Post-Project Appraisal of a Channel Reconstruction on Cuneo Creek, California

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ABSTRACT

In this study a post-project appraisal was conducted for a channel reconstruction that was implemented on Cuneo Creek in Humboldt County, California. In 1991 a reach of lower Cuneo Creek was reconstructed into a sinuous meandering channel in an effort to develop a 'stable' configuration. The original design was based on a Rosgen stream classification scheme and called for a 5,200-foot reach to be constructed with 43 meander bends in a sinuous pattern. The actual reconstruction involved a reach of only 1,700-feet with 8 meander bends and less sinuosity than the original design. A 30-year flood in 1996 caused the creek to abandon and bury the constructed channel. I analyzed changes in channel configuration shown in historical aerial photographs and found that the original channel design, and to a lesser extent the implemented channel form, were inconsistent with the historical forms. The basis of the project design was poorly documented, but was likely based on the 'bankfull discharge' concept using a 1.5-year flood. However, in Mediterranean-climate streams with episodic flow regimes, channel-forming flows are likely to be larger (longer recurrence interval), and cross-sections surveyed in the 1980's support this notion that large floods are the channel-forming events. The only evidence of the project I found in the field was a few remnants of vortex rock weirs and debris detention structures. This study adds to the growing library of literature casting doubt on the applicability of stream classification systems and bankfull discharge in episodic high-energy stream systems.

INTRODUCTION

Although the popularity of stream restoration projects in California has increased dramatically over the past two decades, the knowledge base gained from these projects has not increased in a commensurate fashion due to the lack of funding and interest in conducting post-project evaluations (Kondolf 1995a). Additionally, much attention has been focused on in-stream restoration techniques and not on catchment-scale approaches that incorporate a geomorphologic understanding of the watershed conditions (Sear 1994). When 161 similar aquatic enhancement projects were evaluated in the nearby states of Oregon and Washington, results indicated that nearly two-thirds of the projects were damaged or ineffective (Frissel and Nawa 1992). In a region with dramatically diverse geomorphology, it is of utmost importance to conduct adequate pre and post-project monitoring for two reasons: (1) To acknowledge the uncertainty in geomorphologic manipulation and attempt to gain an understanding about which techniques are proven to be effective in specific situations; and (2) To study long-term performance of a restoration project and determine whether stated goals were met.

In this study I evaluated a channel reconstruction project that occurred on Cuneo Creek in northern California. In 1991 approximately 1,700-feet of nearly sinuous meandering channel was created in an attempt to develop a 'stable' channel configuration in a highly dynamic watershed. During a 30-year flow in 1996, the creek abandoned the sinuous channel in favor of a different path. Channel abandonment has been documented in a number of other similar channel reconstruction projects conducted in the United States that have attempted to develop a stable channel configuration using a stream classification scheme (Kondolf et al 2001, Smith 1997). The purpose of this study was to evaluate the proposed and constructed channel configurations by first obtaining an understanding of the geomorphologic processes operating within the watershed. To adequately understand the geomorphic processes, I reviewed a variety of historical photographs and data, reviewed project documents, conducted a flood frequency analysis, interviewed professionals familiar with the basin, conducted a site visit to document any features remaining from the project, and visited surrounding areas.

SITE DESCRIPTION

Cuneo Creek drains 10.8 km^2 in the Coast Ranges of northern California, approximately 400 km north of San Francisco, and is a tributary to Bull Creek, and thence the South Fork Eel River (Figure 1). The Cuneo Creek basin experiences a Mediterranean climate with cool, wet winters and warm, dry summers. Average annual precipitation ranges from 78 inches in lower elevations and 110 inches in upper elevations, which primarily occurs as rainfall from October to April (Rantz 1969).

The geology within the Cuneo Creek watershed consists of easily erodible Yager and Franciscan Formations, locally composed of mudstone, shale, siltstone, greywacke and other conglomerates (Spittler 1982). Tectonic deformation of the area has resulted in northwest trending structures and steep hillslopes, which further accentuate erosion potential.

In 1946, the introduction of an annual tax on standing timber and the post World War II building boom encouraged the harvesting of Douglas fir, the predominant species of the watershed. Logging techniques included clearcutting and select cutting with tractor yarding, which by the mid-1960's denuded nearly all hillsides within the basin and created a maze of skid trails across slopes (Figure 2). Much of the vegetation that was not logged was consumed by severe wildfires that occurred in the basin in the late 1950's (Gilligan, 1966).

The basin's climate and geology, combined with the effects of logging in the 1950's and '60's, created a high susceptibility to erosion. High-intensity storms hit the region in 1955 and 1964 and caused extensive erosion in the headwaters of Cuneo Creek and equally impressive channel widening and aggradation in lower Cuneo Creek as a result of the sediment deposition. Aerial photographs clearly illustrate the change in channel morphology during this period (Figure 3). Since 1955 the Cuneo Creek basin has been contributing large amounts of sediment to Bull Creek, which has led to destruction rare old-growth redwood groves through channel aggradation in the Bull Creek flats. Approximately 5 meters of sediment was deposited on top of the floodplain of lower Cuneo Creek in 1955 and another 5 meters was deposited in 1964, each time burying the bridge spanning Cuneo Creek (Figure 4). In the late 1960’s, the Humboldt Redwoods State Park (Park) purchased all of the land encompassing the Bull Creek watershed and began restoration efforts to protect the large redwood trees growing in lower Bull Creek. The South Fork of Cuneo Creek is currently still plagued with active landslides, such as the Devil’s Elbow landslide, which contribute large amounts of sediment to the basin during significant rain events (Short 1993). The objective of the channel reconstruction project in 1991 was to reduce sediment transport to Bull Creek flats in an effort to protect the old growth redwood groves (US ACE Permit).

METHODS

I conducted the study in the following five phases: (1) Reviewing aerial photographs and channel survey data to gain an understanding of the geomorphologic processes operating within the basin;(2) Reviewing project documents; (3) Evaluating the design of the proposed channel and actual channel that was constructed; (4) Conducting a flood frequency analysis; and, (5) Visiting the site to document existing conditions.

To understand the historical changes in channel configuration, I reviewed aerial photographs and survey data obtained from Bonnie Smith at the U.S. Forest Service Redwood Sciences Laboratory. Aerial photographs were available from 1942, 1947, 1954, 1956, 1960, 1963-66, 1974, 1984, 1988, 1993, and 1996-98. The survey data was collected at ten cross-sections along lower Cuneo Creek in 1976, 1982, 1983, 1985, 1986, 1998, and 2003. No survey data were available during the time period between 1991 when the channel reconstruction was completed and 1996 when the creek abandoned the constructed channel. However, I analyzed cross-sectional data and streamflow data from the mid-1980’s to determine the approximate flood frequency that caused a specific channel migration.

