Coldstream Canyon Watershed Assessment

Final Report

Prepared for: The Truckee River Watershed Council
Prepared by: River Run Consulting and Hydro Science

With Contributions by:
Swanson Hydrology and Geomorphology
Valley and Mountain Consulting
EcoSynthesis
Wildlife Resource Consultants
Tallac Applied Ecology and Design

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River Run Consulting P. O. Box 362, Cedarville, CA 96104

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EXECUTIVE SUMMARY

This report assesses the condition of Coldstream Canyon, a 12.5 acre watershed near Truckee, California, tributary to the Truckee River. The assessment focuses on geomorphic function and processes. Watershed geomorphic function prior to human disturbance is described, as well as important characteristics of the streams, floodplains, and riparian ecosystems. Major human disturbance to watershed function is identified and resulting effects on the current condition of streams and their associated riparian ecosystems are discussed. Finally, conceptual opportunities for restoring or improving watershed and stream function are identified and evaluated.

Prior to human disturbance, natural rates of sediment yield were relatively high in the watershed due to many factors: the rocks forming the watershed are susceptible to high rates of erosion; glacial erosion and sediment deposition resulted in highly erodible hillslopes and other landforms; and the local climate is characterized by large, infrequent but regularly-occurring storms that are capable of substantial erosion and sediment transport. Upper portions of the watershed are steep and highly erosive and provide substantial coarse and fine sediment to lower portions of the fluvial system.

The production and transport of sediment through the watershed, especially coarse sediment, has important implications for stream and floodplain form and function. The upper portion of the watershed tends to produce and export sediment. Streams are relatively straight in these areas and the floodplain is poorly developed. Other portions of the watershed have been primarily depositional over geologic recent history. The stream channel also tends to be straight in these areas, and has been relatively dynamic. Finally, in some part of the watershed the fluvial system is balanced in terms of erosion and deposition, and the stream in these areas tends to be meandering.

There has been a long history of human disturbance of the Coldstream watershed. The Central Pacific Railroad, constructed in the 1860's, required extensive drainage modification and, in one location, a crossing of Cold Creek that highly modified the stream channel and floodplain. Logging began with the construction of the railroad, and intensified with the demand for timber from Nevada mines in the 1870's to 1890's, and demand for wood fiber in the first part of the 20th century. Logging of second growth was widespread in the 1960's. Most of the watershed was logged at some point, with the construction of an extensive system of roads. Gravel mining occurred during the 1960's and 1970's at two locations in the watershed, most extensively in the lower mile, where the stream was channelized and much of the surrounding floodplain was mined. Downstream of the confluence with Donner Creek, the channel and floodplain were completely altered through the construction of Interstate 80, the Truckee High School, and other urban infrastructure.

At times when watershed disturbance was widespread, such as heavy logging in the 1960's, our analysis suggests that cumulative impacts in upland areas were likely significant and probably caused stream degradation by increasing the size of peak floods, increasing the sediment supply to the channel, or both. Cumulative watershed impacts are far lower today, as roads have stabilized and logged areas have revegetated. However, during larger storms, a substantial amount of fine sediment is generated from erosion sources directly related to human disturbance. These include roads and other areas where natural drainage patterns have been disrupted.

Direct alterations of the stream channel or floodplain have probably had more substantial and long-lasting impacts to the stream system. In two locations, portions of the channel network that were formerly depositional now produce sediment due to channel alterations. This sediment not only has negative impacts for aquatic habitat downstream, it also has caused destabilization of downstream channel reaches. These altered reaches themselves have often responded by incising, with degradation of instream aquatic habitat and the complete loss of adjacent riparian vegetation communities.

Within the Coldstream watershed, human disturbance has therefore resulted in a substantial loss of riparian habitat and degraded aquatic habitat. Erosion in the Coldstream watershed has likely had impacts downstream as well. Fine sediment export to the Truckee River has increased due to human disturbance, and is among the highest in the entire Truckee River watershed.

Opportunities for restoring the watershed were evaluated for four general areas: the upland road network; a degraded portion of the channel system in the middle of the watershed, including adjacent gravel pit ponds; and the channelized lower portion of the watershed. Several conceptual alternatives were analyzed for addressing impacts in each of these areas. Feasible opportunities for improving watershed function and riparian and aquatic habitat are identified in each of these locations.

The full assessment and all data, including Geographic Information System (GIS) files, are available from the Truckee River Watershed Council (530-550-8760, www.truckeeriverwc.org).

1. INTRODUCTION

The following report is an assessment of the Coldstream Canyon Watershed near Truckee, California. The assessment has been funded and directed by the Truckee River Watershed Council, utilizing a 319h water quality improvement grant from the Lahontan Regional Water Quality Control Board (LRWQCB).

Cold Creek, the principal stream in the watershed, is a tributary to Donner Creek about 1.5 miles upstream from its confluence with the Truckee River. Coldstream Canyon has long history of human use. The Central Pacific Railroad was constructed within the canyon in the 1860's, crossing the mainstem of Cold Creek in the middle of the watershed. Because the railroad crossed the steep Sierra Nevada just to the west of the watershed at Donner Pass, railroad engineering required a long, curving route through Coldstream Canyon to gain elevation and reduce slope, with extensive embankment. Throughout the late 1800's, several timber mills operated within the watershed, supplying lumber to the railroad, nearby towns, and Nevada mines. Mill ponds were constructed on the stream in at least two locations during this period.

Extensive logging in the watershed continued throughout the early 1900's, especially of softer woods for the pulp mill at Floriston. After a lull in logging throughout the middle of the century, activity increased again in the 1960's, focusing on second-growth timber. Beginning in the early 1960's, gravel mines were developed in the lower part of the watershed to provide material for construction of I-80. The stream was channelized throughout most of the lower two miles, and the adjacent floodplain was developed. Donner Creek downstream of the Cold Creek confluence was also channelized throughout most of its length, to the confluence with the Truckee River.

This history of human development has had significant impacts on water quality and ecosystem function in the Coldstream watershed. Within the watershed, erosion and sediment supply have increased, the channel has become unstable in several locations, and riparian and aquatic habitat has been degraded. Watershed instability has had effects outside the watershed; the supply of fine sediment from Coldstream Canyon to the Truckee River system has increased due to human disturbance. Because Coldstream is a major contributor of sediment to the Truckee River (McGraw et al. 2001), and the Truckee River is currently considered impaired by fine sediment by the LWRQCB, sediment production from the watershed is a significant concern for the Truckee River system.

The primary objective of this assessment is to provide a geomorphically-based analysis of watershed function and the impacts of human disturbance. Based on an understanding of geomorphic processes and the impacts of human development, we then explore opportunities to restore watershed function, with the goals of increasing watershed and channel stability, reducing sediment yield and improving habitat. These objectives require a thorough understanding of the geomorphic function of the undisturbed watershed and how this function has been altered by human disturbance.

This document is organized in the following way. Chapter 2 provides an overview of the watershed and an analysis of pre-disturbance geomorphic function. Using an array of data sources and analysis tools, including historic photos, historic aerial photographs, topographic modeling, and assessment of geomorphic processes in mountainous watersheds, we describe geomorphic function of the watershed prior to human disturbance. Chapter 3 then reviews patterns of human disturbance in the watershed, and analyzes the geomorphic and, to a lesser extent, the ecosystem consequences of these actions. Finally, Chapter 4 presents opportunities and constraints for restoration of watershed geomorphic function.

This assessment and all data, including the GIS data developed for the project, are available from the Truckee River Watershed Council (530-550-8760, www.truckeeriverwc.org).

2. Watershed Overview and Geomorphic Function Prior to Human Disturbance

The 12.5 square-mile Coldstream Canyon watershed is located near Truckee, California (Figure 2-1). Cold Creek, the primary stream in the watershed, flows into Donner Creek near Donner Lake Memorial State Park, about 1.5 miles upstream of where Donner Creek enters the Truckee River. Elevations range from 5,910 ft at the mouth to 8,949 ft at the top of Tinker's Knob, the highest peak. The upper portions of the watershed on the west side are the crest of the Sierra Nevada mountain range.

This mountainous watershed has a high degree of relief and varied terrain. The western half of the watershed, the highest portion, consists of narrow valleys and high gradient streams (Figure 2-2). The valley widens considerably near the middle of the watershed, before narrowing again in a short canyon near the eastern boundary. From the exit of the canyon, Cold Creek flows across the relatively wide Donner Creek valley floor to its confluence with Donner Creek.

2.1 Geology

The Coldstream Canyon watershed lies on the western slope of the Sierra Nevada physiographic province. The Paleozoic to Jurassic metamorphic rocks in the Sierra Nevada are the oldest in the region. They are intruded by the granitic rocks of the Sierra Nevada batholith and are overlain unconformably by Miocene and younger rocks and sediments. During late Miocene and early Pliocene time, andesitic volcanic mudflow breccias and lava flow accumulated throughout the region from sources east of the Sierra Nevada. The volcanic rocks of Tertiary age are as old as 7.4 million years before present. The bulk of the flows in the area appear to have erupted in mid- to late-Pliocene time, more that 3 million years ago, prior to the uplift of the Sierra Nevada range. During Pleistocene time there was general uplift of the entire region and renewed volcanic activity with flows from vents near the Virginia City area. Some of these flows extended westward over what is now the western slopes of the Sierra Nevada to beyond the city of Folsom.

There are no exposures in the watershed of the oldest metamorphic rocks (Figure 2-3). Most of the materials exposed at the surface in the upper third (western portion) of the watershed and at higher elevations elsewhere are Miocene age and younger volcanic deposits or material eroded from these deposits. There are isolated outcrops of intrusive granitic rocks near the crest at the western edge of the watershed (Figure 2-4). Valley bottoms throughout the watershed are Pleistocene-age glacial deposits, including tills, moraines, and outwash.

The volcanic rocks comprising much of the upper watershed have important characteristics for understanding processes of erosion. Volcanic rocks are extrusive; they solidify at the earth's surface following eruption. They are similar to intrusive rocks such as granite or andesite in that both are derived from underground sources of magma. However, the intrusive rocks solidify under the surface into large, cohesive rock masses. Volcanic rocks, on the other hand, take a number of forms depending on how they were extruded. While some of these forms, such as lave flows, solidify in large masses somewhat similar to intrusive rocks, many of the volcanic rocks in the Coldstream watershed have far different forms. These include lahars, which are formed from volcanic mudflows and tuffs, which are formed from volcanic ash.

Examples of intrusive and extrusive volcanics in the watershed are shown in Figure 2-4. Extrusive rocks derived from lahars or ash are common in the watershed. They typically have a very fine matrix, often supporting larger clasts. These types of extrusive rocks tend to be highly erosive, as depicted in the photos, and weather to fine particles (silt and smaller). They are also capable of eroding into very steep landforms. In contrast, granite and other intrusive rocks, while highly erosive in some environments, tend to weather into less steep and abrupt landforms and into larger particles (sand).

Another important factor for watershed erosive processes is faulting, which influences valley shape and gradient. A fault is mapped along the outcrop of granitic rocks in the western portion of the watershed, and influences watershed gradient in this location.

2.2 Hydrology

Cold Creek drains into Donner Creek approximately 0.8 miles below the outlet of Donner Lake. The area immediately upstream from the confluence of Donner Creek has been highly modified through gravel mining. This area now drains internally to a number of groundwater supported lakes, and no longer drains to Cold Creek. Prior to human disturbance, the drainage area of the watershed was therefore slightly larger.

Cold Creek's runoff regime is typical of that of watersheds along the east side of the Sierra Crest. The vast majority of runoff is generated as a result of snowmelt runoff, which typically begins in March, peaks in May or early June, and then gradually recedes during the summer, reaching a minimum during September. Summer low flows are variable within the watershed. Some reaches of the creek are commonly dry while others have perennial flow during most years. Reaches that exhibit perennial flow are associated with bedrock either at the surface or at shallow depths; whereas dry reaches occur where the valley fill is locally thicker.

This general pattern of runoff is occasionally altered. Summer thunderstorm activity is highly variable and there are often years that entirely lack thunderstorms. When they do occur they tend to be highly localized and are not sufficiently large to generate peak flows. For example, none of the 45 years of recorded annual peaks for Blackwood Creek near Tahoe City have occurred during the period of July-September (http://nwis.waterdata.usgs.gov). In contrast, frontal rain storms which generally occur from November through May are the source of the largest peak flows (Hydro Science and River Run 2005). Most often these take the form of rain-on-snow events. As a result, there are two populations of peak flows, rain-on-snow peaks and those associated with snowmelt runoff, which are smaller, exhibit less variance, and have an upward limit defined by maximum snowmelt rates controlled by temperature, vapor pressure, and solar radiation.

Cold Creek is an ungauged basin. However, Donner Creek has been gauged at the Highway 89 Bridge since March 1993 and at the outlet from Donner Lake continuously since 1958. Streamflow from Cold Creek can be estimated by subtracting Donner Lake's outflow from

Donner Creek at Highway 89. Approximately four percent of the total drainage area at the Highway 89 gauge is unaccounted for using this method. However, much of the former gravel pit area drains internally into the ponds, and the remainder of the drainage area contributes an insignificant amount of runoff except during rain-on-snow peaks.

An additional complication arises when using the technique to estimate instantaneous peak flows from Cold Creek. The storage effects of Donner Lake commonly results in a one day delay between the peak flow at Highway 89 versus the peak outflow from Donner Lake. The instantaneous peak flow from Cold Creek for those cases when the peaks at Highway 89 and from Donner Lake were not simultaneous was estimated by taking the Donner Creek peak at Highway 89 and subtracting the average of the mean daily flow from Donner Lake on the same day, with the instantaneous peak reported for the subsequent day.

Figure 2-5 gives the flow duration curves for Cold Creek and the Donner Lake outlet. Although the storage effects from Donner Lake do affect the timing and amount of peak flows, the overall effect of the reservoir is modest, because of the limited allowable drawdown of the reservoir. The median streamflow of Cold Creek is 11 cubic feet/second (cfs). Flows over 100 cfs occur 13 percent of the time.

Table 2-1. Estimated Flood Magnitude.

Recurrence Interval	Flood Estimate (cfs) based on Coldstream Data	Flood Estimate (cfs) Using Extended Record By Blackwood Regression
2	442	439
5	859	758
10	1,230	1,030
20	1,680	1,350
50	2,390	1,850
100	3,030	2,300

A flood flow frequency analysis was performed using two different methods. The first fitted the 14 years of annual peak flow estimates derived from the Donner Creek data as described above to a log-Pearson Type III probability distribution (U.S. Geological Survey 1982). The log-Pearson distribution is a three parameter distribution and the results are highly sensitive to the skew. In cases when there is less than 25 years of data, it is recommended that a regionalized skew coefficient be used to modify the skew of the existing data. With only eleven years of available data, the results should be considered as a preliminary estimate. Table 2-1 gives the computed estimated flows for various recurrence intervals based on the eleven years of available data and using the regional skew estimate. Provisional estimates of December 31, 2005 peak flows were provided by the Carnelian Bay office of the U.S. Geological Survey.

Table 2-1 also shows flood estimates derived by extending the peak flow record through regression analysis against Blackwood Creek near Tahoe City. Blackwood Creek is the best available analog to Cold Creek since it is of similar size, orientation, and geology. Blackwood Creek has 46 years of annual peak flow data. Figure 2-6 gives the results of the regression analysis. The flood frequency analysis using the extended data set was performed based on the computed skew.

Despite the similar size and geology, Cold Creek produces much lower peaks than does Blackwood Creek for flows in excess of 1,000 cfs. It is not known if this is an artifact of differences in the storms for the two highest observed flows, or if Blackwood indeed consistently produces higher peaks during rare flood events. The higher flood flow estimates produced using just the 14 peak flow observations from Cold Creek produces higher flow estimates because the small data set, by coincidence, includes the 1997 event, which is the flood of record for many of the streams in the area. The inclusion of that outlier in a small data set results in a larger skew coefficient. It is reasonable to conclude that the true recurrence interval estimates lie somewhere between the estimates derived by the two different analyses.

While Cold Creek floods tend to be smaller than those in Blackwood Creek, it is important to note that very large floods do occur fairly regularly. The largest floods generally occur between November and February, and are the result of warm winter frontal storms, often producing large amounts of rain on snowpack. As will be discussed more thoroughly in following sections, these floods have a large impact on channel morphology, with far more potential for channel changes than during the typical snowmelt flood.

2.3 Soils and Vegetation

Two general groups of soils are found in the Coldstream watershed; those formed on glacial moraines and outwash (the Tallac series), and soils formed over bedrock (the Waca and Meiss series) (Figure 2-7). The Tallac soil has a weakly cemented silica hardpan at 40-70 inches deep which can act as a restricting horizon for the continued downward movement of water. The latter two soils are differentiated by the parent material. Waca soils are formed over andesitic tuff, which are generally softer materials, whereas the Meiss soils formed over harder andesitic rock. Much of the main valley bottom is Tallac soils, developed over glacial deposits, while valley walls are the Waca and Meiss soils. Most of the barren areas in steeper upper portions of the watershed are mapped as undifferentiated rockland or rock outcrop complexes.

The watershed is forested throughout, except within the headwaters. General vegetation community types, classified by California Wildlife Habitat Types, are shown in Figure 2-8, mapped by the Forest Service using remote sensing. In general, the upland vegetation follows the typical elevational gradient with Jeffery pine common in the lowest areas, with an increasing percentage of white fir with elevation. In the higher elevations, red fir predominates and some white pine can also be found. Where the forest cover is low, a brush understory often occurs, as along much of the south-facing slopes on Shallenberger ridge. Brush is less common on north-facing slopes. Lodgepole forest is common in the valley bottoms and along streams, with small patches of wet meadow and aspens in some locations.

2.4 Glaciation

Four Pleistocene glaciations are thought to have occurred in the northern Sierras. Widespread evidence of three is found in the Tahoe Basin region. The Donner Lake glaciation is dated as pre-Wisconsin, commencing approximately 400,000 to 600,000 years before present (ybp) (Birkeland 1963). Because evidence of the younger glaciations is found inset and downslope of Donner deposits where they occur in the same area, the Donner is often considered the most extensive glaciation. A long interglacial probably separated the Donner Lake glaciation from the two Wisconsin age glaciations; the Tahoe from about 90,000 to 60,000 ybp, followed by the Tioga, from 30,000 to 10,000 years ybp (Hyne et. al., 1972). Deposits of the Tahoe glaciation are found upslope of Tioga deposits where the two are found together, and it is therefore generally considered to be larger (Birkeland 1963). During any of these glaciations, many advances and retreats of ice are likely to have occurred.

Extensive glaciation produces unique landscape features which strongly influence modern watershed geomorphic processes. Glacial features can generally be considered in two classes; those created by glacial erosion, and those created by glacial and fluvial-glacial deposits. Both of these types of glacial features are found in the Coldstream watershed.

2.4.1 Glacial Erosion

Glacial erosion features are common at the upper elevations, particularly in the western portion of the watershed. The formation of extensive glaciers over the highly erosive volcanic bedrock resulted in exceptionally steep, sharp landscape features. Figure 2-9 is a three-dimensional perspective view of the watershed created from digital elevation data. Steep-sided bowls or cirques at the head of each of the forks of Cold Creek were the source areas for glacier formation, and had the deepest ice development. Glacial erosion created very steep, knife-edged ridges between the cirques (Figure 2-10). Many of these steep slopes are still erosive today, with low ground cover, especially where they occur in weak volcanic rock types (for example, photo 8-31-06 11 on Figure 2-10). Even well-vegetated slopes are often so steep that some erosive areas still occur, as shown by a picture taken in a portion of the watershed that has never been logged, where erosion is entirely natural (photo 8-12-06 004, Figure 2-10).

Because glaciers from the Coldstream sub-watersheds were of different sizes, the degree of valley scour varied, creating discontinuity in valley bottom gradient. For example, the Emigrant Fork glacier appears to have had a fairly small source area, and entered the main valley well downslope of where the middle and south fork glaciers came together. As a result, the Emigrant Fork valley was not as deeply eroded as the main valley. There is a substantial discontinuity in valley gradient where these two valleys converge (the discontinuity can be seen on the 3-d perspective views in Figure 2-9; see also valley profiles, described in a following section, in Figure 2-18). The Emigrant Fork has subsequently eroded a canyon in this area between the two glacial valleys where local watershed slope is high, an erosional process which continues today (Figure 2-11, photo 8-31-06 1). Similar processes have led to a canyon at the mouth of the South Fork (Figure 2-11, photo 9-2-06 025) and at the exit of Cold Creek into the Donner Creek valley. Based on the size of the Donner valley, the glacier here appears to have been much larger than the Coldstream glacier--perhaps fed by an ice dome near the Sierra crest--and eroded a deeper valley.

Discontinuity in watershed slope also occurs where rock types under the glaciers changed abruptly. Intrusive granitic rocks, which are more massive and resistant to erosion than most of the volcanics, were less deeply eroded. The resulting discontinuity in watershed slope is clearly visible on three-dimensional perspective views around the band of granitic rocks in the western part of the watershed (Figure 2-9; see also profiles in Figure 2-18).

Abrupt variations in watershed slope are important factors in erosion and sediment production. Rapid changes in base level and slope typically result in high rates of erosion and sediment production. This occurs in the Coldstream watershed in areas where glacial erosion has resulted in watershed slope breaks, such as the confluence of valleys or borders between different types of rocks.

2.4.2 Glacial Deposition

An extensive array of depositional features is created by glaciation, either directly by glaciers or by running water cause by glacial melting. Figure 2-12 shows several of these landforms in modern glaciated environments. Moraines are berm-like mounds deposited on the lateral and terminal margins of the glacier, and can be quite large; the east end of Donner Lake is a moraine, and smaller terminal moraines formed as the Donner glacier receded are clearly visible on perspective topographic views as small spurs along the south valley wall just west of the Cold Creek canyon (Figure 2-9). Ground till is deposited directly by glaciers in various patterns on valley floors Fluvial deposits laid down in glacial environments, during periods of high supply of both sediment and water, include braided outwash plains, kame terraces along glacier margins, and alluvial fan and deltaic deposits. Ponding behind moraines, till, or in braided outwash plains results in lacustrine (lake) deposits.

All of these features influence subsequent drainage and stream channel development when glaciers melt. Post-glacial stream channels develop a new drainage network in the absence of ice, and must erode through features created when ice forced different drainage patterns. For example, lateral moraines from the Middle Fork glacier were deposited across the mouths of both the Emigrant Fork and South Fork valleys. A portion of the canyons at the mouth of both of these valleys was eroded in moraine deposits; note the unsorted morainal material exposed in hillslopes in both areas in Figure 2-11. The landforms in Figure 2-12 highlight the enormous amount of erosion that must occur for modern fluvial landforms to develop on glaciated landscapes.

At the end of the Pleistocene, a warming climate resulted in retreat of ice. In the entire glacial cycle, the period of deglaciation probably results in the highest sediment yield (Benn and Evans, 1998) due to exposed, unvegetated eroded slopes and glacial deposits. As deglaciation came to a close, invading vegetation began to stabilize the watershed. Both sediment supply and water yield began to decline, a process that has continued to the present. Since deglaciation, glacial landforms have been modified as drainage networks develop in the absence of ice. It is important to note, however, that glaciation still influences geomorphic processes in the watershed today. Benn and Evans (1998) note the effects of glaciation likely persist in the valleys of mountainous watersheds for many thousands of years, perhaps until the next glaciation. Much of the natural erosion in the Coldstream watershed today is continued modification of glacial landforms.

2.5 Overview of Channel-Forming Processes in Mountainous Environments

Although stream channels are enormously complicated landforms, the basic geomorphic processes responsible for channel form can be simplified with the recognition that the principle physical role of streams is to transport water and sediment, and this role determines their shape. Given that most streams are alluvial (they build their own streambanks and bed from sediment transported by the stream), the interplay between sediment and water (which provides the physical energy to transport the sediment) is an important geomorphic process responsible for channel form.

2.5.1 Sediment Transport

Sediment (sediment is generally inorganic particles—i. e., sand, gravel, rocks--ranging in size from small clay to large boulders) is transported in streams by the power of running water. The power of water is determined primarily by the depth of the flow and the slope or gradient of the stream channel. Thus the maximum size of particle that can be transported by a stream at a particular location is determined by the size, shape and slope of the channel. Channels with low slope and depth cannot transport boulders, for example. Different particle sizes are transported in different ways by streams. The smallest particles, sand size and below, are generally carried in suspension. Larger particles are termed bedload because they are transported by hopping or rolling along the streambed. Smaller particles can be carried by most flows, but coarse bedload particles are transported only by larger floods.

The form (planform, cross section shape and size, size and shape of the floodplain) of a stream at a particular location has developed in response to water and sediment supply over years, decades and centuries. Conceptually, the channel form is considered to be that most efficient for transporting the average sediment and water yield supplied at any particular location (Leopold 1994; Knighton 1998), and reflects a balance between sediment supply and the power (amount of water, slope of the channel) needed to transport available sediment.

As noted previously, in many geomorphic landscapes functional undisturbed alluvial channels are relatively stable, evolving to a form which balances water and sediment supply (Figure 2-13). Small changes in channel form may occur from time to time in response to larger floods or changes in sediment supply, but the form tends to return to some average over time. This condition, generally stable with small deviations that tend to return to an average form over time, is termed dynamic equilibrium (Lane 1955).

The equilibrium form varies widely from stream to stream, however, depending on the type and quantity of sediment supplied to the channel. Streams which receive large quantities of coarser sediment are straight and begin to develop multiple channels (Figure 2-14). Streams with low quantities of finer sediment are generally sinuous and have a single channel. Though there are exceptions, these relationships are remarkably consistent due to the basic physical processes involved; transporting larger sediment requires more power, which is provided by a straighter channel. Similarly, transporting large sediment through a bend takes far more power than transporting the sediment in a straight line.

Although the word equilibrium denotes stability, many functional channels are relatively dynamic. Like overall channel form, the relative stability of channels is closely related to the type and quantity of sediment transported (Figure 2-14). Streams with a high supply of coarse sediment tend to be relatively dynamic; it is often easier for the channel to erode adjacent streambanks than to move large bars of coarse sediment. Moreover, streams with a high supply of coarse sediment tend to have relatively high energy (high channel slope), and are therefore highly erosive.

As the discussion in the previous section showed, recently glaciated, mountainous watersheds like Coldstream Canyon have high energy and ample coarse sediment supply. However, Coldstream exhibits a wide range of landscape forms, from high gradient, highly transportational streams formed in bedrock, to lower gradient alluvial channels. Understanding sediment supply and transport through the watershed, especially coarser sediment, is a key to assessing channel condition and will be considered for various portions of the watershed later in this chapter.

2.5.2 The Influence of Valley Form

In mountainous environments, stream channels and floodplains are far more influenced by the shape of the valley through which they flow than in lowland landscapes. In mountain streams, valley walls often impinge upon or constrain the channel, and the slope of the valley floor is frequently determined by geologic or glacial controls rather than by sediment deposited by the stream itself (Wohl 2000). Because valley walls are usually near the channel, hillslope erosion processes often supply sediment directly to the channel or floodplain. Thus valley form affects both the amount and type of sediment supplied to the channel and the capacity of the channel to transport sediment.

2.5.2.1 Sediment

Depositional glacial landforms form much of the valley bottom and lower hillslopes in the Coldstream watershed. Current fluvial erosion of these landforms produces an ample supply of sediment, with a large proportion of coarse material. For example, the walls of the canyons eroded at the mouths of the South and Emigrant Forks are partially composed of morainal deposits. Larger cobbles and boulders are a significant component of sediment being supplied to the stream at these locations (Figure 2-11). Glacially oversteepened volcanic landforms also occur close to the stream channels (Figure 2-10) and have high rates of sediment yield, which often contains larger sediment particles, especially the breccias formed from mudflows. Mass movements of sediment such as landslides or debris flows are important processes in some locations in the watershed, especially in the middle portion of the Middle Fork, where the south valley wall is mapped as landslide deposits (Figure 2-3). Enormous quantities of sediment are rapidly delivered to the channel system in these areas, usually during larger rain-on-snow storms.

In many locations throughout the watershed, the current channel is eroding fluvial deposits created during or shortly after glaciation. Outwash terraces, remnants of floodplains of braided outwash streams during the glacial period, occur in the broader valley throughout the middle portion of the watershed. Throughout much of the Holocene (the last 10,000 years since deglaciation), declining sediment yields from the upper watershed have caused the modern channel to erode and entrench into the outwash floodplain, creating the modern floodplain at a lower level as outwash deposits are transported out of the watershed. This process has led to a series of benches along the modern floodplain (Figure 2-15). In some locations, the current channel migrates into the outwash terraces. Because they were formed in a period of high supply of both sediment and water, these deposits are often composed of very coarse materials (Figure 2-15, top and middle photos). Similarly, the stream is eroding coarse Pleistocene deposits in the alluvial fan at the mouth of the canyon (Figure 2-15, bottom photo). Outwash deposits border and underlie much of the modern floodplain throughout the watershed.

Other types of geomorphic processes have influenced sediment available to the channel in the broader middle valley of Coldstream Canyon. Along the western end of this valley, Shallenberger Ridge drainage to the north is carried in a number of small, disconnected, ephemeral streams. At deglaciation, a long lateral moraine was deposited in this area perpendicular to drainage (for an example of this process, see the top left and lower right photos, Figure 2-12). Throughout the Holocene, the small drainages have reworked the morainal deposits, constructing a broad bench gently sloping from the hillslope toe to the channel (see Figure 2-16 for a schematic representation of this process). The bench is composed of coarser materials near the mountain face, and finer materials at the distal end near the current channel. This process was likely responsible for extensive deposits of finer material common in this reach in the upper portions of eroding streambanks.

2.5.2.2 Sediment Transport Capacity

Valley slope throughout Coldstream Canyon is highly variable, reflecting the geologic and glacial processes described previously. Variability in valley slope is clearly seen in valley bottom profiles (Figures 2-17 and 2-18). At nearly all junctions of sub-watersheds, as well as at the junction of the mainstem with the Donner Creek watershed, there are abrupt changes in valley slope due to differential glacial erosion. Other abrupt changes in valley slope occur in the Middle Fork due to changes in underlying geology, and higher up in smaller tributaries due to various processes of erosion and deposition.

Because valley gradient determines, to a large extent, channel gradient, abrupt changes in valley gradient are important because they strongly influence the transport of sediment, especially coarser bedload. Locations where stream gradient changes rapidly tend to be dynamic. Within these transitions, the steeper channel has relatively more capacity to transport sediment, and also tends to be in landscape location (confined canyons, for example) where sediment supply is high. In landscape locations where the steeper reach is on the upstream end of the transition, the high sediment yield of steeper reaches is supplied to lower gradient reaches with lower sediment transport capability. Aggradation (deposition on the streambed) is common in these locations, forcing the stream to migrate or avulse (create an entirely new channel). As transport of coarse bedload occurs during high discharge, channel dynamics are common in areas of transitional slope following larger floods. These locations occur at the base of confined canyons throughout the Coldstream watershed.

Valley width also strongly influences sediment transport. In areas where streams are highly confined by valley walls, water cannot spread out over floodplains at high discharges as happens in broad valley flats. Depth and velocity in confined reaches are therefore higher, and the stream is capable of transporting more sediment, especially the larger, coarser bedload. Since confined areas also tend to produce more sediment from nearby valley walls, steep, confined reaches tend to yield high rates of sediment, especially coarse sediment.

2.5.3 Alluvial Fans

An important landform resulting from variability in sediment supply and transport in mountainous watersheds is the alluvial fan. Fans are created where a stream rapidly loses its sediment transporting ability because of either an abrupt reduction in slope or a sudden change from confined to unconfined valley morphology (Knighton 1998). Alluvial fans are typically constructed at mountain fronts where valley gradient and confinement are abruptly reduced, resulting in sediment deposition. Another landscape for alluvial fan development is the high-angled junction of a steep tributary valley with a gentler main stream.

An alluvial fan is composed of sediment deposited due to the abrupt change in sediment transport capability. Where the channel above the fan is capable of transporting coarse sediment, this material will be deposited within the stream channel near the top of the fan, causing the channel to avulse. The characteristic fan-like shape develops as the channel migrates around this point of bedload deposition at the head of the fan over long periods of time. The coarsest sediment is deposited near the head of the fan, and sediment deposits get finer toward the distal end.

Over long periods of time, alluvial fans go through periods of active construction and relative quiescence depending on climatic conditions and sediment supply. Active construction occurs when sediment yield from the watershed is very high. These periods certainly occurred in Coldstream Canyon during glacial retreat or deglaciation, when abundant sediment was available on hillslopes and the valley floor upstream. The channel actively migrated across the fan surface, and was likely braided. Periods of active construction in alluvial fans are separated by times when sediment supply from the upper watershed declines. At these times, the balance between sediment and discharge changes, and the stream becomes capable of moving sediment at the top of the fan rather than depositing. The stream channel incises within the fan surface, forming terraces and a single-thread channel. Even when the channel incises slightly within the fan, however, alluvial fans tend to be areas of sediment deposition. However, deposition only occurs during these periods within the entrenched portion of the fan, rather than across the entire surface of the fan.

Although the name fan denotes a characteristic shape, alluvial fans exhibit a wide range of morphologies. In Coldstream, the alluvial fan at the mouth of the main canyon has a typical fan-like shape. However, there is also an alluvial fan farther up in the watershed where the Middle, South and Emigrant Forks converge. In this complex environment, the alluvial fan has a less distinct form, but the same processes of sediment deposition are responsible for its formation.

2.5.4 Woody Debris

Large woody debris can be the most important component affecting the behavior and morphology of small streams in forested environments (Lisle 1986). Several processes involving woody debris improve channel stability. Woody debris works as a hydraulic roughness element within the channel, reducing stream power and erosion capability. Trees and large wood also both directly stabilize streambanks, either by root structure or by directly protecting the banks from erosive force. In some situations, trees and woody debris stabilizing one bank promote erosion on the opposite bank. These effects tend to be localized, however, because in forested environments trees and woody debris are likely to found in almost all locations, and will limit the amount of erosion that can occur. Where localized bank retreat does occur, the banks erode more slowly because of the high density of vegetation on the floodplain.

Woody debris sorts and stores sediment, especially coarse sediment, by trapping it behind debris jams. This allows the channel to absorb pulses of sediment without changing form (Napolitano 1996). Lisle (1995) found that removal of woody debris from a channel supplied with large volumes of sediment following the Mt. St. Helens eruption resulted in the transport of much of the sediment from the treated reach, with the loss of pools and other aquatic habitat.

Woody debris also plays a key role in stabilizing the channel and floodplain by providing resistance to erosion on adjacent floodplains. Individual trees or downed logs break up floodplain flow paths. In highly forested areas, this effect can be very important, ensuring that flood forces do not concentrate, which would result in channel incision and erosion. Moreover, individual logs store sediment, and are particularly effective at sorting sediment into fine lee deposits that become important areas for riparian vegetation colonization, which further stabilizes the floodplain.

The influence of woody debris on channel morphology varies by region. Woody debris loading rates in stream channels is far higher in coastal California redwood forests than in the Sierra Nevada (Lisle 1999). Woody debris volume is also highly variable within an individual watershed, especially in the Sierra, where forested reaches are interspersed with meadows and wide bands of riparian shrubs. In Coldstream Canyon, woody debris is most common in the eastern portion of the middle valley, where debris jams are relatively common.

It is also important to note that the function of woody debris is highly dependent on its size relative to the channel. In small northern California streams in redwood forest, individual trees are large enough relative to channel dimensions to create significant changes in channel grade, and will persist for decades if not centuries (Napolitano 1996). Smaller woody debris in larger rivers tends to be readily transported and has little effect on channel stability.

2.6 Landform Analysis

Using this background in watershed characteristics and geomorphic processes, we identified distinct landform units with consistent geomorphic processes, function and form. These landforms units are shown on Figure 2-19 and are described in following sections. This analysis describes the geomorphic function of these landforms prior to human disturbance, which is summarized in Table 2-2.

