Final Technical Report

Sediment Source Assessment:
A Component of the
Watershed Management Plan for the
Carneros 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

Pacific Watershed Associates

Arcata, California

(707) 839-5130

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Final Technical Report

Sediment Source Assessment, Carneros Creek Watershed, Napa County, California

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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 Carneros 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 1942, 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 Carneros 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, grazing 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, approximately 43 miles of road had been constructed in the Carneros Creek watershed. Of the 43 miles of road, 23 miles (52%) were constructed as of the 1942 air photo period, 14 miles (33%) were constructed as of the 1985 air photo period and 6 miles (14%) were constructed as of the 2002 air photo period. The majority of roads in the watershed were constructed along the mainstem of Carneros Creek and along the eastern hillslopes of the watershed. Very few roads were constructed on the steep western slopes of the watershed.

As of the 1942 air photo period, land use in the Carneros Creek watershed was dominated by grazing and agricultural activities such as orchards and other activities excluding vineyards. Between the 1942 and 2002 air photo periods, grazing activity and non viticulture activities decreased in the watershed. By the time of the 2002 air photo period, vineyard development had increased dramatically through the conversion of grazing and "other" agricultural areas. Rural residential development in the watershed increased slowly over the entire air photo period.

One hundred one (101) landslides were identified in the historic air photo analysis. Landslide types included debris landslides and debris flows. The majority of the landslides occurred on the eastern side of the Carneros Creek watershed and appeared to be controlled by the local geology rather than by management-related activities. Approximately 11,500 yds^3 of sediment was estimated to have been delivered to Carneros Creek and its tributaries as of the 2002 air photos. The majority of landslides occurred in grassland settings within steep headwall swale areas and on streamside slopes.

Phase 2-Roads- Approximately 24 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 147 sites of future episodic erosion and sediment delivery were identified from the 24 miles of inventoried road. Of the 147 sites, 128 were recommended for erosion control and erosion prevention treatment including 90 stream crossings, 7 potential landslides, 16 ditch relief culverts and 15 "other" sites. Approximately 11.4 miles of road were identified as "hydrologically" connected to streams along roads inventoried in the Carneros Creek watershed. Of the 11.4 miles of connected road, 10.3 miles were recommended for erosion control and erosion prevention treatment. If left untreated, it is estimated that up to 11,030 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 24 miles of inventoried in the Carneros Creek watershed is estimated at approximately $493,000. The cost estimate includes the costs to upgrade approximately 6 miles of county maintained roads.

Stream channels- Approximately 3.7 miles of tributary channel was inventoried to identify past, current and future sediment sources that could deliver sediment to the stream system. A total of 47 sites with >20 yds^3 of past and/or future erosion and sediment delivery were identified in the assessment. From the 47 sites, approximately 2,306 yds^3 of sediment have been delivered to streams in the past and nearly 965 yds^3 is estimated to be delivered in the future. Of the 47 sites, 45% of the sites were classified as bank erosion and 41% were classified as debris landslides. Approximately 49% had no apparent management cause, 27% were associated with grazing activities, 13% were associated with reservoirs and 2% of the sites were associated with the road system. Ninety-four (94) small sites (<20 yds^3) were also identified in the assessment. Approximately 1,170 yds^3 of sediment is estimated to have been delivered to streams from these small features.

Other sediment sources- Reservoirs, grazing activities, viticulture and rural residential activities were evaluated as part of the non road-related sediment source sampling. Fifty-seven reservoirs were identified in the Carneros Creek watershed constituting approximately 2% of the total watershed area. Of the 57 reservoirs, 19 were classified as on-stream reservoirs and these collect runoff from approximately 32% 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.

Grazing activities were observed in the northeastern portion of the Carneros Creek watershed. The majority of erosion from grazing activity resulted from the trampling of steep stream banks in the upper portions of the watershed. No exclusionary fencing was noted to keep cattle away from unstable stream banks which resulted in stream bank failures and surface erosion.

Five vineyard plots were inspected in the watershed to assess impacts of vineyard related erosion and sediment delivery. Vineyard plots ranged in size from 1.6 acres to 28.2 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 sources of erosion and sediment delivery in the Carneros Creek watershed over the past 50 years resulted from road-related chronic surface erosion and gullying (29%), mainstem bank erosion (26%), and vineyard surface erosion (20%). 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. The estimate of past erosion and sediment delivery from vineyard surface erosion may be high since 35% of the active vineyards drain to reservoirs that may act as large sediment traps.

Of the past sediment sources assessed in the Carneros Creek watershed, management-related erosion and sediment delivery can 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 by applying 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.

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. Vineyard avenues should be disconnected from the stream system through the installation of road surface drainage structures such as ditch relief culverts, rolling dips and/or water bars.

Surface erosion associated with grazing activities can be reduced through the rotation of cattle to prevent over grazing. Exclusionary fencing can be useful to keep cattle away from sensitive hillslope areas and erodible or potentially unstable stream channel banks.

In contrast to management-related erosion and sediment delivery, bank erosion along the mainstem and tributary stream channels can 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 Carneros 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.

Introduction

Carneros Creek is an approximately 9 mi^2 third order tributary to the Napa River located in Napa County (Figure 1). As mapped on the USGS Napa, Sonoma, and Cuttings Wharf 7.5' minute topographic quadrangle maps, Carneros Creek contains approximately 25 miles of blue-line streams and tributaries. The mainstem of Carneros Creek is approximately 11 miles in length and an additional 14 miles of tributary streams drain to the mainstem of Carneros Creek. Elevations in the watershed range from mean sea level at the confluence with the Napa River to approximately 1,660 feet above mean sea level in the headwaters of Carneros Creek.

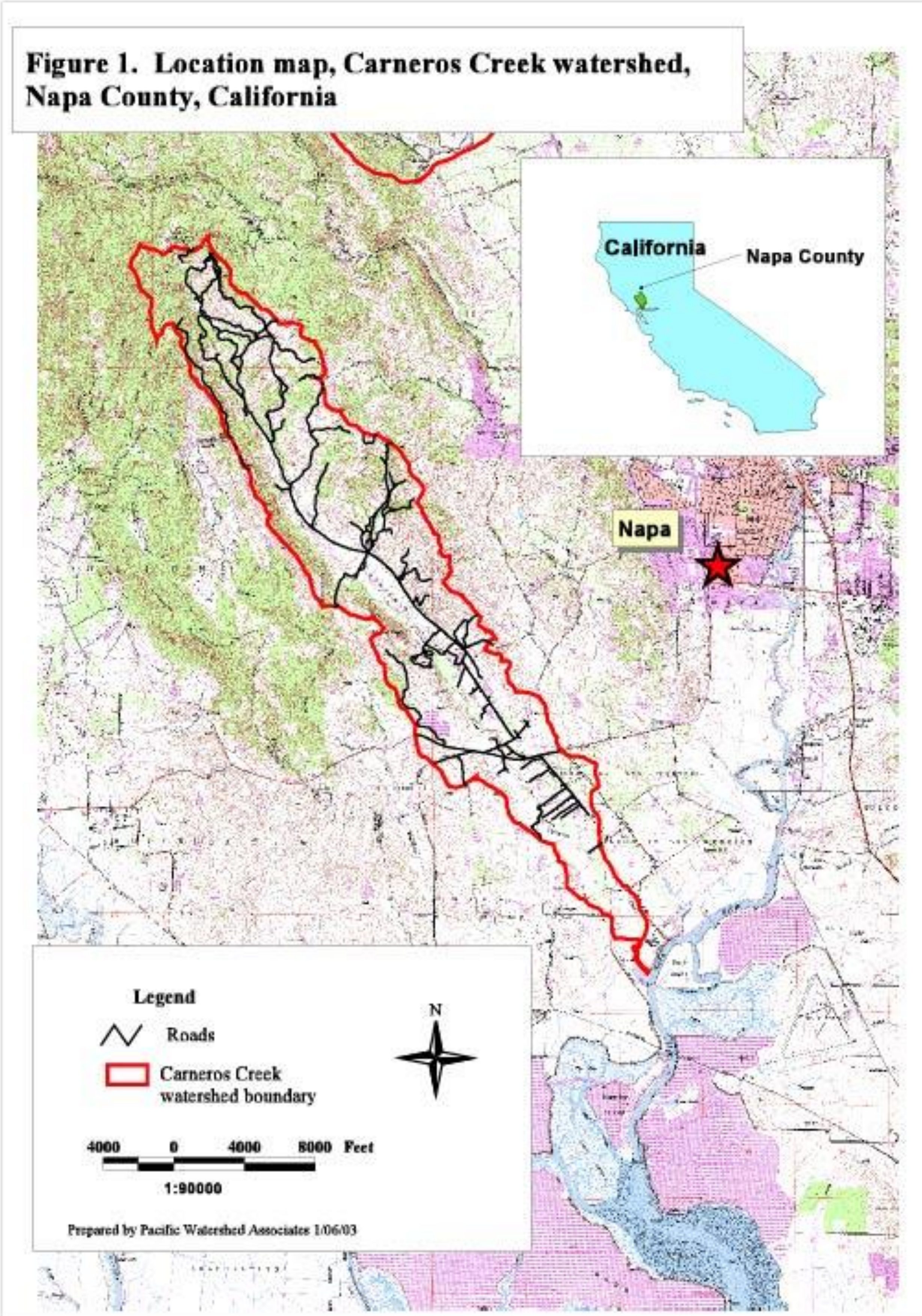
The Carneros Creek watershed is privately owned and is primarily composed of vineyards, cattle ranches, rural subdivision residences and unmanaged open space. Vegetation in the Carneros Creek watershed is dominated on the eastern side of the watershed by annual grasses and oak woodlands. The western side of the basin is dominated by mixed conifer and other hardwood species. The Carneros Creek watershed has experienced grazing and general agricultural activities since the 1820's (Historical Ecology Report, Grossinger). To date, much of the general agricultural lands within the watershed have been converted to vineyards and residential property. In addition, portions of the grazing areas in the middle and lower portion of Carneros Creek have also been converted to vineyards and residential areas (see land use section IV-B of this report). Currently, the upper eastern side of the watershed is being commercially grazed. The watershed contains a historic and existing network of native and rock surface roads, as well as paved county road networks along the mainstem of Carneros Creek and along the upper slopes of the eastern side of the watershed.

