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

June 2004

TABLE OF CONTENTS

Tables

ACKNOWLEDGEMENTS

Buzz McCann, the Mohawk Valley Watershed Restoration Committee, and local landowners initiated this study through their recognition of the importance of the Sulphur Creek watershed to the health of area and the Middle Fork Feather River.

Members of the Feather River Coordinated Resource Management Group (FR-CRM) promoted this comprehensive watershed study as the key element to the development an integrated restoration strategy.

Donna Lindquist and Dr. Burkhard Bohm, Plumas Geo-Hydrology, were researched historical records and conducted interviews of people familiar with the history of Sulphur Creek.

Laurel Collins, Watershed Sciences, developed a map titled *Geomorphic Map of Sulphur Creek, Plumas County, California, 2003,* and was the prime reviewer of the draft report, providing valuable content suggestions.

Clay Clifton, consulting Biologist, and Kevin Ponce, student, surveyed the road system and provided valuable information about watershed attributes and conditions.

Mack Bishop developed the computer storage and data analysis programs used to analyze the road data.

Michelle Petroelje, coordinator for the FR-CRM Sulphur Creek Citizen Monitoring program, provided valuable water flow and quality data and providing a direct means for communicating with local landowners and others interested in the project.

Tim Sagraves, Sagraves Environmental, has installed flow staff-gages at four monitoring sites and in the process of installing a constant recording station to provide long-term data for the monitoring program and project designs.

This project was funded by a grant from the California State Water Resources Control Board under agreement number 01-127-255-0.

FR-CRM staff, Leslie Mink, Jim Wilcox, and Terry Benoit, along with John Sheehan, Director of Plumas Corporation, coordinated the surveys and conducted the final analyses and report writing in consultation from the above-mentioned individuals.

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.

<u>What about the roads</u>? 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.

<u>How should we fix the problem</u>? 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.

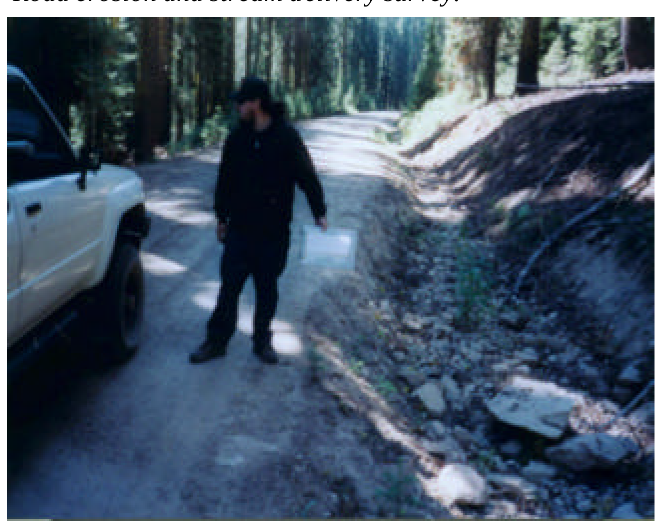
Headcut at the bottom McNair Meadow.

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**] Soil drainage 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

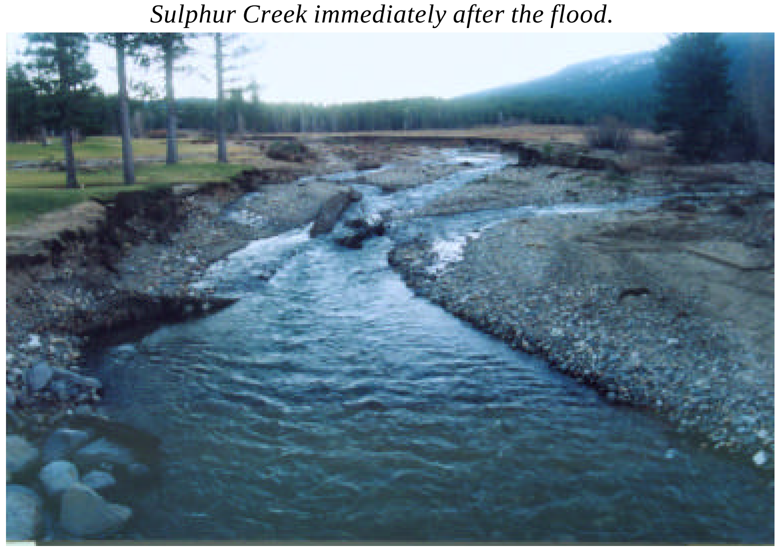
Of all the mechanisms in the watershed that create change, major flood flows are the greatest. High flows occur frequently during spring snowmelt. The lower size, but frequent and longer duration, flows are critical to channel and habitat maintenance. Floods of unusually high magnitude are rare but very 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).

Sulphur Creek at Whitehawk Bridge, Jan. 1997.

Hydrology: Runoff. Runoff is defined as that 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 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 <u>alluvial fan</u> 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.

<u>Vegetation</u>. 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.

<u>Roads and Stream Crossings</u>. 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

Inside ditch draining directly to a stream.

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 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.

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.

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

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.

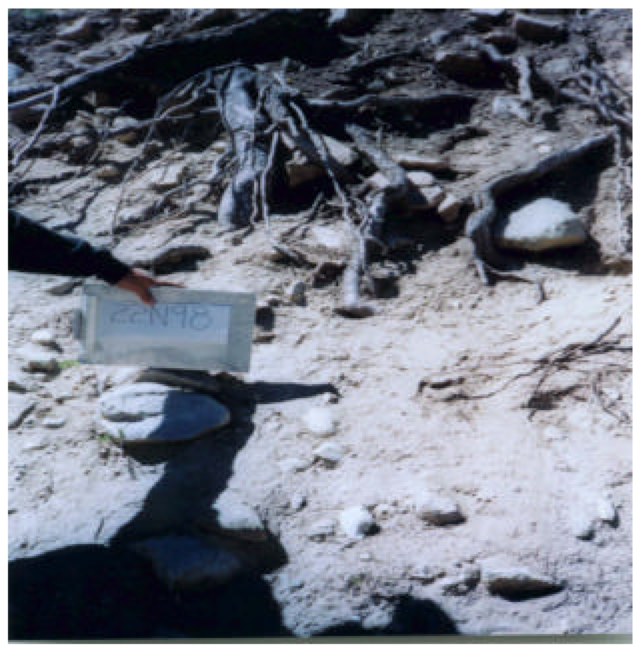
Only those observations defined as moderate to severe problems were inventoried. The second and third columns on the forms define what is considered moderate and severe. Essentially, to be included in the inventory, the road must be eroding and the eroded material must be entering a stream channel directly 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.

Degraded stream channel, incised into the meadow.

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.

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.

Yarrington Meadow (located in Subwatershed 9b) are in good condition, but headcuts, located at the bottom of each, threaten to degrade them.

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

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.

BIBLIOGRAPHY

Benoit, Terry A. 2003. *Sulphur Creek Watershed Analysis, Aerial Photograph Interpretations*. Plumas Corporation, Feather River Coordinated Resource Management Group (FR-CRM).

Clifton, Clay C. 1992. *Stream Classification and Channel Condition Survey, With an Inventory of Sediment Sources From roads and Stream Crossings, Conducted in the Last Chance and Spanish Creek Watersheds, Plumas National Forest.* USDA Forest Service, Plumas National Forest and the East Branch North Fork Feather River Coordinated Resource Management Group (EBNFFR-CRM) [now the FR-CRM). A 205(J) Study.

Collins, Laurel 2003. "Geomorphic Map of Sulphur Creek, Plumas County, California". Watershed Sciences, Berkeley, California.

Dunne, Thomas and Luna B. Leopold 1978. *Water in Environmental Planning*. W. H. Freeman and Company, San Francisco.

Durrell, Cordell 1987. *Geologic History of the Feather River Country, California*. University of California Press, Berkeley and Los Angeles, California.

Durrell, Cordell, circa 1960. *A Brief Geologic History of Plumas County and Adjacent Lands*. University of California, Davis.

Harr, Dennis R., Warren C. Harper, and James T. Krygier 1975. *Changes in Storm Hydrographs After Road Building and Clear-Cutting in the Oregon Coast Range*. American Geophysical Union, Vol. 11, No. 3, pp 436-444.

Lindquist, Donna and Burkhard Bohm 2003. *Historical Records Search and Reporting, Summary and Analysis of Interview Accounts, Sulphur Creek Watershed Assessment, Middle Fork Feather River (MFFR) Basin, Sierra Nevada, California.* Prepared for the Feather River Coordinated Resource Management.

Linsley, Ray K. 1955. *Water Resources and Ultimate Water Requirements, Feather River Basin, Plumas and Sierra Counties, California*. Carroll E. Bradberry & Associates, Consulting Engineers. Whitecliff 8-8203.

Manley, Patricia N., et al. 1995. *Sustaining Ecosystems, A Conceptual Framework, Version 1.0.* U.S. Department of Agriculture, Forest Service, Pacific Southwest Region and Station, San Francisco, CA.

Ritter, Dale F., R. Craig Kochel, and Jerry R. Miller 1995. *Process Geomorphology, Third Edition*. Wm. C. Brown Publishers

Rosgen, Dave 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, Colorado.

Soil Conservation Service (SCS) 1989. *East Branch North Fork Feather River Erosion Inventory Report, Plumas County, California*. River Basin Planning Staff, USDA-Soil Conservation Service, Forest Service, Davis, California

U.S. Department of Agriculture, Forest Service, Plumas National Forest (USDA FS). Soil Resource Inventory (SRI) 1988.

Waananen, A. O. and J. R. Crippen 1977. *Magnitude and Frequency of Floods in California*. U. S. Geological Survey, Water Resources Division. Menlo Park, California. Water-Resources Investigations 77-21.

APPENDIX A

FLOOD-FREQUENCY ANALYSIS

1. **Tables Displaying Methods Used and Estimates of Flood-frequency by Subwatershed.**

2. **Flood of January 1, 1997, in Sulphur Creek Above and Below Boulder Creek Inflow.**

SULPHUR CREEK WATERSHED ANALYSIS

Gaged Watersheds Similar to the Subwatersheds of Sulphur Creek

From MAGNITUDE AND FREQUENCY OF FLOODS IN CALIFORNIA by A.O. Waananen and J.R. Crippen, June 1977, USGS Water-Resources Investigations 77-21

Station Number	Name	Years of Record	Drainage Area (mi^2)	Ave Ann Ppt (in)	Main Channel Slope (ft/ft)	Average Elevation (ft)	Main Channel Aspect	Peak Discharge (cfs) at indicated recurrence intervals: 2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
11391423	1. Cottonwood Cr nr Sierraville	11	7.08	33	0.0320	6400	WNW	42	84	122	181	235	297
11391460	2. Miller Cr nr Sattley	13	7.60	50	0.0852	6000	E	110	270	436	730	1020	1380
11391500	3. Big Grizzly Cr at Grizzly Valley Dam	30	45.50	22	0.0030	5800	SE	467	1200	1970	3350	4750	6500
11392300	4. Willow Cr tributary nr Blairsden	11	1.08	27	0.0629	5200	S	22	45	67	102	134	172
11392500	5. Middle Fork Feather River nr Clio	50	686.00	20	0.0049	5100	NW	3230	6980	10500	16100	21300	27400

Sulphur Creek Subwatersheds

Number	Name	Drainage Area (mi^2)	Ave Ann Ppt (in)	Main Channel Slope (ft/ft)	Average Elevation (ft)	Main Channel Aspect	Best Fit Gage(s)
1	Lower Sulphur Creek	1.87	35	0.0145	4487	NW	1, 3, & 5
2	Bear Wallow	1.30	40	0.1666	5640	NE	2
3a	South Calfpasture Creek	3.18	35	0.0712	5315	SW	1 & 4
3b	North Calfpasture Creek	3.12	35	0.0741	5360	W.	1 & 4
4	Wash Creek	2.81	50	0.1664	6212	NE	2
5	McKenzie Creek	0.77	40	0.2036	5773	NE	2
6	Boulder Creek	2.01	45	0.1409	6407	NE	2
7	Raap Creek	1.50	42	0.1886	6080	NE	2
8	Haskell Ravine	1.76	45	0.1708	6612	NE	2
9a	Lower Barry Creek	3.15	35	0.0698	5520	SW	1 & 4
9b	Upper Barry Creek	2.60	35	0.0547	5520	S	1 & 4
10	Middle Sulphur Creek	3.97	45	0.1414	6503	N	2
11	Upper Sulphur Creek	3.07	48	0.1183	6622	NE	2
12	McNair Meadow	2.08	44	0.1775	6562	NW	2
	Total	33.19					
	Average		41	0.1256	5901	NW	1, 3, & 5

SULPHUR CREEK WATERSHED ANALYSIS

From MAGNITUDE AND FREQUENCY OF FLOODS IN CALIFORNIA
by A.O. Waananen and J.R. Crippen, June 1977, USGS Water-Resources Investigations 77-21

Number	Name	Total Drainage Area (mi^2)	Gaged Wtsd No.	Gaged Wtsd Area (mi^2)	(A_u/A_g)	Peak Discharge (cfs) at indicated recurrence intervals 2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
					$( )^b$	$( )^{0.88}$	$( )^{0.82}$	$( )^{0.80}$	$( )^{0.79}$	$( )^{0.78}$	$( )^{0.77}$
1	Lower Sulphur Creek*	33.19	1	7.08	4.69	164	298	420	613	784	976
	Lower Sulphur Creek*	33.19	3	45.50	0.73	354	926	1531	2611	3714	5098
	Lower Sulphur Creek*	33.19	5	686.00	0.05	225	582	931	1471	2006	2660
2	Bear Wallow	1.30	2	7.60	0.17	23	63	106	181	257	354
3a	South Calfpasture Creek	3.18	1	7.08	0.45	21	44	64	96	126	160
	South Calfpasture Creek	3.18	4	1.08	2.94	57	109	159	239	311	395
3b	North Calfpasture Creek	3.12	1	7.08	0.44	20	43	63	95	124	158
	North Calfpasture Creek	3.12	4	1.08	2.89	56	107	157	236	307	389
4	Wash Creek	2.81	2	7.60	0.37	46	119	197	333	469	641
5	McKenzie Creek	0.77	2	7.60	0.10	15	41	70	120	171	237
6	Boulder Creek	2.01	2	7.60	0.26	34	91	150	255	361	496
7	Raap Creek	1.50	2	7.60	0.20	26	71	119	203	288	396
8	Haskell Ravine	4.91	2	7.60	0.65	75	189	307	517	725	986
9a	Lower Barry Creek*	5.75	1	7.08	0.81	35	71	103	154	200	253
	Lower Barry Creek*	5.75	4	1.08	5.32	96	177	255	382	494	623
9b	Upper Barry Creek	2.60	1	7.08	0.37	17	37	55	82	108	137
	Upper Barry Creek	2.60	4	1.08	2.41	91	173	246	362	466	584
10	Middle Sulphur Creek*	9.12	2	7.60	1.20	129	314	504	843	1176	1588
11	Upper Sulphur Creek	3.07	2	7.60	0.40	50	128	211	357	503	687
12	McNair Meadow	2.08	2	7.60	0.27	35	93	155	262	371	509

* Drainage area is total of all subwatersheds draining to this subwatershed.

