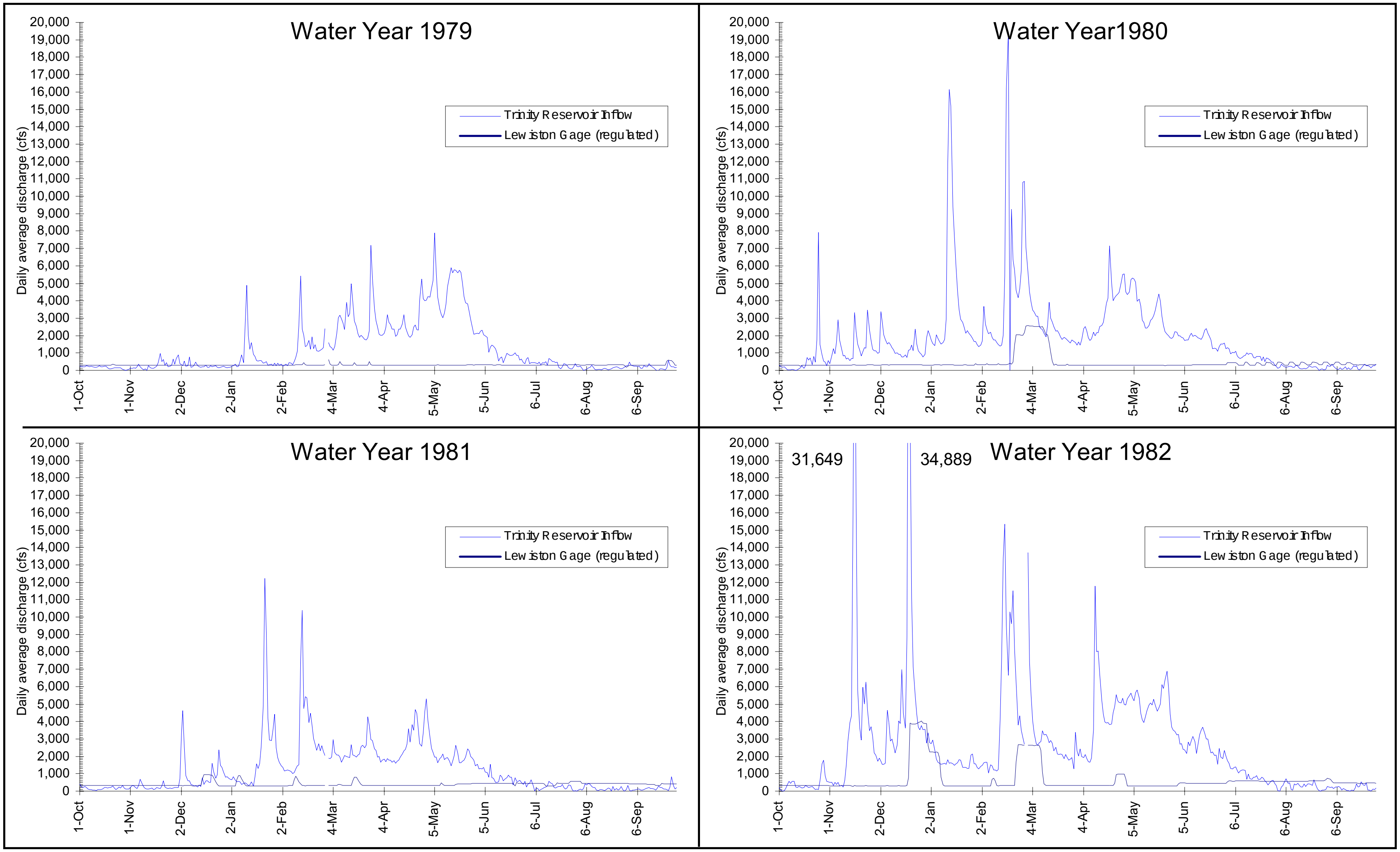


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

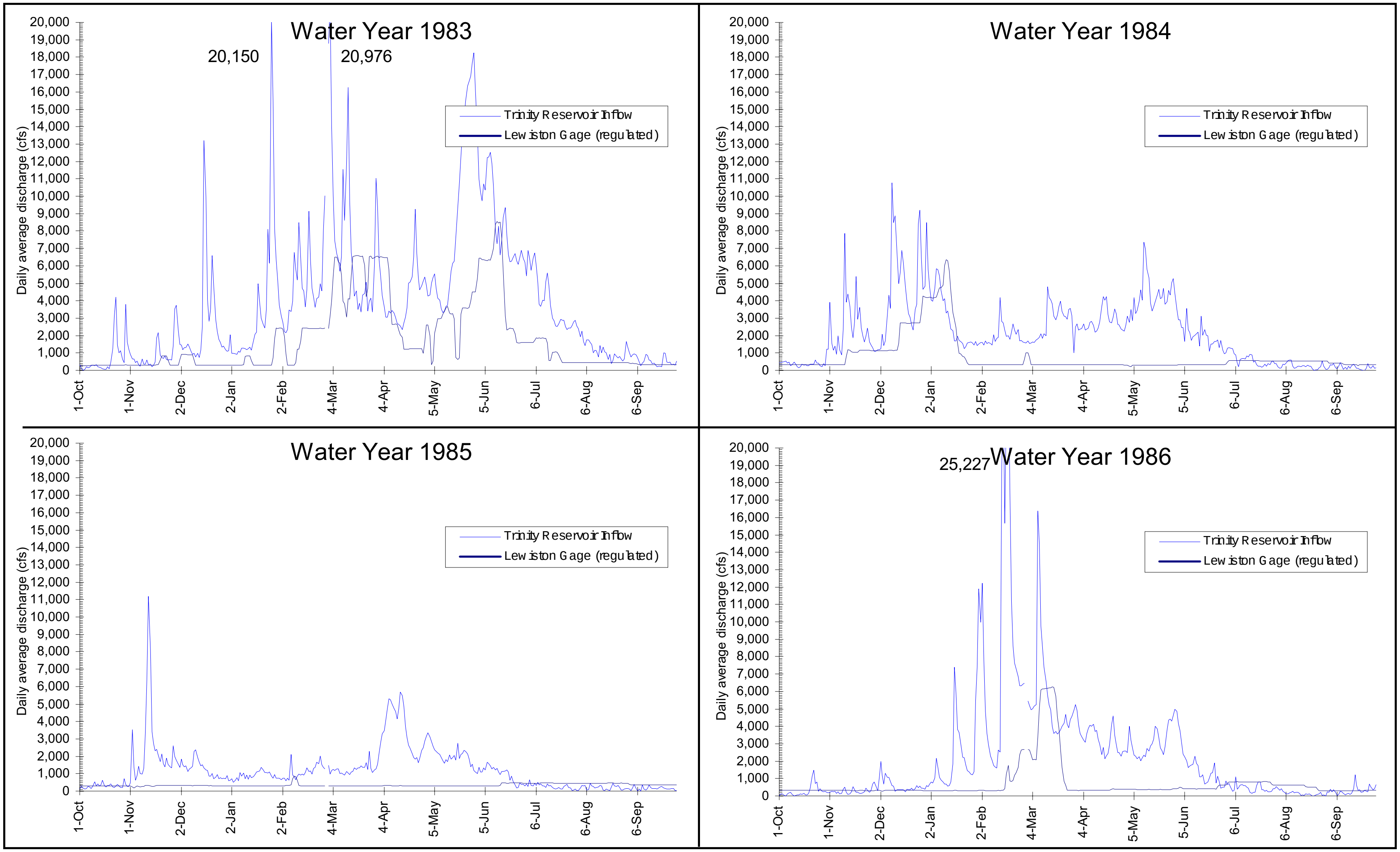


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

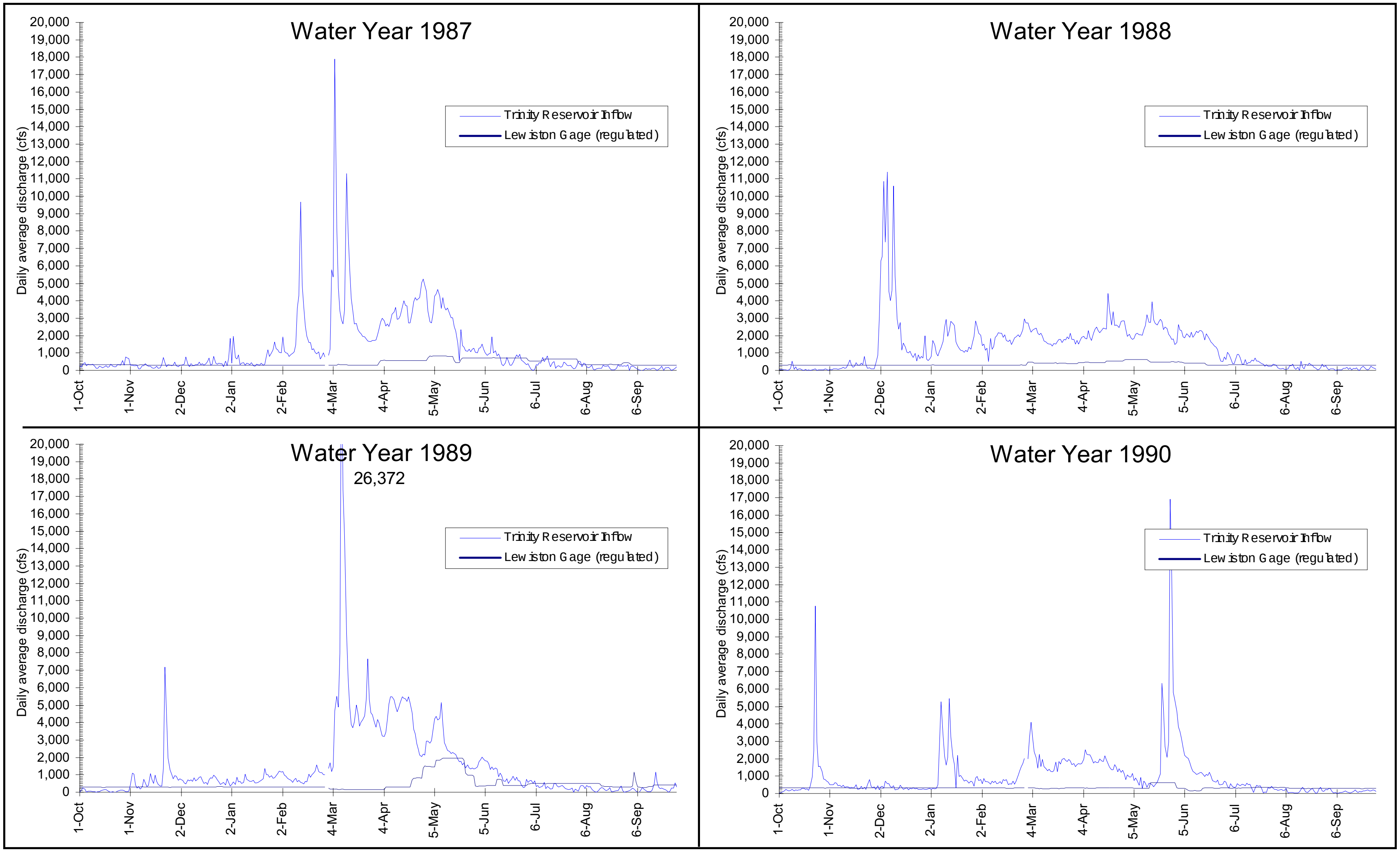


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

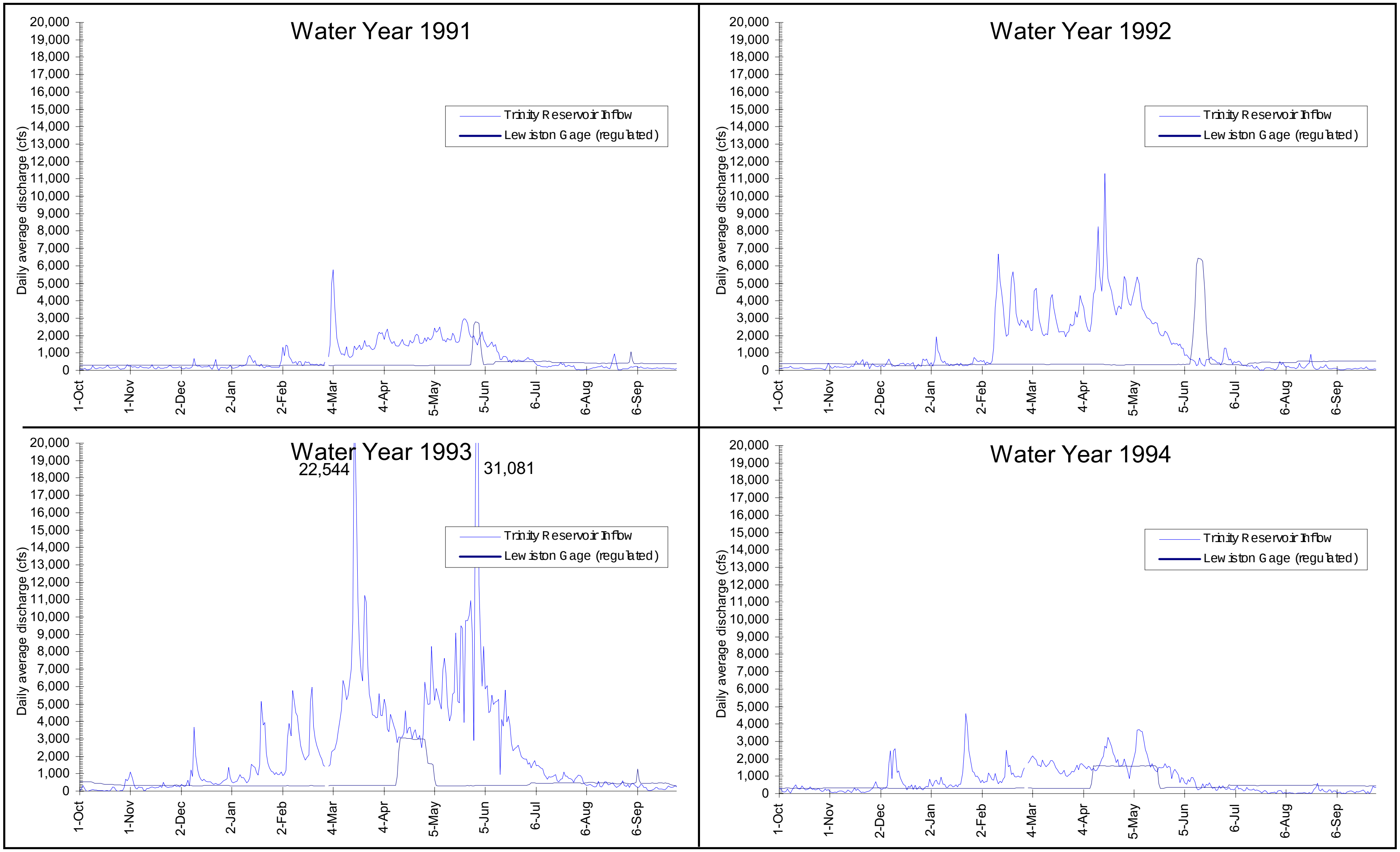


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

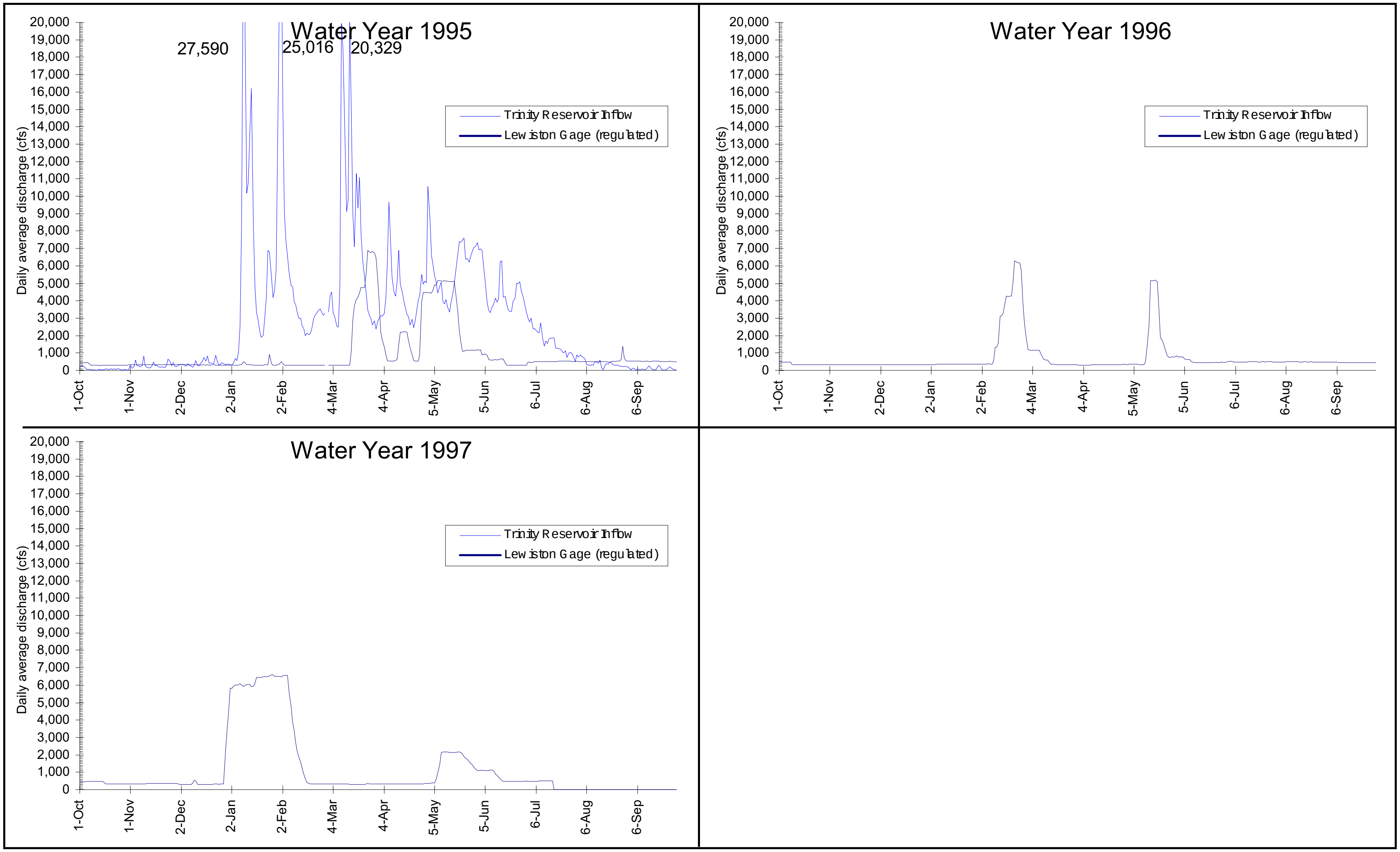


Figure A-1 continued. Trinity River at Lewiston daily average annual hydrographs for water years 1912 to 1997.

APPENDIX B
TRINITY RIVER SEDIMENT BUDGET SUPPORTING DOCUMENTATION

DEADWOOD CREEK at LEWISTON

Observations of Stage and Summary of Data Collected -- Water Year 1997

Date	Time	Gage Ht	Rising/Falling	Data Collected	Notes
12/4/96	1656	1.23	R		First significant storm of WY
12/4/96	2002	1.67	R	SS (1), BLM (1)	At culvert mouth, leaves and small amt. sand
12/4/96	2245	2.00	R	SS (1), BLM (1)	mostly leaves
12/5/96	0050	1.98	F	SS (1), BLM (1)	mostly leaves
12/5/96	0922	1.72	F		slightly murky
12/8/96	1335	1.65	R	QM	
12/29/96	0955	1.95	R		slightly murky, no bedload moving audible
12/29/96	1700	2.08	R	BLM (1)	low bedload mvmt audible in culvert
12/29/96	1730	2.10	R	QM	
12/29/96	1800	2.11	R	SS (1)	
12/30/96	1100	1.99	F	QM	
12/30/96	1130	1.97	Steady	BLM (1)	
12/31/97	1345	2.37	F	BLM (1), QM	falling limb, not very turbid
12/31/96	1420	2.35	F	SS (1)	
1/3/97	1217	1.62	F		flow clear, peak ~ 3.0-3.5
1/3/97	1630	1.44	F		flow clear, note rating shift obvious
1/6/97	1435	1.23	F		flow clear
1/22/97	1445	0.82			
1/25/97	1550	1.10	R		murky
1/26/97	1540	1.58	R	SS (1), BLM (2)	virtually nothing moving
1/31/97	1128	1.32	F	QM, BLM (2), SS (1)	no bedload movement
2/5/97	1055	1.05	Steady	QM, BLM	
2/21/97	1400	0.79/1.37		QM	new staff gage installed upstream culvert old/new
2/28/97	1832	0.73/1.32			
5/2/97	1515	0.94/1.19			summer rock dam in place d/s culvert
5/29/97	1100	1.10		QM	
7/15/97	0944	0.99(new)			new gh only.

NOTES: QM = Discharge Measurement, BLM = Bedload Measurement, SS = Suspended Sediment Measurement
(n) = Number of sample replicates collected

DEADWOOD CREEK near LEWISTON

SUSPENDED SEDIMENT LOAD SUMMARY WATER YEAR 1997

Sample #	Date	Time	Gage ht	Stage Change	Discharge	Pass	Stations	Verticals	Concentration		Total Transport Rate	Notes
		(2400 hrs)	(feet)	(R/F/S)	(cfs)	(#/total)			(mg/l)		(tons/day)	
DC 97-01	12/4/96	2001	1.67	R	21.7	1/1	-na-	4	77		4.5	At culvert outlet
DC 97-02	12/4/96	2237	2.00	R	28.5	1/1	-na-	4	120		9.2	At culvert outlet
DC 97-03	12/5/96	0055	1.98	F	28.1	1/1	-na-	4	70		5.3	At culvert outlet
DC 97-04	12/29/96	1800	2.11	R	76.7	1/1	-na-	4	24		5.0	At culvert outlet
DC 97-05	12/31/96	1420	2.35	F	98.9	1/1	-na-	4	24		6.4	At culvert outlet
DC 97-06	1/26/97	1538	1.58	steady	38.8	1/1	-na-	4	12		1.3	At culvert outlet
DC 97-07	1/31/97	1128	1.32	steady	25.4	1/1	-na-	4	2		0.1	At culvert outlet

DEADWOOD CREEK near LEWISTON

BEDLOAD MEASUREMENT SUMMARY WATER YEAR 1997

Date	Time	Gage Ht	Discharge	Rising/ Falling	Pass	Stations	Verts	Duration	Total Time	Total Width Sampled	Net Wet Weight	Net Dry Weight	Dry/Wet Ratio	Unit Rate	Width Moving Bed	Total Transport Rate
	(2400 hrs)	(feet)	(cfs)	(R/F)	(#/total)			(sec)	(sec)	(feet)	(grams)	(grams)		(g/sec/ft)	(feet)	(tons/day)
12/4/96	2002	1.67	21.7	R	1/1	1	1	120	120	0.25	40.5	23.0	0.57	0.19	3.5	0.26
12/4/96	2245	2.00	28.5	R	1/1	1	1	120	120	0.25	105.5	30.0	0.28	0.25	3.5	0.33
12/5/96	0050	1.98	28.1	F	1/1	1	1	120	120	0.25	53.5	7.5	0.14	0.06	3.5	0.08
12/29/96	1700	2.08	74.2	R	1/1	4-6.5@0.5'	6	60	360	1.5	-na-	2050.0	-na-	5.69	3.5	7.59
12/30/96	1130	1.97	65.2	Steady	1/1	3-6@0.5'	7	60	420	1.75	-na-	40.0	-na-	0.10	3.5	0.13
12/31/96	1345	2.37	100.9	F	1/1	4-6@1'	3	varies	140	0.75	-na-	200.0	-na-	1.43	3.5	1.91
1/26/97	1540	1.58	38.8	R	1/2	1	1	60	60	0.25	-na-	4.5		0.08	3.5	0.10
					2/2	1	1	60	60	0.25	-na-	6.0		0.10	3.5	0.13
1/31/97	1128	1.32	25.4	F	1/1	2-8@1'	7	30	210	1.75	-na-	0.0		0.00	0	0.0
2/5/97	1055	1.05	14.8	Steady	1/1	1-5@1'	5	30	150	1.25	-na-	0.0		0.00	0	0.0

DEADWOOD CREEK near LEWISTON

SUSPENDED SEDIMENT DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				36.21								
2				5.42								
3				1.17								
4			1.92									
5			1.78									
6			0.09									
7			0.06									
8			0.15									
9			0.46									
10			0.34									
11			0.15									
12			0.12									
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25				0.06								
26				0.58								
27				0.25								
28				0.63								
29			2.98	0.36								
30			5.04	0.25								
31			29.73	0.23								
TOTAL	0.0	0.0	42.8	45.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WATER YEAR 1997 TOTAL:			88.0									

TRINITY RIVER TRIBUTARY SEDIMENT BUDGET -- WATER YEAR 1997

Observations of Stage and Summary of Data Collected
Site: Rush Creek near Lewiston

Date	Time	Gage Ht	Rising/Falling	Data Collected	Notes
12/4/96	1650	4.75	R		First storm of WY97
12/4/96	1940	5.57	R	SS (1), BLM (2)	
12/4/96	2015	5.75	R	SS (1)	Barely wadeable
12/4/96	2220	6.15	R	SS (1), BLM (1)	Msmts not quite to center of channel
12/5/96	0040	6.18	Peak?	SS (1), BLM (1)	edge-center of channel
12/5/96	0905	5.48	F	SS (1), BLM (1)	wadeable, water much clearer
1/3/97	1155	7.05	F		still muddy, channel change u/s
1/3/97	1620	6.75	F		peak ~12-12.5?
1/6/97	1430	6.5 +/- 0.1	F		lower staff missing
1/22/97	1522	5.96	R		muddy
1/25/97	1600	6.55	R		very muddy (red)
1/26/97	1600	6.95	R	SS (1), BLM (1)	muddy, barely wadeable
1/28/97	1500	7.05	F	QM, SS (2), BLM (2)	significant shift in rating evident
2/21/97	1236	5.99/1.53	F	QM	clear water, steelhead holding at pool
					new staff gage installed at upstream
					site (old/new)
2/28/97	1817	5.91/1.48			
5/2/97	1545	5.91/1.56			download datalogger, old gh from data
5/28/97		5.82/1.40		QM	
7/15/97	1002	5.42			download datalogger, u/s gage not obs.

NOTES: QM = Discharge Measurement, BLM = Bedload Measurement, SS = Suspended Sediment Measurement

RUSH CREEK near LEWISTON

SUSPENDED SEDIMENT MEASUREMENT SUMMARY -- WY 1997

Sample #	Date	Time	Gage ht	Stage Change	Discharge	Pass	Stations	Verticals	Concentration		Total Transport Rate	Notes
		(2400 hrs)	(feet)	(R/F/S)	(cfs)	(#/total)			(mg/l)		(tons/day)	
RC 97-01	12/4/96	1940	5.57	rising	244	1/1			95		62.6	Depth Integrated
RC 97-02	12/4/96	2015	5.75	rising	306	1/1			110		90.9	Barely wadeable, Depth Integrated
RC 97-03	12/4/96	2220	6.15	rising	492	1/1			190		252.4	Not wadeable, Depth Integrated on left 1/2
RC 97-04	12/5/96	0035	6.18	rising	509	1/1			220		302.3	
RC 97-05	12/5/96	0906	5.48	falling	217	1/1			22		12.9	Wadeable, Depth Integrated
RC 97-06	12/8/96	1530	6.00	steady	413	1/1			160		178.4	
RC 97-07	12/29/96	1445	6.77	rising	970	1/1			330		864.3	D-I on left 1/4 of channel
RC 97-08	12/31/96	1600	7.80	rising	2117	1/1			1400		8002.3	D-I on left edge of channel
RC 97-09	1/26/97	1600	6.95	rising	309	1/1			310		258.6	
RC 97-10	1/28/97	1500	7.05	falling	358	1/2			170		164.3	
RC 97-11	1/28/97	1505	7.05	falling	358	2/2			170		164.3	
RC 97-12	1/31/97	1354	6.64	falling	180	1/1			79		38.4	

DEADWOOD CREEK near LEWISTON

BEDLOAD MEASUREMENT SUMMARY WATER YEAR 1997

Date	Time	Gage Ht	Discharge	Rising/ Falling	Pass	Stations	Verts	Duration	Total Time	Total Width Sampled	Net Wet Weight	Net Dry Weight	Dry/Wet Ratio	Unit Rate	Width Moving Bed	Total Transport Rate
	(2400 hrs)	(feet)	(cfs)	(R/F)	(#/total)			(sec)	(sec)	(feet)	(grams)	(grams)		(g/sec/ft)	(feet)	(tons/day)
12/4/96	2002	1.67	21.7	R	1/1	1	1	120	120	0.25	40.5	23.0	0.57	0.19	3.5	0.26
12/4/96	2245	2.00	28.5	R	1/1	1	1	120	120	0.25	105.5	30.0	0.28	0.25	3.5	0.33
12/5/96	0050	1.98	28.1	F	1/1	1	1	120	120	0.25	53.5	7.5	0.14	0.06	3.5	0.08
12/29/96	1700	2.08	74.2	R	1/1	4-6.5@0.5'	6	60	360	1.5	-na-	2050.0	-na-	5.69	3.5	7.59
12/30/96	1130	1.97	65.2	Steady	1/1	3-6@0.5'	7	60	420	1.75	-na-	40.0	-na-	0.10	3.5	0.13
12/31/96	1345	2.37	100.9	F	1/1	4-6@1'	3	varies	140	0.75	-na-	200.0	-na-	1.43	3.5	1.91
1/26/97	1540	1.58	38.8	R	1/2	1	1	60	60	0.25	-na-	4.5		0.08	3.5	0.10
					2/2	1	1	60	60	0.25	-na-	6.0		0.10	3.5	0.13
1/31/97	1128	1.32	25.4	F	1/1	2-8@1'	7	30	210	1.75	-na-	0.0		0.00	0	0.0
2/5/97	1055	1.05	14.8	Steady	1/1	1-5@1'	5	30	150	1.25	-na-	0.0		0.00	0	0.0

RUSH CREEK near LEWISTON

SUSPENDED SEDIMENT DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	3.6	14486.5	14.7	0.4	0.5	1.2	0.0	0.0		
2	0.0	0.0	1.6	3432.8	9.3	0.7	0.5	1.0	0.0	0.0		
3	0.0	0.0	1.3	327.3	6.4	0.5	0.4	1.3	0.0	0.0		
4	0.0	0.0	21.9	45.0	4.9	0.4	0.4	1.1	0.0	0.0		
5	0.0	0.0	66.7	18.5	3.5	0.4	0.4	1.2	0.0	0.0		
6	0.0	0.0	7.0	8.7	2.7	0.4	0.4	1.0	0.0	0.0		
7	0.0	0.0	14.1	4.9	2.2	0.4	0.3	0.8	0.0	0.0		
8	0.0	0.0	170.3	3.2	1.8	0.4	0.3	0.9	0.0	0.0		
9	0.0	0.0	891.3	2.3	1.6	0.4	0.3	0.9	0.0	0.0		
10	0.0	0.0	323.2	1.8	1.4	0.4	0.3	1.8	0.0	0.0		
11	0.0	0.0	45.8	1.4	1.2	0.4	0.3	1.8	0.0	0.0		
12	0.0	0.0	23.4	1.1	1.0	0.4	0.3	1.5	0.0	0.0		
13	0.0	0.0	12.2	0.9	0.9	0.3	0.3	1.5	0.0	0.0		
14	0.0	0.0	5.7	0.7	0.8	0.3	0.3	1.3	0.0	0.0		
15	0.0	0.0	3.3	0.6	0.7	0.4	0.4	1.1	0.0			
16	0.0	0.0	2.3	0.5	0.6	1.5	0.8	1.1	0.0			
17	0.0	0.7	1.8	0.7	0.6	1.3	0.8	1.1	0.0			
18	0.0	31.0	1.4	0.6	0.5	0.9	9.2	0.9	0.0			
19	0.0	59.2	1.1	0.5	0.6	0.9	14.7	0.7	0.0			
20	0.0	17.1	1.2	0.4	0.6	1.8	46.0	0.5	0.0			
21	0.0	5.1	1.4	0.5	0.5	2.0	11.1	0.4	0.0			
22	0.0	5.4	1.3	0.5	0.6	1.5	9.7	0.3	0.0			
23	0.0	3.7	1.2	0.4	0.6	1.7	12.4	0.2	0.0			
24	0.0	2.3	1.1	0.5	0.5	1.7	3.7	0.2	0.0			
25	0.0	1.9	1.2	8.3	0.5	1.7	2.9	0.1	0.0			
26	0.0	1.4	10.7	140.7	0.5	2.0	3.4	0.1	0.0			
27	0.0	1.1	14.4	50.6	0.5	1.9	3.5	0.0	0.0			
28	0.0	1.1	21.4	106.3	0.5	1.2	2.2	0.0	0.0			
29	0.0	1.0	352.3	41.6		0.9	1.4	0.0	0.0			
30	0.0	0.9	1596.6	18.9		0.8	1.4	0.0	0.0			
31	0.0		7819.2	15.8		0.7		0.0				
TOTAL	0.0	132.0	11420.1	18722.6	60.4	28.8	128.6	24.0	0.0	0.0	0.0	0.0
WATER YEAR 1997 TOTAL:			30516.6									

RUSH CREEK near LEWISTON

BEDLOAD DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				18,550	15							
2				5,345	6.3							
3				585	2.5							
4			7.9	71	1.0							
5			23	21	0.1							
6				5.5								
7			1.1	1.1								
8			88	0.1								
9			725									
10			201									
11			8.3									
12			1.1									
13												
14												
15												
16												
17												
18		4.6					11					
19		16.8					16					
20		0.7					74					
21							9.0					
22							8.4					
23							12.4					
24							0.3					
25				6.2			0.0					
26				254			0.2					
27				82			0.3					
28			1.1	189								
29			246	65								
30			2,190	22								
31			5,844	17								
TOTAL	0.0	22	9,337	25,213	25	0.0	131	0.0	0.0	0.0	0.0	0.0

WATER YEAR 1997 TOTAL: 34,728

INDIAN CREEK near DOUGLAS CITY

Observations of Stage and Summary of Data Collected -- WY 1997

Date	Time	Gage Ht	Rising/Falling	Data Collected	Notes
12/7/96	1535	1.32	R	QM	Staff gage installed
12/8/96	0945	1.59	R	QM	
12/30/96	0927	2.44	R	QM	
12/30/96	1030	2.47	R	BLM (1), SS (1)	
12/30/96	1455	2.77	R	QM	
12/30/96	1545	2.90	R	BLM (1), SS (1)	
12/31/96	1630	4.05	R	SS (1)	
1/3/97	1255	3.12	F		muddy, peak at ~8
1/3/97	1650	2.83	F		
1/22/97	1420	2.00	Steady		
1/25/97	0801	2.05	R		muddy
1/25/97	1230	2.10	R		muddy
1/26/97	1315	2.75	R	QM, SS (2), BLM (2)	shift in rating evident
1/27/97	1730	2.63	F		peak on 1/26 from csg=2.81
1/28/97	1125	2.80	F	QM, SS (2), BLM (4)	lots of bedload moving
1/29/97	1645	2.65	F		
1/31/97	1046	2.44	F	QM, SS	
2/5/97	1325	2.20	F	QM	
2/17/97	1600	1.91	F	QM	section at gage
2/28/97	1852	1.75	F		
3/5/97	1330	1.71			
3/26/97	1550	1.65			download datalogger
5/2/97	1629	1.51			download datalogger, adjust offset 0.04
5/29/97	0900	1.38		QM	
7/15/97	0900	1.18			download datalogger, offset ok

NOTES: QM = Discharge Measurement, BLM = Bedload Measurement, SS = Suspended Sediment Measurement
(n) = Number of sample replicates collected

INDIAN CREEK near DOUGLAS CITY

SUSPENDED SEDIMENT LOAD SUMMARY WATER YEAR 1997

Sample #	Date	Time (2400 hrs)	Gage ht (feet)	Stage Change (R/F/S)	Discharge (cfs)	Pass (#/total)	Stations	Verticals	Concentration (mg/l)		Total Transport Rate (tons/day)	Notes
IC 97-01	12/30/06	1015	2.50	rising	311	1/1			42		35.3	
IC 97-02	12/30/96	1550	2.95	rising	521	1/1			210		295.4	
IC 97-03	12/31/96	1630	4.05	rising	1077	1/1			1200		3489.5	grab sample at large upwelling 10' d/s gage
IC 97-04	1/26/97	1315	2.75	rising	250	1/2	12-30 @ 2'	10	300		202.5	Section ~ 40' d/s gage
IC 97-05	1/26/97	1320	2.75	rising	250	2/2	12-30 @ 2'	10	260		175.5	Q Section ~ 200' u/s gage
IC 97-06	1/28/97	1120	2.78	falling	262	1/2	12-42 @ 2'	16	120		84.9	Q Section ~ 200' u/s gage
IC 97-07	1/28/97	1325	2.78	falling	262	2/2	12-42 @ 2'	16	150		106.1	Q Section ~ 200' u/s gage
IC 97-08	1/31/97	1046	2.44	falling	150	1/1	12-42 @ 2'	16	33		13.4	Q Section ~ 200' u/s gage

INDIAN CREEK near DOUGLAS CITY

BEDLOAD SUMMARY WATER YEAR 1997

Date	Time	Gage Ht	Discharge	Rising/ Falling	Pass	Stations	Verticals	Duration	Total Time	Total Width Sampled	Net Wet Weight	Net Dry Weight	Dry/Wet Ratio	Unit Rate	Width Moving Bed	Total Transport Rate
	(2400 hrs)	(feet)	(cfs)	(R/F)	(#/total)			(sec)	(sec)	(feet)	(grams)	(grams)		(g/sec/ft)	(feet)	(tons/day)
12/30/96	1030	2.47	299	R	1/1	13-33 @ 4'	6	60	360	1.5	-na-	2950.0	-na-	8.19	24	74.9
12/30/96	1545	2.90	497	R	1/1	14-39 @ 5'	6	60	360	1.5	-na-	9950.0	-na-	27.64	34	358.0
1/26/97		2.75	250	R	1/2	12-26 @ 2'	8	30	240	2	27203.5	26233.0	0.964	109.30	19	791.3
			250		2/2		8	30	240	2	24051	20827.5	0.866	86.78	19	628.2
1/28/97	1125-1145	2.78-2.80	270	F	1/4	12-42 @ 2'	16	30	480	4	34088	31178.0	0.915	64.95	31	767.2
	1150-1205	2.8 @ 1206	270		2/4		16	30	480	4	13507	12156.0	0.900	25.33	31	299.1
	1205-1220		270		3/4		16	30	480	4	27285	24557.0	0.900	51.16	31	604.3
	1220-1235		270		4/4		16	30	480	4	32938	29644.0	0.900	61.76	31	729.4
1/31/97		2.44	149.5	F	1/2	11.5-34 @ 1.5'	16	30	480	4	7400	6660.0	0.900	13.88	23	121.6
			149.5		2/2		16	30	480	4	5039	4535.0	0.900	9.45	23	82.8
2/5/97	1409-1417	2.20	95.7	F	1/1	7-35 @ 2'	15	30	450	3.75	442.5	399.5	0.903	0.89	29	9.8

INDIAN CREEK near DOUGLAS CITY

SUSPENDED SEDIMENT DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				3754.9	27.9	0.8						
2				626.9	19.9	1.0						
3			0.1	323.1	14.6	0.8						
4			0.8	159.2	11.7	0.7						
5			1.8	84.5	9.0	0.7						
6			0.4		7.3	0.6						
7			1.7		6.2	0.6						
8			5.5		5.2	0.6						
9			174.3		4.7	0.5						
10			216.1		4.2	0.5						
11			37.6		3.6	0.5						
12			15.3		3.2	0.4						
13					2.8	0.4						
14					2.5	0.4						
15					2.2	0.4						
16					2.1	1.0						
17					2.1	1.1						
18					1.8	0.7						
19					1.8	0.7						
20					1.5	0.6						
21					1.4	0.6						
22					1.3	0.6						
23					1.2	0.6						
24					1.1	0.5						
25				6.3	1.0	0.5						
26			3.5	64.2	1.0	0.5						
27			4.3	62.4	0.9	0.5						
28			5.6	68.2	0.9	0.4						
29			161.3	45.7		0.4						
30			391.6	27.0		0.4						
31			1712.8	27.0		0.4						
TOTAL	0.0	0.0	2732.9	5249.4	142.9	18.4	0.0	0.0	0.0	0.0	0.0	0.0
WATER YEAR 1997 TOTAL:			8143.7									

INDIAN CREEK near DOUGLAS CITY

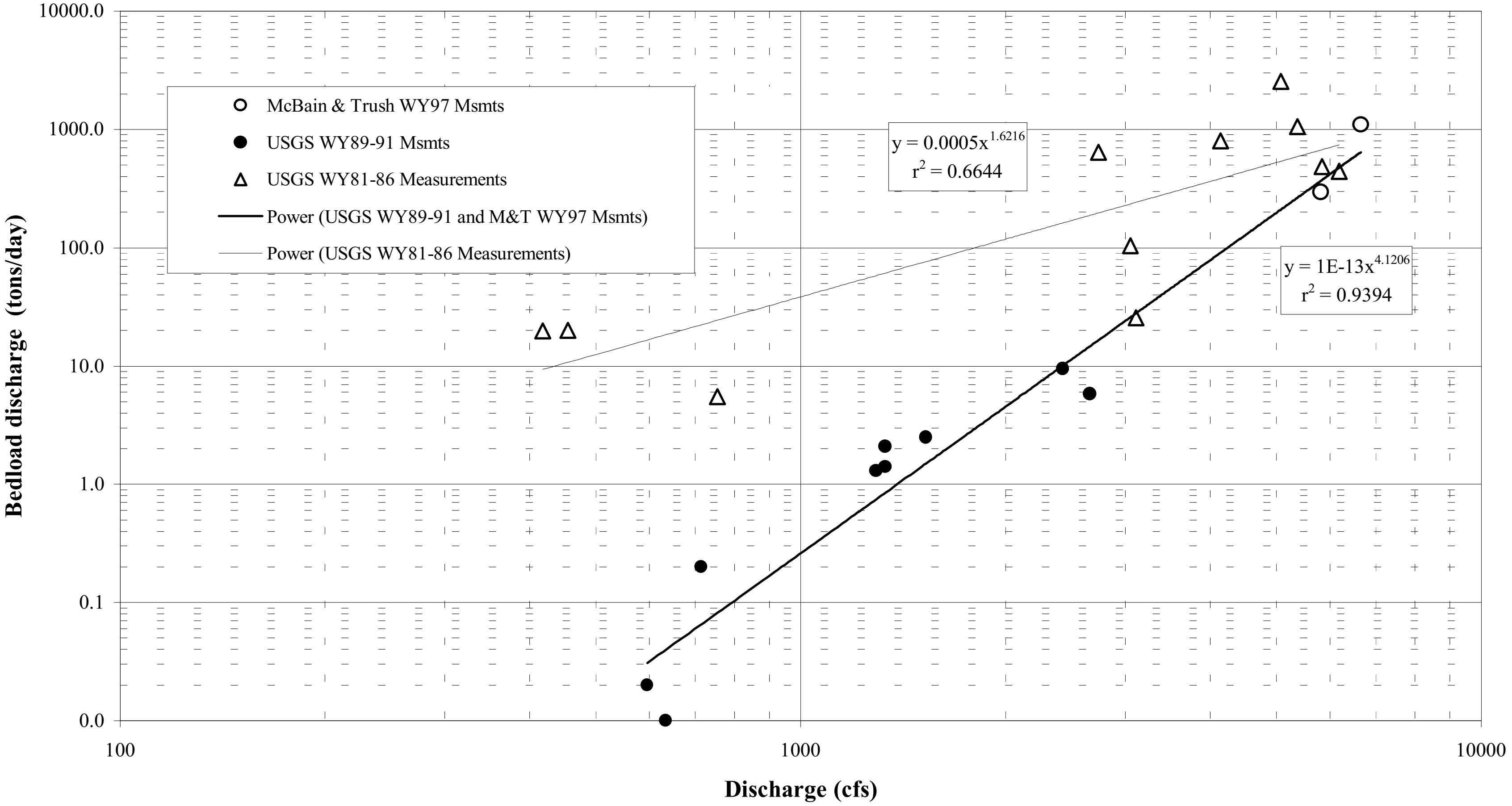
BEDLOAD DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				16,540	136							
2				8,081	78							
3				3,680	45							
4			0.2	1,529	31							
5			0.5	671	18							
6			0.1		11							
7			0.4		7.3							
8			1.8		4.5							
9			145		3.3							
10			183		2.2							
11			20		1.3							
12			6.3		0.8							
13					0.4							
14					0.2							
15					0.1							
16					0.1							
17					0.1							
18												
19												
20												
21												
22												
23												
24												
25				11								
26			1.0	476								
27			1.3	447								
28			1.8	503								
29			136	286								
30			451	129								
31			2,714	130								
TOTAL	0.0	0.0	3,662	32,483	339	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WATER YEAR 1997 TOTAL: **36,484**

TRINITY RIVER below LIMEKILN GULCH, near DOUGLAS CITY

Bedload Transport -- WY 1997 and USGS Data WY81-91



TRINITY RIVER at LEWISTON

BEDLOAD DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				465	888							
2				454	948							
3				504	966							
4				545	966							
5				551	966							
6				569	346							
7				595	89							
8				551	5							
9				515								
10				539								
11				557								
12				569								
13				569								
14				515								
15				515								
16				627								
17				864								
18				856								
19				864								
20				872								
21				897								
22				905								
23				897								
24				905								
25				939								
26				1,001								
27				992								
28				922								
29				905								
30			0.1	905								
31			51	905								
TOTAL	0.0	0.0	51	22,271	5,173	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WATER YEAR 1997 TOTAL: **27,495**

TRINITY RIVER below LIMEKILN GULCH near DOUGLAS CITY

BEDLOAD DISCHARGE (tons/day), WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				4,205	861							
2				1,303	881							
3				897	879							
4				776	870							
5				704	859							
6				670	413							
7				658	178							
8				606	50							
9			0.8	566	19							
10			0.6	574	2							
11			0.1	583								
12				586								
13				581								
14				537								
15				533								
16				609								
17				769								
18				760								
19				762								
20				765								
21				782								
22				788								
23				778								
24				784								
25				858								
26				1,093								
27				1,090								
28				1,067								
29			7	892								
30			174	897								
31			2,224	897								
TOTAL	0.0	0.0	2,405	27,370	5,014	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WATER YEAR 1997 TOTAL: **34,789**

APPENDIX C

CROSS SECTION AND LONGITUDINAL WATER SURFACE PROFILE PLOTS FOR ALL BANK REHABILITATION SITES

Figure C-1 - see Plate 12

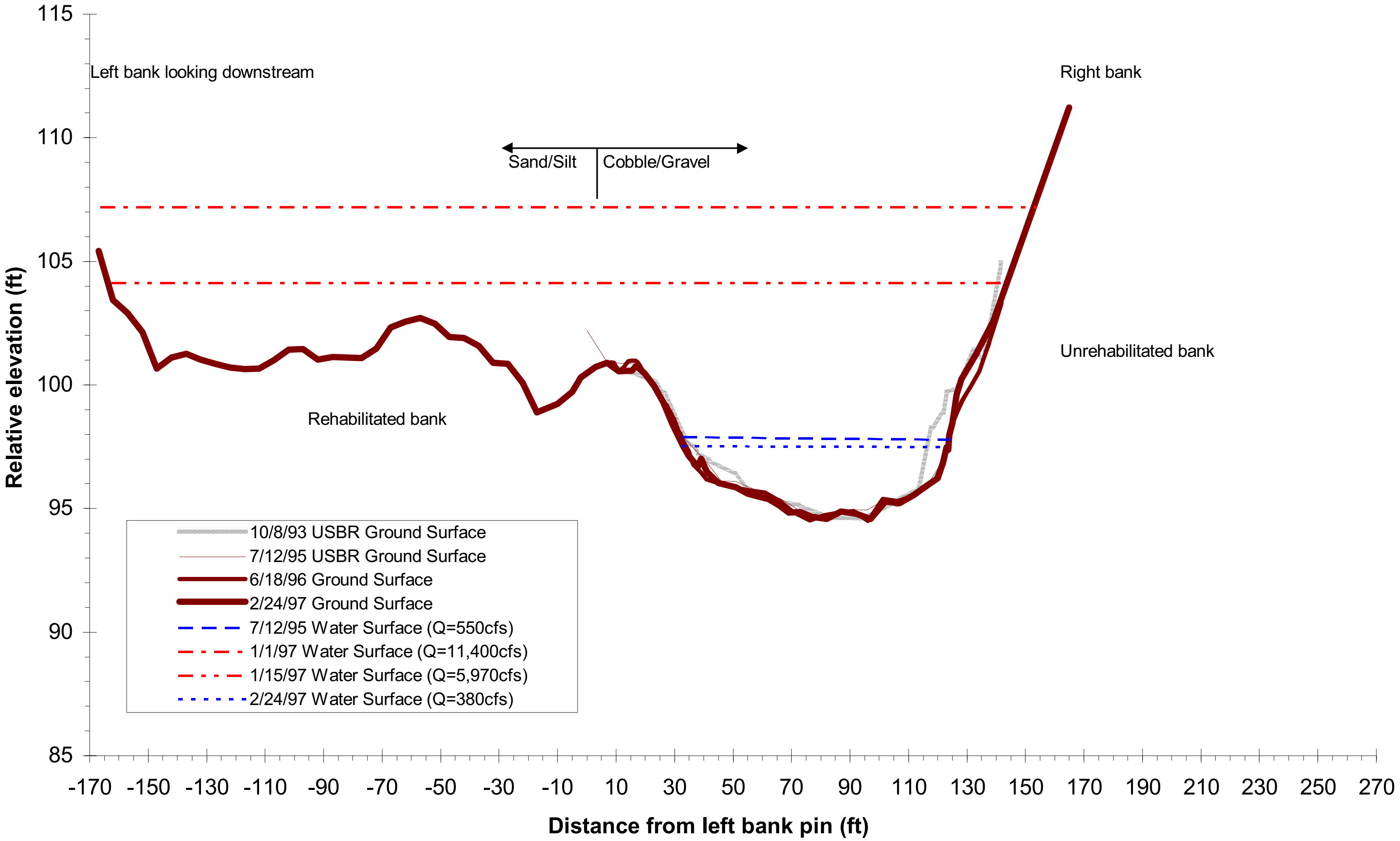


Figure C-2 Ground surface profiles and water surface elevations at cross section 10+00, Bucktail rehabilitation site.