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 Carneros Creek Stewardship is a relatively new stewardship group that is interested in assessing the condition of the Carneros 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 the watershed management plan development process. This report presents the results of the work conducted by Pacific Watershed Associates, with the assistance of staff from the Napa RCD, between August 2002 and January 2003.

Figure 1. Location map, Carneros Creek watershed, Napa County, California



III. 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.

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: 1942, 1985 and 2002. Available photography for the analysis included partial coverage for the 1942 and 1985 air photo sets and full coverage of the watershed for the 2002 air photos. The air photo analysis was conducted to document road construction, land use, landslide and stream channel disturbance histories for the Carneros 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 Carneros 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 23.5 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 Carneros 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 non-point sediment sources related to vineyards, reservoir development and maintenance, grazing, and rural residential development. With the cooperation of Carneros Creek private landowners, PWA staff reviewed grazing and vineyard practices on a variety of landowner properties within the watershed. Specific information regarding current land use practices was documented at each field review 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 erosion and sediment delivery to streams within the Carneros Creek watershed. The work plan is specific on a site-by-site basis 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 23.5 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.

IV. Geologic setting of the Carneros Creek watershed

The area of northwestern California between San Francisco and Cape Mendocino lies within the tectonically active translational margin between the continental North American plate to the east and the oceanic Pacific Plate to the west. 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 the creation of a deep oceanic trench off shore and a large forearc basin to the east. Continued subduction resulted in continental accretion of the trench sediments in a broad complex of highly deformed oceanic rocks to the western margin of the North American plate. These accreted rocks now comprise the Franciscan complex, which constitutes much of the Coast Range province 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 western portion of the California Coast ranges within the study area is partly composed of these Great Valley sediments.

Approximately 30 million years ago subduction of the 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. Within the study area volcanic rocks are represented by the Pliocene Sonoma Volcanics and are located between the Franciscan Complex and the Great Valley sediments.

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 Range 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 mountains and valleys near the Carneros Creek watershed study area. Bends in translational fault systems result in either compression or extension adjacent to the fault zone. 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 along the fault zone. This type of faulting tends to form inter-mountain valleys known as pull-apart basins. Regionally, within the vicinity of the Carneros 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. The Carneros Creek basin has a similar development history and resides at the southern flank of the hills dividing Napa and Sonoma Valleys.

Within the study area, the northwest trending extensional Carneros Creek fault runs along the eastern side of Carneros valley separating Miocene sedimentary rocks (San Pablo Group and Monterey Group) and Tertiary volcanic rocks (Sonoma Volcanics) on the southwest side of the fault from Lower Cretaceous to upper Jurassic Great Valley sediments on the northeast side of the fault.

The upper reaches of Carneros Creek drains both tertiary volcanic rocks which originate from the west side of Carneros Fault and Great Valley sedimentary rocks originating from the east side of the fault. Lower in the basin, Carneros Creek flows through Miocene sedimentary rock, primarily marine sandstones and shale. The geology in the lower watershed is dominated by Pliocene/Pleistocene sandstone, shale and gravel deposits. Quaternary alluvium and colluvial deposits on the hillslopes are interstratified where the hillsides are adjacent to active and historic fluvial terraces.

V. Carneros Creek aerial photo analysis

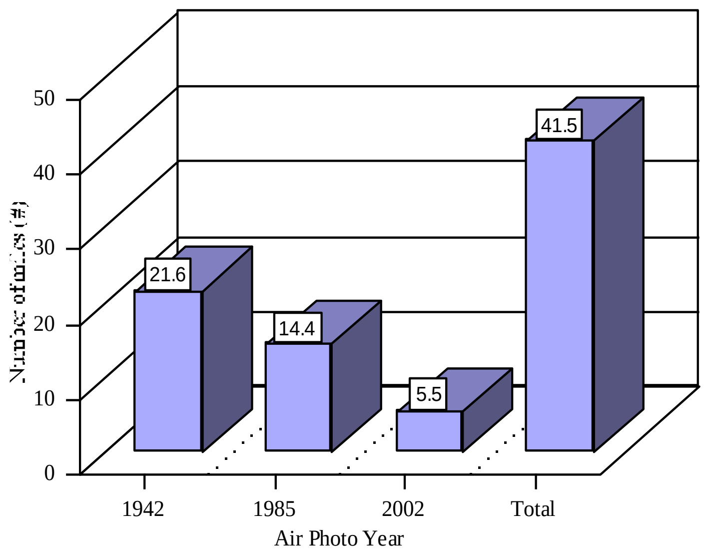
Phase I of the Carneros Creek hillslope/tributary sediment source assessment involved sequential air photo analysis to document the histories of road construction, land use activity, landslide occurrence and stream channel disturbance in the Carneros Creek watershed from three different sets of vertical aerial photography: 1942 (1:20,000), 1985 (1:24,000), and 2002 (1:24,000). Air photo sets for the 1942 and 1985 years were incomplete for the Carneros Creek watershed. The 1942 air photos covered approximately 80% of the watershed and the 1985 air photos covered approximately 75% of the watershed. As a result, the air photo histories for the 1942 and 1985 photo years do not represent the entire Carneros Creek watershed. Any estimates of activity obtained as part of the air photo analysis of the 1942 and 1985 photos represent minimum estimates.

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 Carneros Creek, as derived from the analysis of historical aerial photography. A total of 41.5 miles of road were constructed in the watershed by the 2002 aerial photography.

Figure 2. Road construction history, Carneros Creek, Napa Co



As of the 1942 air photos, 21.6 miles of road had been constructed. This represents 52% of the total road mileage in the watershed. Roads constructed as of the 1942 air photos include a number of private roads and all of the county maintained roads including Henry Road, Dealy Lane, Old Sonoma Highway, Los Carneros Road and Partick Road. The majority of the county roads extend up the mainstem of Carneros Creek. The majority of private roads and the county maintained Dealy Road were constructed on the upper, northeastern hillslopes. As of 1942, very few roads had been constructed on the steep western hillslope of Carneros Creek.