To determine the project objectives, design specifications, and motives for altering the original design, I reviewed all documents related to the project that were available from the from the Park office in Eureka, California. The documents included: (1) Application for US Army

Corps of Engineers Clean Water Act Section 404 Permit; (2) Portions of the Bull Creek Watershed Restoration Plan (Rosgen 1991); (3) Lower Cuneo Channel Dimensions Report of Findings (Burnson 1992); (4) Post-project letter from design consultant in response to Channel Dimensions Report of Findings (Rosgen 1992); and, (5) Proposed Bank Stabilization for Eel River, California (Rosgen 1987).

To evaluate the design of the channel reconstruction I compared the proposed and the constructed channel configurations with historical channel configurations observed over the past 40 years. Additionally, any differences between the proposed and constructed channels that may have influenced channel stability were noted.

To understand the rainfall conditions and flooding frequency at the site I compiled annual peak flows from the U.S. Geological Survey stream gauge on Bull Creek (USGS Station 11476600), located about 4 kilometers downstream of the confluence of Cuneo Creek and Bull Creek, and then conducted a flood frequency analysis (Dunne and Leopold 1978). Daily peak streamflow data was available from October 1, 1960 through September 7, 2002 and was used to determine the frequency of floods of similar magnitude to that observed during the winter of 1996-97, in which Cuneo Creek abandoned the constructed channel.

On October 25-26, 2003 a colleague and I visited the site to document the current status of the channel and photograph any evidence of the channel reconstruction project such as channel bank revetments or vortex rock weirs. We also hiked into the upper reaches of the South Fork of Cuneo Creek and documented the largest landslide (the Devil's Elbow slide) within the basin.

RESULTS

Historical Data Review

A review of historical aerial photographs dated between 1942 and 1998 show that the lower reach of Cuneo Creek has consistently favored a slightly meandering and occasionally braided channel since severe channel aggradation occurred in 1955 and 1964. It is also evident from the photographs that the channel configuration and position have been consistently changing over the years (Figure 5).

Using cross sectional data and aerial photographs from previous years, I calculated the approximate flood frequency that caused a channel migration observed in the mid-1980's. Cross-sections along transect *xs25+46*, surveyed by Darci Short in 1983 and 1986 show a thalweg migration of approximately 40 feet to the right looking downstream (Figure 6). Assuming this migration resulted from the high flow observed in February of 1986, the channel-forming flood that caused the migration was estimated to have a recurrence interval of about 6 years. Based on a combination of the photographic evidence, cross-sectional surveys and streamflow data, it is evident that channel form in Cuneo Creek is influenced by floods with frequencies greater than the common 'bankfull' approximation of 1.5 years. Unfortunately, consistent cross-sectional survey data were not available to conduct a similar analysis within the lifetime of the reconstructed channel (1991-1996).

Review of Project Documents

The document review yielded insight into the history of the project, project objectives, and the concerns regarding differences between the proposed and constructed channels. The Park submitted a 12-page application to the US Army Corps of Engineers on June 4, 1991 which stated that restoration actions necessary for the Bull Creek watershed included: protecting old growth trees in Bull Creek flats; reducing accelerated erosion from roads, landslides, and old skid trails, and; improving the fluvial geomorphology, cold water habitat and water quality of the basin. According to the application, the Cuneo channel reconstruction was focused on reducing sediment transport through Bull Creek.

A 5-page portion of the Bull Creek Watershed Restoration Plan (Rosgen 1991) was reviewed that was attached to a separate document, the Lower Cuneo Channel Dimensions Report of Findings (Burnson 1992). The portion of the Restoration Plan that was reviewed included design specifications for the proposed channel including bankfull width, mean bankfull depth, water surface slope, meander wavelength, radius of curvature, number of bends, and stream length to be restored. The entire Bull Creek Watershed Restoration Plan was not available at the Park office and could not be located by various Park personnel; however, it may have contained more specific information discussing the origin of the design specifications.

After construction of the project, the design consultant submitted a letter to the Park that that I reviewed indicating concern about the potential instability of the channel due to inconsistencies between the constructed channel and the design specifications. In response to this letter, David Burnson, an Engineering Geologist for the Park, prepared a Report of Findings document intended to illustrate that although the proposed and constructed channels were different in form and design, the hydraulic characteristics of the constructed channel were consistent with the specifications.

Design Evaluation

The original design for the channel reconstruction involved a reach of 5,200 feet and was to construct a total of 43 sinuous meander bends (Figure 7). Revetments composed of logs, root boles, and rock were proposed to stabilize the outside of each meander bend and the cross-over reaches were to be stabilized using a series of two “vortex rock weirs” (grade control structures) upstream and two downstream of each bend (Rosgen 1992, also in Figure 7). Detailed documentation discussing the geomorphic basis for the channel design was not available, but the project appeared to be a straightforward application of the Rosgen classification scheme (C3-type channel) based on an estimate of the bankfull discharge (usually $Q_{1.5}$). These projects typically involve two steps: (1) Determining the ‘proper’ stream type using data collected on site and expectations of transitions from one type to another; and, (2) Using heavy equipment to construct ‘proper’ channel configuration with the expectation that it will be inherently stable (Kondolf et. al 2003).

In comparison with historical channel configurations, as seen in aerial photographs, the proposed sinuous channel is drastically inconsistent with the form that has been preferred by the creek for the past 40 years. No evidence was presented supporting that such a channel would naturally occur in the watershed, had historically occurred, or that such a channel could be expected to be stable in such a dynamic environment. Additionally, the channel was designed using the bankfull concept, which may not be appropriate for stream channels that tend to be dominated by more infrequent floods and periodic disturbance, as is common in a Mediterranean climate (Kondolf et. al 2003).

The channel actually constructed involved a reach of only 1,700 feet and included only 8 meander bends (Figure 8). David Burnson modified the proposed design specifications after field observations indicated that significant recovery had occurred in the upper portion of project reach (Burnson 1992). Modifications of the proposed C3-type channel design led to construction of a channel that was slightly less sinuous and meandering and more closely resembled a B-3 configuration (Conversation with David Burnson 2003). The outside of the meander bends were stabilized with rock and log revetments as designed, but only one vortex rock weir was built along the cross-over reaches upstream and downstream of each bend. Surveys were conducted along certain transects after project completion and indicated that the channel was built within the tolerance limits of the design specifications (Burnson 1992). In addition to the channel reconstruction, low profile groins constructed of half-buried upright logs were constructed along the valley floor to buffer future debris flows.

