AUSTIN CREEK WATERSHED ASSESSMENT

Austin Creek Watershed.

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I. INTRODUCTION

Austin Creek is a major tributary to the Russian River (see Figure 1). The Austin Creek watershed is primarily rural with no incorporated cities and the Town of Cazadero as the most populous area of the drainage. Austin Creek, as part of the Russian River watershed, is listed as impaired by fine sediment levels under section 303(d) of the Clean Water Act. The California Department of Fish and Game identified Austin Creek in the Coho Salmon Recovery Plan as an important steelhead and Coho salmon stream. Coho salmon are listed as endangered under the federal and state Endangered Species Acts. Steelhead trout are listed as threatened under the Federal Endangered Species Act.

This watershed assessment primarily involves use of a Geographic Information System (GIS) to complete an analysis of the features of the Austin Creek watershed, documentation of past land uses and trends in the system. The focus of the analysis is erosion problems, areas of major vegetation changes and other features related to water quality and anadromous fish habitats. The assessment also includes recommendations to improve water quality and aquatic habitats.

The Austin Creek Watershed Assessment was prepared by Laurel Marcus and Associates and Dennis Jackson under contract to the Sotoyome Resource Conservation District. Partial funding was provided by the State Water Resources Control Board.

The Role of Watershed Assessment and Monitoring in Stream Restoration

Coho salmon and steelhead trout are cold water fish and require clean, cold water, spawning gravel with a minimum of silt and complex stream habitat with large wood, deep pools, and dense riparian vegetation to provide shade. For salmon and steelhead to complete their life cycle successfully, the freshwater environment must support a number of steps - in-migration and spawning by adults; egg incubation and emergence of young; juvenile rearing over the hot summer months and out-migration by juveniles.

The freshwater environment, particularly aquatic and riparian (streamside) habitats are created and sustained by watershed processes. For example, spawning habitat requires deposits of clean gravel within the creek. Flood events deposit, erode and sift gravel and change the natural form of the creek, its meanders and banks. For fish spawning the gravel needs to have air and water spaces and be relatively free of fine silt, usually a product of excessive erosion in the watershed. If the creek receives few flood events due to reservoirs, or has been straightened and managed for flood control, spawning habitat may be compromised or non-existent. Similarly, if erosion from roads and gullies is too great, spawning may occur, but the eggs will be smothered with silt and not survive.


Austin Creek Watershed Assessment
Figure 1. Regional Location
Prepared by: Laurel Marcus and Associates
Map Source: Sonoma County Water Agency
RUSSIAN RIVER WATERSHED AND TRIBUTARIES
AUSTIN CREEK WATERSHED
POTTER VALLEY
CALPELLA
UKIAH
HOPLAND
CLOVERDALE
ASTI
GEYSERVILLE
HEALDSBURG
WINDSOR
CAZADERO
GUERNEVILLE
FORESTVILLE
MONTE RIO
JENNER
DUNCANS MILLS
SANTA ROSA
SEBASTOPOL
ROHNERT PARK
COTATI

Salmonid rearing habitat requires adequate cold water to support juvenile fish over the hot, dry summer. The shade of dense riparian tree cover, deep pools, and groundwater help to keep the water below 65º F. when summer air temperatures exceed 100º F. Groundwater availability is a function of the watershed's ability to infiltrate and store rainfall, the geology of the drainage, the condition of the creek, and the extent and timing of water diversions and storage.

Each watershed is a unique combination of features such as geology, vegetation, topography, soil types, rainfall events, land development and management and historic land uses. The condition of a creek at any one time is the result of the interaction of these features over both the short-term such as last winter's floods, as well as the long-term, such as the last ice age or geologic epoch. The ability of a creek to support aquatic life is affected by both natural processes and man-made watershed conditions, as well as direct management practiced on the creek, its vegetation and its floodplain.

These many interacting factors in watersheds and creeks create a complex system that is difficult to evaluate by just "taking a look" at the creek. Assessing the many features of a watershed and evaluating what past events and processes are limiting the quality or extent of aquatic habitats allows for a complete picture of this system to be created. Once a watershed is understood for its processes and primary limiting factors, restoration projects can be focused to produce the greatest benefit.

Monitoring of certain parameters, done at the same locations and following the same methods allow for comparisons over time and the development of an even more detailed understanding of stream and watershed processes. Long-term monitoring also allows for documentation of improvements as projects and improved management practices are implemented. Unfortunately very little monitoring and data collection has been done in the Austin Creek watershed by either government agencies or university researchers. Recommendations for monitoring of the Austin Creek watershed are included.

The Austin Creek watershed is primarily private land. The manner in which each landowner, large or small, manages their property affects the nearby creek. The overall effects of numerous small actions will cumulatively impact a creek with positive or negative effects. State and federal laws and regulations such as the Clean Water Act, Endangered Species Act, Porter Cologne Act, and the Ca. Fish and Game Code were passed to protect and improve water quality, fish and wildlife and salmonid habitat. However, many watershed residents must enact changes in their actions to accomplish the recovery of salmon and steelhead trout including the reduction of fine sediment, the protection and restoration of stream corridors and riparian forest, adequate cold water flows, reforestation of slopes, closure of roads, and many other actions.

II. METHODS AND INFORMATION SOURCES

Collecting Information

A number of tasks were completed to collect information and evaluate features of the Austin Creek watershed.

Literature Review

A literature review and internet search was completed for information on stream flows, rainfall, geology, soils, vegetation, anadromous fish habitat, land use, rare and endangered plants and wildlife specific to the Austin Creek watershed. Information from a number of agencies was requested and on-line publication lists of the U.S. Geologic Survey (USGS), State Water Resources Control Board, Ca. Department of Fish and Game and the California Geological Survey were queried. Historic information was collected from the Russian River Historical Society, Healdsburg Museum, Bancroft Library at U.C. Berkeley and published sources.

Geographic Information System (GIS)

A Geographic Information System (GIS) was created for the Austin Creek watershed and used for most of the analyses in the watershed assessment. Readily available digital sources of information were collected and a number of new layers were created. Ortho-photography from 2000 was acquired from Sonoma County and used to represent the current conditions in the drainage. The Russian River GIS, a joint project of the National Oceanic and Atmospheric Administration (NOAA) and Circuit Rider Productions Inc., was used as a source for data layers depicting perennial and seasonal streams, major roads in 2000, vegetation types in 2000 (CalVeg layer) and general land use. The Russian River GIS is a compilation of data from the U.S. Geologic Survey (USGS), the California Division of Forestry (CDF) and a few other sources. Data layers for geology (1:62,500 scale) were obtained from the USGS. Soil information (1:20,000 scale) was obtained from the Natural Resource Conservation Service. (NRCS)

Digital topographic quadrangles (1:24,000 scale) from the USGS were also added to the GIS. Topography and slope data were generated from ten meter digital elevation models (DEMS) obtained from the USGS. Historic fire data layers were obtained from CDF. The occurrence records for rare, threatened and endangered plant and animal species were obtained from the California Natural Diversity Data Base (CNDDB) operated by the California Department of Fish and Game (CDFG). Data layers summarizing the results of recent (1990-2004) stream habitat surveys were obtained from CDFG. The California Habitat Restoration Projects Database (CHRPD) layers for Austin Creek were also obtained. The CHRPD is a project of NOAA-Fisheries and CDFG. Data layers depicting general plan designations, assessor parcel lines, public lands and allowed density of housing units was obtained from the Sonoma County Planning and Resource Management Department. From these data layers the following maps were created:

- Sub-basins and stream networks
- Place and stream names
- Slopes in four slope classes – 0-15%, 15-30%, 30-65%, >65%
- Watershed roads including roads on slopes in excess of 30%
- Confined and unconfined channel reaches and slope classes of Austin Creek and major tributaries
- Elevation
- Vegetation types
- Geology
- Fire history
- CDFG stream surveys
- Restoration projects

Methods

A major part of this watershed assessment involved collecting historic aerial photographs and delineating changes in each set of aerials. Aerial photographs were obtained from two sources – the California Geologic Survey (formerly the California Division of Mines and Geology) in San Francisco and the Natural Resource Conservation Service in Petaluma. Each set of photographs covers the entire Austin Creek watershed for the years 1941/1942, 1961, and 1980. While the 1941/42 photographs include two separate flights they allow for coverage of the entire drainage for the earliest time period.

The aerial photographs were all black and white and at a 1:24,000 scale. Each photograph was scanned at 600 dpi resolution. The photographic scans were then georeferenced using the 2000 digital orthophotography as the reference data. Geo-referencing was performed using the ESRI ArcMap Geo-referencing Tool.

Caution must be used with this technique, since the ArcMap Geo-referencing Tool does not provide an orthorectified image product. The more mountainous an area, the more of an offset results between the historical georeferenced image and the orthorectified image. We digitized the same areas in all sets of imagery and the orthorectified imagery, where we could recognize the area as being the same in the different datasets. These test areas were roughly the same size as the cleared areas. We found that the same area digitized in a historic georeferenced image calculated a different acreage than the same area in the orthorectified image, but the acreages were +/- 10% of the orthorectified acreage, even in the more mountainous areas of this watershed. Digitizing lines, such as roads, we came within

+/-6% of the orthorectified image. When comparing acreages and miles between the dates, this is an important consideration.

As each set of historic aerial photographs was geo-referenced a photo mosaic layer as well as the individual photos were added into the GIS and used in conjunction with the 2000 aerials, CalVeg 2000 layer, topographic quads and fire layer.

Delineating Land Use and Ground Disturbance

For each historic aerial layer three features were digitized – visible roads, disturbance not clearly related to logging and usually involving residential or agricultural uses, and logging areas. All aerials were evaluated at a scale of 1:7000. For the 1941/42 aerials only obvious changes were digitized. While there were areas where trees had been cut at some previous time there was no obvious ground disturbance, just a lack of dense coniferous canopy (see Figure 2).

For later years (1961, 1980, 2000) the set of aerials that preceded the set of interest was used for comparison to demonstrate that forest occurred in the area previously and had been logged (see Figure 3 and 4). For the 1980 and 2000 aerials the amount of clear-cutting had greatly diminished and selective harvest was carried out. Selective timber harvest is difficult to distinguish on the aerial photos unless it was being carried out when the photo was taken. For the most part the selectively-logged areas would be indicated as having roads and ground disturbance but not necessarily for having been logged.

The recovery of previously logged areas was also evaluated. The 1961 aerials show the largest areas of logging and clear–cutting. The 1961 logged areas were reviewed on the more recent 1980 and 2000 aerials. If a polygon designated as logged in 1961 when compared to the 1980 photo showed a lack of conifer regrowth, then the extent of the polygon without regrowth was digitized as a layer in the 1980's data set (see Figure 4). The same method was used for the 2000 aerials by comparing them to the 1961 and 1980 logged areas. If the 1961 logged areas showed obvious ground disturbance such as white bare dirt areas in the 2000 aerial, the area was digitized as still disturbed in the 2000's data set. Figures 5 and 6 illustrate examples of these different delineations. If there was no sign of disturbance, or the conifer forest had regrown to a dense canopy the area was not digitized. For the 1980 and 2000 aerials the still disturbed areas may also represent selective logging operations. If a formerly logged area becomes housing it was designated as "disturbed" under a different delineation from those areas that were formerly logged and still disturbed.

We reviewed GIS data delineating THP areas available from CDF. As is stated in the metadata with these files, "data is derived from maps contained in Timber Harvest Plans (THPs), reflects that record, and is generally limited to what is required in the

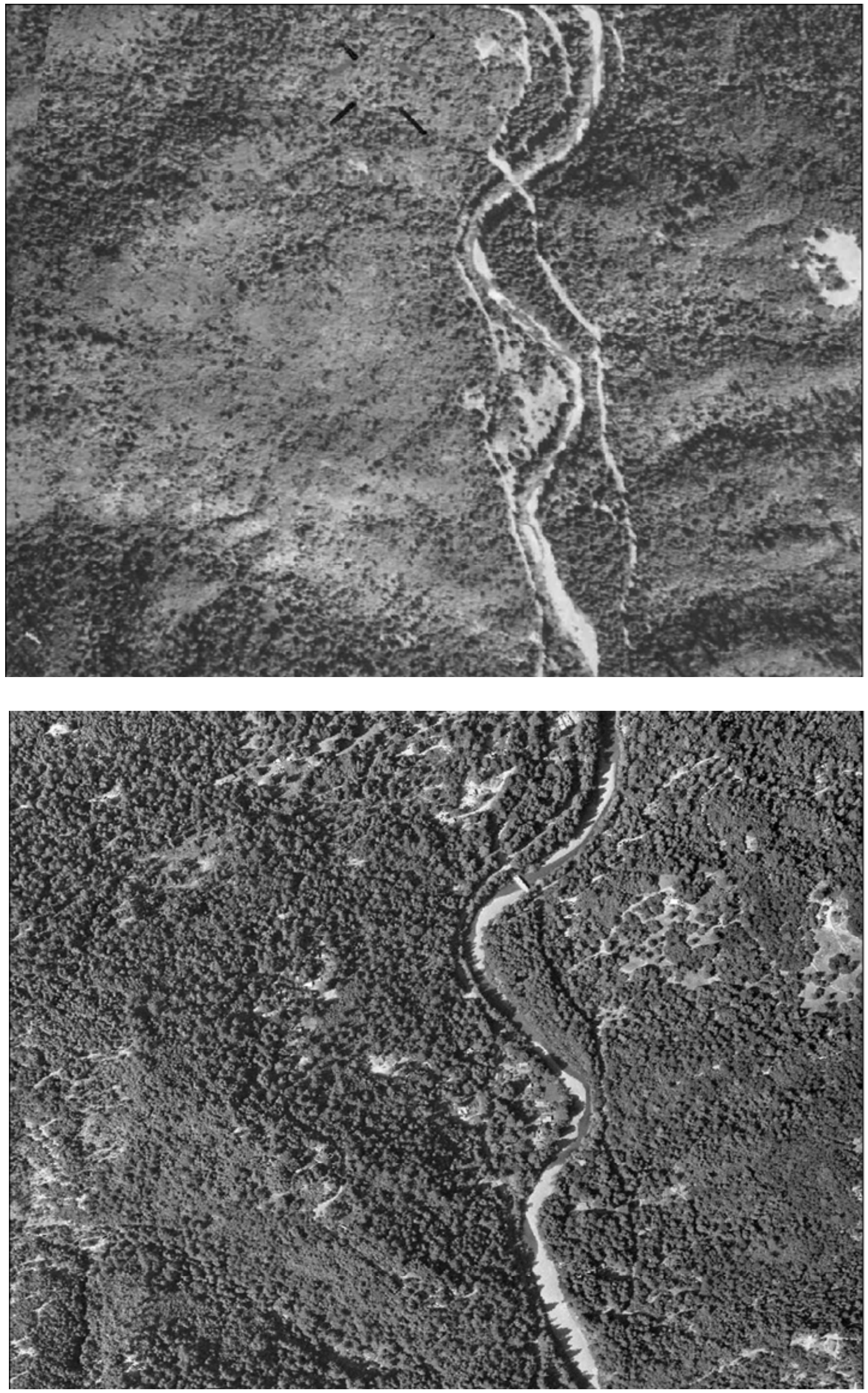


Figure 2. Top: 1941/42 aerial showing cleared conifer forest in Lower Austin Creek Sub-basin Bottom: 2000 aerial showing regrown conifer forest at same location

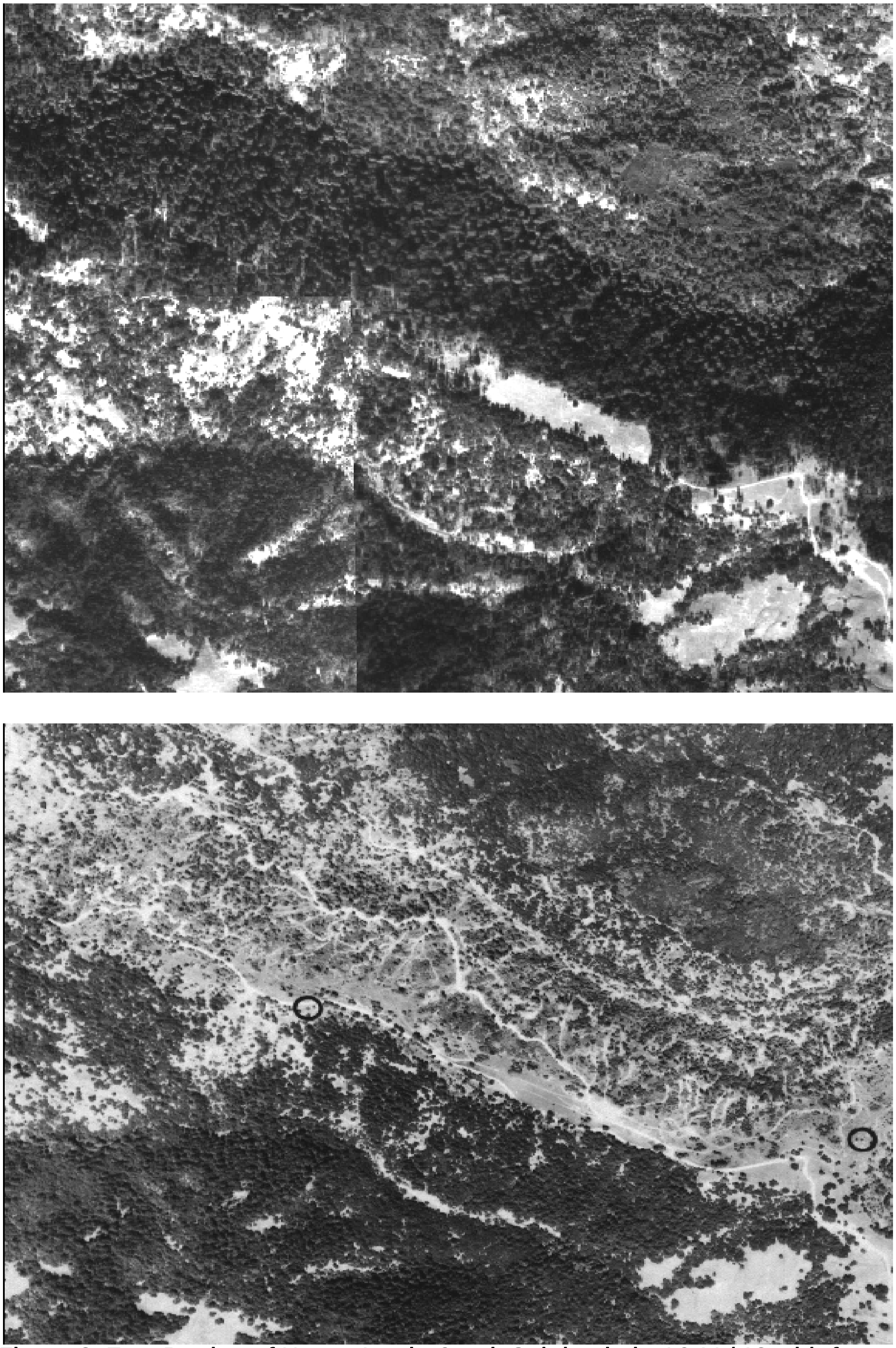


Figure 3. Top: Portion of Upper Austin Creek Sub-basin in 1941/42 with forest
Bottom: Same area in 1961 aerial photo showing extensive clear-cut logging

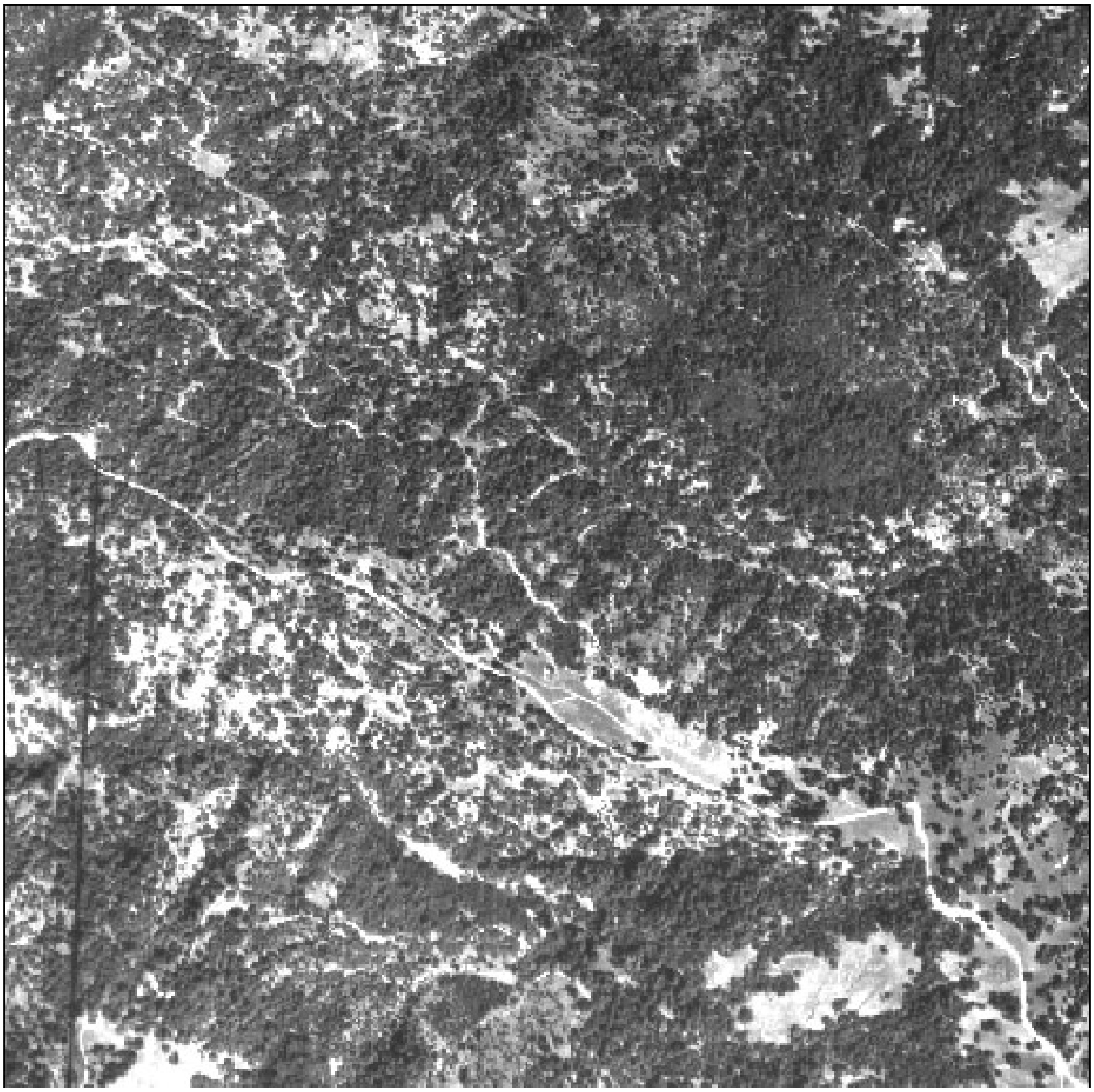


Figure 4. Same location as Figure 3 in 1980 showing lack of conifer regrowth and continued ground disturbance as well as additional timber harvesting

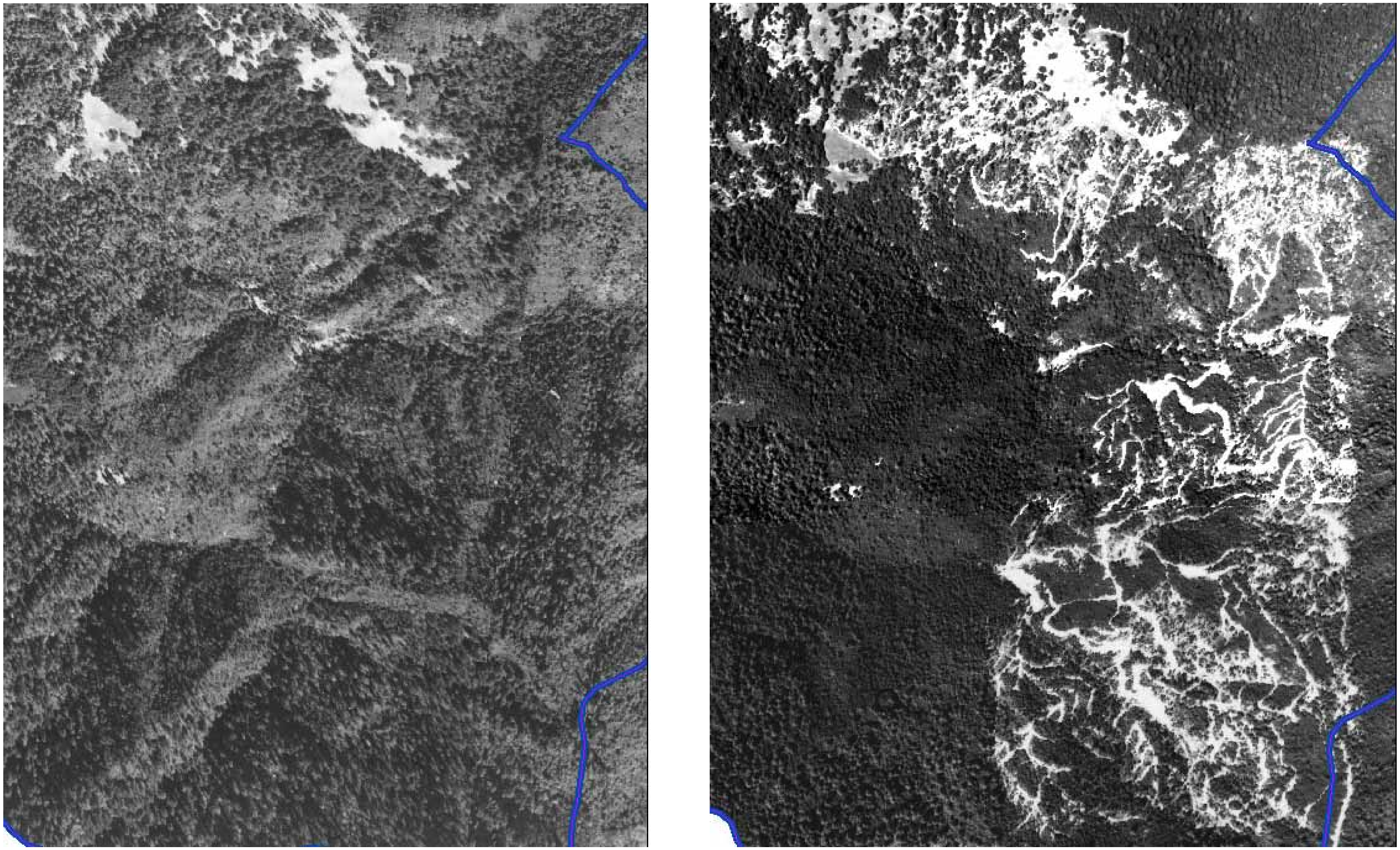


Figure 5. Photo on left is in the Kidd/St Elmo Creeks Sub-basin in 1940. Photo on right is the same location in 1961 showing clear-cut logging

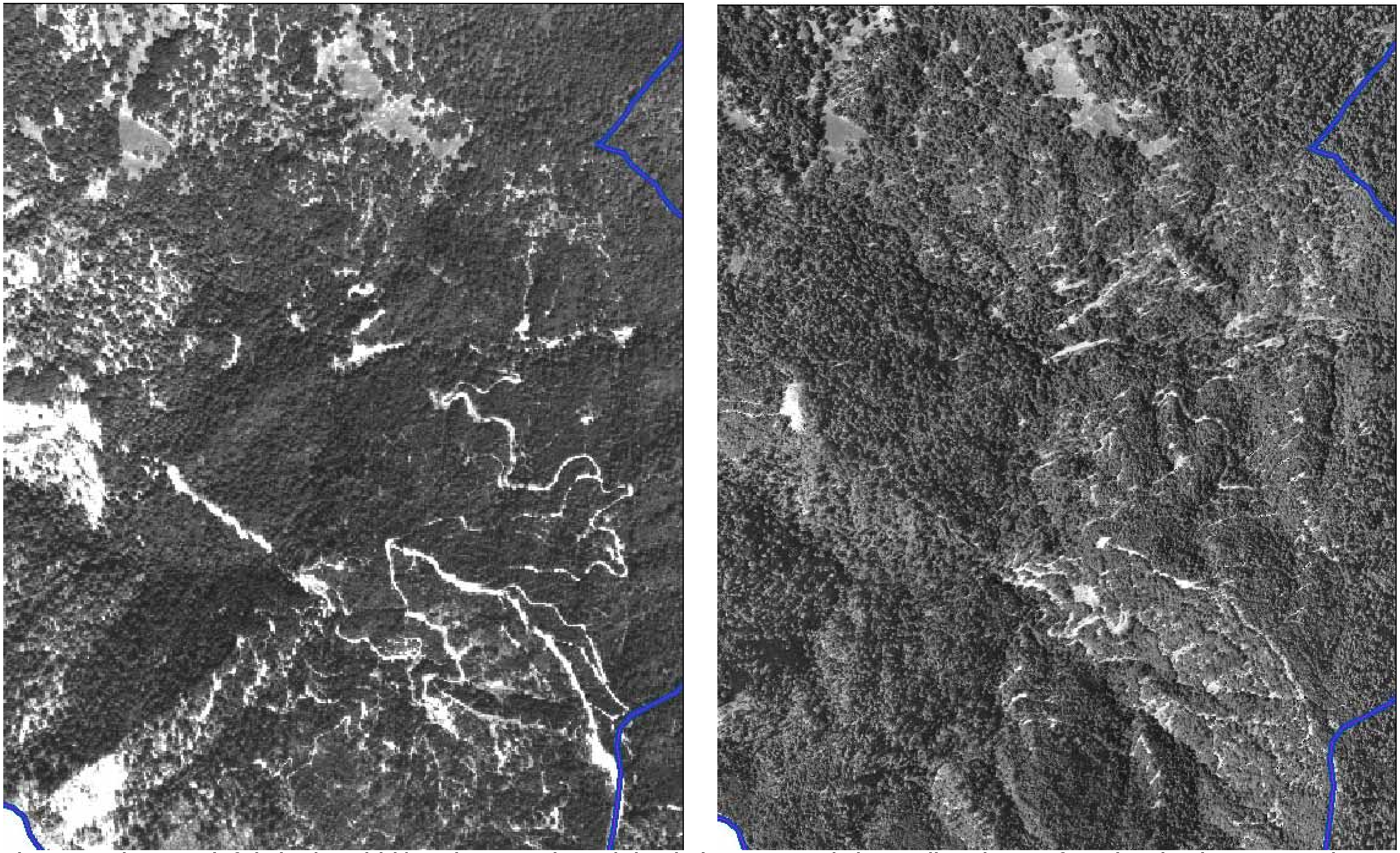


Figure 6. Photo on left is in the Kidd/St Elmo Creeks Sub-basin in 1980 and shows disturbance from logging in 1961 and additional logging on left part of photo. Photo on right is the same location in 2000 showing logging roads and disturbance

California Forest Practice Rules for the particular year the THP was approved. Data represented is a reflection of the public record and only is as accurate as the information contained within that record. Most data has not been ground truthed by CDF. Thoroughness of feature representation is limited to what is represented in the source material (Timber Harvesting Plans)...The State of California and the Department of Forestry and Fire Protection make no representations or warranties regarding the accuracy of data or maps."

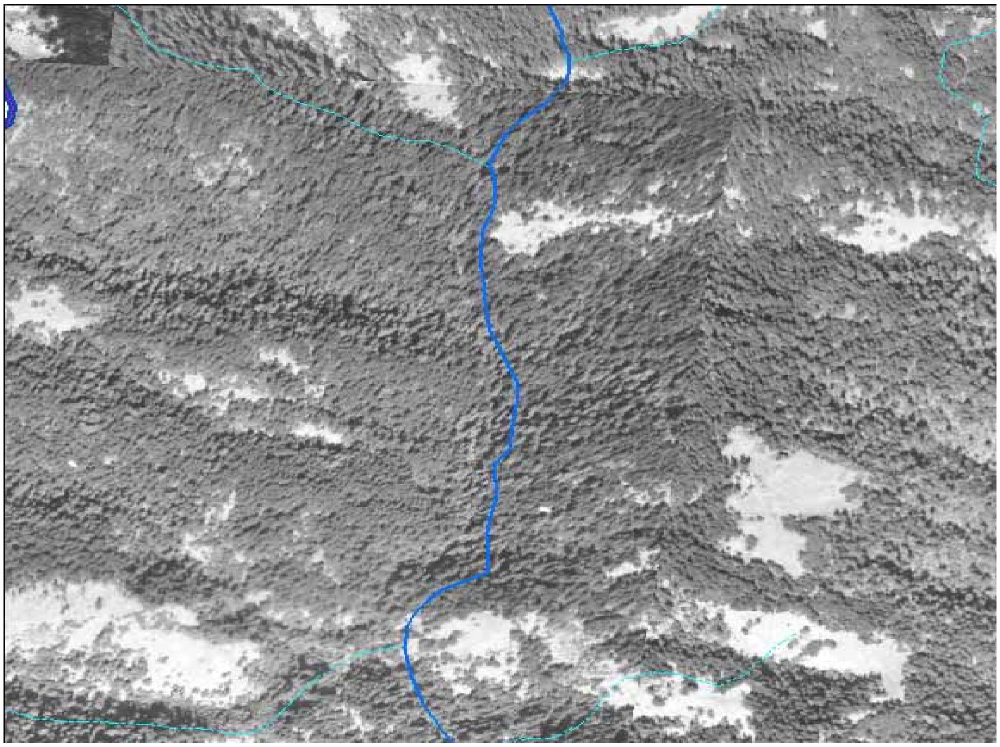
We reviewed the THP areas whose completed status was prior to 2000 and silvicultural treatment was "Clear-cut" or "Selective-cut" by looking at these areas in the 2000 aerial photography. In the 2000 photos there were trees in these supposedly clear-cut areas and the areas looked similar to the forested areas around them. Upon inquiring with CDF we learned that the areas in the THP layer may not be spatially accurate since the data comes from the Timber Harvest Plans and the person submitting the plan may not have the area accurately drawn in the plan. Also, they may not have performed the harvest as expected since "most data has not been ground truthed by CDF" because of budget constraints. As a result, we felt this data-set needed more verification to be useful for this watershed assessment.

Delineating Vegetation Changes

In addition to delineating land use changes, vegetation changes were also digitized. The 1941/42 aerials were compared to the 2000 CalVeg layer. Those areas indicated as hardwood forest/chaparral in the CalVeg layer which were dense coniferous forest in the 1941/42 aerials were digitized. Each polygon which showed this vegetation change was re-checked by comparing the 1941/42 aerial and 2000 aerials to confirm dense forest in 1941/42 and little to no coniferous forest in 2000 (see Figure 7).

Another vegetation change was documented based on observations of the 1941/42 aerial photographs. Large areas of the Upper East Austin Creek sub-basin and Upper Austin Creek sub-basin appear burned or cleared of vegetation when compared to later aerial photographs. These areas were near to serpentine barrens but did not include the barrens. Figure 8 illustrates this comparison. These areas were digitized by comparing the 1941/42 photos to the 2000 photos. Then each polygon was described by the type of vegetation which occurred on the site in the 2000 CalVeg layer. The acreage of the 1941/42 burned/cleared areas was then totaled by the 2000 vegetation types.

Areas which had been obviously cleared of vegetation for agriculture in 1941/1942 but had regrown in natural vegetation were delineated. These areas were totaled by the 2000 vegetation type shown in the CalVeg layer.



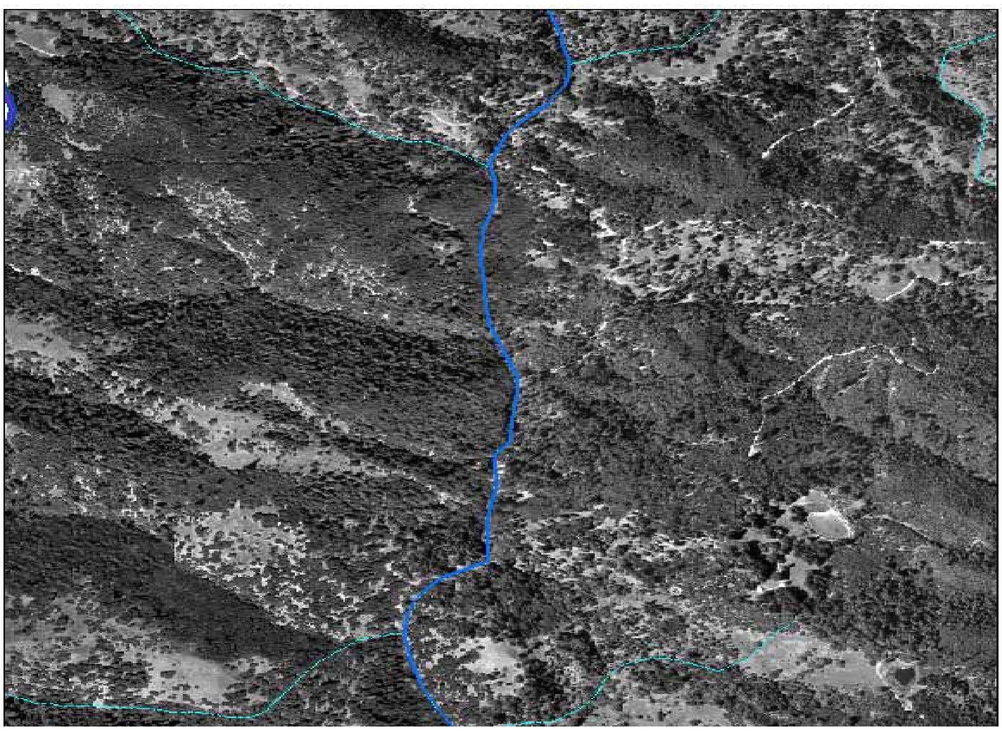


Figure 7. Top photo shows area of Ward Creek in 1941/42 with conifer forest. Bottom photo shows same area in 2000 with primarily hardwood forest, chaparral and grassland. Small areas of conifer forest are located in creek canyons.

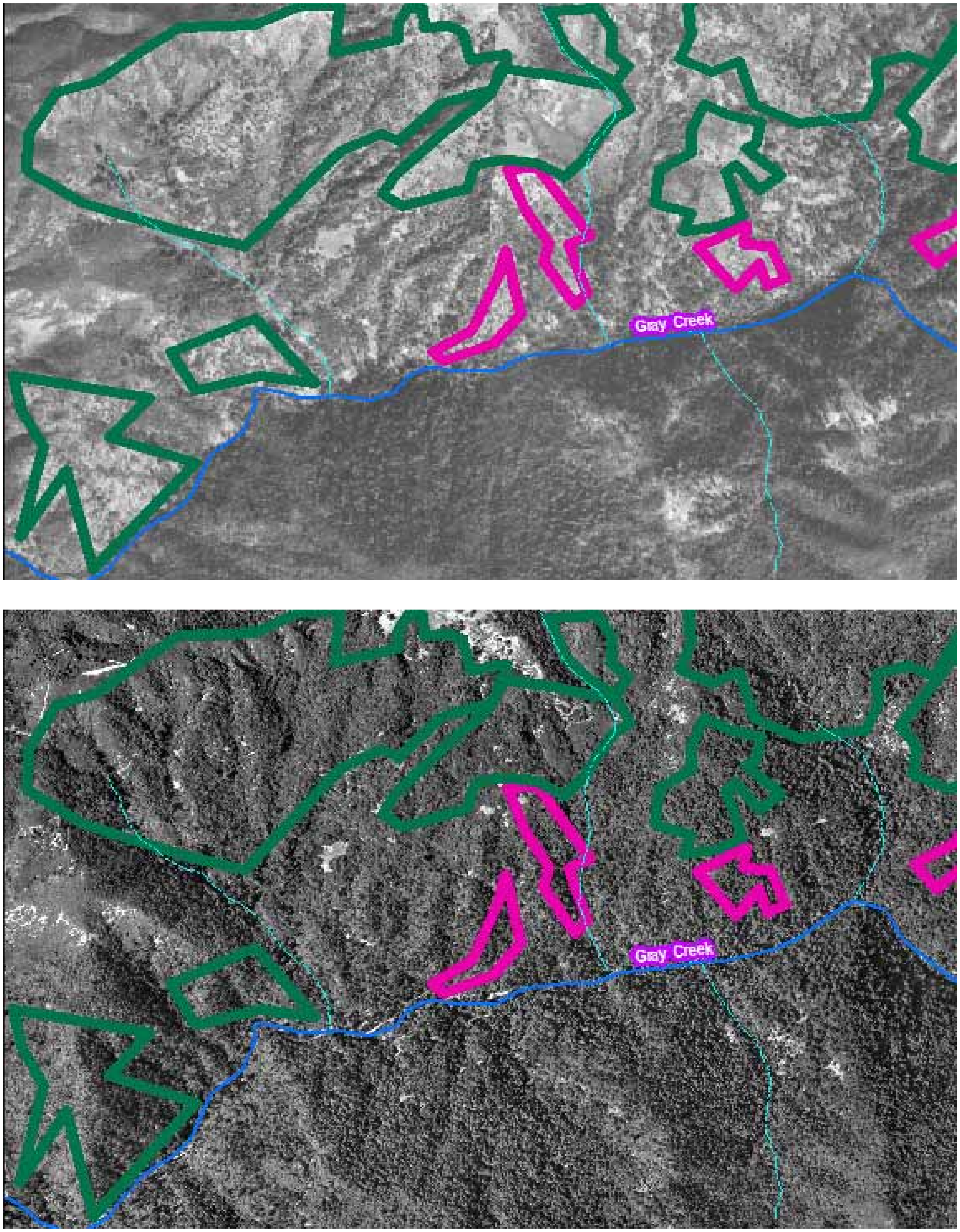


Figure 8. Area of Upper East Austin Creek Sub-basin showing burned or cleared vegetation in 1941/42 in upper photo and regrown vegetation in lower photo. Green lines indicate areas of hardwood forest/chaparral in 2000; pink lines indicate areas of conifer/mixed conifer forest in 2000

Two reviewers separately evaluated all the delineations made on the aerial photographs and the delineations were revised if both reviewers did not agree on the boundaries or the interpretation. Both reviewers had over 20 years of experience in aerial photo interpretation particularly for vegetation analysis.

Monitoring, Assessments and Studies

There is very little monitoring information available for the Austin Creek watershed. There are several rainfall gauges and three USGS stream flow gauges with very short periods of record. The CDFG has completed stream habitat surveys of many of the creeks in the Austin Creek watershed (see Appendix B).

The Sotoyome Resource Conservation District carried out monitoring activities in 2005 as part of a grant from the State Water Resource Control Board (Sierra Cantor pers. comm.). This monitoring program is only funded through 2005. These activities include:

- General water quality monitoring is being conducted on a monthly basis at 5 stations along the main stem of Austin Creek. Parameters include: instantaneous temperature, pH, dissolved oxygen, conductivity.

- Bacteria monitoring (total coliform and E. coli) is being conducted at 5-6 stations on the Austin Creek main stem under high septic demand periods under both dry season, low flow and saturated soil, high flow conditions. Due to the 2005 late rains and flow that has persisted into the summer monitoring was completed over Memorial Day, 4th of July and Labor Day weekends and is scheduled to occur Thanksgiving weekend as well.

- Temperature data loggers have been placed on study reaches in Upper Austin, East Austin and Kidd Creeks. One air and three water loggers have been deployed in Upper Austin Creek (King Flats) upstream of, at the confluence with and downstream of Red Slide Creek. One air and two water loggers have been deployed in Lower East Austin Creek. One air and two water loggers have been deployed in lower and mid Kidd Creek.

- Macroinvertebrate sampling was conducted using the 2005 SWAMP compliant bioassessment protocol and the targeted riffle approach in Upper Austin and Kidd Creeks.

- Bulk sampling to quantify baseline sediment composition was conducted at 8 pool tail outs in reaches on Upper Austin, East Austin and Kidd Creeks.

The University of California Cooperative Extension, working in conjunction with the California Department of Fish and Game, NOAA Fisheries, U.S. Army Corps of Engineers, Sonoma County Water Agency and others, is carrying out a captive broodstock program for Coho salmon in the Russian River watershed. Two of the five creeks where the juvenile Coho are being released are in the Austin Creek watershed.

According to the most recent summary of the program, “Program partners capture fish from tributaries of the Russian River and raise them in the Lake Sonoma Congressman Don Clausen Warm Springs Hatchery for two years at which point they are spawned. The resulting offspring of wild fish are then planted into streams, where they spend their first winter before swimming to the ocean. If all goes well, after about a year and a half at sea, the fish will return to the Russian River and spawn naturally in the tributaries in which they were stocked. In 2001, Department of Fish and Game biologists collected juvenile Coho from the few streams where they remain, often saving fish from pools that were drying up or getting too hot for fish to survive. These fish were taken to the hatchery where they were carefully raised to maturity and spawned. The hatchery staff is faced with many challenges in raising these fish through their lifecycle in fresh water. For the broodstock, special diets and feeding protocols were developed, disease outbreaks were overcome, and new holding tanks were built to increase fish activity. All of these measures contribute to raising healthy fish to mature adults with viable eggs and sperm for successful spawning.”

“After the young hatch, special rearing protocols are followed with young fish. Visual contact with people is minimized so fish will retain their natural tendency to seek shelter on observing movement. This is a flight response to a potential predator. Feeding protocols were adapted and implemented that encourage active feeding behavior.”

Captive bred Coho salmon were released into Ward Creek in 2004 and 2005 and Grey Creek in 2005. Outmigration is being monitored and the 2004 released fish have been caught in the downstream migrant trap and released. Return of adult Coho salmon in 2006 will also be monitored. Captive-bred fish will be released each year until a decision is made to halt the program (David Lewis pers. comm.). In addition to monitoring the fish, stream stage height and temperature is being recorded for Ward Creek. Temperature only is also being monitored for Gray Creek.

NOAA-Fisheries and Trout Unlimited have worked closely with Bohan and Canelis, a local gravel mining firm, and the California Department of Fish and Game to improve habitat in Lower Austin Creek for Coho salmon and steelhead. A large sediment load has accumulated at the mouth of Austin Creek, raising the channel elevation. As a consequence, stream flow goes subsurface in the late summer and does not return until winter storms create sufficient runoff. This restricts adult Coho salmon from swimming upstream to spawn. In addition, significant numbers of juvenile steelhead become stranded in pools in the project reach as flows recede in late summer. These pools are dominated by California roach and Sacramento suckers (in the hundreds), but there is also an unusually high density of older age-class steelhead. As surface flow in the upper watershed recedes and habitat space diminishes, many juveniles move downstream to rear. They then become “compressed” into the limited habitat available in the lower reach. As these pools dry up, the fish perish. Although the primary objective of the proposed mining and restoration proposal in this area is to improve access for migrating adult salmon, it would also clearly benefit the production of rearing juvenile salmonids by reconnecting the channel to the groundwater table and re-establishing perennial pools.

While previous gravel mining had removed aggraded material, the method of skimming gravel bars has not been conducive to creating a well defined channel with suitable structure and complexity for migration. NOAA-Fisheries initiated the idea to mine only the interior portions of gravel bars and excavate pools when the mouth of Austin Creek dries up in the summer. With the help of high flows in winter, this would create a more defined channel, reconnect the creek to the Russian River, and provide improved fish habitat year-round. In addition the California Department of Fish and Game provided technical assistance in the design and implementation of in-stream habitat structures to promote self-sustaining pool structures, provide habitat complexity, and ensure the stabilization of stream banks (NOAA-Fisheries 2005).

This project involved a detailed pre-project topographic survey of the channel and a post-project survey to evaluate if the concept is working to implement the habitat goals. To date no evaluation has been finalized.

The Nature Conservancy (TNC) has included Austin Creek as a Tier 1, or most important, potential conservation area. TNC typically protects natural resources through the use of conservation easements over private lands with purchase of development rights from landowners. TNC has not yet purchased any easements in the Austin Creek watershed (George Yandell, pers comm.).

California State Parks have a large holding - the Austin Creek State Recreation Area in the East Austin Creek Sub-basin. This area is managed for low impact recreation and wildlife habitat. The park has completed road repair projects, projects to remove invasive French broom along East Austin Creek and revegetation with native riparian species (Brendan O'Neil, pers. comm.).

Background and Sources of Information for the Assessment

The following information provides background on the various watershed features evaluated in the assessment. The sources and limitations of specific types of information are also discussed.

Geographic and Topographic Features

Different parts of the watershed play different roles in the generation, movement and storage of stormflow and sediment. Storms tend to release more rainfall in the taller mountains of the drainage. These steep mountains are also the main sites for the generation of sediment into the stream system through erosion and landslides. The creeks in these mountainous areas will be steep and prone to debris flows and other rapid movements of water and sediment. Steep creek channels often have very large rocks and boulders with cascades or small, closely spaced pools. Sediment may consist of large boulders, cobbles, gravel, as well as fine material such as silt and clay particles. Steep channels are usually confined or dominated by bedrock on their bed and banks. They have little to no floodplain so floodwater does not spread out and slow down, but instead becomes deeper and fast moving. In steep channels, transport processes typically dominate over depositional processes meaning that little material is stored in or along the channel over time. Confined channels may support fish habitats and a limited area of riparian forest along the channel edge. Trees on the slopes of the canyon may serve to shade the confined channel.

In valleys, streams have a lower slope and are usually unconfined. This area of the watershed has streams that both store sediment and transport it and usually have a well-defined floodplain. Stormflows slow down and spread out on the floodplain. Stream channels are likely to have glides, bars, pools and riffles. Rather than being dominated by large rock and boulders as in the steeper channels, cobble and gravel line the stream bed of the valley streams. The meandering stream with a corridor of riparian trees is typical of this area. When low slope streams receive large inputs of sediment from the watershed, it may take many years for transport processes to move it out. These processes as well as direct management of creek channels have a large effect on their condition and ability to support aquatic habitat.

The slope class and confinement of the main tributary streams in the Austin Creek watershed were determined from USGS 7.5-minute topographic quadrangles according to the methodology described in Appendix A. Channel confinement evaluations were field-checked to the greatest extent feasible.

The acreage of four slope classifications (0-15%, 15-30%, 30-65%, >65%) was calculated for each sub-basin using the Digital Elevation Models (DEMs) in the GIS. These slope classes were used in evaluating erosion hazards.

