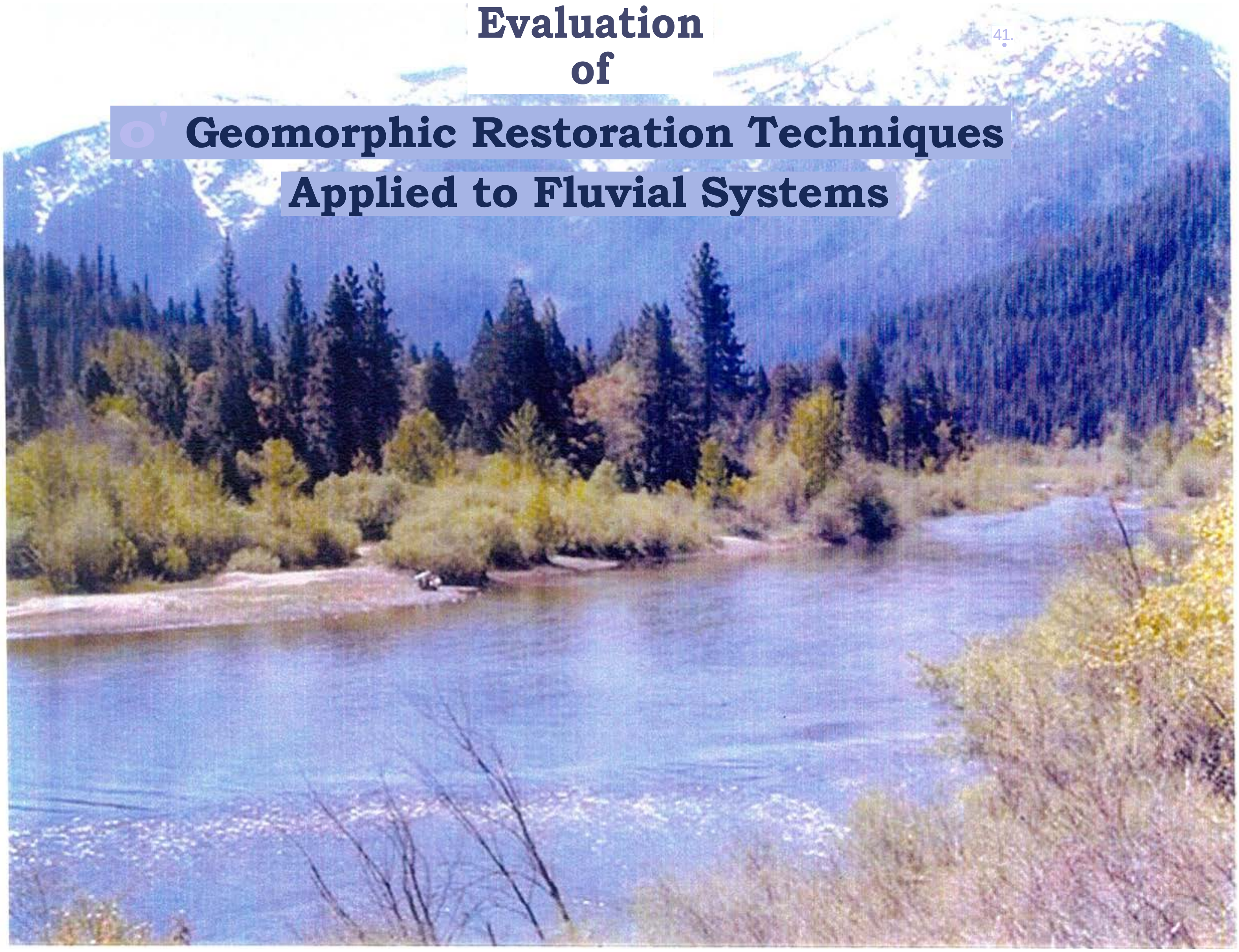
Evaluation of Geomorphic Restoration Techniques Applied to Fluvial Systems



EVALUATION
of
GEOMORPHIC RESTORATION TECHNIQUES APPLIED TO FLUVIAL SYSTEMS

December 2001

Feather River Coordinated Resource Management Group

Plumas Corporation

State of California Water Resources Control Board

University of California Cooperative Extension

Northwest California-based Collaborative Learning Circle

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ACKNOWLEDGEMENTS

This booklet is a compendium of experiences of many individuals both inside the Feather River Coordinated Resource Management (FR-CRM) group and across the country. No written work on geomorphic restoration can ignore the significant contribution of the work of Dave Rosgen. Likewise, much of that work was built on the scientific foundation of river behavior developed by Dr. Luna Leopold and numerous colleagues. Without the pioneering work of these individuals there would be no experiences to share.

The individuals, agencies and landowners comprising the FR-CRM have promoted and supported the innovative use of the technologies described in this booklet. Without their willingness to take a risk, or to think 'outside the box', much of what we have to share would still be lessons yet to learn. The authors have been involved in virtually all the projects described and bring that unique perspective to this work.

Numerous other individuals and organizations, in California and across the U.S., are undertaking many of the same river problems and solutions described herein. While the general landscape discussion afforded by this booklet is valuable for conceptualizing landscape issues and solutions, it must be recognized that this is not intended as a how-to manual. Highly detailed and technical data collection and analysis is required for designing and implementing fluvial geomorphic restoration projects. Those subjects are far beyond the scope of this booklet.

In closing, we speak for all those individuals who have contributed to this material, and hope that it is of value to you, the reader, and ultimately, to the river.

Thank you.

Foreword

This booklet was funded by the California State Water Resources Control Board and primarily authored by Feather River Coordinated Resource Management Group staff at Plumas Corporation. Because of the evolving nature of the material presented in this booklet, it must be considered a draft. Many concepts and observations are presented here that may be controversial to other practitioners, as well as to other members of the Feather River CRM. As such, there is some danger in putting these observations in print. They are presented in this booklet not as hard fact, but as a means to foster discussion and further the development of watershed restoration techniques. Some readers will no doubt find issue with the lack of data and references herein. Again, this booklet should not be construed as a peer-reviewed scientific presentation. It is solely a forum for sharing our experiences.

The Feather River Coordinated Resource Mana2ement Group

The Feather River Coordinated Resource Management Group is an alliance of natural resource agencies, local land owners, private interests, and the public that works on erosion control and watershed restoration. Our organization began in 1984 when the Pacific Gas and Electric Company began a long-term effort to manage sediment at their Rock Creek Reservoir on the North Fork of the Feather River. They initiated a series of meetings with agencies responsible for controlling erosion upstream of their dams. At those meetings, the agencies agreed that any significant attempt to control erosion needed to be cooperative, across jurisdictional boundaries. In 1985, the agencies organized themselves into a Coordinated Resource Management Group. Participants signed a Memorandum of Understanding (MOU) that set up guidelines and goals for working together on erosion control projects across the entire watershed. Those goals are:

- Identifying erosion sources
- Coordinating between public and private landowners
- Implementing erosion control projects where practical
- Ensuring project cost-effectiveness for contributors
- Developing a cooperative regional erosion control plan

Signatory members of the Feather River CRM:

Federal

Plurnas National Forest (USFS/USDA)
Natural Resource Conservation Service (USDA)
North Cal-Neva Resource Conservation and Development Area (USDA)
US Army Corps of Engineers
Farm Services Agency (USDA)
US Fish and Wildlife Service (USDOI)

State of California

Department of Fish and Game
Department of Forestry and Fire Protection
Department of Parks and Recreation
Department of Transportation
Department of Water Resources
Central Valley Regional Water Quality Control Board
University of California Cooperative Extension

Local Government

Plumas County
Plumas County Community Development Commission
Plumas Unified School District
Feather River Resource Conservation District
Feather River College

Private

Pacific Gas and Electric Company
Salmonid Restoration Federation
Plumas Corporation

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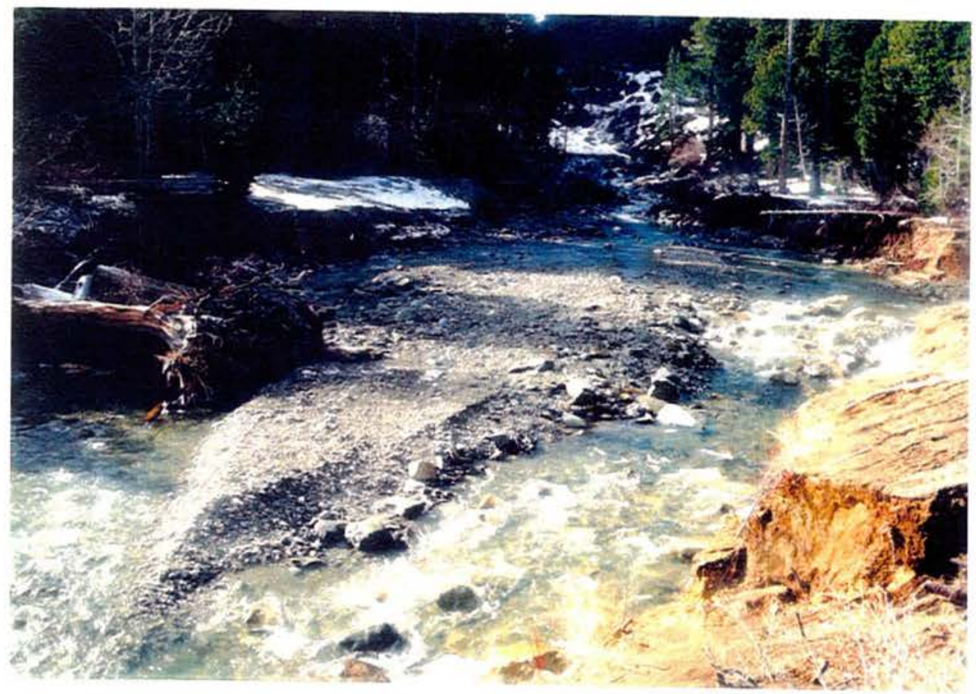
Section 1 - Introduction & Overview

The purpose of this booklet is to share what we have learned from 15 years of geomorphic and biotechnical restoration projects implemented in the Feather River watershed. It is primarily intended for use by experienced river restorationists, as well as those contemplating restoration. Because of the limited scope of this booklet, it could best be used in conjunction with other restoration technique manuals such as Dave Rosgen's Applied River Morphology (1996), Water Bioengineering Techniques (Scheichtl and Stern), Stream Corridor Restoration (Federal Interagency Stream Restoration Group), etc.

Over the years, we have experimented with, and installed a significant array of both structural and vegetative techniques in a variety of situations. The science and art of geomorphic restoration is relatively new and as such there is much to learn. Mistakes in this field are costly, not only to the landscape, but also financially, and in the public's acceptance of these techniques. It is crucial that restorationists throroughly monitor and evaluate their projects and share what they've learned, both qualitatively and quantitatively, to ensure the continued growth in the knowledge base of this science. This booklet focuses on structural techniques and their applicability, function, and limitations in a variety of channel and riparian restoration settings.

We have found that the best way to describe the diversity of settings in which we have attempted restoration is the Geomorphic River Classification system as explained in Dave Rosgen's Applied River Morphology. This system is based on the fundamental principles of river behavior developed by Dr. Luna Leopold and expanded upon by many other researchers. The majority of the projects discussed in this book are set in alluvial landforms characterized by mobile boundaries. We must stress the importance of a comprehensive fluvial investigation and analysis before attempting to use the restoration techniques presented Ire. We have used the investigative and analytical system developed by Dave Rosgen. This system is thoroughly presented inApplied River Morphology, as well as in Dave's ongoing series of short courses. Rosgen pioneered many of the structural restoration techniques discussed in this booklet.

The material in this booklet has been organized into three sections by general landscape setting. Section 2 discusses the challenges of implementing geomorphic restoration within entrenched channels in alluvial landscapes. The mechanism of entrenchment may vary, however the end result is a loss of floodplain area and concentration of flows. These systems are generally classified as F or G streamtypes (see Rosgen 1996), and they all require a restoration approach that recognizes how the limited floodplain width and capacity alters the dynamics of the channel/floodplain system. Feather River Coordinated Resource Management (CRM) partners have worked on projects of this type at Poplar Creek (1994-95) (Figure 1.1), Clarks Creek (1992), Walker Mine (1994-96), Jamison Creek (1995) (Fig. 1.2 & 1.2a), Wolf Creek (1989-93), Greenhorn Creek (1991), Red Clover Creek (II) (1994-95), Black Rock Creek (1996), and Poco Creek (1986).



The Problems of Working Within Entrenched Channels...

Figure 1.1 (above) Members of the Feather River Coordinated Resource Management Group evaluate step pool structures with vegetative bank protection on Poplar Creek in the summer of 1996.

Figure 1.2 (above right) The CRM installed rock weirs in the entrenched Jamison Creek channel in 1995.

Figure 1.2a (right) Structures within the entrenched channel were buried as the 1997 flood carried in a large amount of sediment from upstream, and carved out additional floodplain width. As a result of such adjustments, the CRM has developed and worked with additional techniques.