SULPHUR CREEK WATERSHED ANALYSIS

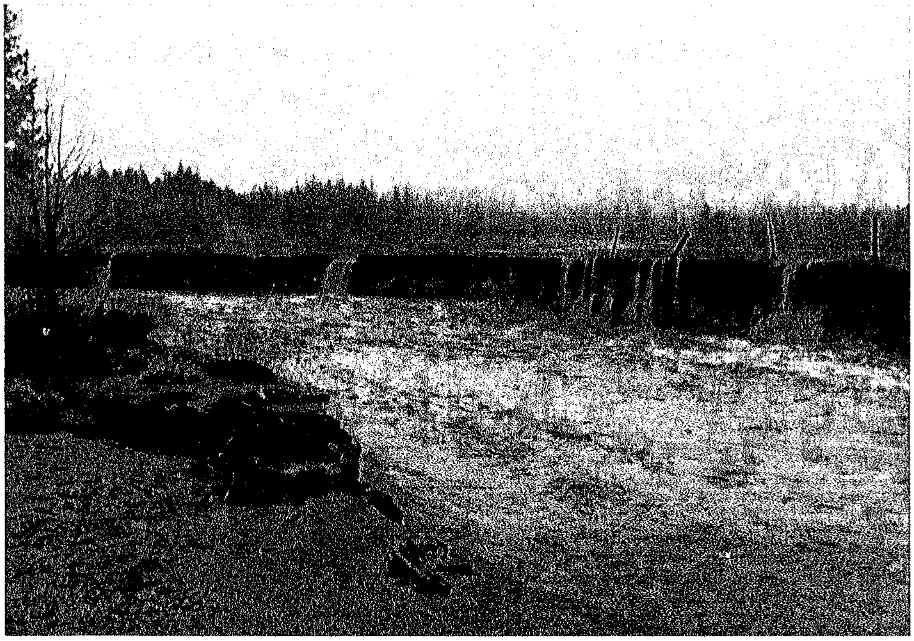
From MAGNITUDE AND FREQUENCY OF FLOODS IN CALIFORNIA

by A.O. Waananen and J.R. Crippen, June 1977, USGS Water-Resources Investigations 77-21

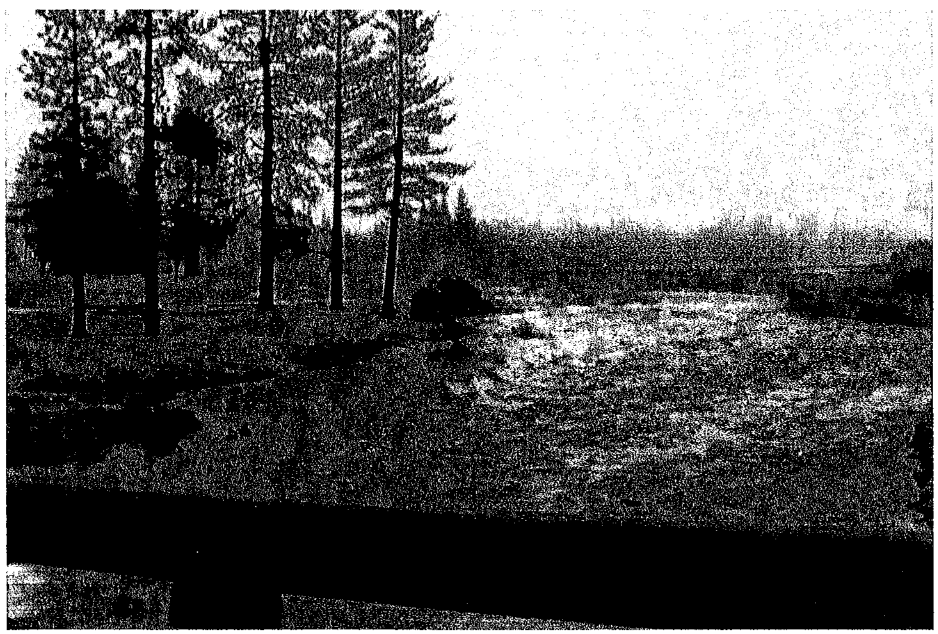
No	Name	Total Drainage Area (mi^2)	Gaged Wtsd No.	Gaged Wtsd Area (mi^2)	(A_u/A_g)	Peak Discharge (cfs) at indicated recurrence intervals 2 yr	Q_2/mi^2	5 yr	Q_5/mi^2	10 yr	Q_{10}/mi^2	25 yr	Q_{25}/mi^2	50 yr	Q_{50}/mi^2	100 yr	Q_{100}/mi^2
					$()^b$	$()^{0.88}$		$()^{0.82}$		$()^{0.80}$		$()^{0.79}$		$()^{0.78}$		$()^{0.77}$	
1	Lower Sulphur Creek*	33.19	1	7.08	4.69	164	5	298	9	420	13	613	18	784	24	976	29
	Lower Sulphur Creek*	33.19	3	45.50	0.73	354	11	926	28	1531	46	2611	79	3714	112	5098	154
	Lower Sulphur Creek*	33.19	5	686.00	0.05	225	7	582	18	931	28	1471	44	2006	60	2660	80
2	Bear Wallow	1.30	2	7.60	0.17	23	18	63	49	106	82	181	139	257	198	354	273
3a	South Calfpasture Creek	3.18	1	7.08	0.45	21	7	44	14	64	20	96	30	126	40	160	50
	South Calfpasture Creek	3.18	4	1.08	2.94	57	18	109	34	159	50	239	75	311	98	395	124
3b	North Calfpasture Creek	3.12	1	7.08	0.44	20	7	43	14	63	20	95	30	124	40	158	51
	North Calfpasture Creek	3.12	4	1.08	2.89	56	18	107	34	157	50	236	76	307	98	389	125
4	Wash Creek	2.81	2	7.60	0.37	46	16	119	42	197	70	333	118	469	167	641	228
5	McKenzie Creek	0.77	2	7.60	0.10	15	19	41	54	70	91	120	155	171	222	237	307
6	Boulder Creek	2.01	2	7.60	0.26	34	17	91	45	150	75	255	127	361	180	496	247
7	Raap Creek	1.50	2	7.60	0.20	26	18	71	48	119	79	203	135	288	192	396	264
8	Haskell Ravine	4.91	2	7.60	0.65	75	15	189	38	307	63	517	105	725	148	986	201
9a	Lower Barry Creek*	12.79	1	7.08	1.81	71	6	136	11	196	15	289	23	373	29	468	37
	Lower Barry Creek*	12.79	4	1.08	11.84	194	15	342	27	484	38	719	56	921	72	1154	90
9b	Upper Barry Creek	9.64	1	7.08	1.36	55	6	108	11	156	16	231	24	299	31	377	39
	Upper Barry Creek	9.64	4	1.08	8.93	288	30	506	52	703	73	1020	106	1296	134	1602	166
10	Middle Sulphur Creek*	9.12	2	7.60	1.20	129	14	314	34	504	55	843	92	1176	129	1588	174
11	Upper Sulphur Creek	3.07	2	7.60	0.40	50	16	128	42	211	69	357	116	503	164	687	224
12	McNair Meadow	2.08	2	7.60	0.27	35	17	93	45	155	74	262	126	371	178	509	245

*Drainage area is total of all subwatersheds draining to this subwatershed.

FLOOD OF JANUARY 1, 1997
SULPHUR CREEK ABOVE AND BELOW
BOULDER CREEK INFLOW



FLOOD FLOW ESTIMATED AT 2400 CUBIC FEET PER SECOND



PHOTOS BY BUZZ MCCANN

FLOOD FLOW ESTIMATED AT 2900 CUBIC FEET PER SECOND

FLOOD ESTIMATES FOR SULPHUR CREEK
UPSTREAM OF CONFLUENCE WITH BOULDER CREEK

Watershed Area = 18.13 mi^2

Average Elevation = 5337 feet

Average Annual Precipitation = 39 inches

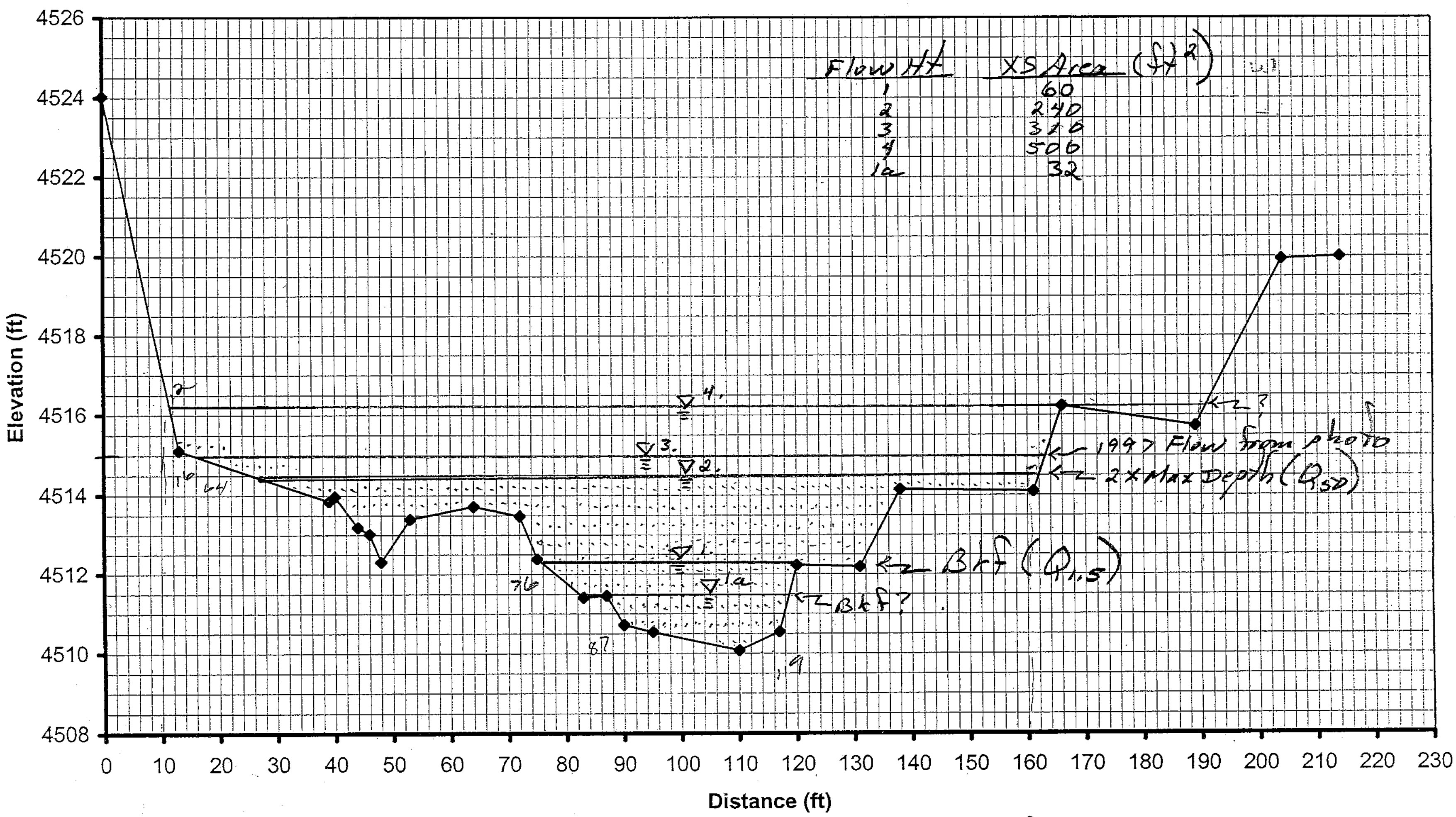
Gaged	Gaged Wtsd		Peak Discharge (cfs) at Indicated Recurrence Intervals					
Wtsd No.	Area (mi^2)	(A_u/A_g)	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
1	7.08	2.56	96	182	259	380	489	613
2	7.60	2.39	236	551	874	1451	2010	2695
3	45.50	0.40	208	564	944	1619	2317	3200
4	1.08	16.79	263	455	640	947	1209	1509
5	686.00	0.03	132	355	574	913	1252	1670
Average	——	——	187	421	658	1062	1456	1938

Flow	Flow	XS	Width	Hydraulic	Gradient	Roughness	Calculated	Calculated
Elev No.	Description	Area (ft^2)	(ft)	Depth (ft)	(ft/ft)	(n)[1]	Velocity (fps)[2]	Discharge (cfs)
1a	Bankfull	32	32	1.00	0.014	0.040	4.40	141
1	Bankfull	60	44	1.36	0.014	0.040	5.41	325
2	2 X Max Depth (Q_{50})	240	131	1.83	0.014	0.039	6.76	1623
3	1997 Flood (Q_{100})	310	147	2.11	0.014	0.038	7.63	2365
4	?	500	179	2.79	0.014	0.037	9.46	4729

1. From Rosgen's F4 and G4 stream types, "n" = 0.033 - 0.040.
2. From Manning's Equation.

Sulphur Creek Upstream of Boulder Creek Confluence

11/4/02 (each cell = 1.0 sq. ft.)



Longitudinal Profile slopes = 0.014 for channel
0.007 for upper terrace

APPENDIX B

FIRE CONDITION CLASS

CONDITION CLASS

Condition class descriptions: Condition classes are a function of 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. One or more of the following activities may have caused this departure: fire exclusion, timber harvesting, grazing, introduction, and establishment of exotic plant species, insects and disease (introduced or native), or other past management activities.

Condition class	**Attributes**	**Example management options**
Condition Class 1	• Fire regimes are within or near an historical range. • The risk of losing key ecosystem components is low. • Fire frequencies have departed from historical frequencies by no more than one return interval. • Vegetation attributes (species composition and structure) are intact and functioning within an historical range.	Where appropriate, these areas can be maintained within the historical fire regime by treatments such as fire use.
Condition Class 2	• Fire regimes have been moderately altered from their historical range. • The risk of losing key ecosystem components has increased to moderate. • Fire frequencies have departed (either increased or decreased) from historical frequencies by more than one return interval. This results in moderate changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns. • Vegetation attributes have been moderately altered from their historical range.	Where appropriate, these areas may need moderate levels of restoration treatments, such as fire use and hand or mechanical treatments, to be restored to the historical fire regime.
Condition Class 3	• Fire regimes have been significantly altered from their historical range. • The risk of losing key ecosystem components is high. • Fire frequencies have departed from historical frequencies by multiple return intervals. This results in dramatic changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns. • Vegetation attributes have been significantly altered from their historical range.	Where appropriate, these areas may need high levels of restoration treatments, such as hand or mechanical treatments. These treatments may be necessary before fire is used to restore the historical fire regime.

APPENDIX C

CHRONOLOGY OF HISTORICAL EVENTS

1. **Sulphur Creek Watershed Analysis Chronology of Significant Channel Changes and Watershed Impacts From AD 1848 to 2000.**

2. **Sulphur Creek Watershed Analysis Aerial Photograph Interpretations.**

SULPHUR CREEK WATERSHED ANALYSIS
CHRONOLOGY OF SIGNIFICANT CHANNEL CHANGES AND WATERSHED IMPACTS
From AD 1848 to 2000

1848. California Gold Rush begins at Sutters Mill, Coloma, and crude mining begins at Bidwell Bar on the Feather River.

1849-1900. Dairy farms and ranches produce food supplies for miners and others moving into the area. Grazing is almost synonymous with mining because horses needed to be boarded. Highland meadows were used early for hoses and cattle. The dairy industry began using meadows in the 1870s. At this time some meadowlands were plowed and hay corps for feed grown. Whether or not the shift from perennial to annual grasses occurred at this time is still debated, but the intensity of the grazing and plowing would have favored annual grasses. During the late 1800s and early 1900s, sheep began to be routed to the high elevation meadows.

Within the Sulphur Creek watershed, timber cutting occurred primarily for local use as building material and firewood. Wildfires were infrequent. "Mohawk Valley is a notable pasture tract, but is mostly under fence and cultivation. It is not largely utilized as pasture until late in the season, when the hay crop has been cut" (Leiberg 1902).

