Final Technical Report

Sediment Source Assessment, A Component of the Watershed Management Plan for the Sulphur Creek Watershed, Napa County, California

prepared for

Stewardship Support and Watershed Assessment in the Napa River Watershed: A CALFED Project
CALFED contract no. 4600001703

by

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I. Executive Summary

In March 2002, Pacific Watershed Associates was contracted to conduct a sediment source assessment as a part of the watershed management plan for the Sulphur Creek watershed. The assessment consisted of 3 work elements to identify past and potential sediment sources that may be affecting water quality and fish habitat. The first phase of the assessment included a historic air photo analysis of the 1940, 1985 and 2002 air photo periods. The historic air photo analysis was conducted to record road construction, land use, landslide and stream channel disturbance histories for the Sulphur Creek watershed.

The second phase of the project involved a systematic field inventory of road systems in the watershed to identify road-related sites that pose a risk of sediment delivery to streams. Sites of potential sediment delivery identified in the road inventory were characterized and quantified, and prioritized treatment prescriptions were suggested to reduce or eliminate future erosion and sediment delivery. The second phase of the assessment also included a stream channel erosion assessment of selected tributaries to identify sites of past and future erosion and sediment delivery and the need for erosion control and erosion prevention treatment.

Finally, Phase 2 of the assessment also included a field review and reconnaissance sampling of non road-related sediment sources associated with a variety of other land uses including viticulture, reservoir development and maintenance, and rural residential development. Land use practices were evaluated in the field for their contribution to erosion and sediment delivery to streams.

The third phase of the sediment source assessment involved the development of a prioritized erosion control and erosion prevention treatment plan to cost effectively control current and potential road-related erosion and sediment delivery. It also included a cursory evaluation of the magnitude of past sources of erosion and sediment delivery in the watershed, as well as an evaluation of current non road-related land use practices that may still be contributing erosion and sediment delivery to streams.

Phase 1- As of the 2002 air photo period, nearly 50 miles of road had been constructed in the Sulphur Creek watershed. Of the 50 miles of road, 25 miles (50%) were constructed as of the 1940 air photo period, 18 miles (36%) were constructed between the 1940 and 1985, and 7 miles (14%) were constructed between 1985 and 2002. The majority of roads in the watershed were constructed within Sulphur Canyon, Heath Canyon and within the small sub-basin located north of the lower reach of Sulphur Canyon.

As of the 1942 air photo period, land use in the Sulphur Creek watershed was primarily composed of open space with some localized areas characterized by grazing, viticulture and agricultural activities such as orchards and other activities. Between the 1942 and 2002 air photo periods, grazing activity and non viticulture agricultural activities decreased in the watershed and vineyard development increased dramatically. By the time of the 2002 air photo period, vineyard development had increased steadily through the conversion of open space, grazing and "other" agricultural areas. Rural residential development in the watershed increased slowly over the entire air photo period.

Eighty-four (84) landslides were identified in the historic air photo analysis. Landslide types included debris landslides, deep seated landslides, composite landslides and debris flows. The majority of landslides appear to be controlled by the local geology rather than by management-related activities. Approximately 419,600 yds^3 of sediment was estimated to have been delivered to Sulphur Creek and its tributaries during the period of photo record. Approximately 49% (206,500 yds^3) of the total estimated sediment delivery from air photo identified landslides in the watershed originated from one large composite landslide identified in the 1940 air photo set. The majority of landslides occurred in oak woodland and mixed conifer settings on steep inner gorge and streamside slopes.

Phase 2-Roads- Approximately 23.7 miles of road were field inventoried to identify road-related sites of current and future sediment delivery to streams. Two basic types of erosion were identified in the road assessment including episodic erosion and persistent or chronic road surface erosion. Episodic erosion occurs in response to large and infrequent storms and includes stream crossing washouts and road-related landslides and gullying. Persistent road surface erosion is caused by excessive road and ditch lengths that are "hydrologically connected" to streams. Road surface erosion is generated from the mechanical breakdown of the road surface from vehicle use, cutbank erosion and failures, and ditch erosion.

A total of 188 sites of future episodic erosion and sediment delivery were identified from the 23.7 miles of inventoried road. Of the 188 sites, 156 were recommended for erosion control and erosion prevention treatment including 112 stream crossings, 3 potential landslides, 30 ditch relief culverts and 11 "other" sites. Approximately 10.8 miles of road were identified as "hydrologically" connected to streams along roads inventoried in the Sulphur Creek watershed. Of the 10.8 miles of connected road, 9.6 miles were recommended for erosion control and erosion prevention treatment. If left untreated, it is estimated that up to 16,281 yds^3 of fine sediment could be delivered to streams. Other treatments include upgrading stream crossing culverts to handle the 100 year design storm flow, excavating potential road-related landslides that could deliver sediment to streams, and disconnecting the road surface and ditch from streams and stream crossing culverts.

Treatments in the watershed were prioritized based on their immediacy and included consideration of factors such as the potential volume of sediment to be delivered to streams, the likelihood of future erosion, the urgency of treating the site, and the ease and cost of the accessing the site for treatment. Costs to implement treatments along the 23.7 miles of inventoried in the Sulphur Creek watershed is estimated at approximately $458,000. The cost estimate includes the costs to upgrade approximately 1.8 miles of county maintained roads.

Stream channels- Approximately 1.5 miles of tributary stream channel was inventoried to identify past, current and future sediment sources that could deliver sediment to the stream system. Two 0.5 mile reaches were inventoried in Sulphur Canyon and one 0.5 mile reach was inventoried in Heath Canyon. A total of 25 sites with >20 yds^3 of past and/or future erosion and sediment delivery were identified in the assessment. From the 25 sites, approximately 1,922 yds^3 of sediment have been delivered to streams in the past and nearly 572 yds^3 is estimated to be delivered in the future. Of the 25 sites, 72% of the sites were classified as debris landslides, 24% were classified as bank erosion and 4% were classified as gully erosion. Approximately 65% of the sites had no apparent management cause and 35% were associated with viticulture activities. Seventy-one (71) small sites (<20 yds^3) were also identified in the assessment. Approximately 710 yds^3 of sediment is estimated to have been delivered to streams from these small features.

Other sediment sources- Reservoirs, viticulture and rural residential activities were evaluated as part of the non road-related sediment source sampling. Ten reservoirs were identified in the Sulphur Creek watershed constituting less than 1% of the total watershed area. Of the 10 reservoirs, 6 were classified as on-stream reservoirs and these collect runoff from approximately 8% of the watershed area. The majority of observed erosion from reservoirs resulted from a few reservoir outlets where flow discharged onto unprotected slopes causing large hillslope gullies.

In general, reservoirs act as large effective sediment retention traps allowing the majority of fine and coarse sediment transported from upstream areas to settle out before flow is released into a natural stream. Although reservoirs can be used as sediment traps, sediment infilling can occur and result in lowered capacity and an increase in the likelihood of failure and overtopping. Reservoirs should be monitored regularly it they are used as sediment traps.

Five vineyard plots were inspected in the Sulphur Creek watershed to assess the magnitude of vineyard related erosion and sediment delivery. Vineyard plots ranged in size from 3 acres to 20 acres. The majority of erosion from vineyards consisted of sheet, rill and gully erosion along bare sections of vineyard rows and along long sections of undrained vineyard avenues. Rilling and gullying on vineyard slopes was more prominent on steeper slopes (>10%). Once cover crops were established along vineyard rows, rilling and gullying were significantly reduced in the observed vineyards. Another source of erosion from vineyards resulted from slope drainage pipes that discharge flow onto stream banks above the stream channel causing local stream bank collapse and/or gullying.

Past sediment sources- The largest source of erosion and sediment delivery in the Sulphur Creek watershed over the past 50 years were non road-related debris landslides (74%). As mentioned previously, fifty percent (206,500 yds^3) of the erosion and sediment delivery from debris landslides originated from one large composite landslide identified in the 1940 air photo set.

The estimate of past erosion and sediment delivery from roads is a minimum because it does not include past erosion from stream crossing washouts and small road-related landslides that have been repaired and are no longer visible.

Although management related past erosion and sediment delivery represents only 10% of the total past erosion and sediment delivery estimated for the Sulphur Creek watershed, management-related sources can be eliminated or reduced through a variety of treatments or changes in land management practices. Road-related erosion and sediment delivery can be addressed by disconnecting the road system from nearby streams by: 1) applying adequate road drainage, 2) upgrading stream crossings to the 100-year design storm flow and 3) excavating landslides that could deliver sediment to streams. Road-related erosion and sediment delivery is the most easily identified and the most cost effectively treated sediment source in the watershed.

Vineyard surface erosion can be reduced through the more extensive application of cover crops along vineyard rows and avenues before the winter period. In vineyards which currently drain to streams, local improvements can be made so that slope drainage discharges into sediment retention traps or is downspouted directly to streams (rather than on steep, unstable streambanks). Vineyard avenues should be disconnected from the stream system through the installation of road surface drainage structures, including ditch relief culverts, rolling dips and/or water bars.

The majority of debris landslides identified in the air photo analysis had no management related cause. In contrast to management-related erosion and sediment delivery, debris landslides caused by natural processes are difficult and expensive to control. These features are primarily influenced by the local geology and climatic conditions.

Other non management related sources of erosion including bank erosion along the mainstem and tributary stream channels can also be difficult to control. Engineered structures can be constructed to control bank erosion but they can be costly and potentially ineffective. The key to reducing sediment production and delivery in the Sulphur Creek watershed should not be to control natural erosion and sediment delivery, but to reduce the amount of management-related erosion and sediment delivery to the stream system through the application of relatively straightforward and cost-effective erosion prevention measures and land management actions.

II. Introduction

Sulphur Creek is an approximately 9.5 mi^2 tributary to the Napa River located in Napa County on the eastern side of the Mayacaama Mountains (Figure 1). As mapped on the USGS Kenwood, Calistoga, Saint Helena and Rutherford 7.5' minute topographic quadrangle maps, Sulphur Creek contains approximately 24 miles of blue-line streams and tributaries. The watershed contains the 2.9 mi^2 Heath Creek sub-basin and the 5.6 mi^2 Sulphur Canyon that drains through the town of Saint Helena. Elevations in the watershed range from approximately

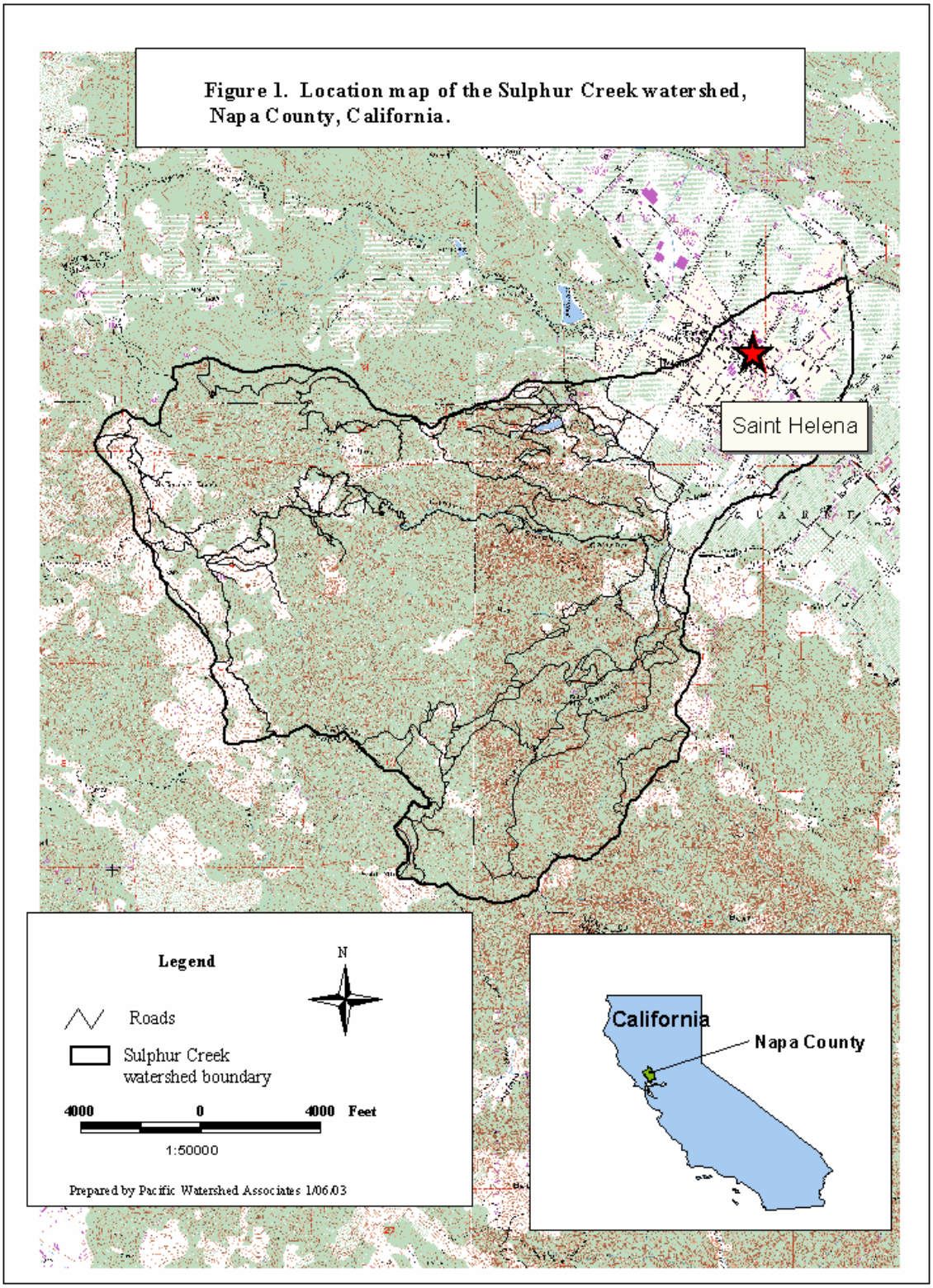


Figure 1. Location map of the Sulphur Creek watershed, Napa County, California.
Saint Helena
Legend
N
Roads
Sulphur Creek watershed boundary
4000 0 4000 Feet
1:50000
Prepared by Pacific Watershed Associates 1/06/03
California
Napa County

200 feet at the confluence with the Napa River to approximately 2,730 feet above mean sea level at Bald Mountain.

The Sulphur Creek watershed is privately owned and is primarily unmanaged open space with some vineyard development in the upper portions of Heath Creek Canyon and Sulphur Canyon. Rural residential areas are scattered throughout the upper portions of the watershed and concentrated in the lower portion of the watershed into Saint Helena. The Sulphur Creek watershed has experienced historic gravel mining for more than 50 years along the mainstem from the Heath Canyon confluence downstream for approximately 4,000 feet. Gravel mining in the watershed ceased in 1999 (Katzel and Larsen, 1999). Historically, the Sulphur Creek watershed has experienced grazing activities since since the 1820's (Historical Ecology Report, Grossinger). Currently, only a small amount of grazing is occurring in Heath Canyon.

Vegetation in the upper portions of Sulphur Creek Canyon is dominated by annual grasses and oak woodlands with some redwood and other hardwood species concentrated along the mainstem and adjacent slopes. Vegetation in Heath Canyon is dominated by redwood and other hardwood species.

The watershed contains a historic and existing network of native and rock surfaced roads, as well as White Sulphur Springs road, a paved county road along the mainstem of Sulphur Creek. Some of the roads observed in the watershed assessment area are currently causing erosion and delivering sediment to Sulphur Creek.

In 1999, a watershed assessment was prepared for Mennen Environmental Foundation to characterize existing stream channel processes and aquatic habitat conditions. The study found that pool habitat and cover for steelhead trout is lacking in the mainstem of Sulphur Creek due to high sediment loads and lack of woody debris. The report recommends that a sediment budget assessment should be conducted to determine the sources and magnitude of sediment contribution in the watershed (Katzel and Larsen, 1999).

Over the past ten years, the Napa County Resource Conservation District (Napa RCD) has helped foster the development of local watershed stewardship groups that are interested in the health and the future management of their watersheds. The Sulphur Creek Watershed Task Force is an active watershed stewardship group that is interested in assessing the condition of the Sulphur Creek watershed and creating a voluntary management plan that is aimed at improving fish habitat and overall water quality.

