Appendices

Technical Addendum to

Zayante Area Sediment Source Study

Presented to

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by

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Environmental Setting

for the

Zayante Area Sediment Source Study

Appendix A. Environmental Setting of the Zayante Streams Study Area

Appendix A.1 Physical Description

The San Lorenzo River drains 138 square miles of predominately forested land in north central Santa Cruz County **(Figures 1.1 and 1.3 in main document)**. The drainage basin extends from the top of the Santa Cruz Mountains at an elevation of 2,600 feet above sea level to the Pacific Ocean at the City of Santa Cruz. It is the largest stream draining the Santa Cruz Mountains and a dominant geomorphic force forming the landscape of the San Lorenzo Valley and the City of Santa Cruz. The San Lorenzo River Watershed consists of a network of relatively steep, low order tributary streams dissected within an uplifted terrain draining into narrow alluvial valleys, the largest of which is the San Lorenzo Valley. The watershed is underlain by predominately marine sedimentary rocks. A key exception is the western boundary of the watershed formed by Ben Lomond Mountain, an uplifted mass of relatively resistant basement rocks including granite, marble, and metamorphic rock. Most streams in the watershed are narrow and bounded by steep forested hillslopes covered with weak soils that are prone to landsliding and erosion. Lower watershed streams flow on valley floors composed of alluvial terraces and floodplains.

The primary streams of the Zayante Area **(Figure 1.3, in main document)**, Bean, Newell, Zayante and Love Creeks, are tributary to the San Lorenzo River and drain the eastern side of the San Lorenzo River Watershed. The Zayante streams drain a total of 39 square miles (27% of the San Lorenzo Drainage basin) through a predominately mountainous terrain before flowing into the San Lorenzo River along the eastern edge of the San Lorenzo Valley**.** A set of GIS maps showing geology, road coverages and 200-foot buffer zones along major streams (an approximation of inner gorge slopes) for each subwatershed is found in **Appendix D**. Most streams in the study area flow on the floors of deep canyons lined with resistant bedrock, with steep canyon walls and forested hillslopes composed of weak, deeply weathered soils. In the lower stream reaches, small alluvial valleys occur with streams usually incised deeply within the alluvial terraces of the valley floor.

AppendixA..2 Rainfall and Streamflow

The San Lorenzo River Watershed experiences a Mediterranean climate with warm, dry summers (May through October) and cool, wet winters (November to April). Average rainfall in the winter months range from about 30 inches along the coast, increasing due to orographic effects, to about 60 inches along the ridge of Ben Lomond Mountain. Over 50 inches of rainfall per year occurs along the summit ridge of the Santa Cruz Mountains above the Zayante Streams study area.

Two important themes in the description of sediment supply are that rainfall is the driving force for sediment production and year to year rainfall amounts are highly variable. In fact, rainfall amounts have been exceeded by over 150 percent in some "El Nino" years. Wet years usually include intense rainfall periods that trigger landslides and high rates of hillslope erosion. Six to ten consecutive days of rainfall is not unusual, producing saturated soil conditions. When deep saturation of the watershed is followed by six or eight hours of intense rainfall (above 0.5 inches per hour), the result is usually catastrophic. Numerous roads fail and repairs and stabilization work can take years. Significant erosion can also occur in years when rainfall is slightly above average and constant, producing numerous consecutive days when streamflow is at levels effective to erode and transport sediment (1.5 year recurrence). This level of flow is often the dominant flow, carrying the greatest volume of sediment over time. This was the case in the 1999-2000 water year where numerous days of sustained flow caused many erosion problems (calls regarding significant erosion problems to SH&G's office were numerous) but there was little flooding to declare a state of emergency.

Streamflow in the Santa Cruz Mountains is characterized by rainfall-induced winter floods over a base flow that is recharged during the winter months and gradually reduced through summer to minimum levels by October. The seasonal flow pattern is shown in the average seasonal hydrographs for the San Lorenzo River at Big Trees and Zayante Creek **(Figures A-1 and A-2**). Storm runoff generally does not increase streamflow levels significantly until a level of soil saturation occurs (usually the first 5 to 10 inches of rainfall). The highest flows, and related erosion and sediment transport, typically occur from late December through March, when soil saturation is high. Streamflow and sediment transport declines sharply after winter rains decrease. There is no snowmelt in the Santa Cruz Mountains to supplement late season runoff.

Appendix A.3 Geology

The San Lorenzo River Watershed is located at the boundary of two major tectonic plates the Pacific Plate to the west and the North American Plate to the east. Crustal movement between these two plates has occurred along the San Andreas Fault System, which some believe extends from faults offshore in Monterey Bay (i.e. San Gregorio Fault) across the Great Basin to Utah. The evolution of this plate boundary has played a fundamental role in the landscape and geology of the Santa Cruz Mountains and Zayante Area. The most notable events are the episodes of crustal depression, basin formation and accumulation of marine sedimentary rocks during the Tertiary period (8 to 60 million years before present) now exposed in the Zayante Area, to the more recent period of tectonic uplift (3 mybp). Older Mesozoic rocks found on Ben Lomond Mountain represent earlier episodes of basin and mountain building and the apparent translocation of limestone reefs from the latitude of Acapulco, Mexico.

Three geologic terrains distinguished by geologic structure and rock types occur within the San Lorenzo River Watershed **(Figure A-3).** Each terrain has different hydrologic and geomorphic characteristics that affect erodibility, sediment size, water quality and streamflow. Two of these terrains occur in the Zayante Study area and are separated into north and south units by the Zayante Fault **(Figure A-4)**. A third Ben Lomond Mountain unit, bounds the west side of the San Lorenzo River Watershed and is characterized by

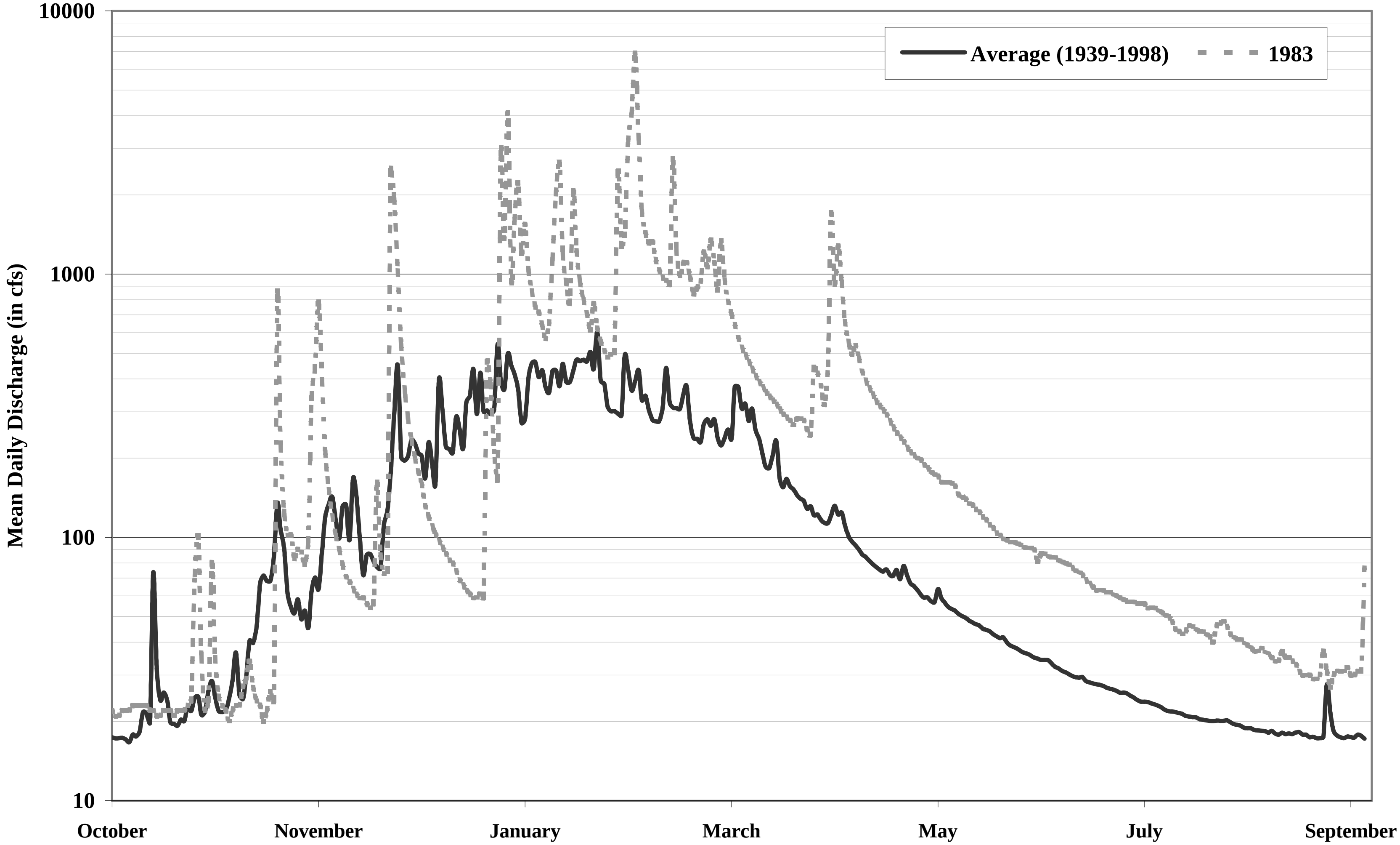

Figure A-1. Long-term average daily mean streamflow and average daily flow for water year 1983 is shown for the San Lorenzo River at Big Trees (Station # 11160500).