Section 3 addresses entrenched channels in an alluvial landscape. but discusses the geomorphic approach of eliminating or abandoning the entrenched channel. Stability of the system is achieved by restoring the functionality of wide floodplains in the alluvial setting. This requires a different investigation and analysis approach than is required when working within an entrenched channel. Functioning systems with this configuration are generally classified as C, D. DA or E streamtypes (see Rosgen 1996). The Feather River CRM has worked on projects of this type at Big Flat (1995), Bagley Creek (1996), Ward Creek (1999). Clarks Creek (2001). Stone Dairy (2001), Rowland Creek (1998). Boulder Creek (1998), and Red Clover Creek (I) (1985) (Fig. 1.3).

Figure 1.3 Red Clover Creek was the CRM's first demonstration project. On the left. CRM members meet on-site to evaluate the project's success. The photo on the right shows the pre-project condition. Note the elevation of the water and the conversion of sagebrush to grass in the pre- vs. post-project photos.

Section 4 addresses the most difficult challenge facing restorationists for decades: headcut control. Headcuts are the most persistent and pernicious problem to address, particularly where fish passage is desired. Headcuts. can occur in virtually any streamtype except highly competent bedrock. They are associated with the initial incision process that transforms stable C. D. DA or E streamtypes into unstable F or G streamtypes. Subsequent incision cycles can deepen an entrenched channel and move up into the watershed, creating additional channel systems. The CRM has implemented numerous geomorphic projects with the objective of converting the F or G headcut to more stable. fish passable A or B streamtypes, namely at Poplar Creek (1994-95). Haskins Creek (1993) (Fig. 1.4). Dolly Creek (1994-95). Willow Cr (1996). and Little Stony Creek (1996) (Fig. 1.5).

Fig. 1.4 This photo, taken in 1994, shows the headcut on Haskins Creek that threatened a wetland area. The CRM treated the headcut in 1994 using geomorphic technology. A flood in 1995 returned the repaired channel to its original condition.

Fig. 1.5 Headcut treatment on Little Stony Creek. built in late 1996. was severely damaged during the 1997 flood.

But first, another word about investigation

The synergy of bedload supply and character and the available discharge are inextricably entwined within the dynamic equilibrium of a stable channel, whether altered or pristine. While this concept is fundamental and of utmost importance. there is frequently only rudimentary knowledge of the interplay between channel stability and effective sediment (particularly bedload) transport in restoration project designs. The stability of restoration projects will be determined by the dynamic and synergistic interplay between the sediment/discharge relationships, the structural materials (naturally recruited or human-installed) in the system, and the landscape itself.

A thorough geomorphic investigation of a project site can frequently determine what combination of structural attributes (e.g. large woody debris, dominant bed material, geometry. vegetation. etc.) were present in the previously stable channel. This also provides information about the degree of departure of the existing, unstable channel from its stable condition. This understanding is important for developing a restorative channel geometery and correctly choosing which structural features to pursue for restoration. The application of appropriate structural technologies is actually quite simple once the more elusive understanding of the processes at work (past and present) is achieved.

Figure 1.6 Meticulous data collection is of primary importance when planning restoration projects.

SECTION 2 - Workin2 within Entrenched Channels

Key Fluvial Characteristics

Stream channels become entrenched through a myriad of mechanisms, both natural and human-induced. Some of the more common mechanisms of entrenchment are:

– Concurrent natural incision of a channel/floodplain system often induced by climatic or tectonic change;
– Deposition of adjacent material through colluvial/alluvial fan development, landslide processes or natural channel levee deposits;
– Rapid channel incision without concurrent lowering of the floodplain, induced by land management or channel manipulation practices;
- Construction of entrainment levees (with or without a subsequent incisement response).

While there are many mechanisms or processes that lead to channel entrenchment, the basic effects on the fluvial system are the same (with the exception of where climatic or tectonic changes have occurred).

Development and analysis of conceptual design alternatives must include: 1) an understanding and quantification of the impaired channel function; and, 2) an analysis of the degree of departure in both channel and landscape morphometry; both vertically and horizontally, from the original condition. Geomorphically-focused data collection and analyses should provide the information necessary for design development (i.e. cross-sections, longitudinal profiles, bankfull and flood flow frequencies and distribution, characterization and quantification of sediment, etc.).

The stresses exerted on the entrenched streambed, bank and floodplain features increase exponentially with the depth of the entrenchment. The depth, velocity, and erosive energy of flows will be higher in the entrenched setting than in the historic, unconfined setting (Fig. 2.1). As a consequence, the entrenched channel is subjected to greater and greater stresses as the entrenchment deepens, placing most features and structures at greater risk of damage during high flow events. Following is a discussion of some of the techniques we have used and modified over the years within entrenched channels. It is important to note that even though the techniques are discussed separately, they should be conceived, designed and implemented as an integrated set of techniques within a single project.

Figure 2.1 This series of photos shows flood waters remaining within the entrenched Wolf Creek channel. This sequence of flood pictures from 1995 illustrates the extreme depths that entrenchment can produce in a stream channel. Depths here exceeded 11 feet in the channel at peak stage.

Techniques

Channel reconstruction

Our earliest restoration experiences within the entrenched setting began with channel reconstruction in the form of realignment and/or shaping at Wolf and Greenhorn Creeks. The decision to realign a stream channel. and whether to increase or decrease sinuosity. must bd carefully analyzed for applicability if the entrenchment ratio cannot be significantly altered. It has been our experience that highly entrenched channels tend to return to their pre-restoration alignment (following the dominant flood flow alignment) under the stress of high flows and sediment loads during large flood events (Fig. 2.2). This has been particularly true where the pre-project alignment was supplanted by relatively unprotected. newly constructed floodplain features (Fig. 2.3). To avoid this tendency. we now rarely use the re-alignment strategy. but rather design a shape and form that is similar to the existing morphometry. We've found this to be better than attempting to impose a "normal.- pre-entrenchment channel pattern. Our experience has been that converting F or G streamtypes to a **B** streamtype. irrespective of gradient. has been more successful than attempting to recreate a C streamtype, when working within the confines of entrenchment. Structures such as revetments, vanes, vortex weir structures, and constrictions have also shown to be successful in the entrenched setting.

Fig. 2.2 This channel bank revetment structure was abandoned on Wolf Creek during the flood of 1995. Note the deposition of bedload.

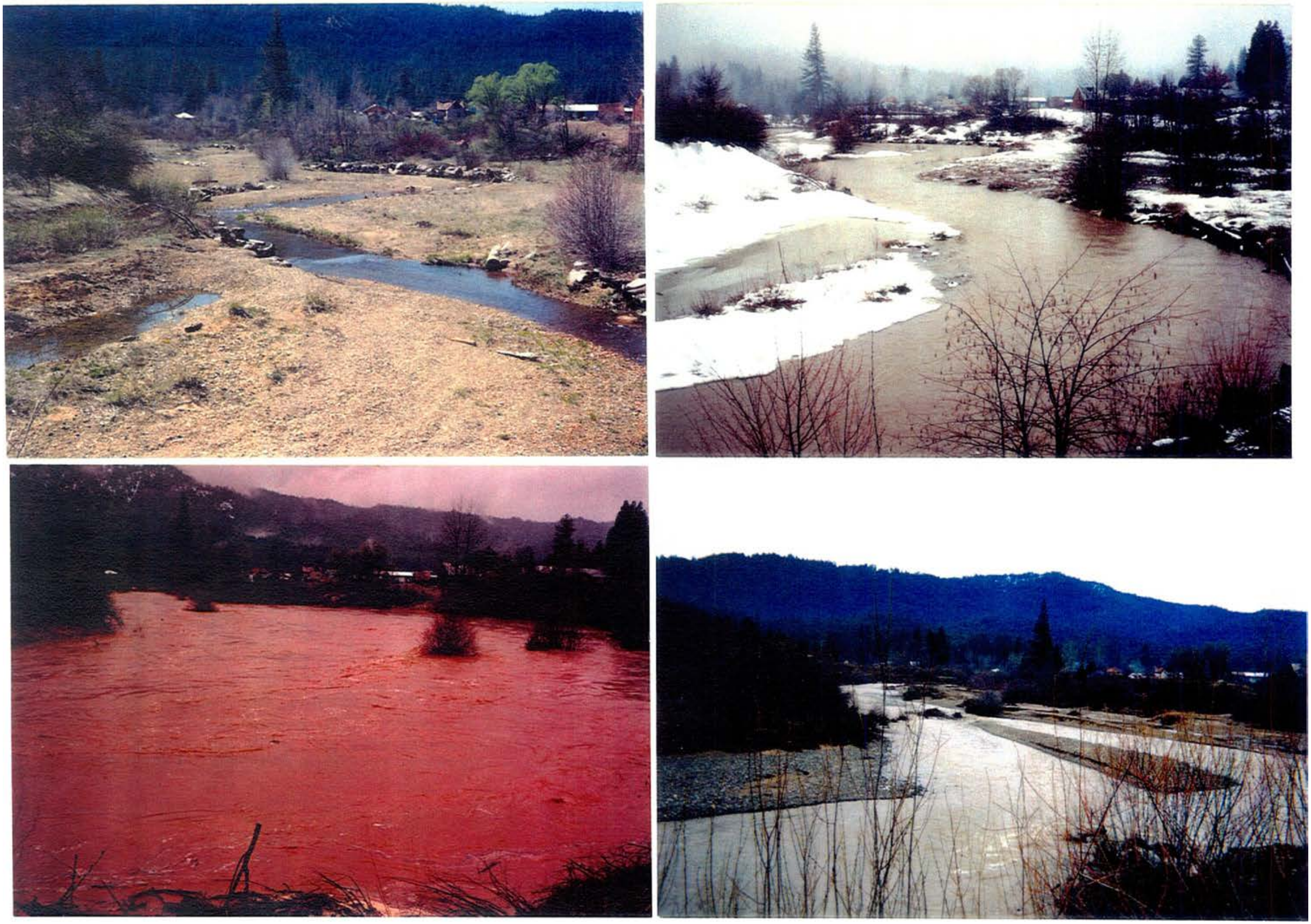


Fig. 2.3 This series of photos of the Wolf Creek Phase I project show the evolution of the as-built project in 1991(upper left), through rising flood waters in 1995, and the resultant channel re-alignment to near its pre-project location (lower right).

Why do B stream types work better? Stable B stream types tend to exist in entrenched settings (Fig. 2.4). The morphometry of the B stream type is conducive to transporting the greater sediment load contained in high flows. The moderate area of floodplain remains narrow or steep. increasing stream power as flows increase. C stream types. however, are associated with broad and fairly level floodpiains. High flows containing high sediment loads lose their transport capacities as flows overbank and sediment deposition occurs. Thus. the equilibrium between stream power and sediment load is lost.

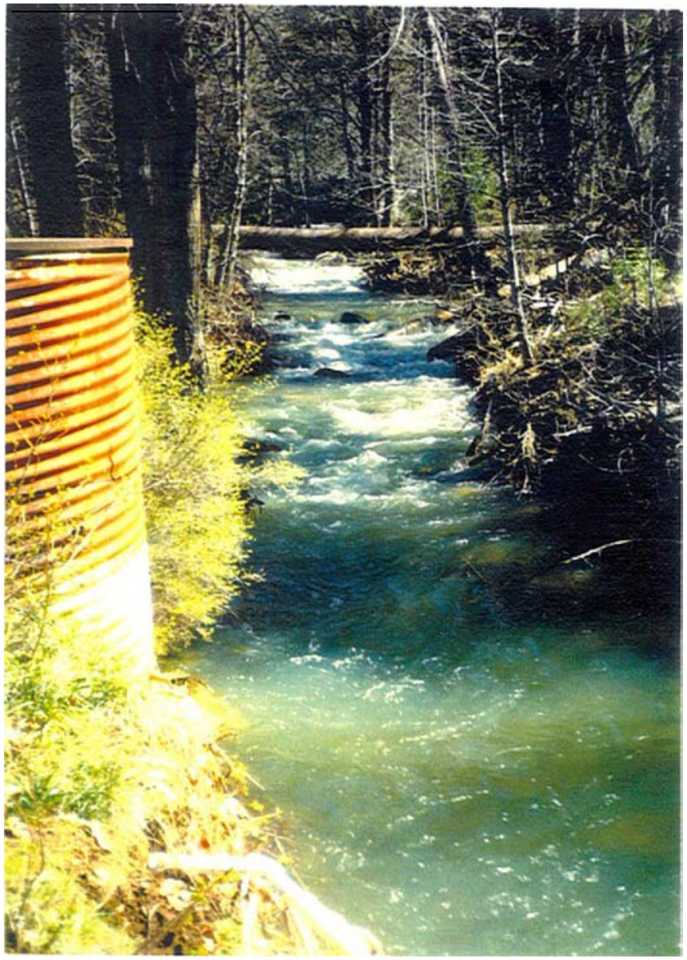


Fig. 2.4 To the left is a typical. naturally-occurrin2 B channel. Below is a constructed B channel on the Phase II section of Wolf Creek.

Recently entrenched channels rarely have a uniform entrenchment as some sections will laterally expand more rapidly than others. The pattern of an entrenched channel is strongly influenced by the alignment and width of the valley, and floodplain constriction and expansion areas (Fig. 2.5). This often results in a combination of both **B** and C channel forms in a given reach. Flood stages in constricted areas result in increased depth and velocity, and are effective in sediment transport. However, higher flood stages also create a momentary backwater effect immediately upstream of the constriction, resulting in reduced velocity, and thereby inducing deposition. Floodplain constriction/expansion sequences are often repeated numerous times throughout a reach and must be addressed in the channel design layout as streamtypes transition back and forth. The exception is where the floodplain is to be excavated so that a consistent width is created.