Geologic Features

The geologic make-up of the watershed is the basis of many of the processes that affect streams. For example, Franciscan Formation Graywacke and Mélange are sedimentary rock types known for erodibility and mass wasting. In comparison the Metabasalt and Metagraywacke in the Austin Creek watershed are metamorphic rocks and are hard and durable with lower erodibility. The more erosion-prone rock types are likely to have creeks with larger amounts of silt if there are significant levels of land disturbance. Geologic maps also show natural areas prone to erosion, such as landslide deposits. A digital geologic map which includes the Austin Creek watershed at the 1:62,500 scale is the most detailed reference available (Blake et al 2002). Information on the rock types in the watershed was used in evaluating the natural erosion hazard for each sub-basin.

Rainfall and Stream Flow Gauging Data

The USGS operated three stream gauging stations in the Austin Creek watershed including Ward Creek near Cazadero, Big Austin Creek at Cazadero, and Austin Creek near Cazadero. Data from these stations was collected and analyzed. Rainfall data from in and near the Austin Creek watershed was collected and analyzed. Sources included the National Climatic Data Center, California Department of Water Resources, Armstrong Woods State Park and the Sonoma County Water Agency rainfall observer program

Watershed Vegetation

Table 1 lists the primary plant species in the vegetation types depicted in the watershed vegetation map. For readability, several vegetation types were combined into the generalized types listed in Table 1. The current vegetation mapping was compared with historic aerial photographs to evaluate changes in vegetation types. Land uses, such as cropland, urban areas and water (reservoirs) are also depicted.

The digital layer for vegetation (CalVeg 2000 layer) was created from 2000 satellite imagery and there are limitations on the size of vegetation patches the layer depicts. No object smaller than a pixel is included on this layer. Satellite imagery has pixels of 30 meters and requires a 2.5-acre minimum size. In rural environments, this limitation often misses houses, barns, narrow riparian corridors and some vegetation types, such as wetlands and vernal pools, or small patches of one vegetation type within another.

Riparian corridors were not specifically delineated in the Austin Creek watershed. For most creeks coniferous forest made up the streamside vegetation as well as the hillside vegetation. Narrow strips of deciduous riparian forest including alder, willow, maple and other species occur interspersed with conifers, but are not large enough to easily discern and map.

Roads

The historic aerial layers were also evaluated for the presence of roads. Visible roads were digitized. Forest canopy can obstruct roads in the aerial photographs. Only those sections of the road which were visible were digitized. The roads appear as white or grey linear features against the darker vegetation. Skid trails were also digitized and included in the road data layer for each year. In the heavily logged areas the disturbed ground associated with roads was often greater than the area digitized as a road had landings and wider disturbed areas. Evaluations of the aerials for roads were done at a 1:7000 scale.

Fish Habitat Surveys

The CDFG periodically conducts qualitative surveys of fish habitat in creeks. These may include biological surveys of fish, completed by electro-fishing, to determine the numbers of juvenile salmonids and other species. The habitat survey uses an approach outlined in the California Salmonid Habitat Restoration Manual (CDFG 1998).

California Habitat Projects Database

This database was queried for completed projects in the Austin Creek watershed. Planning and surveying projects were not included. Road projects were depicted in total for all their elements instead of each culvert being represented by a separate dot as in the database.

Table 1. Dominant Plant Species in the Vegetation Types of the Austin Creek Watershed, Using Wildlife Habitat Relationships Data and CalVeg layer

Generalized Vegetation Type Used on Map	*Distinct Vegetation Groups included in General Vegetation Type*	*Common Plant Species*
Chaparral	Mixed Chaparral – Dominant Type of Chaparral in Austin Creek Watershed	leather oak
		scrub oak
		ceanothus
		chamise
		silk-tassel
		toyon
		manzanita
		yerba santa
		California buckeye
		California coffeeberry
		California buckthorn
	Chemise – Redshank Chaparral	chamise
		redshank
		ceanothus
		manzanita
		scrub oak
		toyon
		California coffeeberry
Coniferous Forest	Douglas Fir Forest – Dominant Type of Coniferous Forest in Austin Creek Watershed	Douglas fir
		tan oak
		Pacific madrone
		California huckleberry
		snowbrush ceanothus
		California coffeeberry
		California buckthorn

Table 1. Dominant Plant Species in the Vegetation Types of the Austin Creek Watershed, Using Wildlife Habitat Relationships Data and CalVeg layer (cont.)		
Generalized Vegetation Type Used on Map	*Distinct Vegetation Groups included in General Vegetation Type*	*Common Plant Species*
Closed-cone Pine/Cypress Forest	In the Austin Creek watershed the Cedars is comprised of a pure stand of Sargent cypress.	Sargent cypress
		chamise
		ceanothus
		leather oak
		manzanita
		scrub oak
Redwood Forest	Redwood Forest	coast redwood
		tan oak
		Pacific madrone
		California bay laurel
		Oregon ash
		big leaf maple
		Douglas fir
Hardwood Forest	Montane Hardwood Forest – Dominant Type of Hardwood Forest in Austin Creek Watershed	interior live oak
		Douglas fir
		tan oak
		canyon live oak
		Pacific madrone
		California black oak
		coast live oak
		California bay laurel
		manzanita
	Coastal Oak Woodland	coastal live oak
		Oregon white oak
		California black oak
		canyon live oak
		Pacific madrone
		tan oak
		greenleaf manzanita
		chamise
		ceanothus
		toyon
		California bay laurel
	Montane Riparian	big leaf maple
		dogwood
		box elder
		white alder
		willow
	Eucalyptus	blue gum eucalyptus
		red gum eucalyptus

Table 1. Dominant Plant Species in the Vegetation Types of the Austin Creek Watershed, Using Wildlife Habitat Relationships Data and CalVeg layer (cont.)		
Generalized Vegetation Type Used on Map	*Distinct Vegetation Groups included in General Vegetation Type*	*Common Plant Species*
Mixed Hardwood/Coniferous Forest	Montane Hardwood/ Conifer Forest – Dominant Type of Mixed Hardwood/Coniferous Forest in Austin Creek Watershed	ponderosa pine
		Douglas fir
		California black oak
		coast live oak
		tan oak
		Pacific madrone
		Oregon white oak
		big leaf maple
		interior live oak
Rangeland/Grassland	Annual Grassland – Introduced European grasses	wild oats
		soft chess
		ripgut brome
		red brome
		wild barley
		foxtail fescue
		true clovers
		bur clovers
		filarees
		turkey mullein
		California poppy and other wildflowers
Valley Foothill Riparian	This vegetation type occurs in the watershed, but does not appear on the digital vegetation layers because it occurs in areas too small or narrow to be detected by the satellite imagery and computer technology used to generate the vegetation layer.	cottonwood
		valley oak
		white alder
		red alder
		box elder
		big leaf maple
		Oregon ash
		willow

III. WATERSHED ASSESSMENT

Description of the Austin Creek Watershed

Austin Creek watershed is located on the western side of the Russian River watershed and encompasses 70 square-miles. Austin Creek enters the Russian River several miles upstream from the river mouth.

This report describes the features of the Austin Creek watershed and then discusses each major sub-basin in detail. Maps of various features of the watershed are contained in the Figures section following page 150.

Geographic and Topographic Features

The Austin Creek watershed is made up of two major drainage basins. East Austin Creek with its main tributaries Grey, Gilliam, Schoolhouse, Devil and Sulphur Creeks meets Main or Big Austin Creek near the center of the watershed. The East Austin Creek watershed covers 32.06 square miles. The other main drainage basin is Main or Big Austin Creek and its primary tributary creeks – Ward, Bearpen, Kidd and St. Elmo Creeks. This basin covers 37.97 miles. Table 2 lists the primary sub-basins and their size (see Figure 9).

Table 2. The Austin Creek watershed is divided into six sub-basins

Sub-basin	Acres	Sq. miles
Kidd & St Elmo Creeks	4,391	6.86
Lower East Austin Creek	8,984	14.04
Lower Austin Creek	3,042	4.75
Upper Austin Creek	9,328	14.57
Upper East Austin Creek	11,532	18.02
Ward Creek	7,545	11.79
Total for Austin Creek	**44,822**	**70.03**

Both of these main drainage basins are dominated by steep mountains. Elevations range from near sea level at the confluence with the Russian River to about 2,320 feet on Mohrhardt Ridge, which is the divide between Ward Creek, Bearpen Creek and the Gualala River watershed.

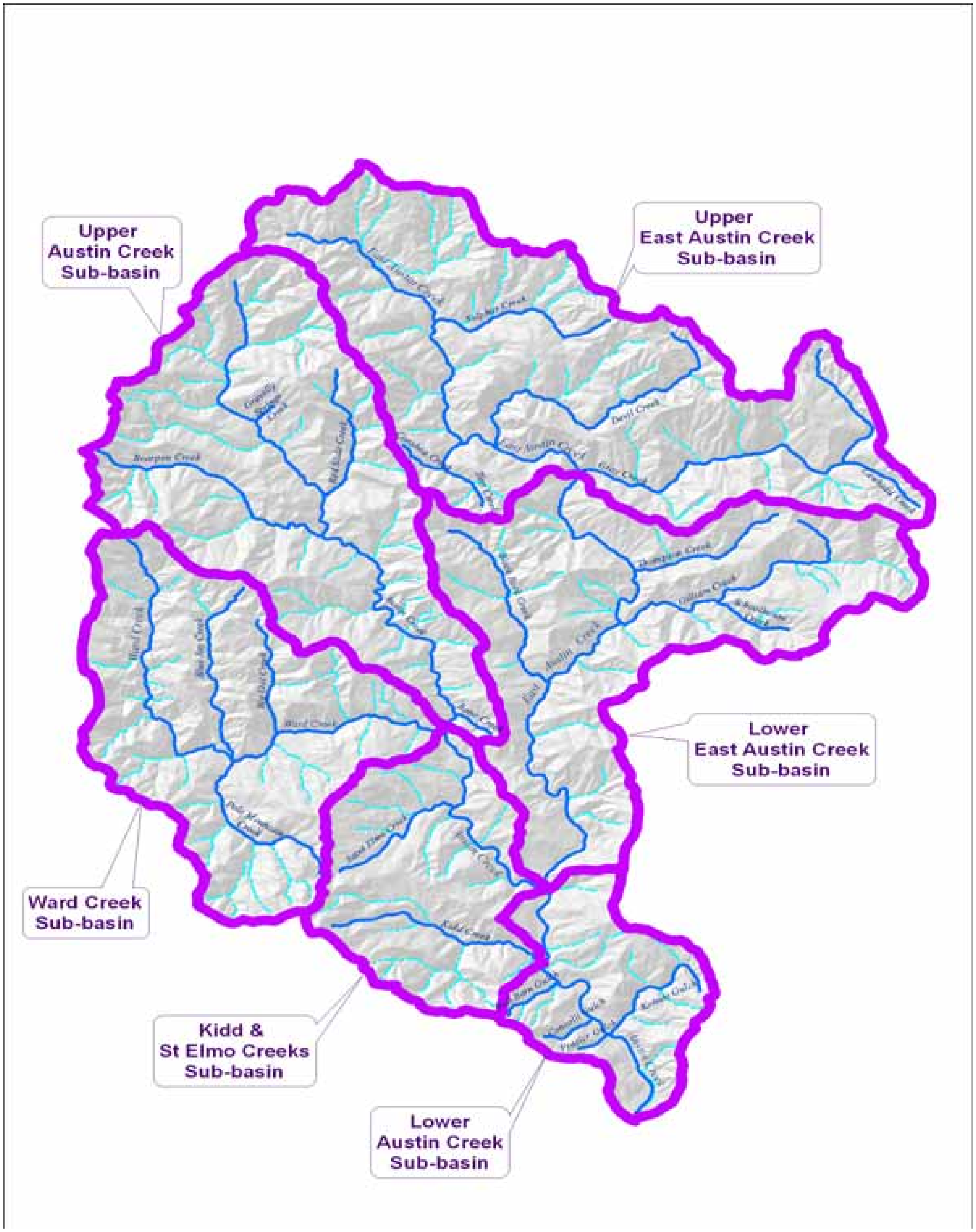


Figure 9. Sub-basins of the Austin Creek Watershed

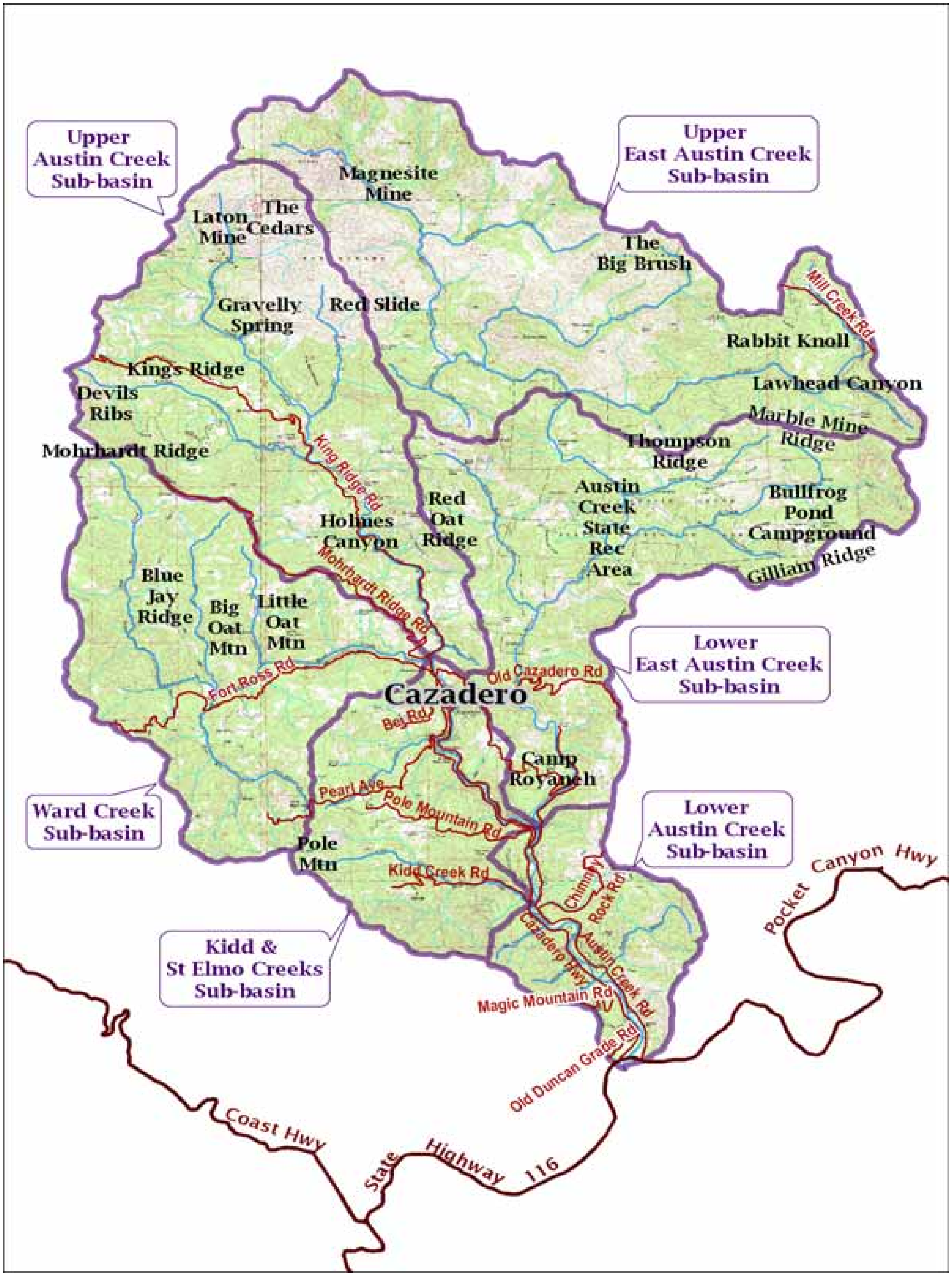


Figure 10. Road, Creek and Place Names in the Austin Creek Watershed

Figure 52 shows the slope classes and level of confinement of the main creeks in the watershed. Most creeks are confined and steep in their headwaters dropping to the generally low slope of main Austin Creek. Table 3 lists the lengths of the perennial and seasonal (blueline) creeks in the watershed.

Table 3: Perennial and Seasonal Streams of the Austin Creek Watershed

Stream	Length in miles
Austin Creek	15.8
Bearpen Creek	3.3
Big Oat Creek	1.7
Black Rock Creek	2.7
Blue Jay Creek	2.7
Bull Barn Gulch	0.8
Conshea Creek	1.0
Consolli Gulch	0.7
Devil Creek	4.3
East Austin Creek	14.0
Frazier Gulch	0.4
Gilliam Creek	3.7
Gravelly Springs Creek	0.3
Gray Creek	5.6
Kidd Creek	2.8
Kohute Gulch	1.9
Pole Mountain Creek	2.5
Red Slide Creek	2.0
Saint Elmo Creek	1.8
Schoolhouse Creek	1.0
Sulphur Creek	2.4
Thompson Creek	2.0
Tiny Creek	0.7
Ward Creek	7.0
Unnamed tributaries	94.4
Total	175.4

Table 4 shows that about 61% of the Austin Creek watershed is in the 30%-65% slope class and 15% of the watershed has slopes greater than 65%. Therefore, about 76% of the watershed has slope greater than 30%. The distribution of slope classes in each sub-basin is roughly the same.

Selby (1993) reports that Salter et al. (1981) studied the landslides triggered by an intense storm of three days duration in New Zealand. Salter observed no landslides on slopes less than 8-degrees (14.1%) and that 97% of the failures occurred on slopes over 20-degrees (36.4%). The predominance of slopes greater than 30% indicate that land sliding is likely to occur in the Austin Creek basin.

Table 4. Percentage of each sub-basin in various slope classes

Sub-basin	Slope Class				
	<30%	30%-50%	50%-65%	> 65%	> 30%
Kidd & St Elmo Creeks	36.5%	34.9%	16.2%	12.4%	63.5%
Lower East Austin Creek	24.5%	43.8%	20.4%	11.3%	75.5%
Lower Stem Austin Creek	26.4%	39.3%	21.8%	12.6%	73.6%
Upper Austin Creek	20.2%	38.8%	23.2%	17.8%	79.8%
Upper East Austin Creek	20.3%	38.9%	24.4%	16.4%	79.7%
Ward Creek	28.0%	35.8%	21.3%	15.0%	72.0%
Austin Creek Watershed	24.4%	39.0%	21.8%	14.8%	75.6%

Rainfall

There is a significant increase in the average annual precipitation from the eastern edge to the western edge of the Austin Creek watershed. The average annual precipitation along the eastern edge of Austin Creek is about 55 inches and increases to about 75 inches near the western edge (see Table 5 and Figure 12). The average annual precipitation for the entire Austin Creek watershed is about 64.62 inches per year.

Table 5. Average Annual Precipitation for the Austin Creek sub-basins

Sub-basin	Average Annual Precipitation in inches
Kidd & St Elmo Creeks	66.2
Lower East Austin Creek	59.2
Lower Austin Creek	53.6
Upper Austin Creek	67.5
Upper East Austin Creek	63.4
Ward Creek	72.8
Total/Average for Austin Creek	64.6

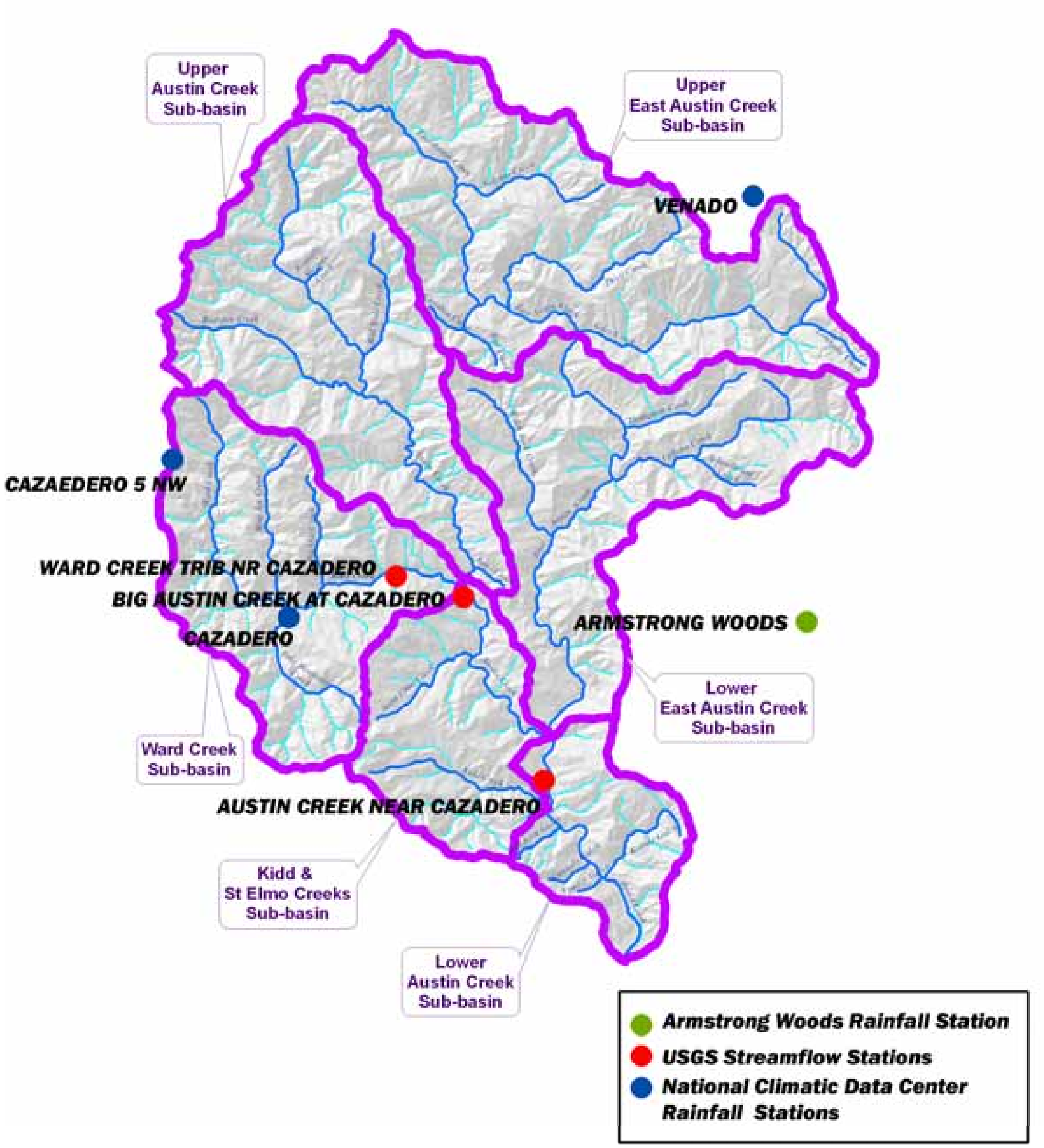


Figure 11. Rainfall and streamflow stations in the Austin Creek Watershed

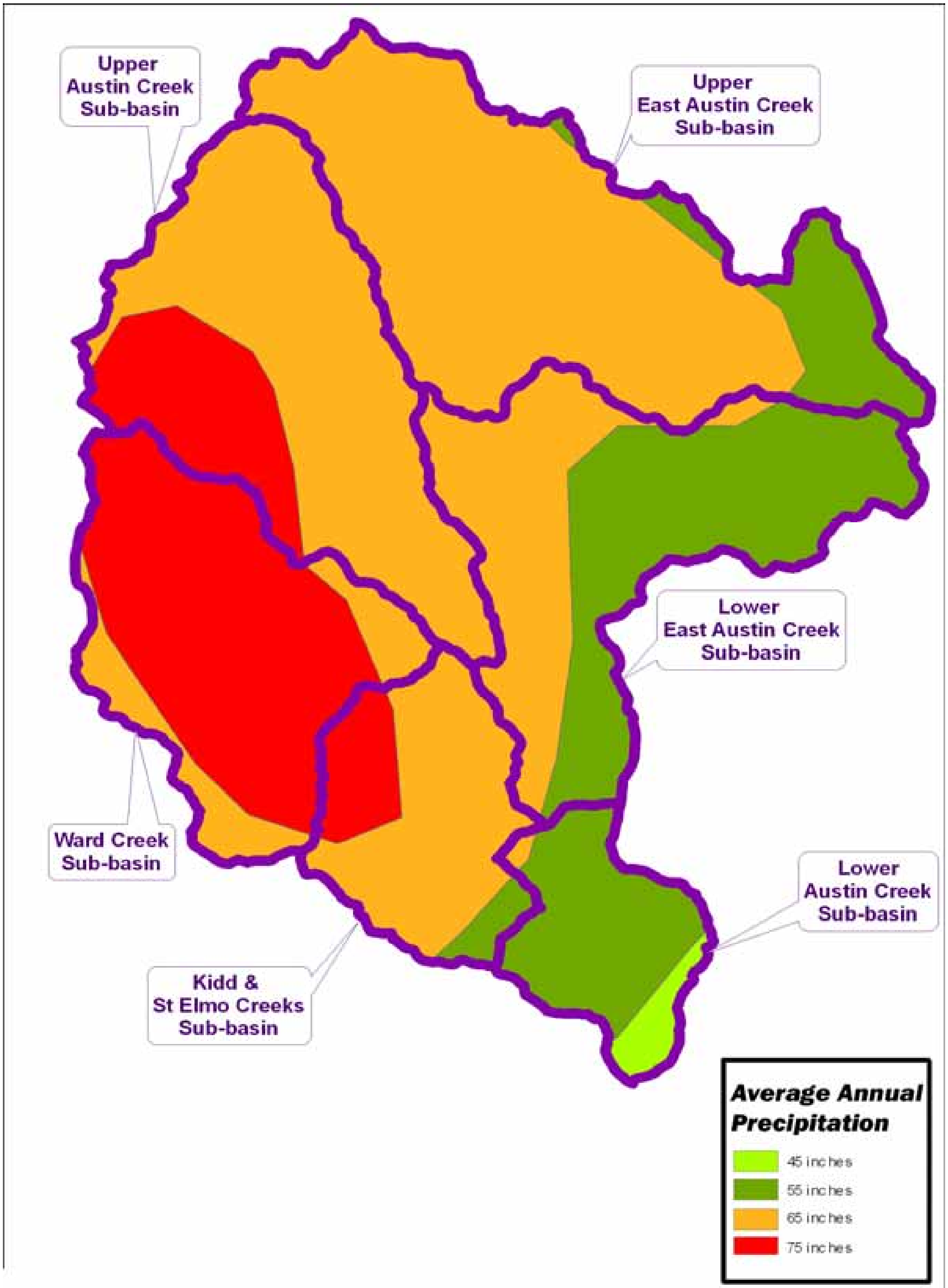


Figure 12. Average annual precipitation for the Austin Creek Watershed

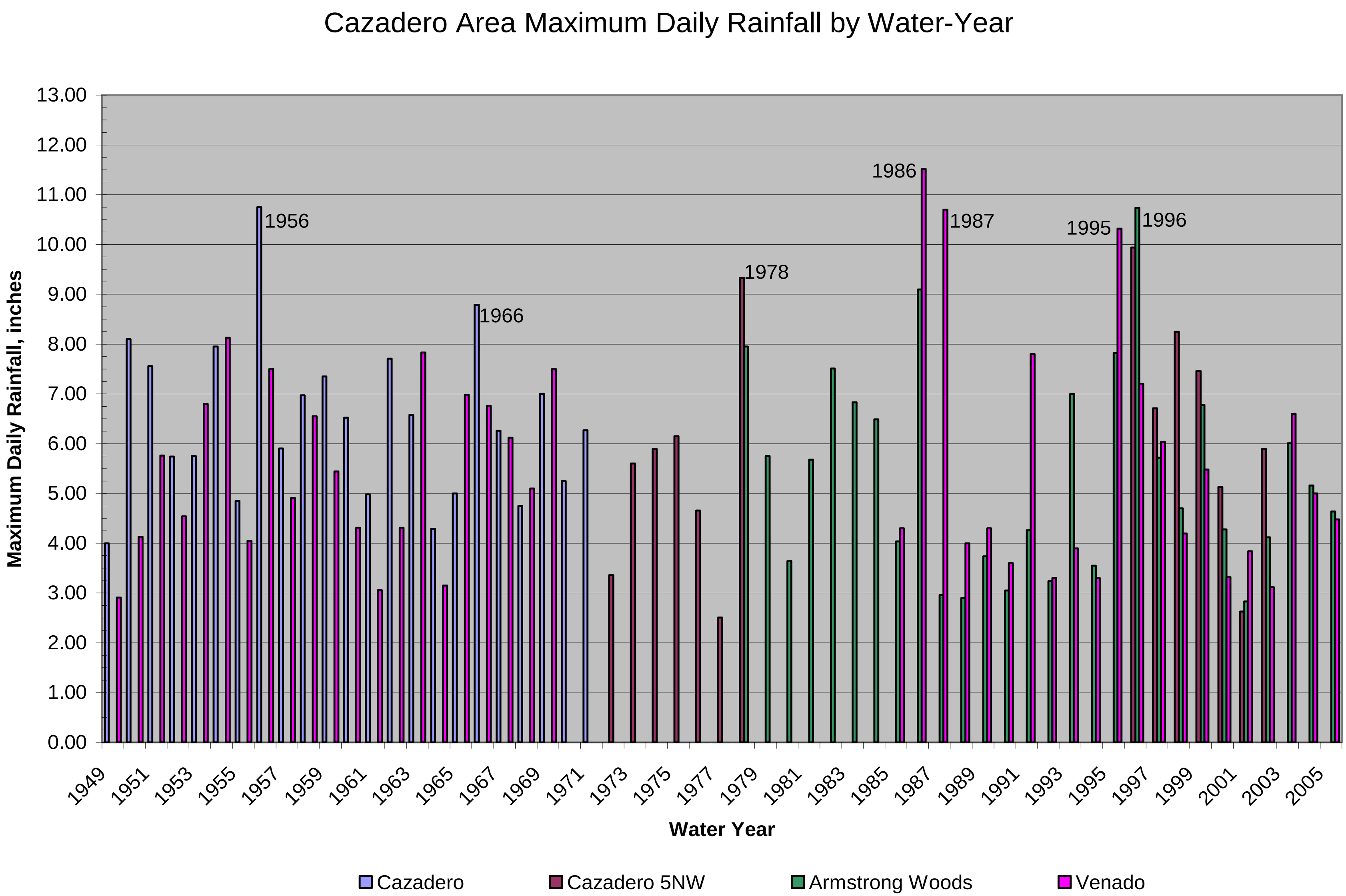


Figure 13. The Annual Maximum Daily Rainfall for Four Stations Near Cazadero

Geologic Features

The geology of the Austin Creek watershed is complex. Figure 54 shows the USGS geologic map for the Austin Creek watershed. The Austin Creek Watershed is composed of two major rock complexes: Great Valley Complex and Franciscan Complex. The origin of these complexes involves the long history of coastal plate movements, termed plate tectonics, that has formed coastal California.

What is now coastal California was largely ocean in the distant past, 350 million years ago. As the North American Plate and Oceanic Plate collided the primordial Sierra Nevada was formed and created the first western shoreline of California. This collision of continents involved an oceanic trench and the movement of one plate into the trench with a resulting period of mountain building along the edge of the trench.

This pattern of oceanic trenches, plate collisions and mountain building continued. About 200 million years ago the Sierran trench appeared and the North American Plate collided with the Oceanic Plate as the North American continent drifted westward. New mountains were built along the western edge of the ancient Sierras from this collision.

Then in early Cretaceous time (130 million years ago) the line of collision between the North American and Oceanic Plates moved westward 60 miles. In the north the Klamath Mountains detached from the Sierras. The intervening gap became the Great Valley and the new western collision zone was termed the Franciscan trench. Over many millions of years sediments from the ancient Sierra eroded and filled the Great Valley. The ocean floor moved eastward into the Franciscan trench and underneath the Great Valley and formed the Great Valley complex of rocks. As the oceanic plate was thrust downward into the earth’s mantle many of the sedimentary ocean floor layers were metamorphosed into other types of rock. The subduction of the ocean plate also allowed other rocks such as Serpentinite from the upper mantle to extrude into cracks and faults in the surface layers. As the collision of plates along the trench continued the western side of the trench elevated and formed the coastal range mountains. These mountains had many areas where portions of the subducted plate were ground and shattered and moved up to the surface. The coastal mountains also included areas of Great Valley Complex especially along the eastern margin.

About 15-30 million years ago the Franciscan trench off of the northern California coast had completely subducted the nearby oceanic floor, termed the Farrallon Plate. The North American Plate met the Pacific Plate along a new boundary termed the San Andreas Fault system. The San Andreas Fault probably first formed in southern California and lengthened northward as the North American and Pacific Plates met piece by piece. By 16 million years ago the San Andreas Fault reached its current length ending its northwest trend at the Mendocino triple junction where the last

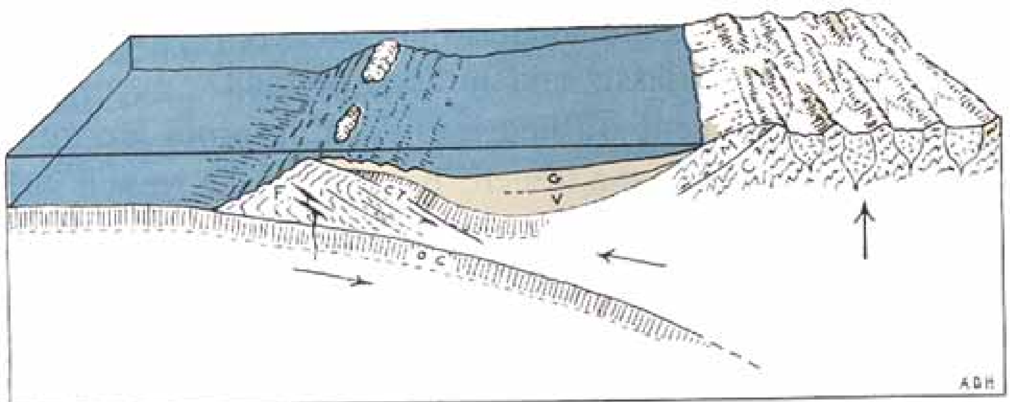


Figure 14

Late Cretaceous landscape, 100 to 65 million years B.P. Elevation of the Sierra resulted in accelerated stream erosion and removal of the volcanic cover and much of the metamorphic rock from above the granite batholiths. Considerable granitic debris (G) was added to the sediments in the offshore basin. In the trench, the accumulating sediments were crumpled and sheared and parts were forced under the edge of the basin sediments along the Coast Range Thrust (CT). The trench sediments comprise the present Franciscan Assemblage (F). The buckled edge of the upper plate appeared locally above water, probably as a string of islands. (OC—Oceanic crust.)

From: Geologic History of Middle California by A.D. Howard remnant of the Franciscan trench occurs. As California's earthquakes attest the plates continue to interact and move along the new fault.

The Franciscan Complex is comprised of a jumbled assortment of sedimentary rocks with large pieces of basalt ocean floor. The Franciscan Complex consists of the rocks which were carried into the oceanic trench and then sheared, changed and carried upward as the plates collided. Due to the jumbled, mixed nature of this complex it is often called the Franciscan Mélange.

The primary component of the Franciscan is Graywacke, muddy sandstone formed in the nearshore ocean from continental erosion. Some types of Franciscan rock such as chert were formed in very deep ocean and illustrate the large area of the sea floor, perhaps thousands of miles that sank into the Franciscan trench and was eventually uplifted.

Forming the solid eastern edge of the Franciscan trench was an ocean area that was not folded downward into the trench but remained relatively intact (Figure 14). This base layer of ancient oceanic floor is called the Coast Range Ophiolite and on top of this floor lies the Great Valley Complex. Great Valley Complex consists of layers of oceanic sediments laid down at about the same time as the Franciscan rock. However, the Great Valley Complex was not as extensively subducted, sheared and deformed as the Franciscan rocks. Instead the Great Valley Complex was tilted up on its side as the mountains to the west were uplifted from the plates colliding.

The San Andreas Fault, the current location of the plate boundary is actually a series or zone of parallel faults oriented on a northwest/southeast trend. Some of the faults in the zone are named, such as the Hayward Fault or Rodgers Creek Fault. Others are not named and may be inactive, or not studied well enough to determine their level of recent movement, or activity.

For the most part the San Andreas Fault system is a right lateral fault with the western side of the fault, the Pacific Plate moving northward along the edge of the North American Plate. As the faults move, rocks along the boundary grind against one another and may catch or snag. The fault can then build up pressure until an earthquake ruptures the rocks and propels them forward along the fault.

One feature of the Franciscan Complex is that the eastern side of the complex has the rocks that were earliest subducted and metamorphosed, while the western side of the complex has the more recently subducted and non-metamorphosed rocks (Blake et al 2002). The older rock types have also slid along faults northward away from their original location and may occur adjacent to the younger Franciscan material. The San Andreas Fault lies about four miles west of the Austin Creek watershed. Numerous unnamed faults of the San Andreas system dissect the Austin Creek watershed and define the boundaries between major rock types. Figure 54 depicts the geology of the Austin Creek watershed. In the Austin Creek watershed there are bands of a variety of Franciscan rocks having undergone certain levels of subduction, and for some, metamorphosis.

Franciscan Formation Graywacke and Mélange (KJfs) is the most abundant rock in the Austin Creek watershed. About 42% of the watershed is Franciscan Graywacke which is a muddy sandstone, a sedimentary rock which has not undergone metamorphosis.

Within the watershed are wedges of several other Franciscan Complex rocks including:

- Greenstone block (gs)
- Metabasalt (KJfmg)
- Metagraywacke (KJfm)
- Sandstone-Maastrichtian (TKfss)
- Sandstone-Turonian (Kfss)
- Serpentinite (sp)
- Small Silica Carbonate outcrops (sc)

A large area of Great Valley Conglomerate (KJgvc) also occurs on the western side of the watershed and is flanked by large blocks of the Metabasalt with a small area of Metagraywacke.

Each of these rock types varies in its erodibility or hardness. The Franciscan Graywacke is highly erodible and well-known for its large landslides and instability. A broad band of Serpentinite, which occurs across the northern portion of the watershed, is a highly sheared form of this rock and is also highly erodible.

In contrast the Metabasalt and Metagraywacke having been altered or metamorphosed through the heat and pressure of the subduction process are hard and durable rock types. Greenstone occurs in large blocks and also represents a harder more durable rock type. The two sandstones, named for the age within the Cretaceous in which they were formed, are also harder and more durable. One very large area of sandstone occurs in the northeastern portion of the Austin Creek watershed and small blocks are distributed in the south and west.

The Great Valley Conglomerate, the primary non-Franciscan rock type is located on the western side of the watershed. This rock is also relatively hard and erodes into very large blocks which can be seen in Ward Creek.

The landslides (Qls) mapped in the Geology figure are very large features; many small landslides likely occur but are not indicated on this scale geologic map. Landslide deposits as well as the alluvium (Qal) along creeks in the watershed represent the most erodible, least stable material. Many of the mapped landslides are very large, on steep slopes with a major creek at the toe. These features indicate a high potential for sediment generation into waterways.

The relative erodibility of each rock type was used in evaluating natural erosion hazards for each sub-basin. In addition the location of faults along rock types was also evaluated as rocks along faults are typically sheared and more erodible.

Debris Flows

Debris-flows can deliver a large amount of sediment with a wide range in sizes to the stream channel network. Knowing how often debris flows might occur can aid in understanding the morphology of the stream channel. Estimating when debris flows may have occurred will also suggest in which years detailed aerial photo analysis could be done to aid in the creation of a sediment budget.

Wilson and Jayko (1997) created maps of the total 6-hour and total 24-hour-rainfall associated with the widespread occurrence of debris flows in the San Francisco Bay region. The portion of their map for the Austin Creek watershed is shown in Figure 15. If the 24-hour rainfall total at a gauge equals or exceeds the 24-hour rainfall threshold, then numerous debris flows are expected in the region around the location of the rain gauge. The 24-hour-rainfall totals associated with widespread debris flows shown in Figure 15 should be taken only as an approximate guide since, shorter periods of intense rainfall could also trigger widespread debris flows. For example, the total rainfall in a 6-hour period may be high enough to trigger widespread debris flows but the associated 24-hour rainfall total could be less than the threshold shown in Figure 15.

The 24-hour-rainfall threshold map was used in this study since only daily total rainfall data was available. Daily total rainfall is only an approximation of 24-hour total rainfall. Daily total rainfall is always less than or equal to 24-hour total rainfall.

Figures 11 and 15 show that the Cazadero rain gauge is located in the 11" plus band; the Cazadero 5NW gauge is located in the 10"-11" band and the Armstrong Woods rain gauge is located in the 9.0" to 10.0" band.

Wilson and Jayko point out that the cumulative total rainfall has to satisfy any soil moisture deficit accumulated in the prior dry season before the rainfall threshold shown on their map is valid. This usually occurs by late December or early January. They also point out that debris flows are only going to occur in areas where the slope exceeds about 25%. Sandy soils are more likely to produce debris flows since a high percentage of clay will bind the soil together. Slopes in excess of 30% occur on about 76% of the Austin Creek watershed.

The map showing the 24-hour rainfall totals associated with widespread debris flows was constructed using the storm from January 3-5 of 1982 as a reference, which triggered 18,000 debris flows in the San Francisco region. As a result, some debris flow activity may occur when the 24-hour rainfall is less than the 24-hour rainfall thresholds for the occurrence of widespread debris flow shown in Figure 15.

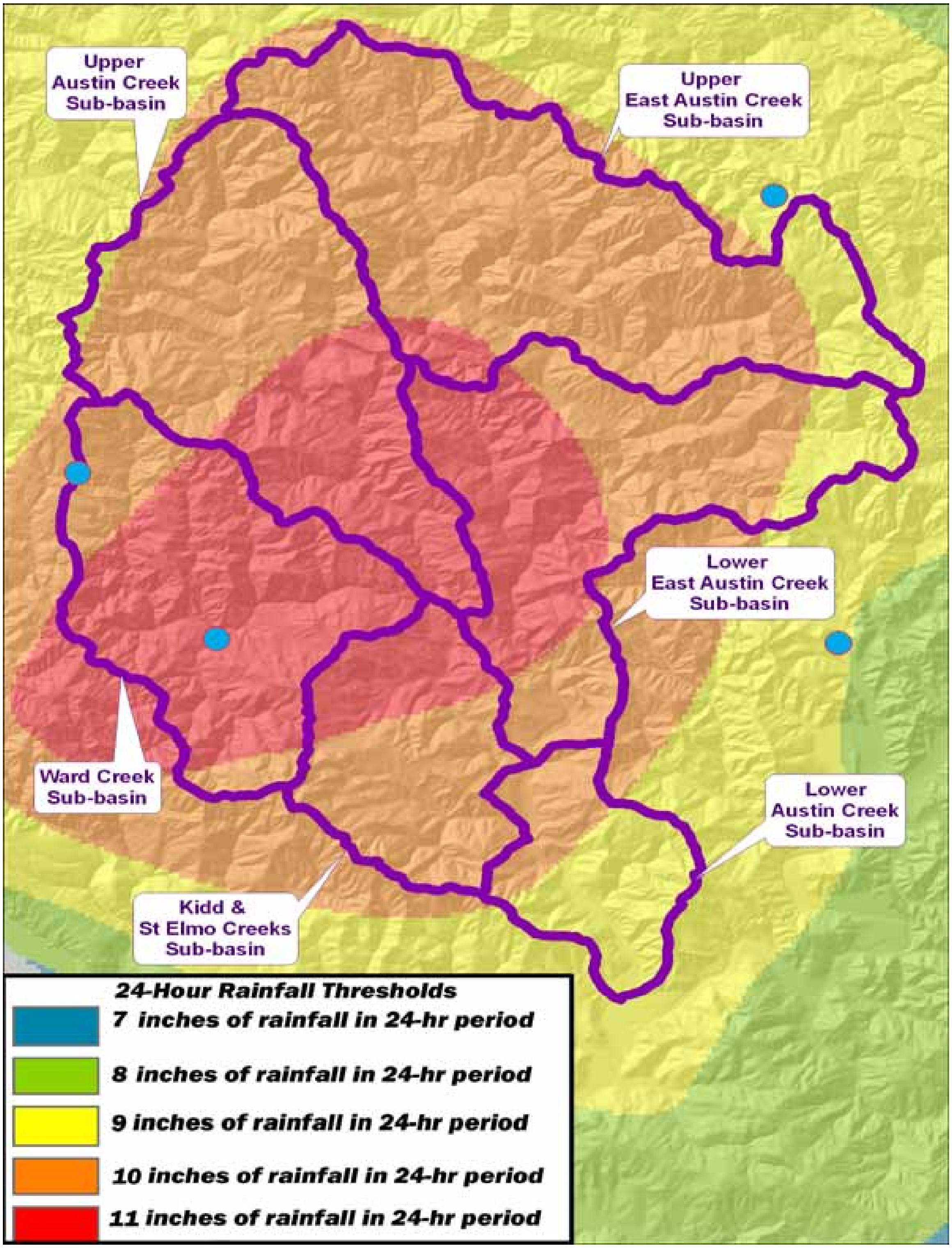


Figure 15. The 24-hour rainfall threshold for the initiation of widespread debris flows. Blue dots indicate rainfall stations (see Figure 11)

Figure 13 shows the annual maximum daily rainfall for four stations in the Austin Creek vicinity. The daily rainfall will always be less than or equal to the associated maximum 24-hour rainfall. For example, suppose the daily rainfall total for a station is based on observations made each day at 8:00 AM and suppose the heaviest rainfall for a 24-hour period occurs between 4:00 PM of one day and 4:00 PM of the next day. Then the rainfall from 4:00 PM until 8:00 AM the next day will be associated with that day's daily total and the rainfall from 8:00 AM to 4:00 PM will be part of the next day's daily total rainfall.

Looking at the maximum daily rainfall for each water-year will give a rough indication of which years may have had a widespread occurrence of debris flows in the Austin Creek watershed. The Cazadero rain gauge covers 1949-1971; the Cazadero 5NW gauge covers the periods 1972-1978 and 1996-2002; the Venado gauge covers the periods 1949-1969 and 1985-2005; and the Armstrong Woods rain gauge provides a record of the daily rainfall for the 1978-2005 water-years. Taken together, the four stations provide a look at the maximum daily rainfall for the 57 year period from 1949-2005. It is important to remember that if the daily rainfall in Figure 12 is less than the widespread debris flow threshold for a rain gauge, it is still possible that the associated 24-hour rainfall total exceeded the threshold for that rain gauge. For example, the Cazadero rain gauge reported a maximum daily total rainfall of 10.75" on December 22, 1955 (1956 water-year). The daily total for the previous day was 4.55" and was 3.53" for the following day. Therefore, it is reasonable to assume that the maximum 24-hour total rainfall on or about December 22, 1955, exceeded the widespread debris flow threshold of 11".

Intense rainfall is usually limited in spatial extent and typically covers only a few square miles. So, it is possible that portions of the Austin Creek watershed may have been subjected to 24-hour rainfall totals greater than the widespread debris flow threshold even in years when Figure 15 shows that the threshold was not surpassed.

The *exceedence probability* is defined by Ward and Trimble (2004) as:

> the probability that an event with a specified magnitude and duration will be exceeded in one time period, which is often assumed to be one year.

The return-period of an event is defined as the reciprocal of the exceedence probability. For example, an event that has a 1% (0.01) chance of occurring during any year has a return-period of (1/0.01) = 100 years.

Table 6 suggests that storms which produce daily maximum rainfall equal to the threshold for widespread debris flows, in the vicinity of the Austin Creek watershed, probably have a return-period of about 15-years. None of the records for the rainfall stations spans all of the 57 years shown in the graph. Only the Venado station has more than 30 years of record, so the reliability of the return-period estimated at the other stations is limited by short rainfall records.

The Guerneville rainfall station has 76 years of data available. A review of the data shows that the station was moved several times consequently, the return-period for the Guerneville maximum daily rainfall was not computed.

The maximum daily rainfall for a year is always less than or equal to the maximum 24-hour rainfall, which is the parameter that the debris-flow-threshold map is based on. When the maximum daily rainfall is greater than 9" in Figure 13, then it is reasonable to assume that the associated 24-hour maximum rainfall was approaching or exceeded the debris flow threshold for the respective rain gauge. Figure 13 shows that the maximum daily rainfall exceeded 9" in 1956, 1978, 1986, 1995 and 1996. Table 7 indicates that the cumulative rainfall, prior to the day of maximum daily rainfall, was sufficient for the occurrence of widespread debris flows only in 1956, 1986, 1987 and 1995.

Table 6. The return period for the annual maximum daily rainfall based on a regional estimate of the rainfall frequency. The widespread debris flow threshold for three of the four stations appears to be exceeded about every 15 years. The other station's threshold is exceeded about every 20 years.

		24 Hour Rainfall in inches by Station (see Figure 11 for station locations)			
Return Period	Exceedence Probability	Cazadero	Cazadero 5NW	Armstrong Woods	Venado
2	50.0%	6.14	5.31	5.12	5.23
5	20.0%	8.64	7.48	7.21	7.26
10	10.0%	10.30	8.92	8.59	8.60
15	6.7%	**11.24**	9.73	**9.37**	**9.36**
20	5.0%	11.89	**10.29**	9.91	9.89
25	4.0%	12.40	10.73	10.33	10.30
50	2.0%	13.95	12.07	11.63	11.56
100	1.0%	15.49	13.41	12.91	12.81
200	0.5%	17.03	14.74	14.19	14.05
Years of Record		23	15	28	42
Debris Flow Threshold		+11"	10 -11"	9 -10"	9 -10"

Table 7. Widespread debris flows require intense rainfall and sufficient prior rain to satisfy the soil moisture deficit. Cumulative rainfall prior to the day of the daily maximum rainfall indicates that widespread debris flows were only likely in 1956, 1986, 1987 and 1995. Isolated debris flows may have occurred in the 1978, 1986 and 1996.

Water Year	Date	Station	Maximum Daily Rainfall	Cumulative Total Prior to Day of Maximum	Debris Flows Likely
1956	12/22/1955	Cazadero	10.75	37.07	**Yes**
1978	11/21/1977	Cazadero 5NW	9.33	4.45	No
1986	12/2/1985	Venado	11.52	4.30	No
1986	2/17/1986	Armstrong Woods	9.10	41.36	**Yes**
1987	3/12/1987	Venado	10.70	30.50	**Yes**
1995	1/8/1995	Venado	10.32	21.08	**Yes**
1996	12/13/1995	Armstrong Woods	10.74	1.89	No
1996	12/12/1995	Cazadero 5NW	9.94	5.04*	unknown
*Data for October and November 1995 not available.					
December cumulative prior to daily maximum = 5.04"					

It is unlikely that widespread debris flows occurred in 1978, 1986 or 1996 since the cumulative rainfall prior to the day of maximum rainfall was low. However, isolated debris flows may have occurred in the 1978, 1986 and 1996.