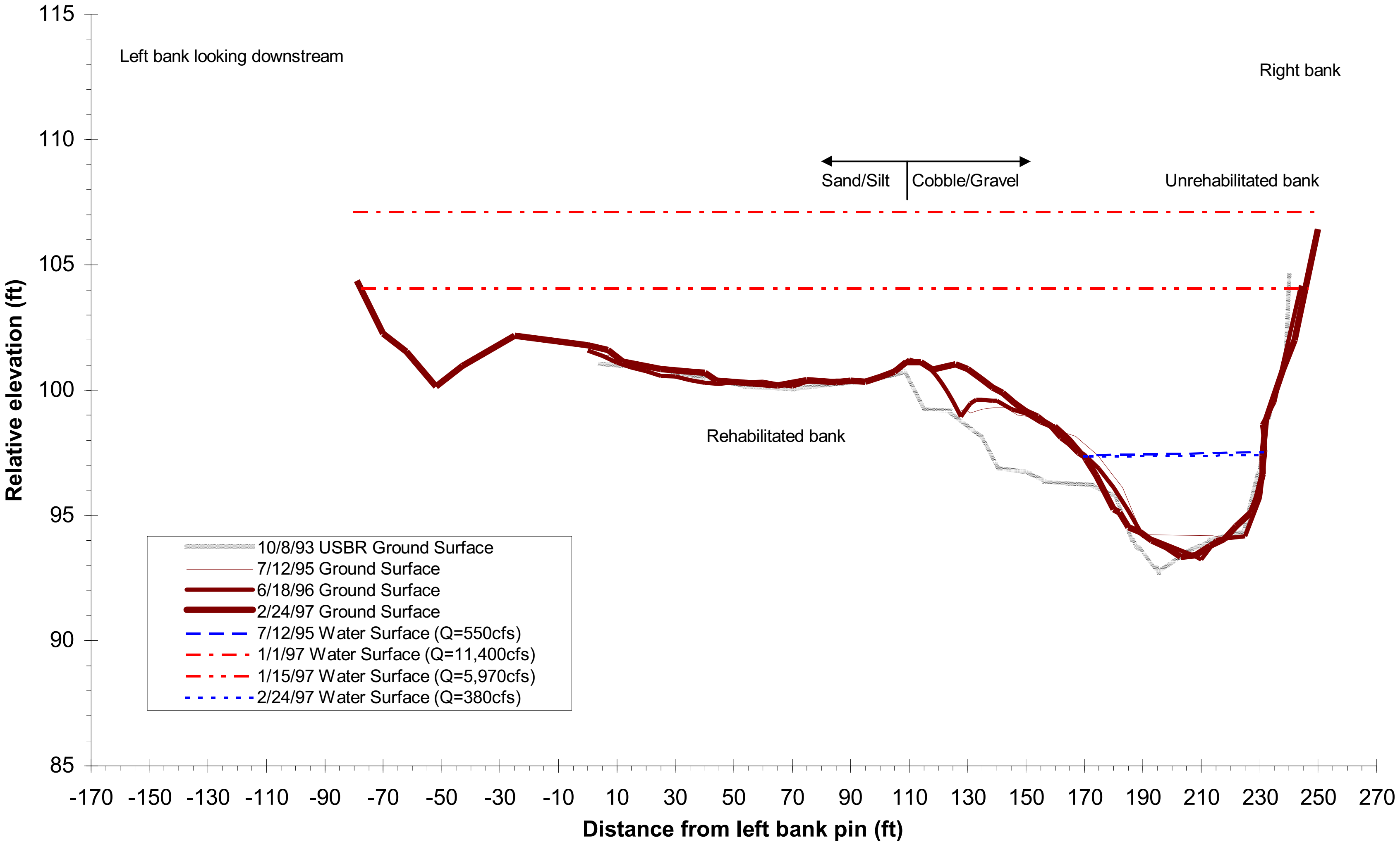


Figure C-3 Ground surface profiles and water surface elevations at cross section 11+00, Bucktail rehabilitation site. Note the continued bar development along the left bank at this section.

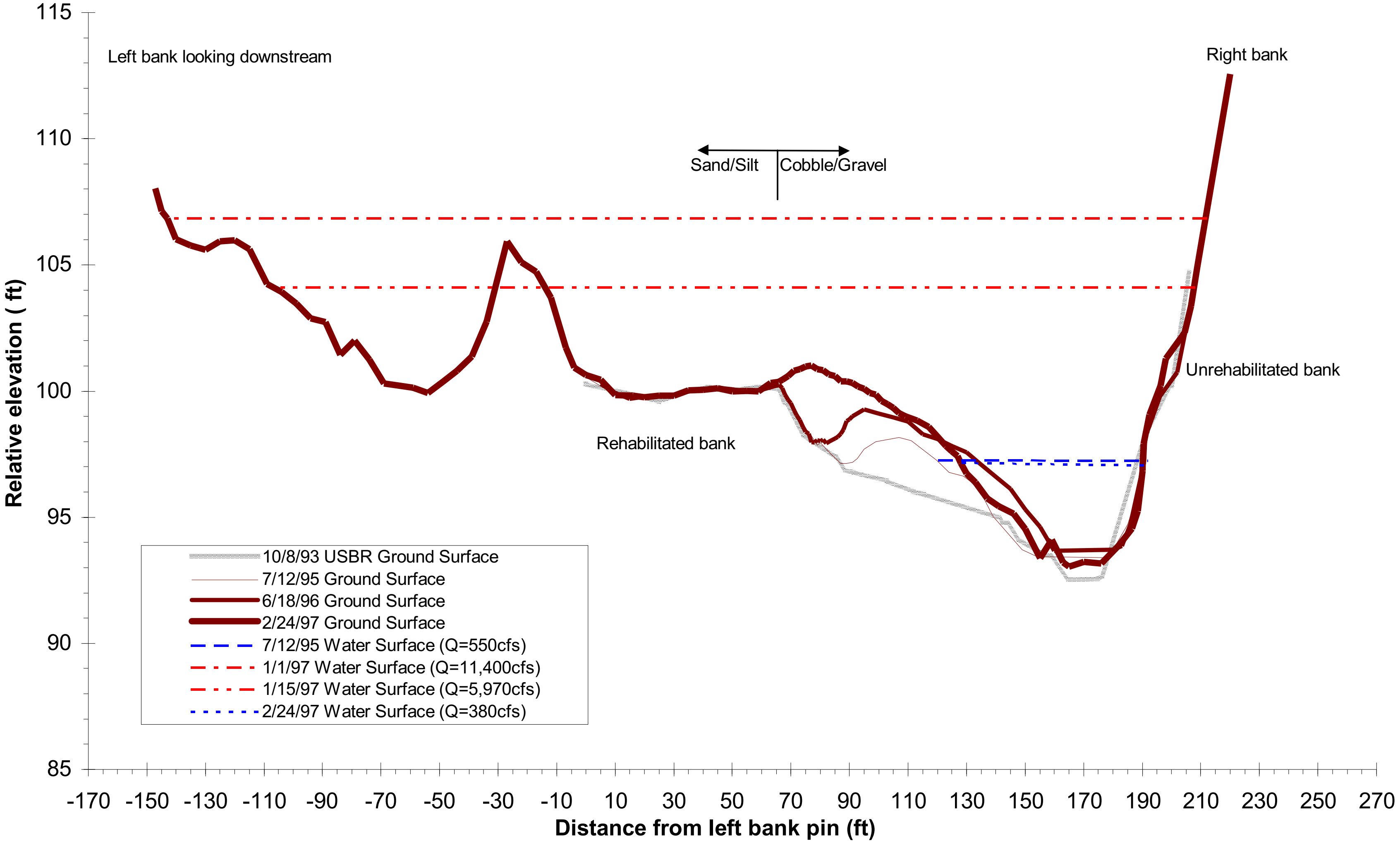


Figure C-4 Ground surface profiles and water surface elevations at cross section 12+00, Bucktail rehabilitation site. Note the continued bar development along the left bank at this section similar to cross section 11+00.

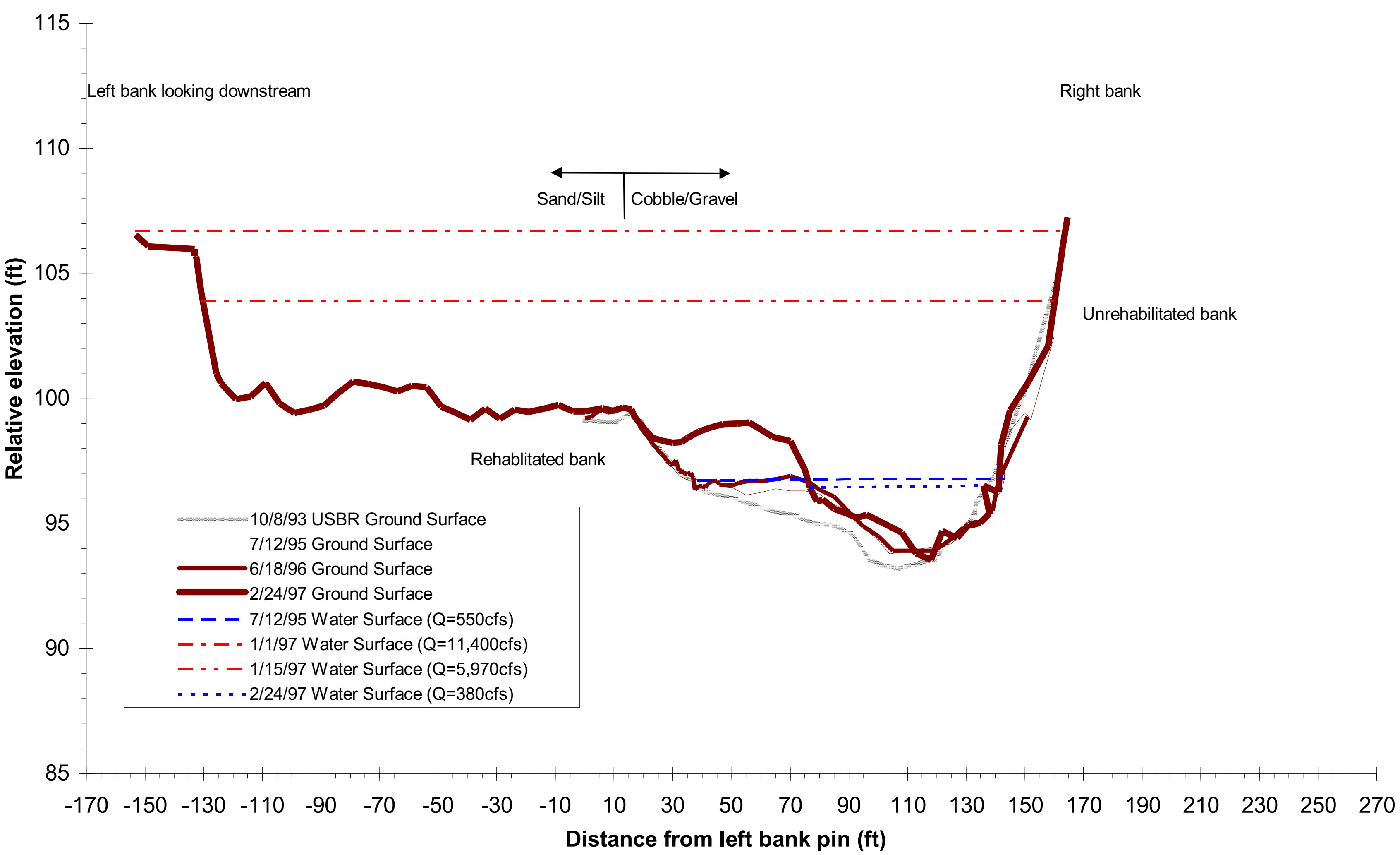


Figure C-5 Ground surface profiles and water surface elevations at cross section 13+00, Bucktail rehabilitation site. Bar development continued here as the bar extended downstream from cross section 12+00.

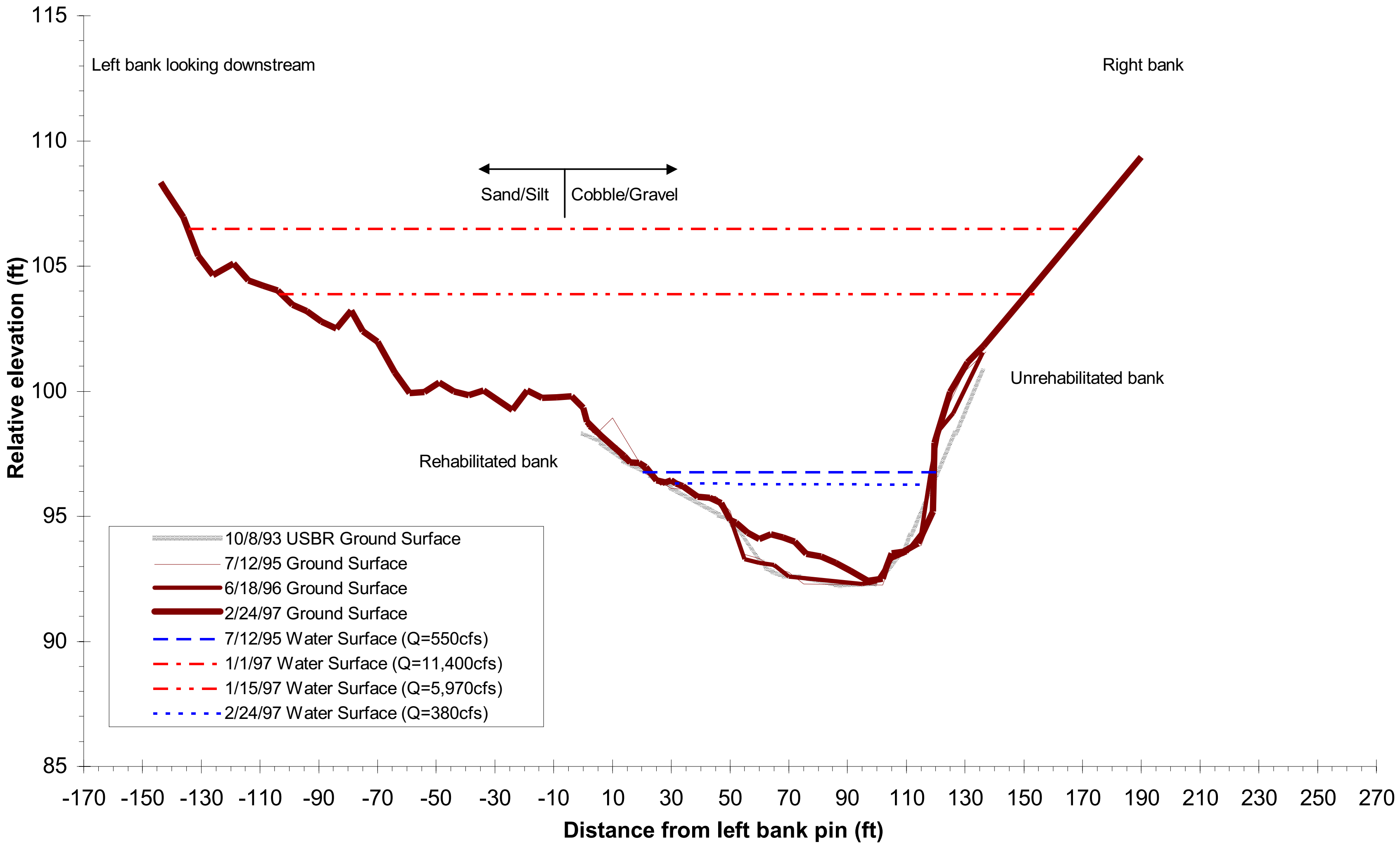


Figure C-6 Ground surface profiles and water surface elevations at cross section 14+00, Bucktail rehabilitation site. There was not as much bar development here as in upstream cross sections but some aggradation did occur in 1997.

Figure C-7 - see Plate 13

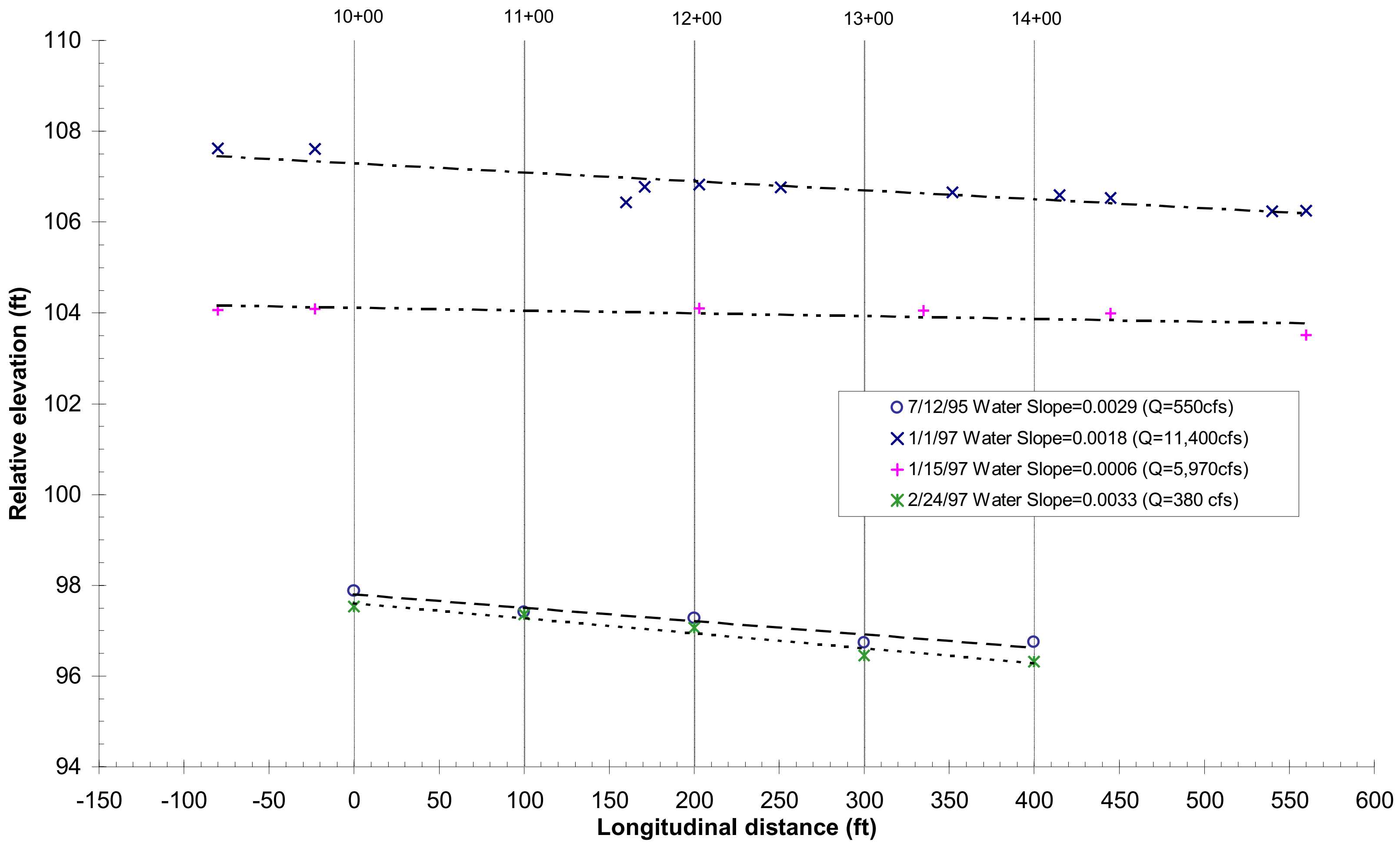


Figure C-8 Longitudinal water surface profiles for the Bucktail rehabilitation site.

Figure C-9 - see Plate 14

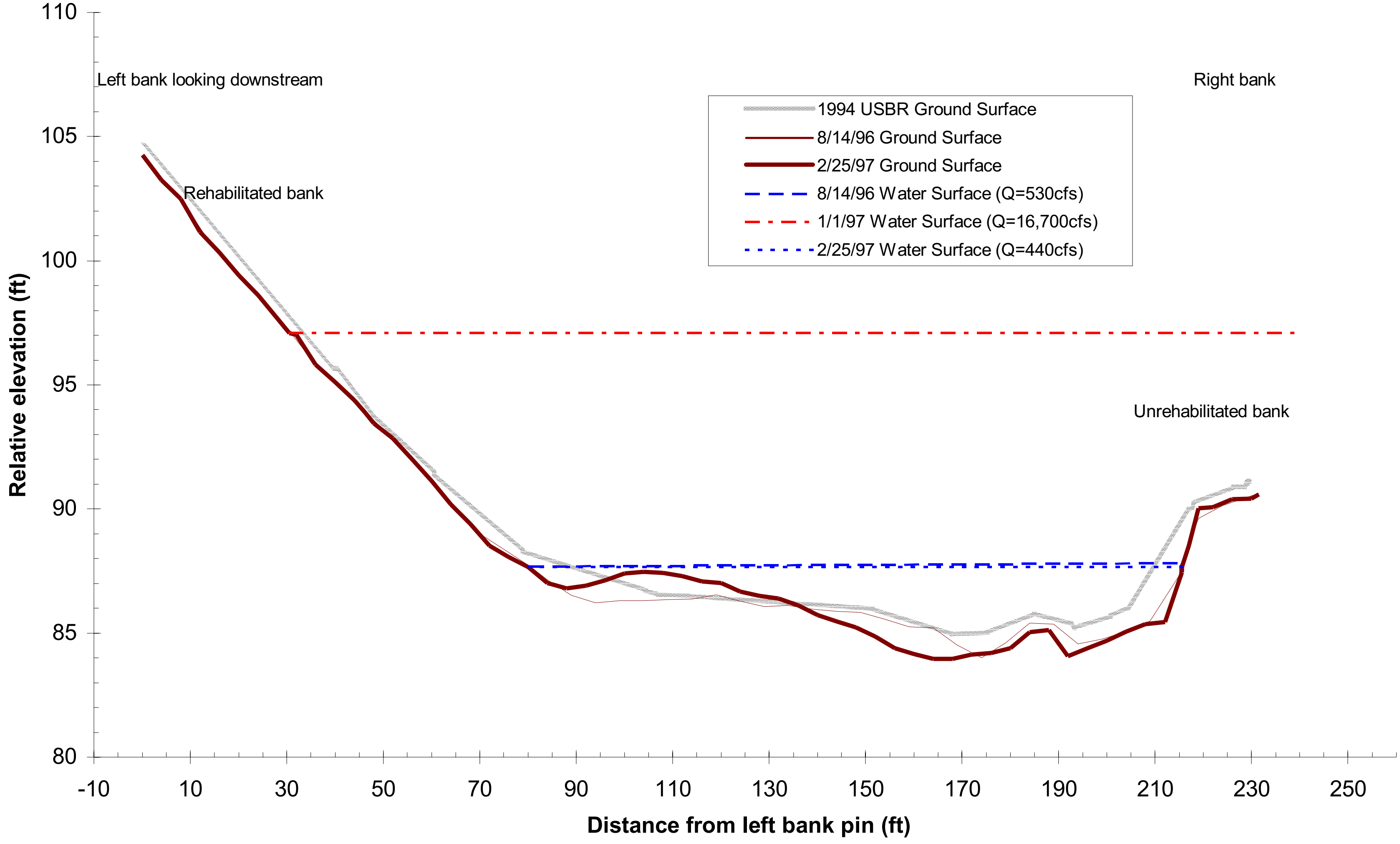


Figure C-10 Ground surface profiles and water surface elevations at cross section 10+00, Limekiln rehabilitation site. Note the subtle bar development along the left bank.

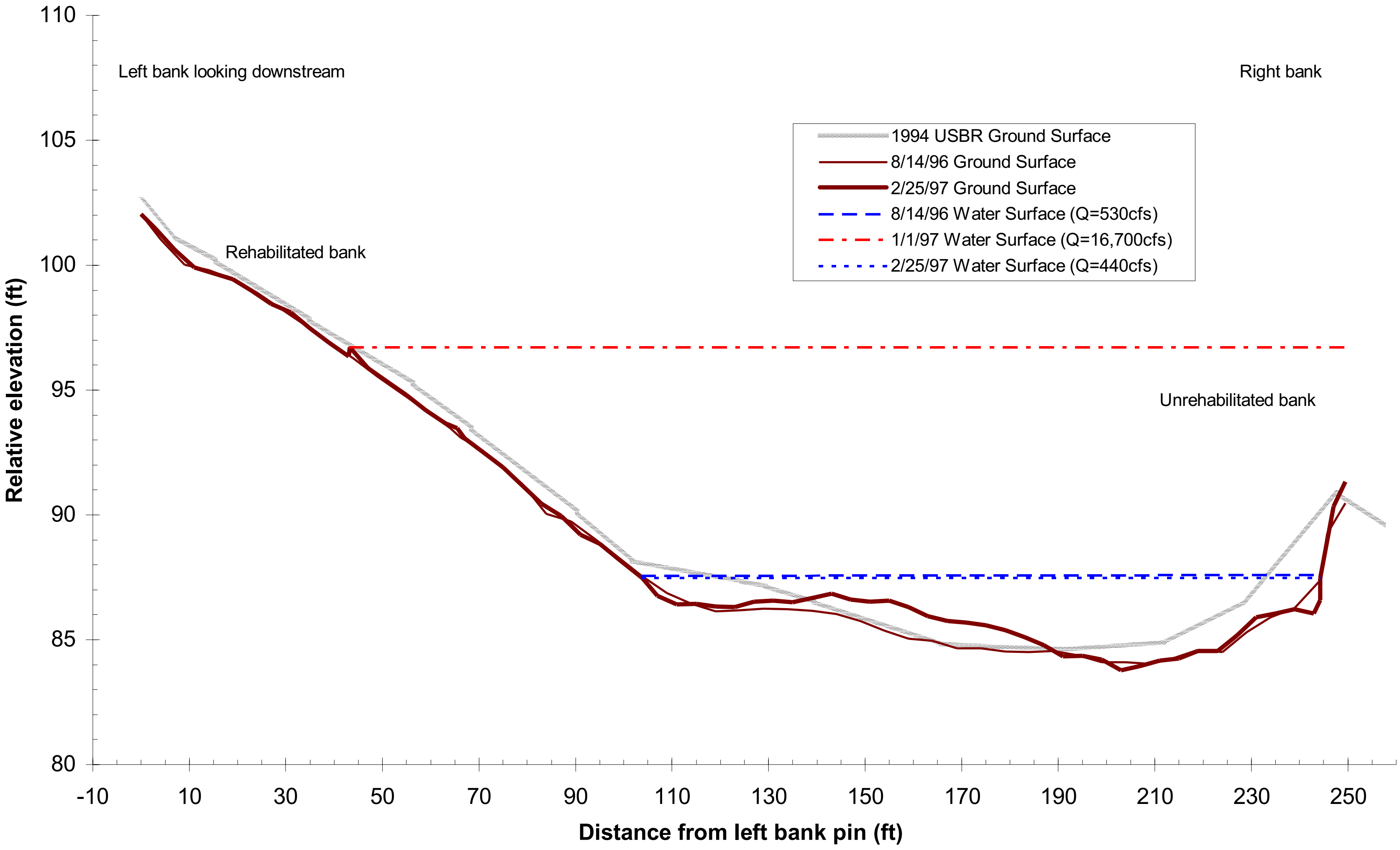


Figure C-11 Ground surface profiles and water surface elevations at cross section 11+86, Limekiln rehabilitation site. Aggradation along the left bank resulted in the development of a bar below the low water surface.

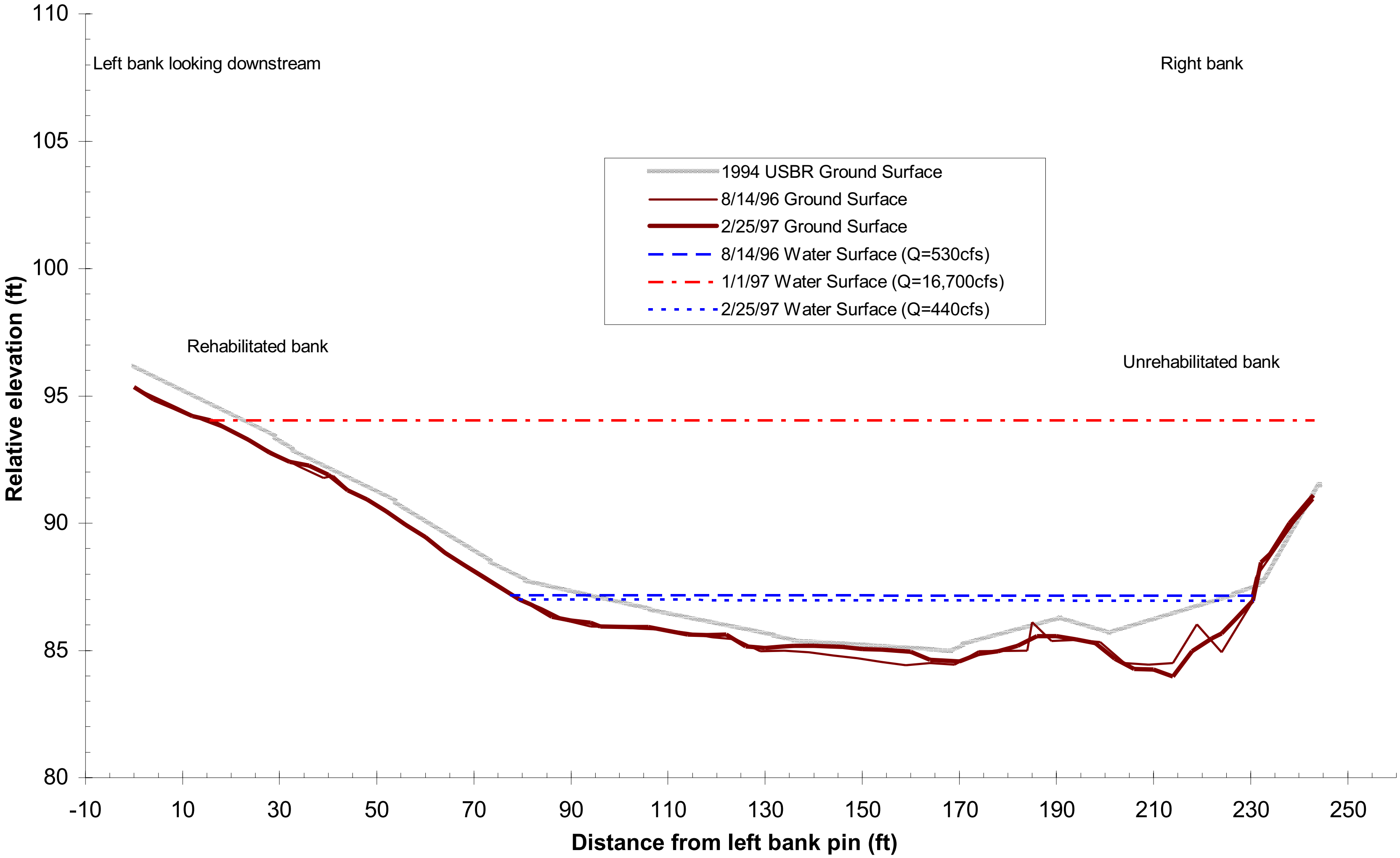


Figure C-12 Ground surface profiles and water surface elevations at cross section 14+85, Limekiln rehabilitation site.

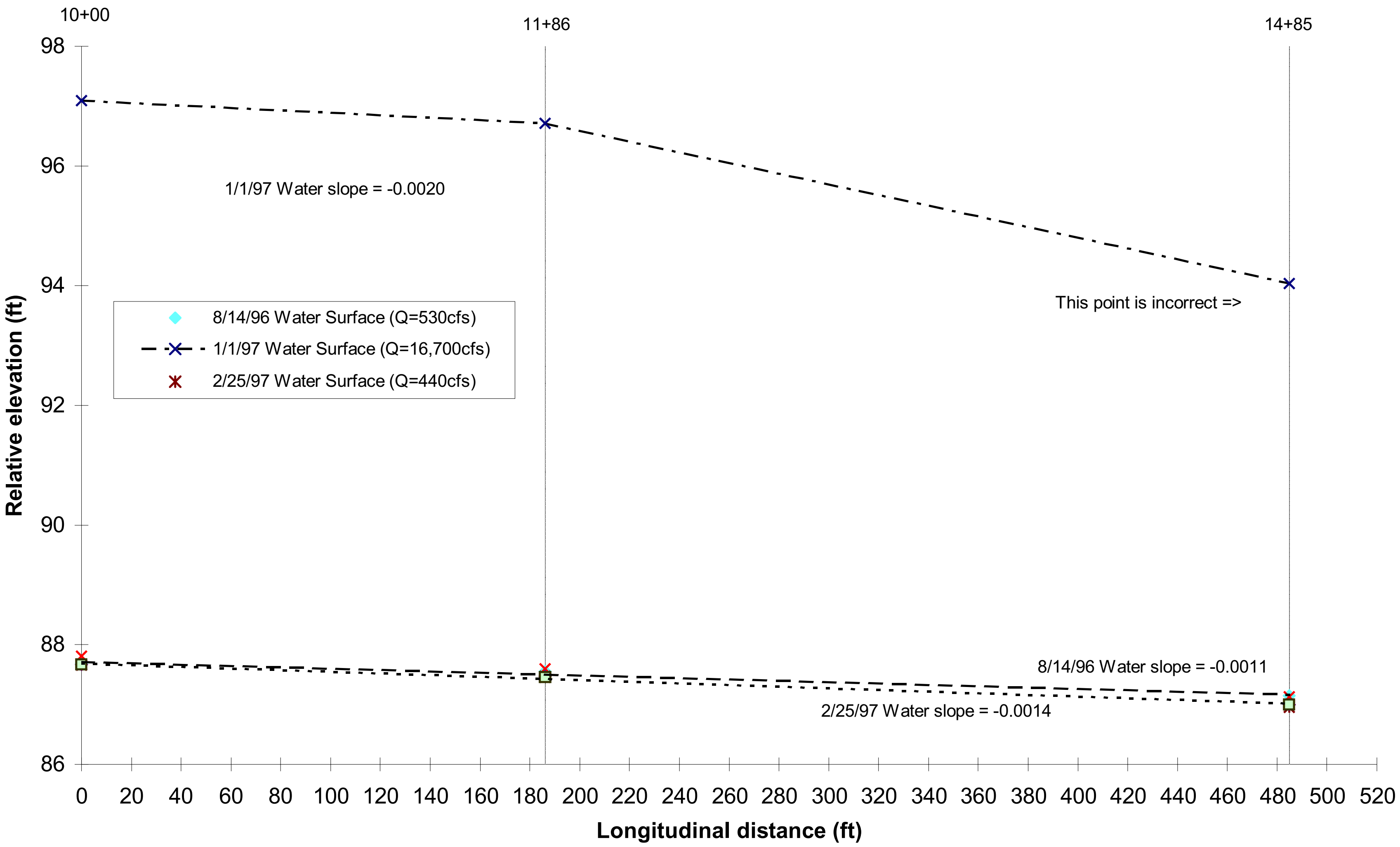


Figure C-13 Longitudinal water surface profiles for the Limekiln rehabilitation site.

Figure C-14 - see Plate 15

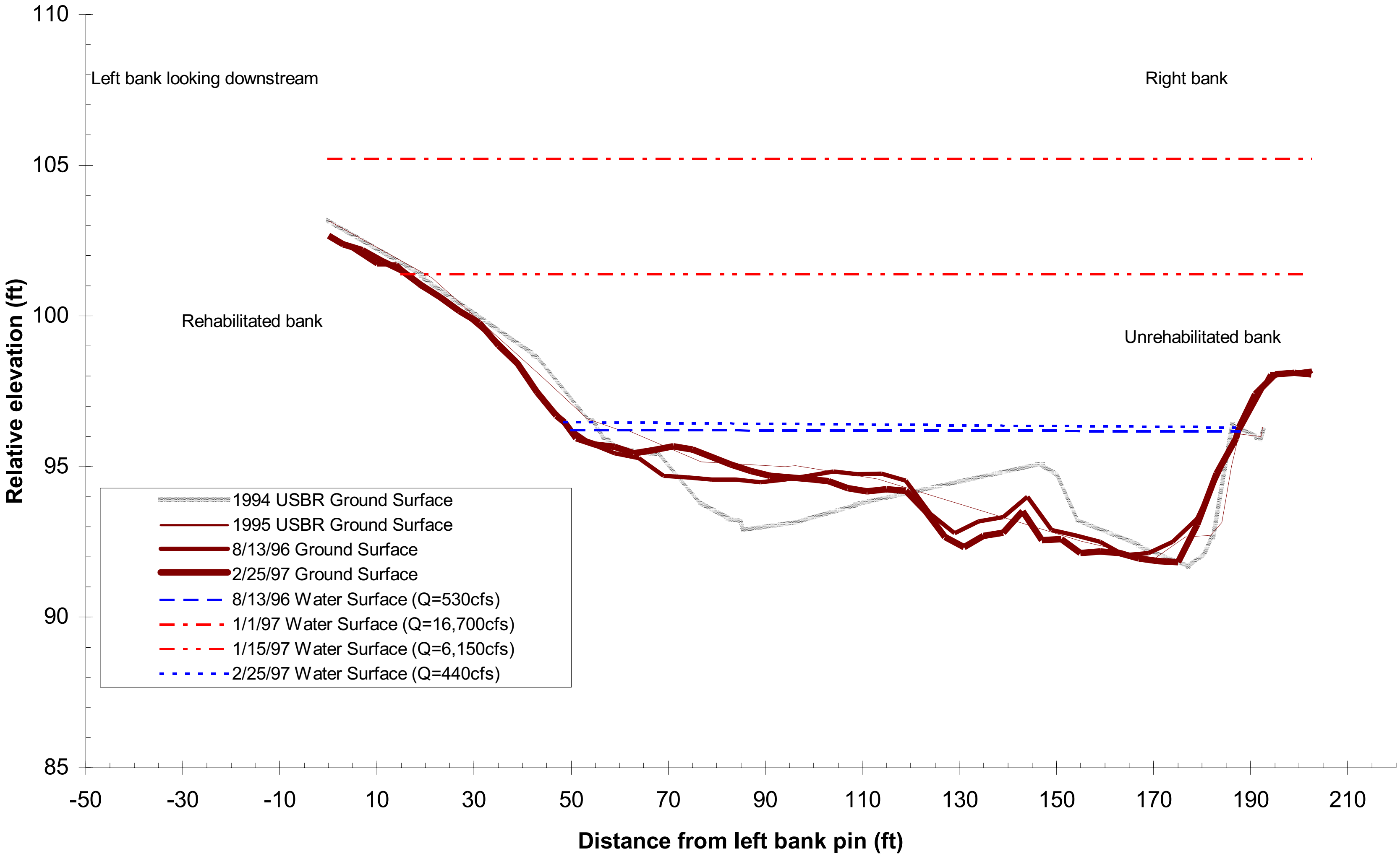


Figure C-15 Ground surface profiles and water surface elevations at cross section 10+00, Steel Bridge rehabilitation site. Aggradation during the 1995 flood began building a bar along the left bank.

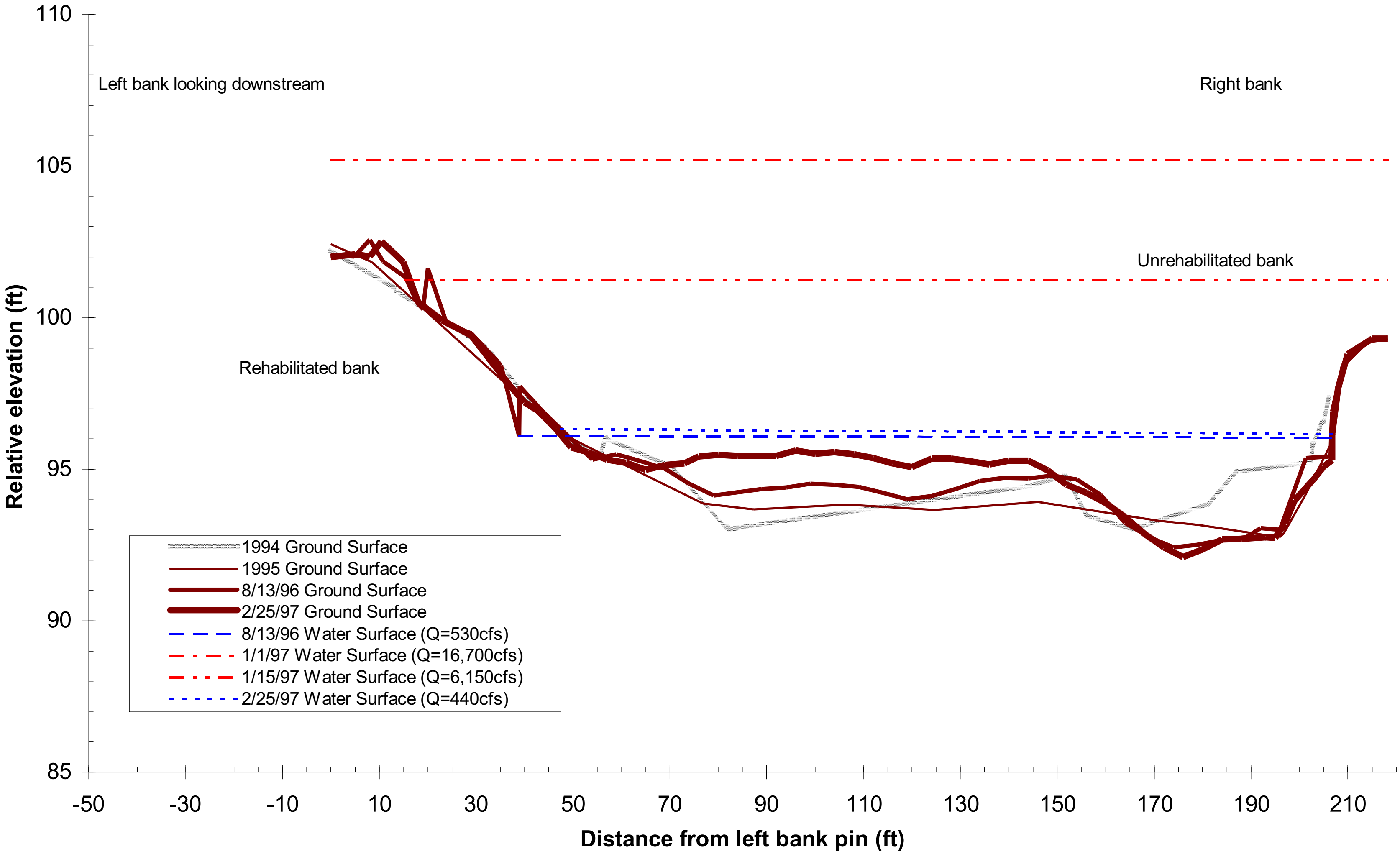


Figure C-16 Ground surface profiles and water surface elevations at cross section 11+10, Steel Bridge rehabilitation site. Aggradation in 1995 and 1997 resulted in the development of a bar along the left bank, below the low water surface.

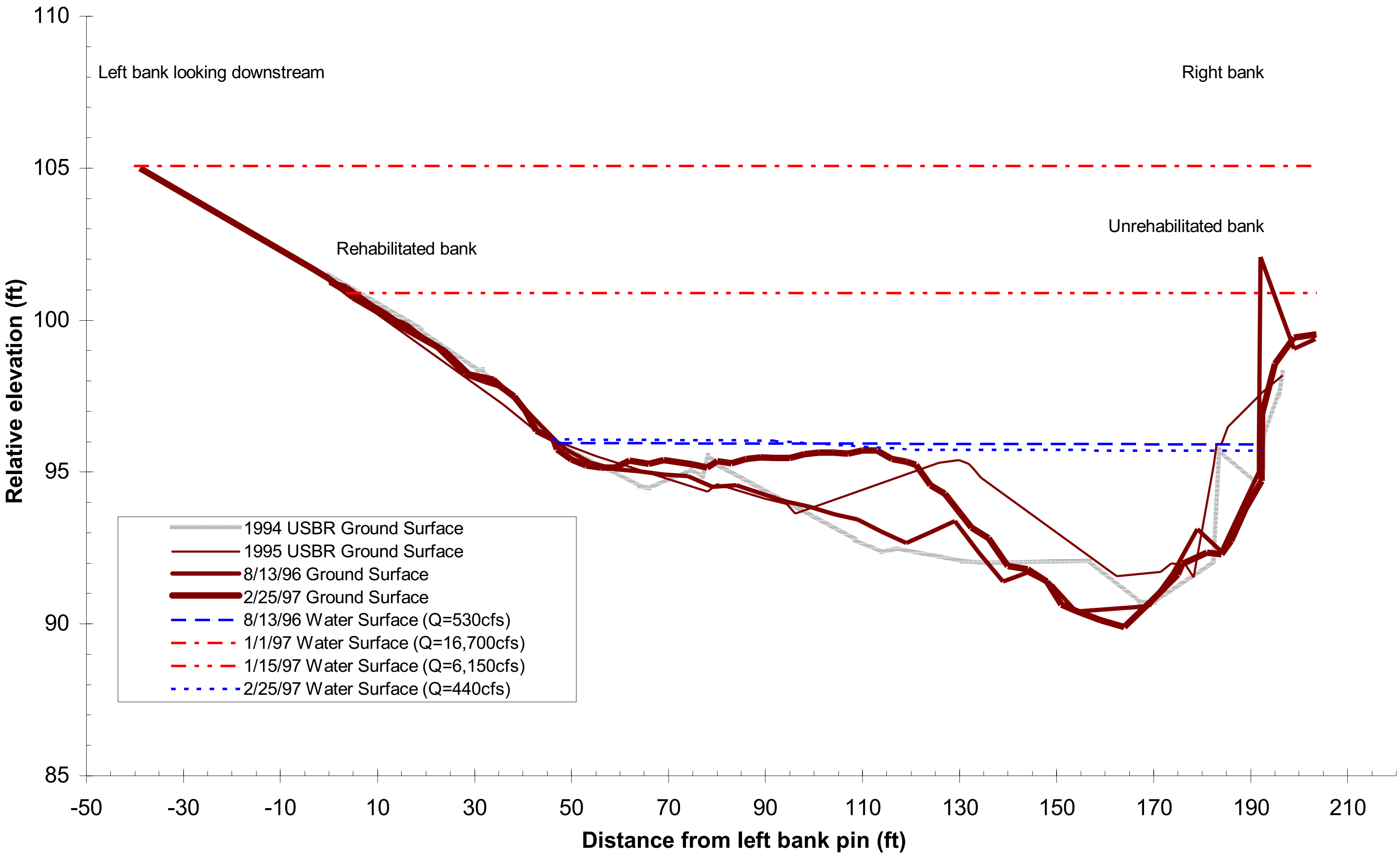


Figure C-17 Ground surface profiles and water surface elevations at cross section 12+10, Steel Bridge rehabilitation site. Aggradation in 1997 built a bar that was just below the low water surface.

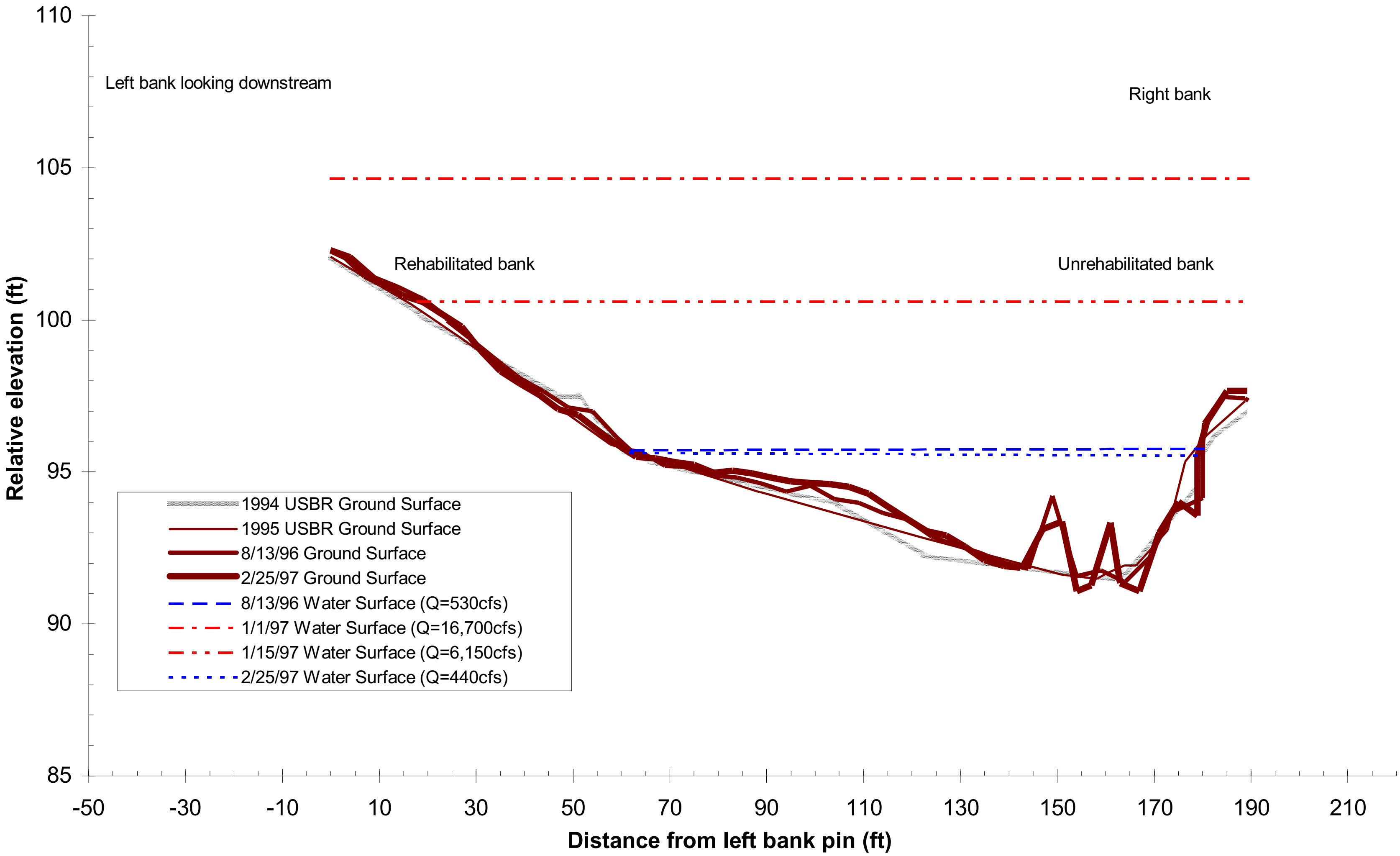


Figure C-18 Ground surface profiles and water surface elevations at cross section 13+10, Steel Bridge rehabilitation site. Bar development along the left bank at cross section 12+10 did not extend to this cross section.