In March 2002, the Napa RCD was granted funds through the CALFED Bay-Delta Program to provide support in the development of two local watershed stewardship groups in the Carneros and Sulphur Creek watersheds. In addition, the project involves developing watershed management plans for each watershed, in cooperation with each watershed stewardship group. The development of these watershed management plans involves a multi-disciplinary approach to assessing water quality, channel geomorphology, fish habitat and hillslope/tributary sediment sources in each watershed.

In March 2002, Pacific Watershed Associates (PWA) was contracted by the Napa RCD to conduct the hillslope/tributary sediment source assessment for the Carneros Creek and Sulphur Creek watersheds, as part of developing the watershed management plan. This report presents the results of the work conducted in the Sulphur Creek watershed by Pacific Watershed Associates, with the assistance of staff from the Napa RCD, between August 2002 and January 2003.

II. Study Approach

The hillslope/tributary sediment source assessment consisted of three main work items: 1) an analysis of historic air photos of hillslopes and stream channel systems, 2) a field assessment of upland sediment sources to identify road-related and other non road-related management-related sediment sources that are currently delivering or have the potential to deliver sediment to streams, and 3) preparation of a prioritized plan-of-action for upland erosion prevention and erosion control. The Sulphur Creek watershed assessment area includes the upland portions of the basin extending upstream from the confluence of Sulphur Canyon and Heath Creek, and the small un-named sub-basin north of Sulphur Canyon, where they emerge from the mountain front (Figure 1).

Phase I - Air photo analysis

Phase I of the hillslope/tributary sediment source assessment involved a sequential air photo analysis using available photography for three air photo years: 1940, 1985 and 2002. The air photo analysis was conducted to document road construction, land use, landslide and stream channel disturbance histories for the Sulphur Creek watershed.

Phase II – Field inventories to delineate controllable sediment sources

Phase II of the assessment involved three separate field inventories to delineate controllable sediment sources in the Sulphur Creek watershed including:

1) A systematic single pass inventory of all roads granted access within the watershed. Inventoried roads included selected private roads and all county roads within the watershed. Approximately 23.7 miles of road were inventoried to identify sites that pose a risk of significant sediment delivery to nearby streams. At each site, attributes were collected including site characterization, quantification of future erosion and sediment delivery to streams, and prioritized treatment prescriptions aimed at reducing or eliminating future anthropogenic erosion and sediment delivery.

2) A stream channel sediment source inventory on selected blue line tributaries in the Sulphur Creek watershed to delineate sites of past and future erosion and sediment delivery to streams. In addition, attributes pertaining to land use and geomorphic association were collected at each inventoried site. Each site was prioritized and evaluated for the need of erosion control and erosion prevention treatment.

3) A field review and reconnaissance sampling of non-road related sediment sources related to vineyards, reservoir development and maintenance, and rural residential development. With the cooperation of Sulphur Creek private landowners, PWA staff

reviewed reservoirs and vineyard practices on a variety of landowner properties within the watershed. Specific information regarding current land use practices was documented at each field site. In addition to the field review and sampling, a literature review was conducted to compare current land use regulations with current land use practices.

Phase III – Development of an erosion control and erosion prevention plan

The final product for the hillslope/tributary sediment source assessment is a prioritized erosion control and erosion prevention plan that can be followed to cost-effectively control accelerated road-related erosion and sediment delivery to streams within the Sulphur Creek watershed. The work plan is specific on a site-by-site basis for the inventoried road system and can be used to directly treat potential work sites, or for the application for additional grant funding for implementation. The elements in the treatment plan include: 1) the identification and quantification of controllable sediment sources from approximately 23.7 miles of road likely to affect water quality or impact fish habitat if left untreated, 2) a site specific, prioritized erosion control and erosion prevention plan for cost effective treatments (listing specific treatments, needed equipment and materials, and estimated costs), and 3) an evaluation of current non road-related land use practices that may be continuing to contribute to accelerated erosion in the watershed, including recommendations and suggestions for landowners on how to reduce the risk associated with their management activities.

III. Geologic setting of the Sulphur creek watershed

The area of northwestern California, between San Francisco and Cape Mendocino, lies within the northern section of the tectonically active, translational margin of the continental North American plate and the oceanic Pacific Plate. However, since the Mesozoic Era, the geologic development of Northern California has been dominated by plate convergence between the ancestral oceanic plate and the North American plate. During the last 140 million years, subduction resulted in a deep oceanic trench off shore and a large forearc basin to the east. Continued subduction resulted in accretion of a broad complex of highly deformed trench sediments to the western margin of the North American plate. These accreted sediments now comprise the rocks of the Franciscan complex, a major constituent of the Coast Ranges of northern California. Contemporaneous with the deposition of the Franciscan Complex, and within the developing forearc basin, the late Jurassic to late Cretaceous Great Valley sediments were deposited. The eastern portion of the California Coast Ranges is partly composed of these Great Valley sediments.

Approximately 30 million years ago, subduction of the ancestral oceanic plate in the vicinity of southern California ceased, resulting in the inception of the San Andreas Fault. The San Andreas Fault is a northwest trending transform (strike-slip) fault that translates rocks on the west side of the fault northward. As the San Andreas Fault continued to grow, the triple junction between the subducting ancestral oceanic plate, the North American plate and the Pacific plate migrated northward. As the triple junction and its associated subducting plate migrated north a slab

window formed which allowed for molten rock to contact the North American plate. As a result, molten rock was able to reach the surface in the form of volcanoes.

Throughout the latest geologic period, the triple junction has migrated as far north as Cape Mendocino and in its present position is referred to as the Mendocino triple junction (Mtj). The continued migration of the Mtj has resulted in major uplift of the Coast Range and erosional stripping of regionally extensive forearc sediments. In conjunction with the northward migration of the Mtj, the stress field north of San Francisco to Cape Mendocino has shifted from a compressional (subduction) faulting regime to a translational (strike-slip) faulting regime. This translational tectonic regime is now rafting large sections of the Coast Ranges northwest along a series of northwest trending translational faults including the San Andreas, Healdsberg, Mayacama, Rogers Creek, and Bartlet Springs Fault zones. These fault systems are currently dissecting the Coast Range of northern California.

Surface faulting and translational deformation of the western edge of North America control the current long term, large scale, morphological development of the Coast Range mountains and valleys. Within the vicinity of the Sulphur Creek study area, local tectonics have created a series of northwest trending valleys and ridges. Structurally controlled, the major drainages of these basins tend to flow at or near the center of the basin. A series of interconnected valleys between Napa and Calistoga currently occupied by the Napa River and are most likely the result of regional trans-extensional faulting. The Sulphur Creek watershed is located on the eastern flank of the hills separating Napa and Sonoma Valleys.

The Sulphur Creek basin has a developmental history closely associated with the active tectonics of the Napa Valley area. Steep topographic relief generated by faulting results in steep highly incised stream valleys, as seen in the watershed.

The Sulphur Creek watershed assessment area is dominated by Franciscan Complex melange geology. The melange is composed of disrupted oceanic trench and slope sediments including sandstone, shale, conglomerate, chert, greenstone, metagraywacke and altered volcanics. These rocks are highly susceptible to erosion and mass wasting due to the nature of the lithology and the high degree of post depositional deformation. Like other steep valleys in Franciscan bedrock, inner gorge hillsides are highly susceptible to catastrophic failure by landsliding during periods of heavy rainfall and earthquake induced shaking. Downstream of the confluence of Sulphur Creek and Heath Creek, the geology is dominated by Quaternary to recent alluvium and terrace deposits that dominate the Napa Valley.

IV. Sulphur Creek aerial photo analysis

Phase I of the Sulphur Creek hillslope/tributary sediment source assessment involved sequential air photo analysis to document the histories of road construction, land use activity, landslide occurrence and stream channel disturbance in the Sulphur Creek watershed assessment area from three different sets of vertical aerial photography: 1940 (1:20,000), 1985 (1:24,000), and 2002 (1:24,000). Complete coverage of the Sulphur Creek watershed was available for all three air photo sets. As mentioned previously, the Sulphur Creek watershed assessment area extends upstream from the confluence of Sulphur Canyon and Heath Creek.

Information mapped on historic aerial photography was transferred to a 1:12,000 scale USGS topographic map and spatially digitized into Arcview GIS. Attribute data for the landslide analysis was entered into a relational database.

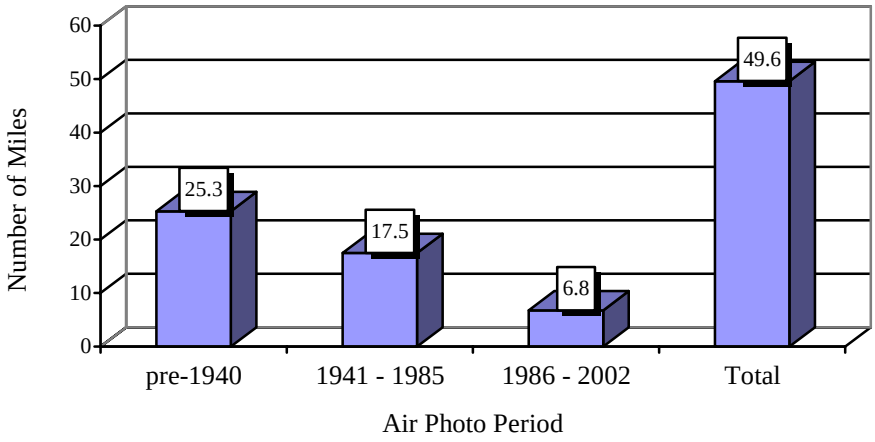
A. Road construction history

The road construction history was documented based on the first occurrence of the road on the historic aerial photos. Figure 2 and Map 1 depict the general road construction history for Sulphur Creek watershed assessment area, as derived from the analysis of historical aerial photography. A total of 49.6 miles of road were constructed in the watershed assessment area by the 2002 aerial photography.

As of the 1942 air photos, 25.3 miles of road had been constructed. This represents 51% of the total road mileage as of the 2002 aerial photography in the watershed. Roads constructed as of the 1942 air photos include private roads throughout the basin and the county maintained White Sulphur Springs Road along the mainstem of Sulphur Canyon.

Between 1940 and 1985, 17.5 miles of road were constructed primarily in Heath Canyon, the lower portion of Sulphur Canyon and the small sub-watershed located north of Sulphur Canyon. Finally, between 1985 and 2002, an additional 6.8 miles of road were constructed, primarily in the upper portions of the Sulphur Creek watershed and in the small northern sub-basin (Map 1).

Figure 2. Road construction history, Sulphur Creek watershed, Napa Co.



B. Land use history

Land use activity was documented on the historic aerial photography by delineating boundaries and assigning a land use classification of rural residential, agriculture, vineyard, grazing or no apparent management. Land use activity was documented on an air photo if physical and visual evidence existed of a specific land use. Typically, if no visual evidence was found (e.g. water troughs and fencing for cattle, hillslope terraces created by cattle grazing, orchards, vineyard plots, etc.), then a “no apparent management” classification was assigned. This applies to

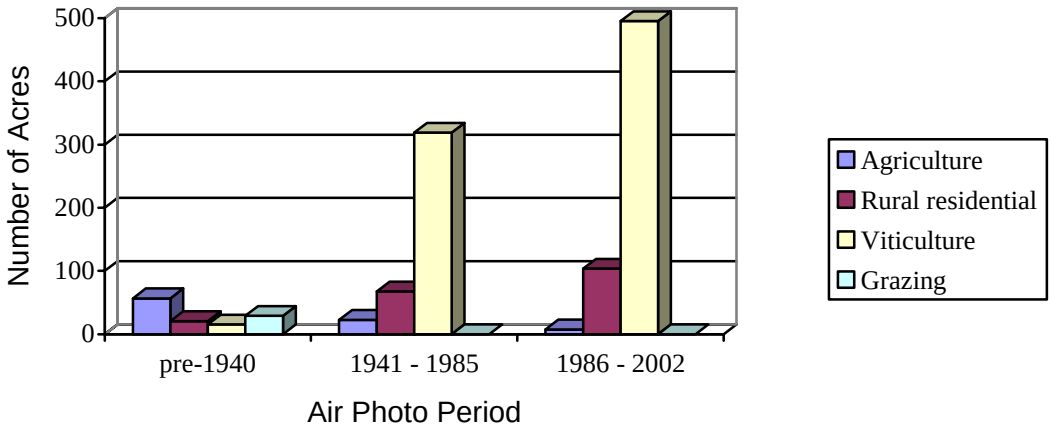
portions of the watershed that may have experienced historic (pre-1940) logging, agriculture, grazing, viticulture and other land uses. This is especially apparent with regards to grazing activity.

Free range grazing activity has reportedly occurred throughout the Sulphur Creek watershed since the early to mid 1800's (Historical Ecology Report, Grossinger). In addition, the scale of the 1940, 1985 and 2002 air photos preclude the ability to confidently identify grazing activity unless the areas showed obvious signs of intense grazing and/or grazing structures (e.g. water troughs, exclusionary fencing). As a result the extent of grazing activity in the watershed is a qualitative estimate and may represent a minimum value.

Figure 3 and Maps 2-4 illustrate land use activity by land use type and historic air photo year. Historic trends in land use activity show that general agricultural activities, such as orchards and other agriculture land uses (excluding vineyards) decreased by 87% from 1940 to 2002. In contrast, vineyard development increased approximately 30 fold from 15 acres by 1942 to nearly 500 acres by 2002. Rural residential development also increased moderately from approximately 20 acres by 1942 to nearly 105 acres by 2002 (Map 2-4).

Grazing activities were recorded as of 1940 in the small subwatershed located to the north of Sulphur Canyon. No grazing activities were noted on the later 1985 or 2002 air photo sets (Figure 3 and Maps 2-4). The increase in vineyard and rural residential development suggest the conversion of general agricultural and grazing areas to vineyards and rural residential uses.

Figure 3. Land use history, Sulphur Creek watershed, Napa Co.



The majority of land use activity in the watershed assessment area was concentrated in the un-named tributary located to the north of Sulphur Canyon. As of 2002, this small watershed contains approximately 48% of the viticulture activities, 66% of the rural residential development and 56% of the general agricultural activities. The remainder of land use activity is

primarily concentrated in the upper portions of Sulphur Creek Canyon with minor amounts in Heath Creek Canyon (Maps 2-4).

C. Landslide history

The Sulphur Creek hillslope and tributary sediment source assessment included an historic analysis of mass wasting (landslides) in the watershed assessment area. Analysis of past landslides does not show where future debris slides will develop, but it can be used to help evaluate the location of slopes or geomorphic settings which are most susceptible to shallow mass wasting in the watershed.

For the landslide history, each new landslide or erosional feature which appeared on the photographs was assigned a unique site number and characterized using a variety of factors. The minimum measurement resolution for features identified on the photos was approximately 35 feet (1940) and 40 feet (1985 and 2002 photo years). The attribute data collected for each landslide included:

1. Year of appearance (photo year)
2. Feature type (debris landslide, debris flow, deep seated landslide, rotational landslide, translational landslide, composite landslide),
3. Certainty of interpretation (definite, probable, questionable),
4. Feature dimensions (length, width),
5. Aspect,
6. Sediment delivery (estimated <25%, 25-50%, 50-75%, 75-100%),
7. Type of stream receiving deposits (perennial, intermittent, ephemeral),
8. Land use history at initiation point (road, timber harvest, agriculture, vineyard, grazing, no apparent management),
9. Geomorphic association (inner gorge, swale, break-in-slope, headwall, etc.),
10. Hillslope steepness passing through initiation point (from topographic map), and
11. Vegetation class (grassland, mixed conifer, oak woodland)

Landslide types were defined based on the Crudden and Varnes classification (Crudden and Varnes, 1996). The Crudden and Varnes landslide classification system is the preferred method used by the California Geological Survey. Generally, landslides fall into 2 categories: 1) shallow, rapid moving and 2) deep-seated. Debris landslides and debris flows are both shallow and fast moving landslides. Debris flows are classified as debris landslides which channelize and scour some length of natural stream channel or gully the hillslope down from the origination point. Deep-seated landslides include rotational landslides, translational landslides and composite landslides. Composite landslides are defined as deep-seated landslides that possess features or styles of movement suggestive of two or more types of sliding (e.g. rotational and translational).