2.6.1 Lower Alluvial Fan

This area is a large alluvial fan formed where Cold Creek exits a steep, narrow canyon and enters the Donner Creek valley. The bulk of the fan was likely constructed during glacial periods or shortly following the last deglaciation. In aerial photographs taken in 1939, prior to human disturbance, there is no evidence that the channel was actively migrating across the entire fan surface (Figure 2-20). However, the channel in the upper half of the fan was relatively dynamic; several distinct channel scars are apparent on the 1939 photo. Channel scars disappear about half-way down the fan. Channel form was generally straighter at the upstream end of the fan, suggesting high rates of bedload transport, and more meandering at the lower end, evidence that much of the bedload was likely being stored in upper portions of the fan, the likely cause of channel dynamics.

2.6.2 Mainstem Canyon

This deep, steep canyon has developed as the stream has incised, often within tertiary volcanic bedrock, in response to the different base levels of the Donner Creek valley and the Cold Creek valley upstream. Canyon walls also consist of morainal deposits, especially near the downstream end. Gradient through this canyon is very steep and it is very confined, and thus has high sediment transport capacity; most of the sediment supplied to this reach is transported downstream to the alluvial fan. The canyon walls are being eroded in a few locations, such that this landform may produce some sediment internally in addition to transporting most of the sediment supplied to it.

2.6.3 Canyon Transition

This landform is transitional between the broader valley landforms upstream and the canyon downstream. It is bordered on both sides by outwash terraces, and is more confined than the valley reaches upstream. The channel form is relatively straight, but there is significant pool and bar development. Sediment supply and transport are generally in balance in this landform.

2.6.4 Lower Valley

The valley is relatively broad through this landform, bordered by outwash terraces. The channel form is meandering, with pools and riffle development. This landform is generally forested, and woody debris is relatively important in channel geomorphology. Sediment supply and transport are generally in balance in this landform.

2.6.5 Upper Valley

This landform has similar characteristics to the Lower Valley, but the channel is straighter. There is some evidence of bedrock or other controls on groundwater elevation in this reach; some portions have relatively high groundwater tables, while other tends to be drier. As in the Lower Valley, sediment supply and transport were likely in balance historically.

2.6.6 Forks Alluvial Fan

This alluvial fan has been constructed where the South Fork, Emigrant Fork and Middle Fork of Cold Creek converge. Both the South Fork and the Emigrant Fork, and to some extent the Middle Fork, exit steep, confined canyons within this landform. The stream channels within this landform were likely somewhat dynamic historically, particularly at the upstream end. Prior to human disturbance, this landform was likely depositional, tending to store sediment, especially the coarser fraction.

2.6.7 Emigrant Fork Canyon

This is a steep canyon on the lower portion of the Emigrant Fork, formed in similar geomorphic processes to the Lower Canyon on the mainstem. Canyon walls here appear to have a more morainal component, however, and are erosional. Most sediment supplied to the landform from upstream is transported through the reach, and some sediment is produced within the landform.

2.6.8 Valley Wall Tributaries

These landforms are small, steep tributaries to the South Fork, draining upper portions of the south valley wall. The small streams have developed very limited drainage networks, most of which are relatively stable. Though they probably have net sediment yield to the valley floor below, sediment transport rates are low.

2.6.9 South Fork Canyon

The South Fork Canyon landform was formed under similar conditions to the Lower and Emigrant Fork Canyons. Valley walls have a morainal component and are erosive, and this landform therefore supplies sediment to lower reaches. It also has a high sediment transport capacity and moves most of the sediment supplied to it.

2.6.10 Confined Tributary Reaches

These landforms are found on the upper forks of Cold Creek above the canyon sections. The valley is generally confined, though somewhat wider than the canyon reaches. Valley gradient is relatively high, and the streams in these landforms have high sediment transport capacity. The valley floor consists of glacial till and outwash deposits, which the modern streams are reworking. In many locations the streams are actively eroding the glacial deposits, and these landforms therefore likely exported sediment prior to human disturbance.

2.6.11 Upper Cirques

The Upper Cirques are the steepest landforms in the watershed, and are actively eroding. The streams are steep and have high transport capacity. These landforms export sediment.

Table 2-2. Pre-disturbance geomorphic function of Coldstream Canyon landforms.

Landform	Sediment Transport Capacity	Internal Sediment Production	Sediment Deposition	Net Sediment Balance
Lower Alluvial Fan	low-moderate	low-moderate	high	storage
Lower Canyon	high	low	low	export
Canyon Transition	low-moderate	low-moderate	low-moderate	balanced
Lower Valley	low	low-moderate	low-moderate	balanced
Upper Valley	low	low-moderate	low-moderate	balanced
Forks Alluvial Fan	moderate	low-moderate	high	storage
Emigrant Fork Canyon	high	moderate	low	export
Valley Wall Tributaries	high	low-moderate	low	export
South Fork Canyon	high	moderate	low	export
Confined Tributaries	moderate-high	moderate-high	low-moderate	export
Upper Cirques	high	high	low	export

3. Human Disturbance and Effects on Watershed Function

3.1 Development in the Watershed

Extensive development of resources and infrastructure in the Coldstream Canyon began relatively early, in the middle of the 19th century. Two primary forces drove the early development; construction of the Central Pacific Railroad (CPRR); and discovery of the Comstock Lode in Nevada, which produced an enormous demand for timber. Logging continued throughout the 1900's, most notably in the 1960's, but the early logging was the most extensive. The other major period of resource development was in the 1960's, with the development of gravel mines in the lower portion of the watershed. There has also been very light residential development in the middle portion of the watershed.

3.1.1 Central Pacific Railroad (CPRR)

Construction of the CPRR through Coldstream Canyon was begun in the mid-1860's, and completed by 1867 (CPRR Photographic History Museum (http://www.cprr.org/Museum/Eastward.html#Construction%20of%20the%20CPRR). The Coldstream Valley was used to gain elevation to get over the Sierra Nevada; the railroad grade follows a semi-circular route around the valley. Along the valley bottom, extensive fill was required to create the appropriate grade, with embankment depths of at least 20 ft in most locations. Subsequent to initial construction, the embankment has been raised and expanded in some locations.

The CPRR has had two primary watershed impacts:

1) The drainage network around the valley bottom has been altered. Culverts were placed in the embankment at major drainages, but drainage in other locations was blocked by the embankment. During larger storms, drainage in these areas must flow along the embankment to culverts. Peak flows during storms are thus increased downstream of the culverts due to drainage diversion. Also, culverts often clog with debris during periods of extreme runoff, diverting flow to other areas, which again results in peak flow increases (L. Hahn, personal communication).
2) The Cold Creek culvert has significantly confined the Cold Creek channel and floodplain. The railroad crossed Cold Creek at the apex of the Horseshoe bend, in the Forks Alluvial Fan landform, where a concrete arch culvert was constructed. The culvert is very narrow, much narrower than the channel upstream and downstream, and embankment fill on either side of the culvert occupies the historic alluvial fan and floodplain. As a result, flood flows are constrained within the narrow culvert, which flows completely full during large rain-on-snow floods (L. Hahn, personal communication). The massive hydraulic force caused by confinement at the downstream end of the culvert has resulted in severe channel erosion and degradation in the downstream channel.

Maintenance of the railroad culvert has had additional impacts. The channel upstream and downstream has been cleared, probably following large floods, to maintain flow through the culvert. Channel maintenance has increased channel size, and berms on the streambanks created during maintenance confine flow to the channel and restrict floodplain access. These activities have contributed to channel erosion and destabilization downstream.

3.1.2 Logging

Initial logging in the Coldstream watershed was likely for railroad construction, and limited to areas near the CPRR. However, high local demand for timber led to the development of mills in Coldstream Canyon, notably one operated by A. P. Stanford from 1868-1882 near the Horseshoe Bend, which cut an average of 30,00 board feet daily (Wilson 1992). A tram was constructed from this mill to Stanford camp high up on the southern boundary of the watershed. Another small mill owned by Angus McPherson operated during this period (1864-1869). This mill was waterpowered, probably using Cold Creek as a source. The last major mill in the watershed, operated by D. Smith from 1887-1898, was constructed upstream from the Stanford Mill location. A dam at this mill floated 700,000 ft of logs, and a flume took the logs 1.5 miles downstream to the CPRR (Wilson 1992).

The Smith mill cut mostly white fir, and other species less desirable as timber, for the pulp mill at Floriston. This suggests that the trees most suitable for timber, such as Jeffrey Pine, had mostly been harvested by the late 1880's or early 1890's. Following harvest of the less desirable species, logging slowed in the first half of the 1900's. A second period of intense harvest of second growth was widespread in the 1960's. Logging has continued sporadically to the present on private parcels, though at a much slower pace.

Watershed impacts of logging included soil disturbance during harvest and construction of numerous roads, which altered drainage patterns and increased erosion. There were also direct impacts to streams; the early mills used water both to transport and condition logs for milling. Millponds were constructed in at least one location on Cold Creek, and just downstream of the confluence with Donner Creek. These ponds significantly altered the channel and floodplain, and disrupted sediment transport.

3.1.3 Gravel Mining

Construction of Interstate 80 through the Sierra Nevada required vast quantities of gravel. A large gravel mining operation was developed in the early 1960's on the lower Cold Creek alluvial fan. This depositional environment was an ideal location to obtain gravel, and was mined extensively throughout the 1960's, continuing through the 1980's. Cold Creek was channelized through the mining area, and the alluvial fan was extensively modified.

Gravel was also mined upstream, in the main valley, in the 1970's. These mines were developed in outwash terraces along the northern margin of the Lower Valley landform. There was also some gravel mining in similar outwash deposits on the northern margin of the valley, near the boundary of the Upper and Lower Valley landforms. Although mining in these locations have had some minor local impacts on local hillslope drainage, they did not impact the modern channel and floodplain.

There is evidence of a grade control structure in Cold Creek on private property near historic gravel mining activity, around the borders of the Upper and Lower Valley landforms. This structure may have been constructed in association with gravel mining activities. The authors of this report were not able to obtain permission to access this area, so the purpose and exact nature of this structure are unknown.

3.1.4 Interstate and Urban Development

Construction of I-80 and urban development in Truckee significantly altered the lowest portion of Cold Creek and much of Donner Creek. To make room for the highway, Donner and Cold Creeks were moved, straightened and channelized. Most of the former floodplain is now occupied by the highway or other urban development.

3.1.5 The Current Watershed

Patterns of modern development in the watershed have been highly influenced by the transfer of former CPRR railroad grant holding to other owners, resulting in a patchwork network of private and public ownership. Limited residential development has occurred at inholdings in the middle of the watershed; roads are maintained to these holdings. State and Federal agencies have consolidated and slightly expanded their ownerships in recent years. Road and ownership patterns in the watershed today are shown on Figure 3-1.

3.2 Upper Watershed Disturbance

As reviewed in an earlier section, channel form is sensitively adjusted to the amount of water and sediment supplied to the channel. Channel shape represents a balance between sediment supply and the power available to transport sediment, which is supplied by water (Figure 2-13). Increases in sediment supply or flood magnitude will result in changes in the stream channel. Human disturbance in the watershed has the potential to increase both sediment supply and the magnitude of floods through a variety of mechanisms.

Sediment supply may be increased by human disturbance through a number of mechanisms (Gucinski et al. 2001). Some sediment may be produced in areas where soil is directly disturbed during timber harvest, but these effects are generally thought to be temporary, lasting a few years. In most cases, long-term erosion and sediment production are tied to road construction and maintenance, through several mechanisms. Roads can increase the potential for mass movement of sediment such as landslides or debris flows in some areas. Roads re-route drainage, forming new channels which export sediment when they are eroded. Sediment is also eroded from the road surface and edges, especially on regularly traveled dirt roads whose surface is regularly disturbed.

Land uses can also alter a watershed's hydrologic response (Gucinski et al. 2001). Reduction of ground cover and the creation of impervious surfaces, especially connected ones, serve to translate more of the rainfall to overland flow, which then reaches the channel sooner. Runoff rates increase and the time of concentration decreases, resulting in higher peak flows and lower recessional flows. In the Coldstream watershed, past and present land uses have had some degree of influence on the hydrologic response. Logging and road construction can create compacted surfaces, thereby creating overland flow. Roads and skid trails can act as new channels, effectively increasing channel density, which capture and route surface runoff, decreasing the time of concentration. Roads and banked skid trails which have cut and fill slopes can intercept subsurface flow and translate it to overland flow.

Because these processes can result in increases of both sediment supply and the magnitude of large floods, it is important to note that the geomorphic effect on stream channels is cumulative in two important ways. First, single disturbances can affect both erosion and hydrology. For example, construction of a road may not only introduce sediment into the stream, but that the road itself will alter the hydrologic response of the watershed to rainfall by increasing runoff rates from its surface and intercepting and routing runoff to the stream quicker. In so doing, it may increase peak flows, and cause channel erosion downstream from where the road was built. Second, the channel is subject to the impact of many such disturbances across the watershed Any given road is probably insufficient to alter peak flows to cause damage to the stream, but cumulatively, all of the roads in a watershed may indeed result in such an impact. Cumulative watershed effects therefore focus on the integrity of the channel system as a whole, as opposed to site specific impacts to the channel as might result from bridge construction, or damage to riparian areas by livestock use.

The basis for concerns regarding cumulative watershed effects arose from paired watershed studies conducted by the Forest Service in the 1960's and 1970's (Hydro Science and River Run 2005). These experiments, conducted on first-order streams in Colorado, Arizona, Oregon, New Hampshire, Pennsylvania and other states were designed to assess the influence of vegetation on streamflow characteristics. They often resulted in extreme treatments involving the partial or complete removal of timber and other vegetation (EPA 1980; Anderson et al. 1976). However, light treatments tended to show little change in streamflow. Paired watershed studies for larger basins become impractical for a number of reasons which made assessing the impacts of typical watershed disturbances on hydrologic response very difficult to document, in spite of widespread acceptance that such impacts can occur. However, one of the principal authors for this assessment performed a double mass analysis on 44 consecutive annual peak flows of two watersheds in far northern Idaho of 53 and 93 square miles and found that peak flows in the basin that received moderate to heavy logging and roading began to deviate substantially from the other basin once those activities were initiated. Using regression analysis, he determined that peak flows for a moderate sized flood increased 22 percent from what was predicted prior to watershed disturbance.

One of the earliest methods to assess cumulative impacts focused on the impacts of forest harvest on snowmelt and runoff processes (EPA 1980). Later research has shown that road construction may be as great, or greater (and more long-lived) than forest harvest-related impacts (Wemple et al. 1996). In an important and extensive study, Jones and Grant (1996) assessed changes in stormflow characteristics in both a small paired watershed and large basins in Oregon, up to 600 km^2. They found that forest harvest, primarily clearcutting, and associated road construction caused increases in peak flows of up to 50 percent in small basins, and up to 100 percent in large basins. Because of the potential for upper watershed disturbance to affect channel geomorphic processes, we performed a cumulative effects analysis on the Coldstream watershed.

3.2.1 Cumulative Effects Analysis

We analyzed cumulative watershed effects over time using aerial photography in 1939, 1966, 1983 and 2005. The general approach in analyzing cumulative watershed effects is the conversion of various land use impacts into a common unit, typically Equivalent Roaded Area (ERA). In circumstances where the landscape recovers from the impact, such as with fires or logging, the assigned ERA value begins to decline after some initial period, eventually declining to zero. In other cases, such as active roads (excluding vegetated cut and fill slopes), buildings, and railroads, the impact is permanent, and there is no recovery. The computed ERA acreage is then converted to a percent of the total watershed area. This value is then compared to a "Threshold of Concern" (TOC) which is the level of watershed disturbance beyond which there is believed to be a risk of inducing adverse impacts on the channel system.

The TOC value typically varies as a function of the channel system's ability to withstand changes in peak flows and the value of unimpaired water quality and aquatic habitat. Within California, TOCs of from 10-20 percent have been used in the past by the Forest Service. However, there has been a trend to adopt lower TOCs, such as within the Tahoe Basin, and also to better relate them to the sensitivity of the entire channel system to induced impacts. Watersheds that have steeper, stable streams with abundant rocks and boulders in the bed and banks can withstand much larger watershed disturbance than where the main channel has a lower slope and there is a finer balance with respect to sediment supply and transport.

For the Lake Tahoe Basin Management Unit (LTBMU), Jones and Stokes (2001) performed a cumulative watershed effects analysis using this methodology and determined that the TOC was 7.3. This relatively conservative value reflects a management approach designed to provide a very high level of water quality protection for Lake Tahoe. In recognition of Truckee River's listing as an impaired water body due to high suspended sediment concentrations, it is reasonable to set a similarly conservative TOC for Cold Creek at 7 percent. Given this TOC, levels of disturbance in excess of seven percent represent an increased risk of induced impacts to the channel system, and any proposed new watershed disturbance should undergo careful analysis to prevent the initiation of cumulative watershed effects on the channel system.

The methodology is a simple accounting system which tracks disturbances such as impervious coverage (paved areas, rooftops, etc.), logging and related road construction, and fires. Each disturbance activity is assigned an Equivalent Roaded Area (ERA) coefficient. For example, a paved road has an ERA coefficient of 1.0, while a heavy, ground-based logging operation has an ERA coefficient of 0.21 (each acre harvested creates the equivalent of 0.21 acres of bare disturbed soil). Each disturbance activity also has a "recovery curve" which reduces the ERA for each activity over time to zero. For example, a logged area will eventually revegetate, eliminating bare ground to the point where sediment is no longer transported off site and where the hydrologic response is essentially the same as it was prior to the impact. The recovery curves have no recovery for some period of time, up to 10 years, depending on the impact, and then decline linearly to zero over a maximum period of 30 years. Impervious surface and active dirt roads, of course, have no recovery.

For roads, we accounted for the total initial clearing width associated with the cut and fill slopes, which increases with increasing slope (assuming the road is oriented parallel to the contour). After approximately 30 years, however, it was assumed that the cut and fill slopes had revegetated such that the remaining disturbed area consisted only of the roadbed itself, which was assumed to average 11 feet.. For current conditions, we segregated the roads into active and inactive roads, based on whether there was a bright photographic signature indicating active use. Inactive roads were primarily roads constructed prior to the1970s on the south side of the watershed. Inactive roads were assumed to have lost 50 percent of their ERA.

ERA was estimated for five different periods in time: the late 1800's, 1939, 1966, 1983 and the present. To evaluate watershed condition in the 1800's, we made a crude estimate of the area that may have been logged during that time, which was probably restricted to the valley bottom and gentler slopes adjacent to the railroad. For other years, we used the available sets of aerial photography from 1939, 1966, 1983 and the present to estimate ERA at those points in time. For each time period, all identifiable graded or cleared roads and skid trails were identified and segregated into slope classes (Figure 3-2). Some minor adjustments were made in this initial classification to account for prominent features which were either oriented perpendicular to the contour, such that there was no cut or fill slope, or were initially identified but appeared to no longer consist of bare ground. The most notable example of such a feature is the logging aerial tramway, constructed in the early 1900s, which ran directly downslope from the Old Stanford Wood Camp to the railroad.

In 1939 photographs, logging roads are prevalent in the vicinity of the Old Stanford Wood Camp, located near the watershed boundary in the southeast quadrant of the watershed (Figure 3-3). Overall, the watershed has the appearance of having undergone substantial logging, but clearcutting is not evident. It is also possible that the overall level of forest cover was lower during that period due to more routine forest fires.

The 1966 photography shows extensive road construction, primarily in the upper portions of the watershed (Figure 3-3) Logging during that period might be best described as selection cutting wherein the larger, more valuable timber was removed. Gravel mining was underway in the lower part of the watershed, but it probably had little direct effect on Cold Creek since it tended to create internally drained areas which no longer contributed runoff, or sediment, into the creek. Because it is difficult to project what the original watershed boundary was on the alluvial fan, we did not include any ERA associated with it.

The 1983 photographs show limited additional road construction, and also indicate that many of the roads constructed during the 1960s were already no longer routinely used. Some additional roading and logging is evident in the lower south sides of the watershed, and a new road was constructed in the Emigrant Canyon drainage, although additional substantial logging there was not evident. The major source of new disturbance in the 1980s was gravel mining operations on the valley floor. This resulted in the formation of two large pits on the north side of the creek, and a smaller mined area on the south side of the creek farther up the valley. While the gravel mining did result in extensive ground disturbance, it also resulted in small lakes in the two large pits which serve to trap sediment and also dampen hydrologic response since the larger pit does not drain to Cold Creek at all, whereas the lower pit drains poorly and there is substantial storage associated with runoff which reaches it. As a result, for the purpose of this analysis, most of the effects of the gravel mining were transitory and are no longer evident, with the exception of the wide access road leading to the area, and residual disturbed area associated with an adjacent private parcel.

Table 3-1 gives the results of the cumulative watershed effects analysis and also provides a breakdown of the acreage of ERA into various categories. In spite of the early heavy disturbance in the valley bottom (which may have had substantial direct impacts on the creek itself), and the limited logging which occurred prior to 1940, it was the modern logging episode in the 1960s and 1970s which had the greatest impact on the watershed. In 1966, the estimated ERA is 771 acres, comprising almost 10 percent of the watershed area and exceeding the TOC. Since that time, there has been a substantial recovery which has occurred mostly since the reduction of logging in the late 1970s or early 1980s, and the cessation of gravel mining in the 1980s. Currently, the ERA is at 1.3 percent, well below the estimated TOC of seven percent.

During the period that the TOC was exceeded during the 1960s and probably for some period in the 1970s, the watershed may have been particularly vulnerable to the exceptional number of floods that occurred during that period (large floods occurred in 1955, 1963 and 1964). It is possible that flooding itself may have been exacerbated by the relatively poor watershed conditions at the time. Cumulative watershed effects during this period may have impacted stream channels in the watershed, particularly the lower gradient channel in the main valley.

Table 3-1. Results of cumulative watershed effects analysis.

Equivalent Roaded Area	1880 (acres)	1939 (acres)	1966 (acres)	1983 (acres)	Present (acres)
Railroad	31	31	31	31	31
Logging	323	188	499	325	0
Roads	10	65	238	125	68
Buildings, cleared areas	50	5	3	10	10
Total Area (acres)	414	289	771	491	109
Percent of Total Watershed	4.6	3.6	9.6	6.1	1.3
Threshold of Concern (%)	7.0	7.0	7.0	7.0	7.0

3.2.2 Mass Wasting

Roads, through re-routing of drainage, can influence the stability of steep slopes, sometimes leading to increases in the frequency of landslides or other types of mass wasting (Gucinski et al. 2001). These effects tend to be most significant in geological formations which are prone to mass wasting prior to road development; landslides are often associated with roads in poorly consolidated marine sediments found on the north coast of California, for example. Mass wasting is not a common geomorphic process in most of the Coldstream watershed, and no significant mass wasting associated with roads was noted during our field surveys on State or Federal ownerships. However, some slumping and landsliding is clearly evident along the Middle

Fork on air photos, and watershed residents suggested during public meetings that mass wasting in this area may be exacerbated by roads. These areas are on private lands that were not accessible to the researchers for this study.

3.3 Direct Channel Disturbance

Significant changes in channel planform have occurred from the Forks Alluvial Fan downstream over the past few decades. We mapped the channel on 1939, 1966 and current aerial photography (Figure 3-4). Over this period, the most significant channel changes occurred in the Lower Alluvial Fan and Forks Alluvial Fan landforms. Channel length decreased substantially in the Lower Alluvial Fan during this period, primarily due to direct alteration during gravel mining and highway and urban development (Table 3-2). Although the channel length did not decrease in the Forks Alluvial Fan, mapping shows that the channel was highly dynamic. We also surveyed the channel from the Forks Alluvial Fan downstream for the presence of eroding streambanks. Similar to the changes in channel planform over time, the distribution of eroding banks is highly concentrated in the Lower Alluvial Fan and the Forks Alluvial Fan (Figure 3-5).

Cold Creek in these two landforms units has become significantly less stable over time. Two lines of evidence suggest that instability is the result of direct modifications to the stream channel rather than changes in watershed condition or other factors. First, if channel destabilization were due to degradation of the upper watershed and resulting hydrologic or sediment impacts, all of the lower-gradient alluvial channel would likely respond similarly, which has not been the case. Major channel adjustments have been primarily restricted to only two of the landform units. Second, the most highly unstable channel is closely associated with the two major channel modifications; the railroad culvert, and the reach channelized for gravel mining and development.

To assess the geomorphic function and stability of the channel from the Forks Alluvial Fan downstream, where direct disturbance of the channel has been most prevalent, we surveyed a number of cross sections, concentrating on areas of known disturbance and channel instability, and performed a hydraulic and sediment mobility analysis. These results are presented in the next section.

Table 3-2. Changes in channel planform characteristics over time.

	Length (m)				Sinuosity			
Landform	1939	1966	2005	Percent Change	1939	1966	2005	Percent Change
Donner Creek Meadow	2,526	1,673	1,661	-34.2%	1.32	1.04	1.03	-21.8%
Lower Alluvial Fan	1,116	1,009	1,040	-6.9%	1.15	1.08	1.12	-2.9%
Mainstem Canyon	946	976	958	1.3%	1.11	1.15	1.13	1.3%
Canyon Transition	858	833	878	2.4%	1.10	1.06	1.12	2.4%
Lower Valley	1,405	1,483	1,373	-2.2%	1.29	1.37	1.26	-2.2%
Upper Valley	1,963	1,970	1,966	0.2%	1.25	1.26	1.26	0.2%
Forks Alluvial Fan	1,034	1,067	1,043	0.9%	1.02	1.05	1.03	0.9%

3.3.1 Hydraulics and Sediment Transport

Hydraulic analyses were performed at 15 surveyed cross-sections in order to assess the relationship between the channel and adjacent floodplain, and to evaluate sediment transport by the stream during peak flows. The analysis provides a perspective on the relative stability of the channel, and possible trends or potential for incision or aggradation. Figure 3-5 shows the locations of the cross sections.

The U.S. Forest Service (2005) WINXSPRO computer program was used to compute a stage-discharge relationship using Manning's equation at each cross-section, based on the surveyed cross-section, local stream gradient, and the estimated Manning's "n" value (range over the range of stage. At each cross-section, the flood flow estimates for the 2, 5, 10, 20, 50, and 100 year recurrence interval events were made by linear interpolation based on drainage area at the cross-section versus the drainage area for the entire watershed at its confluence with Donner Creek. Cross-sections 1-3 are on Donner Creek below the confluence. Flood flow estimates there were derived using the same log Pearson Type III probability analysis as described above, using the 14 annual peak observations at the Highway 89 gauge. The estimated 100-year flood on Donner Creek is 4,800 cfs, compared to the range of 2,300 to 3,000 cfs for Coldstream Creek alone.

In a few instances there was a debris line in the streamside vegetation from which the approximate peak stage during the December 31, 2005 peak could be documented. This provided for a single "known" value on the computed stage-discharge relationship from which the "n" value in the Manning's equation could be estimated. In general, however, the computed stage discharge relationship was derived through an "n" value based on professional judgment.

The discharge associated with a particular stage is determined from the computed stage-discharge relationship. This type of analysis is approximate. There are many potential sources of errors, including estimation of stream gradient at high discharges, which was determined during low-water conditions, and the assumed range of "n" values. The "n" value can change with the season, being much lower during the winter, when smooth snowbanks confine the flood flows, as opposed to late spring when the flows are in full contact with riparian vegetation. The stage-discharge relationship is often directly affected by downstream woody debris, which can lower the hydraulic gradient, and thus give the channel much less capacity. Although there are several potential sources of error, this type of analysis is nonetheless valuable for evaluating larger trends in channel form and function. Cross sections and the estimated stages for flows of 2-, 10- and 100-year recurrence intervals are shown on Figures 3-6, 3-7, 3-8 and 3-9.

Examination of the sections shows that, in many locations, larger floods are carried entirely within a fairly small channel, and do not access a larger floodplain. While this channel morphology might be expected in areas where geologic constraints occur, such as steep canyons, it is not typical of more alluvial landforms such as alluvial fans and floodplains, where the 100-year floodplain tends to be far wider than the main stream channel (Rosgen 1996). High confinement of larger floods is often indicative of human disturbance (channelization, levees, etc.) or substantial incision. To evaluate the degree of channel confinement, we calculated the ratio of the width of the channel during a 100-yr flood to the width of the channel during the 2-yr flood. Higher ratios are reflective of the broad floodplains typically found in highly alluvial environments, while lower ratios are reflective of highly confined areas. Where confined sections are found in highly alluvial landforms such as fans or broad valley floors, human disturbance or incision may have occurred.

The streambed mobility analysis was performed by taking a 50-point pebble count of the streambed material within 20 feet above and below the cross-section. A "percent finer" plot was then prepared (Rosgen 1996). For the analysis, the median and eighty-fourth percentiles (D50, or the particle that is larger than 50% of the sample, and D84, or the particle that is larger than 84% of the sample) were used, and the approximate recurrence interval associated with the flow that resulted in incipient motion is reported. In general, streambeds are composed of a wide range of materials, but it is the larger materials, such as the D(84) and larger, which control complete mobility of the streambed. Once these larger sizes are mobile, then the channel can easily change its shape. Channels which are resistant to change from, for example, the routine snowmelt peak flows, may have their median size mobile, but the larger materials will remain in place. Channels that are actively aggrading or are braided may have their D(84) mobile during flows with low recurrence intervals.

For the mobility analysis, a number of equations were initially considered. Two equations based on velocity were discarded because they tended to give results which showed high stability of small materials (Bureau of Reclamation 1984). However, the modified Shields equation and the original Shields formula were used, and the average of the two was used to compute the maximum grain size stable at a given flow (Bureau of Reclamation 1984; Kappesser 1991). It is important to recognize that bedload transport is an extremely complex physical process. A number of equations have been developed and each tends to work best in a specific set of circumstances. The results reported here should be considered good quantitative first approximations. The flows considered in the analysis were the 2, 5, 10, 20, and 50 year recurrence interval floods. No attempt was made to interpolate between these values for the mobility analysis.

Table 3-3 below gives the results of the hydraulic and streambed mobility analysis. Though variability among sections is high, as is typical of natural systems, some important themes are apparent. These are described in following sections, by landform.

3.3.1.1 Lower Alluvial Fan

Cross sections 1 through 11 are in the lower alluvial fan landform, from downstream to upstream (Figure 3-5 shows the locations of all sections). Sections 1 to 3 are below the confluence with Donner Creek; the Teichert bridge is located just upstream of Section 7.

In the lower portion of the landform (Sections 1-6, 8), the D84 particle on the streambed tends to be immobile in all but the largest floods, suggesting that much of the streambed sediment was deposited during these events. In the upper portion of the landform (Sections 7, 9-11), which is steeper and has a higher capability to transport sediment, the D84 particle is mobilized during much smaller floods. Given that the streambanks are highly unstable, these data suggest that sediment may be eroded and transported from the upper portion of the landform, and this sediment tends to be deposited, especially during large floods, in the lower portion.

Table 3-3. Hydraulic characteristics of measured cross sections.

Cross-Section Number	Landform	Width @2-yr Recurrence Interval	Width @100-yr Recurrence Interval	Ratio 100-yr Width/2 -yr Width	D(50) Particle Size Becomes Mobile at	D(84) Particle Size Becomes Mobile at
1	Lower Alluvial Fan	45	66	1.47	Q2	Q100
2	Lower Alluvial Fan	60	125	2.08	Q20	Q100
3	Lower Alluvial Fan	71	138	1.94	Q10	Q100
4	Lower Alluvial Fan	45	205	4.56	Q20	Q100
5	Lower Alluvial Fan	100	160	1.6	Q50	Q100
6	Lower Alluvial Fan	62	135	2.18	Q5	Q50
7	Lower Alluvial Fan	45	65	1.44	Q2	Q5
8	Lower Alluvial Fan	33	65	1.97	Q20	Q100
9	Lower Alluvial Fan	39	63	1.62	Q2	Q5
10	Lower Alluvial Fan	43	64	1.49	Q2	Q2
11	Lower Alluvial Fan	55	93	1.69	Q2	Q10
12	Lower Valley	54	>200	>3.7	Q2	Q20
13	Upper Valley	68	120	1.76	Q2	Q2
14	Forks Alluvial Fan	35	43	1.23	Q5	Q50
15	Forks Alluvial Fan	42	>200	>4.76	Q2	Q20

The 100-year floodplain width is very narrow in the upper portion of the landform, from Section 7 (just downstream of the Teichert bridge) upstream. In this area, which has been channelized, the narrow floodplain is maintained by rip-rap and by the constraint of the narrow bridge. With the exception of Sections 1 and 7, the 100-year floodplain is at least twice as wide downstream of the Teichert bridge. The width of Section 1 has been effectively constrained by massive rip-rap, while width at Section 7 is constrained by rip-rap protecting the bridge. At the other lower sections, the higher 100-year width is likely the result of widening since channelization. Widening occurs in areas without bank protection when coarse bars are deposited during the largest floods; the bars force flow into adjacent streambanks, causing substantial lateral erosion. This process is especially active just upstream of the Donner Creek confluence in Sections 4 and 5, where backwater caused by Donner Creek has led to the development of a coarse bar at least 100 ft. wide.

3.3.1.2 Lower Valley

Section 12 was surveyed in this landform, near the upper end of one of the large gravel pits (Figure 3-5). It was placed in this location to evaluate the potential for capture of the pond during larger floods. Flow becomes essentially unconfined on the substantial right bank floodplain at about a 20-year recurrence interval (Figure 3-8), at least six feet below the stage required to overtop the berm separating the creek from the gravel pit. Though there is some erosion on the left bank, toward the gravel pit, it is not likely that the stream will capture the pit by overtopping the berm.

Hydraulic and sediment transport characteristics of this section are typical of alluvial floodplains. Much of the streambed consists of sediment moved during relatively frequent flows, though the largest particles are only moved during rain-on-snow type events, a characteristic shared by many mountainous streams in the Tahoe region (Hydro Science and River Run 2005). A high ratio of the 100-year to 2-year widths shows that the stream is relatively unconfined, which is typical of alluvial streams on recently-formed floodplains.

3.3.1.3 Upper Valley

Section 13 is located near the middle of this landform, just downstream of the upper part of the landform, which has become highly unstable. It has a very wide 2-year channel, comprised of sediment moved during relatively frequent floods, suggesting that it is actively aggrading. The 100-year floodplain is only moderately wide, which may be due to confinement by glacial outwash terraces or natural levees.

3.3.1.4 Forks Alluvial Fan

Section 14 is located downstream of the railroad culvert, and Section 15 is located upstream. The differences in hydraulic characteristics between these sections are striking. While both sections are relatively narrow at the 2-year recurrence interval, Section 15 is wide at the 100-year flood stage. Section 14, on the other hand, is extremely narrow during the 100-year flood—the narrowest of all surveyed sections. The streambed is also coarser at Section 14, with a substantial portion of the bed that does not move until the 50-year flood. Streambed mobility may even be lower, as our field surveys noted that the bed is highly cemented.

3.4 Geomorphic Impacts of Human Disturbance

With this background, the geomorphic impacts of human disturbance on the stream channel and floodplain are described, by landform, in the following section.

3.4.1 Upper Cirques and Valley Wall Tributaries

Prior to human disturbance, these areas exported sediment. Floodplains were limited in extent, and the channel was likely fairly erosive and dynamic. Human disturbance has probably increased sediment and water supplied to the channel to some extent during certain periods in time but, because the channel was already relatively dynamic, these changes have had a minor effect on geomorphic processes. There has been little recent human disturbance in these areas.