Between 1942 and 1985, 14.4 miles of road were constructed primarily in the low gradient areas along the mainstem valley, on the upper northeastern hillslope and on the steep western hillslope of the valley. Finally, between 1985 and 2002, an additional 5.5 miles of road were constructed in the watershed, primarily on the northeastern hillslope.

B. Land use history

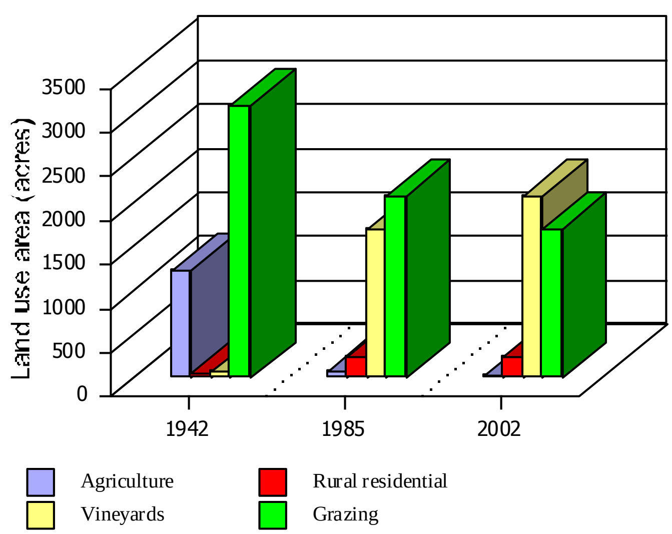
Land use activity was documented on the historic aerial photography by delineating boundaries and assigning a land use classification of rural residential, agriculture, vineyard, grazing or no apparent management. Land use activity was documented on an air photo if physical and visual evidence existed 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 Carneros Creek watershed since the early to mid 1800's (Historical Ecology Report, Grossinger). In addition, the scale of the 1942, 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). Ultimately, the extent of grazing activity was estimated based on the written and verbal history of grazing in the watershed, as well as from visual evidence identified on the air photos. As a result the extent of grazing activity in the watershed is a qualitative estimate and may represent a minimum value.

As mentioned previously, air photo sets for the 1942 and 1985 years are incomplete for the entire Carneros Creek watershed. Gaps in the air photo record can result in non-representative rates of land use activity. At best, the land use history determined from available historic aerial photography can be used to document general trends in land use activity in the watershed, but not for absolute values of area or extent of land use.

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 98% from 1942 to 2002. In contrast, vineyard development increased dramatically from 1942 to 2002. In addition, rural residential development also increased between 1942 and 2002. The sharp decrease in general land use and increase in vineyard and rural residential development suggest the conversion of general agricultural areas to vineyards and rural residential uses. This is very apparent on the

Figure 3. Land use activity, Carneros Ceek



eastern slopes and along the mainstem of Carneros Creek from mid basin at Scott Creek to the confluence of Carneros Creek and the Napa River (Map 2-4).

The decrease in grazing activity from 1942 to 2002 is not necessarily representative of historic grazing activity in the Carneros Creek watershed, because of the difficulty in identifying grazed areas on the historic aerial photography. Air photo analysis and field observation identified the majority of grasslands that are currently being used for grazing are located in the upper northeastern portion of the watershed, north of Scott Creek (Map 2).

Rural residential development has occurred throughout the watershed, but the majority of rural residential development has occurred in the low gradient areas located south of the intersection of Dealy Lane and Henry Road to the confluence of Carneros Creek and the Napa River (Map 2). The steep northwestern portion of the Carneros Creek watershed has had no rural residential development.

C. Landslide history

The Carneros 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 necessarily 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 and/or deep-seated 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 (1942) 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, slow 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.).

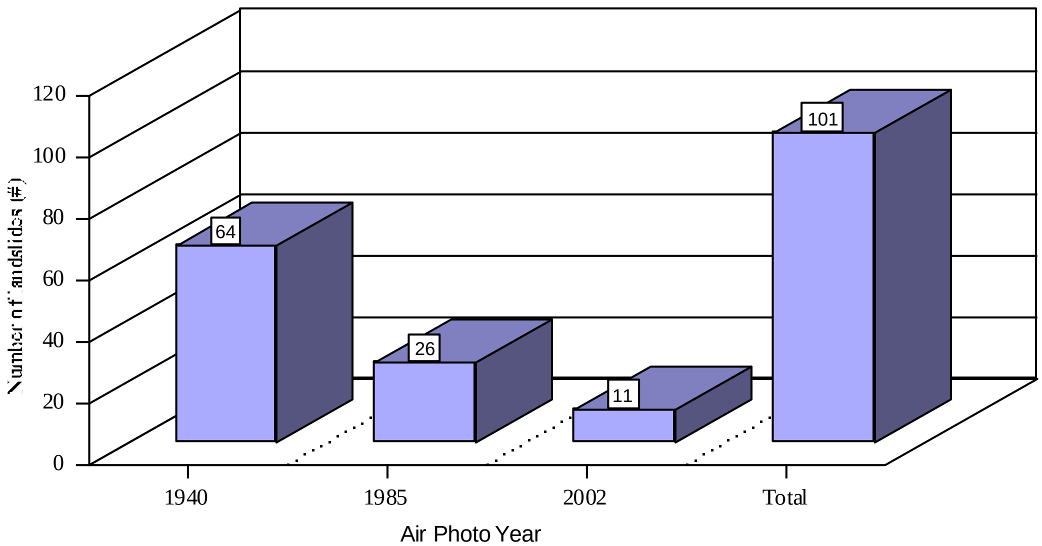
Table 1. Estimated depths based on landslide areas, Carneros Creek, Napa County, California

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

Landslide frequencies for each of the photo periods are shown in Figure 4. A total of 101 landslides were identified in the air photo analysis for Carneros Creek (Map 3). Of the 101 landslides identified, sixty-four (64) landslides were identified on the 1942 air photos, 26 landslides were identified on the 1985 air photos and 11 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 Carneros Creek watershed. There is a forty-three (43) year break between the 1942 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 (1942 -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.

Figure 4. Frequency of air photo identified landslides



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.

Landslide frequencies in the Carneros Creek watershed were highest in photo years 1942 and 1985; both air photo periods containing one or more locally significant storms (1940, 1942; 1985, respectively). Some of this increase may be associated with increases in land use activity (such as road building) during the same period, but it is most likely associated with the magnitude and frequency of major storms. Although 1997 was a large storm year, only 11 new landslides were identified in the 2002 historic air photos. This may be due to the revegetation of landslide scars over the 5 year period between the large storm event and the year the photo was taken.
Of the 101 landslides identified in the air photo analysis, two (2) were landslides that re-activated once in a later air photo period. The remaining landslides are discrete landslides that have not experienced further re-activation.

Of the 101 landslides identified in the air photo analysis, thirty (30) landslides had no apparent sediment delivery to Carneros Creek and its tributaries. The remaining seventy-one (71) landslides delivered an estimated total of 11,500 yds^3 of sediment (Table 2). As of the 1942 air photos, approximately 6,800 yds^3 of sediment was delivered to Carneros Creek and its tributaries from landsliding. Between 1942 and 1985, approximately 2,700 yds^3 of sediment was delivered to streams and nearly 2,000 yds^3 of sediment was delivered between 1985 and 2002. In general, landslides in the Carneros Creek watershed consisted of small debris landslides with an average length of 60 feet and an average yield of 110 yds^3 of sediment delivered to the stream system.

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

Photo period	Number of landslides (#)	Total past sediment delivery (yds^3)	Average delivery (%)	Average length (ft)	Average yield (yds^3)
1948[1]	64	6,800	25	60	110
1985[2]	26	2,700	40	60	100
2002	11	2,000	30	100	180
Total	101	11,500	30	60	110

[1] Aerial photo coverage for approximately 80% of the watershed area.
[2] Aerial photo coverage for approximately 65% of the watershed area

Landslide distribution and association with landforms - Landslide distribution in a watershed is dependent on a number of factors, including underlying geology and soils, hillslope gradient, geomorphic position, land use activity and localized precipitation intensity. In all three years of analysis, the majority of debris landslides (55%) occurred within moderate gradient swales and headwall areas (Table 3). Table 2 lists the geomorphic associations, and landslide frequencies, for each of the photo periods analyzed. The majority of the landslides identified in the air photo analysis were located on the northeastern slopes of the watershed. The northeastern slopes are primarily composed of less resistant Great Valley sedimentary rocks.