Drought years associated with high pressure and cold air: 1850-51, 1862-63, 1976-77, and 1897-98.

Flood years during winter with heavy rainfall and rapid melt of the snowpack: 1851-52, 1861-62, 1866-67, 1883-84, and 1889-90.

A large earthquake occurred near Clio in 1875. The strength of the quake, usually measured on the Richter Scale, is unknown, but it is reported, "...that cracks in the ground opened and that steam and hot water were emitted" (Durell 1987).

Most of the stream channels draining the Watershed's westside have been scoured for centuries by debris flows, a naturally occurring sediment transport mechanism in this landscape.

1901-1939. The roadway that is to be Highway 89 has been constructed, crossing Sulphur Creek immediately downstream from the present crossing location. The channel is single thread and narrow with good riparian vegetation. Most of the valley is under irrigation.

Riparian vegetation along Sulphur Creek for approximately 2000 feet upstream of the highway crossing is sparse. The area is heavily used for hay production and grazing.

Both private and federal forestlands were being intensively logged. Much of the headwater areas, including the slopes surrounding McNair Meadow, the Barry Creek subwatershed, and some of the Calfpasture Creek subwatershed have been extensively logged by 1939. Logging on the westside extended from McNair Meadow to the valley, downstream to the confluence with Barry creek, along the lower slopes. Initially logging used horse and mule power, the logs being loaded onto wagons for transport. Next came the big wheels, which suspended one end of the log, increasing its drag on soils. By the 1890s, Steam Donkey technology was used, whereby logs were dragged to a collection point, greatly accelerating soil erosion. Clearcutting became feasible at this time and, along with railroad transportation, was the most economical way to remove timber.

The 1920s saw a plethora of literature about overgrazing. Livestock grazing in the Sulphur Creek watershed is similar to that found elsewhere. Overgrazing is the norm and as stream channels degrade, riparian vegetation is beginning to disappear.

Drought years: 1912-13, 1919-20, and 1923-24.

Flood years: 1904-05, 1905-06, 1906-07, 1908-09, 1910-11, 1913-14, 1914-15, 1915-16, and 1937-38.

1940-1941. Lower Calfpasture Creek has been straightened and the Sulphur Creek channel begins to incise immediately downstream of the new confluence to the highway crossing, approximately 700 feet, and downstream of the highway crossing for approximately 1700 feet.

The mouth of Sulphur Creek at Clio is in its present location. (Note. It is suspected that the confluence of Sulphur Creek with the Middle Fork Feather River has been relocated upstream from its original location, possibly a result of the construction of Highway 89. It is also possible that the MFFR has also been altered at the site of the original confluence. If so, channel incision would have been initiated at this time, both in the MFFR and Sulphur Creek.)

Logging continues in the upper watershed areas with emphasis on the Calfpasture Creek subwatershed. Roads have been constructed very close to the main Calfpasture Creek channel.

No drought. Flood years: 1940-41.

1942-1953. The Highway 89 crossing with Sulphur Creek is reconstructed and straightened and the main channel upstream and downstream of the crossing is also straightened. The riparian area for approximately 2000 feet upstream and 500 feet downstream of the crossing is sparse to devoid of vegetation. Channel incision is evident along Sulphur Creek upstream and downstream of the new Highway 89 crossing approximately 2000 feet in both directions. Large, barren gravel bars have developed upstream of the crossing. Efforts to eradicate willows occurred during this time.

Logging and road construction have extended into all parts, on both sides, of the Watershed. The use of dozers to pull logs to landings was now used extensively, although cable yarding was used to log steep slopes.

No droughts. Flood years: 1942-43 and 1951-52.

1954-1972. Channel incision is evident in the MFFR and in Sulphur Creek from its mouth upstream to at least its confluence with Barry Creek. There is evidence that channel incision has progressed upstream of the lower Loop Road bridge and into Barry Creek, which, by now, has been relocated up against southwest side of its valley (its present location).

Calfpasture Creek and most of the tributary channels entering the main valley from the westside show evidence of a lowered watertable and, possibly, channel incision. Irrigation kept most of the main valley green, including along the tributary channels to near their confluence with Sulphur Creek.

In 1972, a large dam, apparently constructed of soil material, is located in the main channel near the Mohawk Valley Ranch. This dam appears to be vulnerable to breaching and washing out, but no major washouts are evident at this time.

The channel upstream of the highway crossing is very straight, degraded, and cutting its banks. Channel straightening must be occurring after each flood event. Because the channel has incised and no longer accesses its floodplain annually, the gully is widening and straightening itself. It is evident that the channel is relocating itself frequently. Instream gravel extraction occurred upstream of Highway 89 bridge beginning in the late 1950s and continuing into the 1960s.

The Sulphur Creek Loop road was constructed in the mid-1950s and the Mohawk-Chapman Road was completed in 1957.

Drought years: 1960-61.

Flood years: 1955-56, 1957-58, and 1964-65.

1973-1997. The main Sulphur Creek channel has widened further, developing large sand and gravel bars. The channel upstream of the Highway 89 crossing is no longer being straightened but the active channel area and bars show little evidence of revegetation. Some riparian vegetation is developing downstream of the crossing, but still very sparse. Channel incision has progressed upstream along the main stem as far as it can; to a stream reach composed of bedrock and boulders and located between the two Loop Road bridges.

Channel incision has also occurred upstream of the bedrock reach and has reached the lower end of McNair Meadow. Headcuts are located just upstream of the confluence of McNair Meadow creek with the main Stem of Sulphur Creek. The Forest Service by this time has constructed loose-rock headcut control structures to slow headward expansion of the gully. The stringer meadow area between the upper Loop Road bridge and the bedrock reach has gullied (the channel is located along the west side of the meadow) and the meadow was logged. The beaver that were present here are now gone.

Irrigated lands remain green, but the lowered water table with livestock grazing are causing drying along the upper channel banks, including many of the tributary channels. This is weakening the natural bank protection provided by plant roots, accelerating bank erosion and gully widening.

The soil dam that was present in the main channel in 1972 is no longer present and the channel is very much wider downstream of that structure location than upstream. This is approximately the downstream end of the Whitehawk Ranch reach (formerly the Mohawk Valley Ranch). The golfcourse is now in place.

Large areas of private uplands surrounding the valley have been extensively re-logged.

Drought years: 1975-1977 and 1986-1988.

Flood years: 1980-83, 1986, 1995, and 1997. Several sizable landslides occurred in the upper watershed during the 1986 and 1997 events.

1998-2000. The main channel of Sulphur Creek upstream and downstream of Highway 89 crossing is still widening, but riparian vegetation, mostly willows, is moving into the new, lowered floodplain and mid-terrace areas. These areas are beginning to show signs of recovery, but gully widening is still very active.

Logging activities are active on private lands, while the federal lands show little sign of such activities in the recent past. The Forest Service treated the Locke Mine area, dramatically reducing erosion and sediment loss.

Cattle still graze within the active channel, floodplain and riparian areas developing within the widening Sulphur Creek gully.

Few indicators of beaver activities remain in the watershed except at the confluence of Barry Creek and Sulphur Creek and on the stringer meadow immediately downstream of the upper Loop Road bridge.

SULPHUR CREEK WATERSHED ANALYSIS
AERIAL PHOTOGRAPH INTERPRETATIONS
Benoit, 3/12/03

1. By 1941, riparian vegetation upstream of the Highway 89 crossing with Sulphur Creek is sparse to non-existent for at least 2000 feet. Downstream of the crossing, riparian vegetation was sparse for approximately 500 feet.

2. By 1941, the lower section of Calfpasture Creek had been straightened and Sulphur Creek from the Highway 89 bridge upstream to the confluence with Calfpasture Creek is downcutting. Irrigation channels were in place over the outflow area of Calfpasture Creek. Upper watershed areas have been accessed and logging begun. Most of the road system is close to the main channel of Calfpasture.

3. By 1953 much of the stream channel upstream of the crossing was in poor condition, with active bank erosion, channel straightening, and loss of most of the riparian vegetation.

4. Between 1941 and 1953, Highway 89 crossing over Sulphur Creek was reconstructed and the channel was straightened for approximately 1000 feet upstream and 500 feet downstream. The bridge was also relocated upstream from the old bridge.

5. Much of the headwater area around McNair Meadow and the Barry Creek watershed had been logged (jammer logged with steam donkeys) by 1939. Some of the Calfpasture watershed had also been logged in this way by then. By 1939, logging on the westside extended down from McNair Meadow to the valley (downstream to the confluence with Barry Creek) along the lower slopes (subwatershed # 10). By 1953, almost all of the eastside and the lower slopes of the westside had been logged.

6. By 1953, main channel degradation had migrated upstream of Highway 89 to where subwatershed # 4 flows in, at least 2000 feet, and downstream of Highway 89 approximately the same distance.

7. The 1939 photo shows little to no logging on the westside of the valley, but most of the stream channels are scoured by debris flows.

8. Most of the valley was being irrigated by 1939.

APPENDIX D

ROAD INVENTORY FORMS

1. **Roads, Skid Trails, Landings and Mine sites Problem Assessment and Volume Estimate.**
2. **Stream and Meadow Crossings Problem Assessment and Volume Estimate.**

Sulphur Creek Watershed Assessment
Roads, Skid Trails , Landings and Mine sites Problem Assessment and Volume Estimate

Road #______________ GPS_______, Skid Trail GPS__________, Landing GPS________Mine site GPS____
Survey Date:_______________ Observer____________________Subwatershed________ MP_______________

Discription of Problem
___________________________________Mod.________________________SEV______________________
Sediment Movement/Hydraulic Conection

Sediment to Nearest channel	[ ] sediment being deposited within 100' of stream channel, and high High potential flood flow transport.	[ ] sediment deposited in channel or direct hydraulic linkage.
Stream flow	[ ] dry	[ ] wet

Facility type [ ]Road [ ] Skid trail [ ] landing [ ] mine site

1. **Road Location/Alignment:**

	[ ] less than 1000' parallels a stream channel, or is more than 100' away from channel	[ ] most of road parallels a stream channel and is within 100' of the channel or most of fill slope is actively eroding to stream channel

2. **Cut Slope:**

Sheet / rill / gully and Slope failure	[ ] Sheet/Rill on >10% area [ ] height, [ ] width, [ ] length	[ ] Gullying / slope failure [ ]] height, [ ] width, [ ] length

Cut slope recession [ ] length, [ ] height [ ] set back
Not including gullies and slope failure

3. **Road Surface: [ ] dirt, [ ] gravel, [ ] paved, [ ] HWY, [ ] driveway.**

Sheet / rill / gully and Slope failure	[ ] Sheet/Rill on >10% area [ ] height, [ ] width, [ ] length	[ ] Gullying / slope failure [ ]] height, [ ] width, [ ] length

4. **Fill Slope:**

Sheet / rill / gully and Slope failure	[ ] Sheet/Rill on >10% area [ ] height, [ ] width, [ ] length	[ ] Gullying / slope failure [ ]] height, [ ] width, [ ] length

5. **Darinage structures:**
[ ] water bars and rolling dips, [ ] inside ditch and cross drains, [ ] out-sloped road; berms with over-side drain, [ ] no structure present.

Erosion of structure	[ ] active erosion occurring. Inside ditch <18" deep or minor Breaching of water bars, rolling dips [ ] length, [ ] width, [ ] depth	[ ] active erosion occurring. inside ditch >18" deep or water bars and dips washed Out [ ] length, [ ] width, [ ] depth
Erosion below structure	[ ] gully is <1' top width [ ] length, [ ] width, [ ] depth	[ ] gully is >1' top width [ ] length, [ ] width, [ ] depth

Enter the number of MOD> and SEV. descriptors for each of the numbered items

	Mod.	Sev.
1. Location/ alignment	________	________
2. Cut slope	________	________
3. Road Surface	________	________
4. Fill slope	________	________
5. Drainage	________	________
Total	________	________

Sediment Volume by site;

Cut slope ________

Road Surface ________

Fill slope ________

Drainage ________

Total Sediment ________ Cubic feet

Notes:

Sulphur Creek Assessment
Stream and Meadow Crossings Problem Assessment and Volume Estimate

Date___________ Observer_________________ Subwatershed________ Road #___________ MP______

Stream/Meadow Crossing *__________ Geomorphic unit____________________, GPS_________________

Crossing Type: [ ]CMP, [ ]Box,[ ]LWC.[ ]RCP: Number_____________________. Size_______________

	Mod.		Sev.
Sediment Movement			
Water or Sediment to Nearest channel	[ ]	Sediment being deposited within 100' of a stream channel, but Not to the channel	[ ] sediment deposited in channel or direct hydraulic linkage
Stream flow	[ ] dry		[ ] wet

Stream Crossing Meadow Crossing {circle one)

1. Crossing Approaches

A] Approach Grade	[ ] "0" grade (level)	[ ] "+" grade (drops down from crossing)
Cut Slope: Sheet / rill / gully and Slope failure	[ ] Sheet/Rill on >10% area [ ] height, [ ] width, [ ] length	[ ] Gullying / slope failure [ ]] height, [ ] width, [ ] length
Cut slope recession Not including gullies and slope failure	[ ] length, [ ] height [ ] set back	

Road Surface: [ ] dirt, [ ] gravel, [ ] paved, [ ] HWY, [ ] driveway.		
Sheet / rill / gully and Slope failure	[ ] Sheet/Rill on >10% area [ ] height, [ ] width, [ ] length	[ ] Gullying / slope failure [ ]] height, [ ] width, [ ] length
Fill Slope: Sheet / rill / gully and Slope failure	[ ] Sheet/Rill on >10% area [ ] height, [ ] width, [ ] length	[ ] Gullying / slope failure [ ] height, [ ]width,[ ]length

Darinage structures:
[ ] water bars and rolling dips, [ ] inside ditch and cross drains, [ ] out-sloped road; berms with over-side drain, [ ] no structure present.

. Erosion of Structure	[ ] erosion of inside ditch <1' deep or minor breaching of water Bars [ ] width, [ ]depth, [ ]length	[ ] erosion of inside ditch>1' deep or water bars washed out [ ] width,[ ]depth,[ ]length

2. Stream channel above crossing

A. Scour and erosion	[ ] moderate bed scour Headcutting <24' deep or Bank erosion <24' high	[ ] significant bed scour headcutting>24' deep or bank erosion > 24' high
B. Ponding	[ ] significant deposition above Crossing	[ ] roadway has topped during past flows or could be topped
C. Obstructions	[ ] partial blockage of channel or Culvert or moderate potential For development	[ ] mass drift has severely restricted channel or culvert area or high potential for development

3. Stream Channel Below Crossing

	Mod.	Sev.
A. Scour at Culvert outfall	[ ] active scour hole <24' deep	[ ] active scour hole >24' deep
B. Scour and Erosion	[ ] moderate bed scour <12' deep or bank erosion <24' high	[ ] significant bed scour >12' deep or bank erosion >24' high
4. **Crossing**	[ ] no culvert and water flows over roadway	[ ] crossing washed out or recently replaced

Enter the number of Mod. and Sev. descriptors for each of the numbered items.