During the analysis phase of the project, landslide lengths measured from the aerial photography were corrected using a multiplier based on slope gradients measured from topographic maps. Depths were estimated for air photo identified landslides based on field observations of area versus depth relationships (Table 1).

Landslide frequencies for each of the photo periods are shown in Figure 4. A total of 84 landslides were identified in the air photo analysis for Sulphur Creek (Map 5). Of the 84

landslides identified, 35 landslides were identified on the 1940 air photos, 22 landslides were identified on the 1985 air photos and 27 landslides were identified on the 2002 air photos. The number of landslides identified in the air photo analysis represent the minimum number of landslides identified in the Sulphur Creek watershed. There is a forty-five (45) year break between the 1940 and 1985 air photo periods and a seventeen (17) year break between the 1985 and 2002 air photo periods. Many more mass wasting features could have occurred during these breaks in time between air photo periods. In addition, the scale of the photos (1940 -1:20,000, 1985 - 1:24,000, and 2002 - 1:24,000) make air photo identification of features difficult. The identification of landslides and estimates of future erosion and sediment delivery become more problematic when air photo scales are larger than 1:12,000.

Table 1. Estimated depths based on landslide areas, Sulphur Creek, Napa County, California

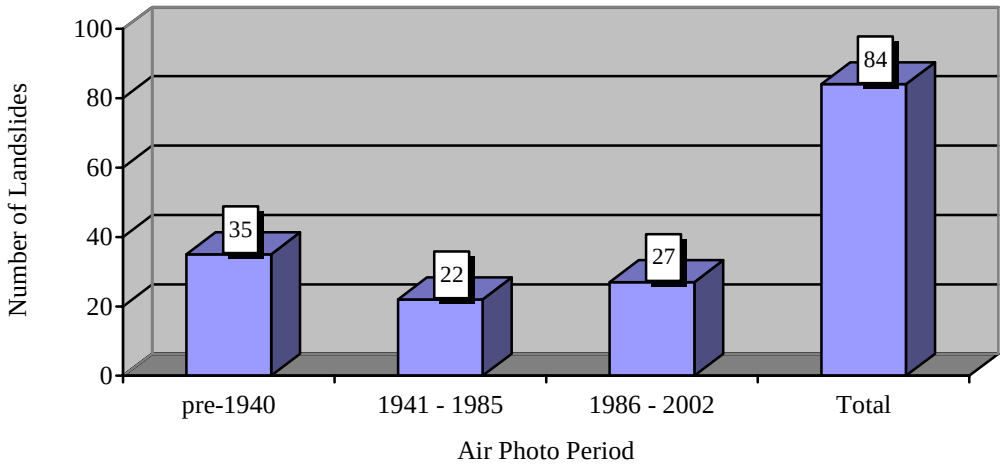
Landslide area (ft^2)	Estimated depth (ft)
< 4,000	2
4,001 - 10,000	3
10,001 - 15,000	4
15,001 - 17,000	5
17,001 - 20,000	6
20,001 - 30,000	8
>30,000	10

The Napa River basin has experienced numerous large flood events from 1940 to 2002. Large storms are considered to be triggering mechanisms for mass wasting (landslides). Examples of large storms in the Napa River basin that are bracketed by the photography used in the air photo analysis occurred in 1940, 1942, 1983 and 1997. The relationship between large storms and landsliding is most evident when historic air photo years bracket the time of large storms.

Of the 84 landslides identified in the air photo analysis, eight (8) were landslides that re-activated at least once in a later air photo period. The remaining landslides are discrete landslides that have not experienced further re-activation.

Of the 84 landslides identified in the air photo analysis, fifteen (15) landslides had no apparent sediment delivery to Sulphur Creek and its tributaries. The remaining sixty-nine (69) landslides delivered an estimated total of 419,600 yds^3 of sediment (Table 2).As of the 1942 air photos, approximately 302,100 yds^3 of sediment was delivered to Sulphur Creek and its tributaries from landsliding. Between 1942 and 1985, approximately 83,500 yds^3 of sediment was delivered to streams and nearly 34,000 yds^3 of sediment was delivered between 1985 and 2002 (Table 2). In general, landslides in the Sulphur Creek watershed consisted of large debris landslides, deep

Figure 4. Frequency of air photo identified landslides, Sulphur Creek watershed, Napa Co.



seated landslides, composite landslides and debris flows with an average length of 160 feet and an average of 5,000 yds^3 of sediment delivered to the stream system.

Approximately 50% (206,500 yds^3) of the total sediment delivered from air photo identified landslides in Sulphur Creek originates from one large composite landslide located near the ridge of the south-facing slope above Sulphur Canyon. This landslide occurred as of the 1940 air photo set and portions of the landslide have re-activated by the time of the 1985 and 2002 air photo years. Sediment generated from this landslide pushed the stream against the opposite bank and resulted in a large debris landslide on the opposite hillside delivering nearly 50,000 yds^3 to the stream.

Table 2. Landslide characteristics, by photo period, Sulphur Creek watershed

Photo period	Number of landslides (#)	Total past sediment delivery (yds^3)	Average sediment delivery (%)	Average length (ft)	Average volume of sediment delivered (yds^3)
1940	35	302,100	40	200	8,600
1985	22	83,500	50	150	3,800
2002	27	34,000	40	120	1,300
Total	84	419,600	40	160	5,000

Landslide distribution and association with landforms- In all years of analysis, landslides were divided into 3 categories: steep inner gorge slopes, moderately steep streamside slopes and steep headwall/swale areas (Table 3). Inner gorge slopes are here defined as slopes that are steeper than 65% which occur below the last (lowest) significant break-in-slope next to a stream channel. For this study, streamside slopes occupy the same slope positions, but occur on slopes less than 65%. Table 3 lists the geomorphic associations, landslide frequencies, average lengths and average volumes delivered for each of the photo periods analyzed.

Table 3. Frequency, length and volume of air photo identified landslides, Sulphur Creek watershed

Photo year	No. of inner gorge slides	Average length (ft)	Average volume delivered (yds^3)	No. of streamside slides	Average length (ft)	Average volume delivered (yds^3)	No. of headwall/ swale slides	Average length (ft)	Average volume delivered (yds^3)
1940	18	160	4,500	5	60	150	12	290	18,300
1985	4	130	4,700	15	150	4,000	3	200	1,800
2002	10	100	700	10	150	2,700	7	90	70
Totals	32	140	3,300	30	140	3,000	22	220	10,300

Inner gorge landslides accounted for approximately 38% of the air photo identified landslides in Sulphur Creek. Landslides located on moderately steep slopes accounted for approximately 36% of identified landslides and approximately 26% of identified landslides were located in steep headwall swale locations. Although inner gorge landslides were the most common in the watershed area, headwall swale landslides had larger average lengths (220 feet) and the greatest average volume delivered (10,300 yds^3) to the stream system. Estimates of average length and average volume for headwall/swale landslides may be skewed due to the large (206,500 yds^3) composite landslide identified on the 1940 air photo set. In any case, Sulphur Creek is a deeply incised watershed composed of highly unstable and sheared Franciscan bedrock. Landslide failures in the watershed had a tendency to occur in steep headwall areas and on steep inner gorge slopes. Landsides typically traveled for long distances to streams and resulted in the delivery of large quantities of sediment.

Vegetation associations and mass wasting

Landslides identified in the air photo analysis were located within three vegetation classes: mixed conifer, oak woodlands and grasslands (Table 4). The majority (69%) of landslides identified in the air photo analysis occurred in oak woodland locations, 21% of the landslides occurred in areas dominated by mixed conifer and 10% of the landslides occurred in grassland locations.

D. Stream channel disturbance history

In addition to the road construction, land use and landslide histories, the historic aerial photography was analyzed to document the location and extent of stream channel disturbance in

Table 4. Vegetation associations with mass wasting, Sulphur Creek watershed				
Photo Year	Mixed conifer (#)	Oak woodland (#)	Grassland (#)	Total (#)
1940	7	27	1	35
1985	10	12	0	22
2002	1	19	7	27
Total	**18**	**58**	**8**	**84**
Percent of Total	**21**	**69**	**10**	**100**

the Sulphur Creek watershed. Stream channel disturbance is defined as locations of the mainstem channel and tributary channels that have experienced stripping of riparian vegetation or notable sediment aggradation. Causes of stream channel disturbance can be from a variety of factors including bank erosion, stream channel meandering, landslides, large flood events and a variety of management activities. On the historic aerial photography, these stream channel sections appear wide and bare as opposed to adjacent sections of less impacted channel.

Map 5 illustrates the age and location of stream channel disturbance in the watershed. In total, approximately 3.8 miles of channel in the Sulphur Creek watershed was identified as "disturbed". This represents approximately 16% of the 24 miles of USGS blue line streams in the basin. Of the 3.8 miles of "disturbed" channel, 3.4 miles (89%) were located in tributaries of Sulphur Canyon, 0.1 (4%) miles were located in Heath Canyon and 0.3 miles (7%) were located in other tributary channels of Sulphur Creek. Possible causes for stream channel disturbance in the mainstem channel of Sulphur Creek include stream channel migration, bank erosion and flood events. Causes for stream channel disturbance in tributary channels appears to result from bank erosion, landslides and flood events.

V. Sulphur Creek Road Assessment and Sediment Reduction Plan

A. Project Description

In Phase I of the Sulphur Creek road inventory and assessment, all roads within the watershed were identified and age dated from historic aerial photography. Aerial photographs were analyzed to identify the location and approximate date of road construction. A composite map of the road systems in Sulphur Creek was developed from GIS layers provided by the Napa County RCD and updated through analysis of aerial photos. GIS base maps used in the field inventory were generated using the air photo identified roads, and they depict the primary road network in the watershed and show the location of sites with future erosion and sediment delivery to the stream system.

Phase II of the Sulphur Creek hillslope and tributary sediment source assessment involved a complete inventory of 23.7 miles of county maintained roads and privately owned roads, selected hillslope areas and major tributary stream channels within the Sulphur Creek assessment area. In

addition, Phase II involved the development of a prioritized erosion control and erosion prevention treatment plan for the 23.7 miles of inventoried road. The assessment process used in this project was developed by Pacific Watershed Associates and is one of the preferred methods outlined in the Stream Habitat Restoration Manual published by the California Department of Fish and Game (CDFG, 1998).

Technically, this assessment was neither an erosion inventory nor a road maintenance inventory. Rather, it was an inventory of sites where there is a potential for future sediment delivery to the stream system. All roads, including both maintained and abandoned routes, were walked and inspected by trained personnel from Pacific Watershed Associates with the assistance of Napa County RCD staff. All existing and potential erosion sites were identified and described. Sites, as defined in this assessment, include locations where there is direct evidence that future erosion or mass wasting could be expected to deliver sediment to a stream channel. Sites of past erosion were not inventoried unless there was a potential for additional future sediment delivery. Similarly, sites of future erosion that were not expected to deliver sediment to a stream channel were not included in the inventory. Non-delivery sites include small shallow fillslope failures, cutbank landslides and gullies that are located far enough from a stream that they do not have the potential to deliver to a stream channel.

Inventoried sites generally consisted of stream crossings, potential and existing landslides related to the road system, gullies below ditch relief culverts and long sections of uncontrolled road and ditch surface runoff which currently discharge to the stream system. For each identified existing or potential erosion source, a database form was filled out and the site was mapped on a mylar overlay over a 1:12,000 scale topographic map. The database form (Figure 5) contained questions regarding the site location, the nature and magnitude of existing and potential erosion problems, the likelihood of erosion or slope failure and recommended treatments to eliminate the site as a future source of sediment delivery.

Stream class was identified at each stream crossing according to the @California Forest Practice Rules@ outlined by the California Department of Forestry. Generally, a class I stream is defined as a fish-bearing stream or a domestic water source, a class II stream is defined as non-fish bearing stream that supports other types of aquatic life, a class III stream is defined as capable of sediment transport but not supporting any aquatic life, and a class IV stream is defined as a man-made watercourse.

The erosion potential (and potential for sediment delivery) was estimated for each major problem site or potential problem site. The expected volume of sediment to be eroded and the volume to be delivered to streams was estimated for each site. The data provides quantitative estimates of how much material could be eroded and delivered in the future, if no erosion control or erosion prevention work is performed. In a number of locations, especially at potential stream diversion sites, actual sediment loss could easily exceed field predictions. All sites were assigned a treatment priority, based on their potential to deliver deleterious quantities of sediment to stream channels in the watershed and the cost-effectiveness of the proposed treatment.

In addition to the database information, tape and clinometer surveys were completed on virtually all stream crossings. These surveys included a longitudinal profile of the stream crossing

Figure 5. Road erosion inventory data form used in the Sulphur Creek sediment source assessment

ASAP____	**PWA ROAD INVENTORY DATA FORM** (3/02 version)						*Check____*
GENERAL	**Site No:** _____	GPS:	Watershed:		CALWAA:		
Treat (Y,N):	Photo: _____	T/R/S:	Road #:		Mileage: _____		
	Inspectors:_____	Date: _____	Year built:_____	Sketch (Y):			
	Maintained	Abandoned	Driveable	Upgrade	Decommission	Maintenance	
PROBLEM	Stream xing	Landslide (fill, cut, hill)	Roadbed (bed, ditch, cut)	DR-CMP	Gully	Other	
	Location of problem (U, M, L, S)	Road related? (Y)	Harvest history: (1=<15 yrs old; 2=>15 yrs old) TC1, TC2, CC1, CC2, PT1, PT2, ASG, No		Geomorphic association: Streamside, I.G., Stream Channel, Swale, Headwall, B.I.S.		
LANDSLIDE	Road fill	Landing fill	Deep-seated	Cutbank	Already failed	Pot. failure	
	Slope shape: (convergent, divergent, planar, hummocky)			Slope (%) _____	Distance to stream (ft) _____		
STREAM	CMP	Bridge	Humboldt	Fill	Ford	Armored fill	
	Pulled xing: (Y)	% pulled _____	Left ditch length (ft) _____		Right ditch length (ft) _____		
	cmp dia (in) _____	inlet (O, C, P, R)	outlet (O, C, P, R)	bottom (O, C,P, R)	Separated?		
	Headwall (in) ____	CMP slope (%) _____	Stream class (1, 2, 3)	Rustline (in)			
	% washed out ____	D.P.? (Y)	Currently dvted? (Y)	Past dvted? (Y)	Rd grade (%) _____		
	Plug pot: (H, M, L)	Ch grade (%) _____	Ch width (ft) _____	Ch depth (ft) ____			
	Sed trans (H, M, L)	Drainage area (mi^2) _____					
EROSION	E.P. (H, M, L)	Potential for extreme erosion? (Y, N)		Volume of extreme erosion (yds^3): 100-500, 500-1000, 1K-2K, >2K			
Past erosion...	Total past erosion (yds) _____	Past delivery (%) _____	Total past yield (yds) _____	Age of past erosion (decade)_____			
Future erosion...	Total future erosion (yds) _____	Future delivery (%) _____	Total future yield (yds) _____	Future width (ft) _____	Future depth (ft) _____	Future length (ft) _____	
TREATMENT	Immed (H,M,L)	Complex (H,M,L)	Mulch (ft^2)				
	Excavate soil	Critical dip	Wet crossing (ford or armored fill) (circle)		sill hgt (ft) ___	sill width (ft) _____	
	Trash Rack	Downspout	D.S. length (ft) _____	Repair CMP	Clean CMP		
	Install culvert	Replace culvert	CMP diameter (in) _____	CMP length (ft) _____			
	Reconstruct fill	Armor fill face (up, dn)	Armor area (ft^2) _____	*Clean or cut ditch*	*Ditch length (ft)* _____		
	Outslope road (Y)	*OS and Retain ditch (Y)*	*O.S. (ft)* _____	*Inslope road*	*I.S. (ft)* _____	*Rolling dip*	*R.D. (#)* __
	Remove berm	*Remove berm (ft)* _____	*Remove ditch*	*Remove ditch (ft)* _____		*Rock road - ft^2* _____	
	Install DR-CMP	*DR-CMP (#)* _____	Check CMP size? (Y)	Other tmt? (Y)	No tmt. (Y)		
COMMENT ON PROBLEM:							
EQUIPMENT HOURS	Excavator (hrs) _____	Dozer (hrs) _____	Dump truck (hrs) _____	Grader (hrs) _____			
	Loader (hrs) _____	Backhoe (hrs) _____	Labor (hrs) _____	Other (hrs) _____			
COMMENT ON TREATMENT:							

through the road prism, as well as two or more cross sections. The survey data was entered into a computer program that calculates the volume of fill in the crossing. The survey allows for an accurate and repeatable quantification of future erosion volumes (assuming the stream crossing was to washout during a future storm), decommissioning volumes (assuming the road was to be closed) and/or excavation volumes that would be required to complete a variety of road upgrading and erosion prevention treatments (culvert installation, culvert replacement, complete excavation, etc.).

