SULPHUR CREEK WATERSHED ANALYSIS

FEATHER RIVER
COORDINATED RESOURCE MANAGEMENT GROUP

AND

MOHAWK VALLEY WATERSHED RESTORATION COMMITTEE

PLUMAS CORPORATION
550 Crescent Street
P.O. Box 3880
Quincy, California 95971
(530) 283-3739

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TABLE OF CONTENTS

Figures

Tables

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EXECUTIVE SUMMARY

Watershed Description. Located on the eastern edge of the Sierra-Nevada crest (Mohawk Ridge), the Sulphur Creek watershed abuts the headwaters of the North Yuba River to the west and the Carman Creek watershed to the east. Sulphur Creek flows directly to the Middle Fork Feather River at Clio.

The Sulphur Creek watershed is distinctly divided into a western half and an eastern half by the Mohawk Fault zone. Hot springs located in this area attest to the fact that the zone is still quite active.

The westside slopes draining to the main stem of Sulphur Creek rise from the valley floor at an elevation of 4500 feet to over 8000 feet at Haskell Peak. This contrasts sharply with the eastside, where the elevation rise is 2000 feet less, ranging from the valley floor to just over 6100 feet. The effect is the formation of a "rain-shadow" on the eastern half. The average annual precipitation along the western half is from 40 inches near its base to over 60 inches near its summit, much in the form of snow. Along the eastern half, precipitation ranges from 30 to 40 inches. Adjacent Sierra Valley receives an average of only 12 inches annually.

Another striking difference between the two sides of the watershed is their aspect (the general compass direction and angle to the suns rays). The western side generally faces north and east, receiving much less direct sun throughout the year than the eastern side, which generally faces south and west. The eastern side also contains gentler slopes that are exposed to the suns rays' overhead during the hottest time of the day. The eastside of the Sulphur Creek watershed not only receives less precipitation, but the greater evaporation and vegetation transpiration leads to less runoff than that from the west side of the watershed. The westside receives more snow and it lasts longer into the year. There is also more water available on the westside to percolate into the ground, feeding more springs and streams with more water. Most of the streams on the westside tend to flow yearlong, while the two tributaries draining the eastside become dry, or nearly so, most years.

The watershed westside (rising to the crest of the Sierra Nevada mountain range) is tectonically active, rising much faster than the eastside, which appears to be standing still and eroding away, compared to the westside. This has very important implications on how these two very different sides of the Sulphur Creek watershed behave. Surface erosion dominates the eastside while slope failures are common on the much steeper westside. Occurrences of massive slope failures on the westside are random and episodic, responding to either rain-on-snow or seismic events. The latest flood event occurred in January 1997. During this rain-on-snow event, massive amounts of rock and soil, along with whole trees, moved into Sulphur Creek and onto the valley floor.

Rock types within the Sulphur Creek watershed are a mixture of metamorphic, granitic and volcanic. Granitic rock types occur on both sides of the watershed and the sandy soils associated with this rock type are very erodible. Highway 89 was constructed through this highly weathered and erodible rock type along the eastside of Sulphur Creek at the Plumas Sierra county line. Soils derived from the other rock types break down into sand and smaller size particles. These soils are much less erodible, but can still provide large quantities of sediment if water flows are concentrated, as along roadside drainage ditches and on bare, steep slopes.

In the distant past (60,000 to 75,000 years ago), an arm of Lake Mohawk extended into what is now the lower and middle reaches of Sulphur Creek. Lakebed deposits topped out at the 5040-foot elevation (Durrell 1987). Erosion of these lakebeds continues today and forms the sloping meadowlands on both sides of the Sulphur Creek valley. The existing entrenched channel (gullied) of Sulphur Creek flows along the lowest elevation of this meadowland and is removing large amounts of meadow soil. Before the turn of the twentieth century, the stream channel and its floodplain were located on top of the meadow as a stable system. Much of the channel degraded during the past 50 years.

Before Lake Mohawk drained, the climate of the region had been cooling and drying, culminating in the formation of glaciers. The latest glacial advances, the Tioga glaciation, reached its maximum extent 20,000 years ago and as recently as 8,000 years ago, also marking the end of Mohawk Lake (Durrell 1987). The lower ends of many of the glaciers rode out into the lake, leaving behind glacial moraines as they receded. Several of the more recent moraines were deposited onto the lakebeds along the watershed westside.

Because of the gently sloping sides from the eroding lakebed material, the valley bottom is not a typical, nearly level meadow floodplain. The floodplain of Sulphur Creek was much narrower than the valley width, at about 400 feet. It was the product of small lake that extended up into Sulphur Creek about two miles, formed by the blockage of the Middle Fork Feather River by the formation of the Frazier Creek Fan (formed during a massive rock and sediment debris flow). This small lake naturally drained about 600 years ago (Durrell 1987).

The watershed westside is composed of many, parallel draining tributary channels, as compared to only two tributary channels draining the eastside (Barry Creek and Calfpasture Creek). This contrast in drainage patterns supports the idea that the eastside is older and more stable. A parallel drainage pattern usually denotes a young landscape while a highly branched drainage pattern denotes a mature landscape.

Where each stream channel opens out into the valley, alluvial fans composed of coarse material have formed. The alluvial fans on the watershed eastside are composed of mostly fine material, as opposed to the very coarse material of the westside fans. The January 1997 flood is the most recent event to move large amounts of material onto these fans. Mass wasting and landslides provide an abundance of material to the streams along the steep westside and debris flows are a common and very important mechanism for transporting this material downstream to the valley.

<u>What condition are the streams in</u>? There are essentially two types of streams, those that move sediment because they are steep and narrow (transport channels) and those that respond to changes in the watershed because they are gently sloping and include broad floodplain areas (response channels). Most, if not all, of the stream channel degradation (gullying) has occurred in the response channel types. At the headward expansion of each gully is a headcut (a rapidly eroding waterfall) and the gullies themselves have become narrow, but highly erodible, transport channels. The valley bottom is still considered a depositional landscape and deposition of material from upper watershed areas has formed gravel bars, islands and braided channels. These depositional features of coarse sediment are forcing streamflows against the highly erodible banks, expanding gully widths.

Streams flowing into the valley from the east deliver mostly fine sediment to Sulphur Creek, degrading water quality and aquatic habitats. Groundwater elevations are lowered by drainage into the gullies, requiring extensive irrigation to maintain growing conditions. Headcuts are migrating up the tributary channels as a response to the lowered elevation of Sulphur Creek. Both Calfpasture Creek and Barry Creek are now entrenched into their historic floodplain, the meadow.

Gullying of the main Sulphur Creek channel has progressed upstream to a short bedrock-control section located at an elevation of approximately 5000 feet, the elevation of the Mohawk Lake deposits. Flood flows no longer access the historic floodplain anywhere, but are confined to the gully (entrenched), passing quickly down valley and providing little groundwater recharge to the valley aquifer. Most of the sediment generated in the upper watershed will eventually move through the entrenched channel of Sulphur Creek and on into the Middle Fork Feather River at Clio. Channel adjustments caused by the increased water and sediment flow is widening the channel through bank erosion. The process is expected to continue until adequate channel geometry and floodplain widths are established.

<u>What are the causes of the degradation</u>? There is no one obvious, direct cause. Gullying is usually a result of some instability or drop in the stream channel elevation (base level) downstream. The MFFR has certainly degraded where Sulphur Creek flows into it. The mouth of Sulphur Creek, where it discharges in the MFFR, has, apparently, been relocated from south of the Clio bridge to upstream of the bridge. Other factors either played into the many potential causes or are aggravating existing conditions. Upper watershed areas are probably delivering water faster than they did, leading to higher streamflow peaks and downstream adjustments. Upper

watershed areas are also eroding more and delivering more sediment to the downstream reaches. The increase in the flow of water and sediment are responsible for continued channel instability. Certainly other factors such as overgrazing and bank trampling by livestock and channel straightening contribute to the instability.