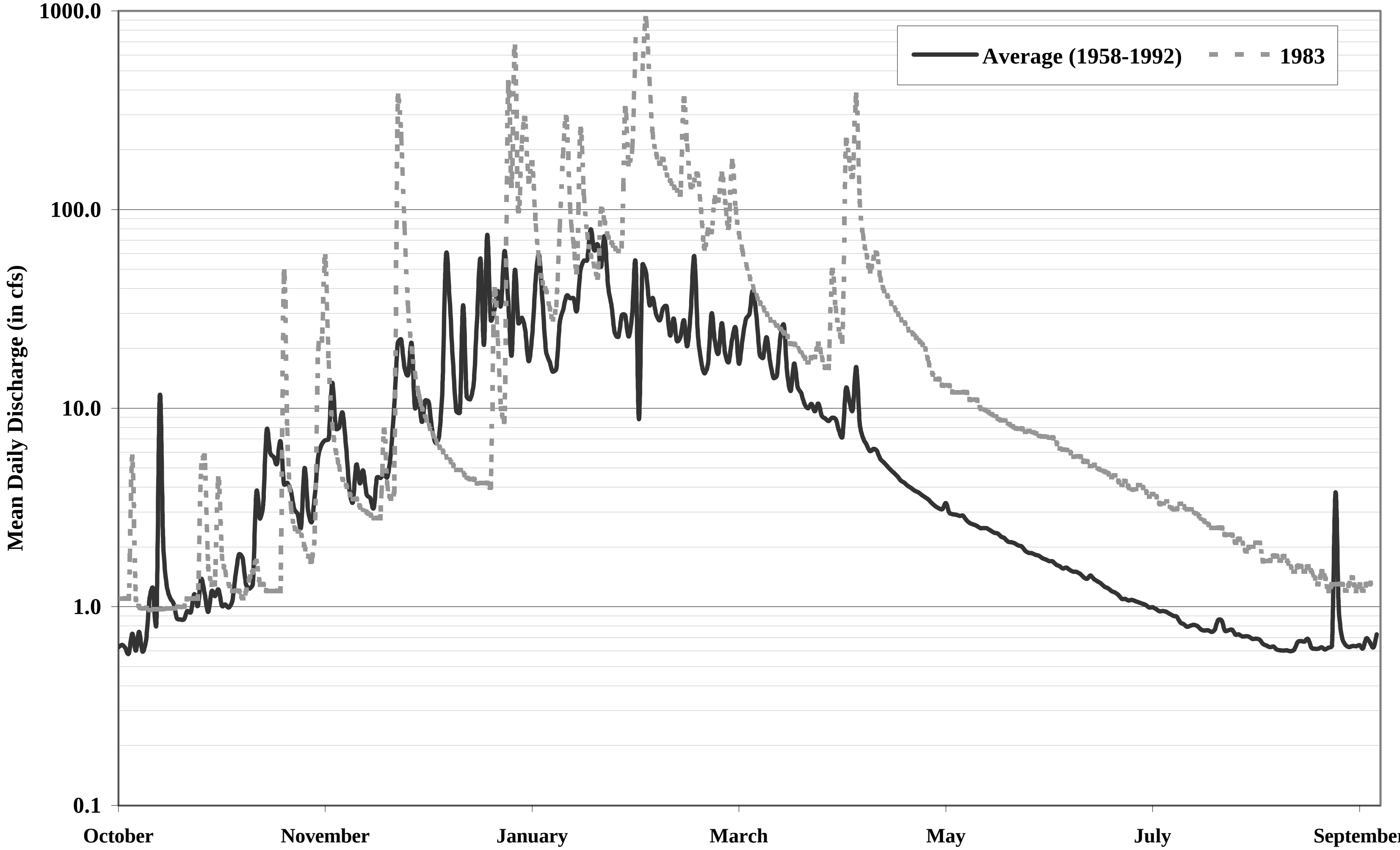

Figure A-2. Long-term average daily mean streamflow and average daily flow for water year 1983 is shown for Zayante Creek at Zayante (Station # 11160300).

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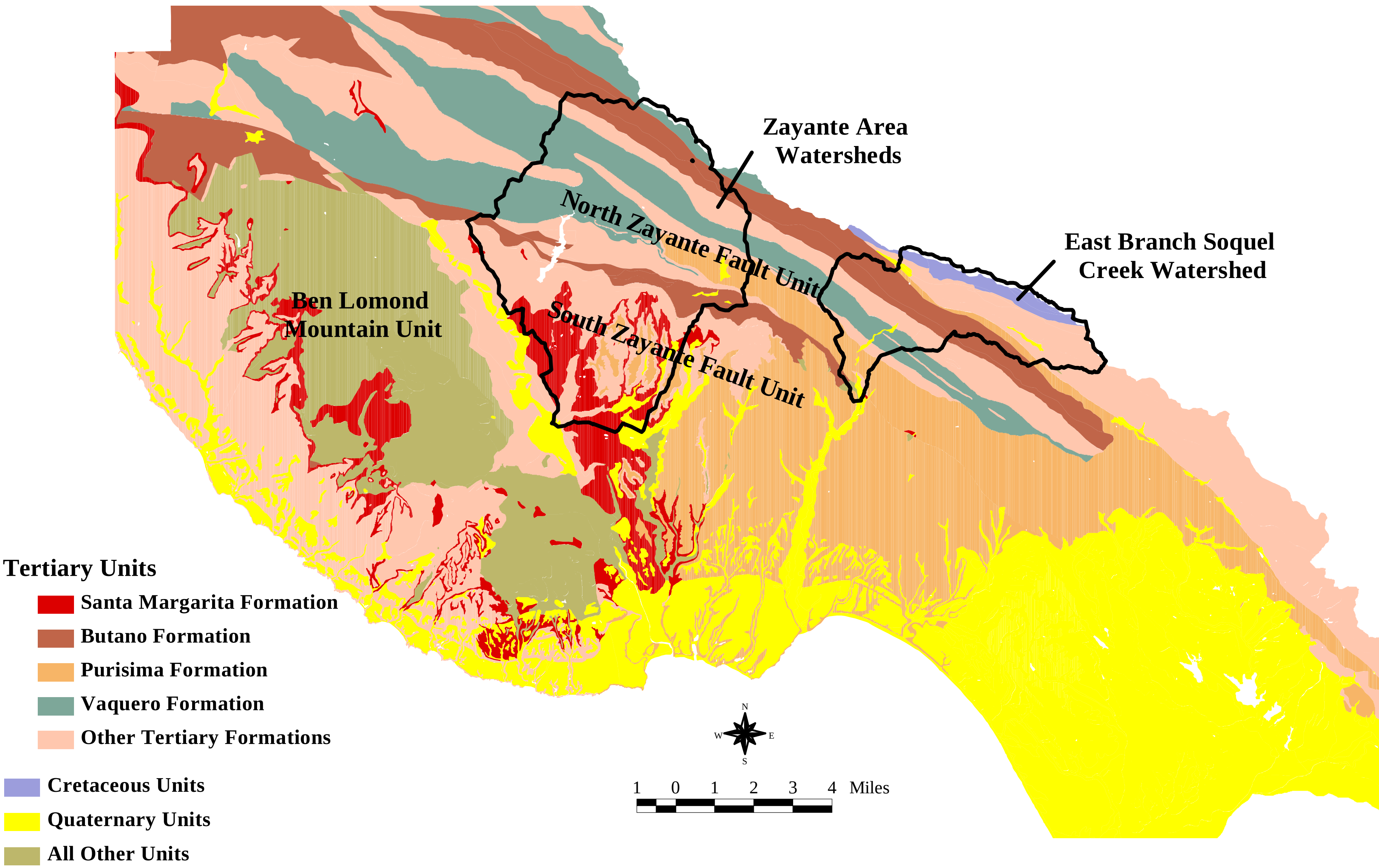

Figure A-3: Regional geology of Santa Cruz County. Lithologic units were classified into lithologic types where necessary. The three general terrains discussed in the text are shown along with the watershed boundaries for the Zayante Area Streams and the East Branch of Soquel Creek.