Flood Frequency Analysis:

Annual peak flows (measured as momentary discharge) at the Bull Creek stream gauge from 1960-2002 varied between 173 cubic feet per second (cfs) to 7,830 cfs (Figure 9a). The 1996 flood that washed out the constructed channel was the highest momentary peak flow on record (7,830 cfs), even greater than the historic 1964 flood (6,520 cfs). By constructing a flood frequency plot (Figure 9b) a linear flood frequency curve was developed with the following equation:

$$Q_T = 2029.3Ln(T) + 1059.1, \quad R^2 = 0.9599$$

where Q_T is equal to the peak flow measured in cfs and T is recurrence interval measured in years (Dunne and Leopold 1978). Using this equation, I calculated the recurrence interval of the flood observed in 1996 flood to be approximately 30 years.

Site Visit (October 25-26, 2003):

During the field visit in October 2003, a colleague and I utilized aerial photographs to determine the approximate locations the meander bends that were constructed in 1991 and had washed out by 1996. We explored these areas for any structural evidence of the project and found only a few large boulders at two upstream locations that were potentially remnants from the bank revetments or vortex rock weirs (Figure 10). The majority of remnants that were observable were the debris flow structures that were constructed on the valley floor outside of the active channel (Figure 10E). During the field visit, we also inspected the Devil's Elbow landslide, the largest landslide in the basin that actively contributes large amounts of sediment during heavy rains to the South Fork of Cuneo Creek (Figure 11).

CONCLUSION

The geomorphic processes operating within a drainage basin most often dictate the natural channel configuration of any river or creek. In a dynamic watershed such as Cuneo Creek, with periods of intense rain, unstable slopes, active landslides, and highly erodible soils, it is hard to conceive that any channel re-configuration could be stable without addressing the overlying problems of erosion and sediment transport within the watershed. The classification system used to design the project predicted a single-thread sinuous meandering channel for the creek although there was no historical evidence that such a channel would be stable at this site. On the contrary, a review of historical photographs showed that the creek has preferred a slightly meandering and occasionally braided channel.

Although the constructed channel appears slightly more consistent with historical channel configurations than the proposed design, a geomorphic analysis would have shown that attempting to create a stable channel within this episodic high-energy system was of questionable merit. The channel reconstruction appeared to focus on fixing the symptom of a watershed problem (accelerated sediment transport), but did not address the overlying problem itself. A more holistic approach to restoration, acknowledging the geomorphic processes of the basin, likely would have focused more on decommissioning unused roads or stabilizing landslides before in-stream channel reconstruction was attempted.

In correspondence after construction of the channel, the design consultant raised concerns that the project would not be stable due to the as-built channel cross-over reaches having only one vortex rock weir, instead of two as designed (Rosgen 1992). However, since the flood of 1996 was the highest on record and active landslides were still occurring within the upper Cuneo Creek basin, it is plausible that the revetments and grade control structures were not eroded, but instead were buried in sediment brought down from active landslides. Additionally, the creek may have abandoned the channel as it cut through the largely unvegetated floodplain, which likely had a low frictional resistance and high overbank flow velocities leading to chute erosion across meander bends. This tendency has been observed in similar classification-based channel reconstruction projects such as the Deep Run project evaluated by Smith (1997), and was presumed to be the cause for failure of a project on Uvas Creek (Kondolf 2001). In combination, these studies are beginning to raise important questions regarding the use of the Rosgen classification system in the design of river and creek restoration projects.

Lastly, this study illustrates the inherent uncertainty associated with channel reconstruction and the importance collecting adequate pre- and post-project data as a mechanism to further the overall knowledge base of successful techniques. This trend has been observed in numerous restoration projects, where sponsoring agencies prefer to spend available funding on tangible construction projects rather than intangible monitoring and evaluation studies (Kondolf 1995a). Had the Park acknowledged the inherent uncertainty of the channel reconstruction project, or simply opted to evaluate whether the project goal of reducing sediment transport through Bull Creek was achieved, cross-sectional surveys of the preexisting transects could have been conducted. Analysis of pre-and post-project data may have yielded valuable information regarding successful and unsuccessful stream restoration techniques for similar areas (Kondolf 1995b).

ACKNOWLEDGMENTS

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LIST OF FIGURES:

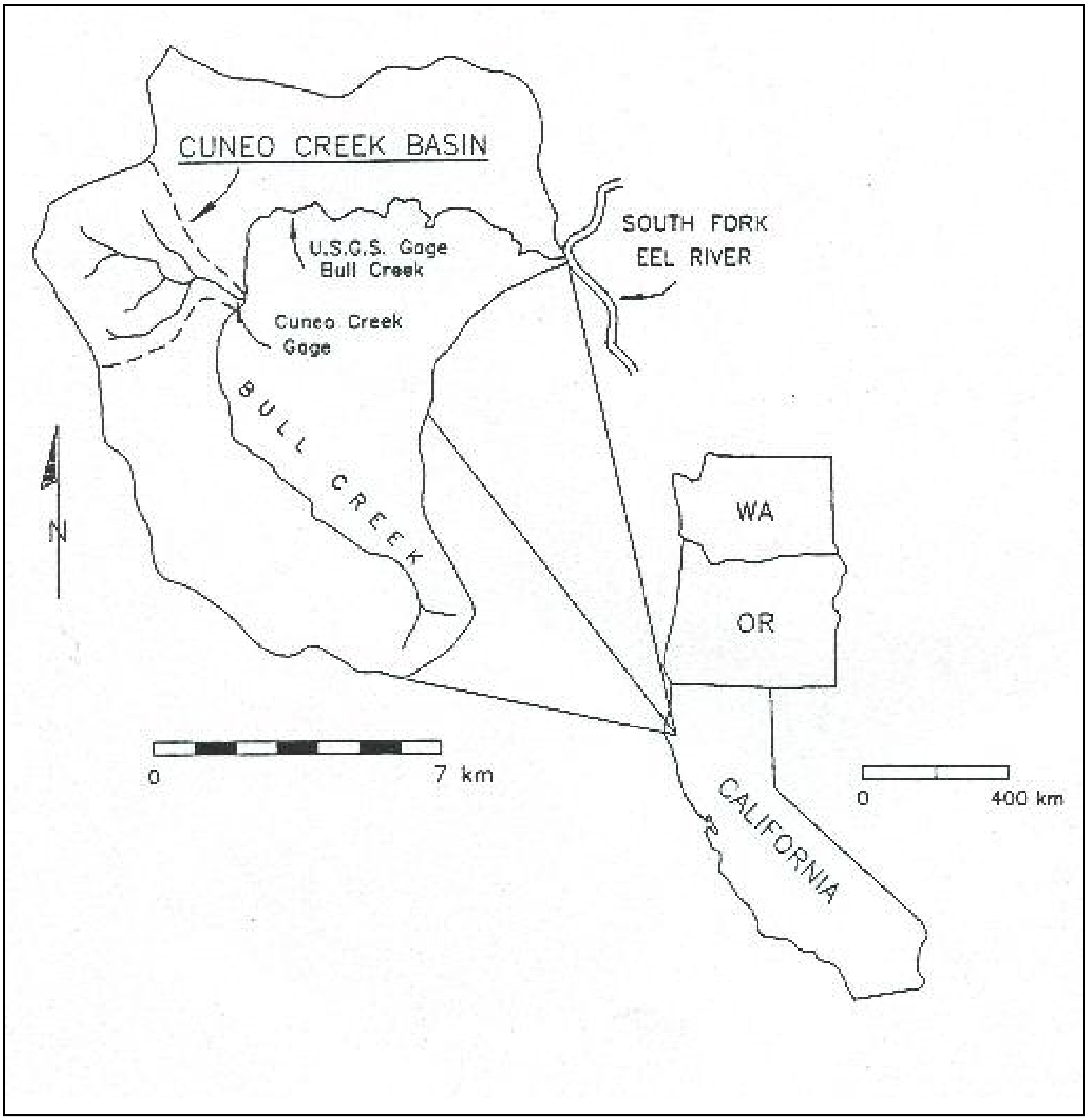


Figure 1: Location Map. Cuneo Creek is located in Humboldt County, California within the Bull Creek watershed, a tributary of the South Fork Eel River. (Short 1993)

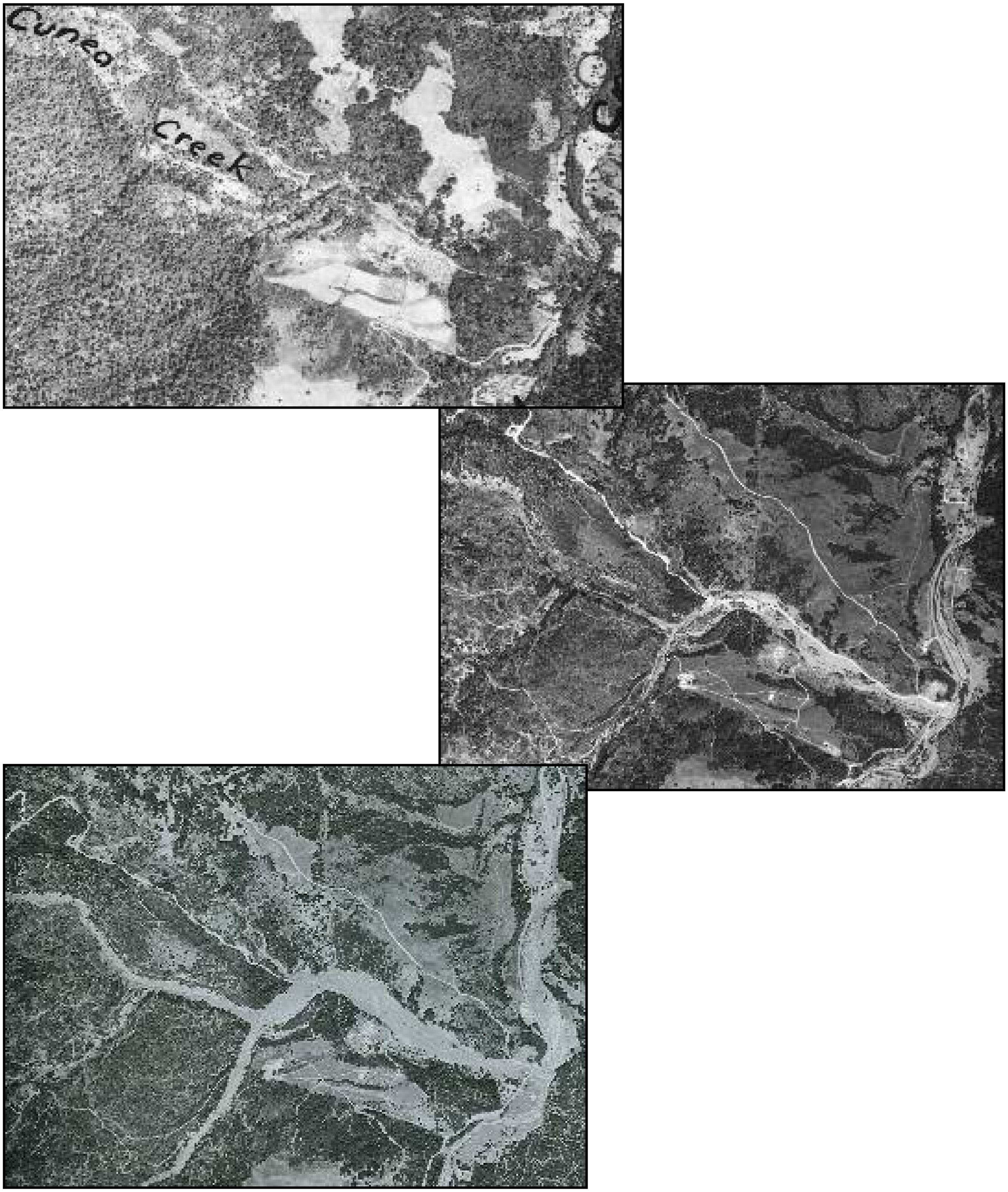
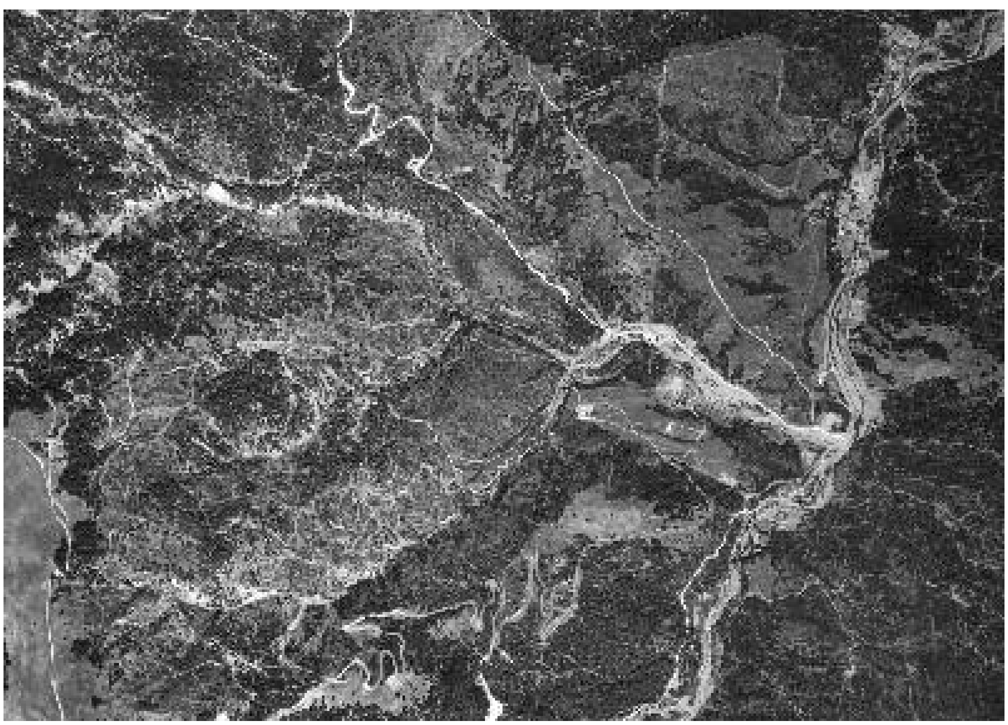