3.4.2 Confined Tributaries

In these landforms, floodplains are relatively narrow and consist of poorly sorted glacial, glacial-fluvial and more recent fluvial sediments. Over the past several thousand years, the stream channels have been reworking valley floor sediments resulting from geomorphic processes other than stream transport; either glacial deposits, or sediment eroded from glacially-steepened adjacent hillslopes, and channel erosion rates have therefore been typically high. In a few discrete locations, particularly in the Middle Fork, adjacent valley walls are also unstable and prone to mass wasting. Smaller landslides are probably relatively common during large storms, and may contribute substantial quantities of both coarse and fine sediment directly to the stream channel.

Within this landform, we surveyed road systems in much of the Emigrant Fork and the highest portions of the South Fork. Roads have been constructed in all of these drainages, often near the channel. In a few locations, roads have diverted drainage, resulting in erosion and gullying. Although this erosion has contributed sediment to the channel (with potential ecologic effects downstream), it has had relatively little effect on channel geomorphic function given the high rates of channel erosion and dynamics prior to human disturbance.

Extensive roading has also occurred in the Middle Fork, in areas more prone to mass wasting. We were unable to review these areas, which are on private land. It is possible, given the density of roads, that roading has exacerbated mass wasting. Aerial photo analysis suggests that mass wasting is a component of natural function in this area; increases in rates of mass wasting therefore probably have limited geomorphic consequences for the stream channel when considered over long time-scales. However, the amount of sediment transported to the channel by individual slides can be large and have substantial effect on short-term geomorphic function, and may have biological consequences downstream as well.

3.4.3 South and Emigrant Fork Canyons

Inner gorges of these landforms are exceptionally steep and thus have seen little direct human disturbance. It is possible that upstream watershed disturbance has increased the sediment supply to these landforms, or increased the size of floods. However, such changes would have little effect on channel morphology or geomorphic function in these areas, where the channel form is reflective of long-term fluvial response to glacial erosional and depositional patterns or larger-scale geologic processes such as faulting. The channels tend to have resistant boundaries composed of boulders, and high sediment transport capacity due to high slope and confinement. The changes in sediment supply or hydrology due to human disturbance are not of sufficient magnitude to have significant effects on channel morphology or geomorphic processes.

3.4.4 Forks Alluvial Fan

Prior to disturbance the Forks Alluvial Fan was a depositional and transitional landform. Channel patterns in the upper portion were straight and the channel was dynamic due to deposition of coarse sediment. The channel became somewhat more meandering in the downstream portion, as the available sediment was reduced by deposition above. Given that this is a transitional landform, the downstream boundary cannot be defined exactly. A 1919 photograph of the area suggests that the fan extended well downstream of the Emigrant Fork confluence based on the presence of drier vegetation types on the surrounding floodplain (Figure 3-10). For this study, we have placed the boundary fairly far downstream, where a significant change in channel character occurs today. The railroad was constructed across this landform in the middle portion.

Current channel function upstream of the culvert (Section 15, Table 3-3) is likely reflective of historic landform geomorphic processes, prior to human disturbance. During large floods, the floodplain is very wide. Our hydraulic analysis also suggests that the channel is depositional, as the median particle diameter is mobile at relatively frequent flows. These functional characteristics certainly extended downstream prior to construction of the culvert.

The railroad culvert cut off the floodplain and forced all flood flows through a relatively small opening, greatly increasing erosive power in the channel downstream and causing incision. It is also possible that the stream captured a road downstream of the culvert; the channel is suspiciously straight in the 1939 photograph (Figure 3-11). Whatever the sequence of events, human disturbance has caused very substantial channel incision; the streambed has degraded by about four to five feet below the culvert based on the elevation difference between the floor of the culvert and downstream apron above the incised channel. Maintenance activities have likely reinforced incision. We found evidence of channel clearing for the first 1,000 feet or so downstream of the culvert, probably carried out to remove sediment and maintain channel capacity. Excavated material was placed in berms on both sides of the channel, further reinforcing incision.

The resulting channel, as noted in the previous section, is very narrow (Section 14, Table 3-3). Incision appears to have occurred into very tightly packed and welded alluvial sediments, probably of outwash origin, and the channel bed has armored. As a result, the incised channel is highly resistant to erosion and, because it is incised and narrow, retains a very high sediment transport capacity. The net effect on sediment transport at the site of the culvert has been to transform the area downstream, which was historically depositional, into a reach capable of transporting all sediment supplied to it, essentially extending the zone of coarse sediment transport further down the valley into the Upper Valley landform. It is important to note that the process of destabilization and incision also sent a large quantity of coarse sediment downstream.

Effects of the narrow railroad culvert extend upstream as well. During floods, some sediment is stored just upstream of the culvert due to backwater created by the narrow opening (Figure 3-11). This sediment, which was probably historically distributed across the floodplain in the lower portion of the landform, creates problems with maintenance. There is evidence that channel clearing has been undertaken in this area after larger floods in the past. In the absence of clearing, the large sediment bars are probably slowly eroded during smaller floods, transported through the culvert, and from there through the incised channel downstream to the Upper Valley landform.

As the channel has incised downstream of the culvert, another important effect of the culvert has been to protect the channel and floodplain upstream from destabilization. Reduction of base level caused by incision downstream would result in substantial channel incision upstream if the concrete and stone culvert were not holding grade. Removal of the culvert and floodplain embankment, without addressing channel incision downstream, would cause substantial erosion and channel incision upstream.

3.4.5 Upper Valley

Based on the meandering planform of the channel within the Upper Valley landform, it was not historically supplied with high quantities of coarse sediment (see Figure 2-14). Incision of the channel downstream of the railroad culvert, directly upstream of this landform, generated a great deal of coarse sediment to this area. Furthermore, the railroad culvert transformed the lower portion of the Forks Alluvial landform into a transportation rather than depositional reach, and additional coarse sediment from the upper portion of the watershed is now transported into the Upper Valley. These changes, which have introduced a large supply of coarse sediment to the meandering channel in this landform, have led to dramatic instability (Figure 3-11). The instability has progressed slowly downstream over time (Figure 3-11), driven by substantial channel dynamics during large rain-on-snow floods, when coarse sediment is transported and erosive power is high.

Channel instability in this area is extremely high, with large-scale changes in cross section and planform during larger rain-on-snow storms. Cross sections repeated over time by California State Parks near the upstream end of the landform show that individual locations are both laterally and vertically unstable, aggrading in some events and degrading in others (Figure 3-12). High rates of erosion produce large quantities of sediment from within the reach, much of it coarse, which contributes to instability. Instability will continue in the reach for the foreseeable future as the channel adjusts to the sediment supply available from both the upper watershed and sediment produced by channel adjustment within the reach. The net effect has been to convert a landform which was likely neutral in terms of sediment deposition and erosion prior to human disturbance into a landform which primarily exports sediment.

Part of the destabilization in this area may also be attributable to impacts on upper watershed condition. As the highest landform in the watershed with a broad alluvial floodplain, the Upper Valley is likely particularly sensitive to changes in water and sediment supply resulting from watershed degradation. Aerial photo series suggest that much of the destabilization in this reach began to appear around the time of the 1966 photo, a time when watershed condition was particularly low. However, it is important to also note that channel instability is also highly correlated with larger rain-on-snow floods, at least three of which occurred between 1955 and 1964. Large floods, occurring during a period of low watershed condition, certainly caused substantial erosion.

While watershed condition was likely a factor in the progression of channel destabilization in the Upper Valley, it is highly unlikely that it was the primary or causative factor. As noted earlier, the destabilization is highly correlated spatially with substantial channel modifications associated with the railroad, suggesting that the channel modifications created the conditions for destabilization downstream. Moreover, if degraded watershed condition was primarily responsible for channel destabilization, channel within the entire broad alluvial valley in the middle of the watershed would likely have become unstable, which has not occurred.

Note that between 1983 and 2005, the destabilized reach in the Upper Valley eroded dramatically (Figure 3-11); most of this erosion occurred during the 1997 flood, when the channel moved by nearly 100 ft. in some locations, threatening a historic portion of the Emigrant Trail on State Parks land (Cynthia Walck, California State Parks, personal communication). Our cumulative watershed analysis showed that watershed condition had improved considerably by 1997, yet massive channel erosion still occurred.

Clearly, improvement in upper watershed condition will have little effect on channel erosion in this area. During large floods, the culvert still concentrates flood flow and sediment transport to the destabilized reach. Probably just as importantly, increases in channel area and depth within the destabilized area itself have been great enough that the current channel form is intrinsically erosive. Channel morphology has crossed a threshold in terms of the geomorphic processes which it can support; the channel is now fundamentally erosional, and will only become depositional and eventually stable over time after going through the several stages of the incised channel evolution model (Schumm 1999, described in the Lower Alluvial Fan section, below).

The cycle of erosion started at the upper end of the Upper Valley may have effects on downstream areas, as the sediment generated by high rates of erosion is transported downstream. There is some evidence that this effect may have already occurred; the upper end of the Lower Valley appears to have become more unstable since 1939 (Figure 3-11). Continued instability in the Upper Valley has the potential to cause instability downstream.

Channel response to increased sediment supply is highly variable. The surveyed cross section in the Upper Valley (Section 13, Figure 3-5), which is directly downstream of the destabilized reach and is receiving elevated levels of sediment from it, is actively aggrading with very little erosion. The net effect is that much of the sediment generated from destabilization upstream is being stored in this area, far different than the highly erosional response of the destabilized reach upstream. The depositional response appears to be due to extremely stable and erosion-resistant streambanks. We speculate that geological factors are creating a high groundwater table, which results in dense riparian vegetation highly resistant to erosion.

A substantial dam and reservoir are visible near the lower end of this landform in the 1939 photograph (Figure 3-11), fairly recently dewatered. Remnants of the dam were easily identified during our field surveys. This structure was likely a pond for one of the early mills in the Coldstream Valley. Within the reservoir, the channel form had been basically obliterated by 1939, through sediment deposition and loss of riparian vegetation. Over the sequence of aerial photos in Figure 3-11, bare ground within the reservoir has been reduced, and the channel has become well-established, a trend which continued through the 1997 flood. While there is still bank instability within the former reservoir, this area is restoring itself over time.

The dam in this area interrupted sediment supply, but the effects were apparently minor for downstream reaches. In 1939, the channel downstream of the reservoir area appears very stable. Because the dam was constructed in a fairly broad alluvial floodplain, where erosion and deposition were essentially in balance and sediment export rates were low, interruption of sediment transport by the dam apparently had little effect downstream.

Near the boundary between the Upper and Lower Valley landforms, a small dam in the main channel is visible on aerial photographs. We were unable to survey this area for this project, and the specific function and nature of this structure are unknown. It appears to be controlling a substantial amount of grade, and its failure would therefore have significant consequences for channel stability upstream. Stability of this structure should be evaluated, if possible, and the effects of removal or modification carefully evaluated for potential upstream and downstream impacts.

3.4.6 Lower Valley

Channel stability is generally high throughout this landform, with the exception of a few eroding streambanks near the upstream end (Figure 3-5). We were unable to obtain access to the uppermost portion of this reach, however, which includes the instream dam. Bright signatures on aerial photographs suggest that the streambanks are highly unstable in this area. Instability in the upper portion of this landform may represent a response to increased sediment supply from upstream erosion.

Large gravel pits were constructed on the north side of the valley floor in this landform. As discussed in a previous section, these pits mined glacial outwash terraces and did not occupy the modern floodplain. In a few locations, however, the pits border the modern floodplain. A low levee or berm was constructed along the edge of the pits to keep the creek out of the pits. Currently, the channel has moved into the berm in a couple of locations. One of our surveyed sections, Section 13, was placed in one of these locations, where the creek comes closest to the upper pit. Hydraulic analysis of this section showed that the channel and floodplain function as expected in this geomorphic environment, and capture of the pit is unlikely by overtopping of the berm. However, it is possible that the stream may continue to erode the berm; stabilization in limited areas should be considered.

During most of the year, the gravel pit ponds are a closed system hydrologically, with no outflow. Typically, there is limited outflow during snowmelt; based on observations by the project team and by State Park personnel, snowmelt discharge is less than one cubic foot per second (cfs) and is generally clear. However, higher outflows have been observed during severe rain-on-snow storms in the winter season (November to April). For example, members of the project team observed the area during a large storm on December 31, 2005. Rill and small gully erosion was common along the steeper, north slopes of both ponds and both ponds were turbid.

Erosion observed during these larger storms is mostly due to human watershed disturbance. Rills and gullies active along the north slope of the ponds are due to drainage alteration by the main Coldstream Canyon road above them, as well as the instability created by excavation of the slopes during gravel mining. The ponds therefore buffer Cold Creek from fine sediment resulting from human disturbance. Much of the sediment eroded from adjacent hill slopes is probably captured by the ponds, and this sediment has helped build soils in the gravel-mined areas. However, during larger storms, turbid water has been observed leaving the lower pond, exporting fine sediment to the Cold Creek floodplain and channel. Improving soil depth and organic content around the ponds would help improve infiltration capacity, and would reduce the export of turbid water. Also, increasing the density of wetland and riparian vegetation would improve the ability of the area to filter and store fine sediment eroded from adjacent uplands.

3.4.7 Canyon Transition

There has been little direct modification of the channel in this area. It is relatively confined between adjacent outwash terraces, and it therefore somewhat less responsive to changes in sediment supply or hydrology. It has been buffered from more dramatic channel changes upstream by the Lower Valley landform. It also has substantial woody debris supply, which tends to buffer it as well. Although there are spots of streambank instability, we did not note obvious human disturbance influence during our surveys.

3.4.8 Mainstem Canyon

As for the upstream canyons, the main determinants of channel form and geomorphic processes in this area are longer-term glacial and geologic processes. The extremely coarse, steep and confined channel is extremely resistant to changes resulting from human disturbance, and there is no evidence that human disturbance has substantially altered channel form or function.

3.4.9 Lower Alluvial Fan

Prior to human disturbance, the channel and a fairly wide floodplain were likely entrenched within the fan. The bulk of the fan was constructed during glacial periods of high sediment yield. The modern channel has entrenched somewhat within the older, glacial deposits. The extent of the floodplain in 1939 can be estimated from vegetation characteristics and is drawn on the 1939 photograph in Figure 3-13. The 1939 photograph also shows that the lower portion of the reach had a meandering planform. Multiple channels near the upstream end of the reach suggest that the stream was dynamic at the mouth of the canyon, and may have abruptly switched locations, possibly during large floods, while depositing substantial quantities of sediment.

This landform has seen extensive human disturbance. Figure 3-13 shows the same area in 1939, 1966 and 2005. In 1939, a large, recently active dam is visible just downstream of the confluence with Donner Creek. Starting around 1960, much of the floodplain was mined for gravel and the stream was channelized throughout most of its length. Donner Creek was also channelized downstream of the historic confluence with Coldstream Creek to make way for the highway. Much of the former floodplain, especially around the Donner Creek confluence, has been occupied by development.

These disturbances, and subsequent channel response, have led to substantial changes in the channel and floodplain over time. Figure 3-14 depicts changes over time at a generalized cross section of the floodplain (see Figure 3-13 for the location of this section). In 1939, prior to human disturbance, extensive floodplain allowed for dissipation of energy during larger floods. In the mid-1960's, following channelization, the channel no longer had access to a floodplain. Much of the former floodplain was likely mined and filled, and the straightened channel had also likely incised somewhat. Streambanks were very high, and even the largest floods were carried entirely within the channel, creating enormous erosive stress on streambanks. Since channelization, extensive streambank erosion and deposition of coarse gravels bars, particularly during large floods in 1964, 1997 and 2005, has created a new inset floodplain in the current channel. Several erosional features are clearly visible on the 1966 photo (Figure 3-13), taken shortly after the 1964 flood. A large section of Deerfield Drive was lost in this flood.

The new floodplain is being created by an identifiable set of geomorphic processes. As the high streambanks retreat during erosion, large cobbles and boulders are left behind. These larger materials are common in the banks, which are composed of older outwash deposits created during glacial periods. The coarse bars created by this process are rapidly colonized by riparian shrubs and become new floodplain. Some of the larger material is transported downstream during large floods, where it tends to be deposited in wider reaches or in developing bars., thus reinforcing floodplain development. Much of the channelized reach today is wider than when originally constructed due to erosion, but is still far narrower than prior to human disturbance. In most locations, new floodplain is covered by dense riparian vegetation, including mature cottonwood trees, and provides excellent habitat.

In the upstream portion of the landform, active widening is currently occurring during larger floods. Very high streambanks are continuing to fail as the stream constructs a wider floodplain (Figure 3-14). This reach is now highly erosional and a significant source of sediment, both finer sediment that impairs water quality, and coarse sediment transported as bedload. This coarse bedload causes streambank instability downstream where it is eventually deposited in large bars. In fact, much of the coarse bedload deposited near the Donner Creek confluence in the 1997 flood probably came from this area.

In the lower part of the landform, recent widening has been relatively slow, as remaining streambanks are rip-rapped and a great deal of widening has already occurred. A narrow bridge in this reach disrupts coarse bedload transport, however. During the 1997 flood, a large bar of coarse sediment was deposited several hundred feet upstream of the bridge due to the flow constriction. Although this deposit did not cause substantial bank erosion and widening, it reduced overall channel capacity and may lead to flooding or streambank erosion and widening in the future. Also, because the bridge is so narrow and causes ponding upstream, the bar that formed during the 1997 flood is extremely high, relatively dry, and in many places has not been colonized by riparian vegetation.

Although the bridge interrupts coarse sediment transport to a certain extent, it is important to note that this highly incised lower reach still has high transport capacity compared to the original meandering channel in this location and is capable of transporting large quantities of both fine and coarse sediment. In terms of sediment yield, human disturbance has caused the Lower Alluvial Fan to transition from a landform which tended to store sediment (Table 2-2) to one in which sediment is created and exported.

Export of sediment, especially coarse sediment, has negative consequences for downstream reaches. Much of the coarse material has been deposited in a large, coarse bar just upstream of the confluence with Donner Creek (visible on the 2005 photo in Figure 3-13). During channel surveys, we noted large bar forms composed of coarse sediment in the straight channel well downstream of the confluence (Figure 3-14). While this reach is heavily rip-rapped, and coarse sediment is not causing the channel to widen, the lobular form of these bars indicates that they are actively moving downstream, where they have the potential to cause instability.

Models of incised channel evolution predict that, where banks have not been stabilized with rip-rap, widening and sediment export is likely to continue in the future. Simon et al. (2004) and

Schumm (1999) present similar conceptual models for evolution of incised river systems Incision is driven by land use changes, such as channel straightening, that increase the erosive capacity of the channel with respect to its bed (Stage 2). In Stage 3, the channel begins to incise its own bed due to increased erosive power in the larger channel. As incision progresses, the surrounding floodplain becomes drier and riparian vegetation is lost, decreasing bank stability. In Stage 4, an increase in streambank height, increased shear stress at the toe, and reduced vegetative stability lead to widening in addition to continued degradation. Progressive widening will eventually create conditions conducive to aggradation (deposition and increase in elevation of the streambed), both by producing excess sediment through erosion and through reduction in sediment transport capacity in the wider, shallower section. In Stage 5, widening slows and aggradation becomes the dominant process, with the eventual formation of a new floodplain, typically at a lower base level (Stage 6). This conceptual model has been extensively peer-reviewed and is widely accepted among researchers and managers of incised channels.

Shumm (1999) notes that once incision begins, evolution through the entire sequence is likely to occur in the absence of intervention. Most of the channel in this landform is in Stage 3, and will continue to widen without intervention until a floodplain approximately similar to the pre-disturbance floodplain is created.

3.5 Human Disturbance and Sediment Production

The Truckee River has been listed on the California 303(d) list as impaired by sediment. The Desert Research Institute (DRI) undertook a study to assess the various possible sources of sediment entering the Truckee River (McGraw et al. 2001). The study used available suspended sediment data from various Truckee River and tributary gauging stations to develop sediment rating curves, from which total suspended sediment load was computed. This was done based on sediment and discharge measurements for 1996 and 1997. They also used the AnnAGNPS watershed model to assess sediment loading and evaluate how changes in land use might reduce sediment loading into the Truckee River. Several observations from this study highlight the importance of the Coldstream Canyon watershed for sediment supply to the Truckee River system.

There are no suspended sediment data available for Cold Creek. However, 22 suspended sediment samples were available for Donner Creek at the Highway 89 gauge. The sediment rating curves and raw data were not supplied, so it is difficult to assess the accuracy of the derived sediment loads. However, sediment load is highly correlated to streamflow, so a lack of suspended sediment measurements during floods, which often produce the vast majority of the annual sediment load, can have a have a large impact on the accuracy of this technique.

Because nearly the entire watershed area for Donner Creek above its confluence with Cold Creek must flow through Donner Lake, which has a large surface are and a maximum depth of over 300 feet, most sediment from the Donner watershed is likely trapped in the lake. As a result, nearly all of the suspended sediment measured at the Highway 89 gauge is from Cold Creek. At times, there is undoubtedly some limited contribution from the local area tributary to the creek between the gauge and the Coldstream confluence. This is most likely associated with the delivery of road abrasives, primarily during the winter and early spring. Nonetheless, Donner Creek at Highway 89 is a reasonable proxy for Cold Creek itself with respect to suspended sediment concentrations.

Figure 3 from the DRI report is shown on our Figure 3-15. It displays the modeled average annual suspended sediment load from the principal tributaries. We assume that since the values displayed are the predicted sediment inputs associated with application of the AnnAGNPS model, they represent the total sediment delivered to the creek. As a result, the Little Truckee River is shown as by far the greatest contributor of sediment to the Truckee River. In fact, however, the actual contribution to the Truckee River from the Little Truckee is low, since most of the upland sediment generated within the Little Truckee River watershed is trapped in Stampede and Boca reservoirs. Although the watershed downstream from Boca may contribute some sediment, it is very minor in area; the outlet from Boca is only 2,000 feet from the Truckee River. We suspect the same holds true for the predicted sediment yield from Prosser Creek. Given that sediment from these watersheds is trapped in the reservoirs, Donner Creek, and thereby Cold Creek, is the largest contributor of sediment to the Truckee River based on the analysis performed by DRI.

Figure 3-15 also shows Figure 12 from the DRI report. It displays the predicted annual sediment loads normalized by drainage area on a log scale, based on sediment samples taken at stream gauges. The drainage area for the Donner Lake gauge is 29.1 square miles. However, the drainage area for Cold Creek, which is approximately 12.5 square miles, represents nearly all of the sediment loading, such that the approximate sediment load for Cold Creek approaches 2.3 times that reported for Donner Creek, giving it a loading rate of 209 tons/square mile. As such it is one of three principal sediment producers into the Truckee River on a per unit area basis (Squaw Creek 309 tons/square mile/year; Grays Creek 226 tons/square mile/year).

3.5.1 Current Sources of Fine Sediment Loading

There are three principal sources of fine sediment (silts and clays) contributing to the degraded water quality of Cold Creek:

- natural erosion associated with steep glaciated volcanic topography that forms the headwaters and lower reaches of the principal tributaries,
- road erosion, dominantly from active roads, and
- streambank erosion

The first source of sediment, regardless of its magnitude, can be considered as background, since it is associated with natural processes and would be impractical to control. This includes sediment yield from steep, glaciated slopes with highly erodible geology, or yield from areas where natural fluvial erosion rates are high. Erosion from roads, on the other hand, is entirely preventable from the perspective of eliminating the delivery of fine sediment to the creek. A large proportion of the streambank erosion can also be considered anthropogenic in origin given the channelization of the Lower Alluvial Fan, and current rates of lateral instability in other areas, which appear to have been triggered by direct manipulation of the channel.

The flood of December 31, 2005 resulted in large scale erosion of streambanks and roads, primarily those at lower elevations. This provided an opportunity to estimate and compare the amount of erosion from both sources and to assess the relative importance of each during the type of event which is typically responsible for the majority of sediment yield from watersheds like Coldstream Canyon (Hydro Science and River Run 2005).

Streambank erosion, particularly within the valley, is a high concern for water quality because the upper portion of the streambank is often composed of a nearly uniform layer of sands and finer materials. The other important feature of streambank erosion is that all of the sediment eroded from the streambanks is delivered directly to the creek and entrained in the flow, although there may be opportunities for subsequent deposition, which holds true regardless of the sediment source. This differs markedly from the physics of sediment delivery from a road, which may be located hundreds of feet from any tributary capable of transporting it to the creek. Typically, when roads are far away from the creek, much of the sediment eroded from the road is deposited in intervening areas before it reaches the creek. Where the road is immediately adjacent to the channel, most sediment from the road is delivered directly to the channel.

For this assessment, we computed the load of fine sediment delivered to the creek from streambank and road erosion. For the streambanks, we surveyed the entire channel up to the railroad crossing at the upper end of the valley. Streambank lengths of less than 50 feet were not recorded since eroding reaches of less than 50 feet are typically associated with woody debris or natural channel dynamics. Eroding reaches were identified through the comparison with pre-flood aerial photographs, and from the fresh exposure of roots. At each location, the length, height and thickness of the eroded material was measured. We also classified the streambank material by the percent of gravel and cobble present and we also subdivided the height to account for vertical stratification of the material with respect to coarse fragments. We then computed the total mass of fine sediment, using the assumption that the silt and clay fraction composes 30 percent of the residual sand, silt, and clay after coarse fragments were deducted. Figure 3-5 shows the locations of streambanks eroded during the December 31, 2005 flood.

For the delivery of fine sediment from the road network, we relied primarily on a detailed survey of road erosion performed by California State Parks during the spring of 2006. The surveyed roads included most of the main road up the valley and roads on State Parks lands. Their survey recorded the varying depth and width of erosion over the road surface, which allowed for a volumetric calculation of erosion from each surveyed road. The survey covered 14.5 miles of road. Based on their survey data, the average eroded depth (weighted by road segment length) was computed to be 2.6 inches.

The amount of silt and clay was uniformly assumed to be 30 percent of the total eroded sediment. This probably results in an overestimation of the eroded fine sediment, since many of the roads are in rocky substrates. Finally a delivery ratio was estimated for each surveyed road, taking into account the location of the road, and the general condition of the area between the road and the nearest ephemeral drainage capable of conveying fine sediment to the main channel, and also considering the proportion of the road draining directly into a drainage channel. Field observations of rills and runoff patterns from runoff exiting the surveyed roads indicated that most sediment was deposited within 100 feet of the road and rarely entered a channel except where the road crossed one. The exception were the valley bottom roads, which were assigned delivery ratios up to 90 percent, in recognition of the fact that runoff from the roads was often conveyed only short distances to reach a channel.

The method described above provided an estimate of the sediment load delivered to the channel from the surveyed roads on CDPR lands. To account for erosion from the remaining roads, from private or federal lands, the total mileage of active roads was computed from the aerial photographs. Inactive roads are no longer used, typically have water bars or rolling dips, and are undergoing decompaction and revegetation through natural processes. They typically have dull photographic signatures, in contrast to known active roads, which have a brighter photographic signature. Inactive roads were assumed to be no longer actively eroding, and limited field observations confirmed this.

The total mileage of active roads was computed to be 25.4 miles. Most of the unsurveyed 10.9 miles of road is on the south side of the watershed at higher elevations and subject to only occasional traffic. Fine sediment eroded from these unsurveyed roads was estimated by taking the average eroded depth measured from the surveyed roads, and assuming a uniform fine sediment content of 30 percent, a delivery ratio of 10 percent, and an average width of 11 feet. Finally, an adjustment factor of 50 percent was applied to account for the observed lower rate of erosion on these roads.

We estimate that 990 tons of fine sediment was delivered to Cold Creek during the December 31, 2005 flood from streambanks, and 620 tons were delivered from roads. Streambanks accounted for 61 percent of the fine sediment and, based on this analysis, represented the primary source of fine sediment attributable to human associated disturbance. Road erosion nonetheless is still a major contributor. Erosion control measures should be considered for both sources.

4. Restoration Opportunities and Constraints

The previous section identified four areas in the watershed where human disturbance has impacted function and restoration opportunities exist: upland areas, the Forks Alluvial Fan and the Upper Valley, Lower Valley gravel ponds, and the Lower Alluvial Fan. In this section, restoration opportunities and constraints for these three areas are briefly explored. The primary objective of the restoration opportunities developed is to restore, to the extent feasible, natural rates of erosion, sediment yield, and channel stability.

Restoration opportunities were analyzed with respect to several factors:

- Geomorphic function and channel stability;
- Water quality improvement,
- Habitat improvement; and
- Construction feasibility.

In general, no significant constraints to restoration practices were identified in terms of special status plants and animals (see Appendices A and B). The various restoration opportunities and their constraints are described in following sections.

4.1 Upland Areas

Because this assessment occurred less than one year after a large storm on December 31, 2005, road and drainage concerns were readily apparent. We visually surveyed roads in most of the watershed to which we had access. Virtually all of the erosion problems in the upper watershed caused by human disturbance are related to roads. Many of the older skid trails from timber harvest are vegetated, stable and no longer a concern for erosion (Figure 4-1), although some may divert or concentrate flow in some areas. However, most of the roads that are recently or currently in use showed some evidence of localized flow diversion and erosion during the extreme 2005 event (Figure 4-1). These roads are often fairly steep and have berms that divert and disrupt natural flow patterns. They concentrate water, form rills, and fine sediment is eroded from their surfaces.

Disconnecting roads and other human features from the drainage network given the hydrology of Coldstream Canyon is a difficult problem. Many roads are poorly laid out and cross topographic contours, resulting in steep, confined areas that may require reconstruction to reduce erosion. Much of the erosion occurs after road construction or maintenance, when fine materials are removed from the surface. Most of the road network functions reasonably well during average annual conditions such as typical rainstorms or snowmelt. However, the rain-on-snow hydrology of the watershed assures the occurrence of far larger storms on decadal-time scales. Because these storms are so much larger, they present an entirely different set of design challenges. Most of the active roads in Coldstream captured drainage during the extreme December 31, 2005 storm (Figure 4-2). The resulting concentrated flows caused significant erosion. Drainage through the railroad embankment suffers similar problems during large storms; culverts clog and diverted flow often creates erosion (L. Hahn, personal communication).

There are several opportunities for dealing with the problems associated with roads and other drainage in the watershed:

- Road removal, topographic restoration and revegetation, if feasible candidates can be identified
- Upgrades of existing roads, including re-routing into more favorable topography, and improving drainage
- More regular road maintenance to remove berms and maintain and improve drainage.

The use of any of these measures at any particular location is a highly site-specific decision; all roads function differently depending on their topographic position. Regular maintenance of drainage dips may be adequate in low-relief locations, while re-design may be required where road alignment is across topographic relief. As noted by Gucinski et al. (2001), developing plans for improving road networks is an extremely complicated task that must consider social concerns as well as technical hydrologic issues. Such an analysis is beyond the scope of this assessment, but is recommended for the Cold Creek watershed, and should incorporate the following basic principles(from Gucinski et al. 2001):

- Locate roads to minimize effects; conduct careful geologic examination of all proposed road locations.
- Design roads to minimize interception, concentration, and diversion potential, including measures to reintroduce intercepted water back into slow (subsurface) pathways by using outsloping and drainage structures rather than attempting to concentrate and move water directly to channels.
- Evaluate and eliminate diversion potential at stream crossings.
- Design road-stream crossings to pass all likely watershed products, including woody debris, sediment, and fish—not just water. Regular inspection and clearing of crossings is necessary.
- Consider landscape location, hillslope sensitivity, and orientation of roads when designing, redesigning, or removing roads.
- Design with failure in mind. Anticipate and explicitly acknowledge the risk from existing roads and from building any new roads, including the probability of road failure and the damage to local and downstream resources that would result. Decisions about the acceptable probability and especially consequences of failures should be informed through explicit risk assessments. The many tradeoffs among road building techniques to meet various objectives must be acknowledged. For example, full bench road construction may result in lower risk of fill slope failure, but it also may increase the potential for groundwater interception; outsloping of the road tread may reduce runoff concentration on the road surface but also increase driving hazard during icy or slippery conditions.

4.2 The Forks Alluvial Fan and the Upper Valley

Restoration opportunities for these landforms are considered together as geomorphic processes are strongly linked. As described in previous sections, construction of the railroad culvert, with some influence from other watershed impacts, has resulted in incision of the channel in the lower

Forks Alluvial Fan. Though the channel in this area is currently relatively stable, it has been disconnected from the surrounding floodplain, and now effectively transports sediment from the upper portion of the watershed to the Upper Valley landform downstream. This sediment, and the sediment created when the channel in the lower portion of the Forks Alluvial Fan incised, has caused massive channel instability in the upper portion of the Upper Valley landform.

Stream and floodplain improvements in the Upper Valley landform are of high priority due to the extensive instability and high rates of erosion, and should have the objective of stabilizing the channel and reducing sediment production within the reach. Achieving these objectives would not only improve water quality and aquatic habitat but would help protect downstream reaches from becoming more unstable due to inputs of coarse sediment transported downstream from this area.

Ideally, restoration of the channel within the Forks Alluvial Fan would include removing the confinement of the railroad culvert and reestablishing the relationship of the incised channel downstream with the adjacent floodplain. This would have important geomorphic and ecosystem benefits. However, realizing these objectives in this complicated geomorphic environment will be difficult. Complete restoration of pre-disturbance function, considered below, may not be technically feasible, and would certainly be very costly and highly uncertain in outcome. Therefore, opportunities for more limited restoration of some of the pre-disturbance function are also described below; the last three alternatives focus on problems within the destabilized portion of the Upper Valley.

4.2.1 Complete Channel and Floodplain Geomorphic Restoration

Complete restoration of pre-disturbance geomorphic function would have several components. First, the current crossing would have to be replaced with a structure that allowed for not only flood access to the adjacent floodplain, but a substantial amount of channel dynamics, as the stream was historically fairly active. Second, the incised channel downstream would have to be reconstructed, for a distance of about 1,500 ft., with a raised bed. Finally, at least 2,000 ft of highly unstable channel in the upper portion of the Upper Valley would have to be reconstructed; as with the incised channel upstream, the streambed elevation would have to be raised. These measures, if successful, would restore historic channel and floodplain geomorphic function.

However, there are significant constraints to this approach. The first is cost. Construction of a railroad bridge or other structure capable of crossing the floodplain, several hundred feet wide, without impeding flow, would be very expensive. Reconstruction of the incised channel downstream of the culvert and in the destabilized portion of the Upper Valley would be very costly also; based on our experience with projects of similar scale in the area, design and construction costs would likely be in the range of at least $500 per lineal foot.

The second major constraint to complete geomorphic restoration is the technical feasibility of channel reconstruction. For the incised reach, which was historically in a depositional area, the technical challenge is to construct a channel that provides initial stability but is capable of storing sediment, with resulting dynamic function. While higher gradient, step-pool channels that transport all sediment supplied to them have been successfully constructed, the authors are aware of no successful complete restoration of a channel designed to mimic the sediment storage function of an alluvial fan.

Reconstruction of the disturbed channel in the upper portion of the Upper Valley also presents substantial technical challenges. The scale of destabilization in this range is dramatic (Figure 3-11, lower right). Again, we are not aware of a complete channel reconstruction project which successfully restored geomorphic and ecosystem processes in a similarly-disturbed environment. Among the technical obstacles to successful reconstruction are: bank stabilization, given the droughty setting, and the inevitable occurrence of a large rain-on-snow flood within five years of project completion; streambed stability, given the high energy environment and the potential for large-scale coarse bedload transport; and maintenance of water quality during and following construction, given the extent of grading and floodplain disturbance. These factors strongly suggest the complete restoration would be not only very costly, but a realistic appraisal of success would have to conclude that there is a very high level of uncertainty.