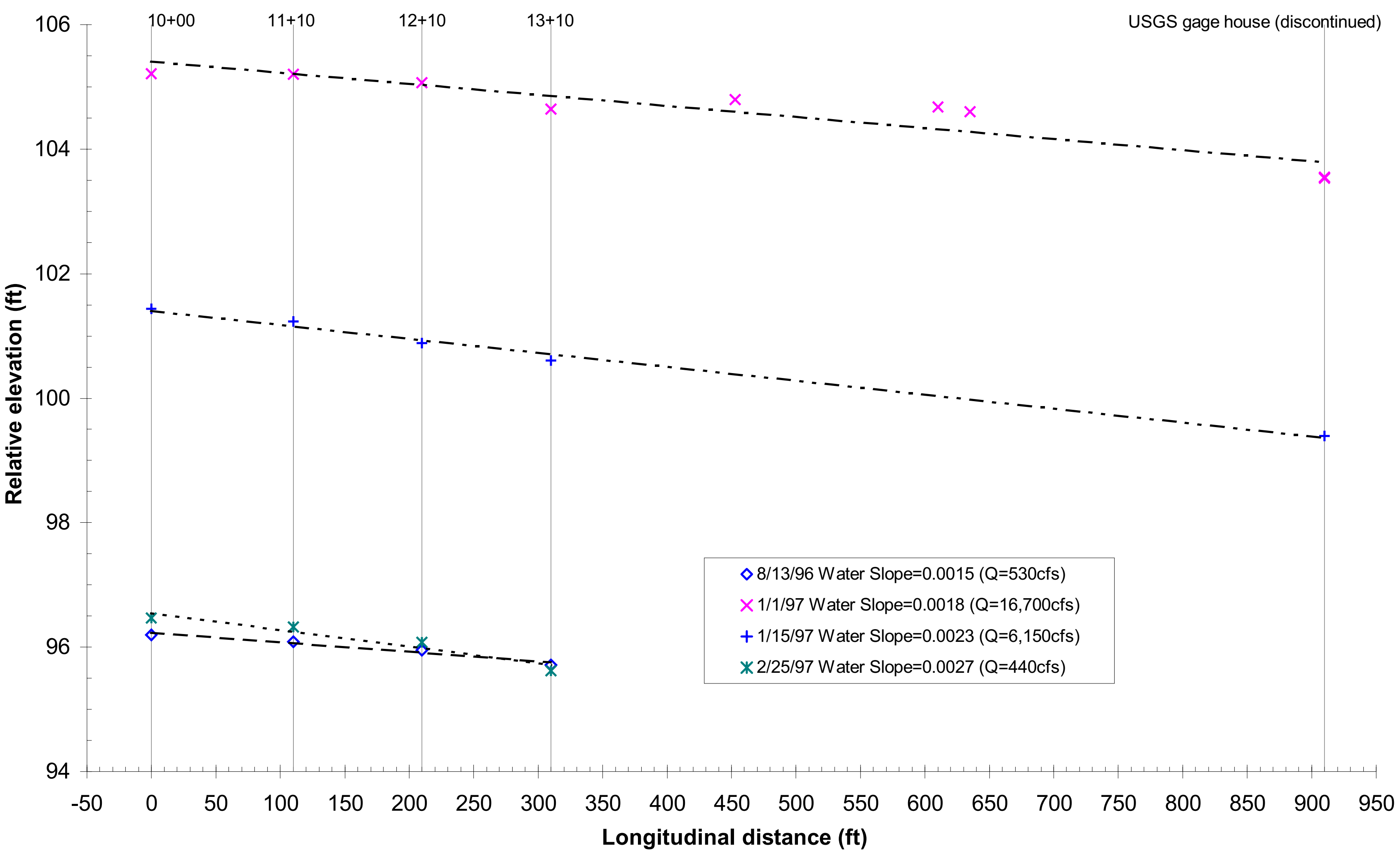


Figure C-19 Longitudinal water surface profiles for the Steel Bridge rehabilitation site.

Figure C-20 - see Plate 16

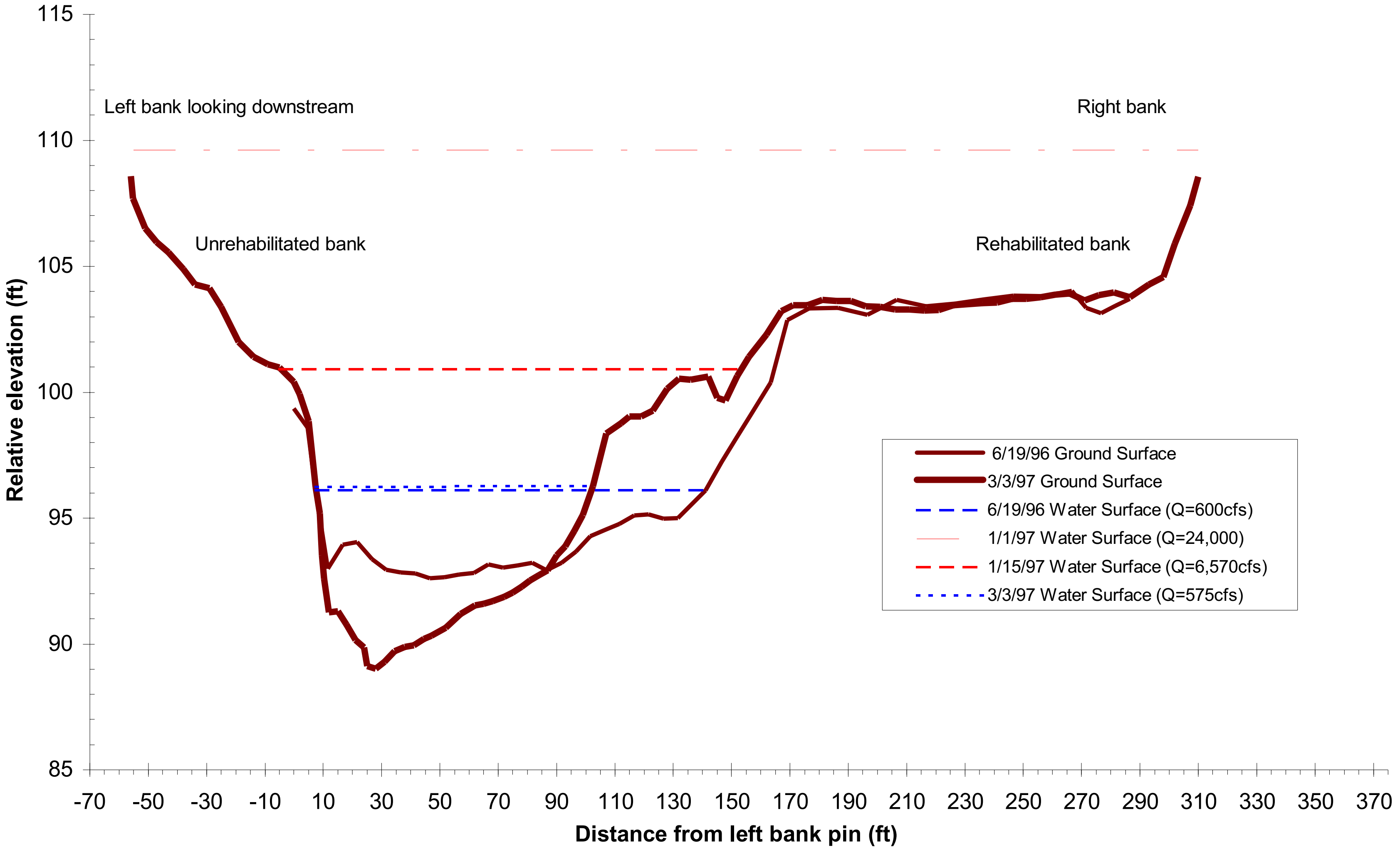


Figure C-21 Ground surface profiles and water surface elevations at cross section -0+69, Steiner Flat rehabilitation site. Significant bar development took place along the right bank during the 1997 flood.

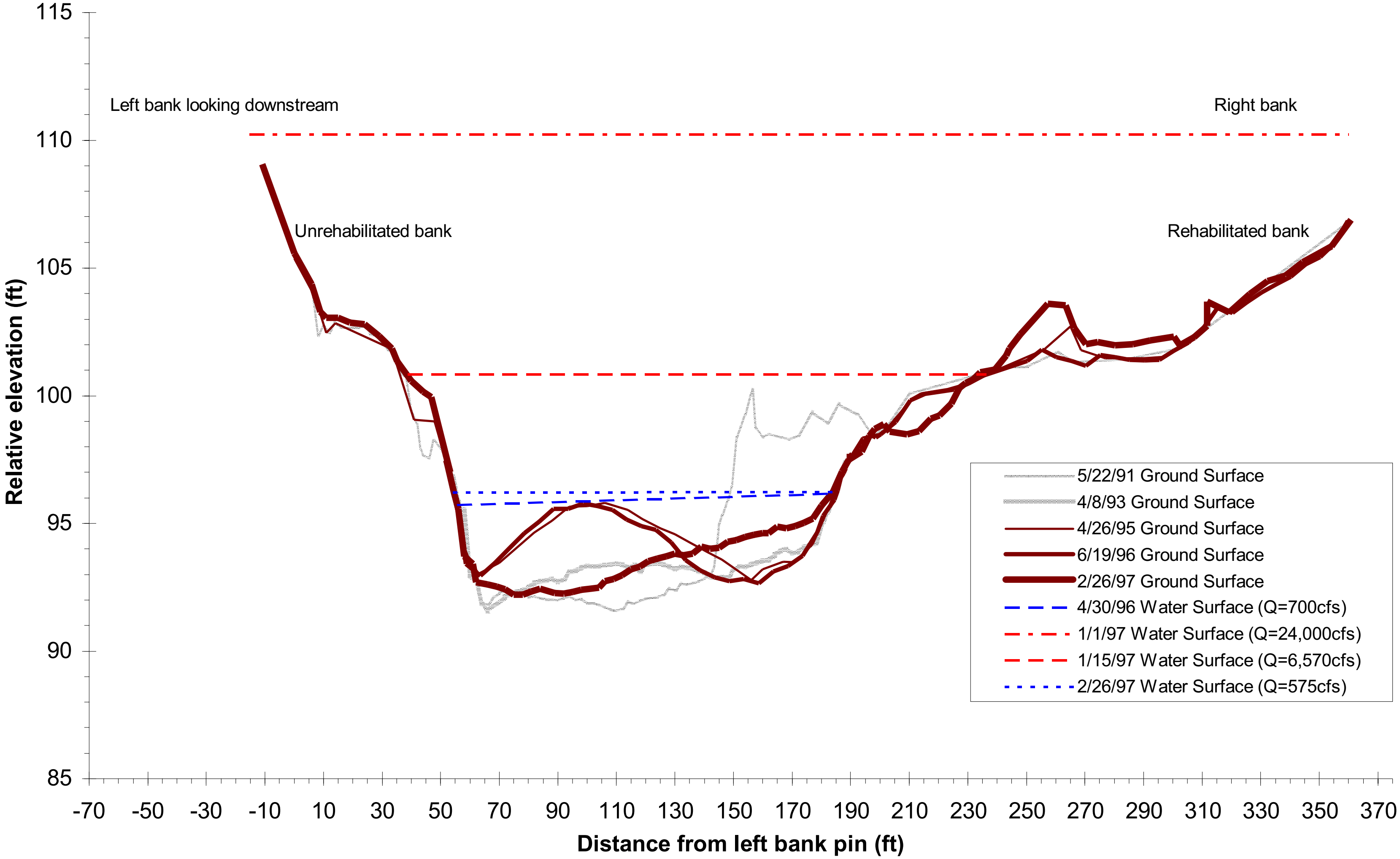


Figure C-22 Ground surface profiles and water surface elevations at cross section 0+45, Steiner Flat rehabilitation site. The medial bar developed during the 1995 flood was degraded during the 1997 flood as aggradation took place along the right bank.

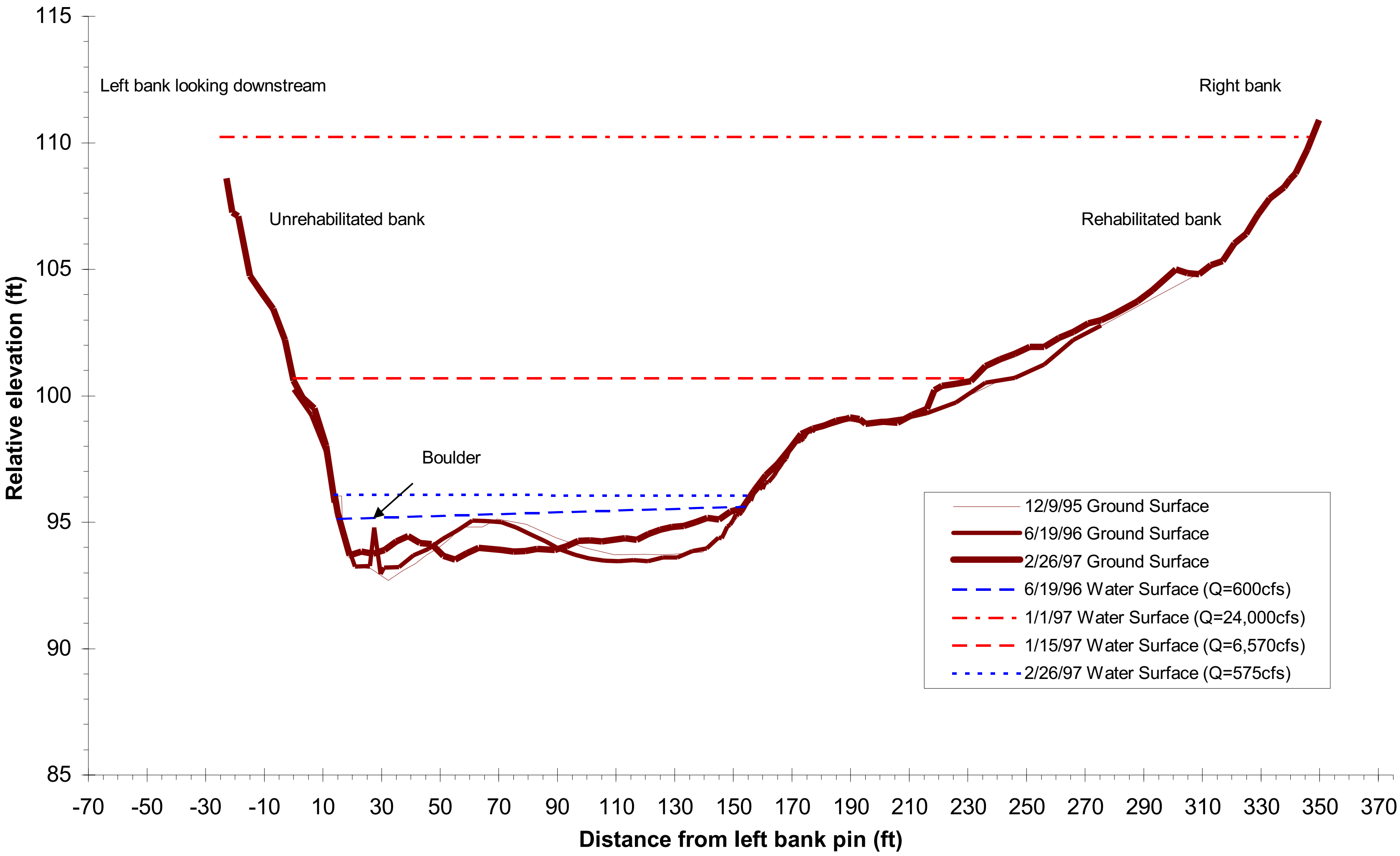


Figure C-23 Ground surface profiles and water surface elevations at cross section 1+45, Steiner Flat rehabilitation site. The downstream end of the medial bar developed during the 1995 flood was degraded during the 1997 flood.

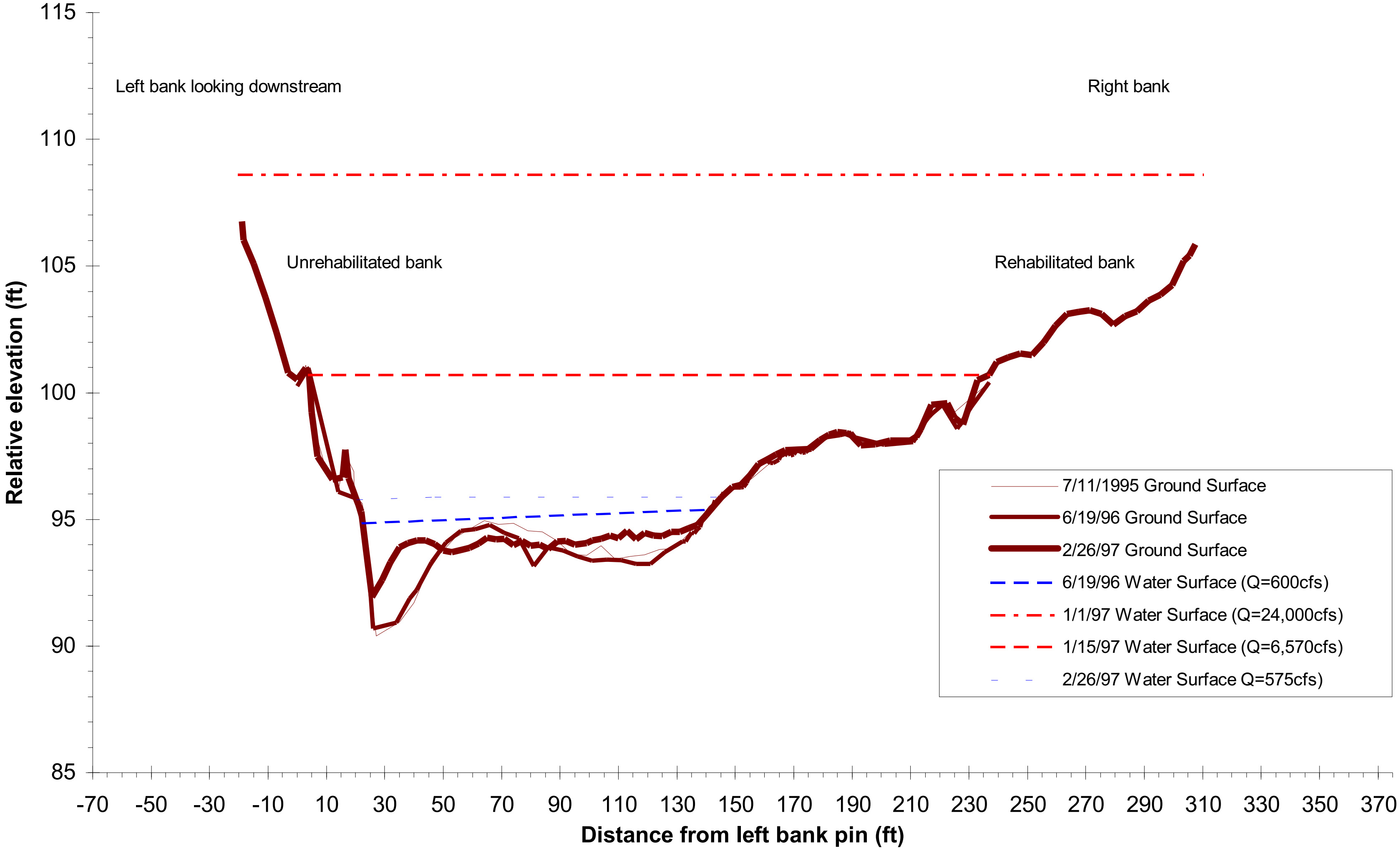


Figure C-24 Ground surface profiles and water surface elevations at cross section 2+31, Steiner Flat rehabilitation site. Aggradation at this cross section was caused by downstream transport of the medial bar sediments degraded at cross sections 0+45 and 1+45.

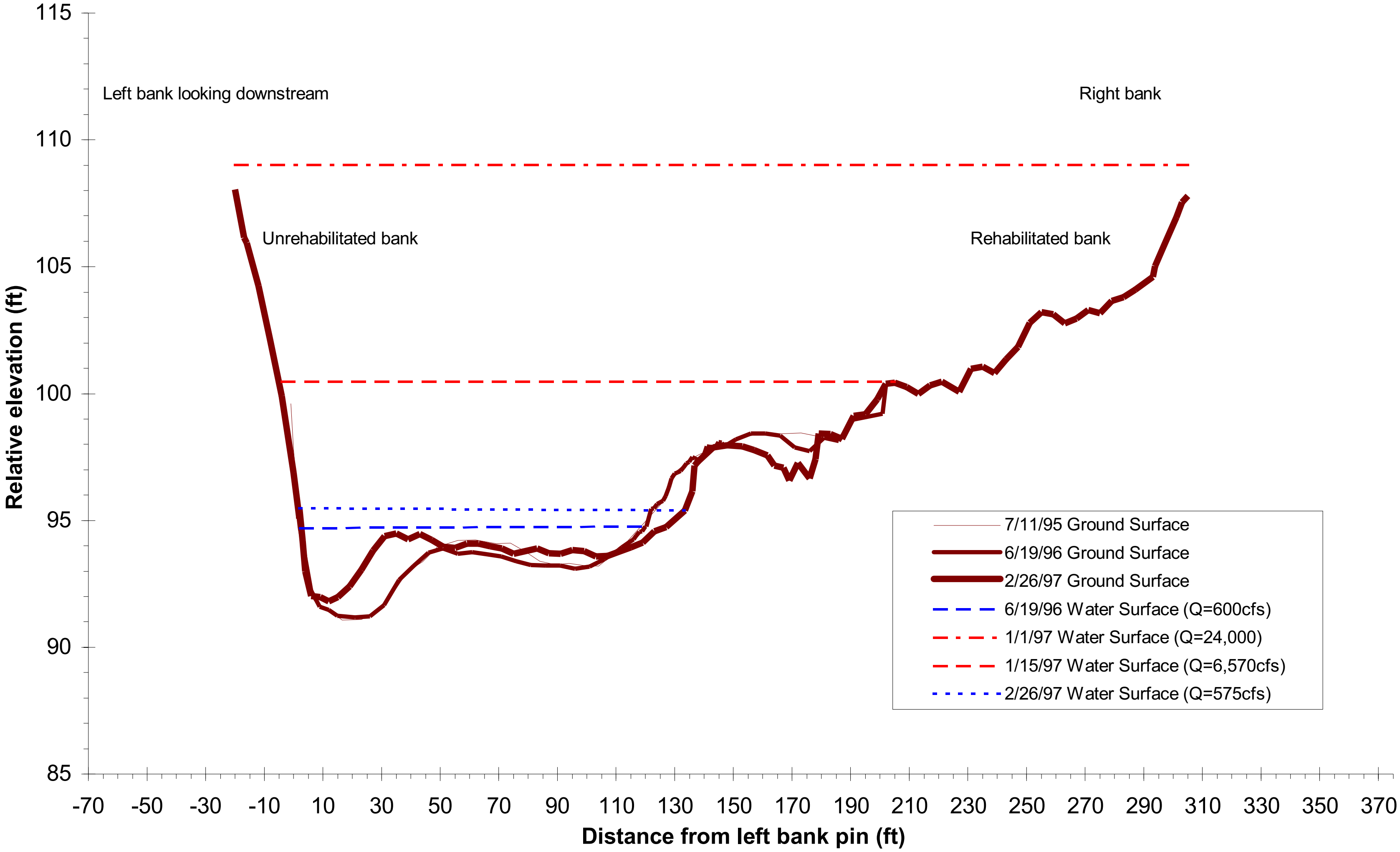


Figure C-25 Ground surface profiles and water surface elevations at cross section 3+31, Steiner Flat rehabilitation site. Aggradation resulted in a small medial bar just below the low water channel at this cross section.

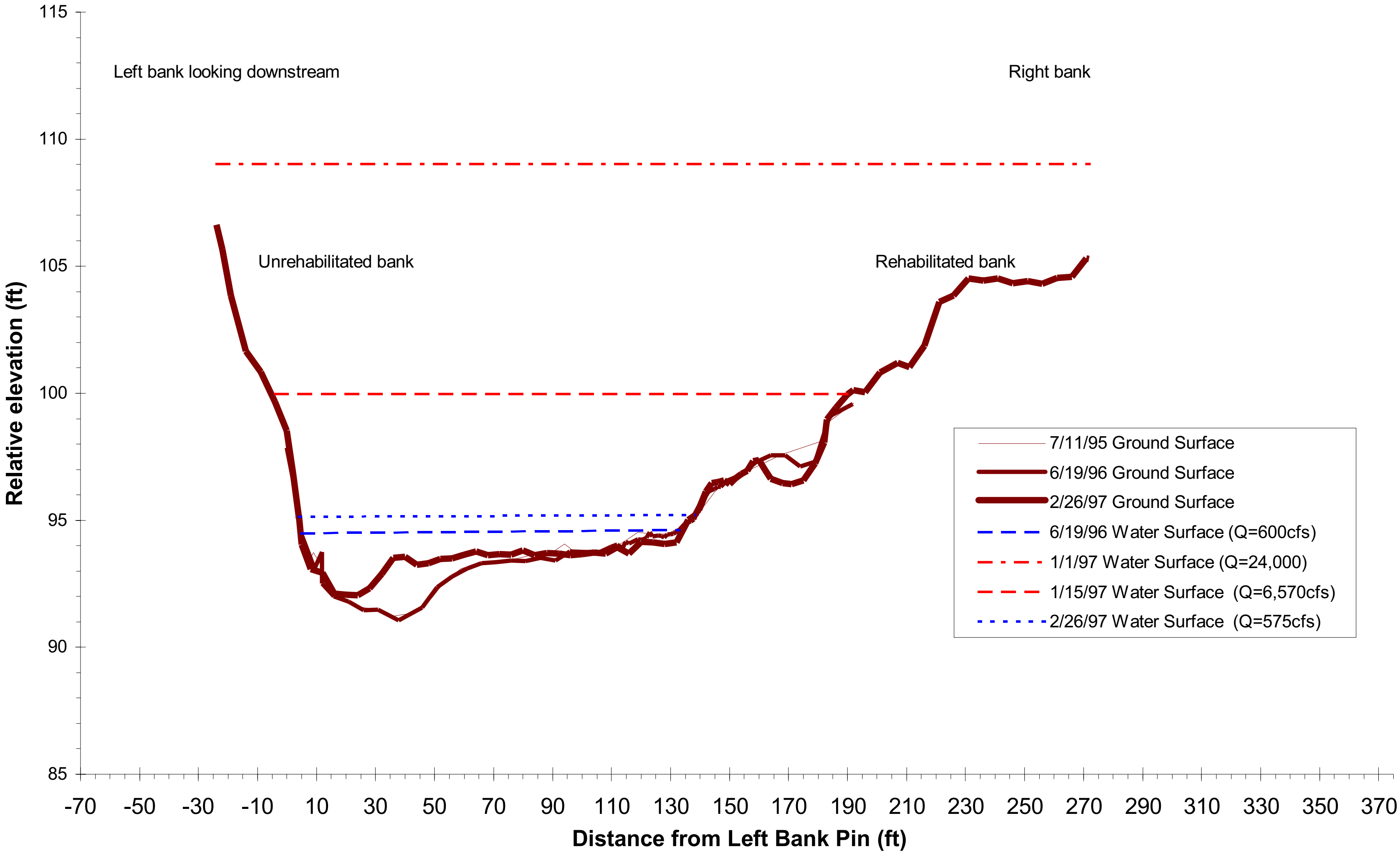


Figure C-26 Ground surface profiles and water surface elevations at cross section 4+31, Steiner Flat rehabilitation site. Aggradation of the low water channel at this cross section was caused by downstream transport of the medial bar sediments.

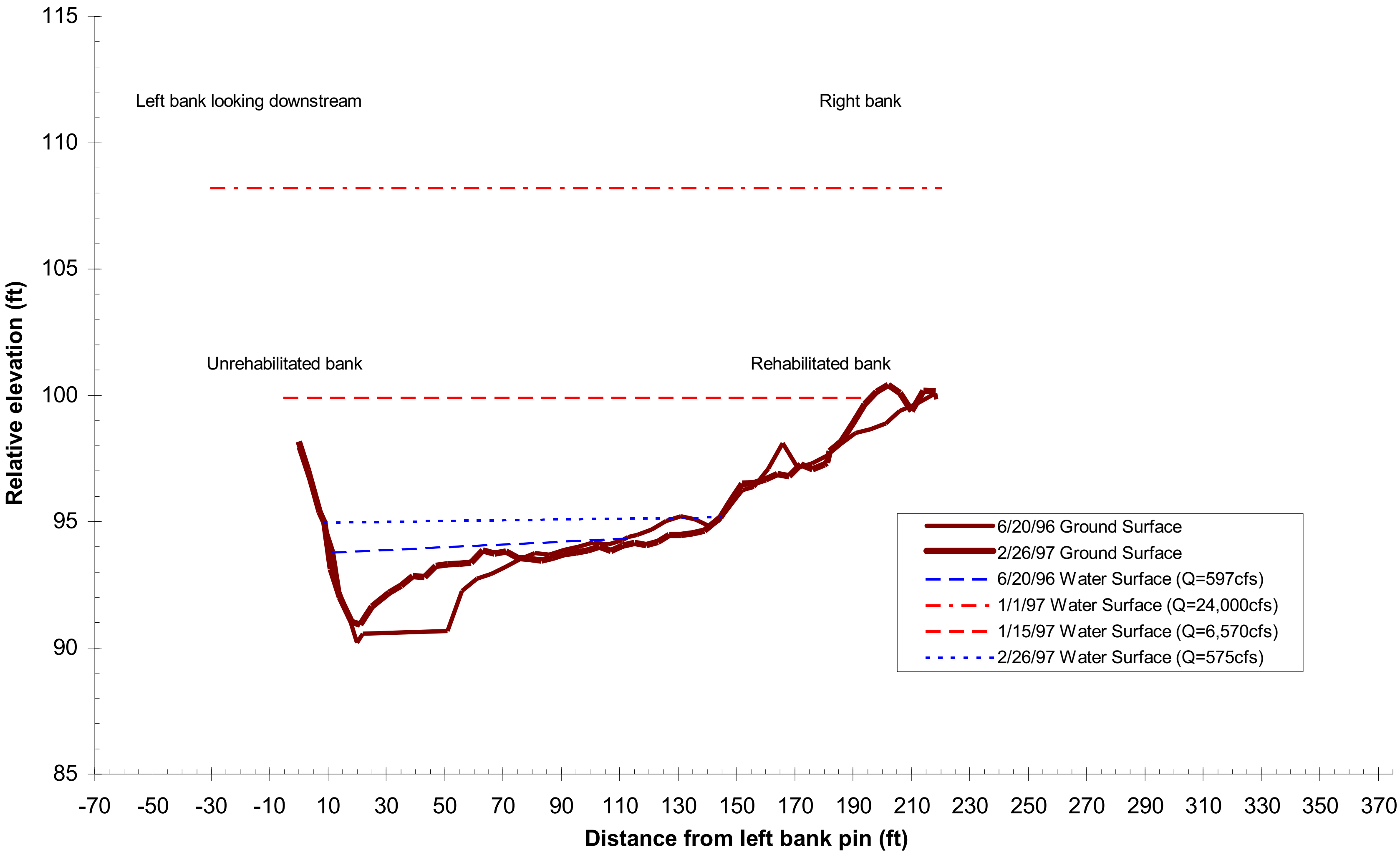


Figure C-27 Ground surface profiles and water surface elevations at cross section 5+02, Steiner Flat rehabilitation site. Aggradation and bar development at this cross section was caused by downstream transport of the medial bar sediments.

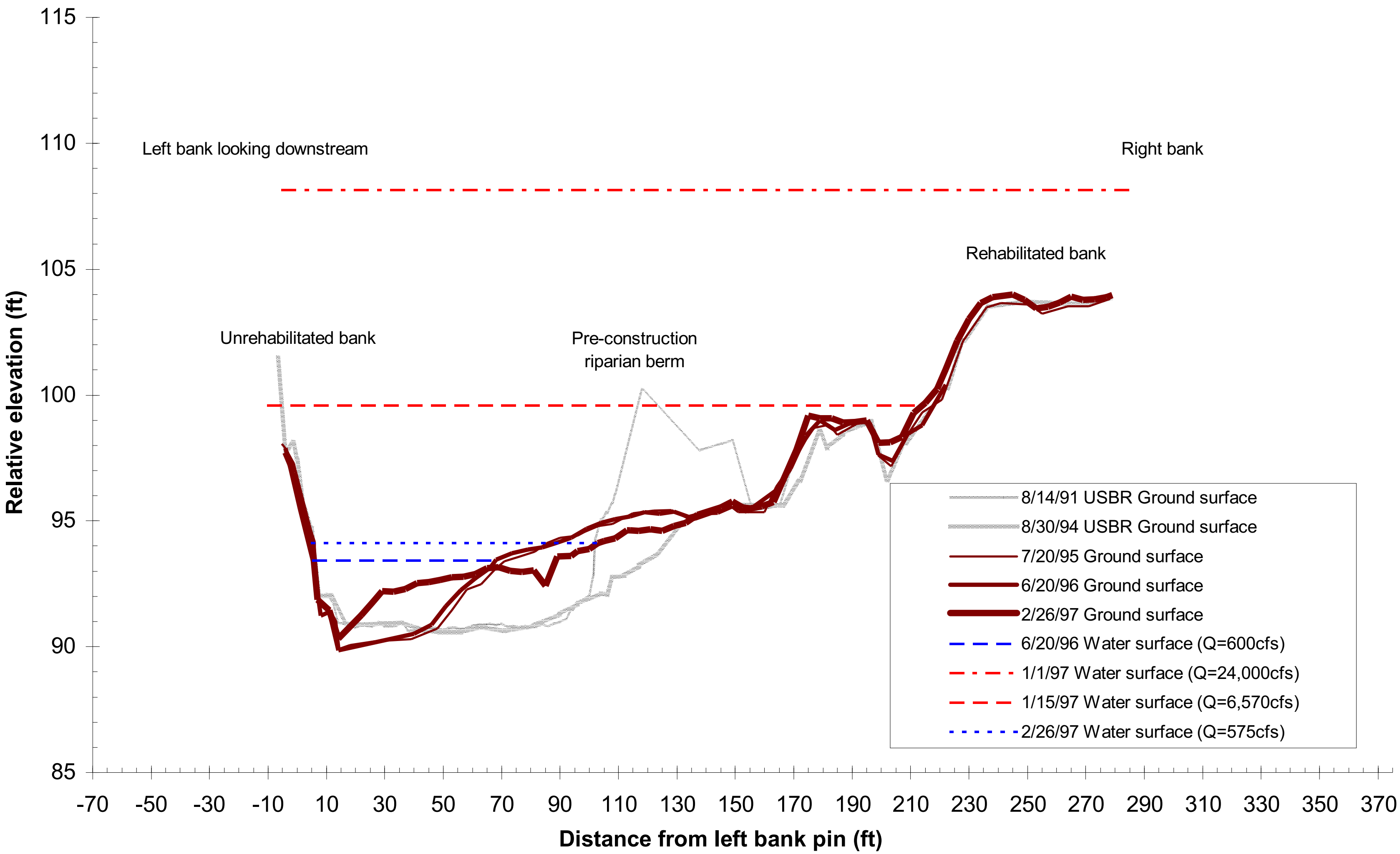


Figure C-28 Ground surface profiles and water surface elevations at cross section 5+98, Steiner Flat rehabilitation site. Aggradation and bar development at this cross section was caused by downstream transport of the medial bar sediments.

Figure C-29 - see Plate 17

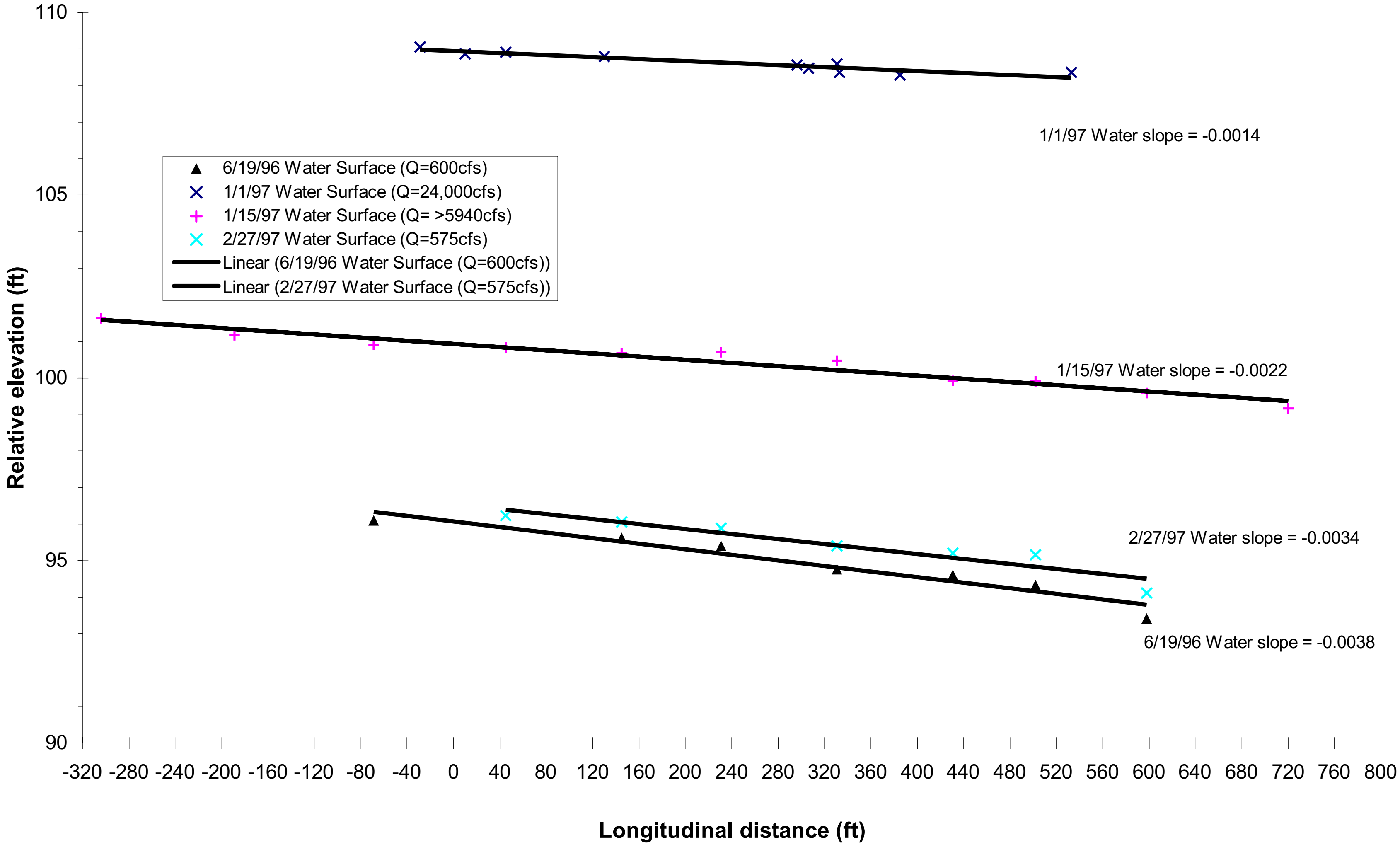


Figure C-30 Longitudinal water surface profiles for the Steiner Flat rehabilitation site.

Figure C-31 - see Plate 18

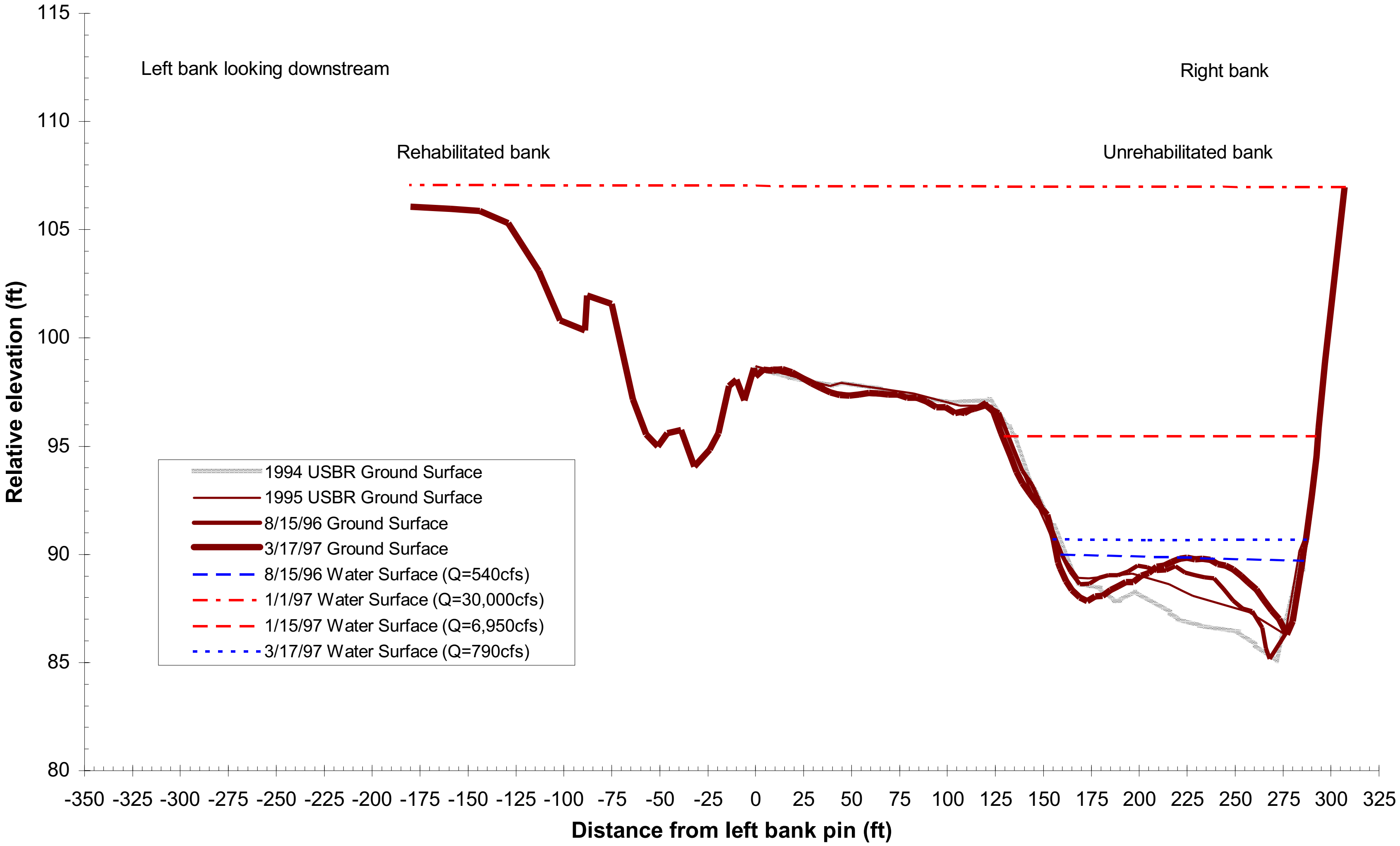


Figure C-32 Ground surface profiles and water surface elevations at cross section 10+00, Bell Gulch rehabilitation site. A medial bar developed at this cross section following bank construction.

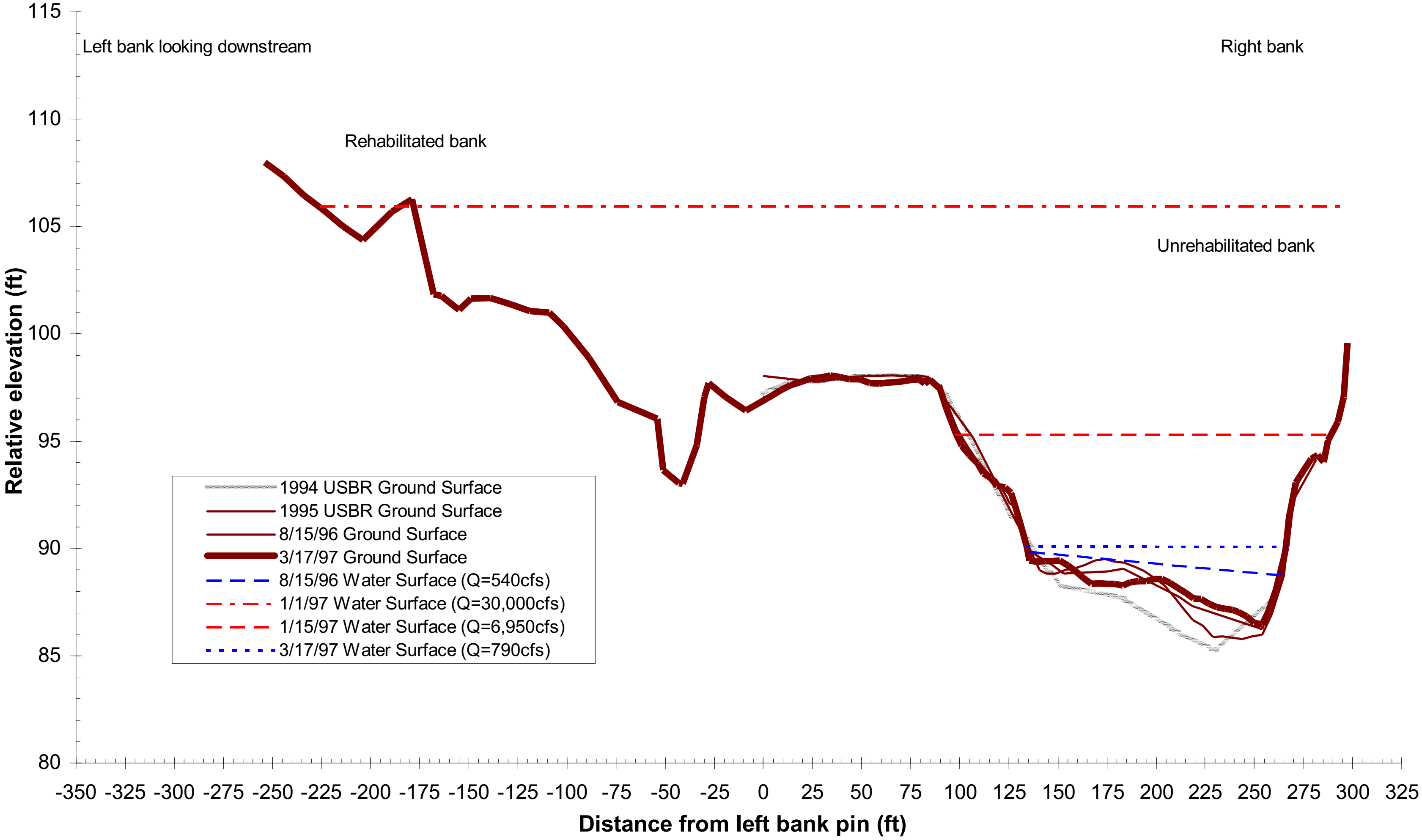


Figure C-33 Ground surface profiles and water surface elevations at cross section 11+50, Bell Gulch rehabilitation site. Aggradation and bar development were apparent along the left bank at this cross section

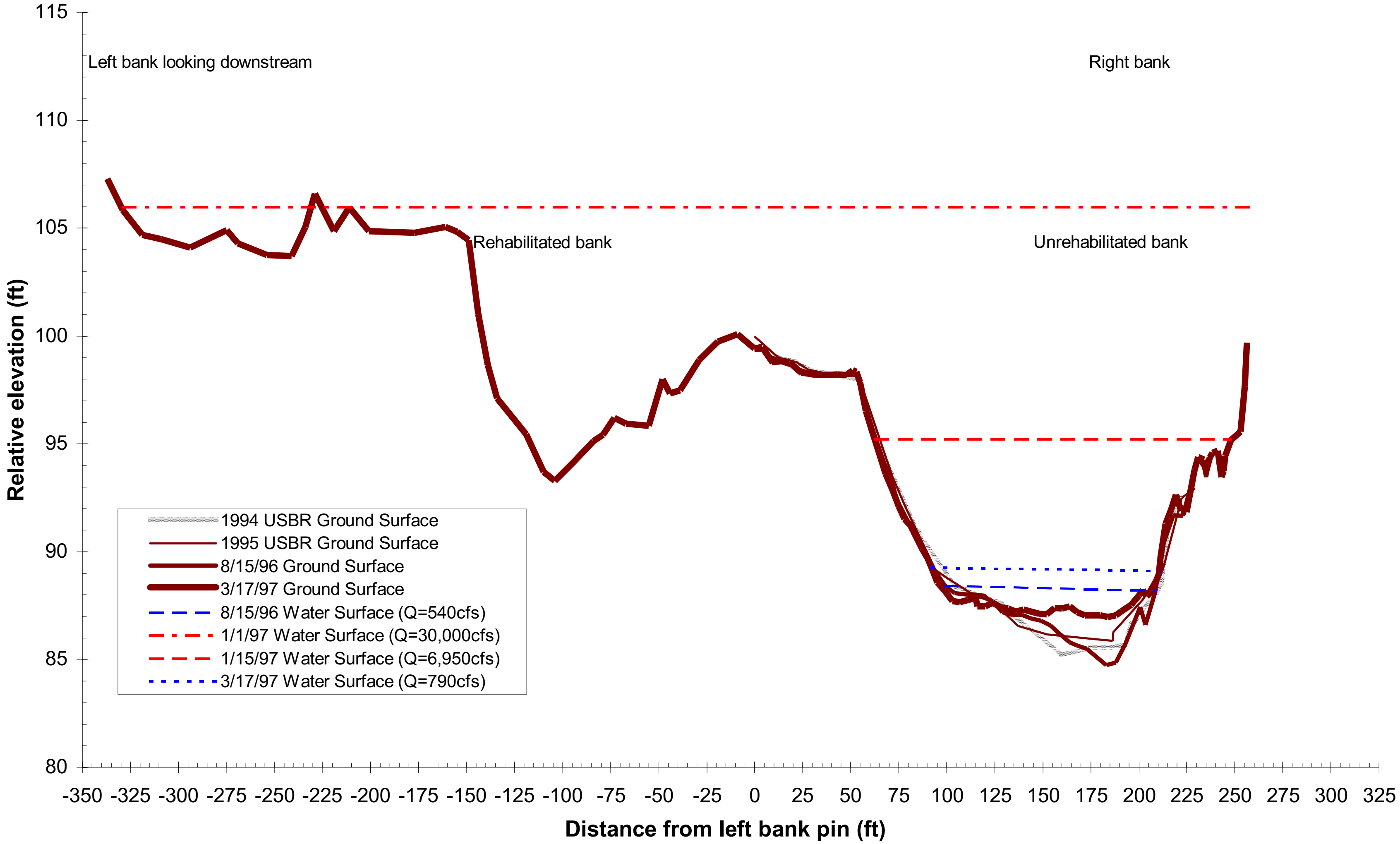


Figure C-34 Ground surface profiles and water surface elevations at cross section 13+05, Bell Gulch rehabilitation site.