	Mod.	Sev.
1. Crossing Approaches	______	______
2. Stream Channel Above Crossing	______	______
3. Stream Channel Below Crossing	______	______
4. Crossing	______	______
Total	______	______

Sediment Volume by site;

Cut slope ________

Road Surface ________

APPENDIX E

ROAD INVENTORY RESULTS

EROSION VOIDS

1. **Tables Displaying the Number of Problems and Erosion Void Volumes by Subwatershed.**
2. **Tables Displaying the Erosion Void Volumes by Road.**

TOTAL OF ROAD PROBLEMS INVENTORIED BY LOCATION

Watershed	Name	Drainage Area (mi^2)	Number of Road Prism Problems	Number of Road Crossing Problems	Total Problems for Subwtsd	Percent of Total	Ttl Problems per mi^2
1	Lower Sulphur Creek	1.87	1	3	4	1	2.14
2	Bear Wallow Creek	1.30	0	2	2	1	1.54
3a	**South Calfpasture Creek**	3.18	5	32	37	14	**11.64**
3b	**North Calfpasture Creek**	3.12	12	25	37	14	**11.86**
4	**Wash Creek**	2.81	0	21	21	8	**7.47**
5	McKenzie Creek	0.77	0	3	3	1	3.90
6	Boulder Creek	2.01	0	14	14	5	6.97
7	Raap Creek	1.50	0	10	10	4	6.67
8	**Haskell Ravine**	1.76	2	16	18	7	**10.23**
9a	**Lower Barry Creek**	3.15	4	28	32	12	**10.16**
9b	Upper Barry Creek	2.60	2	11	13	5	5.00
10	**Middle Sulphur Creek**	3.91	3	47	50	18	**12.79**
11	**Upper Sulphur Creek**	3.07	4	25	29	11	**9.45**
12	McNair Meadow	2.08	2	0	2	1	0.96
	Total =	**33.13**	**35**	**237**	**272**	100	100.75
	Average =		**2.50**	**16.93**	**19.43**		**7.20**
	Percent of Total =		**13**	**87**	**100**		

SULPHUR CREEK WATERSHED
ROAD EROSION VOIDS BY SUBWATERSHED
(NOT INCLUDING A SINGLE, LARGE SLOPE FAILURE)

		Volume of Erosion Voids (ft^3)						
Subwatershed Number	**Name**	**Cut Slope**	**Road Surface**	**Fill Slope**	**Drainage Structure**	**Total Volume (ft^3)**	**Total Volume (tons)**	**Percent of Total**
1	Lower Sulphur	558	0	0	10,280	10,838	22,001	1
2	Bear Wallow	280	240	0	0	520	1,056	0
3a	South Calfpasture	84,561	95,228	11,759	8,713	200,261	406,530	12
3b	North Calfpasture	49,916	8,375	42,839	18,311	119,441	242,465	7
4	Wash	136,172	112	1,217	2,584	140,085	284,373	9
5	McKenzie	18,277	0	72	760	19,109	38,791	1
6	Boulder	7,162	819	3,156	944	12,081	24,524	1
7	Raap	10,650	522	117,046	887	129,105	262,083	8
8	Haskell Ravine	39,639	998	**15,698**	4,348	60,683	123,186	4
9a	Lower Barry	33,248	10,250	5,388	36,140	85,026	172,603	5
9b	Upper Barry	1,230	2,264	72	1,070	4,636	9,411	0
10	Middle Sulphur	649,048	944	21,869	28,877	700,738	1,422,498	44
11	Upper Sulphur	24,304	11,730	16,192	16,884	69,110	140,293	4
12	McNair Meadow	0	0	0	0	0	0	0
	Unknown	27,195	884	29,049	375	57,503	116,731	4
	Total =	1,082,240	132,366	264,357	130,173	1,609,136	3,266,546	100

15,698: Does not include large fill slope failure of 1,700,000 ft^3.

SULPHUR CREEK WATERSHED
ROAD EROSION VOIDS BY SUBWATERSHED
(INCLUDES A SINGLE, LARGE SLOPE FAILURE)

		Volume of Erosion Voids (ft^3)						
Subwatershed Number	Name	Cut Slope	Road Surface	Fill Slope	Drainage Structure	Total Volume (ft^3)	Total Volume (tons)	Percent of Total
1	Lower Sulphur	558			10,280	10,838	22,001	0
2	Bear Wallow	280	240			520	1,056	0
3a	South Calfpasture	84,561	95,228	11,759	8,713	200,261	406,530	6
3b	North Calfpasture	49,916	8,375	42,839	18,311	119,441	242,465	4
4	Wash	136,172	112	1,217	2,584	140,085	284,373	4
5	McKenzie	18,277		72	760	19,109	38,791	1
6	Boulder	7,162	819	3,156	944	12,081	24,524	0
7	Raap	10,650	522	117,046	887	129,105	262,083	4
8	Haskell Ravine	39,639	998	**1,715,698**	4,348	1,760,683	3,574,186	53
9a	Lower Barry	33,248	10,250	5,388	36,140	85,026	172,603	3
9b	Upper Barry	1,230	2,264	72	1,070	4,636	9,411	0
10	Middle Sulphur	649,048	944	21,869	28,877	700,738	1,422,498	21
11	Upper Sulphur	24,304	11,730	16,192	16,884	69,110	140,293	2
12	McNair Meadow					0	0	0
	Unknown	27,195	884	29,049	375	57,503	116,731	2
	Total =	1,082,240	132,366	1,964,357	130,173	3,309,136	6,717,546	100

1,715,698: Includes a large fill slope failure of 1,700,000 ft^3.

SUMMARY: NUMBER OF ROAD PROBLEMS BY SOURCE WITH VOLUME OF EROSION VOIDS

	Road Cut Slope		Road Fill Slope		Road Surface		Road Drains		Total	Total	Percent
Watershed	Problems	Volume	Problems	Volume	Problems	Volume	Problems	Volume	Problems	Volume	of Total
1	2	558	0	0	0	0	2	10280	4	10838	0.87
2	1	280	0	0	1	240	0	0	2	520	0.04
3a	21	84561	21	11759	14	95228	13	8713	69	200261	15.98
3b	22	49916	15	42839	21	8375	12	18311	70	119441	9.53
4	26	136172	8	1217	4	112	10	2584	48	140085	11.18
5	3	18277	1	72	0	0	2	760	6	19109	1.53
6	10	7162	4	3156	5	819	10	944	29	12081	0.96
7	7	10650	5	117046	3	522	3	887	18	129105	10.31
8	11	39639	9	**15698**	2	998	12	4348	34	60683	4.84
9a	17	33248	9	5388	14	10250	15	36140	55	85026	6.79
9b	2	1230	2	72	9	2264	3	1070	16	4636	0.37
10	28	**292740**	10	21869	3	944	35	28877	76	344430	27.49
11	22	24304	7	16192	10	11730	16	16884	55	69110	5.52
12	0	0	0	0	0	0	0	0	0	0	0.00
Unk	4	27195	4	29049	4	884	4	375	16	57503	4.59
Totals	176	725932	95	264357	90	132366	137	130173	498	1252828	100.00

Wtsd 8, Road Fill Volume: Reduced 1,700,000 ft^3 because it was a single mass failure (Obs. 207; Loc. 221).

Wtsd 10, Cut Slope Volume: Reduced 192,000 ft^3 for a single large gully (Obs. 252; Loc. 266) and
reduced 164,308 ft^3 due to a miss-calculation (Obs. 215; Loc 228)
for a total reduction of 360,780 ft^3.

EROSION VOIDS BY ROAD

2002

Road ID*	Watershed Side	Cutslope Voids	Fillslope Voids	Road Surface Voids	Drainage Structure Voids	Total Voids (ft^3)
22N98 (Mohawk Chapman Rd)	westside	538,844	1,834,911	330	16,388	**2,390,473**
Hwy 89	eastside	387,235	0	60	40,132	**427,427**
22N13	eastside	273,857	74,796	27,707	37,092	**413,452**
21N27	westside	31,125	6,620	11,412	1,119	50,276
Others		33,564	3,613	1,800	467	39,444
22N12	eastside	20,879	8,406	6,179	1,540	37,004
21N02 (Loop Rd)	westside	19,671	96	1,664	10,141	31,572
Hwy 114	eastside	4,212	0	0	16,785	20,997
21N83	westside	4,950	12,000	960	116	18,026
21N09	westside	6,070	0	1,800	6,436	14,306
21N94	westside	5,826	0	647	460	6,933
21N91	westside	6,176	282	57	0	6,515
22N48	eastside	750	1,057	784	0	2,591
21N01	westside	405	0	0	1,248	1,653
21N31	westside	600	1	91	42	734
21N29	westside	640	0	0	36	676
22N03	eastside	288	0	370	0	658
21N06	westside	516	0	39	0	555
Friendly Way	westside	280	0	240	0	520
21N03	eastside					
21N11	eastside					
21N56	westside					
Total =		**1,335,888**	**1,941,782**	**54,140**	**132,002**	**3,463,812**

* Includes all named and unnamed spur roads connecting to the named road.

2,390,473: The single, large slope failure (1,700,000 ft^3) was deleted.

SUMMARY: EROSION VOIDS BY ROADS SEPARATED INTO EAST AND WEST SIDES

			2002	
Westside Roads	**Total Erosion Volume (ft^3)**		**Eastside Roads**	**Total Erosion Volume (ft^3)**
22N98	2,390,473		Hwy 89	427,427
21N27	50,276		22N13	413,452
21N02	31,572		22N12	37,004
21N83	18,026		Hwy 114	20,997
21N09	14,306		22N48	2,591
21N94	6,933		22N03	658
21N91	6,515		21N03	
21N01	1,653		21N11	
21N31	734		other	19,722
21N29	676			
21N06	555			
Friendly Way	520			
21n56				
Other	19,722			
Total =	**2,541,961**			**921,851**
Grand Total =	**3,463,812**			
Percent of Gr. Ttl =	**73**			**27**

APPENDIX F

ROAD INVENTORY RESULTS

HYDRAULIC LINKS

1. **Tables Displaying the Change in Drainage Density and Hydraulic Linkages by Subwatershed.**
2. **Table Displaying the Hydraulic Linkages by Road.**
3. **Road-Drainage Channels, A Comparison with First-Order Streams as an Estimate of Equivalency.**

STREAM CHANNEL DRAINAGE DENSITY INCREASE DUE TO ROAD LINKS

2002

Watershed	Name	Wtsd Area (square miles)	Stream Channel Drainage Density (mi/mi^2)	Road Links (mi/mi^2)	Total Stream Channel Drain Density (mi/mi^2)	Percent Increase to Stream Drain Density
1	Lower Sulphur Creek	1.87	4.49	0.15	4.64	**3.23**
2	Bear Wallow Creek	1.30	5.77	0.01	5.78	0.17
3a	South Calfpasture Creek	3.18	5.09	0.13	5.22	2.49
3b	**North Calfpasture Creek**	3.12	3.69	0.25	3.94	**6.35**
4	Wash Creek	2.81	4.06	0.12	4.18	**2.87**
5	McKenzie Creek	0.77	5.7	0.12	5.82	2.06
6	Boulder Creek	2.01	3.68	0.05	3.73	1.34
7	Raap Creek	1.50	8.08	0.05	8.13	0.62
8	**Haskell Ravine**	1.76	4.43	0.21	4.64	**4.53**
9a	Lower Barry Creek	3.15	5.01	0.15	5.16	**2.91**
9b	Upper Barry Creek	2.60	3.47	0.05	3.52	1.42
10	**Middle Sulphur Creek**	3.91	4.18	0.2	4.38	**4.57**
11	**Upper Sulphur Creek**	3.07	4.03	0.17	4.2	**4.05**
12	McNair Meadow	2.08	4.42	0.01	4.43	0.23
Total		33.13	66.10	1.67	67.77	36.82
Average		2.37	4.72	0.12	4.84	2.63

Road Related Hydraulic Linkages to Stream Channels as a Length in Feet

2002

Watershed	Name	Wtsd Area (square miles)	Total Problems	Ttl Problems per mi^2	Total Linkage (ft)	Adjusted Linkage (ft X 0.25))	Ttl Linkage per mi^2	Road Links (mi/mi$^{2)}$	Percent of Total
1	Lower Sulphur Creek	1.87	4	2	6,040	1,510	**807**	0.15	9.11
2	Bear Wallow Creek	1.30	2	2	200	50	38	0.01	0.43
3a	South Calfpasture Creek	3.18	37	**12**	8,684	2,171	**683**	0.13	7.70
3b	**North Calfpasture Creek**	3.12	36	**12**	16,582	4,146	**1,329**	0.25	14.99
4	Wash Creek	2.81	21	7	7,131	1,783	634	0.12	7.16
5	McKenzie Creek	0.77	4	5	1,907	477	619	0.12	6.98
6	Boulder Creek	2.01	14	7	2,310	578	287	0.05	3.24
7	Raap Creek	1.50	10	7	1,660	415	277	0.05	3.12
8	**Haskell Ravine**	1.76	18	**10**	7,680	1,920	**1,091**	0.21	12.31
9a	Lower Barry Creek	3.15	32	**10**	9,921	2,480	**787**	0.15	8.88
9b	Upper Barry Creek	2.60	13	5	2,986	747	287	0.05	3.24
10	**Middle Sulphur Creek**	3.91	49	**13**	16,270	4,068	**1,040**	0.20	11.73
11	**Upper Sulphur Creek**	3.07	28	**9**	11,301	2,825	**920**	0.17	10.38
12	McNair Meadow	2.08	2	1	530	133	64	0.01	0.72
Total		33.13	270	101	93,202	23,301	8,865	1.68	100.00
Average		2.37	19	7	6,657	1664	633	0.12	

HYDRAULIC LINKAGES BY ROAD IN THE SULPHUR CREEK WATERSHED

2002

Road ID	Watershed Side	Cutslope	Hydraulic Linkages(ft) Fillslope	Rd Surface	Drains	Ttl Hyd Link for Rd (ft)	Percent of Total
21N01	westside	150			520	520	0.71
21N02 (Loop Rd)	westside	3,765	40	720	8,315	8,315	11.32
21N03	eastside						0.00
21N06	westside	260		330		330	0.45
21N09	westside	2,830		600	3,430	3,430	4.67
21N11	eastside						0.00
21N27	westside	6,691	797	4,092	2,145	3,660	4.98
21N29	westside	200			60	200	0.27
21N31	westside	140	20	80	140	140	0.19
21N56	westside						0.00
21N83	westside	815	100	60	420	815	1.11
21N91	westside	812	93	47		812	1.11
21N94	westside	950		580	590	950	1.29
22N03	eastside			110		110	0.15
22N12	eastside	3,240	180	1,705	1,400	3,240	4.41
22N13	eastside	11,044	1,317	2,866	8,363	**13,382**	**18.22**
22N48	eastside	175	120	201		201	0.27
22N98 (Mohawk Chapman Rd)	westside	12,022	1,505	115	12,365	**14,576**	**19.84**
Friendly Way	westside	100		100		100	0.14
Hwy 114	eastside	1,090			4,530	4,530	6.17
Hwy 89	eastside	5,880	815	100	9,980	**16,675**	**22.70**
Others			217	1,480	1,330	1,480	2.01
					Total =	73,466	100

ROAD-DRAINAGE CHANNELS
A COMPARISON WITH FIRST-ORDER STREAMS AS AN ESTIMATE OF EQUIVALENCY

Benoit, 2003

Problem Statement: Roads receive both surface and subsurface water, carrying this water either directly off the road surface and onto the slopes below or, as in many cases, water collects in constructed drainage channels, where it is either discharged onto the slopes below the roads or directly to stream channels. Road-drainage channels perform very similar to stream channels, collecting slowly moving groundwater into surface flowing systems, then concentrating and delivering it to down-channel areas. Where these drainage channels connect directly to natural streams, water that would have been delivered to stream channels over an extended period of time is now delivered rapidly. This increases the total flow within the natural stream system during storm and snowmelt runoff episodes. Even though the total amount of water yielded by a watershed isn't changed, the timing of that flow is reduced, manifesting itself as increased peak flows (larger volume of water during the height of runoff events). Increased peak flows can result in channel adjustments, especially where channels have formed within small-grained, easily eroded material, such as in meadows. These adjustments can result in gully formation or, where gullies already exist, in an increase in the rate of the adjustment process, usually as gully widening.