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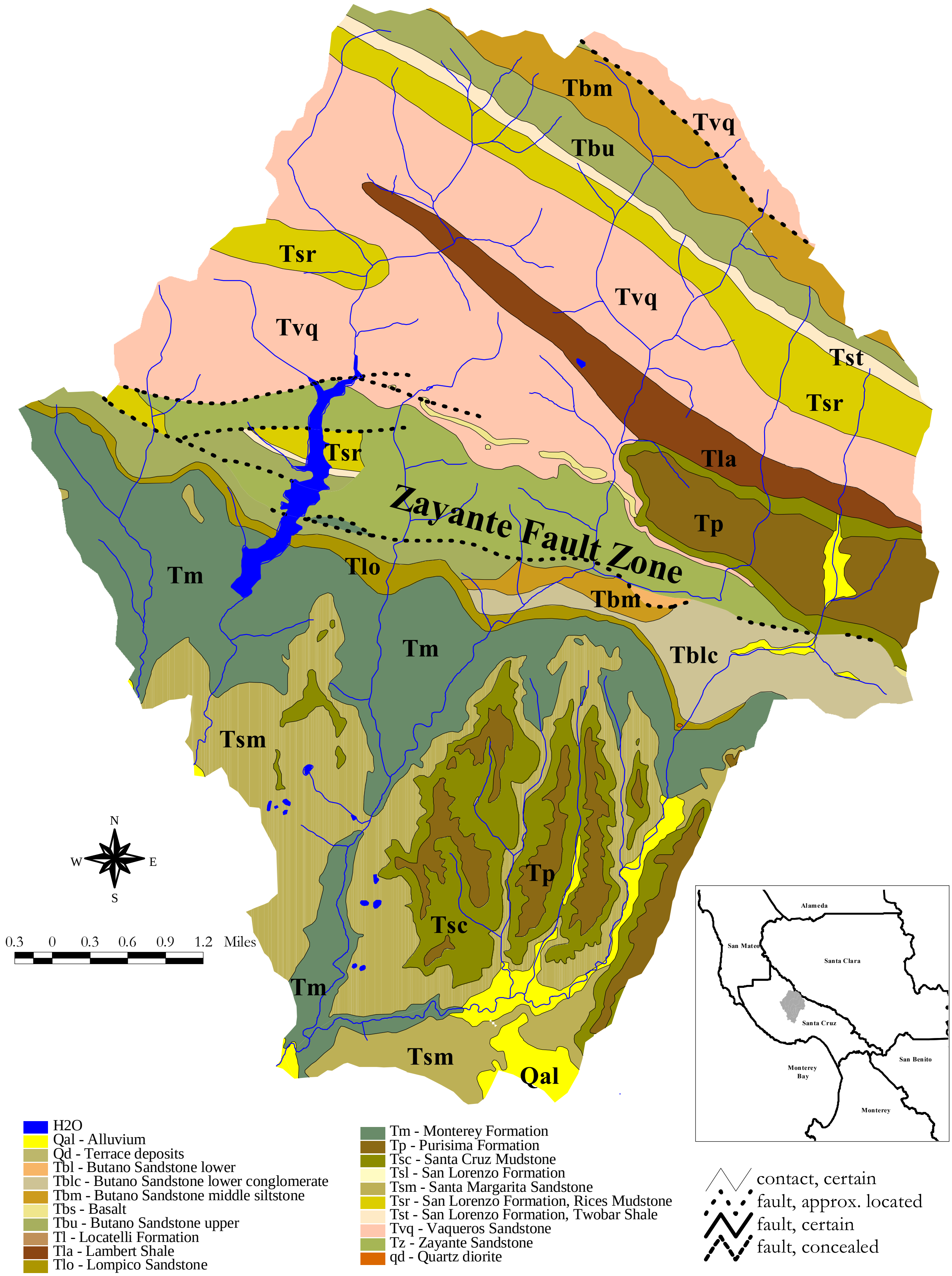

Figure A-4: Geologic rock type of Zayante, Newell, and Love Creeks from 1:24,000 USGS maps

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steep watersheds underlain by granite, marble and metamorphic rocks, producing relatively high water quality. The extent of each geologic formation within the subwatersheds of the Zayante Study Area, shown in **Figure A-5**, is expressed as the percentage of watershed area within the Zayante Area stream (**Table A-1).**

The following discussion of the three distinctive geologic terrains in the San Lorenzo Watershed has been adapted from Hecht and Kittleson (1998).

A.3.1 North of Zayante Fault

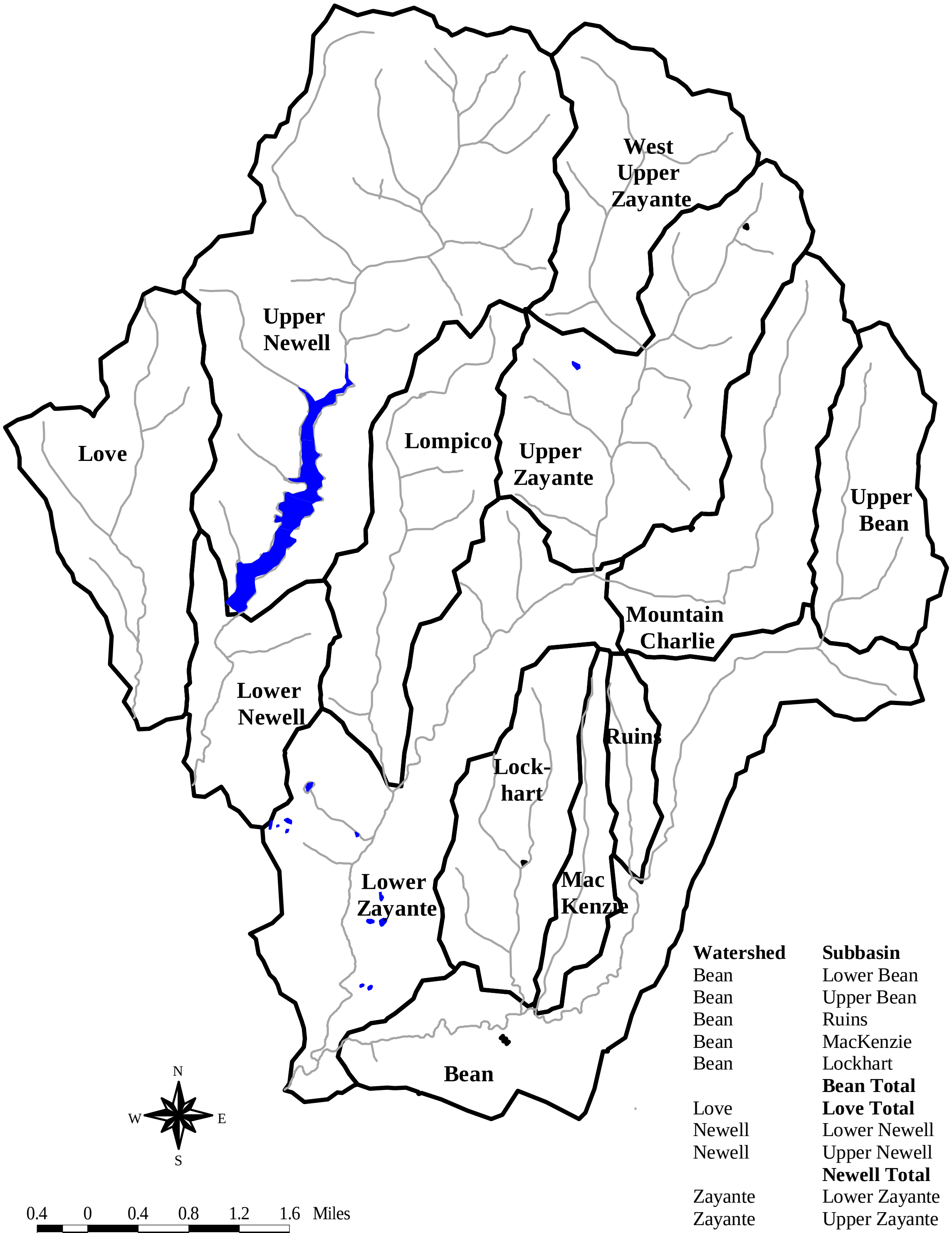
The unit north from the Zayante Fault extends to the Santa Cruz Mountain summit and drainage divide. It is distinguished by a geologic structure of uplifted, steeply dipping and folded strata of Tertiary aged marine, sedimentary rocks (sandstone, shale, and mudstone). Soil genesis from these rocks results in a complex mosaic of coarse-grained loamy soils ranging in depth from a thin veneer less than a foot thick to deep, organic-rich sandy clay loam on valley terraces. Vegetation varies from sparse chaparral and scrub in dry sandy soils on south facing slopes to dense conifer forests on shaded east and north-facing slopes. These diverse physiographic conditions result in a wide variety of sediment sources (boulder to clay sizes) with diverse mechanisms for delivery to streams (surface sheet flow to landsliding).

The upper watersheds in the Zayante Study Area include upper Love Creek, upper Bean Creek, upper Newell Creek, upper Zayante Creek, and Lompico Creek basins. Uplift along the Butano Fault has brought a ridge of erosion-resistant sandstone rising abruptly along the summit above these basins and the San Lorenzo River. This area consists of a combination of steep slopes and coarse soils. As a result, significant erosion is found where roads and clearings are cut in the landscape.

The response to land use disturbance varies spatially, but due to the unconsolidated and deeply weathered nature of the steep hillslopes, it is often negative. Upper East Zayante Road and its frequent roadcut slope failures are a prime example of the conflicts between unstable geology and road management. In the steep road network of the upper Zayante area watersheds, exposed weathered mudstones and shales continually provide easily moved sediments. Dry-season flows are generally lowest in this area, with streams often drying to isolated pools during mid-summer. In circumstances of limited stream flow, sedimentation impacts are often amplified and the impact to aquatic habitat, recreation, and water quality is more severe.

A.3.2 South of the Zayante Fault

The geologic unit south of the Zayante fault extends eastward across the San Lorenzo River to Ben Lomond Mountain. It includes lower Bean Creek, lower Love Creek and the southern portions of the Zayante and Newell Creek watersheds, as well as the Branciforte Creek watershed. It is distinguished by generally flat-lying sandstone and conglomerates of the Santa Margarita (Tsm) and Purisima Formations (Tp) overlying



Watershed	Subbasin	Area (in acres)
Bean	Lower Bean	2667
Bean	Upper Bean	1226
Bean	Ruins	342
Bean	MacKenzie	525
Bean	Lockhart	1310
	Bean Total	**6070**
Love	**Love Total**	**1923**
Newell	Lower Newell	1053
Newell	Upper Newell	5301
	Newell Total	**6354**
Zayante	Lower Zayante	3105
Zayante	Upper Zayante	2561
Zayante	Lompico	1770
Zayante	Mountain Charlie	1813
Zayante	W Upper Zayante	1559
	Zayante Total	**10809**
	Total TMDL Area	**25156**

Figure A-5: Subwatersheds of Zayante, Newell, and Love Creeks. Watershed area for each subbasin is presented as acreage along with totals for each major basin.