Soils

The Sonoma County Soil Survey data layer was used to evaluate soils in the Austin Creek watershed and their erodibility. Table 43 lists the soil types in the Austin Creek watershed, their relative frequency of occurrence and their erodibility ratings. Soil types were used as part of an analysis of natural erosion hazards for each sub-basin.

Streamflows

The USGS operated three stream gauging stations in the Austin Creek watershed. Table 8 shows the station name and number for each of the three stations and when each station operated plus the number of years of flood record. Figure 11 shows the locations of these stations.

Table 8. USGS stream gauges in the Austin Creek watershed.

USGS Station Number	Station Name	Years of Record	Start of Record	End of Record
11467040	Ward Creek Tributary Near Cazadero, CA	12	1966	1977
11467050	Big Austin Creek At Cazadero, CA	3	1958	1962
11467200	Austin Creek Near Cazadero, CA	8	1960	1966, 2004

USGS Flood Data

The flood record at all of these three stations is too short to reliably estimate the flood frequency. Therefore, a regional flood frequency analysis was conducted. Stations from the Gualala River watershed and the Garcia River were combined with the two Austin Creek stations with at least 7 years of flood data, see Table 9. The normal distribution was used to estimate the magnitude of selected return-period events.

Figure 16 shows the mean annual flood versus the watershed area for the six stations in Table 9. Table 9 shows the regression coefficients for the various return period floods versus watershed area. The regional equations in Table 9 can be used to estimate the selected return-period discharge for any location in the Austin Creek watershed. Estimates for the mean-annual, 10-year and 15-year floods, based on the results of the regional analysis shown in Table 9, are shown in Table 10. Floods were only estimated for only the three sub-basins that receive no drainage from other sub-basins that is they are headwater sub-basins. The mean annual flood has a 2-year return-period for the normal distribution.

Table 9. USGS stream gauging stations used in regional flood frequency analysis. Flood return-periods were estimated using the normal distribution. The mean annual flood has 2-year return-period for the normal distribution.

Station Number	Station Name	Years Record	Area Sq-Mi	Mean Annual Flood cfs	10-Year Flood cfs	15-Year Flood cfs
11467040	Ward C Tributary Near Cazadero Ca	12	0.11	27.4	44.0	46.8
11467200	Austin C Near Cazadero Ca	7	63.1	11,840	15,268	15,856
11467300	Unnamed Tributary To Wheatfield Fork Gualala R Near Annapolis	9	0.19	78.6	139.7	150.2
11467500	S Fork Gualala R Near Annapolis Ca	21	161	28,235	43,103	45,650
11467560	China Gulch	12	0.54	76.9	111.4	117.4
11467600	Garcia River near Point Arena	26	98	16,061	26,998	28,872

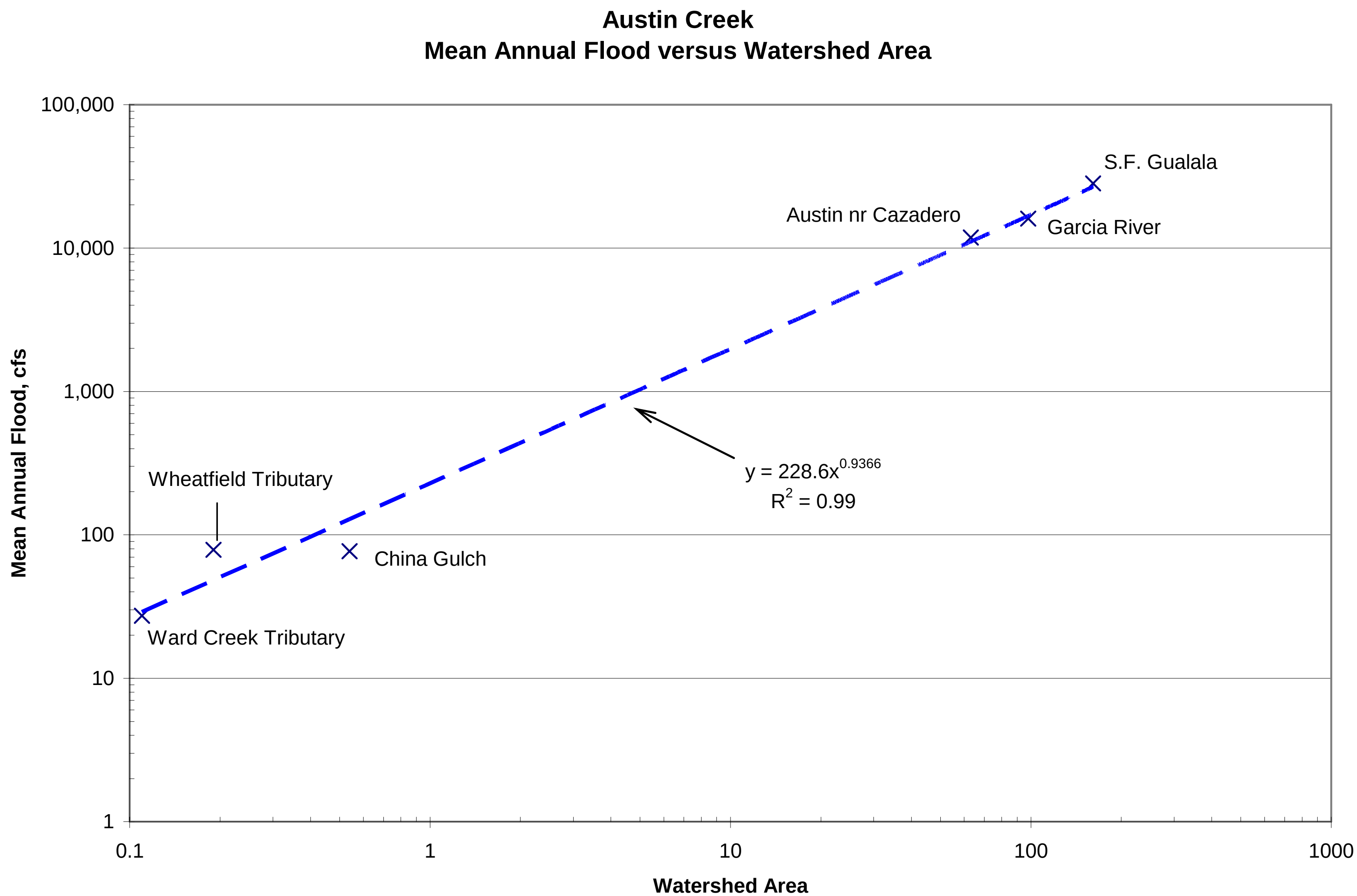


Figure 16. The mean annual flood versus watershed area for six stations near Austin Creek

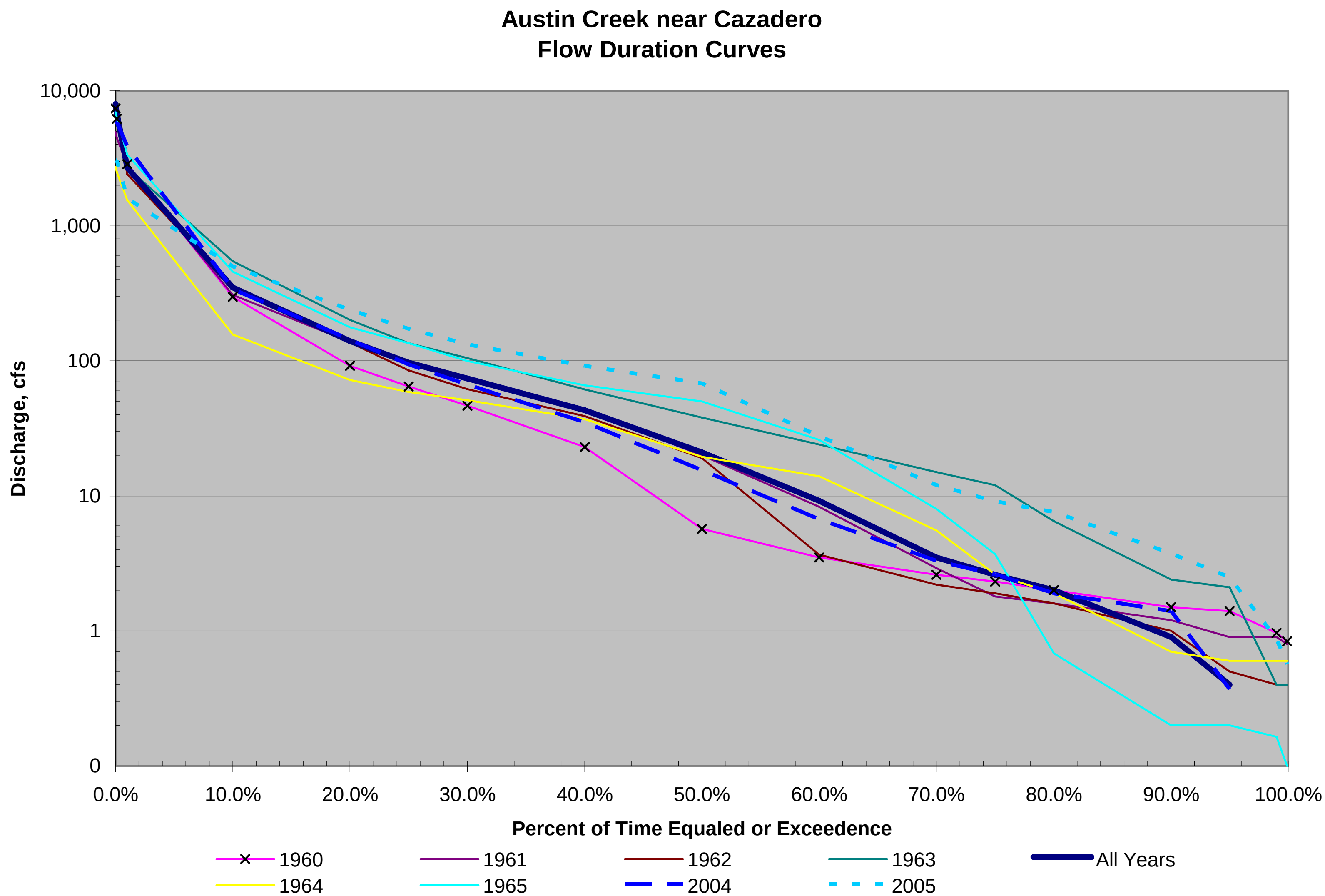


Figure 17. Flow duration curves for the Austin Creek near Cazadero stream gauge

Table 10. The coefficients and exponents for power equations derived from the regional flood frequency analysis. The watershed area (sq-miles) is the independent variable used to estimate the various return-period floods. The equations are of the form Return-Period Discharge = $b*(Area)^c$, where b is the coefficient and c is the exponent. R^2 is a measure of the "goodness of fit" of the equation. The mean annual flood has a 2-year return period on the normal distribution.

	Coefficient	Exponent	R^2
Mean Annual Flood	228.6	0.9366	0.990
10-Year Flood	360.58	0.9241	0.985
15-Year Flood	382.98	0.9227	0.985

Table 11. Estimates for the mean-annual flood, 10-year flood and 15-year flood based on the results of the regional analysis shown in Table 9. Only estimates for headwater watersheds were made. The mean annual flood has 2-year return-period for the normal distribution.

	Area sq-miles	Mean Annual Flood cfs	10-Year Flood cfs	15-Year Flood cfs
Upper Austin Creek	14.57	2,810	4,287	4,536
Upper East Austin Creek	18.02	3,429	5,217	5,519
Ward Creek	11.79	2,305	3,525	3,731
Total for Austin Creek	70.03	12,228	18,291	19,312

USGS Daily Discharge Data

Daily discharge data was collected at the Austin Creek near Cazadero (11467200) stream gauge from June 8, 1959 to September 30, 1966. Daily discharge measurement was resumed on September 12, 2003 and continues to the present. Table 12 presents a summary of the calendar-year daily discharge record for Austin Creek near Cazadero. The data collection period for 2005 is still in progress.
Table 12 shows that there were 40 days of zero discharge during the period of record at the Austin Creek near Cazadero stream gauge. There was a 30 day period of zero discharge in 1959 and a 9 day period of zero discharge in 2004. There was a single day of zero discharge reported in 1966 but, the gauge was suspended on September 30, 1966. Table 11 also shows the minimum 7-day discharge for each month from August through November. The period of lowest discharge tends to be in either September or October.

Table 13 estimates the return period for the 7-day minimum discharge. The data indicate that a 7-day discharge of zero can be expected about every 10 years. The median annual minimum 7-day discharge is 0.40 cfs.

Table 14 presents the flow duration analysis, by water-year, for the Austin Creek near Cazadero stream gauge. Figure 17 is a graphical presentation of the data in Table 14. The flow duration curves shown in Figure 17 demonstrate that the data for 2004 and 2005 are very similar to the curves for 1960-1966 water-years, suggesting that no significant change in flow patterns occurred between 1966 and 2004. Of course, this conclusion is based on a limited set of data and applies only to the flow at the Austin Creek near Cazadero stream gauge.

Table 12. Summary of the daily discharge record at the Austin Creek near Cazadero stream gauge. There are a significant number of days with no record in 1959, 1966, 2003 and 2005.

Calendar Year				Minimum 7-Day Discharge				Days of zero Discharge	
Year	Days of Record	Mean	Median	Aug	Sept	Oct	Nov	Aug	Sept
1959	**214**	**6.52**	**2.60**	0.00	0.00	2.71	2.50	**13**	**17**
1960	366	188.55	20.00	1.40	0.94	0.84	2.94	0	0
1961	365	153.55	24.00	1.20	0.90	0.91	2.94	0	0
1962	365	192.75	25.00	0.99	0.40	0.44	15.00	0	0
1963	365	205.86	50.00	2.44	1.99	1.96	14.86	0	0
1964	366	147.53	18.00	0.60	0.60	0.20	54.14	0	0
1965	365	157.80	41.00	0.27	0.14	0.10	1.66	0	0
1966	**273**	**179.81**	**23.00**	0.44	0.09	n/a	n/a	0	**1**
2003	**115**	**209.07**	**4.60**	n/a	4.39	1.50	1.49	0	0
2004	366	154.79	17.00	1.23	0.00	0.26	7.76	0	**9**
2005	**292**	**180.80**	**80.50**	4.74	2.53	n/a	n/a	0	0

Table 13. The return-period for the 7-Day Minimum Discharge at the Austin Creek near Cazadero stream gauge. The return-period was estimated using the Weibull Plotting Position method. Data from 1966 was not used since the gauge was suspended after September 30, 1966. Data from 2003 was not used since data collection resumed on September 12, 2003. Data from 2005 was used since its relatively high discharge indicates that the discharge is not likely to approach zero by the end of November.

Calendar Year	Annual Minimum 7-Day Discharge	Rank	Return Period Years	Probability Discharge will be Less than Observed
1959	0.00	1	10.00	10.00%
2004	0.00	1	10.00	10.00%
1965	0.10	3	3.33	30.00%
1964	0.20	4	2.50	40.00%
1962	0.40	5	2.00	50.00%
1960	0.84	6	1.67	60.00%
1961	0.90	7	1.43	70.00%
1963	1.96	8	1.25	80.00%
2005	2.46	9	1.11	90.00%
Number of Years =		9		

Table 14. The discharge associated with selected exceedence probabilities for each water-year of record at the Austin Creek near Cazadero stream gauge. For example, for the 1960 Water-Year, the 1% exceedence probability indicates that only 1% of the discharges for the water-year were greater than or equal to 2,868 cfs. The 50% exceedence probability is the median for the year. The 0.0% exceedence probability is the maximum discharge for the year.

Exceedence Probability	1960 Water Year	1961 Water Year	1962 Water Year	1963 Water Year	1964 Water Year	1965 Water Year	1966 Water Year	2004 Water Year	2005 Water Year	All Years
0.0%	7,390	4,930	7,970	6,820	2,740	6,910	7,870	5,880	3,060	7,970
0.1%	6,182	4,497	6,398	5,666	2,510	6,368	7,269	5,869	3,045	6,869
1.0%	2,868	2,792	2,414	2,691	1,545	3,366	2,263	3,845	1,593	2,689
10.0%	298	308	354	546	157	459	310	340	499	349
20.0%	92	138	137	201	72	177	162	143	238	140
25.0%	64.5	94.0	85.0	135	58.8	135	123	93.8	172	97.0
30.0%	46.5	72.8	61.8	104.8	51.0	99.8	88.6	66.5	132.4	74.0
40.0%	23.0	43.4	39.0	61.4	37.0	66.0	46.4	35.0	92.0	43.0
50.0%	5.7	20.0	19.0	38.0	19.5	50.0	30.0	15.5	68.0	21.0
60.0%	3.5	8.3	3.7	24.0	14.0	26.0	10.6	6.7	27.6	9.2
70.0%	2.6	2.9	2.2	15.0	5.6	8.0	2.7	3.3	12.0	3.5
75.0%	2.3	1.8	1.9	12.0	2.6	3.7	1.7	2.6	9.1	2.6
80.0%	2.0	1.6	1.6	6.5	1.9	0.7	0.9	1.9	7.6	2.0
90.0%	1.5	1.2	1.0	2.4	0.7	0.2	0.2	1.4	3.7	0.9
95.0%	1.40	0.90	0.50	2.10	0.60	0.20	0.10	0.37	2.50	0.40
99.0%	0.97	0.90	0.40	0.40	0.60	0.16	0.10	0.00	0.87	0.00
99.9%	0.84	0.80	0.40	0.40	0.60	0.10	0.04	0.00	0.57	0.00

Watershed Vegetation

A variety of vegetation types, including coniferous forest, redwood forest, cypress forest, hardwood forest, mixed hardwood/coniferous forest, chaparral and grassland cover the Austin Creek watershed (Figure 55 and Table 15). Hardwood forest and conifer forest are the primary types of vegetation. The conifer forest shown in Figure 55 depicts redwood forest and closed-cone pine/cypress forest separately from the general category of conifer forest which is primarily Douglas fir forest. Taken together the three categories of coniferous forest represent the largest coverage of vegetation in the Austin Creek watershed. Redwood forest tends to occur in the creek valleys and the wettest hillsides. Coniferous forest covers the valleys and hillsides along most of the Austin Creek and the center of the watershed. Hardwood forest is more concentrated around the perimeter of the watershed.

One of the unique features of the vegetation in the Austin Creek Watershed is serpentine endemic species. Serpentinite rock weathers to create serpentine soils. These soils have chemical qualities which create difficult growing conditions for most plants (Figure 30). Serpentine soils contain high levels of certain chemicals including magnesium, low levels of calcium, low levels of nutrients such as nitrogen, potassium and phosphorous, high concentrations of heavy metals-such as chromium and nickel and low levels of molybdenum. Serpentine adapted plant species have various adaptations which allow them to grow in a hostile environment. Plant adaptations to serpentine soils include exclusion, uptake, or sequestering of one or more of the chemicals in serpentine soils (Kruckeberg 1984). In general there are three categories of plants which grow on serpentine soils- endemic species which are restricted to serpentine soils, plants which grow on non-serpentine soils but are found on serpentine soils in other locales and can serve as indicators of serpentine conditions, and plants which grow continuously on both adjacent areas of serpentine and non-serpentine soils.

Serpentine endemics may be physically shorter, slower growing and lower in density. Indicators grow differently (shorter and smaller) on serpentine soils than non-serpentine areas. California has the most diverse serpentine flora in the world (Kruckeberg 1984). Many of the rare plants in the Austin Creek watershed are serpentine endemic species. Sargent cypress forest is a unique forest type which occurs on the serpentine soils of the drainage.

Table 15. Vegetation Types and Land Use in the Austin Creek Watershed

Vegetation types*	Acres	Sq. miles
Grassland/Rangeland	3,534	5.5
Barren	991	1.5
Chaparral	2,445	3.8
Closed cone pine-cypress	3,354	5.2
Conifer	10,484	16.4
Cropland	49	0.1
Hardwood	14,758	23.1
Mixed Hardwood/Conifer	5,396	8.4
Redwood	3,740	5.8
Urban	24	0.0
Water	43	0.1

* This information is created from satellite imagery, which does not record features less than 30 meters and 2.5 miles in extent and therefore some features are not included.

Roads

Roads in the watershed, both public and private, are often the primary sources of fine sediment pollution to creeks. Table 16 lists the total miles of roads and the miles of roads at different slopes in the Austin Creek watershed (Figure 56). Overall the ratio of miles of roads to square miles of watershed is over 5 a high number. A ratio of less then 2 is recommended for a watershed to support anadromous fish (Meehan 1991).

Table 16. Roads in the Austin Creek Watershed

Roads	Miles	Miles/sq Mile
Total miles of roads in watershed	355.6	
Miles of road/sq mile of watershed		5.07
Total miles of roads >30% slope in watershed	236.7	
Miles of road>30% slope/sq mile of watershed		3.38
Miles of road on 1-30% slope	112.0	
Miles of road on 30-50% slope	137.5	
Miles of road on 50-65% slope	62.2	
Miles of road on >65% slope	37.0	

Rare and Endangered Plants and Wildlife

The California Natural Diversity Data Base (CNDDB) was queried for records of occurrences for rare and endangered species in the Austin Creek watershed. Table 17 lists the plant and animal species that have recorded occurrences in the Austin Creek watershed in the CNDDB. Many of the plant species occur on serpentine soils and have a relatively restricted range. Only one of the rare plants, the Cedars manzanita is listed under the state Endangered Species Act as Rare. For the unlisted plants protection occurs through the California Environmental Quality Act (CEQA) process in which the permit for a land development includes mitigation measures for effects on the rare plant population. However the mitigations can be removed by the local, or state, agency which grants a use or development permit. For the one listed plant the Department of Fish and Game has oversight authority and can render a jeopardy opinion for any development that would adversely affect the listed plant.

There are also several rare animals that have been found in the Austin Creek watershed.

Table 17
California Department of Fish and Game
Natural Diversity Database
Special Status Plants and Animals Recorded in the Austin Creek watershed

Scientific Name	Common Name	STATUS[1]			
		Federal	California	CDFG	CNPS
Plants					
Amorpha californica var napensis	Napa false indigo	None	None		1B
*Arctostaphylos bakeri ssp sublaevis**	The Cedars manzanita	None	Rare		1B
*Calochortus raichei**	The Cedars fairy-lantern	None n	None		1B
Ceanothus purpureus	Holly-leaved ceanothus	None	None		1B
Chlorogalum pomeridianum var minus *	Dwarf soaproot	None	None		1B
*Erigeron angustatus**	Narrow-leaved daisy	None	None		1B
*Erigeron serpentines**	serpentine daisy	None	None		1B
*Eriogonum nervulosum**	Snow mountain buckwheat	None	None		1B
Leptosiphon jepsonii	Jepson's leptosiphon	None	None		
Sidalcea malviflora ssp.	Purple-stemmed	None	None		1B

Table 17 California Department of Fish and Game Natural Diversity Database Special Status Plants and Animals Recorded in the Austin Creek watershed					
		STATUS[1]			
Scientific Name	Common Name	Federal	California	CDFG	CNPS
purpurea	checkerbloom				
*Streptanthus glandulosus var hoffmanii**	Second jewel-flower	None	None		1B
*Streptanthus morrisonii**	See individual subspecies	None	None		1B
Trifolium buckwestiorum	Santa cruz clover	None	None		1B
<u>Lichen</u>					
Usnea longissima	Long-beard lichen	None	None		
<u>Crustaceans</u>					
Syncaris pacifica	California freshwater shrimp	Endangered	Endangered		
<u>Amphibians</u>					
Rana boylii	Foothill yellow-legged frog	Species of concern	None	SC	
<u>Fish</u>					
Lavinia symmetricus parvipinnis	Gualala roach	Species of Concern	None	SC	
Oncorhynchus kisutch	Coho salmon	Endangered	Endangered		
Oncorhynchus mykiss	Steelhead trout	Threatened	Threatened		
<u>Mammals</u>					
Arborimus pomo	Red tree vole	Species of Concern	None	SC	

1 Federal and California indicates listing status under the state and federal Endangered Species Act; CDFG is California Department of Fish and Game species of concern designation; CNPS is the California Native Plant Society list of rare plants.
* Indicates plant species know to grow on serpentine soils

California Freshwater Shrimp (*Syncaris pacifica*)

The California freshwater shrimp (Syncaris pacifica) is a 10-legged crustacean of the family Atyidae. The shrimp have small surface and internal color-producing cells clustered in a pattern to disrupt perception of their body outline and maximize the illusion that they are submerged, decaying vegetation. Undisturbed shrimp move slowly and are virtually invisible on submerged leaf and twig substrates, and among the fine, exposed, live roots of vegetation along undercut stream banks. According to Serpa, "California freshwater shrimp are detritus feeders, feeding on small, diverse particles brought downstream to their pools by the current. As the water slows, the particles are filtered out by the exposed roots and other vegetation. The shrimp simply brush up the food with tufts at the ends of their small claws, and lift the collected morsels to their mouths. Colonized by algae, bacteria, fungi, and microscopic animals, the particles are more nutritious than they seem. Although shrimp usually walk slowly about the roots as they feed, these crustaceans will undertake short swims to obtain particularly tasty items." (Serpa 1996)

California freshwater shrimp have evolved to survive in a broad range of stream and water temperature conditions characteristic of small, perennial coastal streams. They have been found only in low-elevation and low-gradient (<1%) streams. Excellent habitat conditions include: streams of 12 to 36 inches in depth with exposed live roots of trees such as alder and willow along undercut banks greater than 6 inches with overhanging woody debris or stream vegetation and vines such as stinging nettles, grasses, vine maple and mint. Such areas may provide refuges from swift currents as well as some protection from high sediment concentrations associated with high stream flows. During the winter, the shrimp is found in undercut banks with exposed fine root systems or dense, overhanging vegetation.

Historically, the shrimp was probably common in low elevation, perennial freshwater streams in Marin, Sonoma, and Napa counties. Today, it is found in sixteen stream segments within these counties. The distribution can be separated into four general geographic regions including tributary streams in the lower Russian River drainage, and Austin Creek. Existing populations of the California freshwater shrimp are threatened by introduced fish, deterioration or loss of habitat resulting from water diversion, impoundments, livestock and dairy activities, agricultural activities and developments, flood control activities, gravel mining, timber harvesting, migration barriers and water pollution.

Foothill Yellow-Legged Frog (*Rana boylii*)

The foothill yellow-legged frog is small sized frog (1.5-2.8 in) with gray, brownish, or olive coloring, tending to match the background of its habitat. Frogs can be plain or mottled with dark spotting with yellow underneath on the rear legs and lower abdomen.

Foothill yellow-legged frogs are found near streams and rivers in chaparral (dense shrubs) and forests in the foothills of the Sierra Nevada Mountains and the Coastal Range from Oregon to central California. Frogs come out on the banks to sun themselves, but dive to the bottom if a predator, or a threat, approaches. They stay still along the river bottom and their color helps camouflage them.

Mating and egg-laying occurs in water from mid-March until early June when streams have slowed from winter runoff. Clusters of eggs are attached to the downstream side of submerged rocks. Tadpoles transform in about 15 weeks, from July to September.

Foothill yellow-legged frogs have disappeared from much of their range in California (possibly up to 45%). Populations south of southern Monterey County are now apparently extinct. They are also gone from 66% of its range in the Sierra Nevada mountains, especially south of Highway 80. These frogs have been recorded from locations on Upper and Lower Austin Creek and Ward Creek.

Gualala roach (*Lavinia symmetricus parvipinnis)*

Gualala roach are endemic, small (2.5 inches) fish and, according to Moyle (1976), capable of withstanding water temperatures of 95^{o} F. The Gualala roach has a competitive advantage in warm water over other native fishes by being able to survive in locations where other fish cannot. Such locations include intermittent pools with high water temperatures and low dissolved oxygen. The roach has always been present in the Gualala River basin, but was formerly present only at low levels. It has risen to dominance with land uses creating more warm water habitats, but the roach too faces a threat to survival from a reduction in surface flows.

There is one record of the Gualala roach in Main Austin Creek in 1999.

California Red Tree Vole (*Arborimus pomo*)

California red tree vole occurs along the coast from Sonoma Co. to the Oregon border, being more or less restricted to the fog belt. Reported to be rare to uncommon throughout its range this vole occurs in old-growth and other forests, mainly Douglas fir, redwood, and montane hardwood-conifer habitats.

Red tree voles feed on the needles of Douglas fir. Vole collect needles and twigs and, either eat the needles immediately, or bring them back to the nest. Drinking water is required, but in a lab a colony subsisted entirely on moistened needles. Under natural conditions, water probably is obtained from food, but voles also lick dew and rain off needles of coniferous trees in the vicinity of their nests.

Male red tree voles nest most frequently in a tree nest constructed of fir needles, or, less frequently, in shallow burrows at the base of fir trees, beneath litter. Females seem to spend most of their lives in trees, constructing large, domed nursery nests of Douglas fir needles, from 6-150 ft. above the ground. Nests may be occupied by succeeding generations, increasing in size with each generation. The home range of a vole probably encompasses one to several fir trees, with females often living in one tree and males visiting several trees.

The spotted owl is the main predator of red tree voles throughout the geographical distribution, but saw-whet owls also are predators and perhaps raccoons. Steller's jays may be the most important predators of tree voles. Severe winter storms probably also adversely affect local populations.

There is one CNDDB record of a red tree vole occurrence on Lower East Austin Creek.

Coho Salmon (*Oncorhynchus kisutch*)

This description was derived from the Endangered Species Petition: Coho Salmon (*Oncorhynchus kisutch*) prepared by the Salmon and Steelhead Recovery Coalition (SSRC) July, 2000. Coho salmon have demanding habitat requirements and are most abundant in undisturbed, heavily forested watersheds. Coho are fairly large salmon, with spawning adults typically attaining 22 to 28 inches in length and weighing 6.5-13 pounds.

Most Coho salmon return to their natal streams after spending two years in the ocean. In California, spawning migrations begin after heavy late fall or winter rains breach the sand bars to the mouths of coastal streams, allowing the fish to move into the streams. However, migration typically occurs when stream flows are either rising or falling, not necessarily when streams are in full flood.

Coho salmon migrate and spawn mainly in small coastal streams that flow directly into the ocean, or in the tributaries of large rivers. Females choose the spawning sites (redds), usually near the head of a riffle (at the tail of a pool) at, or slightly upstream of the hydraulic control, where the water changes from smooth to turbulent flow and there is a medium to small gravel substrate (1/2" to 4.4"). The flow characteristics at the location of the redd usually ensure good aeration, and the circulation facilitates fry emergence from the gravel. Each female builds a series of redds, moving upstream as she does so she deposits a few hundred eggs in each. Both males and females die soon after spawning. Spawning sites are typically at the head of riffles or tail of pools where there are beds of loose, silt free, course gravel and where cover exists nearby for adults. Unlike other salmon species, Coho salmon redds can be situated in substrates composed of up to 10% fines (Emmett, et al, 1991, California Department of Fish and Game 1991). Spawning depths are 4-21 inches, with water velocities of 6.5 to 26.2 feet per second (Hassler 1987).

Optimal temperatures for development of embryos in the gravel are 43-50° F., although eggs and alevins can be found in 40-70° F. water. Dissolved oxygen levels should be above 8 mg/l for juveniles (Emmett, et al. 1991). Eggs hatch after 8-12 weeks of incubation, the time being related to water temperature. Hatchlings remain in the gravel until their yolk sacs have been absorbed, 4-10 weeks after hatching. Upon emerging, they seek out swallow water along the stream margins. Initially they form schools, but as they grow bigger the schools break up and the juveniles (parr) set up individual territories. The larger parr tend to occupy the heads of pools. Juveniles require water temperatures that do not exceed 71-77º F. for any extended time and oxygen and food (invertebrates) levels remain high. Preferred temperatures are 50-59º F. Preferred water velocities for juveniles are 0.25 to 1.5 feet per second depending on habitat. Juveniles prefer deep (greater than 3 feet), well shaded pools with plenty of overhead cover; highest densities are typically associated with logs and other woody debris in the pools or runs. (Hassler, 1987, Emmett, et al, 1991). Young and adult Coho salmon are found over a wide range of substrates, from silt to bedrock. High turbidity is detrimental to emergence, feeding and growth of young Coho.

As the fish continue to grow, they move into deeper water and expand their territories until, by July and August, they are in deep pools. Between December and February, winter rains result in increased stream flows and by March, following peak flows, fish again feed heavily on insects and crustaceans and grow rapidly. Toward the end of March and the beginning of April they begin to migrate downstream and into the ocean. Out-migration in small California streams typically peaks from mid-April to mid-May, if conditions are favorable. Migratory behavior is related to rising, or falling, water levels, size of fish, day length, water temperature, food densities and dissolved oxygen levels. At this point, the outmigrants are about one year old and 5-6 inches in length. Parr marks are still prominent in the early migrants, but later migrants are silvery, having transformed into smolts.

After entering the ocean, the immature salmon initially remain in near-shore waters close to their natal stream. They gradually move northward staying over the continental shelf. Coho salmon can range widely in the north Pacific. The movements of California fish were poorly known until the Pacific States Marine Fisheries Commission's Regional Mark Information System (PSMFC 1994). Coded wire tag data from this study indicates that at least 65-92% of California's' Coho salmon feed in the oceans off our coast. Adult Coho salmon are primarily piscivores, but shrimp, crabs and other pelagic invertebrates can be important foods in some areas.

In California, Coho salmon were distributed in all accessible streams on the coast north of Big Sur. Brown and Moyle (1991) found historical records of occurrence of Coho in 582 California streams, ranging from the Smith River near the Oregon border to the Big Sur River on the central coast. More recent surveys available for 42% of these streams indicate that 46% have lost their populations (Brown and Moyle, 1991). The Wilderness Society estimates in California, that Coho salmon are extinct in 26% of their range, endangered in 22%, and threatened in the remaining 52% of the historic range.

The National Marine Fisheries Service evaluated the stocks of Coho salmon in California and the West Coast. They determined that at least two Evolutionary Significant Units (ESUs) could be established in California, Central California coast and the Southern Oregon/Northern California ESU. Austin Creek is contained in the Central California ESU.

Historical information on state-wide Coho salmon abundance are estimates made by fisheries managers, based on limited catch data, hatchery records and personal observations of runs in various streams. Estimates for the number of Coho spawning in the state in the 1940's range from 200,000 – 500,000 to close to 1 million (California Advisory Committee on Salmon Steelhead and Trout, 1988). According to some researchers (Brown and Moyle 1991), Coho populations held at about 100,000 in the 1960's and dropped to an average of 33,500 during the 1980's (Brown and Moyle 1991). The reliability of these estimates is uncertain, and they must be viewed only as "order-of magnitude" approximations.

The California Department of Fish and Game summarized recent data and determined that most remaining Coho salmon were hatchery fish although some wild Coho may still remain in small tributaries. This same report concluded "Coho salmon in California, including hatchery stocks, could be less than 6% of their abundance in the 1940's, and have experienced at least a 70% decline in numbers since the 1960's," and many populations have been eliminated and others have runs only 1 out of 3 years, indicating two brood years have been lost and extinction is imminent.

Human development and its associated impacts are primarily responsible for the decline of Coho salmon populations. The long-term decline of Coho salmon populations parallels the deterioration of freshwater habitat caused by human disturbances (Lawson 1993). Coho are especially vulnerable to loss or degradation of spawning, summer rearing, and winter rearing habitats (Pearcy 1992). Pearcy (1992) pointed to degradation of freshwater habitat as perhaps the largest contributor to long-term declines of Coho populations. The National Marine Fisheries Service (NMFS) reviewed the past destruction, modification and curtailment of freshwater habitat. NMFS found that the factors for decline of habitat on the west coast were due to dams (blocking juvenile and adult passage), water withdrawal (stranding fish, entraining juveniles, and increasing temperatures), flood control (stream channelization and simplification), logging and agriculture (loss of LWD, sedimentation, loss of riparian vegetation, habitat simplification), mining (gravel removal, dredging, and pollution) and urbanization (vegetation removal, pollution, channelization, increased runoff, and habitat simplification).

Coho habitat is lost when large woody debris and the stable, complex channels and wetlands associated with floodplain forests are damaged or destroyed by logging, grazing, channelization, cropland agriculture, or urbanization. Sedimentation, debris flows, loss of channel stability and complexity, and increases in turbidity, or summer stream temperature, often result from disturbance of small headwater slopes and stream channels by logging roads and timber harvest. These impacts alone may be sufficient to damage or destroy Coho populations even where buffer zones are left along larger, fish-bearing streams. Clear-cutting of entire basins has the effect of increasing ambient air temperature and decreasing humidity. Instream water temperatures show direct response to this increase in ambient air temperature and decrease in humidity.

Habitat protection is the key to conservation and recovery of wild Coho salmon, because the technological ability to restore habitats once they are damaged is severely limited, mostly due to our lack of understanding of how to best provide for Coho salmon and the need for improvements in the technology. Although millions of dollars have been invested in artificial habitat alterations in attempts to improve habitat for Coho and other fish, there have been few examples of successful large-scale recovery of Coho populations attributable to man made habitat improvements (Salmon and Steelhead Recovery Coalition 2000). Unfortunately the cost of restoring a significant portion of altered streams using these technologies is prohibitive (Pearcy 1992). In many streams in the Pacific Northwest existing technology for channel restoration has failed to treat the causes of habitat degradation (Klamath Basin Fisheries Task Force 1991).

Steelhead rainbow trout (*Oncorhynchus mykiss*)

This description is derived from the Steelhead Restoration and Management Plan for California by the CA. Department of Fish and Game, Feb. 1996. Steelhead rainbow trout (Oncorhynchus mykiss) were once abundant in California's coastal rivers and streams. Like many of California's anadromous fish, steelhead numbers are declining.

Steelhead are the anadromous form of rainbow trout, a salmonid species native to western North America and the Pacific coast of Asia. In California, known spawning populations are found in coastal rivers and streams from Malibu Creek in Los Angeles County to the Smith River near the Oregon border, and in the Sacramento River system. The present distribution of steelhead in California has been greatly reduced from historical levels.

Steelhead are similar to Coho salmon in their ecological requirements. They are born in freshwater, emigrate to the ocean where most of their growth occurs, and then return to freshwater to spawn. Unlike Coho salmon, steelhead do not necessarily die after spawning. Post-spawning survival rates are generally quite low and vary considerably between populations. Steelhead can also tolerate higher temperature water than Coho salmon and thus are found in a wider range of aquatic habitats (Leitritz and Lewis 1980; Shapovalov and Taft 1954)

Optimum temperature requirements of steelhead may vary depending on season, life stage, and stock characteristics. Egg mortality begins to occur at 56º F. Steelhead have difficulty extracting oxygen from water at temperatures greater than 70º F. (Hooper 1973; Royal 1972; Barnhart 1986). In California, low temperatures are not as much of a concern as high temperatures, especially high temperatures that occur during adult migration, egg incubation, and juvenile rearing.

Rough estimates place the total statewide population at about 250,000 adults, probably less than half of the population of 30 years ago. An accurate estimate of the statewide population is not available, but there are reliable estimates on select streams and rivers throughout the state. All populations for which there are good estimates show a declining trend.

The decline of California's steelhead population is inextricably linked to the increase in the State's human population. Past and present development activities in rivers and watersheds, together with ever-increasing development of the State's water resources, have affected every river system and watershed in the State to some degree.

A substantial amount of steelhead habitat has been lost or degraded, due primarily to decreased stream flows because of water diversions and groundwater extraction, blocked or hindered access to spawning and rearing areas by dams and other structures, unscreened or poorly screened diversions which entrain juvenile fish, and soil disturbances resulting from poor land use practices in the watersheds. Natural events, such as droughts and floods, and adverse ocean conditions have probably also played a role in the decline.

Land Use/Planning

Land use plays a major role in the condition of the watershed, including the generation of fine sediment, the volume and timing of stormwater flows, the type and concentration of water pollutants, the extent of riparian forest and the condition of creek channels. Land uses in the Austin Creek watershed are predominantly timber harvest, sheep and cattle ranching, recreation and tourism and rural residential housing. Rural residential development is concentrated along main Austin Creek and in the Cazadero area. Timber harvest has occurred in all the sub-basins and is described in the next section.

The Sonoma County General Plan designates much of the Austin Creek watershed for resources and rural development with 120, 160- and 320-acre minimums in most of the watershed. Along Austin Creek and in the Cazadero area the minimum acreage per unit is 2-10 acres and many existing residences are on very small lots. All residential units are on septic systems and wells and many have private dirt roads.

From a review of current land use and conditions in the watershed there appears to be a great potential for future residential development in many areas of the Austin

Creek watershed. Along the main public roads in the watershed especially the southern areas of the drainage are existing houses and a large number of dirt road systems remaining from past logging. In many areas of California logging and road building provides the template for dense residential development. Mill Valley, the Oakland hills, Los Gatos and Saratoga are examples of logging areas where temporary roads became permanent urban roads. The lower Russian River region, including the Cazadero area, has recently seen a significant increase in home values and home sales. New home construction has also increased.

Limitations to residential development include water availability and the lack of appropriate sites for septic leach fields. However all the other similar areas had similar limitations which were overcome through water and sewer development.

From the standpoint of aquatic habitat restoration and watershed management residential development is one of the most difficult land uses to make compatible with good water quality and healthy aquatic habitat. This problem arises from having subdivisions of relatively small acreage (<1 acre to 10 acres) where intensive uses and highly disturbed ground often occurs. Gardens, fences, dogs and cats, horses and livestock, roads and impervious surfaces especially on steep hillsides can rapidly produce high sediment loads into creeks, become sources of invasive plants along creeks and permanently fragment habitat. Maintaining productive forest land and avoiding small lot subdivisions and conversion of forest to housing may be the greatest land use challenge facing the Austin Creek watershed over the next 20-30 years

Fish Habitat

Table 18 summarizes the stream surveys completed in the Austin Creek watershed and are available for review. Appendix B depicts the results of all the stream surveys completed including those for which no reports were available (see Table 18). The results of these surveys are discussed for each sub-basin.

Table 18. Fish and Game Stream Surveys of Tributaries in Austin Creek Watershed

Creek Name	Creek Area Surveyed	Year of Recent Surveys	Year of Historic Surveys	Summary of Findings
East Austin Creek	from confluence with Big Austin Creek upstream 12.4 miles	7/96	7/47, 5/62, 10/68, 4/77, 7/77	No hatchery stocking, transfers or rescues known, no introduced fish species recorded. Historic surveys found good spawning areas in upper creek. Biological inventory found low numbers of steelhead in 1996 but relatively high numbers in 1947, 1962 & 1977. Instantaneous temperature measured one day in 1996 of 57-78º F. No data loggers used. Low levels of riparian canopy found in 1996 and low levels of embeddedness in the streambed.
Conshea Creek	from confluence with East Austin Creek upstream 3,000 ft. to the confluence with Tiny Creek	9/96	5/62 and 7/77	Biological inventory found steelhead in 1962, 1977 & 1996. Instantaneous temperatures of 57-63º F. measured one day in 1996. High level of riparian canopy and low level of embeddedness found in 1996.
Tiny Creek	from confluence with Conshea Creek upstream 188 ft.	9/96	none	Moderate level of riparian canopy and low level of embeddedness found in 1996.
Unnamed tributary- "8th crossing" upstream of Conshea Creek confluence	from confluence with East Austin Creek upstream 1276 ft.	10/96	none	High level of riparian canopy and low level of embeddedness found in 1996.

Table 18. Fish and Game Stream Surveys of Tributaries in Austin Creek Watershed (cont.)

Creek Name	Creek Area Surveyed	Year of Recent Surveys	Year of Historic Surveys	Summary of Findings
Grey Creek	from confluence with East Austin Creek upstream 5.25 miles	8/96	5/62, 8/77, 9/82	Biological inventories found steelhead trout and Coho salmon in 1962 and steelhead trout in 1977 and 1996. Instantaneous temperatures measured in 1996 of 51-65 degrees F. High levels of riparian canopy and high levels of embeddedness found in 1996. Roads in upstream are of watershed likely cause of high silt levels in creek.
Main or Big Austin Creek	from confluence with Ward Creek upstream past confluence with Bearpen Creek to waterfall for 8.95 miles total	95/96	6/54, 8/56, 10/68, 4/77, 7/77	Historic surveys documented intermittent flow conditions in 1977 during an extreme drought. Historic surveys also documented steelhead redds in Austin Creek downstream of the Ward Creek confluence. Biological surveys found steelhead juveniles in 1954, 4956, 1968 and 1977 in various locations on Austin Creek. Coho salmon were found in 1954. Recent survey measured instantaneous temperatures in 1995/96 of 59-76°F. Canopy levels were moderate to low. Silt levels were moderate to high. Biological surveys in 95/96 found low numbers of steelhead and one Coho salmon. Hatchery raised steelhead trout were stocked or transferred into Austin Creek in 1956, 57, 58, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70 and 72. The 1995/96 survey recommends road repairs to reduce sediment delivery into stream, increasing riparian canopy.
Bearpen Creek	from confluence with Austin Creek upstream 3 miles.	1995	10/68, 7/77	Historic surveys found steelhead trout in Bearpen Creek in 1968 and 1977. The 1977 survey was done during a drought and noted that Bearpen Creek had cool rearing habitat. Hatchery-raised steelhead trout were stocked or transferred into Bearpen Creek in 1959, 60, 61, 62, 63, 66, 67 and 70. The 1995 survey found a low level of riparian canopy and a moderate to low level of embeddedness. Instantaneous temperatures only were measured on one day and ranged from 59-65°F. Juvenile steelhead in three size classes were found in 1995 along with large numbers of Pacific Giant Salamanders. Recommendations included increasing riparian canopy and treating roads to reduce sediment delivery.

Table 18. Fish and Game Stream Surveys of Tributaries in Austin Creek Watershed (cont.)

Creek Name	Creek Area Surveyed	Year of Recent Surveys	Year of Historic Surveys	Summary of Findings
Ward Creek	from confluence with Austin Creek 7.2 miles upstream	7/96	9/65, 10/68, 12/70, 7/77, 6/82	Historic surveys noted large log jams and huge boulders as barriers and low levels of canopy in 1977. Biological surveys found steelhead trout in 1965, 1968, 1970, 1977, and 1982. Coho salmon were found in 1970. Survey in 1996 found steelhead trout and two Coho salmon. No introduced fish species have been recorded and no historic hatchery stocking transfers or rescues have occurred in the Ward Creek Sub-basin. Survey in 1996 measured instantaneous temperatures of 57-77°F. One data logger near mouth recorded 55-73°F. Canopy levels were relatively low and embeddedness level was fair. Recommendations include treating roads to reduce fine sediment, revegetation to increase canopy and in-stream structures and wood.
Unnamed tributary #1	from confluence with Ward Creek upstream 1426 feet	7/96	none	Relatively high embeddedness of small cobble dominated streambed. High canopy level and instantaneous water temperatures of 62-65°F
Unnamed tributary #2	from confluence with Ward Creek upstream 105 feet	8/96	none	Instantaneous water temperatures of 69°F measured. Moderate canopy and embeddedness levels observed.
Unnamed tributary #3	from confluence with Ward Creek upstream 188 ft.	8/96	none	Instantaneous water temperature of 61°F measured. High canopy level and moderate embeddedness level recorded.

Table 18. Fish and Game Stream Surveys of Tributaries in Austin Creek Watershed. (cont.)

Creek Name	Creek Area Surveyed	Year of Recent Surveys	Year of Historic Surveys	Summary of Findings
Pole Mountain Creek	from confluence with Ward Creek upstream 1.9 miles	8/96	8/65	The 1965 Historic survey noted few spawning areas and on-going logging. Survey in 1996 measured instantaneous water temperatures of 58-68°F, moderate embeddedness and good levels of canopy. Steelhead trout found in 1965 and 1996. No introduced species found. No hatchery stocking or transfer recorded. Recommendations include road treatments for fine sediment control, increase of canopy through re-vegetation and in-stream structures and wood retention.
Blue Jay Creek	from confluence with Ward Creek upstream 1.47 miles	9/95, 9/96	none	Biological survey found steelhead juveniles in three age classes. Instantaneous temperatures recorded from 52-77°F. High embeddedness levels and good canopy cover were recorded. Recommendations include road treatments for fine sediment control, increase of canopy through re-vegetation and in-stream structures and wood retention.

Austin Creek Watershed: Historic Conditions

The events and changes in the Austin Creek watershed since Russian, Spanish, Mexican and American settlements have affected natural and aquatic resources. Watersheds respond to land disturbances, changes to creek channels, deforestation, grazing, road building and other activities over long periods of time. This section explores early settlement history and natural resource development in the Austin Creek watershed.

Native Americans

The first inhabitants of the Austin Creek watershed were Native Americans of the Kashaya Pomo tribe. Native Americans did not inhabit the dense redwood forest along the Russian River, Austin Creek and Sonoma Coast. The Kashaya Pomo lived in open areas next to the ancient forest and along the Russian River.

The Pomo lived in small triblets with various names along the length of the Russian River and Clear Lake. The Pomo are considered some of the greatest basketmakers in the world (Powers 1976). The Pomo, like many Native California Indians, were exquisite managers of their environment. They used fire to encourage food plants, to trap game, and to reduce insect pests in oaks and protect the acorn harvest.

The Kashaya Pomo worked for the Russians at Fort Ross and, unlike other Indians in the region, were never forced into service through any of the missions (Clar 1954). However, with American settlement, the Kashaya were denied access to their traditional lands and had to work on the American farms. A small reservation was created for the Kashaya Pomo in the Gualala River watershed in 1914 (Schubert 1997).

Russian Settlement

The first European settlement in the area was Ft. Ross, established on the coast in 1812 due west of the Austin Creek watershed. Fort Ross was a Russian colony and trading post created to exploit sea otter, beaver and other furbearing animals. The Russians controlled parts of Alaska including Kodiak Island, the Aleutian Islands and Sitka. Once sea otter populations were diminished by 1820, Fort Ross became a ranching and farming center. In 1841 the Russians sold Ft. Ross to John Sutter but since the Mexican government did not grant Sutter the land, he took the fort's assets to Sacramento where he established Sutter's Fort. Ft. Ross eventually became part of a ranch owned by American William Benitz and later George Call.