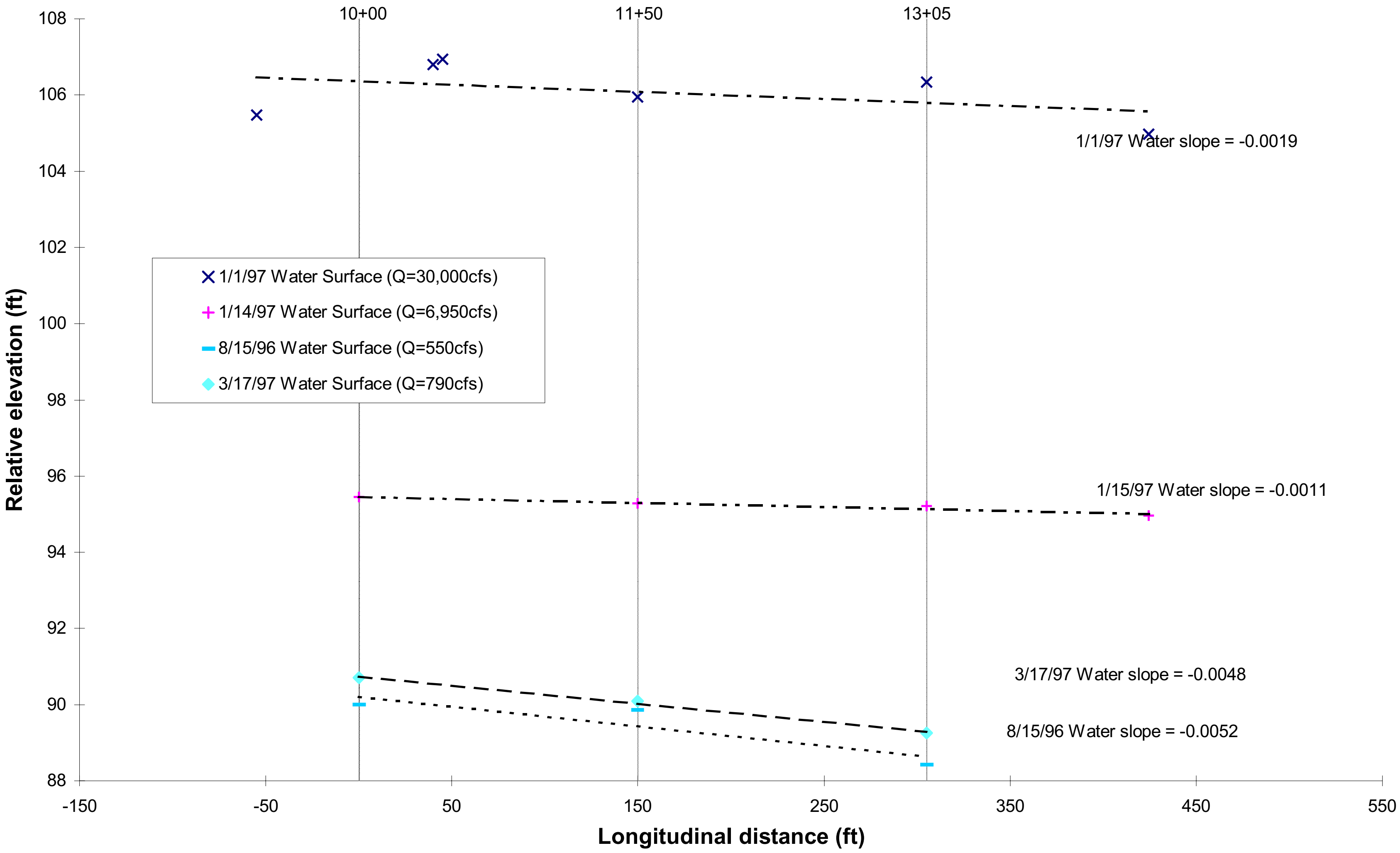


Figure C-35 Longitudinal water surface profiles for the Bell Gulch rehabilitation site.

Figure C-36 - see Plate 19

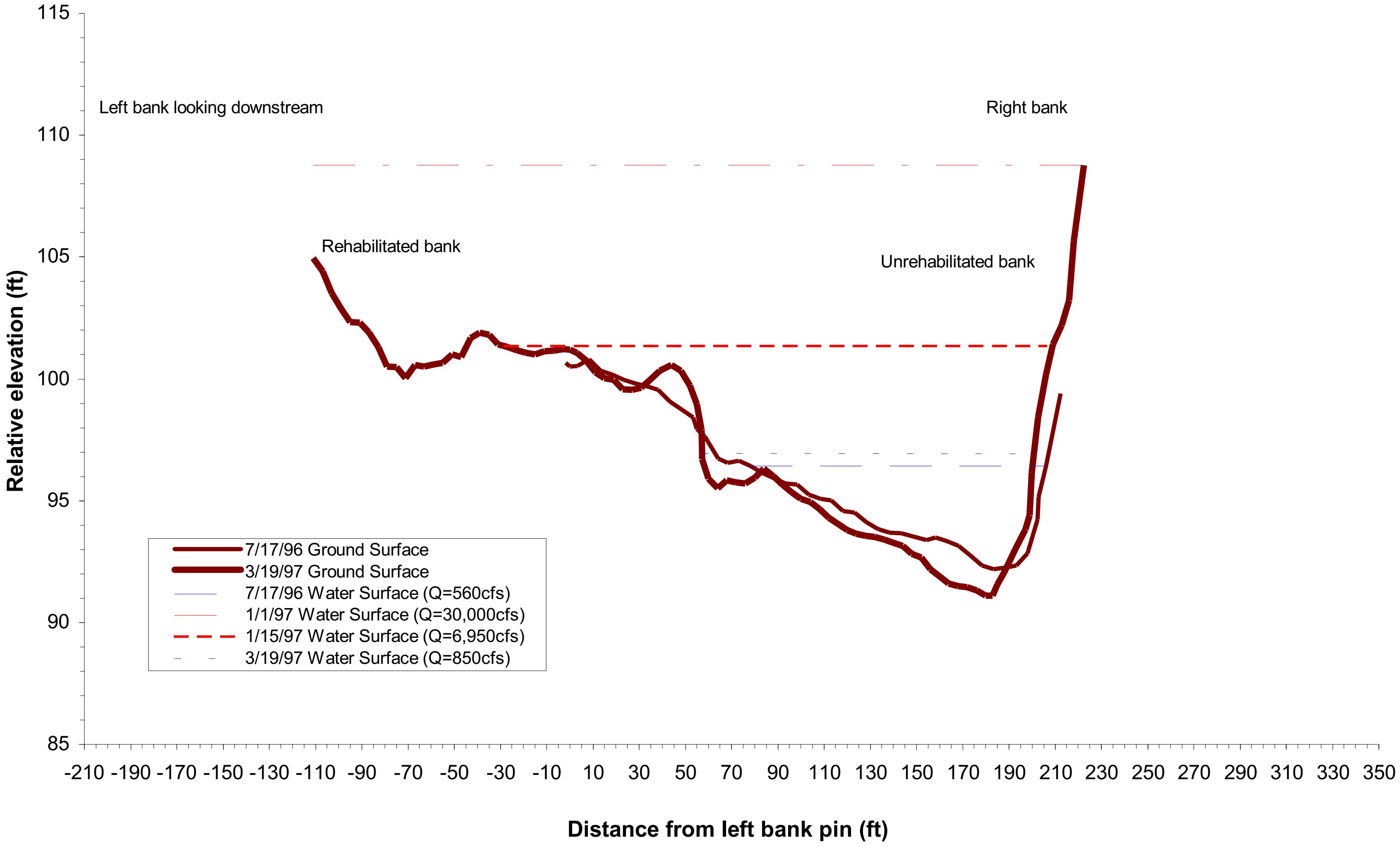


Figure C-37 Ground surface profiles and water surface elevations at cross section 10+00, Deep Gulch rehabilitation site. Degradation occurred along the left bank of the low water channel during the 1997 flood.

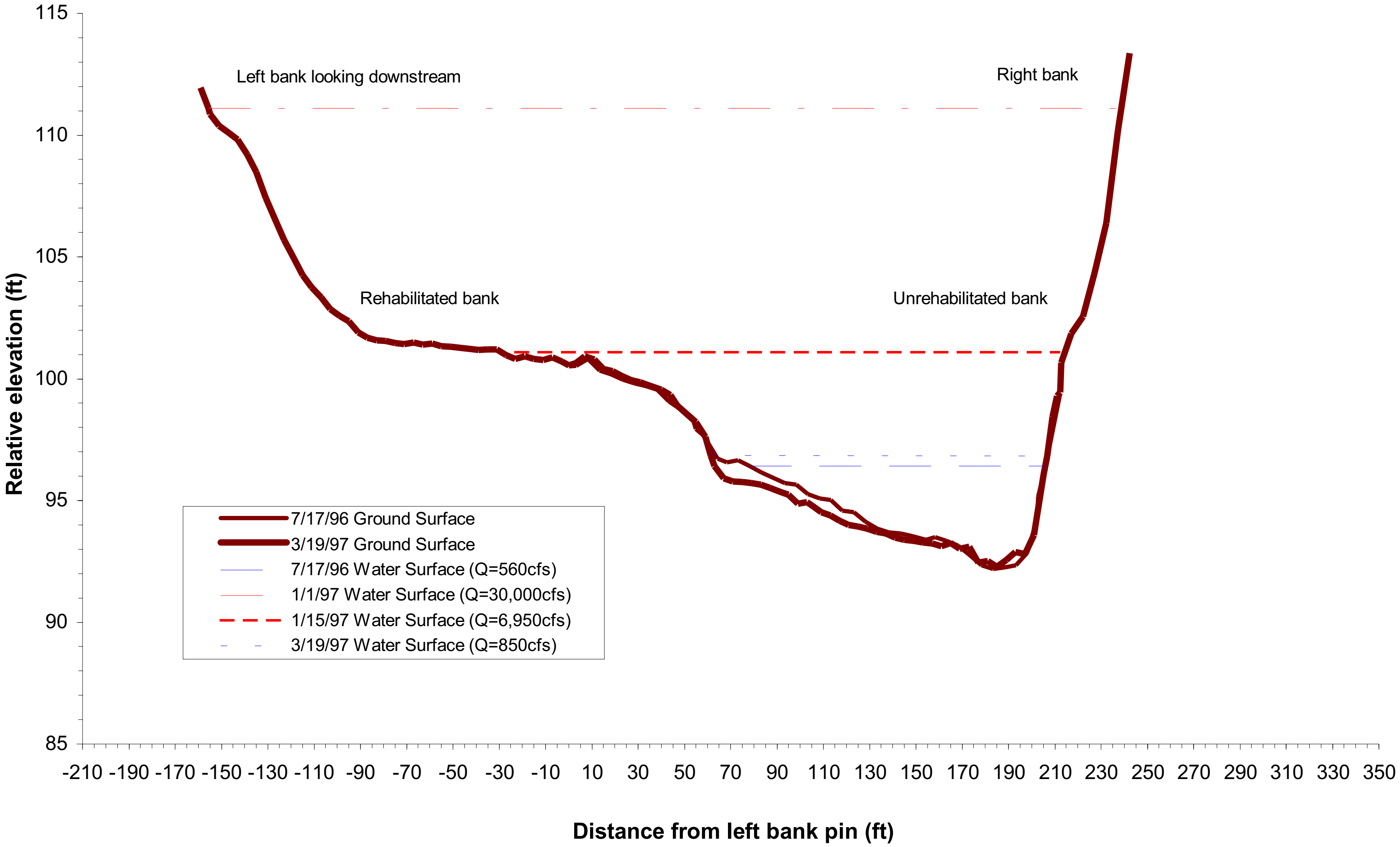


Figure C-38 Ground surface profiles and water surface elevations at cross section 11+95, Deep Gulch rehabilitation site. A small amount of degradation occurred along the left bank of the low water channel during the 1997 flood.

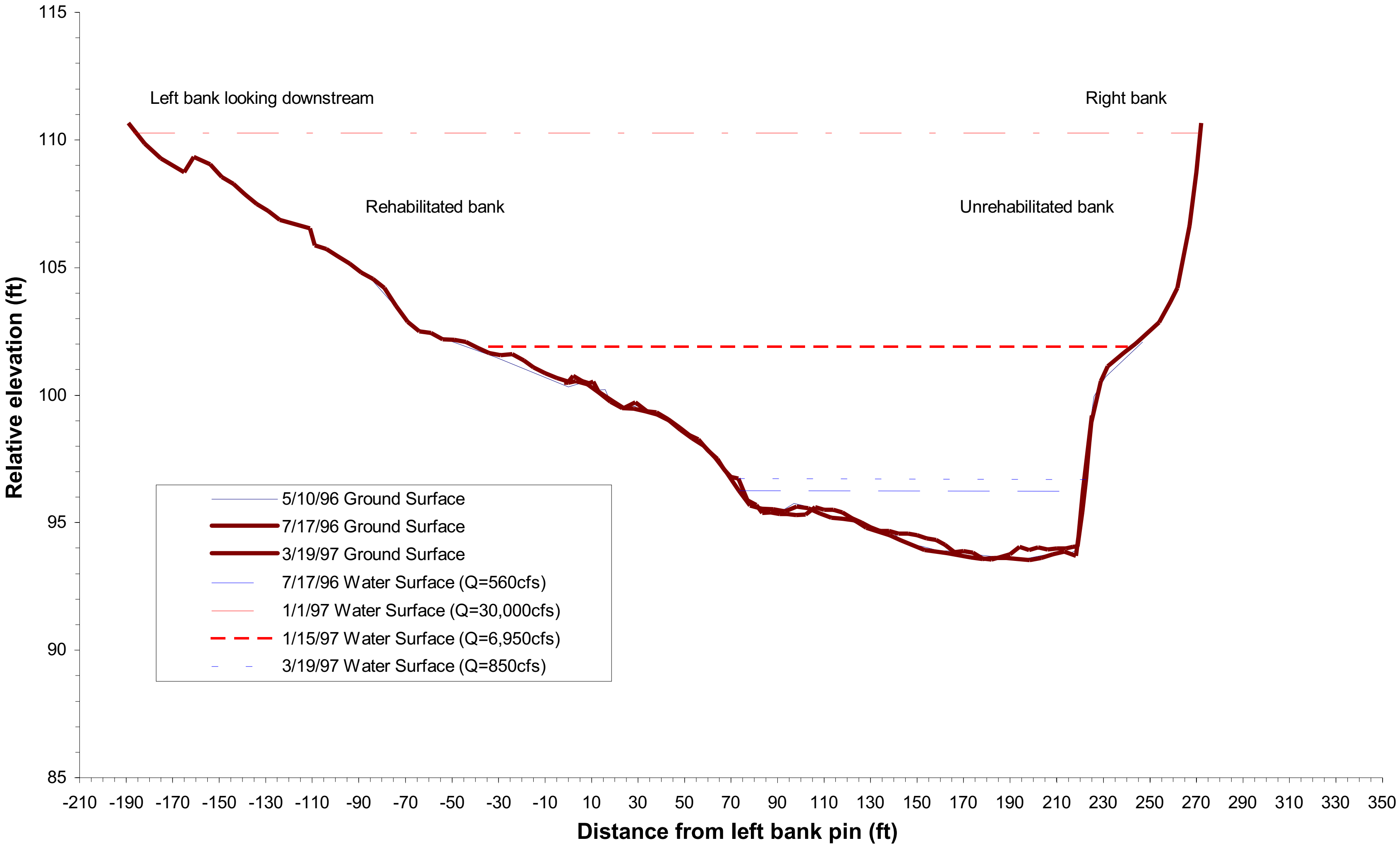


Figure C-39 Ground surface profiles and water surface elevations at cross section 13+90, Deep Gulch rehabilitation site. Very little change was observed at this cross section following bank construction.

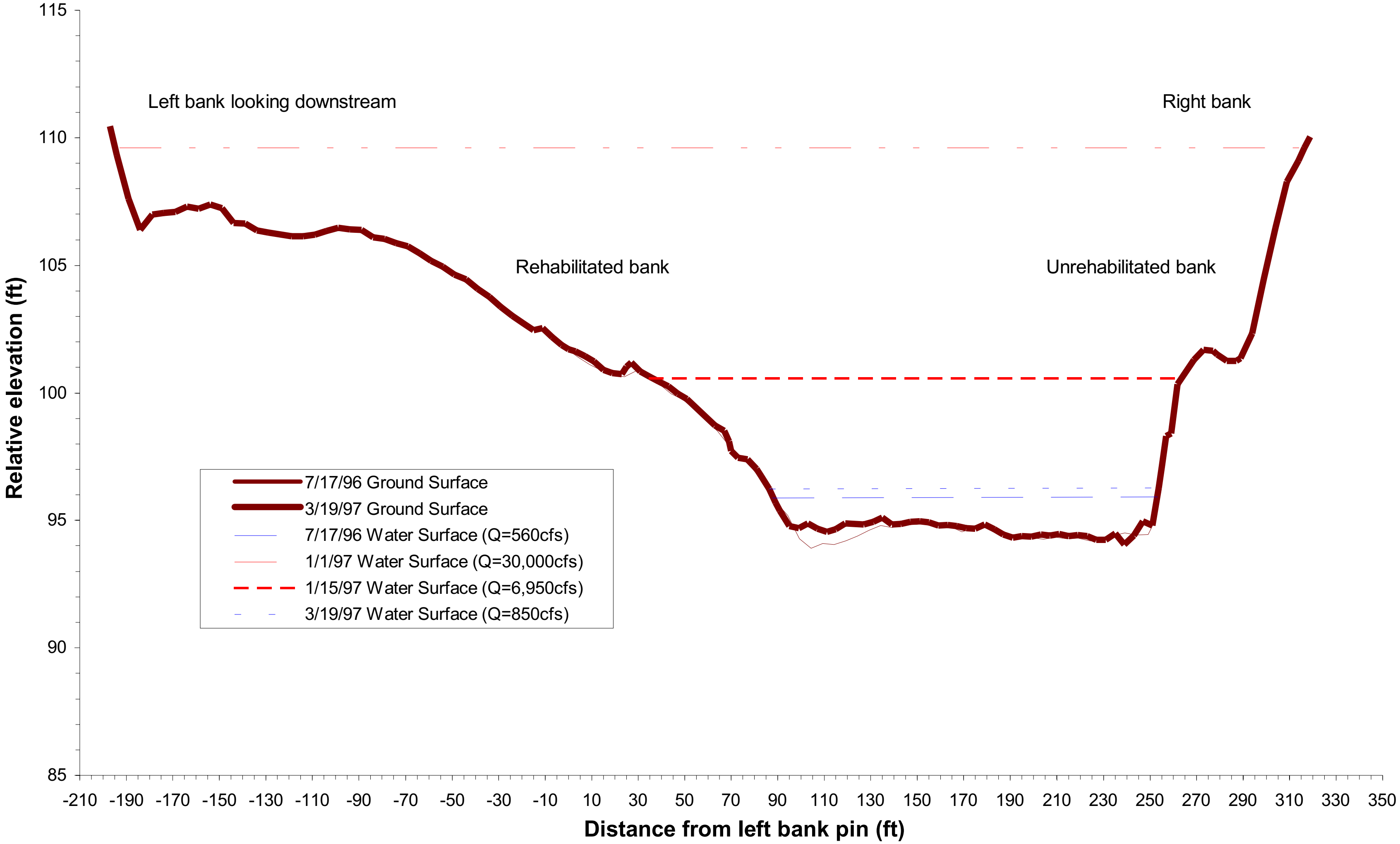


Figure C-40 Ground surface profiles and water surface elevations at cross section 16+00, Deep Gulch rehabilitation site. Very little change was observed at this cross section following bank construction.

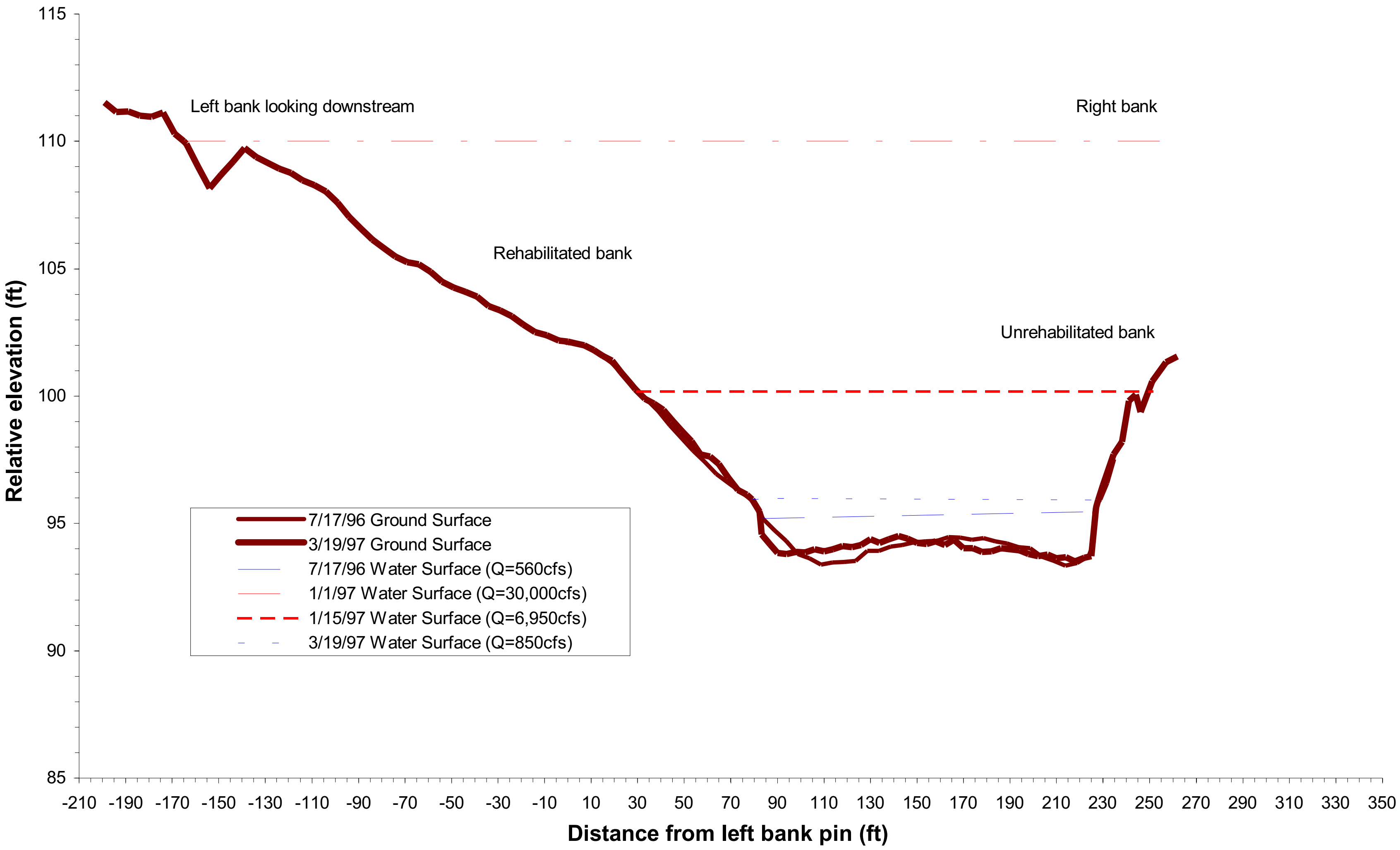


Figure C-41 Ground surface profiles and water surface elevations at cross section 17+80, Deep Gulch rehabilitation site. Very little change was observed at this cross section following bank construction.

Figure C-42 - see Plate 20

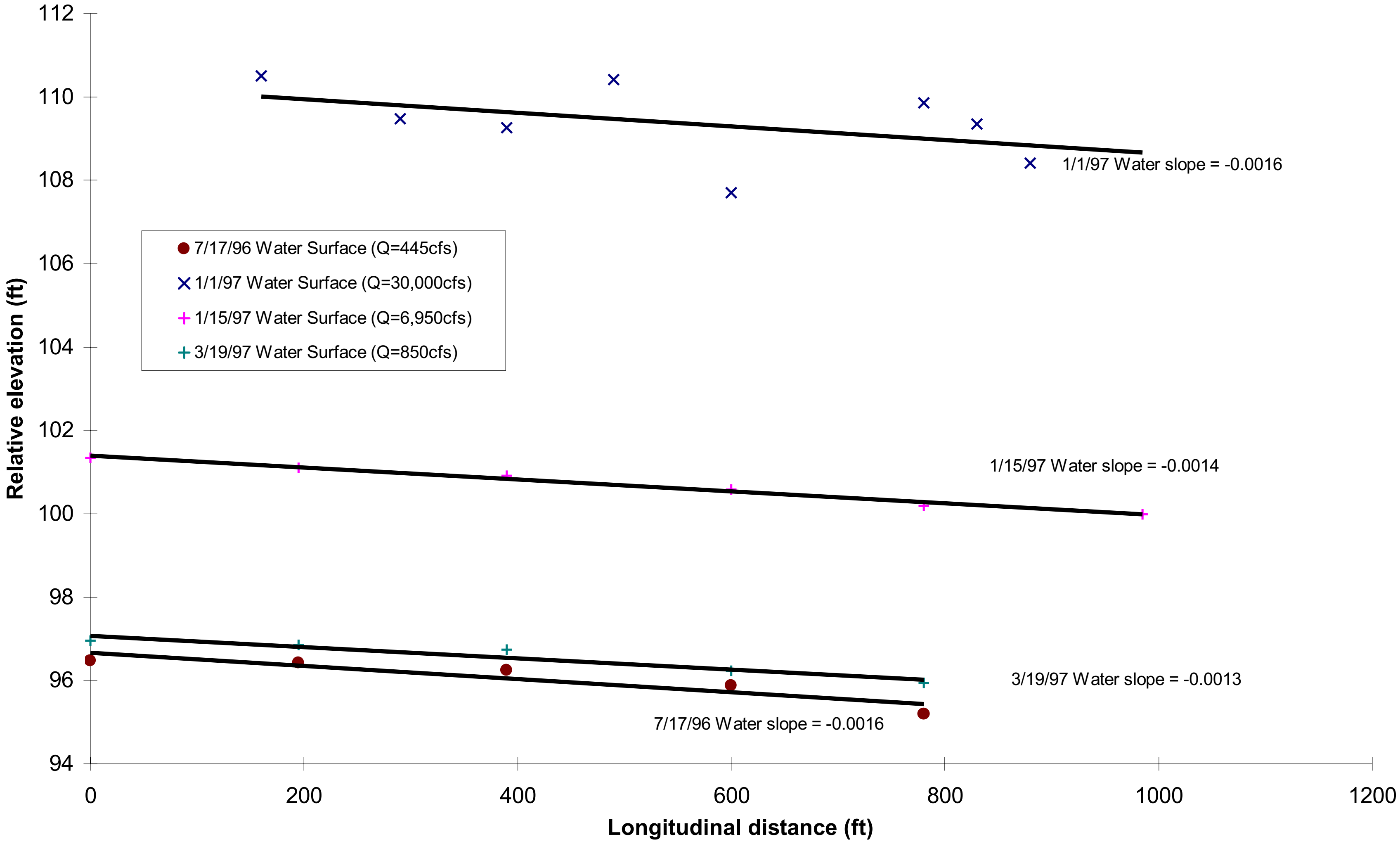


Figure C-43 Longitudinal water surface profiles for the Deep Gulch rehabilitation site.

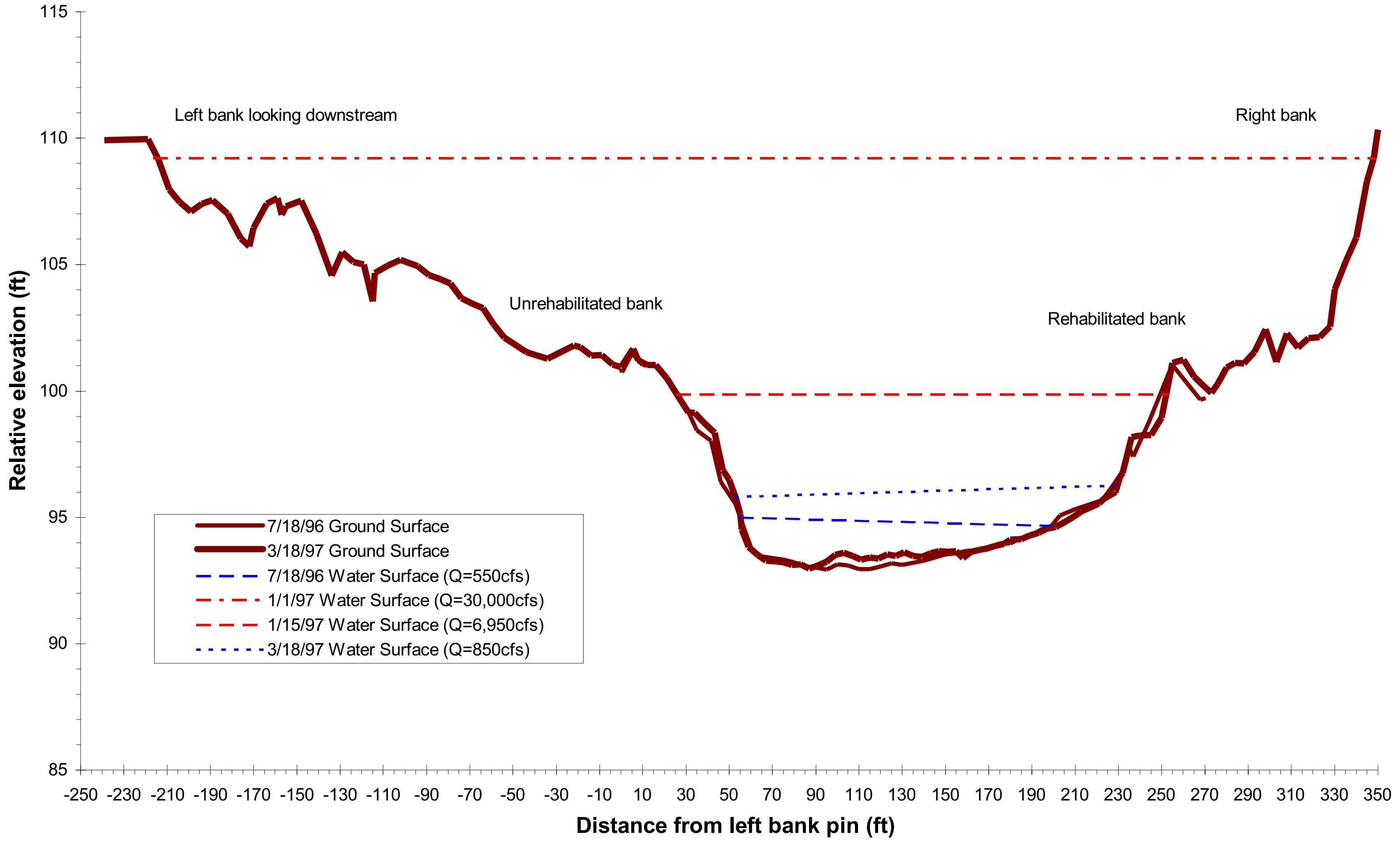


Figure C-44 Ground surface profiles and water surface elevations at cross section -0+65, Sheridan Creek rehabilitation site. There was no significant change at this cross section between 1996 and 1997.

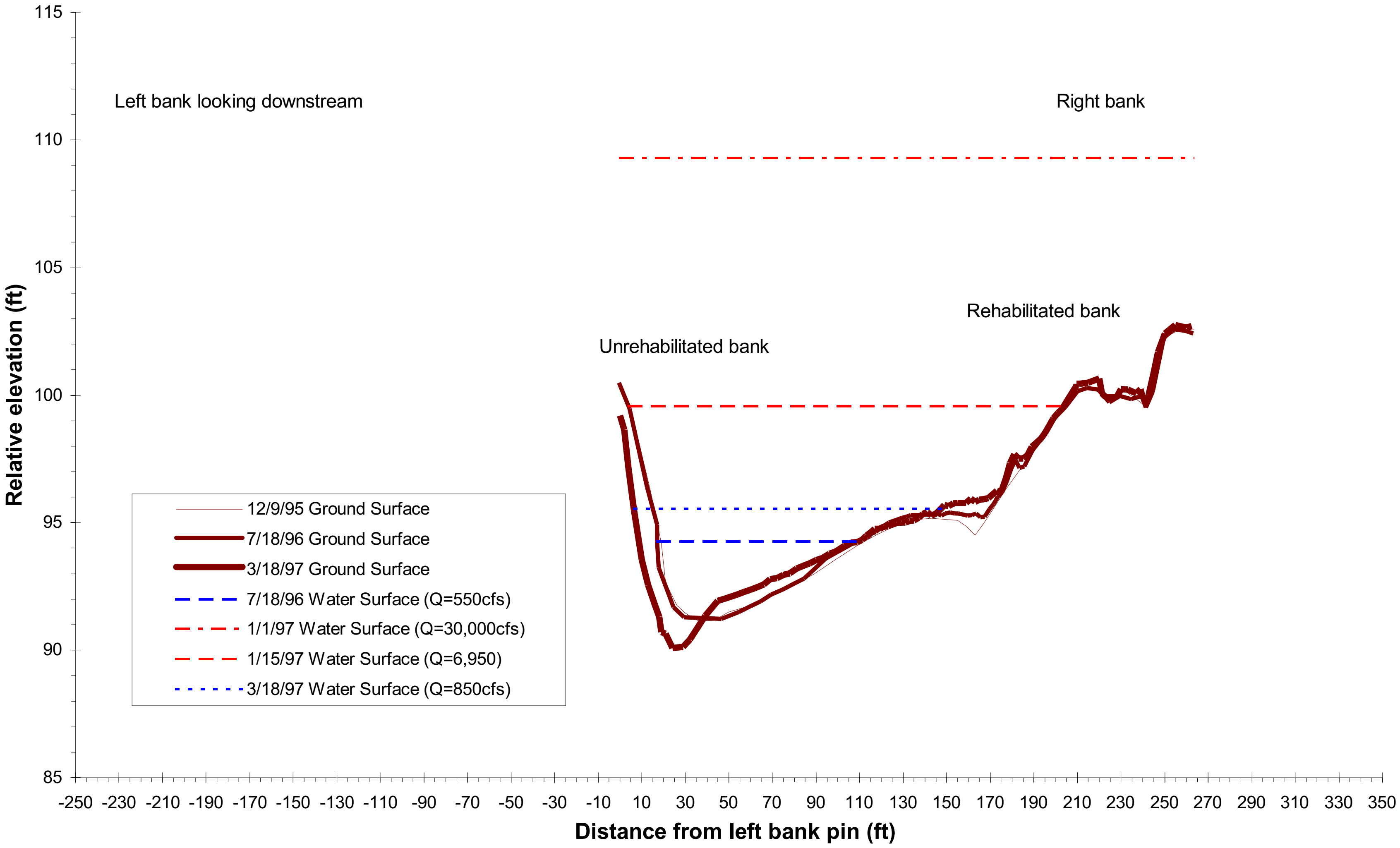


Figure C-45 Ground surface profiles and water surface elevations at cross section 1+35, Sheridan Creek rehabilitation site. Some bank erosion occurred here during the 1997 flood and the thalweg shifted to the left as some aggradation took place along the right bank.

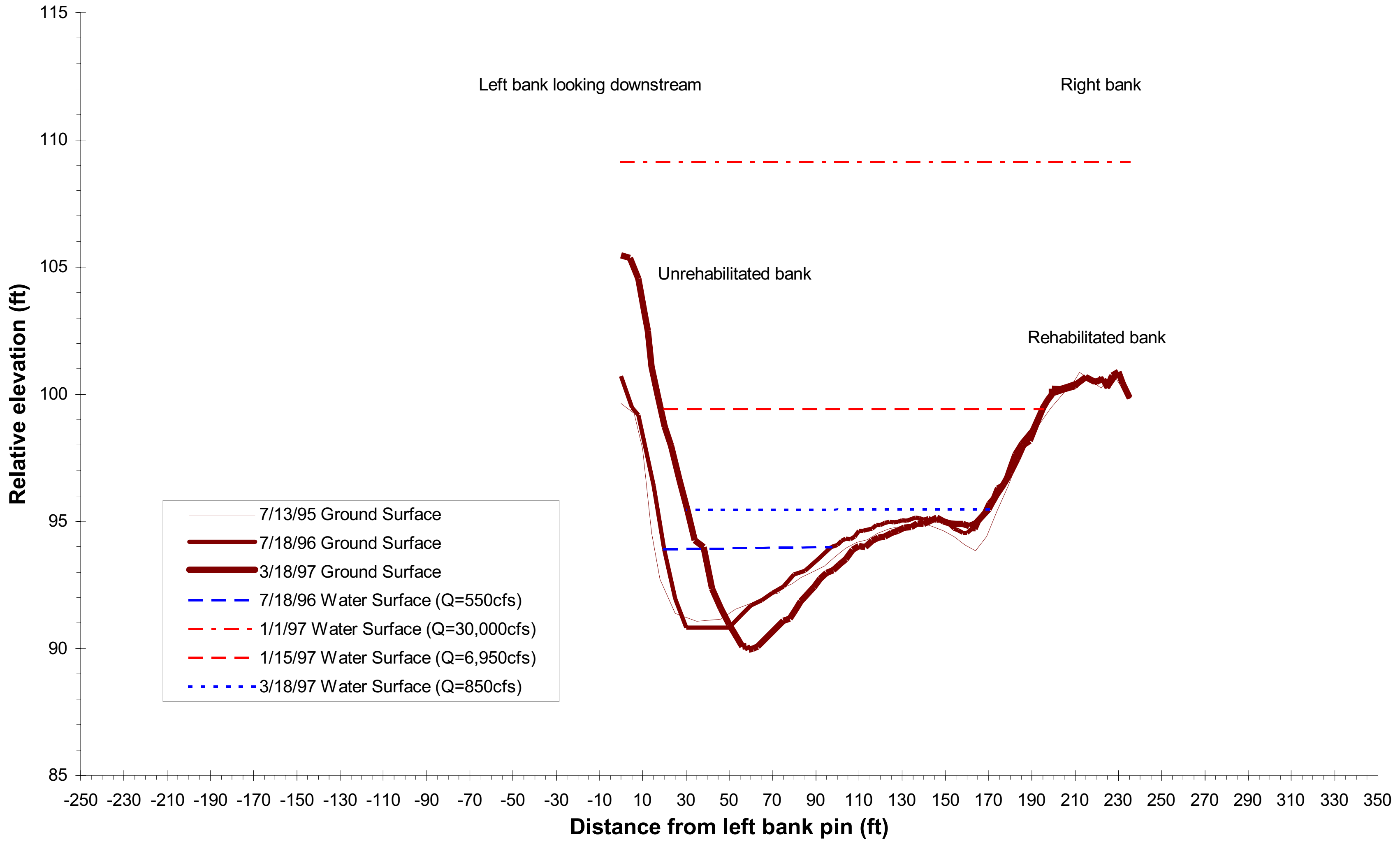


Figure C-46 Ground surface profiles and water surface elevations at cross section 2+35, Sheridan Creek rehabilitation site. Aggradation occurred along the left bank here during the 1997 flood as the thalweg shifted to the right. The right bank also degraded.

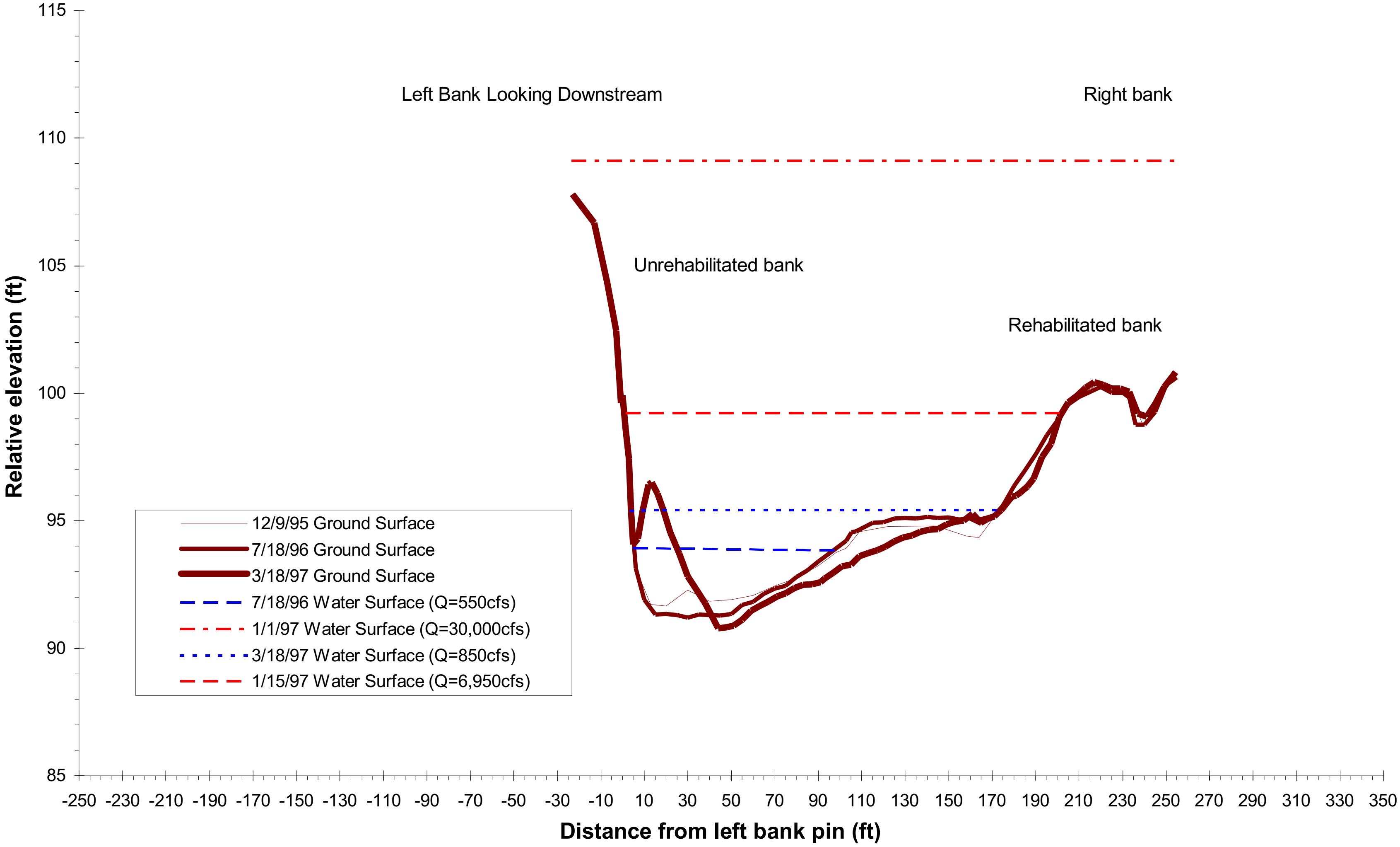


Figure C-47 Ground surface profiles and water surface elevations at cross section 3+35, Sheridan Creek rehabilitation site. Degradation of the right bank at this cross section was accompanied by aggradation along the left bank in 1997.

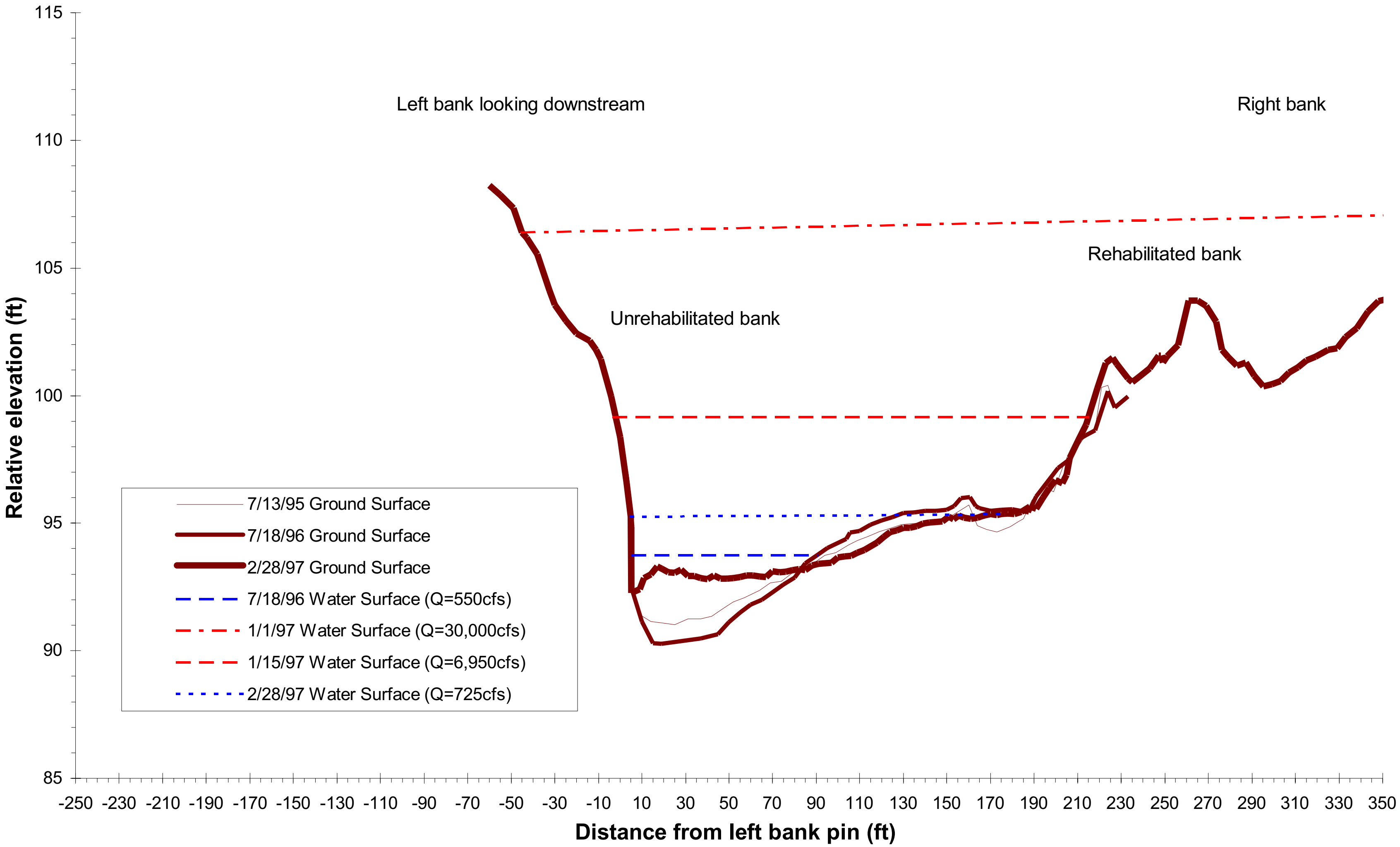


Figure C-48 Ground surface profiles and water surface elevations at cross section 4+35, Sheridan Creek rehabilitation site. Significant aggradation of the low water channel took place at this cross section in the 1997 flood.

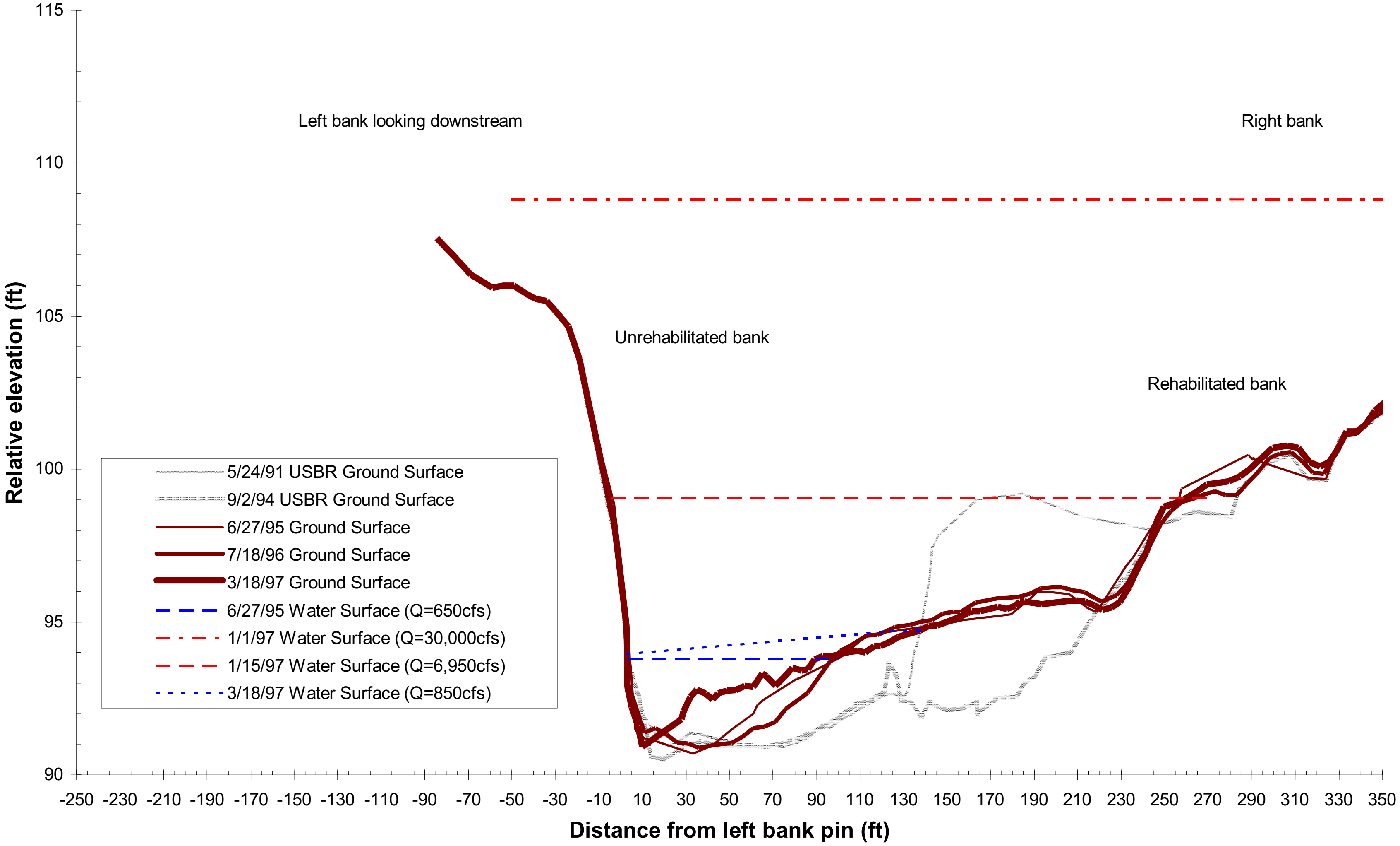


Figure C-49 Ground surface profiles and water surface elevations at cross section 5+35, Sheridan Creek rehabilitation site. This cross section experienced significant bar development each year following bank construction.