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Subwatershed	Vaqueros Sandstone	San Lorenzo Formation Rices Mudstone	San Lorenzo Formation Twobar Shale	Butano Sandstone upper	Butano Sandstone middle Siltstone	Lambert Shale	Water	Zayante Sandstone	Lompico Sandstone
Lower Bean	0%	0%	0%	0%	0%	0%	0%	0%	1%
Upper Bean	19%	18%	4%	3%	1%	8%	0%	0%	0%
Ruins	0%	0%	0%	0%	0%	0%	0%	0%	0%
MacKenzie	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lockhart	0%	0%	0%	0%	0%	0%	0%	0%	0%
Love	21%	3%	0%	12%	0%	0%	0%	5%	3%
Lower Newell	0%	0%	0%	0%	0%	0%	0%	0%	0%
Upper Newell	50%	14%	3%	10%	3%	4%	3%	8%	1%
Lower Zayante	0%	0%	0%	3%	4%	0%	0%	5%	3%
Upper Zayante	40%	7%	2%	7%	5%	15%	0%	12%	0%
Lompico	25%	0%	0%	5%	0%	1%	0%	29%	6%
Mountain Charlie	14%	14%	3%	5%	7%	7%	0%	14%	1%
W Upper Zayante	43%	8%	3%	13%	28%	2%	0%	0%	0%

Subwatershed	Basalt	Monterey Formation	Santa Margarita Sandstone	Santa Cruz Mudstone	Purisima Formation	Alluvium	Butano Sandstone lower conglomerate	Butano Sandstone lower	Quartz diorite
Lower Bean	0%	15%	43%	10%	7%	22%	22%	0%	1%
Upper Bean	0%	0%	0%	9%	31%	5%	2%	0%	0%
Ruins	0%	24%	51%	22%	3%	0%	0%	0%	0%
MacKenzie	0%	1%	18%	42%	29%	9%	0%	0%	0%
Lockhart	0%	8%	19%	51%	20%	1%	0%	0%	0%
Love	0%	50%	6%	0%	0%	0%	0%	0%	0%
Lower Newell	0%	46%	49%	4%	0%	0%	0%	0%	0%
Upper Newell	0%	4%	0%	0%	0%	0%	0%	0%	0%
Lower Zayante	0%	30%	40%	8%	4%	1%	3%	0%	0%
Upper Zayante	1%	0%	0%	3%	7%	0%	0%	0%	0%
Lompico	1%	29%	3%	0%	0%	0%	0%	0%	0%
Mountain Charlie	0%	1%	0%	7%	18%	0%	9%	1%	0%
W Upper Zayante	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table A-1: Percent of each lithologic unit by subwatershed within the Zayante study area folded and tilted strata of predominately Monterey (Tm) and Santa Cruz Mudstone (Tsc) Formations.

The Santa Margarita and Purisima Formations are often highly erodible due to weak cementation, deep weathering and massive uniform bedding structure. Sandstones and shales form highly erodible soils which tend to be either very sandy or clay rich. The Purisima contains expansive clays that enhance landslide failures. Sandy soils overlying the smaller grained mudstones and shale are extremely erodable. Erosion rates are often high to extreme in this terrain, especially where sandy soils occur in steep headwater areas or near channels. The sandy soils, which were capable of absorbing nearly all rainfall under natural conditions, often form steep-walled gullies where runoff from paved or covered surfaces is concentrated. Land use disturbances are among the densest in the San Lorenzo Watershed and include residential, commercial and industrial uses, including surface mining for construction aggregate.

The resistance of the mudstone units in the Monterey and Santa Cruz Mudstone Formations can vary considerably. There are many areas where these rock units form bluffs along valleys and stream banks, which are often fractured and prone to rockfalls. In other areas, they can be very weak as reflected by the occurrence of large-scale active and dormant landslides. Where geologic structure is inconspicuously weak and coincides with the hillslope grade the results can be catastrophic, as was the case in the dip-slope failure of the Love Creek Slide in 1982.

A.3.3 Ben Lomond Mountain Unit

The Ben Lomond Mountain geologic unit within the San Lorenzo River Watershed includes the steep eastern slope of Ben Lomond Mountain from the Zayante Fault on the north to the University of California at Santa Cruz campus on the south. This unit is not part of the Zayante streams study area. Movement on the Ben Lomond Fault uplifted Ben Lomond Mountain, forming the southwestern edge of the San Lorenzo River Watershed. Ben Lomond Mountain is an uplifted mass of basement bedrock consisting of hard, crystalline rock, principally Mesozoic-age granite, schist, and marble overlain by thin soils and alluvium.

The eastern slope of Ben Lomond Mountain has numerous landslides, a mix of deeply weathered soils underlying steep and small, forested watersheds. Background erosion rates are low to moderate and, in contrast to the other geologic zones, streams clear quickly after storm runoff. The lower portion of these watersheds intersects the Tertiary Monterey, Santa Margarita and Lompico Formations where in some cases massive landslides in sandstone and mudstone occur. The landslide hazard is especially high where failure planes occur along stratigraphic bedding coinciding with the fall line of hillslope (i.e. - "dip-slope" failures).

The principal watersheds in the Ben Lomond Mountain unit are Fall, Alba, Clear and Sweetwater Creeks. Peavine and Jameson Creeks flow into the southern portion of the Boulder Creek basin, a major tributary to the San Lorenzo River draining the north end of Ben Lomond Mountain. Summer flows are generally sufficient to support relatively high perennial stream flows and diverse aquatic habitat. The lower reaches of streams emanating from the eastern slope of Ben Lomond Mountain are used by steelhead and may have once supported coho salmon.

Appendix A.4 Landslides, Debris Flows and Mass Wasting

A variety of landslides ranging from shallow debris flows to rotational slumps over a hundred feet deep are found in the Santa Cruz Mountains and the San Lorenzo River Watershed. Landsliding (or mass wasting) is the dominant geomorphic process in the Santa Cruz Mountain landscape.

Landsliding results from weak geologic formations, steep topography caused by tectonic uplift, and occurrence of intense periods of rainfall and seismic forces. Landslides often terminate at and impinge upon stream channels, sometimes feeding a seemingly endless supply of sandy material directly into the channels (e.g. Mount Hermon Landslide at Bean Creek). In the worst cases, chronic sediment loading from landslides can eliminate pools, riffles and coarse substrate for hundreds of feet below the point of delivery.

Steep slopes are an important factor in erosion in general and for landslides in particular. **Figure A-6** shows slope class gradients for the Zayante Area. The steepest slopes are shown in the headwaters near the summit and within the Zayante Fault Zone where greater uplift and weaker rocks may be important factors for canyon incision over geologic times (perhaps on the scale of over 20,000 years before present). The lowest gradients are found in the alluvial valleys along streams in the lower watershed areas.

Mapped landslides make up a substantial proportion of the land surface in the study area **(Figure A-7).** The large slides are deep failures that often extend from ridge top to the canyon floor and stream. The speed of the active mass can range from inches per year to tens of feet per day. As a large slide moves along a distinct failure plane, the landmass on the upper part of the slide is lowered and depleted, while the lower toe area expands and bulges into the stream canyon or valley. The bulging of the toe has several significant effects on sediment delivery and sensitivity to land disturbance. First, the rock is fractured, weakened and subject to saturation and greater weathering while it is being transported closer to the stream; this makes the mass simultaneously steeper and weaker, enhancing gully erosion and shallow mass failures on the toe face. As the stream incises or if a road is cut along the canyon wall, the landslide toe is eroded and the mass buttressing the slide above is removed, causing the slide to move further down slope. This lower zone of canyon slopes where incision dominates is called the "inner gorge". The inner gorge is generally steeper than the hillslope above and in addition to landslide toes; it often contains deeply weathered bedrock and colluvium.