American Settlement and Development

Americans began moving to Sonoma County in the 1840's during the Mexican era and came in even larger numbers after statehood in 1850.

The Austin Creek watershed and surrounding lands were largely dense forests of redwood and fir. Only the coastline and interior valleys near Healdsburg, Santa Rosa and Sebastopol had easily planted ranch and farmland.

Some of the first developments in this region were lumber mills and schooner landings along the coast west of Austin Creek. At Fort Ross, Salt Point, Fisk's Landing (Stewart's Point) and the Gualala River lumber mills were built to process logs from the nearby forest. Lumber was shipped to San Francisco via schooners. A chute on the coastal headland was used to load lumber onto the schooner (Figure 21). In 1854 the first land claim was made in Guerneville, southeast of the Austin Creek area, and the first mill began operation in the late 1850's along the eastern boundary of the watershed. Mill Creek and Healdsburg had lumber mills and moved timber along Mill Creek to Healdsburg. In the 1860's and 1870's a journey from Healdsburg to Guerneville required traveling up Mill Creek Road to the Ladder which ascended out of the Mill Creek drainage and descended into East Austin Creek watershed. From here the traveler went down Grey Creek and Gilliam Creek, over Mt. Jackson and down Canyon 7 into Rio Nido and then along the river to Guerneville. The upper East Austin Creek area was more connected to areas to the east rather than Cazadero or Guerneville (Clar 1954).

In the early years of logging, logs were transported to the mill using teams of oxen (Figure 22). The redwood trees were so large that it was very difficult to move the felled trees even once they were cut into pieces. This early 1870's account provides a vivid picture of the early logging,

> "A tree four feet in diameter is called undersized in these woods; and so skillful are the woodchoppers that they can make the largest giant of the forest fall just where they want it, as they say, they 'drive a stake with a tree.
>
> "To chop down a redwood tree, the chopper does not stand on the ground, but upon a stage sometimes twelve feet above the ground. Like the sequoia, the redwood has a great bulk near the ground, but contracts somewhat a few feet above. The chopper wants only the fair round of the tree, and his stage is composed of two stout staves, shod with a pointed iron at one end, which is driven into the tree.
>
> "The outer ends are securely supported; and on these staves he lays two narrow, tough boards on which he stands and which spring at every blow of his axe. In chopping down the larger ones, two men stand on the stage and chop simultaneously at the cut, facing each other One would be left-handed and the other right-handed.
>
> "They first begin what is called the undercut. The undercut goes in about two thirds the diameter. When it is finished the stage is shifted to the opposite side. While the chopping is being done, other men are building a

crib, sometimes taking three days to make. A crib cushions the shock of the falling tree so that it will not shatter.

"When the choppers are working on the second cut, it is a remarkable sight to see the tall, straight mass begin to tremble as the axe goes in. It usually gives a heavy crack about fifteen minutes before it means to fall. The chopper thereupon gives a warning shout, so that all may stand clear – not of the tree, for he knows very well where that will go, and in a cleared space men will stand within ten feet of where the top of a tree is to strike, and watch its fall; his warning is against the branches of other trees which are sometimes torn off and flung to a distance by the falling giant, and which occasionally dash out men's brains.

"At last the tree visibly totters, and slowly goes over; and as it goes the chopper gets off his stage and runs a few feet to one side. Then you hear and see one of the grandest and most majestic incidents of forest life. There is a sharp crack, a crash, which, when you hear it from a little distance, is startlingly like an actual and severe thunder peal. To see a tree thus go down is a very great sight, not soon forgotten." (Schubert, 1997)

For most areas the forest around the mill site was cut and more distant forest was not harvested. When the forest was exhausted the mill closed or relocated. The Duncan brothers originally had a mill at Salt Point in 1854 which they relocated to Bridgehaven (Highway 1 bridge) on the Russian River in 1860 to take advantage of a new supply of lumber. The mill was moved again in 1876 to its present site just downstream from the mouth of Austin Creek to take advantage of the new railroad and new areas of uncut forest.

The 1870's were an era of rapid change in the region. In 1876 the Northwestern Pacific Railroad (NWPRR) connected Duncans Mill and Guerneville to Santa Rosa and Sausalito. The railroad allowed lumber to be moved quicker and more efficiently and greatly increased harvest rates.

Small temporary rail lines were extended farther away from the mill to more distant timber stands. By 1876 most of the large mills in the area had 30-40 oxen teams delivering logs on a daily basis (Wilson 1999). In 1865 it was estimated that one acre of redwood forest produced 1,431,500 board feet of timber (Clar 1954). Table 19 summarizes the total board feet cut in many areas. In addition to lumber redwood shingles and posts were a major product. Tan oak was another major forest product used in leather tanning at Ft. Ross and other locations.

The Austin Creek watershed did not have a lumber mill in the 1800's but did have timber harvest operations in the watershed. The Ft. Ross Road was built in 1877. Timber was likely harvested along this road and transported to the coastal mills and schooner landings. Along the eastern side of the drainage the forests in the Grey Creek area were harvested as there was a mill on Mill Creek and an established haul road. Along lower Austin Creek logs would have been cut and hauled to Duncans Mill along a new road built in 1877 connecting Guerneville, Cazadero and Ft. Ross.

Cazadero was first established as a hunting resort in 1869 by Silas Ingram and was called Ingram's. The name changed to Cazadero in 1888 when George Montgomery bought the resort. In 1886 a spur line of the railroad was extended along Austin Creek to Cazadero. This rail line moved logs from areas along Austin Creek and the adjacent slopes and creek valleys to Duncans Mill. The railroad also increased tourism and recreation in the area. The Austin Creek watershed did not have a mill during this period.

By the early 1900's most of the easily accessible forest had been logged and many of the mills closed. Duncans Mill had produced 25,000 board feet of timber daily. The Guerneville mill produced 40,000 board feet daily.

Table 19 .Timber Harvest in 1877 in the Lower Russian River (from Schubert 1997)

Location	Operator	Cut Yield
Elliot Canyon	Korbel Brothers	22,000,000 bd. ft.
220 acres across river from Guerneville	R.E. Lewis	10,800,000 bd. ft
60 acres in Pocket Canyon	S.H. Torrance	3,600,000 bd. ft.
120 acres in Pocket Canyon	Henry Beaver	7,200,000 bd. ft.
Dutch Bill Creek to Hulbert and Mission Canyon- 700 acres	Several owners	42,000,000 bd. ft.
Hulbert Canyon- 2000 acres	Heald and Guerne	120,000,000 bd. ft.
Big Bottom-Guerneville 160 acres	W.H. Willets	10,000,000 bd. ft.
Big Bottom-Guerneville 200 acres	R.B. Lundsford	12,000,000 bd. ft.
Big Bottom -Guerneville 360 acres	Heald and Guerne	21,600,000 bd. ft.
Guerneville	Murphy Brothers	15,000,000 bd. ft.
120 acres	Ike and Tom Smith	7,200,000 bd. ft.
420 acres	J.B. Armstrong	20,000,000 bd. ft.
40 acres	James Peugh	60,000,000 bd. ft.
40 acres	H. Speckerman	4,000,000 bd. ft.
160 acres	J.K. Wood	6,400,000 bd. ft.
200 acres	Henry Miller	12,000,000 bd. ft.
20 acres	S.B. Torrance	3,000,000 bd. ft.
Total Harvest		**376,800,000** bd. ft.

Figures 18 and 19. Logging using oxen in the lower Russian River region

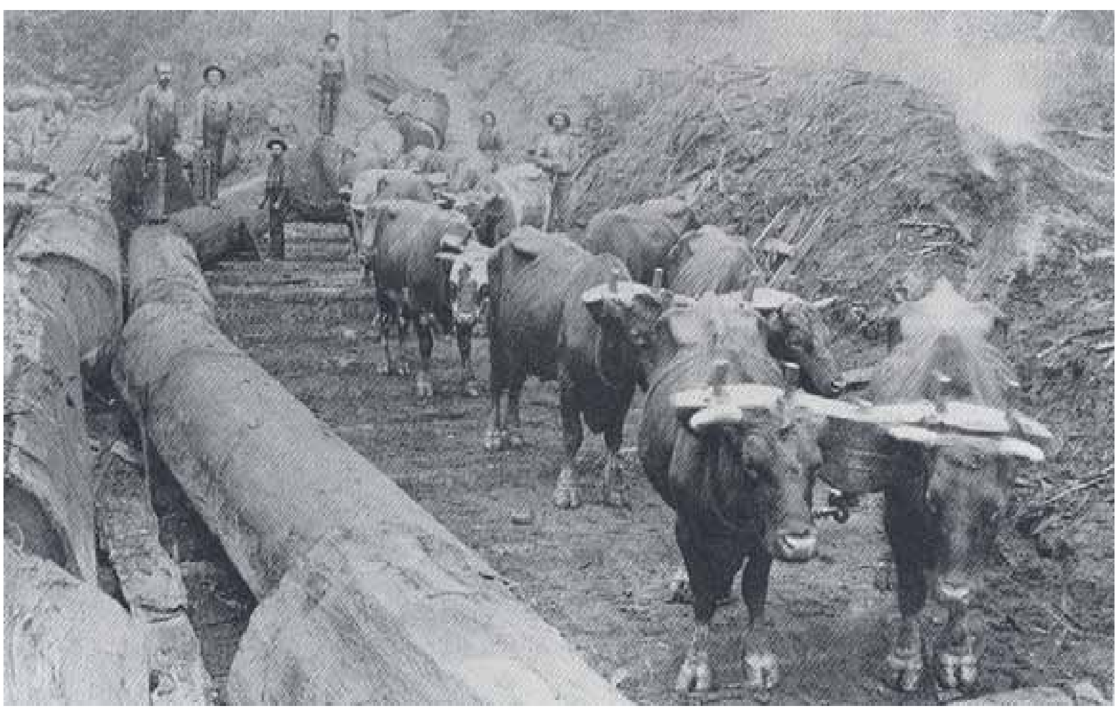


Figure 20. Logging crew standing in cut in giant redwood

Figure 21. Chute to load schooners at Fort Ross cove

Figure 22. Oxen and steam donkey used in logging

Figure 23. Steam train used for logging

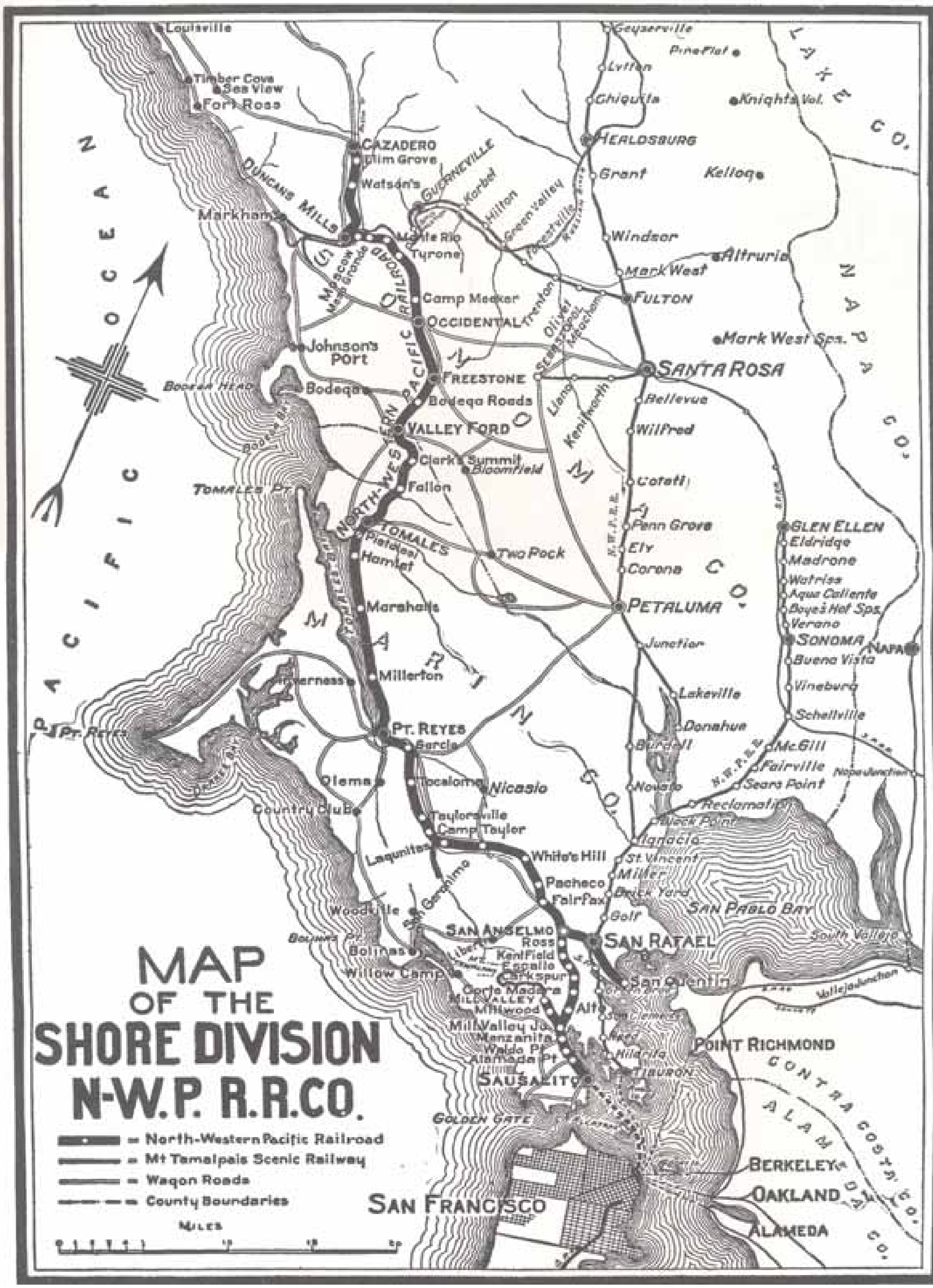


Figure 24. Map of North Western Pacific Railroad line

Figures 25 and 26. Logging trucks from the 1950's.

Figures 27 and 28 Tractor logging of the 1950 and 1960s

Several smaller mills continued operations such as on Hulbert Creek. In 1909 a small railroad was extended up Mission Creek and timber was cleared from the slopes and from Finley and Kohute Gulches along lower Austin Creek and carried to the mill on Hulbert Creek (Guernewood Park). The 1906 earthquake and fire in San Francisco created a need for lumber which was partly filled by logs from the Austin Creek area.

During the late 1800's several areas of the Austin Creek watershed were settled by homesteaders. The East Austin drainage was not as dense with coniferous forest and homesteaders like Gilliam established ranches and hunting resorts. East Austin Creek was known for its trout fishing. (Clar 1954)

As the forest was cut more areas were opened up as farm land and grazing land and the region's economy changed. Sheep and cattle grazing, fruit orchards, hop fields, tourism and the development of recreational camping areas became more prevalent in the Austin Creek watershed although it is likely that land clearing and timber harvest continued to some extent.

There were several mines in the watershed. The Laton mine was located along upper Austin Creek in the Cedars Canyon. This was a chromite (chromium) mine operated from 1916 to 1946. On Upper East Austin Creek the Sonoma Magnesite Company operated a mine from 1905 to 1925. The mine had a very narrow (24") gauge railroad from the mining site along the creek to Watson's Station where the ore was reloaded onto NWPRR cars. Before the mining railroad was built the ore was transported by horse team over the Morrison, Dutton, and Gilliam grades to Mines Road (now Armstrong Woods Rd.) and into Guerneville. (Clar 1954)

There were smaller mining operations on Marble Mountain (gold), Mohrhardt Ridge (gold prospects) and the Aho manganese mine west of Ward Creek sub-basin.

Following World War II the demand for lumber increased enormously as the San Francisco Bay area underwent a population and development boom. Large-scale logging occurred in the late 1940's and early 1950's in the Austin Creek watershed and most of the northern California coastal ranges. Unlike the first period of logging which used handsaws, animal teams, steam engines and trains. The second major period used chainsaws, bulldozers, and trucks to cut and haul timber. This new technology created extensive systems of skid trails, log landings and roads. There was little regulation in the 1950's and 1960's and many of the logging practices were harmful to creeks. For example, streambeds were bulldozed to create summer haul roads and left to erode in winter rains. Most logging roads were temporary and constructed without culverts at the crossings of smaller creeks, without proper drainage and with little concern for long-term use or stability. The new logging technology allowed for the forest to be harvested in distant ravines, or on very steep slopes. Areas not reached in the first logging period were cut in the second. Logging proceeded during this second period much quicker than the first leaving large areas clear-cut over a 10-25 year time period. The first logging period clear-cut a smaller area over a much longer time.

In 1976 the California Forest Practice Rules were amended and timber harvest became more strictly regulated. Logging had been somewhat regulated since the 1940's, but the focus had been on timber production and restocking rather than environmental effects. In the 1970's the population declines in Coho salmon, Chinook salmon and steelhead trout became more apparent and public concerns over logging increased. As a result, the regulation of timber harvest was dramatically changed in 1976 (Arvola 1976). The detrimental effects of this second logging period of the 1950-60's on aquatic habitats are well established (Ziemer 1991, Salmon and Steelhead Recovery Coalition 2000).

Unlike many river and creek watersheds on California's north coast, the forest lands in the Austin Creek watershed were not primarily owned by huge corporate timber companies but by local smaller owners. The first sawmill in Austin Creek was established by the Berry family in Cazadero in 1941 on the site of the old train depot. According to the Berry's Mill website in the 1940's the mill was processing logs produced by land clearing operations by farmers and ranchers. One aspect of the timber regulations at this time allowed for the removal of trees to convert lands to other uses. This exemption was widely used in the north coast to remove Douglas fir and redwood on ranch land and increase the acreage of grazing lands (Arvola 1976). A review of this conversion practice found that between 1946 and 1975 almost 1 million acres of forest land had been logged and converted to grazing lands in the northern part of the state (Arvola 1976).

As part of this watershed assessment land conditions in 1941/42, 1961, 1980 and 2000 were evaluated and digitized. The results of this evaluation are reported in detail in the sub-basin sections and depicted in Figures 59-78.

Overall, the historic aerial layers show distinct, large scale changes in the watershed. The 1941/42 photos show dense coniferous forest in many areas of the watershed and clearing/burning in the northeastern areas of the drainage. The 1961 photographs depict clear-cut logging and road building in nearly all areas of the watershed with coniferous forest. The 1980 aerials show additional logging and some previous clear-cut areas with dense regrowth of conifers and many with little re-growth and continued visible ground disturbance on logging roads. The 1980 photos also show an expansion of rural residential housing in previously logged areas around Cazadero and along Austin Creek. The 2000 aerials depict a forest landscape which has regrown in many formerly clear-cut areas but has undergone a conversion of coniferous to hardwood forest. Table 20 lists the tabulation of these changes for the entire Austin Creek watershed.

Table 20. Historic Conditions in Austin Creek Watershed

Historical Conditions	Acres	Sq. Miles	Miles	Miles of road/sq. mile of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	103	0.1		
Logged	152	0.2		
Roads			52.5	0.75
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	283	0.4		
Logged	7,546	11.8		
Roads			401.7	5.73
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	267	0.4		
Logged between 1961 and 1980	1,846	2.9		
Logged by 1961, has not regrown conifer by 1980	2,936	4.6		
Roads			341.7	4.87
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	158	0.2		
Logged by 1961, has not regrown conifer by 2000	1,164	1.8		
Logged by 1961, still disturbed in 2000	774	1.2		
Logged between 1961- 1980, has not regrown conifer by 2000	471	0.7		
Logged between 1961- 1980, still disturbed in 2000	98	0.2		
Roads			355.6	5.07
Vegetation changes 1940 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	462	0.7		
Bare in 1940, Conifer/Mixed Conifer in 2000	39	0.1		
Bare in 1940, Hardwood/Chaparral in 2000	872	1.4		
Cleared for Ag/Grazing in 1940, Hardwood/Chaparral in 2000	27	<1		
Cleared for Ag/Grazing in 1940, Redwood/Conifer/Mixed Conifer in 2000	33	<1		
Conifer in 1940, Hardwood/Chaparral in 2000	3,636	5.7		

Fire History

The extent and date of major fires since 1950 are available from California Department of Forestry (CDF). Figure 57 depicts the extent of post-1950 fires in the Austin Creek watershed, total acreage of the fire including areas outside the watershed and the year of occurrence. Table 21 lists the fires and acreages in the watershed. There were a number of small fires in the 1950s and 1960s. The largest fire in the Austin Creek watershed was the Creighton Ridge Fire in 1978. This fire was a crown fire and killed most of the conifers in many areas.

Table 21. Major Fires in the Austin Creek Watershed since 1950.

Fire Name	Year	Acreage in Watershed	Percent of Total Watershed
CHARLES	1954	664	1
HOLLOW TREE -	1959	4	<1
MCCRAY RIDGE -	1959	1	<1
NO NAME	1960	1,651	2.6
ROADSIDE #44	1961	1,040	1.6
P.G.&E. #6	1965	1,901	3
CREIGHTON RIDGE	1978	6,443	10.1

* Austin Creek watershed is 44,822 acres.

Restoration Projects

The California Restoration Projects Database has a number of projects mapped for the Austin Creek watershed. Figure 29 illustrates these projects. While road repairs are the largest component of the projects the miles of roads treated is relatively small compared to the total road miles in the watershed.

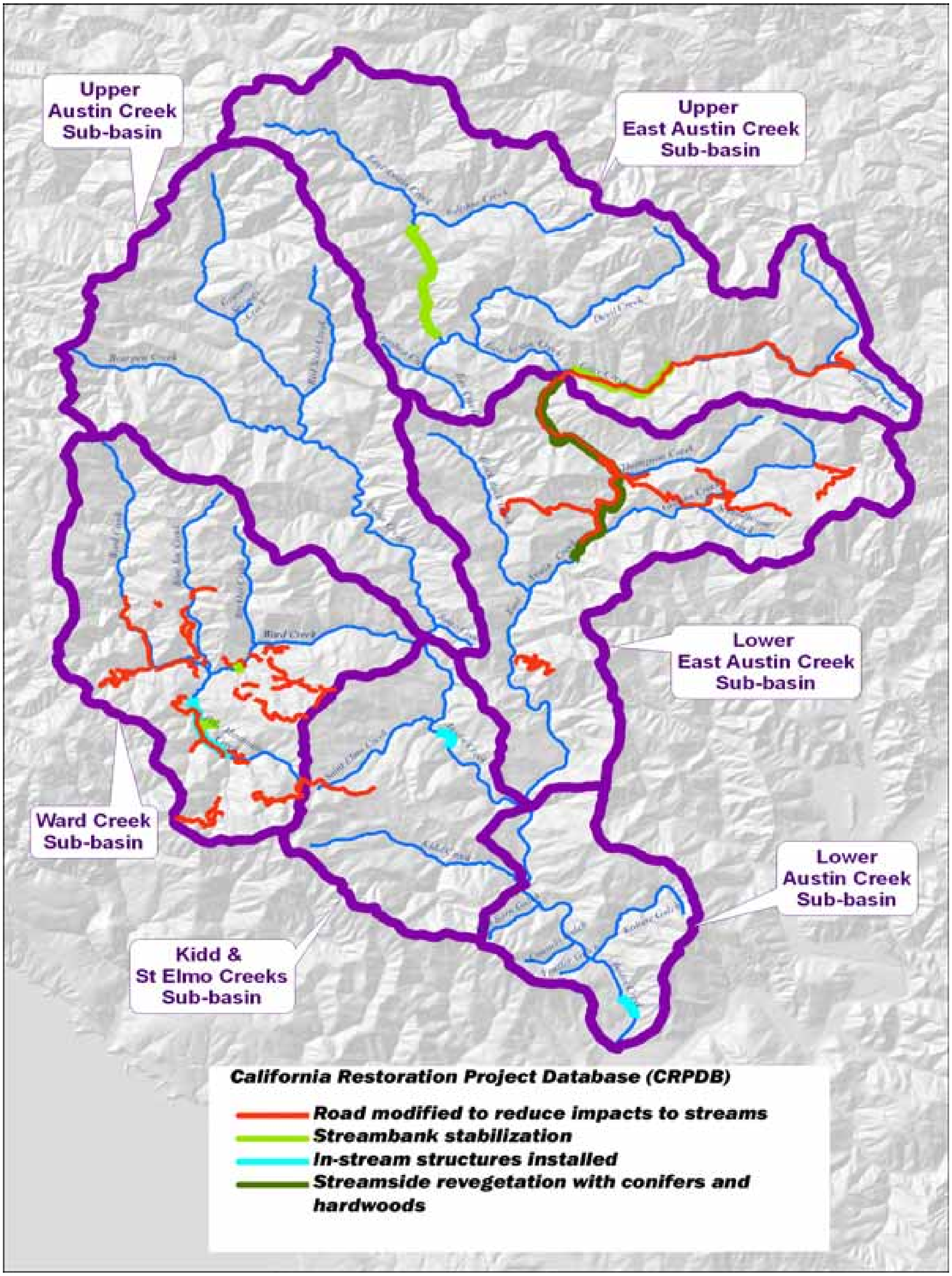


Figure 29. California Restoration Projects Database projects in the Austin Creek Watershed

IV. Austin Creek Watershed Sub-basins

The Austin Creek watershed is made up of six sub-basins:

- Upper East Austin Creek Sub-basin including Sulphur Creek, Devil Creek, Grey Creek, Conshea Creek and Tiny Creek
- Lower East Austin Creek Sub-basin including Thompson Creek, Gilliam Creek, Schoolhouse Creek and Black Rock Creek
- Upper Austin Creek Sub-basin including Bear Pen, Red Slide, Gravelly Springs and Bone Creek
- Ward Creek Sub-basin including Blue Jay Creek, Big Oak Creek and Pole Mountain Creek
- St Elmo and Kidd Creek Sub-basin
- Lower Austin Creek Sub-basin including Bull Barn Gulch, Frazier Gulch, Consolli Gulch and Kohute Gulch

The natural features, historic and present land uses are discussed for each sub-basin. For the 1941/42 and 1961 set of historic aerial photographs visible roads, areas logged and areas showing ground disturbance associated with housing, agriculture or other activities are depicted. For the most part, logging in 1941/42 and 1961 used clear-cutting techniques. For the 1980 aerial photographs roads, and clear-cut logging since 1961, and disturbance were delineated. In addition those areas shown as logged in the 1961 photos were reviewed and delineated if they had not regrown conifer forest. For the 2000 aerial photographs roads and disturbance was delineated. Additionally those areas logged in 1961 and 1980 were each reviewed for their condition in 2000. The previously-logged areas were delineated for a lack of conifer regrowth, or continued and obvious ground disturbance.

A review of long-term changes in vegetative cover types also was completed. The 1941/1942 aerial photographs were compared with the CalVeg vegetation layer prepared by CDF. A number of other changes were delineated including: those areas appearing largely bare of vegetation due either to logging, clearing or fire in 1941/1942 and covered in one of three vegetation types in 2000; those areas cleared for active agriculture in the 1941/1942 and covered in one of three vegetation types in 2000; and those areas covered in coniferous forest in 1941/1942 which were covered in hardwood forest in 2000.

Documenting vegetation and land use changes can indicate the causes of changes in aquatic habitats as well as indicate those areas of previous disturbance still generating fine sediment.

Upper East Austin Creek Sub-basin

Geography and Topographic Features

The Upper East Austin Creek Sub-basin is located in the northeastern corner of the Austin Creek watershed. This sub-basin encompasses over 11,500 acres and is the largest sub-basin. Steep lands in excess of 30% slope make up over 82% of this sub-basin. Overall the Upper East Austin Creek Sub-basin consists of very steep mountainous lands.

The portion of East Austin Creek in this sub-basin is 6.1 miles long. Figure 52 illustrates the slope and confinement of the East Austin Creek channel. In its headwaters East Austin Creek is in the >20%, 8-20% and 4-8% slope classes with a confined channel. About a mile upstream of the confluence with Sulphur Creek, East Austin Creek takes a gentler slope of 1-2% and 2-4% in a confined channel extending to the confluence with Conshea Creek. At this confluence East Austin Creek becomes nearly flat with a slope of <1% and remains in a confined channel. The East Austin Creek slope increases slightly to 1-2% at the confluence with Grey Creek and the channel remains confined. Most of the steeper confined channel sections in excess of 4-8% will transport sediment to the lower slope unconfined downstream areas of the channel.

Channel slope and confinement was also calculated for the Grey Creek channel. At its headwaters the Grey Creek channel is 8-20% slope rapidly transitioning to a 2-4% slope until the creek moves around Rabbit Knoll where it passes through a steep canyon of 8-20% channel slope. From the canyon at Rabbit Knoll, Grey Creek slowly reduces in slope from 4-8% to 2-4% to 1-2% at the confluence with East Austin Creek. Throughout its length Grey Creek has a confined channel. Grey Creek has a total length of 5.6 miles and one named tributary, Lawhead Creek.

In addition to Grey Creek there are a number of other significant tributaries to Upper East Austin Creek including Sulphur Creek (2.4 miles long), Devil Creek (4.3 miles long), Conshea Creek (1.0 miles long), Tiny Creek (0.7 miles long) and unnamed blue line tributaries totaling 23.5 miles in length.

Geologic Features

The Upper East Austin Creek Sub-basin contains four primary rock types: Sandstone (TKfs) of the Turonian age of the late Cretaceous period, Franciscan Formation Graywacke and Mélange (KJfs) of the Cretaceous and Jurassic period with blocks of Greenstone (gs) and Serpentinite (sp) (see Figure 54). These rock formations are aligned along northwest/southeast trending faults which are part of the San Andreas Fault System.

Franciscan Formation Graywacke/Mélange and Greenstone dominate the western and northern sections of this sub-basin. Franciscan Formation Mélange is well-known for its instability, landslides and high erosion rates especially on steep slopes. A number of large landslides are indicated on the geologic map; numerous small slides likely occur but are not mapped. Sandstone (TKfs) dominates the Upper Grey Creek area and eastern portion of the sub-basin and is a more erosion resistant rock than the Franciscan Formation.

There are small outcrops of Metagraywacke (KJfm) within the Franciscan. There is also a large area of Serpentinite including smaller areas of silica carbonate rock. Serpentinite occurs primarily as sheared rock. Serpentinite weathers to create serpentine soils which have very high levels of magnesium and low levels of calcium. There are a limited number of plant species which have the adaptations needed to live on these soils. In a number of locations in this sub-basin the serpentine soils support little to no vegetation and are termed serpentine barrens (Figure 30).

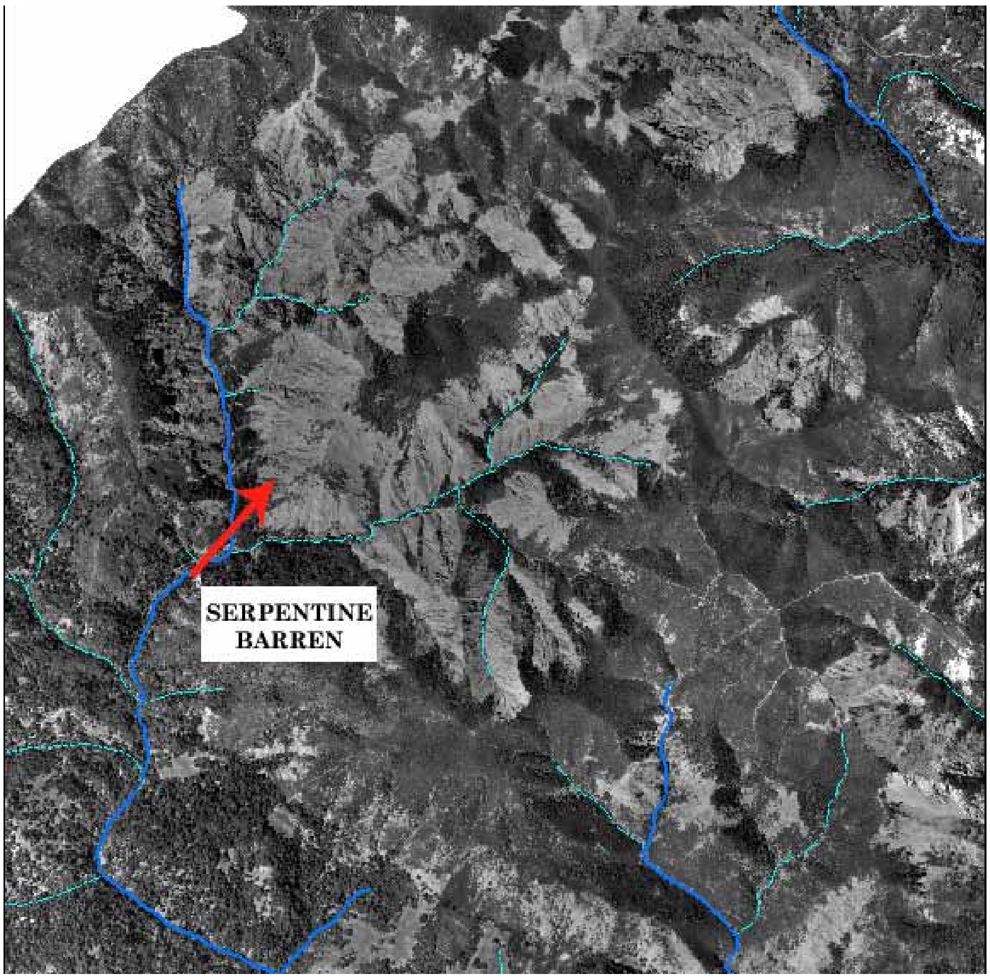


Figure 30. Serpentine barrens in Upper East Austin Creek Sub-basin

A number of unnamed faults cross through this sub-basin along a northwest/southeast alignment (see Figure 54). The faults generally define the boundaries and contacts between the major rock types. Along the contact between the Sandstone and Serpentinite in the Gilliam Creek drainage a number of springs are indicated. Faults and contacts between rock types are locations where groundwater may come to the surface due to changes in rock density and porosity and to the fracturing caused by the fault. In some locations where streams cross faults surface flows may be lost to groundwater as well.

Sub-basin Vegetation- Present Day

Figure 55 depicts vegetation types in the East Austin Creek Sub-basin. Hardwood forest and chaparral, interspersed with grassland, are the primary vegetation types and dominate the western side of the sub-basin. A band of closed-cone pine/cypress forest occurs in the northern and central area of the sub-basin where serpentine soils are found. In this watershed the Sargent cypress (Cypressus sargentii) is the dominant species in this vegetation type. Closed-cone pine species do not occur. Within this band of Sargent cypress are serpentine barrens without vegetative cover (Figure 30).

Coniferous and mixed coniferous hardwood forest dominates the Grey Creek drainage and also occurs in the Tiny and Conshea Creek drainages. There are small areas of redwood forest in the creek canyons of Grey and Devil Creek.

The California Natural Diversity Data Base (CNDDB) has a number of records of rare plants in this sub-basin. These include the Cedars fairy-lantern (Calochortus raichei), the Cedars manzanita (Arctostaphylos bakerii ssp sublaevis), second jewel-flower (Streptanthus glandulosus var. hoffmanii), and Streptanthus morrisonii. None of these plant species are federally-listed as threatened or endangered. The Cedars manzanita is State-listed as rare. No rare, threatened or endangered animal species are recorded in the CNDDB for this sub-basin.

Table 22. Vegetation types in Upper East Austin Creek Sub-basin

Vegetation types	Acres	Sq. miles
Grassland/Rangeland	807	1.26
Barren	380	0.59
Chaparral	1,783	2.79
Closed cone pine-cypress	1,950	3.05
Conifer	1,768	2.76
Hardwood	3,887	6.07
Mixed Hardwood/Conifer	780	1.22
Redwood	177	0.28

Land Use

The Upper East Austin Creek Sub-basin is entirely private land. Current land uses include ranching, timber harvest, rural residential and recreation. The Sonoma General Plan designates most of this sub-basin as Resource and Rural Development. There are primarily parcels greater than ten acres in size in this sub-basin limiting housing development in the near future.

Roads-Present Day

Figure 62 depicts dirt roads in the Upper East Austin Creek Sub-basin. There are a total of 60.2 miles of roads in the sub-basin for a ratio of 3.34 miles of roads/square mile of sub-basin. Of this total, there are 42.2 miles of roads on hillsides in excess of 30% slope for a ratio of 2.34 miles of roads/square mile of sub-basin. This ratio of total roads/total sub-basin is moderately high. Table 23 lists road miles in various slope classes.

Table 23. Present day roads in the Upper East Austin Creek Sub-basin

Roads	Miles	Miles of road/sq. mile of sub-basin
Total miles of roads in sub-basin	60.2	3.34
Total miles of roads >30% slope in sub-basin	42.2	
Miles of road >30% slope/sq mile of sub-basin		2.34
Miles of road on 1-30% slope	15.2	0.84
Miles of road on 30-50% slope	25.5	1.42
Miles of road on 50-65% slope	10.9	0.61
Miles of road on >65% slope	5.7	0.32

Fish Habitat Surveys

The California Department of Fish and Game surveyed Upper East Austin Creek, Grey Creek, Tiny Creek, Conshea Creek and an unnamed tributary in 1996. Table 18 summarizes the results of these surveys. Juvenile steelhead were found in East Austin Creek and many tributaries. Coho salmon were recorded in Grey Creek in 1962.

Historic Conditions

Several early developments are documented in the Upper East Austin Creek Sub-basin. A magnesite mine operated from 1905-1925 near the Red Slide area. Magnesite is a type of serpentinite rock and is mined for use in steel making, refractatories and making magnesium/magnesia products. A narrow-gauge railroad extended along the edge of East Austin Creek to the mine site. This type of mine is operated through surface excavation, not tunnels, and the ore was extracted, treated in a calcining plant and then moved by a mining railroad to Guerneville. It is unlikely that the mine site required large amounts of timber for this type of operation. In 1915, 70 mine workers resided near the mine on a seasonal basis (Clar 1954).

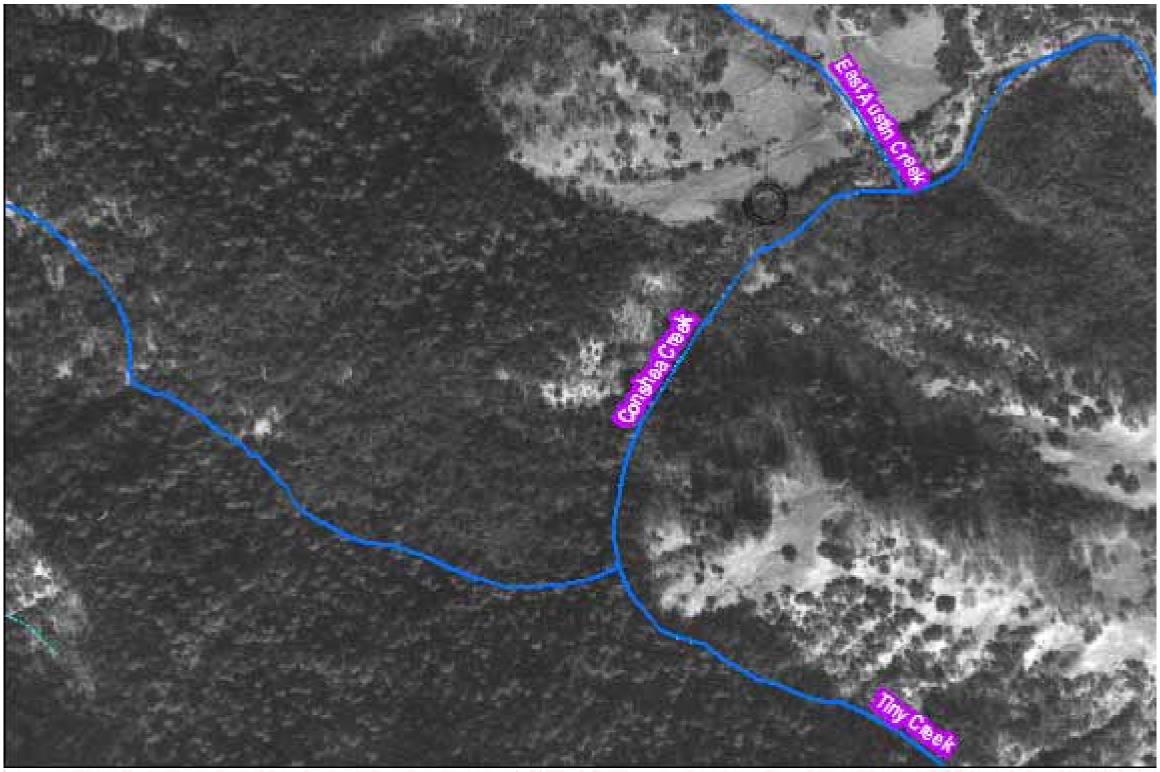
Timber harvesting occurred in the 1800's along the upstream area of Grey Creek which was reached from the east by Mill Creek Road. Timber was likely transported through the Mill Creek watershed to Healdsburg.

Aerial Photographs – 1941/1942

The 1941/1942 aerial photographs depict a number of features (Figures 59 and 63). Generally there are a very low number of roads visible. Development of orchards is visible along and near Upper Grey Creek. One of the most widespread features in the 1941/1942 photographs is the appearance of cleared or burned vegetation in the upper East Austin Creek Sub-basin.

Figure 8 illustrates the burned/cleared area in 1941/1942 compared to its much more vegetated state in 2000. There are several possible activities which could have been occurring in 1941/42. Many areas in the Austin Creek watershed were cleared of tree cover to increase grazing land. Although it is not possible to determine the exact vegetation types which occurred in 1941/42, we can compare the cleared/burned areas with vegetation maps made in 2000. This analysis found that approximately 739 acres of hardwood forest/chaparral, 39 acres of coniferous/mixed coniferous forest and 462 acres of cypress forest have a cleared, or burned, appearance in 1941/1942 for a total of 1240 acres. Most of this area does not contain trees desirable for other uses such as lumber so any intentional clearing was unlikely motivated by the value of the harvested trees and probably was done to improve the area for grazing.

It is also very likely that there was a major fire in this area shortly before the photographs were taken. The available documentation for fires in this area starts in the 1950's. These types of vegetation, especially the cypress and hardwood forest and chaparral, are fire adapted.



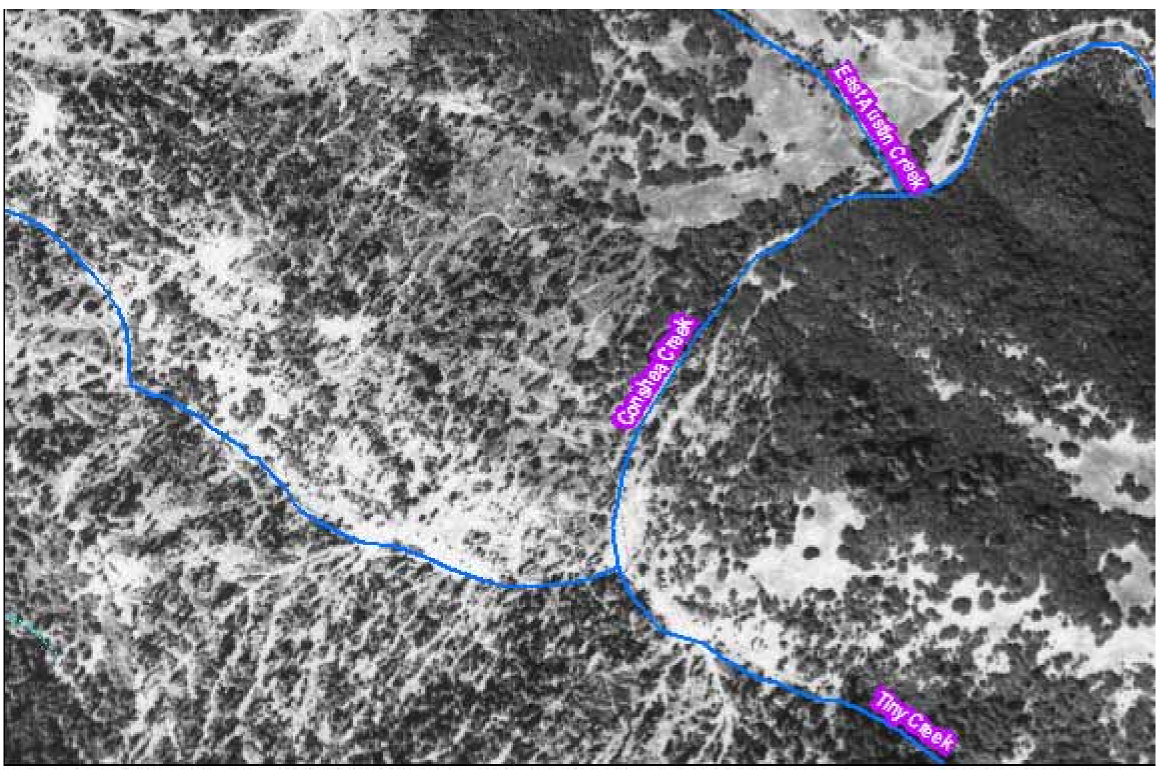


Figure 31. Top photo shows Conshea Creek area of Upper East Austin Creek Sub-basin in 1941/42. Bottom photo shows same location in 1961 after clear-cut logging

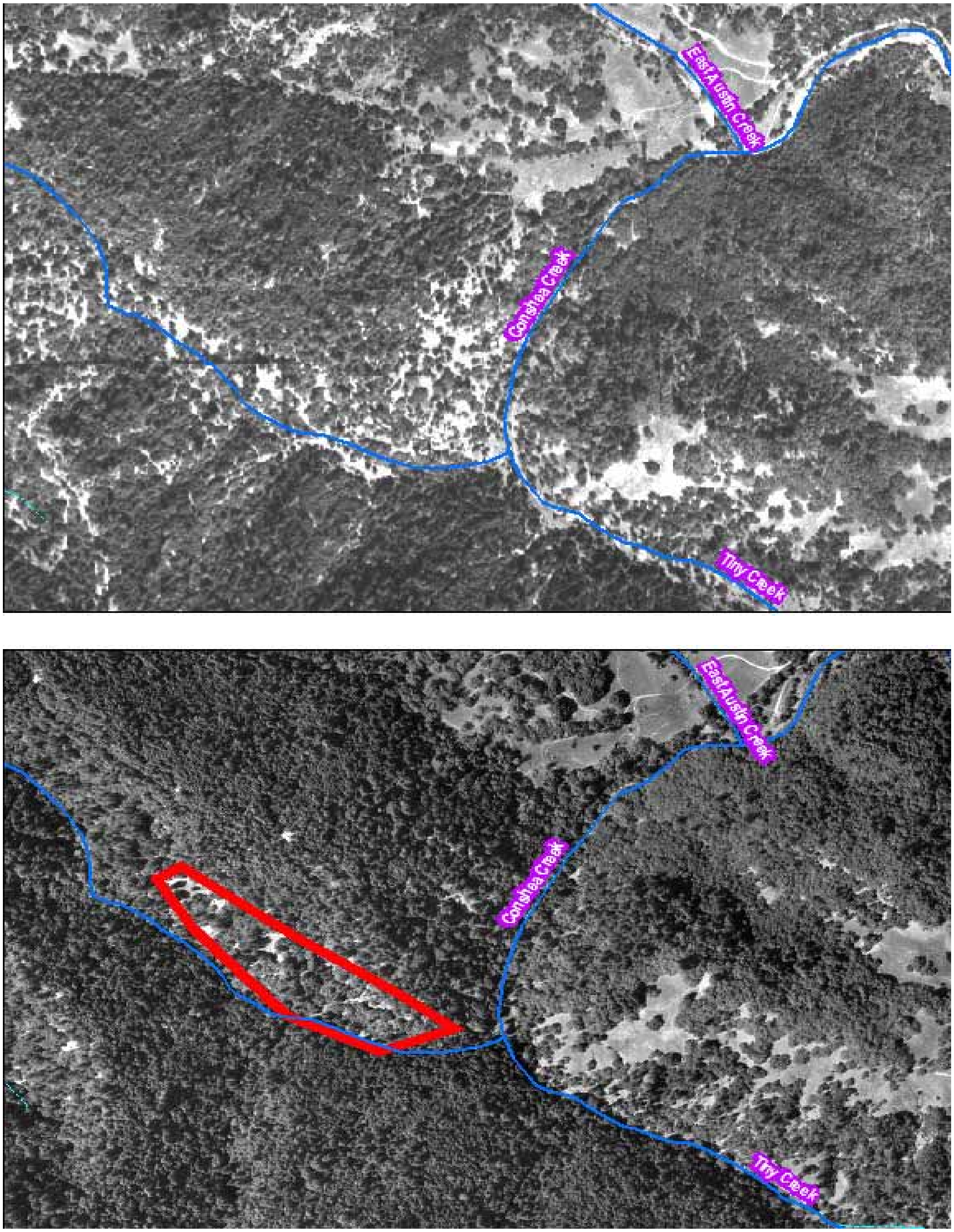


Figure 32. Top photo is Conshea Creek area of Upper East Austin Creek Sub-basin in 1980 showing continued ground disturbance following the 1961 logging. Bottom photo shows same location in 2000 with red outline around example of still disturbed area

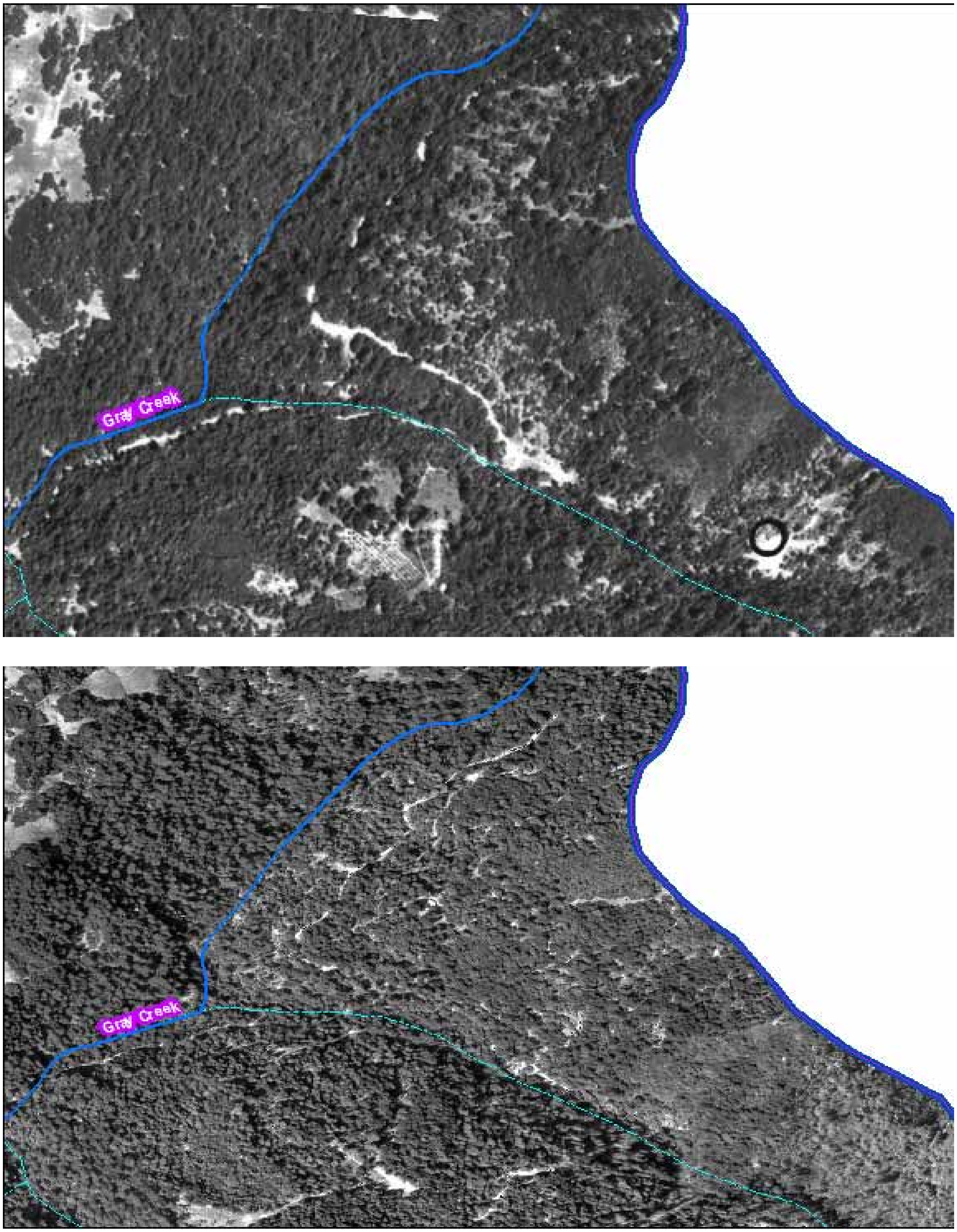


Figure 33. Top photo is eastern area of the Grey Creek drainage in 1961 showing road and orchard development. Bottom photo is same location in 2000 showing continued ground disturbance from roads. A road project was completed on one small area of this road network.