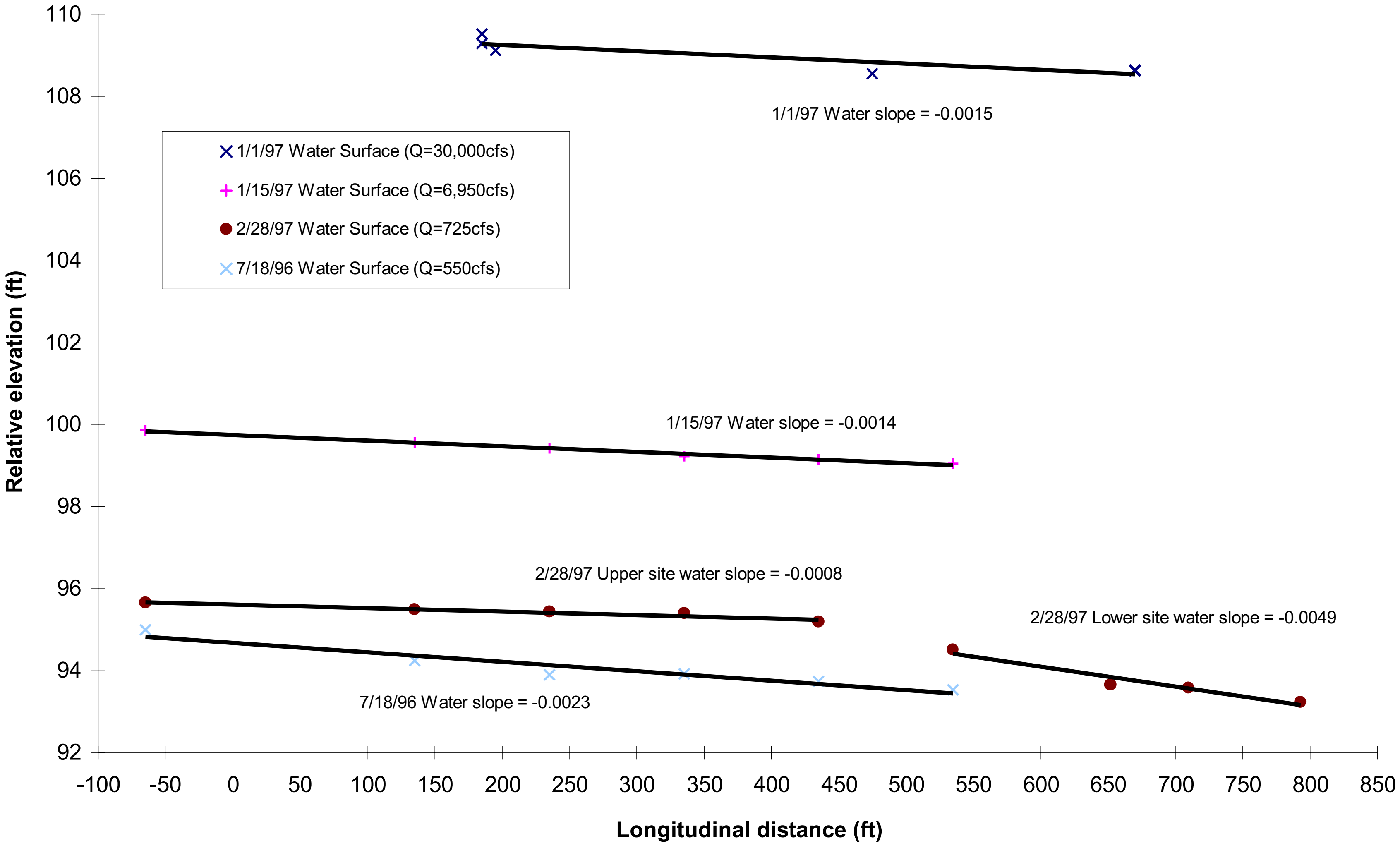


Figure C-50 Longitudinal water surface profiles for the Sheridan Creek rehabilitation site.

Figure C-51 - see Plate 21

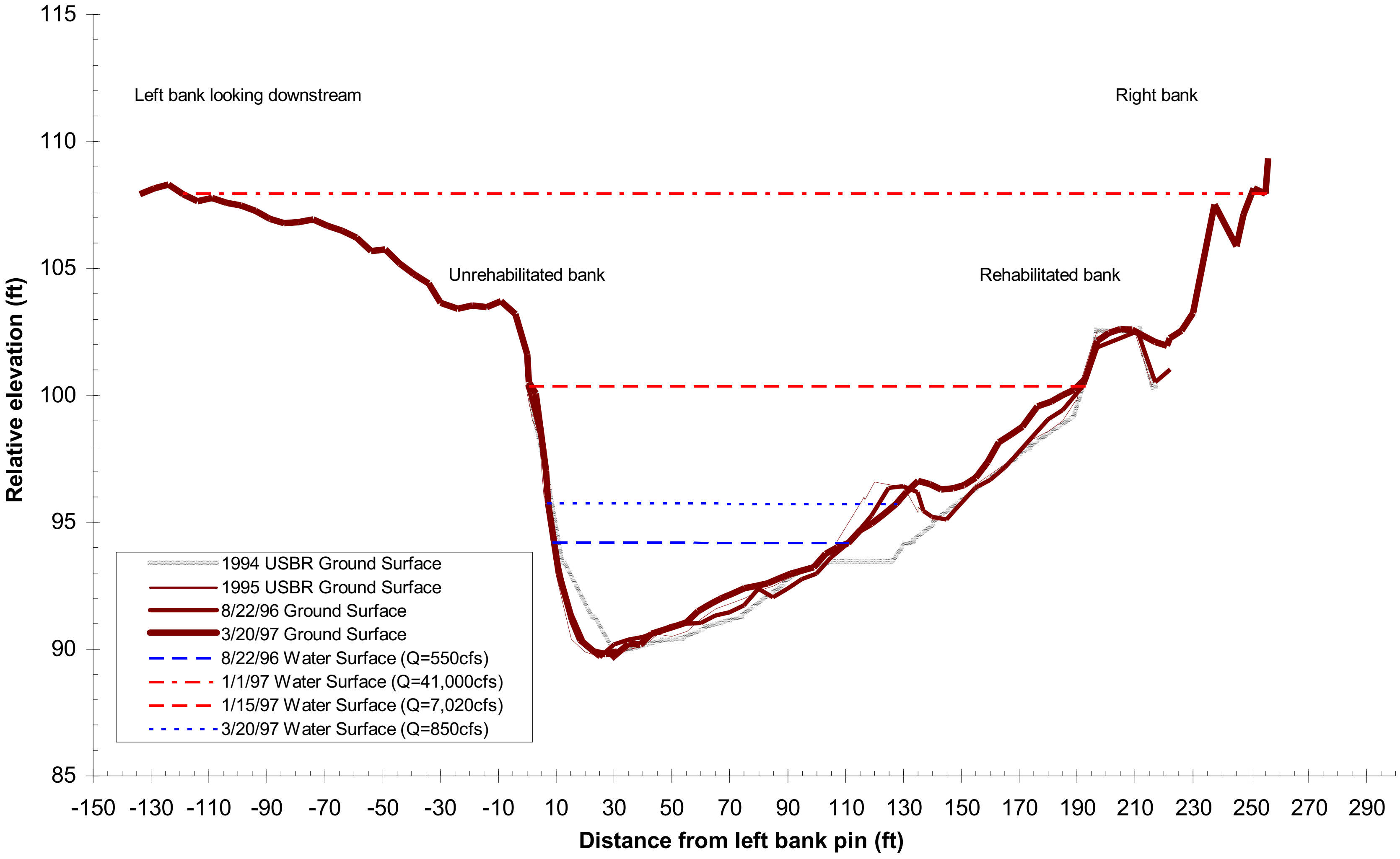


Figure C-52 Ground surface profiles and water surface elevations at cross section 10+00, Jim Smith rehabilitation site.

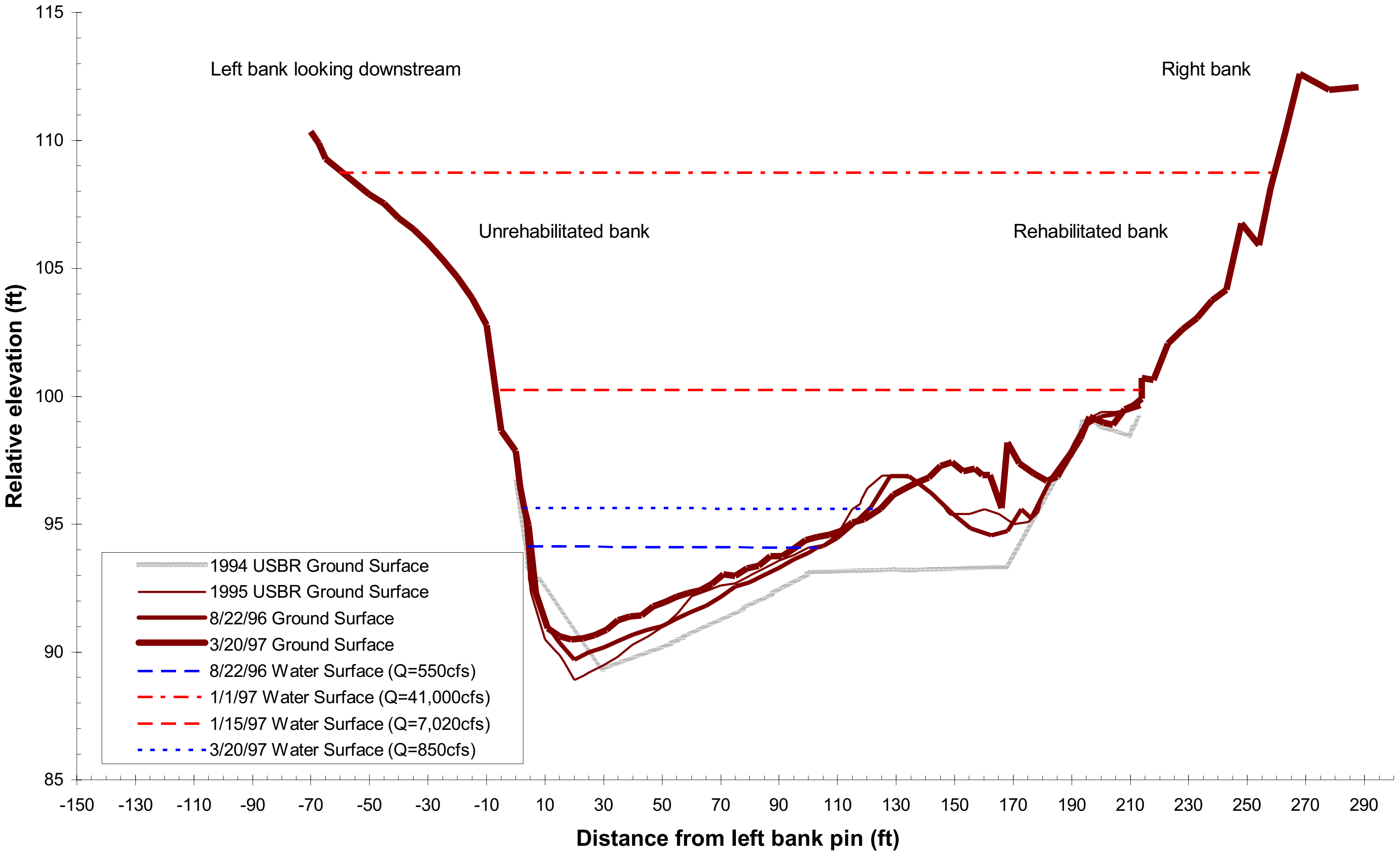


Figure C-53 Ground surface profiles and water surface elevations at cross section 11+10, Jim Smith rehabilitation site. Note the aggradation of the bar along the upper portion of the right bank.

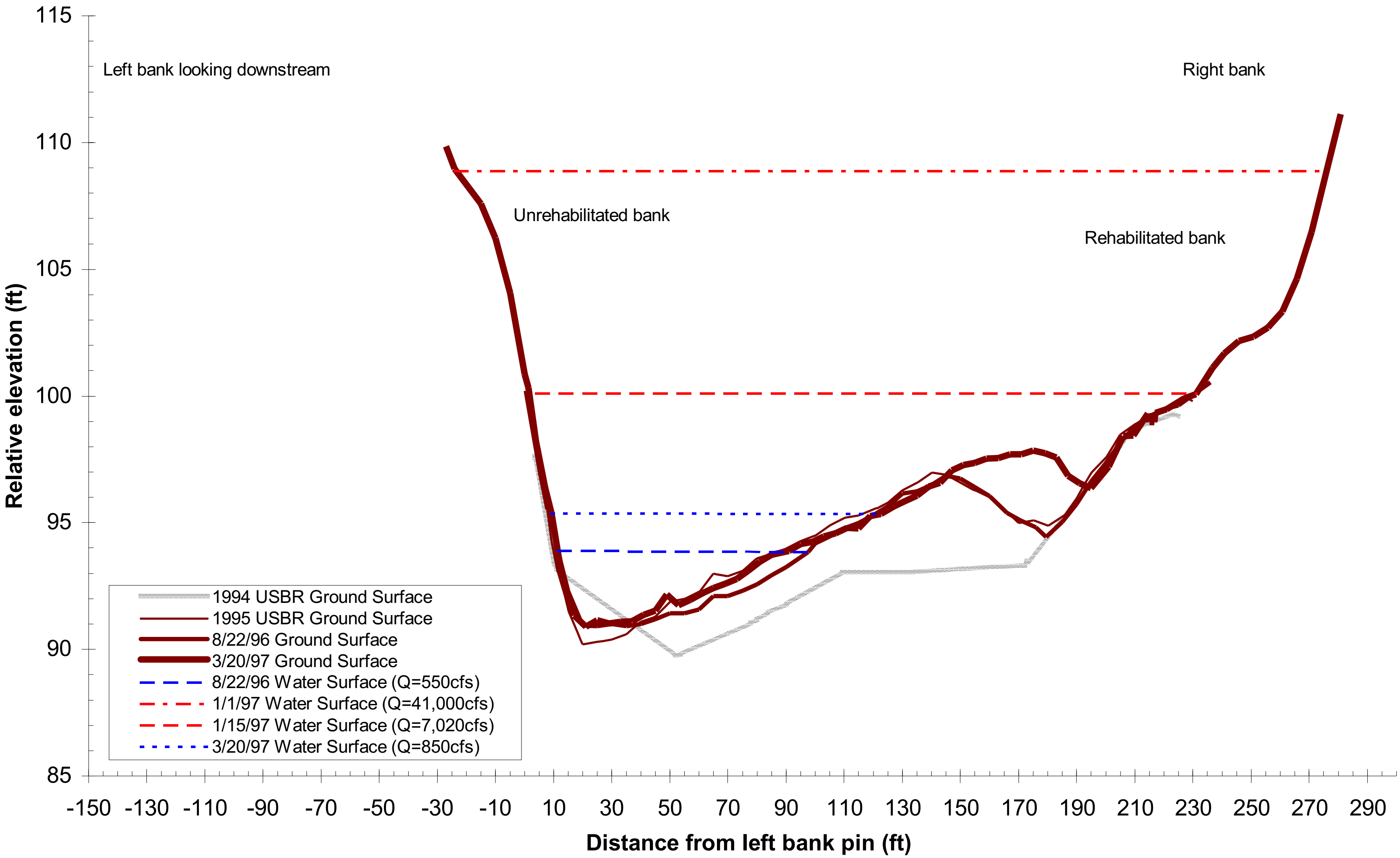


Figure C-54 Ground surface profiles and water surface elevations at cross section 12+10, Jim Smith rehabilitation site. Aggradation continued along the upper portion of the right bank at this cross section in 1997.

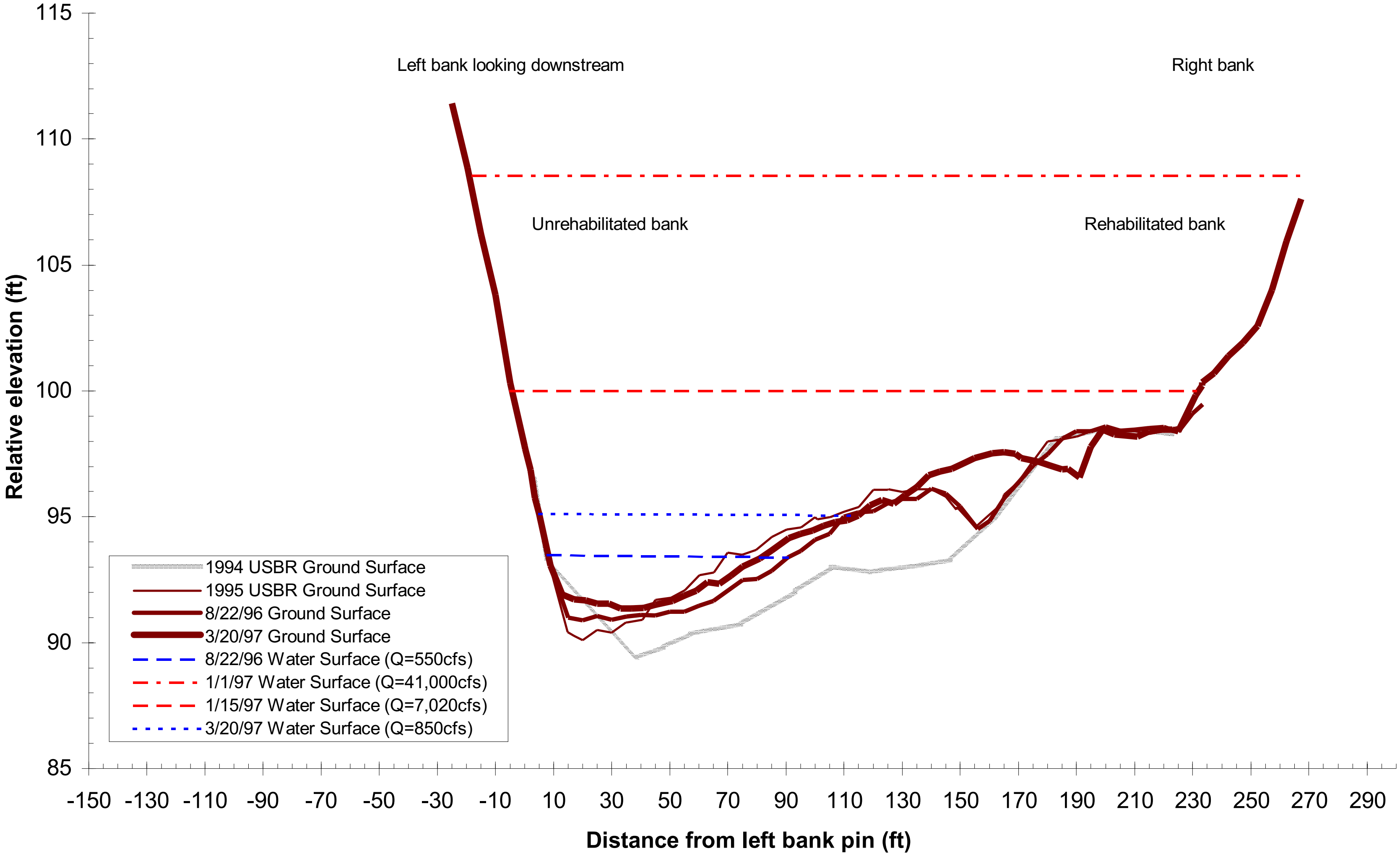


Figure C-55 Ground surface profiles and water surface elevations at cross section 13+00, Jim Smith rehabilitation site. Aggradation continued along the upper portion of the right bank at this cross section in 1997.

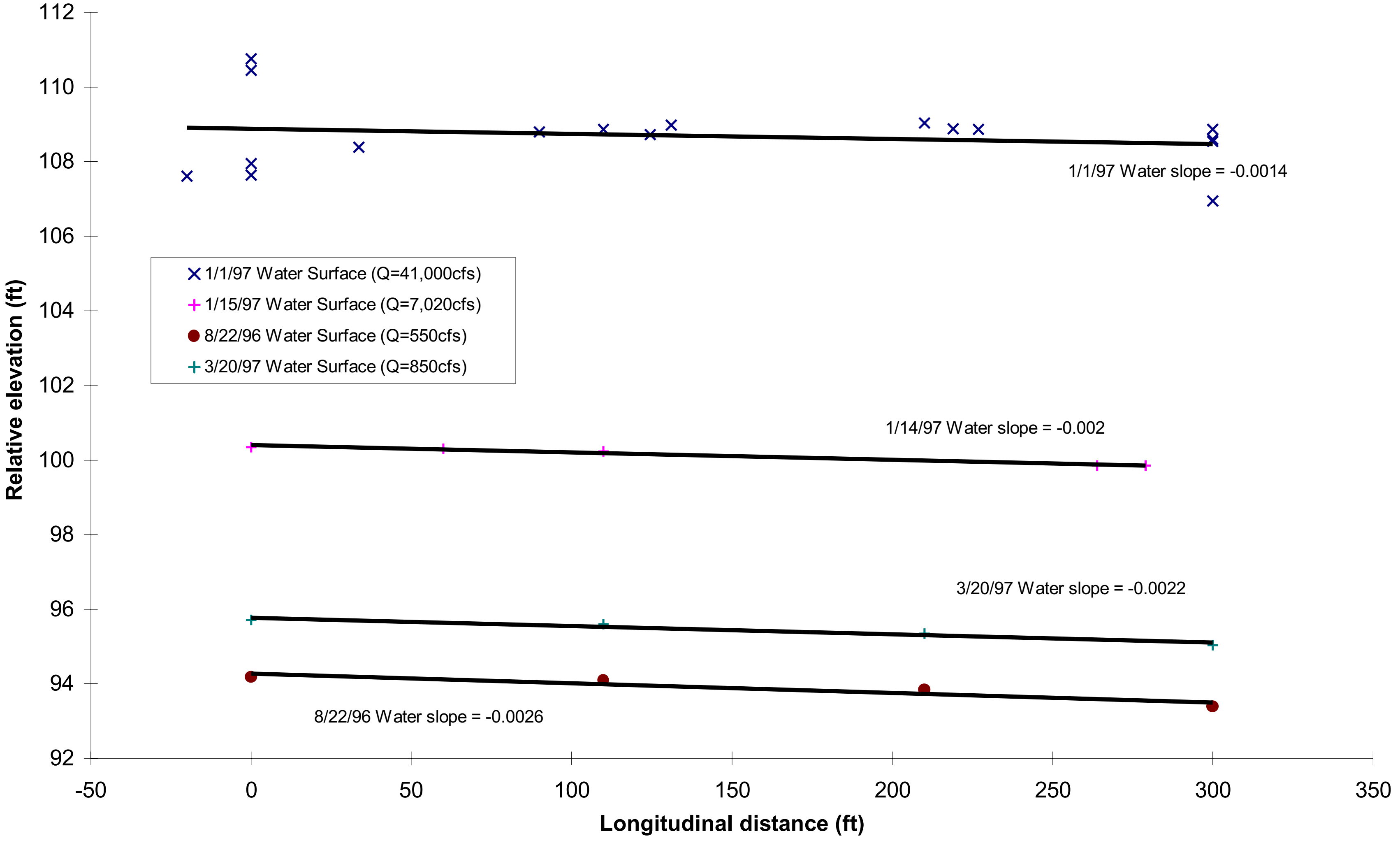


Figure C-56 Longitudinal water surface profiles for the Jim Smith rehabilitation site.

Figure C-57 - see Plate 22

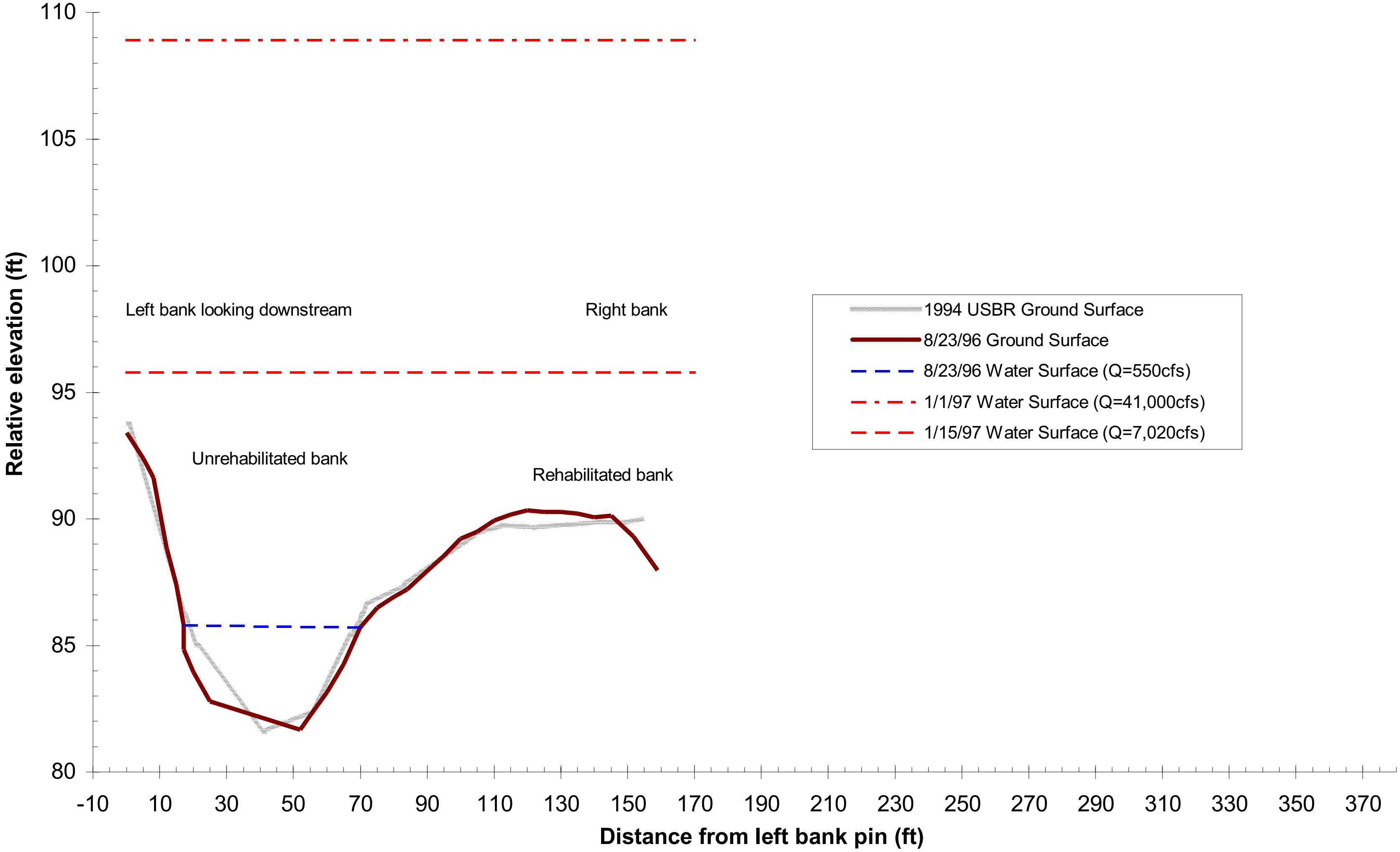


Figure C-58 Ground surface profiles and water surface elevations at cross section 10+00, Pear Tree rehabilitation site.

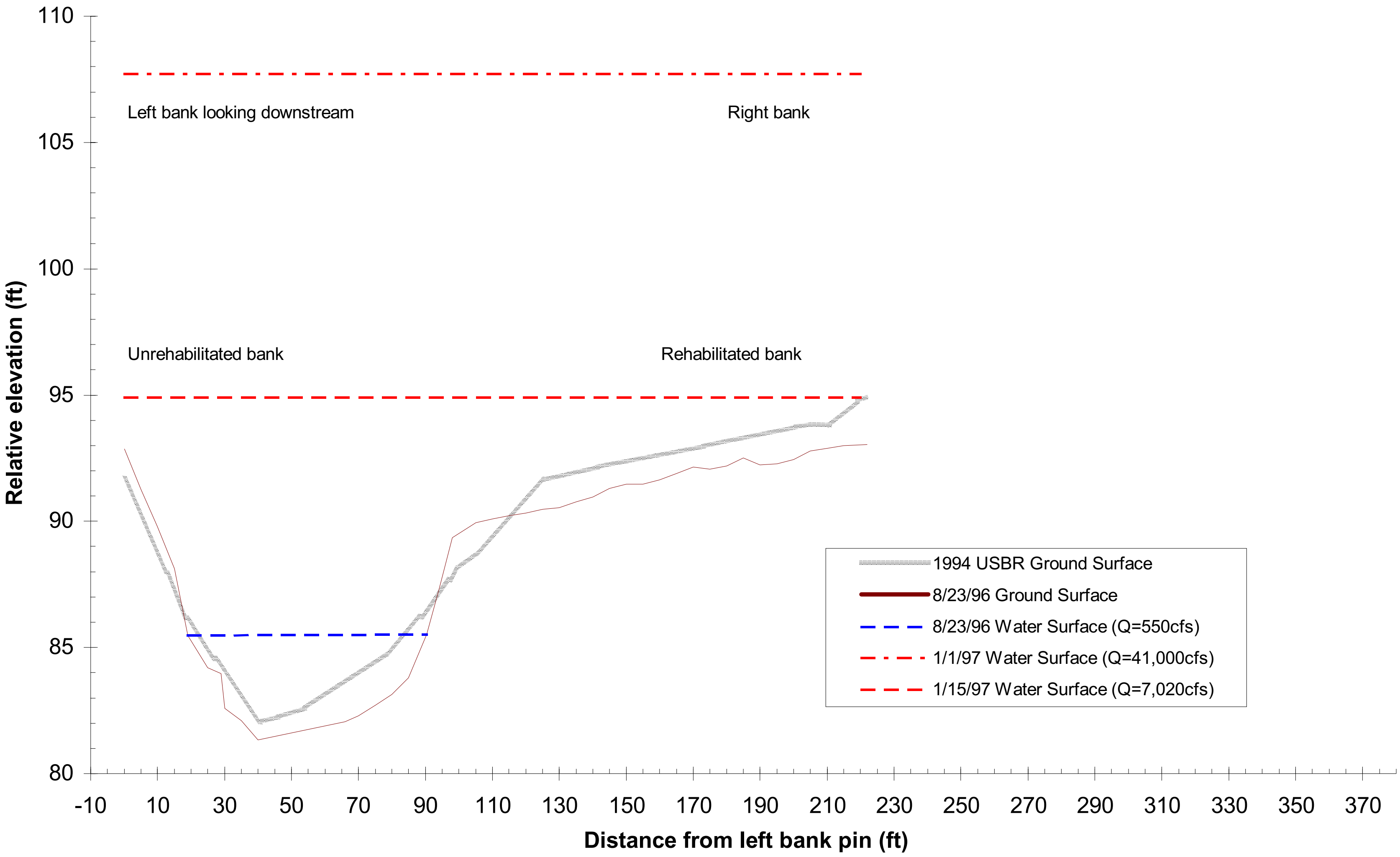


Figure C-59 Ground surface profiles and water surface elevations at cross section 11+86, Pear Tree rehabilitation site. Note the bar development along the upper portion of the right bank.

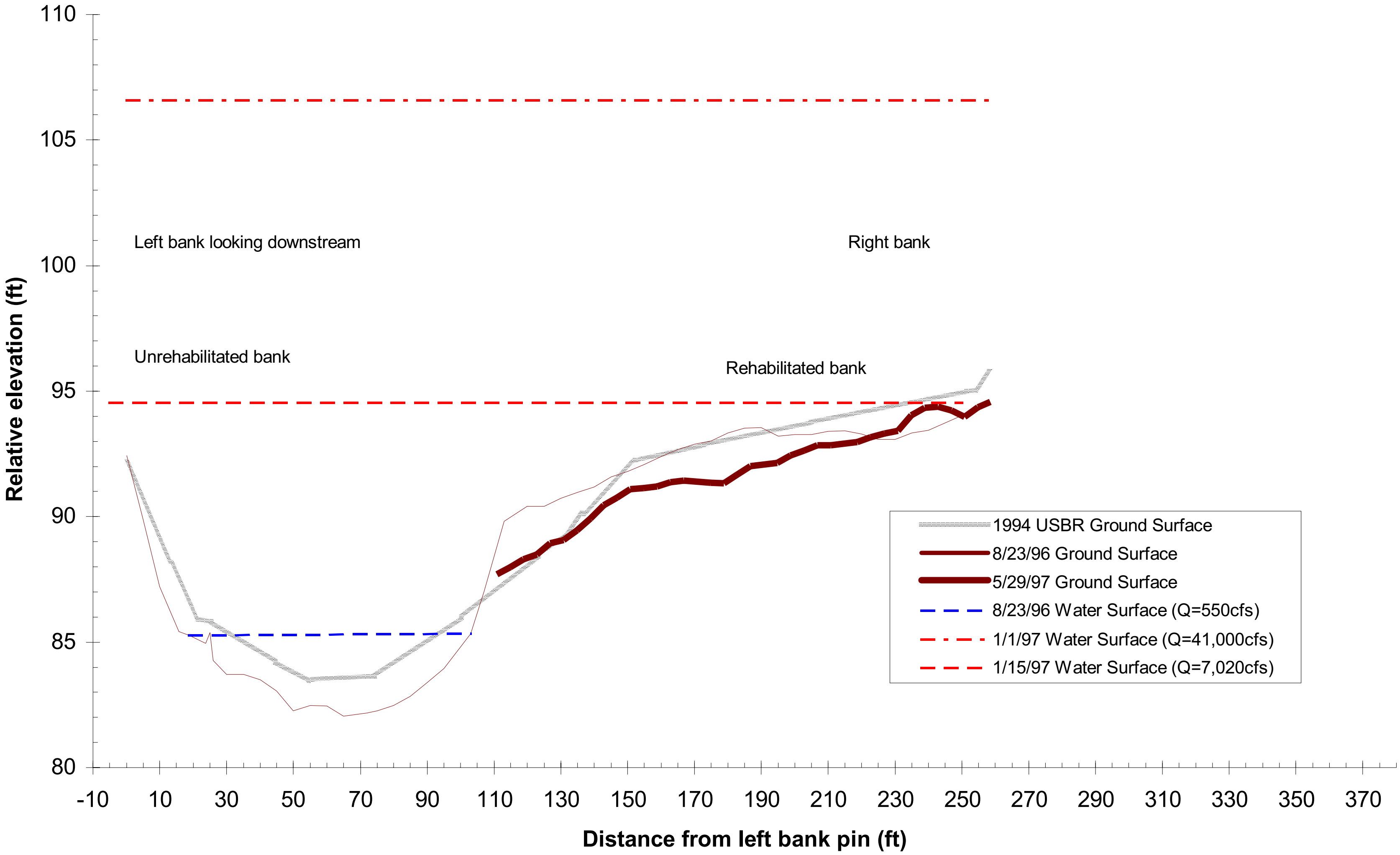


Figure C-60 Ground surface profiles and water surface elevations at cross section 12+72, Pear Tree rehabilitation site. Note the bar development along the upper portion of the right bank. The 1997 survey could not be completed across the channel due to high flows.

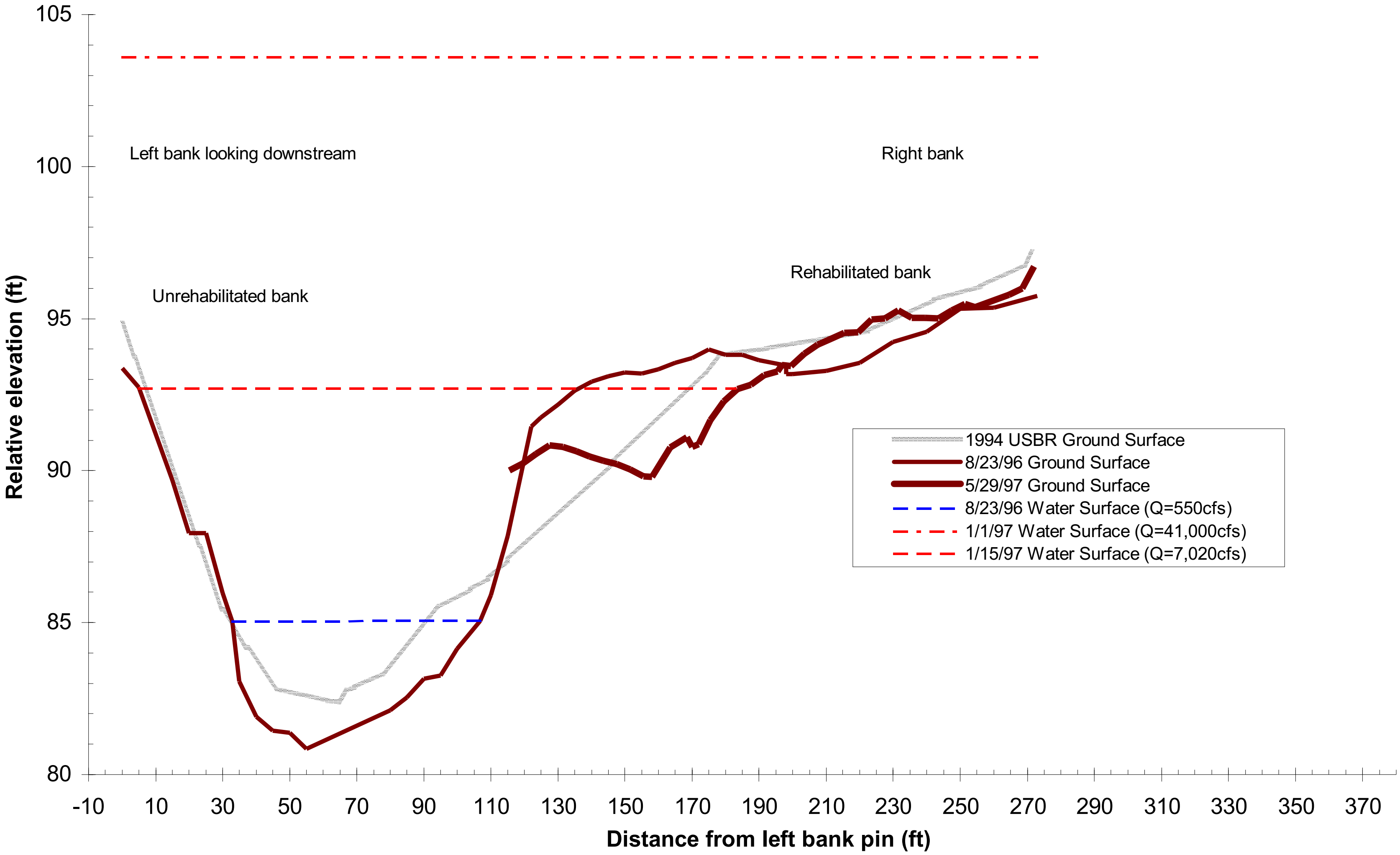


Figure C-61 Ground surface profiles and water surface elevations at cross section 14+10, Pear Tree rehabilitation site. Note the bar development along the upper portion of the right bank. The 1997 survey could not be completed across the channel due to high flows.

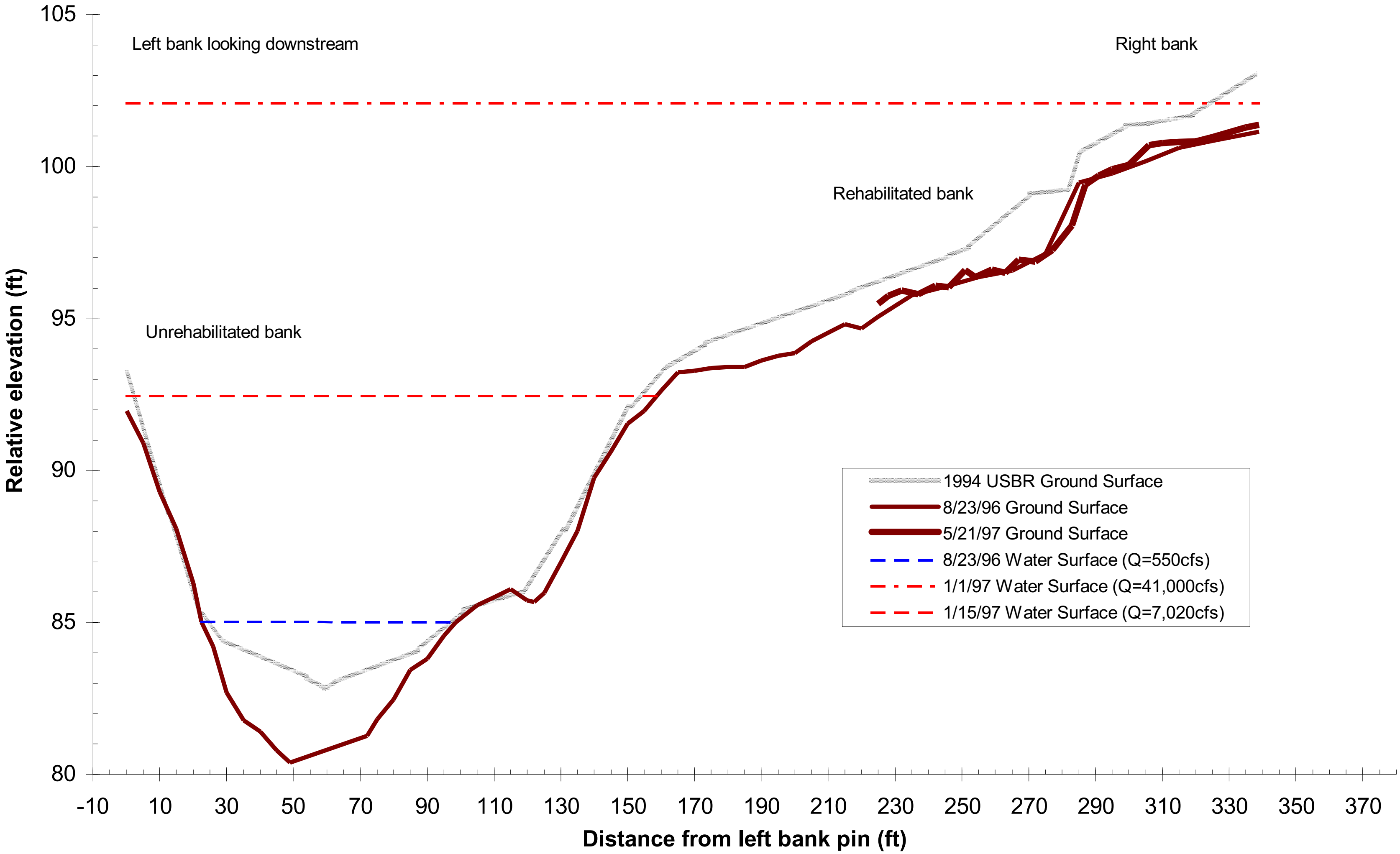


Figure C-62 Ground surface profiles and water surface elevations at cross section 15+00, Pear Tree rehabilitation site. The 1997 survey could not be completed across the channel due to high flows.

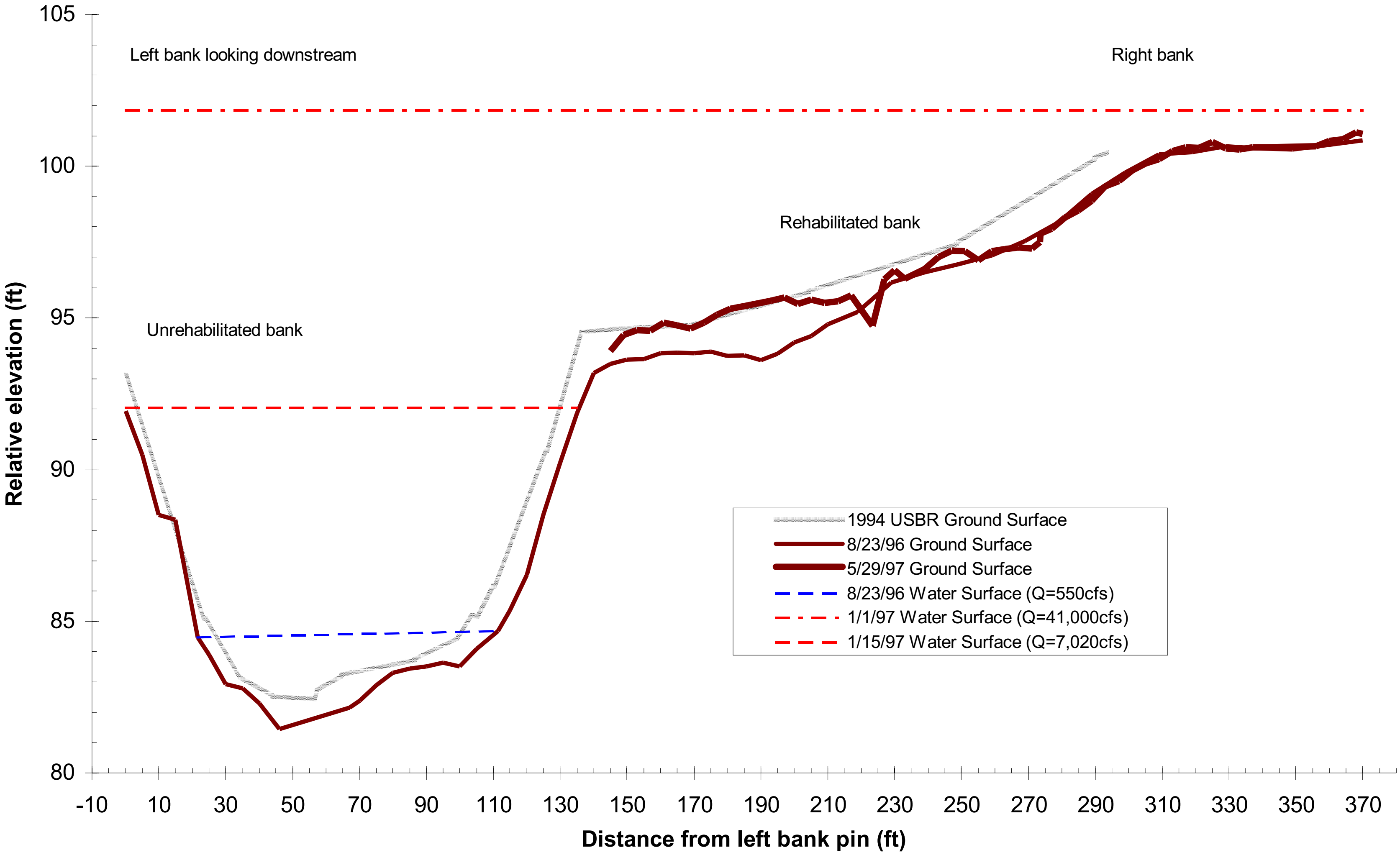


Figure C-63 Ground surface profiles and water surface elevations at cross section 16+00, Pear Tree rehabilitation site. The 1997 survey could not be completed across the channel due to high flows.

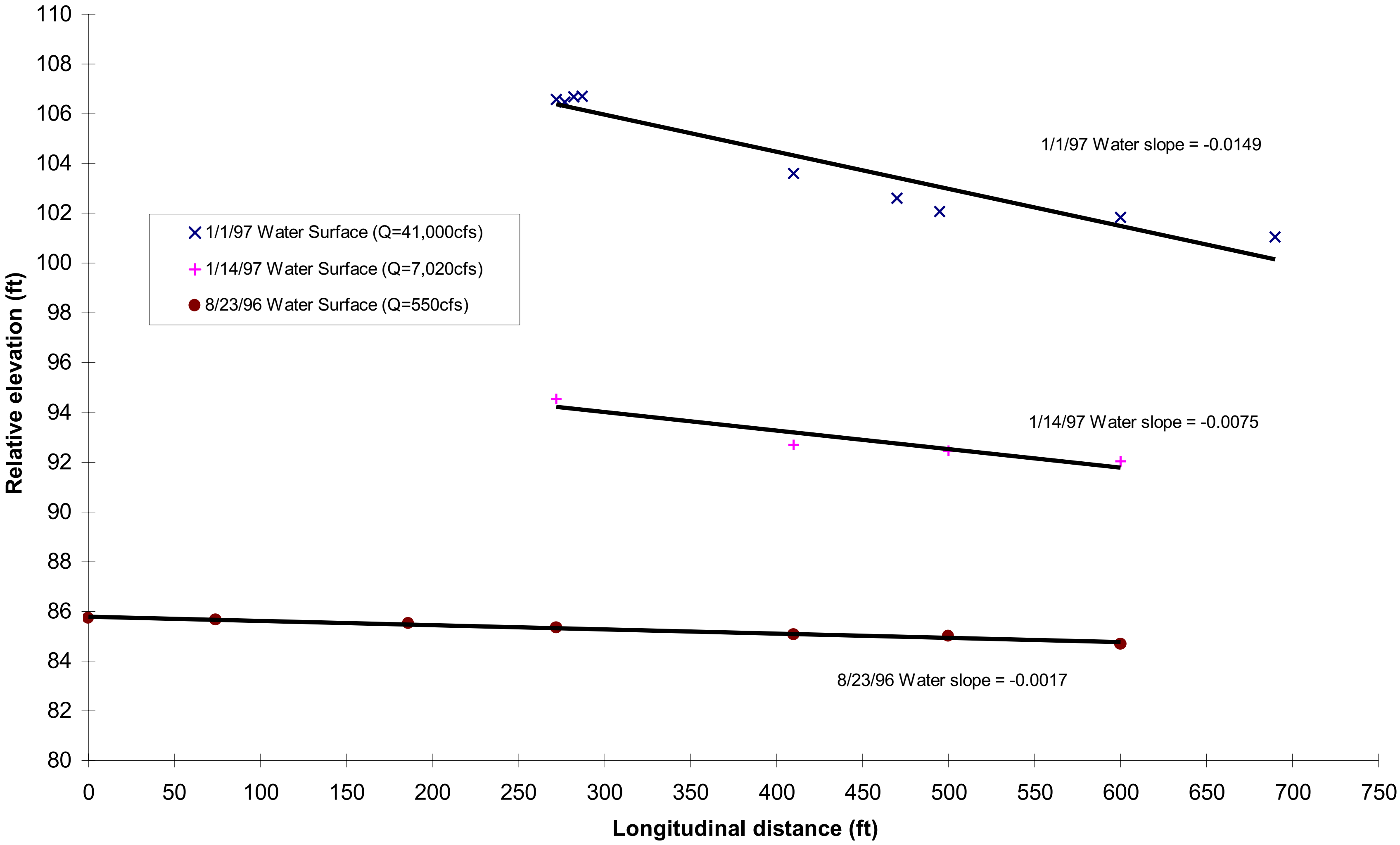


Figure C-64 Longitudinal water surface profiles for the Pear Tree rehabilitation site.