Weathered bedrock, soils and colluvium are subject to saturation by rainfall. Saturated conditions can produce a nearly instantaneous and deadly failure of a rapidly moving landslide called *debris flows*. Debris flow failures are common along the inner gorge slopes of the Santa Cruz Mountains. Debris flows occur during intense periods of rainfall after hundreds of years of persistent slope wash and colluvium accumulation in swales. The swales are often bedrock, which has a lower permeability than the overlying

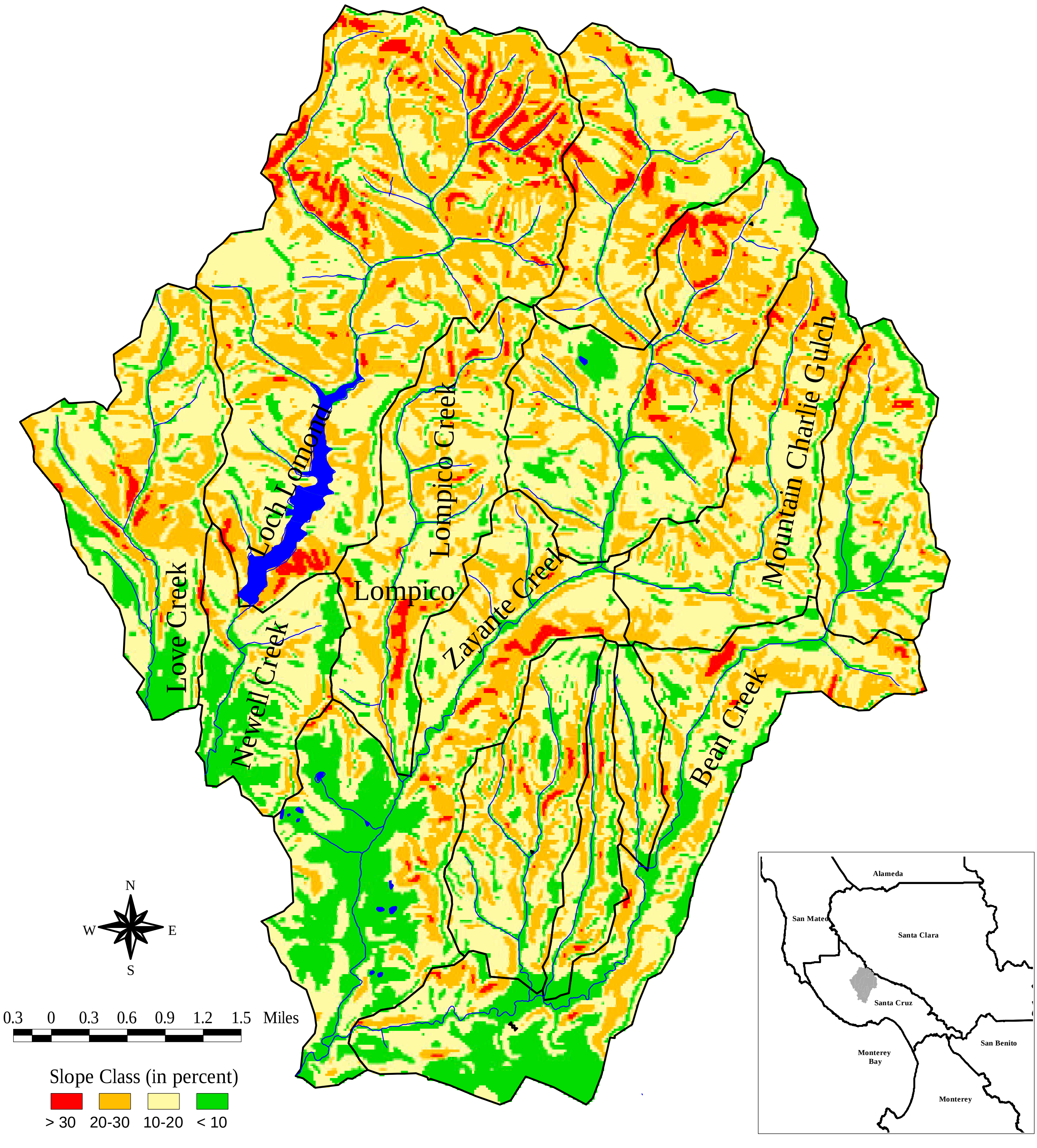

Figure A-6: Slope classes for Zayante, Newell, and Love Creeks. Slopes were generated from USGS 30-meter digital elevation models (DEM) and classified into slope class categories.

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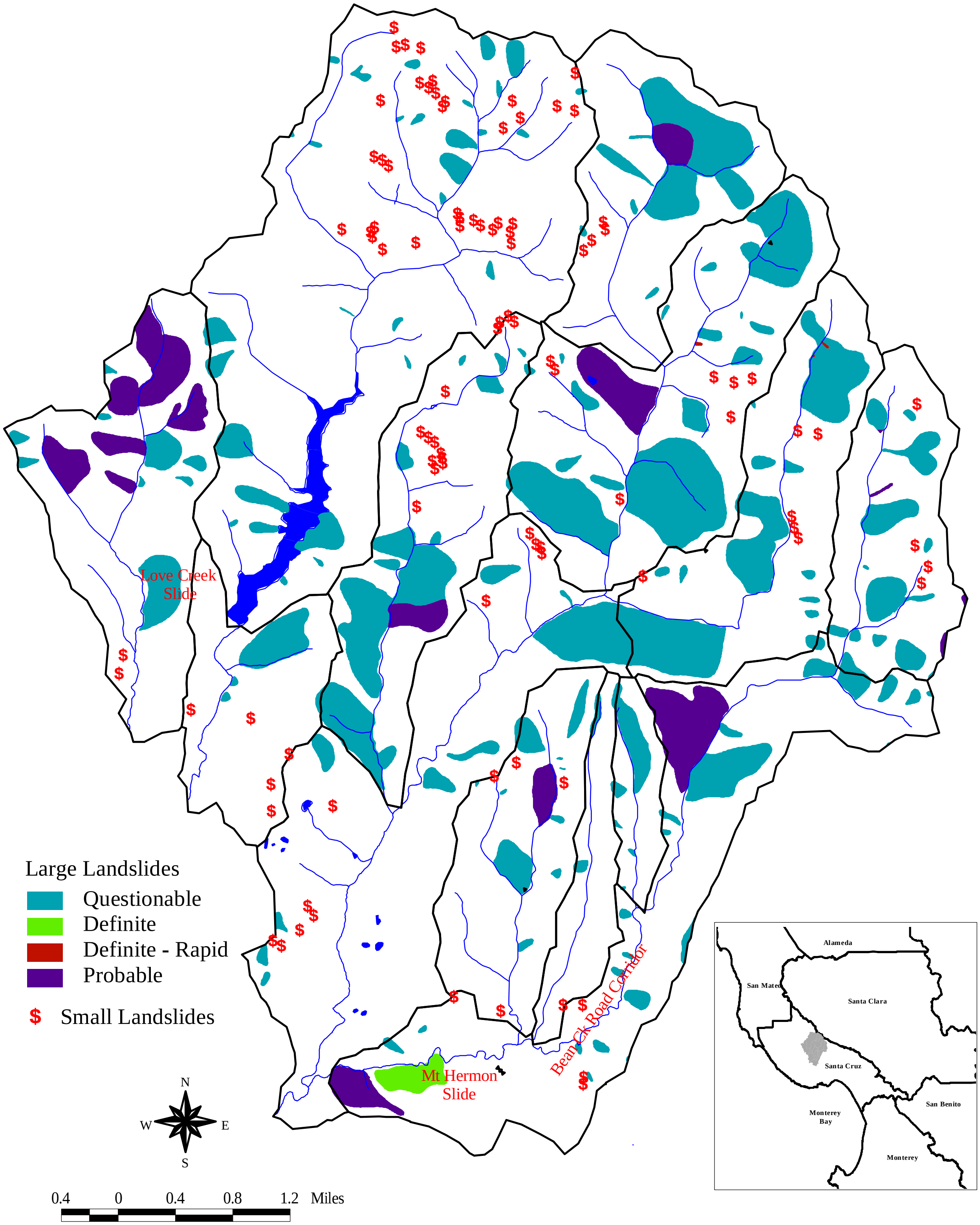

Figure A-7: Mapped landslides for Zayante, Newell, and Love Creeks. Landslides were digitized by the USGS based on a preliminary map of landslide deposits in Santa Cruz County, California, by Cooper-Clark and Associates, 1975. Note - Landslides occurring after 1970 are not represented on this map.

colluvium. When the rate of rainfall exceeds the rate that the colluvium and soil can drain water off, the saturated zone or water table above the less permeable bedrock deepens. When the saturated mass overcomes the resistance holding it on the hillslope, the mass liquefies instantly and moves down the hillslope carrying trees, soil, propane tanks and sometimes entire houses. In some cases, water separates from the debris flow mass as it reaches lower gradients and a debris torrent is unleashed - a wall of mud and debris that moves very fast and is extremely destructive. Debris flows and torrents commonly form the small alluvial fans distributed along the edges of higher order stream valleys at the end of ephemeral tributary basins. In the January 2-4, 1982 storms, debris flows and nearly continuous shallow failures in the inner gorge slopes occurred throughout the Santa Cruz Mountains.

Appendix A.5 Soils

Soils vary depending upon underlying parent materials, geomorphic history, microclimate, aspect, vegetative cover, and local relief. On ridgetops and upper hillslopes, bedrock units dominate the parent material with soil units being differentiated by slope, aspect and vegetation cover. On landslide masses, in colluvium and alluvium, parent materials have mixed lithologies and the soils exhibit a variety of textures and structure. These mixed soils overlay alluvial and terrace deposits along the major streams and on the colluvial slope deposits that fill many swales and hollows in headwater areas.

In general, it can be stated that soils underlain by permeable sandstones, typical of the south of Zayante Fault Geology area, are classified as deep and well drained to excessively well drained. These sandy and sandy loam soils are dispersed throughout the San Lorenzo Valley, most notably in areas underlain by the Santa Margarita formation. Soils formed from mudstones and shales tend also to be deep and somewhat less well drained. Steep slopes and the gradual loss of topsoil to erosive forces often limit depths of soils in the study area. In alluvial areas, soils are generally deep and well drained. Several of the other sandstone formations and decomposed granite weather to soils that (western San Lorenzo River Watershed) are also sandy, deep to very deep, excessively well drained, and extremely erodible.