The watershed area contributing water to road drainage channels is much less than that of natural, first-order channels. The contributing watershed area for a road drainage channel consists of the slope above the channel plus the road surface. The contributing watershed area for a natural, first-order stream channel consists of the two slopes adjoining the channel plus the entire watershed area upstream of the definable channel, the zero-order watershed area.

Analysis: To estimate the first-order channel equivalency for the road drainage channel, the following simple analysis was performed.

1. Assume the contributing watershed area for the average first-order channel is roughly pear shaped and that a simple equilateral triangle can be used for this analysis (Figure 1 & 3).

2. Assume the average definable first-order channel extends half the distance from the mouth to the watershed divide (Figure 1).

3. Assume the contributing watershed area for a road drainage channel consists of only the upslope area along the length of the channel and the contributing area can be estimated using a rectangle (Figure 2).

The result of this simple analysis is that a single unit of road drainage channel is roughly equivalent, on the average, to ¼ of a first-order channel.

Figure 1. First-order Channel Contributing Watershed Area.

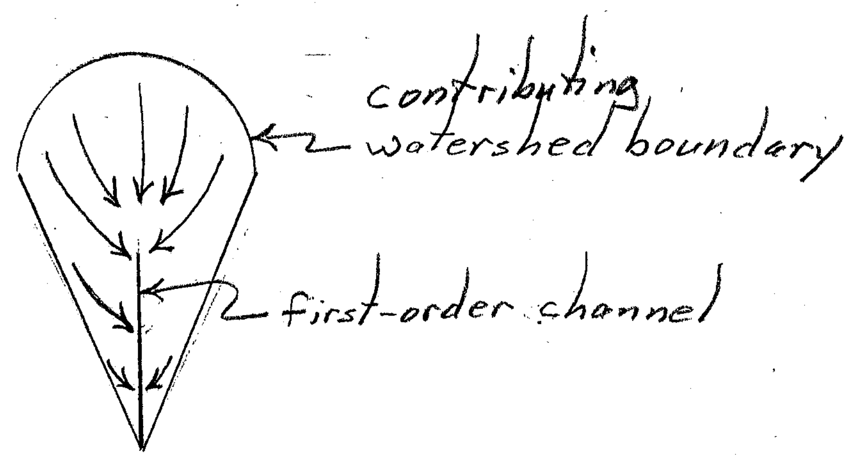


Figure 2. Road Drainage Channel Contributing Watershed Area.

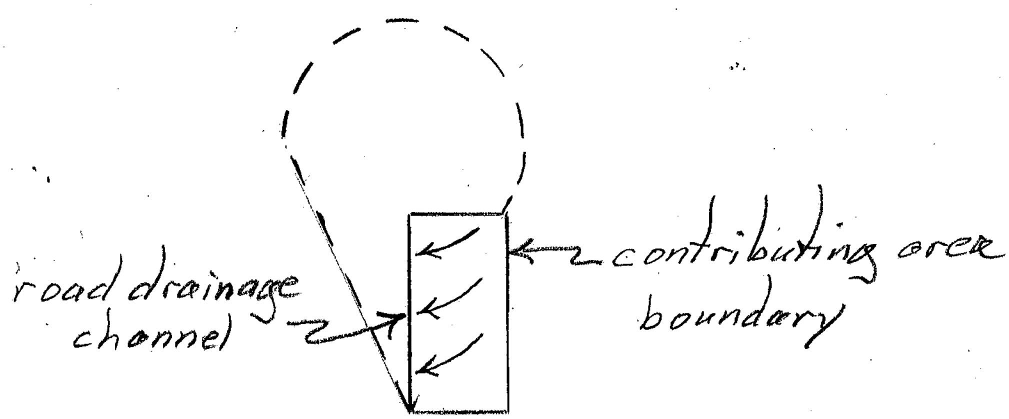
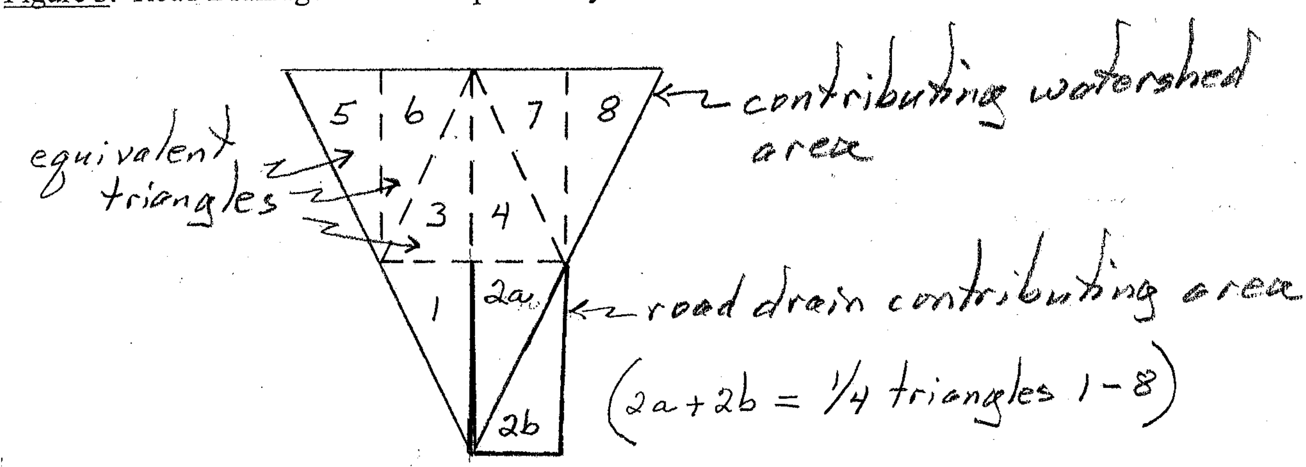


Figure 3. Road Drainage Channel Equivalency to a First-order Channel.



APPENDIX G

ROAD INVENTORY RESULTS

SELECTED ROADS

1. **Summary Table.**

2. **Tables for Each Selected Road.**
    a. **FS 22N98 (westside)**
    b. **FS 21N27 (westside)**
    c. **Highway 89 (eastside)**
    d. **FS 22N13 (eastside)**

SUMMARY OF SELECTED ROADS WITHIN THE SULPHUR CREEK WATERSHED

EROSION VOIDS (tons/mi) AND HYDRAULIC LINKS (mi/mi)

2002

	Highway 89			Forest Service 22N13		
Wtsd No	Obs/mi	Vol. Loss (tons/mi)	Hyd. Link (mi/mi)	Obs/mi	Vol. Loss (tons/mi)	Hyd. Link (mi/mi)
1	3	18	0.30			
2	0	0	0.00			
3a	6	91	**0.55**	5	854	0.09
3b	0	0	0.00	8	**4,746**	0.14
4						
5						
6						
7						
8						
9a	12	509	**0.44**	9	**1,386**	0.10
9b						
10	12	**10,437**	**0.61**			
11						
12	1	82	0.07			

	Mohawk Chapman Rd (FS 22N98)			Forest Service 21N27		
Wtsd No	Obs/mi	Vol. Loss (tons/mi)	Hyd. Link (mi/mi)	Obs/mi	Vol. Loss (tons/mi)	Hyd. Link (mi/mi)
1						
2	0	0	0.00	0	0.00	0.00
3a						
3b						
4	7	**104,612**	0.22	5	0.25	0.03
5	4	**24,135**	0.17			
6	5	**13,145**	0.06	5	0.20	0.03
7	2	**16,110**	0.05	5	2.08	0.01
8	5	**59,129**	0.08	3	0.12	0.04
9a						
9b						
10	2	**29,221**	0.07	4	0.54	0.01
11	3	**19,149**	0.06	0	0.00	0.00
12	0	0.00	0	0	0.00	0.00

MOHAWK CHAPMAN ROAD (FS 22N98) IN THE SULPHUR CREEK WATERSHED

EROSION VOIDS AND HYDRAULIC LINKAGES

2002

				Volume Eroded				Hydraulic Link			Hyd Link
Wtsd No	**Length (mi)**	**Obs.**	**Obs/mi**	**ft^3**	**yd^3**	**tons**	**tons/mi**	**ft**	**adjusted (ft)**	**miles**	**mi/mi**
2	0.76	0	0.00	0	0	0	0	0	0	0.00	0.00
4	1.18	8	6.78	60,809	2,252	123,442	**104,612**	5,496	1,374	0.26	**0.22**
5	0.46	2	4.35	5,469	203	11,102	24,135	1,620	405	0.08	**0.17**
6	0.86	4	4.65	5,569	206	11,305	13,145	1,090	273	0.05	0.06
7	1.05	2	1.90	8,333	309	16,916	16,110	1,005	251	0.05	0.05
8	1.06	5	4.72	***1,730,875***	64,106	3,513,676	**3,314,789**	1,770	443	0.08	**0.08**
10	1.33	3	2.26	19,145	709	38,864	29,221	1,995	499	0.09	0.07
11	1.18	3	2.54	11,131	412	22,596	19,149	1,600	400	0.08	0.06
total =	**7.88**	**27**		**1,841,331**	**68,197**	**3,737,902**		**14,576**	**3,644**	**0.69**	

				Volume Eroded				Hydraulic Link			Hyd Link
Wtsd No	**Length (mi)**	**Obs.**	**Obs/mi**	**ft^3**	**yd^3**	**tons**	**tons/mi**	**ft**	**adjusted (ft)**	**miles**	**mi/mi**
2	0.76	0	0.00	0	0	0	0	0	0	0.00	0.00
4	1.18	8	6.78	60,809	2,252	123,442	**104,612**	5,496	1,374	0.26	**0.22**
5	0.46	2	4.35	5,469	203	11,102	24,135	1,620	405	0.08	**0.17**
6	0.86	4	4.65	5,569	206	11,305	13,145	1,090	273	0.05	0.06
7	1.05	2	1.90	8,333	309	16,916	16,110	1,005	251	0.05	0.05
8	1.06	5	4.72	***30,875***	1,144	62,676	**59,129**	1,770	443	0.08	**0.08**
10	1.33	3	2.26	19,145	709	38,864	29,221	1,995	499	0.09	0.07
11	1.18	3	2.54	11,131	412	22,596	19,149	1,600	400	0.08	0.06
total =	**7.88**	**27**		**141,331**	**5,234**	**286,902**		**14,576**	**3,644**	**0.69**	

30,875: Single large failure deleted.

MOHAWK CHAPMAN ROAD (FS 22N98) IN THE SULPHUR CREEK WATERSHED						
	EROSION VOIDS AND HYDRAULIC LINKAGES					
			2002			
				Erosion	**Hydraulic**	
Wtsd No	**Loc No**	**Assessment**	**Problem**	**Vol (ft^3)**	**Link (ft)**	
2	0	none	none			
total =	**0**			**0**	**0**	
4	44	crossing	cutslope and inside ditch	3,540	470	
4	202	crossing	cutslope and inside ditch	8,930	470	
4	203	crossing	cutslope and inside ditch	2,580	430	
4	204	crossing	cutslope and inside ditch	1,200	200	
4	205	crossing	cutslope and inside ditch	2,600	500	
4	206	crossing	cutslope and inside ditch	32,436	2,151	
4	207	crossing	cutslope and inside ditch	6,580	940	
4	225	crossing	cutslope and inside ditch	2,943	335	
total =	**8**			**60,809**	**5,496**	
5	208	crossing	cutslope and inside ditch	525	500	
5	209	crossing	cutslope and inside ditch	4,944	1,120	
total =	**2**			**5,469**	**1,620**	
6	210	crossing	cutslope and inside ditch	800	200	
6	211	crossing	cutslope and inside ditch	1,480	370	
6	212	crossing	cutslope and inside ditch	1,014	195	
6	213	crossing	cutslope and inside ditch	2,275	325	
total =	**4**			**5,569**	**1,090**	
7	214	crossing	cutslope and inside ditch	4,973	585	
7	215	crossing	cutslope and inside ditch	3,360	420	
total =	**2**			**8,333**	**1,005**	
8	221	road	entire prism	1,700,000	500	
8	217	crossing	cutslope and inside ditch	8,000	500	
8	218	crossing	cutslope and inside ditch	2,400	200	
8	219	crossing	cut & fill slopes and inside ditch	10,035	300	
8	220	crossing	cut & fill slopes and inside ditch	10,440	270	
total =	**5**			**1,730,875**	**1,770**	
10	226	crossing	cutslope and inside ditch	5,357	675	
10	227	crossing	cutslope and inside ditch	5,400	800	
10	228	crossing	cutslope and inside ditch	8,388	520	
total =	**3**			**19,145**	**1,995**	
11	128	road	drainage structure	9,625	1,100	
11	121	crossing	cutslope and inside ditch	210	140	
11	128	crossing	cutslope and inside ditch	1,296	360	
total =	**3**			**11,131**	**1,600**	
TOTAL =	**27**			**1,841,331**	**14,576**	

FS ROAD 21N27 IN THE SULPHUR CREEK WATERSHED
EROSION VOIDS AND HYDRAULIK LINKAGES
2002

				Volume Eroded				Hydraulic Link			Hyd Link
Wtsd No	Length (mi)	Obs.	Obs/mi	ft^3	yd^3	tons	tons/mi	ft	adjusted (ft)	miles	mi/mi
2	0.67	0	0.00	0	0.00	0.00	0.00	0	0	0.00	0.00
4	1.44	7	4.86	6,849	0.18	0.37	0.25	1,015	254	0.05	0.03
6	1.75	8	4.57	3,733	0.17	0.34	0.20	1,100	275	0.05	0.03
7	0.19	1	5.26	597	0.19	0.40	2.08	60	15	0.00	0.01
8	1.56	4	2.56	5,170	0.09	0.19	0.12	1,325	331	0.06	0.04
10	0.53	2	3.77	173	0.14	0.28	0.54	160	40	0.01	0.01
11	1.25	0	0.00	0	0.00	0.00	0.00	0	0	0.00	0.00
total =	**7.39**	**22**		**16,522**	**0.78**	**1.58**		**3,660**	**915**	**0.17**	

	FS ROAD 21N27 IN THE SULPHUR CREEK WATERSHED				
	EROSION VOIDS AND HYDRAULIK LINKAGES				
			2002		
				Erosion	Hydraulic
Wtsd No	**Loc No**	**Assessment**	**Problem**	**Vol (ft^3)**	**Link (ft)**
2	0	0		0	0
total =	**0**			**0**	**0**
4	188	crossing	cut and fill slopes	1,468	190
4	311	crossing	cutslope	495	110
4	312	crossing	cutslope	822	140
4	313	crossing	cut and fill slopes	622	115
4	314	crossing	cutslope	720	200
4	315	crossing	cutslope, fillslope, and rd surface	862	110
4	316	crossing	cutslope and drainage structure	1,860	150
total =	**7**			**6,849**	**1,015**
6	272	crossing	inside ditch	0	160
6	273	crossing	road surface	480	160
6	304	crossing	cutslope, fillslope, and drain struc.	1,490	120
6	305	crossing	cutslope, rd surface, and drain struc.	645	150
6	306	crossing	cut, fill, surface, and drain structure	180	250
6	307	crossing	cutslope and drainage structure	99	70
6	308	crossing	road surface and fillslope	100	50
6	310	crossing	cutslope and road drainage structure	739	140
total =	**8**			**3,733**	**1,100**
7	303	crossing	cutslope, fillslope and road surface	597	60
total =	**1**			**597**	**60**
8	299	crossing	cutslope, fillslope, and drain structure	333	100
8	300	crossing	cutslope and drainage structure	972	260
8	301	crossing	cutslope, fillslope, and drain structure	1,849	515
8	302	crossing	cutslope and drainage structure	2,016	450
total =	**4**			**5,170**	**1,325**
10	297	crossing	cutslope, fillslope, and drain structure	173	130
10	298	crossing	drainage structure	0	30
total =	**2**			**173**	**160**
11	0			0	0
total =	**0**			**0**	**0**
Total =	**22**			**16,522**	**3,660**

HIGHWAY 89 IN THE SULPHUR CREEK WATERSHED
EROSION VOIDS AND HYDRAULIC LINKS

2002

	Subwatershed	Approx. Length Hwy (mi)*[1]	Observations	Obs./mile of Hwy	Volume Eroded ft^3	Volume Eroded yd^3	Volume Eroded tons*[2]	tons/mi of Hwy	Hydraulic Linkages ft	Hydraulic Linkages Adjusted (ft)*[3]	Hydraulic Linkages miles	Hydraulic Link mi/mi of Hwy
1	Lower Sulphur Creek	0.95	3	3.16	270	10	17	18	5,980	1495	0.28	0.30
2	Bear Wallow Creek	0.34	0	0.00				0				0.00
3a	**South Calfpasture Creek**	0.33	2	**6.06**	480	18	30	**91**	950	238	0.18	**0.55**
3b	North Calfpasture Creek	1.23	0	0.00				0				0.00
9a	**Lower Barry Creek**	0.52	6	**11.54**	4,228	157	265	**509**	1,205	301	0.23	**0.44**
10	**Middle Sulphur Creek**	2.51	29	**11.55**	418,542	15,502	26,198	**10,437**	8,040	2010	1.52	**0.61**
12	McNair Meadow	1.37	1	0.73	1,800	67	113	82	500	125	0.09	0.07
	Total =	7.25	41		425,320	15,753	26,622		16,675	4,169	2.31	

*1 Measured using 1981 U.S.G.S. maps, 1:24,000 scale.