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APPENDIX D
PLATES

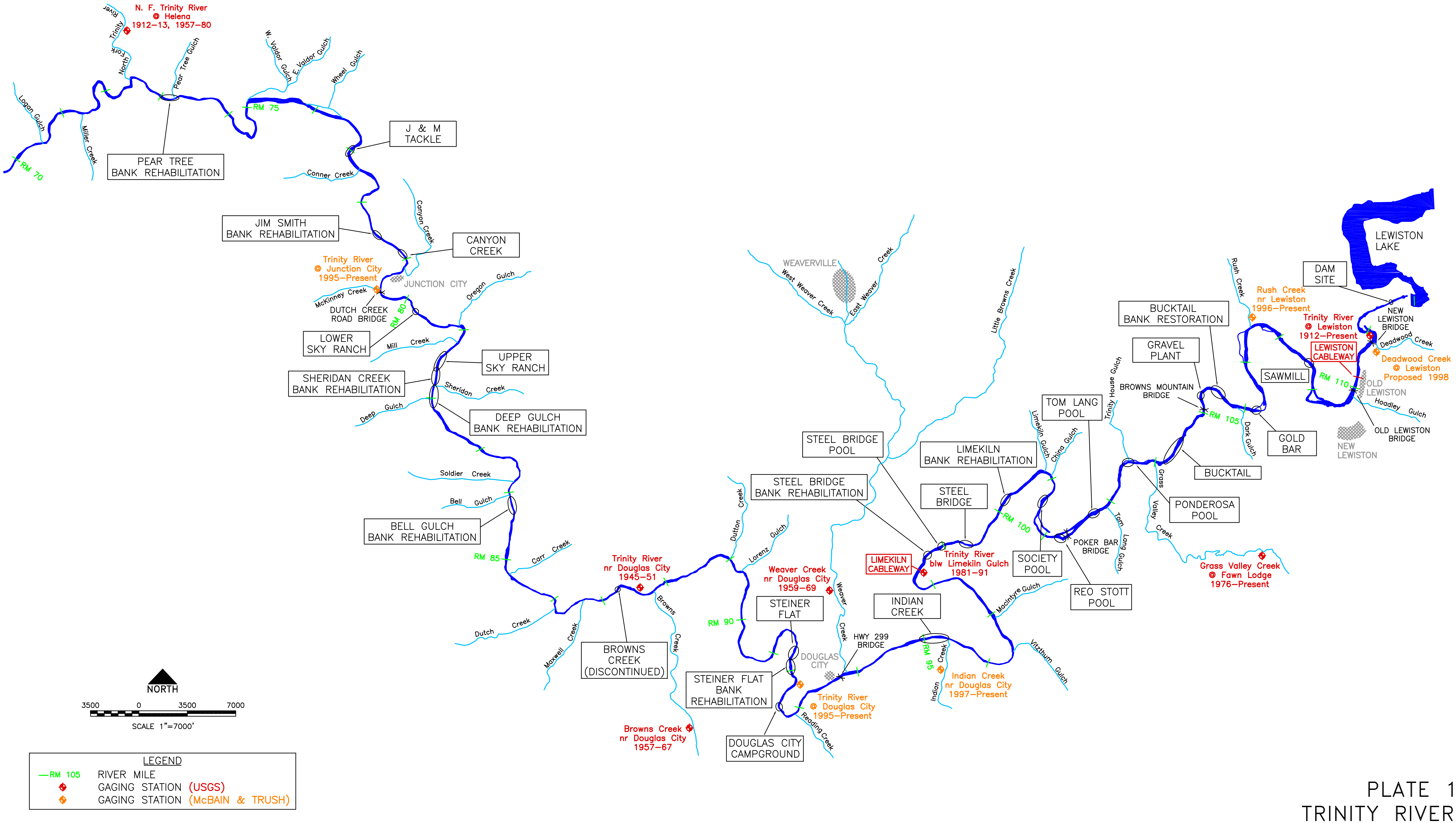
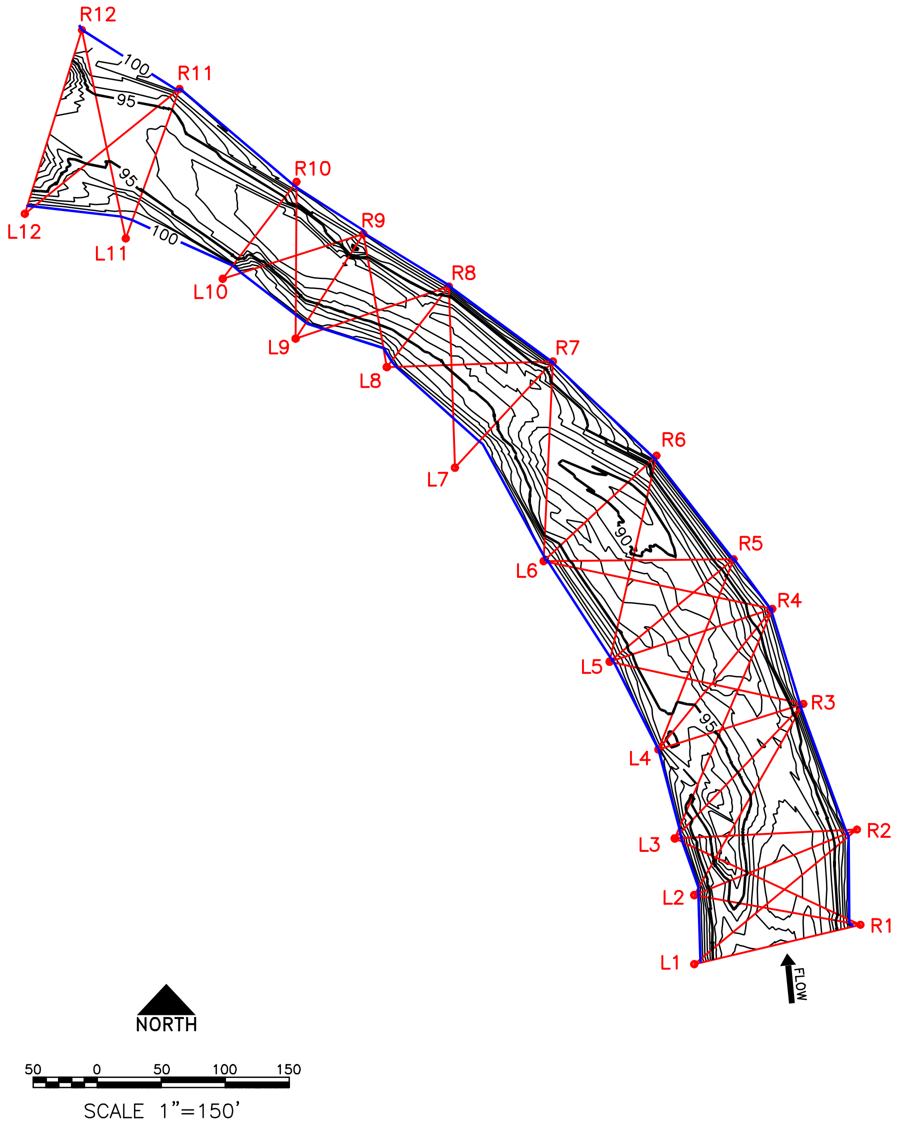


PLATE 1
TRINITY RIVER MAINTENANCE FLOW STUDY: STUDY SITE LOCATIONS

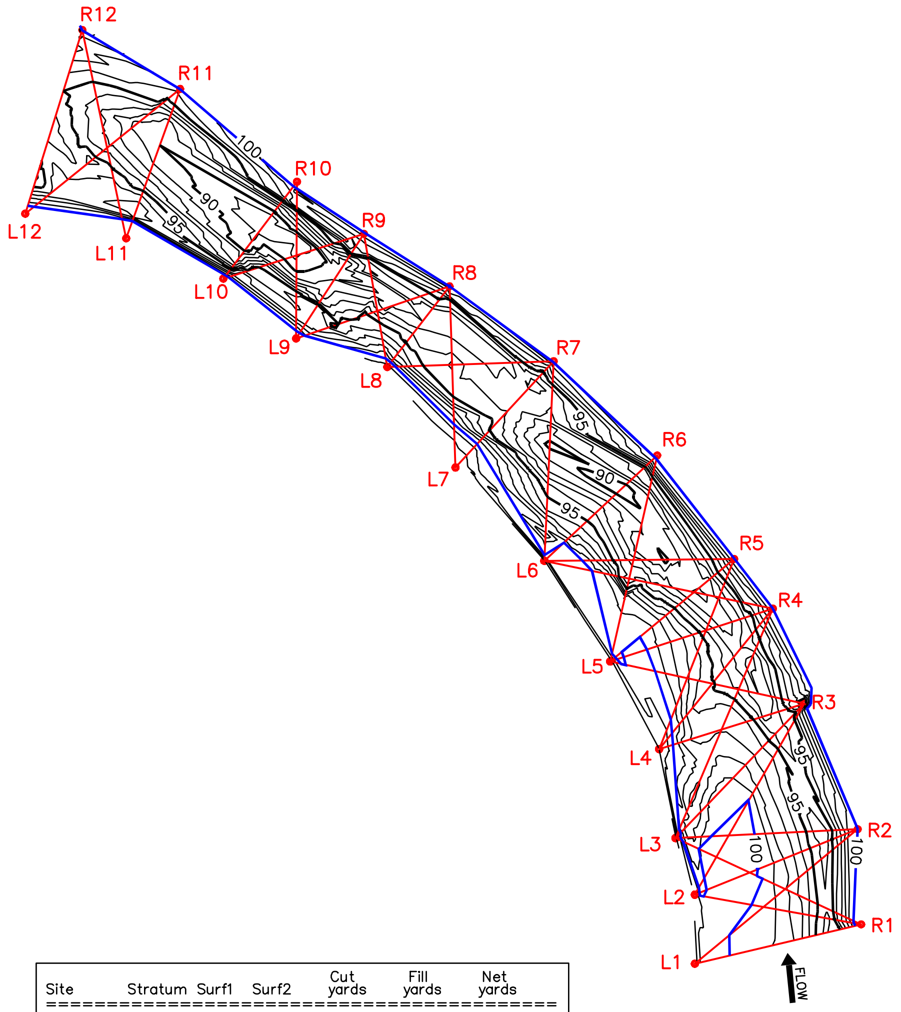
McBain & Trush 1997

11/13/97

1993 TOPOGRAPHY
(Surveyed by CEDR)



1997 TOPOGRAPHY



Site	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
trinpool	93–97	93pon	97pon	1555	5605	4050 (FILL)

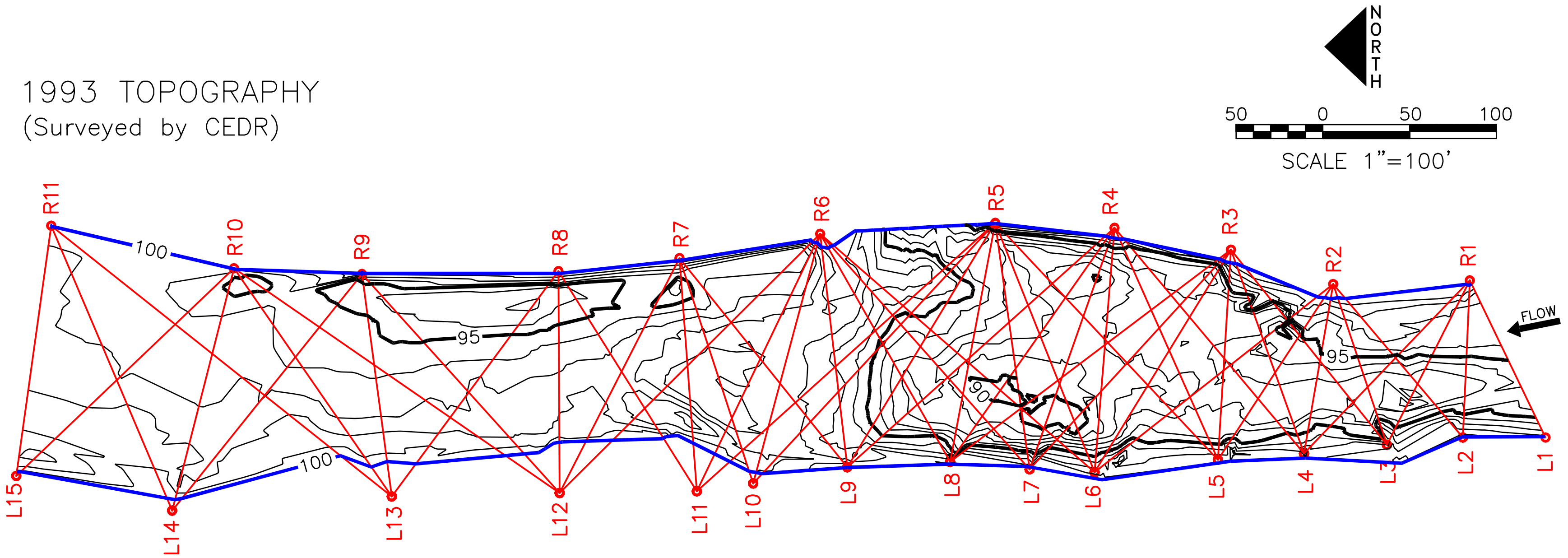
Arbitrary 100' datum is 450cfs water surface

PLATE 2
TRINITY RIVER MILE 103.6
PONDEROSA POOL

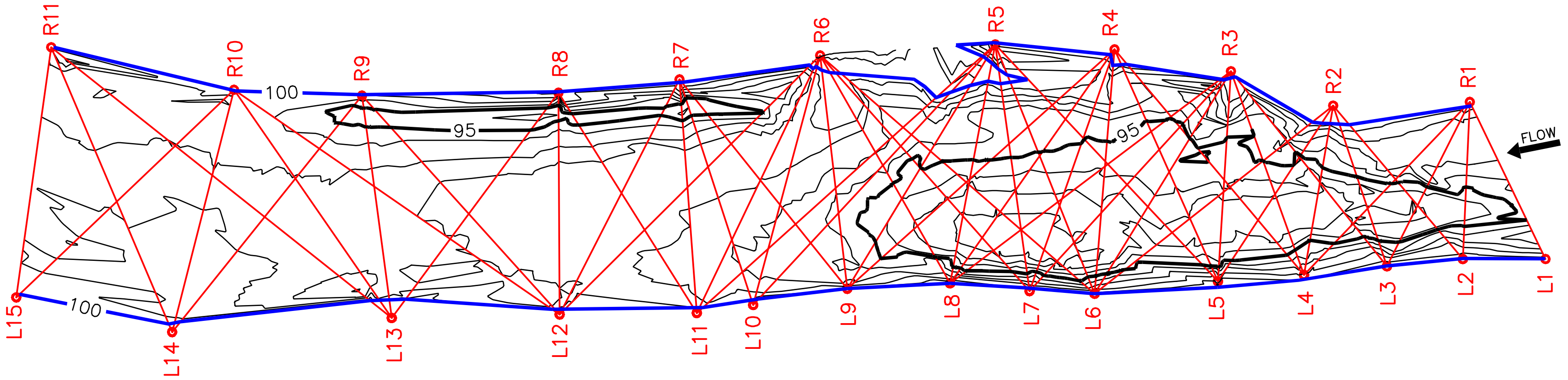
McBain & Trush 1997

11/13/97

1993 TOPOGRAPHY
(Surveyed by CEDR)



1997 TOPOGRAPHY



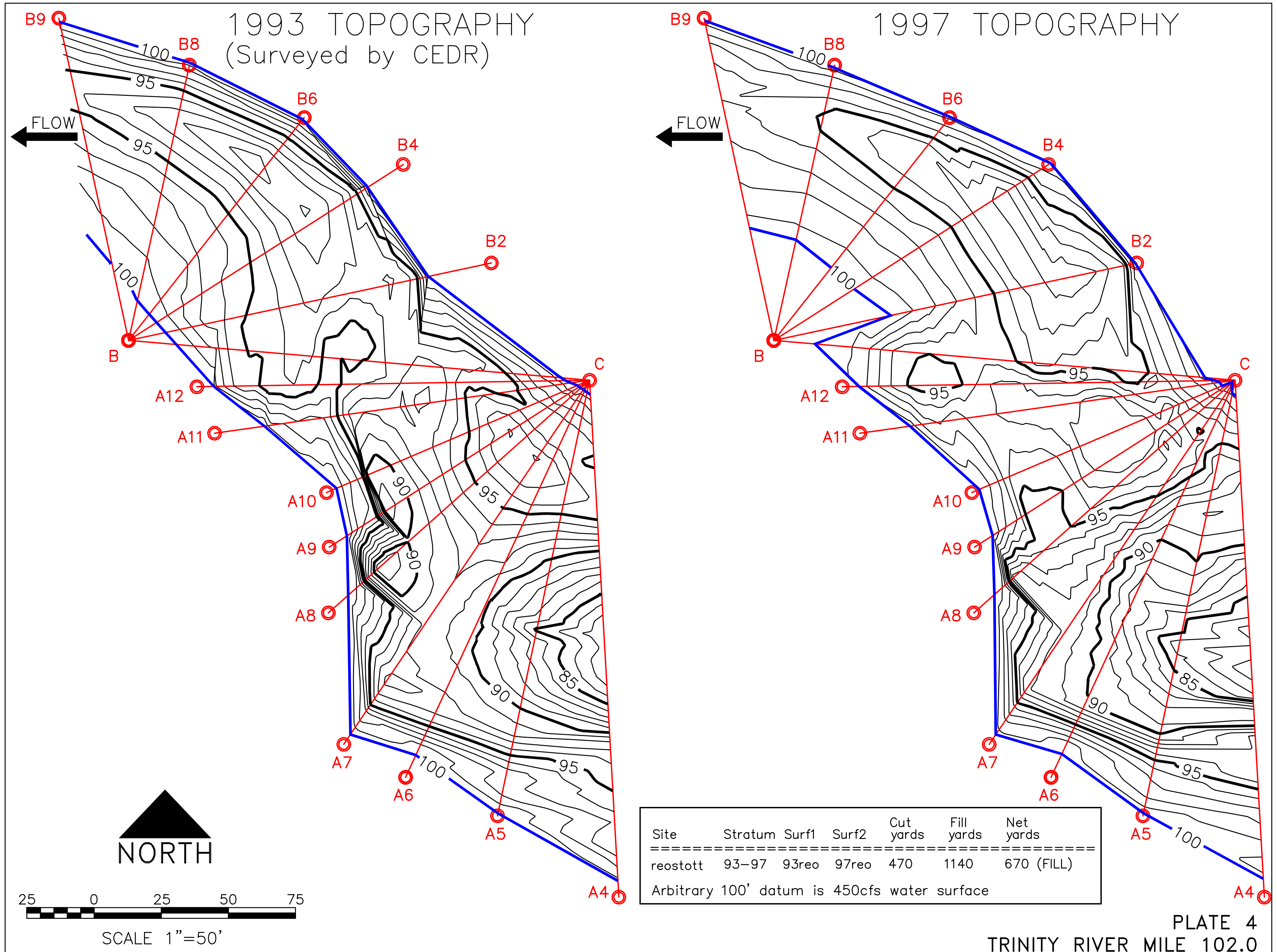
Site	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
tomlang	93–97	93tom	97tom	560	3830	3270 (FILL)

Arbitrary 100' datum is 450cfs water surface

PLATE 3
TRINITY RIVER MILE 102.8
TOM LANG POOL

McBain & Trush 1997

11/13/97



Site	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
reostott	93-97	93reo	97reo	470	1140	670 (FILL)

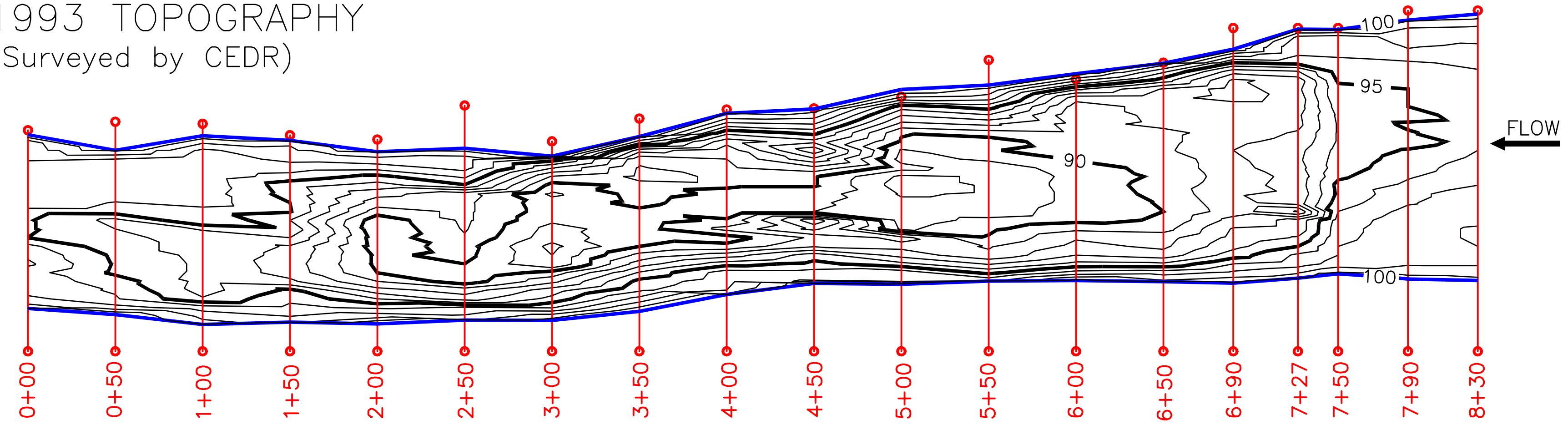
Arbitrary 100' datum is 450cfs water surface

PLATE 4
TRINITY RIVER MILE 102.0
REO STOTT POOL

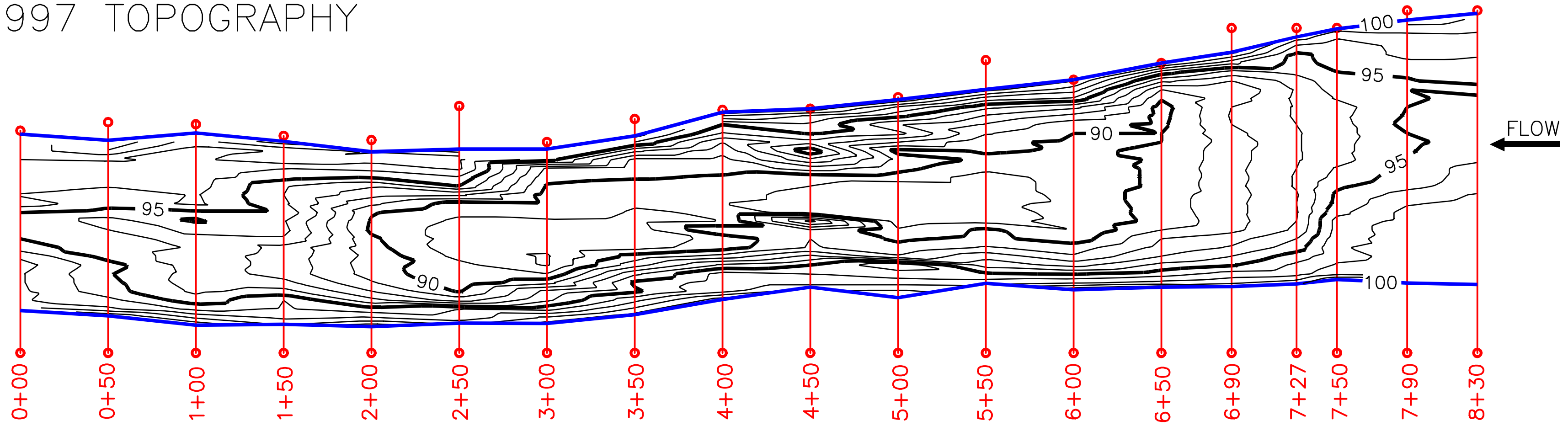
11/13/97

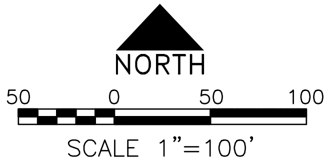
McBain & Trush 1997

1993 TOPOGRAPHY
(Surveyed by CEDR)



1997 TOPOGRAPHY





Site	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
society	93–97	93soc	97soc	1110	495	615 (CUT)

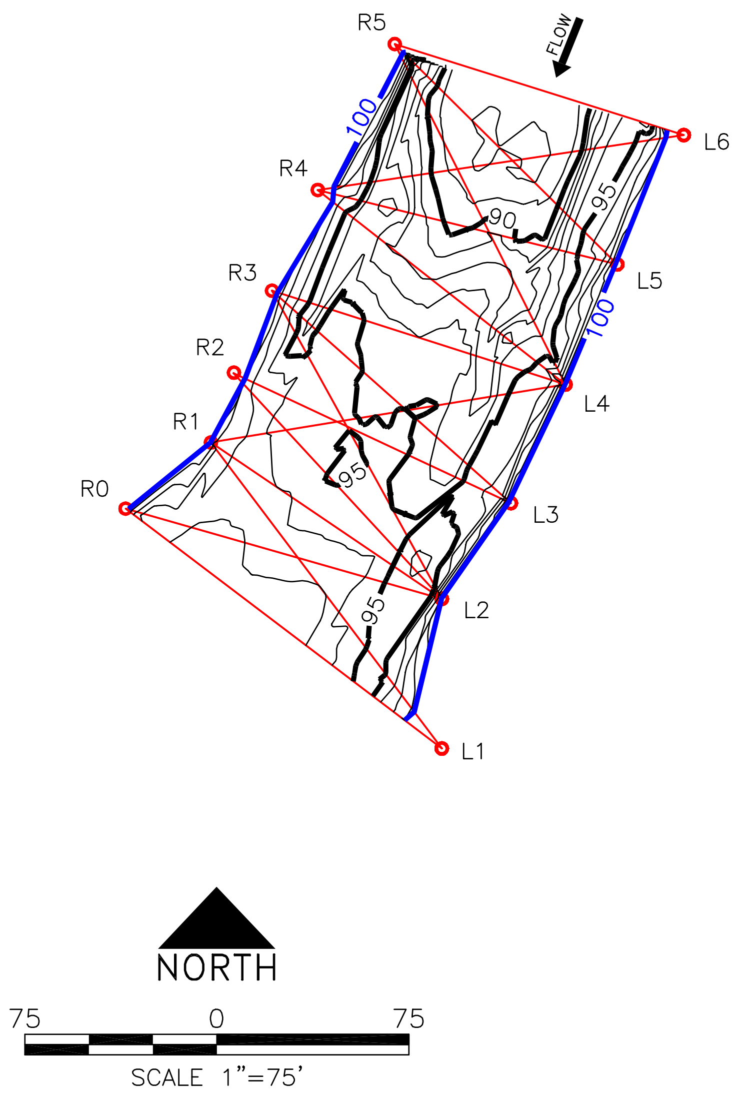
Arbitrary 100' datum is 450cfs water surface

PLATE 5
TRINITY RIVER MILE 101.3
SOCIETY POOL

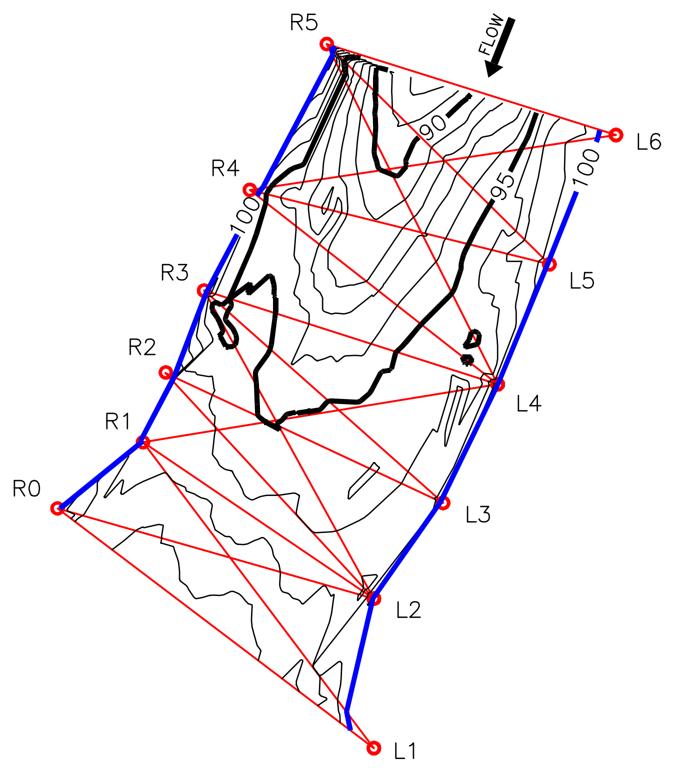
McBain & Trush 1997

11/13/97

1993 TOPOGRAPHY
(Surveyed by CEDR)



1997 TOPOGRAPHY



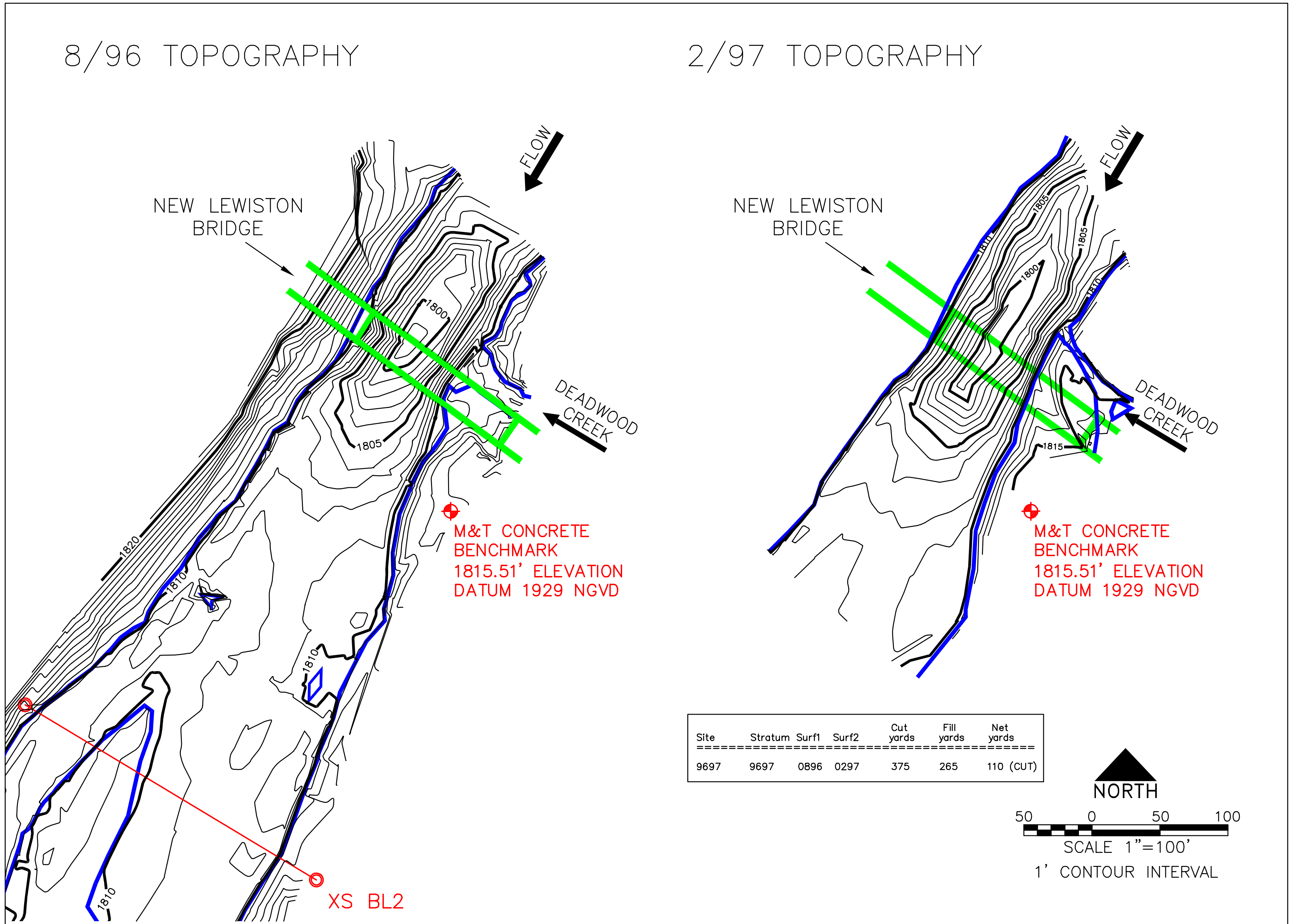
Site	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
steelbr	93-97	93ste	97ste	100	980	880 (FILL)

Arbitrary 100' datum is 450cfs water surface

McBain & Trush 1997

PLATE 6
TRINITY RIVER MILE 99.0
STEEL BRIDGE POOL

11/13/97



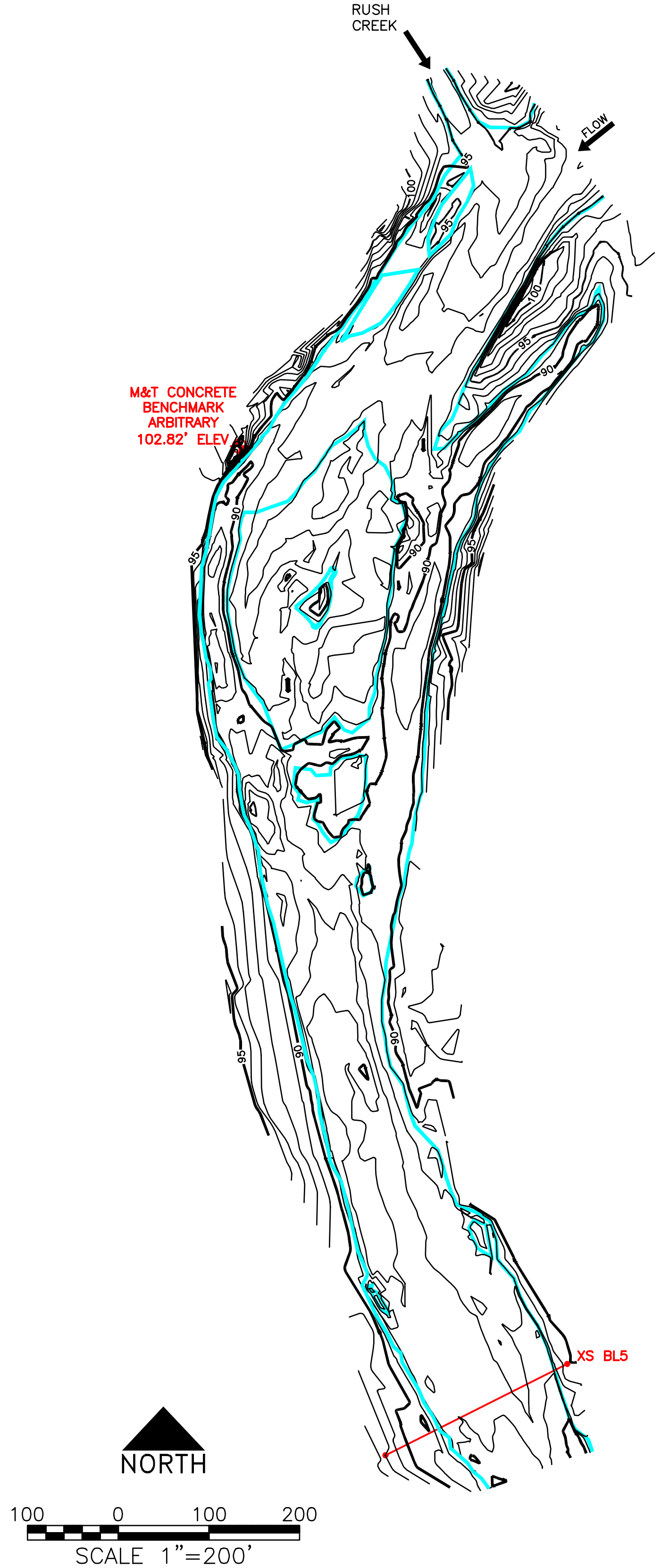
Site	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
9697	9697	0896	0297	375	265	110 (CUT)

PLATE 7
TRINITY RIVER MILE 110.8
DEADWOOD CREEK DELTA

11/13/97

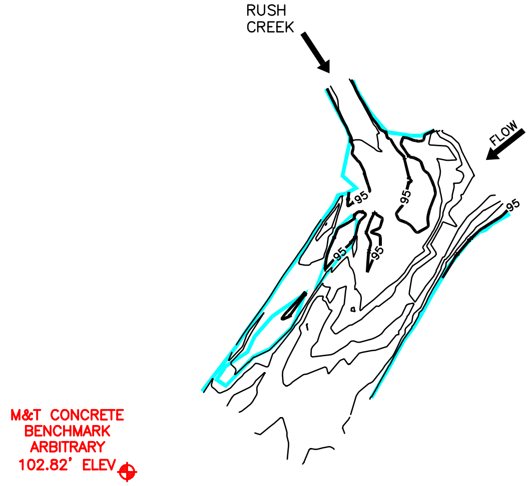
McBain & Trush 1997

8/96 TOPOGRAPHY



SCALE 1"=200'
1' CONTOUR INTERVAL

12/96 TOPOGRAPHY



VOLUMETRIC CHANGE BETWEEN 8/96 SURVEY TO 12/96 SURVEY

Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
9696	0896	1296	22	724	702 (FILL)

VOLUMETRIC CHANGE BETWEEN 12/96 SURVEY TO 3/97 SURVEY

Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
9697	1296	0397	2525	7640	5115 (FILL)

3/97 TOPOGRAPHY

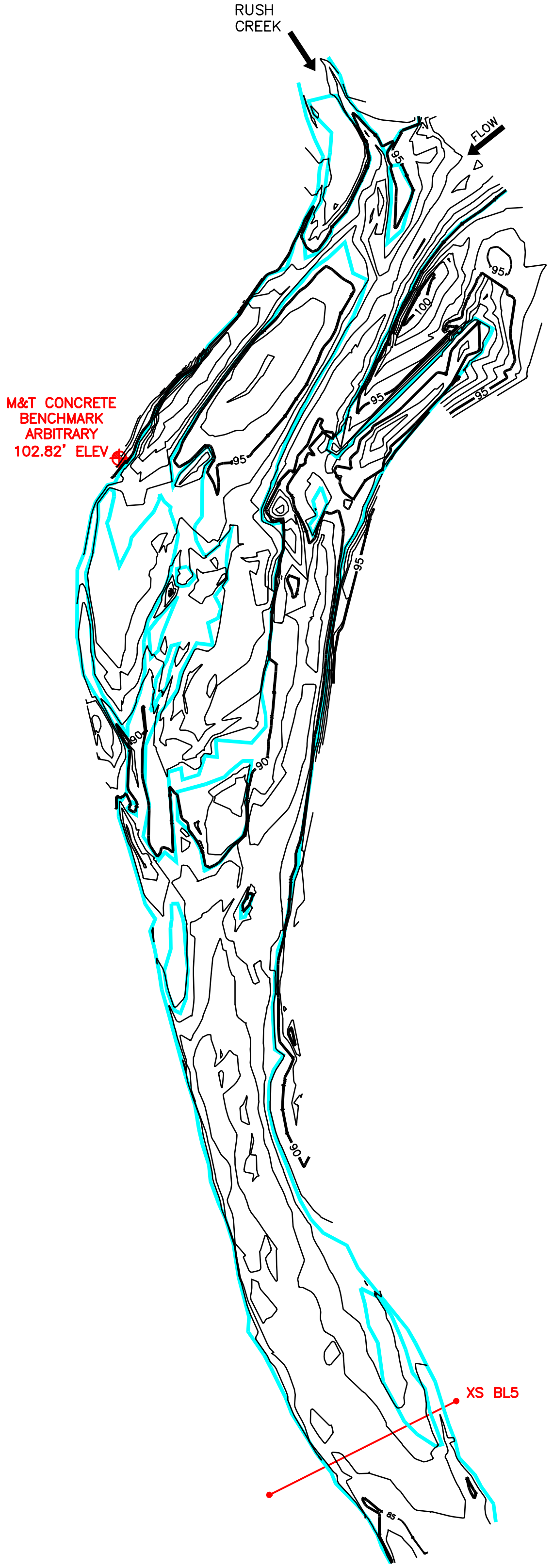
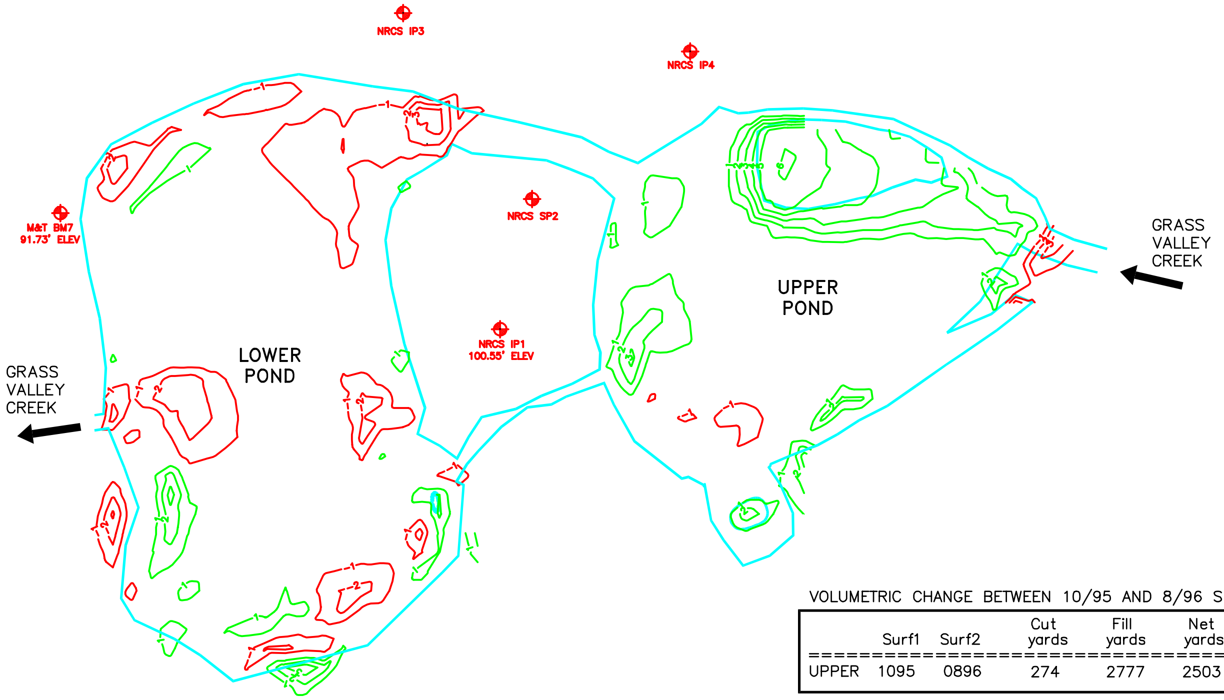


PLATE 8
TRINITY RIVER MILE 107.5
RUSH CREEK DELTA

McBain & Trush 1997

11/13/97

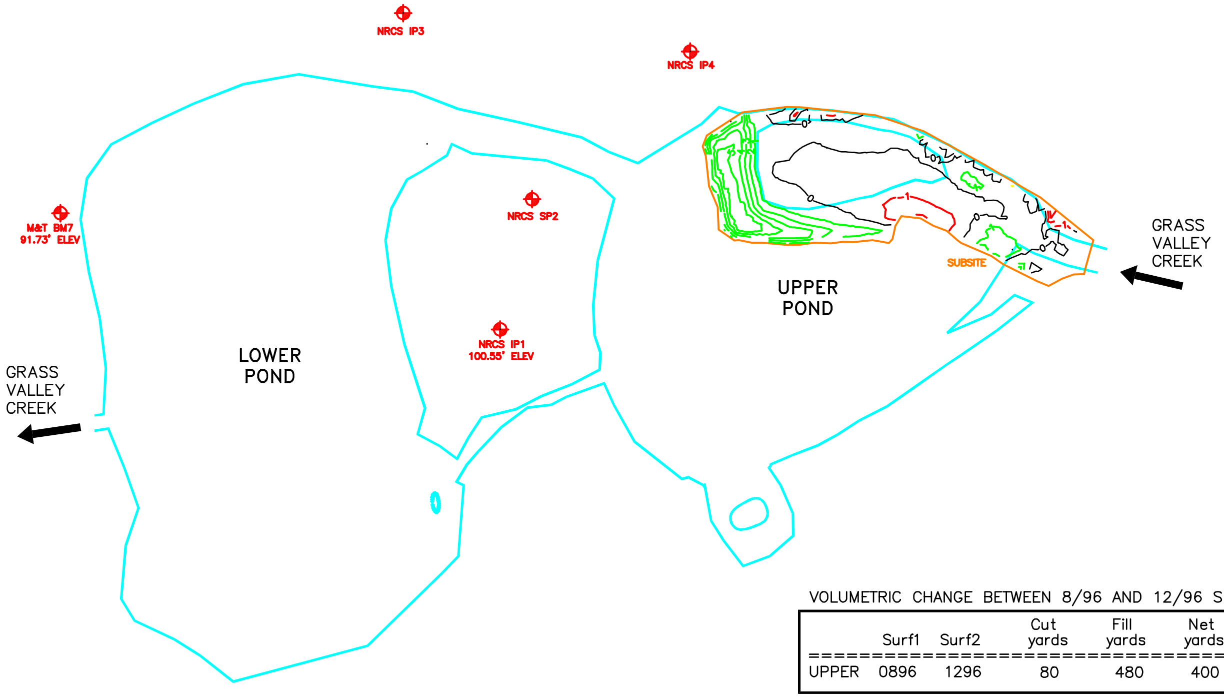
CUT & FILL CONTOURS – 10/95 TO 8/96



VOLUMETRIC CHANGE BETWEEN 10/95 AND 8/96 SURVEYS

	Surf1	Surf2	Cut yards	Fill yards	Net yards
UPPER	1095	0896	274	2777	2503 (FILL)

CUT & FILL CONTOURS – 8/96 TO 12/96



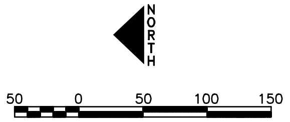
VOLUMETRIC CHANGE BETWEEN 8/96 AND 12/96 SURVEYS

	Surf1	Surf2	Cut yards	Fill yards	Net yards
UPPER	0896	1296	80	480	400 (FILL)

CUT & FILL CONTOURS – 12/96 TO 1/97

VOLUMETRIC CHANGE BETWEEN 12/96 AND 1/97 SURVEYS

	Surf1	Surf2	Cut yards	Fill yards	Net yards
UPPER	1296	0197	495	7875	7380 (FILL)
LOWER	1296	0197	0	2199	2199 (FILL)



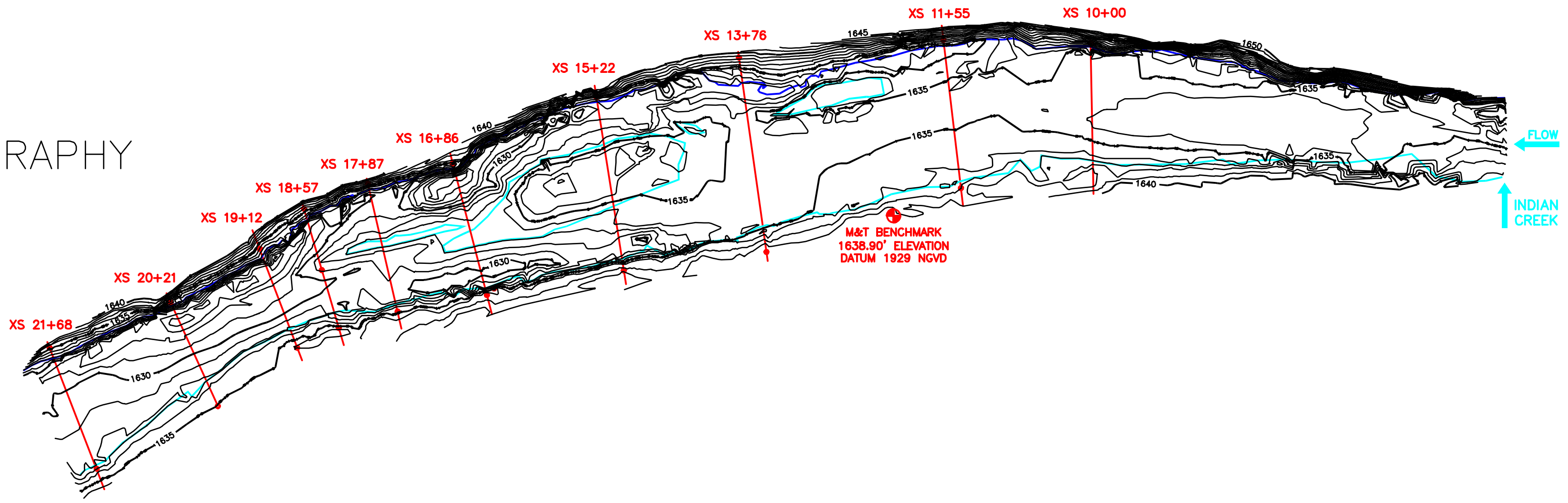
SCALE 1"=150'
1' CONTOUR INTERVAL

PLATE 9
NEAR TRINITY RM 104.0
GRASS VALLEY CREEK
SEDIMENTATION PONDS

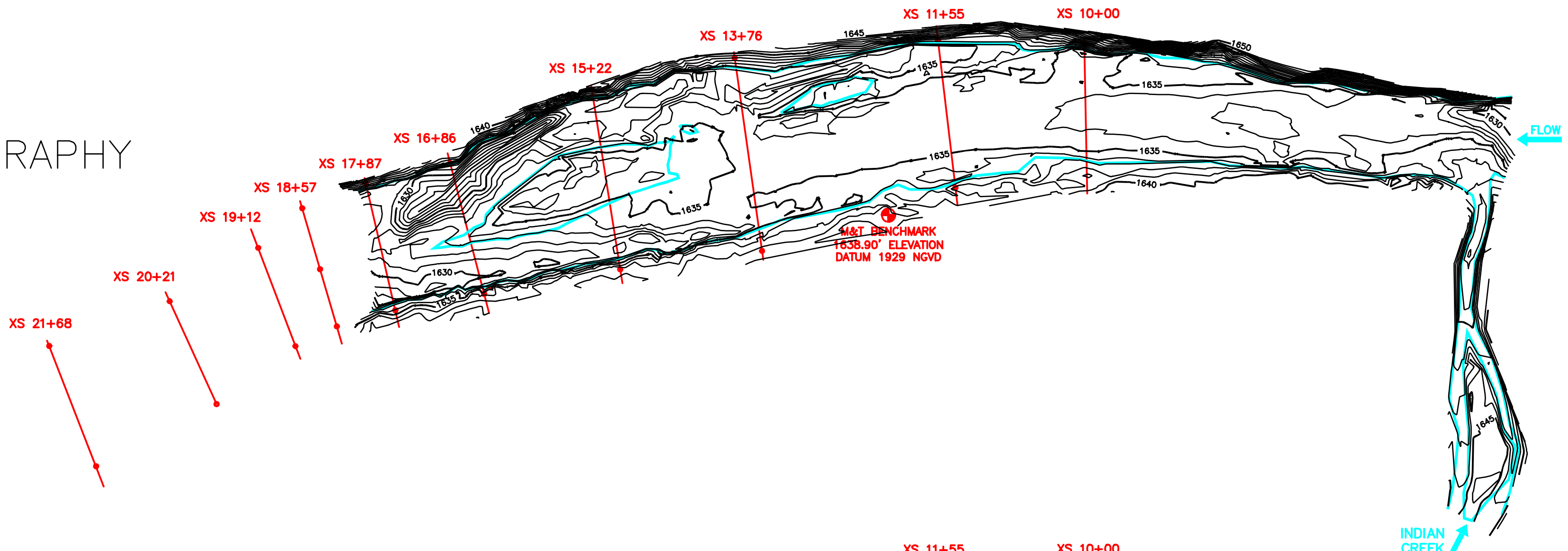
McBain & Trush 1997

11/13/97

1995 TOPOGRAPHY



1996 TOPOGRAPHY



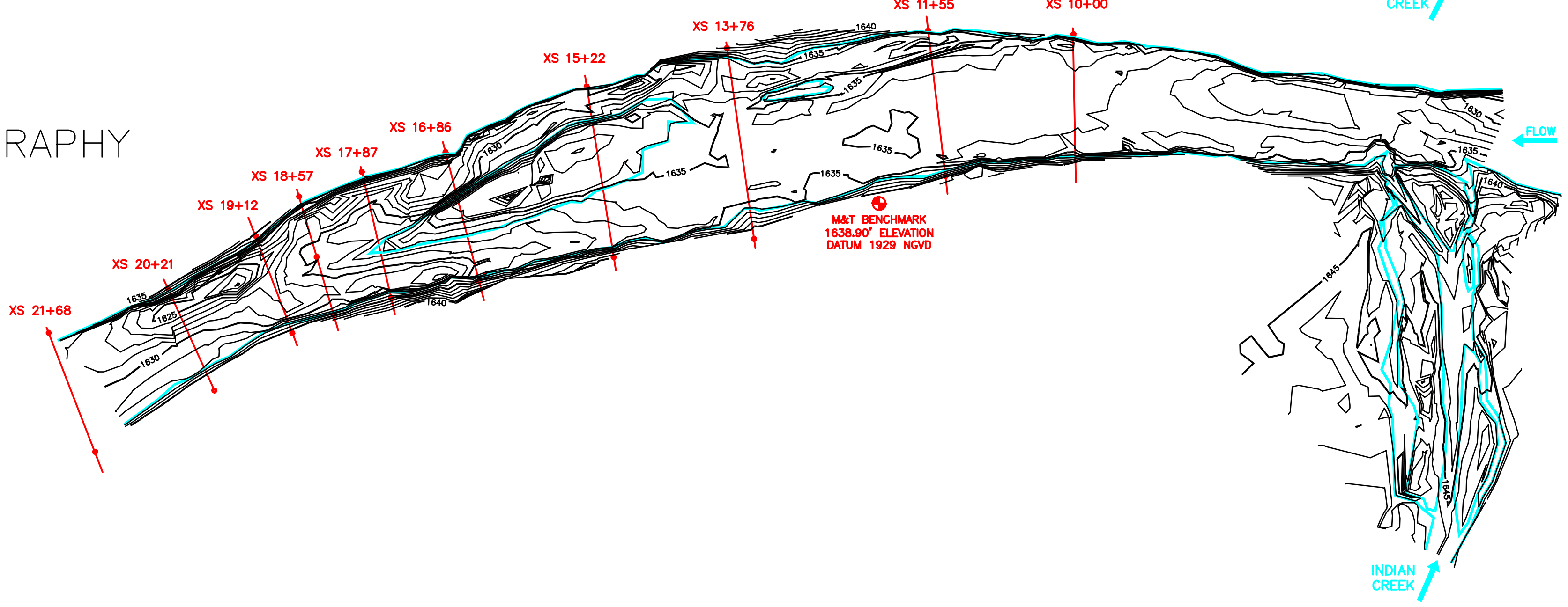
VOLUMETRIC CHANGE BETWEEN 7/95 SURVEY AND 8/96 SURVEY