Because channel reconstruction is costly and risky, replacing the current culvert with a longer crossing to allow for floodplain function, but allowing the rest of the channel to adjust on its own, is a potential alternative for complete restoration. This will be a relatively slow process that will take at least decades to restore the historic channel characteristics. It is important to recognize that extensive erosion will take place, far in excess of current erosion rates. When the grade control of the current structure is removed, a head cut, between five and ten feet in depth, will make its way upstream for at least several hundred feet. Coarse sediment generated by this erosion may help fill the incised channel downstream, but this process will likely occur in unpredictable ways with substantial lateral erosion and instability. Much of the coarse sediment generated during this process will also be transported further downstream, further contributing to instability in the Upper Valley. Substantial erosion will also occur because the channel downstream of the culvert has incised well below the surrounding floodplain. Opening up the floodplain at the railroad crossing and allowing flood flows onto the floodplain will result in erosion where these flows reenter the incised channel over steep, unvegetated streambanks. Thus, while this alternative would restore channel and floodplain function over time, it would require significant short-term erosion and instability.

Finally, it is important to note that, although the narrow railroad culvert is the primary factor responsible for destabilization of the Upper Valley reach downstream, modifications of the culvert area alone are unlikely to result in any short-term improvements in the Upper Valley. As noted previously, this channel has already enlarged substantially, and has abundant sources of additional sediment, such that it will continue to erode unless stabilization measures are applied to the channel within the destabilized area.

4.2.2 Culvert Modifications

Alternatives for modifying rather than replacing the current railroad culvert, with more limited objectives, can be developed. Generally, there would be two primary objectives of culvert modification: reduce hydraulic constriction and allow flood access to the floodplain; and allow for fish passage through the culvert. Specific designs to meet the hydraulic objectives would include widening the culvert and installing floodplain culverts through the embankment to provide for floodplain flow. Improving fish passage would require baffles or extensive modification of the culvert interior, along with extensive channel modification downstream, such as the construction of step-pool channel, to allow fish to access the culvert.

Widening of the culvert, or allowing for flood flow through floodplain culverts, would reduce flood velocity in the culvert and directly downstream. This would help promote stability of the culvert itself, and would lessen erosive stress on the downstream channel. As noted previously, however, continuing erosion is not a substantial problem in the downstream channel, which has already incised and is highly armored. The hydraulic changes resulting from widening or floodplain flows are unlikely to promote significant improvements in the incised channel downstream.

Floodplain culverts should not be considered without either reconstructing or stabilizing the banks of the channel downstream. Without these measures, water flowing through the culverts would likely cause substantial erosion where it enters the incised channel downstream, resulting in headcuts with the potential to destabilize the railroad embankment. The benefits of floodplain culverts, in the absence of other measures, would be limited. For example, the incised channel downstream effectively drains local groundwater, so floodplain culverts alone would not have a significant benefit for floodplain vegetation in the incised reach.

Floodplain culverts could be considered in conjunction with a widened culvert, and reconstruction of the incised channel downstream into a step-pool configuration for fish passage, with extensive side-slope stabilization to protect against erosion during floods. While this alternative would be expensive, it is technically feasible and is reasonably certain of success, based on our experience with similar projects. This alternative would restore fish passage, would increase channel stability, and could restore a limited portion of the historic alluvial fan function. However, it is unlikely to have substantial benefits for the Upper Valley destabilized reach.

It is important to note reconstruction of the culvert for fish passage could conflict with informal local access. Rather than modifying the existing culvert, a shorter bridge may be required to address this concern. A short bridge would also improve the function of the area with respect to hydraulics. Such an alternative probably represents the most feasible project associated with modification of the current railroad crossing.

4.2.3 Upper Valley Streambank Stabilization

This alternative would stabilize eroding streambanks within the destabilized portion of the Upper Valley landform, a significant source of sediment. Streambanks would be stabilized with rip-rap and/or biotechnical techniques. There are substantial constraints to this approach, which include the following;

- Widespread disturbance of adjoining areas would be required;
- Revegetation would be difficult due to the drier conditions created by incision;
- Rip-rap stabilization would be very expensive.

The success of stabilization would also be highly uncertain in this reach. As demonstrated in the previous section, this area is unstable both laterally and vertically. Streambank stabilization is very vulnerable to vertical scour, which causes structure failure by undermining. While it may be possible to engineer stable streambanks in such an environment, design and construction costs would be extremely high. Given the substantial constraints and uncertainty associated with this alternative, we do not consider it feasible.

4.2.4 Upper Valley Floodplain Excavation

Given the constraints and uncertainty associated with stabilization of the existing channel form within the Upper Valley, this alternative was developed to meet the limited objective of reducing fine sediment yield by excavating adjacent floodplain soils rather than attempting to stabilize the streambanks. Upper floodplain soils would be removed in a band along both streambanks. These bands would be at least 10-20 feet wide to assure that any additional erosion would not create additional fine sediment recruitment. This alternative also has numerous constraints:

- Excavation would cause enormous floodplain disturbance;
- The lowered streambanks would be very difficult and expensive to stabilize—erosion of the lower banks would provide additional coarse sediment to lower reaches, causing additional channel instability;
- Disposal of excavated material would be difficult and expensive.

Given the limited benefits and substantial constraints, we do not consider this alternative feasible.

4.2.5 Upper Valley Woody Debris Placement

As described previously, woody debris functions in mountainous environments to store sediment and help stabilize the channel and floodplain (see Section 2.5.4). Under this alternative, woody debris jams would be constructed within the unstable portion of the Upper Valley to promote geomorphic processes that would reduce erosion, promote sediment deposition, and begin to rebuild the channel and adjacent floodplain. It should be noted that this alternative does not constitute restoration in the strictest sense of the word; there is no evidence that woody debris was an important geomorphic component of this area prior to human disturbance. However, given the enormous constraints and uncertainty involved with other stabilization techniques, woody debris offers a potentially more feasible opportunity to restore geomorphic function.

Woody debris jams would be placed throughout the unstable reach. The objectives of jams would be to reduce flood velocity, encourage sediment deposition and protect streambanks from erosion. It must be recognized that this approach would rely on geomorphic processes to reconstruct the channel and floodplain over time, especially the processes of sediment transport during larger floods. As such, benefits would be realized slowly, relying on the geomorphic work performed by the channel itself during larger floods. If successful, this alternative would reduce sediment yield from within this reach, promote the deposition of sediment from upstream sources, and thus protect downstream reaches from further destabilization. Significant constraints to this approach include.

- Reestablishment of riparian plant communities would be a slow process due to the disruption of the groundwater table resulting from incision (see Appendix A);
- Sources of woody debris may be difficult to find, although surrounding second-growth forest would likely benefit ecologically from thinning that would provide ample woody debris;

- The processes of erosion and deposition are complex in this reach, and designing woody debris jams that will achieve the objectives carry a relatively high degree of uncertainty.

Although there is some uncertainty regarding the design approach, it should also be noted that this alternative has little risk of causing additional damage. The reach is already highly unstable; woody debris placement is very unlikely to make the channel more erosional. Project construction disturbance could be minimized through careful consideration of access and construction techniques. This alternative is also relatively inexpensive, and uncertainty associated with this approach could be managed by phasing implementation, using smaller demonstration projects to study the effects and function of woody debris jams. With these caveats, we consider this alternative feasible at some level, and it represents the best opportunity to restore geomorphic function to the Upper Valley and help protect downstream reaches from additional instability.

4.3 Lower Valley Gravel Ponds

Gravel ponds were constructed in this area on glacial outwash terraces. The terraces were well above the modern floodplain topographically and mining had only limited impacts on the stream and floodplain. Gravel mining and construction of the main Coldstream Canyon road, however, altered drainage patterns and made the hillslopes far more susceptible to erosion. Rills and gullies have developed throughout the mined hillslopes and continue to erode; erosion is especially high during larger rain-on-snow storms.

Drainage from the eroding hillslopes enters the ponds, where turbid water is stored and sediment slowly settles. The ponds therefore reduce the impact of gravel mining and road construction on the adjacent hillslopes. Typically, outflow from the ponds is relatively clear when inflow to the ponds is low, as during snowmelt runoff. During larger storms, when discharge to the ponds and its sediment concentration is high, outflow from the ponds is turbid and sediment is delivered to the adjacent Cold Creek floodplain.

Upon cessation of mining, only limited effort was made to restore soils and vegetation around the pits. Restoration efforts probably consisted primarily of limited grading and revegetation primarily focused on erosion control. There is no evidence that an effort was made to restore soils; the highly compacted, gravelly sediment comprising the bottom of the pits following mining was not amended. Over time, fine sediment entering the pits from adjacent hillslopes, and decomposed organic material from vegetation, have begun to rebuild soils. This is a very slow process, however; the current soils around the ponds are very gravelly and shallow, and support sparse, discontinuous wetland and riparian vegetation.

Restoring and improving soil, restoring infiltration in compacted areas, and increasing wetland vegetation around the ponds would increase infiltration of stormwater, decrease runoff and store fine sediment before it gets into the Cold Creek floodplain. Several different techniques are available to improve water infiltration and sediment storage around the ponds: importing or amending soils; reducing compaction by removing roads or other access areas; topographic modification of the pond margins to expand wetlands; and revegetation. All of these techniques are feasible in this location, and are likely to be successful in reducing fine sediment yield to the Cold Creek floodplain, especially during larger storms.

4.4 Lower Alluvial Fan

Human disturbance of the Lower Alluvial Fan includes channelization of lower Cold Creek and Donner Creek below the confluence; fill of the historic Cold and Donner Creek floodplains; channel confinement through development on the floodplain, rip-rap, and a narrow bridge. Analysis of channel response to human disturbance in previous sections showed that substantial portions of the Lower Alluvial Fan continue to erode, widening to recreate a floodplain similar to that which existed prior to human disturbance. As a result, this landform now exports sediment, whereas it tended to store sediment prior to human disturbance. The following restoration opportunities were developed to promote channel stability and reduce erosion and sediment yield.

4.4.1 Streambank Stabilization

Under this alternative, eroding streambanks would be stabilized in place throughout the landform. Most of the instability is in the upper portions of this landform, so most of the work would occur here. Due to the very high energy of this reach, effective stabilization would require large rip-rap. Some stabilization of the upper portion of streambanks could utilize revegetation, but substantial channel incision has created a difficult, dry environment for establishing plants.

If successful, this alternative would substantially decrease both fine and coarse sediment yield from this landform. As the analysis in previous sections showed, coarse sediment derived from erosion is at least partly responsible for continued channel dynamics both within this landform and downstream. Reducing the coarse sediment supply would help promote channel stability, and reducing the fine sediment supply would improve water quality both here and in downstream waters.

This alternative would not recreate the historic depositional function of this landform, however. Incision created by human disturbance and subsequent channel response has resulted in a very deep, highly confined channel with a steep gradient that has a high transport capacity. The bridge, which is narrow and enforces confinement, would not be widened. Stabilization of the streambanks will likely enhance sediment transport capacity, with the effect that much of the sediment supplied from the upper watershed will be efficiently transported below this landform. Sediment supply to the lower reaches of Cold Creek and the upper portions of Donner Creek may result in significant channel instability.

Note that streambank stabilization, especially in the upper portions of the landform, would be a fairly substantial and expensive project. Eroding streambanks are extremely high in many areas (Figure 3-14). Nonetheless, streambank stabilization is feasible, although the potential risks of continued destabilization of areas downstream should be carefully considered.

4.4.2 Floodplain Restoration

This alternative was developed with the recognition that geomorphic trends throughout this reach are to widen to create a floodplain like that which existed historically. It would basically mimic the anticipated geomorphic evolution of the channel by excavating floodplain on either or both sides of the channel. By actively creating the floodplain, the amount of fine sediment introduced to the creek during streambank erosion can be significantly reduced, and the process of riparian vegetation and floodplain development can be significantly accelerated. The project would have both water quality and habitat benefits.

Constructed floodplain width would be based on several factors: cost, benefits, development constraints, etc. Because the 1939 channel configuration was relatively stable, the constructed floodplain should be designed to accommodate the approximate geometry of the channel in 1939, to the extent feasible. To avoid instability, the bridge would likely have to be widened to allow for continuity of flow and sediment transport.

Riparian vegetation has rapidly colonized most of the bars constructed by the river since channelization. This suggests that revegetation of the constructed floodplain will take place naturally, and extensive revegetation will not be required, though low-cost biotechnical approaches such as willow staking and wattling would be very effective. Measures to protect water quality could include constructing the floodplain of screened material with a low proportion of fine sediment.

The active stream channel would not be modified under this conceptual design. Existing riparian vegetation would be protected. Rather than the channel constraints imposed by rip-rap stabilization, under this alternative the stream channel would be allowed to slowly evolve over time, likely increasing length and sinuosity. To avoid extensive erosion of slopes connecting the new floodplain to higher adjacent surfaces, groups of larger rock (barbs) could be placed at the toe of the slope to direct the channel to the floodplain. Given that much of the energy during large floods would be dissipated on the constructed floodplain, and that the source of much of the coarse sediment forming large bars would be eliminated, it is likely that the channel would evolve by slow migration of meanders over time rather than by episodic avulsion. Widening the existing bridge to some extent would likely provide benefits in terms of sediment transport continuity.

An additional water quality improvement opportunity may exist. New floodplain next to the ponds could likely be constructed to allow the stream to overflow into one or more of the adjacent ponds, at least during the largest floods when the greatest quantity of fine sediment is in transport. The ponds would act as settling basins, trapping fine sediment that otherwise would be transported to the Truckee River.

It is important to note that the channel would be widened considerably with the construction of floodplain, significantly reducing sediment transport capacity and encouraging sediment deposition. This alternative would thus restore much of the historic depositional function of the Lower Alluvial Fan prior to human disturbance, storing sediment supplied to the fan from upstream portions of the watershed. Given that coarse sediment supply from within the landform would also be eliminated, this alternative would promote stabilization of downstream reaches.

In summary, this restoration opportunity would address past human disturbance of Coldstream Creek. It is designed to work with natural processes that have been occurring since the stream was channelized in the 1960's. The creek would be stabilized; several acres of high quality riparian habitat would be created; and fine sediment yield would be substantially reduced. We believe this alternative is feasible and is the recommended approach to restoring the Lower Alluvial Fan.

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6. APPENDIX A: VEGETATION

6.1 Introduction

The vegetation of most of the area of the Coldstream Canyon watershed that lies at higher elevation than the railroad tracks is, if not necessarily in the ideal mosaic of patches in different seral stages (especially in that late seral stages are scarce), at least supporting the same general character of mixed coniferous forest that probably occurred in the area prior to settlement. Notwithstanding the elevated sediment yields from roads and other specific disturbances, which are remediable on a site-specific basis, the overall vegetation ecological processes of the upper watershed are functioning more or less as desired.

Accordingly, the discussion of vegetation in this document focuses primarily upon the riparian zone of the lower portions of the watershed, downstream of the railroad crossing, where we have identified feasible restoration actions that have the potential to realize significant environmental benefits for low to moderate costs. Not all areas are addressed; the analysis focuses on areas relevant to restoration. Vegetation is discussed by reaches, from downstream to upstream.

Ecological affinities of plant species are often discussed in terms of the U. S. Fish and Wildlife Service wetland indicator status categories (USFWS, 1996). Despite imperfections, this system and the statuses of many common riparian plant species are widely known, even if they are not universally agreed to be accurate. Thus, it is an extremely useful communications tool, and is used in the following discussion. The status definitions are as follows, with comments on the soil moisture regime that is often found along with plants in each category:

Obligate (OBL). Species found in wetlands >99 percent of the time; occurrence of vegetation dominated by plants in this category is usually strongly correlated with soils subject to annual prolonged near-surface saturation. However, certain common OBL species of the northern Sierra Nevada are very tenacious and can persist in a site for decades after the soil moisture regime has become much drier; vigor and patterns of recent plant establishment must be considered in interpreting the significance of occurrence of, or even dominance by, these OBL species.

Facultative Wet (FACW). Species found in wetlands 67 to 99 percent of the time; usually correlated with near-surface saturation through at least a portion of the summer in most years. Same comment pertaining to persistence after shifts in soil moisture regime applies to FACW species as to OBL.

Facultative (FAC). Species found in wetlands 34 to 66 percent of the time; species in this category are frequently found in a wide range of soil moisture conditions, from short-duration saturation during most years to almost never saturated during the growing season.

Facultative Upland (FACU). Species found in wetlands 1 to 33 percent of the time; correlates with soil that is almost never saturated, or is only saturated very briefly during the early part of the growing season.

Upland (Upl). Species found in wetlands <1 percent of the time (also notated NI or "--" in the USFWS lists); correlates with soils that are never subject to prolonged saturation during the growing season.

The assignments of indicator status are subject to much question and discussion. For the present report, the most important issue is that many common wetland-associated species (FACW or OBL) become established only under a wetland hydrologic regime, but are able to persist for long periods of time even if the soil moisture regime becomes much drier. This can be misleading in making wetland or vegetation type determinations, but is extremely useful in interpreting ecological history and trend. Finally, some species that are closely associated with wetland soil saturation regimes may nevertheless require more dissolved oxygen than other wetland species

Table 6-1. Plants mentioned in the text and their wetland indicator status.

Scientific Name	Common Name	Status	Comments
Achillea millefolium	yarrow	FACU	
Alnus incana ssp. *tenuifolia*	mountain alder	OBL	
Artemisia ludoviciana	silver wormwood	FACU	
Carex nebrascensis	Nebraska sedge	OBL	Very persistent even if soil becomes drier
Carex praegracilis	field sedge	FACW	
Cornus sericea	red-twig dogwood	FACW	
Elymus elymoides	squirrel tail	Upl	
Elymus glaucus	blue wild rye	FACU	
Juncus balticus	Baltic rush	FACW	Very persistent even if soil becomes drier
Juncus chlorocephalus/ nevadensis	rush	FACW	Need early season material to be certain of species
Lonicera conjugialis	twinberry	FAC	
Lupinus lepidus	dwarf lupine	Upl	
Pinus contorta ssp. *murrayana*	lodgepole pine	FAC	
Pinus jeffreyi	Jeffrey pine	Upl	Occurs both in arid east side habitat and in riparian floodplains or high terraces
Poa palustris	fowl bluegrass	FACW	
Poa pratensis	Kentucky bluegrass	FAC(U)	Old indicator status (FACU) is correct
Populus tremuloides	quaking aspen	FAC	
Populus trichocarpa	black cottonwood	FACW	
Purshia tridentata	bitterbrush	Upl	
Ribes inerme	white-stemmed gooseberry	FAC	
Salix exigua	coyote willow	FACW	In our area, often indicative of degraded riparian system
Salix lemmonii	Lemmon's willow	OBL	
Salix lucida ssp. *lasiandra*	shining willow	OBL	
Veratrum californicum	corn lily	OBL	Very persistent even if soil becomes drier

and consequently tend to be found in wet areas where the water is flowing rather than stagnant. Such examples include black cottonwood and shining willow (refer to Table 6.1 for scientific names). Notwithstanding these considerations, the familiar USFWS wetland indicator status list does provide a useful *relative* categorization of the soil moisture regime with which the listed species are associated (Table 6.1).

6.2 Lower Alluvial Fan

6.2.1 Existing Conditions

The Lower Alluvial Fan is a highly confined reach with a riparian zone of very limited width. Where sediment bars exist, they tend to be composed of relatively large particles, and the tattered appearance of the plants shows that they experience high flow velocities regularly. The most common colonizing plant is black cottonwood, which is present as a variety of early-seral age classes (the few oldest are probably 15-20 years old at most; youngest are 1-2 years old). Many of the plants are resprouts. Other riparian pioneers are present in variable densities (mountain alder and three species of willows), but other than these species, shrubs and herbaceous plants are very scarce. Portions of the bars and adjacent steep banks are colonized by coyote willow, which, in a montane setting, often occurs in degraded or poorly functioning riparian systems.

Bars are composed of relatively large material, and, when flooded during spring or summer, appear to be subject to sufficiently high flow velocities that illuviation of fines into the interior of the bars is limited, and many seeds that might be dispersed to the site would be washed away. The water-holding capacity of the bars is consequently similarly limited, so that soil moisture during the summer and early autumn is not available to support the successful establishment of seedlings of plants that may have germinated during the late springtime.

6.2.2 Ecological Consequences of Recommended Restoration

The recommended restoration action in this reach is to excavate the present high banks to create a floodplain that is wider than the existing one. The restored floodplain width does not necessarily need to be constant throughout the reach. In addition to merely enlarging the area of riparian vegetation, widening of the floodplain will allow for sufficient meandering of the creek channel that diversity in flow velocities, and consequently in the size of deposited and illuviated sediments, will increase. In particular, altering the system to increase the deposition and illuviation of fines will have a direct beneficial impact on water quality in the Truckee River watershed, which is impaired by fine sediment.

In addition, creation of a wider floodplain with more diverse substrates will allow for colonization by a much greater variety of species than is possible on the present very narrow floodplain. This in turn greatly increases the habitat values of the existing (and future) cottonwood trees for the many species that depend upon food or cover resources of riparian understory as well as on the presence of large cottonwood trees. An increase in diversity and biomass of the riparian understory will support a larger insect and plant-based food chain, which in turn supports the more highly visible elements of riparian wildlife. For example, berry-forming species such as dogwood, honeysuckles, and currants are all common riparian understory plants in properly functioning systems in our region, but are virtually absent from the lowest reach of

Cold Creek. An increase in the density of such species would support higher populations of small and medium sized frugivorous birds of various species.

6.3 Upper Valley Reference Reach

This reach is the stable portion of the Upper Valley just downstream of the unstable reach, generally the middle portion of the landform (Figure 3-4). In terms of vegetation, if not necessarily in every respect of fluvial geomorphology, the ecological processes of this reach of Cold Creek are functioning in a manner that is more similar to the pre-settlement conditions than is the case for any other reach between the railroad and the confluence with Donner Creek. Vegetation communities in this reach were evaluated to provide context for evaluation of restoration opportunities in the unstable reach upstream.

In places within this reach, the meadow vegetation adjacent to the geomorphically active creek and floodplain appears to be drier than one would normally expect for that setting, suggesting that some relatively recent (decade-scale) incision might have occurred at those locations. (This is a locality- specific observation based solely upon plant vigor, and may or may not be generalizable to the whole reach.) Nevertheless, the composition of that vegetation remains to provide a reference for the desired functioning of other reaches.

6.3.1 Existing Vegetation

The recently deposited or reworked sediment bars in this reach are composed of a mixture of particle sizes, many large cobbles but with somewhat more fine-textured material than is obvious further upstream and downstream. Some large debris of recent origin is present (individual whole lodgepole trees, but not jams composed of multiple trunks). Fragments of intact wet or mesic meadow turf, derived from bank erosion within the reach, have become stranded on the bars and continued to grow. Other colonization on the bars is largely of FACW and OBL species (alder, cottonwood, rushes, and hydrophytic grasses), but includes also a scattering of upland species (wormwood, lupine, and yarrow) that are found on bars of all moisture regimes.

The high floodplain or terrace outside the most geomorphically active part of the riparian system exhibits the typical vegetation for this setting. The canopy varies from solid to broken, with meadow clearings. Dominant trees are lodgepole pine, locally mixed with aspen groves that are believed to be persistent from the immediate post-glacial era. Jeffrey pine is found occasionally, usually some distance from the creek but still within the terrace vegetation. The understory is rarely shrubby except in very occasional wet spots where species such as alder, gooseberry, dogwood, or twinberry are present. The herbaceous layer is a classic mesic meadow, mesic forb assemblage that is characteristic of riparian lodgepole wetlands throughout the northern Sierra Nevada: dominated by blue wild-rye and Kentucky bluegrass, with variable amounts of many forbs, mostly FAC but some FACW or OBL: *Fragaria virginianum, Geum macrophyllum, Heracleum lanatum, Smilacina stellata, Thalictrum fendleri,* and *Veratrum californicum*.

Some areas of mesic to wet meadow vegetation were observed that were dominated mostly by strongly hydrophytic species (field sedge, Nebraska sedge, Baltic rush, *Aster alpigenus*; also with typical FAC or drier meadow species such as *Penstemon rydbergii* and *Achnatherum nelsoni*), but where the plants, especially the rush, appeared to be of reduced vigor and in particular were mostly nonflowering. This is often indicative of areas that have become drier at some point within the last two or more decades. It is uncertain whether this is related to a small amount of channel incision, or to continuing processes that began with the abandonment of the mill pond in this area.

With regard to soil moisture regime, the vegetation of this reach is indicative of an area with prolonged availability of moisture during the early to mid summer at least. Base flow was observed throughout the autumn of 2006 and presumably is present year round in almost every year. Evidence of the possibility that springs or seeps are present was briefly sought but not found. However, strongly cemented glaciofluvial material was observed below the soil profile in one high eroded stream bank, and very fine uniform silty soil in another nearby. Accordingly, a reasonable interpretation of the vegetation and upper soil profile is that water derived from both melting of the snowpack that lies immediately upon it, and from high stream stage during the spring perches seasonally on the layers of cemented or fine-textured subsoil (or both), providing a water resource that lasts well into the growing season. It is also possible that the fine-textured material that is within the zone of influence of springtime high water merely retains a sufficient amount of plant-available water to support the FAC or wetter plant communities. Whichever interpretation, or combination of them, most accurately explains the vegetation, these circumstances are relevant to restoration actions in the reach immediately upstream.

6.4 Upper Valley Destabilized Reach

This reach is at the upper end of the Upper Valley landform, where Cold Creek is highly unstable (Figure 3-4). Because this reach is a focus of restoration opportunities, vegetation community structure was analyzed, as well as the potential consequences of the preferred restoration alternative.

6.4.1 Existing Vegetation

The tree stratum of the upland forest of this reach is generally similar to that of the functional reach immediately downstream: dominated by lodgepole pine, with small to extensive aspen groves. There is somewhat more Jeffrey pine and colonization by small white fir than is present downstream. Notably, both the shrubby understory (scattered *Ceanothus* [three species], bitterbrush, and even manzanita) and the herbaceous stratum (squirreltail, mountain brome, dwarf lupine, needlegrass, and even mule's-ears) are characteristic of fully upland settings, such as arid mountain slopes.

Within the active channel, it is very notable that the majority of the colonizing plant species on higher sediment bars are upland species, many of them typical of arid slopes (*Chaenactis douglasii*, *Eriogonum nudum, Monardella odoratissima* [mountain or coyote mint], dwarf lupine, squirreltail, rabbitbrush, *Ceanothus* spp.). Even on lower bars, the mixture of species is primarily FACU (yarrow, *Potentilla glandulosa*, wormwood), along with some cottonwoods and many lodgepole seedlings.

Thus, the vegetation of this reach, from the active sediment bars up into the terrace vegetation, is decidedly more arid than that of the reaches downstream. This is consistent with the fact that there is no autumn base flow in this reach, whereas such flow occurs both up- and downstream of this area. Significantly, many of the stumps in the area where the lodgepole pine forest was thinned exhibit a pronounced reduction in the growth rate of the trees, occurring roughly about 50-60 years ago. This would be consistent with (but does not necessarily prove) a relatively sudden period of channel incision at about that time. If this interpretation is correct, it is unlikely that feasible restoration actions within the active floodplain will also result in rewatering of the higher terrace and a shift back to vegetation such as that of the function reach downstream.

6.4.2 Ecological Consequences of Recommended Restoration

The recommended restoration alternative for this reach is the placement of large woody debris jams in the floodplain. This will provide immediate benefits in terms of removal of fine sediment from the system, and increased vegetation diversity and biomass within the floodplain. This is sufficient benefit both in water quality and habitat values to justify the restoration actions. However, it is likely to take a significant period of time before sufficient fines accumulate to provide the water-holding capacity that is necessary to support establishment of vegetation dominated by FAC and wetter riparian species. Realistically, even though the ultimate result will be a generally functional riparian system with substantial components of hydrophytes (at least FAC to FACW), the short-term vegetation target should be merely increase in cover and overall species diversity.

6.5 Upper Valley Abandoned Mining Area

This area is directly to the south of the abandoned reservoir in the lower portion of the Upper Valley, and shows up on aerial photographs as a bright signature, indicating low vegetation cover (clearly seen on Figure 3-4). Although the mining here was on outwash terraces, and did not affect the channel or floodplain, the area is addressed because the current vegetation community, primarily dense lodgepoles, is so clearly dysfunctional.

6.5.1 Existing and Desired Vegetation

The vegetation of this former mining area is very low diversity both structurally and in terms of species composition: very dense small lodgepole pines with Luna wheatgrass (a non-native erosion control grass) and some bitterbrush. The desired future vegetation would be more sparsely spaced (fewer) but larger trees, with more diversity in the understory.

6.5.2 Possible Restoration Actions

This site is a former mine site, where the present soil profile is highly compacted and contains very little organic material and fine soil particles. Thus, any ecological restoration is fundamentally a question in mine reclamation rather than merely revegetation. Very little habitat improvement can realistically be expected to be achieved in this area without drastic actions to improve the soil profile. Alternatives include repeated deep-ripping (least expensive but also least effective in mixing amendments into the lower soil profile), decompaction with an excavator (usually the best compromise between cost and effectiveness), or use of other less commonly available equipment. In whichever case, it is also necessary to concurrently incorporate and mix into the soil profile (not merely apply to the surface) substantial amounts of organic material such as chipped trees or tub-ground wood shreds, modest amounts of compost, and preferably also fine soil material (fine sand to clay). Excessively high application rates of compost or slow-release fertilizer are sometimes recommended, but are not necessary for the desired plant community at this site (and many others). These amendments have the potential to leach nutrients that are not taken up by the vegetation into the groundwater, which in turn ultimately enters the surface waters not far downstream.

Inevitably, much or all of the existing vegetation would be destroyed or greatly thinned in order to achieve the necessary soil profile improvement. However, the excessively dense population of lodgepole pines could be chipped or ground on site to provide part of the organic amendments. Revegetation subsequent to soil profile improvement should be ecologically designed to rapidly re-establish the type of community that would naturally occur in the setting, but with an eye toward long-term persistence and fire resistance of the mature community (for example, tree palette should emphasize resistant species such as Jeffrey pine over susceptible species such as white fir and lodgepole pine). Understory and herbaceous species should incorporate a significant component of early-successional nitrogen fixers such as lupine and even tobacco brush (despite its other disadvantages).

6.6 Special-status Plants

The potential distribution of special status plants within the watershed was also evaluated with respect to potential influence on restoration opportunities. Seven species of special-status plants are recorded from the Norden quadrangle and nearby portions of the Truckee quadrangle (Table 6-2). Although none are specifically recorded from the exact areas where restoration actions are contemplated, suitable habitat for some of them is definitely or possibly present. The likelihood that populations of any of these species would be affected by proposed restoration options is low, but surveys for suitable habitat or the species themselves would be necessary to support environmental analysis and permitting of restoration projects.

Table 6-1. Special-status plant species recorded from Norden quadrangle and western portion of Truckee quadrangle. The last two columns pertain to presence of habitat and recorded occurrences specifically within areas that might be affected by potential restoration actions, not the watershed as a whole.

Species	Habitat	Habitat present?	Species recorded?
Botrychium lunaria common moonwort	Mesic meadows in upper montane and subalpine coniferous forest	Yes	No
Bruchia bolanderi Bolander's bruchia	Very wet meadows and seeps in montane coniferous forest landscape	Maybe	No
Epilobium oreganum Oregon fireweed	Bogs, fens, wet meadows in coniferous forest	Maybe	No
Erigeron miser starved daisy	Rock outcrops, especially granitic, usually in crevices	No	No
Eriogonum umbellatum var. *torreyanum* Donner Pass buckwheat	Exposed slopes and ridge tops, rocky volcanic soils, usually in very sparsely vegetated areas	No	No
Lewisia longipetala long-petaled lewisia	Vernally mesic or wet sites in rocky substrates	No	No
Scutellaria galericulata marsh skullcap	Wet meadows in montane coniferous forest	Yes	No

Botrychium lunaria is a relatively uncommon species in a group of particularly ancient ferns. It is a FAC species, occurring in dry to wet meadow sites, mostly scattered in east side locations (e.g., Mono County) at much higher elevations than the restoration areas. Suitable habitat for this species occurs within potential restoration areas, but the plant itself is not recorded.

Bruchia bolanderi is a moss that occurs in wet meadows and obligate sedge marshes, usually in very level settings. As for any moss, the small stature of the plants makes it difficult for them to persist when there is very much competing vegetation. Thus, wetland mosses are most often found in relatively nutrient poor wetlands where the graminoid vegetation is not overly dense or tall. Most of the mesic to wet meadows of the lower part of Coldstream Valley are probably not wet enough to support this species, and the competing meadow vegetation is usually quite dense and tall, but small areas of suitable habitat could occur.

Epilobium oreganum is a strongly hydrophytic (OBL) species of very wet sites in coniferous forest landscapes. Most of the mesic to wet meadows of the lower part of Coldstream Valley are probably not wet enough to support this species, but areas of suitable habitat may occur.

Erigeron miser is a species of granite rock crevices. Suitable outcrops probably do not occur within the areas where restoration actions are expected to take place.

Eriogonum umbellatum var. *torreyanum* grows in highly exposed subalpine situations from Castle Peak southward along the Sierra Crest. It is unknown to occur in any valley bottom situation; suitable habitat does not occur within the potential restoration areas.

Lewisia longipetala is a species of vernally wet rocky sites at elevations usually higher than 8,000 feet. Suitable habitat for this species does not occur within the restoration areas.

Scutellaria galericulata is another plant of particularly wet marshy habitat. Most of the mesic to wet meadows of the lower part of Coldstream Valley are probably not wet enough to support this species, but some of the species that are recorded as co-occurring with *S. galericulata* are present, so areas of suitable habitat may occur.

7. APPENDIX B: WILDLIFE

7.1 Introduction

This document reports the results of Wildlife Resource Consultants' wildlife surveys and evaluation for the Coldstream Canyon Watershed Assessment. The evaluation consisted of two components: (1) perform wildlife surveys to characterize the wildlife habitat; and (2) determine the possible existence of any wildlife issue that could influence or affect restoration projects within the Coldstream Canyon Watershed Assessment project area.

7.2 Methods

The Sacramento office of the United States Fish and Wildlife Service (USFWS) was informally contacted via their website http://sacramento.fws.gov/es/spplists for a copy of their most current list of threatened, endangered, proposed, and candidate species that may be present in the United States Geological Survey's (USGS) Norden and Truckee, CA quadrangles and the Tahoe National Forest. In addition, information on potential occurrences of threatened, endangered, sensitive, and candidate (TESC) species was obtained from the California Natural Diversity Data Base (CNDDB) and the United States Forest Service (USFS) Truckee Office of the Tahoe National Forest. Information was also obtained from previous projects performed in the project area (Wildlife Resource Consultants 2001) and from informal hikes in the project area prior to and after acquisition of lands by the California Department of Parks and Recreation (CDPR).

Reconnaissance level surveys were performed in September and October 2006. The survey area consisted of publicly owned lands, either CSPR or USFS lands within Coldstream Canyon. The surveys were performed on foot and by car. An effort was made to cover prominent topographic features such as ridgelines, rock outcrops, and drainages, as well as biological features such as standing snags and down logs. Observations of special status wildlife species or their sign (e.g., scat, feathers, tracks) were recorded with a hand-held GPS unit.

7.3 Data Base Search Results

The USFWS lists the bald eagle (*Haliaeetus leucocephalus*) and Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) as federally listed threatened species that may occur within the Tahoe National Forest and the Norden quad. Mountain yellow-legged frog (*Rana muscosa*) and pacific fisher (*Martes pennanti*) are federally listed candidate species that may occur within the Tahoe National Forest and the Norden and Truckee, CA quads. No federally listed or proposed species are known to occur in the project area, and no formal consultation should be anticipated.

The CNDDB data base has records for nesting bald eagle, northern goshawk, osprey, and Sierra Nevada mountain beaver (*Aplodontia rufa*) within two miles of the Coldstream Canyon Watershed Assessment project area.

The Truckee California, USFS office has records for nesting northern bald eagles, ospreys, goshawks, and spotted owls in USGS Norden and Truckee, CA quads.