Aerial Photographs – 1961

The 1961 aerial photographs illustrate an increase in road building and several areas of clear-cut logging (Figure 60). Figure 31 shows a close up of the Conshea Creek tributary area with clear indications of timber harvest, ground disturbance and road building. Table 24 summarizes the miles of roads in 1961 as a total of 68 miles and a ratio of 3.77 road miles per square mile of sub-basin.

The 1961 aerials also show that the areas indicated as burned or cleared in 1941/42 (Figure 8) have regrown vegetation.

Aerial Photographs – 1980

The 1980 aerial photographs do not show any additional logging after the 1961 period and visible roads total 47.5 miles (Figure 61). The total road miles is lower than the total visible in 1961 probably due to the increase in vegetative cover which obscures roads in the photograph. Portions of the area in the Conshea Creek tributary area logged in the 1961 period are delineated for not having regrown dense conifers (Figure 32).

Aerial Photographs – 2000

The 2000 aerial photographs show a total of 60.2 miles of visible roads, a higher total than 1980 but lower than 1961 (Figure 62). There are a number of sites which were logged by 1961 and show continued ground disturbance in 1980 and 2000 (Figure 32). These areas total 88 acres, representing 16% of the area originally logged during this period. One of these areas is in the Upper Grey Creek tributary basin (Figure 33). Another feature documented using the aerial photographs is change in vegetative cover types between 1941/1942 and 2000 (Figure 63). Areas which were clearly conifer forest in 1941/1942 and delineated as hardwood/chaparral totaled 259 acres in this sub-basin.

Restoration Projects

The California Restoration Project Database (CRPDB) lists a number of restoration projects in the Upper East Austin Creek Sub-basin (see Figure 29). These projects include stream bank stabilization on East Austin and Grey Creeks. A road along most of the length of Grey Creek has been repaired and modified to reduce fine sediment delivery to the creek.

Grey Creek is one of two locations in the Austin Creek Watershed where captive-raised Coho salmon juveniles were released by the California Department of Fish and Game and University of California Extension in the Spring 2005. Downstream migration will be monitored as well as summer rearing and mortality and water temperature.

Table 24. Historic Conditions in the Upper East Austin Creek Sub-basin

Historical Conditions	Acres	Sq Miles	Miles	Miles of roads/sq. mile of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	29	<0.1		
Logged	12	<0.1		
Roads			7.7	0.43
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	70	0.1		
Logged	527	0.8		
Roads			68.0	3.77
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	0	0		
Logged between 1961-1980	0	0		
Roads			47.5	2.64
Logged by 1961, has not regrown conifer by 1980	43	0.1		
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	2	<0.1		
Roads			60.2	3.34
Logged by 1961, has not regrown conifer by 2000	0	0.0		
Logged by 1961, still disturbed in 2000	88	0.1		
Logged between 1961- 1980, has not regrown conifer by 2000	0	0.0		
Logged between 1961- 1980, still disturbed in 2000	0	0.0		
Vegetation Changes 1940 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	462	0.7		
Bare in 1940, Conifer/Mixed Conifer in 2000	39	0.1		
Bare in 1940, Hardwood/Chaparral in 2000	739	1.2		
Conifer in 1940, Hardwood/Chaparral in 2000	259	0.4		
Major Fires since 1950				
HOLLOW TREE FIRE - 1959	4	<0.1		
NO NAME FIRE - 1960	886	1.4		

Lower East Austin Creek Sub-basin

Geographic and Topographic Features

The Lower East Austin Creek Sub-basin encompasses 8984 acres, or 14 square miles. This sub-basin includes the portion of East Austin Creek downstream of the confluence with Grey Creek to the confluence with Austin Creek. Significant tributaries to lower East Austin Creek include Black Rock Creek (2.7 miles), Schoolhouse Creek (1.0 mile), Thompson Creek (2.0 miles), and Gilliam Creek (3.7 miles). A total of 29.8 miles of unnamed blue line tributary streams also drain into Lower East Austin Creek.

This sub-basin consists primarily of steep mountains with slopes in excess of 30% making up 78.5% of the total land area. The Lower East Austin Creek Sub-basin has slightly less area of steep slopes than Upper East Austin Creek (Figure 53).

Lower East Austin Creek is low in slope ranging between 1-2% and <1%. Lower East Austin Creek is 7.8 miles in length. In the upstream 5.5 miles Lower East Austin Creek flows through a confined canyon. In the lower 2.2 miles the creek channel is unconfined (Figure 52). This low slope unconfined area of East Austin Creek is more likely to experience sediment deposition and storage than the upstream higher slope and confined channels.

Geologic Features

Lower East Austin Creek Sub-basin includes four primary rock types: Franciscan Formation Graywacke and Mélange (KJfs), Greenstone (gs), Serpentinite (sp) and Sandstone of the Turonian age of the late Cretaceous period (TKfs) (Figure 54). There is also a small outcrop of Metabasalt (KJfmg) in the southern area of this sub-basin and very small area of Metagraywacke (KJfm) in the northern area of the sub-basin. Silicate carbonate (SC) rock lies within the Serpentinite and sandstone blocks in the northeast area of this sub-basin.

These rock formations are aligned in northwest/southeast trending blocks reflecting the fault system. Lower East Austin Creek Sub-basin like Upper East Austin Creek is dissected by faults which define the contacts between the major rock types. Franciscan Mélange with areas of Greenstone make up most of the central and southern portion of this sub-basin. Franciscan Formation is well-known for its instability, landslides and high erosion rates especially on slopes over 30%. There are a number of large landslides (Qls) indicated along the hill slopes adjacent to East Austin Creek. There are likely many smaller landslides not indicated on the geological map.

Sandstone (TKfs) occurs in the Gilliam Creek tributary and a portion of the Thompson Creek tributary. This sandstone is harder and more erosion resistant than either the Franciscan Graywacke or Serpentinite.

Serpentinite occurs as sheared rock and crosses through the sub-basin in one band in the Thompson Creek and Schoolhouse Creek tributaries. Serpentinite weathers to form serpentine soil which has a high level of magnesium and supports specially-adapted plant species.

Sub-basin Vegetation-Present Day

Table 25 lists the acreages of various vegetation types found in the Lower East Austin Creek Sub-basin in 2000. These are also depicted in Figure 55. Hardwood forest with grassland and various kinds of coniferous forest cover the eastern area of this sub-basin. Sargent cypress forest and chaparral cover the serpentine soil areas. The northwestern and southern portion of this sub-basin is dominated by coniferous and mixed coniferous/hardwood forest interspersed with hardwood forest and grassland. Redwood forest dominates the floodplain and hillsides along the creek.

Table 25. Vegetation types of the Lower East Austin Creek Sub-basin

Vegetation types	Acres	Sq. Miles
Grassland/Rangeland	931	1.46
Chaparral	320	0.50
Closed cone pine-cypress	100	0.16
Conifer	2,839	4.44
Cropland	2	<0.1
Hardwood	3,079	4.81
Mixed Hardwood/Conifer	1,258	1.97
Redwood	456	0.71

The California Natural Diversity Data Base (CNDDB) list a number of rare plants in the Lower East Austin Creek Sub-basin. On the serpentine soil area in the Thompson and Gilliam Creek tributaries the Cedars fairy lantern (Calochortus raichei), the Cedars manzanita (Arctostaphylos bakeri ssp. sublaevis), jewelflower (Streptanthus morrisonii) occur. Dwarf soaproot (Chlorogalum pomeridianum var. napensis), Jepson's narrow-leaved daisy (Erigeron angustatus), Napa false indigo (Amphora californica var. napensis), leptosiphon (Leptosiphon jepsonii) occur in the southern portion of the sub-basin. The Cedars manzanita is state-listed as rare.

There are a number of rare animals in this sub-basin. Federally-listed endangered Pacific freshwater shrimp (Syncaris pacifica) has been recorded along the lower 2.4 miles of East Austin Creek. Foothill yellow-legged frog (Rana boylii) have been recorded in two locations, in Schoolhouse Creek and Thompson Creek. Red tree vole (Arborimus pomo) has been recorded near East Austin Creek. The freshwater shrimp is officially listed as endangered under federal law.

Land Use

The largest landowner in the Lower East Austin Creek Sub-basin is the California Department of Parks and Recreation. The East Austin Creek Recreation Area provides non-motorized back country recreation and camping and has one car-camping area accessible by public road.

Private lands make up the rest of the sub-basin and support ranching, timber harvest, rural residential housing, which is concentrated on the downstream mile of East Austin Creek and recreation including a Boy Scout Camp (Camp Royaneh). The Sonoma County General Plan designates most of the private land as Resource and Rural Development. Very few parcels are smaller than 10 acres making further residential development unlikely in the near term.

Roads – Present Day

A total of 50.3 miles of roads are visible in the 2000 aerial photography (Figure 67). This is a moderate ratio of 3.58 miles of roads per square mile of sub-basin. Of this total, 31.6 miles of roads are on slopes >30% for a ratio of 2.25 miles of road over 30% slope to square mile of sub-basin.

Table 26. Present day roads in the Lower East Austin Creek Sub-basin

Roads	Miles	Miles of roads/sq. mile of sub-basin
Total miles of roads in sub-basin	50.3	
Miles of road / sq mile of sub-basin		3.58
Total miles of roads >30% slope in sub-basin	31.6	
Miles of road>30% slope/sq mile of sub-basin		2.25
Miles of road on 1-30% slope	16.7	1.19
Miles of road on 30-50% slope	19.5	1.39
Miles of road on 50-65% slope	7.6	0.54
Miles of road on >65% slope	4.5	0.32

Fish Habitat Surveys

The California Department of Fish and Game (CDFG) surveyed Lower East Austin Creek, Black Rock Creek, Thompson Creek, Gilliam Creek and Schoolhouse Creek. Reports were not available for any of these creeks other than East Austin Creek; however, GIS layers were obtained which summarize some of the survey findings (Appendix B). This GIS layer indicates that tributaries to Lower East Austin Creek have good canopy of 70-100%, but Lower East Austin Creek has poor canopy of 0-40%.

Despite this high level of canopy cover most of the tributaries had water temperatures >70ºF as did all of Lower East Austin Creek. Most CDFG surveys report instantaneous temperatures measured only on the day and time of the survey with a thermometer. The

GIS layer also indicates low levels of embeddedness recorded in Lower East Austin Creek and its tributaries.

Historic Conditions

Aerial Photographs 1941/1942

The aerial photographs show a low level of disturbance and logging of only 128 acres total in 1941/42 (Figure 64). Sixty acres of the area which was delineated as disturbed in 1941/1942 re-grew to conifer/mixed conifer forest (5 acres), hardwood/chaparral (27 acres) and redwood forest (28 acres) by 2000. There are a total of 12.1 miles of visible roads for a very low ratio of 0.86 miles of roads per square mile of sub-basin.

There are also areas in this sub-basin which like the Upper East Austin Creek Sub-basin shows signs of vegetation clearing or fire. These areas cover 133 acres and are delineated as hardwood forest/chaparral in the 2000 vegetation layer.

Aerial Photographs-1961

Extensive road building and logging is obvious in 1961 in all areas of this sub-basin with coniferous forest. Figures 34 and 35 show a close-up of the headwaters of Gilliam Creek in 1941/1942, 1961, 1980 and 2000 and the downstream area of East Austin Creek in 1941/42 and 1961. Logging covers a total of 1,092 acres with 61.6 miles or roads (Figure 65). This sub-basin has a moderately high ratio of miles of roads to square miles of sub-basin of 4.39 in 1961. Another disturbance factor occurring in this period was wild fires. About 40 acres of this sub-basin were burned in the 1961 Roadside #44 Fire (see Figure 57).

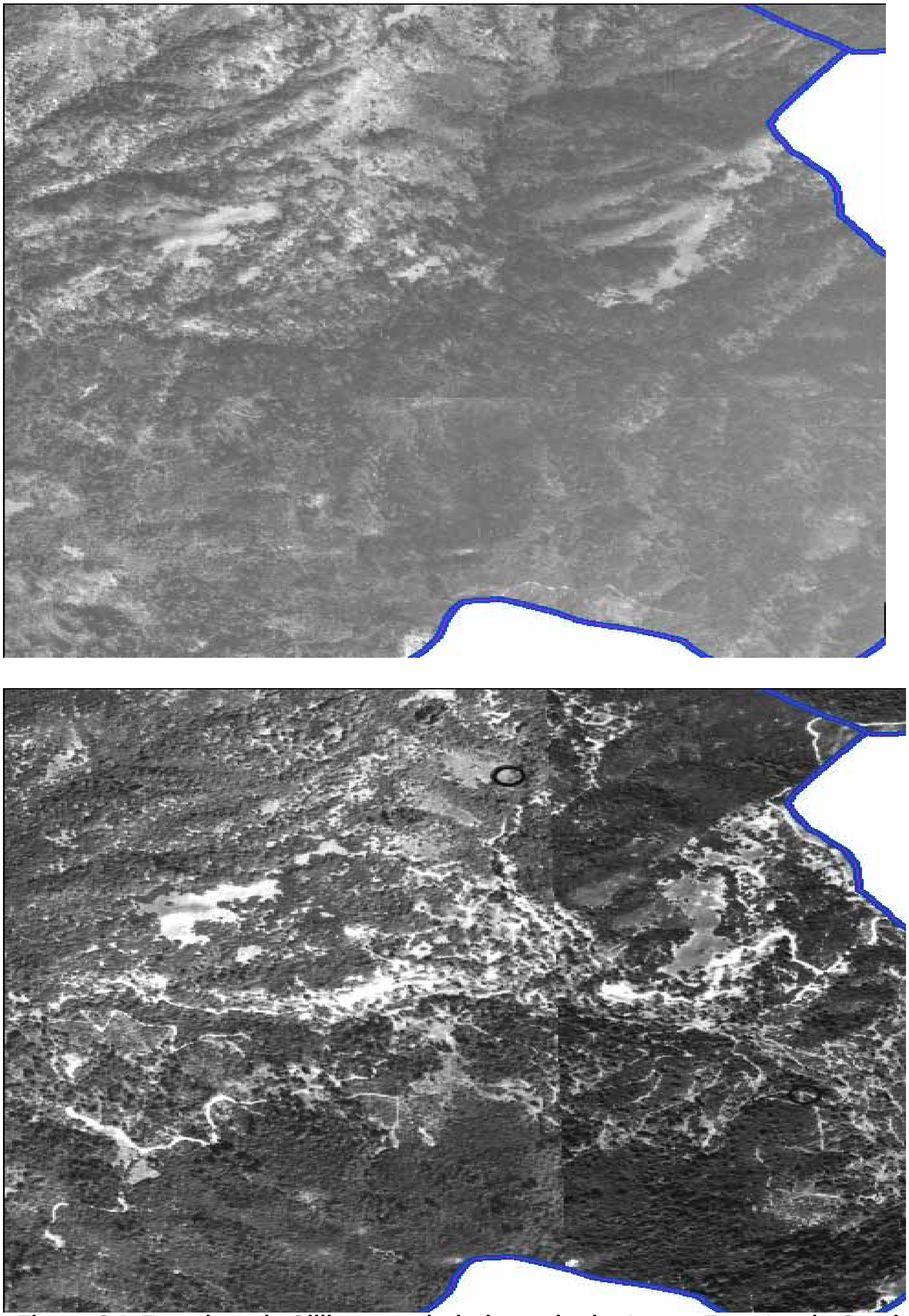


Figure 34. Top photo is Gilliam creek drainage in the Lower East Austin Creek Sub-basin in 1941/42; Bottom is same location in 1961 showing extensive clear-cut logging.

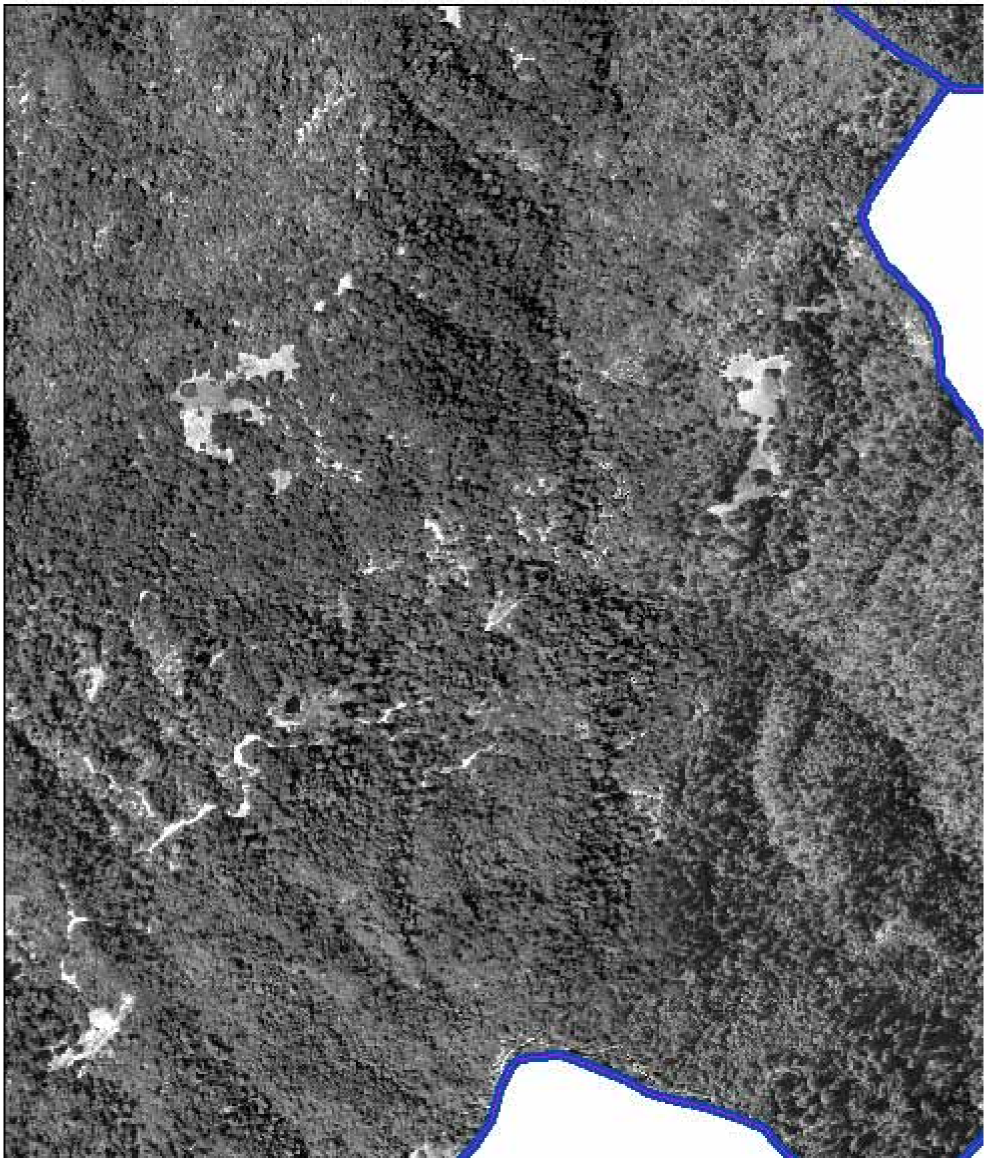


Figure 35. Gilliam creek drainage in the Lower East Austin Creek Sub-basin in 2000 showing roads and some ground disturbance.

Aerial Photographs-1980

The 1980 photographs show a small area logged between 1961 and 1980 for a total of 34 acres (Figure 66). Many roads are still visible from the 1961 logging for a total of 43.2 miles. Many miles of roads may be obscured in the 1980 photographs by vegetation.

Another feature in the 1980 photographs are areas that were logged by 1961 but have not re-grown conifers. These areas encompass 225 acres, representing 20% of the total area logged in 1961.

Aerial Photographs-2000

The 2000 photographs show an extensive road network with a total of 50.3 miles and a ratio of 3.56 miles of road per square mile of sub-basin (Figure 67). This ratio is higher than 1980 but lower than 1961. Areas logged between 1942-1961 and 1961-1980 were reviewed to determine those areas which had not re-grown conifers and those with obvious ground disturbance (see Table 27 and Figures 34 and 35). About 60 acres still show obvious disturbance representing 5% of the original logged area.

The 2000 aerials and vegetation layer were compared with 1941/42 aerial photographs (Figure 68). About 199 acres, which in 1941/42 was conifer forest, is hardwood forest/chaparral in 2000.

Restoration Projects

A number of restoration projects have been completed particularly in the State Park. Roads in the Thompson, Schoolhouse and Gilliam Creek drainages and along East Austin Creek in the park have been repaired and modified to reduce fine sediment delivery into creeks (Figure 29). Revegetation along East Austin Creek in the park has also been completed. One small road modification project on private land in the downstream area of East Austin Creek has also been completed.

Table 27. Historic Conditions in Lower East Austin Creek Sub-basin

Historical Conditions	Acres	Sq. miles	Miles	Miles of road/sq. mile of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	36	0.1		
Logged	92	0.1		
Roads			12.1	0.86
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	45	0.1		
Logged	1,092	1.7		
Roads			61.6	4.39
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	33	0.1		
Logged between 1961- 1980	34	0.1		
Logged in 1961, has not regrown conifer by 1980	225	0.4		
Roads			43.2	3.08
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	8	<0.1		
Logged by 1961, has not regrown conifer by 2000	13	<0.1		
Logged by 1961, still disturbed in 2000	60	0.1		
Logged between1961- 1980, has not regrown conifer by 2000	15	<0.1		
Logged between1961- 1980, still disturbed in 2000	0	0.0		
Roads			50.3	3.58
Vegetation Changes 1941 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	0	0.0		
Bare in 1940, Conifer/Mixed Conifer in 2000	0	0.0		
Bare in 1940, Hardwood/Chaparral in 2000	133	0.2		
Cleared for Ag/Grazing in 1940, Hardwood/Chaparral in 2000	27	<0.1		
Cleared for Ag/Grazing in 1940, Redwood/Conifer/Mixed Conifer in 2000	33	<0.1		
Conifer in 1940, Hardwood/Chaparral in 2000	199	0.3		
Major Fires since 1950				
MCCRAY RIDGE - 1959	1	<0.1		
ROADSIDE #44 - 1961	40	0.1		

Upper Austin Creek Sub-basin

Geographic and Topographic Features

The Upper Austin Creek Sub-basin stretches from the mountainous northwestern boundary of the watershed to nearly the center of the drainage at the confluence of Austin and Ward Creeks. Mohrhardt Ridge defines the southern boundary of this sub-basin while the steep mountains of the Cedars serve as the northern boundary. Kings Ridge within this sub-basin separates Main Austin Creek from Bearpen Creek. Upper Austin Creek Sub-basin is dominated by steep slopes with 82% of the land area over 30% slope and only 0.1% flat land (Figure 53). This sub-basin encompasses 9,328 acres, or 14.6 square miles, and has two major creeks: Austin Creek (8.3 miles) also called Main, or Big, Austin Creek and Bearpen Creek (3.3 miles). Other significant tributaries include Gravelly Springs Creek (0.3 miles), Red Slide Creek (2.0 miles) and a total of 23.3 miles of blue line creeks.

The slope and confinement of the Main Austin and Bearpen Creek channels were evaluated (Figure 52). At its headwaters in the Cedars, Main Austin Creek has a >20% slope and confined channel which gradually changes slope from 8-20% to 4-8%, then 2-4%, then 1-2% in the Cedars Canyon. The Upper Austin Creek channel steepens slightly to 2-4% downstream of the confluence with Gravelly Springs Creek then once again flattens out from 1-2% to <1% at the confluence with Red Slide Creek. Upper Austin Creek is in a confined channel from its headwaters to the confluence with Bearpen Creek where a small section of the channel is unconfined. Downstream of the Bearpen Creek confluence, Upper Austin Creek ranges between the 2-4%, 1-2% and < 1% slope classes and is mostly in a confined channel. In the vicinity of Holmes Canyon the Upper Austin Creek channel is only partially confined.

Bearpen Creek also begins with a channel at >20% slope in its headwaters and gradually descends from 8-20% to 4-8% then 2-4% raising slightly back to 4-8% then to 1-2% midway down its length. Then the channel increases in slope again to 4-8%, 8-20% as it courses through large landslides that flank both sides of the channel. Downstream of the landslide area Bearpen Creek drops from a 2-4% slope channel to a <1% slope channel until the confluence with Austin Creek. For most of its length Bearpen Creek has a confined channel; the last half-mile of the creek is in an unconfined low-slope channel.

In general both Upper Austin and Bearpen Creeks have confined higher slope channels which primarily transport sediment. In the lower slope areas near and downstream of the confluence of the two creeks, sediment deposits and is stored and is represented on the geologic map (Figure 54) as alluvium.

Geologic Features

The Upper Austin Creek Sub-basin is criss-crossed by faults which define the boundaries between rock types. Franciscan Formation Graywacke and Mélange with isolated blocks of Greenstone are the main rock types making up the southern area of the sub-basin.

Franciscan Formation is well known for its high erodibility and landslides. A large area of Serpentinite makes up the northern area of the sub-basin and headwaters of Austin Creek. This Serpentinite is made up of sheared rock. Sandstone from the Turonian and Maastrichtian ages of the late Cretaceous period cross the sub-basin in two bands and is a more erosion resistant rock type than either the Graywacke or Serpentinite. Another prominent feature in this sub-basin is large landslides in several areas of the creek canyons. While these mapped landslides are large, it is likely many smaller landslides also occur. All of the mapped landslides occur in the Franciscan Formation.

Faults are very numerous in the Upper Austin Creek Sub-basin and give the creek network a northwest-southeast trend (Figure 54). When creeks cross faults they may gain or lose flow. In much of the Austin Creek Watershed faults mark the contact between major rock types and my also serve as locations of springs especially when a more porous rock type such as sandstone lies against a less porous rock such as Franciscan Graywacke. Gravelly Springs Creek occurs at the faulted contact between the Sandstone, Franciscan Graywacke and the Serpentinite, where a large landslide occurs. Gravelly Springs Creek is fed by a large spring. There are a few other springs indicated on the USGS topo quad which also lie on, or near, faults and between rock types.

Sub-basin Vegetation-Present Day

Figure 55 depicts vegetation types in the Upper Austin Creek Sub-basin. In the northern headwaters area where Serpentinite dominates, Sargent cypress trees and chaparral grow next to serpentine barrens. The unusual chemistry in serpentine soils make them too toxic for many plant species. In the Cedars, plant species occur which have evolved special adaptations to live on serpentine soils. A mosaic of hardwood forest, mixed conifer/hardwood forest and coniferous forest occur in the southern portion of this sub-basin. There are also smaller areas of redwood forest and grassland (Table 28).

The Californian Natural Diversity Data Base has a number of rare plants recorded in the Upper Austin Creek Sub-basin. These include Jepson's leptosiphon (Leptosiphon jepsonii), Napa false indigo (Amorpha californica var. napensis), Santa Cruz clover (Trifolium buckwestiorum), Snow mountain buckwheat (Eriogonum nervulosum), The Cedars fairy lantern (Calochortus raichei), the Cedars manzanita (Arctostaphylos bakeri ssp. sublaevis), dwarf soaproot (Chlorogalum pomeridianum var. minus), narrow-leaved daisy (Erigeron angustatus), purple-stemmed checkerbloom (Sidalcea malviflora ssp. purpurea), second jewel-flower (Streptanthus glandulosus var. hoffmanii), serpentine daisy (Erigeron serpentines) and Streptanthus morrisonii. Of these, only the Cedars manzanita is officially listed as rare under the State endangered species act.

Table 28. Vegetation types in the Upper Austin Creek Sub-basin

Vegetation types	Acres	Sq. miles
Grassland/Rangeland	548	0.86
Barren	591	0.92
Chaparral	226	0.35
Closed cone pine-cypress	1,305	2.04
Conifer	2,921	4.56
Cropland	12	0.02
Hardwood	2,313	3.61
Mixed Hardwood/Conifer	1,155	1.80
Redwood	257	0.40

A rare lichen, long-beard lichen (Usnea longissima) has also been found in this sub-basin.

The foothill yellow-legged frog (Rana boylii) has been recorded along Austin Creek.

Land Use

The Upper Austin Creek Sub-basin is entirely private land used for ranching, vineyard, rural residential, recreation and timber harvest. King's Ridge Road, a major public road crosses through this sub-basin. The Sonoma County General Plan designates this sub-basin for Resource and Rural Development and a density of 320 acres per unit. Most of this sub-basin has large parcels and little to no housing. Parcels less than ten acres in size occur in a few locations adjacent to Austin and Bearpen Creek along public roads.

Given the current parcel sizes it is unlikely large scale residential development will occur in the near future.

Roads-Present Day

Roads are numerous in this sub-basin totaling 61 miles for a moderately high ratio of 4.19 miles of road per square mile of sub-basin (Figure 72). A large percentage of these roads are on slopes greater than 30% for a total of 44.3 miles and a ratio of 3.04 miles of road over 30% slope per square mile of sub-basin (Table 29).

Table 29. Present Day Roads in the Upper Austin Creek Sub-basin

Roads	Miles	Miles of roads/sq. mile of sub-basin
Total miles of roads in sub-basin	61.0	
Miles of road/sq mile of sub-basin		4.19
Total miles of roads >30% slope in sub-basin	44.3	
Miles of road>30% slope/sq mile of sub-basin		3.04
Miles of road on 1-30% slope	16.7	1.15
Miles of road on 30-50% slope	26.7	1.83
Miles of road on 50-65% slope	11.4	0.78
Miles of road on >65% slope	6.2	0.43

Fish Habitat Survey

There are habitat surveys available for a portion of Upper Austin Creek and Bearpen Creek. These surveys are summarized in Table 18. Steelhead juveniles have been found in Austin Creek in 1954, 1956, 1968, 1977 & 1995. Coho salmon were found in 1954 and 1995. Steelhead juveniles were found in Bearpen Creek in 1968, 1977 & 1995.

Historic Conditions

Upper Austin Creek had a number of mining sites. Laton Mine is located adjacent to Upper Austin Creek in the Cedars area and was a chromite (chromium) mine from 1916 to 1946. The Laton Mine was a surface mine of less than two acres where ore was removed by excavating the ground and sidecasting tailings on the site. Ore was hauled back to Cazadero and transported to a location outside the watershed for processing. There wasn't a furnace on the mining site but some sorting was done using redwood shaking tables (Dave McCrory pers. comm.) Some minor gold prospects have also been excavated on Mohrhardt Ridge along the western edge of this sub-basin.

Aerial Photographs- 1941/42

The 1941/42 aerial photographs show relatively little active ground disturbance with only ten acres of disturbed area and 22 acres of active logging (Figure 69). Unlike the lands to the east of this sub-basin, the Upper Austin Creek Sub-basin does not show areas of burning or clearing.

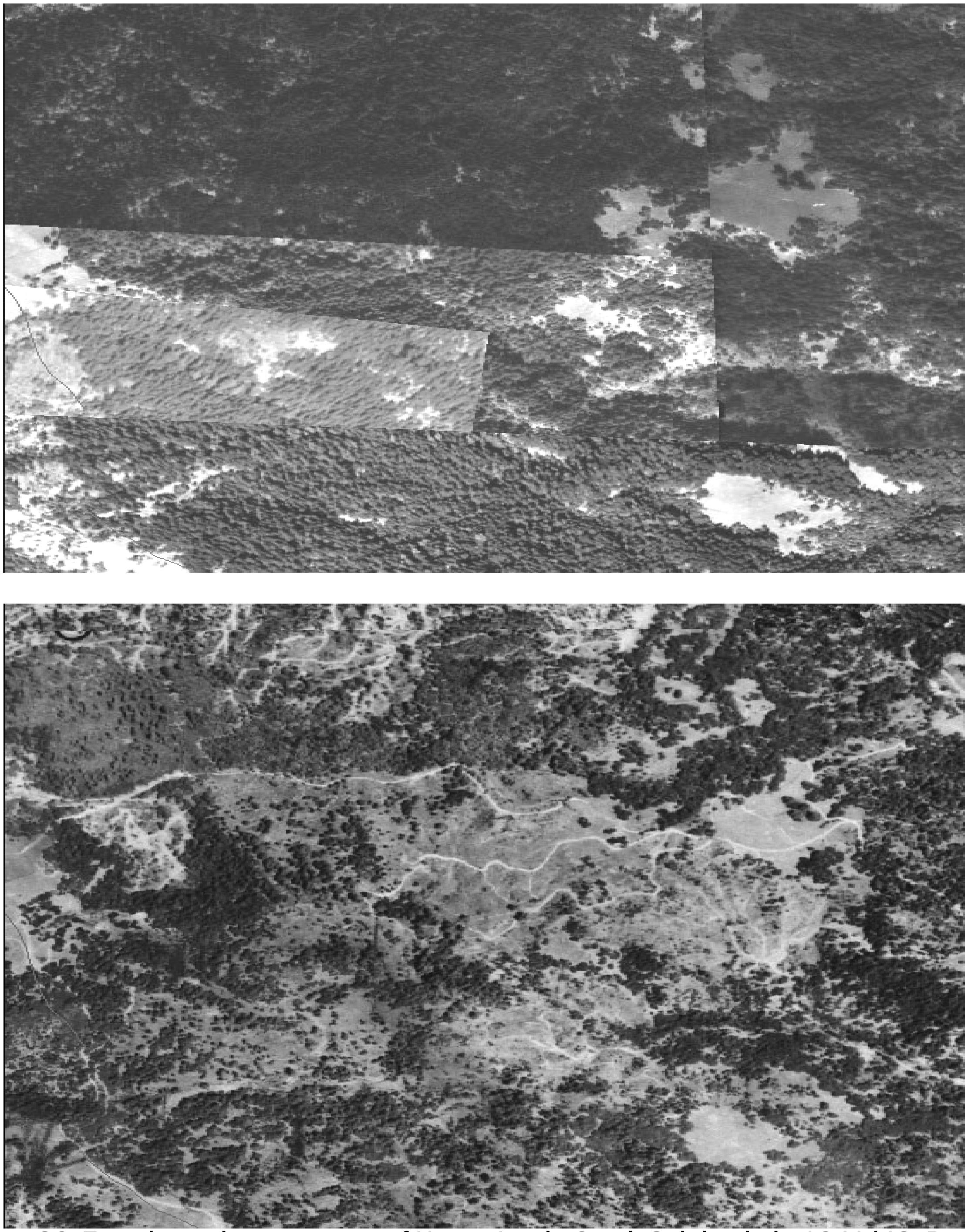
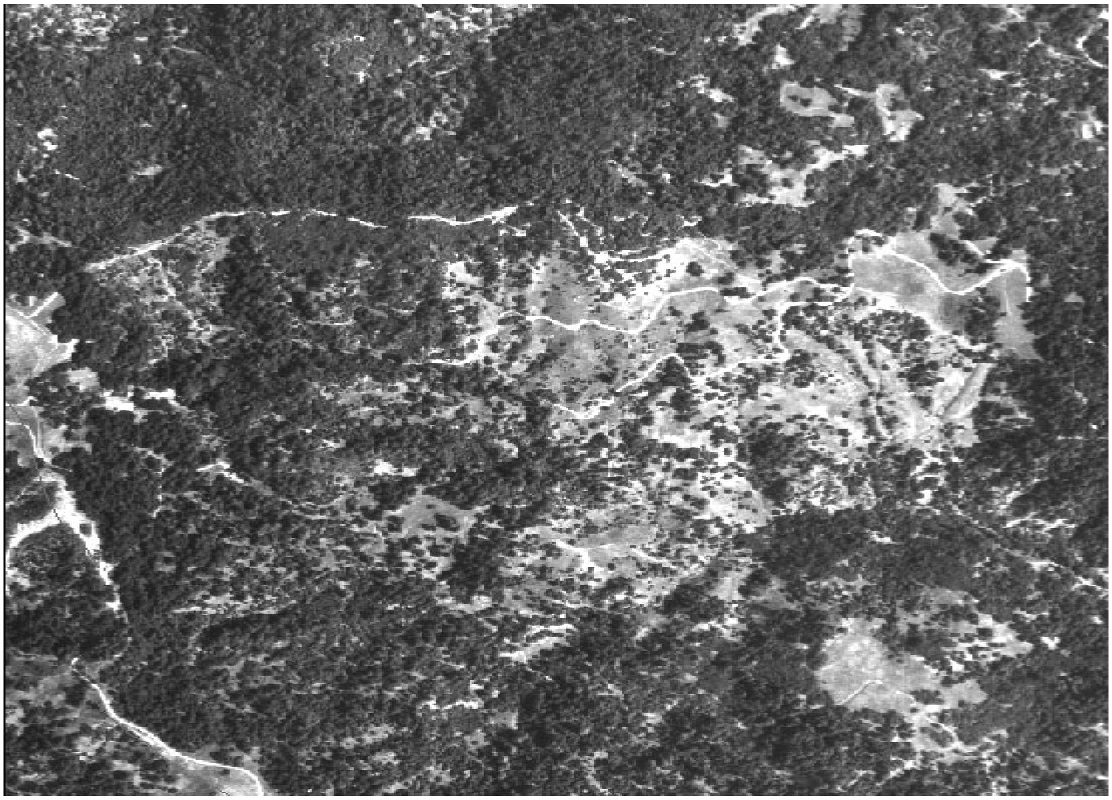


Figure 36. Top photo shows an area of Upper Austin Creek Sub-basin in 1941/42. Bottom photo shoes same area in 1961 after clear-cut logging



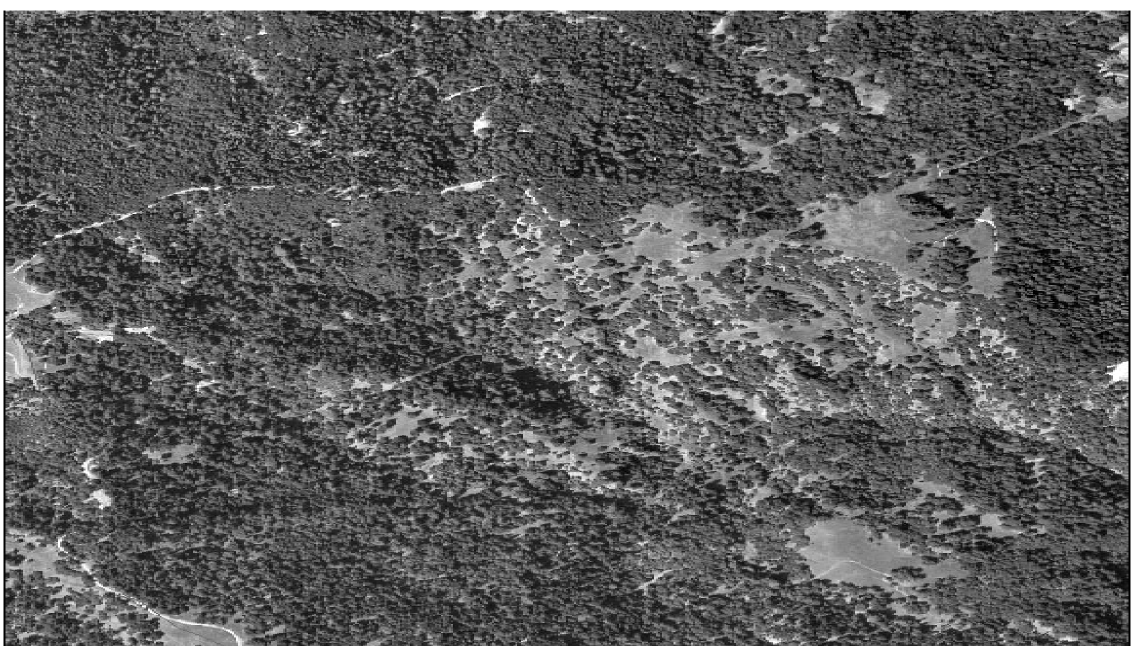


Figure 37. Top photo shows area of Upper Austin Creek Sub-basin in 1980. Bottom photo shows same area in 2000 showing an overall reduction in conifer forest and remaining roads

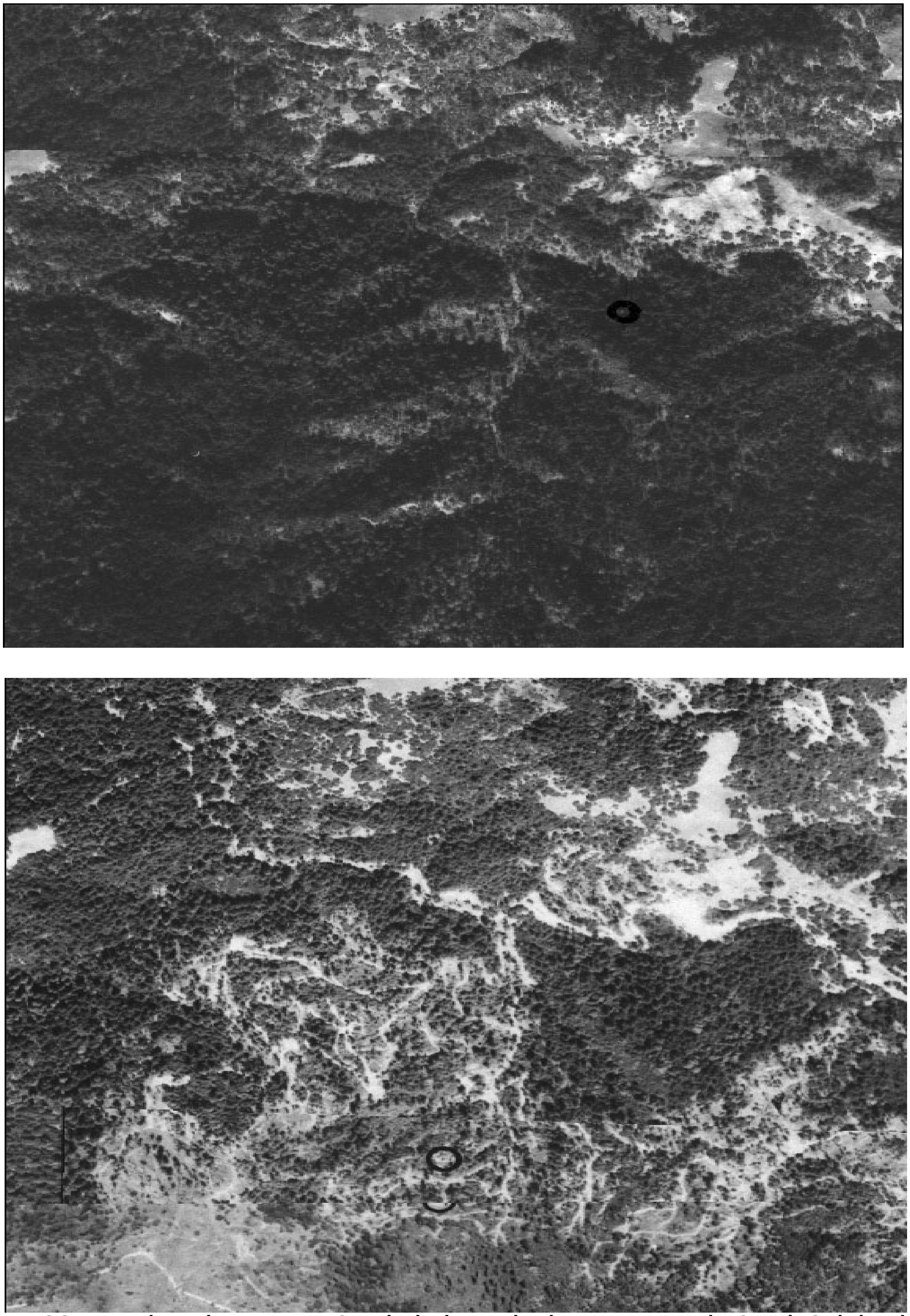
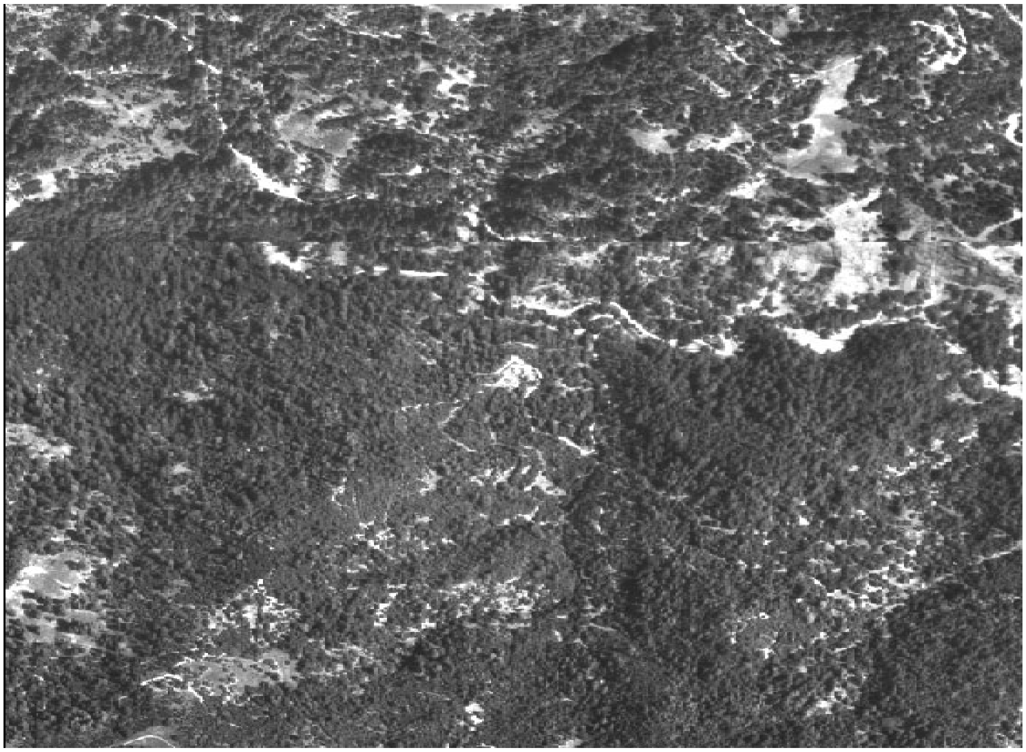


Figure 38. Top photo is Bearpen Creek drainage in the Upper Austin Creek Sub-basin in 1941/42. Bottom is same location in 1961 following clear-cut logging



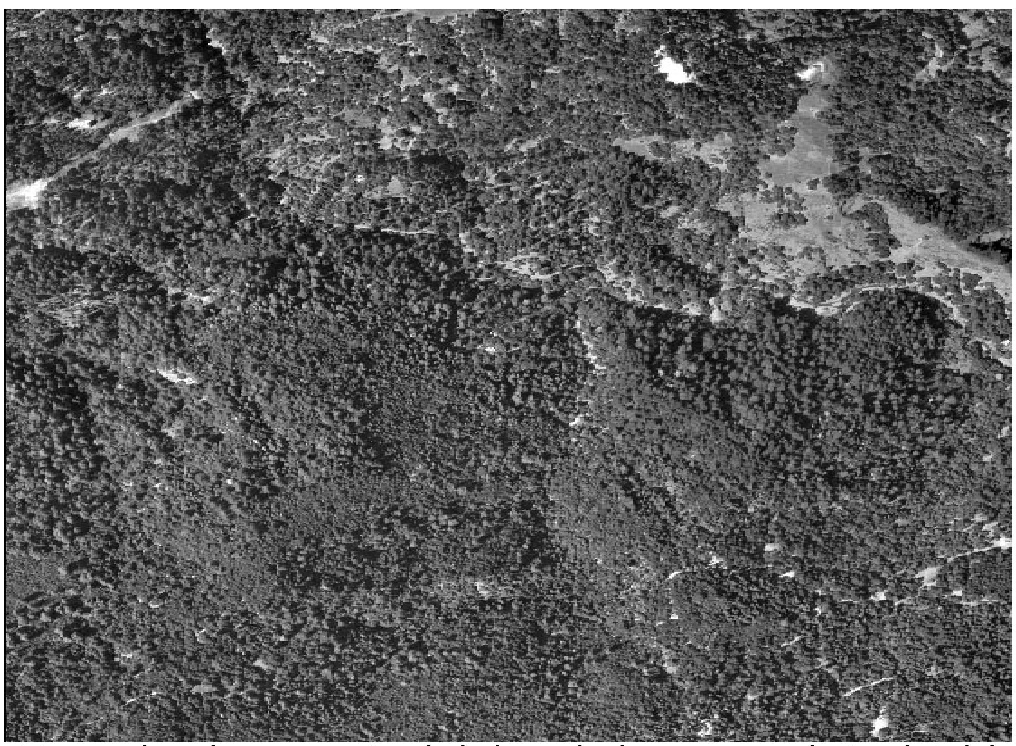


Figure 39. Top photo is Bearpen Creek drainage in the Upper Austin Creek Sub-basin in 1980. Bottom photo is the same location in 2000 and shows remnant roads systems from the 1961 period

Aerial Photographs- 1961

The 1961 aerial photographs show a significant level of logging and road building throughout the sub-basin (Figure 70). Only the northern area of the Cedars, a portion of the Bearpen Creek drainage and a largely roadless area east of Austin Creek are not actively being logged.