Table 3. Landform associations with mass wasting, Carneros Creek watershed

Photo Year	Inner gorge	Streamside	Swales and Headwalls	Break-in-slope	Total number of slides
1942	3	22	35	4	64
1985	0	11	15	0	26
2002	0	4	6	1	11
Total	**3**	**37**	**56**	**5**	**101**
Percent of Total	**3**	**37**	**55**	**5**	**100**

Thirty-seven streamside landslides were identified in the air photo analysis and represent 37% of the landslides identified in the Carneros Creek watershed. Streamside landslides are here defined as slides that occur on slopes that are less than 65% gradient which occur below the last (lowest) significant break-in-slope next to a stream channel.

Vegetation associations and mass wasting
Landslides identified in the air photo analysis were located within two vegetation classes: oak woodlands and grasslands (Table 4). The majority (91%) of landslides identified in the air photo analysis occurred in grassland locations and 9% of the landslides occurred in oak woodlands. With regards to landslide location, vegetation class correlates with the geology in the Carneros Creek watershed. Grasslands in the Carneros Creek watershed are underlain by less resistant Great Valley sedimentary rocks. Landslides are also more easily seen in open grassland areas.

Table 4. Vegetation associations with mass wasting, Carneros Creek watershed

Photo Year	Oak woodland	Grassland	Total number of slides
1942	5	59	64
1985	3	23	26
2002	1	10	11
Total	**9**	**92**	**101**
Percent of Total	**9**	**91**	**100**

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 the Carneros 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 3 illustrates the age and location of stream channel disturbance in the watershed. In total, approximately 2.7 miles of channel in the Carneros Creek watershed was identified as "disturbed". This represents approximately 11% of the 25 miles of USGS blue line streams in the basin. Of the 2.7 miles of "disturbed" channel, 1.1 miles (41%) were located in the mainstem channel of Carneros Creek and 1.6 miles (59%) were located in tributary channels. Possible causes for stream channel disturbance in the mainstem channel of Carneros 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.

Of the 1.6 miles of disturbed channel located in tributaries of Carneros Creek, 1.4 miles (88%) of were located in grassland areas. In contrast, only 0.2 miles (12%) of disturbed tributary channels were located in oak woodland settings. The landslides and concentration of tributary stream channel disturbance in grassland areas may be a result of the relatively unstable geology in these areas, together with better visibility.

VI. Carneros Creek Road Assessment and Sediment Reduction Plan

A. Project Description

In Phase I of the Carneros 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 Carneros 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. 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 Carneros Creek hillslope and tributary sediment source assessment involved a complete inventory of 23.5 miles of county maintained roads and privately owned roads, selected hillslope areas and major tributary stream channels within the Carneros Creek assessment area. In addition, Phase II involved the development of a prioritized erosion control and erosion prevention treatment plan for the 23.5 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 that 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

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

ASAP____ **P W A R O A D I N V E N T O R Y D A T A F O R M** (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:							

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 were 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 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 41.5 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 41.5 miles in the Carneros Creek watershed assessment area, approximately 21.6 miles were constructed as of 1940, 14.4 miles were constructed between 1940 and 1985, and 5.5 miles were constructed between 1985 and 2002. Of the 41.5 miles of road in the Carneros Creek watershed assessment area, 23.5 miles were granted access for the road-related sediment source assessment, including 5.9 miles of county maintained roads and 17.6 miles of private roads.

Approximately 23.5 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 147 sites were identified with the potential to deliver sediment to streams. Of these, 128 were recommended for erosion control and erosion prevention treatment. Approximately 70% (n=90) of the sites recommended for treatment are classified as stream crossings, 5% (n=7) as existing or potential landslides, and 13% (n=16) as ditch relief culverts (Table 5 and Map 4). The remaining 12% (n=15) of the inventoried sites recommended for treatment consist of ■other• sites which include road surface, gullies, stream bank erosion and springs.

Table 5. Site classification and sediment yield from all inventoried sites with future sediment delivery, Carneros Creek, 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	101	90	5,366	37	12	27
Landslides	7	7	312	--	--	--
Ditch relief culverts	23	16	97	--	--	--
Other	16	15	145	--	--	--
Total (all sites)	147	128	5,920	37	12	27
Persistent surface erosion[2]	11.40	10.32	11,030	--	--	--
Totals	**147**	**128**	**16,950**	**37**	**12**	**27**

[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.

Stream crossings - One hundred and one (101) stream crossings were inventoried in the Carneros Creek watershed assessment area including 64 culverted crossings, 26 unculverted fill crossings, 6 ford crossings and 5 bridges. 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 101 stream crossings identified in the assessment, 90 have been recommended for erosion control and erosion prevention treatment. Approximately 5,366 yds^3 of future road-related sediment delivery could originate from stream crossings if they are not treated (Table 5). This amounts to about 29% of the total sediment yield from the road system. The most common problems that cause erosion at stream crossings include: 1) crossings with no or undersized culverts, 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. Any 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, 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 ■diversion 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 94 stream crossings inventoried and recommended for erosion control and erosion prevention treatment in the Carneros Creek watershed, 37 have the potential to divert in the future and 12 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 Carneros Creek watershed.

Approximately 89% (n=90) of the stream crossings inventoried in the Carneros Creek assessment area will need to be upgraded for the roads to be considered ■storm-proofed.• For example, 42% (n=27) of the existing culverts have a ■moderate• to ■high• plugging potential and nearly 37% of the stream crossings exhibit a diversion potential (Table 5). 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. Seven (7) potential landslides were identified and these account for approximately 5% of all inventoried road-related sites in the Carneros Creek assessment area (Table 5). The 7 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 seven (7) inventoried landslides have been recommended for erosion control and erosion prevention treatment. Potential landslides recommended for treatment are expected to deliver up to 312 yds^3 of sediment to Carneros 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 Carneros 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 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 –Twenty-three (23) ditch relief culvert sites were identified to have future sediment yield to stream channels. Of the 23 ditch relief culverts, 16 were recommended for erosion control and erosion prevention treatment (Table 5). These sites are attributed to excessive ditch length contribution that causes a gully below the outlet that delivers sediment to a stream channel. Approximately 97 yds^3 of future sediment yield is expected to occur associated with these ditch relief culvert sites. These sites represent less than 1% of the total predicted sediment yield from road related erosion.

■Other• sites - A total of 16 ■other• sites were also identified in the assessment area. ■Other• 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 16 “other” sites, 15 have been recommended for erosion control and erosion prevention treatment. We estimate 145 yds^3 of sediment could be delivered to streams if they are left untreated (Table 5). Sediment delivery from these sites represents nearly 1% of the total potential sediment yield from sites recommended for erosion control and erosion prevention treatment.

***Chronic erosion* -** Road runoff is also a major source of fine sediment input to nearby stream channels. We measured approximately 11.40 miles of road surface and/or road ditch (representing 49 % 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 Carneros Creek watershed assessment area (Table 5). These roads are said to be ■hydrologically 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 11.40 miles of road surface and/or road ditch contribution, 10.32 miles have been recommended for treatment. From the 10.32 miles, we calculated approximately 11,030 yds^3 (65%) of sediment could be delivered to stream channels within the Carneros 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 the road surface, 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 private roads.

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 ■likelihood• for future erosion (erosion potential - high, moderate, low),
3) the ■urgency• 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 future 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 ■High•, ■Moderate• or ■Low.• 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 ■treatment 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 ■quickly• perform erosion control or erosion prevention work. It is also defined as ■High•, ■Moderate• and ■Low• 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 ■High•. *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.

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 250yds^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 comparatively 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 5.9 miles of county public roads in the Carneros 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 ■erosion-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.

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.

FIGURE 6. CHARACTERISTICS OF STORM-PROOFED ROADS

The following abbreviated criteria identify common characteristics of ■storm-proofed• roads. Roads are ■storm-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 ■guidelines• can occur at specific sites within a forest, ranch or 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 ■disconnected• 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 ■disconnected• 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

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 ■hydrologically invisible• as is possible, that is to disconnect the road from the stream system and thereby preserve aquatic habitat.