7.4 Special Status Wildlife Species Occurrence Accounts

7.4.1 Bald Eagle

The bald eagle is a federally listed threatened species. Habitat consists of mature coniferous forests with the presence of dominant and co-dominant trees (defined as trees taller and with a greater circumference of the upper canopy relative to the surrounding stand) in close proximity to large bodies of water (Golightly 1991). Bald eagle nests are usually located in uneven-aged (multi-storied) stands with old growth components. Trees selected for nesting are characteristically one of the largest in the stand or at least co-dominant with the overstory (Lehman et al. 1979). Snags, trees with exposed lateral limbs, or trees with dead tops are often present in nesting territories and are used for perching or as points of access to and from the nest. Most tree perches selected by eagles provide a good view of the surrounding area (USDI 1986).

7.4.1.1 Occurrence in Project Area

Bald eagles have not been recorded in the project area (USDA 2006). However, the USFS and the CNDDB have records for nesting bald eagles on the central south shore of Donner Lake, which is located approximately one mile north of the project area. Bald eagles have been observed foraging at Teichert Ponds, which are located less than one mile east of Donner Lake. Bald eagles could potentially forage on waterfowl and fish in the two ponds in Coldstream Canyon, but they have not been documented in this location. These two ponds do not support the same abundance of waterfowl and fish as do the Teichert Ponds (personal observation).

It is considered unlikely that bald eagles would nest on the south-facing slopes of Schallenberger Ridge because this area is dominated by montane shrub habitat. Moreover, concentrated food sources are closer to the north facing slopes of Schallenberger Ridge (e.g., Donner Lake). While it is possible that patches of suitable nesting habitat are present in the upper elevations of Coldstream Canyon, it is considered unlikely that bald eagles would nest in these locations due to their distance from preferred food sources. There are no known communal or winter roost sites in or near the project area. Bald eagles are unlikely to use the Coldstream ponds for winter foraging because both ponds are frozen during much of the winter.

7.4.1.2 Recommendation

No disturbance to bald eagle breeding activities and habitat are anticipated to occur from any projects within the Coldstream Canyon Watershed project area. If bald eagles are found to nest in the project area, agencies (e.g., USFS, USFWS) typically apply a limited operating period from March 1 to August 31 within 0.5 miles of any active nest.

7.4.2 Northern Goshawk

The northern goshawk is a USFWS species of concern and a USFS Region 5 sensitive species. Preferred habitat consists of older-age, mixed coniferous and deciduous forest habitat. The habitat also consists of large trees for nesting, a closed canopy for protection and thermal cover. Open spaces are necessary to allow maneuverability below the canopy (USDA 1988). Snags, down logs, and high canopy cover are critical habitat features. The former two are also an important component used by numerous prey species. Many of the species that provide the prey base for goshawks are associated with open stands of trees or natural openings containing an understory of native shrubs and grass.

Goshawk nest sites and perch locations are associated with forest stands that have a higher basal area, more canopy cover, and more trees per hectare than surrounding areas. Nest trees for this species are commonly located on benches or basins surrounded by much steeper slopes (Call 1979). Mature trees serve as nest and perch sites, while plucking posts are frequently located in denser portions of the secondary canopy (i.e. crown closure is 80% or greater). The same nest might be used for several seasons, but alternate nests are common within a single territory.

7.4.2.1 Occurrence in Project Area

The CNDDB has a record for nesting goshawks in Section 35, on private property. In 2001, Wildlife Resource Consultants conducted northern goshawk surveys in the area in accordance with Region 5 USFS survey protocol (Wildlife Resource Consultants 2001). A single adult bird was observed in Section 26. The bird responded to the taped alarm call with a begging call. No nest was located during the first or second survey. A nesting pair of northern goshawks was detected in the same area by Tahoe National Forest wildlife biologists in 2002. Two juveniles were observed. No other protocol nesting surveys have been performed in subsequent years.

During a reconnaissance survey conducted October 7, 2006, two goshawk flight feathers were found in a lodgepole forest near a meadow and Cold Creek (NAD 27; 0736571 4353385). These feathers could have been from a foraging goshawk, or a pair of goshawks could potentially nest in the vicinity.

7.4.2.2 Recommendation

Any project activities that occur within ¼ mile of an active goshawk nest could be delayed due to implementation of a limited operating period from February 15 to September 15. Coordination with Tahoe National Forest and California State Parks and Recreation wildlife biologists or pre-project surveys using the Survey Methodology for Northern Goshawks in the Pacific Southwest Region, U.S. Forest Service (9 August 2000) should be conducted to determine the location of any active goshawk nests. Dawn acoustical surveys can be performed in winter to determine territory activity. Two surveys are required. Dawn acoustic surveys are most successful in known territories. Acoustic broadcast surveys can be performed in summer with the second survey being completed no later than mid-August. This type of survey is best performed when large areas need to be surveyed. Thus, a dawn acoustic survey should only be performed if potential project activities will occur within ¼ mile of the known nest territories.

7.4.3 Spotted Owl

The spotted owl is a USFWS species of concern and a USFS Region 5 sensitive species. Spotted owls occupy mixed conifer, ponderosa pine, red fir and montane hardwood vegetation types. According to the California Spotted Owl Sierran Province Interim Guidelines Environmental Assessment (USDA 1993), nesting and roosting habitat typically includes a forest stand with greater than 70% canopy cover. Optimum habitat consists of dense, mature trees with multiple canopies and abundant snags and down woody material. Nesting habitat is characterized by dense canopy closure (>70%) with medium to large trees and usually at least two canopy layers present. In addition, nest stands usually have some large snags and an accumulation of logs and limbs on the ground (USDA 1993). Foraging habitat can include all medium to large tree stands with 50% or greater canopy closure (Verner et al. 1992).

7.4.3.1 Occurrence in Project Area

From 1995 through 1998, Tahoe National Forest wildlife biologists conducted surveys for the California spotted owl in accordance with Forest Service Region 5 protocol. Surveys were performed on USFS land in the vicinity of Horseshoe Bend. Vocal responses and visual observations of spotted owls were recorded during these surveys. Two detections were made in the area in 1995 and 1996. In 1997 and 1998, a nesting pair of spotted owls was recorded in the area. The pair fledged at least one young in 1997.

A pair of spotted owls was detected in April 2006 in the vicinity of the 1997-1998 nest location. From the survey results, it did not appear that the owls successfully nested in 2001. A pair of spotted owls was detected in the same territory during protocol surveys conducted in 2002 by Tahoe National Forest wildlife biologists. No fledglings were detected.

7.4.3.2 Recommendation

Any project activities that occur within ¼ mile of an active spotted owl nest could be delayed due to implementation of a limited operating period from March 1 through August 31. Coordination with Tahoe National Forest and California State Parks and Recreation wildlife biologists or pre-project surveys should be conducted to determine the location of any active spotted owl nests.

7.4.4 Mountain Yellow-Legged Frog

The mountain yellow-legged frog is a USFWS candidate species for listing as threatened or endangered under the Endangered Species Act and a USFS Region 5 sensitive species. Preferred habitat for mountain yellow-legged frog is well-illuminated, sloping banks of meadow streams, riverbanks, isolated pools, and lake borders with vegetation that is continuous to the water's edge (Zeiner et al. 1988; Martin 1992). Suitable breeding habitat is considered to be low gradient (up to 4%), perennial streams and lakes. These stream types generally have the potential for deep pools and undercut banks, which provide habitat for this frog. In the Sierra Nevada, this frog occurs from 4,500 to 12,000 feet in elevation (Behler 1979; Jennings and Hayes 1994). Aquatic and terrestrial invertebrates are the primary foods for adults. These frogs are seldom observed far from water, although they will move overland to disperse to other pond habitats (USDA 1999b).

Breeding occurs between May and August in high elevations, after meadows and lakes are free of snow and ice. In lower elevations, breeding occurs between March and June once high water in streams subsides. Eggs are deposited underwater in clusters along stream banks or on emergent vegetation. Tadpoles require at least one year before metamorphosis, but at high elevations may take up to three years before transformation (Knapp 1994). Tadpoles and adults overwinter underwater in deep pools with undercut banks that provide cover (Martin 1992). At high elevations, this frog requires relatively deep lakes (over 5 feet) that do not freeze solid in winter (USDA 1999b).

Garter snakes and introduced trout prey on mountain yellow-legged tadpoles (Zeiner et al. 1988). The decline of mountain yellow-legged frogs in the Sierra Nevada has been attributed to the introduction of trout during the last century (Bradford et al. 1993; Knapp 1994). Because the adults overwinter underwater and the tadpoles take more than one season to metamorphose, they are vulnerable to predation by introduced fish (Knapp 1994).

7.4.4.1 Occurrence in Project Area

Mountain yellow-legged frogs and their larvae were not detected along the main channel of Cold Creek during the late season surveys. There are no agency records of mountain yellow-legged frog occurring in the Coldstream Canyon Watershed Assessment project area. Cold Creek is not considered suitable habitat because it is inhabited by nonnative trout, which prey on mountain yellow-legged frogs and larvae. Mountain yellow-legged frogs are typically found in lakes and streams without trout.

7.4.4.2 Recommendation

No action is needed as any potential projects are unlikely to affect this species or its habitat.

7.4.5 Pacific Fisher

The pacific fisher is a U.S. Fish and Wildlife Service (USFWS) candidate species for listing as threatened or endangered under the Endangered Species Act. Preferred habitat for fishers includes extensive, continuous canopies, such as dense lowland forests, or mature to old-growth spruce-fir forests with high canopy closure. Fishers use greater percentages of mid-early seral stages for foraging in summer months, but still appear to need and use mature/old growth stands for denning, especially in areas with high snowfall. Forest stands with no understory or with sparse coniferous understory appear to be used most often.

Besides maternal dens, fishers use temporary shelters, such as hollow logs, brush, rock piles, tree nests, or burrows, for sleeping and shelter from bad weather (USDA 1991). Fisher home ranges are as large as ten square miles. Fishers are solitary except during the breeding season between March and May. Females usually give birth in tree dens located in high cavities of large trees. The fisher is primarily a predator, eating small mammals, such as porcupines, snowshoe hares, squirrels, shrews, and mice.

Numerous and heavily traveled roads are not desirable components of fisher habitat because they can lead to habitat disruption and animal mortality (both fisher and their prey). Such roads can also act as behavioral barriers to movement (Freel 1991). However, fishers can tolerate some degree of human activity such as low-density housing, farms, roads, small clear cuts, gravel pits, and intense trapping pressure, as long as their movements are not restricted by development or forest conversion. Few observations of fishers are made because they are nocturnal and secretive.

7.4.5.1 Occurrence in Project Area

There are no agency records of pacific fisher occurring in the Coldstream Canyon Watershed Assessment project area. However, no surveys for fishers are known to have been conducted in the project area.

7.4.5.2 Recommendation

Potentially suitable habitat is present in the project area. Any projects that encompass extensive disturbance in upland portions of the watershed (such as road removal) may have to consider fisher impacts. Riparian projects along the mainstem of Cold Creek downstream of the railroad culvert are unlikely to affect this species or its habitat. However, the project proponent should know that various regulatory measures apply to pacific fishers. The USFS delineates protected activity centers (PACs) for pacific fisher den sites. The PAC consists of 700 acres of the highest quality habitat in a compact arrangement surrounding den sites in the largest, most contiguous blocks available. The USFS enforces a limited operating period from March 1 through June 30 to fisher den sites during denning season to protect breeding adults and their offspring.

7.4.6 Willow Flycatcher

The willow flycatcher is a USFS Region 5 sensitive species and a California state-listed endangered species. Willow flycatchers are summer resident breeders in the Sierra Nevada. Suitable breeding habitat for willow flycatchers includes large, open stands of willows in wet meadows. The presence of water during the breeding season is an important habitat component. The minimum size meadow is assumed to be 0.62 acres (Fowler 1988). While wet meadows are the most common habitat used for breeding, willow flycatchers have been found breeding in riparian habitats of various types and sizes, including grasslands, boggy areas, riparian deciduous shrubs along streams, and small lakes and ponds surrounded by willows with a border of meadow or grassland. Breeding populations of willow flycatchers in the Sierra Nevada can occur in isolated mountain meadows up to 8,000 feet in elevation (Harris et al. 1988).

Willow flycatchers arrive at their breeding territories in early May and nesting begins between late May and late July. The cup-shaped nests are usually between 3.7 to 8.3 feet above the ground and are found most often near the edge of clumps of deciduous riparian shrubs (Sanders and Flett 1989). Eggs are incubated about twelve days and chicks fledge after 12-15 days. The adults and fledglings generally remain in the breeding area through August. Willow flycatchers forage by either aerially gleaning or hawking insects.

Alteration and loss of riparian habitats are believed to be the main causes for declining breeding populations of willow flycatchers (Sanders and Flett 1989; USDA 1992a). Other factors that might have contributed to its decline include nest parasitism by brown-headed cowbirds (*Molothrus ater*), disturbance and habitat degradation from grazing, and events occurring on wintering grounds (Serena 1982; Harris et al. 1988).

7.4.6.1 Occurrence in Project Area

There are no agency records of willow flycatchers occurring in the Coldstream Canyon Watershed Assessment project area.

7.4.6.2 Recommendation

Suitable nesting habitat is present in the riparian habitat associated with Cold Creek. Any projects that occur in this habitat could potentially affect nesting willow flycatchers. The California Department of Fish and Game (CDFG) and the USFS enforce limited operating periods around a variable radius for active willow flycatcher nests. It should be expected that protocol-level willow flycatcher surveys will need to be performed if project activities occur before August 31 (prior to nestlings fledging). The two single-season surveys must be conducted before July 15. A habitat assessment could be conducted to delineate and rank potentially suitable willow flycatcher nesting habitat. This would provide the project proponents with needed information on where project implementation might be delayed if nesting willow flycatchers are found.

7.4.7 Sierra Nevada Mountain Beaver

The Sierra Nevada mountain beaver is a California state species of concern. The herbivorous mountain beavers occupy moist forest habitat typically near streams. They are fossorial and occupy a shallow labyrinthine burrow system. Although their burrow system is extensive and includes a maze of underground tunnels leading to places where food and water are easily obtained, the burrows encompass a small area. The burrow system includes a nest chamber, dead-end tunnels where feces and rejected food are deposited, and separate chambers for food storage (Whitaker 1996). Water often trickles through some of the tunnels. Runs above ground are usually conspicuous due to cut vegetation. Riparian shrubs and down logs often form an impenetrable barrier above their burrows. Several mountain beaver are usually found living together as a colony. They cut green vegetation and leave it to wilt in piles above ground. They then take the cut plants below ground to eat or store. Although not a good climber, they do climb trees to cut off small limbs. Active throughout the year, they are primarily nocturnal but occasionally browse during the day. Because they cannot concentrate urine, they must drink large quantities of water daily. They rely on water running through their underground burrows so they have a constant flow of drinking water. The breeding season begins in February and ends in early April. The gestation period is about 28-30 days. Two to three kits are the normal litter size. The young are born in spring, weaned by autumn and disperse soon after.

7.4.7.1 Occurrence in Project Area

The CNDDB has records for Sierra Nevada mountain beaver in the Emigrant Canyon portion of the Coldstream Watershed Assessment project area. Suitable habitat is present in riparian areas and seeps with perennial water. Such locations are distributed in drainages found at various elevations in the project area, as well as along Cold Creek. However, no mountain beavers or their signs (e.g., burrows, hay piles) were noted in the vicinity of Cold Creek.

7.4.7.2 Recommendation

Any project activities that occur within a riparian area with perennial water should be surveyed for Sierra Nevada mountain beaver prior to disturbance. If this species is found, the CDFG should be consulted.

7.5 Citations

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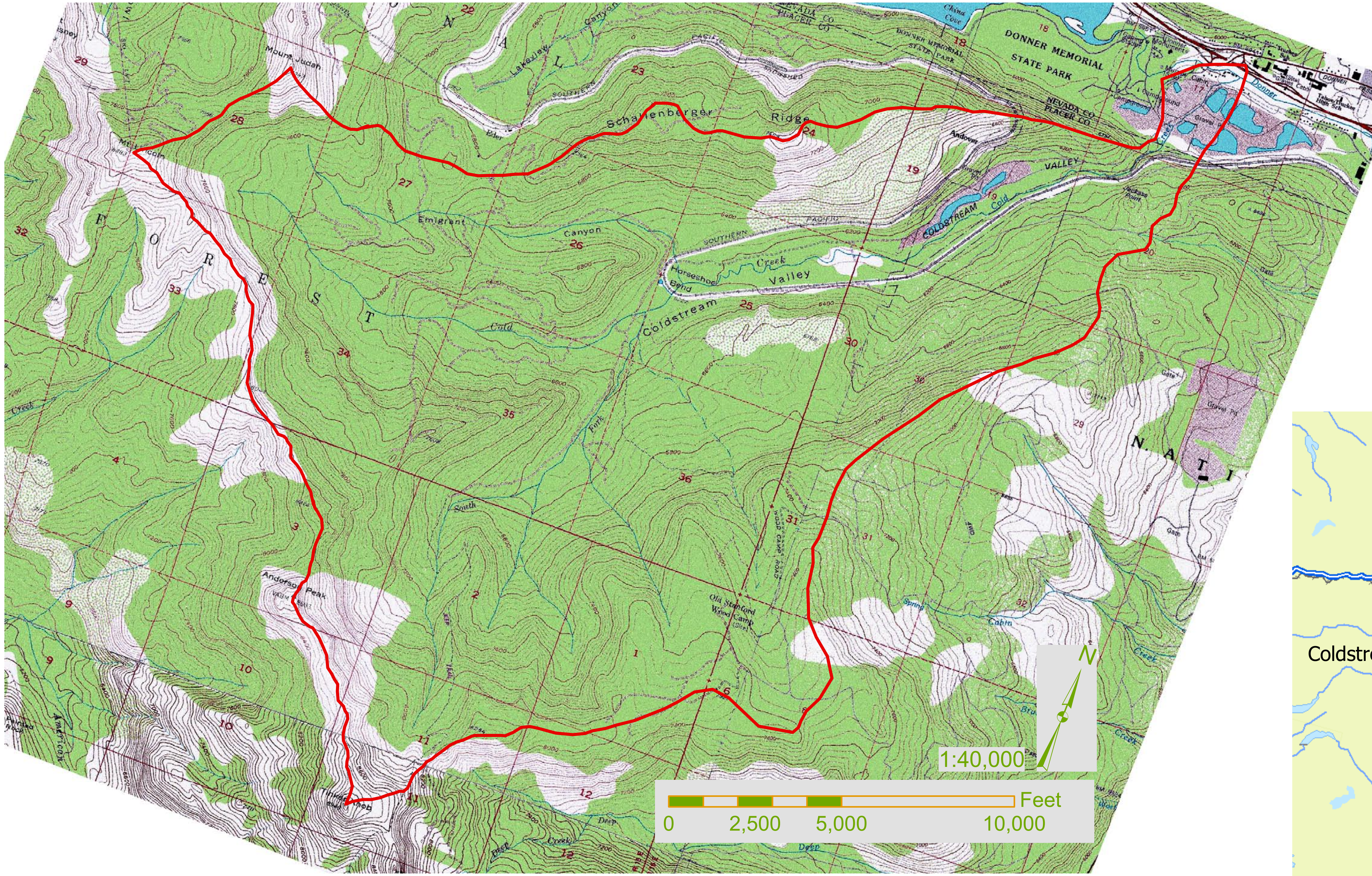
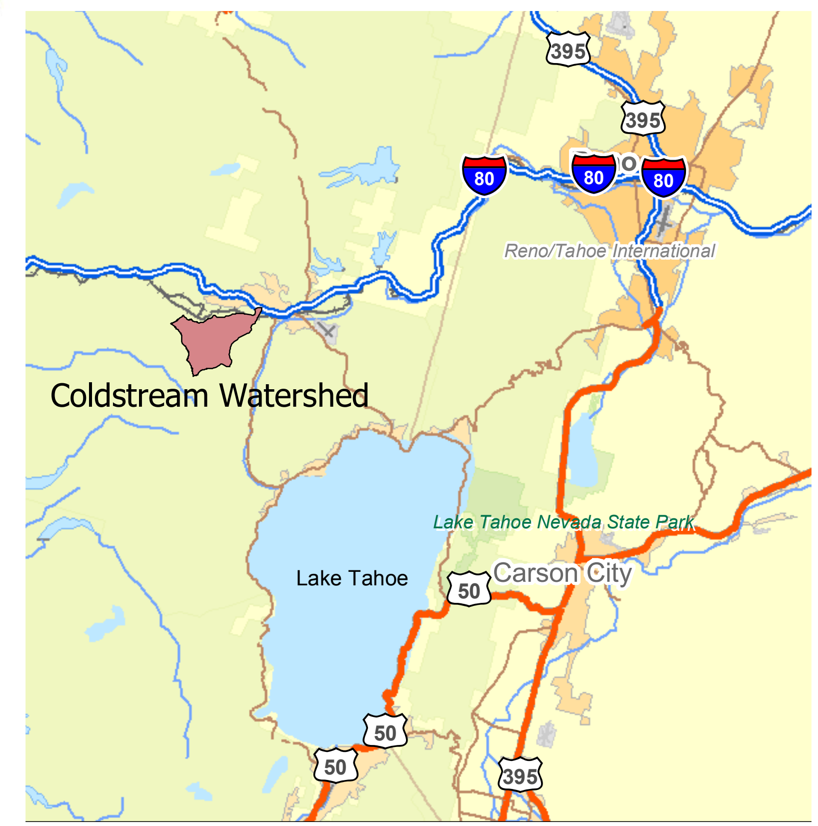
8. APPENDIX C: FIGURES





RIVER RUN consulting
P. O. Box 562
Cedarville, CA
96104
530 279 2400

Coldstream Canyon Watershed Assessment

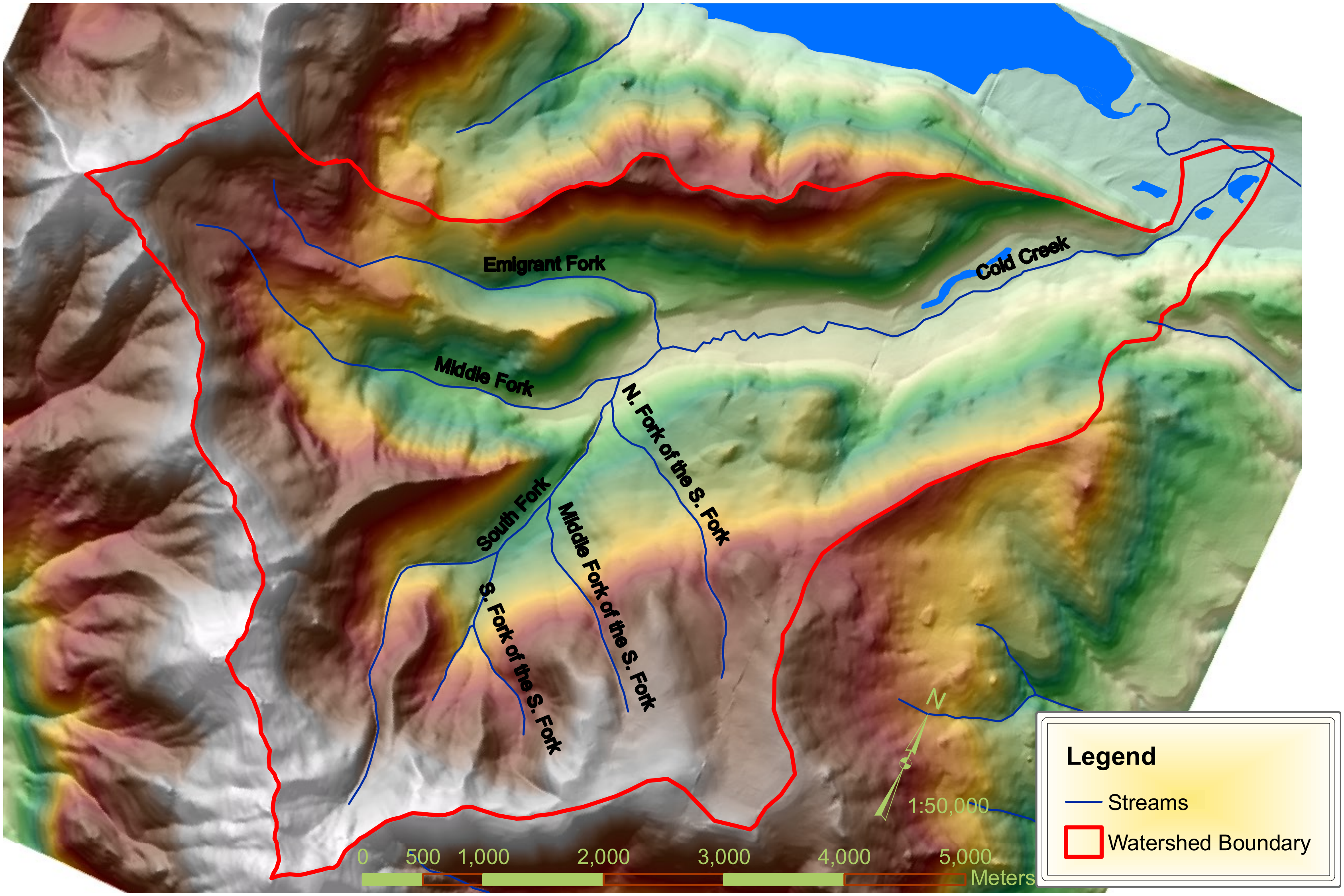
Final Report, March 2007

Prepared for:
Truckee River Watershed Council
Truckee, CA

Topographic map and watershed location.

Topographic map from USGS 7.5 minute series mapping. Data for location map from ESRI.

Figure 2-1



RIVER RUN consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@hughes.net

Coldstream Canyon Watershed Assessment

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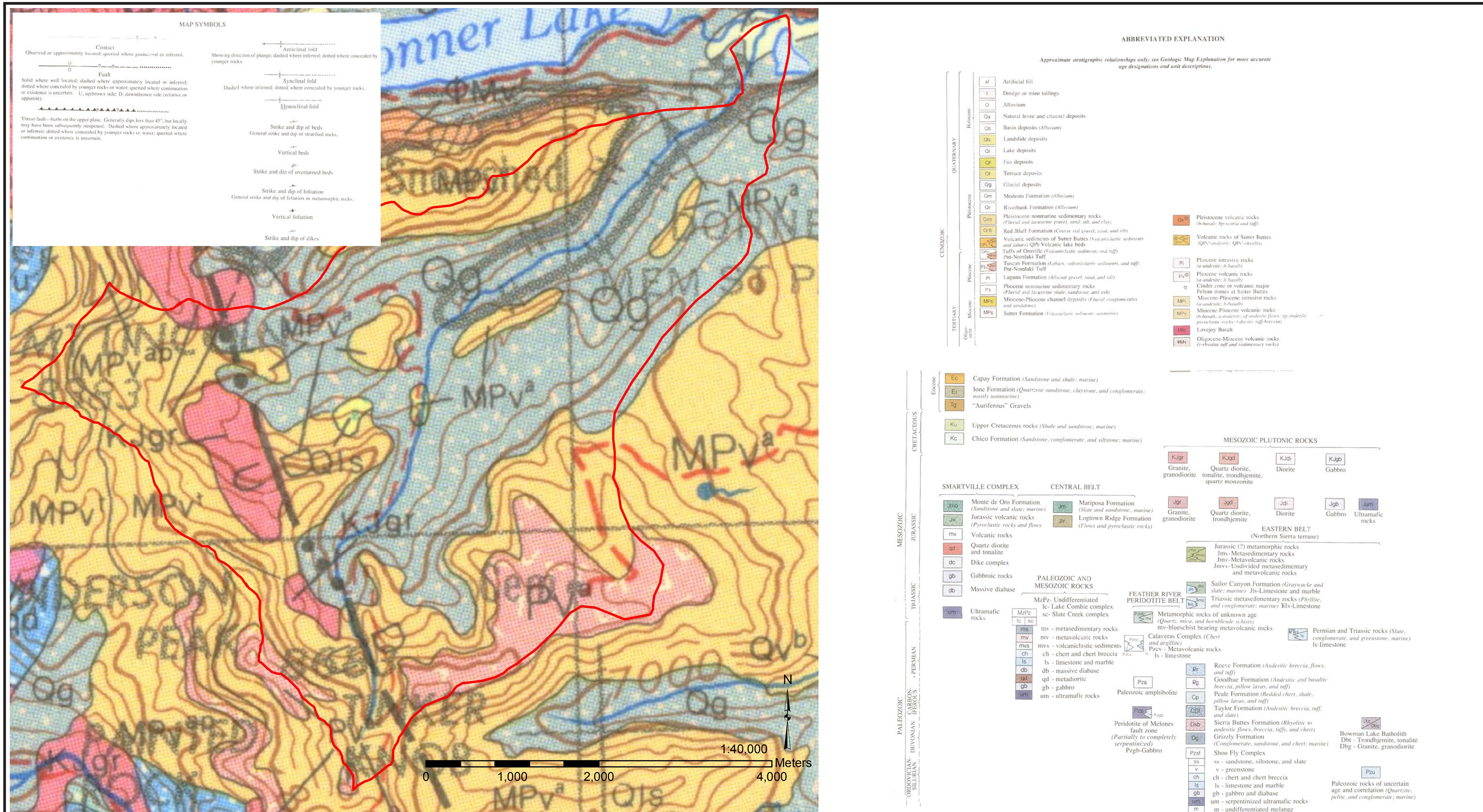
Prepared for:
Truckee River Watershed Council
Truckee, CA

Topography and streams.
Shaded digital elevation model, from USGS 10m data.

Figure 2-2



RIVER RUN consulting
P. O. Box 362
Cedarville, CA 96104
530 279 2400

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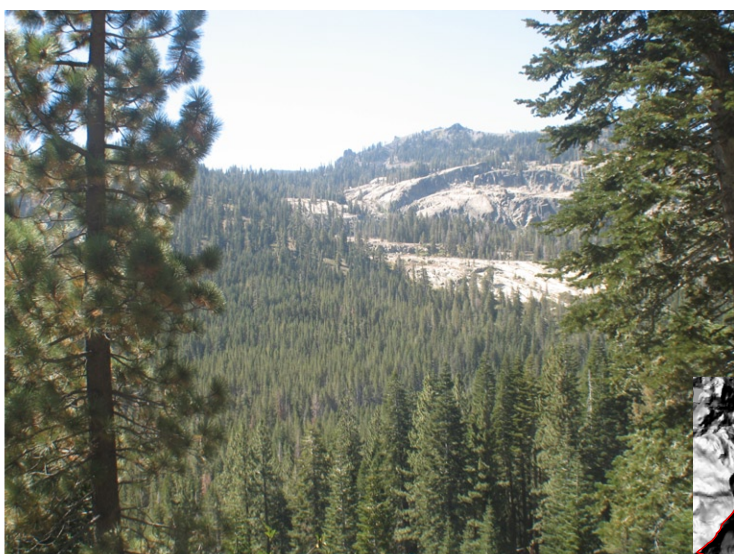
Truckee River Watershed Council
Truckee, CA

Geology.
Map from California Bureau of Mines and Geology, Regional Geologic Map Series, Chico Quadrangle (Map No. 7a), 1:250,000.

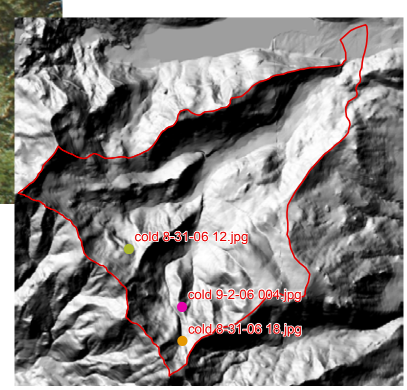
Figure 2-3

Cold 8-31-06 18

Cold 9-2-06 24



Cold 8-31-06 12



RIVER RUN consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@hughes.net

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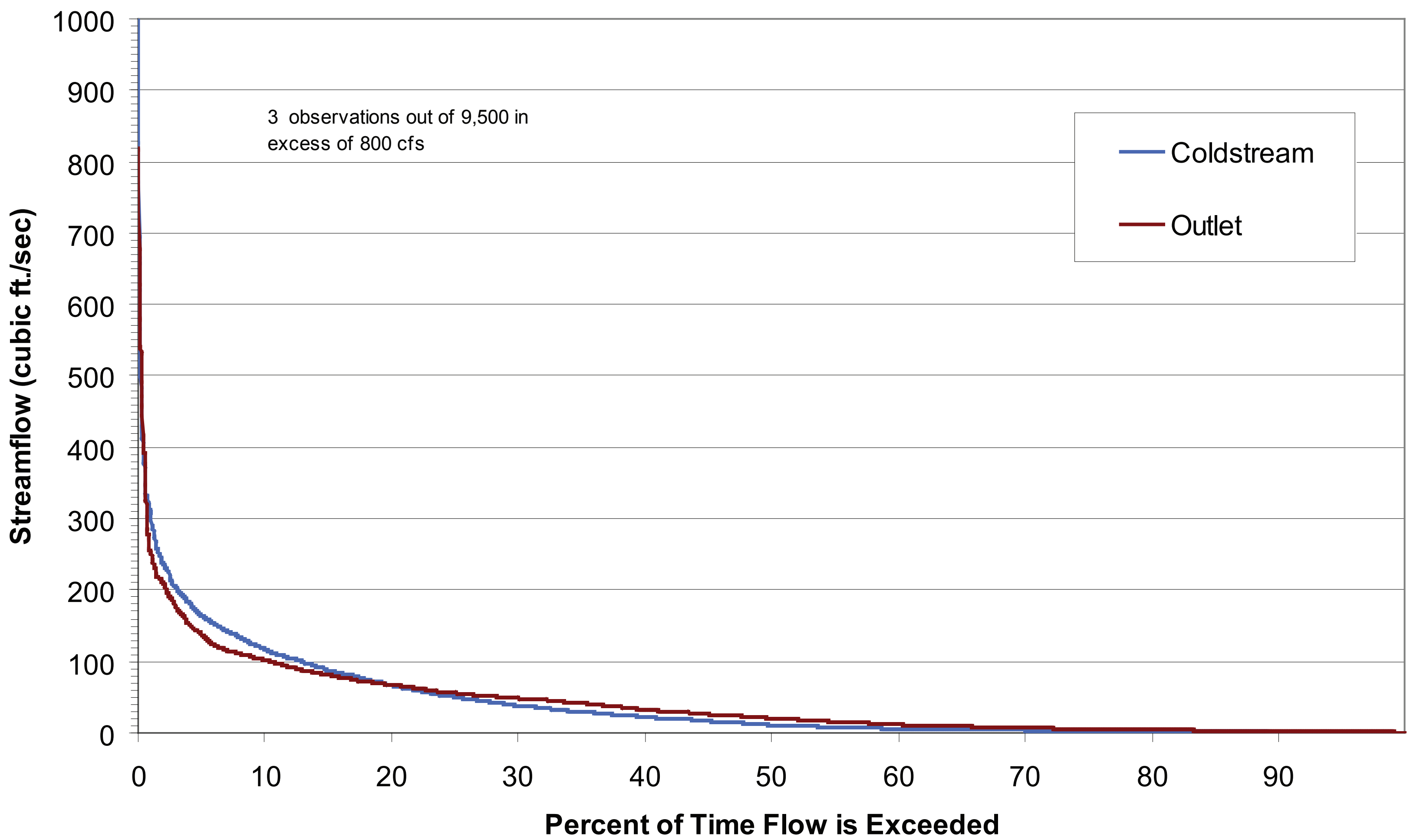
Truckee River Watershed Council
Truckee, CA

Representative geology.

Top photos of typical volcanic rocks (extrusive), lower photo of granite (intrusive) outcrop.