*2 Dense sand = 1.69 tons/yd^3.

*3 Hydraulic Link in feet adjusted by 0.25, an estimate of the watershed contributing area as equivalent to an order 1 stream channel.

		HIGHWAY 89 IN THE SULPHUR CREEK WATERSHED					
		EROSION VOIDS AND HYDRAULIC LINKS					
				2002			
						Erosion	Hydraulic
Wtsd No.	**Loc. No.**	**Easterly**	**Northerly**	**Assessment**	**Problem**	**Vol (ft^3)**	**Link (ft)**
1		unk	unk	crossing	inside ditch	0	2,840
1	170	708635	4400760	crossing	inside ditch at Sulphur Cr. Xing	0	2,840
1	173	711049	4399555	crossing	cutslope and inside ditch	270	300
total =	**3**					**270**	**5,980**
3a	169	710235	4399992	crossing	cutslope and inside ditch	480	350
3a	171	710616	4400089	crossing	inside ditch	0	600
total =	**2**					**480**	**950**
9a	172	711461	4398832	crossing	inside ditch	0	160
9a	174	711295	4399239	crossing	cutslope and inside ditch	1,360	850
9a	175	711512	4398631	crossing	cutslope	1,350	100
9a	176	711631	4398226	crossing	fillslope	900	10
9a	177	711655	4398201	crossing	fillslope	338	15
9a	178	711678	4398130	crossing	cutslope and inside ditch	280	70
total =	**6**					**4,228**	**1,205**
10	46	714587	4395161	road	cutslope and drainage structure	25,900	700
10	105	712941	4396547	crossing	inside ditch	0	200
10	106	712767	4396702	crossing	fillslope and inside ditch	150	250
10	107	712594	4396765	crossing	cutslope and inside ditch	7,200	450
10	108	712512	4396824	crossing	fillslope	8,450	100
10	123	713035	4396435	crossing	cutslope and inside ditch	21,875	350
10	150	712473	4396839	crossing	fillslope	270	60
10	151	711702	4397938	crossing	cutslope and inside ditch	61,425	585
10	152	711856	4397794	crossing	cutslope and inside ditch	7,200	320
10	153	711952	4397683	crossing	cutslope and inside ditch	11,250	180
10	154	711968	4397662	crossing	cutslope and inside ditch	20,250	270
10	155	712041	4397524	crossing	cutslope and inside ditch	16,875	225
10	156	712062	4397486	crossing	cut & fill slopes and inside ditch	31,165	350
10	157	712739	4397356	crossing	cut & fill slopes and inside ditch	36,750	300
10	158	712180	4397281	crossing	cut & fill slopes and inside ditch	6,525	200
10	159	712223	4397217	crossing	cutslope and inside ditch	43,200	270
10	160	712247	4397146	crossing	cut & fill slopes and inside ditch	41,250	300
10	161	712302	4397054	crossing	cut & fill slopes and inside ditch	28,800	230
10	162	712410	4396949	crossing	cutslope and inside ditch	12,250	140
10	163	712354	4396927	crossing	cutslope and inside ditch	17,220	120
10		714812	4395025	crossing	inside ditch	0	450
10		714104	4395813	crossing	cut & fill slopes and inside ditch	319	60
10		714169	4395726	crossing	cutslope and inside ditch	5,625	150
10		714251	4395696	crossing	cutslope and inside ditch	2,000	250
10		714364	4395642	crossing	cutslope and inside ditch	7,500	525
10		714483	4395580	crossing	cutslope and inside ditch	1,800	300
10		715770	4396079	crossing	cutslope and inside ditch	1,200	600
10		713281	4396299	crossing	fillslope	203	45
10		712863	4396510	crossing	cutslope, road surface, fillslope	1,890	60
total =	**29**					**418,542**	**8,040**
12	45	715073	4394993	road	cutslope and inside ditch	1,800	500
total =	**1**					**1,800**	**500**
TOTAL =	**41**					**425,320**	**16,675**

FS ROAD 22N13 IN THE SULPHUR CREEK WATERSHED
EROSION VOIDS AND HYDRAULIK LINKAGES

2002

				Volume Eroded			Vol Loss	Hydraulic Link			Hyd Link
Wtsd No.	Length (mi)	Obs.	Obs/mi	ft^3	yd^3	tons	tons/mi	ft	Adjusted (ft)	miles	mi/mi
3a	2.53	13	5	28,746	1,065	2,161	854	4,774	1,194	0.23	0.09
3b	0.86	7	8	54,282	2,010	4,081	4,746	2,465	616	0.12	0.14
9a	2.96	27	9	54,567	2,021	4,103	1,386	6,143	1,536	0.29	0.10
total =	**6.35**	**47**		**137,595**	**5,096**	**10,345**		**13,382**	**3,346**	**0.63**	

	FS ROAD 22N13 IN THE SULPHUR CREEK WATERSHED				
	EROSION VOIDS AND HYDRAULIK LINKAGES				
			2002		
				Erosion	**Hydraulic**
Wtsd No	**Loc No**	**Assessment**	**Problem**	**Vol (ft^3)**	**Link (ft)**
3a	35	road	surface and fillslope	422	300
3a	61	road	road surface	637	700
3a	238	road	location, cut, fill, and rd surface	5,246	1,136
3a	145	crossing	cutslope and inside ditch	1,647	250
3a	146	crossing	inside ditch	38	45
3a	224	crossing	cutslope and inside ditch	1,870	370
3a	232	crossing	cutslope and fillslope	11,862	250
3a	233	crossing	road surface	25	100
3a	234	crossing	cutslope and inside ditch	3,976	568
3a	235	crossing	cutslope and inside ditch	630	300
3a	236	crossing	cutslope, fillslope, and inside ditch	330	275
3a	237	crossing	cutslope, rd surface and inside ditch	1,500	250
3a	239	crossing	cutslope and inside ditch	563	230
total =	**13**			**28,746**	**4,774**
3b	240	crossing	cutslope and inside ditch	750	100
3b	241	crossing	cutslope and inside ditch	324	120
3b	242	crossing	cutslope, fillslope and inside ditch	10,800	675
3b	243	crossing	fillslope and inside ditch	32,547	380
3b	244	crossing	cutslope and inside ditch	6,901	795
3b	245	crossing	cutslope, fillslope and inside ditch	2,946	375
3b	246	crossing	fillslope	14	20
total =	**7**			**54,282**	**2,465**
9a	39	road	cutslope and inside ditch	2,157	1,211
9a	47	road	fillslope	1,022	852
9a	37	crossing	cutslope, fillslope and inside ditch	561	100
9a	38	crossing	cutslope, rd surface, and inside ditch	2,336	400
9a	39	crossing	road surface and fillslope	143	60
9a	40	crossing	road surface	128	40
9a	85	crossing	cutslope and inside ditch	2,130	284
9a	86	crossing	cutslope and inside ditch	29,536	1,136
9a	87	crossing	cutslope and inside ditch	2,314	325
9a	90	crossing	cutslope and inside ditch	1,406	125
9a	91	crossing	cutslope and inside ditch	975	85
9a	92	crossing	cutslope, fillslope, and road surface	1,365	75
9a	93	crossing	cutslope and road surface	2,780	425
9a	141	crossing	cut, fill, rd surface, and inside ditch	2,534	275
9a	142	crossing	cutslope and inside ditch	1,620	300
9a	143	crossing	cutslope and inside ditch	572	150
9a	144	crossing	cutslope and inside ditch	2,988	300
total =	**27**			**54,567**	**6,143**
TOTAL =	**47**			**137,595**	**13,382**

APPENDIX H

GULLY, STREAM CHANNEL AND FLOODPLAIN ANALYSIS

1. Analysis of Individual Channel Gully Sections
2. Bankfull Morphometric Measurements and Bankfull Discharge Estimates
3. Simplified Version of the Rosgen Stream Classification System.

SULPHUR CREEK CHANNEL ANALYSIS

2002

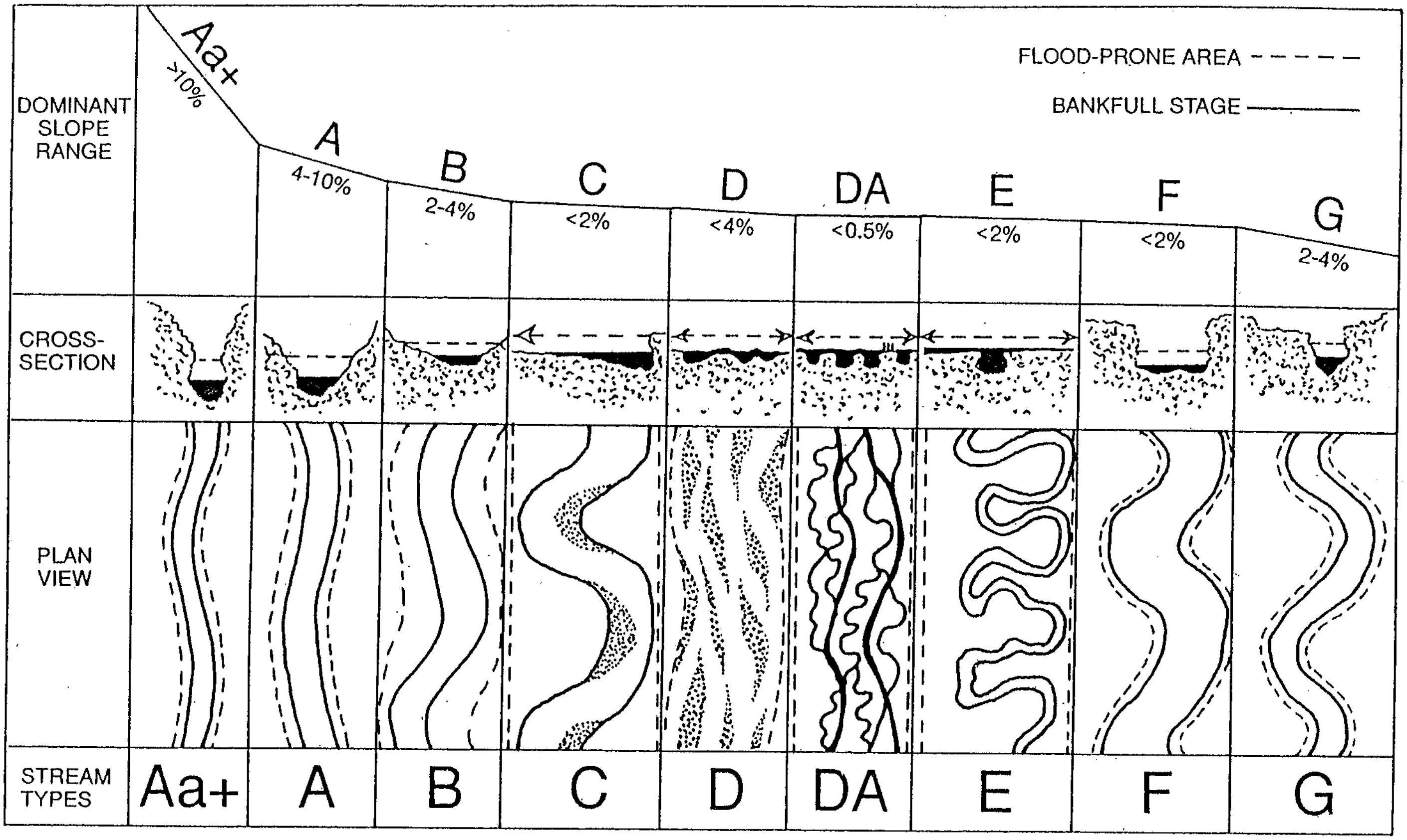
XS ID	XS Location	Watershed Area (mi^2)	Bankfull Width (ft)	Mean Bankfull Depth (ft)	Measured Floodprone Area Width (ft)	Measured Total Gully Width (ft)	Calculated Meander Belt Width (ft)	Entrenchment Ratio	Width/Depth Ratio	Sinuousity	Channel Gradient (ft/ft)	Channel Material (D_{50})	Stream Type
SC-1a	Just blw up Loop Rd bridge	5.15	26.20	0.59	152	217	167	5.80	44.41	low	0.029	cobble	C3b
SC-1a	Remnant channel	5.15	6.20	0.32	13		33	2.02	19.38	moderate	unk	cobble	B3
SC-1b	550 feet below SC-1a	5.15	25.00	1.26	45	110	158	1.80	19.84	low	0.029	cobble	B3
	Average =		**25.60**	**0.93**	**98.50**	**163.50**	**162.45**	**3.80**	**32.12**		**0.029**		
SC-2a	Abv fan & 1/2 btwn Loop bridges	9.12	23.60	0.27	33	194	148	1.40	87.41	moderate	0.004	cobble	B3c
SC-2b	370 feet below SC-2a	9.12	36.00	0.81	41	204	238	1.14	44.44	moderate	0.004	gravel	B4c
SC-3a	SCI site on fan (blw SC-2b)	9.12	19.85	1.02	40	56	122	2.00	19.46	low	unk	gravel	B4c
SC-3b	Blw SC-3a	9.12	10.56	0.98	77	80	60	7.31	10.78	low	unk	gravel	C4
SC-3c	Blw SC-3b	9.12	16.67	1.02	23	148	100	1.39	16.34	low	unk	gravel	B4c
SC-4a	1500 ft abv Lower Loop Rd bridge	9.12	16.10	1.33	43	135	97	2.64	12.11	moderate	0.022	gravel	C4b
SC-4b	400 ft abv Lower Loop Rd bridge	9.12	28.70	0.65	73	171	185	2.53	44.15	moderate	0.022	gravel	C4b
	Average =		**21.64**	**0.87**	**47.00**	**141.14**	**135.77**	**2.63**	**33.53**		**0.013**		
SC-5	Abv cfl w/ Boulder Cr	18.13	43.00	1.44	131	193	290	3.05	29.86	moderate	0.014	gravel	C4
SC-6	Whitehawk at McCann Bldg	20.14	55.00	0.68	90	260	383	1.64	80.88	moderate	0.009	gravel	D4
SC-7a	Upper Luczo XS-1	20.91	70.00	0.62	185	325	501	2.64	112.90	moderate	0.008	gravel	C4
SC-7b	Upper Luczo XS-2	20.91	125.00	1.12	386	409	959	3.09	111.61	moderate	0.008	gravel	D4
	Average =		**97.50**	**0.87**	**285.50**	**367.00**	**730.29**	**2.87**	**112.26**		**0.008**		
SC-7c	Lower Luczo	23.72	55.00	0.87	131	311	383	2.38	63.22	moderate	0.004	gravel	C4
SC-8a	Narrow reach near mouth	33.19	47.00	1.03	85	104	321	1.81	45.63	moderate	0.005	gravel	B4c (F4)
SC-8b	Below SC-8a	33.19	35.00	1.03	72	153	231	2.06	33.98	moderate	0.005	gravel	B4c (F4)
SC-8c	Below SC-8b	33.19	54.00	1.33	168	280	375	3.11	40.60	moderate	0.005	gravel	C4 (F4)
SC-9	Near SC-8, upper constriction	33.19	47.00	0.97	66	96	321	1.40	48.45	moderate	0.005	gravel	B4c (F4)
	Average =		**45.75**	**1.09**	**97.75**	**158.25**	**311.73**	**2.10**	**42.17**		**0.005**		
	Barry Creek nr cnfl w/ Sulphur Cr	5.75	27.20	0.81	46	268	174	1.68	33.58	moderate	0.020	gravel	B4
Bldr-1	Boulder Cr abv headcut	2.00	102.00	0.32	600	0	764	5.88	318.75	moderate	0.038	sand & silt	DA6
Bldr-2	Boulder Cr blw headcut	2.00	9.70	0.91	13	95	55	1.32	10.66	low	0.030	gravel	G4