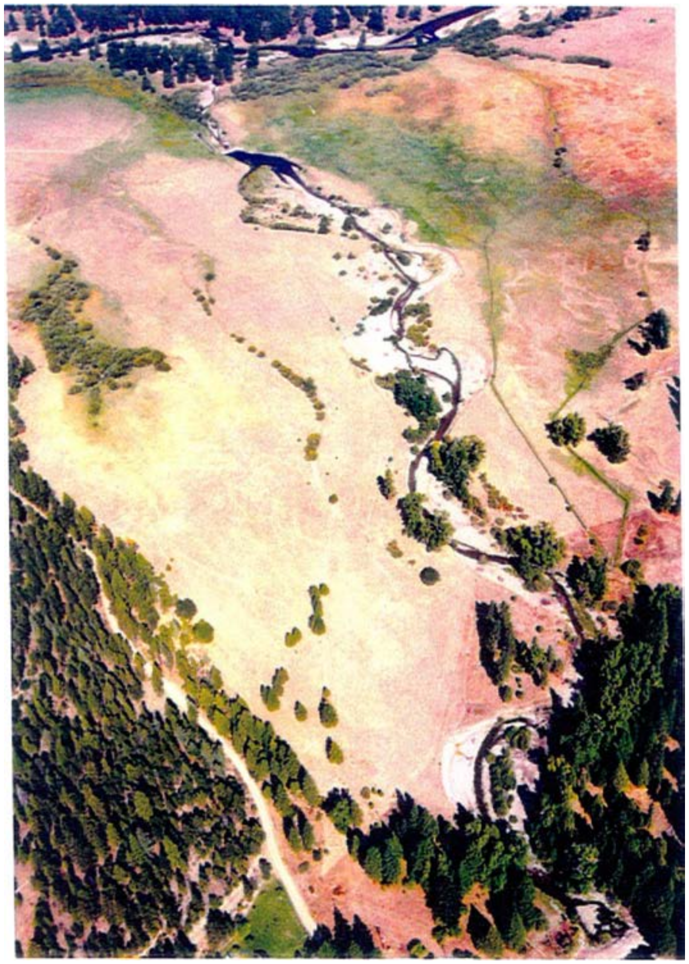


Figure 2.5 This pre-project photo of Ward Creek shows varying gully widths due to valley variations and constrictions.

Channel Structures- Log Revetments

Channel bank revetment structures are typically installed in moderate to low radius of curvature (Re <5) bends where extremely high stress will be exerted on unprotected new banks. Revetments will always be opposed by a point bar. The point bar is sloped to provide optimum depth and velocity for sediment transport at all stages while its maintenance and growth is regulated by the resistance of the revetment. Log revetments are composed of whole trees (root wads, limbs, twigs, log protrusions, etc.) which provide a large amount of surface area and roughness to dissipate multi-dimensional velocity vectors present near the bank (Fig. 2.6). The resistance of the structure directs much of the residual velocities into the bed, thus creating and maintaining a pool feature. Beyond the physical function of the revetment material, the resultant pool scour creates some undercut bank for cover and shade while incorporating organic material to the stream (Fig. 2.7).

It should be kept in mind, however, that these structures have a finite lifespan. Climate, the type of wood, and its exposure to air, all determine the lifespan of any wood structure. The intent of log revetments, in general, is to provide initial protection until vegetation can become established and mature enough to resist flood stresses. It is incumbent on the builder to incorporate and hasten the colonization of that vegetation. Cottonwood, alder and tree willow, used as primary revetment material, can foster immediate suckering of new plants. It must be emphasized, however, that proper handling of these materials is required if they are expected to regenerate growth. Frequently, existing whole plant(s) (willow, alder, cottonwood,etc.) need to be removed from other areas of the project. To the extent possible, this should be coordinated with structural installation so these plants can quickly be transplanted into or around the revetments, (or any other structures) as backfilling is being placed. If there is a paucity of transplants, placing large quantities of six to eight-foot long willow whips (or other shoot-rooting species) into the revetments, prior to, and during backfilling can be a successful method of hastening woody vegetation establishment (Fig. 2.8).

Important Note: Installation of revetments or individual components must be continuously supervised and evaluated for proper function at base flow, bankfull flow and flood flows. This includes the orientation of the whole structure and its individual components as well as their resistance to flood stresses.

Fig. 2.6 (above) Revetments are constructed with a high degree of roughness. Note the point bar (foreground) that was constructed in conjunction with the revetment.

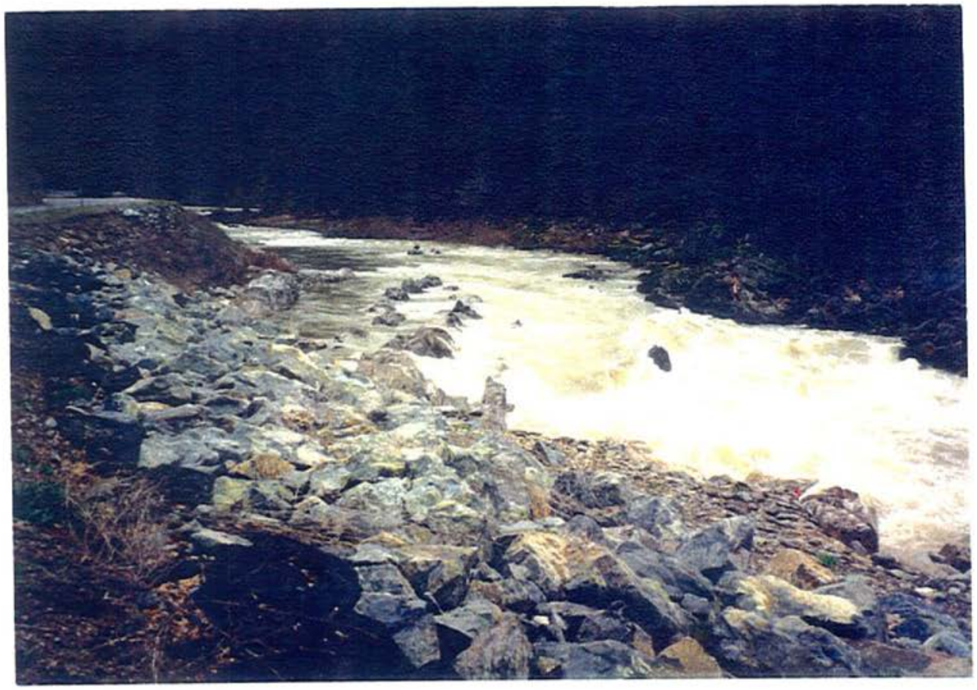
Fig. 2.7 (above right) This revetment has filled
in nicely with vegetation, maintaining bank protection as well as a shaded pool for fish habitat.

Fig. 2.8 (right) Backfilled with plants during construction, this revetment structure is well on its way to long term replacement with vegetation.

Channel Structures- Vanes

A "vane" is any resistant material that is oriented at an effective upstream angle and slope in the streambed which deflects flows away from the bank toward the center of the channel. Effective placement of a vane structure demonstrates the principle that a fluid will tend to cross a resistant, uniform structure at a perpendicular angle. Combining the proper slope with the proper angle strongly accentuates that tendency while simultaneously preventing the diversion of high velocity flows into the streambank (Fig. 2.9). Even more important. unlike groins, spur dikes. bendway weirs, or other commonly used structures, this function is not altered as stage increases. Vanes also require a lot less material to construct. Naturally formed vanes can frequently be found in rivers or streams (Fig. 2.10).

Fig. 2.9 This log vane on Cottonwood Creek demonstrates how flows crossing the vane are diverted away from the bank.



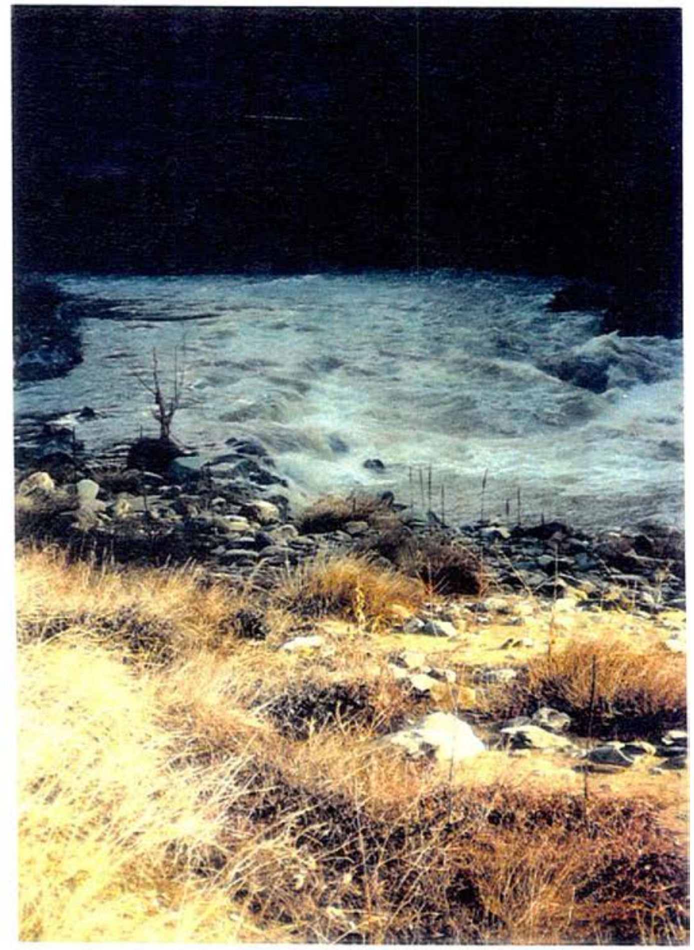
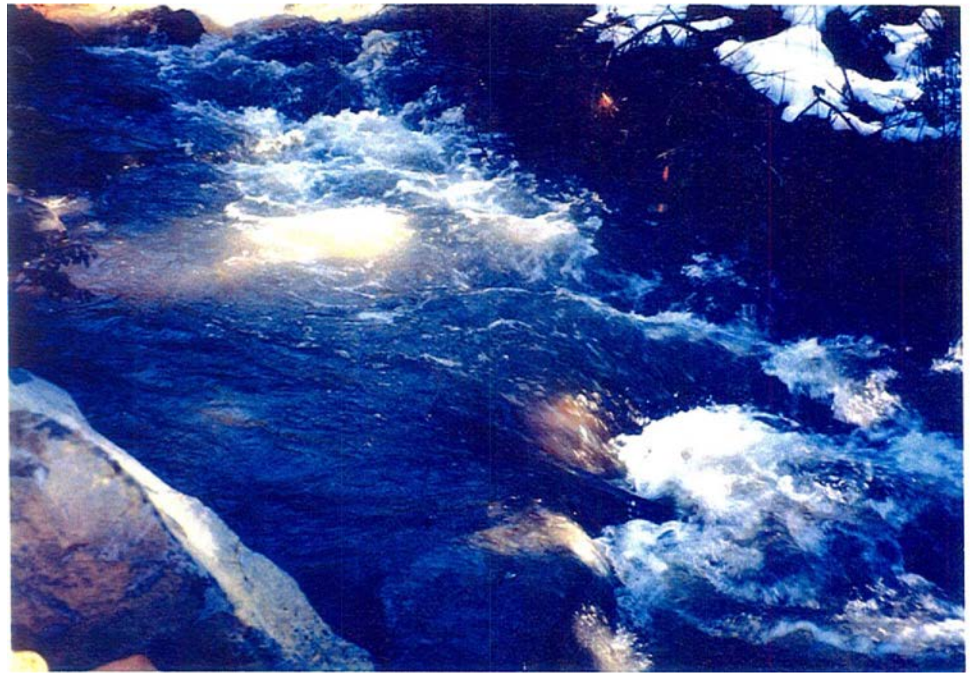


Fig. 2.10 These three photos show a vane on Indian Creek formed by a bedrock fin. Notice how it maintains the low flow in the center of the channel. and turns the flow at higher stages.

Fig. 2.11 A constructed boulder vane on Hamilton Branch turns the flow toward the center of the channel.



Vanes, in conjunction with vegetation transplants or biotechnical structures. are an effective, low profile and inexpensive structural technique that protect streambanks from toe erosion until protective bank vegetation can become established (Fig. 2.12). A properly constructed vair maintains the core of the highest flow velocities and stresses away from the bank toe and toward the center of the channel. The resultant convergence of flows through the vane maintains a small pool for energy dissipation. Vanes can be used on meander bends with a high radius of curvature (Rc >5), and on straight riffle streambanks composed of poorly consolidated fill. They can be constructed of logs. whole trees. boulders. even plant bundles, depending on site characteristics.

Vanes, as is the case with most geomorphically designed structures. are ultimately intended to be functionally supplanted by vegetation. It should be noted that they do not provide as much resistance to the erosive forces of flows as revetments do; they operate more by re-directing those flows. While near bank stresses are reduced by vanes, they are still present and must be addressed. This has been accomplished successfully using herbaceous and woody transplants as well as biotechnical structures. The interval of unprotected bank between vanes is subjected to back-eddying. And while this eddying effect results in some sand and fines deposition, the eddy currents can erode the bank and expose the ends of the vanes. To avoid the erosion, and enhance the depositional tendency of this area, willow matting (Fig. 2.13) has been shown to be an excellent, cost-effective treatment that jump starts the revegetation process while providing initial structural protection.