Figure 2-4



RIVER RUN consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@
hughes.net

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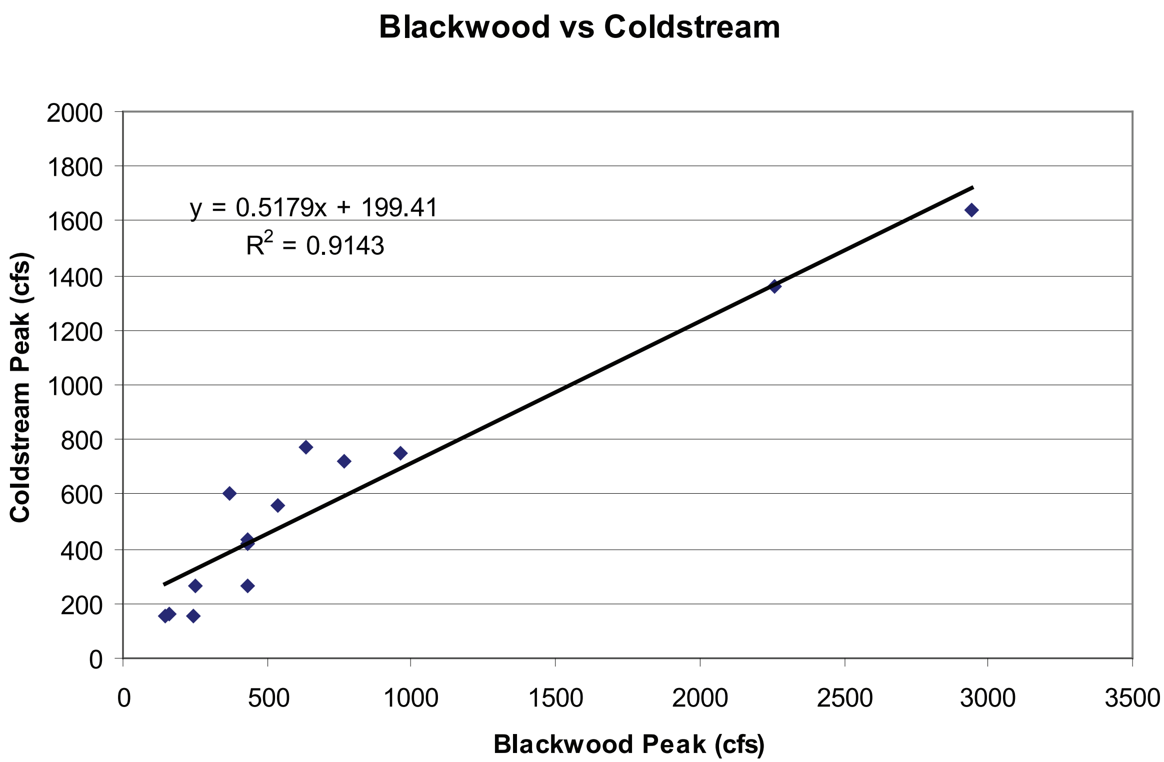
Truckee River Watershed Council
Truckee, CA

Flow duration curves.

Flow duration curve for Donner Creek at the outlet of Donner Lake, and the calculated flow duration curve for Cold Creek.

Figure 2-5



RIVER RUN consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@
hughes.net

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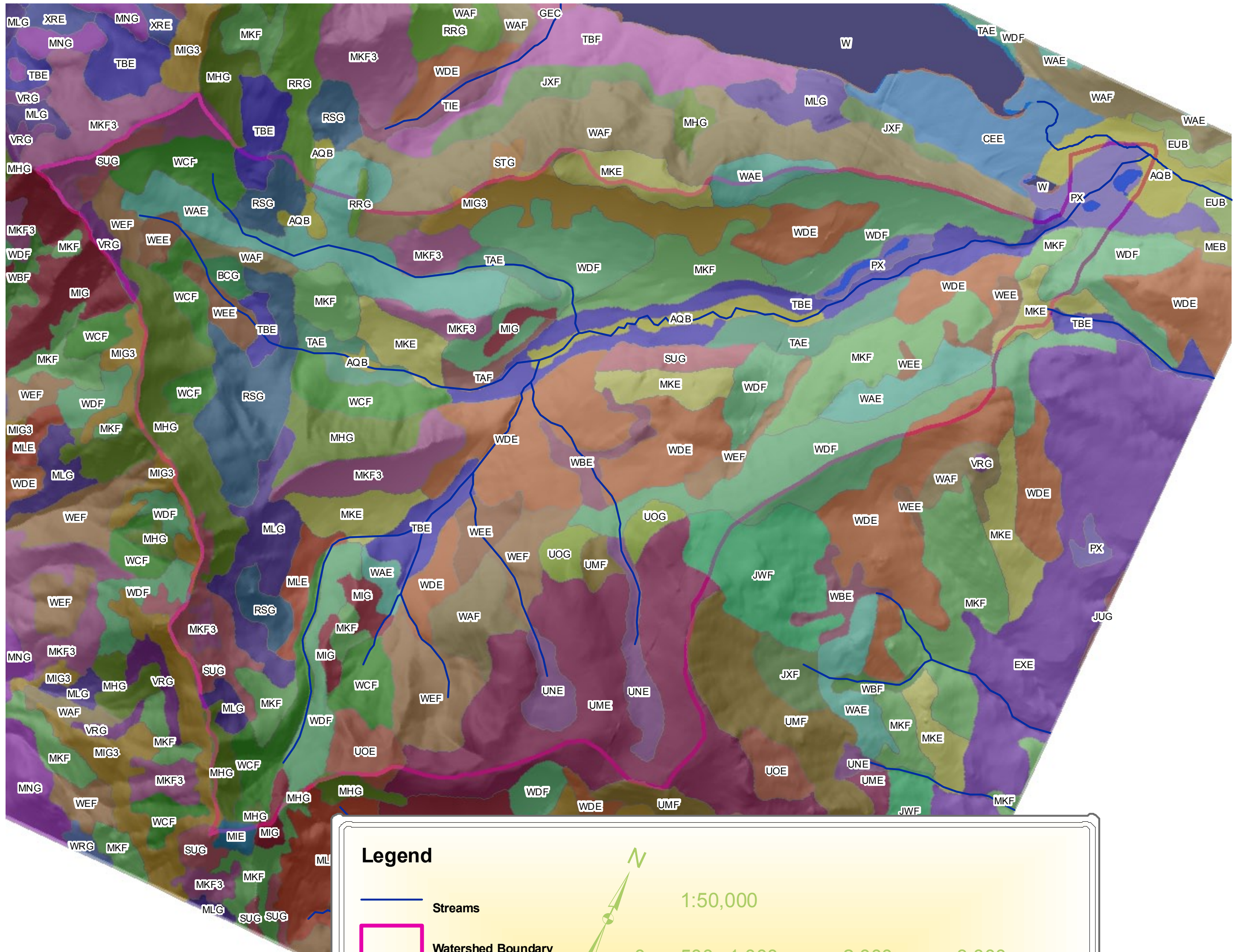
Truckee, CA

Peak flow regression analysis, Cold Creek and Blackwood Creek.

Regression analysis used to derive peak flood estimates for Cold Creek.

Figure 2-6



Legend

Streams

Watershed Boundary

N

1:50,000

0 500 1,000 2,000 3,000 Meters

Cold_Stream_Soils

MYSYM, Name

- ACE, AHART-WACA, RHYOLITIC SUBSTRATUM, 2 TO 30 PERCENT SLOPES
- ACF, AHART-WACA, RHYOLITIC SUBSTRATUM COMPLEX, 30 TO 50 PERCENT SLOPES
- ADE, AHART-WACA, RHYOLITIC SUBSTRATUM-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- ADF, AHART-WACA, RHYOLITIC SUBSTRATUM-CRYUMBREPTS, WET COMPLEX, 30 TO 50 PERCENT SLOPES
- AEE, AHART-ROCK OUTCROP-LEDMOUNT VARIANT COMPLEX, 2 TO 30 PERCENT SLOPES
- AEF, AHART-ROCK OUTCROP-LEDMOUNT VARIANT COMPLEX, 30 TO 50 PERCENT SLOPES
- AQB, AQUOLLS AND BOROLLS, 0 TO 5 PERCENT SLOPES
- BCG, BUCKING-BUCKING VARIANT COMPLEX, 30 TO 75 PERCENT SLOPES
- CEE, CELIO-GEFO-AQUOLLS COMPLEX, 2 TO 30 PERCENT SLOPES
- EUB, EUER-MARTIS VARIANT COMPLEX, 2 TO 5 PERCENT SLOPES
- EXE, LORACK VARIANT GRAVELLY LOAM, 2 TO 30 PERCENT SLOPES
- GEC, GEFO-AQUOLLS-CELIO COMPLEX, 2 TO 9 PERCENT SLOPES
- GID, GEFO VARIANT-CRYUMBREPTS, WET COMPLEX, 2 TO 15 PERCENT SLOPES
- GRG, ROCK OUTCROP, GRANITIC
- JUG, JORGE-RUBBLE LAND COMPLEX, 30 TO 75 PERCENT SLOPES
- JWE, JORGE-WACA-TAHOMA COMPLEX, 2 TO 30 PERCENT SLOPES
- JWF, JORGE-WACA-TAHOMA COMPLEX, 30 TO 50 PERCENT SLOPES
- JXF, JORGE-WACA-CRYUMBREPTS, WET COMPLEX, 30 TO 50 PERCENT SLOPES
- MEB, MARTIS-EUER VARIANT COMPLEX, 2 TO 5 PERCENT SLOPES
- MHG, MEISS-GULLIED LAND-ROCK OUTCROP COMPLEX, 30 TO 75 PERCENT SLOPES
- MIE, MEISS-ROCK OUTCROP COMPLEX, 2 TO 30 PERCENT SLOPES
- MIG, MEISS-ROCK OUTCROP COMPLEX, 30 TO 75 PERCENT SLOPES
- MIG3, MEISS-ROCK OUTCROP COMPLEX, 30 TO 75 PERCENT SLOPES, SEVERELY ER ODED
- MKE, MEISS-WACA COMPLEX, 2 TO 30 PERCENT SLOPES
- MKF, MEISS-WACA COMPLEX, 30 TO 50 PERCENT SLOPES
- MKF3, MEISS-WACA-ROCK OUTCROP COMPLEX, 30 TO 50 PERCENT SLOPES, SEVERE LY ERODED
- MLE, MEISS-WACA-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- MLG, MEISS-WACA-CRYUMBREPTS, WET COMPLEX, 30 TO 75 PERCENT SLOPES
- MMRG, ROCK OUTCROP, METAMORPHIC-TINKER-CRYUMBREPTS, WET COMPLEX, 30 TO 75 PERCENT SLOPES
- MNG, ROCK OUTCROP, METAMORPHIC-WOODSEYE COMPLEX, 30 TO 75 PERCENT SLO PES
- PX, PITS, BORROW
- RRG, ROCK OUTCROP, GRANITIC-TINKER COMPLEX, 30 TO 75 PERCENT SLOPES
- RSE, ROCK OUTCROP, GRANITIC-TINKER-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- RSG, ROCK OUTCROP, GRANITIC-TINKER-CRYUMBREPTS, WET COMPLEX, 30 TO 75 PERCENT SLOPES
- RUG, ROCK OUTCROP-WOODSEYE VARIANT-UMPA COMPLEX, 30 TO 75 PERCENT SLO PES
- STG, RUBBLE LAND-JORGE COMPLEX, 30 TO 75 PERCENT SLOPES
- SUG, RUBBLE LAND-ROCK OUTCROP COMPLEX
- TAE, TALLAC VERY GRAVELLY SANDY LOAM, 2 TO 30 PERCENT SLOPES
- TAF, TALLAC VERY GRAVELLY SANDY LOAM, 30 TO 50 PERCENT SLOPES
- TBE, TALLAC-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- TBF, TALLAC-CRYUMBREPTS, WET COMPLEX, 30 TO 50 PERCENT SLOPES
- TIE, TINKER-ROCK OUTCROP, GRANITIC-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- TIG, TINKER-ROCK OUTCROP, GRANITIC-CRYUMBREPTS, WET COMPLEX, 30 TO 75 PERCENT SLOPES
- UME, UMPA STONY SANDY LOAM, 2 TO 30 PERCENT SLOPES
- UMF, UMPA STONY SANDY LOAM, 30 TO 50 PERCENT SLOPES
- UNE, UMPA-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- UOE, UMPA-ROCK OUTCROP COMPLEX, 2 TO 30 PERCENT SLOPES
- UOG, UMPA-ROCK OUTCROP COMPLEX, 30 TO 75 PERCENT SLOPES
- VRG, ROCK OUTCROP, VOLCANIC
- W, WATER
- WAE, WACA-WINDY COMPLEX, 2 TO 30 PERCENT SLOPES
- WAF, WACA-WINDY COMPLEX, 30 TO 50 PERCENT SLOPES
- WBE, WACA-CRYUMBREPTS, WET-WINDY COMPLEX, 2 TO 30 PERCENT SLOPES
- WBF, WACA-CRYUMBREPTS, WET-WINDY COMPLEX, 30 TO 50 PERCENT SLOPES
- WCF, WACA-GULLIED LAND-CRYUMBREPTS, WET COMPLEX, 30 TO 50 PERCENT SLO PES
- WDE, WACA-MEISS COMPLEX, 2 TO 30 PERCENT SLOPES
- WDF, WACA-MEISS COMPLEX, 30 TO 50 PERCENT SLOPES
- WEE, WACA-MEISS-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES
- WEF, WACA-MEISS-CRYUMBREPTS, WET COMPLEX, 30 TO 50 PERCENT SLOPES
- WRG, LEDFORD VARIANT-ROCK OUTCROP COMPLEX, 30 TO 75 PERCENT SLOPES
- XRE, TINKER-ROCK OUTCROP, METAMORPHIC-CRYUMBREPTS, WET COMPLEX, 2 TO 30 PERCENT SLOPES

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P. O. Box 362
Cedarville, CA
96104
530 279 2400
rkiesse@
hughes.net

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Watershed Assessment

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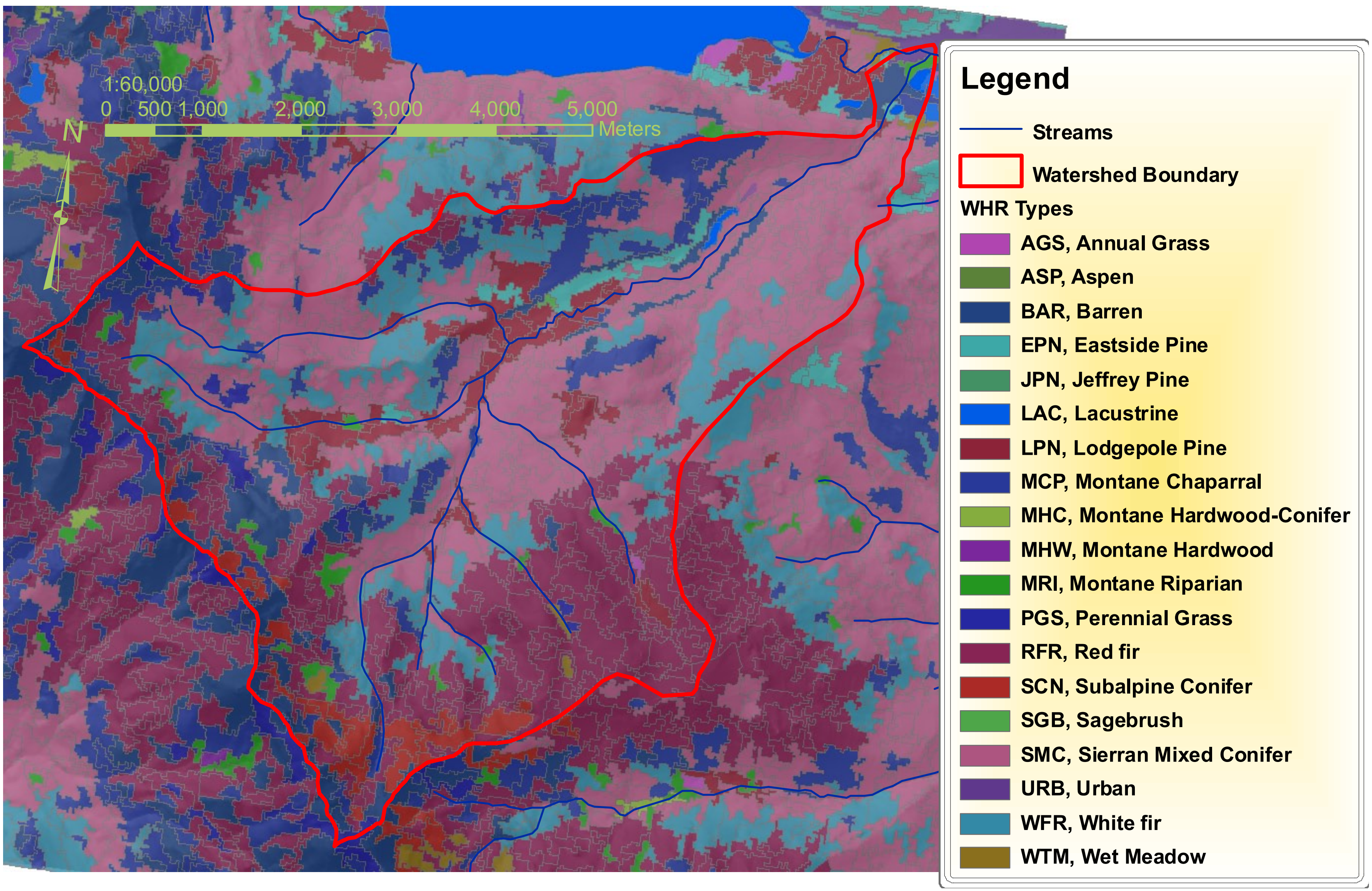
Watershed soils.

Data from the National Resources Conservation Service.

Figure 2-7



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P. O. Box 362
Cedarville, CA 96104
530 279 2400
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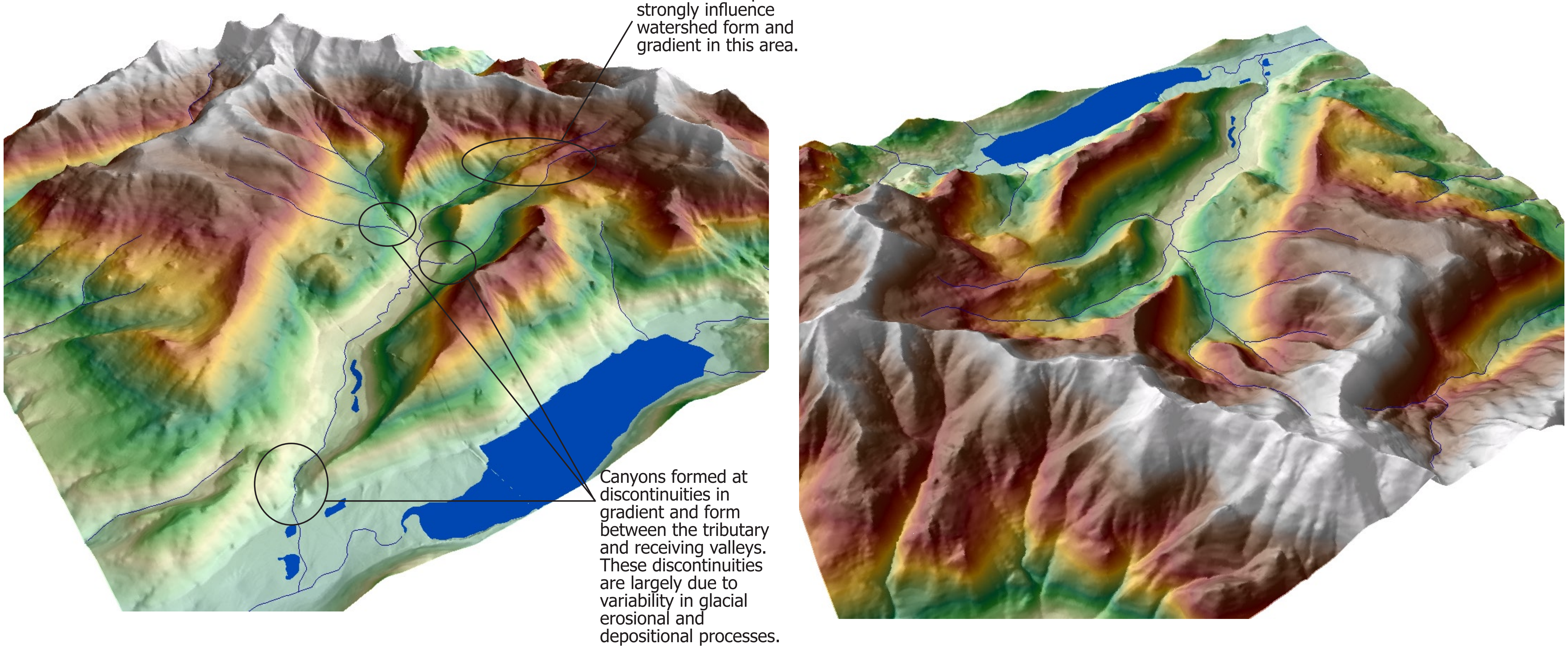
Vegetation and wildlife habitat types.
California Wildlife Habitat Relationships (WHR) vegetation types. Data from US Forest Service remote sensing.

Figure 2-8



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P. O. Box 362
Cedarville, CA 96104
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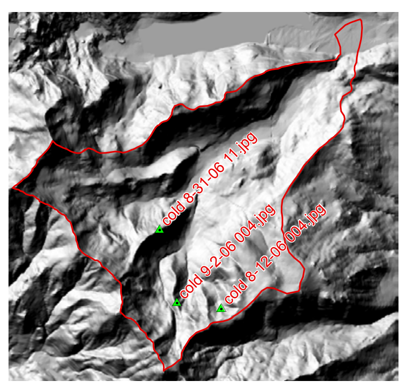
Three-dimensional watershed topography.
USGS 10m digital elevation model of the Coldstream watershed, colorized and projected in perspective views. Looking from the northeast (left) and southwest (right). 2x vertical exaggeration.

Figure 2-9

Cold 9-2-06 004

Cold 8-12-06 004

Cold 8-31-06 11



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consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@
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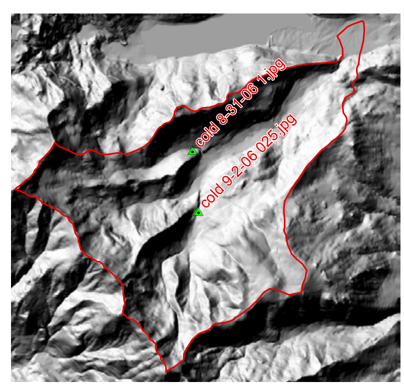
Glacial erosion.

Steep slopes created by glacial erosion in the upper portions of the watershed.

Figure 2-10

Cold 8-31-06 1

Cold 9-2-06 025



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96104
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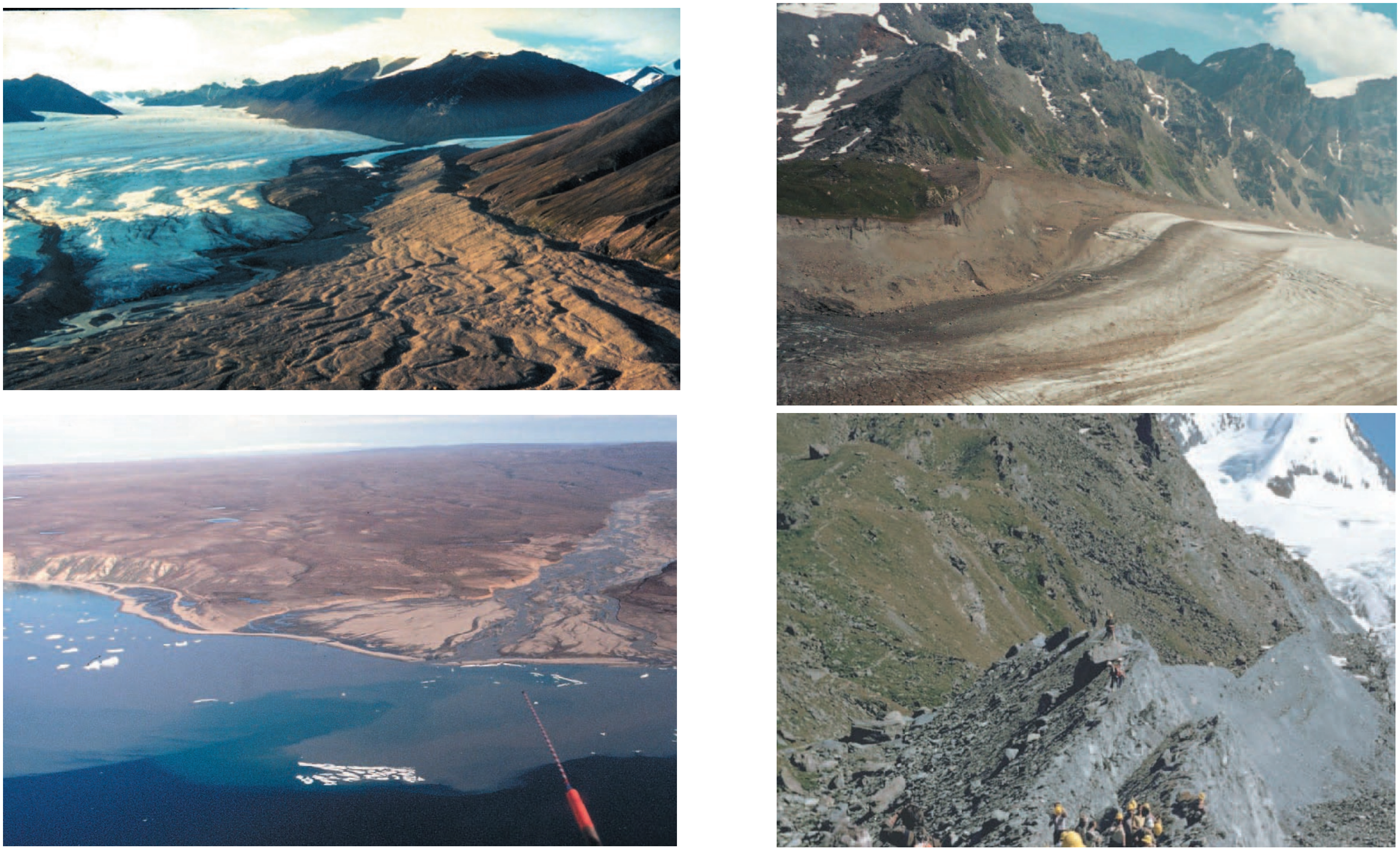
Stream response to glacial erosion.

Channels eroding canyons in areas of discontinuous watershed gradient.

Figure 2-11



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P. O. Box 362
Cedarville, CA
96104

530 279 2400

mkiesse@
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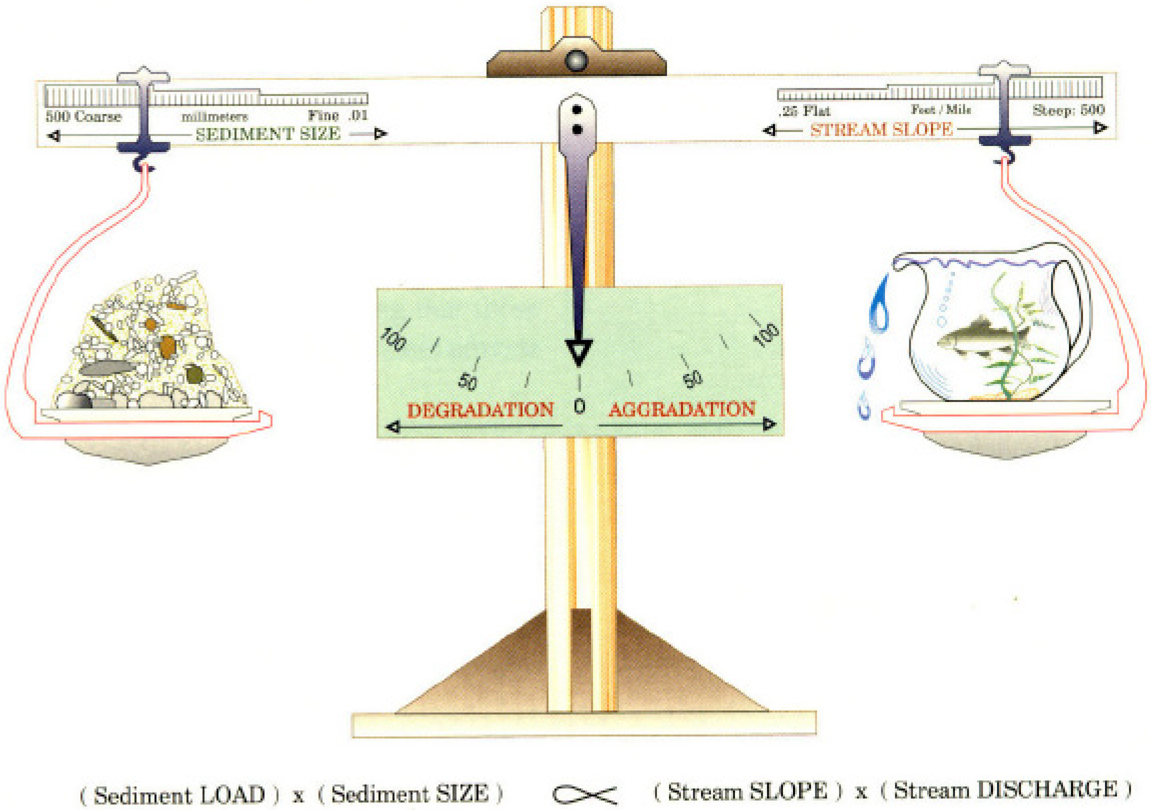
Glacial depositional landforms. **Top Left: Lateral moraines confining braided outwash plain. Note drainage development on and though moraines, and outwash plains developing between the ice and adjacent moraines (kame terraces). Bottom Left: Delta in active construction at mouth of braided outwash plain. Top Right: Retreating glacier, hillslopes and moraines recently deglaciated. Bottom Right: Recently deglaciated moraine. Note instability and deposits from hillslope erosion developing between ice and toe of slope.**

Figure 2-12



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P. O. Box 362
Cedarville, CA
96104
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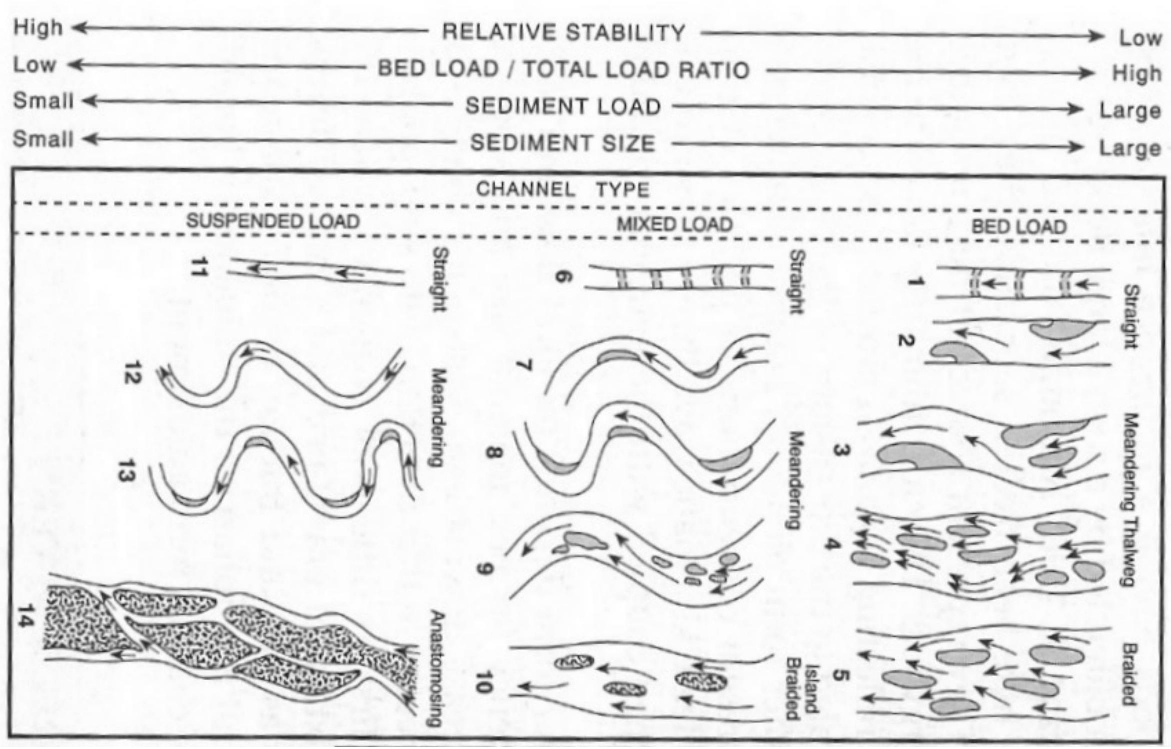
Water and sediment balance in alluvial channels.

From Rosgen (1996). The channel form develops over time to transport water and sediment supplied to it. Changes in water or sediment supply will cause the channel form to change.

Figure 2-13



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consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
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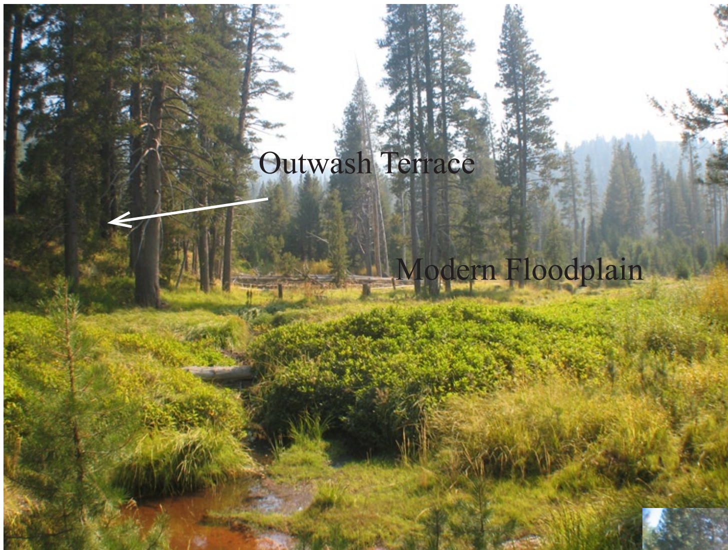
Channel form, stability and sediment relationships.
From Knighton (1998).

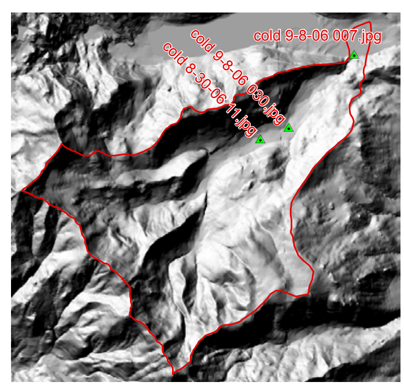
Figure 2-14



Cold 9-8-06 030

Cold 8-30-06 11

Cold 9-8-06 007



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consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@
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Sediment supply from glacial deposits.

Top-outwash terrace. Middle-eroding outwash terrace; note coarse sediment. Bottom-eroding outwash in alluvial fan.