SULPHUR CREEK BANKFULL MORPHOMETRY

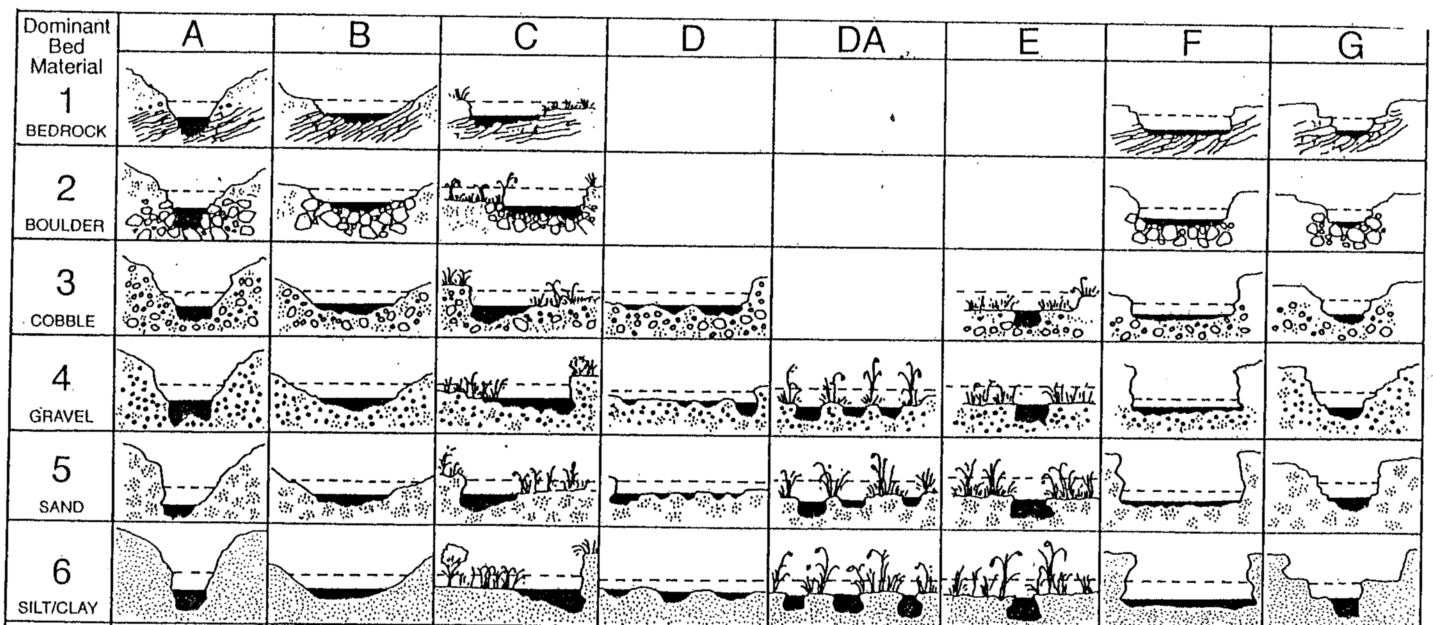
2002

XS ID	Watershed Area (mi^2)	Ave Measured W_{bkf} (ft)	Estimated W_{bkf} (ft)	Ave Measured D_{bkf} (ft)	Estimated D_{bkf} (ft)	Ave Measured A_{bkf} (ft^2)	Estimated A_{bkf} (ft^2)	Ave Measured Q_{bkf} (cfs)	Q_{bkf}/mi^2 (cfs)	Estimated Q_{bkf} (cfs)	Q_{bkf}/mi^2 (cfs)	Est Velocity for Measured (fps)	Velocity from Estimated (fps)
SC-1	5.15	25.60	**12.00**	0.93	1.25	23.81	15.00	134	26.03	80	15.53	5.63	**5.33**
SC-2, 3, & 4	9.12	21.64	**16.00**	0.87	1.25	18.83	20.00	106	11.62	125	13.71	5.63	**6.25**
SC-5	18.13	43.00	**20.00**	1.44	1.85	61.92	37.00	349	19.23	190	10.48	5.63	**5.14**
SC-6	20.14	55.00	**23.00**	0.68	1.74	37.40	40.00	211	10.45	220	10.92	5.63	**5.50**
SC-7a&b	20.91	97.50	**23.00**	0.87	1.74	84.83	40.00	478	22.84	220	10.52	5.63	**5.50**
SC-7c	23.72	55.00	**23.00**	0.87	1.91	47.85	44.00	269	11.36	250	10.54	5.63	**5.68**
SC-8 & 9	33.19	45.75	**28.00**	1.09	1.79	49.87	50.00	281	8.46	300	9.04	5.63	**6.00**
Average=		**49.07**	**20.71**	**0.96**	**1.65**	**46.36**	**35.14**	**261**	**15.71**	**198**	**11.53**	**5.63**	**5.63**
Barry Cr	5.75	27.20	**15.00**	0.81	**1.07**	22.03	**16.00**	119	20.61	**86**	**14.96**	5.38	**5.38**
Bldr-1	2.00	102.00	**10.00**	0.32	**0.92**	32.64	**9.20**	49	24.48	**52**	**26.00**	1.50	**5.65**
Bldr-2	2.00	9.70	**10.00**	0.91	**0.92**	8.83	**9.20**	50	24.94	**52**	**26.00**	5.65	**5.65**

ROSGEN STREAM CLASSIFICATION SYSTEM



Stream types: gradient, cross-section, plan view (adapted from Rosgen 1994). Original drawings by Lee Silvey. Courtesy of Catena Verlag.



	A	B	C	D	DA	E	F	G
ENTRH.	<1.4	1.4-2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	<12	<12
SLOPE	.04-.099	.02-.039	<.02	<.04	<.005	<.02	<.02	.02-.039

Cross-section view of stream types (adapted from Rosgen 1994). Original drawings by Lee Silvey. Courtesy of Catena Verlag.

Appendix I
Sulphur Creek Citizen Monitoring 2003

Background

A core group of citizen monitors collected flow and turbidity data during winter and spring of 2003. The goal of the group was to assist the FR-CRM in collecting data that would contribute to an understanding of watershed processes, and document pre-restoration project conditions. Another goal of the group was to begin a data collection regime in order to gain experience, and refine methods as needed.

The purpose of the flow monitoring was to compare streamflow to precipitation, in order to determine how much of a spike there was in the hydrograph compared to precipitation events. The purpose of the turbidity measurements was as a surrogate for total suspended solids. These two parameters were monitored with the assumption being that spikes in streamflow and high turbidity are indicators of hydrologic dysfunction in the watershed.

Methods

In summer 2002, an FR-CRM sub-contractor, Sagraves Environmental, installed four gage plates at the following locations in the watershed:

- Main Stem Sulphur Cr just above the upper Loop Road bridge
- Main stem Sulphur Cr just below the lower Loop Road bridge
- Barry Creek just above the Highway 89 culvert
- Boulder Creek, about 200' upstream of its confluence with Sulphur Cr.

Stage levels were monitored at these stations as well as a fifth location off of the temporary railing of the Highway 89 bridge above the mouth of Sulphur Creek (bridge still under construction during this period). The elevation of the bridge railing was tied to a benchmark, however, the other locations were not.

From summer 2002 to summer 2003 three to five flow measurements were taken using either a Marsh-McBirney or a pygmy flow meter at each the four gage locations in order to develop stage-discharge relationships. Only one measurement was taken at the 89 bridge, so no relationship could be developed for that site.

From January-May 2003, gage heights were read at all five locations, and water samples were sometimes taken for turbidity analysis. The schedule of readings was generally random, and not coordinated between the volunteers, although an attempt was made to make sure that readings were made in conjunction with storm events. Precipitation was recorded by personnel at the Beckwourth Ranger Station.

Results

Figure A-1 shows derived discharges (from the gage readings) for the four rated gage locations, and precipitation from the Beckwourth RD. Discharge data points are not connected because discharge is unknown between the gage readings. It should also be noted that due to a small number of rating flow measurements, the ratings can only be considered to be moderately accurate.

Figure A-2 shows turbidities that were collected at various gage readings (stages) for the four gage stations. Only one turbidity sample was collected at the 89 bridge, so that site is not included. An attempt was made to add a trend line to each graph. A polynomial relationship provided the best correlation, however, even that correlation is not strong.

Discussion

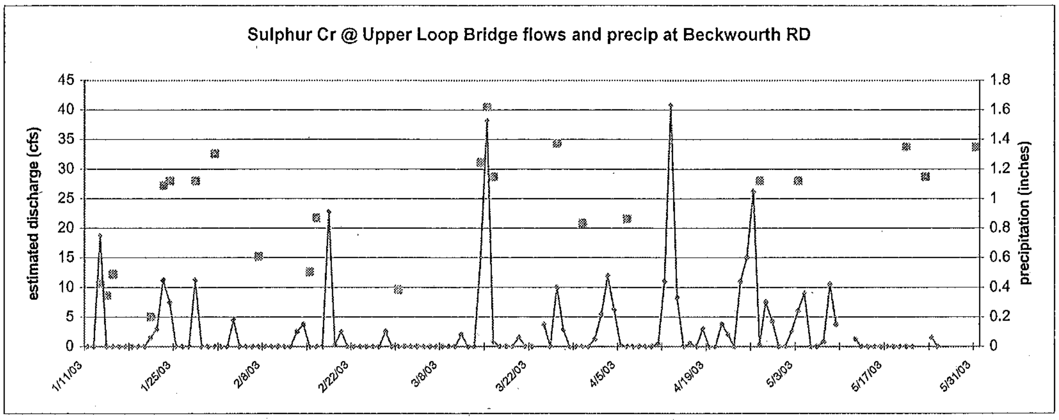
Figure A-1 shows that gage readings were, indeed, taken in conjunction with some of the storm events. However, because of the few readings, it is difficult to get a clear picture of the hydrograph. Even more regularly scheduled readings may not catch peak flows. During storm events, it would be best to get 3-4 readings per day. As this is a volunteer program, I don't know if that is feasible. Some of the volunteer gage readings do not show up on the graph because there was not a corresponding rating measurement to convert the gage reading to a discharge. One disconcerting observation is that the graphs shows discharges at the Upper Loop bridge site to be greater than those at the Lower Loop bridge site. And at one point, the discharge at Barry Creek was also higher than the Lower Loop site. Either there is significant subsurface flow, or there was an error in the rating measurements at the Lower Loop site or another site. 2004 data are expected to provide further information on flows at all of the sites, and graphs similar to figure A-1 will be developed.

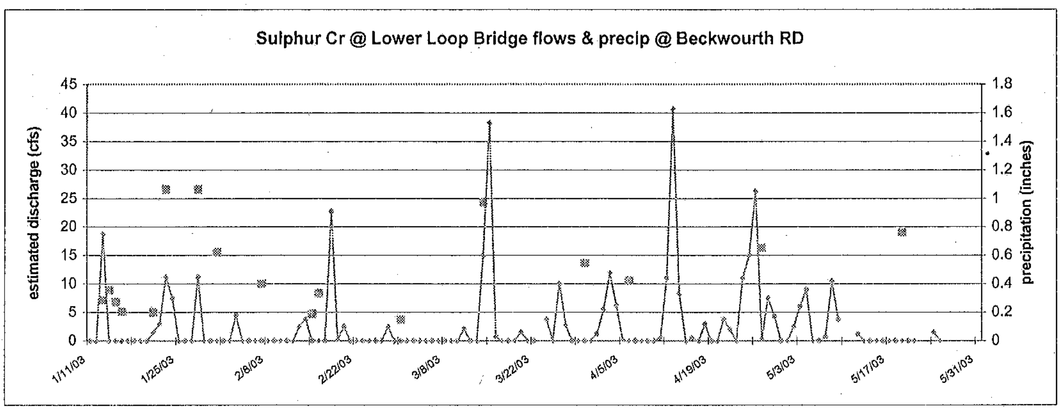
The turbidity data, displayed in Figure A-2 as a function of stage, show a relatively weak relationship. Here again, turbidity samples were collected during events, but usually only once a day at best. Turbidity is also a function of precipitation and whether or not the sample was collected on the rising or the falling limb of the storm. Most sites in Figure A-2 show varying turbidity at the same stage. Here again, turbidity, or even Total Suspended Solids may have to be collected more often during events in order to see if watershed restoration has an effect on these parameters. The CRM will be installing a continuous recording station near the mouth of Sulphur Creek, which will record flow and temperature every hour (this will be the CRM's 9^{th} station of this type in the Upper Feather). It is hoped that this station, together with the citizen monitoring data, will provide a clear picture of the ability of the watershed to retain precipitation for release later in the drier periods of the year.