What about the roads? The roads are contributing significant amounts of sediment and adding to the apparent peaks during high water flow events. Because of these increases, downstream conditions and adjustments are affected. These stream channel adjustments to the amount and timing of water and sediment is contributing to the instability that is of concern today. This is especially true for the roads on the westside, where debris torrents are common. Several roads actually increase the risk and magnitude of naturally occurring debris torrents. The Mohawk-Chapman Road is the most notable example of this problem.

How should we fix the problem? Because human and natural disturbances are generating large amounts of sediment and the historic streamflow regime has been altered, restoration of basic sediment storage features and floodplain function are of highest priority. Reducing the sources of sediment should occur simultaneously by treating high priority roads and streams.

This report documents the findings of an assessment of watershed condition. A strategy for restoring and rehabilitating vital functions and stream channel conditions will be a separate document that will be finalized later this year. Some treatments can be considered restoration of full function, but the general strategy deals with rehabilitating the watershed while taking into account natural and human constraints, such as recreation, land developments, livestock grazing and other uses.

Up valley view with Sulphur Creek on the left.

INTRODUCTION

Background. The Sulphur Creek watershed encompasses a significant portion of Mohawk Valley and is formed by the main, north-south trending fault that defines the eastern edge of the Sierra-Nevada mountain range. The watershed has experienced nearly 150 years of land and resource use. These uses included mining, timber harvesting, livestock grazing, road construction, water diversions, channel straightening and realignment, urban developments, and wildfire suppression and ignition.

Urban development.

Pasture land and timberland.

The cumulative effects of these activities have caused changes to streamflow and sediment supply, resulting in rapid stream channel adjustments. The adjustments have formed an extensive gully system *(deep, rapidly eroding channels cut by running water in which the streams become entrenched and are rarely able to escape*). This system of gullies continues to develop as it grows in both length and width. Other changes include impaired water quality, lost aquatic and riparian habitats, and diminished aesthetic values.

Since 1995, various landowners and managers in the Sulphur Creek watershed have been working with the Feather River Coordinated Resource Management group (FR-CRM) to initiate restoration of the main channel and several of its tributaries. In November 1999, recognizing the need for an integrated, watershed wide approach, the Mohawk Valley Watershed Restoration Committee (MVWRC) formed for the purpose of collaboratively implementing a watershed restoration effort, including National Forest lands. In January 2001, the MVWRC requested that the FR-CRM apply for funding under the Proposition 13 Watershed Protection Program to conduct a watershed analysis of the Sulphur Creek watershed. Approval came in March 2002 with the signing of an agreement with the State of California Water Resources Control Board (SWRCB) to analyze the watershed, develop a strategic plan for restoration, and develop a Citizen Monitoring Program (Appendix I).

Purpose. The purpose of the watershed analysis is to assess the condition of the stream channels and adjacent landscape features, identify the major sources of soil erosion and channel instability, analyze the causes of the identified instabilities, and to develop an integrated restoration strategy. Data and information were collected that describe historic and current conditions, and the processes at work in the watershed. Restoration opportunities and constraints are to be identified and, finally, a list of project areas and activities is to be developed and ranked. This prioritized project list will be used as a strategy to guide the MVWRC and the FR-CRM in a watershed-scale restoration effort. The Citizen Monitoring Program will monitor improvements in conditions of water flow and water quality and the FR-CRM with the MVWRC will monitor each project until functional stability is reached.

Sulphur Creek upstream of Whitehawk Ranch.

Problem Description. Historic and current land uses are the most likely causes for much of the stream and riparian degradation that is apparent throughout the watershed.

This degradation is in the form of reduced water quality, reduced aquatic and riparian habitats, property loss, and deteriorated aesthetic values. This analysis is not intended to evaluate timber harvesting, grazing, mining, and urban development practices; but it will evaluate the potential impacts of these practices where they still affect stream and riparian conditions. Other studies conducted in the Feather River basin of stream and riparian conditions have been linked to two primary elements (USDA-Soil Conservation Service 1989 and Clifton 1992). They are 1) roads and road like features that directly affect or drain to stream channels and 2) stream channels that have become gullied.

Methods Used. The methods used for this study consist of a reconnaissance level overview of hill slopes, streams, roads, mines, etc., followed by more intensive, ground-level surveys. The reconnaissance level work relied on known information from historic files, Geographic Information System (GIS) databases, aerial photos, maps, etc. The intensive survey looked at the main Sulphur Creek channel, the lower reaches of tributary channels (where active channel erosion is occurring), roads and stream crossings, urban areas, and mine sites. Upper watershed stream channels were assessed during the reconnaissance stage of this analysis and were found to not need further study except where they are directly affected by roads.

Channel cross-section survey.

Headcut at the bottom McNair Meadow.

The entire length of Sulphur Creek, from McNair Meadow downstream to the Middle Fork Feather River, was surveyed. The lower reaches of the tributary channels that flow through the main valley bottom were also surveyed. Cross-sections and longitudinal profile surveys were conducted along locations deemed representative of conditions of each stream reach.

The point where initial channel incision is occurring, commonly referred to as a headcut, (see photo next page) was located along each tributary channel. The initial incision cycle, forming the existing, main-channel gully, has traveled the full length of the valley and into the upper valley reach, a total of 5.2 miles. The incision is presently controlled by bedrock at its terminus. Upstream of the bedrock, additional channel incisions have taken place and are now located at the downstream end of McNair Meadow.

Subcontracts were let to gather historic information and to conduct a reconnaissance level geomorphic study (designed to identify both natural and human caused disturbances). A seasonal crew of two people conducted surveys of the road system while FR-CRM staff conducted stream channel surveys.

Road erosion and stream delivery survey.

Headcut on Calfpasture Creek.

LOCATION AND VITAL STATISTICS

Location:	Immediately east of the Sierra-Nevada crest and tributary to Middle Fork Feather River at Clio in T21N & T22N, R12E & R13E, MDB&M.
Size:	21,243 acres (33.2 square miles).
Elevation:	Average, 5900 feet. Eastside ranges from 4500 to 6100 feet. Westside ranges from 4500 to 8000 feet.
Aspect:	General aspect is northwest (main channel flow direction). Eastside watershed aspect is southwest. Westside watershed aspect is northeast.
Geology:	Metamorphic, volcanic, and granitic rock types, some covered by landslide material, in the upper watershed areas. Lakebed material (Mohawk Lake) is overlain by glacial moraine, along the western margins of the valley with alluvium in the valley bottom. Alluvial fans are located at the mouths of all tributaries.
Hydrology:	Average annual precipitation is 41 inches (65% falling as snow). Average annual runoff is 21 inches. Eastside average precipitation and runoff is 35 and 16 inches. Westside average precipitation and runoff is 45 and 26 inches.

LANDSCAPE SETTING

Geology and Geomorphology. The watershed is located at the contact between the Sierra Nevada Mountains to the west and the Diamond Mountains, of the Basin and Range Province, to the east (Figure 1). From west to east, Mohawk Ridge is part of the crest of the Sierra-Nevada mountains. The land falls steeply as a fault scarp to the valley bottom and then rises gently over the relatively rounded slopes and peaks of the eastside. The eastside ridges are approximately 1200 feet lower in elevation than the crest of the westside (Figure 2).

Figure 4 displays the major rock types in the watershed and subwatersheds. These rock types include meta-sedimentary, meta-volcanic with intruded granitics. The steep westside consists of granitic rock interspersed with glacial moraine and landslide material, while the eastside encompasses mostly volcanic mudflow material and some granitic rock. The valley bottom consists of eroding lakebed (Mohawk Lake) and recent alluvium. Alluvial fans have formed at the mouths of the canyons, where tributary channels flow into the valley.

View across Sulphur Valley to west towards Mills Peak.