Figure 2: Changes in Cuneo Creek Channel Configuration (1942-1965). Upper photograph is from 1941 prior to extensive logging. Middle photograph is from 1964, after extensive logging and channel aggradation due to 1955 flood. Lower photograph is from 1965 after further logging and shows extreme channel aggradation due to 1964 flood.

a) 1947: Cuneo Creek watershed prior to extensive logging.



b) 1964: Cuneo Creek watershed after extensive logging.

Figure 3: Logging Impacts. a) The aerial photograph from 1947 shows pre-logging state of the watershed with a large amount of Douglas fir covering hillslopes. b) The aerial photograph from 1964 shows significant decrease in vegetative cover on the hillslopes due to logging. Also notice the maze of skid trails.

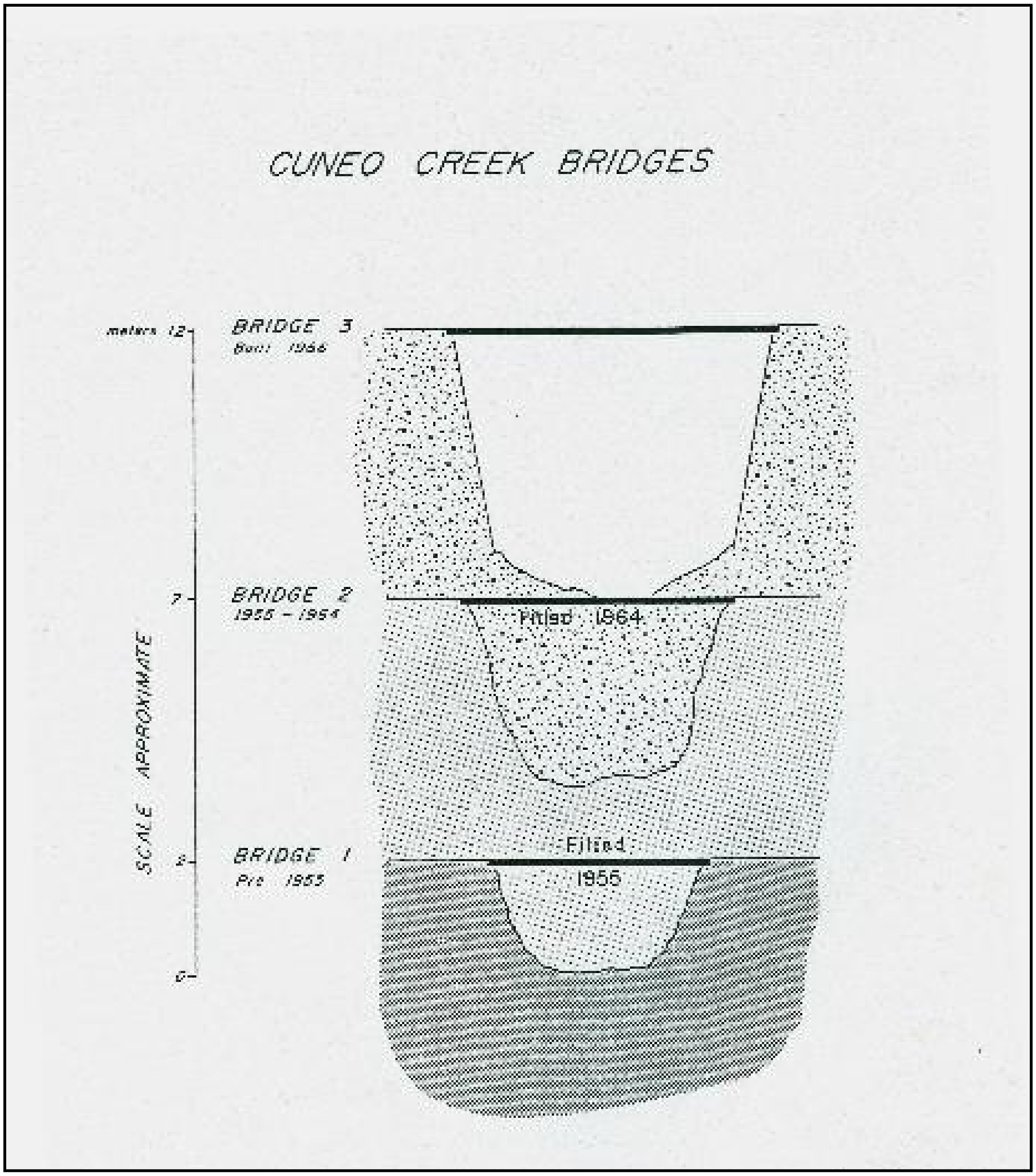


Figure 4: Cuneo Creek Bridges. Shows succession of three bridges over Cuneo Creek and approximate sediment deposited (Short 1993).