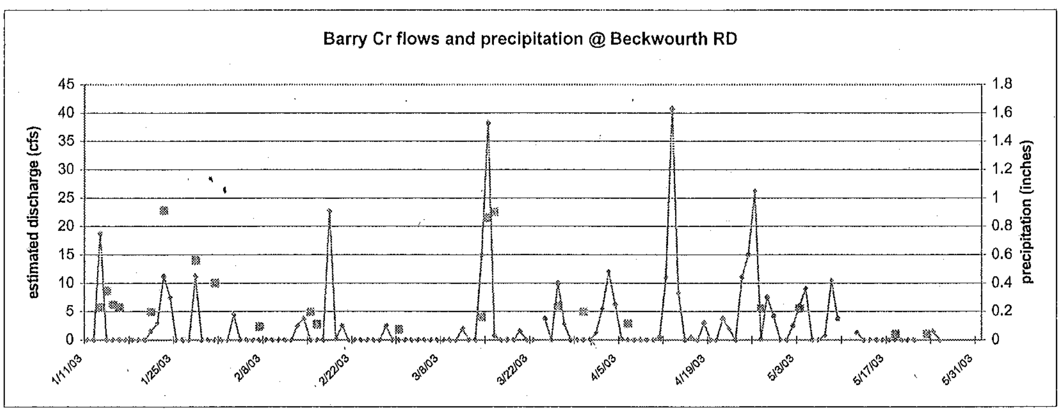
Recommendations

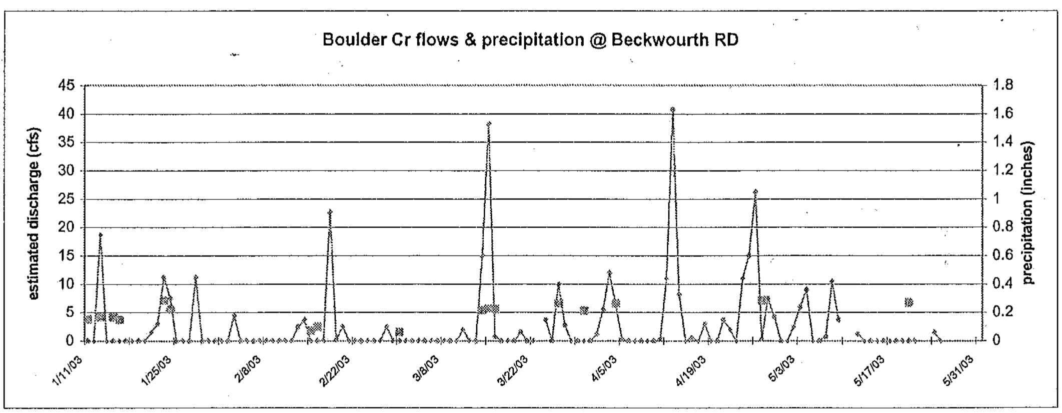
As mentioned in the beginning of this appendix, one of the goals of citizen monitoring in early 2003, was for the monitors to begin getting experience collecting the data. The CRM staff also wanted to see how informative the data would be. A number of recommendations came from this first year of monitoring:

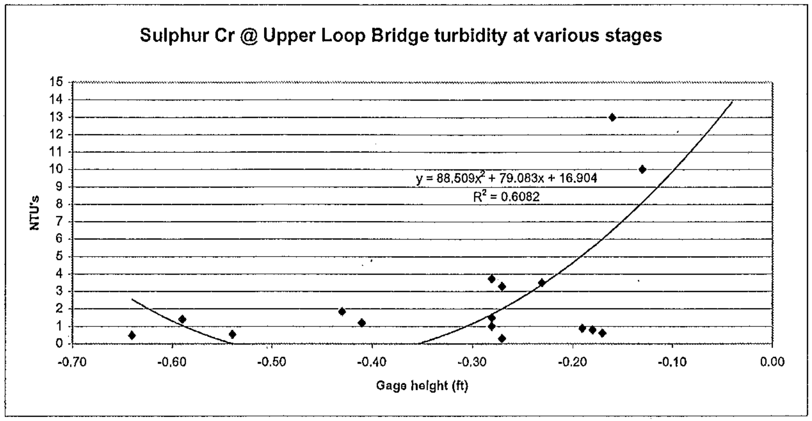
- An attempt should be made to get more volunteers, and to collect data on a more regular schedule. The random nature of the flow data made it difficult to discern what may have happened between readings.
- The gages need to be moved so that they are in the water. (This was completed by Sagraves Environmental in summer 2003.)
- The new gage locations need to be surveyed in and elevations tied to a benchmark.
- We need to have many more rating measurements. (To date, about 5 measurements have been made per site.)

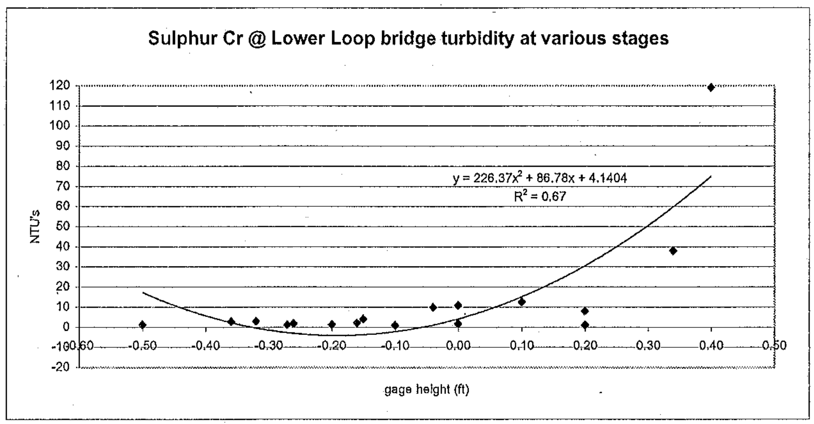

Sulphur Cr @ Upper Loop Bridge flows and precip at Beckwourth RD
estimated discharge (cfs)
precipitation (inches)
1/11/03
1/25/03
2/8/03
2/22/03
3/8/03
3/22/03
4/5/03
4/19/03
5/3/03
5/17/03
5/31/03

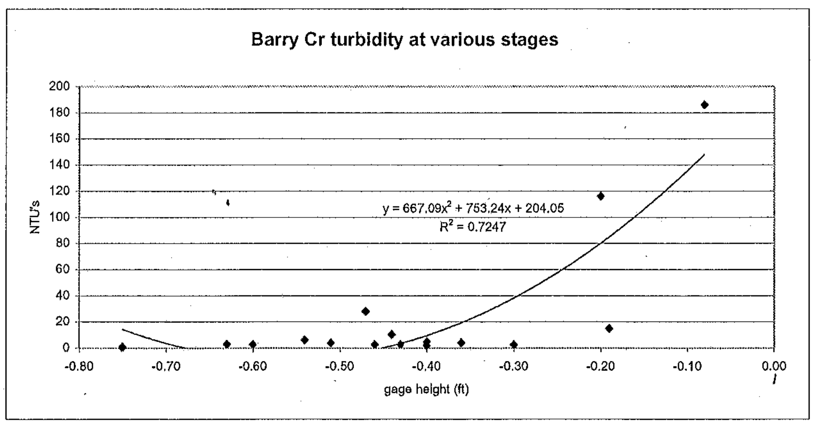

Sulphur Cr @ Lower Loop Bridge flows & precip @ Beckwourth RD
estimated discharge (cfs)
precipitation (inches)
1/11/03
1/25/03
2/8/03
2/22/03
3/8/03
3/22/03
4/5/03
4/19/03
5/3/03
5/17/03
5/31/03

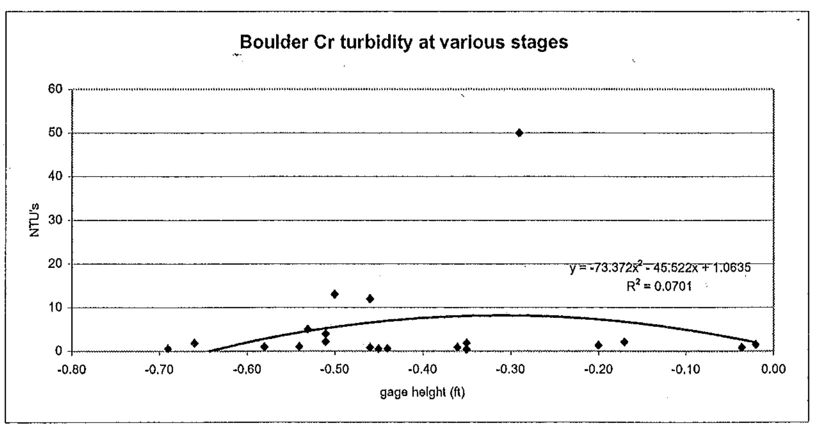

Barry Cr flows and precipitation @ Beckwourth RD
estimated discharge (cfs)
precipitation (inches)
1/11/03
1/25/03
2/8/03
2/22/03
3/8/03
3/22/03
4/5/03
4/19/03
5/3/03
5/17/03
5/31/03


Boulder Cr flows & precipitation @ Beckwourth RD
estimated discharge (cfs)
precipitation (inches)
1/11/03
1/25/03
2/8/03
2/22/03
3/8/03
3/22/03
4/5/03
4/19/03
5/3/03
5/17/03
5/31/03


Sulphur Cr @ Upper Loop Bridge turbidity at various stages
y = 88.509x² + 79.083x + 16.904
R² = 0.6082
NTU's
Gage height (ft)


Sulphur Cr @ Lower Loop bridge turbidity at various stages
y = 226.37x² + 86.78x + 4.1404
R² = 0.67
NTU's
gage height (ft)


Barry Cr turbidity at various stages
y = 667.09x² + 753.24x + 204.05
R² = 0.7247
NTU's
gage height (ft)


Boulder Cr turbidity at various stages
y = -73.372x² - 45.522x + 1.0635
R² = 0.0701
NTU's
gage height (ft)

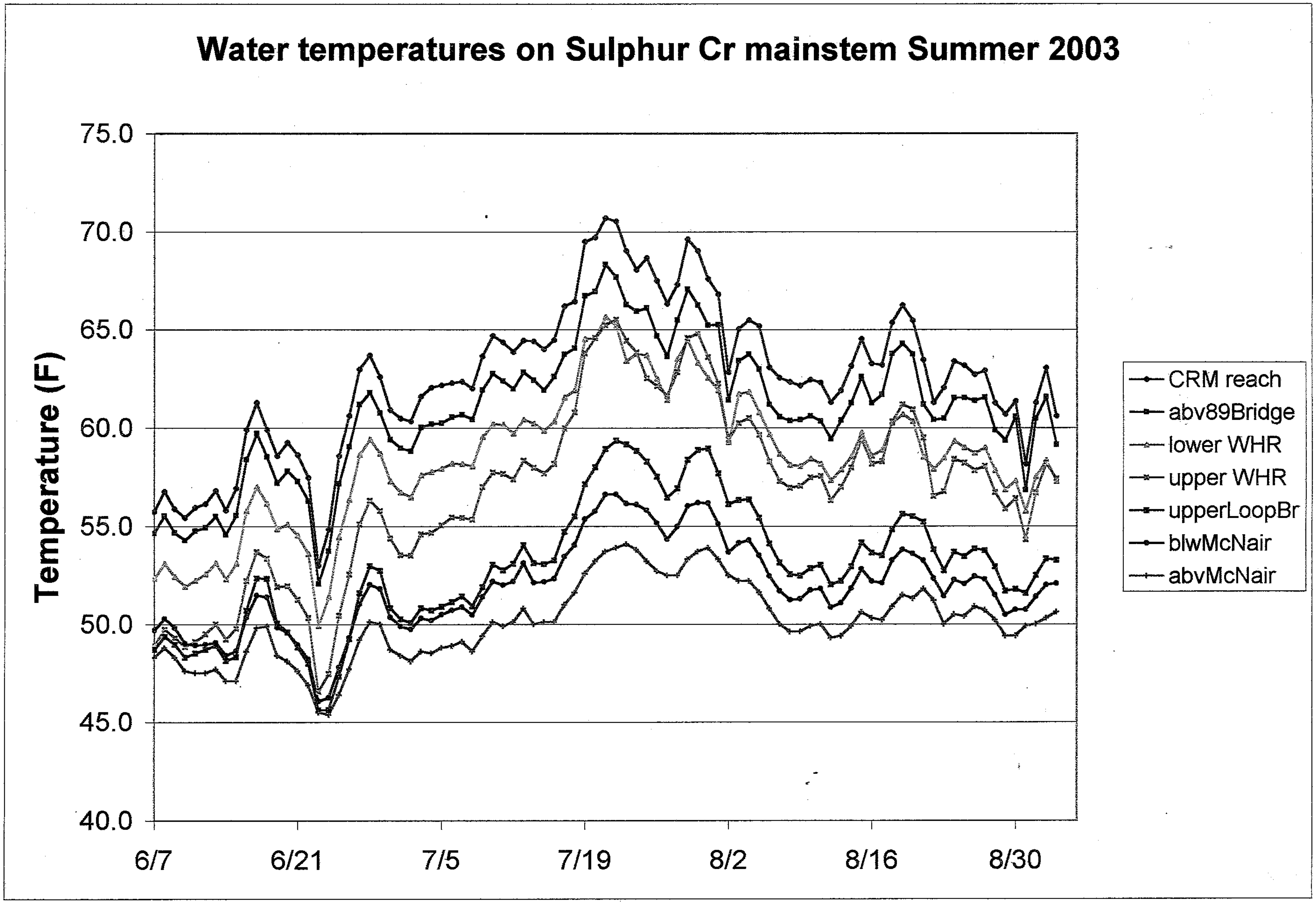
Appendix J
Sulphur Creek Water Temperatures

In conjunction with this Sulphur Creek Watershed Assessment and Restoration Strategy, is a study by University of California Cooperative Extension and Dr. Lisa Thompson of UC Davis on the availability and use of refugia for coldwater fishes in rangeland streams. Sulphur Creek is one of several study sites throughout California. As part of this study, seven continuous recording thermographs were installed on the mainstem of Sulphur Creek. The thermographs record temperature once every hour, and are displayed here in Farenheit. Average daily temperatures are displayed in Figure A-1. The following table displays some summary statistics for water temperatures at the seven locations from June 7 through September 3, 2003, compiled by FR-CRM staff.. The statistics are as follows:

Absolute daily MAX water temp = The highest 1 hour-long temperature that was recorded during the sampling period.
MAX 7-day avg of daily avg = A running 7-day average was calculated throughout the sampling period. This column displays the highest of those seven-day averages.
 # 7-day averages >66F = This column displays the number of running seven day averages that were greater than 66 degrees Farenheit. The importance of this parameter is biological, in that if the water is an average temperature greater than 66F for seven days, it is probably not conducive to a coldwater fishery.
 # days with max >75F = This column displays the number of days that had an absolute 1-hour long temperature greater than 75F. The importance of this parameter is also biological, in that if the water has a short-term maximum greater than 75 degrees Fahrenheit, then it is probably not conducive to a coldwater fishery.
Max diurnal fluctuation = This column shows the greatest fluctuation in temperature in a 24-hour period during the sampling period.

Thermograph location	Absolute Daily Max Wtr Temp	Max 7-day avg of daily avg	# of 7-day avgs >66F	# of days with max >75F	Max diurnal fluctuation
Abv McNair Meadow	56	53	0	0	7
Blw McNair Meadow	63	56	0	0	12
Upper Loop Bridge	66	59	0	0	12
Upper White-hawk Ranch	79	64	0	1	27
Lower White-Hawk Ranch	80	64	0	15	27
Abv 89 Bridge	83	67	5	43	29
Mouth	83	69	16	38	28

In general, temperatures are conducive for trout production in Sulphur Creek, especially in the reaches above the valley. The valley itself lacks good riparian vegetation, and it is not suprising to see temperatures steadily increase from the top to the bottom of Sulphur Creek. While the worst temperature conditions appear at the mouth of Sulphur Cr, it should be noted that electrofishing surveys at the mouth in 2001 and 2003 did show the presence of trout. Trout are known to exist in other sections of Sulphur Creek, however, this creek has never been known as an excellent cold-water fishery.



Water temperatures on Sulphur Cr mainstem Summer 2003
Temperature (F)
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
6/7
6/21
7/5
7/19
8/2
8/16
8/30
CRM reach
abv89Bridge
lower WHR
upper WHR
upperLoopBr
blwMcNair
abvMcNair