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 ■hydrologically 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 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.

Road decommissioning basically involves ■reverse road construction,• except that full topographic obliteration of the road bed is not 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.

Recommended treatments

Basic treatment priorities and prescriptions for inventoried roads in the Carneros Creek watershed were formulated concurrent with the identification, description and mapping of potential sources of road-related sediment yield. Table 6 and Map 5 outline the treatment priorities for all 128 inventoried sites with future sediment delivery that have been recommended for treatment in the Carneros Creek watershed assessment area. Of the 128 sites with future sediment delivery, nineteen (19) sites were identified as having a high or high-moderate treatment immediacy with a potential sediment delivery of approximately 3,477 yds^3. Eighty-

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

Treatment Priority	Upgrade sites (#)	Decommission sites (#)	Problem	Future sediment delivery (yds^3)
High	4	0	4 stream crossings	802
High Moderate	12	3	10 stream crossings, 3 landslides, 2 other	2,675
Moderate	32	3	25 stream crossings, 1 landslide, 5 ditch relief culverts, 4 other	4,260
Moderate Low	44	3	32 stream crossings, 1 landslide, 7 ditch relief culverts, 7 other	5,324
Low	26	1	19 stream crossings, 2 landslides, 4 ditch relief culverts, 2 other	3,889
Total	**118**	**10**	**90 stream crossings, 7 landslides, 16 ditch relief culverts, 15 other**	**16,950**

two (82) sites were listed with a moderate or moderate-low treatment immediacy and account for nearly 9,584 yds^3 of future sediment delivery. Finally, twenty-seven (27) sites were listed as having a low treatment immediacy with approximately 3,889 yds^3 of future sediment delivery.

Table 7 summarizes the proposed treatments for sites on inventoried roads in the Carneros 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 ■blind• reaches may require the use of a pilot car.

It is estimated that erosion prevention work will require the excavation of approximately 4,319 yds^3 at 56 sites (Table 7). Approximately 60% of the volume excavated is associated with upgrading and decommissioning stream crossings. A total of 272 yds^3 of 1.0 to 3.0 foot diameter mixed and clean rip-rap sized rock will be needed to armor nineteen (19) inboard/outboard fill faces and inboard ditches, and 81 yds^3 is required to construct 10 armored fill crossings and 12 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 50 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. Six (6) flared inlets have been prescribed for installation to increase the inlet capacity at certain stream crossings. A minimum of 28 new ditch relief culverts are recommended for installation along the inventoried road routes to disconnect connected ditches from natural stream channels (Table 7).

Equipment Needs and Costs

Treatments for the 128 sites identified with future sediment delivery in the Carneros Creek assessment area will require approximately 375 hours of excavator time and 331 hours of dozer time to complete all prescribed upgrading and erosion control and erosion prevention work (Table 8). Sixty (60) hours of backhoe time has been listed to conduct shallow excavations, install ditch relief culverts, and clean ditches.

Approximately 141 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

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

Treatment	No.	Comment	Treatment	No.	Comment
Critical dip	13	To prevent stream diversions	Back fill at culvert non-trench installations with clean rock	2	Backfill at non-trench culvert installations with 504 yds^3 of clean rock
Install CMP	12	Install a CMP at an unculverted fill	Back fill at culvert trench installations with 2 sack slurry mix	24	Backfill with 769 yds^3 slurry mix at stream crossing and ditch relief culvert trench installations
Replace CMP	38	Upgrade an undersized CMP	Clean/cut ditch	3	Clean/cut 135 feet of ditch
Excavate soil	56	Typically fillslope & crossing excavations; permanent excavation of 4,319 yds^3	Inslope road	1	Inslope 90' of road to improve road surface drainage
Down spouts	8	Installed to protect the outlet fillslope from erosion	Install/Replace ditch relief CMP	28	Install 20 ditch relief culverts and replace 8 ditch relief culverts to improve road surface drainage
Clean CMP	1	Remove debris and/or sediment from CMP inlet	Install rolling dips	56	Install rolling dips to improve road drainage
Install wet crossing	22	Install 10 armored fill crossings and 12 fords using 81yds^3 rip rap size rock	Install cross road drains	18	Install cross road drains on decommission roads to improve surface drainage
Armor fill face	19	Rock armor to protect outboard fillslope from erosion using 191 yds^3 of rock	Remove berm	5	Remove 840 feet of berm to improve road surface drainage
Trash rack	6	Install trash rack at culvert inlet to prevent plugging	Rock road surface	25	Rock road surface using 1,087 yds^3 road rock at 6 rolling dips, 4 stream crossing culvert installations, 3 ditch relief culvert installations and 12 site specific locations
Install bridge	1	Install bridge at class I stream	Other treatment	2	Miscellaneous treatments
Flared inlet	6	Install flared inlet to increase culvert capacity	No treatment recommended	19	

sites are not available. Approximately 317 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 308 hours have been allocated for traffic control and includes a crew of two flagmen during heavy equipment work hours. Approximately 54 hours for a roller and 54 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 $492,986 for an average cost-effectiveness value of approximately $29.08 per cubic yard of sediment prevented from entering Carneros 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 Carneros Creek assessment area. Total estimated costs do not include the daily travel costs to transport equipment and labor to the treatment sites.

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 <u>only</u> 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 ■site,• or the time needed for work 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 ■Handbook 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 14.7 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 25%

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

Treatment Immediacy	High, High/Moderate	Moderate, Low/Moderate	Low	**Total**
Site (#)	19	82	27	**128**
Total Excavated Volume (yds^3)[2]	3,074	2,954	1,279	**7,307**
Excavator (hrs)	98	187	90	**375**
Dozer (hrs)	110	153	68	**331**
Loader (hrs)	0	3	3	**6**
Dump Trucks (hrs)	11	83	47	**141**
Grader (hrs)	9	26	8	**43**
Labor (hrs)	61	198	58	**317**
Traffic Control (hrs)	12	222	74	**308**
Roller (hrs)	2	40	12	**54**
Broom (hrs)	2	40	12	**54**
Pavement cutter (hrs)	1	24	6	**31**
Backhoe (hrs)	3	46	11	**60**

[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.

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 547 hours for ■supervision• 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.

C. Conclusion

The expected benefit of completing the erosion control and prevention planning work lies in the reduction of long term sediment delivery to Carneros 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 the road shapes and locations.

Good land stewardship requires that roads either be upgraded and maintained, or intentionally closed (■put-to-bed•). The old practice of ■crisis 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 ■erosion-proof• and to ■storm-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

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 Carneros Creek watershed, 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	3	--	3	300
	Dozer	100	3	--	3	300
Heavy Equipment requirements for site specific treatments	Excavator	165	375	113	488	80,520
	Dozer	140	265	80	345	48,300
	Dump truck	75	130	39	169	12,675
	Water truck	90	62	19	81	7,290
	Backhoe	85	1	0	1	85
	Loader	140	6	2	8	1,120
	Pavement cutter	140	16	5	21	2,940
	Broom	55	32	10	42	2,310
	Roller	50	32	10	42	2,100
Heavy Equipment requirements for road drainage treatments	Dozer	140	66	20	86	12,040
	Backhoe	85	59	18	77	6,545
	Grader	110	43	13	56	6,160
	Dump truck	75	11	3	14	1,050
	Water truck	90	61	18	79	7,110
	Pavement cutter	140	15	5	20	2,800
	Broom	55	22	7	29	1,595
	Roller	50	22	7	29	1,450
Laborers[7]		40	365	110	475	19,000
Traffic control laborers		30	308	92	400	12,000
Rock Costs: (includes trucking for 1,087 yds^3 of road rock, 272 yds^3 of rip-rap sized rock and 504 yds^3 of clean backfill)						55,890
Backfill Slurry Costs: (includes trucking and pouring for 769 yds^3 of backfill slurry)						73,055
Bridge costs (includes materials and flat car bridge)						20,000
Culvert materials costs (30' of 12", 1,860' of 18', 890' of 24", 270' of 30", 270' of 36", 390' of 42", 480' of 48", 210' of 54" and 70' of 96". Costs included for couplers, flared inlets and elbows)						82,779
Paving for 6,360 ft^2 @ $ 0.63/ft^2						4,007
Mulch, seed and planting materials for approximately 3 acres of disturbed ground[8]						1,650

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 Carneros Creek watershed, Napa County, California

Cost Category[1]	Cost Rate[2] ($/hr)	Estimated Project Times: Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	Total Estimated Costs[5] ($)
Layout, Coordination, Supervision, and Reporting[9]	45	--	--	367	16,515
	60			140	8,400
	75			40	3,000
Total Estimated Costs					**$ 492,986**
Potential sediment savings: 16,950 yds^3					
Overall project cost-effectiveness: $ 29.08 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 Carneros 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.