The principle faults outlining the Sierra-Nevada mountains are located along the southwest side of Sierra Valley, then cross into Mohawk Valley (Figure 3) before extending through American Valley (Durrell 1987). During each episode of faulting the Sierra Nevada rises higher relative to the land to the east. This fault zone is still considered active, given that the historic earthquake near Clio in 1875 was quite large and frequent minor earthquakes have been recorded in Plumas County to the present (Durrell, 1960; 1987).

It is notable that only two tributary stream systems drain the eastside, Calfpasture Creek and Barry Creek. Each of these tributaries drains approximately 6.5 square miles. The westside is significantly different, not only because it is much steeper, but also because it is drained by seven, somewhat parallel, tributary channels. The average area of these subwatersheds is 1.75 square miles, the largest being 2.0 square miles.

The last major land-shaping event was the formation of the Frazier Creek Fan (actually a large debris flow deposit), which blocked the Middle Fork Feather River for several hundred years. The small lake that developed behind the debris dam extended up Sulphur Creek approximately 2 miles and was filled with gravel and finer sediment before the dam breached, an estimated 600 years ago (Durrell 1987). Most of the lake sediment has eroded away except for distinct terrace features just upstream from the existing mouth of Sulphur Creek. The large meadow area where the MFFR and Sulphur Creek once joined (across Highway 89 from the Clio bridge) is the eroded surface of the lake.

Small land slump.

Looking downstream at the original confluence of Sulphur Creek and the Middle Fork Feather River.

Geologic Hazards. The eastern portion of watershed contains few landslide mass wasting features. They are mostly associated with channel "inner gorges" (over-steepened slopes adjacent to stream channels). The westside is a steep, fault scarp where slumps and landslides are common. Significant amounts of coarse material are delivered and stored in headwater stream channels, creating large debris flows that deposit onto the valley bottom during major flood events (Durrell 1987 & Collins 2002). Even though massive erosion events are random and episodic (responding to either intense precipitation, rain-on-snow, or seismic events) they occur frequently enough to play a pivotal role in forming the channels and developing morphologic features such as alluvial fans.

During the past 7,000 – 10,000 years, the valley floor evolved as a large reservoir or "sink" for water, sediment and nutrients flowing from upper watershed areas. The effect of the sink includes distributing flood flows across the valley (attenuating peak floods), providing a groundwater source for late summer streamflow (increasing base flow), and good quality water (filtering the water and providing cold water). The valley bottom collected nutrients and stored sediment on its extensive floodplain. Of note is that the large amount of woody debris and coarse bedload naturally transported by the tributary channels to the valley was captured and stored, creating alluvial fans, while the finer suspended sediments washed out onto the meadow and deposited as alluvial overbank deposits (Durrell 1987 & Collins 2002).


Debris flow deposit entering Sulphur Creek.

Soils. The soils reflect the parent material (rock type) from which it originated. The Sulphur Creek watershed is within the Waca-Inville-. Woodseye soil complex (Plumas National Forest Soil Resource Inventory). The soil complex is described as:

> *Gently sloping to very steep, moderately deep or deep, well drained*[1] *loamy soils on steep side slopes and terraces.*
>
> *The strongly sloping to very steep Waca soils are on side slopes and near ridgetops. They are moderately deep, well to somewhat excessively drained loamy soils that are moderately erosive.*
>
> *The gently sloping to steep Inville soils are on toe slopes and broken side slopes. They are deep, well to somewhat excessively drained, very gravelly loam soils that are underlain by slightly weathered volcanic breccia*[2].
>
> *The moderate to very steep Woodseye soils are on south facing side slopes and ridgetops. They are shallow, well to somewhat excessively drained very cobbly loam soils that are underlain by slightly weathered volcanic breccia.*
>
> *The Gibsonville soils* [a minor soil type] *are on strongly sloping to very steep side slopes and long, narrow ridgelines. They are shallow, well drained very cobbly loam soils that are underlain by slightly weathered volcanic breccia.*

[**1**] <u>Soil drainage</u> refers to the rate at which water is removed from the soil, the period of wetness, and any possible affect on the growth of plants.

[**2**] Volcanic breccia is pyroclastic material. In the Sulphur Creek watershed it is of the mudflow variety and consists of angular to slightly rounded blocks of volcanic rock in a matrix of volcanic mud (Bonta Formation).

These soil complexes also include rock outcrops and rubble land.

The following two soil water attributes are important for this analysis:

1. Hydrologic Soil Group. An estimate of the surface runoff potential from precipitation. Soils are grouped according to their ability to take in water when they are thoroughly wet and receive precipitation from long duration storms. The groups range from low to high runoff potentials.

2. Maximum Erosion Hazard. A quantitative rating that predicts the potential for sheet, rill and gully erosion if vegetation and litter are removed. The factors used to determine this rating are soil type, topography, climate and vegetative cover. The ratings range from low to very high hazards.

Again there is a marked difference between the two sides of the watershed. The very steep westside is highly unstable and the soils are moderately erodible. Numerous active and inactive slumps and slides have been identified along with the development of large alluvial fans where each tributary channel opens out into the valley (Figure 4 and large scale map developed by Laurel Collins in 2002 and located in the Plumas Corporation office in Quincy). Much of this eroded material is delivered during infrequent events as debris flows, when large quantities of large size material are transported.

The eastside is dominated more by surface erosion that generates small size sediment, as compared to the higher landslide frequency of the westside that generates a higher proportion of coarse sediment. Except for the over-steepened slopes found along some stream channels where the few landslides are found, most of the eastside landscape is "rounded" in appearance, having experienced a long history of erosion with little tectonic uplift.

Looking east across the Sulphur Creek valley towards Beckwourth Peak. Note the rounded appearance.

The potential for soil erosion is moderate to high, primarily where soils have been exposed. Much of the eroded material (sediment) is deposited into headwater stream channels where it is eventually transported downstream.

Hydrology: Climate and Precipitation. Winter precipitation events move in off the Pacific Ocean as frontal storms. As the moist air mass lifts over the Sierra-Nevada mountain range most of the moisture is transformed into water and ice, falling mostly on the western slopes (Sacramento Valley foothills to Lakes Basin), leaving the eastside much drier (rain-shadow effect). East of the Sierra-Nevada mountains, only the highest peaks can squeeze out significant moisture. Even though the eastside of Sulphur Creek is lower in elevation, it receives fair amounts of precipitation, albeit much less than the westside. Most of the winter precipitation is snow with a much deeper snow pack accumulating on the watershed westside. Summer thunderstorms are prevalent in the area and can cause localized downpours, erode unprotected soils, and transport material into headwater stream channels for later transport when winter and spring streamflows occur.

The average annual precipitation amount of 41 inches (average over the entire watershed) ranges from 35 inches in the valley bottom to 55 inches along Mohawk ridge and 40 inches along the eastern ridge. Figure 5 displays lines of equal precipitation and runoff and Table 1 displays precipitation and runoff in each subwatershed. In the Feather river Basin, precipitation and runoff is distributed unevenly through the year, falling mostly during the winter and spring months (Figure 6). There are no long-term precipitation or runoff data documenting annual and storm specific patterns and amounts for the Sulphur Creek watershed but most years are either greater or lesser than the average figures described. Precipitation and streamflow measurements are included in the Citizen Monitoring Program.

Air and Water Temperatures. A product of solar radiation, slope aspect, and elevation, air temperatures are typically not only cooler during winter months but also cooler at higher elevations. This is especially true on the westside, where the slope faces away from the sun most of the year and for much of the day during summer months. Air temperatures can directly impact stream water temperatures, especially where streams are exposed to the direct rays of the sun.

The shade provided by riparian vegetation not only blocks direct solar radiation from streams but also maintains cooler, more humid air over them. Good riparian cover also insulates streams from the extremes of airflow and air temperature, both during the winter and summer seasons.

Where riparian vegetation is sparse or missing, stream water temperatures can reach thresholds that are lethal to aquatic life both during the summer and winter.

Upper reach of Sulphur Creek.