Appendix A.6 Faults and Seismic Activity

Faulting and seismicity pose a potential geologic hazard and contribute to overall sediment loading in the Santa Cruz Mountains. Evidence of past and active faulting is found within the study area. The San Andreas Fault parallels the northern boundary of the project area approximately two miles to the north. Numerous faults cross the San Lorenzo Valley, including the Zayante Fault, which runs east to west and crosses Ben Lomond Mountain (**Figure A-4**).

Movement along faults over geologic time has uplifted the Santa Cruz Mountains creating steep terrain. Over shorter periods, earthquakes may be responsible for large landslides, as was the case on Hinckley Creek in the Soquel Creek Basin in the 1906 quake where a logging camp was reportedly buried.

Earthquake movement could also theoretically enhance landslide failures if one were to coincide with a period of winter watershed saturation. The 1989 Loma Prieta Quake (magnitude 7.1) occurred during the least saturated time of the year and during a three-year drought period, but loosened and fractured hillsides, forcing the closure of Highway 17 through the Santa Cruz Mountains for several weeks. Significant damage to structures, roadways, and utilities occurred. Landslides and the reconstruction of residences and infrastructure contributed to both habitat impairing bed sedimentation and persistent turbidity in area streams and surface waters.

Appendix B

Framework for Estimating Sediment Delivery to Stream by Source

for the

Zayante Area Sediment Source Study

Appendix B. Framework for Estimating Sediment Delivery to Streams by Source

Quantifying sediment sources involves constructing a watershed sediment budget. A sediment budget is an accounting of the volume of sediments eroded by source (i.e. landslide, roads, etc.) and delivered to a selected discharge point, usually at the drainage outlet of the watershed where sediment transport in the stream has been measured. Ultimately, this study seeks to define sediment loads to a point where "excessive" sediment loading caused by land disturbance can be distinguished from natural "background" erosion.

In a sediment budget, the basic relation to be solved is the sediment continuity equation where:

$$O = I +/- \Delta S$$

Where:

O = Outflow of sediment at the discharge point (synonymous with sediment yield)

I = Inflow of sediment from erosion sources

ΔS = Change in alluvial storage in terrace, flood plain areas and channels where it is available for erosion and remobilization to the outlet discharge point.

The units for the variables are often expressed in tons per year (t/yr).

For natural background conditions, the Sediment Inflow (I) variable can be expanded to detail individual sources as follows:

Sediment Inflow (I) =

+ Landslides (debris flows, slumps that deliver sediment to the stream channel or to alluvial storage)

+ Surface erosion (sheet, rill and gully erosion)

+ Bed and bank channel erosion from tributary streams

For the disturbed condition, the following factors are added to the Sediment Inflow (I) variable:

+ Road surface erosion (road surface, shoulders, drainage ditches, sidecast and road cuts)
+ Road-caused surface erosion related to concentrated flow and drainage modification (e.g. gullies, culvert blow-outs)
+ Road-caused landslides due to side cast or fill failure and/or including hillslope failures caused by drainage and slope modifications
+ Surface erosion from areas cleared for urbanization or agriculture.
+ Accelerated channel erosion in tributary and trunk streams caused by aggradation from excessive delivery of sediment from hillslope and road sources, or by geomorphic response to direct modification (e.g. filling canyon floor with road fill and re-directing flow into hillslope).

For this study, the following steps were used to estimate sediment by the sources listed above in the disturbed condition sediment continuity equation. The sources were combined into natural source and land disturbance categories in order to assess treatment options:

1) Annual sediment yield data, represented by stream sediment transport measurements of suspended and bedload data was collected and analyzed to estimate the sediment outflow component (O). This data was taken by USGS gages at various time periods between 1970 and the early 1990s.
2) Field observations, existing data and reports, and experiences of previous investigators were compiled to differentiate sediment sources, land disturbance effects and define sediment source categories.
3) A GIS database layer of road types (paved, unpaved, private and public) was developed to quantify road densities by subwatershed. Field data supplemented assumptions regarding components of road sources (i.e. shoulders, road cuts, ditches and sidecast spoils and road geometry).
4) Sediment inflow estimates, by source, were developed by integrating roads and land use coverages in the GIS database with sediment yield rates for roads and cleared areas derived by CDF field studies (Cafferata and Poole, 1993). Adjustments to the CDF sediment yield rates were made based on site specific field work. These estimates are the equivalent of a non-point source analysis for a TMDL.

The product of this effort is an initial estimate of sediment sources causing impairment of aquatic habitat. Professional judgment is then applied to what percentage of each source is feasible to eliminate with erosion control measures and could, as a first approximation, achieve success in removing regulatory impairment. The initial focus of erosion control treatments will be a reduction in the supply of chronically eroded fine sediments within the proximity of streams.

Appendix B.1 Estimated Sediment Yields from Previous Studies

This section summarizes sediment yield data from previous studies using reservoir sedimentation, suspended sediment measurements taken at stream gages on Zayante

Creek and the mainstem San Lorenzo River, and published sediment yield estimates from other researchers. All of these studies were conducted after considerable land use disturbance had already affected the basin, and generally represent modern conditions. These measurements will be used to estimate sediment outflow (O) and compare results calculated by use of GIS data by subwatersheds (I), published erosion rates from study plots (CDF, 1993) and recent field surveys by SH&G staff.

B.1.1 Reservoir Sedimentation Rates at Loch Lomond Reservoir on Newell Creek

The Newell Creek Dam and the Loch Lomond Reservoir impoundment are located within the City of Santa Cruz watershed lands in the middle of the San Lorenzo River Watershed. The City of Santa Cruz Water Department controls land uses over 2,760 acres or 43 percent of this watershed, so that to a significant extent the land use is controlled. Land use in this area has been managed for multiple uses including recreation, timber harvest and open space, with sensitive habitat areas closed to the public. The remaining watershed area has a combination of timber harvest areas and private rural residential land.

Table B-1: Loch Lomond Reservoir Sedimentation Study Results

Year Measured (reference)	Calculated Sediment Yield	Notes
1998 (MacPherson and Harmon, 2000)	825 tons/mi^2/yr	Underestimation of sediment deposits in backwater area may have occurred.
1982 (Fogelman and Johnson, 1985)	Not Calculated	Reservoir sedimentation rate not done as survey results show an increase in reservoir storage.
1971 (Brown, 1973)	1100 tons/mi^2/yr	Based upon surveys of backwater delta deposits at the mouths of streams entering reservoir.

Since its completion in 1960, the reservoir has trapped an estimated 95 percent of inflowing sediments from 9.9 square miles (6,350 acres) of contributing drainage area. Measurements of trapped sediments by sequential reservoir capacity surveys were completed in 1971, 1982, and 1998 (**Table B-1**). These surveys have provided general erosion rates with limited success due to the differences in surveying methods and precision (Brown, 1973; MacPherson and Harmon, 2000).

The 1998 survey concluded a reduction of 55 acre-feet since 1982, however there were problems with comparisons to earlier surveys due to changes in measurement techniques. In addition, it appears that deposits in backwater areas of streams were excluded from the 1998 survey. Given the drainage area above the dam, the resulting rate of erosion would be 825 tons/mi^2/year.

Earlier sediment yield estimates (Brown, 1973) were derived from reservoir surveys conducted in 1971 and compared with the original survey of the impoundment area in

1960. An estimate of 46 acre-feet of sediment accumulated over an 11-year period from 1960 to 1971, resulting in a sediment yield from the contributing watershed of 1,100 tons/mi^2/year.

Bathymetric data from a survey conducted in 1982 yielded a reservoir capacity of 8,824 acre-feet, exceeding the original 1960 survey of 8,600 acre-feet. The authors of the 1982 study concluded that

> "…***accuracy of the base maps and initial surveys does not allow reasonable estimates of the quantity of sediment deposited since 1960."*** (Fogelman and Johnson, 1985).

An explanation is not provided regarding why the 1982 survey did not yield reasonable results in contrast to the 1971 survey. Brown (1973) states in the 1971 survey that the precision of the 1960 topographic survey is probably +/- 3.0 feet, though he does not address accuracy and precision in detail.

B.1.2 SEDIMENT YIELD ESTIMATES FOR THE ZAYANTE AREA & OTHER CALIFORNIA COASTAL RANGE RIVERS

Since sediment yield estimates are often location dependent and subject to large annual variations due to changing climatic and land use conditions, they should be compared to other local and regional estimates. When extrapolating sediment yield values between drainage basins, consideration of the differences in geology, soils, terrain, land use, drainage basin area and stream order must be considered. Headwater streams will tend to have higher sediment yields than trunk streams due to relatively steeper channel gradients and lack of floodplain storage. This section will outline sediment yield estimates on Zayante Creek made by other investigators, yield estimates made on other creeks and rivers in the region and results from reservoir sedimentation studies on other creeks in the California Coast Range.

Table B-2 summarizes published estimates made by HEA (1980) and U. S. Department of Agriculture Soil Conservation Service (SCS, 1979) as part of the Zayante Dam feasibility study. The methods used for these estimates were to take measured suspended sediment load data from the Zayante Creek gage and extrapolate the results to the other watersheds based on known differences in geology, soils, and land use.

Tables B-3 and **Table B-4** summarize sediment yield estimates and reservoir sedimentation studies made for creeks and rivers throughout the Coast Ranges of California from Humboldt to Los Angeles Counties. The numbers suggest a wide range in sediment yield estimates due to a variety of land uses, geology, soils, climate, and, in some cases, a limited period of record. Low sediment yield values are found in areas of resistant rock and a relatively dry climate like Coyote Creek, whereas high sediment yields are found in areas of erodible rock (Los Angeles County streams) or wet, heavily forested areas with intensive land use (Humboldt County).