B. Inventory Results

Approximately 49.6 miles of road were identified in the sequential air photo analysis of the 1940, 1985 and 2002 air photo set years (Map 1). Of the 49.6 miles in the Sulphur Creek watershed assessment area, approximately 25.3 miles were constructed as of 1940, 17.5 miles were constructed between 1940 and 1985, and 6.8 miles were constructed between 1985 and 2002. Of the 49.6 miles of road in the Sulphur Creek watershed assessment area, 23.7 miles were granted access for the road-related sediment source assessment including 1.8 miles of county maintained roads and 21.9 miles of private roads.

Approximately 23.7 miles of roads were inventoried for future sediment sources. Inventoried road-related erosion sites fit into one of two treatment categories: 1) upgrade sites - defined as sites on maintained county roads and open private roads that are to be retained for access and management and 2) decommission sites - defined as sites exhibiting the potential for future sediment delivery that have been recommended for either temporary or permanent closure. Virtually all future road-related erosion and sediment yield in the assessment area is expected to come from three sources: 1) erosion at or associated with stream crossings (from several possible causes), 2) failure of road fills (landsliding), and 3) road surface and ditch erosion.

Site Types

A total of 188 sites were identified with the potential to deliver sediment to streams. Of these, 156 were recommended for erosion control and erosion prevention treatment. Approximately 72% (n=112) of the sites recommended for treatment are classified as stream crossings, 2% (n=3) as existing or potential landslides, and 19% (n=30) as ditch relief culverts (Table 5 and Map 6). The remaining 7% (n=11) of the inventoried sites recommended for treatment consist of Aother@ sites which include road surface, gullies, stream bank erosion and springs.

Stream crossings - One hundred and thirty-two (132) stream crossings were inventoried in the Sulphur Creek watershed assessment area including 109 culverted crossings, 18 unculverted fill crossings, 4 bridges and 1 ford crossing. An unculverted fill crossing refers to a stream crossing with no drainage structure to carry the flow through the road prism. Flow is either carried beneath or through the fill, or it flows over the road surface, or it is diverted down the road surface to the inboard ditch. The majority of the unculverted fill crossings are located at small Class III streams that exhibit flow only in larger runoff events.

Of the 132 stream crossings identified in the assessment, 112 have been recommended for erosion control and erosion prevention treatment. Approximately 5,397 yds^3 of future road-related sediment delivery could originate from stream crossings if they are not treated (Table 5). This amounts to about 24% of the total sediment yield from the road system. The most common

problems that cause erosion at stream crossings include: 1) crossings with no culverts or with culverts that are undersized, 2) crossings with culverts that are likely to plug, 3) stream crossings with a diversion potential and 4) crossings with gully erosion at the culvert outlet. The sediment delivery from stream crossing sites is always classified as 100% because any sediment eroded is delivered to the channel. Even sediment delivered to small ephemeral streams will eventually be transported to downstream higher order stream channels.

At stream crossings, the largest volumes of future erosion can occur when culverts plug or when potential storm flow exceeds the culvert capacity (i.e., the culvert is undersized or prone to plugging) and flood runoff spills onto or across the road. When stream flow goes over the fill,

Table 5. Site classification and sediment yield from all inventoried sites with future sediment delivery, Sulphur Creek watershed, Napa County, California.

Site Type	Number of sites or road miles	Number of sites or road miles to treat	Sites recommended for treatment			
			Future yield (yds^3)	Stream crossings w/ a diversion potential (#)	Streams currently diverted (#)	Stream culverts likely to plug (plug potential rating = high or moderate)
Stream crossings	132	112	5,397	64	15	44
Landslides	3	3	164	--	--	--
Ditch relief culverts	41	30	398	--	--	--
Other	12	11	261	--	--	--
Total (all sites)	188	156	6,220	64	15	44
Persistent surface erosion[2]	10.75	9.62	16,281	--	--	--
Totals	**188**	**156**	**22,501**	**64**	**15**	**44**

[2] Assumes average 25' wide road prism and cutbank contributing area, and 0.4' of road/cutbank surface lowering over 2 decades on rocked and native roads. Assumes average 8' cutbank and ditch contributing area and 0.4' of cutbank/ditch surface lowering over 2 decades on paved roads.

part or all of the stream crossing fill may be eroded. Alternately, when flow is diverted down the road, either on the road bed or in the ditch (instead of spilling over the fill and back into the same stream channel), the crossing is said to have a Adiversion potential@ and the road bed, hillslope and/or stream channel that receives the diverted flow can become deeply gullied or destabilized. These hillslope gullies can be quite large and can deliver significant quantities of sediment to

stream channels. Alternately, diverted stream flow which is discharged onto steep, potentially unstable slopes can also trigger large hillslope landslides. Of the 112 stream crossings inventoried and recommended for erosion control and erosion prevention treatment in the Sulphur Creek watershed, 64 have the potential to divert in the future and 15 streams are currently diverted (Table 5).

Three road design conditions indicate a high potential for future erosion at stream crossings. These include 1) undersized culverts (the culvert is too small for the 100 year design storm flow), 2) culverts that are prone to plugging with sediment or organic debris and 3) stream crossings with a diversion potential. The worst scenario is for the culvert to plug and the stream crossing to wash out or the stream to divert down the road in a major storm. These road and stream crossing conditions are easily recognizable in the field and have been inventoried in the Sulphur Creek watershed.

Approximately 85% (n=112) of the stream crossings inventoried in the Sulphur Creek assessment area will need to be upgraded for the roads to be considered Astorm-proofed.@ For example, 40% (n=44) of the existing culverts have a Amoderate@ to Ahigh@ plugging potential and nearly 48% of the stream crossings exhibit a diversion potential (Table 1). Because most of the roads were constructed many years ago, culverted stream crossings are typically under-designed for the 100 year storm flow. At stream crossings with undersized culverts, or where there is a diversion potential, corrective prescriptions have been outlined on the data sheets and in the following tables.

Preventative treatments include such measures as constructing critical dips (rolling dips) at stream crossings to prevent stream diversions on rocked and native private roads, installing larger culverts wherever current pipes are under-designed for the 100 year storm flow (or where they are prone to plugging), installing culverts at the natural channel gradient to maximize the sediment transport efficiency of the pipe and ensure that the culvert outlet will discharge on the natural channel bed below the base of the road fill, installing debris barriers and/or downspouts to prevent culvert plugging and outlet erosion, respectively, installing flared inlets to increase the culvert capacity, and armoring the downstream fill face of the crossing to minimize or prevent future erosion.

Landslides - Only those road-related landslide sites with a potential for sediment delivery to a stream channel were inventoried. Three (3) potential landslides were identified and these account for approximately 2% of all inventoried road-related sites in the Sulphur Creek assessment area (Table 5). The 3 potential landslide sites were found along roads where material had been sidecast during earlier construction and now shows signs of instability, where roads were built across the channel and are being undercut by high flows, where roads are built along the stream inner gorge and/or where roads were built along the steep headwall areas of Class 3 streams.

All three (3) inventoried landslides have been recommended for erosion control and erosion prevention treatment. Potential landslides recommended for treatment are expected to deliver up to 164 yds^3 of sediment to Sulphur Creek and its tributaries in the future. Correcting or

preventing potential landslides associated with the road is relatively straightforward, and involves the physical excavation of potentially unstable road fill and sidecast materials.

There are a number of potential landslide sites along roads in the Sulphur Creek assessment area that did not, or will not, deliver sediment to streams. These sites were not inventoried using data sheets due to the lack of expected sediment delivery to a stream channel. They are generally shallow and of small volume, or located far enough away from an active stream such that sediment delivery is unlikely to occur. For reference, all landslide sites were mapped on the mylar overlays of the topographic maps, but only those with the potential for future sediment delivery were inventoried using a data sheet (Figure 5).

Ditch relief culverts –Forty-one (41) ditch relief culvert sites were identified to have future sediment yield to stream channels. Of the 41 ditch relief culverts, 30 were recommended for erosion control and erosion prevention treatment. These sites are attributed to excessive ditch length contribution that causes a gully below the outlet that delivers sediment to a stream channel. Approximately 398 yds^3 of future sediment yield is expected to occur associated with these ditch relief culvert sites. These sites represent approximately 2% of the total predicted sediment yield from road related erosion.

AOther@ sites - A total of 12 Aother@ sites were also identified in the assessment area. AOther@ sites include road surface, ditch, major springs, gullies and bank erosion sites which exhibited the potential to deliver sediment to streams. One of the main causes of existing or future erosion at these sites is surface runoff and uncontrolled flow from long sections of undrained road surface and/or inboard ditch. Uncontrolled flow along the road or ditch may affect the road bed integrity as well as cause hillslope gully erosion.
Of the 12 “other” sites, 11 have been recommended for erosion control and erosion prevention treatment. We estimate 261 yds^3 of sediment could be delivered to streams if they are left untreated (Table 5). Sediment delivery from these sites represents approximately 1% of the total potential sediment yield from sites recommended for erosion control and erosion prevention treatment.

Chronic erosion **-** Road runoff is appears to be a major source of fine sediment input to nearby stream channels. We measured approximately 10.75 miles of road surface and/or road ditch (representing 45 % of the total inventoried road mileage) which currently drain directly to stream channels and deliver ditch flow, road runoff and fine sediment to stream channels in the Sulphur Creek watershed assessment area (Table 5). These roads are said to be Ahydrologically connected@ to the stream channel network. This does not include inaccessible spur roads and driveways that also contribute runoff and sediment to the inventoried roads and their drainage structures. When these roads are being actively maintained and used for access, they represent a potentially important source of chronic fine sediment delivery to the stream system.

Of the 10.75 miles of road surface and/or road ditch contribution, 9.62 miles have been recommended for treatment. From the 9.62 miles, we calculated approximately 16,281 yds^3 (72%) of sediment could be delivered to stream channels within the Sulphur Creek watershed over the next two decades, depending on road use, if no efforts are made to change road drainage patterns. This will occur through a combination of 1) cutbank erosion (ie., dry ravel, surface

erosion, freeze-thaw processes, cutbank failures and brushing/grading practices) delivering sediment to the ditch, 2) inboard ditch erosion and sediment transport, 3) mechanical pulverizing and wearing down of unpaved road surfaces, and 4) erosion of the road surface during wet weather periods.

Relatively straight-forward erosion prevention treatments can be applied to upgrade road systems to prevent most of this fine sediment from entering stream channels. These treatments generally involve dispersing road runoff and disconnecting road surface and ditch drainage from the natural stream channel network. Road surface treatments include the addition of ditch relief culverts on paved county roads and adding frequent ditch relief culverts and/or rolling dips on rocked and native surfaced private roads.

B. Treatment Priority

An inventory of future or potential erosion and sediment delivery sites is intended to provide information which can guide long range transportation planning, as well as identify and prioritize erosion prevention, erosion control and road decommissioning activities in the watershed. Not all of the sites that have been recommended for treatment have the same priority, and some can be treated more cost effectively than others. Treatment priorities are evaluated on the basis of several factors and conditions associated with each potential erosion site. These include:

1) the expected volume of sediment to be delivered to streams (future delivery - yds^3),
2) the potential or Alikelihood@ for future erosion (erosion potential - high, moderate, low),
3) the Aurgency@ of treating the site (treatment immediacy - high, moderate, low),
4) the ease and cost of accessing the site for treatments, and
5) recommended treatments, logistics and costs.

The ***erosion potential*** of a site is a professional evaluation of the likelihood that erosion will occur during a future storm event. Erosion potential is an estimate of the potential for additional erosion, based on field observations of a number of local site conditions. Erosion potential was evaluated for each site, and expressed as AHigh@, AModerate@ or ALow.@ The evaluation of erosion potential is a subjective estimate of the probability of erosion, and not an estimate of how much erosion is likely to occur. It is based on the age and nature of direct physical indicators and evidence of pending instability or erosion. The likelihood of erosion (erosion potential) and the volume of sediment expected to enter a stream channel from future erosion (sediment delivery) play significant roles in determining the treatment priority of each inventoried site (see Atreatment immediacy,@ below). Field indicators that are evaluated in determining the potential for sediment delivery include such factors as slope steepness, slope shape, distance to the stream channel, soil moisture and evaluation of erosion process. The larger the potential future contribution of sediment to a stream, the more important it becomes to closely evaluate its potential for cost-effective treatment.

Treatment immediacy (treatment priority) is a professional evaluation of how important it is to Aquickly@ perform erosion control or erosion prevention work. It is also defined as AHigh@, AModerate@ and ALow@ and represents both the severity and urgency of addressing the threat of sediment delivery to downstream areas. An evaluation of treatment immediacy considers erosion potential, future erosion and delivery volumes, the value or sensitivity of downstream

resources being protected, and treatability, as well as, in some cases, whether or not there is a potential for an extremely large erosion event occurring at the site (larger than field evidence might at first suggest). If mass movement, culvert failure or sediment delivery is imminent, even in an average winter, then treatment immediacy might be judged AHigh@. *Treatment immediacy is a summary, professional assessment of a site=s need for immediate treatment.* Generally, sites that are likely to erode or fail in a normal winter, and that are expected to deliver significant quantities of sediment to a stream channel, are rated as having a high treatment immediacy or priority.

C. Evaluating Treatment Cost-Effectiveness

Treatment priorities are developed from the above factors, as well as from the estimated cost-effectiveness of the proposed erosion control or erosion prevention treatment. Cost-effectiveness is determined by dividing the cost ($) of accessing and treating a site, by the volume of sediment prevented from being *delivered* to local stream channels. For example, if it would cost $2000 to develop access and treat an eroding stream crossing that would have delivered 250 yds^3 (had it been left to erode), the predicted cost-effectiveness would be $8/$yds^3$ ($2000/250 yds^3).

To be considered for priority treatment a site should typically exhibit: 1) potential for significant (>25-50 yds^3) sediment delivery to a stream channel (with the potential for transport to a fish-bearing stream), 2) a high or moderate treatment immediacy and 3) a comparably favorable cost-effectiveness value. Treatment cost-effectiveness analysis is often applied to a group of sites (rather than on a single site-by-site basis) so that only the most cost-effective groups of sites or projects are undertaken. Typical measures of treatment cost-effectiveness for forest, ranch and rural subdivision roads are not directly comparable to values which might be developed for the treatment of county public roads, such as the 1.8 miles of county public roads in the Sulphur Creek watershed. Here, the costs for treatments are typically much higher, and the resulting cost-effectiveness values will be less favorable.

Regardless of the absolute values, cost-effectiveness can be used as a tool to prioritize potential treatment sites throughout a sub-watershed (Weaver and Sonnevil, 1984; Weaver and others, 1987). It assures that the greatest benefit is received for the limited funding that is typically available for protection and restoration projects. Sites, or groups of sites, that have a predicted marginal cost-effectiveness value, or are judged to have a lower erosion potential or treatment immediacy, or low sediment delivery volumes, are less likely to be treated as part of the primary watershed protection and Aerosion-proofing@ program. However, these sites should be addressed during future road reconstruction or when heavy equipment is performing routine maintenance or restoration at nearby, higher priority sites.

D. Types of Prescribed Heavy Equipment Erosion Prevention Treatments

Forest roads can be storm-proofed by one of two methods: upgrading or decommissioning (Weaver and Hagans, 1994). The characteristics of storm-proofed roads, including those which are either upgraded or decommissioned, are depicted in Figure 6.

Road upgrading involves a variety of treatments used to make a road more resilient to large storms and flood flows. The most important of these include stream crossing upgrading (especially culvert up-sizing to accommodate the 100-year storm flow and debris in transport,

and to eliminate stream diversion potential), removal of unstable sidecast and fill materials from steep slopes, and the application of drainage techniques to improve dispersion of road surface runoff. Road drainage techniques include rolling dips and/or the installation of ditch relief culverts. The goal of all treatments is to make the road as Ahydrologically invisible@ as is possible.