Middle reach of Sulphur Creek

Of all the mechanisms in the watershed that create change, major flood flows are the greatest. High flows occur frequently during spring snowmelt. The lower size, but frequent and longer duration, flows are critical to channel and habitat maintenance. Floods of unusually high magnitude are rare but very important because they deliver significant amounts of sediment and debris to stream channels.

In the Sulphur Creek watershed, summer air temperatures can reach 100°F during the hottest time of the day and well below freezing during the winter, sometimes reaching 0°F and lower. Air and water temperatures were monitored during the summer months of 2002 and 2003. The water temperature in the main Sulphur Creek channel, especially as it flows through the valley, mimicked the diurnal changes in air temperature (Figures 7 & 8). During the months of July and August, water temperatures during the hottest time of the day exceeded 70°F, which is lethal to coldwater fisheries (Appendix J).

Hydrology: Runoff. Runoff is defined as that part of precipitation appearing in surface streams. The average annual runoff amount is estimated at 21 inches over the entire watershed. This ranges from 16 inches in the valley bottom and eastside to 45 and 48 inches along Mohawk Ridge (Figure 5). The average annual runoff pattern is fairly predictable, occurring mostly in the late winter and spring (Figure 6).

Sulphur Creek at Whitehawk Bridge, Jan. 1997.

Sulphur Creek immediately after the flood.

These rare floods are usually a result of intense rainfall during warm, moist storms moving in from the subtropical Pacific combined with a pre-existing snow cover (rain-on-snow events). The Sierra Nevada mountain range is unusual in that its infrequent large floods occur during the winter instead of during the spring snowmelt period. Several large floods have occurred during the past few decades that have significantly affected the Sulphur Creek watershed and its stream channel. These flood events occurred during the years 1955, 1963, 1986, and 1997.

Flood-frequency analyses are used to determine the probability of occurrence of floods of different magnitudes. The probability that a particular flood will occur is referred to as a "return frequency", such as "the 100-year flood". Actually, the probability that the "100-year" recurrence interval flood will occur is 1% each and every year, or one chance out of a 100. This method of viewing flood occurrences gives predictable results within the period of record for gaged watersheds, but should be cautiously extrapolated beyond that period. The flood-frequency analysis developed for this project has been extrapolated from gaged subwatersheds within the larger watershed of the upper Middle Fork Feather River to the ungaged subwatersheds of Sulphur Creek. For this reason and the fact that all of the gaged sites had to be compared to long-term sites, the analysis performed for the Sulphur Creek watershed (Appendix A) is only an approximation. It is still very useful for further work in the watershed but will need to be verified with field surveys at project level analyses. The flood frequency analysis in Appendix A gives an estimate of floods of different magnitudes and frequencies for each subwatershed and the larger, Sulphur Creek watershed. The estimated flood flows would be expected to occur near the mouth of each subwatershed.

Even though the analysis conducted for this study only projects estimated flood flows up to the 100-year event, the very large floods are generally expected to have recurrence intervals between a 50-year interval (2 % chance of occurrence) and a 200-year interval (0.5 % chance of occurrence). It is possible that even greater floods have occurred in the past and can occur in the future. It is the very large events that carry the majority of the large sized bedload to the valley bottom. Coarse material stored within alluvial fans can be mobilized, redeposited or transported farther down the channel network.

According to the "Glossary of Geology", produced by the American Geological Institute, 1980, an alluvial fan is defined as *a low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases.*

Alluvial fans are typically areas of high instability due to the collection of unconsolidated or poorly consolidated coarse material in a matrix of finer materials, usually creating surface slopes greater than 2% (0.02 feet per foot). The

Upstream end (apex) of the Boulder Creek alluvial fan.

entire fan may continue to grow with time, but stream downcutting may cause fan incision. Eventually the entire fan is dissected as the incision reaches the apex of the fan and captures the trunk stream as it emerges from the mountain (Ritter 1995). Additionally, alluvial fans disperse water flows that pass over and through them, helping to recharge local groundwater aquifers. When the trunk stream is captured, this process is greatly diminished.

When the effectiveness of the alluvial fan as a coarse material storage feature is lost, the material that would have deposited on the fan is transported into the gully system, further accelerating gully bank erosion. Because of the high sediment load and unstable nature of the gullies in the Sulphur Creek watershed, channel and riparian recovery must restart after each large flood.

The Citizen Monitoring program will monitor the distribution and changes in streamflows. Staff and crest-stage gages have been installed on Boulder Creek, Barry Creek, Sulphur Creek at the upper Loop Road bridge and at the lower Loop Road bridge. A continuous recording streamflow gage will be installed near the Highway 89 bridge this year. Participants in the Citizen Monitoring program have been reading the gages and will be developing stage-discharge relationships for each site.

Vegetation. Again there is a significant difference between the two sides of the watershed. The westside, which faces mostly northeast, receives less incident solar radiation than the eastside, which faces mostly southwest. This and the fact that the more gently sloping eastside also has many, broad ridges, means that the eastside, which receives less annual moisture initially, loses more through evaporation and transpiration. Streamflows from the eastside are mostly intermittent (seasonal) until they reach the valley, where they become perennial (year-long), but very low. The westside channels are perennial most of their lengths, supported by greater snowpack accumulations and groundwater input.

US Forest Service vegetation maps show westside vegetation types to be red fir at the highest elevations, ponderosa pine at mid-elevations, and mixed conifer at the lower elevations. The eastside is predominantly mixed conifer throughout, while the valley bottom is a mosaic of wet meadow and grasslands (Figure 9).

Major vegetation modifications will have effects on evaporation and transpiration rates, groundcover conditions, the reflection and absorption of solar radiation, snow accumulation and melt, and the occurrence and intensity of wildfires. These changes in turn affect the amount and rate at which water infiltrates into the soil, the amount of moisture evaporating back to the atmosphere, erosion/sedimentation rates, and ultimately watershed hydrology by increasing peak flows and decreasing low flows. Generally, dense vegetation cover results in dense ground cover, high infiltration rates, low evaporation rates, high transpiration rates, low erosion and sedimentation rates, and high intensity wildfires, while light vegetation cover can have opposite effects.

Wildfire. Fire is a key ecosystem process in California and the Sierra. The frequency of occurrence and the intensity of burn should be highest on the Sulphur Creek watershed's eastside. Recent, recorded wildfire history for the watershed shows only one large fire, a 900-acre burn that occurred in 1937. Approximately 270 acres of upper Calfpasture Creek was involved in the burn, with the remainder of the fire in the Carman Creek drainage. The fire was most likely a result of a lightning strike. All other reported wildfires burned three acres or less and the causes are mostly unidentified. Of the identified causes, all are human related (Figure 10).

Fire and fuels experts in the State are now using Condition Classes to identify "…the degree of departure from historical fire regimes resulting in alterations of key ecosystem components such as species composition, structural stage, stand age, and canopy closure (Appendix B contains the complete description of the Fire Condition Classes)." Three Condition Classes are used as follows:

Table 2. Fire Condition Class

Condition Class	Departure from Historical Fire Size, Frequency, and Intensity
1	Little
2	Moderate
3	Dramatic

A preliminary map of the Sulphur Creek watershed titled "National Fire Plan Condition Class, Sierra Nevada Framework Project" by George Terhune, 2002 (Copy in the Plumas Corporation office, Quincy), illustrates the watershed fire condition classes. The westside is rated Class 1 near its crest and Class 2 in the mid- to low- slope areas. Class 2 dominates most of the eastside, except Calfpasture Creek, where it is rated Class 3. The map is considered to be a general estimate and a more specific evaluation will need to be made, but it does agree well with "Map I, Fire Susceptibility Analysis, Draft Environmental Impact Statement, Herger-Feinstein Quincy Library Group Forest Recovery Act, June 1999." This map shows mostly low susceptibility on the westside and moderate susceptibility, with areas of high susceptibility, on the eastside. Currently, the Forest Service is planning the construction of major fuel reduction zones, called Defensible Fuel Profile Zones (DFPZs), within the

Sulphur Creek watershed on Plumas National Forest lands.