Table B-2. Selected Sediment Yield Estimates from Previous Studies for Zayante Area Streams

Location	Drainage Area (mi^2)	Source	Years	Estimated Yield
Zayante Creek	6.4	HEA	1980	3000 $tons/mi^2/yr$
Mountain Charlie Gulch	2.8	HEA	1980	3000 $tons/mi^2/yr$
Lompico Creek	1.3	HEA	1980	2800 $tons/mi^2/yr$
Upper Bean Creek	2.6	HEA	1980	3000 $tons/mi^2/yr$
Bean Creek	9.3	SCS	1979	1340 $tons/mi^2/yr$

Table B-3. Published Annual Sediment Yields for the Coast Ranges of California

River/Stream	Sediment Yield ($tons/mi^2$)	Watershed Area (mi^2)	Period of Record	Investigator	County
Redwood Creek	4750	278	1954-1997	USEPA and Knott, J.M. (1981)	Humboldt
Redwood Creek	5485	278	1954-1997	Madej and others (unpubl)	Humboldt
Garcia River	1400	114	1952-1997	PWA (1997)	Mendocino
South Fork Caspar Creek	680	1.83	1962-1998	PWA (1997)	Mendocino
North Fork Caspar Creek	1111	1.64	1962-1998	PWA (1997)	Mendocino
Navarro River	1200	303	1980-1988	Trihey and Assoc. (1997)	Mendocino
Arroyo Grande Creek	380	13.5	1943-1972	Knott, J.M. (1976)	San Luis Obispo
Lopez Creek	1800	21.6	1943-1972	Knott, J.M. (1976)	San Luis Obispo
Santa Rita Creek	1100	18.2	1943-1972	Knott, J.M. (1976)	San Luis Obispo
Uvas Creek	1337	21	1967-1969	Knott, J.M. (1973)	Santa Clara
Coyote Creek	813	109	1967-1969	Knott, J.M. (1973)	Santa Clara
Arroyo Valle	1000	147	1967	Knott, J.M. (1973)	Contra Costa
Colma Creek	6768	10.8	1966-1970	Knott, J.M. (1973)	San Mateo
Little Santa Anita Canyon	22262	2.4	1938, 1943, 1952	Tatum (1965)	Los Angeles
Pickens Canyon	43069	1.7	1938, 1943, 1954	Tatum (1965)	Los Angeles

Table B-4. Reservoir Sedimentation Rates for the Coast Ranges of California

Stream	Drainage Area (mi^2)	Annual Sedimentation Rate ($tons/mi^2$)
Stony Creek	741	6824
Los Gatos Creek	5.3	387
Walker Creek	5.7	1161
Eel River	288	1718
Matanzas Creek	11.6	2081
Atascadero Creek	1	1161
Walnut Creek	3.1	1597
Coyote Creek	120	774
Carmel River	125	1921
San Francisco	23	943
Russian River	105	2250

B.1.3 SEDIMENT YIELD DATA MEASURED FROM FIELD GAGES

Table B-5. Suspended Sediment Yields estimated from USGS Stream Gage Sediment Data

Gage Location (drainage area)	Suspended Sediment Measurement Record	Published Daily Streamflow Record	Average Yield for period sediment measured	Average Synthetic Suspended Sediment Yield over flow record	Notes
San Lorenzo River, Big Trees (106 mi^2)	1973-1982	1939-1998 (gage still active)	2770 $tons/mi^2/yr$	2320 $tons/mi^2/yr$	Synthetic yields were derived by comparing measured yields to flow volume
Zayante Creek (11.1 mi^2)	1970-1973	1958-1992	2350 $tons/mi^2/yr$	4900 $tons/mi^2/yr$	

The longest record of sediment discharge and stream flow in the San Lorenzo River Watershed was measured by the U.S. Geological Survey at Big Trees gaging station at Henry Cowell State Park in Felton (**Table B-5. –** Drainage Area = 106 square miles). To extend the sediment yield record beyond the limited years measured, an annual sediment yield rating curve **(Figure B-1)** was generated by plotting measured annual suspended sediment yield against annual stream flow volume. This rating curve was then used to extrapolate sediment yields over the longer stream flow record (1939-1998) yielding an average rate of 2,320 $tons/mi^2/yr$ (**Figure B-2)**. The long-term average sediment yield for the Big Trees gage using the synthetic record is 2,320 $tons/mi^2/yr$ with a range between 16,400 $tons/mi^2/yr$ and 40 $tons/mi^2/yr$.

The same procedure was applied to the suspended sediment data measured at the USGS Zayante Creek Gage (Drainage Area = 11.1 square miles) between 1970 and 1973 (**Table B-5**). The average sediment yield for the period of sediment measurements is 2,350 $tons/mi^2/yr$. A sediment yield rating curve was developed **(Figure B-3)** and extended over stream flow

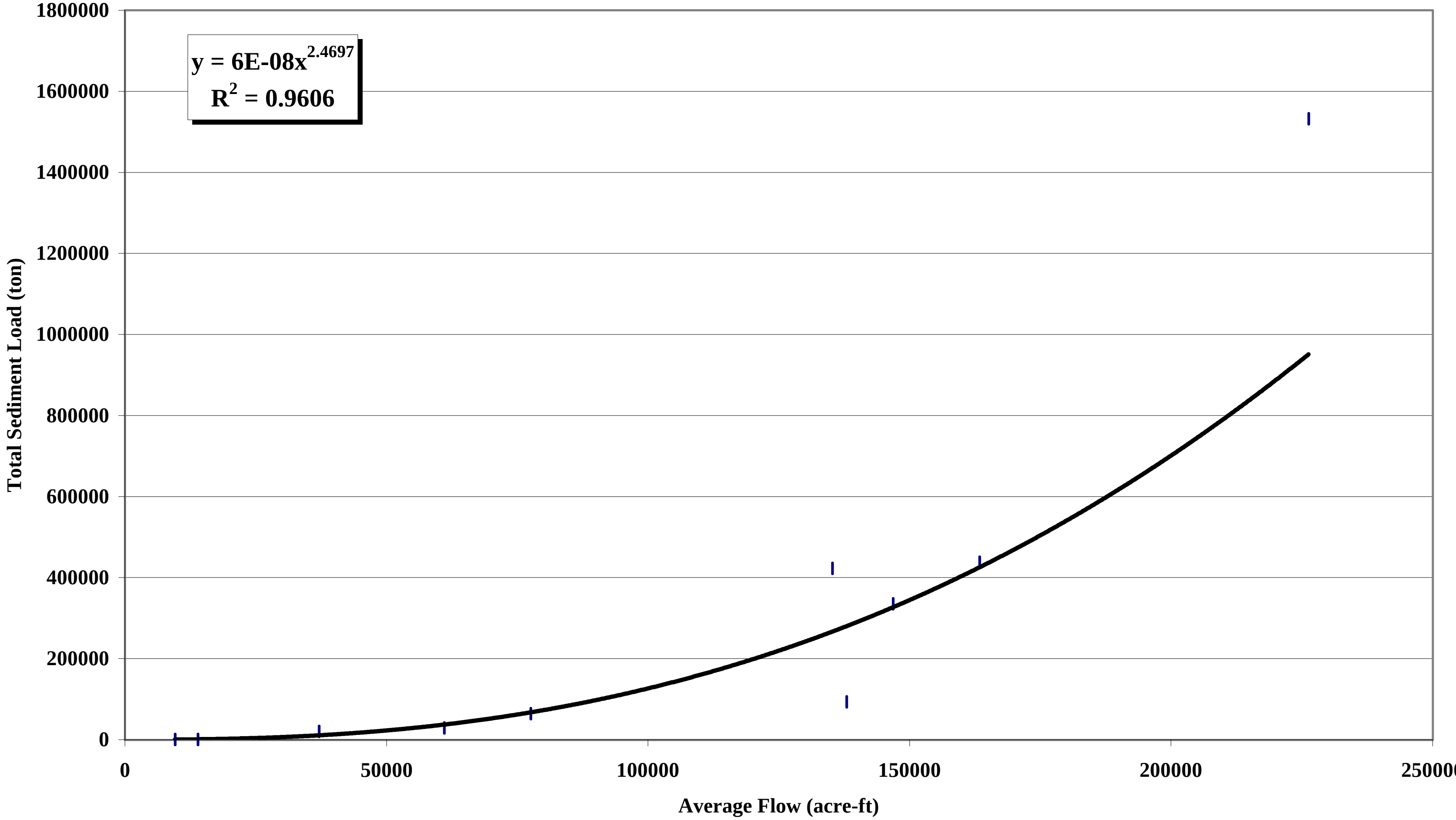

Figure B-1: Sediment yield rating curve for the San Lorenzo River at Big Trees (Station #11160500). Data points represent sediment gaging from 1973 to 1982 with concurrent flow data.