Heavy equipment conducting stream crossing culvert upgrades on county roads will utilize two different methods to install new pipes. Methods are dependent on the depth of road fill at the stream crossing site. For a stream crossing that has a <8' deep road fill, a trench will be excavated. The new pipe will be installed and the crossing excavation will be back filled with an aggregate concrete slurry. All of the road fill that is excavated for the new culvert installation will be endhauled away from the site. Estimated excavator and backhoe times are based on a excavation production rate that is determined by the complexity of the work site. Dump trucks will endhaul spoil to a temporary storage area located by Napa County Department of Public

FIGURE 6. CHARACTERISTICS OF STORM-PROOFED ROADS

The following abbreviated criteria identify common characteristics of Astorm-proofed@ roads. Roads are Astorm-proofed@ when sediment delivery to streams is strictly minimized. This is accomplished by dispersing road surface drainage, preventing road erosion from entering streams, protecting stream crossings from failure or diversion, and preventing failure of unstable fills which would otherwise deliver sediment to a stream. Minor exceptions to these Aguidelines@ can occur at specific sites within a forest, ranch county road system.

STREAM CROSSINGS

- Y all stream crossings have a drainage structure designed for the 100-year flow
- Y stream crossings have no diversion potential (functional critical dips or other measures are in place)
- Y stream crossing inlets have low plug potential (trash barriers & graded drainage)
- Y stream crossing outlets are protected from erosion (extended, transported or dissipated)
- Y culvert inlet, outlet and bottom are open and in sound condition
- Y undersized culverts in deep fills (> backhoe reach) have emergency overflow culvert
- Y bridges have stable, non-eroding abutments & do not significantly restrict design flood flows
- Y fills are stable (unstable fills are removed or stabilized)
- Y road surfaces and ditches are Adisconnected@ from streams and stream crossing culverts
- Y decommissioned roads have all stream crossings completely excavated to original grade
- Y Class 1 (fish) streams accommodate fish passage

ROAD AND LANDING FILLS

- Y unstable and potentially unstable road and landing fills are excavated (removed)
- Y excavated spoil is placed in locations where eroded material will not enter a stream
- Y excavated spoil is placed where it will not cause a slope failure or landslide

ROAD SURFACE DRAINAGE

- Y road surfaces and ditches are Adisconnected@ from streams and stream crossing culverts
- Y ditches are drained frequently by functional rolling dips or ditch relief culverts
- Y outflow from ditch relief culverts does not discharge to streams
- Y gullies (including those below ditch relief culverts) are dewatered to the extent possible
- Y ditches do not discharge (through culverts or rolling dips) onto active or potential landslides

Y decommissioned roads have permanent road surface drainage and do not rely on ditches

Works (Napa DPW). A loader or dozer will be located at the temporary storage area to work the spoils.

Once the new pipe is set at or close to the natural channel gradient a cement truck will haul slurry material to backfill the excavated crossing. Each trench crossing will be backfilled with a slurry to ensure a hardened surface that will not settle after the new pipe installation is completed. Cement trucks can haul 10 yds^3 of slurry and are able to backfill at a rapid 10 yds^3 in 10 minutes. Costs for the cement truck are based on the cost of the material delivered to the average work site. The crossing then will be capped with new pavement whose surface area is based on the width and length of the excavation. Then the crossing then will be swept with a mechanical broom.

For crossings >8' deep and fill depths beyond the reach of an excavated trench, a non-trenched excavation will be applied. To install a new pipe at the natural channel gradient, a deep crossing will require the excavator to open up a crossing completely to safely allow room for laborers to replace or install the pipe deep in the fill. This treatment will require sideslopes be excavated back at a 1:1 slope (at least), which differs significantly from a typical trenched excavation. Approximately 100 yds^3 of material will be stockpiled on-site and the remaining road fill will need to be endhauled to a temporary storage location. The new pipe will be installed using the locally stockpiled spoils for a compacted bed. The remaining excavation will then be backfilled with clean quarry fill.

Upgraded roads are kept open and are inspected and maintained. Their drainage facilities and fills are designed or treated to accommodate or withstand the 100-year storm. In contrast, properly decommissioned roads are closed and no longer require maintenance. The goal of storm-proofing is to make the road as Ahydrologically invisible@ as is possible; that is to disconnect the road from the stream system and thereby preserve aquatic habitat.

Road decommissioning basically involves Areverse road construction,@ except that full topographic obliteration of the road bed is <u>not</u> normally required to accomplish sediment prevention goals. Generic treatments for decommissioning roads and landings range from outsloping or simple cross-road drain construction to full road decommissioning (closure), including the excavation of unstable and potentially unstable sidecast materials and road fills, and all stream crossing fills. Four (4) sites located on private subdivision roads have been recommended for temporary or permanent closure.

E. Recommended treatments

Basic treatment priorities and prescriptions for inventoried roads in the Sulphur Creek watershed were formulated concurrent with the identification, description and mapping of potential sources of road-related sediment yield. Table 6 and Map 7 outline the treatment priorities for all 128 inventoried sites with future sediment delivery that have been recommended for treatment in the Sulphur Creek watershed assessment area. Of the 156 sites with future sediment delivery, seventeen (17) sites were identified as having a high or high-moderate treatment immediacy with a potential sediment delivery of approximately 1,957 yds^3. One hundred and twenty-three (123) sites were listed with a moderate or moderate-low treatment immediacy and account for nearly

18,778 yds^3 of future sediment delivery. Finally, sixteen (16) sites were listed as having a low treatment immediacy with approximately 1,766 yds^3 of future sediment delivery.

Table 7 summarizes the proposed treatments for sites on inventoried roads in the Sulphur Creek watershed assessment area. The database, as well as the field inventory sheets, provide details of the treatment prescriptions for each site. Most treatments require the use of heavy equipment, including an excavator, loader, tractor, dump truck and backhoe. Some hand labor is required at sites needing new culverts, downspouts, culvert repairs, trash racks and/or for applying seed, plants and mulch following ground disturbance activities. Additional labor will be required to conduct traffic control at all county road work sites. Labor necessary to allow vehicles to pass through the work site with minimal delay will require a single flagman on both sides of the work site. The flaggers will be equipped with radios and stop signs and direct traffic to a single lane. Stop signs will replace flaggers during nights or hours when work will not be conducted. Longer or Ablind@ reaches may require the use of a pilot car.

Table 6. Treatment priorities for inventoried road-related sediment sources, Sulphur Creek, Napa County, California.

Treatment Priority	Upgrade sites (#)	Decommission sites (#)	Problem	Future sediment delivery (yds^3)
High	3	0	2 stream crossings, 1 landslide	584
High Moderate	14	0	11 stream crossings, 1 ditch relief culvert, 2 other	1,373
Moderate	55	0	39 stream crossings, 1 landslide, 12 ditch relief culverts, 3 other	9,990
Moderate Low	66	2	48 stream crossings, 1 landslide, 13 ditch relief culverts, 6 other	8,788
Low	16	0	12 stream crossings, 4 ditch relief culverts	1,766
Total	**154**	**2**	**112 stream crossings, 3 landslides, 30 ditch relief culverts, 11 other**	**22,501**

It is estimated that erosion prevention work will require the excavation of approximately 1,648 yds^3 at 30 sites (Table 7). Approximately 86% of the volume excavated is associated with upgrading and decommissioning stream crossings. A total of 291 yds^3 of 1.0 to 3.0 foot diameter

mixed and clean rip-rap sized rock will be needed to armor twelve (12) outboard fill faces and 75 yds^3 is required to construct 6 armored fill crossings and 2 armored fords. Rock armor has been prescribed on steep stream crossing outboard fillslopes to buttress the lower portion of the excavation in order to prevent the newly replaced fill from slumping and/or delivering to the stream network. A total of 49 culverts are recommended to upgrade existing stream crossing culverts or install culverts at unculverted streams (Table 7).

For some stream crossings where pipes are correctly sized for the 100 – year storm flow but are placed high in the fill, downspouts have been prescribed to transport the stream flow beyond the road fill to the natural stream bottom. To prevent potential stream diversions, each site with a high diversion potential has been prescribed to have a critical dip placed at the down road hingeline, an oversized pipe or to have a flared inlet to increase pipe inlet capacity. Critical dips were prescribed on native or rocked surface roads. Oversized pipes or flared inlets were prescribed on paved roads. Nine (9) flared inlets have been prescribed for installation to increase the inlet capacity at certain stream crossings. A minimum of 89 new ditch relief culverts are recommended for installation along the inventoried road routes to disconnect connected ditches from natural stream channels (Table 7).

F. Equipment Needs and Costs

Treatments for the 156 sites identified with future sediment delivery in the Sulphur Creek assessment area will require approximately 326 hours of excavator time and 362 hours of dozer time to complete all prescribed upgrading and erosion control and erosion prevention work (Table 8). Two hundred eighty-eight (288) hours of backhoe time has been listed to conduct shallow excavations, install ditch relief culverts, and clean ditches.

Approximately 68 hours of dump truck time has been listed for work in the basin for end-hauling excavated spoil from stream crossings and at unstable road fills where local disposal sites are not available. Approximately 639 hours of labor time is needed for a variety of tasks such as installation or replacement of culverts, installation of debris barriers and downspouts, and an additional 48 hours of labor are for seeding, mulching and planting activities. Approximately 196 hours have been for traffic control and includes a crew of two flagmen during heavy equipment work hours. Approximately 41 hours for a roller and 40 hours for a mechanical broom have been listed to finish each county road site.

Estimated costs for erosion prevention treatments - Prescribed treatments are divided into two components: a) site specific erosion prevention work identified during the watershed inventories, and b) control of persistent sources of road surface, ditch and cutbank erosion and associated sediment delivery to streams. The total costs for road-related erosion prevention and erosion control at all the inventoried sites with future sediment delivery is estimated at approximately $458,221 for an average cost-effectiveness value of approximately $20.36 per cubic yard of sediment prevented from entering Sulphur Creek and its tributaries (Table 9).

Costs are included for the materials needed to install one flatcar bridge on a private road. In addition, total estimated costs include lowboy costs for one round trip to transport an excavator and a dozer to the Sulphur Creek assessment area. Total estimated costs do not include the daily travel costs to transport equipment and labor to the treatment sites.

Table 7. Recommended treatments for inventoried road-related sediment sources, Sulphur Creek, Napa County, California.

Treatment	No.	Comment	Treatment	No.	Comment
Critical dip	42	To prevent stream diversions	Outslope and remove ditch	1	Outslope and remove ditch along 700' of road to improve road surface drainage
Install CMP	12	Install a CMP at an unculverted fill	Outslope and retain ditch	1	Outslope and retain ditch along 800' of road to improve road surface drainage
Replace CMP	37	Upgrade an undersized CMP	Clean/cut ditch	14	Clean/cut 2,350 feet of ditch
Excavate soil	30	Typically fillslope & crossing excavations; permanent excavation of 1,648 yds^3	Install ditch relief CMP	76	Install ditch relief culverts to improve road surface drainage
Down spouts	29	Installed to protect the outlet fillslope from erosion	Replace ditch relief CMP	13	Replace ditch relief culverts to improve road surface drainage
Clean CMP	8	Remove debris and/or sediment from CMP inlet	Install rolling dips	52	Install rolling dips to improve road drainage
Install wet crossing	8	Install 6 armored fill crossings and 2 fords using 75 yds^3 rip rap size rock	Install cross road drains	2	Install cross road drains on decommission roads to improve surface drainage
Armor fill face	12	Rock armor to protect outboard fillslope from erosion using 216 yds^3 of rock	Remove berm	2	Remove 1,975 feet of berm to improve road surface drainage
Trash rack	10	Install trash rack at culvert inlet to prevent plugging	Install water bars	28	Install water bars on steep upgrade native surfaced roads to improve surface drainage
Install bridge	1	Install bridge at class I stream	Rock road surface	32	Rock road surface using 586 yds^3 road rock
Flared inlet	9	Install flared inlet to increase culvert capacity	Other treatment	10	Miscellaneous treatments
Back fill at culvert trench installations with 2 sack slurry mix	20	Backfill with 334 yds^3 slurry mix at stream crossing and ditch relief culvert trench installations	No treatment recommended	32	

Overall site specific erosion prevention work: Equipment needs for site specific erosion prevention work at sites with future sediment delivery are expressed in the database, and summarized in Table 8, as direct excavation times, in hours, to treat all sites having a high, moderate, or low treatment immediacy. These hourly estimates include only the time needed to treat each of the sites, and do not include travel time between work sites, times for basic road surface treatments that are not associated with a specific Asite,@ or the time needed for work

Table 8. Estimated heavy equipment and labor requirements for treatment of all inventoried sites with future sediment delivery, Sulphur Creek watershed, Napa County, California. [1]

Treatment Immediacy	High, High/Moderate	Moderate, Low/Moderate	Low	**Total**
Site (#)	17	123	16	**156**
Total Excavated Volume (yds^3)[2]	809	3,885	100	**4,794**
Excavator (hrs)	44	269	13	**326**
Dozer (hrs)	40	302	20	**362**
Dump Trucks (hrs)	12	54	2	**68**
Grader (hrs)	6	50	7	**63**
Labor (hrs)	69	523	47	**639**
Traffic control (hrs)	48	136	12	**196**
Roller (hrs)	8	31	2	**41**
Broom (hrs)	8	30	2	**40**
Pavement cutter (hrs)	4	20	1	**25**
Backhoe (hrs)	9	252	27	**288**

[1] Estimated equipment times do not include daily lowboy or travel costs to treatment sites.
[2] Total excavated volume includes permanently excavated material and a percentage of temporarily excavated materials used in backfilling upgraded stream crossings at non-trench installations.

conferences at each site. These additional times are accumulated as "logistics" and must be added to the work times to determine total equipment costs as shown in Table 9.
The costs in Table 9 are based on a number of assumptions and estimates, and many of these are included as footnotes to the table. The costs provided are assumed reasonable if work is performed by outside contractors, with no added overhead for contract administration and pre- and post-project surveying. Movement of equipment to and from the site will require the use of low-boy trucks. The majority of treatments listed in this plan are not complex or difficult for equipment operators experienced in road upgrading. The use of inexperienced operators would require additional technical oversight and supervision in the field. All recommended treatments conform to the general guidelines described in the AHandbook for Forest and Ranch Roads prepared by PWA (1994) for the California Department of Forestry, Natural Resources Conservation Service and the Mendocino County Resource Conservation District.

Treatments prescribed on county maintained roads were modified from these general standards to more closely meet current county procedures and acceptable standards for paved public roads. The specific treatments for the 1.8 miles of county roads outlined in this report will need to be reviewed by County DPW staff on a site-by-site basis to ensure they meet current operating practices that are in place for similar treatments. It should also be noted that approximately 8% of the road length inventoried was on paved county maintained roads where engineers will likely need to be involved in the design of specific upgrade work. Extra costs could include safety flagging, painting, guard rails, etc. This could add a significant cost to completing the proposed work.

Table 9 lists a total of 697 hours for Asupervision@ time for detailed pre-work layout, project planning (coordinating and securing equipment, materials and obtaining plant and mulch materials), on-site equipment operator instruction and supervision, establishing effectiveness monitoring measures, and post-project cost effectiveness analysis and reporting. It is expected that the project coordinator and/or Contracting Officer=s Representative (COR) will be on-site full time at the beginning of the project and intermittently after equipment operations have begun.

G. Conclusion

The expected benefit of completing the erosion control and prevention planning work lies in the reduction of long term sediment delivery to Sulphur Creek, an important salmonid stream and contributing watershed to overall San Francisco Bay and Bay/Delta water quality. A first-step in the overall risk-reduction and water quality enhancement process is the development of a proactive plan for erosion prevention and erosion control on both public and private roads. In developing this plan, selected roads in the watershed are considered for either decommissioning or upgrading, depending upon the risk of erosion and sediment delivery to streams and the use of the road. Not all roads are high risk and those that pose a low risk of degrading aquatic habitat in the watershed may not need immediate attention. It is therefore important to rank and prioritize roads in each sub-watershed, and within each ownership, based on their potential to impact downstream resources, as well as their importance to the overall transportation system and to management needs. PWA can work with road managers to make recommendations that achieve both long term sediment delivery reduction as well as retaining road shapes and locations.