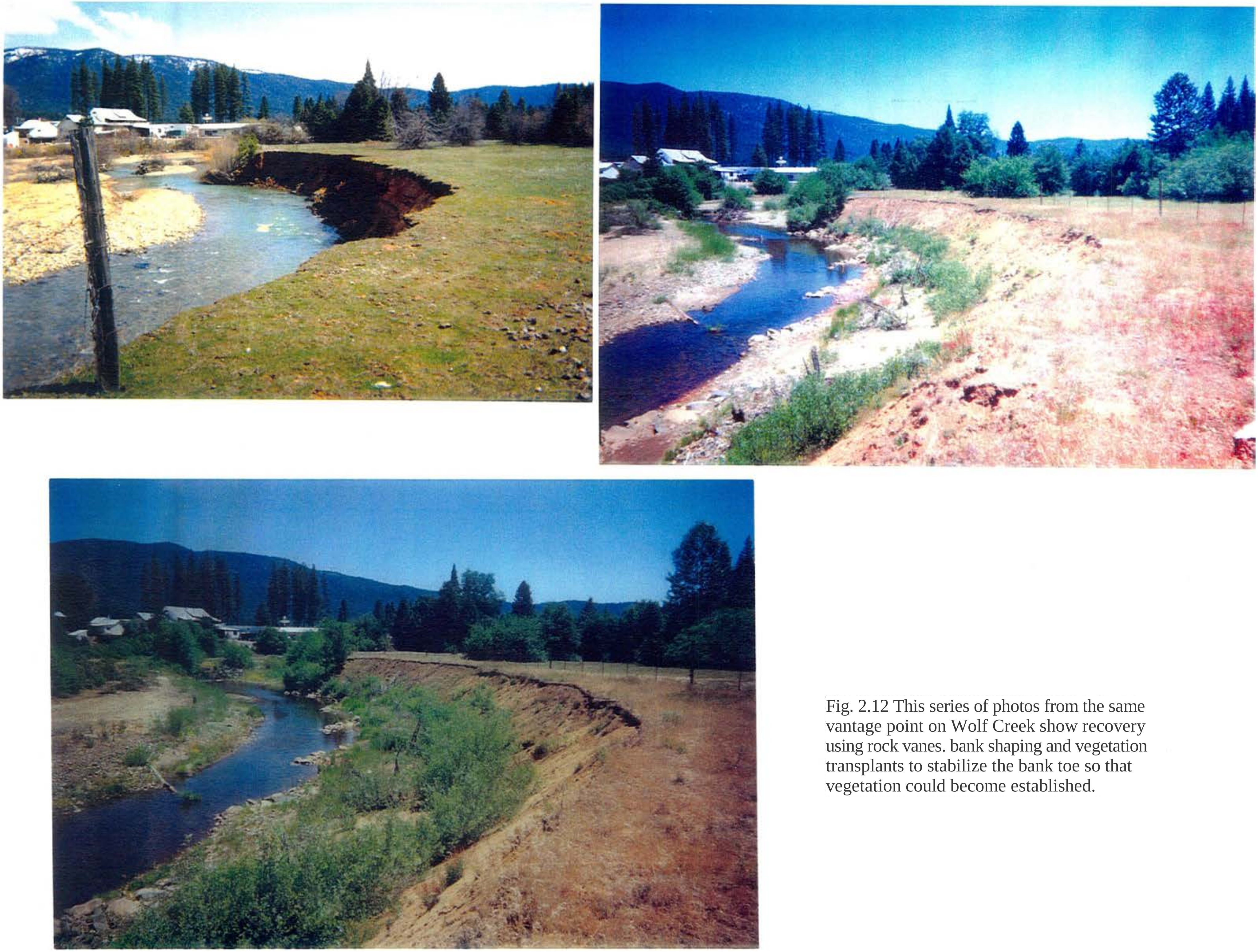
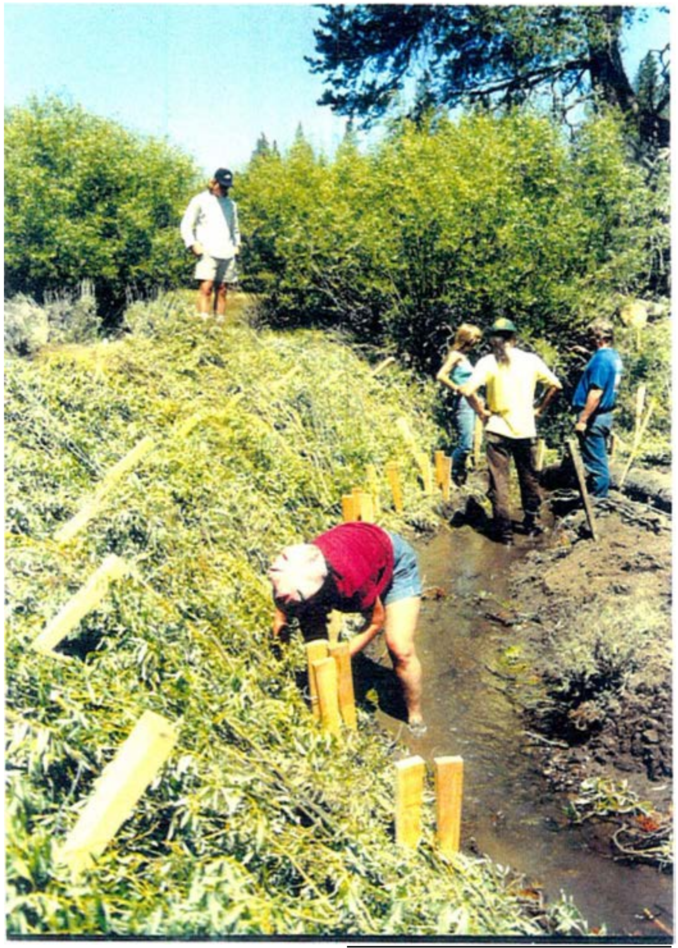


Fig. 2.12 This series of photos from the same vantage point on Wolf Creek show recovery using rock vanes. bank shaping and vegetation transplants to stabilize the bank toe so that vegetation could become established.

Fig. 2.13 Willow matting is one of the many biotechnical structures developed and refined by Dr, Andrew Leiser. William Gray, Robin Sotir and other researchers and restorationists. All of these structural methods have certain fundamental anchoring systems that promote both initial structural protection and plant establishment success. The CRM has used many of these excellent techniques in natural channel and floodplain settings. Here, willow matting on Blakeless Creek helps to stabilize an eroding meander bend.



Channel Structures - Vortex Rock Weirs

Vortex rock weirs were originally developed to provide a structure that would converge streamflow at all stages into a pool feature. The structure also had to allow unimpeded bedload transport. The convergence simultaneously creates pressure and turbulence to maintain a pool while accentuating the pool's energy dissipation function. The FR-CRM has found these structures to be extraordinarily effective at maintaining a pool and dissipating energy. However, we've also found that these structures have been less effective at moving large quantities of coarse bedload, and are subject to debris jamming. The effectiveness of these structures relies quite heavily on stringent design and installation criteria. The vortex weir (or any derivative that provides the same function. such as W weirs. convergence structures, etc.) has to be installed with each component evaluated on its individual influence in the channel as well as its interaction with adjacent components and the structure as a whole, in three dimensions (lateral, vertical, and longitudinal).

The Feather River CRM has installed nearly 300 vortex rock weirs in a wide variety of landscape settings and streamtypes (A. B. C). with channel gradients of 0.5- 5% and bedloads that range from silt/sand to gravelicobble, in high. medium and low quantities (Fig. 2.14). Because of the demonstrated ability of these strong structures to induce positive, and occasionally negative, channel response. considerable time has been devoted to observing and monitoring their performance in a wide range of events. This section will discuss those observations and then installation limitations for **B** and C streamtypes in entrenched channels (To simplify discussion the term "rock" will be used regardless of diameter (18" to 8') size).

Fig. 2.14 This vortex rock weir was installed on Wolf Creek in a re-created C channel with high bedload. Note the upstream horseshoe and the vertical keel shape. (Flow is from right to left.)

The CRM's first use of vortex rock weirs was in the design of C4' streamtypes in entrenched settings in 1990 (Wolf Cr) and 1991 (Greenhorn Cr). They were designed and installed as integrated components of revetted meander and floodplain reconstructions. They were positioned at both the riffle crest and tail for grade control as well as thalweg definition and maintenance. These weirs had the standard configuration, i.e. a horseshoe-shape with the closed end oriented upstream, and a vertical "keel" shape across the structure (see Fig. 2.14). The keel shape is formed by placing the rock in the center at the lowest elevation, with subsequent rocks increasing in elevation toward each bank. (However, it should be noted that, because of the assymetrical bedform of meandering channels, the lowest rock was generally offset slightly from channel centerline.) The channel slope of both projects was 0.5%- 0.6%. Wolf Creek had a high to very high bedload supply, and Greenhorn had a moderate bedload supply. These weirs functioned as designed to discharges up to a stage of 0.5 feet above bankfull.

In 1995, as the stage continued to rise, (undoubtedly influenced by the entrenchment) the weirs began to interfere with the natural channel adjustments that occur during larger flood and sediment supply events. Both project reaches revealed a channel adjustment pattern of pool lengthening and riffle shortening. We also observed this in other entrenched channels. This appears to be a response which increases pool capacity for energy dissipation. We also observed that while the riffle crests appear to move longitudinally, there is no change in crest elevation. The riffle is simply shorter, and consequently, steeper. This steepness decreases under more frequent, but lower magnitude, events, as the riffle builds back headward. We are continuing to monitor in order to quantify this dynamic.

When this channel adjustment process occurred within the Wolf and Greenhorn projects, two visible responses were evident. First, in locations where the pool length was unable to adjust through the weirs, the point bars aggraded laterally and vertically, reducing the cross-sectional area of the channel substantially. This, in turn, shifted a greater percentage of the discharge and sediment transport onto the floodplain, initiating the unwelcome development of chute cut-offs (Fig. 2.15). Second, in locations where the pool length was able to adjust through the weirs, the weir was undermined, and left as a jumble of rock in the bottom of the pool, with the new riffle crest located downstream. The second response was actually the more benign of the two, because the channel alignment remained as designed. The first response generally led to channel re-alignment through the floodplain, or at best, a braided channel. Essentially, at high flow and sediment transport levels, the combination of high channel sinuosity and additional rock in the channel increased roughness, slowed velocities, and induced channel aggradation. Based on these observations, the CRM no longer uses vortex rock weirs on riffle crests, except in unique situations.

Fig. 2.15 Development of chute cut-offs. In the photo on the left, the chute cut-off developed over a constructed floodplain after the 1993 flood on Wolf Creek. On the right, a chute cut-off developed within the Greenhorn project in the 1997 flood. The constructed meander bend and revetment (lower right corner) was abandoned.

Vortex rock weirs have performed much more effectively in '13 streamtype designs in entrenched channel settings. Also, we now place the weirs only at the riffle tail. The riffle crest is left 'uncontrolled'. and free to adjust longitudinally or vertically as necessary. Properly designed and installed, the weirs still act to converge flows into a pool. and to maintain the keel-shaped form and low width to depth ratio (W/D) of the upstream riffle. Its also useful to note that this low W/D facilitates an appropriate velocity distribution and effective bedload transport, as well as improved fish habitat and passage at base flows (Fitz. 2.16).

Fig. 2.16 This series of vortex rock weirs on Wolf Creek converges flows to maintain frequent pools and a lower width to depth ratio. Note the entrenchment of the channel into the now-urbanized historic floodplain.

Section 3 - Reconnecting the Channel with the Floodplain

This section discusses the approach of restoring the stream channel to a fully functional connection with its floodplain. This usually entails raising the elevation of the channel. Regardless of the technique used (gully fill, check dams or complete valley re-grading), we believe that this technique is the closest we come to true restoration because it addresses the functionality of the whole system. This approach requires an entirely different perspective than that used when staying within the gully. While both approaches require a careful analysis of both the existing and proposed condition and processes, this approach will substitute a entirely different set of processes in the system rather than just modifying the existing condition, as in Section 2. For example, existing relic features such as alluvial fans or remnant channels, are likely to provide opportunities to become active, functional components of the system and should be recognized and incorporated into the design. Likewise, the valley configuration plays a more prominent role in this approach. Overall, the channel/floodplain relationship allows channel geometry, soil and vegetation to play a much larger role in design and construction than in the entrenched setting.

What cannot be emphasized enough in the following discussion is that in order to be successful, these treatments must be applied throughout a stream/meadow reach, with (preferably existing) control points at either end. Otherwise, the same incision potential that entrenched the channel in the first place will still be present and will ultimately undue any restoration work.

Key Fluvial Characteristics

As mentioned earlier, the role of sediment is often overlooked in restoration designs. When considering this approach, it is important to remember that the sediment supply and transport characteristics will be altered significantly. Consider the supply differences in valleys where the soil stratigraphy changes rapidly from fine surface deposits to underlying coarse alluvium. The larger particles from the coarse alluvium will comprise a disproportionate percentage of existing entrenched bed and bar material, yet not be representative of the size and quantity of sediment supplied by the watershed (Fig. 3.1), and probably not a significant portion of material in a restored channel.