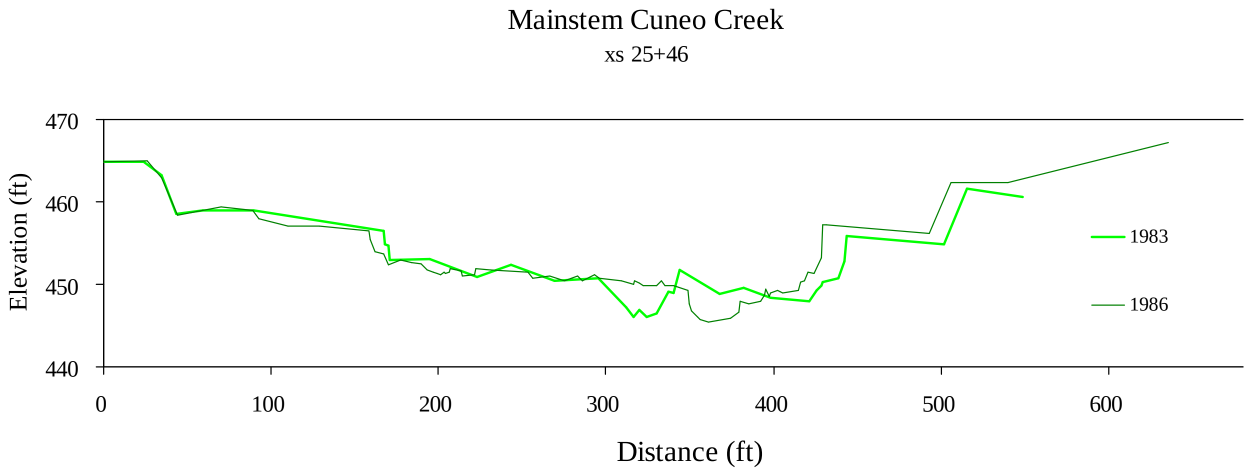
1984: Braided Active Channel

1996: Channel Reconstruction

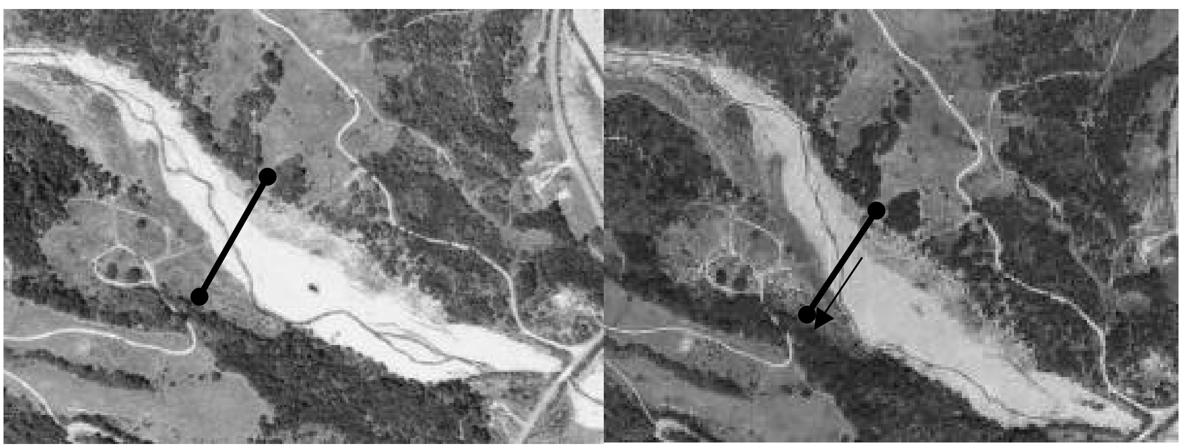
1997: Braided Active Channel

1998: Braided Active Channel

Figure 5: Changes in Active Channel Configuration.

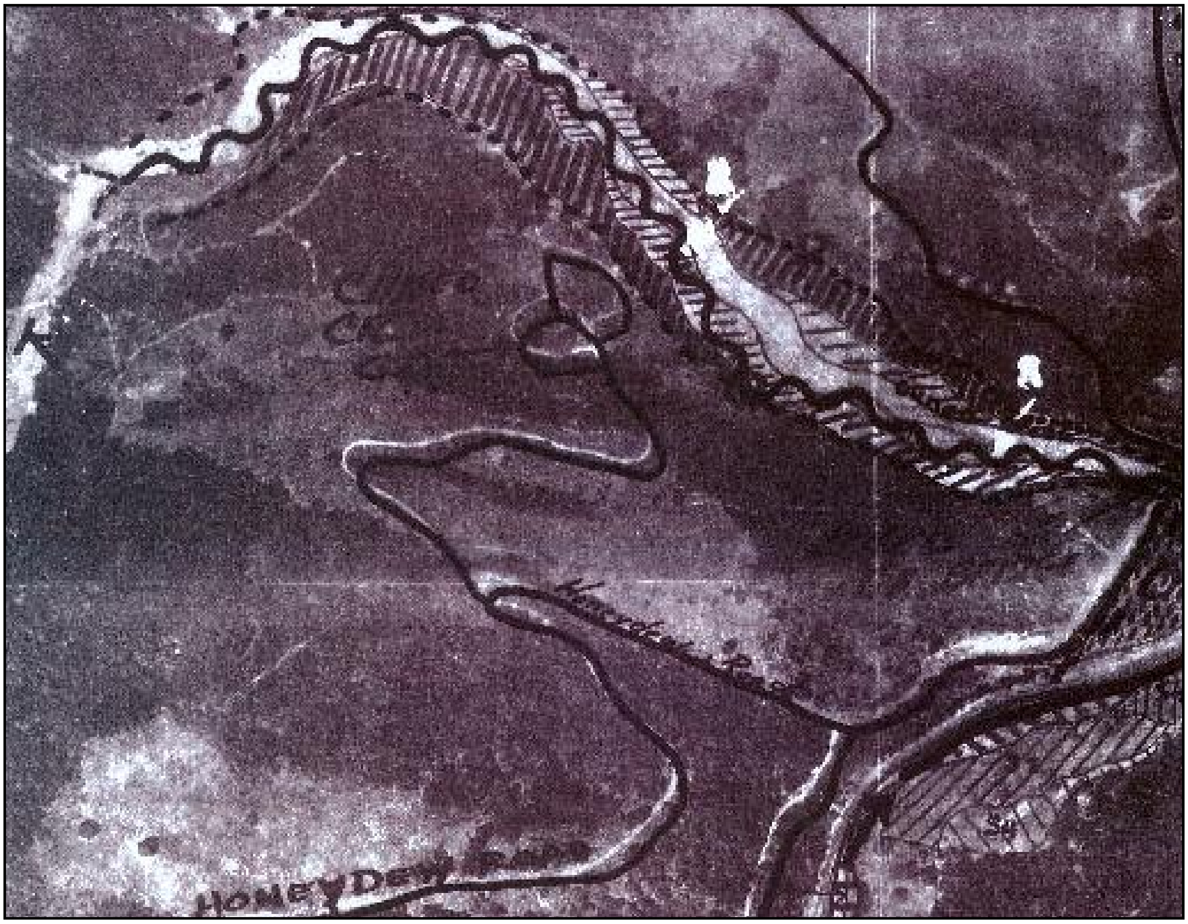


a) Cross sectional survey



b) Aerial photographs from 1984 (left) and 1988 (right) showing channel migration

Figure 6: Channel Migration in 1986. a) The cross-sectional survey shows a channel migration of approximately 40 feet towards the right bank between 1983 and 1986. (Survey conducted by Darci Short). b) Aerial photographs taken in 1984 and 1988 show a similar migration. Black line indicates location of cross section *xs25+46*, arrow in second photograph indicates direction of channel migration.