Hydrophobic soil conditions (the inability of water to soak into the soil) can develop during a fire where the intensity of the fire is high and certain plant waxes present. There is little concern that this condition would develop in the Sulphur Creek watershed.

LAND USE

Land uses within the Sulphur Creek watershed have included all the expected activities, including livestock grazing, timber harvesting, mining, and urbanization (Lindquist and Bohm 2003, Appendix C). Associated with these activities are roads, water diversions, and realignment of stream channels.

Recorded impacts in the Sulphur Creek area began soon after gold was discovered in the Feather River (Appendix C). Although no large deposits of gold were ever discovered in the Sulphur Creek watershed, minor amounts were found. Most of the eastside of the Sierra was exploited for its abundance of grasses and timber. Grasses supplied forage for horses, cattle and other livestock and were able to sustain large dairy farms in nearby watersheds for many years. Timber was a necessary item for mining, but only localized use of timber occurred in the Sulphur Creek watershed until the early 1900s.

Timber Harvesting. Land use impacts in the Sulphur Creek watershed were minor until the early 1900s. Timber extraction began in earnest during World War II. Eastside slopes and westside mid to low slopes were essentially mined of their timber. Timber harvesting continues today, but at a lower rate.

Livestock Grazing. Sheep and cattle grazing that began prior to 1900, primarily for cattle production, also continues to this day throughout most of the valley bottom area. Upper watershed areas are also grazed during summer months, both on private and public lands.

Mining. Copper and gold mining occurred in the headwater areas in both the east and west sides of the watershed. Little to no mining occurs today. The largest of these mines, the Locke Mine, located in subwatershed 6 (Boulder Creek), was severely gullied and was recontoured and vegetation planted by the Forest Service. It is slowly recovering and the sediment supply to the channel substantially reduced. At present, none of the other mine sites within the watershed were found to be contributing significant amounts of sediment or other water polluting substances to the stream systems. Direct runoff from these sites is minimal.

Of note is the instream gravel mining that occurred upstream of the Highway 89 bridge soon after the 1955 flood. Gravel was removed from a section of channel that was previously straightened and was actively downcutting and widening. This reach of stream channel was also receiving large influxes of bedload from upstream areas that were also actively downcutting and widening.

Any stabilizing vegetation growing in the channel was either removed during gravel extraction operations or during season-long livestock grazing.

Urbanization. The construction of buildings and paved roads in the watershed is increasing, primarily in the valley bottom and the surrounding foothills. Urbanization creates impermeable surfaces that frequently drain directly to streams, increasing peak flows and carrying pollutants. The 2002 road survey detected no direct impacts, as described, from the existing developed areas.

Three impacts related to urban development, however, do need to be discussed. These impacts are (1) stream channels constricted by road crossings, (2) bank hardening with rock riprap, and (3) channel filling and loss of floodplain capacity.

Channel constricted by bridge and bank hardened to combat channel migration.

Stream Channels Constricted by Road Crossings. Roads cross the main channel of Sulphur Creek using bridges at six locations (Upper Loop Road Bridge, Lower Loop Road Bridge, two bridges on the Whitehawk Ranch, Highway 89 Bridge, and the bridge to Clio’s Rivers Edge RV Park). No detrimental constriction was detected at either the RV Park bridge or the Upper Loop Road Bridge. The channel is constricted at each of the other four bridges, causing backwater effects during large flood events. These backwater areas slow the flow just enough to cause bedload to deposit, usually in the center of the channel, to flow against one or both banks. By forcing the channel to flow against a bank, it has a tendency to run around (end-run) the bridge. Riprap is eventually added upstream of the bridge to combat this trend. Most stream crossing structures (bridges and culverts) are not designed to convey floods in a similar geometry as the upstream channel. The broad floodplain width is reduced or eliminated, giving the constricted channel the same dimensions as the active channel (*The bankfull channel, or “active channel”, becomes completely filled with water just prior to overbanking onto the floodplain.*) width and this causes increased stress and velocity at the outlet and usually backwater conditions at the inlet. This typically means future maintenance requirements of the structure due to bank erosion upstream and bed incision and/or bank erosion downstream and increased sediment supply to the channel.

Bank Hardening. Bank hardening using rock riprap is a standard technique for stabilizing an actively eroding section of gully bank. Little of this type of work has been performed in the watershed except at stream crossings. The only other bank treated by hardening with rock is along the golf course on the Whitehawk Ranch. This type of treatment redistributes the energy of flowing water both to the opposite bank and downstream (and occasionally upstream), increasing erosion at those sites. The use of riprap along eroding gully banks should only be considered as a temporary measure. There is a high risk of channel incision, repeated failures and high maintenance and reconstruction costs, including replacement costs and the cost for constructing grade control structures. Gully treatments, therefore, should include the entire width and length of the stream reach, including off-site effects, and should include long-term solutions, such as those listed in the restoration strategy for Sulphur Creek (to be completed by the end of 2004).

Channel Filling. The main channel of Sulphur Creek has become entrenched and is in the process of widening at its new elevation to reestablish its floodplain. Until the appropriate width is obtained, the channel will continue to be unstable. Sulphur Creek is becoming less of a gully and more of an entrenched channel with an inner floodplain within the Whitehawk Ranch channel reach. Artificial fill placed on the evolving floodplain reduces its width and effectiveness. Streamflow depths and shear stresses (erosion forces) are increased at those locations and both upstream and downstream of the sites.

Floodplain reduced in size by soil fill.

The stream will eventually remove the fill material in an attempt to regain the needed floodplain width.

<u>Dams, Diversions and Channel Realignments</u>. Small dams, water diversions, levees, channel realignment, and riparian vegetation eradication programs have directly affected stream channel stability, streamflows, and in-channel erosion and sedimentation rates. All of these impacts have been imposed on the valley channel system (Collins 2003, Lindquist and Bohm 2003, and Benoit 2003).

- A single dam was in place upstream of Highway 89 near Mohawk Ranch in 1972. It was apparently constructed of soil and gravel material and subsequently washed out or was removed.
- Water diversions for irrigation have been in place throughout the lower watershed area for nearly 100 years and many still operate today.

- Lower Calfpasture Creek was realigned and straightened before 1940.
- The roadway that was to be Highway 89 was constructed prior to 1940. The confluence of Sulphur Creek with the Middle Fork Feather River was apparently realigned upstream to its present location, just upstream of the bridge to Clio.
- The main Sulphur Creek channel was straightened upstream of the Highway 89 bridge apparently as part of bridge reconstruction in the 1940s. Gravel was mined from this channel area during subsequent years.
- A willow eradication program was implemented in the 1940s (approximate).

The result of these channel changes, along with other impacts occurring in the watershed, was the loss of riparian vegetation and channel incision (gullying) of the main stem of Sulphur Creek. Channel incision and riparian losses has migrated upstream five miles and is now impacting the tributary channels, where headcutting (the headward advance of the incision process) is in progress.

Roads and Stream Crossings. The Sulphur Creek watershed road system was assessed because it is considered a primary contributor to the health of the watershed. Roads are known sources of stream sediment and are likely causes of increased streamflow peaks. Increased sediment and peak flows cause stream channel instability, as channels change their size, shape, and pattern.

Cutbank and road surface eroding next to a stream channel.

Large amounts of gravel are moving from upstream channel reaches into the main valley bottom channel, forming large in-channel features, including point-bars and mid-channel islands. These features in turn further accelerate bank erosion. The finer sediment (silts and clays) stay in suspension and increase turbidity, degrading water quality, while sand sized particles settle to the bottom, affecting channel substrate conditions. The excessive amount of sediment that currently impacts the main Sulphur Creek channel

Inside ditch draining directly to a stream.

is having negative effects on aquatic and riparian habitats and is accelerating property loss through streambank erosion.