Figures 36 and 38 show several areas of the Upper Austin Creek Sub-basin in 1941/42 and 1961 and depict the level of clear cutting and road building. A total area of 1603 acres or 2.5 square miles was delineated as logged and a total of 77.5 miles of roads outlined.

Aerial Photographs- 1980

The 1980 aerial photographs depict 144 acres of additional areas of logging and some additional areas of logging and a total of 55.6 miles of visible roads (Figure 71). There may be additional miles of roads remaining from the 1961 period that are obscured by vegetation.

Another feature delineated for the 1980 photographs are areas which were logged in 1961 and have not re-grown conifers. These areas cover 384 acres representing 23% of the area logged in 1961 (Figure 37).

Aerial Photographs- 2000

The 2000 aerial photographs show an extensive road system totaling 61 miles for a moderately high ratio of 4.19 miles of roads per square mile of sub-basin. Another feature delineated is 113 acres that were logged in 1961 but have not re-grown conifer representing 7% of the original logged area.

Another 25 acres logged in 1961 still exhibits ground disturbance in 2000. Of the area logged between 1961 and 1980, fifteen acres have not regrown conifer by 2000. The other features delineated in the 2000 aerials are areas that were conifer forest in 1941/42 and now are indicated as hardwood forest/chaparral in the CalVeg data layer. In this sub-basin these areas total 724 acres or 1.1 square mile (see Figure 39).

Restoration Projects

The CRPDB data layer does not show any restoration projects in the Upper Austin Creek Sub-basin.

Table 30. Historical Conditions in the Upper Austin Creek Sub-basin

Historical Conditions	Acres	Sq. Miles	Miles	Miles of roads/sq. miles of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	10	<0.1		
Logged	22	<0.1		
Roads			11.2	0.77
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	0	0.0		
Logged	1,603	2.5		
Roads			77.5	5.32
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	1	<0.1		
Logged between 1961-1980	144	0.2		
Logged in 1961, has not regrown conifer by 1980	384	0.6		
Roads			55.6	3.81
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	4	<0.1		
Logged by 1961, has not regrown conifer by 2000	113	0.2		
Logged by 1961, still disturbed in 2000	25	<0.1		
Logged between 1961-1980, has not regrown conifer by 2000	15	<0.1		
Logged between 1961- 1980, still disturbed in 2000	0	0.0		
Roads			61.0	4.19
Vegetation Changes 1940 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	0	0.0		
Bare in 1940, Conifer/Mixed Conifer in 2000	0	0.0		
Bare in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Redwood/Doug Fir in 2000	0	0.0		
Conifer in 1940, Hardwood/Chaparral in 2000	724	1.1		
Major Fires since 1950				
NO NAME - 1960	765	1.2		
CREIGHTON RIDGE - 1978	12	0		

Ward Creek Sub-basin

Geographic and Topographic Features

Ward Creek Sub-basin is located in the western central area of the Austin Creek watershed and encompasses 7,545 acres, or 11.8 square miles. Ward Creek flows from its headwaters on Mohrhardt Ridge 7.0 miles to its confluence with Austin Creek. There are a number of major tributaries to Ward Creek including Big Oat Creek (1.7 miles), Blue Jay Creek (2.7 miles), Pole Mountain Creek (2.5 miles) and a number of unnamed blue line streams (16.6 miles).

Figure 52 depicts the slope class and confinement of Ward Creek. From its headwaters through its first mile, Ward Creek has a slope of >20% and 8-20%. The channel then gradually drops in slope from 4-8% to 2-4% and then 1-2% as the channel changes from a north/south direction to a west/east direction. After making its large turn to the east the channel varies between 2-4% and 1-2% slope. Very near the confluence with Austin Creek the channel slope increases to 4-8% and 8-20% as the creek flows through the toe of a large landslide and then the slope decreases to 2-4% to the confluence with Austin Creek. The Ward Creek channel is confined for most of its length except for the .15 mile of unconfined channel before its confluence with Austin Creek.

The drainage network of Ward Creek has a distinctly different pattern than other sub-basins in the Austin Creek. Ward Creek has a trellis pattern of creeks with most major tributaries perpendicular at their confluence to the main creek channel. A dendritic creek pattern occurs in all the other sub-basins.

Like most of the Austin Creek Watershed, Ward Creek is dominated by steep slopes with nearly 75% of this sub-basin over 30% slope.

Geologic Features

Ward Creek Sub-basin has bands of different rock types lying in a northwest/southeast direction across the sub-basin (Figure 54). Franciscan Formation Graywacke and Mélange (KJfs) occurs in a band across the northern portion of Ward Creek Sub-basin with small areas of Greenstone (gs). Franciscan Graywacke is highly erodible and prone to landslides especially on steep slopes. There are several large landslides mapped near the confluence of Ward Creek and Austin Creek. Two bands of Metabasalt (KJfmg) with a small area of Metagraywacke (KJfm) separated by a band of Great Valley Complex Conglomerate (KJgvc) dominate the central and southern areas of this sub-basin. The Metabasalt and Metagraywake are types of metamorphic rock and are more durable than Franciscan rock.

Great Valley Complex Conglomerate is moderately hard and durable and tends to erode into large blocks. The durable nature of the rock in Ward Creek and tendency for the Great Valley complex to erode in blocks may be the reason the trellis drainage network occurs only in Ward Creek where the geology is different from the other sub-basins. At the very southwestern edge of the Ward Creek Sub-basin is a band of Sandstone from the Turonian age of the late Cretaceous period which also occurs in some of the other sub-basins. There is also a small area of Sandstone from the Maastrichtian age of the late Cretaceous period on the western border of this sub-basin. Both of these types of sandstone are moderately erodible.

Numerous faults dissect the Ward Creek Sub-basin and there are several large landslides mapped along these faults.

Sub-basin Vegetation-Present Day

Currently hardwood forest is the dominant vegetation type of the Ward Creek Sub-basin, particularly in the western and southern area (Figure 55). Coniferous forest occurs mostly along the eastern and northern edge of the sub-basin with redwoods along the most downstream section of Ward Creek. Grassland areas are distributed throughout the Ward Creek Sub-basin. Table 31 summarizes the acreage of various vegetation types in Ward Creek Sub-basin.

The California Natural Diversity Data Base (CNDDB) list several rare plant occurrences in the Ward Creek Sub-basin. These include Jepson's leptosiphon (Leptosiphon jepsonii), Napa false indigo (Amorpha californica var. napensis), holly-leaved ceanothus (Ceanothus purpureus) and narrow-leaved daisy (Erigeron angustatus). None of these plants are federally or state-listed as rare, threatened or endangered. Foothill yellow legged frog (Rana boylii) have been recorded on Ward Creek near the confluence with Austin Creek.

Table 31. Vegetation types in Ward Creek Sub-basin

Vegetation types	Acres	Sq. Miles
Grassland/Rangeland	755	1.18
Chaparral	62	0.10
Conifer	1,429	2.23
Cropland	17	0.03
Hardwood	3,577	5.59
Mixed Hardwood/Conifer	1,234	1.93
Redwood	469	0.73

Land Use

Ward Creek Sub-basin supports ranching, rural residential housing, recreation and timber harvest. The Sonoma County General Plan designates lands in the Ward Creek Sub-basin for Resource and Rural Development. The majority of the parcels in this sub-basin are larger than ten acres. The greatest number of small parcels are clustered near Cazadero and along Fort Ross Road. The potential for residential development is greater in these two areas and limited in the remainder of the sub-basin which has large parcel sizes.

Roads-Present Day

Roads in Ward Creek Sub-basin are depicted in Figure 72. Ward Creek has a total of 82.22 miles of roads for a ratio of 6.97 miles of road per square mile of sub-basin. This is a very high density of roads. Roads on slopes over 30% total 55.7 miles for a ratio of 4.73 miles of road over 30% to square mile of sub-basin (Table 32). This is a high ratio of roads on steep slopes.

Table 32. Present day roads in the Ward Creek Sub-basin

Roads	Miles	Miles of roads/sq. miles of sub-basin
Total miles of roads in sub-basin	82.22	
Miles of road / sq mile of sub-basin		6.97
Total miles of roads >30% slope in sub-basin	55.7	
Miles of road >30% slope/sq mile of sub-basin		4.73
Miles of road on 1-30% slope	26.4	2.24
Miles of road on 30-50% slope	30.9	2.62
Miles of road on 50-65% slope	15.5	1.31
Miles of road on >65% slope	9.3	0.79

Fish Habitat Surveys

Table 18 summarizes the findings of habitat surveys by the California Department of Fish and Game for Ward Creek and its tributaries: Blue Jay, Pole Mountain and three unnamed creeks. Big Oat Creek, another tributary to Ward Creek was not surveyed due to the presence of an impassable natural barrier. Steelhead trout were found in Ward Creek in 1965, 1968, 1970, 1977, 1982 and 1996. Coho salmon were found in 1970 and 1996. Steelhead trout were also found in Pole Mountain and Blue Jay Creeks in 1996.

Historic Conditions

The Ward Creek Sub-basin lies between the town of Cazadero on Austin Creek and Fort Ross on the coast. The Fort Ross Road passes through the sub-basin near to Ward Creek.

Fort Ross was an early settlement in this region. A schooner landing was developed in the 1860's at Fort Ross Cove (Figure 21) (Kalani et al 2004). A number of lumber mills were also built and it is very likely that conifer trees were harvested from the western side of the Ward Creek Sub-basin and hauled to the coast for milling at Fort Ross with shipment by schooner to San Francisco. Tan oak was also harvested for use in leather tanning both at Fort Ross and other locations (Kalani et al 2004). Forests on the east side of the Ward Creek Sub-basin and all along Austin Creek would also likely have been harvested beginning in the 1850's and hauled to the Russian River and coast for milling and transport.

In 1886 a railroad spur line was constructed along Austin Creek connecting Cazadero directly to Duncans Mills (Figure 24). It is likely that these transportation improvements increased the level and extent of logging in the Ward Creek Sub-basin and other areas of the Austin Creek watershed. Outside of Ward Creek to the west there was a narrow-gauge railroad along the Gualala in the current location of Bohan-Dillon Road. The D.H. McEwen Lumber Company had a sawmill at Niestrath and Fort Ross Roads from 1906 to 1917. Logs from the Ward Creek Sub-basin could have been milled at this site. Lumber was milled and then transported via oxen team to Cazadero for transport on the railroad along Austin Creek (Clar 1954).

There was also the Aho manganese mine on Niestrath Road just outside the Ward Creek Sub-basin which operated from 1920-1950's.

Aerial Photographs- 1941/42

The 1941/42 aerial photographs show very little development in the Ward Creek Sub-basin (Figure 69). There are a total of 7.2 miles of roads for a ratio of 0.61 miles of road per square mile of the sub-basin. The photographs also show twenty acres of disturbed lands including agricultural, residential and other non-logging uses and seven acres of logging. Coniferous forest appears to dominate the western side of the sub-basin and the Ward Creek and tributary areas.

Aerial Photographs- 1961

The 1961 aerial photographs show widespread logging, road building and significant ground disturbance (Figure 70). The logged areas cover 3,116 acres representing over 40% of the sub-basin (Figures 40 and 41). Roads are extensive in the 1961 photographs totaling 107 miles and a ratio of 9.16 miles of roads per square mile of sub-basin, an extremely high density. Between 1941/42 and 1961 the Charles Fire of 1954 burned about 609 acres in the Pole Mountain area (Figure 57).

Aerial Photographs- 1980

Between 1961 and 1980 a large fire occurred in the Ward Creek Sub-basin. The Creighton Ridge Fire burned 78% of the Ward Creek Sub-basin encompassing the entire central and western area and the tributary drainages of Blue Jay, Big Oat and Pole Mountain Creeks. In 1974 this area also experienced a rare and significant snow storm resulting in damage to many trees and a build-up of debris. This storm damage combined with the slash remaining from the widespread logging visible in the 1961 aerials (Figures 40 and 41) provided an enormous fuel load for the Creighton Ridge Fire.

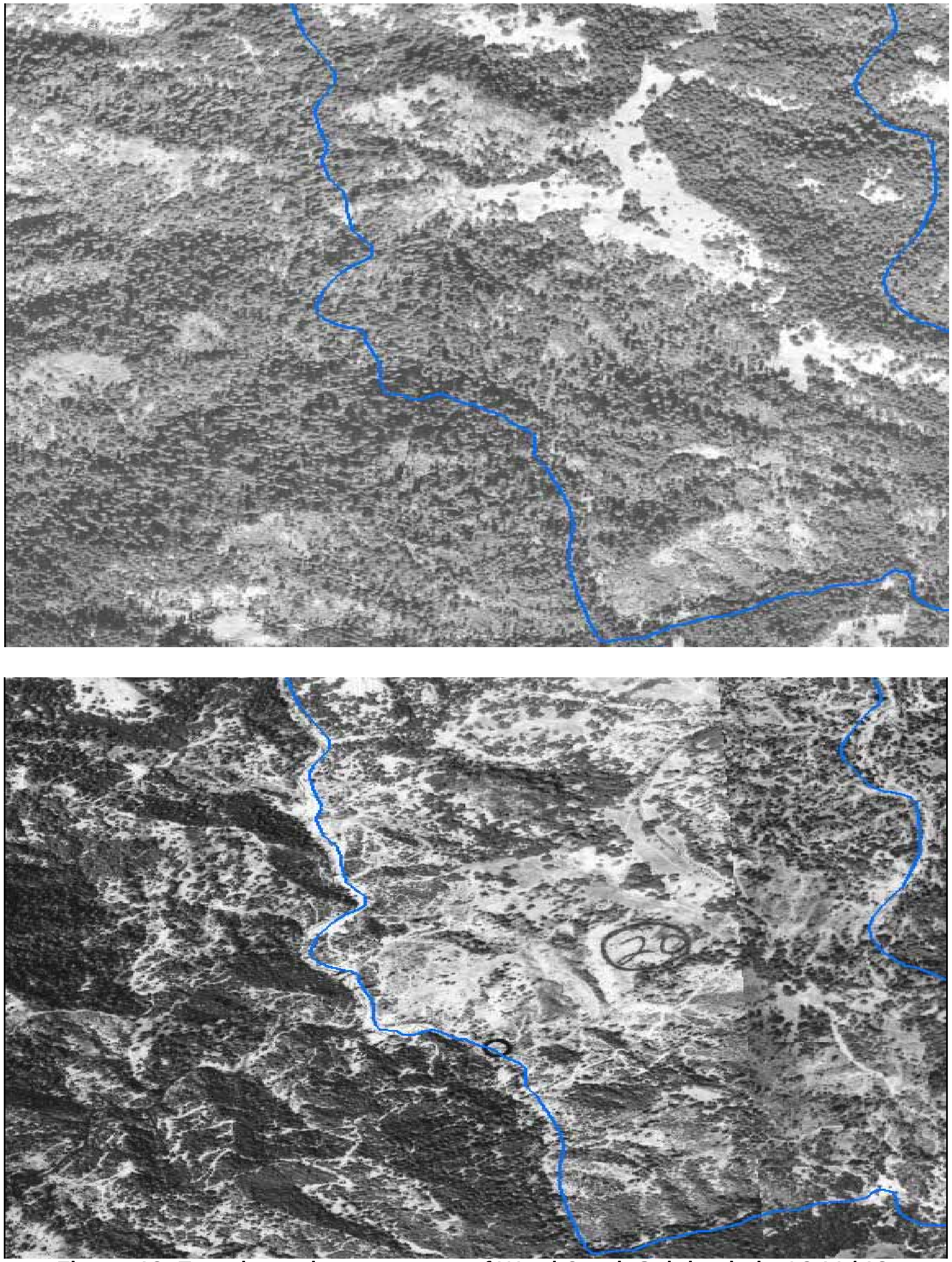
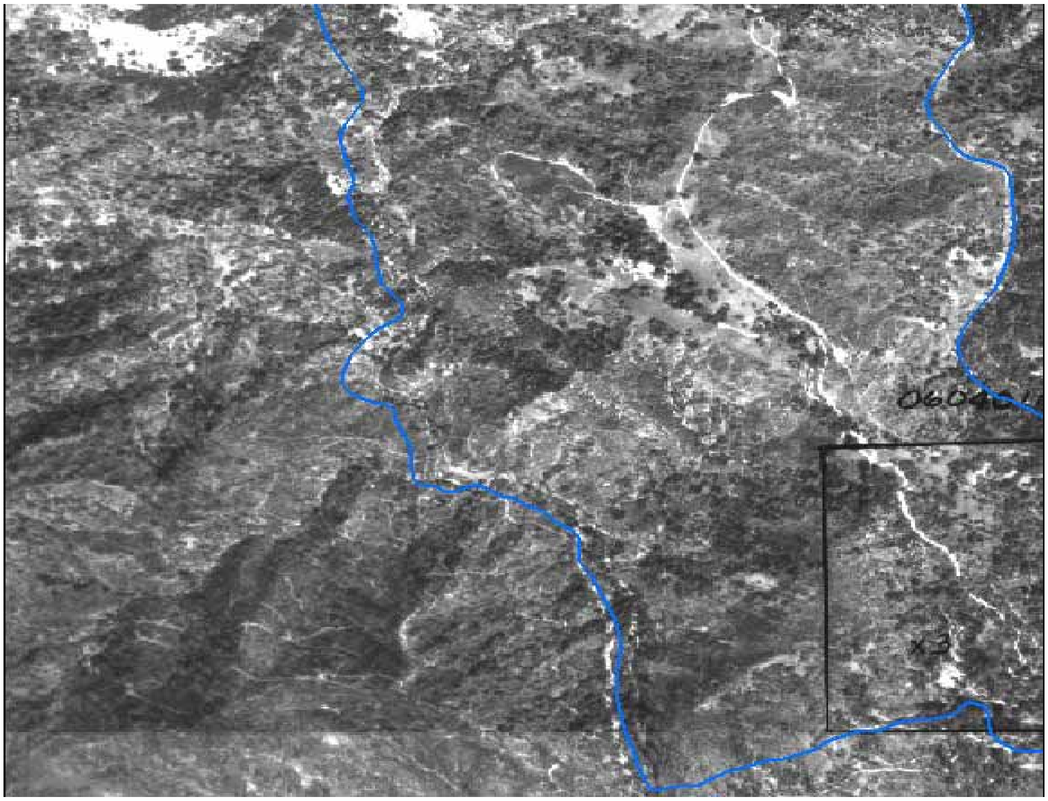


Figure 40. Top photo shows an area of Ward Creek Sub-basin in 1941/42.
Bottom photo is the same location in 1961 after clear-cut logging



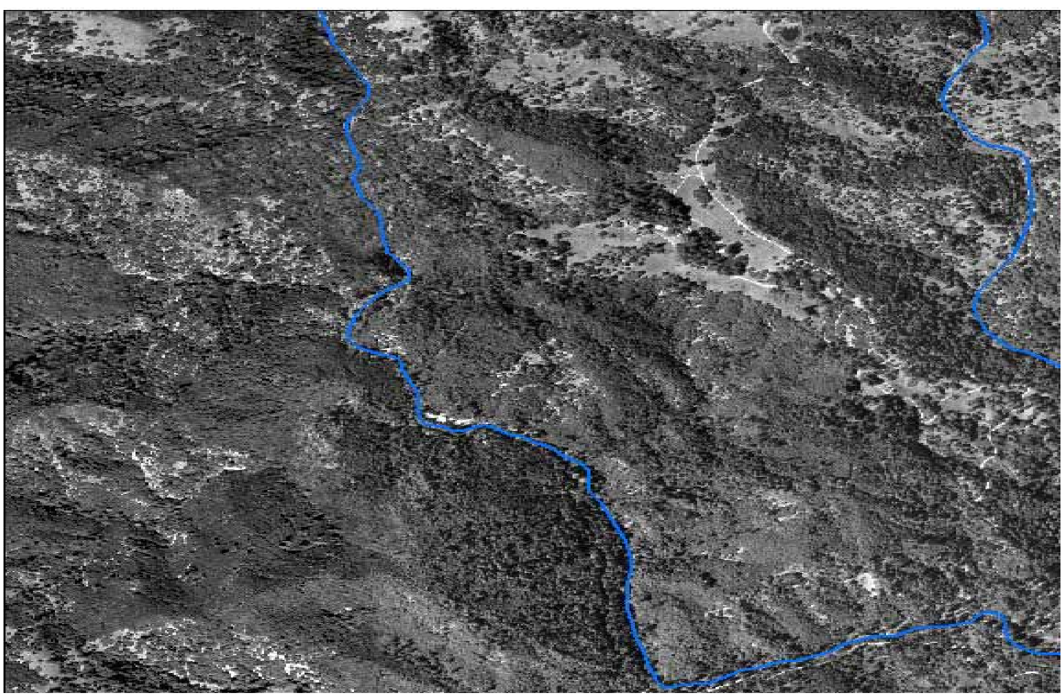
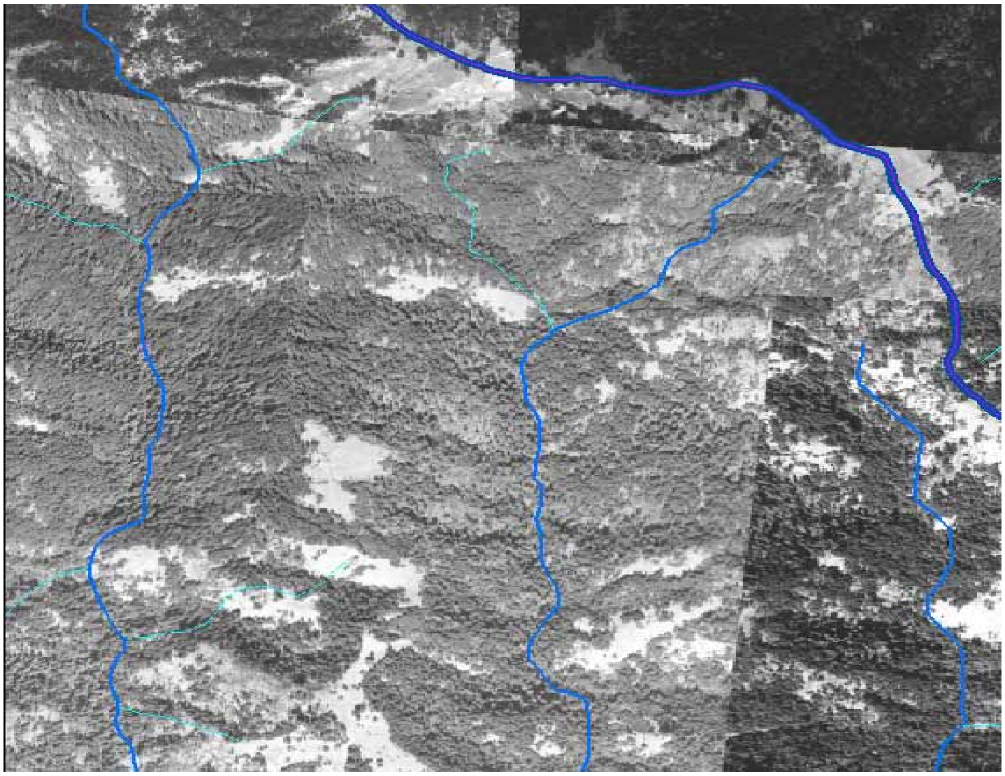


Figure 41 Top photo is same area in 1980 of Ward Creek Sub-basin as Figure 40.
Bottom photo is areas in 2000. Note the lack of conifer forest and remaining roads



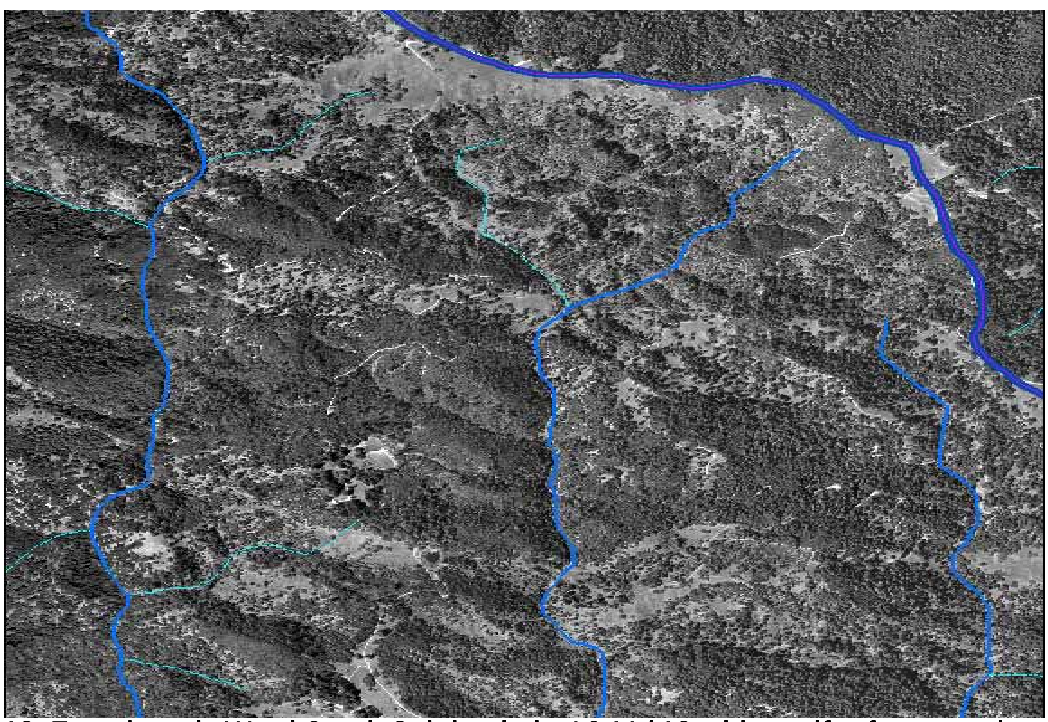


Figure 42. Top photo is Ward Creek Sub-basin in 1941/42 with conifer forest and grassland areas. Bottom photo is the same location in 2000 after hardwood forest has largely replaced the conifers.

The 1980 aerial photographs show additional logging between 1961 and 1980 of 780 acres and an extensive road network (Figure 71). Roads total 96.8 miles, just slightly less than in 1961. The ratio of road miles to square miles of sub-basin is 8.21, a very high ratio. Another feature delineated on the 1980 aerial photographs are areas logged by 1961 that have still not regrown conifer forest and areas logged by 1961 showing significant ground disturbance. These areas total 1,622 acres, over half of the area logged in 1961.

Aerial Photographs- 2000

The 2000 aerial photographs show several different features (Figure 72). Those areas that were logged between 1941/42 - 1961 were delineated if the conifers had not regrown or if the area was still disturbed. The areas logged between 1961 and 1980 were also evaluated and delineated for disturbance and re-growth of conifer. Table 33 summarizes the acres of each of these conditions.

The road network in 2000 is still extensive totaling 82.2 miles for a high ratio of 6.97 miles of road per square mile of sub-basin. Another feature documented in the Ward Creek Sub-basin is widespread change in vegetation types between 1941/42 and 2000. Over 2000 acres of the area covered in conifer forest in 1941/42 is designated as hardwood/chaparral in the CalVeg layer in 2000. This area represents 26% of the Ward Creek Sub-basin. Much of this area also is delineated as having continued ground disturbance and a lack of conifer regrowth (Figure 72). The extent and location of hardwood forest replacement of conifer forest coincides with both the Creighton Ridge Fire of 1978 and the extensive logging prior to 1961 (Figures 42 and 73).

Restoration Projects

Ward Creek is one of the two locations in the Austin Creek Watershed where captive-bred Coho salmon are being released (Lewis 2005). Coho juveniles specially raised at the Lake Sonoma Hatchery to preserve wild characteristics were released into Ward Creek in 2004 and 2005. Movement of salmon smolts downstream are being monitored through the use of traps. Stream flow and temperature are also being measured at the mouth of Ward Creek.

The CRPDB shows a number of road repair projects in the Ward Creek Sub-basin (Figure 29). Several of these are road repairs next to creeks. There are also several small stream stabilization projects and one section of Pole Mountain Creek with In-stream structures.

Table 33. Historic Conditions in the Ward Creek Sub-basin

Historical Conditions	Acres	Sq. Miles	Miles	Miles of road/sq. mile of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	20	<0.1		
Logged	7	<0.1		
Roads			7.2	0.61
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	4	<0.1		
Logged	3,116	4.9		
Roads			107.9895	9.16
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	29	<0.1		
Logged by 1961, has not regrown conifer by 1980	1,622	2.5		
Logged since 1961	780	1.2		
Roads			96.8	8.21
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	12	<0.1		
Logged by 1961, has not regrown conifer by 2000	839	1.3		
Logged by 1961, still disturbed in 2000	438	0.7		
Logged between 1961- 1980, has not regrown conifer by 2000	229	0.4		
Logged between 1961- 1980, still disturbed in 2000	66	0.1		
Roads			82.2	6.97
Vegetation changes 1940 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	0	0.0		
Bare in 1940, Conifer/Mixed Conifer in 2000	0	0.0		
Bare in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Redwood/Doug Fir in 2000	0	0.0		
Conifer in 1940, Hardwood/Chaparral in 2000	2,006	3.1		
Major Fires since 1950				
CHARLES - 1954	609	1		
CREIGHTON RIDGE - 1978	5,881	9.2		

Kidd and St. Elmo Creeks Sub-basin

Geographic and Topographic Features

Kidd and St. Elmo Creeks are separate tributary streams which enter Austin Creek in its southern, or downstream, reach. These two small watersheds are grouped in one single sub-basin along with a section of Austin Creek. This sub-basin encompasses 4,391 acres, or 6.9 square miles.

The Kidd and St. Elmo Creeks Sub-basin is made up of primarily steep slopes with 67% of the drainage over 30% slope and less than 1% of the drainage as flat ground.

The channel slope and confinement of both creeks was determined (Figure 52). Both Kidd and St. Elmo are relatively short steep creeks. The headwaters of St. Elmo Creek lie on the east side of Little Black Mountain. The upstream half of the creek varies between 8-20% and >20% slopes in a confined canyon. St. Elmo Creek takes an abrupt jog to the southeast and then varies between 8-20% and 4-8% slope. Only the most downstream area of St. Elmo Creek is low in slope at 2-4% and unconfined. St. Elmo Creek is 1.8 miles in length.

Kidd Creek has its headwaters just to the east of Pole Mountain. Similar to St. Elmo Creek, Kidd Creek is steep in its upstream half with a channel in the >20% and 8-20% slope classes. Kidd Creek gradually reaches Austin Creek moving from 2-4% to a 1-2% slope class. Almost the entire Kidd Creek channel is confined with only its most downstream reach unconfined. Kidd Creek is 2.8 miles in length.

Unnamed tributary streams to Kidd and St. Elmo Creeks total 11.3 miles in length.

A 3.3 mile reach of the Austin Creek channel lies in the Kidd/St. Elmo Creeks Sub-basin. Austin Creek is very low slope <1% in this reach and changes from a confined channel to an unconfined channel at Cazadero. Austin Creek remains an unconfined, low slope >1% channel to its confluence with Russian River.

Geologic Features

Franciscan Formation Graywacke and Mélange (KJfs) makes up most of the Kidd/St. Elmo Creeks Sub-basin. Two bands of Metavolcanic rock (KJfmg) cross through the sub-basin on a northwest/southeast trend. The Metavolcanic rock is a harder, more erosion resistant rock than the Graywacke. A series of faults separate the rock types. A very small area of Serpentinite occurs along one of the faults on the northwestern edge of this sub-basin (Figure 54).

The Franciscan Formation Graywacke and Mélange are highly erodible and known for large landslides. There are a number of large landslides mapped for this sub-basin especially along St. Elmo Creek.

St. Elmo Creek courses through landslide deposits for much of its length and likely transports a significant sediment load to Austin Creek. Kidd Creek flows through the harder Metavolcanic rock in its steep upper reaches and then as it moves through the more erodible Graywacke and landslide deposits the creek channel has a much lower slope. The lower area of the channel may also have a significant sediment load. Alluvium is mapped along Austin Creek reflecting recent deposits along the low-slope unconfined areas of the channel.

Sub-basin Vegetation- Present Day

Conifer forest dominates the eastern side of the Kidd/St. Elmo Creeks Sub-basin with redwood forest along creek canyons. Mixed coniferous forest/hardwood forest occurs along the western side of the sub-basin (Figure 55). Table 34 lists the acreages of the vegetation types in this sub-basin.

The California Natural Diversity Data Base (CNDDB) lists several rare plants recorded in this sub-basin. These plants include Jepson's leptosiphon (Leptosiphon jepsonii), Napa false indigo (Amorpha californica var. napensis), narrow-leaved daisy (Erigeron angustatus). Rare animals recorded in this sub-basin include Gualala roach (Lavinia symmetricus parvipinnis), foothill yellow-legged frog (Rana boylii), red tree vole (Arborimus pomo). None of these plants or animals are state, or federally listed. California freshwater shrimp (Syncaris pacifica) have also been recorded in an unnamed tributary to Austin Creek in this sub-basin. The California freshwater shrimp is state and federally-listed as endangered.

Table 34. Vegetation types in Kidd/St. Elmo Creeks Sub-basin

Vegetation types	Acres	Sq. Miles
Grassland/Rangeland	347	0.54
Barren	10	0.02
Chaparral	4	0.01
Conifer	1,207	1.89
Cropland	12	0.02
Hardwood	815	1.27
Mixed Hardwood/Conifer	761	1.19
Redwood	1,221	1.91
Urban	13	0.02

Land Use

Timber harvest, ranching, rural residential housing and commercial uses occur in the Kidd/St. Elmo Creeks Sub-basin. The town of Cazadero is located in the Kidd/St. Elmo Creek Sub-basin. Cazadero and the surrounding residential area occur along Austin Creek, lower St. Elmo Creek, lower Kidd Creek and the hillsides just above lower St. Elmo Creek.

These areas have relatively dense rural residential housing on small lots to more dispersed housing on two to ten acre lots. The remainder of the sub-basin is designated for Resource and Rural Development with a density of one unit per 160 acres. This designation and the large size of most of the parcels outside of the immediate Cazadero and Austin Creek area should limit additional residential development in the short term. Additional housing development is likely to occur in the Cazadero area along existing systems of dirt roads.

Roads-Present Day

A total of 57.9 miles of roads were delineated in the Kidd/St. Elmo Creeks Sub-basin for a very high ratio of 8.44 miles of road per square mile of sub-basin (Figure 77). Of this total mileage of roads 34.7 miles are on slopes greater than 30% for a ratio of 5.05 miles of roads over 30% per square mile of sub-basin. Table 35 summarizes current roads in this sub-basin.

Table 35. Present day roads in Kidd/St. Elmo Creeks Sub-basin

Roads	Miles	Miles of roads/sq. mile of sub-basin
Total miles of roads in sub-basin	57.9	
Miles of road / sq mile of sub-basin		8.44
Total miles of roads >30% slope in sub-basin	34.7	
Miles of road >30% slope/sq mile of sub-basin		5.05
Miles of road on 1-30% slope	23.2	3.39
Miles of road on 30-50% slope	18.7	2.72
Miles of road on 50-65% slope	9.0	1.31
Miles of road on >65% slope	7.0	1.02

Fish Habitat Surveys

The Department of Fish and Game has completed stream habitat surveys for Austin Creek (Table 18) and part of Kidd Creek. The information on these surveys was derived from a GIS layer based on the surveys (Appendix B). The complete survey for Kidd Creek was not available. Austin Creek was found to have a low level of canopy cover and a moderate to high level of embeddedness. High water temperatures were measured in Austin Creek.

Lower Kidd Creek and an unnamed tributary were found to have moderate to high levels of canopy cover, cool water temperatures and low embeddedness levels.

Historic Conditions

Kidd and St. Elmo Creeks Sub-basin is adjacent to the town of Cazadero and the main road along Austin Creek. As such it is likely that the forests of this sub-basin were logged beginning in the 1860's using non-motorized methods. Later after 1886 when the railroad was available to move lumber to Duncans Mills more logging was completed.

It is also likely that trees were cut to increase the area of grazing land on the slopes of this sub-basin. According to the website for Berry's Sawmill most of the logging completed during and prior to 1941 was to convert forest to grazing land. The Berry's Sawmill in Cazadero processed the trees into lumber for the ranches to use. This site also states that the sawmill produced the large timbers for the Great Eastern Quicksilver Mine on Sweetwater Springs Road which was reopened during World War II to satisfy the need for mercury for munitions.

Aerial Photographs- 1941/42

The 1941/42 photographs of Kidd/St. Elmo Creeks Sub-basin show few roads and only a few areas of active disturbance or logging (Figure 73). However, a close inspection of the photographs shows forest areas along the eastern side of the sub-basin which have been harvested and have very few large trees (Figure 43). In 1941/42 road building was not yet as extensive in the area as part of timber harvest operations as it would become in later years. The logging shown in Figures 43 could have occurred many years prior to the date of the photograph. Ground disturbance is not visible in these logged areas and therefore these areas were not included in the recently logged delineation in Figure 73. A total of seven acres is indicated as logged and another eight acres is indicated as disturbed (residential, agricultural and other non-logging uses). Roads in the 1941/42 photographs total 5.8 miles for a ratio of 0.84 miles of roads per square mile of sub-basin.

Aerial Photographs- 1961

The 1961 aerial photographs show widespread road building and timber harvest in the Kidd/St. Elmo Creeks Sub-basins (Figure 75). About 846 acres show active logging representing nearly 20% of the land area of this sub-basin. Areas disturbed for other land uses such as residential and agriculture total 35 acres. The total road miles is 51.2, producing a very high ratio of 7.46 miles of roads per square mile of sub-basin.

The Charles Fire of 1954 burned 55 acres on the most western edge of the Kidd/St. Elmo Creeks Sub-basin (Figure 57).

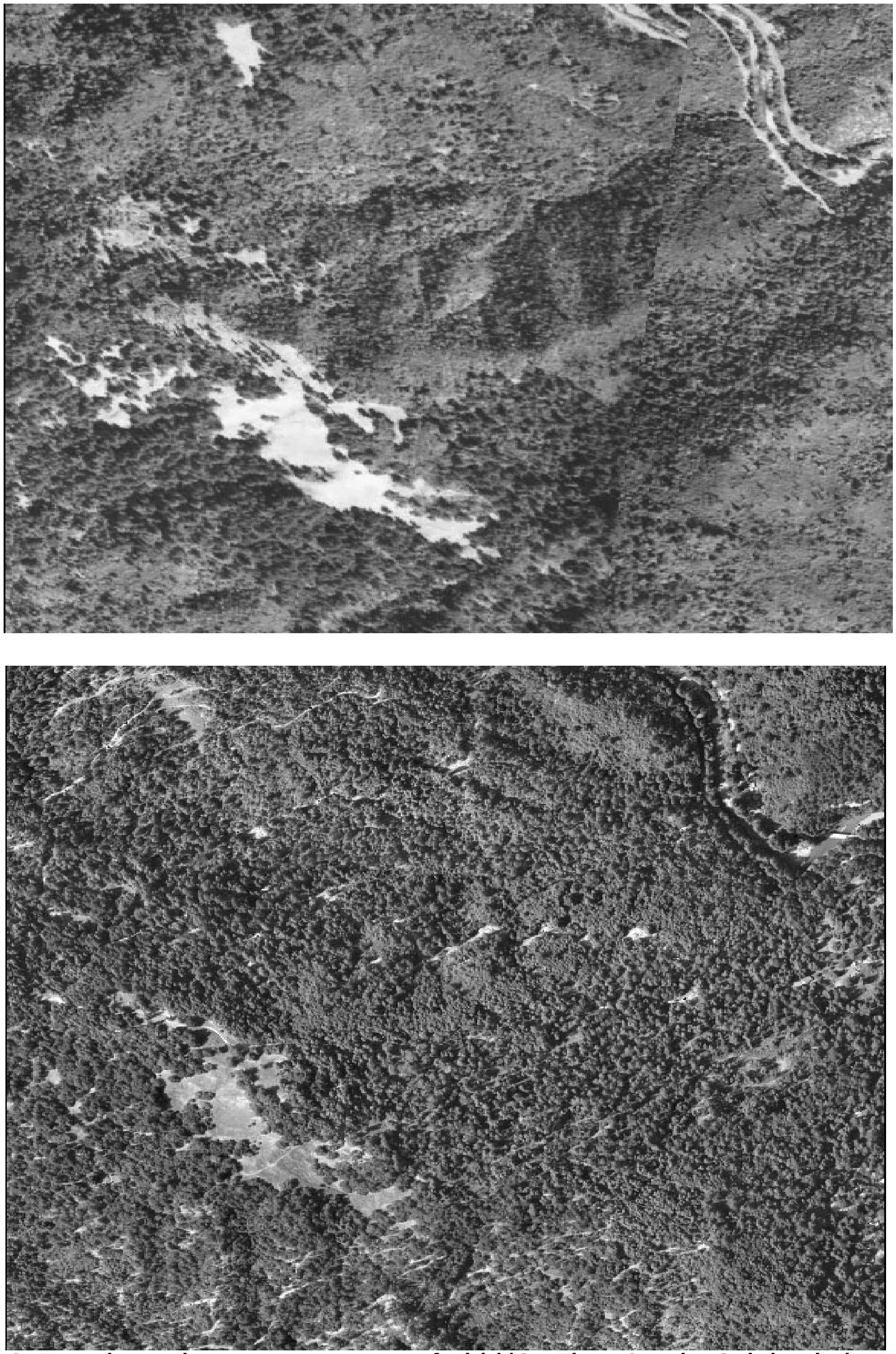


Figure 43. Top photo shows eastern area of Kidd/St. Elmo Creeks Sub-basin in 1941/42 where the conifer forest has been previously logged. Bottom photo is same location in 2000 showing more conifer forest and a number of roads.

Aerial Photographs- 1980

The 1980 aerial photographs show extensive additional logging between 1961 and 1980 of 662 acres (Figure 76). Added together, logging areas of 1980 and 1961 make up 35% of this sub-basin, a very high level of disturbance. Disturbed areas not associated with logging total 59 acres.

Those areas logged by 1961 were reviewed and a lack of regrowth of conifer was indicated totaling 413 acres, almost 50% of 1961 logged areas.

Roads in 1980 total 50.1 miles, almost the same as 1961 for a very high ratio of 7.31 miles of roads per square mile of sub-basin.

Two major fires occurred between 1961 and 1980. The P.G. &E. #6 Fire of 1965 burned 873 acres along Kidd Creek and the southern area of the sub-basin. The Creighton Ridge Fire of 1978 burned 509 acres on the western edge of the Kidd Creek drainage.

Aerial Photographs- 2000

The 2000 photographs include a delineation of roads and an evaluation of the condition of areas logged in 1961 and 1980 (Figure 77). Road miles totaled 57.9 for an extremely high ratio of 8.44 miles of roads per square mile of sub-basin. Disturbed areas total 67 acres reflecting the development of residential areas.

For the areas logged in the 1961 photographs 162 acres did not regrow conifers and 163 acres still show obvious ground disturbance. The majority of these areas are in the Kidd Creek drainage and were burned in the 1965 fire. These two areas represent 38% of the area logged in 1961. Of the 1980 logged areas a total of 100 acres had not regrown by 2000. The 1980 logged areas which are still disturbed in 2000 totaled 32 acres. These two areas represent 20% of the area logged in 1980.

Another feature delineated for 2000 are areas of coniferous forest in the 1941/42 photographs which are indicated as hardwood forest/chaparral in the CalVeg layer (Figure 78). These areas of vegetation type conversion total 313 acres and are all located on the western side of this sub-basin which burned in the 1965 or 1978 fires.

Restoration Projects

The CHRPD database shows one road repair project in the headwaters area of St. Elmo Creek. One area of Austin Creek just downstream of the St. Elmo Creek confluence has had in-stream structures installed.

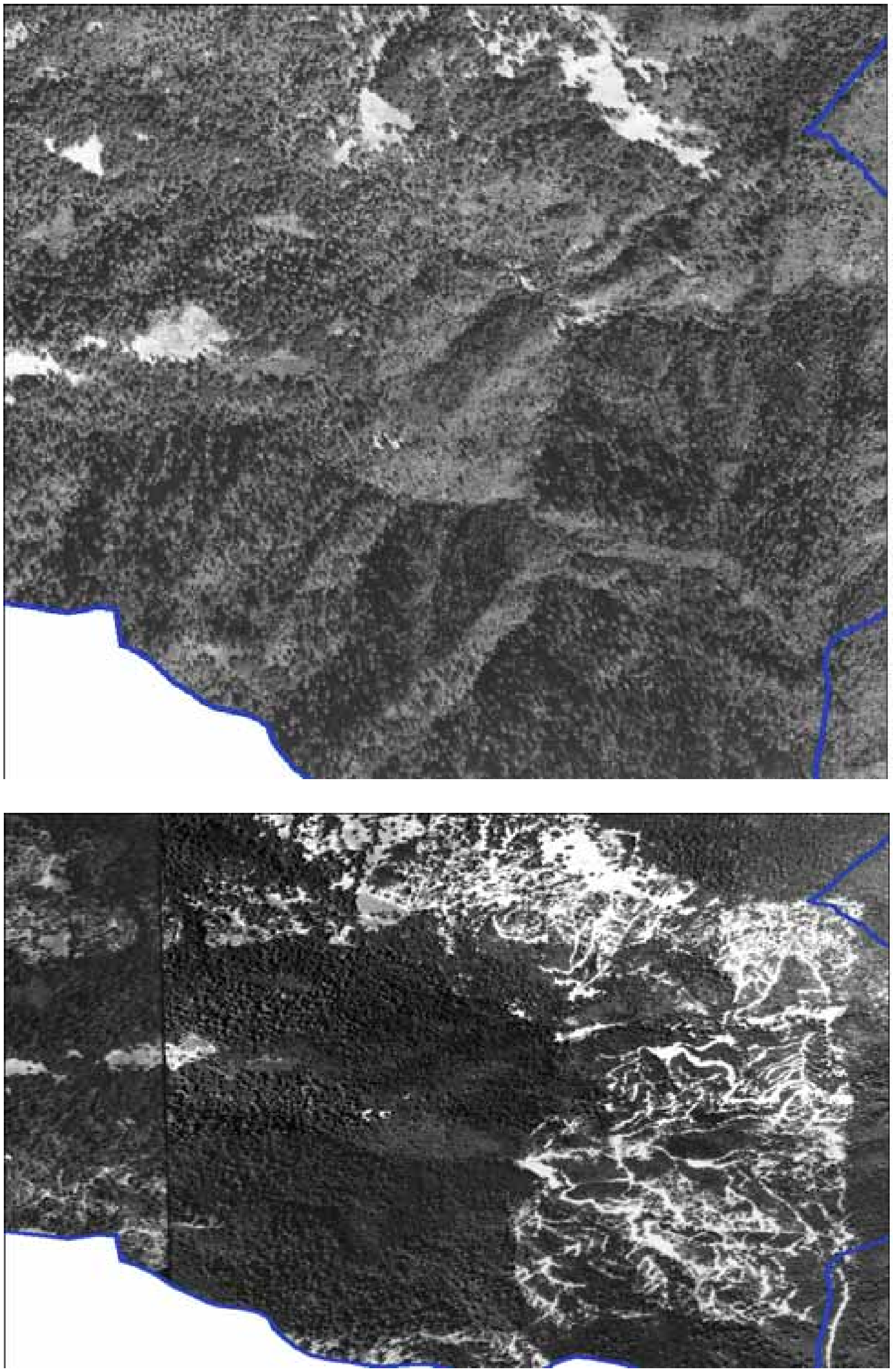
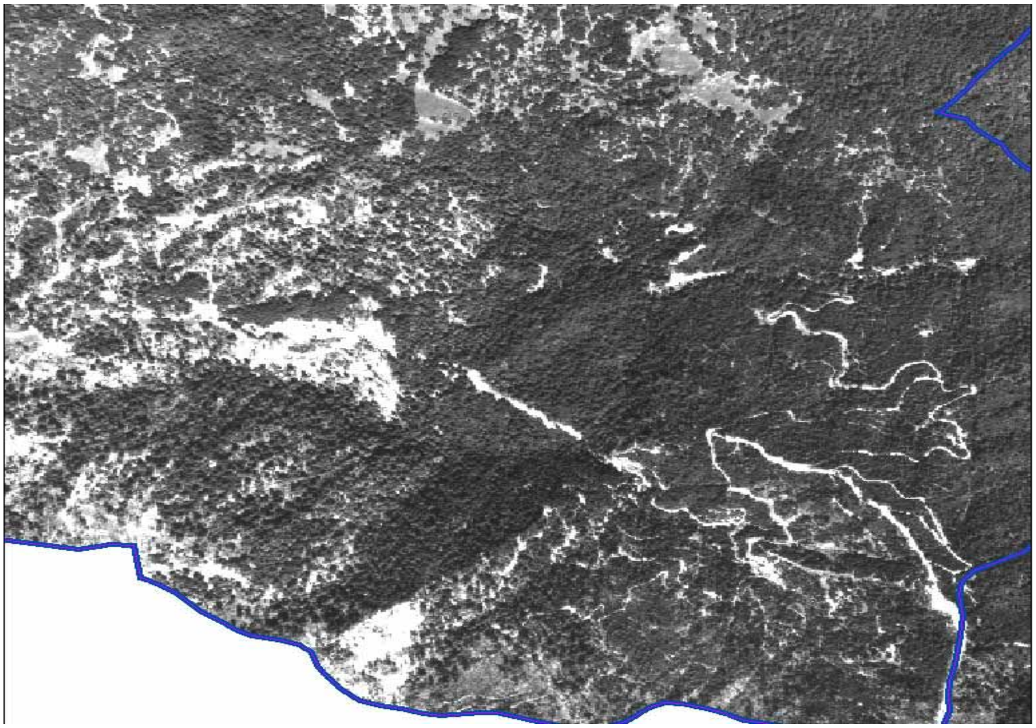


Figure 44 Top photo shows western area of Kidd/St. Elmo Creeks Sub-basin in 1941/42. Bottom photo is the same location in 1961 showing extensive clear-cut logging and road building.