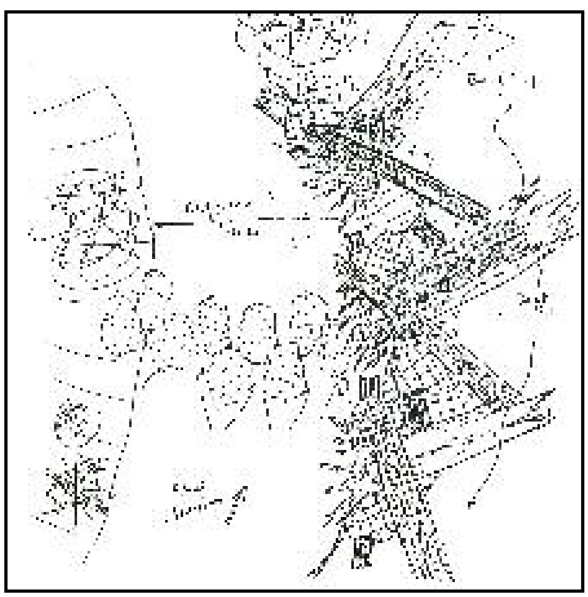
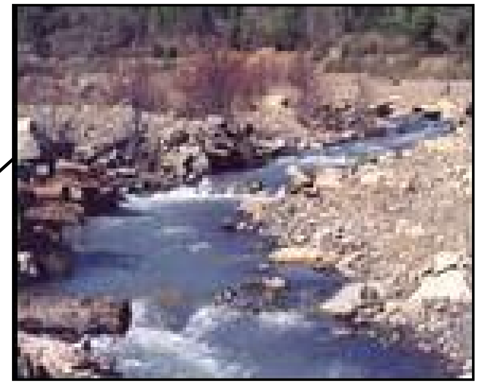


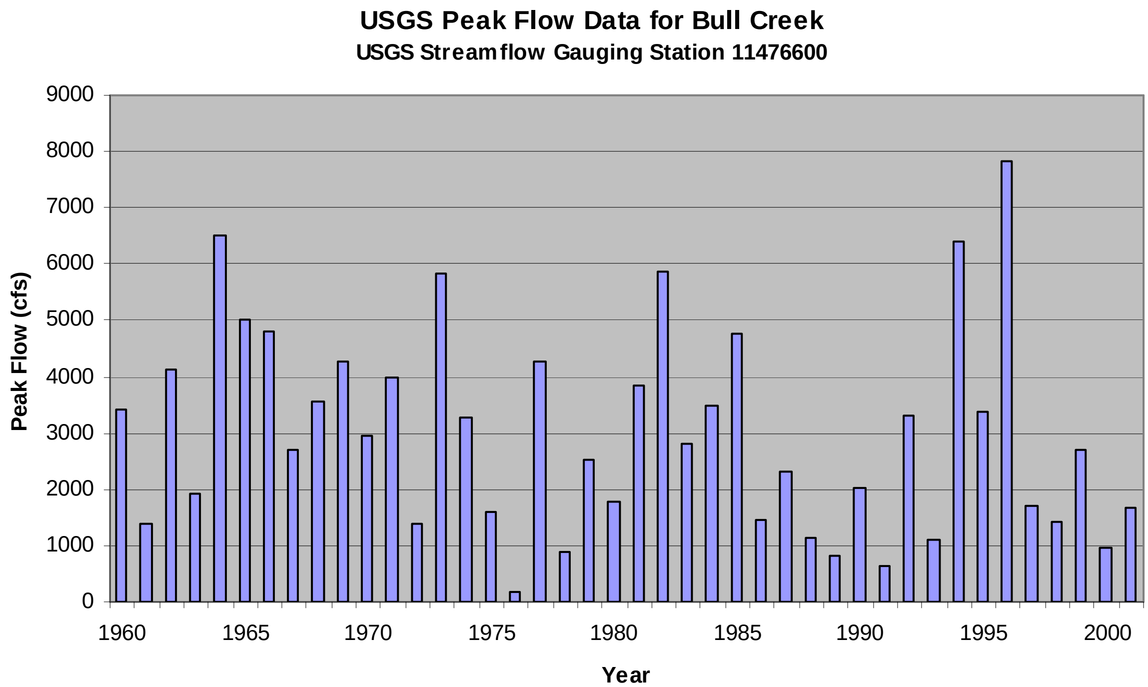
Figure 7: Sketch of Proposed Channel Design. The top sketch shows the proposed sinuous meandering channel along a reach of approximately 5200 feet with 43 bends. The bottom sketch illustrates the proposed bank revetment structure and grade control structures.