In mountainous terrain, the slow, downslope movement of groundwater is interrupted by roads along their cutslopes where it is forced to the surface. Where roads are directly connected to streams, this captured groundwater, plus the rain and snow that falls directly on the road, moves as surface flow directly into the streams, potentially increasing the size and frequency of peak streamflows (Harr et al. 1975). These road sections perform like stream channels, capturing and concentrating water, and, therefore, increasing the density of the stream drainage system. Drainage density is defined as *the length of all channels in the drainage basin divided by the basin area* and is related to the efficiency with which a basin drains (Ritter et al.1995, p. 157). An increase in the drainage density can increase the magnitude and frequency of flood peaks (Figure 11), channel erosion and sediment production (Dunne and Leopold 1978, p. 499-500). Changes in the size and frequency of flood peaks results in changes to downstream channel dimensions (Ritter et al.1995, pp. 155-158). Alluvial stream channels, as found in the valley bottom, are the most likely to be affected. In addition, higher and more frequent peak flows can further aggravate an already degraded stream system.

Channel bank composed of highly erodible silts opposite a less erodible gravel bar.

As stated in the introduction, this study concentrated on the two watershed elements that are considered to be the most responsible for the obvious changes in watershed health: (1) Stream channel condition and (2) roads directly connected to streams. The following describes the watershed road assessment, including a summary of findings. The stream channel assessment is described in a later section.

Inventory Method

A crew of two people spent the summer of 2002 driving most of the roads in the Sulphur Creek watershed. Special permission was obtained from landowners to access and inventory road problems on their properties. The Forest Service is cooperating with this study as it pertains to the National Forest. Highway 89 and Plumas County Road 114 within the Sulphur Creek watershed were also included in the inventory.

The inventory crew used data forms developed for road inventories conducted by the Forest Service and the Feather River Coordinated Resource Management Group (FR-CRM) and modified for this inventory in consultation with Laurel Collins, consulting Fluvial Geomorphologist for this watershed analysis. Appendix D is a copy of the two data forms used: (1) "Roads, Skid Trails, Landings and Mine sites Problem Assessment and Volume Estimates" and (2) "Stream and Meadow Crossings Problem Assessment and Volume Estimate". Nearly 500 problem sites were located and assessed. The completed forms have been cataloged by subwatershed and are stored at the Plumas Corporation office in Quincy.

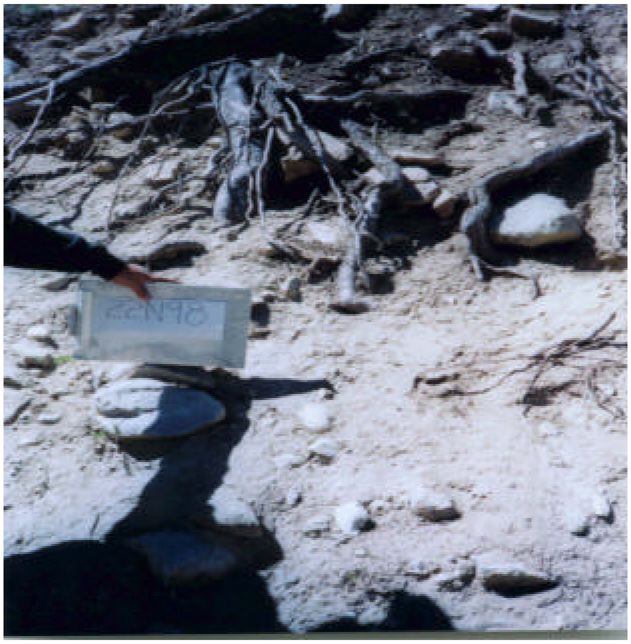
Only those observations defined as moderate to severe problems were inventoried. The second and third columns on the forms define what is considered moderate and severe. Essentially, to be included in the inventory, the road must be eroding and the eroded material must be entering a stream channel directly or is depositing within the streams' floodplain areas, to be picked up later during flood events. There must also be a ditch, gully, or some drainage mechanism that transports water and sediment to the stream channel.

The location of each problem site was recorded using a hand-held Global Positioning System (GPS) device. Each site evaluation was made according to source: Cutslope, fillslope, road surface, and drainage structure. In addition, the affected channel sections above and below each problem stream crossing were also evaluated. The results of the inventory are summarized below (1) by subwatershed and (2) by road (most roads traverse more than one subwatershed). The evaluations focused on (1) the volume of eroded material, measured at each site as "erosion voids" since road construction (e.g. volume of cutslope recession, volume of gullies, etc.) and (2) the length of the hydraulic links (e.g. inside ditches and gullies), measured at each problem site. These data were used to help direct future rehabilitation work by developing a list of priority projects. The remaining data are to be used to further describe each problem site and potential treatment alternatives.

Inventory Results.

1. <u>Erosion Voids</u>. The height, depth, and length of each erosion feature (void) that is directly linked to a stream channel was measured and used in two separate analyses.

Erosion void measured by root exposure.



The first analysis evaluated the total amount of sediment contributed by each subwatershed as measured by erosion voids. The results are as follows (the highlighted subwatersheds contain the greatest amount of eroded material):

A more comprehensive analysis of the data can be found in Appendix E.

Table 3. Erosion Voids by Subwatershed

ID	Subwatershed Name	Drainage Area (square miles)	Normalized Total Volume of Erosion Voids (cubic yards per square mile of drainage area)
1	Lower Sulphur Creek	1.87	5,796
2	Bear Wallow Creek	1.30	400
3a	**South Calfpasture Creek**	3.18	62,975
3b	**North Calfpasture Creek**	3.12	38,282
4	**Wash Creek**	2.81	49,852
5	McKenzie Creek	0.77	24,817
6	Boulder Creek	2.01	6,010
7	**Raap Creek**	1.50	86,070
8	**Haskell Ravine**	1.76	34,479
9a	Lower Barry Creek	3.15	26,992
9b	Upper Barry Creek	2.60	1,783
10	**Middle Sulphur Creek**	3.91	88,090
11	Upper Sulphur Creek	3.07	22,511
12	McNair Meadow	2.08	0

The second evaluation looked at each identified road. They are listed in order of total volume of erosion voids as follows (The highlighted roads are considered to have contributed the most sediment to the Sulphur Creek watershed):

Table 4. Erosion Voids by Road

Road ID	Watershed Side	Total Volume of Erosion Voids (cubic feet)	Erosion Voids for Selected Roads (cubic feet per mile of road)
FS 22N98	West	2,390,473	233,671
Hwy 89	East	427,427	58,665
FS 22N13	East	413,452	21,669
FS 21N27	West	50,276	2,236
Unnamed	East & West	39,444	
FS 22N12	East	37,004	
FS 21N02	West	31,572	
County Rd. 114	East	20,997	
FS 21N83	West	18,026	
FS 21N09	West	14,306	
FS 21N94	West	6,933	
21N91	West	6,515	

FS 22N48	East	2,591	
FS 21N01	West	1,653	
FS 21N31	West	734	
FS 21N29	West	676	
FS 22N03	East	658	
FS 21N06	West	555	
Friendly Way	West	520	

The first three listed roads contain 93% of the volume of all erosion voids measured. The fourth road listed only adds another 2% to the total volume. The top listed road, the Mohawk Chapman Road (Forest Service (FS) road 22N98), contains 69% of the total volume and was identified by the inventory crew as the road most likely to fail during large flood events (It has a history of requiring major repairs after flood events). The road is located on unstable ground and crosses large deposits of unconsolidated material deposited by landslides and slumps. It is in the path of naturally occurring debris torrents and is suspected of exacerbating their downstream force and damages.

The second and third listed roads, Highway 89 and Forest Service road 21N27 (both eastside roads), each contribute 12% to the total volume (Appendix G). Highway 89 contains 2.5 miles of extremely erodible cutslopes and fillslopes where it also parallels Sulphur Creek. Sediment generated along the highway discharges almost directly to Sulphur Creek. Forest Service Road 21N27 is also in highly erodible soil material and drains directly to nearby tributaries of both Calfpasture Creek and Barry Creek.