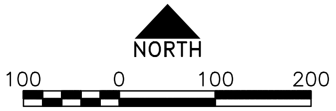
Subsite	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
Mainstem	9596	7/95	8/96	1948	582	1366 (CUT)

VOLUMETRIC CHANGE BETWEEN 8/96 SURVEY AND 3/97 SURVEY

Subsite	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
Mainstem	9697	8/96	3/97	3359	1914	1444 (CUT)
Indian Cr	9697	8/96	3/97	30	949	920 (FILL)

1997 TOPOGRAPHY





SCALE 1"=150'
1' CONTOUR INTERVAL

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PLATE 10
TRINITY RIVER MILE 95.2
INDIAN CREEK DELTA

11/13/97

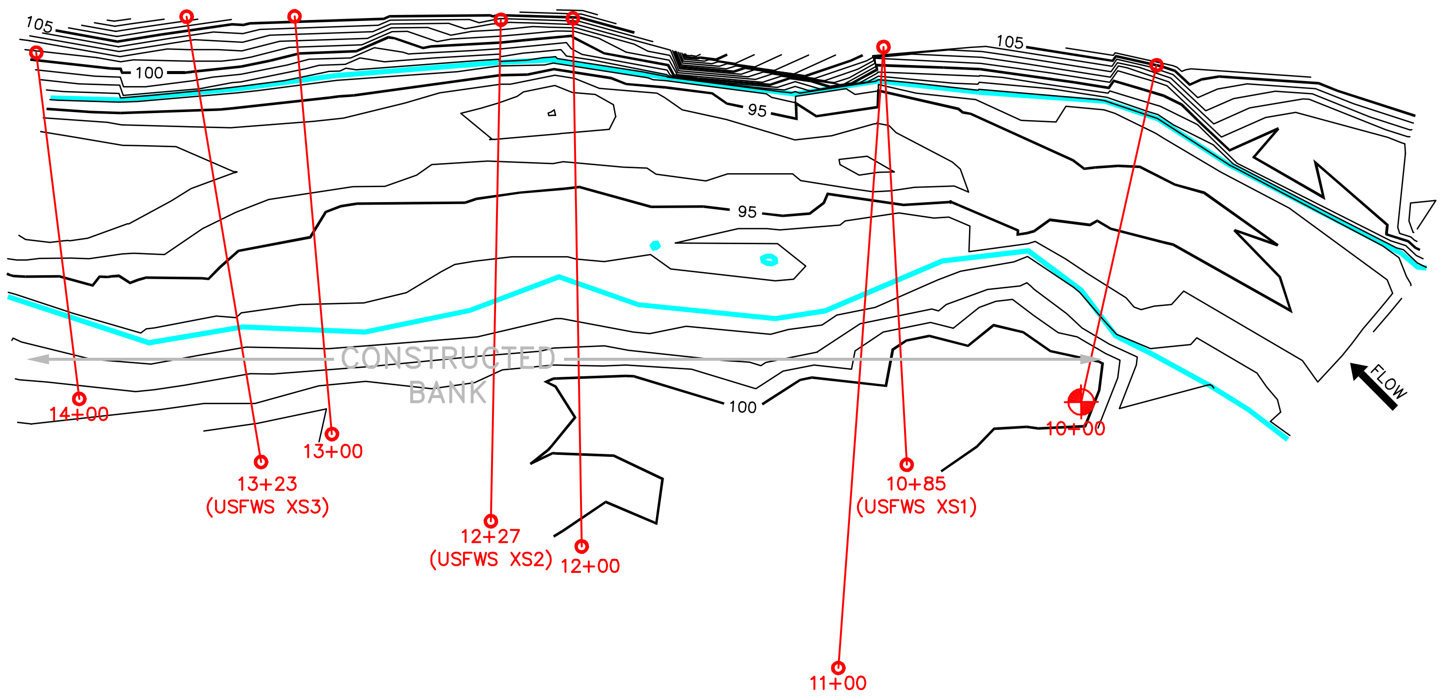
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Shining willow *Salix lucida* ssp. *lasiandra*	Dormant	Dormant and emerging, bud swelling	Dormant and emerging, bud swelling	Begin flowering early to mid-month, leaf out *(4/22/95 flowering)* *(4/2/96 leafing out, no flowers)*	Continue flowering, leaf out, active growth *(5/14/96 seed dispersal)*	Continue flowering, seed dispersal, active growth	Seed dispersal, active growth	Finish seed dispersal early in month, active growth	Leaf abcission (early)	Leaf abcission (normal) *(10/24/96 dormant)*	Leaf abcission (late)	Dormant
Arroyo willow *Salix lasiolepis*	Dormant and emerging, bud swelling	Flowering *(2/11/95 catkins begin)*	Leaves emerging early in month, seed dispersal *(3/31/95 male catkin peak)*	Leaf out, seed dispersal, active growth *(4/9/95 seed dispersal)* *(4/2/96 fruit dehiscing)*	Leaf out, active growth, no flowers *(5/4/96 seed dispersal)*	Active growth	Active growth	Prepare for dormancy, store energy and nutrients	Leaf abcission (early)	Leaf abcission (normal) *(10/24/96 beginning of leaf abcission)*	Dormant, leaf abcission (late)	Dormant
Dusky willow *Salix melanopsis*	Dormant	Dormant	Dormant and emerging, bud swelling	Begin flowering late in month, begin leafing out	Continue flowering, leaf out, active growth *(5/13/96 male flowers in bloom)*	Seed dispersal, active growth	Seed dispersal, active growth	Prepare for dormancy, store energy and nutrients	Leaf abcission (early)	Leaf abcission (normal) *(10/24/96 dormant)*	Leaf abcission (late)	Dormant
Narrow-leaf willow *Salix exigua*	Dormant	Dormant and emerging	Dormant and emerging	Leafing out, flowering early to mid-month *(4/22/95 flowering)* *(4/2/96 begin leafing out)*	Flowering, leaf out, active growth *(5/4/96 leafed out, no flowers)* *(5/13/96 male fls in bloom)*	Continue flowering, seed dispersal, active growth	Flowering to mid-month, seed dispersal, active growth *(7/18/96 seed dispersal mostly complete)*	Seed disperal, prepare for dormancy, store energy and nutrients	Leaf abcission (early)	Leaf abcission (normal) *(10/24/96 dormant)*	Leaf abcission (late)	Dormant
White alder *Alnus rhombifolia*	Male catkins develop and flower end of month	Male catkins develop, bud swelling *(2/11/95 male catkin peak)*	Leaf out, female catkins begin developing	Leaf out, female flowers in full bloom *(4/9/95 pistils fully emerged)*	Growth, female catkins developing	Growth, female catkins developing	Active growth, female catkins developing	Dormancy prep., store energy etc, complete catkin development *(8/23/95 leaves begin color change)*	Leaf abcission, female catkins complete development	Leaf abcission, seed dispersal begins end of month *(10/24/96 begin leaf drop)*	Dormant, leaf abcission (late)	Dormant
Black cottonwood *Populus balsamifera* ssp. *trichocarpa*	Dormant	Dormant, bud swelling	Begin flowering early in month *(3/31/95 leaves emerging, peak of flowering)*	Complete flowering mid-month, leafing out, growth *(4/2/96 leafing out, in flower)*	Seed dispersal, active growth *(5/5/96 capsule swelling)* *(5/14/96 seed dispersal)*	Complete seed dispersal, leaf out, active growth	Active growth	Prepare for dormancy, store energy and nutrients	Leaf abcission (early)	Leaf abcission (normal) *(10/24/96 leaf abcission)*	Dormant, leaf abcission (late)	Dormant
Fremont cottonwood *Populus fremontii*	Dormant	Dormant, bud swelling	Flowering, leaves emerge	Complete flowering (late), leafing out, active growth *(4/2/96 leafing out, full flower)*	Seed dispersal, leaf out, active growth *(5/5/96 capsule swelling)* *(5/14/96 seed dispersal)*	Leaf out, active growth	Active growth	Prepare for dormancy, store energy and nutrients	Leaf abcission (early)	Leaf abcission (normal) *(10/24/96 leaf abcission)*	Dormant	Dormant

PLATE 11
LIFE HISTORY SCHEDULES BY MONTH FOR SEVEN WOODY RIPARIAN PLANT SPECIES

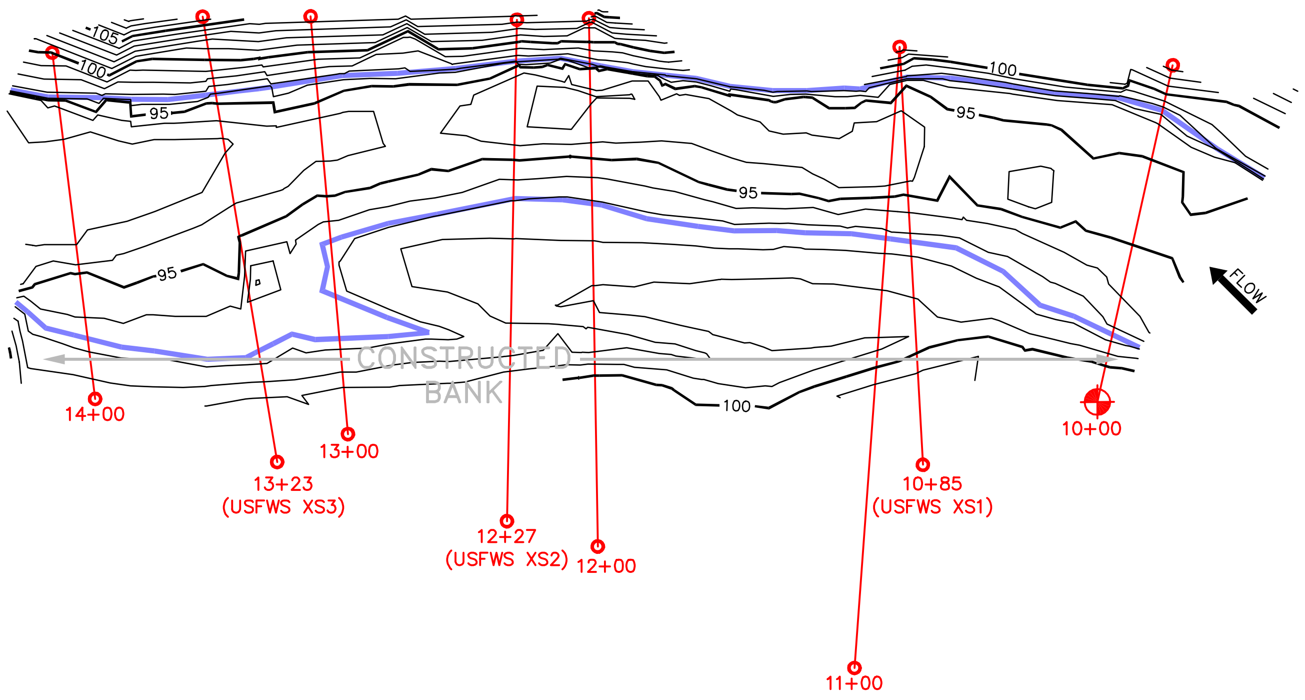
McBain & Trush 1997

11/13/97

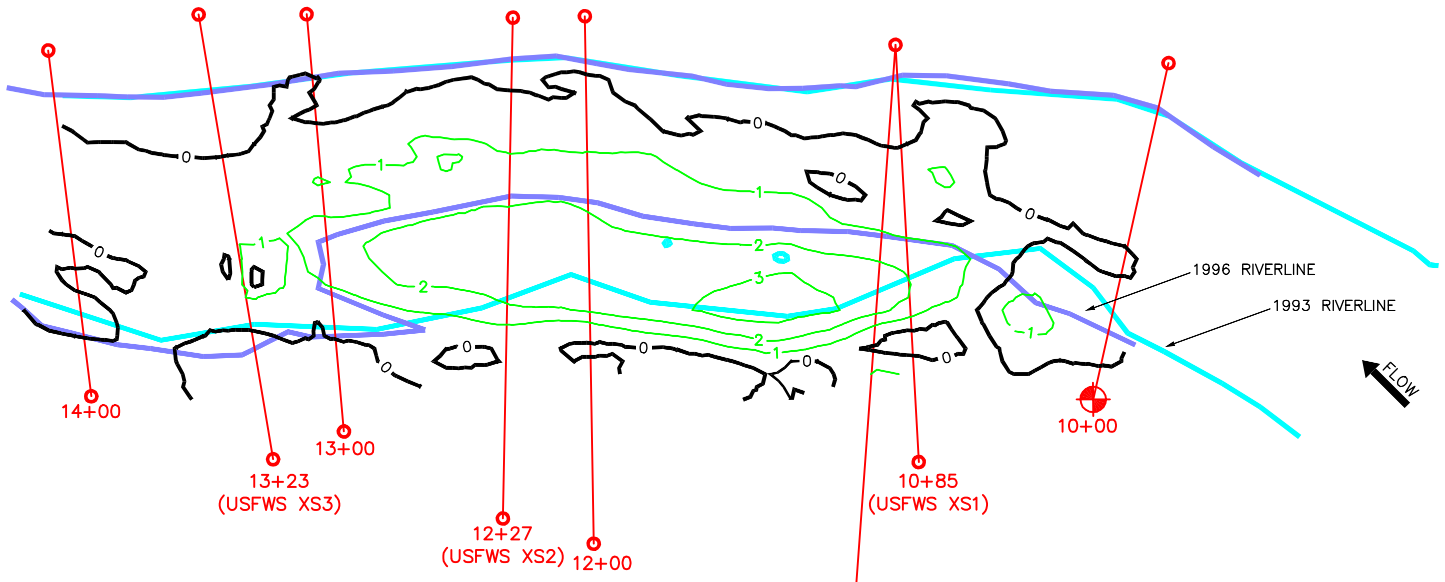
1993 TOPOGRAPHY



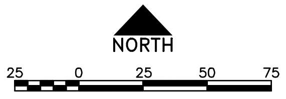
1996 TOPOGRAPHY



1993–1996 CUT/FILL CONTOURS



Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
9396	g103	bt96	24	3162	3138 (FILL)



SCALE 1"=75'
1' CONTOUR INTERVAL

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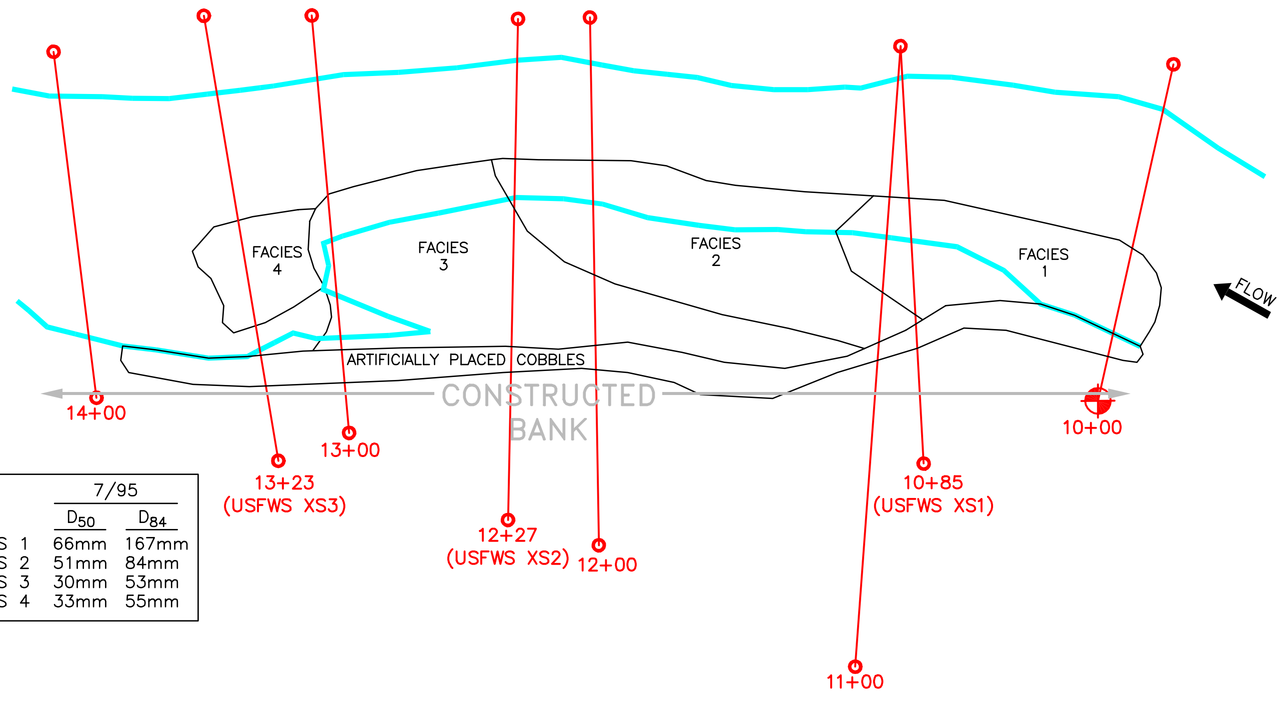
PLATE 12
TRINITY RIVER MILE 105.6
BUCKTAIL BANK
REHABILITATION SITE
TOPOGRAPHY

11/13/97

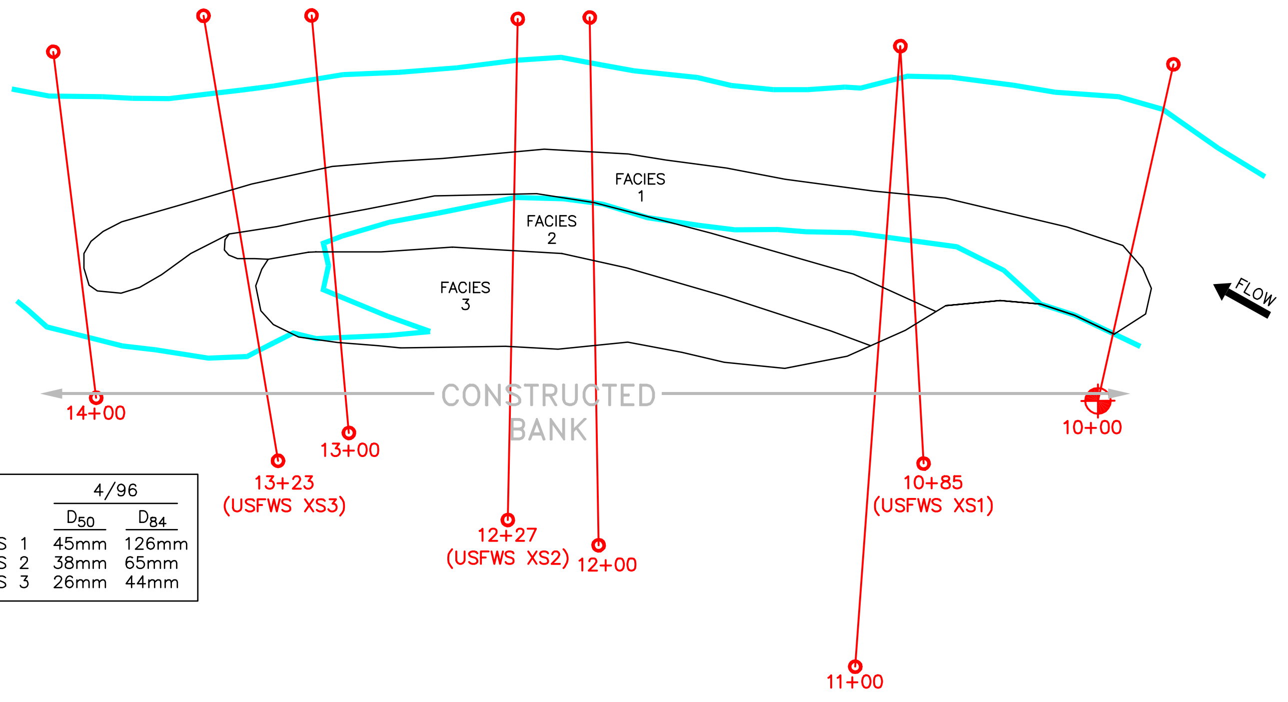
7/95 PARTICLE FACIES



7/95

	D_{50}	D_{84}
FACIES 1	66mm	167mm
FACIES 2	51mm	84mm
FACIES 3	30mm	53mm
FACIES 4	33mm	55mm

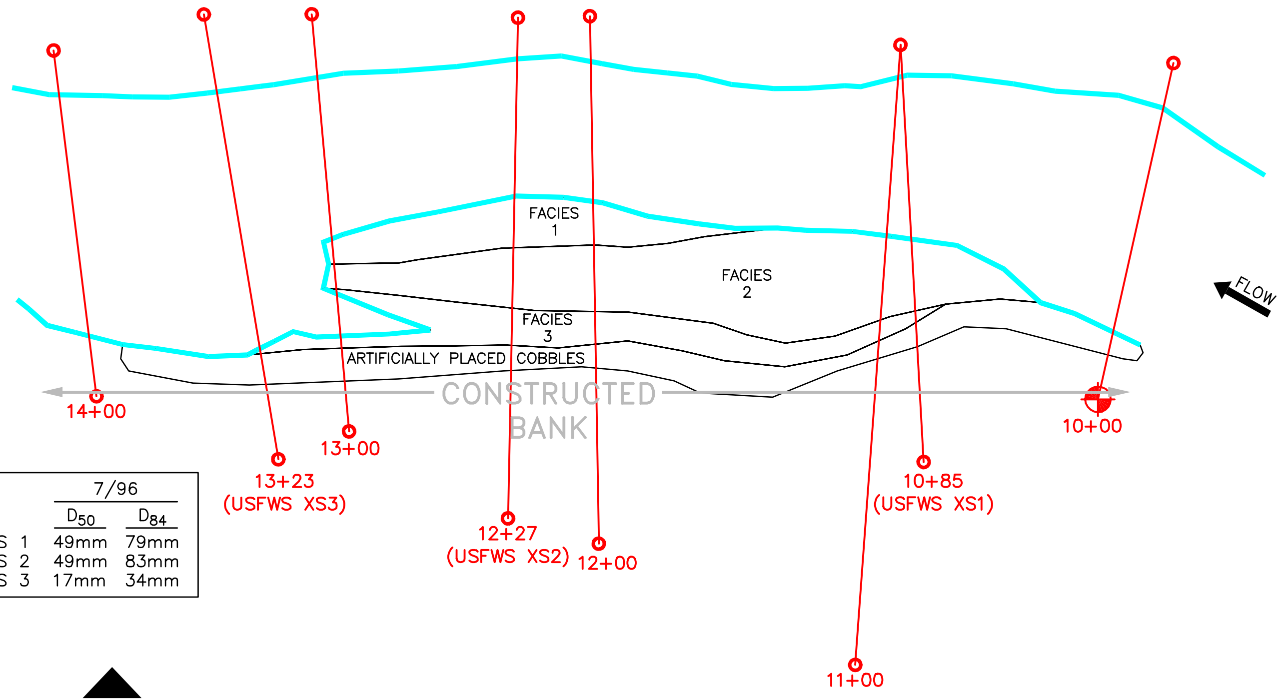
4/96 PARTICLE FACIES



4/96

	D_{50}	D_{84}
FACIES 1	45mm	126mm
FACIES 2	38mm	65mm
FACIES 3	26mm	44mm

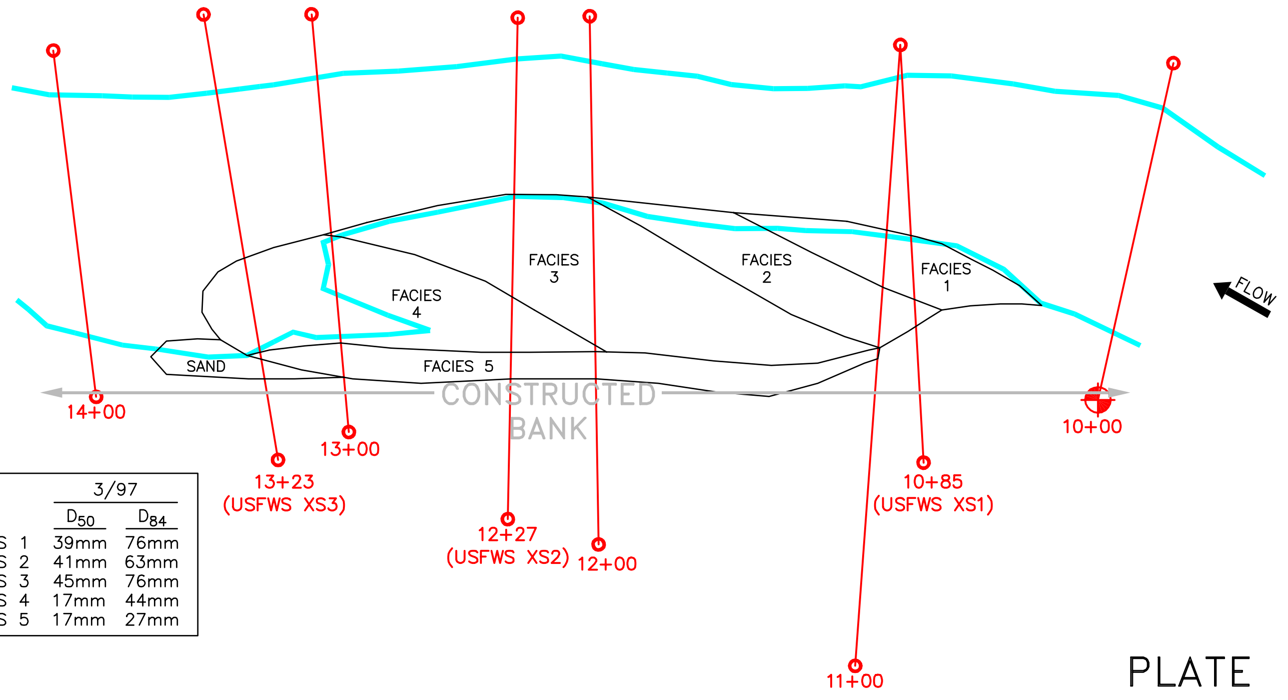
7/96 PARTICLE FACIES



7/96

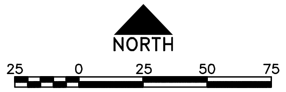
	D_{50}	D_{84}
FACIES 1	49mm	79mm
FACIES 2	49mm	83mm
FACIES 3	17mm	34mm

3/97 PARTICLE FACIES



3/97

	D_{50}	D_{84}
FACIES 1	39mm	76mm
FACIES 2	41mm	63mm
FACIES 3	45mm	76mm
FACIES 4	17mm	44mm
FACIES 5	17mm	27mm



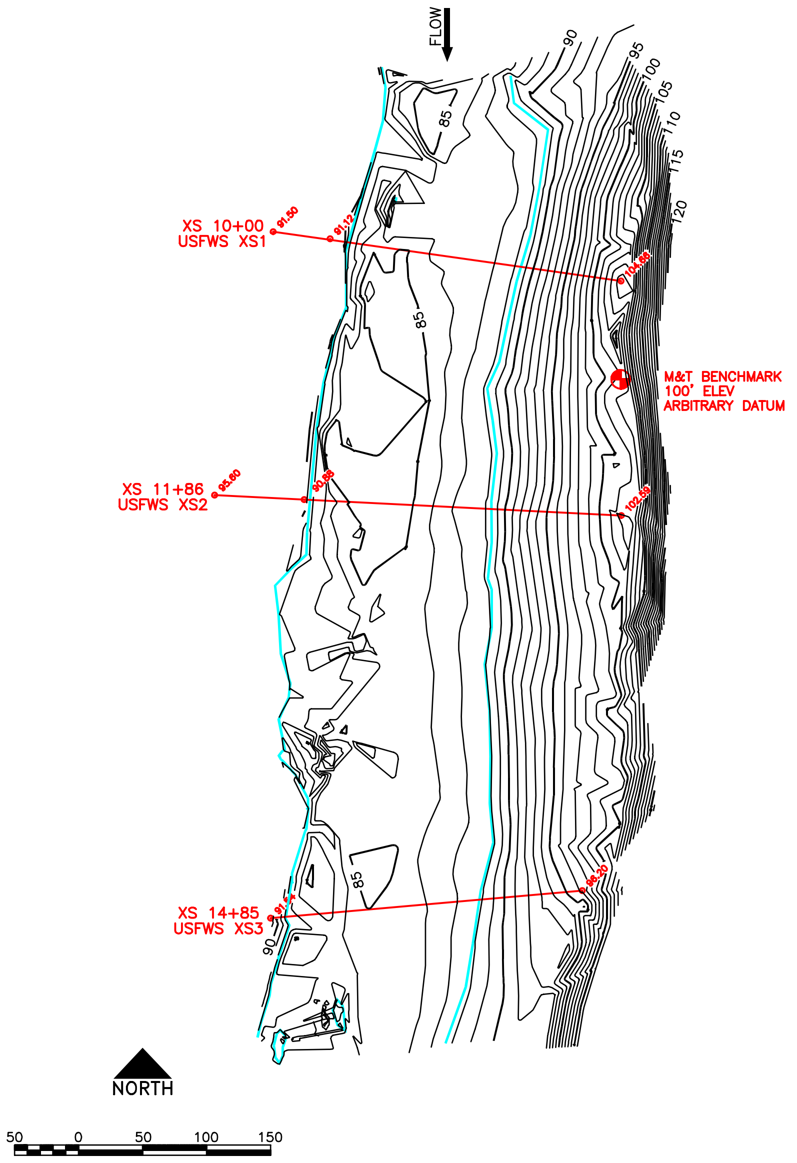
SCALE 1"=75'
1996 RIVERLINE SHOWN

PLATE 13
TRINITY RIVER MILE 105.6
BUCKTAIL BANK
REHABILITATION SITE
PARTICLE FACIES

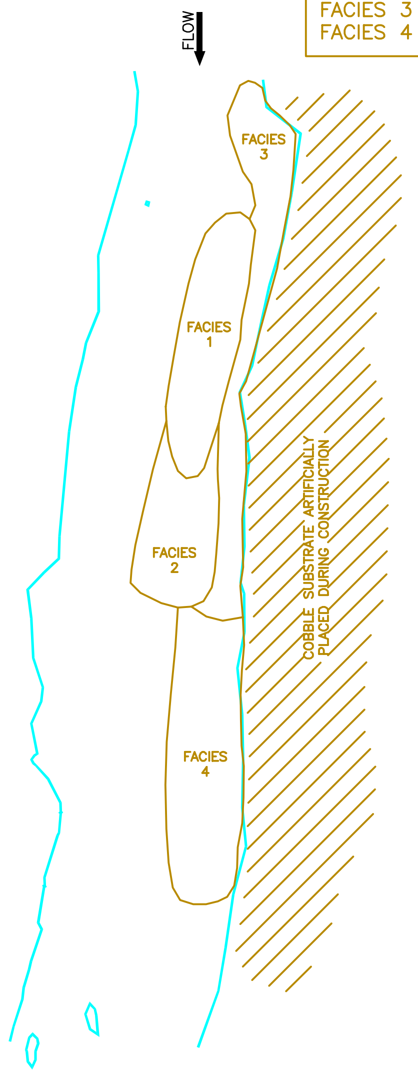
McBain & Trush 1997

11/13/97

1994 TOPOGRAPHY
(Surveyed by BOR)



1997 PARTICLE FACIES

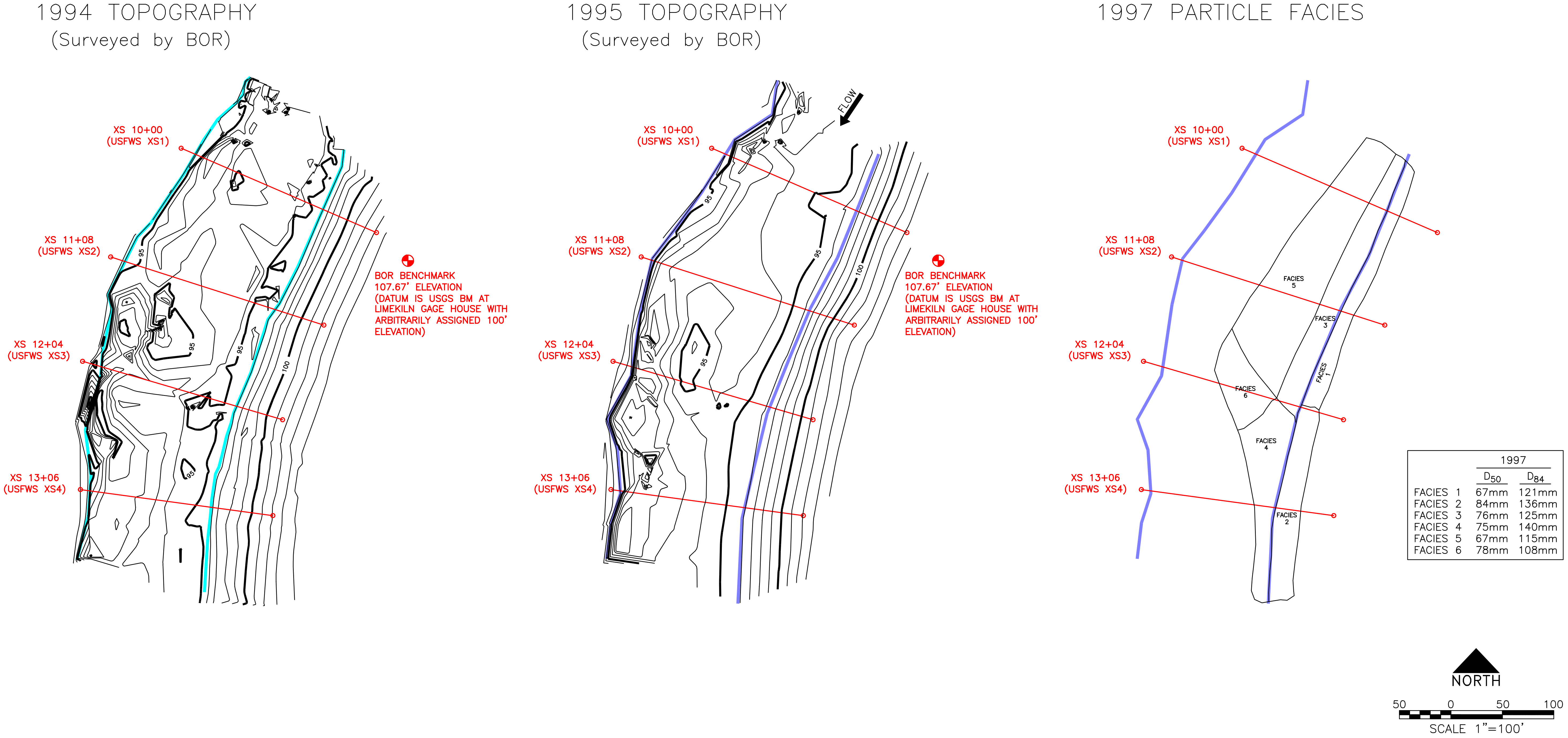


7/97	D_{50}	D_{84}
FACIES 1	52mm	85mm
FACIES 2	62mm	104mm
FACIES 3	50mm	89mm
FACIES 4	49mm	89mm

PLATE 14
TRINITY RIVER MILE 100.2
LIMEKILN BANK REHABILITATION SITE

McBain & Trush 1997

11/13/97

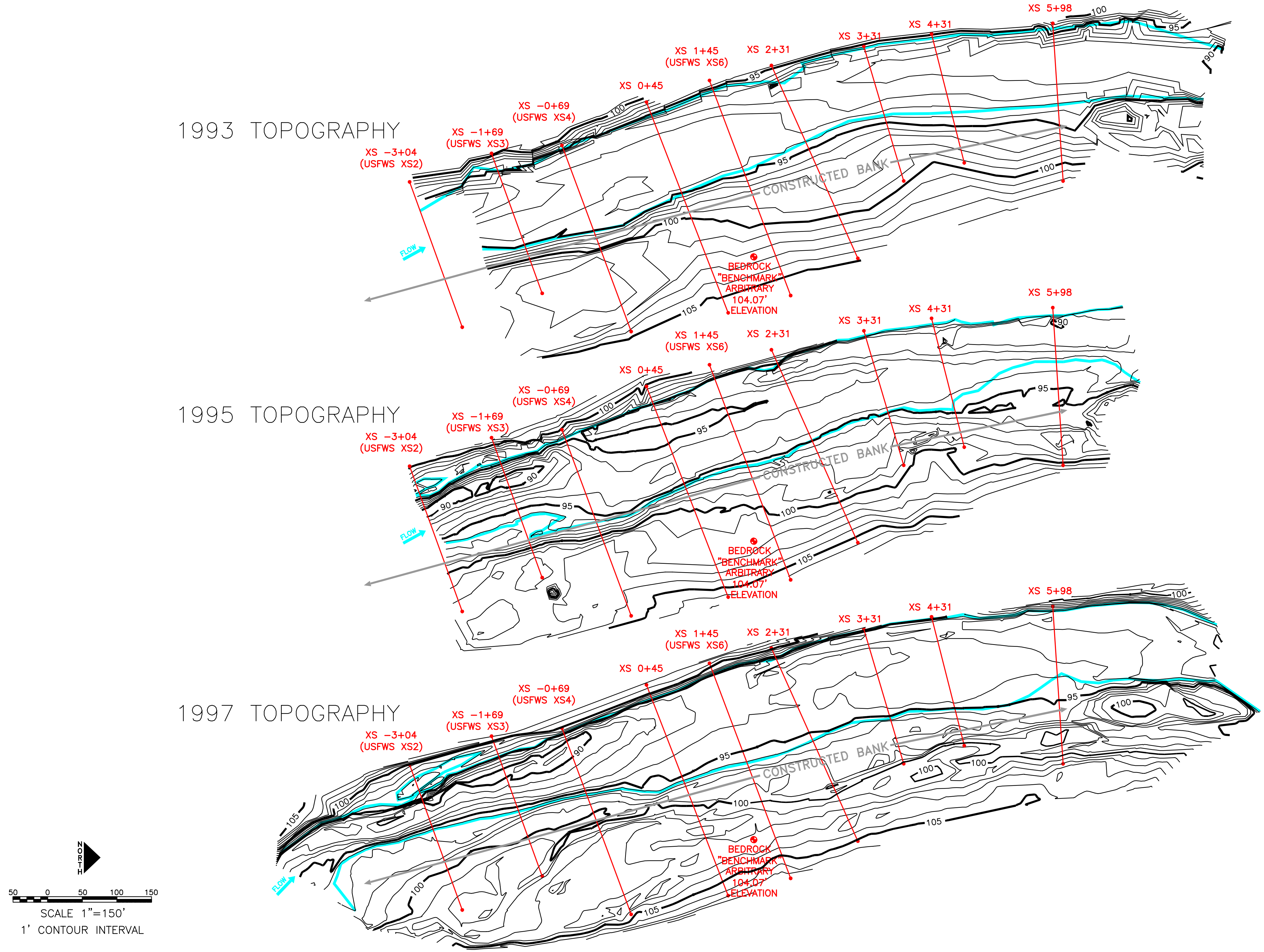


1997	D_{50}	D_{84}
FACIES 1	67mm	121mm
FACIES 2	84mm	136mm
FACIES 3	76mm	125mm
FACIES 4	75mm	140mm
FACIES 5	67mm	115mm
FACIES 6	78mm	108mm

PLATE 15
TRINITY RIVER MILE 98.8
STEEL BRIDGE BANK
REHABILITATION SITE

McBain & Trush 1997

11/13/97

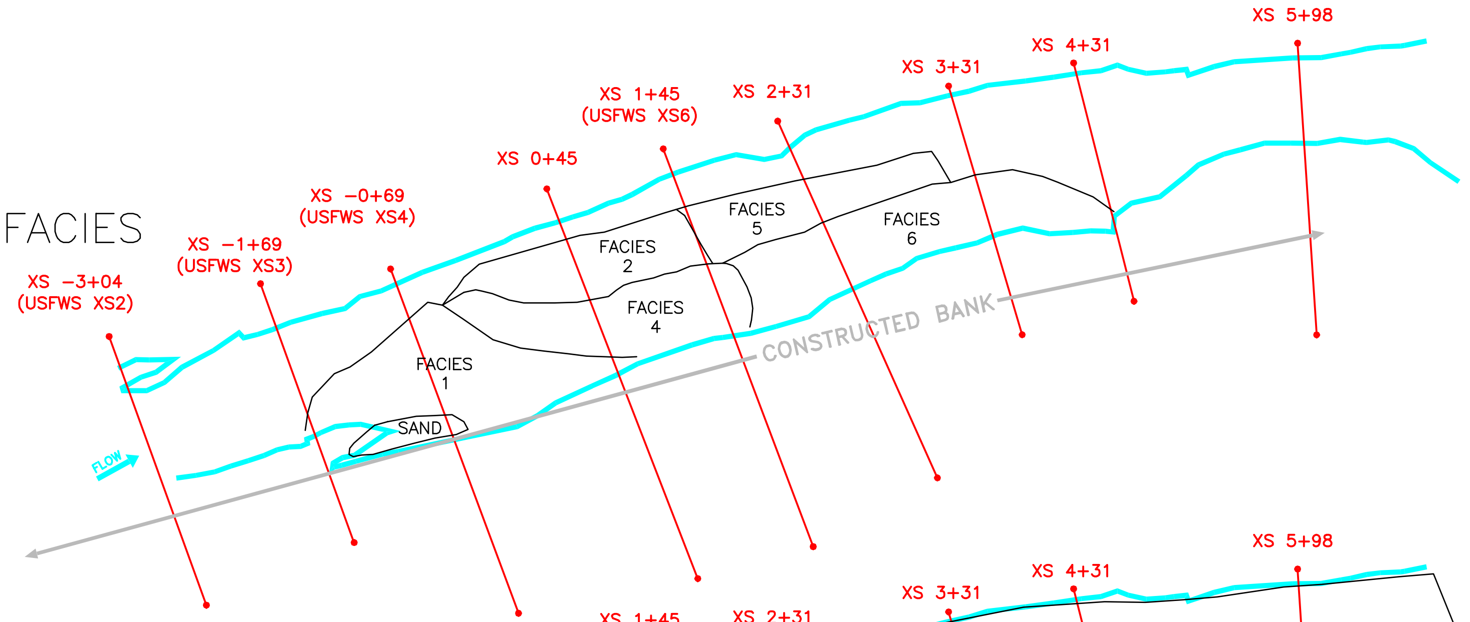


McBain & Trush 1997

PLATE 16
TRINITY RIVER MILE 91.7
STEINER FLAT BANK
REHABILITATION SITE
GROUND TOPOGRAPHY

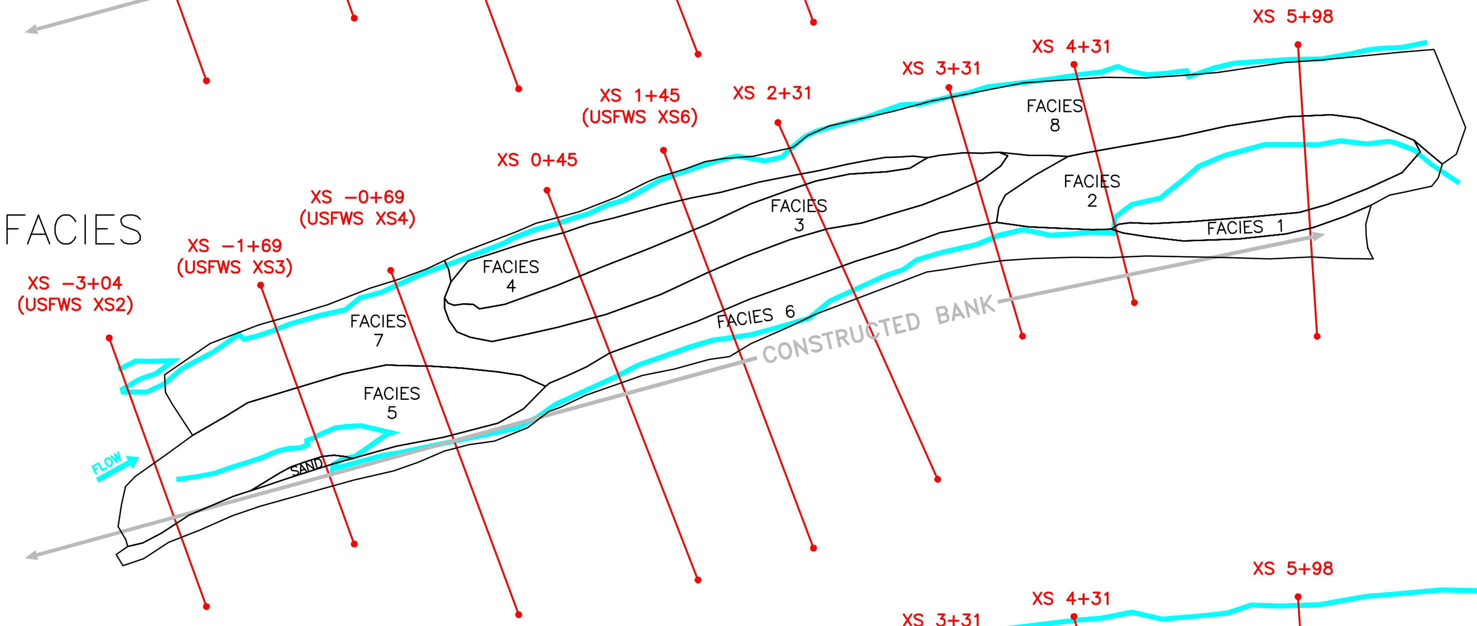
11/13/97

1995 PARTICLE FACIES



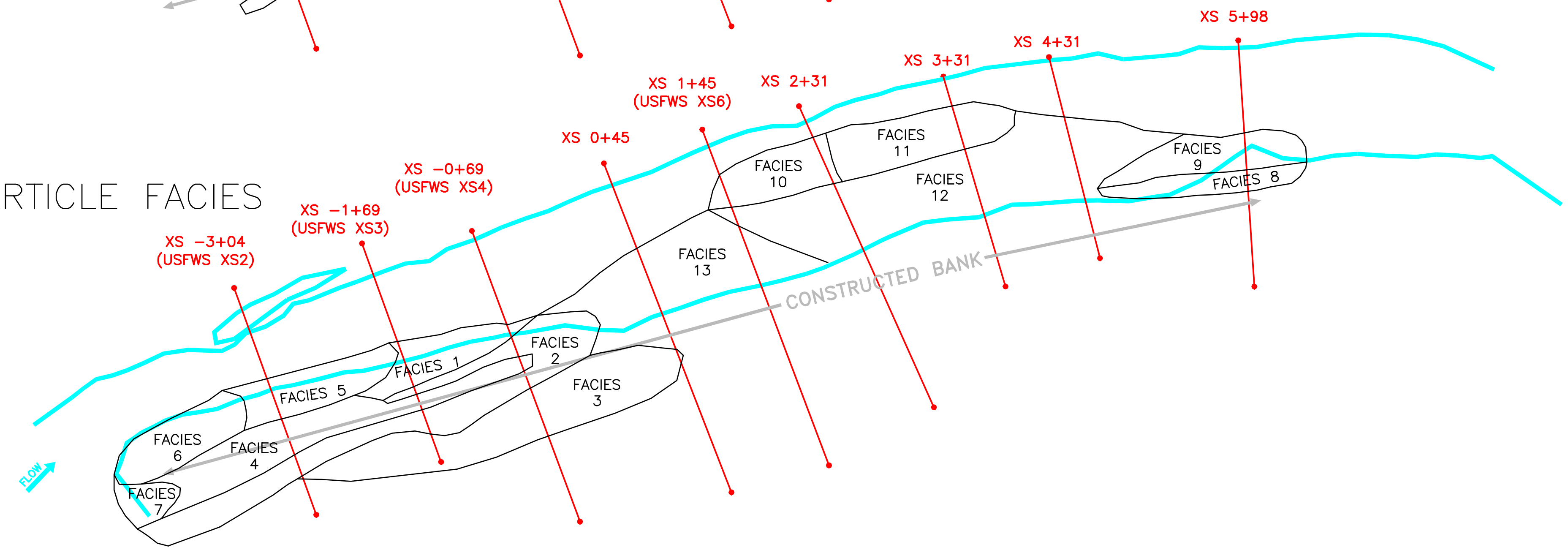
8/95	D50	D84
FACIES 1	40mm	60mm
FACIES 2	58mm	105mm
FACIES 3	NOT SAMPLED	
FACIES 4	68mm	114mm
FACIES 5	64mm	100mm
FACIES 6	81mm	125mm