a) Constructed Channel

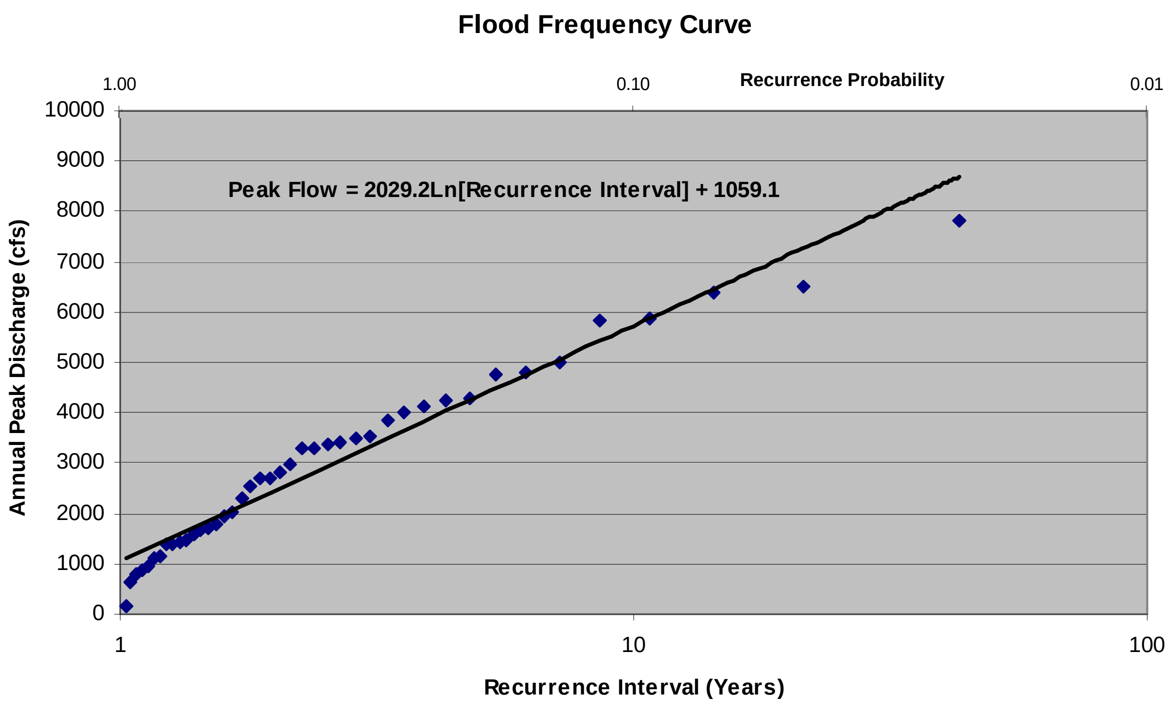


b) Constructed bend

Figure 8: Constructed Channel. a) Aerial photograph from 1996 showing constructed channel configuration. Flow is from upper left to lower right b) Photograph of a constructed bend. Notice rock and log revetments on left of photo. Obtained from http://www.terrawavesystems.com



a) Peak flow data for Bull Creek



b) Flood Frequency for Bull Creek

Figure 9: Flood Frequency. a) Plot of annual peak flow data for USGS stream gauge number 11476600 on Bull Creek about 4 km downstream of confluence of Cuneo Creek with Bull Creek. b) Flood frequency plot showing linearized flood frequency equation and annual recurrence probability.

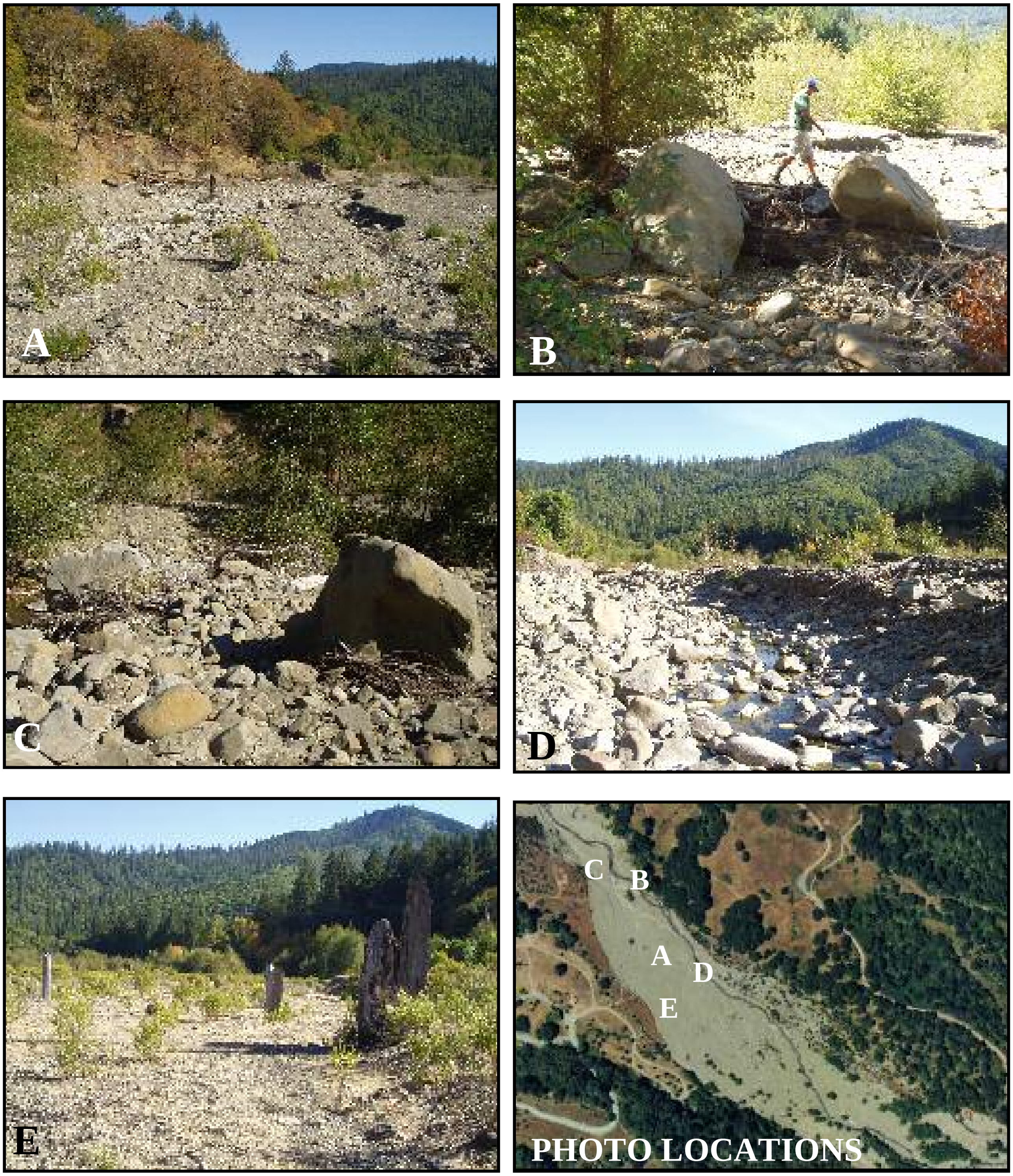


Figure 10: Remnants of Channel Reconstruction Project. A) Abandoned channel B) Suspected remnants of rock and log revetment; C) Suspected remnants of vortex rock weir; D) Active channel looking downstream; E) Vertically placed logs in floodplain that are remnants of debris flow regulation structures.

Figure 11: Devil’s Elbow Landslide. Devil’s Elbow landslide is located in the upper reach of the South Fork of Cuneo Creek and contributes large amounts of sediment to the lower Cuneo Creek. Top photographic overlay shows landslide in October 2003. Bottom aerial photograph is from 1997 showing landslide location with respect to lower Cuneo Creek.