The evaluation of erosion voids by subwatershed tells another story that is best explained by comparing those subwatersheds containing the greatest volume of erosion voids from the top three listed roads only, Table 5.

Table 5. Subwatersheds with Greatest Volume of Erosion Voids

Subwatershed ID	Watershed Side	Percent of Total Erosion Voids
10	West & East	20
7	West	19
3a	East	14
4	West	11
3b	East	9

Approximately 73% of all erosion voids in the Sulphur Creek watershed can be found in these five subwatersheds. Almost all of the voids in the westside watersheds are from the Mohawk Chapman road (22N98). Subwatershed 10 contains segments of both Highway 89 and 22N98, while both subwatersheds 4 and 7 are mostly affected by 22N98. Subwatershed 3a contains both Highway

89 and Forest Service road 22N13, but it's the Forest Service road that contains the significant volume of erosion voids. The road erosion voids located in Subwatershed 3b are almost totally associated with private roads.

Of the total measured voids, 87% were measured at stream crossings and of those, 80% involved cutslopes with an inside ditch. Nearly all roads in the Sulphur Creek watershed are sloped inwards, towards the cutslope side, and are drained by inside (inboard) ditches that either lead directly into streams or to cross drains that spill onto slopes before draining to stream channels.

Eroding cutslope and inside ditch delivering water and sediment to a small stream channel.

2. Hydraulic Links: Using the same inventory forms mentioned above, the length of each hydraulic linkage was recorded for each problem site as the length of the inside ditch, road surface, or gully that is connected to a stream channel. The length of the hydraulic link from both stream-crossing approaches was added together to give a total length for each site. See Appendix F for a detailed accounting of the inventory results.

Hydraulically linked drainage channels associated with roads are considered to be similar to headwater stream channels where precipitation and groundwater is intercepted almost exclusively during storms and snowmelt periods. The contributing watershed area (the catchment area that drains directly to a stream or road segment) for a road drainage channel is not equal to that for a natural headwater stream channel. A determination was made (Appendix F) that a road drain length is equivalent to an estimated ¼ of a headwater stream because the catchment areas (the watershed area that contributes water to the channel) are not equivalent. Road drain lengths were, therefore, reduced by ¾ in order to approximate the volume of water captured by natural headwater stream channels. *Drainage density is defined as the ratio of the total length of all streams within a drainage basin to the area of that basin* (Figure 12).

Table 6 displays the adjusted hydraulic link measurements and additions to the total drainage density, by subwatershed. The highlighted subwatersheds are considered to have significant additions to their drainage densities.

Table 6. Drainage Density Increase by Subwatershed

No	Subwatershed Name	Drainage Density* (mi/mi^2)	Adjusted Length of Hydraulic Link Drainage Channels (mi/mi^2)	New Drainage Density (mi/mi^2)	Percent Increase in Drainage Density (mi/mi^2)
1	Lower Sulphur Creek	4.49	0.15	4.64	+3.23%
2	Bear Wallow Creek	5.77	0.01	5.78	+0.17%
3a	South Calfpasture Creek	5.09	0.13	5.22	+2.49%
3b	**North Calfpasture Creek**	3.69	0.25	**3.94**	**+6.35%**
4	Wash Creek	4.06	0.12	4.18	+2.87%
5	McKenzie Creek	5.70	0.12	5.82	+2.06%
6	Boulder Creek	3.68	0.05	3.73	+1.34%
7	Raap (Guidici) Creek	8.08	0.05	8.13	+0.62%
8	**Haskell Ravine**	4.43	0.21	**4.64**	**+4.53%**
9a	Lower Barry Creek	5.01	0.15	5.16	+2.91%
9b	Upper Barry Creek	3.47	0.05	3.52	+1.42%
10	**Middle Sulphur Creek**	4.18	0.20	**4.38**	**+4.57%**
11	**Upper Sulphur Creek**	4.03	0.17	**4.20**	**+4.05%**
12	McNair Meadow	4.42	0.01	4.43	+0.23%
	Sulphur Creek Total	**4.72**	**0.12**	**4.84**	**+2.63%**

***** *Drainage Density is measured as the total length of all definable stream channels per unit area of watershed, or total miles of channel length per square mile of watershed area (mi/mi^2).*

The average density of streams draining the watershed's eastside (Subwatersheds 3a, 3b, 9a, 9b, & 12) versus the westside subwatersheds (2, 4-8, & 11) are: Eastside = 4.34 mi/mi^2 (range 3.47-5.09), and westside = 5.11 mi/mi^2 (range 3.68-8.08). Eliminating westside subwatershed number 7, Raap (Guidici) Creek, with its high drainage density (8.08 mi/mi^2), the adjusted westside average drainage density is 4.62 mi/mi^2 (range 3.68-5.77). The two sides of the Sulphur Creek watershed are, therefore, considered similar in their potential to drain the land and respond to flood producing storms since the difference between the drainage densities on the two sides is less than 10%. They were, therefore, compared together for this analysis.

Very little was found in the literature that indicates the magnitude of change necessary to create significant changes to streamflows. Ritter et. al. 1995 displays a chart developed by Carlston in 1963 in which he evaluated 13 watersheds with drainage densities of less than 10 mi/mi^2 and developed a regression equation for the mean annual flood ($Q_{2.33}$) per square mile of watershed area of: $\mathbf{Q_{2.33} = 1.3D^2}$, where **D** is the drainage density. $Q_{2.33}$ is the peak streamflow that is equaled or exceeded every 2.33 years on the long-term average (100 years). It is simply the arithmetic mean of all the annual maximum discharges. With this simple relationship, we can see that streamflow is exponentially related to drainage density (as the square of **D**) and is thus greatly magnified by any change in the drainage density. It also tells us that the size of the mean annual flood increases with an increase in drainage density, and vice versa. For example, The mean annual flood for North Calfpasture Creek, which has a 6.8% increase in drainage density, would change from 18 cubic feet per second (cfs) to 20 cfs, a 14% increase.

Ritter's publication does not describe the 13 watersheds evaluated by Carlston, so a comparison with the Sulphur Creek watershed cannot be performed. We cannot use the equation to directly determine what constitutes a significant increase in drainage density for the Sulphur Creek watershed. Sensitive stream channels in erodible, fine alluvium, such as those found in the valley bottom would respond sooner than channels in more resistant material. The condition of those channels also plays a role in how well they can resist more frequent flooding. Where floodwaters easily spread onto floodplains, the risk of channel degradation is low. Where floodwaters are concentrated in entrenched channels, erosion of the channel is accelerated. Though any increase in drainage density could potentially result in negative channel adjustments, we arbitrarily chose an increase of 4% to signify those watersheds most out of hydrologic balance. They are highlighted in the table above.

Stream Channels. Stream channels reflect the dynamic balance of climate with geology, soils, vegetation, geomorphic setting and land uses.

Debris torrent material is temporarily stored in this headwater channel above a road crossing.

Generally, the upland stream channels of Sulphur Creek make major adjustments to this dynamic balance over long periods of time while short-term changes, such as those caused by human disturbances or rare flood events are temporary. Most upland channels are resistant to short-term changes because they are cutting into bedrock or are well armored with coarse sediment from debris flows or boulder inputs.

Also, because they are steep (greater than 4% gradients), most of the sediment delivered to them is quickly transported to lower gradient reaches. These lower gradient reaches are where most of the material eroded from the upland areas is deposited. Low gradient streams (less than 2% slope), formed in alluvium (sediment deposited by the action of streams) are generally located in the valley bottom. As explained above, streams in low gradient, alluvial reaches are sensitive to changes in climate, vegetation and land uses. Those channels already degraded are very sensitive to changes in watershed condition.

Degraded stream channel, incised into the meadow.