Figure 2-15

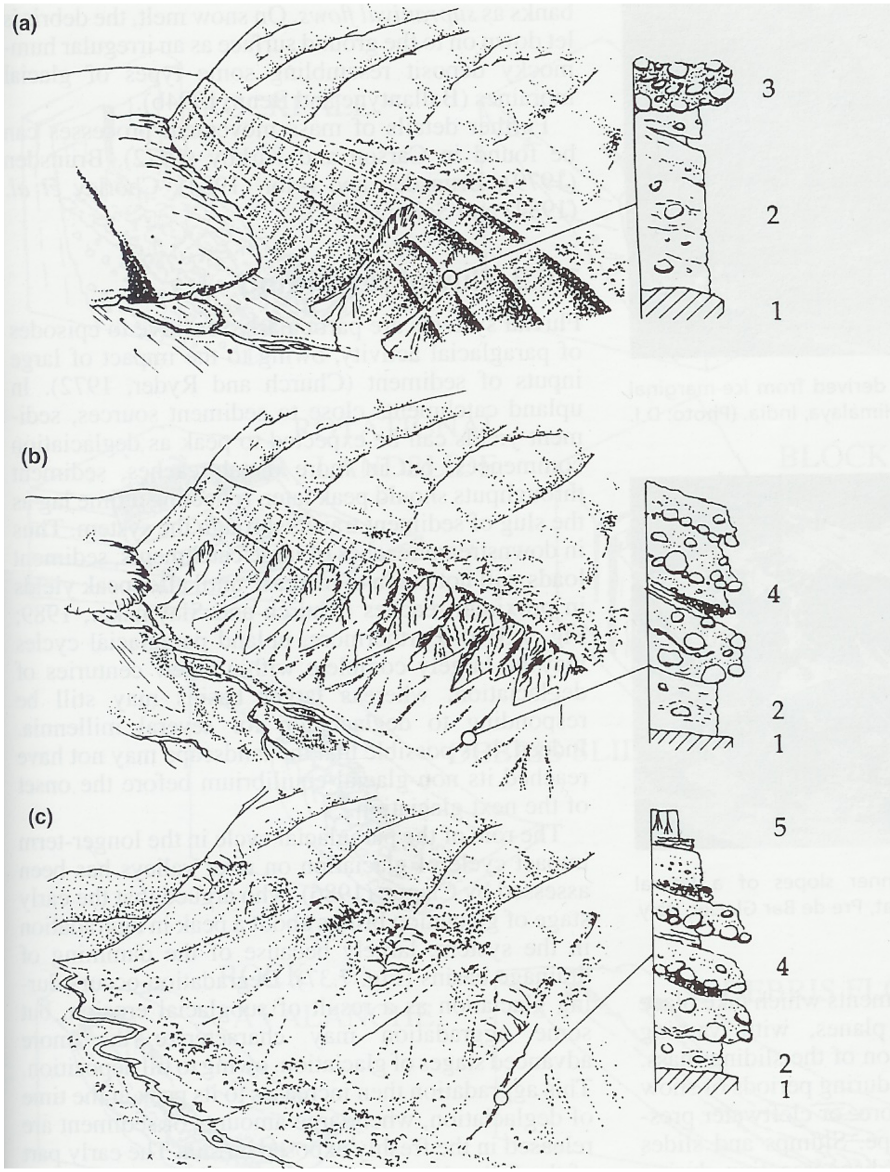

Fig. 7.32 Schematic block diagrams of the landforms and sediments associated with three stages in the paraglacial reworking of steep drift slopes in glaciated valleys. (a) Initial slopes exposed by glacier retreat, showing lateral moraines and the onset of gully incision; (b) advanced gully development and deposition of coalescing debris fans downslope; (c) exposed bedrock and stabilized, vegetated gullies and largely relict debris fans. By this stage, paraglacial reworking and slope adjustment have effectively ceased owing to diminution of debris supply. Facies key: 1: bedrock; 2: subaerial sediments relating to an earlier episode of paraglacial sedimentation; 3: ice-marginal deposits; 4: paraglacially reworked sediment (debris flows and intercalated slopewash deposits); 5: soil horizons. (Modified from Ballantyne and Benn, 1996)

RIVER RUN consulting
P. O. Box 362
Cedarville, CA 96104
530 279 2400
mkiesse@hughes.net

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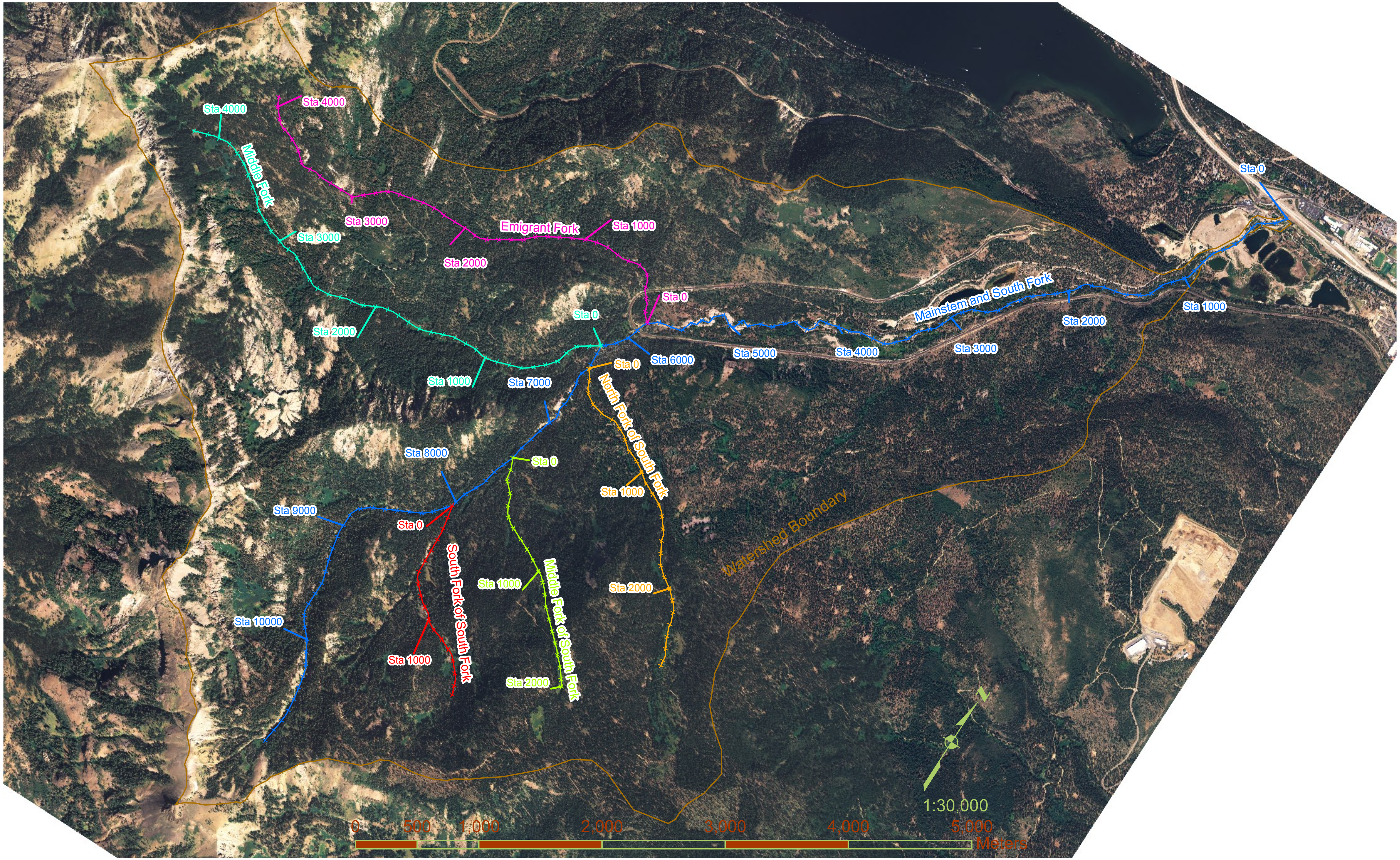
Evolution of moraines at the base of hillslopes.
From Benn and Evans (1998).

Figure 2-16



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Cedarville, CA
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530 279 2400

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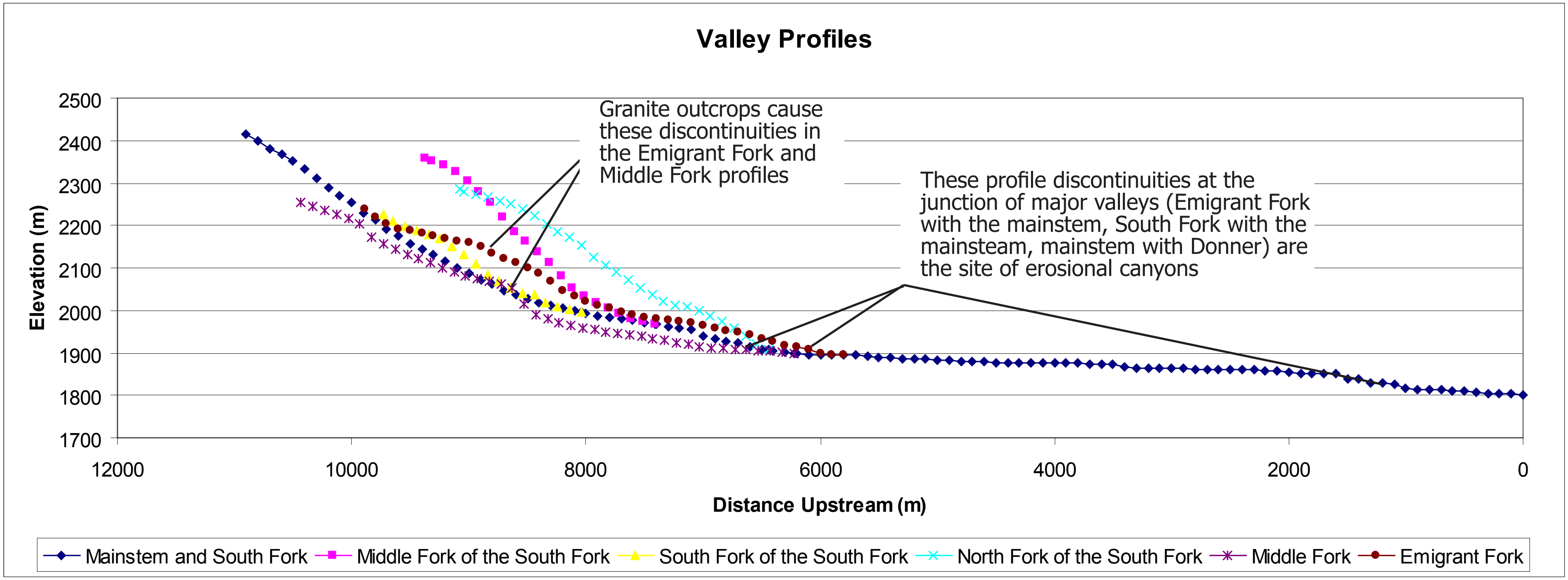
Stationing for valley bottom profiles.

Tics on channel centerlines represent 100m stations. Stationing for the mainstem is distance upstream from the confluence with Donner Creek. Stationing for tributaries is distance upstream from the confluence with the Mainstem-South Fork.

Figure 2-17



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P. O. Box 362
Cedarville, CA
96104
530 279 2400
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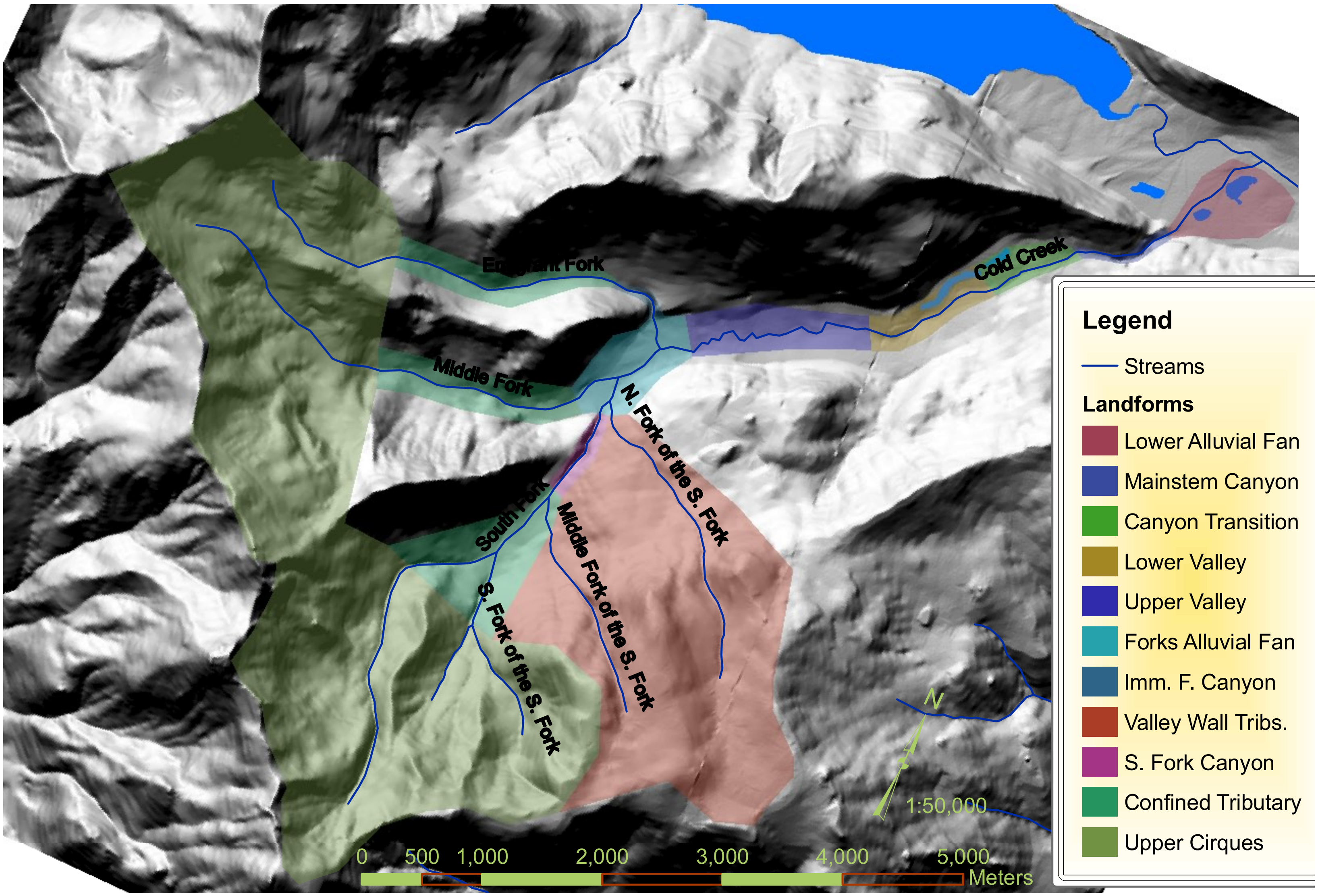
Longitudinal valley profiles of streams in the watershed.
Elevations from USGS 10m digital elevation model. Locations of stations on Figure 2-17.

Figure 2-18



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P. O. Box 362
Cedarville, CA
96104
530 279 2400
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Geomorphic landforms.

General valley and channel geomorphic landforms, overlaid on shaded digital elevation model.

Figure 2-19

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Cedarville, CA
96104
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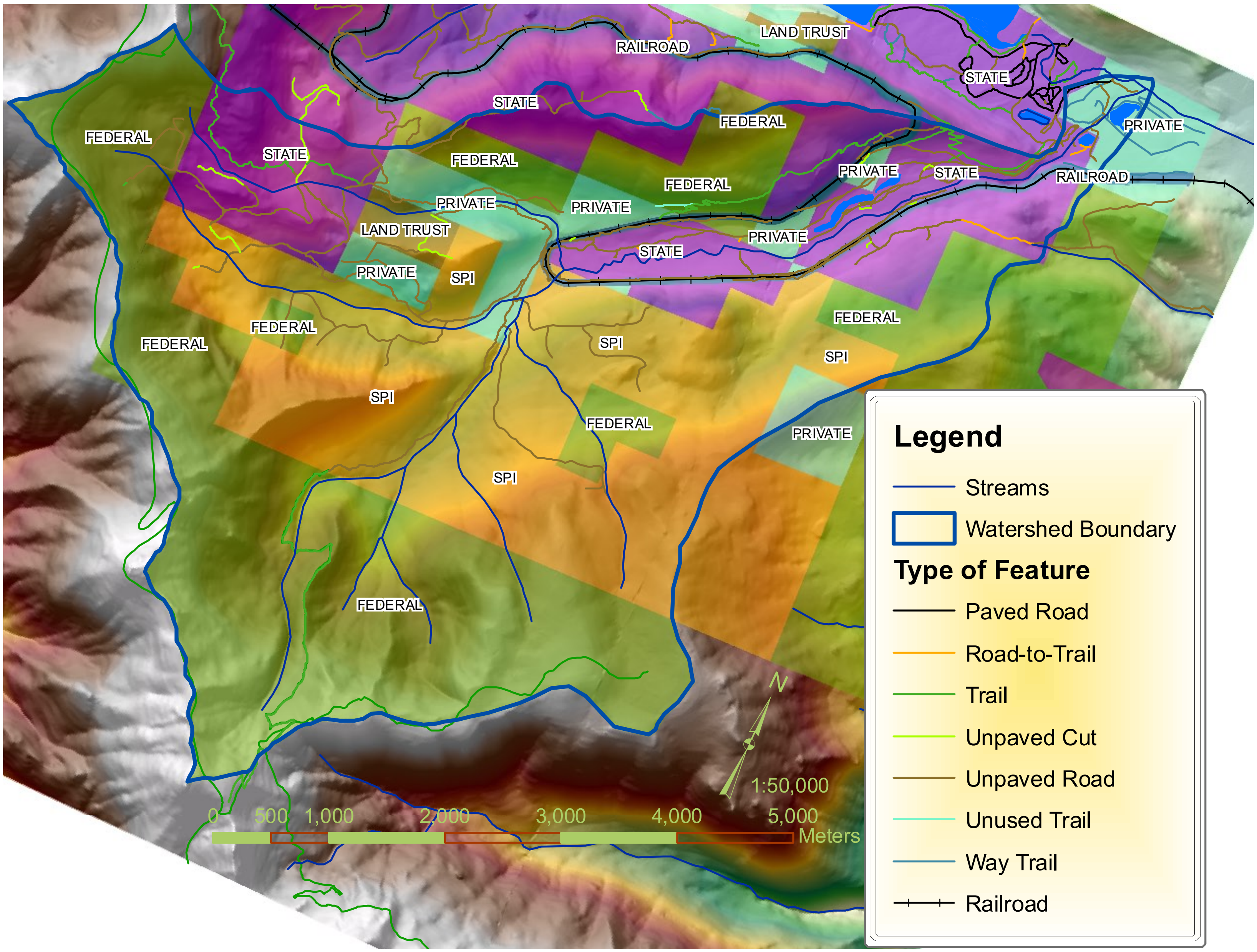
Lower alluvial fan in 1939.

Note evidence of channel dynamism in upper half of fan, and the transition to a meandering channel.

Figure 2-20



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P. O. Box 562
Cedarville, CA
96104
530 279 2400
rkiesse@
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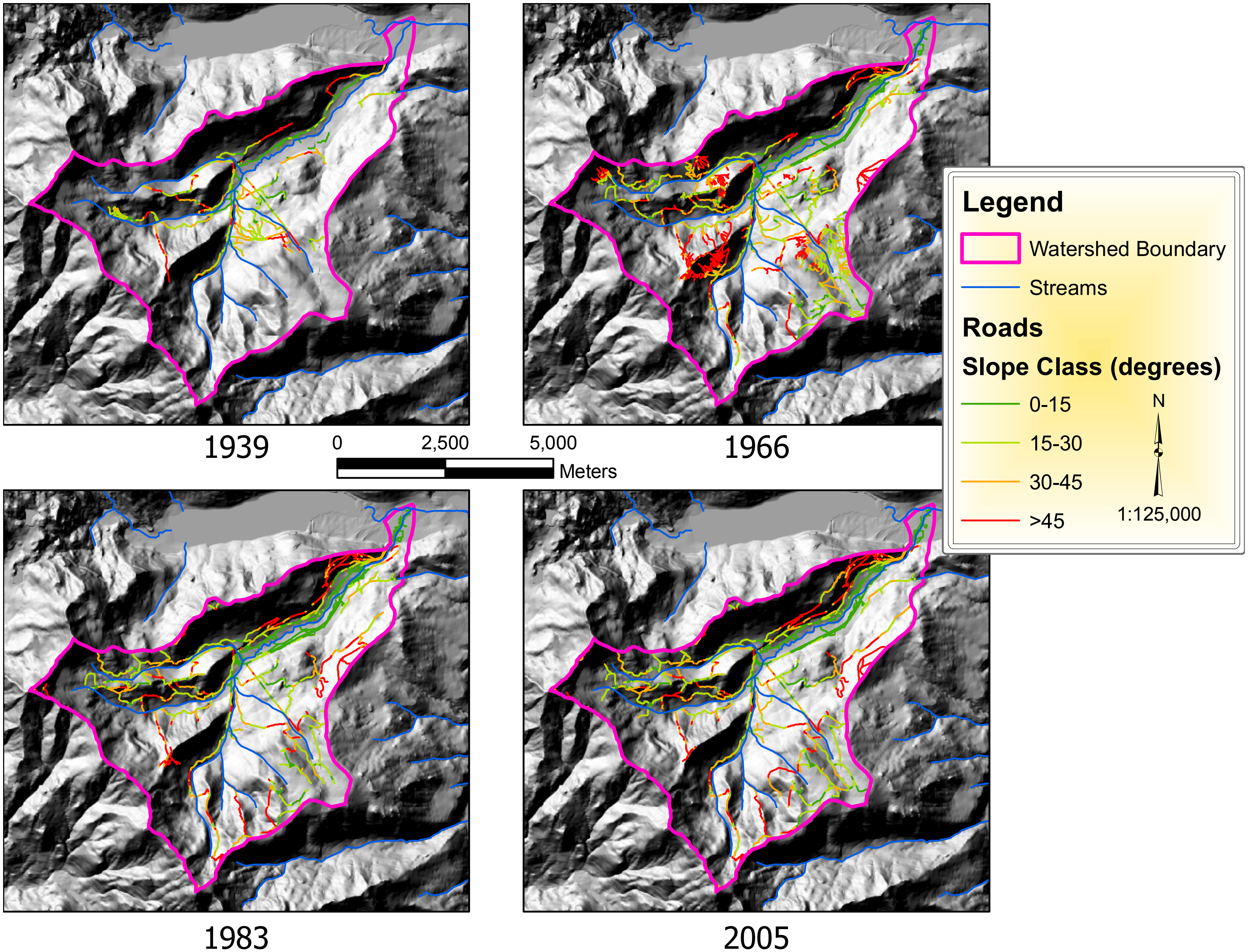
Property ownership and major roads and trails.
From California State Parks data. Not all roads on private property are shown.

Figure 3-1



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consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@
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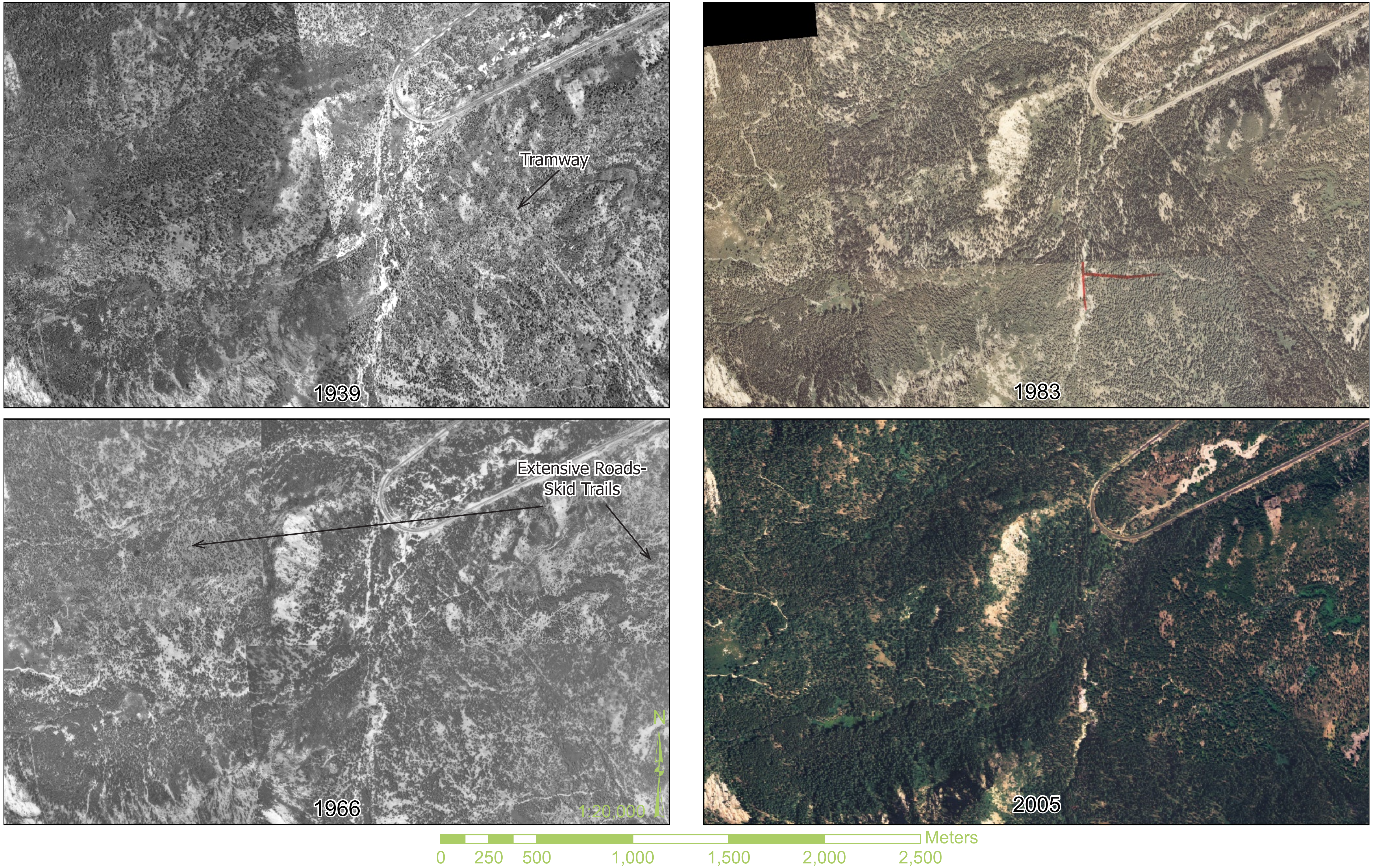
Roads through time.

Watershed roads mapped on rectified aerial photography. Slope classes determined by intersecting roads with slope polygons derived from a digital elevation model. Not all roads can be identified on aerial photos.

Figure 3-2



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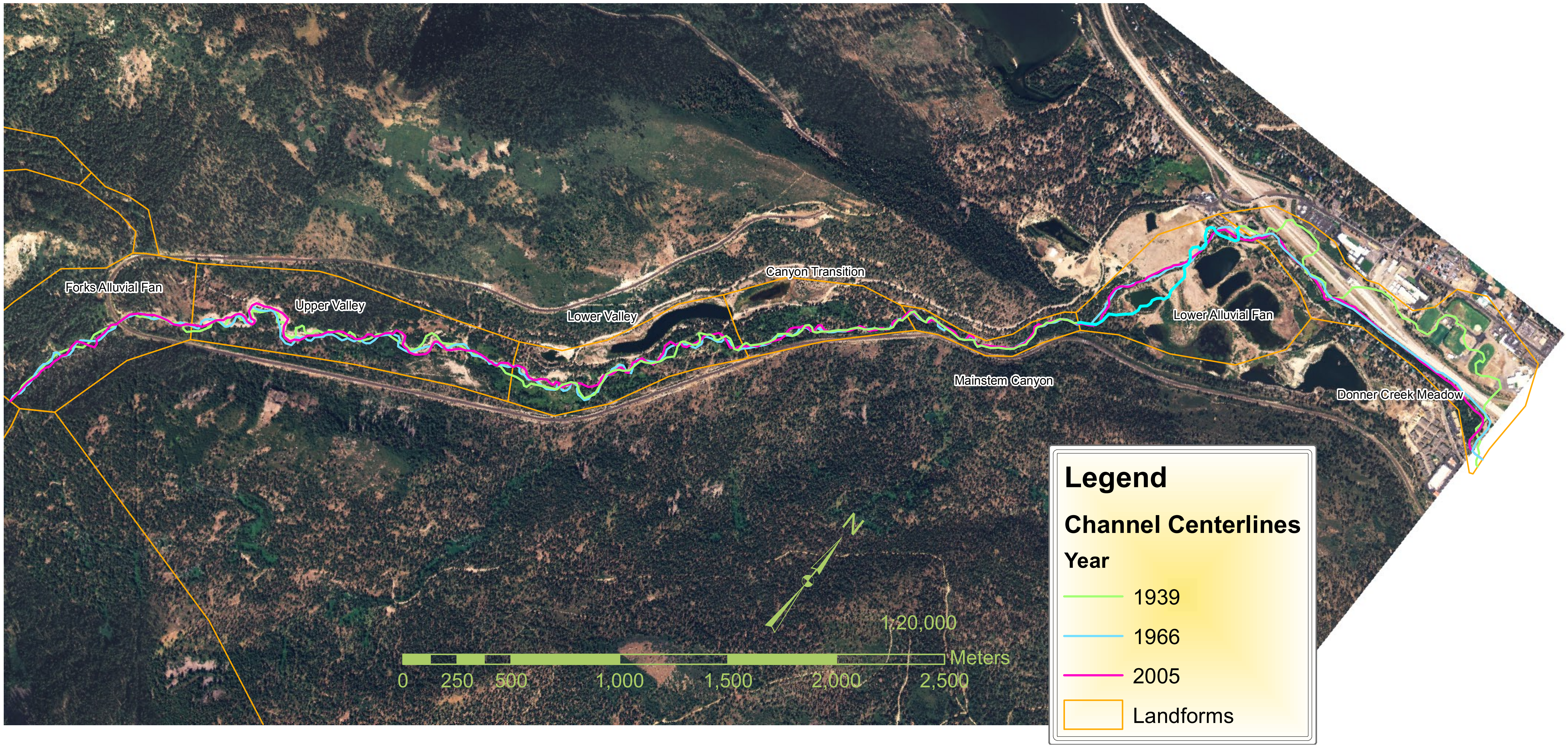
Representative views of watershed condition over time.
Aerial photographs were scanned from USFS archives and partially rectified.

Figure 3-3



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Changes in channel planform over time.
Channel centerlines mapped from rectified aerial photography.

Figure 3-4

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Cedarville, CA
96104
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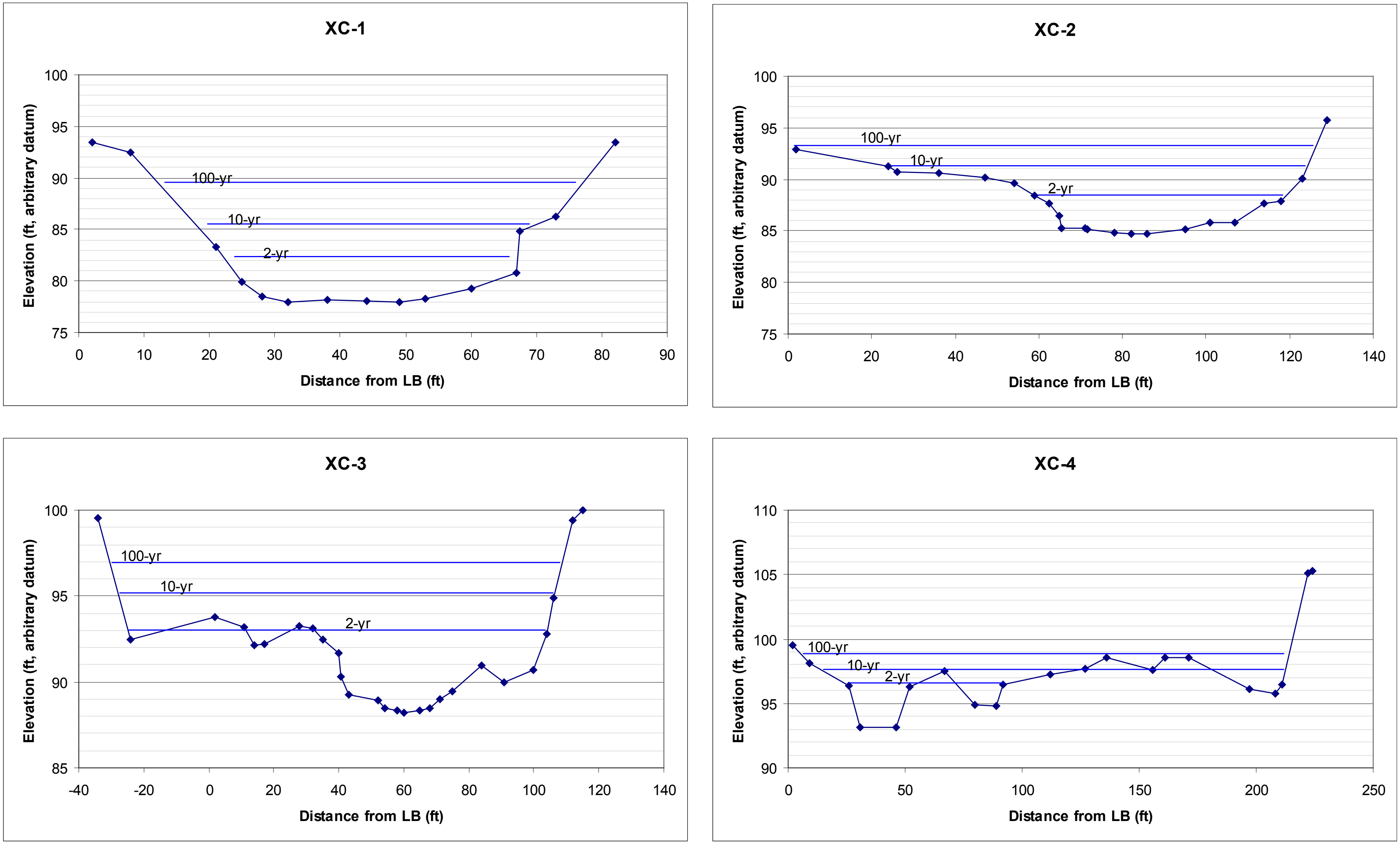
Location of cross section surveys and eroding streambanks.