Since velocities and velocity distribution in a channel/floodplain system are significantly different from those in an entrenched channel, so are sediment transport and deposition. In entrenched channels, sediment tends to be deposited in high profile bars. These bars tend to maintain high shear stresses against the opposite banks, causing more bank erosion and more bar formation downstream, thus perpetuating instability. In a functioning channel/floodplain system of a healthy watershed, however, sediment deposition and transport maintains a more stable dynamic. Finer sediments are frequently distributed across the floodplain in a "veneer" rather than as scattered high profile bars (Fig. 3.2).

Fig. 3.1 This eroding bank on Ward Creek shows the different sized particles from the top of the bank to the bottom. The fine soil at the top reveals the recent pre-degradation floodplain character of the valley.

Fig. 3.2 When flood waters can access the floodplain, sediments are deposited in a thin veneer that contributes to the stability and productivity of the system. as shown in this post-project photo at Big Flat.

Another element to consider is vegetation. In a restored channel/floodplain system, the groundwater table is likely to rise and remain elevated season-long. This should encourage a vigorous regeneration of streambank and floodplain vegetation that will capture sediment for bank building and improve the filtering efficiency of the floodplain.

One critical area in these systems is at the head of the valley, which often coincides with the beginning of a project reach. This is where the upstream, transport channel and the downstream, broad floodplain system are in transition. These are often D- or B-type channels on a channel/alluvial fan, and as such, are subject to very dynamic depositional processes. with a high potential for dramatic response (such as relocation) in major events (Fig. 3.3). Analysis of the slope and configuration of this active alluvial area can provide guidance on the location. form and structural attributes necessary for the channel's initial stability, at least until more stabilizing vegetation can become established.

Fig. 3.3 The mouth of Wapaunsie Creek provides an extreme example of dynamic depositional processes on an alluvial fan. The location of the mouth of the creek frequently changes course, as evidenced from the sparse vegetation on the fan.

Downstream of the fan, the channel will generally assume C. E or DA streamtype characteristics. Frequently. there will be a short reach of C stream channel as progressively smaller-sized particles are deposited. An E streamtype (highly sinuous, very low W/D ratio) then may develop where the gradient and remaining sediment load permit.

Because of their great efficiency and effectiveness, it is highly valuable to observe and study E channel dynamics. In equilibrium. these highly complex channels induce very high shear stress in relation to the gradient without causing undue bed and bank erosion. This channel type maintains a very precise balance between potential energy and kinetic energy that enables transport of gravel-sized particles, but in low volumes. Excess energy is dissipated primarily through friction against the bed and bank, or through turbulence in the water column (Fig. 3.4). The turbulence not only acts to dissipate energy. but also concentrates streampower to maintain effective transport of bedload. These E-channel features seem to be a product of complex interaction between pronounced, yet difficult to observe, bed features and channel geometry. Effective E-channels generally occur at the elevation of the floodplain, which allows another important part of the E-channel dynamic: the ease with which flood flows overbank onto the floodplain, bringing together all the benefits of channel/floodplain interaction.

Fig. 3.4 The broken water surface in the constructed E channel at Big Flat indicates the complexity of the turbulence throughout the water column.

While this approach of abandoning entrenchment is different than modifying an entrenched channel, all the standard channel and floodplain data still need to be collected, quantified and analyzed for these systems. This should include a careful assessment of the pattern, form and profile of any channel type (B, E, C or DA) that is existing or is proposed for the project. Additionally, point bars at the upper end of, or above, the project area that indicate watershed sediment supply should be analyzed. Existing remnant channels should be carefully analyzed and typed (E6, C4, etc.). Remnants should also be noted for their location in the valley and their structural attributes, especially vegetation. The FR-CRM has frequently used remnant channels, and these types of observations help guide decisions on whether to use them without alteration, with minor structural intervention, or to completely reconstruct them. Valley cross-section surveys also identify subtle tilts and crowns (often less than one-half foot) on the valley floor that can significantly affect channel and floodwater routing through the valley. These features and their fluvial effects should be incorporated into design development (Fig. 3.5).

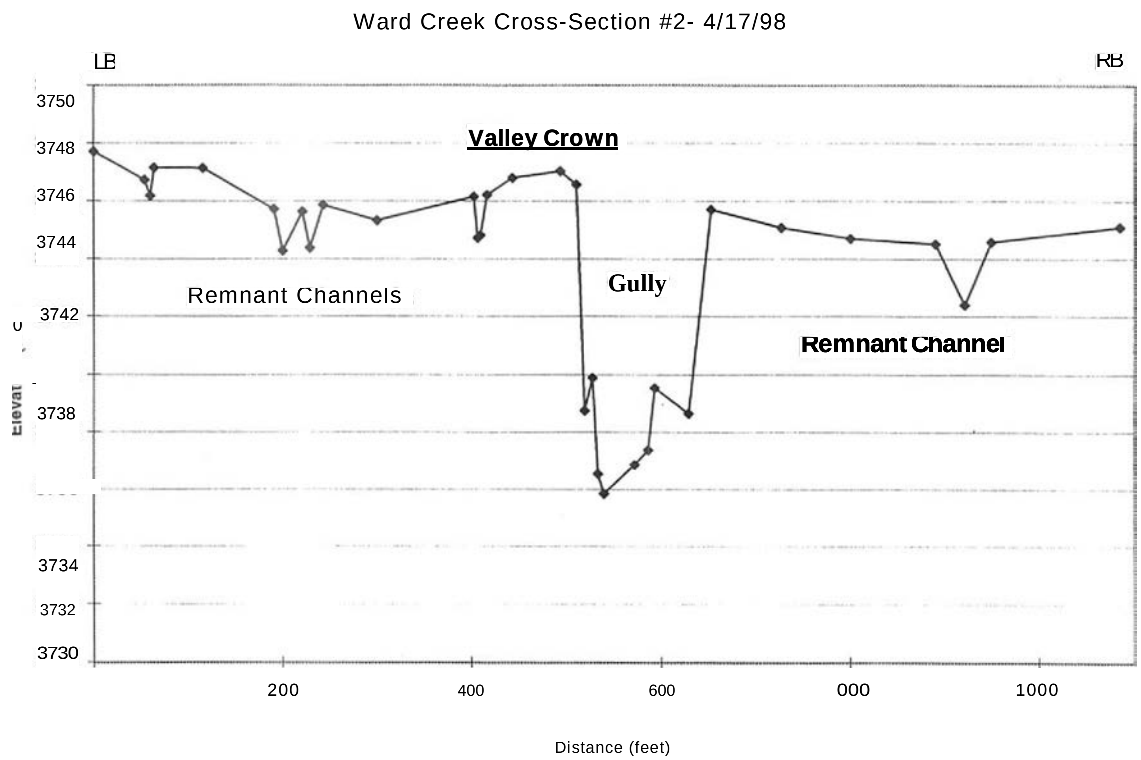


Fig. 3.5 Graphed data from a cross-sectional survey show remnant channels and other important elevational differences that may not be detected otherwise.

Techniques

Channel Reconstruction

The first premise before attempting a restored channel and floodplain project is that it doesn't happen in a vacuum. Success is absolutely as dependent on understanding and incorporating upstream and downstream factors as it is on project site design. It is useful to iterate for a third time how critical it is to consider how and where the coarser bedload particles are deposited. In a functional meadow system. they are deposited in somewhat of a fan at the head of the channel/floodplain valley, rather than being carried further down into a gullied channel. How the new design will adjust to these deposits must be considered when planning the long term success of a project.

One of the CRM's first attempts at channel reconstruction was in 1995 on Cottonwood Creek at Big Flat. Certainly one of the most important lessons to come out of Big Flat is that when flood flows have access to a floodplain, it is better to underconstruct a new channel than to overconstruct it. Despite meticulous calculations on bankfull and flood flows, the E-channel at Big Flat was constructed approximately 150% of the bankfull capacity. The velocities within the channel, consequently. precluded deposition of gravels from the upper watershed. The volume of gravel to be transported through the project reach from the upper watershed was also under-calculated. Despite these errors. the second year after this project was constructed, it functioned as designed. utilizing its entire floodplain in the 1997 flood. At that time. the lack of gravel was still a concern because of the resulting energy imbalance. However, some amount of gravel has moved into the project reach. and point bars and riffles are developing. We expect that these features, as well as improvements in vegetation, will continue to stabilize the constructed channel (Fig.3.6).

Fig.3.6 Features such as gravel point bars and a vegetative root mass are contributing to the stability of the constructed E channel at Big Flat.

As part of the design of the Big Flat channel, we observed and measured several functional E channels in similar settings within the Feather River watershed. This is an example of the type of data collection and observations that should be part of any channel design. The existing channels were analyzed for bed and bank features and channel geometry relationships. We observed that, though not readily obvious, these channels had functional point bars at meander bends, pool features, and a riffle separating the pools. Pool intervals were closely spaced (five channel widths) and we characterized three distinct reproducible pool forms. These pool forms seemed to be due to a characteristically high sinuosity and meander belt width. The first pool type occurred at full meander bends (Fig. 3.7). The other two pool forms have been observed regularly on reaches that are laterally crossing the valley. The second pool type was a simple bend (45-90°) pool, often oriented down- or occasionally up-valley (Fig. 3.8). The third pool type was a more complex double pool, with an initial jog, a sharp diagonal riffle crest feature, then another jog in the opposite direction (Fig. 3.9). In the natural evolution of E channels this third pool type is probably reflective of structural attributes such as buried debris, beaver dams, or willow clumps, etc. that may no longer be present.

E channels may be the climax condition in channel evolution. They can occur in meadows where there is erosion-resistant soil and dense vegetative root structure. Many project areas do not have this critical combination of elements that enables outright construction of this streamtype. Despite design errors of Big Flat, the project is succeeding due to the presence of those critical and necessary stabilization elements. So, while an 'E' channel may be the desired condition, we learned that the constructed design may have to start with a 'C'or `B' streamtype. Restoring the floodplain/channel relationship initiates the surface and subsurface hydrologic conditions necessary for recovery of vegetation and development of the ultimate channel form.

Generally, design and construction of the C or B streamtype will be similar to that outlined in Section 2. However, with a fully functional floodplain, structural protection will typically be less continuous and massive. Often, only a few root wads or a couple of well-anchored willow transplants will suffice for bank protection. Likewise, step pool reaches may only require a 'constricting' structure of transplants, boulders or wood to maintain pool convergence and energy dissipation. Using more structure than is necessary reduces the channel's ability to maintain sediment transport. This can result in central bar deposition or even general channel aggradation.

These figures illustrate pool types constructed at Big Flat, based on observations of natural E channels.

Fig. 3.7 (above) Pool and point bar at a full meander bend (low radius of curvature).

Fig. 3.8 A pool and riffle at a simple bend.

Fig. 3.9 Double bend pools with point bar features at each jog.

Having discussed channel reconstruction, it should be noted that we often question the need to construct a channel in these settings. Frequently. the historic meadow and floodplain still contains a system of intact remnant channels. The CRM has implemented several projects where flows were diverted onto the floodplain and into remnant channels of the meadow. Channel reaches were constructed only where necessary. at the upstream and/or downstream end of the project area (Fig. 3.10). Judiciously spot-planted willows or other minimal structures provide protection until vegetation can become established.

Several projects similar to Big Flat have suggested to us that only where bedload transport through the meadow was a natural part of a particular meadow's evolution is a channel necessary. Most of the meadows we've dealt with do not appear to have historically transported bedload through them, but rather the coarse load was deposited at the head of the meadow. Most of the meadows we've surveyed contain only small remnant channels, or no channel at all, on the meadow surface. Because of the difficulties in exactly predicting all of the variables necessary for channel construction, wherever applicable, we have found the use of remnant channels to be most desirable. However, in some situations. use of a remnant channel is not an option. In these cases, the valley type. along with existing valley and channel characteristics will help determine the appropriate channel type and design attributes.

Fig.3.10 Using remnant channels. On the left, one year after construction, high water accesses the floodplain as it flows down a remnant channel used in the Bagley Creek project. On the right, in this pre-project photo. we've outlined the remnant channel to be used by Clarks Creek in conjunction with gully obliteration.

Entrenched Channel Obliteration

Creating a new channel at the floodplain elevation is only a portion of the design work that is needed in this approach. There is still the small matter of a large void, or gully, in the valley. This feature. if left in place. will rapidly undo all the effort expended in re-establishing flows back on top of the meadow. The gully bottom will undoubtedly be the lowest point in the valley. Consequently. this will act as a drain for both surface and subsurface flows. Such a dewatered meadow cannot sustain vigorous plant growth (Figures 3.11 & 3.12). If left in place. the gully walls will also continue to slough from the pressure of groundwater as it migrates towards the gully. Flood flows will create headcuts when they enter the gully system. Eventually, the gully will re-capture all flows, and the new channel will be abandoned. To avoid such a failure. the entrenched channel **must** be eliminated.

Fig. 3.11 Groundwater becomes less available to vegetation as it is drains out of Carmen Valley, and seeps through the gully walls.

Fig.3.12 Groundwater flow through gully walls also contributes to bank sloughing.