Table 9. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work on inventoried sites with future sediment delivery in the Sulphur Creek watershed assessment area, Napa County, California

Cost Category[1]		Cost Rate[2] ($/hr)	Estimated Project Times			Total Estimated Costs[5] ($)
			Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	
Move-in; move-out[6] (Low Boy expenses)	Excavator	100	4	--	4	400
	Dozer	100	4	--	4	400
Heavy Equipment requirements for site specific treatments	Excavator	165	326	98	424	69,960
	Dozer	140	295	89	384	53,760
	Dump truck	75	56	17	73	5,475
	Water truck	90	78	23	101	9,090
	Backhoe	85	4	1	5	425
	Pavement cutter	140	9	3	12	1,680
	Broom	55	18	5	23	1,265
	Roller	50	18	5	23	1,150
Heavy Equipment requirements for road drainage treatments	Dozer	140	67	20	87	12,180
	Backhoe	85	284	85	369	31,365
	Grader	110	63	19	82	9,020
	Dump truck	75	12	4	16	1,200
	Water truck	90	130	39	169	15,210
	Pavement cutter	140	16	5	21	2,940
	Broom	55	22	7	29	1,595
	Roller	50	23	7	30	1,500
Laborers[7]		40	687	206	893	35,720
Traffic control laborers		30	196	59	255	7,650
Rock Costs: (includes trucking for 586 yds^3 of road rock and 291 yds^3 of rip-rap sized rock)						26,310
Backfill Slurry Costs: (includes trucking and pouring for 334 yds^3 of backfill slurry)						31,730
Bridge costs (includes materials and flat car bridge)						20,000
Culvert materials costs (10' of 12", 40' of 15", 3,320' of 18', 2,160' of 24", 330' of 30", 70' of 36", 40' of 42", 210' of 48" and 120' of 54". Costs included for couplers, flared inlets and elbows)						77,224
Paving for 6,440 ft^2 @ $ 0.63/ft^2						4,057
Mulch, seed and planting materials for approximately 3 acres of disturbed ground[8]						1,650
Layout, Coordination, Supervision, and Reporting[9]		45 60 75	--	--	477 180 40	21,465 10,800 3,000

Table 9. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work on inventoried sites with future sediment delivery in the Sulphur Creek watershed assessment area, Napa County, California

Cost Category[1]	Cost Rate[2] ($/hr)	Estimated Project Times			Total Estimated Costs[5] ($)
		Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	
Total Estimated Costs					**$ 458,221**
Potential sediment savings: 22,501 yds[3]					
Overall project cost-effectiveness: $ 20.36 spent per cubic yard saved					

[1] Costs for tools and miscellaneous materials have not been included in this table. Costs for administration and contracting are variable and have not been included. Costs for replacing excavated striping and reflectors not included.

[2] Costs listed for heavy equipment include operator and fuel. Costs listed are estimates for favorable local private sector equipment rental and labor rates.

[3] Treatment times include all equipment hours expended on excavations and work directly associated with erosion prevention and erosion control at all the sites.

[4] Logistic times for heavy equipment (30%) include all equipment hours expended for opening access to sites on maintained roads, travel time for equipment to move from site-to-site, and conference times with equipment operators at each site to convey treatment prescriptions and strategies. Logistic times for laborers (30%) includes estimated daily travel time to project area.

[5] Total estimated project costs listed are averages based on private sector equipment rental and labor rates.

[6] Lowboy hauling for tractor and excavator, 3 hours round trip for one crew to areas within the Sulphur Creek watershed. Costs assume 2 hauls each for two pieces of equipment (one to move in and one to move out).

[7] An additional 48 hours of labor time is added for straw mulch and seeding post excavation at selected sites.

[8] Seed costs equal $6/pound for erosion control seed. Seed costs based on 50 lbs. of erosion control seed per acre. Straw costs include 50 bales required per acre at $5 per bale. Sixteen hours of labor are required per acre of straw mulching.

[9] Supervision time includes detailed layout (flagging, etc) prior to equipment arrival, training of equipment operators, supervision during equipment operations, supervision of labor work and post-project documentation and reporting.

Good land stewardship requires that roads either be upgraded and maintained, or intentionally closed (Aput-to-bed@). The old practice of Acrisis management@ and treating roads only when a flooding disaster happens, is no longer considered cost-effective or environmentally acceptable. Road upgrading consists of a variety of techniques employed to Aerosion-proof@ and to Astorm-proof@ a road and prevent unnecessary future erosion and sediment delivery. This requires a proactive investment in the basic infrastructure of the transportation network. Erosion-proofing and storm-proofing typically consists of stabilizing slopes and upgrading drainage structures so that the road is capable of withstanding both annual winter rainfall and runoff as well as a large storm event without failing or delivering excessive sediment to the stream system. In fact, many of the drainage structures (culverts) at inventoried stream crossings are nearing the end of their useful life. They are rusted out and beginning to fail through erosion and collapse of the fill. These will need to be replaced, and this presents an opportunity to upgrade the drainage structure with one that better meets today=s higher standards. Finding adequate funding to accomplish this upgrading of the road network will be a challenging task, but one that has rewards in terms

of lowered maintenance and storm damage costs, and increased protection to fish habitat and water quality throughout the watershed.

In identifying potential sediment sources along the county road system, PWA employed a standardized and accepted protocol for identifying, describing and quantifying erosion problems. However, in developing recommended treatments to address the various sediment sources, we employed a modified set of prescriptions that were formulated to be consistent with paved public roads standards. These can be changed globally in the database to provide a revised treatment prescription and/or cost estimate.

With this prioritized plan of action, various private landowners and Napa County Public Works staff can work with the Napa County RCD to obtain funding to implement the proposed projects. However, watershed assessment inventories should be conducted on upland roads, both driveable and abandoned, in the remainder of the Sulphur Creek watershed. This will permit us to continue to refine the prioritization of which sites throughout the watershed pose the most critical threats to water quality, aquatic habitat and salmonid recovery, as well as allow us to know we are spending the limited available restoration funds on the highest priority work sites.

VI. Sulphur Creek tributary stream channel assessment

Approximately 1.5 miles of tributary stream channel was inventoried to identify past and current sediment sources that deliver sediment to Sulphur Creek (Map 8). Tributary channels inventoried in the assessment were chosen based on cooperating landowner access and their ranking as a USGS blue line stream.

The goals of the limited tributary assessment were three fold: 1) to evaluate the general condition of stream banks throughout the tributary reaches, 2) to document the dominant processes, causes and magnitude of sediment production along tributary stream side slopes, and 3) to determine general recommendations for effective erosion control or erosion prevention treatment (e.g. stream bank protection, re-vegetation efforts or modification of land use practices) that could be employed to reduce erosion and sediment delivery to the mainstem and tributary channels of Sulphur Creek.

USGS topographic maps at a 1:12,000 scale were used as base maps to record tributary stream channel observations. Two (2) tributary stream reaches (1.0 mile) located in Sulphur Canyon and one (1) tributary stream reach (0.5 mile) located in Heath Canyon were inventoried in the assessment (Map 8).

Sites of past, currently active and future erosion and sediment delivery were identified in the tributary channel assessment. To be inventoried, sites had to have a minimum of 20 yds^3 of past and/or future erosion and sediment delivery. Each site greater than or equal to 20 yds^3 was assigned a unique site number and was quantified and described using a stream channel inventory data form (Figure 7). Sites less than 20 yds^3 were not inventoried, but were tallied and were mapped on the field base maps. Sites greater than or equal to 20 yds^3 were digitized into Arcview GIS and attribute information was entered into a relational database.

Erosion assessment protocol

The assessment identified most of the localized, larger volume on-going and potential sediment sources along the tributary channels that were inventoried. There was some active bank erosion that was not quantified because it was spread out over long reaches with a relatively small volume (<20 yds^3) in any one localized area. These sites were tallied and mapped on the base maps, but were not inventoried in the field assessment. The following information about each site was collected on a PWA stream inventory data form (Figure 7).

Bank location: Location of the site includes left bank, right bank, or both.

Problem: Problem types identified in the tributary assessment included debris slides, bank erosion, gully erosion, channel incision and Aother@ miscellaneous types of erosion.

Past, Future, Both: Did the erosional feature already fail, will it fail in the future, or has it already failed and have the potential to erode further in the future?

Activity: The activity was documented as active, waiting or inactive. Debris slides with active bank erosion undercutting their toes were listed as active. Those without significant active undercutting but with some future potential were listed as waiting.

Age of erosion: The age of the erosional feature by approximate decade(s) of occurrence.

Figure 7. Stream channel inventory data form used in the Sulphur Creek tributary stream channel assessment

PWA Stream Inventory Data Form (PWA version 1/03)						
General	Site #:	Date:	Mappers:	Air Photo:	Watershed:	Stream:
	Bank (L/R)	Treat?(Y)				
Problem	Debris slide	Bank erosion	Channel incision	Gully	Other	
	Past, future, both	Activity (A, W, IA)	Age (decade):	Hillslope (%):	Land use:	Undercut (Y)
Erosion	Past width:	Past depth:	Past length:	Past vol:	Past del (%)	Past yld (yds):
E.P.:	Future width:	Future depth:	Future length:	Future vol:	Future yld(%)	Future del:
Treatment	Immed: (H,M,L)	Complexity: (H,M,L)	Equipment or labor (E, L, B)		Eqpt access: (Easy, Moderate, Difficult)	
	Excavate soil(Y)	Rock armor/buttress	Log protection (Y)		Remove logs/ rocks/debris (Y)	
***Hours*:**	Excavator:	Dozer:	Dump truck:	Backhoe:	Labor:	Other:
Excavate, buttress, plant area		yds^3	ft^2		Effectiveness (H, M, L)	
Comment on Problem:				Sketch:		
Comment on Treatment:						

Hillslope gradient (%): Gradient of hillslope at feature location.

Land use: Land use classification at site of erosional feature including grazing, viticulture, rural residential and no apparent management

Undercut?: Was the erosional feature caused by stream undercutting?

Volumes: Quantifying erosional features, both past and future, includes an element of professional judgement. Estimation of erosional activity and past and/or future volumes of bank erosion is based on considering factors such as:

1) location (is the site on a relatively straight reach or on the outside of a tight meander bend?);
2) average channel width;
3) stream energy; influenced by the size of the stream, stream gradient, obstructions and their orientation(s), degree of channel constriction and confinement;
4) height of bank or banks being eroded;
5) composition and resistance of the materials in the bank to erosion;
6) presence or absence of natural armor.

Estimation of past and/or future volumes of debris slides is based on considering the geomorphology of the potential slide area and includes factors such as:

1) slope shape; (concave, convex, or planar)
2) break-in-slope; may indicate likely limit of slide or may extend up slope further; and
3) slope gradient or gradients if breaks-in-slope are present;

The estimation of past and/or future bank erosion volumes also depends upon the time frame one is considering. In this survey, a 30 to 50 year time frame was envisioned.

Erosion potential: The erosion potential (likelihood of future erosion) was listed as high, moderately high, moderate, moderately low, or low taking into account the factors previously noted.

Treatment Protocol

Sites were either listed as Atreat@ or Anon-treat@ depending on the individual circumstances. Many sites with past and/or active erosion and sediment delivery were considered non-treat sites due to access limitations, a potential for low effectiveness for the possible treatments, or a potential for aggravating or shifting erosion to adjacent areas. Possible treatments include excavations, armoring, buttressing, riparian enhancement, exclusionary fencing and reshaping stream banks.

Treatment immediacy: The subjective answer to this question lets you decide if the work needs to get done immediately or at a later time. It is analogous to “priority” but it also implies the urgency. Is the feature falling apart and going to change dramatically this coming winter? Does erosion at this site seriously threaten important downslope or downstream resources (e.g. spawning or rearing areas)? This answer is based on the severity of the potential erosion, its volume, its predicted activity level and the sensitivity of the resources at risk. Answered as High, Moderate or Low, the answers can also include combinations, such as HM or ML to cover sites where the answer is not clear-cut.

Estimated costs to implement treatments on tributary assessment sites are not included in this report. The tributary assessment was conducted along sample reaches of tributary channel in order to determine general erosion control and erosion prevention treatment recommendations for the typical problems identified along inventoried tributary reaches, not to develop a specific erosion control and erosion prevention treatment plan.

Results

Table 10 summarizes the erosion types and sediment delivery volumes inventoried along tributary reaches in the Sulphur Creek watershed. A total of twenty-five (25) sites with >20 yds^3 of past and/or future erosion and sediment delivery were documented along the 1.5 miles of inventoried tributary stream channel reaches. It is estimated that approximately 1,922 yds^3 of sediment have been delivered to Sulphur Creek and its tributaries from the 25 inventoried sites and approximately 572 yds^3 is expected to be delivered to streams in the future. Approximately 72% (n=18) of sites were classified as debris landslides, 24% (n=6) were classified as bank erosion and 4% (n=1) were classified as gully erosion.

Debris slides were the dominant sources of sediment input to inventoried tributaries in Sulphur Creek from sites >20 yds^3. We estimate that approximately 1,488 yds^3 of sediment have been delivered to Sulphur Creek and its tributaries in the past from the 18 debris landslide sites and approximately 488 yds^3 could be delivered the stream system in the future. Approximately 404 yds^3 of sediment have been delivered in the past from the 6 bank erosion sites and approximately 72 yds^3 of sediment is expected to be delivered to Sulphur Creek and its tributaries in the future (Table 10).

Table 10. Past and future sediment yield and erosion type for sites inventoried in the in-stream tributary assessment, Sulphur Creek watershed, Napa County, California

Stream Name and Reach	No. of miles (mi)	Debris slides			Bank erosion			Gully			Sites <20 yds^3	
		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Past sediment delivery (yds^3)[2]
			Past	Future		Past	Future		Past	Future		
Sulphur Canyon A	0.5	5	365	62	1	26	2	0	0	0	20	200
Sulphur Canyon B	0.5	8	452	220	3	332	41	1	30	11	19	190
Heath Creek A	0.5	5	671	206	2	46	30	0	0	0	32	320
Totals	**1.5**	**18**	**1,488**	**488**	**6**	**404**	**73**	**1**	**30**	**11**	**71**	**710**

[1] Inventoried sites of estimated future sediment delivery which exceed 20 yd^3

[2] Past sediment delivery for sites less than 20 yds^3 are estimated at 10 yds^3 each based on field observations. Future erosion for sites less than 20 yds^3 was not estimated in the field. Full assessment was only conducted on sites >20 yds^3.

Seventy-one (71) sites with less than 20 yds^3 of past and/or future erosion and sediment delivery were identified in the tributary stream channel assessment in Sulphur Creek. Approximately 710

yds^3 of sediment was estimated to have been delivered to Sulphur Creek and its tributaries from these smaller sites. The majority of less than 20 yds^3 sites include short reaches of bank erosion and small debris slides (Table 10).

Table 11 summarizes inventoried sites greater than 20 yds^3 with past and/or future sediment delivery by land use association. Approximately 60% (n=15) of the inventoried sites in the tributary stream channel assessment had no apparent management cause of past and/or future sediment delivery to Sulphur Creek or its tributaries. Approximately 40% of the tributary stream channel assessment sites were spatially associated with viticulture. The sites were located along the Sulphur Creek B tributary reach. Approximately 38% (0.19 miles) of the tributary reach flows along the base of a vineyard. Sulphur Creek tributary A and Heath Creek Canyon A were located in areas of no apparent land use.[1]

Inventoried sites with no apparent management or land use association represent 65% (1,244 yds^3) of the total past erosion and sediment delivery from inventoried tributary stream channel sites and 55% (316 yds^3) of the potential future erosion and sediment delivery. Approximately 35% (678 yds^3) of past erosion and sediment delivery and 45% (256 yds^3) of future erosion and sediment delivery from stream channel sediment sources is associated with viticulture. These land use associations may or may not represent causal relationships. In addition, these sediment delivery volumes do not include erosion volumes from other sediment sources, such as gullying, rilling or surface erosion, on the adjacent hillslopes.