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 Carneros 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 funds on the highest priority work sites.

VII. Carneros Creek tributary stream channel assessment

Approximately 3.7 miles of tributary stream channel was inventoried to identify past and current sediment sources that deliver sediment to Carneros Creek (Map 6). 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 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 Carneros Creek.

USGS topographic maps at a 1:12,000 scale were used as base maps to record tributary stream channel observations. Three (3) tributary stream reaches (3.1 miles) were inventoried on the east side of the watershed, including 1 tributary channel (■locally• named Scott Creek), 2 tributary reaches that drain to Scott Creek, and 1 un-named tributary located upstream of the confluence of Scott Creek and Carneros Creek. In addition, one tributary stream reach (0.6 miles) located on the steep west side Carneros Creek was inventoried in the assessment (Map 6).

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 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 ■other• 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 either 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.

Figure 7. Stream channel inventory data form used in the Carneros 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:						

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

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 judgment. 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 “treat” or “non-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 Carneros Creek watershed. A total of forty-seven (47) sites with >20 yds^3 of past and/or future erosion and sediment delivery were documented along the 3.71 miles of inventoried tributary stream channel reaches. It is estimated that approximately 2,306 yds^3 of sediment have been delivered to Carneros Creek and its tributaries from the 47 inventoried sites and approximately 965 yds^3 is expected to deliver to streams in the future. Approximately 45% (n=21) of sites were classified as bank erosion, 41% (n=19) were classified as debris landslides, 6% (n=3) were classified as gully erosion, 4% (n=2) were classified as localized areas of channel incision and 4% (n=2) were classified as “other” miscellaneous sites.

Bank erosion and debris slides were the dominant sources of sediment input to inventoried tributaries in Carneros Creek from sites >20 yds^3. We estimate that approximately 795 yds^3 of sediment have been delivered to Carneros Creek and its tributaries in the past from the 21 sites of bank erosion and approximately 228 yds^3 could be delivered the stream system in the future.

Approximately 1,117 yds^3 of sediment have been delivered in the past from the 19 debris landslide sites and nearly 640 yds^3 of sediment is expected to be delivered to Carneros Creek and its tributaries in the future (Table 10).

Ninety-four (94) 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 Carneros Creek. Approximately 1,170 yds^3 of sediment was estimated to have been delivered to Carneros Creek and its tributaries from sites less than 20 yds^3. The majority of less than 20 yds^3 sites include short reaches of bank erosion and small localized areas of channel incision (Table 10).

Table 11 summarizes inventoried sites greater than 20 yds^3 with past and/or future sediment delivery by land use association. Approximately 49% (n=23) of the inventoried sites in the tributary stream channel assessment had no apparent management cause of past and/or future sediment delivery to Carneros Creek or its tributaries. Approximately 27% of the tributary stream channel assessment sites were associated with grazing, 13% of the sites were associated with reservoirs, 9% of the sites were associated with viticulture and 2% of the sites were associated with roads[1].

Inventoried sites associated with grazing and reservoirs represent 48% (1,101 yds^3) of the total past erosion and sediment delivery from inventoried tributary stream channel sites and 60% (579 yds^3) of the potential future erosion and sediment delivery. Approximately 8% (182 yds^3) of past erosion and sediment delivery and 7% (71 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.

Of the forty-seven (47) sites inventoried in the tributary stream channel assessment, 11 were recommended for erosion control and erosion prevention treatment. The primary deciding factor for treating the 11 sites was available access for equipment and materials. The remaining 36 sites were not recommended for treatment due to difficult access and poor cost-effectiveness. Sites recommended for treatment have potential to deliver approximately 300 yds^3 of sediment to Carneros 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.

[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.

Table 10. Past and future sediment yield and erosion type for sites[1] inventoried in the in-stream tributary assessment, Carneros Creek watershed, Napa County, California

Stream Name and Reach	No. of miles (mi)	Debris slides			Bank erosion			Channel incision			Gully			Other			Sites <20 yds^3	
		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Past sediment delivery (yds^3)[1]
			Past	Future		Past	Future		Past	Future		Past	Future		Past	Future		
Scott Creek A	0.55	2	288	223	1	22	2	1	27	7	0	0	0	1	142	10	15	150
Scott Creek B	0.27	1	161	81	1	21	8	1	77	46	0	0	0	0	0	0	1	10
Scott Creek C	0.94	6	184	52	10	325	107	0	0	0	3	125	32	0	0	0	28	280
Scott Creek D	0.56	0	0	0	2	150	63	0	0	0	0	0	0	1	23	5	39	390
East trib A	0.74	10	484	281	7	277	48	0	0	0	0	0	0	0	0	0	23	230
West trib B	0.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	110
Totals	3.71	19	1,117	637	21	795	228	2	104	53	3	125	32	2	165	15	94	1,170

[1] 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.

Table 11. Past and future sediment yield and land use association for sites >20 yds^3 inventoried in the in-stream tributary assessment, Carneros Creek watershed, Napa County, California

Stream Name and Reach	Viticulture			Grazing			Reservoirs			Road			No management cause			Total		
	(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)		(#)	Sediment delivery (yds^3)	
		Past	Future		Past	Future		Past	Future		Past	Future		Past	Future		Past	Future
Scott Creek A	1	9	3	1	22	2	1	279	220	0	0	0	2	169	17	5	479	242
Scott Creek B	0	0	0	0	0	0	1	77	46	0	0	0	2	182	89	3	259	135
Scott Creek C	0	0	0	0	0	0	4	217	50	1	25	21	14	392	120	19	634	191
Scott Creek D	3	173	68	0	0	0	0	0	0	0	0	0	0	0	0	3	173	68
East trib A	0	0	0	12	506	261	0	0	0	0	0	0	5	255	68	17	761	329
West trib B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	4	182	71	13	528	263	6	573	316	1	25	21	23	998	294	47	2,306	965

VIII. Non-Point Sediment Source Sampling

A field evaluation of non road-related non-point sources of sediment was conducted by PWA staff in January 2003 to identify the land use practices that may be contributing sediment to Carneros Creek and its tributaries. The field evaluation focused on sampling areas utilizing the following land use practices: 1) reservoirs, 2) grazing, 3) viticulture and 4) rural residential development. This section of the report discuses the observations and possible solutions for land use practices being used in the Carneros Creek watershed that were locally observed to be causing erosion and sediment delivery.

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 Carneros Creek watershed. After field reconnaissance, it was apparent that reservoirs might be having an important impact on Carneros Creek and its tributaries; both beneficiary and negative.

There are 2 basic types of small reservoirs in the Carneros 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. 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 Carneros 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.

Fifty-seven (57) small reservoirs were identified in Carneros Creek from the air photo analysis. Reservoirs constitute approximately 1.6% (95 acres) of the total watershed area in Carneros Creek. Reservoir surface areas range from 1,600 ft^2 to 31 acres. Nineteen (19) of the 57 reservoirs in the watershed were classified as on-stream reservoirs. Because we did not field inventory all reservoirs in the Carneros 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. Approximately 32% of the Carneros Creek watershed drains to reservoirs.

Observations

Sixteen (16) of the 57 reservoirs (28%) 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. On-stream reservoirs that are filled with culverted stream flow appeared to have had problems if the pipes were undersized for the 100-year storm flow. In a number of locations undersized culverts have caused stream flow to overtop the inlet side of the reservoir dam and erode a gully through the reservoir fill.

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 off-stream reservoirs where flow was discharged from spillways or 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. From field observations, the most effective spillway designs were concrete spillways with concrete energy dissipaters at the base of the spillway.