Gully development and expansion has removed tens, hundreds. or thousands of cubic yards of valley material. Replacing this volume with imported material is generally not economically or environmentally feasible. Also, imported material would likely not be of similar texture to the existing valley soil. We have found the "pond and plug- technique to be a useful way to efficiently eliminate a gully (Fig.3.13). It is important to remember, however, that this technique must be used only where applicable. Other gully elimination techniques are discussed later, but they are a bit slower in achieving results because they depend on natural aggradation rates.

Fig. 3.13 These before and after aerial photos of the Big Flat -pond and plug- project show complete gully obliteration by excavating native material (thus creating the ponds) to fill the gully to meadow elevation (between the ponds). Also note the constructed £ channel on the left side of the photo on the right.

Pond and Plug

This technique is somewhat counter-intuitive. It generally entails widening and deepening the gully in certain areas as a source for fill to plug the gully (Fig. 3.14). The widened, deepened areas form ponds (which become excellent wildlife habitat). The end result is a series of simple to complex ponds with massive fill areas in between (Figures 3.15 & 3.16). In design. placement of the ponds versus the plugs must incorporate the subtle tilts, crowns and swales present in meadows and valleys, particularly in the valley margins. These features should maximize fill volume and at the same time provide habitat diversity. While ponds can be located outside of the gully. wherever possible. they should incorporate a portion of the gully. This reduces the area to be filled and ensures that the material haul is as short as possible.

Fig. 3.14 Construction of the Ward Creek Project entailed excavating ponds within the gully (foreground), and using that material to build the gully plugs (background). Note that equipment haul routes are within the gully. While not shown in this photo, it should also be noted that Ward Creek is not flowing through the construction area — the new channel was constructed first.

Fig. 3.15 These pre- (above) and post- (below) project pictures of Ward Creek are taken from almost the same vantage point (notice the cone shaped hilltop in the background). The post-project picture was taken in 1999, immediately after construction and shows how the gully has been eliminated by the plug. Since construction, the plugs are re-vegetating solely from large transplants and topsoil that was previously stripped from the construction site,

Fig. 3.16 In these pre- (above) and post- (below) project pictures from Ward Creek, a pond has replaced this section of the gully. The plug is being constructed in the background of the upper photo, and is seen in the lower photo.

Of utmost importance is pond drainage. Some portion of the ponds can be subject to floodtlow entry. During flood conditions the pond water level rises as the ground becomes saturated, until the ponds themselves begin to sheet water onto, and receive flows from. the valley surface. In essence, the ponds form a liquid floodplain. However, as open water, the pond water surface will be flat while the valley has some slope. This condition will result in flows exiting the pond at the lowest edge elevation while some floodflows may enter the pond on the up-valley side with a drop that could potentially initiate gullying. To reduce this risk, the ponds generally should have no more than one foot of drop from the highest potential entry point to the lowest exit edge (i.e.. if the valley slope is 1%. then the pond's down-valley width should not exceed 100 feet). Design should ensure that surface water is generally not allowed to enter a pond. except where erosional damage will not occur. Pond location and design should incorporate natural features that lead water away from each pond. And. if such elevation features that direct flood flows away from up-valley pond edges are present. then the longitudinal width can be increased substantially with little increase in risk. This increases the amount of fill available from a given pond source as well as providing an opportunity to construct bays. inlets, points and islands in the ponds. These features provide the greatest complexity for as many terrestrial and aquatic species as possible. This is particularly critical during low flow periods when pond water may be the only surface water in the area (Fig. 3.17).

Fig. 3.17 This aerial view of the Ward Creek project. taken one year after construction, shows the diversity of depths and edges in the ponds that maximizes both fill volume and wildlife habitat diversity. The design of these ponds also incorporated the elevational crown in the valley, which minimizes overland flow into the ponds (see also Fig. 3.5).

As with any other restoration effort, re-vegetation planning should be fully integrated into the design and construction of the ponds and plugs. Following are some simple steps we have used to maximize the vegetative recovery of the disturbed soil:

- First, minimize equipment travel on undisturbed areas by using the gully itself as a haul route as much as possible.
- Second, have equipment remove the top 12-- 18- of soil. plants and litter prior to full excavation, and stockpile it adjacent to the proposed fill areas (Fig. 3.18). Then conduct the fill operation with excavated, less fertile subsoil to the designed elevation. After completing the fill operation, shallow rip the compacted fill, and spread the stockpiled topsoil over the plug. The importance of this step cannot be over-emphasized, not only for fertility, but to provide the enormous seed bank present in that topsoil. We have noticed that even where the spread topsoil is thin, the regeneration from the seed bank generally out-performs all but the most intensively prepared. artificially seeded areas.
- Third. every effort should be made to maximize the utility of existing vegetation. This often entails machine transplantingthe existing sod. willows and other suitable plants that may be buried or inundated by the pond and plug work or by channel construction. This must be planned for. as it often necessitates assigning a specific piece of equipment to perform these tasks (Fig. 3.19).

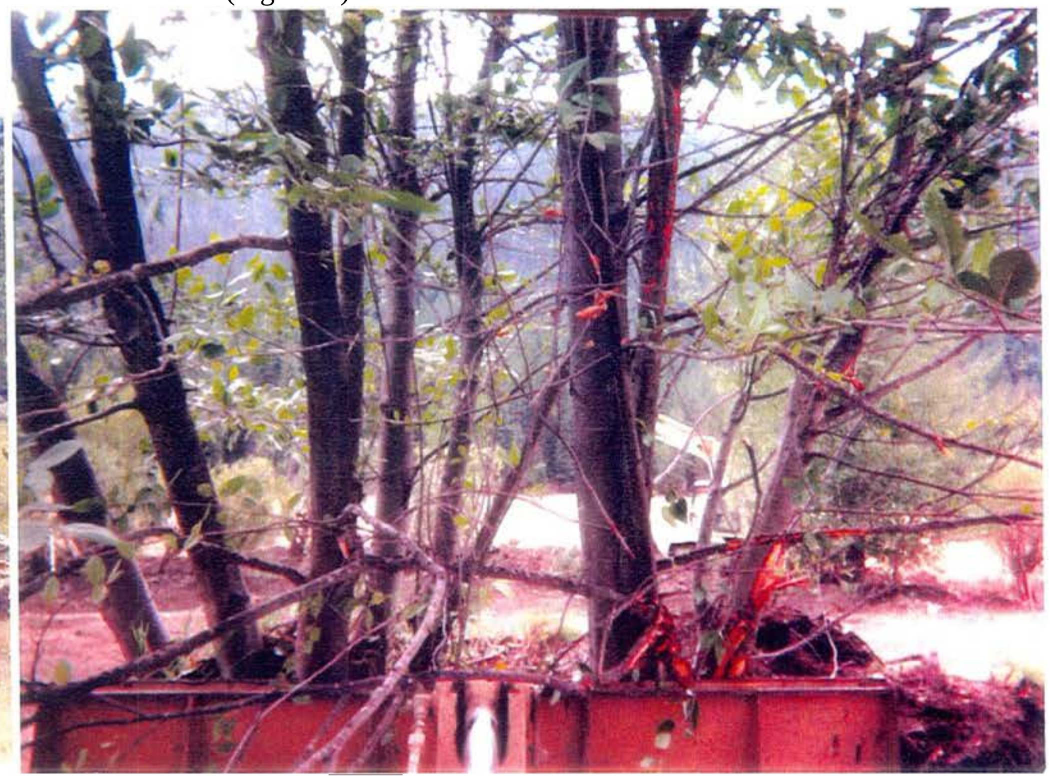


Fig.3.18 (left) This pile of sod and topsoil will be spread in the final stages of plug construction on the Clarks Creek project.
Fig. 3.19 (right) Whole alder trees are transplanted with a trackloader during construction of the Ward Creek project.

Debris Jams

At Boulder Creek, the CRM successfully used large woody debris jams to rapidly aggrade a gully (Figs. 120, 3.21, 3.22). The goal of this technique was to raise the elevation of the channel to near the floodplain elevation by inducing deposition of the high sand load within the gully. There are two key attributes that must be present in order to utilize this technique. The channel must have a high volume of reliable sediment, which is (ideally) mobilized a flows less than bankfull. This is most likely in watersheds dominated by sand. Sediment is needed to aggrade the gully before the structural material deteriorates past its effectiveness. The other necessary attribute is a floodplain and gully banks that sustain erosion-resistant vegetative roots at the design base level of the channel.

The debris jams are composed of whole tree pieces layed parallel to the channel, including root wads, limbs, foliage, etc. The intent is to fill the cross-section with a permeable filter structure that will induce deposition. Leaving the foliage, limbs and roots attached to the larger trunks provides roughness throughout the water column that aids in trapping sediment particles.

Properly built, the action of these debris jams differs from classic check dams because of their porosity. Initially, low flows will pass through the jam rather than ponding and spilling over the top. The porosity reduces lateral erosion of adjoining banks. It also allows for a more metered deposition of particles throughout the reach. Jams allow coarser materials to be deposited near the upstream jams and progressively finer sediments to be deposited downstream, so the entire channel can aggrade simultaneously.

There are two primary construction components of a debris jam of this type. One is a "frame" that defines the desired channel configuration at the desired elevation. The other is a strategic placement of every piece to promote maximum near-bank roughness while converging flows through the design channel frame. While permeable to lower flows, jams are constructed tightly enough so that flows approaching bankfuil stage can spill onto the floodplain. The jams are frequently spaced on a morphologically determined interval, generally, at every riffle, or inflection point, throughout the reach.

Fig. 3.20 (above) Debris jams were installed on Boulder Creek in 1997. The gully in this photo is six feet deep. Low flow water is not visible, but is flowing under and through the structure.

Fig. 3.21 (upper right) Jams were installed at inflection points in the channel, as seen here between two meander bends. In Boulder Creek, there was an average distance of 90 feet between jams.

Fig. 3.22 (lower right) In the spring of 1998, the debris jams began to aggrade the channel. Seventy cubic feet of water per second flowed through and over the debris jam. Sand was deposited both within the channel, and on the floodplain.

Structures of Other Materials

In many small watershed/channel systems, the entrenchment may only be one to three feet deep in a channel that is a couple of feet wide. While this may not be a glaring eyesore, it can be dysfunctional enough to significantly impact vegetation, habitat, and waterquality. as well as possibly leading to further entrenchment. These types of situations often lend themselves to simple. inexpensive treatments that. cumulatively, can have significant effects. At Rowland Creek, the CRM treated such an entrenched E channel by transplanting meadow sod mats onto each riffle crest throughout the degraded reach. This raised the base level of the channel with a flexible self-renewing natural structure without altering the channel gradient (Fig. 3.23).

Fig.3.23 Sod mats, placed on riffles in Rowland Creek help trap sediment and raise the elevation of the streambed so that high flows can easily overbank onto the floodplain.

In conjunction with the debris jam and sod mat projects described above. the CRM also experimented with some composite grade structures. using materials such as rock, woody debris, and vegetative transplants. These composite structures were built to the original channel base level to restore full access to the floodplain (Fig. 3.24). Again, several key features made them successful. They were frequently spaced. allowing only 6-12" of fall at each structure, and keel shaped. with the face arced upstream. This is similar to the convergence achieved with paired vanes or vortex weirs. The downstream apron of each structure was also keel shaped with the apron sloping up to the bank top. The combination of rock. woody debris and/or willow transplants in each of these structures provide roughness. aesthetics. and textural diversity. These structures are obviously more expensive and involved than other techniques and should only be used where absolutely necessary. We used them where the floodplain was limited, the valley gradient steepened. or there was a high risk of re-incision. These structures have withstood flows up to 70 cfs to date.

Fig. 3.24 This composite structure of whole trees and rocks on Boulder Creek traps sediment for the bank on the left as it converges flows down the center of the channel on the lower right.

Section 4 - Headcuts

Key Fluvial Characteristics

Headcuts and their consequent G' streamtype, gullies, are arguably the most difficult channel disturbances to control or reduce. The most effective method for dealing with headcuts is to prevent them from initiating at all. Fluvial processes must be considered in the design of any improvement on the landscape. We are still suffering from the consequences of omitting such considerations in the past. Unfortunately, a lack of fluvial understanding still pervades many landscape project designs. Headcuts leading to systemic channel incision in the Feather River have been traced to such diverse causes as historic beaver trapping, logging railroad grades, channel capture by irrigation ditches, levees, roads, road crossings, and over-grazing. These and other causes can wreak havoc on the river system for miles upstream as the system seeks to re-establish equilibrium. Anyone interested in restoration is all too familiar with these scenarios.

The evolution of headcutting and consequent gullying feeds upon itself in a vicious circle that reinforces instability. The process generally can be described in four phases. Phases one through three can be quite rapid, while phase four can sometimes require decades or centuries to complete. Regardless of cause, the first phase involves the initiation of channel incision that results in the classic "waterfall", cascade or oversteepened riffle associated with the headcut itself as it erodes up-valley. If the incision doesn't follow the original channel's meander pattern, then this process generally results in a shortening of the channel length and consequent steepening of the gradient. Incisions caused by straight line features on the landscape (roads, ditches, trails, etc.) that run down valley often capture flow and initiate this process.