Table 11. Past and future sediment yield and land use association for sites[1] inventoried in the in-stream tributary assessment, Sulphur Creek watershed, Napa County, California

Stream Name and Reach	Viticulture			No management cause			Total		
	(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)	
		Past	Future		Past	Future		Past	Future
Sulphur Canyon A	0	0	0	6	391	64	6	391	64
Sulphur Canyon B	10	678	256	2	136	16	12	814	272
Heath Creek A	0	0	0	7	717	236	7	717	236
Totals	10	678	256	15	1,244	316	25	1,922	572

[1] Inventoried sites of estimated future sediment delivery which exceed 20 yd^3

[1] Because the sampling plan was based on access permission, rather than on statistical parameters, the frequency and volumetric yield associated with various land uses should not be generalized throughout this watershed, or extended to other drainage basins.

Of the twenty-five (25) sites inventoried in the tributary stream channel assessment, 6 were recommended for erosion control and erosion prevention treatment. The primary deciding factor for treating the 6 sites was available access for equipment and materials. The remaining 19 sites were not recommended for treatment due to difficult access and poor cost-effectiveness. Sites recommended for treatment have potential to deliver approximately 145 yds^3 of sediment to Sulphur Creek and its tributaries and are currently showing signs of instability. The general recommendations for treating sites inventoried in the tributary stream channel assessment include excavating soil at debris landslides, gully erosion and bank erosion locations, rock armoring at the toe of debris landslides and along areas of bank erosion, and planting riparian enhancement along bare areas of the tributary channels.

IV. Non-Point Sediment Source Sampling

A field evaluation of non road-related non-point sources of sediment was also conducted by PWA staff in January 2003 to identify other land use practices that may be contributing sediment to Sulphur Creek and its tributaries. The field evaluation focused on sampling areas utilizing the following land use practices: 1) reservoirs, 2) viticulture and 3) rural residential development.

Grazing activities occurred in the historic past of the Sulphur Creek watershed and very little grazing activity is currently occurring in the basin. Hillslopes and grasslands located in areas of historic grazing show no related erosion and sediment delivery. PWA did not evaluate grazing activities in the Sulphur Creek watershed as part of the hillslope/tributary sediment source assessment.

This section of the report discusses the observations and possible solutions for land use practices being used in the Sulphur Creek watershed that were locally observed to be causing erosion and sediment delivery. As such, it represents a non-statistical, observational sampling at a single point in time.

A. Reservoirs

Initially, reservoirs were not considered as a unique land use activity in developing the strategy to evaluate non road-related non-point sediment sources in the Sulphur Creek watershed. After field reconnaissance, it was apparent that reservoirs might be having a locally important impact on Sulphur Creek and its tributaries, both beneficial and negative.

There are 2 basic types of small reservoirs in the Sulphur Creek watershed, including: 1) on-stream reservoirs and 2) off-stream reservoirs. On-stream reservoirs are built directly in the line of the natural stream channel and are fed by upstream surface flow. Off-stream reservoirs are built on hillslopes or other locations outside of the stream channel and are fed by diverted stream flow or other water sources, such as springs, subsurface pipe flow, diverted road ditches, or water pumped from an outside location.

Depending on reservoir construction and maintenance, both types of reservoirs can have negative impacts on the stream system. On-stream reservoirs can prevent the migration of salmonids and resident fish in some watersheds, as well as negatively impact water quality and the stream processes necessary to maintain aquatic habitat (SWRCB, 2001). On-stream reservoirs can

reduce stream peak flows by intercepting and retaining storm flow until the reservoir reaches its maximum capacity. Reservoirs can also trap sediment from upstream areas, and prevent this sediment from impacting downstream habitat.

Off-stream reservoirs are built on hillslopes or other locations outside of the stream channel and are fed by diverted stream flow or other water sources, such as springs, subsurface pipe flow, diverted road ditches, or water pumped from an outside location.

Air photos from 2002 were analyzed to identify the location and surface area extent of reservoirs in the Sulphur Creek watershed. Reservoir locations were mapped on a USGS topographic map and spatially digitized into Arcview GIS. Attribute information regarding surface area and location in relation to blue line streams was collected and entered into an Excel spreadsheet.

Ten (10) small reservoirs were identified in Sulphur Creek from the air photo analysis. Reservoirs constitute less than 1% (12.6 acres) of the total watershed area in Sulphur Creek. Reservoir surface areas range from 0.3 to 2 acres.

Six (6) of the 10 reservoirs in the watershed were classified as on-stream reservoirs. Because we did not field inventory all reservoirs in the Sulphur Creek watershed, reservoirs were classified during the air photo analysis as “on-stream” if they were located in the course of a USGS “blue line” stream. If a reservoir was not in line with a “blue line” stream, it was classified as an off-stream reservoir. Some off-stream reservoirs were located in drainages that were not delineated with a USGS blue line stream. These reservoirs may actually intersect small streams that are not designated blue line on the USGS topographic maps.

Observations

Five (5) of the 10 reservoirs (50%) were evaluated in the field to identify potential problems that may affect water quality, aquatic habitat and fish habitat.

On-stream reservoir inlet types included open stream channels and culverted streams. Off-stream reservoir inlets were typically constructed with small pipes (<10”) that deliver pumped or diverted water to the reservoir. On-stream reservoir inlets that were fed directly from the stream channel typically formed sediment fans in the inlet areas. Areas near the inlet sediment fans were typically vegetated with hydrophyllic vegetation. The sediment fans and vegetation did not appear to cause any problem or blockage to the inflow of water into the reservoir.

Off-stream reservoirs fed by spring flow or other water sources were typically controlled by manual or float controlled inflow valves. It is much easier to control the amount of inflow to off-stream reservoirs as opposed to on-stream reservoirs. On-stream reservoirs are continually receiving stream flow because of their location in the stream channel.

Outlets of reservoirs typically consisted of armored spillways, downspouted culverts or culverts installed at some depth in the reservoir fill dam. Reservoir outlets were the most dominant erosion source from reservoirs evaluated in the field. The most severe erosion from reservoirs was from reservoirs where flow was discharged from culverted outlets onto steep unprotected hillslopes causing very large gullies that deliver eroded sediment directly to the stream system.

On-stream reservoirs with culverted outlets located at some depth in the reservoir fill experienced the least erosion as compared to on-stream or off-stream reservoirs with spillway outlets.

Two reservoirs assessed in the Sulphur Creek watershed did not have emergency overflow spillways or culverted outlets. These reservoirs depended on automated inflow/outflow valves that regulate the amount of water into and out of the reservoir. It is possible that if a mechanical failure occurred, reservoirs could fail and thereby deliver large volumes of sediment to the stream system.

In general, reservoirs act as large, effective sediment retention traps, allowing the majority of bedload and suspended sediment carried by stream inflow to settle out before flow is released into the natural stream channel. As mentioned earlier, on-stream reservoirs develop sediment fans at the reservoir inlet. Sediment fans are typically caused by the change in gradient and stream velocity at the reservoir inlet. Reservoirs can be used as sediment retention dams only if they are monitored and dredged when they become filled with sediment. Reservoir infilling can result in lowered reservoir capacity and an increase in the likelihood of overtopping and failure.

Possible Solutions

1) Reservoir inlet and outlet culverts should be designed to pass the 100-year storm flow. Reservoirs that utilize mechanical drains should also be able to pass 100-year storm flow. Values for the 100-year discharge should include the reservoir contributing area that has been diverted to the reservoir.

2) Effective emergency overflow spillways should be designed for the majority of reservoirs in the Sulphur Creek watershed. Effective spillways include overflow pipes that are down-spouted to natural stream channels or to low gradient slopes. Other effective spillway designs include concrete or rock armored spillways that extend to the base of the reservoir and have energy dissipation at the base of the spillway.

3) Reservoir spillways that are currently eroding should be upgraded to prevent future erosion and sediment delivery to Sulphur Creek and its tributaries.

4) Flow from road ditches can be conveyed to reservoirs via culverts. Road surface and ditch flow can be another water source for reservoirs. In addition, the reservoir can act as a sediment retention trap for chronic fine sediment from the road surfaces and ditches.

5) Reservoirs should be regularly monitored for sediment infilling, inlet and outlet culvert condition, erosion features, dam integrity and spillway condition.

B. Viticulture

As discussed in the land use section (IV-B) of this report, viticulture practices have been employed in the Sulphur Creek watershed since before the earliest air photo set taken in 1940. The land use history demonstrates that vineyard development increased from nearly 15 acres to approximately 495 acres between 1942 and 2002, respectively. Vineyard development has occurred primarily through the conversion of general agricultural and grazing lands. The

majority of vineyards are situated in the upland areas of Sulphur Canyon and in the small sub-basin to the north of Sulphur Canyon (Maps 2-4).

In the upland areas of Sulphur Creek, vineyards were placed in the grassland areas dominated by Franciscan mélange geology. This terrain tends to be very saturated and is locally prone to mass wasting processes. High groundwater tables in the upland areas of Sulphur Canyon make it a prime location for vineyard development. The manipulation of the landscape to develop vineyards and the diversion of subsurface flow and surface runoff has resulted in localized erosion and sediment delivery to Sulphur Creek and its tributaries.

In general, most erosion attributed to vineyards occurs during the first three (3) years after vine planting. This includes vineyards that have been replanted. Each year care is taken to apply adequate erosion control measures such as straw mulch and seeding in the fall after planting to reduce surface erosion. In addition, off-season cover crops are often planted into the vineyards between vine rows in the fall to protect the ground surface during the rainy season.

Vineyards in Sulphur Creek have an intricate system of subsurface drainage pipes and storm drains used to collect water and disperse it off of the vineyard surfaces or to divert it for irrigation uses (i.e. reservoirs). Specific regulations, as part of the required erosion control plans, are in place to regulate the collection and dispersion of storm water in and out of the vineyard. There are no specific regulations regarding subsurface pipe systems that collect and disperse subsurface flow.

In general, access to vineyards is through a network of vineyard avenues. Vineyard avenues support the traffic of large trucks and heavy equipment. These compacted avenues are subject to a large quantity of surface flow from the vineyard plots. Typically, vineyard avenues are unsurfaced and unvegetated, and are subject to chronic surface erosion, rilling and gullying. Avenues located below vineyard plots and immediately adjacent to streams can be significant sources of erosion and sediment delivery.

Current Regulations

Regulations regarding erosion control are imposed on viticulture activities by the County and are aimed at preventing erosion on vineyard plots. Regulations restrict vineyards from being developed on excessively steep slopes, define setbacks from intermittent and perennial streams by slope gradient, and mandate an erosion control plan be approved by the County for vineyards on slopes equal to or greater than 5%. Regulations also require an erosion control plan be submitted to the Napa RCD for all vineyard re-plantings that involve grading. In addition Section 12460.5 states that no one shall cause/allow continued existence of substantial erosion due to human-induced alteration.

Observations

PWA staff reviewed 5 vineyard plots in the Sulphur Creek watershed to document practices that may be contributing sediment to steams. This reconnaissance investigation was meant to be a sampling of practices and activities over a short period of time, and not a comprehensive review of land management practices associated with vineyard development or management. The five vineyard plots observed in the watershed ranged in size from approximately 3 acres to 20 acres.

Vineyard slopes in the Sulphur Creek watershed ranged from approximately 10% to 35%. The majority of the vineyards in the watershed have vine rows oriented parallel to contour. Very few vineyards have vine rows planted perpendicular to contour. Rilling and minor gullying was noted along vineyard rows planted perpendicular to contour at the beginning of the wet season and prior to cover crop growth. Rilling and gullying was more prominent on steeper vineyard slopes (>10%). Once cover crops were established rilling and gullying were significantly reduced in the majority of the vineyards observed.

Vineyards planted in steep areas of Sulphur Creek were constructed with approximately 4' -6' wide contoured terraces with near-vertical terrace faces. In very steep terrain (>20%), some contoured terraces developed minor failures along the outside terrace edge. The majority of the material from failed terrace scarp edges typically collects at the base of the terrace below and does not deliver to a stream. In some locations, unstable terrace edges were buttressed with 0.25' – 0.75' diameter rip rap rock. Any sediment delivery from failed vineyard terraces is a result of transport via surface erosion and rilling to drainage pipes on vineyard slopes that then deliver the eroded sediment to the stream.

Vineyards typically have a network of drainage pipes that convey storm water and in some cases stream flow, away from the vineyard plots. The frequency of drainage pipes used in vineyards is dictated by the steepness of the vineyard plots. Low gradient vineyard plots had few subsurface drainage pipes. In the low gradient plots surface flow and surface erosion was observed to be minimal.

Typically, drainage pipes in vineyard plots were 12" in diameter with drop inlets set nearly flush with the ground surface. In low and moderate gradient vineyards, pipes were placed at irregular intervals in the center of the plots. In steep vineyards, drainage pipes were installed at higher frequency in the center of the vineyard plots and along the vineyard plot edges.

Vineyard subsurface drainage pipes generated the most erosion and sediment delivery associated with viticulture practices in Sulphur Creek. Surface erosion and rilling along the vineyard plots is typically captured by the drainage pipes and conveyed downslope, in some cases for hundreds of feet. Many of the drainage pipes discharge flow in or just above stream channels at the base of vineyard plots. In some locations, drainage pipes that were discharged above natural stream channels caused stream bank collapse and/or gullying. In other locations, downspouts were attached to culverts showing past erosion to reduce or eliminate future erosion. Pipes with outlets that extend completely into the stream channel caused little or no erosion. Whether or not flow was discharged above or in the stream channel, some volume of fine sediment was delivered to the stream channel from the vineyard plots, and in some cases this outflow caused the development of small fans of fine sediment in the stream.

Vineyard avenues typically displayed the same general problems as those associated with unpaved rural road systems. Generally, vineyard avenues were unsurfaced and had very few surface drainage structures. Temporary surface drainage structures such as water bars were the most common drainage structures employed to drain vineyard avenues. Typically, vineyard avenues collected long sections of vineyard avenue surface flow and vineyard surface flow from hillslopes above. This resulted in large amounts of surface erosion and rilling of the avenue

surface. Vineyard avenues located below vineyard plots and adjacent to streams posed the greatest risk for erosion and sediment delivery, because they were so close to the channel. Erosion and sediment delivery from concentrated runoff along the vineyard avenues was caused by gullying at the outside edge of the avenue or hillslope. Gullies that formed above streams typically resulted in streamside bank failures.

Possible Solutions

1) Vineyard drainage culverts that discharge onto slopes above streams should be down-spouted to the stream.

2) Vineyard drainage pipes could drain to sediment retention basins or reservoirs as a method of sediment and water collection. Sediment retention devices should be constructed to retain fine sediment from vineyard drainage culverts that currently discharge directly to stream channels.

3) Vineyard avenues should be drained at regular intervals using more frequent water bars or other surface drainage structures.

4) Vineyard avenues that are not used in the off-season (winter) should be planted with cover crops to prevent surface erosion, rilling and gullying caused by winter runoff.

5) Vineyards should not be planted perpendicular to contour if slopes drain directly to a stream (without room for a sediment retention structure or basin).

6) Stream setbacks should be strictly adhered to and existing stream bank conditions should be evaluated prior to installation and replanting.

7) Vineyard plots over 5% gradient should be planted with a cover crop prior to the winter period.

C. Rural residential development

As discussed in the land use section (IV-B) of this report, rural residential development has occurred in the Sulphur Creek watershed since before the earliest air photo set taken in 1940. The land use history demonstrates that rural residential development increased from approximately 21 acres to nearly 104 acres of the total watershed area between 1940 and 2002. Rural residential development has occurred primarily through the conversion of general agricultural and grazing lands. The majority of rural residential development in the Sulphur Creek watershed assessment area has occurred in the small un-named sub-basin located to the north of Sulphur Canyon and in the lowland area immediately adjacent to this small sub-watershed. Other residential development has occurred sporadically along the mainstem and in the upland areas in Sulphur Canyon. Rural residential development in the upper portions of Sulphur Canyon is associated with vineyard development.

To accurately assess the effects of rural residential development, active construction must being occurring on the landscape to determine specific causes or practices that may be contributing sediment to streams. Unfortunately, no active rural residential activity was observed in the watershed assessment area. At best, only established residences were observed in Sulphur

Canyon. Established rural residential areas showed no obvious signs of erosion and sediment delivery to streams. Access to rural residential properties in the un-named sub-basin north of Sulphur Canyon was not granted for this assessment and therefore they were not evaluated.