1996 PARTICLE FACIES

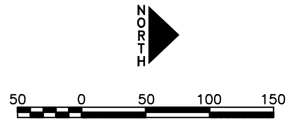


7/96	D50	D84
FACIES 1	43mm	67mm
FACIES 2	51mm	99mm
FACIES 3	77mm	118mm
FACIES 4	46mm	89mm
FACIES 5	38mm	74mm
FACIES 6	72mm	95mm
FACIES 7	85mm	146mm
FACIES 8	40mm	77mm

1997 PARTICLE FACIES



1997	D50	D84
FACIES 1	61mm	113mm
FACIES 2	33mm	74mm
FACIES 3	31mm	60mm
FACIES 4	88mm	126mm
FACIES 5	54mm	115mm
FACIES 6	72mm	111mm
FACIES 7	41mm	70mm
FACIES 8	37mm	86mm
FACIES 9	58mm	105mm
FACIES 10	70mm	127mm
FACIES 11	69mm	121mm
FACIES 12	80mm	120mm
FACIES 13	52mm	89mm



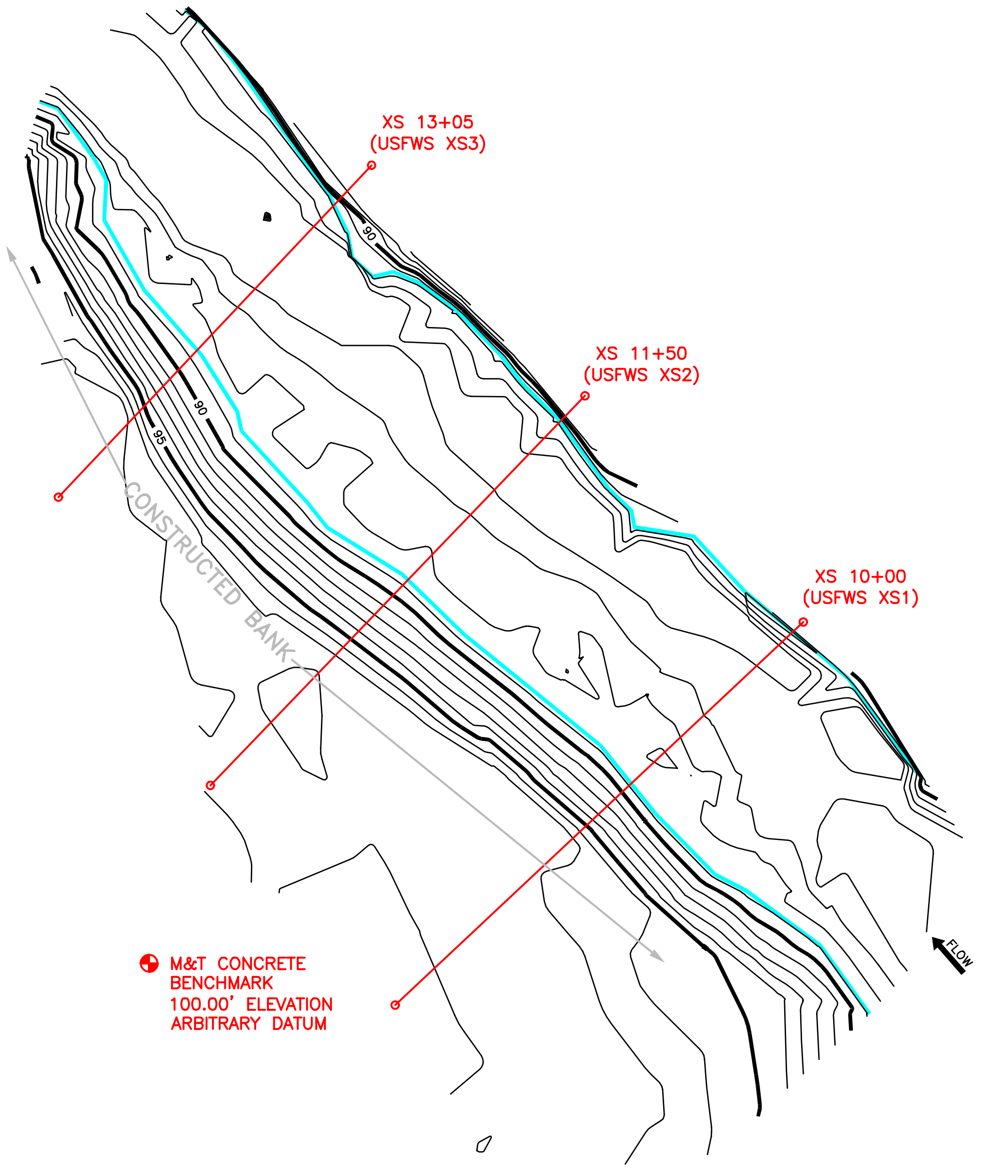
SCALE 1"=150'
1' CONTOUR INTERVAL

PLATE 17
TRINITY RIVER MILE 91.7
STEINER FLAT BANK
REHABILITATION SITE
PARTICLE FACIES

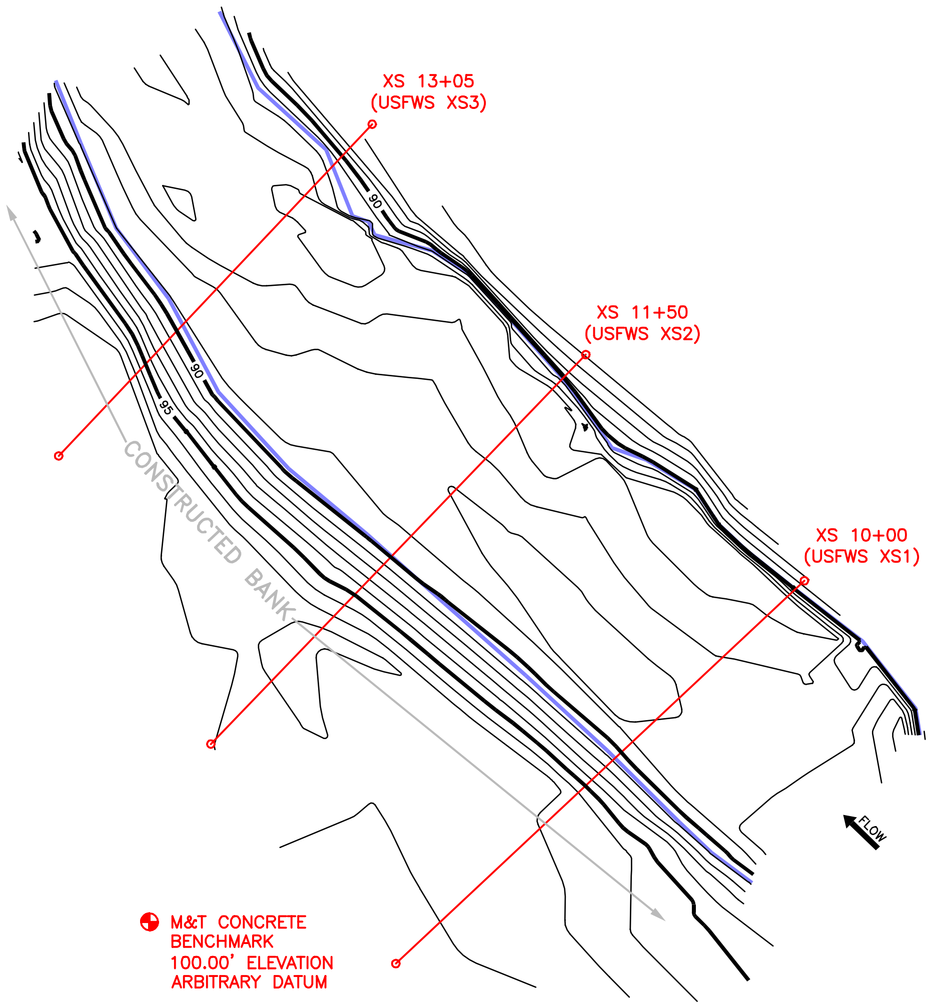
McBain & Trush 1997

11/13/97

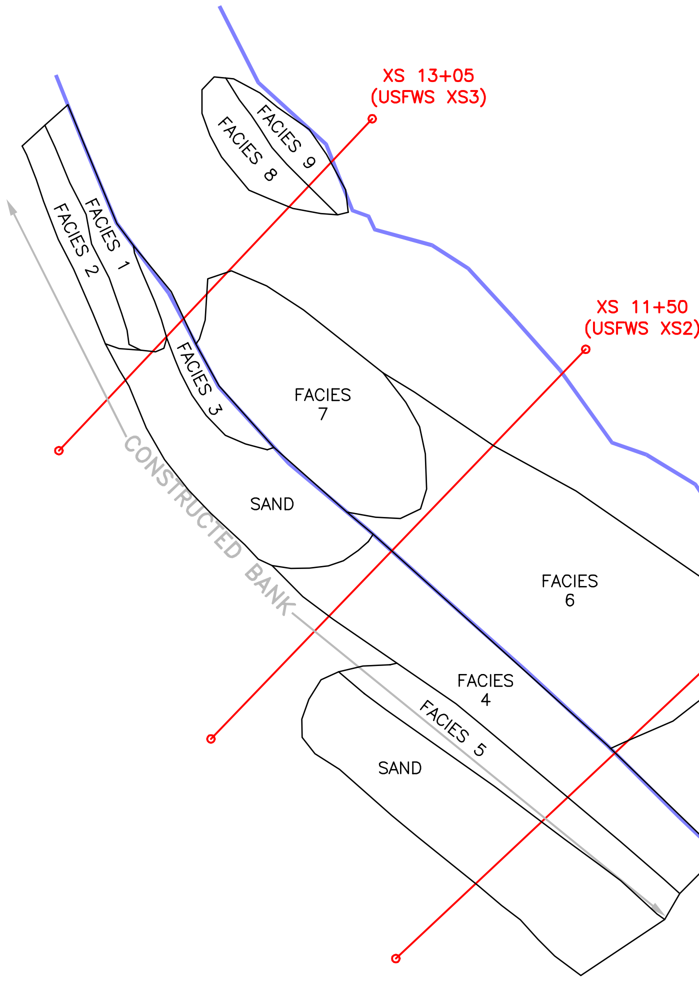
1994 TOPOGRAPHY



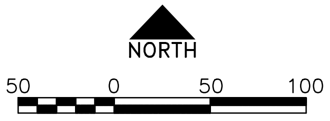
1995 TOPOGRAPHY



1997 PARTICLE FACIES
(1995 RIVERLINE)



	1997	
	D_{50}	D_{84}
FACIES 1	56mm	101mm
FACIES 2	30mm	55mm
FACIES 3	62mm	99mm
FACIES 4	32mm	73mm
FACIES 5	49mm	80mm
FACIES 6	59mm	100mm
FACIES 7	55mm	97mm
FACIES 8	77mm	121mm
FACIES 9	23mm	42mm



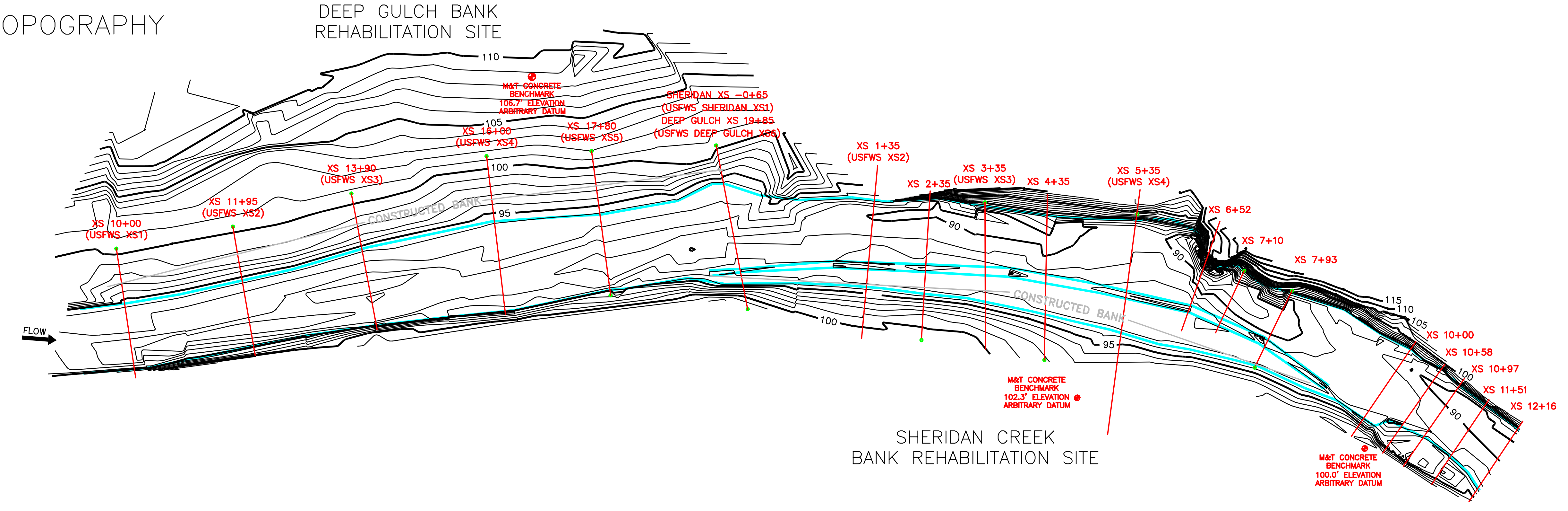
SCALE 1"=100'
1' CONTOUR INTERVAL

McBain & Trush 1997

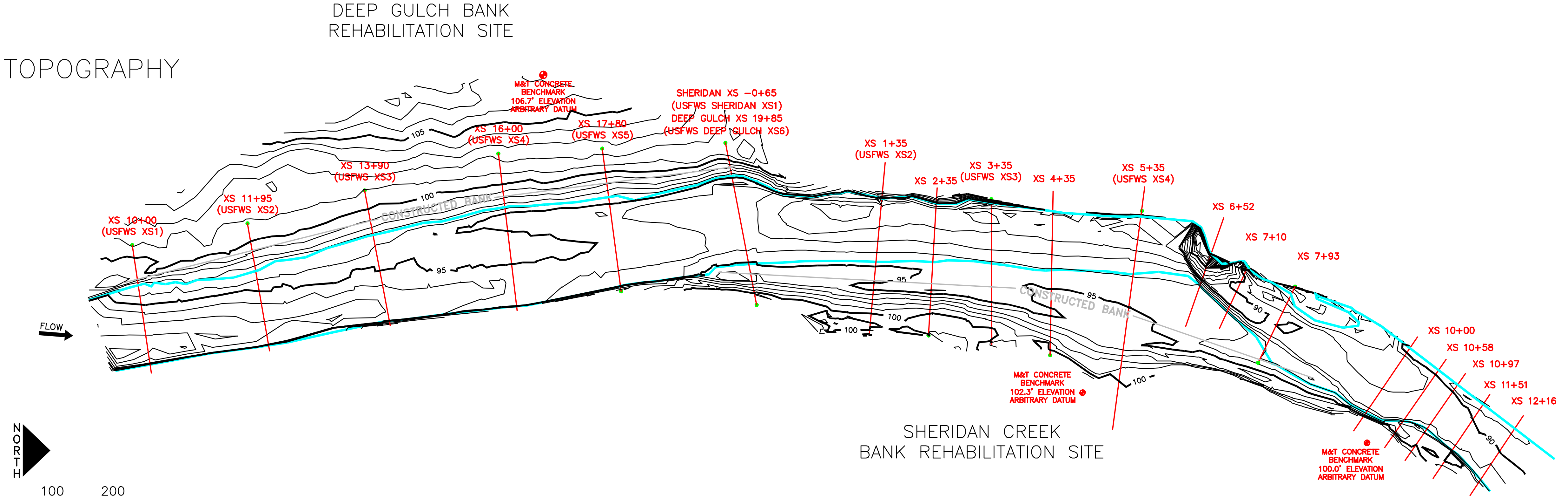
PLATE 18
TRINITY RIVER MILE 84.0
BELL GULCH BANK
REHABILITATION SITE

11/13/97

1993 TOPOGRAPHY



1995 TOPOGRAPHY



100 0 100 200

SCALE 1"=200'

1' CONTOUR INTERVAL

McBain & Trush 1997

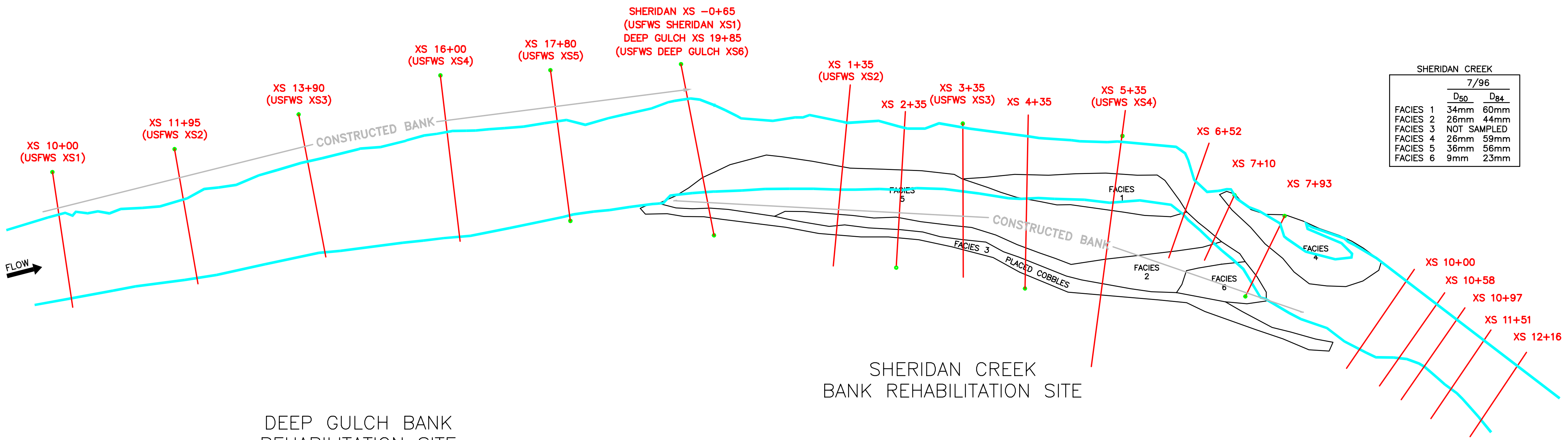
PLATE 19

TRINITY RM 81.1−82.0
SHERIDAN CREEK AND
DEEP GULCH BANK
REHABILITATION SITES

11/13/97

DEEP GULCH BANK
REHABILITATION SITE

1996 PARTICLE FACIES

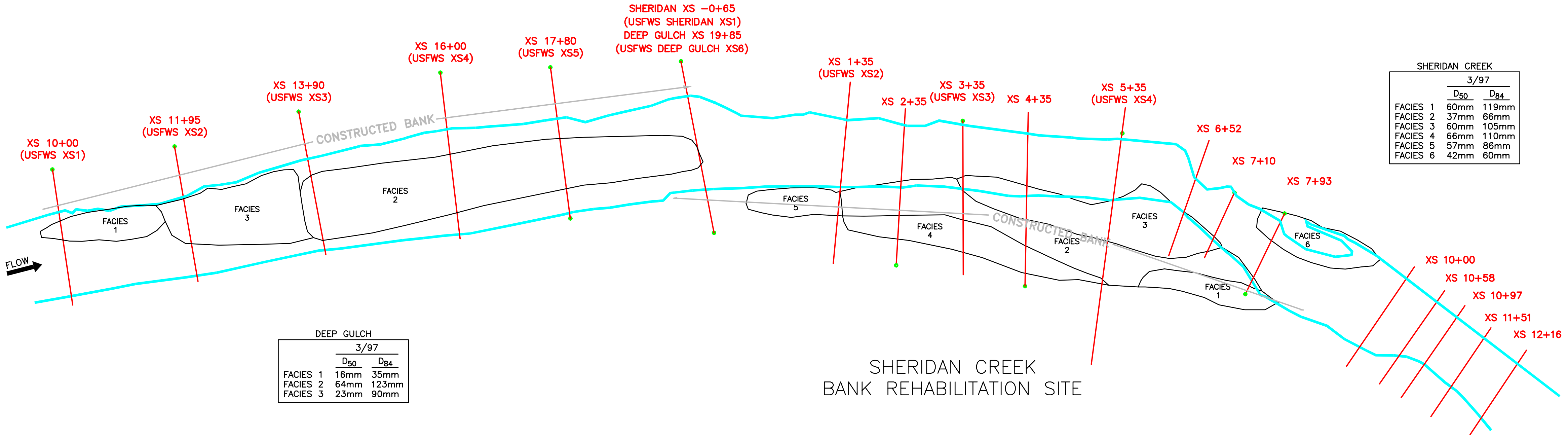


SHERIDAN CREEK

	7/96	
	D_{50}	D_{84}
FACIES 1	34mm	60mm
FACIES 2	26mm	44mm
FACIES 3	NOT SAMPLED	
FACIES 4	26mm	59mm
FACIES 5	36mm	56mm
FACIES 6	9mm	23mm

DEEP GULCH BANK
REHABILITATION SITE

1997 PARTICLE FACIES



SHERIDAN CREEK

	3/97	
	D_{50}	D_{84}
FACIES 1	60mm	119mm
FACIES 2	37mm	66mm
FACIES 3	60mm	105mm
FACIES 4	66mm	110mm
FACIES 5	57mm	86mm
FACIES 6	42mm	60mm

DEEP GULCH

	3/97	
	D_{50}	D_{84}
FACIES 1	16mm	35mm
FACIES 2	64mm	123mm
FACIES 3	23mm	90mm

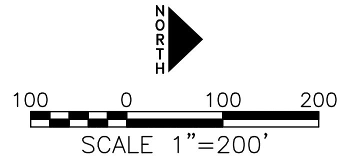
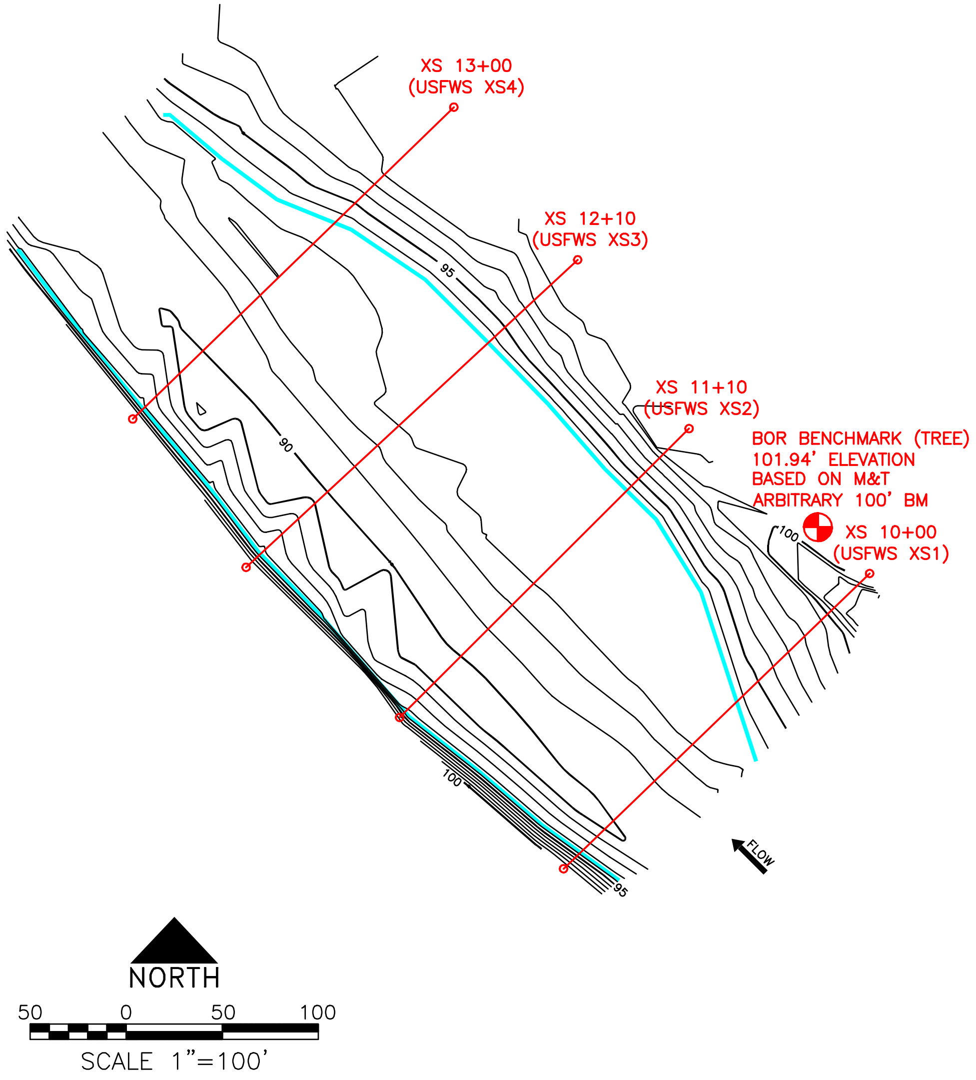


PLATE 20
TRINITY RM 81.1–82.0
SHERIDAN CREEK AND
DEEP GULCH BANK
REHABILITATION SITES
PARTICLE FACIES

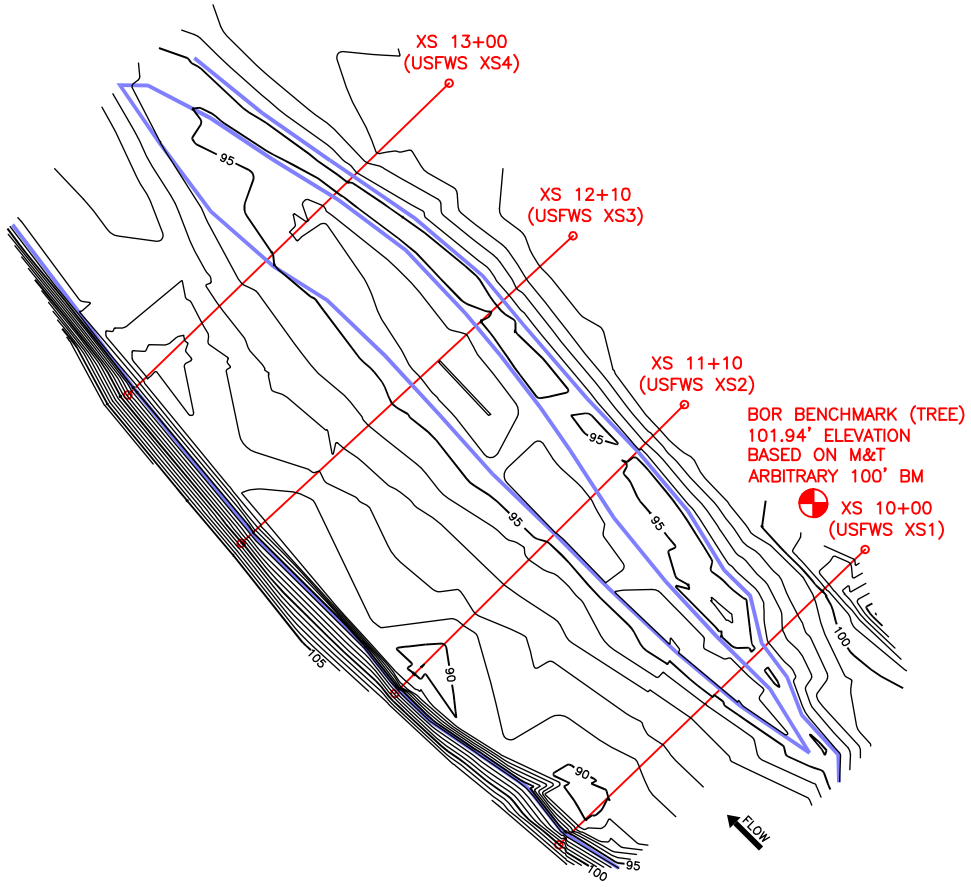
McBain & Trush 1997

11/13/97

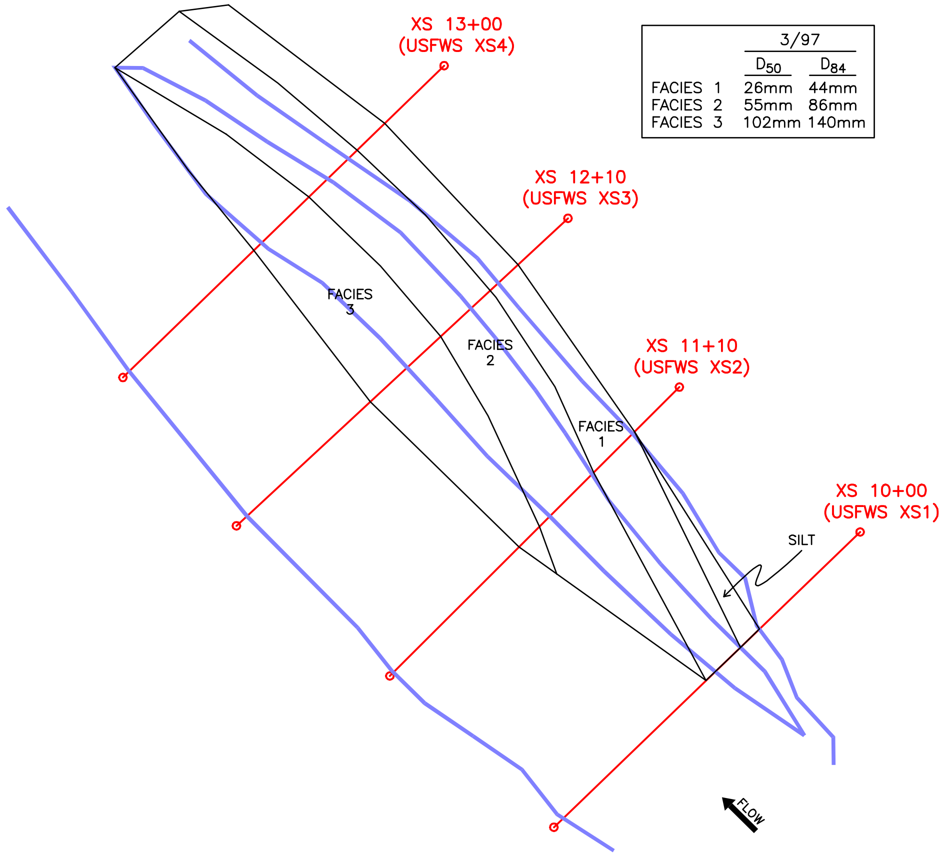
1994 TOPOGRAPHY
(Surveyed by BOR)



1995 TOPOGRAPHY
(Surveyed by BOR)



1997 PARTICLE FACIES

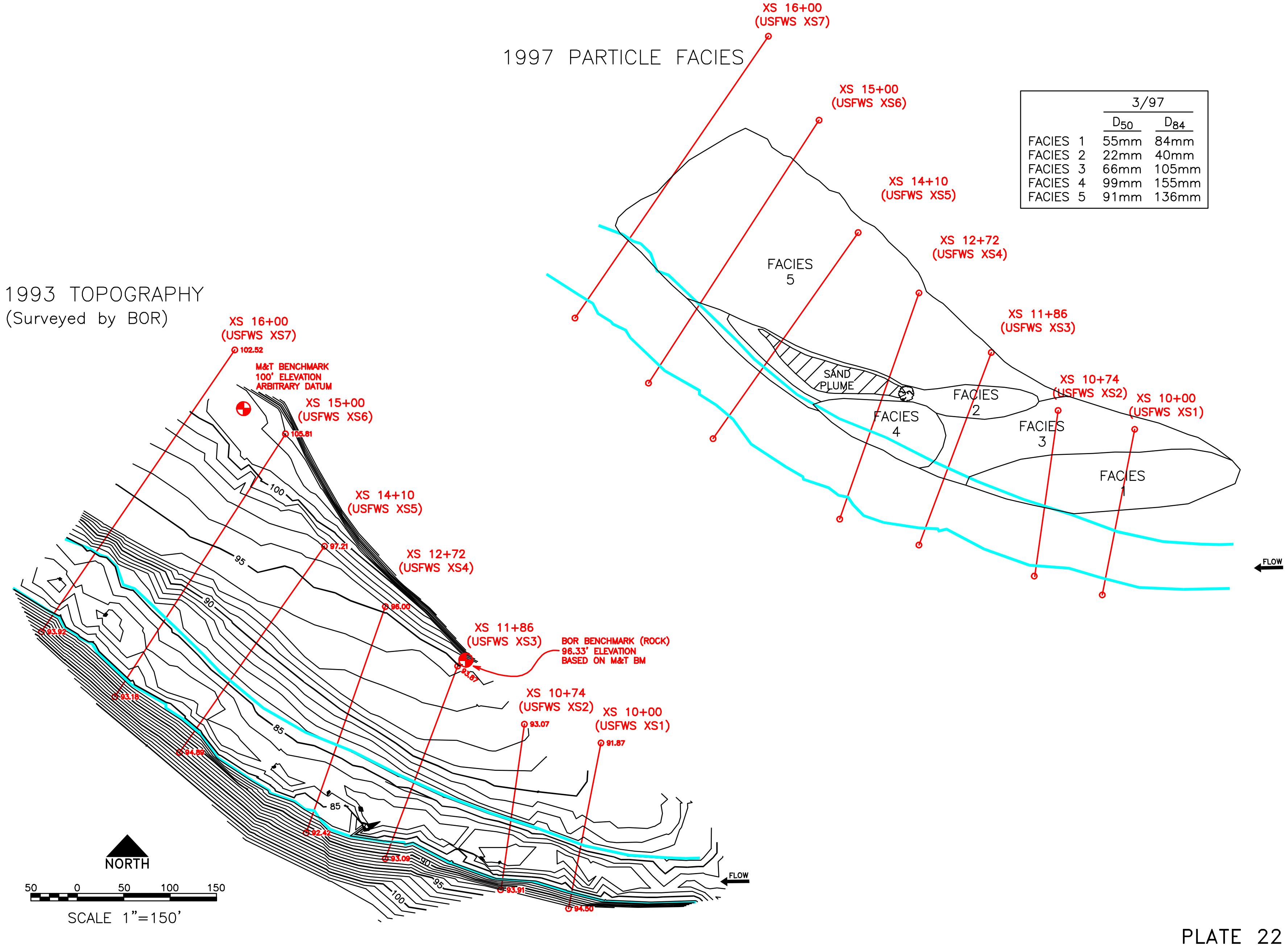


	3/97	
	D_{50}	D_{84}
FACIES 1	26mm	44mm
FACIES 2	55mm	86mm
FACIES 3	102mm	140mm

PLATE 21
TRINITY RIVER MILE 78.5
JIM SMITH BANK
REHABILITATION SITE

McBain & Trush 1997

11/13/97

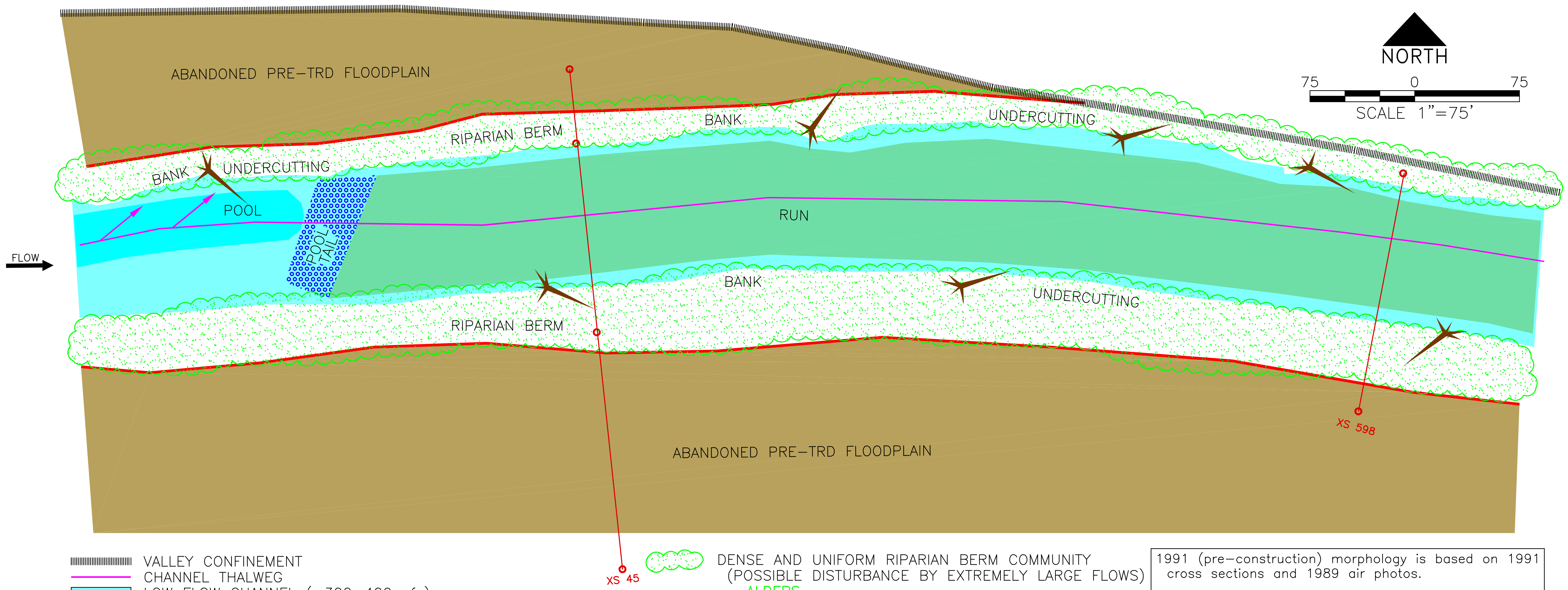


	3/97	
	D_{50}	D_{84}
FACIES 1	55mm	84mm
FACIES 2	22mm	40mm
FACIES 3	66mm	105mm
FACIES 4	99mm	155mm
FACIES 5	91mm	136mm

PLATE 22
TRINITY RIVER MILE 73.1
PEAR TREE BANK REHABILITATION SITE

McBain & Trush 1997

11/13/97



▥ VALLEY CONFINEMENT
— CHANNEL THALWEG
🟦 LOW FLOW CHANNEL (~300–400 cfs)
— TERRACE
(LARGE–EXTREME FLOODS)
🟦 POOL
ADULT CHINOOK AND COHO SALMON HOLDING
ADULT WESTERN POND TURTLE
▨ POOL TAIL
ADULT SALMONID SPAWNING
🟩 RUN
ADULT STEELHEAD HOLDING

DENSE AND UNIFORM RIPARIAN BERM COMMUNITY
(POSSIBLE DISTURBANCE BY EXTREMELY LARGE FLOWS)
ALDERS
TREE WILLOWS
COTTONWOOD (RARE)
VARIOUS RESIDENT AND MIGRANT BIRDS
WESTERN POND TURTLE NESTING
🟫 ABANDONED PRE–TRD FLOODPLAIN
HARDWOODS AND CONIFERS
GRASSES
WESTERN POND TURTLE OVERWINTERING
BANK UNDERCUTTING, EXPOSED ROOTS, AND SUBMERGED BRANCHES
JUVENILE SALMONID REARING
ADULT WESTERN POND TURTLE BASKING AND REFUGE

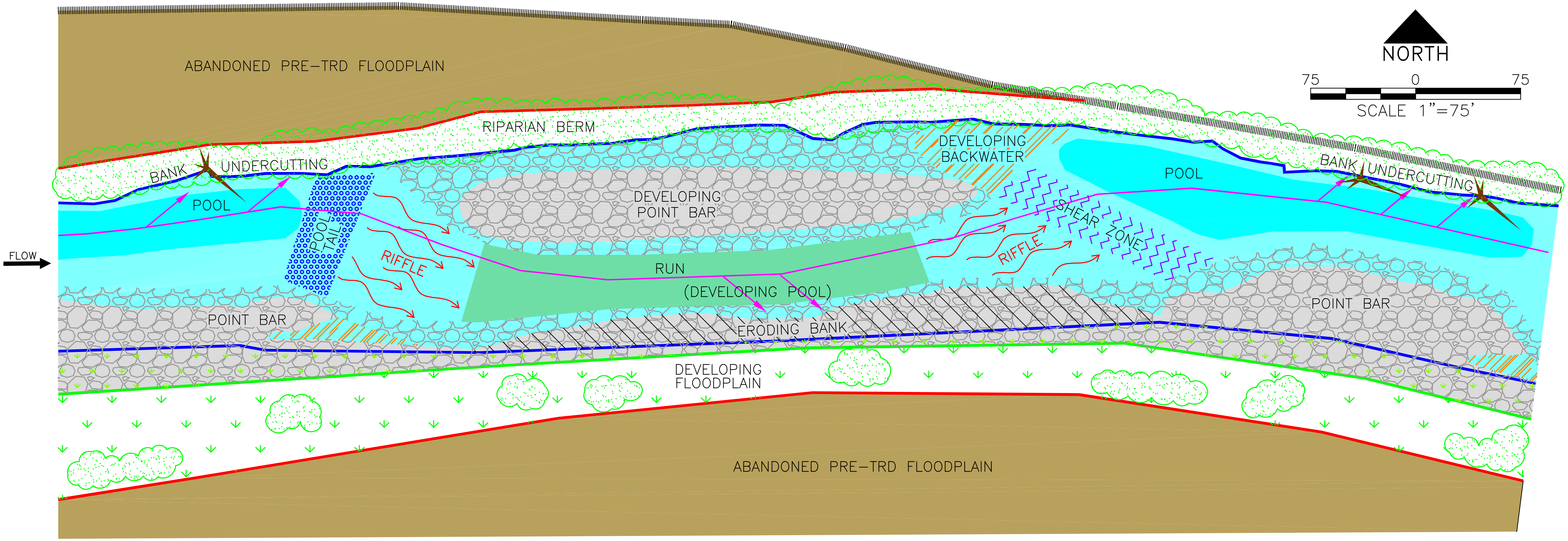
1991 (pre–construction) morphology is based on 1991 cross sections and 1989 air photos.

Site located 20 miles downstream from Lewiston Dam

PLATE 23
TRINITY RIVER MILE 91.7
STEINER FLAT BANK REHABILITATION SITE
1991 PLANFORM MORPHOLOGY

McBain & Trush 1997

11/13/97



🟦 POOL
ADULT CHINOOK AND COHO SALMON HOLDING
ADULT WESTERN POND TURTLE

▦ POOL TAIL
ADULT SALMONID SPAWNING

〜 RIFFLE
ADULT SALMONID SPAWNING
ADULT FOOTHILL YELLOW–LEGGED FROG
AQUATIC INVERTEBRATES

🟩 RUN
ADULT STEELHEAD HOLDING

▭ SHEAR ZONE
JUVENILE SALMONID REARING (FORAGING)

→ CHANNEL MIGRATION DIRECTION -->
BANK UNDERCUTTING AND WOODY DEBRIS INPUT
JUVENILE SALMONID REARING
ADULT WESTERN POND TURTLE BASKING AND REFUGE

▨ BACKWATER
EMERGENT VEGETATION
JUVENILE WESTERN POND TURTLE REARING/REFUGE
FOOTHILL YELLOW–LEGGED FROG EGG/TADPOLE REARING
FRY AND JUVENILE SALMONID REARING

▭ GRAVEL/COBBLE CHANNEL MARGIN
SALMONID FRY REARING
FOOTHILL YELLOW–LEGGED FROG EGG/TADPOLE REARING
JUVENILE WESTERN POND TURTLE REARING
SHOREBIRD NESTING AND FORAGING

▭ EARLY SUCCESSIONAL RIPARIAN COMMUNITY
(BANKFULL FLOW DISTURBANCE)
WILLOWS
GRASSES
ALDER/WILLOW/COTTONWOOD SEEDLINGS
MISC. ANNUALS AND PERENNIALS
WILLOW FLYCATCHER

▭ DIVERSE FLOODPLAIN RIPARIAN COMMUNITY
(LARGE TO EXTREME FLOOD DISTURBANCE)
ALDERS
TREE WILLOWS
COTTONWOODS
WESTERN POND TURTLE SHADING AND REFUGE
VARIOUS RESIDENT AND MIGRANT BIRDS

○ DENSE AND UNIFORM RIPARIAN BERM COMMUNITY
(POSSIBLE DISTURBANCE BY EXTREMELY LARGE FLOWS)
ALDERS
TREE WILLOWS
COTTONWOODS (RARE)
WESTERN POND TURTLE SHADING AND REFUGE
VARIOUS RESIDENT AND MIGRANT BIRDS

🟫 ABANDONED PRE–TRD FLOODPLAIN
HARDWOODS AND CONIFERS
GRASSES
WESTERN POND TURTLE OVERWINTERING
WESTERN POND TURTLE NESTING

▥ VALLEY CONFINEMENT
― CHANNEL THALWEG
🟦 LOW FLOW CHANNEL (~450 cfs)
― ACTIVE CHANNEL WATER SURFACE
(WINTER BASEFLOWS; ~800–2000 cfs)
― BANKFULL CHANNEL WATER SURFACE
(TYPICAL FLOOD; ~6000 CFS)
― TERRACE
(LARGE–EXTREME FLOODS; >8000 cfs)

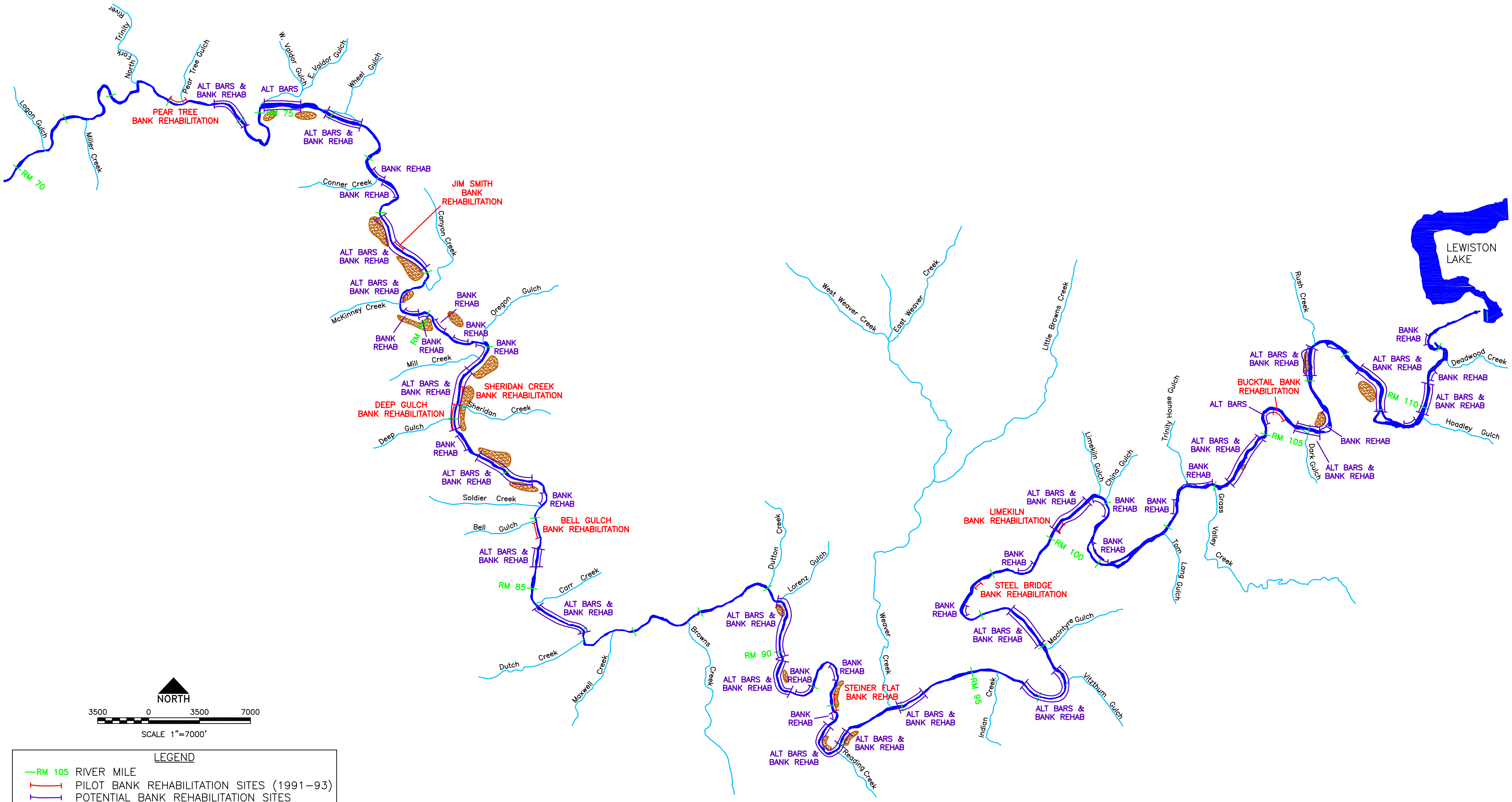
Morphology developed after:
1) USBOR removed right bank riparian berm and widened the channel in 1991–93; and
2) subsequent high flows (>6000 cfs) deposited coarse sediment and formed alternate bars.

Site located 20 miles downstream from Lewiston Dam

PLATE 24
TRINITY RIVER MILE 91.7
STEINER FLAT BANK REHABILITATION SITE
1995 PLANFORM MORPHOLOGY

McBain & Trush 1997

11/13/97



LEGEND

- RM 105 RIVER MILE
- PILOT BANK REHABILITATION SITES (1991–93)
- POTENTIAL BANK REHABILITATION SITES
- DREDGER TAILINGS

ALT BARS: ALTERNATE BARS
Remove alternating sections of riparian berm and restore appropriately sized point bars floodplain
BANK REHAB: BANK REHABILITATION
Remove riparian berm and restore floodplain to be inundated by frequent flood flows (~1.5 year flood)

PLATE 25
TRINITY RIVER MILE 70–112
PILOT AND POTENTIAL
BANK REHABILITATION SITE
PROJECT LOCATIONS

McBain & Trush 1997

11/13/97