Some large reservoirs assessed in the Carneros 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 discharge velocity at the reservoir inlet. Reservoirs can be used as sediment retention dams only if they are monitored and dredged if filled with sediment. Reservoir infilling can result in lowered reservoir capacity and an increase in the likelihood of failure and overtopping.

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 plus any other contributing slope or stream area that has been diverted to the reservoir.

2) Effective emergency overflow spillways should be designed for the majority of reservoirs in the Carneros 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 any future erosion and sediment delivery to Carneros 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, dam integrity and spillway condition.

B. Grazing

Livestock grazing can have significant impacts on the stream system through the removal of riparian vegetation, excessive bank trampling, decreased bank undercuts, increased channel widths, nutrient pollution and general degradation in fish habitat (Kauffman, Krueger and Vavra, 1983, McDowell and Magilligan, 1997). Cattle prefer cooler environments and naturally are drawn to shady, cool streamside areas. In locations where cattle cross the stream, stream banks become severely trampled until they are nearly stripped of riparian vegetation. Riparian vegetation serves many beneficial purposes such as providing shade, stabilizing stream banks and filtering fine sediment from surface erosion from entering the stream.

In addition to the effects of grazing on the stream channel, overgrazing can result in increased runoff and surface erosion on steep hillsopes, which can result in the delivery of fine sediment to the stream system. Vegetation removal from overgrazing results in compacted bare soils and a reduction in the infiltration capacity of the soil. As a result, surface runoff causes increased rates of sheet erosion and/or rill and gully erosion.

Observations

Grazing impacts were evaluated in the northeastern portion of the Carneros Creek watershed. In discussions with landowners, rotation grazing is not currently employed in the Carneros Creek watershed. Cattle are allowed to free range graze throughout ranch-managed lands. As a result, cattle are able to graze the same area year after year without ample time for annual grasses to regenerate in the spring. As a result, overgrazing, along with locally unstable and erodible geology, results in increased surface erosion and bank trampling causing erosion and sediment delivery to Carneros Creek and its tributaries

During the field evaluation, it was apparent that steep stream banks in the upper portions of the watershed were the most prone to failure and accelerated erosion from grazing. This is where grazing was the most intense. It was also noted that no exclusionary fencing was used to keep cattle away from unstable stream banks. Cattle are able to access and trample steep stream banks, which has resulted in bare soil, surface erosion and large stream bank failures (Table 11 – East Trib A). In low gradient areas, cattle appear to have less of an impact on stream bank destabilization and therefore a lower potential to cause erosion and sediment delivery.

Two types of cattle crossings were observed in the field including fill crossings and concrete sill crossings. Cattle fill crossings were created as a slight dip through the stream channel. Typically, these fill crossings were defined by the cattle passing back and forth through the crossing. Stream channel beds at these crossings tended to be very disturbed and “churned up”. Surface erosion rates on hillslopes adjacent to stream channels and stream channel and bank erosion was judged to be high at these sites. Other cattle crossings observed included concrete sill crossings, where a concrete slab was poured across the stream channel. This technique provides a very stable crossing that is resistant to erosion caused elsewhere by constant cattle crossing.

Possible Solutions

1) Exclusionary fencing should be used to keep cattle out of sensitive stream channels, and away from steep unstable stream banks and areas of active mass wasting (landslides, earthflows, etc.).

2) Shade trees or constructed structures should be provided outside of the riparian zone and water troughs provided at locations away from stream channels to focus cattle away from the riparian zone.

3) Rotation grazing should be employed in the Carneros Creek watershed to prevent local over grazing and reduce surface erosion in steep hillslope areas.

4) Cattle crossings should be limited to only those that are necessary.

5) Concrete sill cattle crossings (or other hardened crossings) are recommended to reduce stream channel and bank erosion.

C. Viticulture

As discussed in the land use section (IV-B) of this report, viticulture practices have been employed in the Carneros Creek watershed since before the earliest air photo set taken in 1942. The land use history demonstrates that vineyard development increased dramatically from nearly 75 acres to approximately 1,850 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 on the eastern slopes located mid basin extending to low gradient lands near the confluence of Carneros Creek and the Napa River.

In the upland areas of Carneros Creek, vineyards were placed in the grassland areas dominated by unstable Great Valley Sequence sediments. This terrain tends to be very saturated and is locally prone to mass wasting processes. High groundwater tables in the eastern portion of the basin 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 erosion and sediment delivery to Carneros 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. During this time 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.

Typically, vineyards have an intricate system of subsurface drainage pipes and storm flow pipes 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 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 evaluated 5 vineyard plots in the Carneros 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 1.6 acres to 28.2 acres.

Vineyard slopes in the Carneros Creek watershed ranged from <5% to at least 30%. 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 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. 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.

As stated previously, 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 and in some cases no 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. 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 natural stream channels at the base of vineyard plots. In some locations, drainage pipes that were discharged on slopes immediately above stream channels resulted in stream bank collapse and/or gullying. Pipes with outlets in the stream 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. In one vineyard ownership, wooden cross-road drains were constructed and used at regular intervals to drain the 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.

A few stream crossings were observed along vineyard avenues in Carneros Creek. Typically, vineyard avenue stream crossings were constructed with little fill and included native soil and concrete ford crossings.

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 (e.g. wooden cross road drains).

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

D. Rural residential development

As discussed in the land use section (IV-B) of this report, rural residential development has occurred in the Carneros Creek watershed since before the earliest air photo set taken in 1942. The land use history demonstrates that rural residential development increased from approximately 1% (65 acres) to nearly 5% (286 acres) of the total watershed area between 1942 and 2002. Rural residential development has occurred primarily through the conversion of general agricultural and grazing lands. The majority of rural residential development has occurred in the low gradient areas of the Carneros Creek watershed south of the intersection of Dealy Lane and Henry Road to the confluence of Carneros Creek and the Napa River. Small areas of residential development have occurred in the upland areas of the watershed, primarily on the eastern side of the watershed. No rural residential development has occurred on the steep western side of the watershed.

Access to rural residential properties was not granted and therefore no rural residential areas were observed by PWA staff. Because the majority of the rural residential development has occurred and continues to occur in the low gradient areas of the watershed, it is assumed that very little sediment delivery is generated from these areas. Current regulations for erosion control on construction sites appear to be adequate to manage any erosion caused from on-site construction activities and to prevent the delivery of eroded sediment to nearby streams.

Observations
In other adjacent watersheds, the majority of erosion and sediment delivery generated by past rural residential development in upland settings has been caused by stream diversion and driveway or land access route drainage problems. Stream diversion is common in locations were landowners desire to build a home in the line of a small stream channel. Diversion ditches are constructed to convey flow around the home site to a drainage structure. 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 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.

Possible Solutions
1) Do not construct homes or structures within the 100-year flood zone 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 Carneros Creek

The sediment source assessment conducted in the Carneros 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 road-related sediment sources and a sampling of non road-related sediment sources from a variety of management activities such as viticulture, grazing, rural residential development and reservoir development. A complete sediment budget for the Carneros Creek watershed was above and beyond the work tasks outlined in the sediment source assessment.

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 insignificant.

Figure 8 illustrates the distribution and proportions of major sediment sources and sediment delivery in the Carneros 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 field road inventory was designed to identify current and future road-related erosion and sediment delivery and develop a prioritized erosion control and erosion prevention treatment plan to treat controllable road-related erosion rather than past erosion

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 also an important past 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 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, rainfall, 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 1942, 1985 and 2002 air photos. This estimate is also a minimum value due to 1) the large scale of the aerial photos (1942: 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 determine from the aerial photography used in the analysis. In addition, many more gullies could have occurred on the landscape, but were not captured due to the 43 year gap between the 1942 and 1985 air photo periods and the 17 year gap between the 1985 and 2002 air photo periods.

Approximately 39,000 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 29% of the total estimated past sediment delivery from sediment sources in the Carneros Creek watershed (Figure 8).