As headcuts deepen the channel, higher and higher flow volumes stay within the confines of the gully, rather than dissipating onto the floodplain. Thus, the second phase begins with greatly increased velocity and pressure on the stream bed. This contributes to the rapid deepening of the gully until an equilibrium is achieved between the erosive force of the captured flows, the channel gradient, and the resistance of the stream bed. Once this base-level equilibrium is achieved, the next phase begins in earnest. The third phase involves the lateral widening of the gully at the new base level. Two primary factors contribute to this widening process: 1) the increased stress of the confined streamflow directed into the high, un-vegetated banks, and concurrently; 2) the greatly increased sediment supply (from the eroding banks) being deposited in high-profile point bars and central bars. These two factors further focus stress at the toe of banks and terraces (Fig. 4.1), causing more bank erosion. Gully bank erosion is further exacerbated by groundwater flowing to the gully, creating a force that can dislodge large chunks of bank into the gully. While the capacity of the channel to transport sediment is increased because of the confined flows, this increase frequently does not compensate for the increased load.

The fourth phase is a more gradual evolution of a functional channel and floodplain within the widened gully (Fig. 4.2). This process is often transitory in the beginning. Significant recovery can be observed after a period of favorable streamflows, after which a major flood can completely re-arrange the channel, obliterating vegetation and habitat, as well as further widening the gully. Then a new phase of recovery will begin. Depending on specific site and watershed influences this recovery/response process may occur many times over an extended period. Ultimately, however, the system tends toward equilibrium, and will achieve the width necessary to absorb and survive the stresses of major floods at this lower elevation.

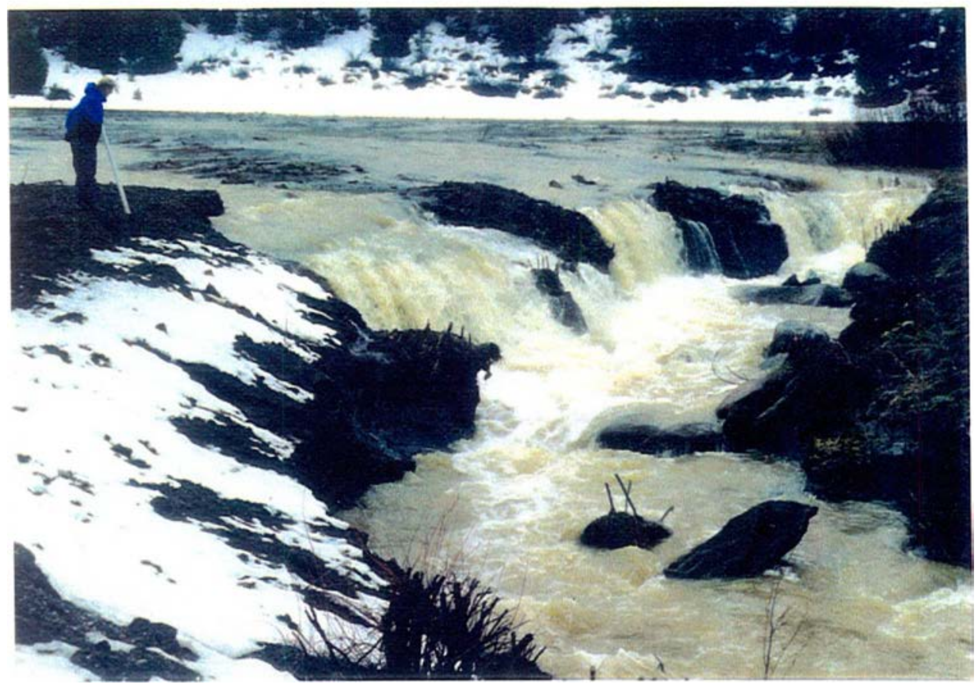
Fig. 4.1 Chunks of streambank fall into Greenhorn Creek as high flows eat away at the bank toe of the entrenched channel.

Fig. 4.2 The beginnings of a functioning floodplain are evident on one side of Last Chance Creek within its gully through Alkali Flat. Note the abandoned floodplain on the left terrace that is now covered in sagebnish.

Any treatment of headcuts requires a basic understanding of the hydraulic forces that are at work to achieve equilibrium. Assuming that the channel upstream of the headcut has a stable geometry and fully functional floodplain, the most obvious headcut feature is a nearly vertical waterfall and its attendant plunge pool. This waterfall may be as little as one foot. to as much as a dozen feet. in height. Generally. the more cohesive the valley alluvium, the more likely it is that the headcut will remain vertical as it moves headward. The movement of these headcuts can be steady, or occur sporadically with years of no movement and then unpredictably move hundreds of feet in a season. Headcuts can also be expressed in less cohesive material as a drastically oversteepened gradient (cascades. multiple small nickpoints. etc.) in a short stream reach. These generally move quickly through a reach because of the higher erodibility of the uncohesive material.

A headcut should generally be considered as the interface between a higher upstream pool of surface/subsurface water and a significantly lower downstream pool. The elevation difference between the two is the hydraulic head. The greater the head. the greater the pressure. This pressure is exerted in vertical, longitudinal and lateral directions. relentlessly. The most obvious point of pressure is exhibited in the surface flow cascade or waterfall and plunge pool associated with the defined channel. However. significant water flow and pressure is exerted by the emergence of groundwater flow in the face of the headcut and gully walls (see Fig. 3.11). Additional. episodic pressure is exerted by the entry of sheeting flood flows from the floodplain down onto the headcut and into the gully. often far down-valley from the active headcut face (Fig 4.3). The combination of varying hydraulic pressures. alluvium characteristics, and vegetation conversion associated with the lowered water table. all contribute to the complex behavior of headcuts. Ultimately. many headcut treatments, aside from total gully and headcut obliteration. fail. In spite of this. we are compelled to stabilize these features. at least temporarily.

Fig. 4.3 The Poplar Creek headcut treatment project is lost in the 1997 flood as flows from the floodplain plunge down the gully walls. This photo is taken from approximately the same location as Figure 1.4.



Techniques Step-pool Treatment

One technique the CRM has implemented for in situ headcut treatment is the construction of an A or B stream type step-pool channel. This is particularly effective where fish passage is an objective. This technique takes the nearly instantaneous release of energy present at a waterfall and dissipates it incrementally over a much longer reach of channel. This treatment consists of a geomorphically determined interval of six-inch steps and associated pools, over hundreds of feet. The steps can be rock, whole tree or a combination of both, incorporated with a roughness component of mature willow or alder transplants. This concept has worked well in diffusing the majority of hydraulic pressures and providing effective fish passage.

The main limitation of this technique is the lack of adequate floodplain in the descending step/pool reach and the re-entry of flood flows back into the gully at some point downstream. The re-entry problem is the most difficult to address, as major floods can move down-valley hundreds of feet beyond the headcut treatment area and initiate a new headcut as they fall into the gully. These new headcuts can move very fast, as the vegetation has often been weakened by the lowered water table. Unfortunately, we have observed this process numerous times. In spite of our best and strongest treatments, we have seen our structures abandoned. Because of this, the CRM now uses this type of treatment in areas where the natural landform or project design will direct flows over the step-pool system at all stages. Such an approach was successful at Dolly Creek (Fig 4.4). Additionally, in natural settings, these stream types require an input of coarse sediment to maintain them. No such source exists at the bottom of these alluvial landscapes. It is therefore imperative that oversized material be used as a "framework" for each step and at each stress point.

There are many "standard" headcut treatments in use today, such as check dams, or sloping the face and laying in fabric and rock. These and similar treatments date back to the 1930's in the Feather River watershed as resource professionals recognized the seriousness of these disturbances. Some of these treatments are still evident and functioning. However, the vast majority were unsuccessful in halting this persistent and pernicious process. These failures were not attributable to 'weak' structures, but because they do not address the underlying hydraulic discontinuity between the static hydraulic elevation of the entrenched gully and the higher hydraulic elevation above the headcut. We have found that the best treatment for headcuts and gullying is elimination of the gully, as described in Section 3.

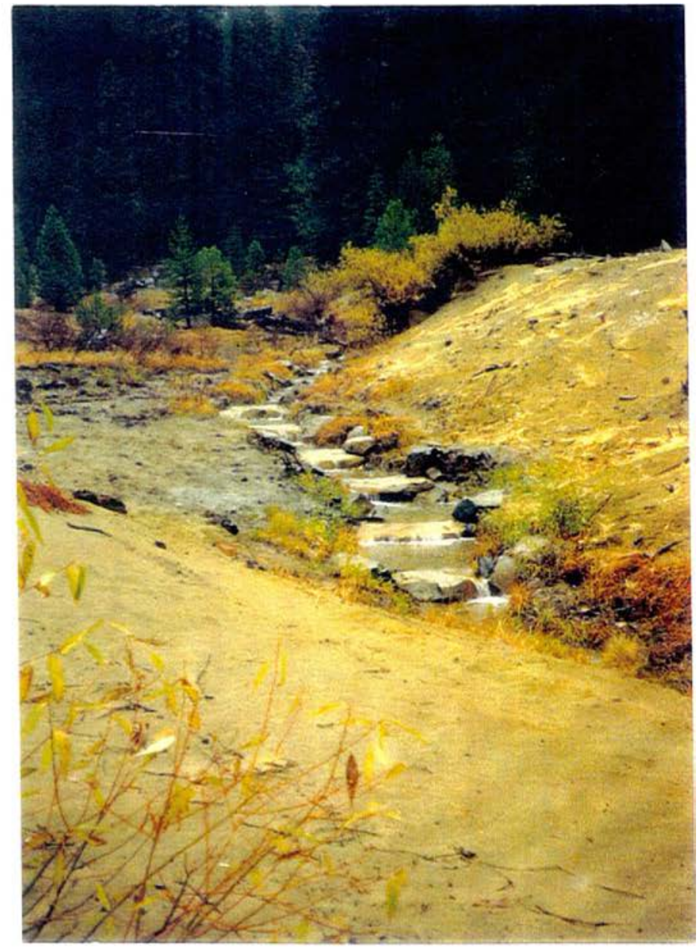
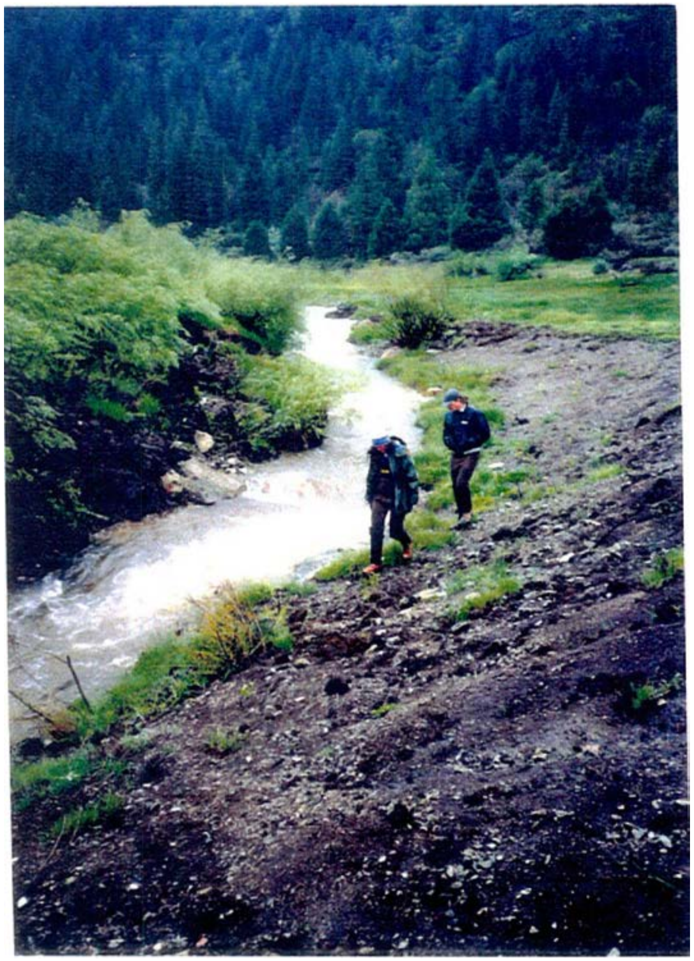


Fig. 4.4 A headcut step-pool treatment was constructed in 1994 on Dolly Creek as part of the Walker Mine Tailings Rehabilitation Project. The photo on the left was taken after the 1997 flood. Notice how the wide floodplain at the upstream end narrows down, thus directing flood flows through the steps and pools.

Section 5 - Monitoring & Evaluation

Most of the information presented in this booklet has been gathered from years of extensive project monitoring and evaluation. Despite the known value of project monitoring, we still find it to be one of the most challenging tasks to fund. Effective monitoring regimes for projects require a long-term commitment. And while our funding comes from a variety of sources. they are all short-term. As funding comes and goes. we've found that our organizational structure of twenty-plus signatory members, has helped keep our commitment to monitoring. This means that our monitoring programs tend to have two phases: the first is funded. and the second mostly isn't.

Most of our project funders require and fund some level of project effectiveness monitoring. The first phase of monitoring is thus project-funded, and provides important pre-project data, as well as immediate post-project data. The second phase of monitoring is where the strengths of a CRM are apparent. One of our strengths is that we are able to access resources from our CRM partner agencies. As restorationists from many disciplines, we want to know how our projects affect different physical and biological processes. As a partner in a CRM project. agencies with technical staff are able to fund and support such work, and include it in their own list of accomplishments. Another strength of groups such as the Feather River CRM, is that we are place-based. We never leave" our projects because we live in the watershed. Even though expensive data-oriented monitoring may not be funded, projects completed over a decade ago still receive casual monitoring visits, especially after high flow events.