Figure 3-5



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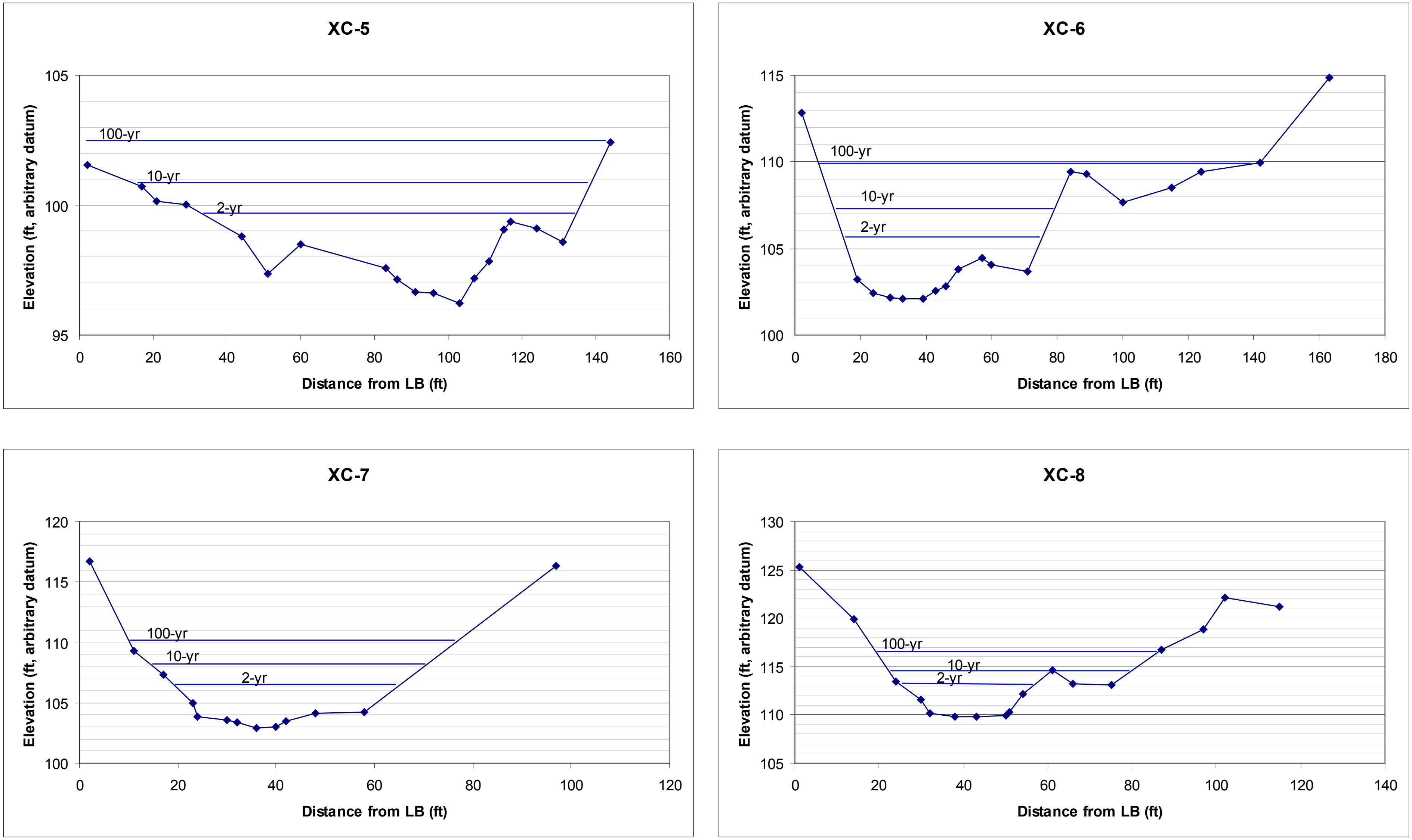
Cross sections 1 to 4.

Figure 3-6



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Cedarville, CA
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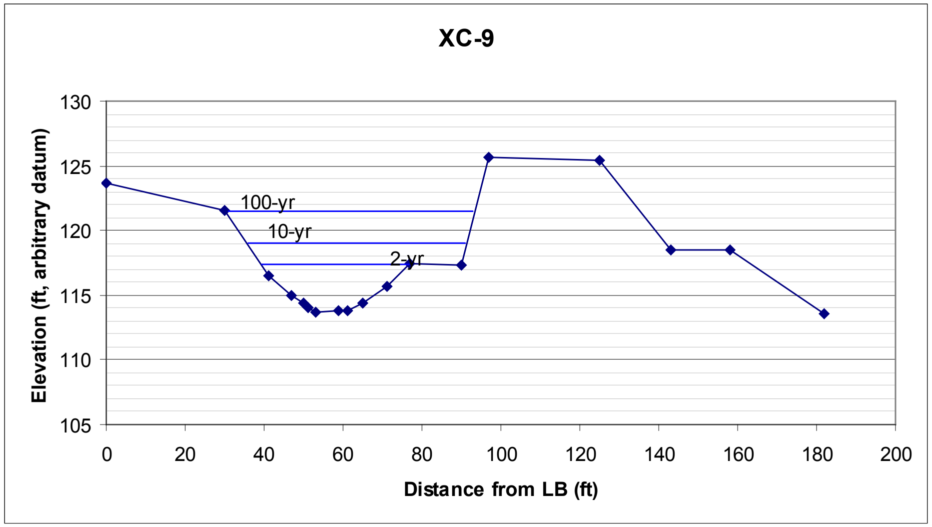
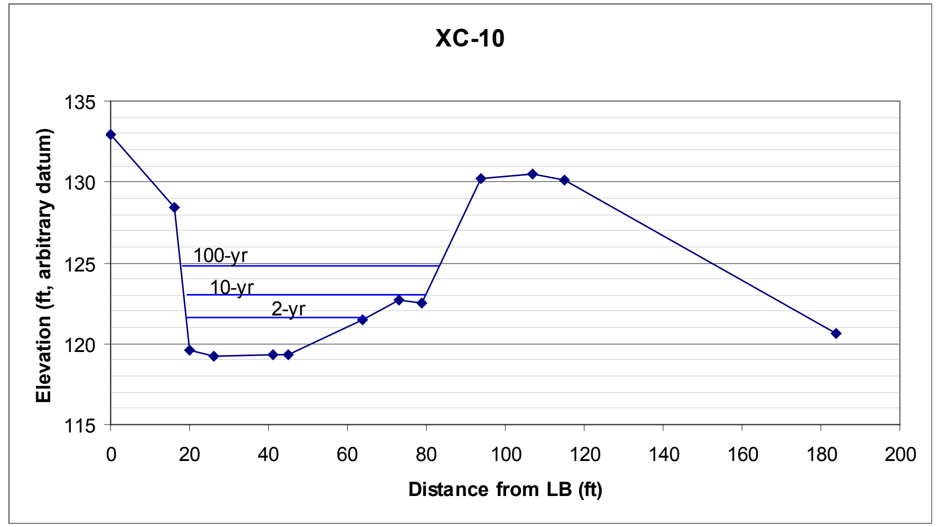
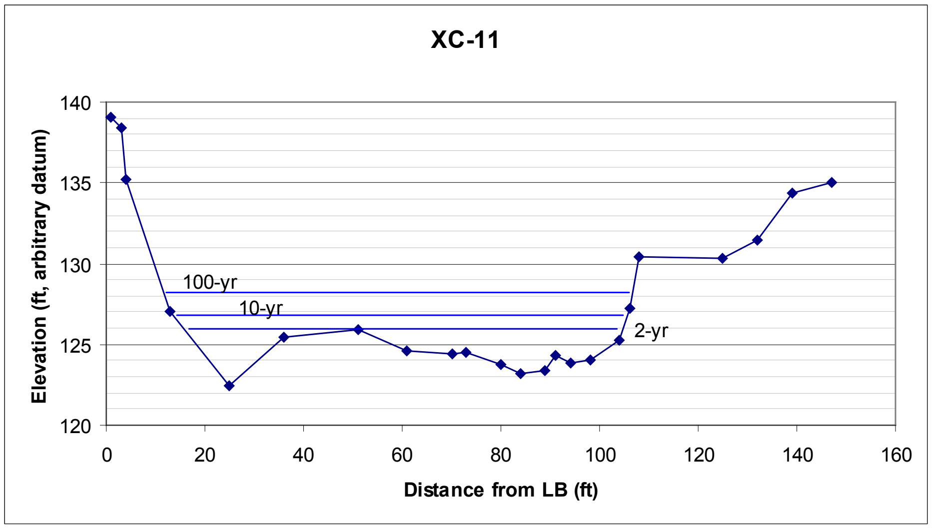
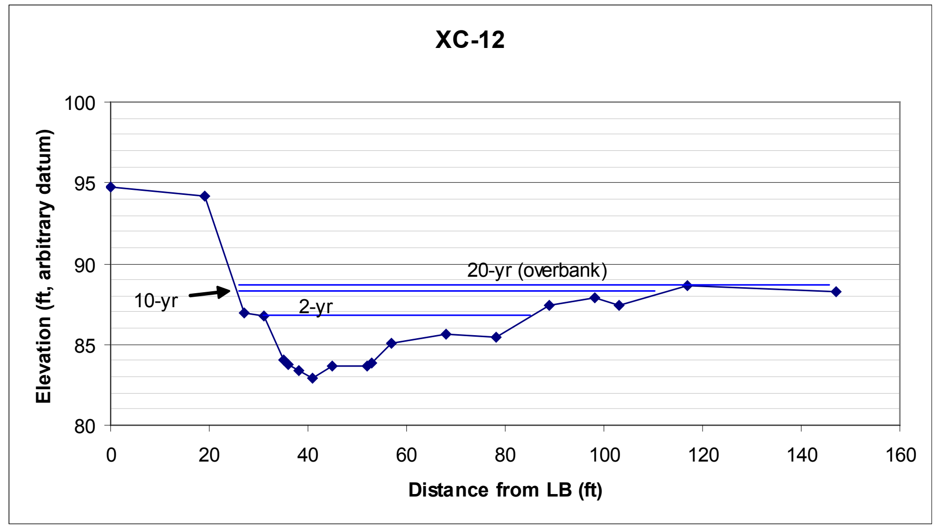
Cross sections 5 to 8.

Figure 3-7









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consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
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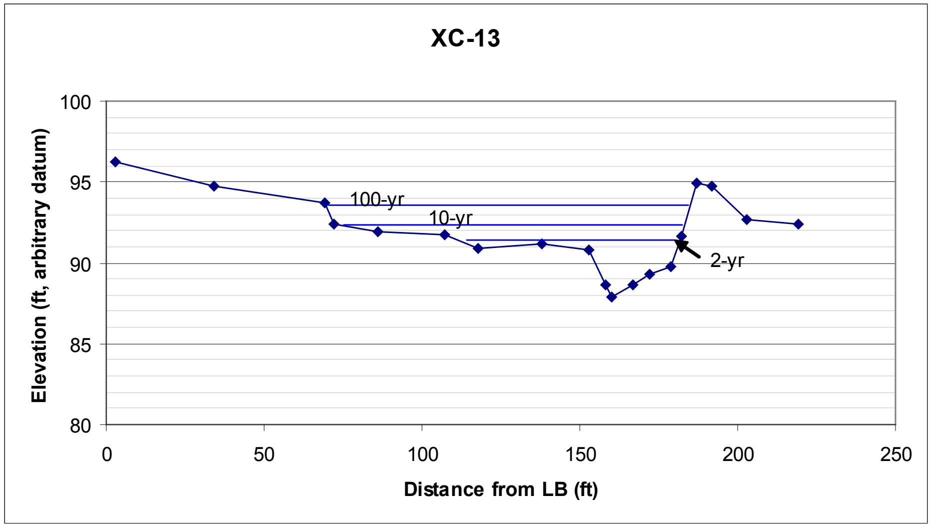
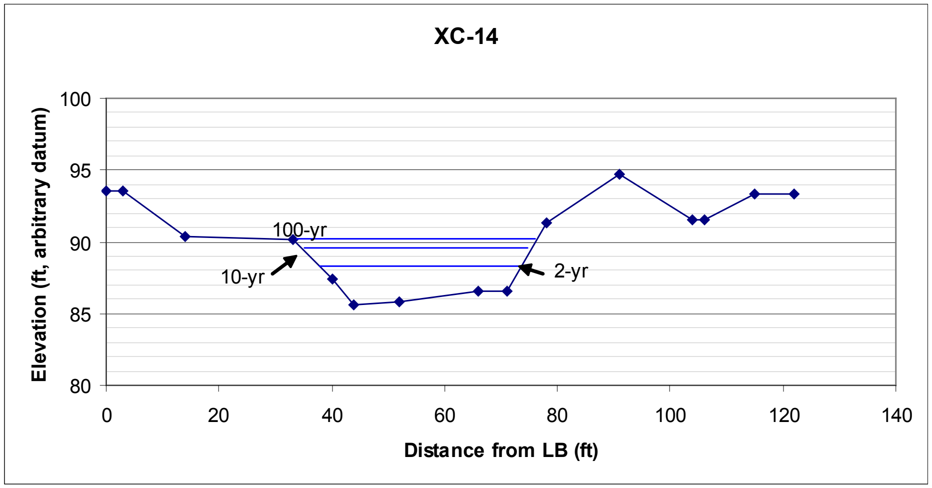
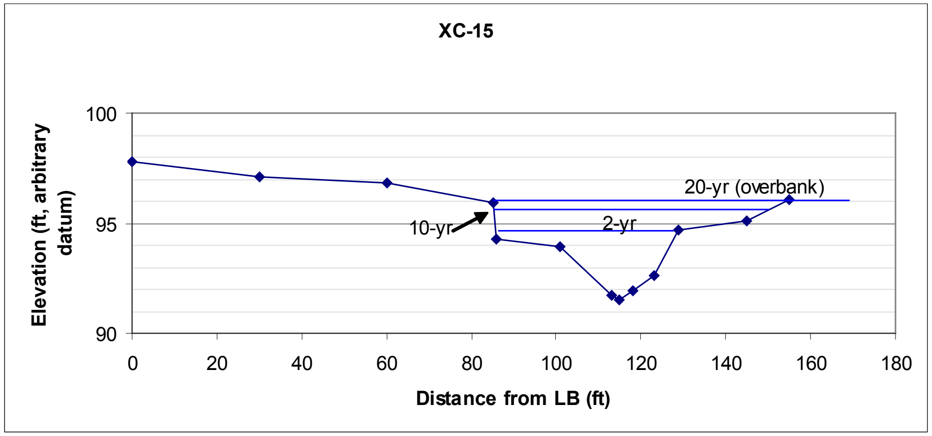
Cross sections 9 to 12.

Figure 3-8







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Cedarville, CA
96104
530 279 2400
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Cross sections 13 to 15.

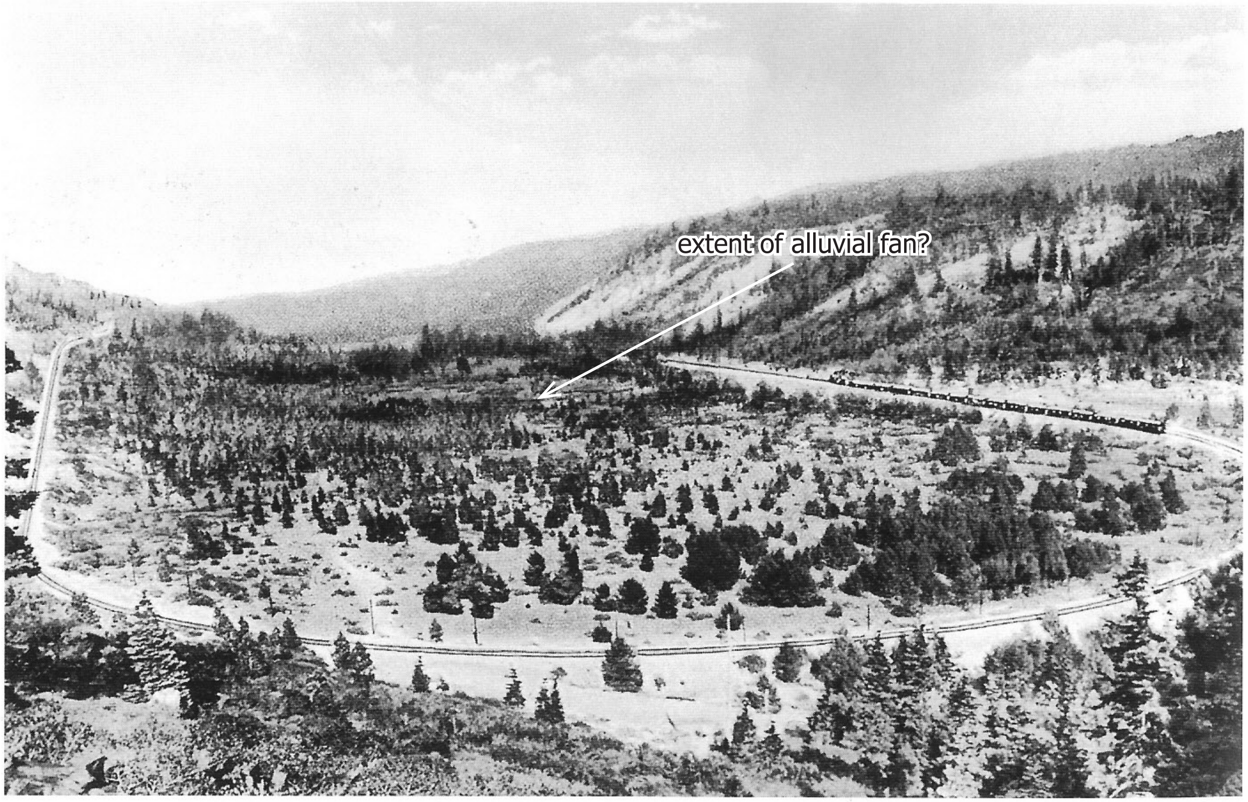
Figure 3-9

COLDSTREAM VALLEY FROM HORSESHOE BEND

Plate 65a
Circa 1919

Elevation:
6,600 feet

Legal Description:
17 N, 15 E, Sec. 26



Taken about 2.5 miles southwest of the previous photo pair, this view looks down Coldstream Valley from Horseshoe Bend. The camera point for plate 64a is at the upper left in the distance. The horseshoe was a unique feat of engineering that allowed the tracks to maintain the specified grade up the mountain. The view shows trees in early stages of regeneration after loggers removed the original stands. The riparian zone to the left of center supports many willows, while shrubs and herbs grow in the openings between trees. —Courtesy Special Collections Department, University of Nevada, Reno

RIVER RUN consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@hughes.net

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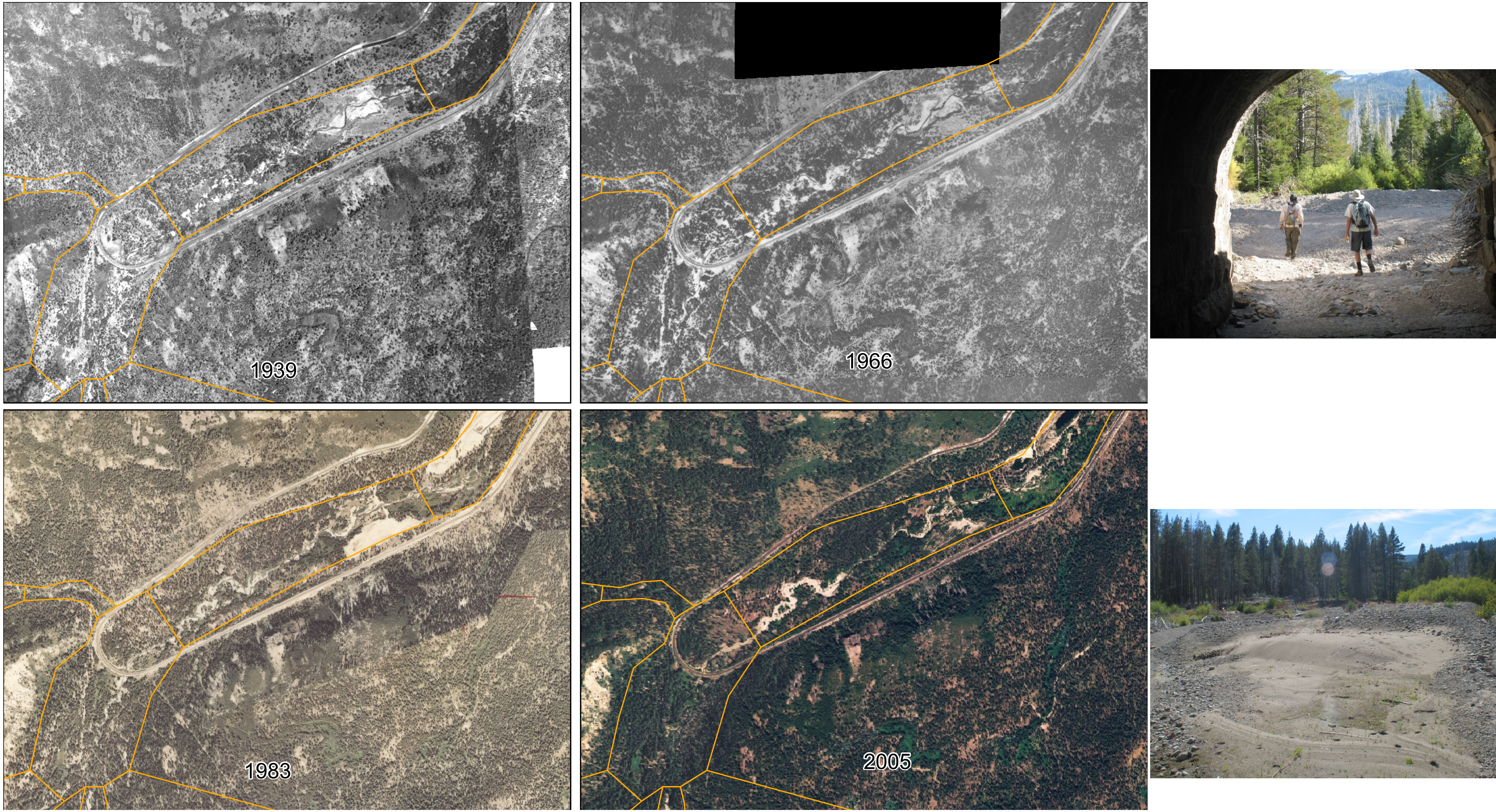
Forks Alluvial Fan in 1919.
Photo from Gruell (2001).

Figure 3-10



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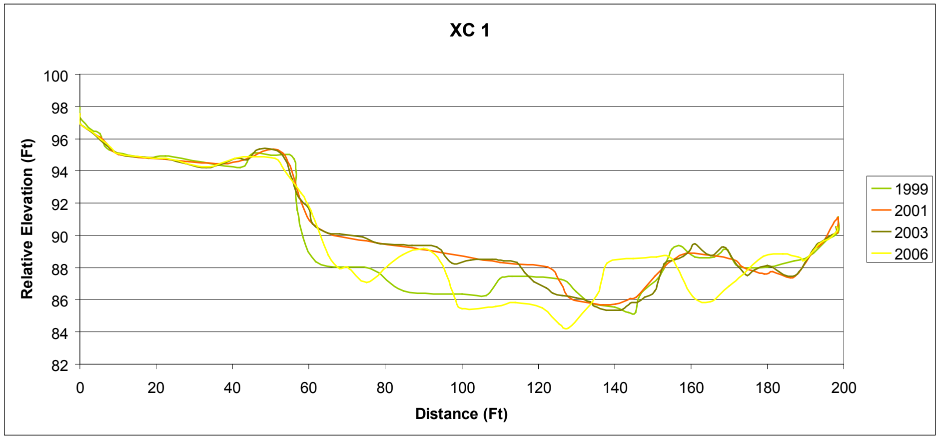
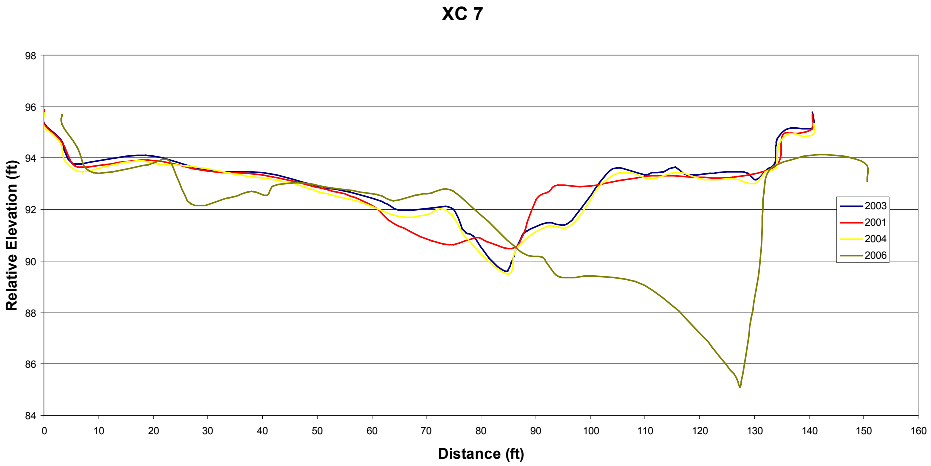
Photos of the Forks Alluvial Fan.
Note progressively increasing erosion over time in reach downstream of railroad culvert. Top right photo shows the narrow railroad culvert, with large bar upstream. Lower right photo is an example of the destabilized channel near the downstream end of the landform.

Figure 3-11





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Cedarville, CA
96104
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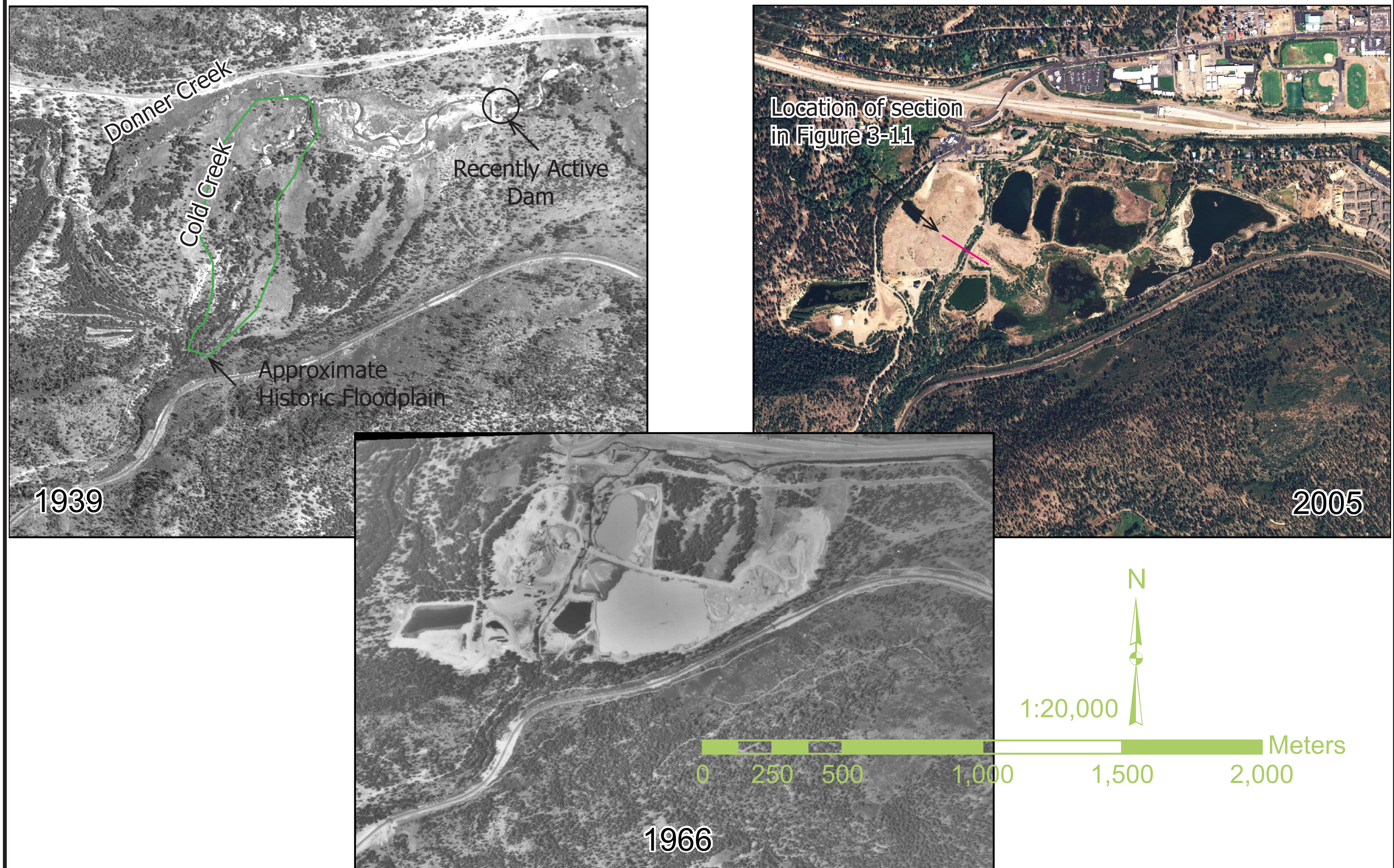
State Park cross sections in the unstable portion of the Upper Valley landform.

Figure 3-12



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P. O. Box 362
Cedarville, CA
96104
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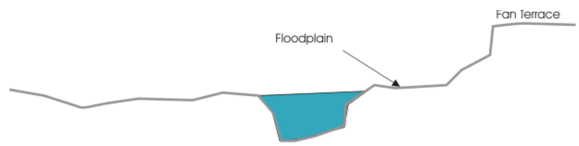
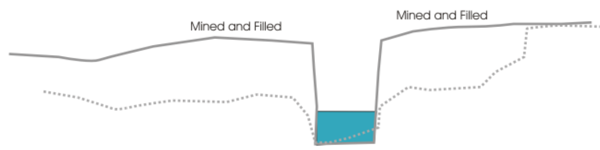
Impacts to the Lower Alluvial Fan landform.

Figure 3-13

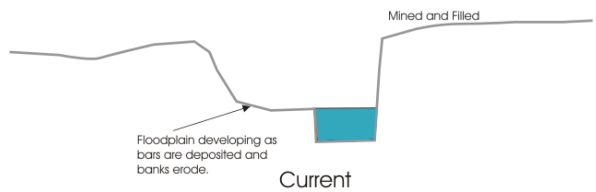
Cold 8-29-06 003



1939

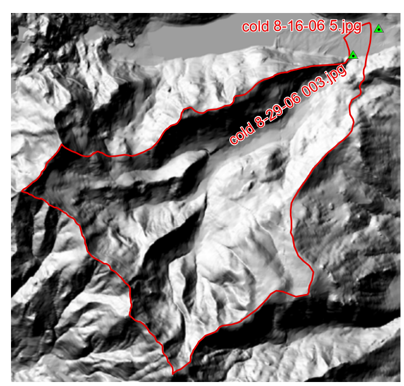


mid-1960's: post-channelization



Current

Cold 8-16-06 5



RIVER RUN consulting
P. O. Box 362
Cedarville, CA 96104
530 279 2400
mkiesse@hughes.net

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Truckee, CA

Lower Alluvial Fan cross section and representative photos.

Top left--erosion in upper section. Bottom left--large bar downstream of confluence.

Figure 3-14

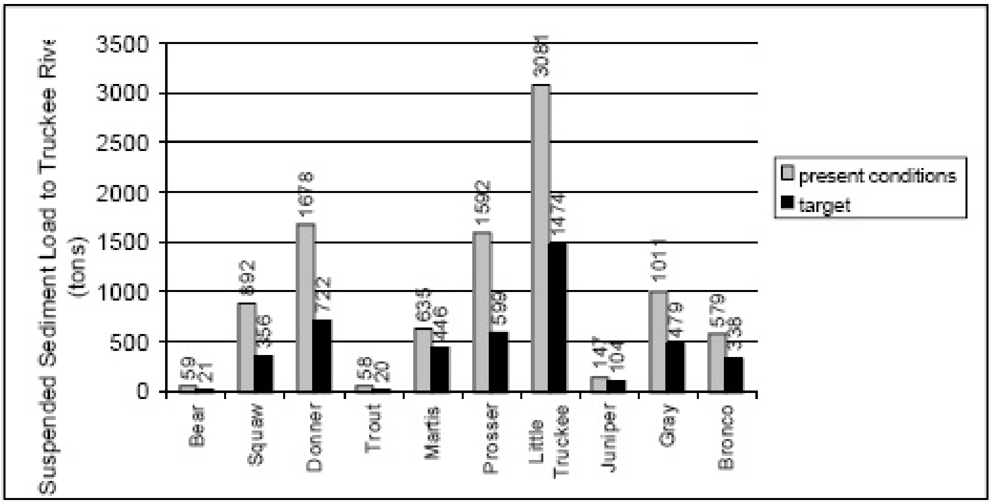

Figure 3. Difference in suspended sediment load between present conditions and target for major sub-basins.

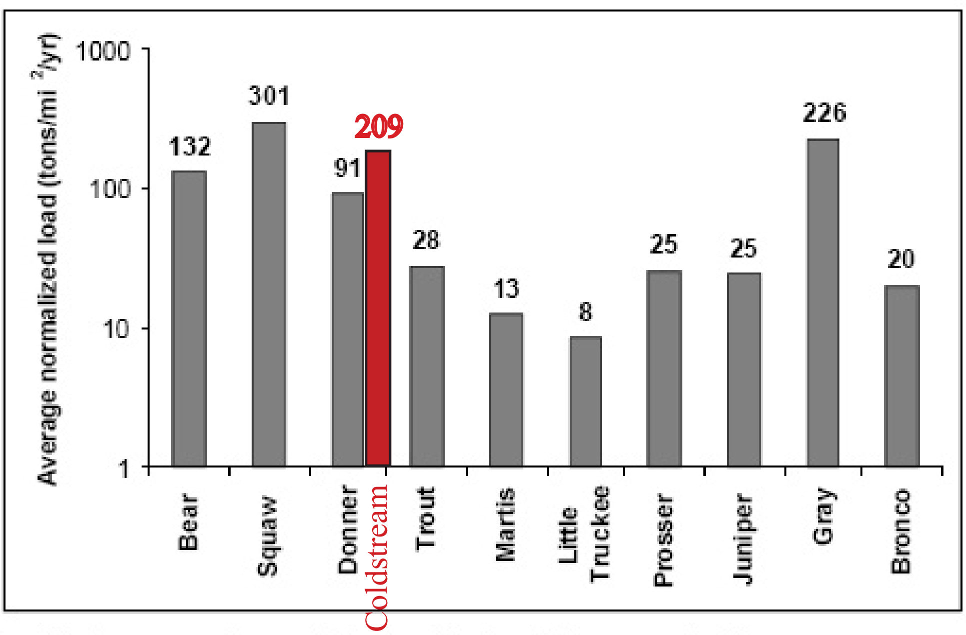

Figure 12. Average annual suspended sediment load predictions, normalized by area.

RIVER RUN consulting
P. O. Box 362
Cedarville, CA
96104
530 279 2400
mkiesse@
hughes.net

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Coldstream Canyon estimated sediment yield.

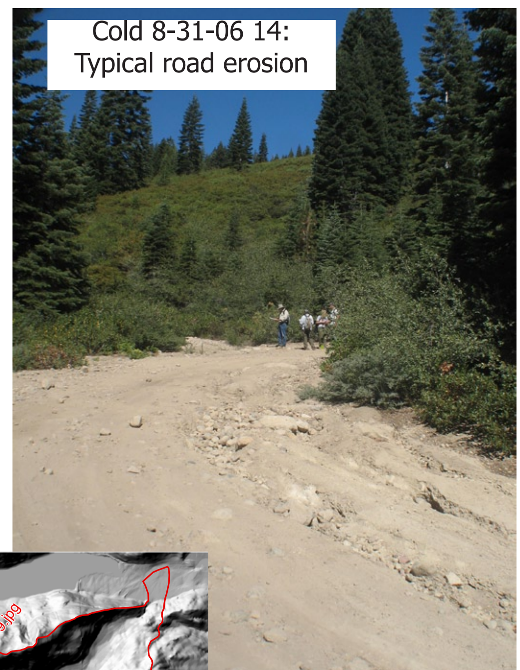
From McGraw et al. (2001). The red bar next to Donner Creek represents a yield per unit area for Coldstream Canyon only.

Figure 3-15

Cold 8-12-06 07:
Older stabilized skid trail

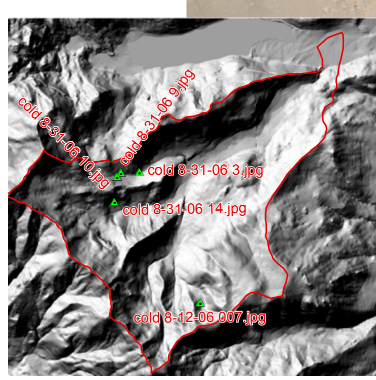
Cold 8-31-06 10:
Stable Humboldt crossing

Cold 8-31-06 3: Older skid trail with some flow concentration



Cold 8-31-06 14:
Typical road erosion

Cold 8-31-06 9: Loss of road surface due to flow diversion down road



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Photos of the condition of various roads.

Figure 4-1

Lower Canyon road
during flood of 12-31-05

Lower Canyon road
during flood of 12-31-05

Lower Canyon road
during flood of 12-31-05

Location of top left
photo in 2006, where
water leaves road

Location of top left
photo in 2006, where
water leaves road

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Road erosion during extreme events.

Figure 4-2