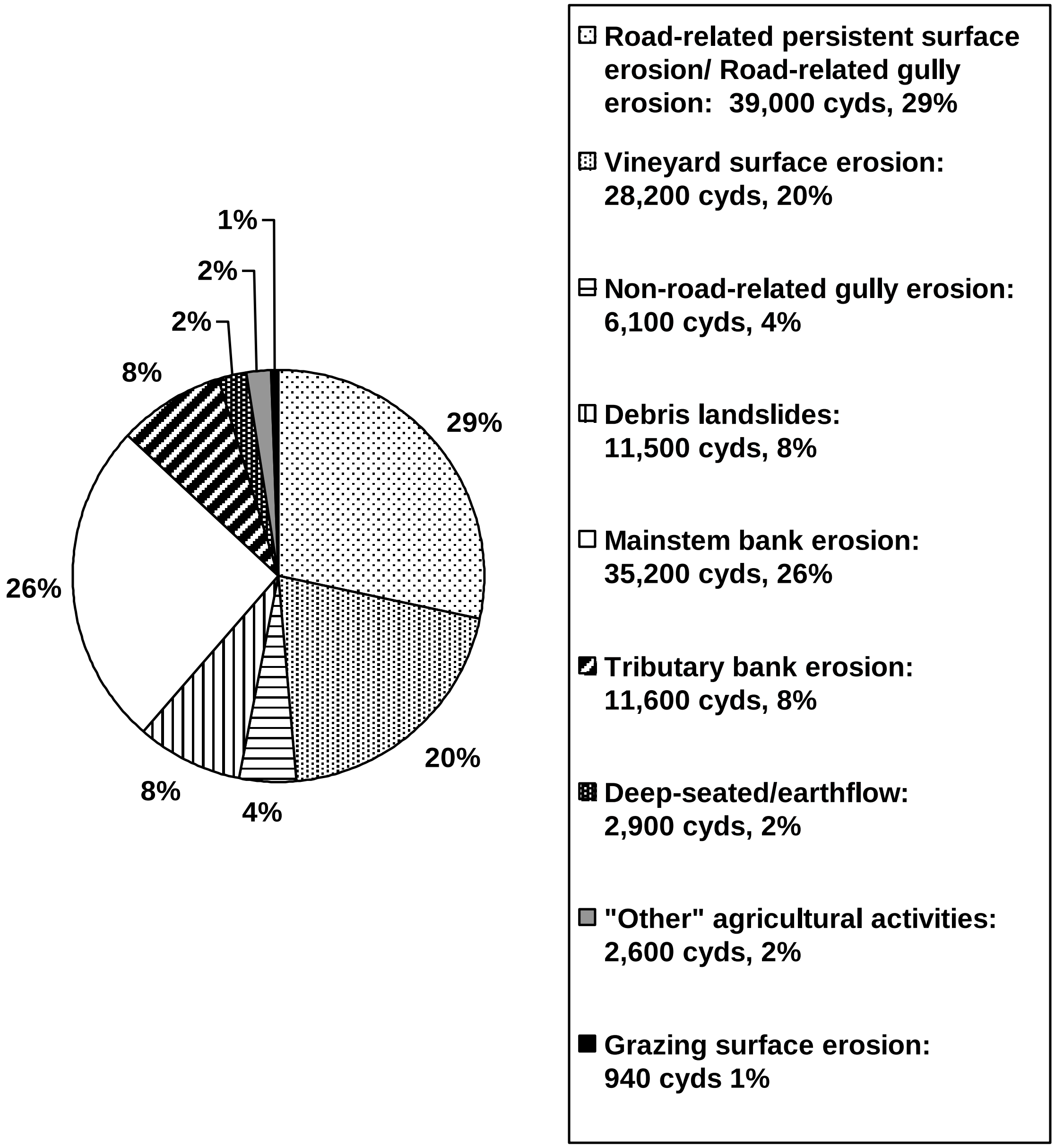


Figure 8. Sediment sources and sediment delivery in the Carneros Creek watershed.

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 1942 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 Carneros 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 Carneros Creek watershed was divided into different type areas based on 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 4 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 0.4 tons/acre/year.

Approximately 28,200 yds^3 was estimated to have been derived from vineyard surface erosion, accounting for nearly 20% of the past sediment delivery from past sediment sources in the Carneros Creek watershed (Figure 8). As of the 2002 air photo period, approximately 35% of active vineyards in the Carneros Creek watershed drain to reservoirs. These reservoirs act as settling basins for both fine and coarse sediment delivered from upstream areas. Therefore actual past sediment delivery volumes to Carneros Creek are expected to be less than portrayed.

It is estimated that approximately 2,600 yds^3 of past sediment delivery was a result of "other" agricultural activities representing approximately 2% 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 1942, 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 11,500 $cyds^3$ of past sediment delivery occurred from debris landslides in the Carneros Creek watershed. This represents 8% of the total past sediment delivery from past sediment sources (Figure 8).
Mainstem channel erosion- Mainstem bank erosion was estimated from work conducted by SFEI as part of the Channel Geomorphology section of the Carneros Creek Management Plan. SFEI measured bank erosion along several "strata" or reaches along the mainstem of Carneros Creek. From data collected by SFEI, we estimated an average rate of approximately 0.6 yds^3/ft for mainstem bank erosion along Carneros Creek. This bank erosion rate was applied to the entire

mainstem length equal to 11 miles (58,368 feet) and resulted in approximately 35,200 yds^3 of past erosion and sediment delivery to Carneros Creek. This represents approximately 26% 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 Carneros Creek were divided into 2 type-areas based on location. The "west side" tributaries were identified west of the Carneros Creek fault. These tributaries are typically steeply incised through resistant Tertiary volcanic bedrock. The "east side" tributaries are located to the east of the Carneros Creek fault and are typically moderately incised through less resistant Great Valley sedimentary rocks. PWA conducted sample tributary assessments to identify bank erosion and small landslides on 1 west side tributary and 2 east side tributaries of Carneros Creek.

Average rates of tributary bank erosion were estimated for each tributary location. The average bank erosion rate for the west side tributaries is approximately 0.08 yds^3/ft and the average bank erosion rate for the east side tributaries is estimated at 0.006 yds^3/ft. Each rate was applied to the entire length of tributaries on the west side (3,413 feet) and east side (17,048 feet). Lengths of tributary streams were estimated from stream GIS coverages obtained from the Napa County RCD. Approximately 11,600 yds^3 of past sediment delivery was estimated from tributary erosion processes and this represents 8% 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. Four (4) small active earthflows and 4 small dormant earthflows were identified in the air photo analysis of Carneros Creek. Active earthflow size ranged in area from approximately 0.9 to 2.4 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 earthflows 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 Carneros Creek watershed.

Approximately 2,900 yds^3 of past erosion and sediment delivery was estimated to originate from earthflow erosion over the last 50 years. This represents 2% of the total sediment delivery from sediment sources in the Carneros Creek watershed.

Grazing- Grazing-related surface erosion and sediment yield was estimated for the Carneros Creek watershed utilizing land use history information obtained during the historic air photo analysis. Average areas of grazing were estimated between the 1942 and 1985 air photo periods and between the 1985 and 2002 air photo periods. It was assumed that approximately 5% of the average grazing areas were bare soil and subject to surface erosion in the form of sheet and rill erosion. The USLE equation defined above was used to estimate annual soil loss from grazing activities. Rates for annual soil loss from grazing ranged from 15 tons/acre/year to 20 tons/acre/yr. These rates were applied to average areas of grazing activity over the span of the historical aerial photography.

Approximately 940 yds^3 of past sediment delivery was estimated to originate from grazing related surface erosion. This represents 1% of the total past sediment delivery from sediment sources in the watershed.

The majority of past erosion and sediment delivery in the Carneros Creek watershed consists of road-related persistent surface erosion and road-related gullies (29%), mainstem bank erosion (26%), and vineyard surface erosion (20%). These past sediment sources represent 75% of the total past sediment delivery to Carneros Creek. The remaining sediment sources appear to be relatively insignificant in magnitude compared to the 3 main sediment sources and together represent 25% 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 by applying 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 and sediment delivery is lower than past erosion rates and a substantial 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 adequate 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 can be used to control surface erosion from “other” agricultural activities through the use of cover crops. Surface erosion associated with grazing can be controlled through the rotation of cattle and/or exclusionary fencing.

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 cannot control bank erosion and can 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 gullies are typically not controllable sediment sources. These features are caused by natural processes. The goal of reducing sediment delivery to Carneros 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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