Why 'Monitor?

All of our project monitoring has three main objectives:

The first objective answers the question- Did it work? Numbers and pictures work well to answer this question. We need to demonstrate to grantors, sponsors, landowners and interested public whether or not the project met its goal. The goal of most of our projects is to reduce erosion by improving the long-term stability of an area. Grantors usually fund this objective, but again, only in the short term. During pre-project design data collection, key areas are benchmarked so that the same data can be collected immediately post-project. Cross-sections easily display the project's changes on the landscape. Groundwater levels usually respond quickly as well, but it is important to get the wells in early, as soon as the project is funded, in order to get good pre-project data. Photos, of course, are invaluable for displaying the impact of a project. Good ground-level photos can show a lot, but we have also found that hiring a photographer and a private plane is well worth the expense, especially when they can fly over several project areas on one trip.

The second objective answers the question- How well is it working? This is more of a qualitative question, and is best answered by getting project participants, and any other interested party, out there together to look at and discuss the project as it changes over time and through weather events. The key individuals who should provide the most intensive, frequent monitoring are the project designers and those involved in construction. These are the individuals who have the most to gain for use in future projects. They are also most familiar with the details of how each component was constructed and how the project as a whole is integrated into a functional system. It is best to get everyone's involvement, as this objective also helps identify the potential need for post-project maintenance or intervention. It is best to get at least one or two group meetings on the ground, and get consensus on the project's success before permits and funding expire.

The third objective answers the question- Now what? It is mostly answered by the vegetation's response to a project. The goal of most of our projects is long-term stability, however, most of our projects also involve major ground-disturbance. This question addresses the short-term recovery of the system, and long-term prevention of future degradation. It is both qualitative and quantitative, as both numbers and participants collaborate to provide the landowner and the CRM with information for use in developing or modifying short- and long-term management decisions. While our projects address erosion sources, another benefit usually is restored productivity of riparian areas. Achieving a new balance for managing both short- and long-term productivity is an integral part of our projects. Without some agreement on post-project management for long-term stability, we don't even start.

What to monitor

Following is a list of parameters used by the CRM for quantitative project monitoring. All, or some combination of these, are used, depending on available resources and project objectives. We have found the parameters listed in bold to be the best indicators of project effectiveness, even for short term monitoring. Also listed is the CRM partner usually responsible for monitoring that parameter.

Hydrologic and Geomorphic - (Plumas **NF** or Plumas Corp.)	**groundwater level** **surface flows** **sediment supply** **channel cross-section** **channel profile**
Vegetation- (NRCS or Plumas Corp)	species or family diversity cover
Wildlife, Fisheries, and Macroinvertebrates- (DWR or CDF&G)	species abundance diversity
Water quality (DWR)	temperature
Overall visible trends (Plumas NF or Plumas Corp.)	photo monitoring

Following is a list of monitoring intervals we strive to achieve for each parameter. They appear to be the minimum short- to medium-term measurement periods to determine project effectiveness. All require pie-project data.

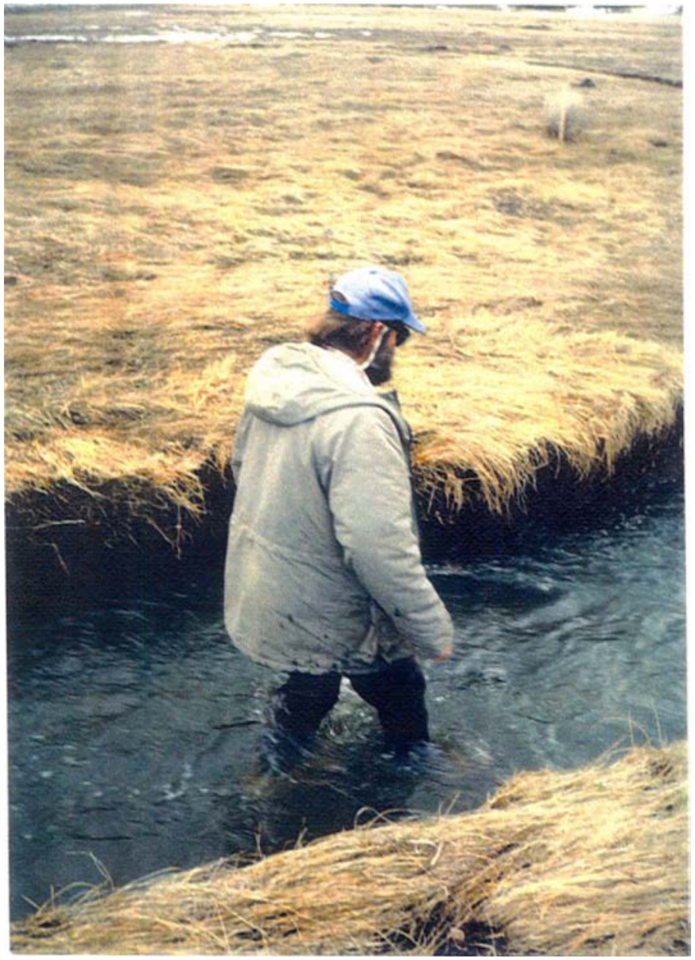
Hydrology- monthly for 5 years
Channel- immediate post-project, then after flood events
Vegetation- annually for 2-3 years, then every 5 years
Wildlife- every 2 years
Fisheries & Macros- every 5 years
Photo- annually or seasonally for **10** years

We are striving to improve our monitoring techniques. Lack of funding has forced us to whittle our monitoring programs down to those that are most informative with the least amount of time and effort. We are now beginning to tie some biological and physical parameters together in the hopes that one can replace the other. We have found that our groundwater monitoring wells have provided dramatic graphical results of pre- versus post-project conditions. However, that requires well installation and monthly readings, not to mention the fact that the well will remain on the landscape long after its usefulness is over.

Several current meadow projects (Clarks Creek, Last Chance Creek and Hosselkus Creek) have vegetation monitoring transects tied to groundwater monitoring wells that are located on permanent, surveyed cross-sections. We hope that tying the vegetation monitoring to the well monitoring will eventually preclude the use of the wells. Monitoring wells can also be used as photo points. This provides a long-term picture of physical, hydrologic and biologic response to restoring the shallow groundwater elevation in one or more spatial lines across a meadow. Carman Creek, implemented by the neighboring Sierra Valley CRM, is being monitored for the above, as well as the response of neo-tropical migrant birds, bats and insects to restored hydrology.

In addition to individual project monitoring, we are interested in the cumulative impact of our projects on our watershed as a whole. One of our CRM members, the Northern District of the Central Valley Regional Water Quality Control Board has funded two cycles of a watershed-wide monitoring program. Twenty strategically tiered sites throughout the watershed are monitored every two years using standard protocols with permanent cross-sections, bank and bed transects, and longitudinal surveys. Water quality, fish populations, and macroinvertebrates are also monitored at these sites. We also have eight continuous recording stations throughout the watershed that monitor temperature and flow, as well as turbidity on an experimental basis. At this writing, we are still in the process of collecting baseline data, however we are hopeful that the impacts of our projects and other improved land management practices will eventually result in positive, measurable trends in the hydrograph, water temperature, turbidity, and other physical attributes.

On a final note, another aspect of our monitoring program, which we are in the process of developing and improving, is our data-sharing capacity. The Feather River CRM has a website on which we have project pages, as well as a map which can be used to pinpoint sites in the watershed, and access site-specific data. While still in the development stages, we are looking forward to working more with the web and the interne to provide a better forum for sharing data between all of our CRM members as well as other interested parties.



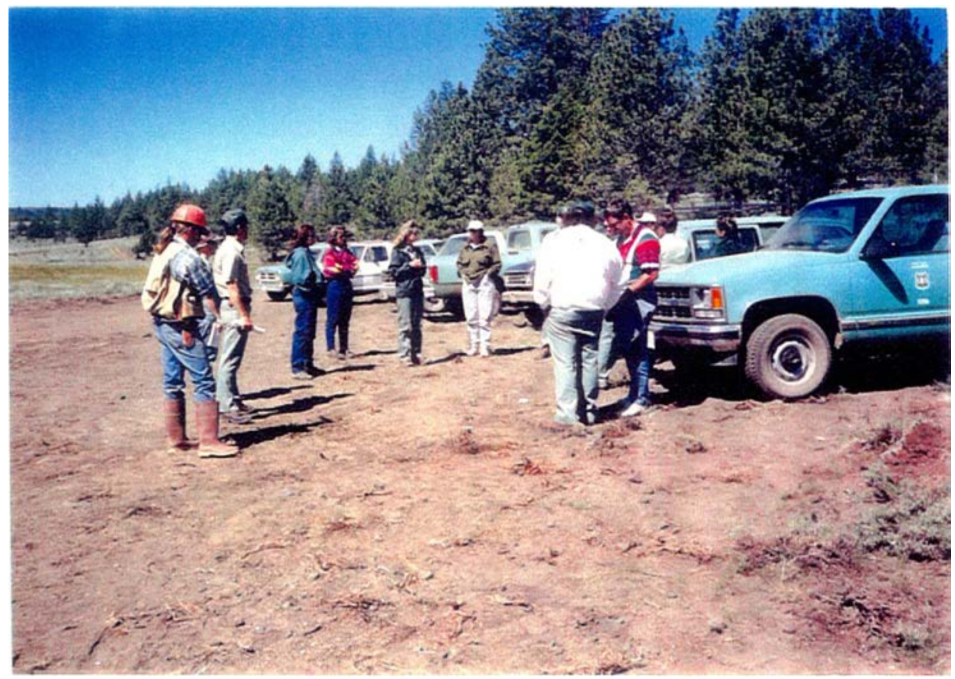


Fig. 5.1 (above) Construction Supervisor. Jim Wilcox visits the Bi 2 Flat E channel after the first winter.
Fig. 5.2 (above right) Hydrologist Terry Benoit digs under the snow at Haskins Creek to observe the project's response to a high flow event.
Fig. 5.3 (right) Members of the CRM visit the Big Flat project after construction for evaluation and discussion.

GLOSSARY

Backwater effect	The effects caused when water is turned back in its course by an obstruction, constriction, log jam, etc., usually manifesting itself as deposition of sediment upstream of the obstruction and scouring of the channel bed downstream of the obstruction.
Bedload	That component of a stream channel sediment supply that slides or bounces (saltates) along the bed during high flows. Generally this is the dominant channel forming/maintaining material.
Biotechnical restoration	In river restoration work, it is the use of naturally occurring vegetation to construct "soft" structures that will stabilize erosible stream banks.
Constriction	A constructed (or natural) feature that reduces the cross-sectional geometry of a stream channel.
Discharge	Quantification of the amount of water flowing in a stream channel. Measured in cubic feet per second (cfs).
Entrenchment	The natural or artificial process of a stream channel disconnecting from its floodplain. Canyon stream channels are naturally entrenched by the landscape.
Entrenchment ratio	Determined by dividing the available floodplain width by the bankfull channel width.
Floodplain	A wide, in relation to channel size, flat depositional feature adjacent to a stream channel that receives frequent (1- 2 years) overbank flows.
Fluvial	Formed by flowing water.
Geometry	Describes the physical configuration of the landscape feature, e.g. stream channel or gully.
Geonzorphic restoration	In river restoration work, it is the application of the morphologic and morphometric attributes found in natural, properly functioning stream systems to rehabilitate degraded systems in like landscape settings.
Headcut	A nearly instantaneous, radical change in water elevation typically represented by the presence of a waterfall or steep cascade that is eroding upstream.

Mobile boundary	Describes river bed material that is frequently moved and re-deposited by the action of water flow.
Morphology	Characterizes the landscape feature through a descriptive term, e.g., a riffle and a pool.
Morphometry	Describes the physical dimensions of a landscape feature through measurements, e.g., the width and depth of a stream channel.
Radius of curvature	Quantifies the degree of curvature in a meander.
Revetment	A facing (as of stone, rootwads, etc.) to sustain a stream bank.
Sinuosity	Describes the relative meandering of a river channel. Is determined by dividing the length of the channel by the straight-line length of the valley.
Stage	The elevation of the water in a stream channel. Typically determined with a ruled metal plate (staff gage) mounted in the water. Frequently used to denote a particular condition i.e. bankfull stage, flood stage.
Stream power	The rate at which work (kinetic energy) is done by the movement of water within a stream channel, usually calculated as streamflow velocity times shear stress.
Shear stress	In fluvial mechanics, it is the force exerted on the bed and banks of a stream channel by the movement of water and sediment. The force exerted when one object pushes, pulls, presses against, or compresses another object. It is usually calculated as the weight of a column of water times the channel gradient.
Vane	A constructed (or natural) channel structure, made of rocks or a log, that diverts streamfiows away from a bank.
Vortex weir	A constructed (or natural) channel structure, usually made of rock, that converges streamflows into a pool.

REFERENCES

Federal Interagency Stream Restoration Group. 1998. Stream Corridor Restoration.

Rosgen, David. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado. (available from Wildland Hydrology Books 1481 Stevens Lane Rd. Pagosa Springs, CO 81147)

Schiechtl, H.M. and R. Stern. 1997. Water Bioengineering Techniques for Watercourse Bank and Shoreline Protection. Blackwell Science Ltd. London.