Table 7 displays the total length of each stream type (resistance to erosion) draining each subwatershed, with an emphasis on the percentage of the channels deemed sensitive to erosion and degradation.

Degrading (gullying) stream channels eventually become entrenched and are unable to access their floodplains and contain most floods. They also transport more sediment downstream, where the response to changes in sediment supply is more sensitive than to changes in water supply. They respond to the added sediment supply by accelerating bank erosion and widening the gully.

Low gradient stream formed in alluvial sediment in the valley bottom.

Table 7. Sensitive Streams by Subwatershed

No.	**Subwatershed Name**	**Miles of Resistant Streams in Subwatershed** (>4% grade)	**Miles of Moderately Resistant Streams in Subwatershed** (2-4% grade)	**Miles of Sensitive Streams in Subwatershed** (<2% grade)	**Percent of Total Miles of Sensitive Streams in Entire Watershed**
1	Lower Sulphur	1.4	1.6	5.4	30%
2	Bear Wallow	5.9	0.8	0.8	4%
3a	South Calfpasture	13.0	0.8	2.4	13%
3b	North Calfpasture	10.9	0.1	0.5	3%
4	Wash	9.4	0.5	1.5	8%
5	McKenzie	3.2	1.2	0.0	0%
6	Boulder	6.3	0.3	0.8	4%
7	Raap	8.0	3.2	0.9	5%
8	Haskell	6.8	0.5	0.5	3%
9a	Lower Barry	12.9	1.8	1.1	6%
9b	Upper Barry	6.3	1.8	0.9	5%
10	Middle Sulphur	14.3	1.1	1.2	7%
11	Upper Sulphur	12.0	0.4	0.0	0%
12	McNair Meadow	6.4	0.9	1.9	11%
	Total =	116.8	15.0	17.9	99%

Yarrington Meadow, upper Barry Creek.

Of the 17.9 miles of sensitive stream channels, 30% are in Lower Sulphur Creek (Subwatershed 1) and completely incised into the meadow and actively widening. All other streams in this subwatershed are in the process of degrading. Both McNair Meadow (located in Subwatershed 12) and Yarrington Meadow (located in Subwatershed 9b) are in good condition, but headcuts, located at the bottom of each, threaten to degrade them.

Moderately resistant stream channels are also listed in the table because they are primarily storage areas for coarse sediment (gravel, cobbles and boulders) and, therefore, should also be considered alluvial. They could have been labeled “moderately sensitive”. Because almost all of these channel types are degraded, much of the coarse material stored in them has moved (and is still in the process of moving)

Coarse alluvium in Boulder Creek just above the valley.

downstream into the degraded channel areas of the valley bottom.

Subwatershed 10 (Middle Sulphur) stored very large amounts of the coarse sediment material that is now moving downstream into the valley bottom.

Each large flood deposits more coarse material into Middle Sulphur to be transported during subsequent high flow events into Lower Sulphur.

Why is this important? Because the coarse material is no longer in long-term storage in the middle reaches of the watershed, it is moving into the lower, very sensitive and degraded reaches of the valley bottom before it moves on into the Middle Fork Feather River. The transport of this coarse material downstream forms large, temporary in-channel depositional features in the form of bars, islands, and braided channel networks. Transporting this coarse material through the main Sulphur Creek channel can take hours to years. As a result of the formation of the large depositional features (gravel bars), erosion of the highly erodible gully banks is accelerating as streamflows are directed at more acute angles into them. Because the depositional bars contain large quantities of coarse sized particles, they are more resistant to erosion than the highly erodible gully banks.

Coarse gravel deposited in Sulphur Creek upstream of Whitehawk, pushing channel against opposite bank.

The entrenched channel continues to widen until an inset floodplain at the lower elevation forms that is of adequate width to balance streamflows with the transported sediment supply. As the inset floodplain forms, dynamic channel stability occurs simultaneously, punctuated by periods of instability, usually resulting from large flood events. The lower Sulphur Creek channel (downstream of Whitehawk Ranch) has widened enough that it is approaching dynamic stablility, i.e. it has enough width to create relatively stable inset floodplains and channel geometry.

Lower Sulphur Creek developing an inset channel and floodplain. Fresh gravel upstream.

Table 8 describes average widths for the existing floodplains, referred to as floodprone width, which includes the floodplain, and the existing entrenched and unstable channel (this is where the new inset floodplain is forming) and compares them with an estimate of the minimum meander belt width. This is the minimum width that the inset floodplain must attain before it and the channel can become stable. The following definitions should help with this understanding:

The floodprone width is the cross-sectional width at a height of two times maximum bankfull depth.

Bankfull depth is the depth of flow when it just fills the stream to its banks.

Bankfull flow occurs approximately every one to two years.

The meander belt is the zone along a valley floor across which a meandering stream shifts its channel from time to time. It may be from 15 to 18 times the width of the stream.

Channel stability is defined as a channel that maintains its geometry of width, depth and gradient, relative to the present climatic regime. A stable channel may laterally migrate but it does not cut down or aggrade its bed to the point that it abandons its floodplain. Changes in either supply of water, or sediment or abundance of riparian vegetation can cause a channel to become unstable.

See Appendix H for a more complete analysis. The numbers in parentheses are the range of widths measured.

Table 8. Comparison of Inset Floodplain and Entrenched Channel Widths with Estimated Meander Belt Widths along the Main Stem of Sulphur Creek, Lower Reaches

Location	Existing Floodprone Width (ft)	Total Width of the Existing Entrenchment (ft)	Estimated Meander Belt Width for the Stable Condition (ft)
Upper main channel (subwatershed 10)	60 (25-150)	150 (60-200)	150
Middle main channel (above Hwy 89 bridge)	190 (90-390)	300 (200-400)	300
Lower main channel (near mouth)	100 (70-170)	160 (100-280)	400

The estimated meander belt widths necessary to achieve dynamic valley and channel stability assumes that the sediment load is near historic levels, which should be very low through the main part of the valley bottom compared to the existing sediment load. The newly forming valley width is at that estimated to achieve dynamic stability along the upper and middle reaches, but the lower reach is still very narrow. Table 9 describes existing channel types and management interpretations as compared to the two expected, historic stream types.

Table 9. Existing Channel Types and Management Interpretations Compared to Historic Stream Types (adapted from Rosgen 1996, pp. 8 & 9)

Main Sulphur Creek Channel Location	Existing Rosgen Stream Type	Sensitivity to Disturbance	Recovery Potential	Sediment Supply	Streambank Erosion Potential	Vegetation Controlling Influence
Upper	B3	Low	Excellent	Low	Low	Moderate
	C4	Very high	Good	High	Very High	Very High
Middle	C4	Very High	Good	High	Very High	Very High
	D4	Very High	Poor	Very High	Very High	Moderate
Lower	C4	Very High	Good	High	Very High	Very High
	F4	Extreme	Poor	Very High	Very High	Moderate
HISTORIC						
Upper	C4	Very high	Good	High	Very High	Very High
Mid - Low	E6	Very High	Good	Low	Moderate	Very High
Mid - Low	DA6	Moderate	Good	Very Low	Very Low	Very High

Existing Rosgen Stream Type. Refer to Appendix H, section 3.

<u>Sensitivity to Disturbance</u>. Includes increases in streamflow magnitude and timing and/or sediment increases.
<u>Recovery Potential</u>. Assumes natural recovery once the cause of instability is corrected.
<u>Sediment Supply</u>. Includes suspended and bedload from channel derived sources and/or from stream adjacent slopes.
<u>Vegetation Controlling Influence</u>. Vegetation that influences width/depth ratio-stability.

The data and information are telling us the following:

1. Even though stream channel has degraded, recovery has begun in the lower reaches.
2. The large sediment loads both from upstream and instream sources are slowing recovery.
3. Historically, coarse sediment was stored in the upstream reaches and only a portion of the fine sediment was transported through the larger valley bottom area to the Middle Fork Feather River.
4. Adequate floodplain and vegetation is key for stable stream channel areas.

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