Observations

In other adjacent watersheds, the most common on-site effect of rural residential development has been caused by stream diversion and driveway or land access route drainage problems. Stream diversion is common in locations were landowners build a home in the line of a small stream channel or on an alluvial fan. Diversion ditches are constructed to convey flow around home sites. These drainage structures may convey flow back into the natural stream channel or divert stream flow down the road to another location. Diverted streams can cause erosion and sediment delivery from flow overtopping diversion ditches or from gullying the ditch, road surface or hillslope if it is diverted.

The most visibly common on-site problem associated with erosion and sediment delivery from rural residential development is from long, poorly drained sections of rural driveways and property access roads. Commonly, these roads have extensive surface erosion such as sheet, rill and gully erosion that is left to drain to county or private drainage structures downslope or down road. This becomes a maintenance issue for downslope or down road property owners.

In studies elsewhere, one off-site effect of residential development has been the increase in small stream peak flows associated with increases in impervious areas (roofs, driveways, etc.) and resultant surface runoff resulting from development. These off-site effects have not been reported in Sulphur Creek but they may be a factor in increased rates of gullying, channel downcutting and bank erosion in small and medium size channels in the watershed. Additional analysis would need to be performed to identify the location and magnitude of these possible effects.

Possible Solutions

1) Avoid constructing homes or structures within the 100-year flood zone of of stream channels (even small stream channels)

2) Rural residential driveways and access roads should follow the same guidelines as outlined in Section V of this report, and as outlined in the “Handbook for forest and ranch roads” (PWA, 1994) for the road-related sediment source assessment.

IX. Relative magnitude and implications of sediment production in Sulphur Creek

The sediment source assessment conducted in the Sulphur Creek watershed was not designed as a comprehensive sediment budget. The sediment source assessment involved the sampling of past sediment sources such as mass wasting and gullying through air photo analysis, a systematic field inventory of current and potential (not past) road-related sediment sources and a sampling of non road-related sediment sources from a variety of current management activities such as viticulture, rural residential development and reservoir development. A complete sediment

budget for the Sulphur Creek watershed was beyond the scope outlined in the sediment source assessment.

In spite of this limitation, an approximation of the relative magnitude of the main sediment sources was determined from the sediment source assessment data. This approximation is based on past sediment delivery from several sediment sources including vineyard surface erosion, grazing surface erosion, surface erosion from "other" agricultural activities, debris landslides (mass wasting), road-related persistent surface erosion and gullying, mainstem and tributary bank erosion, and deep-seated landslides or earthflows. We did not include past erosion from rural residential development. The rate of rural residential development activity in the watershed is and has been relatively low. Most of these development activities would have occurred during the dry season and it is assumed that adequate erosion control measures were in place during construction activities and resulting sediment delivery was minimal.

Figure 8 illustrates the distribution and proportions of major sediment sources and sediment delivery in the Sulphur Creek watershed. Past volumes of erosion and sediment delivery from sediment sources were determined from a variety of methods based on the erosion type.

Roads -Past road-related erosion was determined from persistent road surface erosion and road-related gullies. The estimate of past road-related erosion and sediment delivery is a minimum value because it does not include past stream crossing washouts and small road-related landslides. The road inventory was designed to identify current and future road-related erosion and sediment delivery and to develop a prioritized erosion control and erosion prevention treatment plan to treat controllable road-related erosion. It was not designed to quantify the magnitude of past sediment sources.

Although, the inventory was not designed to quantify past volumes of road-related erosion and sediment delivery, some estimates have been developed. The assessment of future road-related sediment sources suggested that chronic surface erosion was an important sediment source. The estimate of chronic road surface erosion and sediment delivery is based on the following assumptions: 1) for native and rocked surface roads, the road surface was lowered approximately 0.2' per decade based on mechanical breakdown of the road surface through vehicle use and climatic conditions (rainfall and runoff) and 2) on paved sections of road it is assumed that the cutbank and ditch was lowered by 0.2' per decade from a variety of causes such as surface erosion, dry ravel, cutbank failures, etc.

Past volumes of road-related persistent surface erosion were determined from total length of road contributing to streams within the watershed, based on current levels of hydrologic connectivity. The estimate of chronic road-related surface erosion and sediment delivery is projected over a 50 year period to correspond with the earliest age of air photos used in the air photo analysis. This is a minimum estimate because it is assumed that more of the road mileage in the watershed was connected to streams in the past.

Past erosion and sediment delivery of road-related gullies was estimated from air photo analysis of the 1940, 1985 and 2002 air photos. This estimate is also a minimum value due to 1) the large scale of the aerial photos (1940: 1:20,000, 1985: 1:24,000, 2002: 1:24,000) and 2) the large gap

between air photo periods used in the analysis. Gully systems can vary in size and many are very small features that would have been difficult to identify on the aerial photography used in the analysis. In addition, more gullies could have developed on the landscape, but were not visible due to the 45 year gap between the 1940 and 1985 air photo periods and the 17 year gap between the 1985 and 2002 air photo periods.

Approximately 52,800 yds^3 of past erosion and sediment delivery from road-related chronic surface erosion and gullies was estimated over the last 50 years. This represents 9% of the total estimated past sediment delivery from sediment sources in the Sulphur Creek watershed (Figure 8).

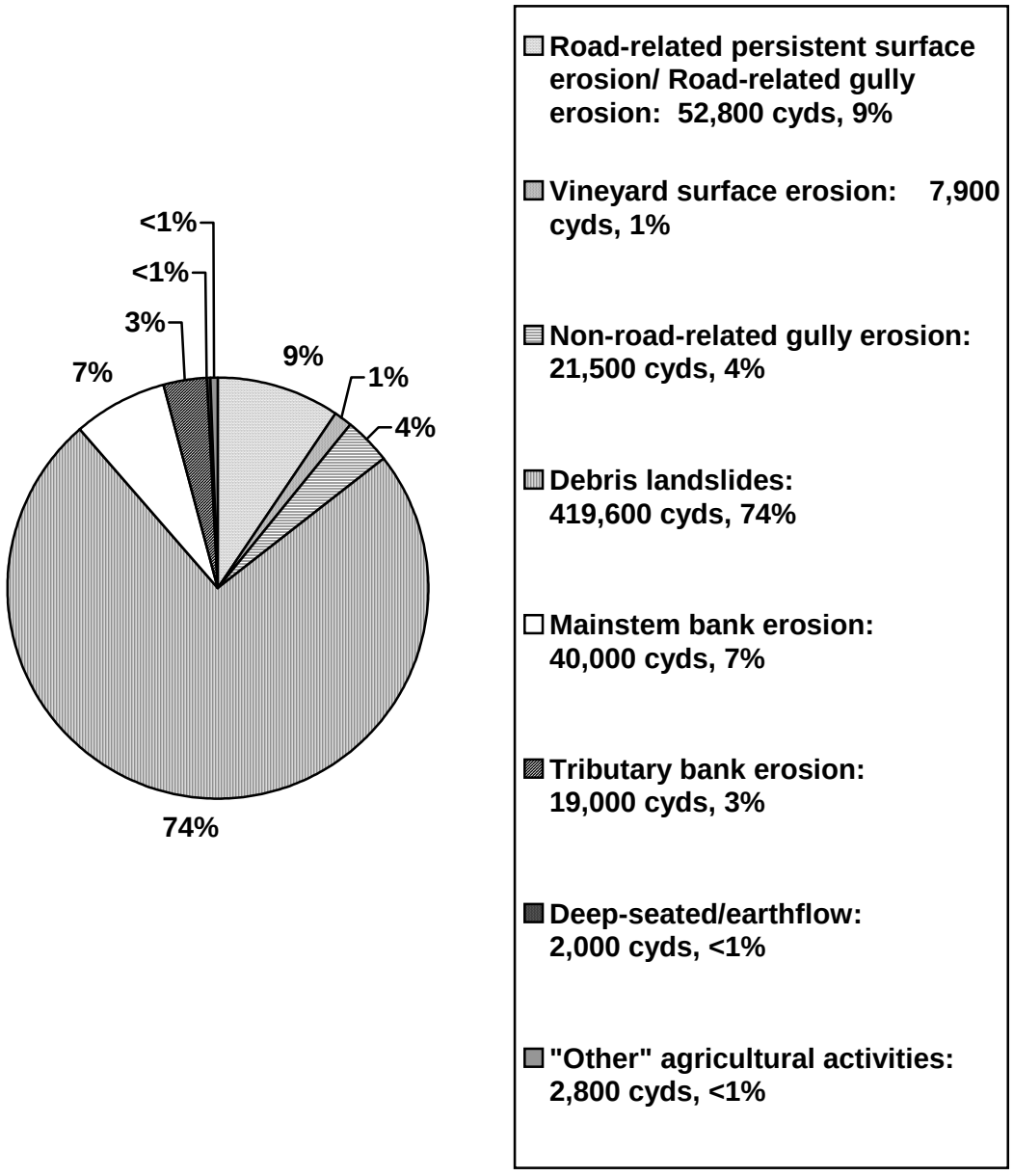


Figure 8. Sediment sources and sediment delivery in the Sulphur Creek watershed.

Vineyards and "other" agriculture - Past erosion and sediment delivery from vineyard surface erosion and "other" agricultural surface erosion was estimated using soil loss rates applied to vineyard and "other" agricultural areas identified in the air photo analysis of land use history. According to studies conducted by the NRCS between 1985 and 1990, average soil loss rates were estimated at 14 tons/acre/year. We estimated that approximately 10% of the annual soil loss generated on vineyard and "other agricultural areas would have been delivered to the stream system. This resulted in a rate of 1.4 tons/acre/year annual soil loss delivered to streams. This estimate was applied to average vineyard and agricultural areas identified between the 1940 and 1985 air photo periods and a portion of the average vineyard and agricultural areas identified between the 1985 and 2002 air photo periods.
Due to concerns regarding soil loss and water quality impacts, the Hillside Ordinance (Conservation Regulations, or Ordinance 991) was put into effect in 1991. Studies since the Hillside Ordinance was enacted show a dramatic decrease in soil loss. In order to determine a current rate of soil loss in the Sulphur Creek watershed, the Universal Soil Loss Equation (USLE) was used and applied to the remaining average areas identified between the 1985 and 2002 air photo periods. The USLE equation is defined as:

$$A = R \times K \times LS \times C \times P$$

where A = soil loss (tons/acre/year)
R = rainfall erosion index
K = soil erodibility factor
LS = slope length and steepness factor
C = vegetative cover factor
P = erosion control practice factor

The Sulphur Creek watershed assessment area was characterized by soil type (Lambert and Kashiwagi, 1978) and slope gradient to determine values of K and LS. Based on current conditions observed in the watershed an average value of annual soil loss was calculated to be approximately 8 tons/acre/year. Assuming 10% of the total soil loss would be delivered to streams, an average annual soil loss delivered to streams was estimated to be 0.8 tons/acre/year.

Approximately 7,900 yds^3 was estimated to have been derived from vineyard surface erosion, accounting for nearly 1% of the past sediment delivery from past sediment sources in the Sulphur Creek watershed (Figure 8).

It is estimated that approximately 2,800 yds^3 of past sediment delivery was a result of "other" agricultural activities representing less than 1% of the total sediment delivery from past sediment sources.

Debris landslides- Past sediment delivery from debris landslides was determined from air photo analysis of the 1940, 1985 and 2002 air photos as outlined in the Landslide History section (V-C) of this report. As mentioned previously, this is a minimum estimate due to the large scale of the aerial photography and the large gaps of time between air photo periods. More debris landslides could have occurred during air photo period gaps. It is estimated that 419,600 $cyds^3$ of past sediment delivery occurred from debris landslides in the Sulphur Creek watershed. This

represents 74% of the total past sediment delivery from past sediment sources (Figure 8). Fifty percent of the past erosion and sediment delivery associated with debris landslides originated from one large composite landslide identified in the 1940 air photo set.

Mainstem channel erosion- Mainstem bank erosion was estimated from work conducted by SFEI as part of the Channel Geomorphology section of the Sulphur Creek Management Plan. SFEI measured bank erosion along several "strata" or reaches along the mainstem of Sulphur Creek and Heath Canyon. Average rates of bank erosion were estimated by SFEI for each measured "strata" or reach. These rates were extended to the watershed assessment area (53,300 feet of stream) and resulted in approximately 40,000 yds^3 of past erosion and sediment delivery to Sulphur Creek. This represents approximately 7% of the total past sediment delivery from sediment sources within the watershed.

Tributary channel erosion- Tributary erosion was estimated from the tributary stream channel assessment conducted by PWA. The tributaries in Sulphur Creek were divided into 3 type-areas based on location, with 2 areas located within Sulphur Canyon (Sulphur Canyon A and Sulphur Canyon B) and 1 area located within Heath Canyon. PWA conducted sample tributary assessments in these areas to identify bank erosion and small landslides.

Average rates of tributary bank erosion were estimated for each tributary location. The average rates of bank erosion for Sulphur Canyon A, Sulphur Canyon B and Heath Canyon are 0.07 yds^3/ft, 0.2 yds^3/ft and 0.12 yds^3/ft , respectively. Each rate was applied to the entire length of tributaries in each sample tributary reach area (total tributary length = 153,100 feet). Lengths of tributary streams were estimated from stream GIS coverages obtained from the Napa County RCD. Approximately 19,000 yds^3 of past sediment delivery was estimated from tributary erosion processes and this represents 3% of the total past sediment delivery from sediment sources in the watershed (Figure 8).

Deep-seated landslides- Earthflows or deep-seated landslides were mapped according to the methods outlined in the Landslide History section (V-C) of this report. Three (3) small active earthflows were identified in the air photo analysis of Sulphur Creek. Active earthflow size ranged from approximately 0.7 to 3.2 acres. These small earthflows do not appear to be very active and very little erosion is apparent at the toes of the slides. Little literature exists on local rates of earthflow movement in Napa County. According to studies on earthflows in Northern California and Oregon, approximate annual earthflow rates can range from 0.2 ft/yr to 95 ft/yr (Nolan and Janda, 1995). Because the active earthflows identified in the air photo analysis do not show appreciable disturbance and movement, a low annual earthflow rate of 0.5 ft/yr was applied over a 50 year period to estimate the past sediment yield from earthflows in the Sulphur Creek watershed.

Approximately 2,000 yds^3 of past erosion and sediment delivery was estimated to originate from earthflow erosion over the last 50 years. This represents less than 1% of the total sediment delivery from all sediment sources in the Sulphur Creek watershed.

The majority of past erosion and sediment delivery in the Sulphur Creek watershed originated from debris landslides. These past sediment sources represent 74% of the total past sediment

delivery to Sulphur Creek and its tributaries. Past erosion and sediment delivery from road-related sources and mainstem bank erosion combined, represent approximately 16% of the total erosion and sediment delivery from past sources. The remaining sediment sources appear to be relatively insignificant in magnitude compared to debris landslides and together represent 10% of the total past sediment delivery.

Of the types of past sediment sources identified in Figure 8, all of the management-related sediment delivery from sediment sources such as road-related erosion, vineyard surface erosion, surface erosion from "other" agricultural activities and grazing activities could be reduced through a variety of land management treatments. Road-related erosion and sediment delivery can be addressed by disconnecting road the road system from streams through application of adequate road drainage, upgrading stream crossings to the 100-year design storm flow and excavating landslides that could deliver to streams. Road-related erosion and sediment delivery is the most easily identified and the most cost effectively treated sediment source in the watershed.

Although current vineyard erosion rates and sediment delivery is lower than past erosion rates and a portion of sediment delivery from vineyard erosion processes is ending up in reservoirs, vineyard surface erosion can be controlled through the application of adequate erosion control including cover crops and improved slope drainage. Sediment delivery can also be controlled through the trapping of fine sediment in sediment catchment basins (i.e. reservoirs). The same kinds of erosion control measures (e.g. cover crops) can be used to control surface erosion from "other" agricultural activities.

In contrast to management-related erosion, bank erosion can be very difficult to control. Elaborate measures can be taken through the use of rip rap revetment or other engineered structures to control bank erosion. These treatments can be very costly and are typically located in areas that are not easily accessible by equipment. In some cases these structures may not control bank erosion and can occasionally cause further destabilization of the stream bank. Vegetation can be planted, but it will not be immediately effective in controlling erosion.

Natural debris landslides, earthflows and large gullies are typically difficult to control. These features are caused by natural processes. The goal of reducing sediment delivery to Sulphur Creek should not be to control natural erosion and sediment delivery, but to reduce the amount of management-related sediment from entering the stream system.

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