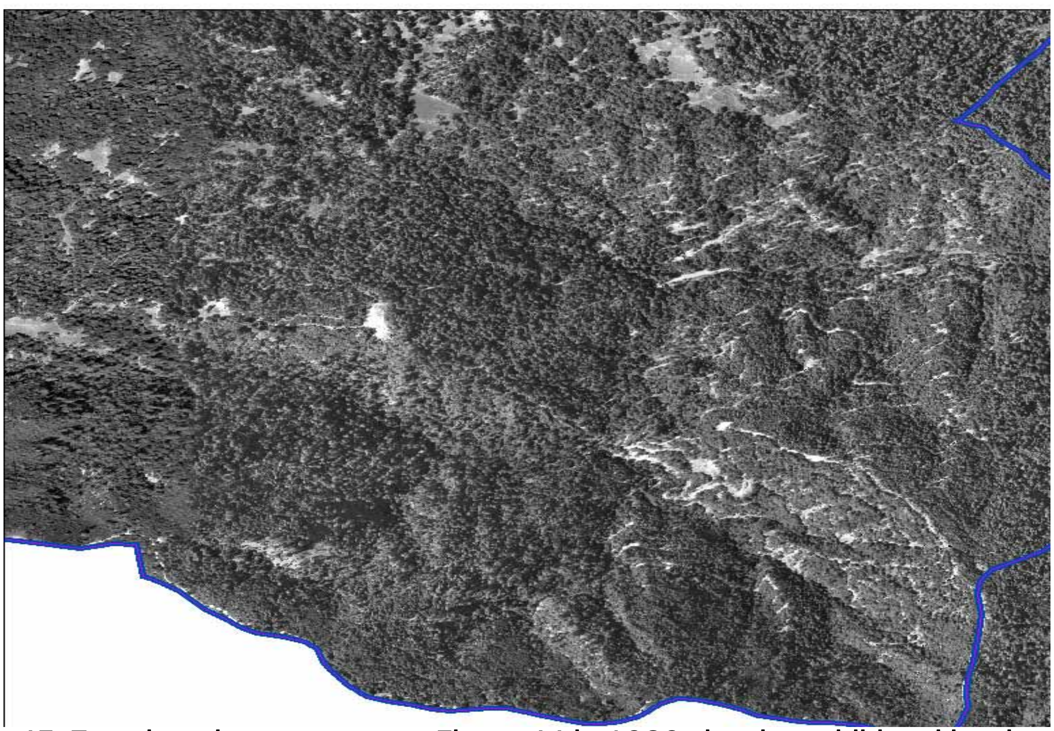


Figure 45. Top photo is same area as Figure 44 in 1980 showing additional logging along the western area of the sub-basin. Bottom photo is same area in 2000 showing continued ground disturbance from roads.

Table 36. Historical Conditions in the Kidd/St. Elmo Creeks Sub-basin

Historical conditions	Acres	Sq Miles	Miles	Miles of Road/sq. mile of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	8	<0.1		
Logged	7	<0.1		
Roads			5.8	0.84
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	35	0.1		
Logged	846	1.3		
Roads			51.1	7.46
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	59	0.1		
Logged between 1961- 1980	662	1.0		
Logged by 1961, has not regrown conifer by 1980	413	0.6		
Roads			50.1	7.31
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	62	0.1		
Logged by 1961, has not regrown conifer by 2000	162	0.3		
Logged by 1961, still disturbed in 2000	163	0.3		
Logged between 1961- 1980, has not regrown conifer by 2000	100	0.2		
Logged between 1961- 1980, still disturbed in 2000	32	0.1		
Roads			57.9	8.44
Vegetation Changes 1940 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	0	0.0		
Bare in 1940, Conifer/Mixed Conifer in 2000	0	0.0		
Bare in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Redwood/Doug Fir in 2000	0	0.0		
Conifer in 1940, Hardwood/Chaparral in 2000	313	0.5		
Major Fires since 1950				
CHARLES - 1954	55	0.1		
P.G.&E. #6 - 1965	873	1.4		
CREIGHTON RIDGE - 1978	509	0.8		

Lower Austin Creek Sub-basin

Geographic and Topographic Features

Lower Austin Creek Sub-basin is the most southern of the sub-basins in the Austin Creek watershed. Lower Austin Creek Sub-basin encompasses 3,042 acres, or 4.8 square miles. This sub-basin includes 4.2 miles of Austin Creek downstream of its confluence with East Austin Creek. Tributaries to Austin Creek in this sub-basin include Bull Barn Gulch (0.8 miles), Consolli Gulch (0.7 miles), Frazier Gulch (0.4 miles) and Kohute Gulch (1.9 miles) and unnamed blueline tributary streams (7.0 miles).

The channel of Lower Austin Creek through this sub-basin is low slope <1% and unconfined (Figure 52).

The Lower Austin Creek Sub-basin is steep and mountainous with nearly 76% of the sub-basin over 30% slope. This sub-basin has the largest area of flat ground (0.9%) with flat areas along the Austin Creek channel (Figure 53).

Geologic Features

Franciscan Formation Graywacke and Mélange are the primary rock type in Lower Austin Creek Sub-basin (Figure 54). There are small areas of Serpentinite (sp) and Greenstone (gs). Franciscan Graywacke is a highly erodible rock type prone to large landslides. Along the eastern side of the sub-basin is an area of Turonian Sandstone separated from the Franciscan Graywacke by faults. The sandstone is harder more erosion resistant than the Graywacke. Alluvial deposits along Austin Creek and its floodplain are also indicated. The Greenstone outcrop appears to be more erosion resistant than the surrounding Graywacke as Austin Creek makes a wide curve to the east around this outcrop.

Sub-basin Vegetation-Present Day

Redwood forest is the dominant vegetation with coniferous forest, mixed hardwood/conifer forest filling the creek canyon and tributary gulches (Figure 55). Hardwood forest is most prevalent on the ridgetops to the east and west. Table 37 summarizes the acreages of vegetation types in Lower Austin Creek Sub-basin.

The California Natural Diversity Data Base (CNDDB) lists one species occurrence for the Lower Austin Creek Sub-basin. California freshwater shrimp (Syncaris pacifica) has been found along the entire length of Austin Creek. California freshwater shrimp is federally and state listed as endangered.

Table 37. Vegetation Types in Lower Austin Creek Sub-basin

Vegetation types	Acres	Sq. Miles
Grassland/Rangeland	145	0.23
Barren	10	0.02
Chaparral	50	0.08
Conifer	321	0.50
Cropland	5	0.01
Hardwood	1,087	1.70
Mixed Hardwood/Conifer	208	0.32
Redwood	1,161	1.81
Urban	11	0.02
Water	43	0.07

Land Use

Land uses in Lower Austin Creek Sub-basin include rural residential housing, timber harvest, gravel mining and recreation. There are numerous small parcels along both sides of Austin Creek extending up the ridge at Magic Mountain Road.

The remaining area of Lower Austin Creek Sub-basin has large parcel sizes and is designated for Resource and Rural Development with a 160 acre per unit minimum.

Roads-Present Day

A total of 44 miles of roads were delineated for a ratio of 9.26 miles of roads per square mile of sub-basin (Figure 77). Roads on slopes over 30% total 28.3 miles for a ratio of 5.95 miles of roads on greater than 30% slopes per square mile of sub-basin. Table 38 summarizes road densities in this sub-basin. The Lower Austin Creek Sub-basin has the highest density of roads of any of the sub-basins.

Table 38. Present day roads in the Lower Austin Creek Sub-basin

Roads	Miles	Miles of Road/sq. mile of sub-basin
Total miles of roads in sub-basin	44.0	
Miles of road / sq mile of sub-basin		9.26
Total miles of roads >30% slope in sub-basin	28.3	
Miles of road >30% slope/sq mile of sub-basin		5.95
Miles of road on 1-30% slope	13.8	2.90
Miles of road on 30-50% slope	16.1	3.39
Miles of road on 50-65% slope	7.8	1.65
Miles of road on >65% slope	4.3	0.91

Fish Habitat Surveys

The California Department of Fish and Game completed a stream survey of Austin Creek in 1996 (see Table 18). The survey found Lower Austin Creek to have low to moderate canopy cover, moderately high water temperatures for salmonids and low embeddedness levels.

Historic Conditions

The Lower Austin Creek Sub-basin forms the southern entrance to the Austin Creek watershed. Roads have marked the sides of Austin Creek for many decades as people and commerce have moved between the Cazadero area, mining areas in the north area of the watershed, timber harvest areas, the Russian River and Sonoma County cities.

The current Cazadero Highway is the route of the NWP narrow gauge railroad spur which operated from 1886 to 1933 (Figure 24). Lower Austin Creek Sub-basin also had early settlements, towns and resorts which played a major role in the development of the Austin Creek watershed.

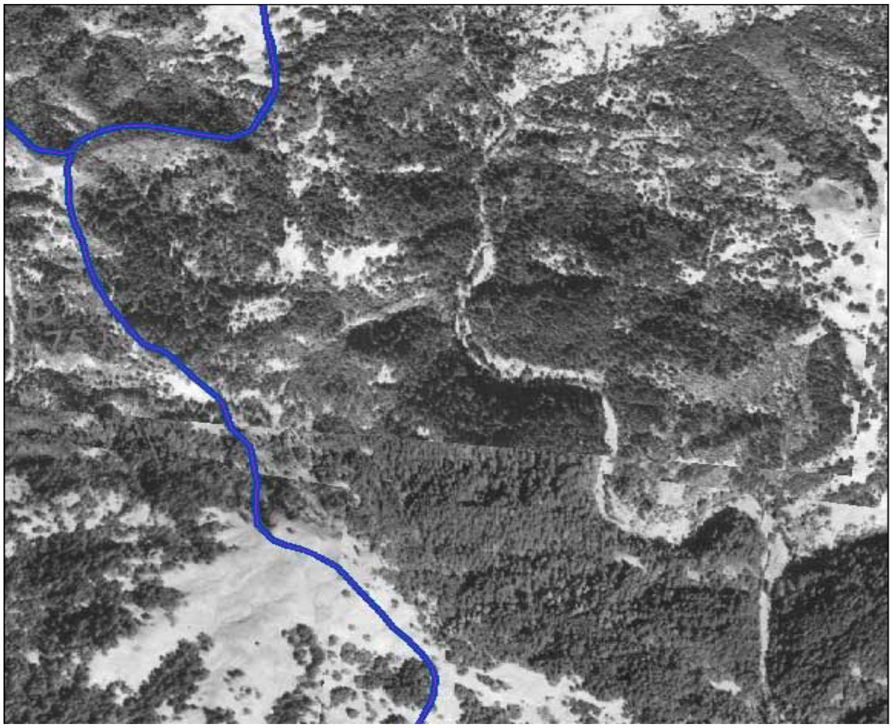
Aerial Photographs-1941/42

The 1941/42 photographs show very little active ground disturbance with only 12 acres of logging and 8.5 miles of roads for a ratio of 1.80 miles of roads per square mile of sub-basin (Figure 73). However, a close inspection of the 1941/42 photographs shows very few large trees in many areas along Austin Creek (Figure 2). There are no signs of ground disturbance in these previously logged areas and the trees could have been cut decades prior to the photo. The 2000 photograph shows both a dense, tall redwood forest and a number of houses and roads.

Aerial Photographs-1961

The 1961 aerial photographs show a significant level (129 acres) of ground disturbance from non-logging uses (agriculture, mining and residential uses) (Figure 74). Logging covers 362 acres, approximately 10% of the sub-basin. Roads cover 35.5 miles for a ratio of 7.45 miles of roads per square mile of sub-basin (Figure 46). This is a very high ratio. Another feature of the 1961 photographs is the development of houses along Austin Creek.

The Roadside #44 Fire burned 1,000 acres on the southeastern side of this sub-basin in 1961 (Figure 57).



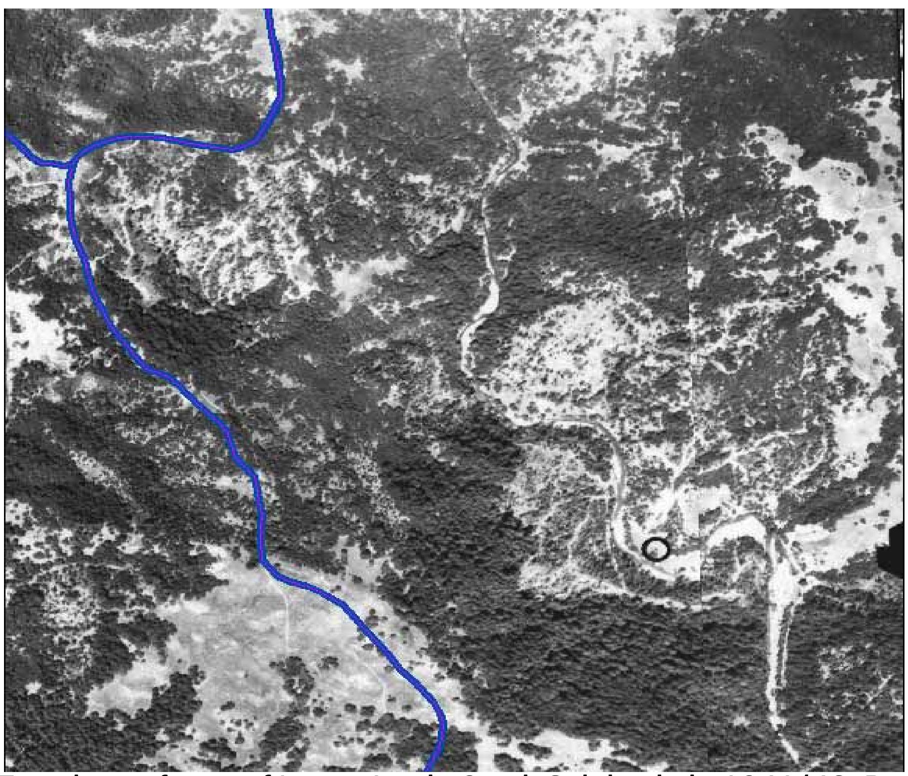


Figure 46 Top photo of area of Lower Austin Creek Sub-basin in 1941/42. Bottom photo shows same location in 1961 with extensive clear-cut logging

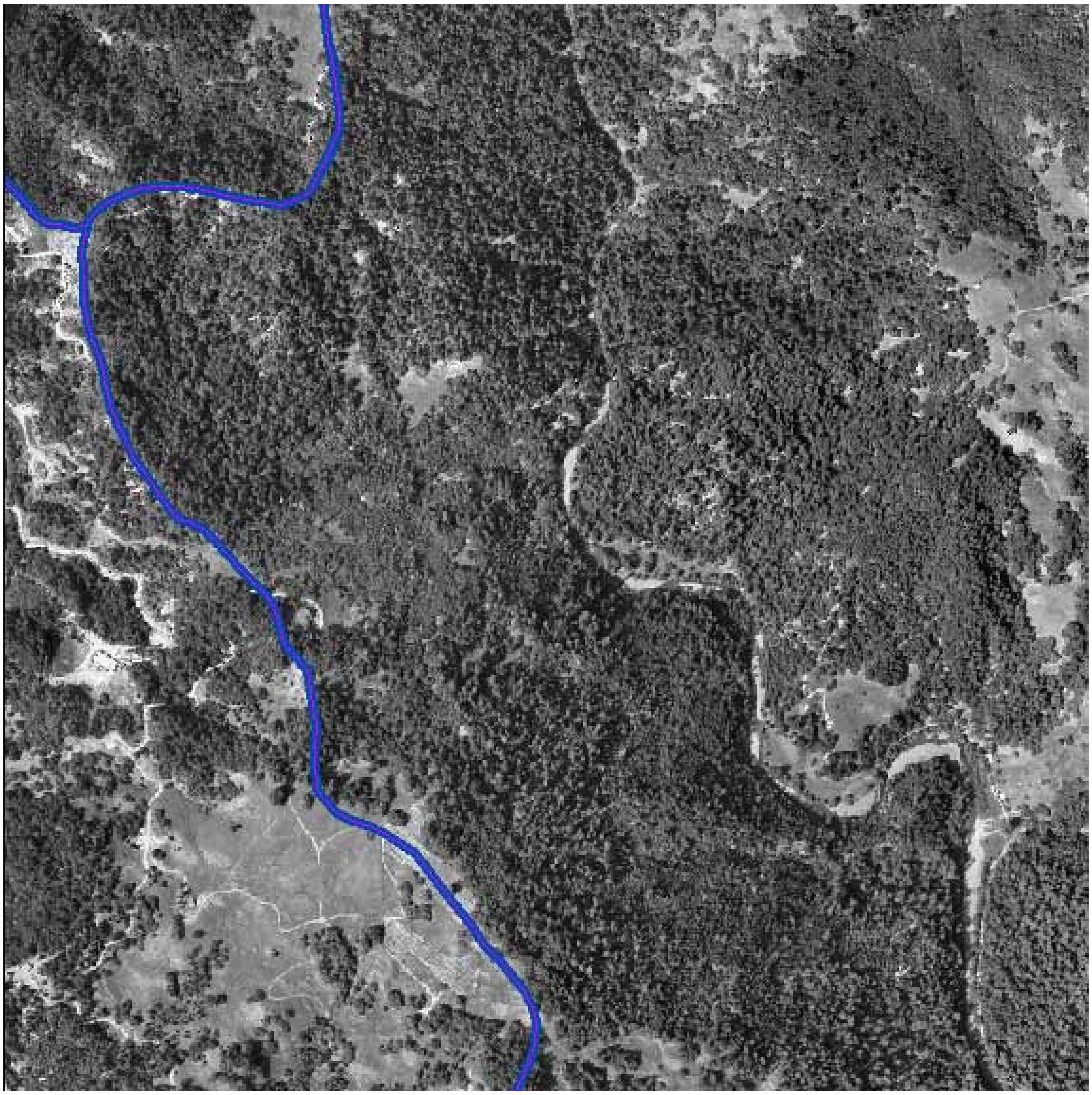


Figure 47. 2000 photograph of same location in Lower Austin Creek Sub-basin as Figure 46. Note the development of housing on the western edge in formerly logged area.

Aerial Photographs-1980

The aerial photographs show 227 acres of logging between 1961 and 1980 (Figure 76). The areas that were logged in the 1961 aerial photographs were evaluated and 249 acres representing 69% of the logged area in 1961 had not regrown conifers. There is also 146 acres of land disturbed by residential development and a quarry. There are 48.4 miles of roads for a very high ratio of 10.18 miles of roads per square mile of sub-basin.

The P. G. & E. #6 Fire burned 1,028 acres in the southwestern area of this sub-basin in 1965. The Creighton Ridge Fire of 1978 burned 48 acres on the southwestern side of this sub-basin (Figure 57).

Aerial Photographs-2000

The 2000 aerial photographs showed 68 acres of disturbed area mostly residential and mining (Figure 77). These areas were also largely delineated in the 1960's and 1980's photos but the residential areas have grown over with vegetation (Figures 46 and 47).

The areas logged in 1961 were evaluated and 37 acres had not regrown conifers. This is about 10% of the area delineated as logged in 1961. For the areas logged in 1980, 112 acres had not regrown conifers representing 50% of the total logged area.

A total of 44 miles of roads were delineated on the 2000 aerial photographs for a very high ratio of 9.26 miles of roads per square mile of sub-basin.

There are 134 acres of land in the Lower Austin Creek Sub-basin that were covered in conifer forest in the 1941/42 aerial photographs but are designated as hardwood forest/chaparral in the 2000 CalVeg layer (Figure 78). Almost all of this area was burned in the 1961 and 1965 fires.

Restoration Projects

The CHRPD data base shows one area of Austin Creek with in-stream structures.

Table 39. Historical Conditions in Lower Austin Creek Sub-basin

Historical Conditions	Acres	Sq. miles	Miles	Miles of road/ sq. mile of sub-basin
1941/1942				
Disturbed (Residential, Agriculture, Mining, etc.)	0	0		
Logged	12	<0.1		
Roads			8.5	1.80
1961				
Disturbed (Residential, Agriculture, Mining, etc.)	129	0.2		
Logged	362	0.6		
Roads			35.5	7.46
1980				
Disturbed (Residential, Agriculture, Mining, etc.)	146	0.2		
Logged between 1961- 1980	227	0.4		
Logged in 1961, has not regrown conifer by 1980	249	0.4		
Roads			48.4	10.18
2000				
Disturbed (Residential, Agriculture, Mining, etc.)	68	0.1		
Logged by 1961, has not regrown conifer by 2000	37	0.1		
Logged by 1961, still disturbed in 2000	0	0.0		
Logged between 1961- 1980, has not regrown conifer by 2000	112	0.2		
Logged between 1961- 1980, still disturbed in 2000	0	0.0		
Roads			44.0	9.26
Vegetation changes 1940 to 2000				
Bare in 1940, Closed cone Pine-Cypress in 2000	0	0.0		
Bare in 1940, Conifer/Mixed Conifer in 2000	0	0.0		
Bare in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Hardwood/Chaparral in 2000	0	0.0		
Cleared for Ag/Grazing in 1940, Redwood/Doug Fir in 2000	0	0.0		
Conifer in 1940, Hardwood/Chaparral in 2000	134	0.2		
Major Fires since 1950				
ROADSIDE #44 - 1961	1,000	1.6		
P.G.&E. #6 - 1965	1,028	1.6		
CREIGHTON RIDGE - 1978	41	0.1		

V. SUB-BASIN SENSITIVITY TO DISTURBANCE

A method was developed to assess the relative tendency of each of the six sub-basins to produce fine sediment under natural (unmanaged) conditions and under the existing managed, or disturbed, conditions. Roads where chosen to act as a surrogate for all types of land use. For simplicity, a sub-basin's tendency to produce fine sediment is referred to as the Erosion Hazard Index (EHI).

The Unmanaged EHI is an estimate of the relative tendency for a sub-basin to produce fine sediment prior to any land use activity, i.e. in its undisturbed condition. The Unmanaged EHI was calculated from geologic, slope and soil data available in GIS format. The lower the Unmanaged EHI, the less sensitive the sub-basin is to disturbance from land use activities. The Managed EHI is an estimate of a sub-basin's relative tendency to produce fine sediment under current land use or disturbance levels.

Rainfall intensity is an important variable in determining the tendency of an area to produce fine sediment. However, detailed information on rainfall intensity is not available for the Austin Creek watershed. The map of estimated average annual rainfall suggests that rainfall intensity decreases from the west to the east. The highest rainfall intensity is expected in Ward Creek (average annual rainfall = 72.8") and the lowest intensity is expected in the southern portion of Lower Austin Creek (average annual rainfall = 53.6").

GIS Model

The Unmanaged EHI was calculated using the following procedure. The calculation of EHI was done in raster format, using ESRI's ArcView Spatial Analyst extension (Redlands, CA). The three layers, soils, slope and geology, were all converted to raster format with a 30 meter cell size. The sources for each are as follows:

Geology

The erodibility of the underlying geology was judged to be the most important variable in estimating the relative production of fine sediment for which reliable spatial data was available (Selby, 1993). The underlying geology is an important factor in the generation of deep-seated landslides. An area that is prone to deep-seated landslides would be expected to produce large amounts of fine sediment relative to an area that is free of slides. The underlying geology also plays an important role in soil genesis and will therefore influence the erodibility of the soil. Proximity to a fault also influences the erodibility of rock. Fractures resulting from the movement within a fault will substantially weaken rocks making them more subject to erosion than a similar rock type that has not been mechanically weakened by movement within a fault.

Table 40. The Percentage of the Various Geologic Units In Each Sub-Basin Is Shown

Geologic Unit	Map Symbol	Relative Erodibility	Kidd & St Elmo Creeks	Lower East Austin Creek	Lower Austin Creek	Upper Austin Creek	Upper East Austin Creek	Ward Creek	Percent of Rock Type in Austin Creek Watershed
Chert block	ch	Moderate				0.01%			0.002%
Greenstone block	gs	Moderate		4.04%	0.57%	4.30%	9.08%	0.40%	4.15%
Metagraywacke	KJfm	Moderate		0.30%			0.57%	2.10%	0.56%
Meta-basalt	KJfmg	Low	24.26%	1.28%	0.51%	0.01%		37.98%	9.07%
Graywacke	KJfs	High	56.63%	56.20%	71.75%	50.02%	16.11%	34.36%	42.02%
Great Valley Conglomerate	KJgvc	Moderate	0.82%					12.48%	2.18%
High Grade Metamorphic block	m	Low	0.07%	0.08%					0.02%
Alluvium	Qal	High	1.64%	0.54%	9.38%	0.79%	0.71%		1.25%
Landslide deposits	Qls	High	15.45%	4.79%		8.49%	1.41%	7.56%	5.88%
Alluvial and Marine Terrace deposits	Qt	High	0.04%		0.10%				0.01%
Silica-carbonate rock	sc	Low		0.72%		0.02%	0.22%		0.21%
Serpentinite	sp	High	1.08%	8.89%	0.93%	21.64%	30.65%	0.45%	14.41%
Sandstone - Turonian	TKfs	Moderate		23.14%	16.57%	12.63%	41.24%	3.28%	19.55%
Sandstone - Maastrichtian	TKfss	Moderate		0.01%		2.09%	0.01%	1.30%	0.66%
Ohlson Ranch Formation	Tor	High						0.10%	0.02%
Water	water	n/a			0.19%				0.01%
Area - acres			4,386	8,996	3,042	9,326	11,532	7,555	44,837
Area - sq-miles			6.85	14.06	4.75	14.57	18.02	11.80	70.06

Table 41. The percentage of each relative geologic-erodibility class in each sub-basin, without consideration of the effect of faulting.

Relative Erodibility	Kidd & St Elmo Creeks	Lower East Austin Creek	Lower Austin Creek	Upper Austin Creek	Upper East Austin Creek	Ward Creek	Percent of Rock Type in Austin Creek Watershed
Low	24.3%	2.1%	0.5%	0.0%	0.2%	38.0%	9.3%
Moderate	0.8%	27.5%	17.1%	19.0%	50.9%	19.6%	27.1%
High	74.9%	70.4%	82.2%	80.9%	48.9%	42.5%	63.6%
n/a	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%

The geology GIS data was obtained from USGS at http://pubs.usgs.gov/mf/2002/2402/ . This consisted of a polygon layer showing the geology unit areas, and a line layer showing the faults (Figure 54).

Table 40 shows the relative erodibility (low, moderate or high) of all of the geologic mapping units within the Austin Creek watershed. The relative erodibility of all mapping units was increased one level if the unit was within 150 feet of a fault. This produced four levels of relative geologic erodibility (low, moderate, high and very high).

Slope

The slope of the ground surface is an important component in fine sediment production. Steep slopes tend to produce more fine sediment than gentle slopes and landslides tend to occur on slopes greater than 30%. Table 42 shows that about 61% of the Austin Creek watershed is in the 30%-65% slope class and 15% of the watershed has slopes greater than 65%. Therefore, about 76% of the watershed has slopes greater than 30%. The distribution of slope classes in each sub-basin is roughly the same.

The *slope rank* for each sub-basin in Table 42 was determined by calculating the area-weighted sub-basin slope class and ranking the results from the gentlest slope = 1 to the steepest slopes = 6.

Slope was calculated using the Spatial Analyst slope tool on the USGS 10 meter DEM. The result was re-sampled to a 30 meter cell size, and collapsed into the four slope classes: <30%; 30% to 50%; 50% to 65%; and >65%. Table 42 shows the percentage of each sub-basin in the four slope classes. Table 42 also shows the relative rank of the overall slope in each sub-basin. Kidd and St Elmo was ranked as the sub-basin with the gentlest slopes (rank = 1) and Upper Austin had the overall steepest slopes (rank = 6).

Table 42. Percentage of each sub-basin in various slope classes

Sub-basin	<30%	30%-50%	50%-65%	> 65%	> 30%	Slope Rank
Kidd & St Elmo Creeks	36.5%	34.9%	16.2%	12.4%	63.5%	1
Lower East Austin Creek	24.5%	43.8%	20.4%	11.3%	75.5%	2
Lower Austin Creek	26.4%	39.3%	21.8%	12.6%	73.6%	3
Upper Austin Creek	20.2%	38.8%	23.2%	17.8%	79.8%	6
Upper East Austin Creek	20.3%	38.9%	24.4%	16.4%	79.7%	5
Ward Creek	28.0%	35.8%	21.3%	15.0%	72.0%	4
Austin Creek Watershed	24.4%	39.0%	21.8%	14.8%	75.6%	

Soils

Soil erodibility was estimated from the tabular data in the Sonoma County Soil Survey obtained from the NRCS soils website (http://soildatamart.nrcs.usda.gov/). The soil erodibility was calculated as:

Soil Erodibility = 10*K-factor + 10*(1/T-Factor)

The K-factor is the soil erodibility factor which quantifies the susceptibility of soil particles to detachment and movement by water. This factor is adjusted for the effect of rock fragments. The T-Factor is the soil loss tolerance factor, which is the maximum amount of erosion at which the quality of a soil as a medium for plant growth can be maintained.

Table 43 gives the K-factor and T-factor for each of the 257 soil mapping units in Sonoma County. This data was obtained from the Revised Universal Soil Loss Equation (RUSLE2) table in the Sonoma County Soil Survey.

Table 43. The K and T factors used to calculated soil erodibility from the Sonoma County Soil Survey

Map Symbol	Map unit name	Kw	T-factor	Soil Erodibility	Soil score	Acres
AdA	ALLUVIAL LAND, SANDY	0.17	5	3.7	1	325
AtF	ATWELL CLAY LOAM, 30 TO 50 PERCENT SLOPES	0.32	5	5.2	1	291
AtG	ATWELL CLAY LOAM, 50 TO 75 PERCENT SLOPES	0.32	5	5.2	1	22
BoE	BOOMER LOAM, 15 TO 30 PERCENT SLOPES	0.37	4	6.2	2	120
BoF	BOOMER LOAM, 30 TO 50 PERCENT SLOPES	0.37	4	6.2	2	225
BoG	BOOMER LOAM, 50 TO 75 PERCENT SLOPES	0.37	4	6.2	2	1,190
CbF	CIBO CLAY, 15 TO 50 PERCENT SLOPES	0.24	4	4.9	1	90
CpG	COMPTCHE GRAVELLY LOAM, 30 TO 75 PERCENT SLOPES	0.37	3	7.03	2	16
CrA	CORTINA VERY GRAVELLY SANDY LOAM, 0 TO 2 PERCENT SLOPES	0.24	5	4.4	1	57
GdE	GOLDRIDGE FINE SANDY LOAM, 15 TO 30 PERCENT SLOPES	0.28	5	4.8	1	10
HeF	HELY SILT LOAM, 30 TO 50 PERCENT SLOPES	0.32	3	6.53	2	4
HeG	HELY SILT LOAM, 50 TO 75 PERCENT SLOPES	0.32	3	6.53	2	17
HgG2	HENNEKE GRAVELLY LOAM, 30 TO 75 PERCENT SLOPES, ERODED	0.37	1	13.7	3	136
HhF	HUGO LOAM, 30 TO 50 PERCENT SLOPES	0.37	4	6.2	2	111
HkF	HUGO VERY GRAVELLY LOAM, 30 TO 50 PERCENT SLOPES	0.37	4	6.2	2	289
HkG	HUGO VERY GRAVELLY LOAM, 50 TO 75 PERCENT SLOPES	0.37	4	6.2	2	16,521
HkG2	HUGO VERY GRAVELLY LOAM, 50 TO 75 PERCENT SLOPES, ERODED	0.37	3	7.03	2	256
HlF	HUGO-ATWELL COMPLEX, 30 TO 50 PERCENT SLOPES	0.37	4	6.2	2	832
HlG	HUGO-ATWELL COMPLEX, 50 TO 75 PERCENT SLOPES	0.37	4	6.2	2	937
HmF	HUGO-BOOMER COMPLEX, 30 TO 50 PERCENT SLOPES	0.37	4	6.2	2	598
HmG	HUGO-BOOMER COMPLEX, 50 TO 75 PERCENT SLOPES	0.37	4	6.2	2	657
HnE	HUGO-JOSEPHINE COMPLEX, 9 TO 30 PERCENT SLOPES	0.37	4	6.2	2	32

Table 43. The K and T factors used to calculated soil erodibility from the Sonoma County Soil Survey (cont.)

Map Symbol	Map unit name	Kw	T-factor	Soil Erodibility	Soil score	Acres
HnG	HUGO-JOSEPHINE COMPLEX, 50 TO 75 PERCENT SLOPES	0.37	4	6.2	2	3,679
HnG2	HUGO-JOSEPHINE COMPLEX, 50 TO 75 PERCENT SLOPES, ERODED	0.37	3	7.03	2	178
HoG	HUGO-LAUGHLIN COMPLEX, 30 TO 75 PERCENT SLOPES	0.37	4	6.2	2	436
HrG	HUGO-LOS GATOS COMPLEX, 50 TO 75 PERCENT SLOPES	0.37	2	8.7	3	483
HsF	HUGO-HELY COMPLEX, 30 TO 50 PERCENT SLOPES	0.32	3	6.53	2	294
HsG	HUGO-HELY COMPLEX, 50 TO 75 PERCENT SLOPES	0.32	3	6.53	2	312
HyG	HUSE STONY CLAY LOAM, 30 TO 75 PERCENT SLOPES	0.43	1	14.3	3	4,575
JoE	JOSEPHINE LOAM, 9 TO 30 PERCENT SLOPES	0.37	4	6.2	2	120
JoF	JOSEPHINE LOAM, 30 TO 50 PERCENT SLOPES	0.37	4	6.2	2	447
JoF2	JOSEPHINE LOAM, 30 TO 50 PERCENT SLOPES, ERODED	0.37	3	7.03	2	39
JoG	JOSEPHINE LOAM,50 TO 75 PERCENT SLOPES	0.37	3	7.03	2	52
KnF	KNEELAND LOAM, 30 TO 50 PERCENT SLOPES	0.32	2	8.2	3	16
LgE	LAUGHLIN LOAM, 2 TO 30 PERCENT SLOPES	0.37	2	8.7	3	53
LgF	LAUGHLIN LOAM, 30 TO 50 PERCENT SLOPES	0.37	2	8.7	3	356
LgG	LAUGHLIN LOAM, 50 TO 75 PERCENT SLOPES	0.37	2	8.7	3	1,016
LgG2	LAUGHLIN LOAM, 50 TO 75 PERCENT SLOPES, ERODED	0.37	1	13.7	3	22
LhG	LAUGHLIN-YORKVILLE COMPLEX, 30 TO 75 PERCENT SLOPES	0.37	2	8.7	3	377
LkG	LOS GATOS LOAM, 30 TO 75 PERCENT SLOPES	0.37	2	8.7	3	1,514
LmG	LOS GATOS GRAVELLY LOAM, 30 TO 75 PERCENT SLOPES	0.37	2	8.7	3	106
McF	MAYMEN GRAVELLY SANDY LOAM, 30 TO 50 PERCENT SLOPES	0.28	1	12.8	3	1,541
MoG	MONTARA COBBLY CLAY LOAM, 30 TO 75 PERCENT SLOPES	0.37	1	13.7	3	23
RaE	RAYNOR CLAY, 15 TO 30 PERCENT SLOPES	0.24	2	7.4	3	9
RnA	RIVERWASH	0.05	0	0	1	20
RoG	ROCK LAND	0	0	0	1	1,711
ShE	SOBRANTE LOAM, 15 TO 30 PERCENT SLOPES	0.37	2	8.7	3	20
ShF	SOBRANTE LOAM, 30 TO 50 PERCENT SLOPES	0.37	2	8.7	3	334

Table 43. The K and T factors used to calculated soil erodibility from the Sonoma County Soil Survey (cont.)

Map Symbol	Map unit name	Kw	T-factor	Soil Erodibility	Soil score	Acres
ShG	SOBRANTE LOAM, 50 TO 75 PERCENT SLOPES	0.37	2	8.7	3	967
SoG	STONYFORD GRAVELLY LOAM, 50 TO 75 PERCENT SLOPES, ERODED	0.37	1	13.7	3	599
StF	SUTHER LOAM, 30 TO 50 PERCENT SLOPES	0.37	3	7.03	2	10
SuF	SUTHER-LAUGHLIN LOAMS, 15 TO 50 PERCENT SLOPES	0.37	3	7.03	2	393
SuG	SUTHER-LAUGHLIN LOAMS, 50 TO 75 PERCENT SLOPES	0.37	3	7.03	2	111
W	WATER	0	0	0	1	47
YuE	YORKVILLE CLAY LOAM, 5 TO 30 PERCENT SLOPES	0.32	4	5.7	2	46
YuF	YORKVILLE CLAY LOAM, 30 TO 50 PERCENT SLOPES	0.32	4	5.7	2	400
YvF	YORKVILLE-LAUGHLIN COMPLEX, 30 TO 50 PERCENT SLOPES	0.32	4	5.7	2	1,739
YwF	YORKVILLE-SUTHER COMPLEX, 0 TO 50 PERCENT SLOPES	0.32	4	5.7	2	42

The soil erodibility equation produced 22 distinct values for the Sonoma County soil mapping units. The values of soil erodibility were divided into four classes (low, moderately low, moderately high and high) by placing the approximately 25% of the Sonoma County soils into each category.

Examination of the distribution of Austin Creek soils in Table 43 showed that, by area, over 50% of the soils received a single value (6.2) which is in the *Moderately High* category. Figure 48 shows the map of soil erodibility classes.

Unmanaged Erosion Hazard Index

Table 44 shows the values to score the three variables used in the Erosion Hazard Index model.

Table 44. Values used to score the three input variables used in calculating the EHI.

		Score Value			
Variable	**Based on**	**1**	**2**	**3**	**4**
Soil	Soil Erodibility	0-5.3	5.4-6.6	6.6-14.3	N/A
Slope	Slope from DEM	<30 %	30-50%	50-65%	>65%
Geology	Relative Erodibility of Geologic Unit	Low	Moderate	High	N/A
	Relative Erodibility of Geologic Unit and within 150' of fault	N/A	Low	Moderate	High

The scores for the Geology, Slope and Soil ratings were combined using the following formula:

Unmanaged EHI = 4 x Geology score + 2 x Slope score + Soil score

The weightings used in the formula are based on professional judgment. Geology was judged to be the most important variable since the characteristics of the underlying rocks are an important factor in determining the type of soil that covers them. The strength of the underlying rocks determines the nature of any mass-wasting that may occur. The strength of the underlying rocks determines the stable slope angle of a hillslope. So both slope and soil properties depend on geology. Slope is important because it provides the energy to move material down slope to the stream channel. Soil mapping units rely on slope as part of their designation.

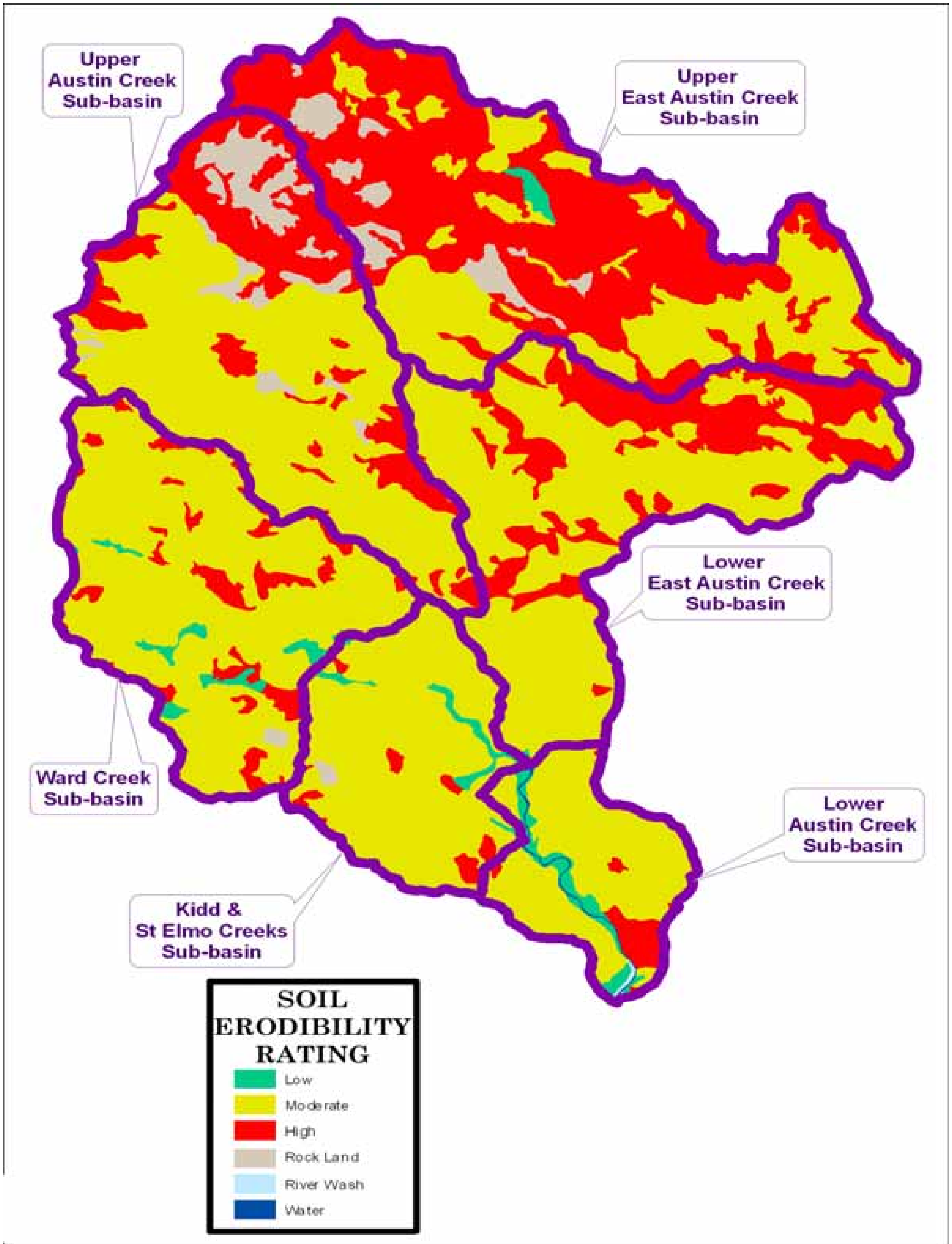


Figure 48. Soil Erodibility Ratings for the Austin Creek Watershed

It would be preferable to base the weightings on the results of field studies in the watershed. However, budget constraints prevent field testing.

The resulting EHI layer was a 30 meter raster layer with values ranging from 6 to 27. These were then collapsed to 4 score values, and the raster was converted to a polygon layer. This layer was then used and the road density within each polygon was determined.

Managed Erosion Hazard Index

The Road Density (miles of roads sq mile of sub-basin) within each unmanaged EHI polygon was used to calculate the Managed EHI by collapsing into the classifications shown in Table 45. The Unmanaged EHI was then multiplied by a weighting factor associated with the respective road density from Table 45 to calculate the Managed EHI. This procedure results in 79 possible values ranging from a value of 14 to 270. These values were then grouped into four classes of relative disturbance with each class having about 25% of the total watershed area.

Table 45. Road density categories and the associated weighting factor used to calculate the Managed EHI.

	Road Density mile/sq-mile	Weighting Factor
Undisturbed	<2	1
Low	2 - 3	2
Moderate	3 - 6	5
High	>6	10

Sub-basin Ranking

Table 46 gives the percentage of area for each sub-basin in each Unmanaged EHI class. Table 46 also gives the overall Sub-Basin Sensitivity Rank for each sub-basin. The Sub-basin Sensitivity Rank is the relative ranking of the area-weighted average Unmanaged EHI Class for each sub-basin. Ward Creek is the sub-basin that has the lowest sensitivity to disturbance. Upper Austin Creek is the sub-basin that is most sensitive to disturbance.

Table 47 gives the percentage of each sub-basin in each Managed EHI Class and the resulting Sub-basin Disturbance Rank. The Sub-basin Disturbance Rank is the relative ranking of the area-weighted average Managed EHI Class for each sub-basin.

Table 46. The percentage area in each Unmanaged EHI Class and the resulting Sub-basin Sensitivity Rank

	Unmanaged EHI Class				
Sub-basin	1	2	3	4	Sub-basin Sensitivity Rank
Kidd & St Elmo Creeks	23.8%	23.0%	22.8%	30.4%	3
Lower East Austin Creek	11.6%	27.9%	33.2%	27.3%	4
Lower Austin Creek	12.8%	24.6%	31.5%	31.0%	5
Upper Austin Creek	8.9%	21.4%	33.6%	36.0%	6
Upper East Austin Creek	18.6%	33.3%	27.2%	20.9%	2
Ward Creek	44.2%	17.9%	19.7%	18.2%	1

Table 47. The percentage area in each Managed EHI Class and the resulting Sub-basin Disturbance Rank

	Managed EHI Class				
Sub-basin	1	2	3	4	Sub-basin Disturbance Rank
Kidd & St Elmo Creeks	20.0%	18.6%	27.4%	34.0%	5
Lower East Austin Creek	26.0%	31.7%	25.2%	17.1%	2
Lower Austin Creek	10.3%	19.1%	22.4%	48.1%	6
Upper Austin Creek	17.9%	32.0%	28.2%	21.9%	4
Upper East Austin Creek	37.8%	25.1%	22.4%	14.7%	1
Ward Creek	35.1%	15.9%	25.4%	23.6%	3

The Sub-basin Disturbance Rank is a relative measure of the amount of disturbance in a sub-basin, relative to sediment production. Upper East Austin is the least disturbed sub-basin and the Lower Austin Creek is the most disturbed sub-basin.

The Sub-Basin Sensitivity Rankings indicate the relative sensitivity of the Austin Creek sub-basins to disturbance by land management activities. The Sub-Basin Disturbance ranking indicates the relative level of disturbance in a sub-basin due to roads. The Sensitivity Ranking and Disturbance Ranking are measures of the expected relative fine sediment production in each sub-basin under natural and managed conditions, respectively. To determine the full impact of sediment production from roads (land management) an estimate of the sediment delivery ratio is needed, that is, how much of the fine sediment produced reaches the stream system?

Stream Crossings

The number of road crossings per-mile-of-stream and the number of miles of road within 100 feet of a stream per-mile-of-stream were used as indexes for the potential for sediment delivery ratio from roads. The higher the values these two parameters have the higher the sediment delivery ratio from the road network must be. Table 48 gives the value of these two measures of the proximity of roads to streams in each sub-basin.

Table 48. The number of stream crossings per mile of stream and the miles of road within 100 feet of a stream per mile of stream were calculated using the length of the blueline streams from 1:24,000 topographic maps. The calculated values using blueline streams will be less than if all CDF Class III streams were considered.

Sub-basin	Total length of Streams* in Sub-basin in miles	Total Number of Stream Crossings	Stream Crossings per Mile of Stream	Miles of Road within 100 ft of Stream	Miles of Road within 100' of Stream per Mile of Stream	Stream Xing Ranking	Miles of Road close to streams Ranking
Kidd & St Elmo Creeks	19.29	44	2.3	5.86	0.304	6	6
Lower East Austin Creek	29.75	22	0.7	4.41	0.148	1	1
Lower Austin Creek	14.93	26	1.7	2.80	0.188	4	3
Upper Austin Creek	37.16	40	1.1	6.86	0.185	3	2
Upper East Austin Creek	43.78	37	0.8	8.44	0.193	2	4
Ward Creek	30.43	55	1.8	7.77	0.255	5	5
**Blue Line Streams on 1:24,000 topographic maps*							

Table 49 compares the Sub-Basin Sensitivity, Disturbance Ranks and the rankings for the two measures of the proximity of roads to streams. The Final Sub-Basin Disturbance Rank includes the effect of the proximity of roads to the stream system. Lower East Austin Creek Sub-basin has the lowest Final Disturbance Rank and so it is the least disturbed sub-basin. The Kidd & St Elmo Creeks Sub-basin has the highest Final Disturbance Rank and so is the sub-basin that is most disturbed.

Restoration Rankings

Adding the Sub-Basin Sensitivity Rankings and the Final Disturbance Ranks creates a ranking of the sub-basins where restoration efforts should be concentrated to produce the most long-term benefits for stream habitat. Table 50 shows the result of adding the Sensitivity and Disturbance ranks together

The sub-basin Restoration Ranking is based on the sum of the sub-basin Sensitivity Rank and the sub-basin Disturbance Rank. Upper East Austin has the most favorable Restoration Ranking since it has both a low Sensitivity and a low Disturbance Ranking. Lower East Austin and Ward Creek have the next best Restoration Ranking. The other three sub-basins have relatively unfavorable Restoration Rankings.

The sum of the Sensitivity Rank and Disturbance Rank was 9 for the Lower Austin, the Upper Austin Creek Sub-basin and the Kidd & St Elmo Creeks Sub-basin. They had different combinations of sub-basin Sensitivity Rank and Disturbance Rank that summed to the value of 9. Therefore, they all received the same Restoration Ranking of 4. Similarly, the sum of the Sensitivity Rank and Disturbance Rank for both Lower East Austin Creek Sub-basin and Ward Creek Sub-basin was 5 which, resulted in them receiving the same Restoration Ranking of 2.

Table 49. Comparison of the Sub-Basin Sensitivity, Disturbance Ranks and the proximity of roads to streams rankings.

		Road Based Rankings				
Sub-basin	Sub-Basin Sensitivity Rank	Sub-Basin Disturbance Rank	Stream Xing Ranking	Miles of Road close to streams Ranking	Sum of Road based Rankings	FINAL Sub-Basin Disturbance Rank
Kidd & St Elmo Creeks	3	5	6	6	17	6
Lower East Austin Creek	4	2	1	1	4	1
Lower Austin Creek	5	6	4	3	13	4
Upper Austin Creek	6	4	3	2	9	3
Upper East Austin Creek	2	1	2	4	7	2
Ward Creek	1	3	5	5	13	4

Table 50. The sub-basin Restoration Ranking is based on the sum of the sub-basin Sensitivity Rank and the sub-basin Disturbance Rank.

Sub-basin	Sub-Basin Sensitivity Rank	Final Disturbance Rank	Sum of Sensitivity Rank and Final Disturbance Rank	Restoration Ranking
Kidd & St Elmo Creeks	3	6	9	4
Lower East Austin Creek	4	1	5	2
Lower Austin Creek	5	4	9	4
Upper Austin Creek	6	3	9	4
Upper East Austin Creek	2	2	4	1
Ward Creek	1	4	5	2

Large Woody Debris

Large Woody Debris (LWD) is recognized to play an important role in the development of suitable salmonid habitat. LWD provides cover for rearing fish and can help stream hydraulics to form pools. Ross et. al (2003) used the channel classification system of Montgomery and Buffington (1993) and the age and type of riparian vegetation to identify potential salmonid habitat.

Montgomery and Buffington (1993) classified stream channels primarily by channel slope (gradient). On a broad level, they identified three basic types of channel reaches, see Table 51. Source reaches are in the headwaters and have slopes greater than 20%. Bedload enters source reaches from the surrounding hillslopes. Transport reaches tend to have a sediment transport capacity that is higher than the load supplied by the watershed. Therefore, relatively little deposition occurs in transport reaches. Transport reaches have slopes between 4% and 20%. Response reaches may not be able to move the sediment load supplied the watershed upstream so some of the load may be deposited. Changes in the amount of sediment supplied by the watershed are most readily observed in response reaches. Response reaches have slopes of less than 4%.

Table 51. Classification of channel reach-type by slope.

Reach Type	Slope
source reaches	slope > 20%
transport reaches	4% ≤ slope < 20%
response reaches	Slope < 4%

Montgomery and Buffington (1997) found that the channel form of response reaches varies with the LWD loading (Figure 50 and Table 52). For channel with slopes of 0.1% to 1% typically exhibit a pool-riffle channel pattern regardless of the LWD loading. Streams with slopes in the range from 1% to 2% with a low level of LWD have a pool-riffle or plane-bed channel pattern. Streams with slopes in the range from 2% to 4% with a low level of LWD have a pool-riffle or plane-bed channel pattern. A high level of LWD load forces the plane-bed channels to a forced pool-riffle pattern.

Figure 49. Large woody debris in stream channel creates complex habitat for salmonids. In some creeks large wood in the channel forms pools.

Table 52. The relationship between channel form and LWD loading for response reaches. Channel form depends on the LWD loading for response reaches with slopes between 1% and 4%. When slope is less than 1% the channel form is independent of LWD loading.

Response Reach Slope Range	Low LWD Loading	High LWD Loading
0.1% to 1%	Pool-Riffle	Pool-Riffle
1% to 2%	Pool-Riffle or Plane-Bed	Forced Pool-Riffle
2% to 4%	Plane-Bed	Forced Pool-Riffle

Consequently, a high level of LWD loading will force the channel pattern to the pool-riffle form. Ross et. al (2003) found that they could roughly correlate the LWD loading to the seral stage of riparian forest. In general, older riparian forests would be expected to produce a high LWD loading compared to young riparian forests. Reaches with no riparian forest would not be expected to produce LWD. Therefore, it is expected that channels in the 1% to 4% slope class bordered by, or downstream of, older near-stream forests have the greatest potential for high quality salmonid habitat.

GIS methods similar to those employed by Ross et all (2003) were employed to estimate the expected LWD loading of the response reaches in Austin Creek. Combining the estimate of LWD loading and channel slope would give an estimate of the potential for high quality salmonid habitat. The condition of the near-stream forest was not quantified in this study. However aerial photos revealed extensive clear-cutting in the 1960's, suggesting a low level of LWD loading in streams in the Austin Creek Watershed (see Figures 65 and 70).

Since a low level of LWD loading is suspected in Austin Creek, channels in the 2% to 4% slope class are expected to exhibit a plane bed channel form. Plane bed channels typically only develop pools in response to the presence of roughness elements such as LWD or boulders. Plane bed channels do not provide high quality salmonid habitat since they tend to lack pools and cover.

Reaches in the 1% to 2% slope class can exhibit either a pool-riffle channel form or a plane bed channel form when the LWD load is low. The expected low LWD loading in the Austin Creek Watershed indicates that the channel form of reaches in the 1% to 2% slope class cannot be estimated from a map of channel slope.

Reaches with slopes less than 1% exhibit a pool-riffle channel form regardless of the LWD loading. Given the expected low LWD loading in the Austin Creek Watershed, the highest potential for pool-riffle habitat appears to be in channels in the 1% to 2% slope class (Figure 50).

Table 53 gives the number of miles of main stream channel in each slope class by sub-basin. Lower East Austin Creek Sub-basin has 6.6 miles of stream in the less than 1% slope class and only 1.2 miles in the 2% to 4% slope class. Table 50 shows that Lower East Austin Creek Sub-basin has the second best Restoration Ranking and the lowest Sub-Basin Disturbance Ranking. Therefore, restoration efforts in Lower East Austin Creek should concentrate on reducing fine sediment inputs to the channel. Increasing the LWD loading in Lower East Austin Creek will not dramatically improve the number of pools since most of the main channel is in the less than 1% slope class. However, conditions in the main channel of Lower East Austin should be investigated to determine if habitat could be improved by increasing the amount of riparian cover.

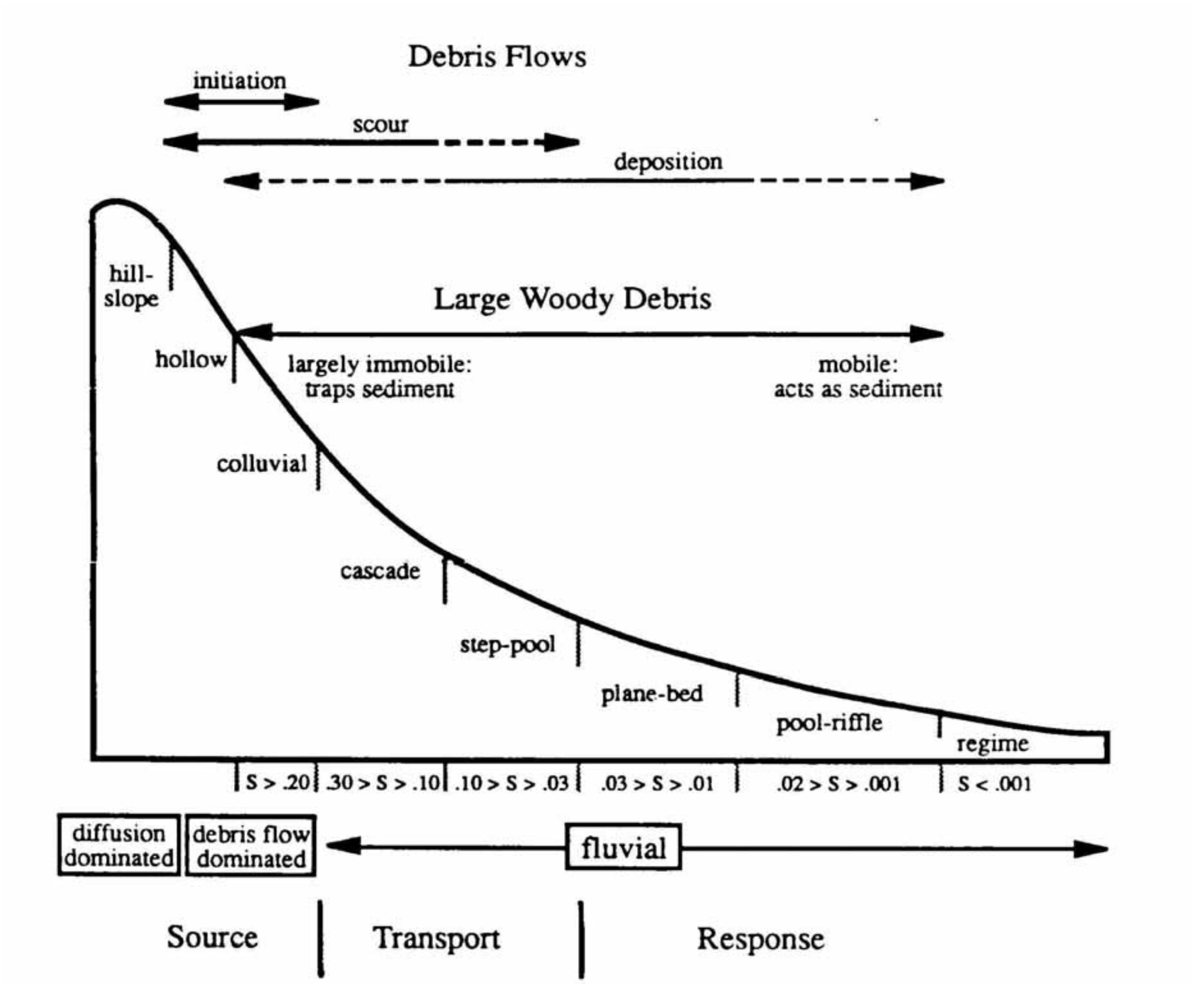


Figure 50. Channel Types. This illustration of an idealized stream shows the general distribution of channel types from the hilltop down through the channel network. From Montgomery and Buffington, 1993.

Upper East Austin Creek has the best Restoration Ranking and the second lowest Sub-Basin Disturbance Ranking. About one-half of the Upper East Austin Creek main channel is a response reach (>4% slope). About 84% of the response reach in Upper East Austin Creek is in the 2-4% slope class. Therefore, a high LWD load is required to force the formation of pools in Upper East Austin Creek. Given the extensive logging in this sub-basin, it is likely that measures need to be taken to increase the LWD load in Upper East Austin Creek. Salmonid habitat could also be improved in Upper East Austin Creek by reducing the fine sediment load.

Table 53. The number of miles of main stream channel in each slope class by sub-basin

	Reach Type						
	Response			Transport		Source	
Sub-Basin	<1%	1-2%	2-4%	4-8%	8-20%	>20%	Grand Total
Kidd & St Elmo Creeks	3.40	0.81	1.06	0.17	0.70	1.84	7.97
Lower East Austin Creek	6.63		1.17				7.80
Lower Austin Creek	4.20						4.20
Upper Austin Creek	3.44	0.75	3.52	2.61	0.88	0.35	11.55
Upper East Austin Creek	0.82	0.19	5.14	3.05	1.45	1.10	11.74
Ward Creek		0.47	3.10	2.84	0.27	0.33	7.00
Grand Total	18.48	2.22	13.99	8.66	3.29	3.61	50.25
Channel Form Depends on LWD Loading	No	Maybe	Yes				

The majority of response reach on the Ward Creek main channel is in the 2-4% slope class. However, about 1.8 miles of the 3.1 miles in the 2-4% slope class flows through the Great Valley Conglomerate. The Great Valley Conglomerate is known to produce large blocks of rock. It is reasonable to expect that the Great Valley Conglomerate could replace a high LWD loading as a source for the roughness elements need to force pool development in the 2-4% slope class channels. Ward Creek is tied for the second highest Disturbance Ranking and is also tied for the second best Restoration Ranking. The potential for the Great Valley Conglomerate to force pools suggests that reducing the fine sediment load is the primary restoration goal for Ward Creek.

About 67% of the Upper Austin Creek main channel is a response reach. About one-half of the response reach in Upper Austin Creek is in the less than 1% slope class and about one-half is in the 2-4% slope class. Therefore reducing the fine sediment load should be the first goal for restoring Upper Austin. Increasing the LWD load would be the next step in restoring salmonid habitat in Upper Austin Creek. Upper Austin Creek has a Disturbance Rank of 3 and a Restoration Rank of 4 (the worst).

The majority of the response reach in the Kidd and St Elmo Creeks Sub-basin is in the less than 1% slope class and is actually the Lower Austin Creek. Therefore, the primary goal for salmonid habitat restoration in the Kidd and St Elmo Creeks Sub-basin should be the reduction of the fine sediment load. The Kidd & St Elmo Creeks Sub-basin has the highest Disturbance Ranking and is tied for the worst Restoration Ranking so concentrating on the sub-basins with the better Restoration Rankings is a reasonable strategy. However, since the main stem of Austin Creek runs through this sub-basin, it is important to ensure that there are no barriers to upstream migration by salmonid adults or downstream migration of juveniles.

The entire main channel in the Lower Austin Creek Sub-basin is in the less than 1% slope class. Therefore, reducing the fine sediment load and ensuring that there are no barriers to upstream, or downstream, migration should be the primary restoration goals for the Lower Austin Creek Sub-basin.

LARGE FIGURES INSERT

VI Discussion

This assessment of the Austin Creek watershed illustrated and quantified a number of changes in the drainage:

- Clear-cutting logging and extensive road networks are visible throughout the watershed in 1961. Clear-cut areas total 17% of the overall watershed and up to 41% of individual sub-basins. Total road miles in 1961 were nearly eight times the total in 1941/42.
- Road densities in 2000 are nearly as high as in 1961 and in all sub-basins exceed by several times the density of roads (2 miles of road per square mile of watershed) recommended to assure healthy salmonid habitat in creeks.
- In 2000 many areas logged in 1961 still show signs of ground disturbance from roads and landings
- There has been a change in forest type from coniferous forest to hardwood forest/chaparral between 1941/42 and 2000. This transition largely occurred on the western side of the watershed in areas either severely logged, burned in wildfires, or both.
- The two areas where endangered Coho salmon continue to persist, the Ward and Grey Creek drainages, are dominated by rock types which are more erosion resistant than the predominant rock type, Franciscan Formation Graywacke/Mélange in the drainage.
- There is very little quantitative monitoring data for the Austin Creek Watershed. Stream flow and rainfall gauging records cover only a few years and most other types of quantitative data such as stream channel geomorphic conditions, turbidity, water quality and temperature are almost completely lacking.

Logging and Road Building

By far the greatest human associated change in the Austin Creek watershed is widespread clear-cut logging. Timber harvesting began in the region in the 1840's and progressively expanded into the 1880's and early 1900. This first round of logging differed greatly in scope and speed from the second major period which extended from the 1950's to the 1980's.

The old growth trees were cut by hand and hauled or yarded by teams of oxen. Oxen could haul logs at about two miles per hour. Late in the 1880's steam powered engines (donkey engines) and cables were used for yarding, but were limited to a mile distance for yarding logs. While many flat areas were completely clear-cut, many steep slopes or remote areas were left as they were too difficult to harvest. The first round of logging did leave considerable ground disturbance as logs were dragged from where they were felled to a railroad, or a mill. Armstrong Woods State Park, which had some areas harvested, has many roads and trails which date to the 1800's and still show considerable erosion.

The effects of the second round of logging are easier to evaluate because we can map the extent of the clear-cutting and the level of ground disturbance. In the 1961 aerials over 17% of the Austin Creek Watershed shows clear-cutting. In some sub-basins, such as the Ward Creek Sub-basin, 41% of the area is clear-cut. The areas showing logging in 1961 and 1980 taken together cover 52% of the Ward Creek Sub-basin, 34% of the Kidd/St. Elmo Creeks Sub-basin and 19% of the Lower Austin Creek Sub-basin.

The logging methods used after World War II employed chainsaws, bulldozers and trucks. Bulldozers could easily cut roads across slopes and drag logs down slopes to roads and landings. Numerous roads and skid trails mark the drainage in the 1961 photographs. In addition streambeds were used for roads (Figure 79). While this technique was probably a practice in the 1800's as well it would not have been used as widely and in as many locations as in 1961.

Additionally the second round of logging took every tree, denuding stream banks and sometimes even removing large trees in stream channels. From 1945-48 the number of sawmills on the California coast tripled and, beginning in 1953 until 1975, one billion board feet of timber was produced every year in the state. This is three times the production prior to 1950 (Barbour et al 2001). Acres of forest could be felled, logs yarded and hauled to the mill in a matter of days in the 1950's. The same area might have required months to a year in the 1800's, if it was possible to log it at all. After 1975 much of the timber cut was from second growth trees. Currently most logging is of remaining second growth and third growth trees.

The Austin Creek watershed, like much of northern California, had much of its forests harvested in the 1950-1980 period. This rapid cutting of forests corresponds with dramatic population increases and housing development in California. Between 1940 and 1960 California's population more than doubled from 6.9 million to 15.7 million requiring substantial timber resources to provide housing. From 1960 to 2000 the population more than doubled again from 15.7 million to 33.8 million (Forstall 1995).

The effects of clear-cut logging are well documented (Chamberlin et al 1991, Kenwyn et al 2004, Lufkin 1991, McEwan and Jackson 1996, Mount 1995, Rice et al 2004, Salmon and Steelhead Recovery Coalition 2000). These effects result from both the complete removal of the forest as well as the construction of roads, skid trails and landings. The complete removal of a forest on a slope changes a number of features which in turn alter physical processes during rainstorms. The forest serves to intercept raindrops and slowly trickle rainfall down to and through the forest floor duff where it infiltrates into soil and eventually becomes groundwater. In undisturbed conifer forest intense rainfall does not result in visible surface flow on the undisturbed forest floor. When the forest is cut and the slope marked with roads and skid trails not only is the forest's function in the interception of rainfall removed,

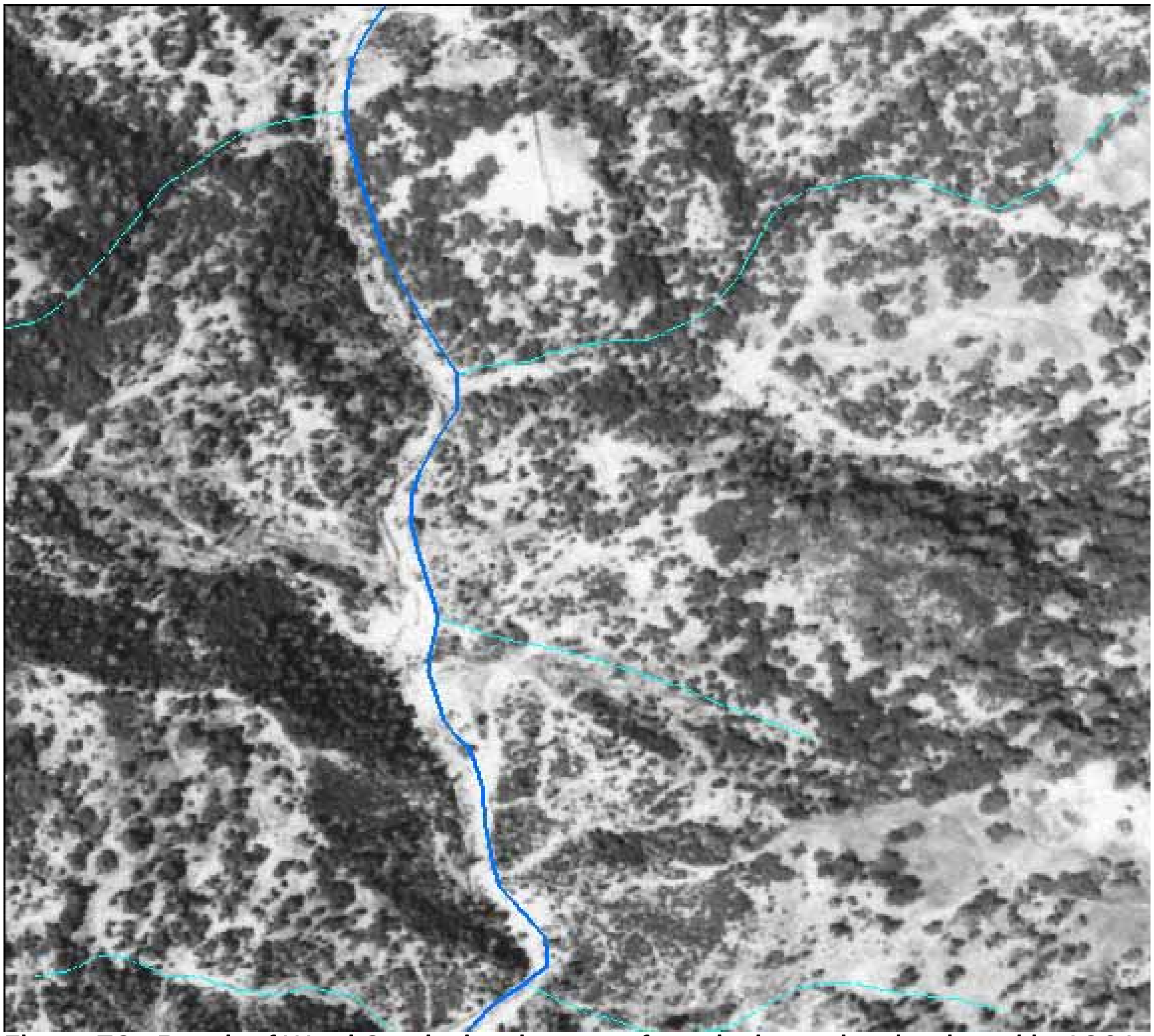


Figure 79. Reach of Ward Creek showing use of creek channel as haul road in 1961. Blue lines indicate approximate locations of creeks.

but the soil is bare and often compacted. These conditions cause lower infiltration rates and higher runoff rates and can greatly increase peak flows into streams. As these larger volumes of stormwater reach the small creeks on hillsides they cause downstream erosion and can initiate slides and debris flows. When this slurry of sediment and water reaches a major creek it will fill up the channel and may cause erosion of banks and adjacent hill slopes, again initiating more erosion and slides.

Roads and landings represent a long-term remnant feature of logging. Many roads created during the 1961 logging period were not intended for long-term use. Often undersized, or no culverts, were installed at stream crossings particularly on ephemeral and seasonal streams. Many crossings were created by bulldozing dirt into the creek and driving over it for a season and letting it erode out in the winter. On steep slopes, roads can become creeks as a filled-in stream re-routes to follow the road. As is depicted in Figure 79 creeks were used as roads, compacting the streambed and removing aquatic habitats.

Between 1941/42 and 1961 the ratio of miles of road to square miles of watershed increased from 0.75 to 5.73 in the Austin Creek watershed. In 2000 that ratio is only slightly reduced to 5.07. Of the 2000 roads more than half (3.38) are on slopes in excess of 30%.

In some sub-basins the road numbers are much higher. Lower Austin Creek Sub-basin has a ratio of 9.25 miles of road per square mile of sub-basin. Kidd/St. Elmo Creeks Sub-basin has a ratio of 8.44 miles of road per square mile of sub-basin and Ward Creek has a ratio of 6.97 miles of road per square mile of sub-basin. In all three sub-basins over half of the roads are on slopes in excess of 30%. These sub-basins are located on the western side of the Austin Creek watershed where rainfall amounts are greatest.

Higher erosion rates occur both immediately following a clear-cut and for many decades after. Following the timber harvest as the ground is left bare, rainstrike, or sheet, erosion is greater. On hillsides where vertical skid trails remain the increased level of runoff can initiate rill and gully erosion. Finally in watersheds, like Austin Creek, where highly erodible Franciscan Graywacke/Mélange occurs on steep slopes, removal of forest, construction of roads on steep slopes and increases in runoff can initiate massive landslides, or debris flows. Sometimes the landslides do not occur until remaining tree stumps and roots decay and their effect on holding soil is lost. Large intense rainfall events may initiate debris flows many years after the clear-cut. (Ziemer 1991). Our review of rainfall intensity in the Austin Creek watershed found that there is a 15-year return period for rainfall amounts typically needed to initiate debris flows.

The effects of this logging legacy are seen in the creeks of the watershed. Some studies suggest that tributary streams continue to adjust to change from clear-cutting for 50-80 years or more (Ziemer 1991). There are aggraded channel conditions in many tributary creeks with shallow pools and high water temperatures (Appendix B). Unfortunately there are few quantitative measurements of channel conditions.

Many of the effects of the 1950-1980's logging are likely still occurring. The potential for continued erosion and landslides from the legacy of the 1950-80's logging is very high as the Austin Creek watershed has high rainfall conditions and large areas of highly erodible rock and soil types. A review of the 2000 aerials does not reveal many of the extensive historic road systems that still remain. However, when the 1961 photographs are compared to the 2000 aerials it is possible to identify numerous remnant road systems that are obscured by vegetation, but are still likely eroding. Road repair projects have been implemented (Figure 29) but they represent less than 10% of the roads in the watershed.

The logging activities of the 1950-1980 period left changes on the Austin Creek watershed landscape that have yet to be addressed and probably represent the primary problem for aquatic habitats.

This watershed assessment included a GIS model and calculation of an Erosion Hazard Index (EHI) for each sub-basin. The results of this model are discussed in the recommendations section.

Changes in Forest Composition

Another major change documented in this watershed assessment is a shift from coniferous forest to hardwood forest/chaparral. This conversion is focused in the western portion of the watershed which has undergone extensive clear-cut logging and burning. There are also logged areas which did not burn that have undergone this conversion.

Fire was a common element of pre-statehood California. According to the 2003 Forest and Range Assessment prepared by the California Department of Forestry, the Austin Creek watershed had intermediate frequency fires (every 35-100 years) of low to mixed severity. Most of the watershed has had one fire since 1950. (California Department of Forestry 2003) A tree ring study in Sonoma County found that redwood forest burned every six years (Barbour 2001).

Fire was used by Native Americans to manage the landscape. These fires were low burning ground fires which removed understory brush and seedling trees. The fires that have occurred in the Austin Creek watershed since American settlement were very different.

With early logging much of the redwood tree was not used. For example, the bark and branches were cut from the trunk and left. Later logging practices also left a considerable volume of slash on the ground. Slash was often burned and it is likely that sometimes these fires escaped and burned large areas.

Dependable fire records from the California Department of Forestry start in the 1950's at the time of the second logging period. There were a number of large fires in the 1960's and 1970's on the western and southern sides of the Austin Creek watershed (Figure 57). The largest of these, the Creighton Ridge Fire, was a crown fire. Crown fires can reach temperatures of 1000º F and kill mature Douglas fir, but may not kill redwood and hardwoods such as madrone and tan oak. Redwood can produce sprouts along the trunk and from its roots. Madrone and tan oak re-sprout from the stump. Since much of the coniferous forest had been clear-cut prior to this fire, hardwood and chaparral species would have had an advantage in re-colonizing the area. Additionally, any conifer seedling that had regrown would have been burned.

Another land use activity that has affected this vegetation change is the removal of conifers from mixed stands and removal of hardwood trees to improve grazing. Following the logging in the 1800's, raising livestock became a major land use in this region. During the 1950's, it was common for ranchers to cut down trees to improve pastures. This practice was advocated by agricultural agencies such as the Soil Conservation Service and the University of California Cooperative Extension. Under the early state regulation of logging ranchers converting forest to rangeland were exempt from permitting and many acres were clear-cut (Arvola 1976). In areas of mixed conifer/hardwood forest, the conifers were logged throughout a site while the edges of the hardwood forest were cut back to increase the acreage of grassland. However, in swales and ravines hardwood forest often remained giving the hardwood an advantage over conifer in re-colonizing cleared areas.

Ecological succession in coastal forests often involves a change from hardwood forest to conifer or mixed conifer forest (California Department of Fish and Game 1988, Barbour et al 1993). Hardwood tree species are typically fire and drought adapted and better able to colonize after a fire. Douglas fir reproduces from seeds after a fire. Their seedlings are better adapted to the drier soil conditions and high heat of a clear-cut, or fire area, than redwood seedlings. Once established the Douglas fir will eventually out-grow and shade out the hardwoods. This succession from one vegetation type to another is documented after natural fires and can take 35-80 years to reach a coverage of small trees (California Department of Fish and Game 1988).

The conditions that have occurred in the Austin Creek watershed are not natural. Clear-cut logging of square miles of the drainage followed by fire and dense regrowth of hardwood may require a longer period to redevelop to a conifer forest. There is also a good chance, given the demand and value of timber, that those conifers which are growing up in the hardwood areas will be harvested, maintaining the conversion to hardwood forest.

The conversion of conifer to hardwood forest has several effects. Hardwood forest intercepts about 20% less rainfall than coniferous forest and therefore runoff volumes can increase (R. Curry pers. comm.). Larger runoff volumes can increase erosion in small hillside creeks and further destabilize areas with erosion problems remaining from logging or fire.

Coniferous forest provides a better shade canopy to streams as conifers grow taller and have denser foliage than hardwoods. Conifers also provide more durable large wood to creeks than most hardwood species (see Figures 80 and 81).

In addition, a mixed conifer forest or Douglas Fir/Redwood forest supports a different set of wildlife species than hardwood forest. Several of the rare wildlife species, Red tree vole and Coho salmon are associated with mature conifer forests.

A final issue that faces the hardwood forests, especially in the Ward Creek Sub-basin, is infection with Sudden Oak Disease (SOD). This area is primarily tan oak and this species is highly susceptible to this disease and it has been documented in these areas (Sudden Oak Disease website 2005). As the tan oak die and their removal is restricted to avoid spreading disease, the fire potential greatly increases. Another hot fire could kill the conifers that are beginning to grow in this area and further set succession back towards hardwood forest.

Coho Salmon

Coho salmon remain in two areas of the Austin Creek watershed, Ward Creek and Grey Creek. These areas have a different geology than most of the Austin Creek watershed. Sandstone dominates the Grey Creek drainage. Metabasalt and Great Valley Conglomerate are prominent in the Ward Creek drainage. The land uses in these sub-basins are not different from the rest of the Austin Creek watershed. Both of the drainages had high levels of clear-cut logging in the 1961 photo. The Grey Creek drainage was also partially cleared for agriculture in the 1941/42 photo.

These rock types are more resistant to erosion and do not produce as much fine sediment as the highly erodible Franciscan Greywacke that dominates the Austin Creek watershed. Another feature of the Great Valley Conglomerate is it breaks down into large blocks. These blocks may serve the same function as large woody debris in creating pools and providing complex aquatic habitat.

These geologic features, rather than land uses, in these two drainages have likely preserved adequate conditions for the Coho salmon. Since these geologic features are not predominant in the Austin Creek watershed, it is not likely that Coho populations will expand beyond these two areas without significant changes to watershed conditions. Expansion of Coho populations is required if the species is to recover to a self-sustaining level and avoid extinction.

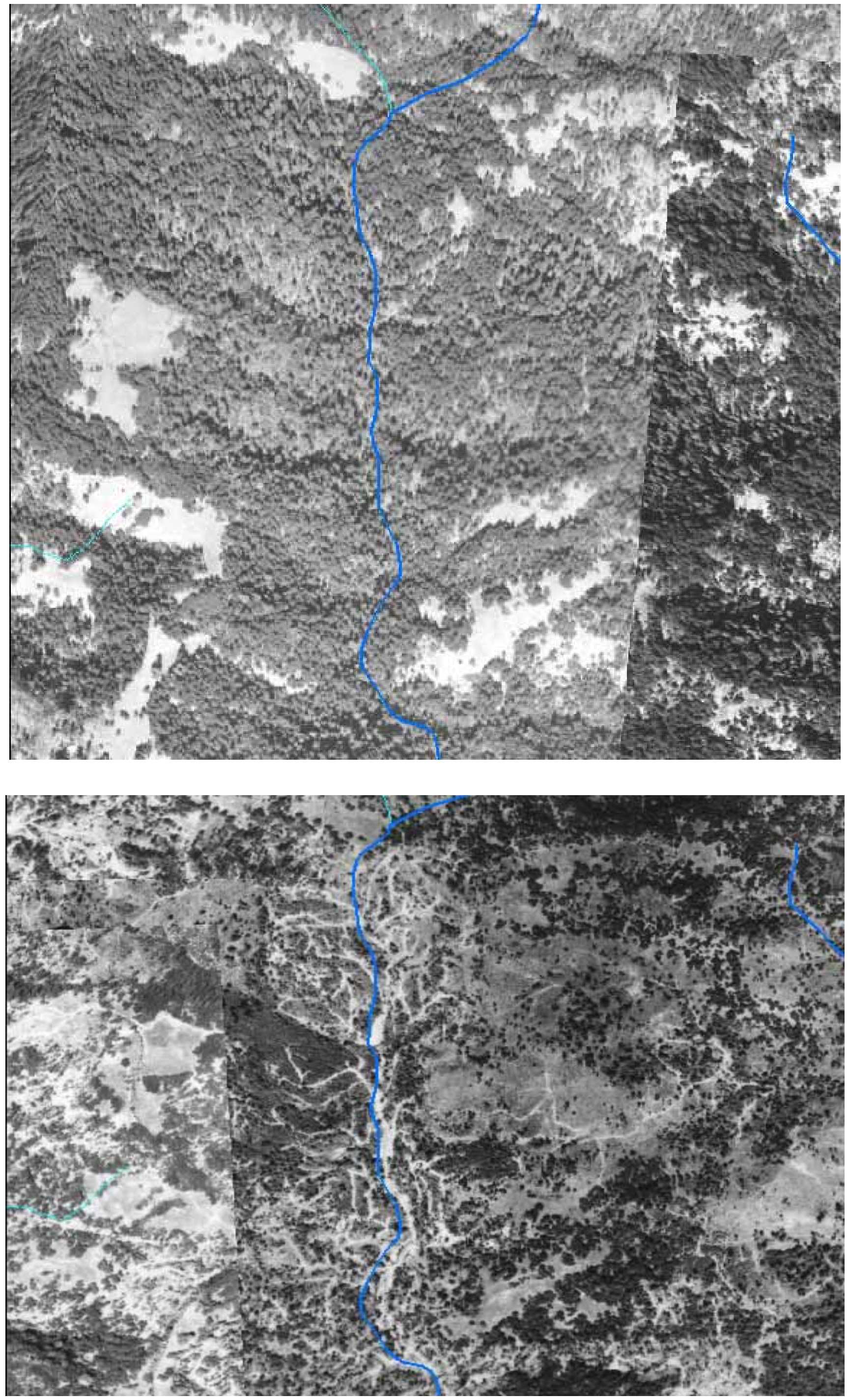


Figure 80. Top photo is a portion of a tributary to Ward Creek in 1941/42 with a dense conifer forest as shade canopy.
Bottom photo is the same location in 1961 after a clear-cut.

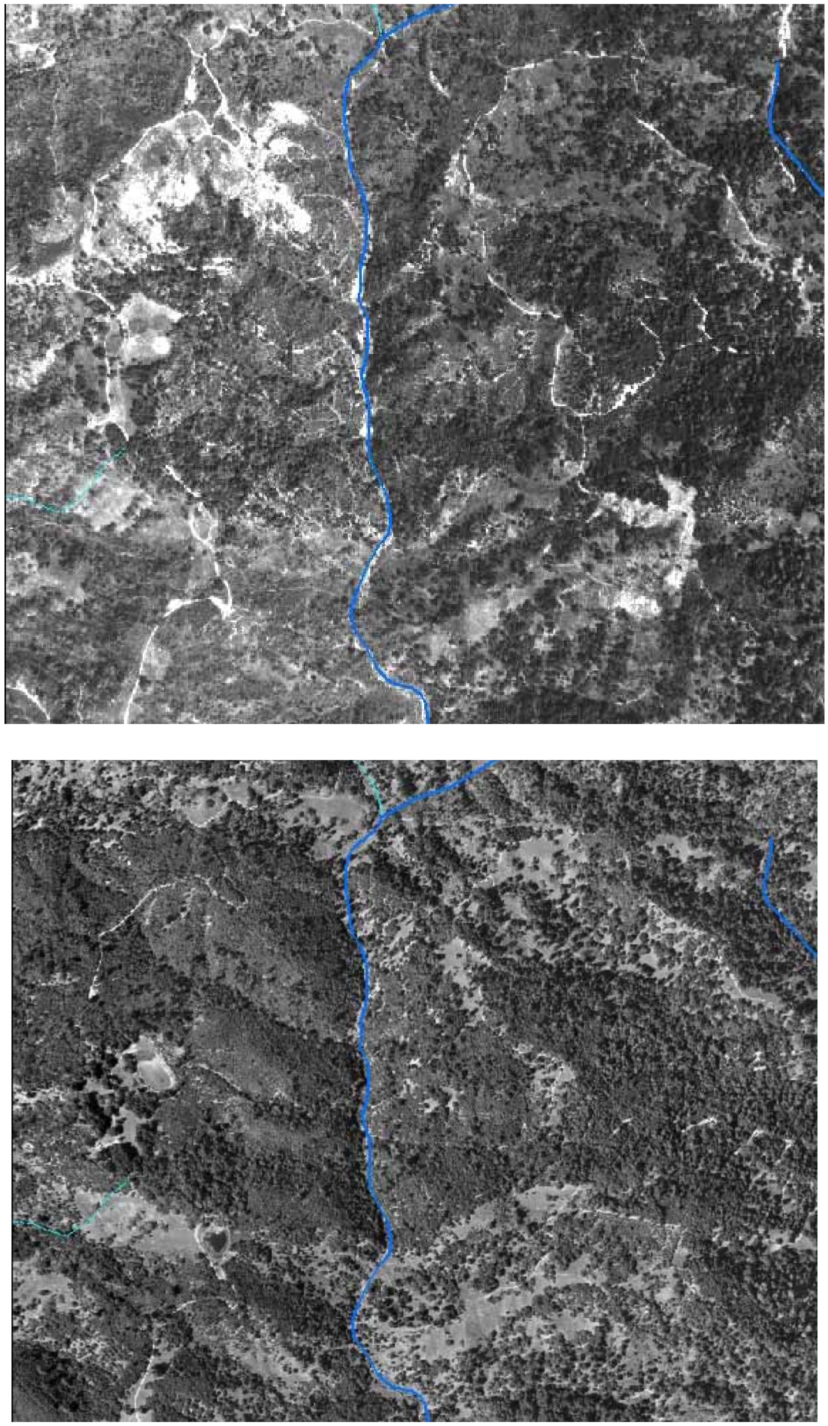


Figure 81. Tributary to Ward Creek in 1980 (top) and 2000 (bottom) showing transition to a hardwood forest stream canopy following logging and fire.

VI. RECOMMENDATIONS

Watershed Wide Recommendations

Watershed Restoration and Management is Needed to Address Aquatic Habitat Issues

The watershed assessment clearly demonstrates the need for a watershed-based restoration and land management approach. Focusing on the creek without addressing the drainage basin will not provide any long-term improvement and is not recommended. Creek restoration projects should be completed in conjunction with a broader view of each sub-basin and implementation of upslope repair and restoration efforts.

Other watersheds with similar issues offer a good example of why a watershed approach to restoration is needed. Bull Creek watershed drains into Humboldt Redwoods State Park. The park was created to preserve old growth redwoods while much of the surrounding land was clear-cut in the 1940-50's using much the same methods as in Austin Creek in the 1950-60's. During the flood of 1955 runoff poured off the clear-cut hillsides and filled Bull Creek and many tributaries with mud and debris and created a logjam of trees and logs. When the logjam broke it scoured over 50 acres out of the park and left a 20 ft deep deposit of silt in one tributary, Cuneo Creek. Many of the old growth trees were undercut and toppled. The 1964 flood had similar consequences. In 1992 a major project to clean out and recontour Cuneo Creek was completed including bioengineered structures in the stream to create fish habitats. In 1995 all of the in-stream work was completely scoured and buried by a flood. A second restoration project was completed in 1997 only to once again be scoured and buried in a flood later that year. The park is now focusing all of its efforts on the watershed to remove and close roads and skid trails and revegetate tributary streams (Barbour et al 2001).

A recent review of large numbers of stream restoration projects came to this conclusion:

"Traditional approaches to habitat management focus on repairing or augmenting specific habitat conditions, rather than on restoring landscape processes that form and sustain habitats. Habitat modifications, such as placing log structures or protecting stream banks, often fail to create expected habitat conditions because they are constructed without consideration of the causes of habitat degradation"(Roni et al 2002).

In Austin Creek there is clear need to focus and address the legacy roads and skid trails and restore slope and runoff processes which will support and sustain healthy creek habitats rather than trying to create these habitats by manipulating creek channels. Ultimately with the high rainfall levels and inherently unstable geology in this drainage the creeks will be most affected by flood events and landslides. The effects of a flood on a creek largely reflect the condition of the watershed. Creek restoration structures or the bioengineering of banks will not alleviate the effects of mass movements and floods and therefore do not address the biggest potential problem in the watershed or protect salmonid habitat from significant degradation.

Need To Work with and Address Needs of Private Landowners

In the past the method used to preserve or protect forestland was to purchase the property and set it up as a state, or national, park. This is a very expensive method and even once a property is owned by the government it does not mean that it is managed to produce the best environmental conditions. Most parks are severely under-funded and cannot implement the restoration and repair, or maintenance, projects needed. Dirt roads and trails in parks are often in worse shape than private roads.

The Austin Creek watershed is primarily private land. The land is used for economic purposes by its owners and restoration programs must integrate the owners' needs while addressing environmental and water quality problems. Addressing legacy problems from the 1950-80's will require interested landowners and incentive-based efforts to provide a long-term sustainable method for repairing and improving watershed lands. In most instances the land manager needs to be engaged in the management actions that will reduce erosion and increase the cover of native vegetation on a property. Clearing culverts in a storm, or fully winterizing roads and pastures need to be completed by an interested and motivated landowner, or land manager. There are few regulations that can force these types of improvements. It is also important that improvements to private land be implemented in order to recover the Coho salmon and to avoid litigation and further legislation mandating changes.

For many landowners there may be a great interest in carrying out actions to assist the salmon. However it is expensive to have qualified professionals complete a road assessment and formulate plans for the repair and closure of roads and erosion sites. There may also be an interest by the owner in retaining some of the existing roads to avoid having to create any new roads in the future. One way to create a greater incentive for landowners is to have a conservation and operation plan for their property that outlines both the needed erosion and road work and the economic needs and plans of the owner over the next 20 years. In some instances there may be grants that could fund the closure of roads and repair of erosion and by having the plan these changes could be evaluated in the context of the property operations. One of the programs that has a similar approach to this is the Fish Friendly Farming (FFF) program which completes these types of plans for properties with vineyards. The concepts used in the FFF program could be expanded to include small timber and livestock operations. These operations could benefit from additional funds to upgrade and improve their properties. The U. C. Extension Ranchland Water Quality

Short Course could also fill this need if it is revised to include professionals to complete detailed road assessments and other on site work.

Monitoring is an Essential Part of Successful Restoration

Restoration actions should be evaluated and informed by quantitative monitoring. Monitoring of creek conditions over the long term indicates the success of the watershed projects. Additionally, there is little to no quantitative monitoring data for most of the tributaries in the Austin Creek watershed. Monitoring should include geomorphic features of stream channels, water temperature, stream flow and water quality including turbidity. Since forest vegetation changes have been extensive, focused studies of hardwood/conifer forest in Ward Creek Sub-basin are needed to determine long-term trends in this drainage. This information is needed to assure that priorities are adjusted to produce the greatest level of improvement in aquatic habitats.

SUB-BASIN SPECIFIC RECOMMENDATIONS

Erosion Hazard Index (EHI)

All of the sub-basins in the Austin Creek watershed have undergone a high level of ground disturbance. As part of this watershed assessment a method was developed to evaluate the sub-basins in order to identify where the greatest improvements could be made.

The GIS was used to assess the relative tendency of each of the six sub-basins to produce fine sediment under natural (unmanaged) conditions and under the existing managed, or disturbed, conditions. Each sub-basin was given a score called an Erosion Hazard Index (EHI).

The Unmanaged EHI is an estimate of the relative tendency for a sub-basin to produce fine sediment prior to any land use activity, i.e. in its undisturbed condition. The lower the Unmanaged EHI, the less sensitive the sub-basin is to disturbance from land use activities. The sub-basin rankings showed that Upper Austin Creek is the most sensitive to disturbance, followed by Lower Austin Creek, Lower East Austin Creek, Kidd/St. Elmo Creeks, Upper East Austin Creek, and finally Ward Creek which is least sensitive to disturbance. This ranking reflects the natural state of the sub-basin and its expected relative fine sediment production under natural conditions.

However as each sub-basin has undergone various levels of disturbance a second ranking was done which uses road densities to evaluate the relative existing disturbance in each sub-basin, or the Managed EHI. The Managed EHI is an estimate of a sub-basin's relative tendency to produce fine sediment under current land use or disturbance levels. Upper East Austin Creek is the least disturbed sub-basin followed by Lower East Austin Creek, Ward Creek, Upper Austin Creek, Kidd/St. Elmo Creeks, and Lower Austin Creek which is the most disturbed sub-basin.

The Final Sub-Basin Disturbance Rank includes the effect of the proximity of roads to the stream system. The Kidd & St Elmo Creeks Sub-basin has the highest Final Disturbance Rank and so is the sub-basin that is most disturbed followed by Ward Creek, Upper East Austin Creek, Lower Austin Creek, and Upper Austin Creek. Lower East Austin Creek Sub-basin has the lowest Final Disturbance Rank and so it is the least disturbed sub-basin.

Adding the Sub-Basin Sensitivity Rankings and the Final Disturbance Ranks creates a ranking of the sub-basins where restoration efforts should be concentrated to produce the most long-term benefits for stream habitat. Table 54 shows the results of adding the Sensitivity and Disturbance ranks together.

Table 54. The Sub-basin Restoration Ranking is based on the sum of the Sub-basin Sensitivity Rank and the Sub-basin Disturbance Rank.

Sub-basin	Sub-Basin Sensitivity Rank	Final Disturbance Rank	Sum of Sensitivity Rank and Final Disturbance Rank	Restoration Ranking
Kidd & St Elmo Creeks	3	6	9	4
Lower East Austin Creek	4	1	5	2
Lower Austin Creek	5	4	9	4
Upper Austin Creek	6	3	9	4
Upper East Austin Creek	2	2	4	1
Ward Creek	1	4	5	2

Upper East Austin Creek Sub-basin has the most favorable Restoration Ranking since it has both a low Sensitivity and a low Disturbance Ranking. Lower East Austin Creek and Ward Creek Sub-basins have the next best Restoration Ranking. The other three sub-basins have relatively unfavorable Restoration Rankings.

Large Woody Debris (LWD)

A review of the potential value of increasing large woody debris (LWD) was completed based on channel slope and the function of LWD in pool formation for different channel slope classifications.

Lower East Austin Creek Sub-basin has 6.6 miles of stream in the less than 1% slope class and only 1.2 miles in the 2% to 4% slope class. Increasing the LWD loading in

Lower East Austin Creek will not dramatically improve the number of pools since most of the main channel is in the <1% slope class.

About 84% of the response reach in Upper East Austin Creek is in the 2-4% slope class. Therefore, a high LWD load is required to force the formation of pools in Upper East Austin Creek. Given the extensive logging in this sub-basin, it is likely that measures need to be taken to increase the LWD load in Upper East Austin Creek.

The majority of response reach on the Ward Creek main channel is in the 2-4% slope class. However, about 1.8 miles of the 3.1 miles in the 2-4% slope class flows through the Great Valley Conglomerate. The Great Valley Conglomerate is known to produce large block of rock. It is reasonable to expect that the Great Valley Conglomerate could replace a high LWD loading as a source for the roughness elements need to force pool development in the 2-4% slope class channels.

The majority of the response reach of Lower Austin Creek in the Kidd and St Elmo Creeks Sub-basin is in the less than 1% slope class.

Highest Priority Actions

Three of the sub-basins have a high restoration ranking when evaluated for their erosion hazard index under unmanaged and managed conditions. These sub-basins - Lower East Austin Creek, Upper East Austin Creek and Ward Creek, should be the primary focus of restoration efforts as investment of restoration dollars will result in the greatest benefit to aquatic habitats.

Lower East Austin Creek Sub-basin

Lower East Austin Creek Sub-basin has the second best Restoration Ranking and the lowest Sub-Basin Disturbance Ranking. Therefore, restoration efforts in Lower East Austin Creek should concentrate on reducing fine sediment inputs to the channel. Conditions along Lower East Austin Creek should be investigated in detail to determine if aquatic habitat could be improved by increasing the amount of riparian cover.

Upper East Austin Creek Sub-basin

This basin includes Grey Creek, a refugia for Coho salmon. The greatest problems in this sub-basin are erosion, mass movements and potential degradation of aquatic habitats by excess sediment. There is also a need to increase large woody debris in the 2-4% slope class area of the channel where it will facilitate pool formation.

Ward Creek Sub-basin

Ward Creek is tied for the second highest Disturbance Ranking and is also tied for the second best Restoration Ranking. The potential for the Great Valley Conglomerate to force pools suggests that large wood is not essential in this creek and that reducing the fine sediment load is the primary restoration goal

For each of the highest priority sub-basins the GIS should be used to identify the logged areas in the 1961 photo and determine the locations of the old road networks on the steepest slopes in the most erodible geologic areas such as Graywacke and Serpentinite. These areas have the greatest potential for mass movement and as sources of fine sediment. The focus should be on road and skid trail closure on steep slopes through re-sloping and revegetation. Widespread reforestation particularly on steep slopes where landslides are most likely is also needed.

Extensive landowner outreach will be needed to address the areas with the highest potential for sediment generation and implement assessment and repair program. As discussed previously, a comprehensive incentive-based approach needs to be implemented to give landowners the greatest support in changing management practices and implementing projects. It is also recommended that programs be explored to compensate landowners for leaving mature conifer forest on private land, particularly along creeks. Tax credits, green subsides or other ideas should be evaluated in conjunction with landowners and resource agencies.

In the Ward Creek sub-basin reforestation to a conifer forest should be a long-term strategy to return the area to its pre-1950's condition. Implementing this type of strategy will need to employ incentives and assistance to landowners. One of the programs which might be applicable here is the Forest Stewardship Program of CDF. This program combined with comprehensive property management plans could be used to implement this type of project over a 20-year or longer period and in conjunction with Sudden Oak Death programs.

Only one creek, Upper East Austin Creek is recommended for placement of large wood and again the landowners on the creek will need to be involved in the process of design and project implementation.

Lower Priority Actions

The primary goal for salmonid habitat restoration in the Kidd and St Elmo Creeks Sub-basin should be the reduction of the fine sediment loads. The Kidd & St Elmo Creeks Sub-basin has the highest Disturbance Ranking and is tied for the worst Restoration Ranking so concentrating on the sub-basins with the better Restoration Rankings is a reasonable strategy. However, since the main stem of Austin Creek runs through this sub-basin, it is important to ensure that there are no barriers to upstream migration by salmonid adults, or downstream migration of juveniles.

The entire main channel in the Lower Austin Creek Sub-basin is in the less than 1% slope class. Therefore, reducing the fine sediment load and ensuring that there are no barriers to upstream, or downstream, migration should be the primary restoration goals for the Lower Austin Creek Sub-basin.

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