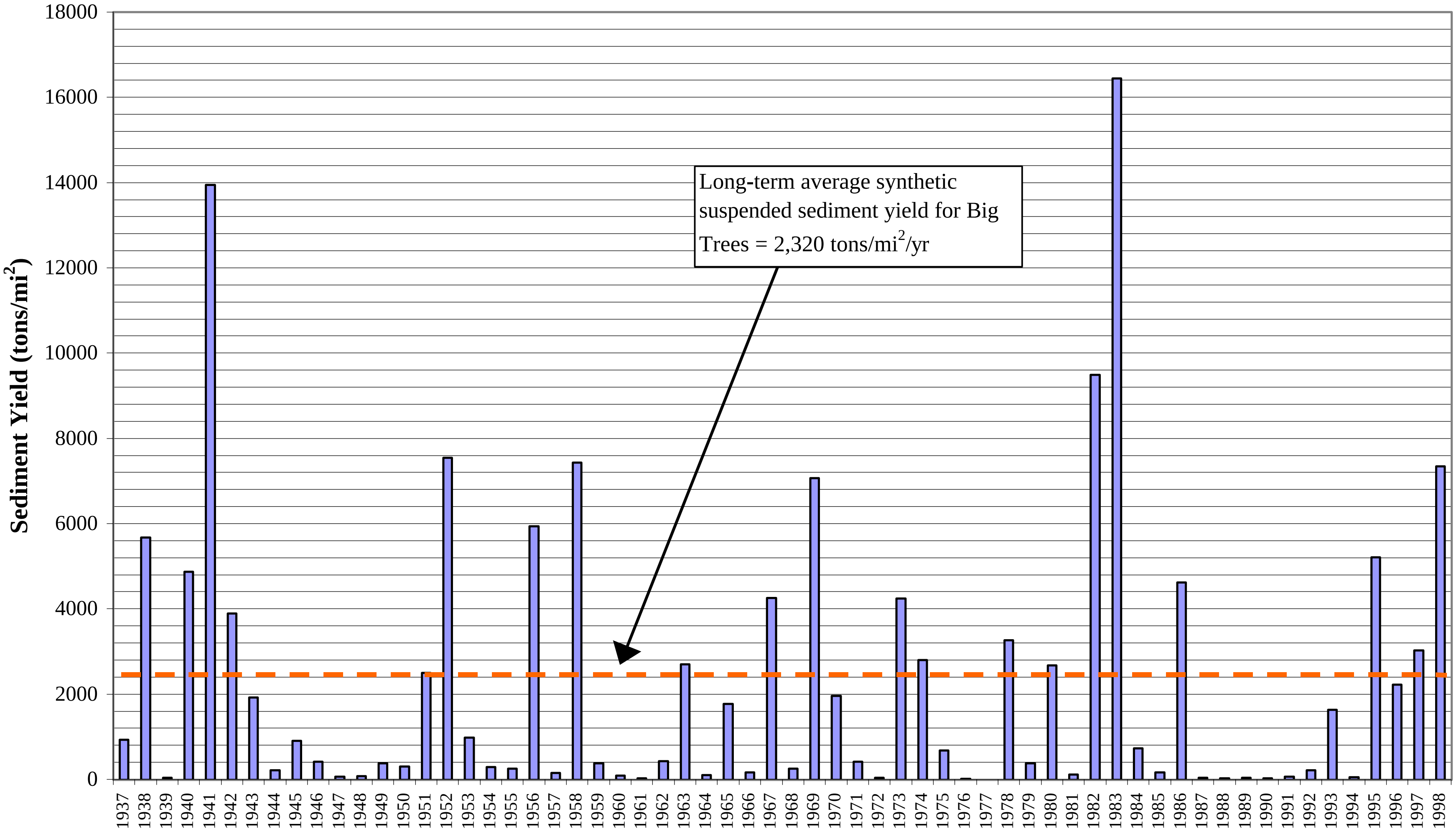

Figure B-2. Synthetic Suspended Sediment Yield for the San Lorenzo River at Big Trees (Station 11160500). The synthetic record was developed from a rating curve of suspended sediment vs flow volume (Figure 13). The dashed line represents the long-term average sediment yield for the synthetic record.

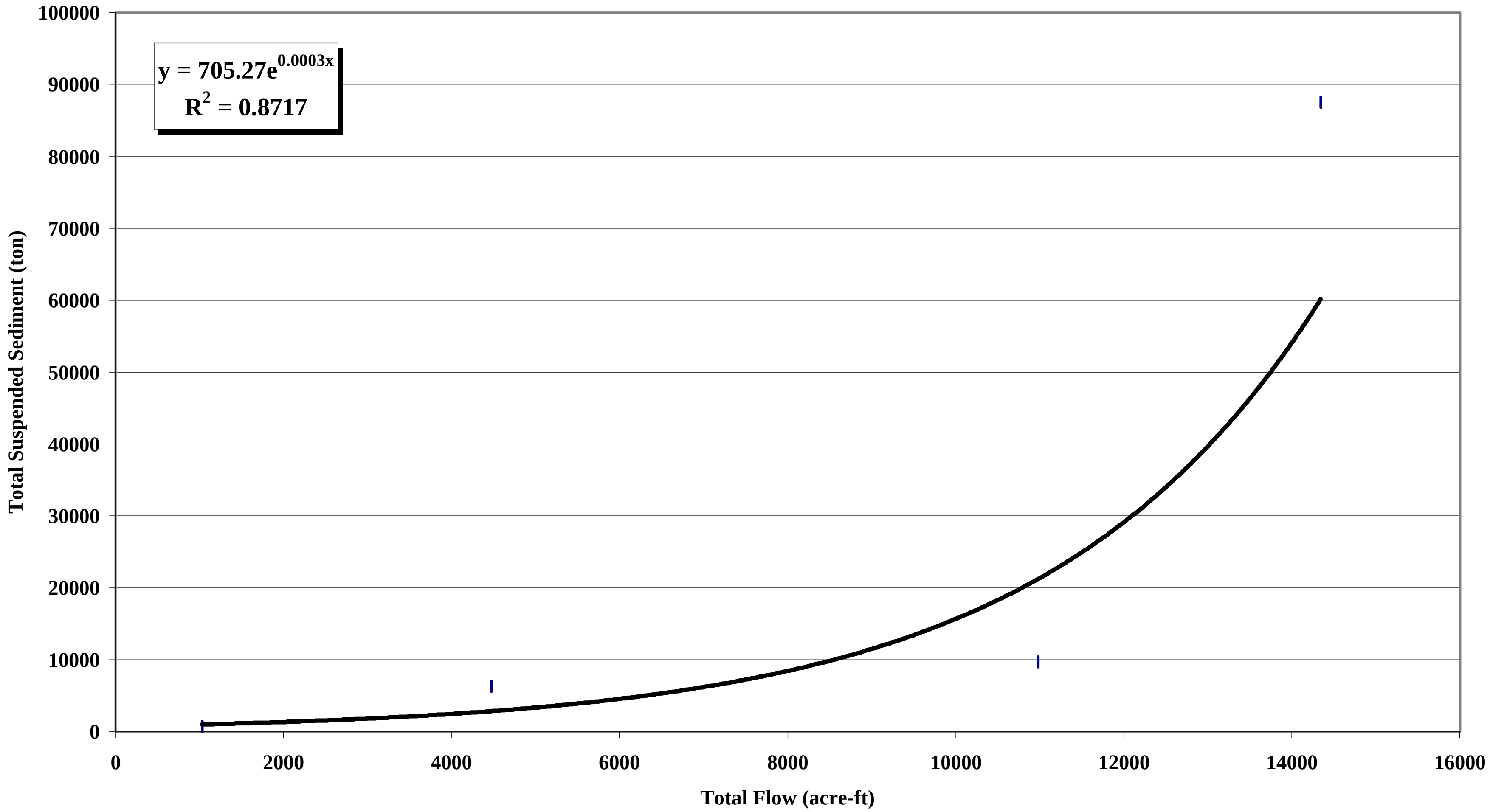

Figure B-3: Sediment yield rating curve for Zayante Creek at Zayante (Station #11160300). Data points represent sediment gaging from 1970 to 1973 with concurrent flow data.

records taken between 1958 and 1992 (**Figure B-4)**. The extended synthetic record produced a suspended sediment yield of 4,900 tons/mi^2/yr after removal of an outlier. The outlier value from 1983 of 760,000 tons/mi^2/yr was removed to produce a reasonable average sediment yield value for the period of flow records. The synthetic yield estimates ranged from 70 tons/mi2/yr to 17,000 tons/mi^2/yr. The extrapolated annual sediment yield may overestimate current yields as land use practices may have improved since the 1970-1973 data collection period. Conversely, land use may have expanded spatially and recent years of heavy rainfall (i.e.- 1995, 1998) has certainly increased the annual yield. Visual observations by Santa Cruz County staff have indicated improvements in surface erosion over the past 20 years due to erosion control ordinances and programs. Bedload was measured at both Big Trees and Zayante Creek gages at various times, however the flow was relatively low when measurements were taken. In general, bedload at the stream gage location probably results in total sediment yields 4-10 percent higher than the suspended loads. In the upper watershed, bedload transport rates would be expected to be higher.

The average sediment yield for both the San Lorenzo River at Big Trees and Zayante provides essential information for this study. Sediment yield data for individual years describes the variability in erosion rates from year to year and reflects the climatic variability typical of streams in Mediterranean climates. Conversely, a long-term sediment yield estimate ignores year-to-year variability and provides a context for determining average erosion conditions in the watershed. In terms of constructing a sediment budget, the long-term sediment yield estimate from gaged locations in the watershed provides the Output (O) in the sediment continuity equation discussed earlier as well as a back check to determine if all sediment sources in the watershed are being considered along with the appropriate magnitudes.

The results from this analysis show that the long-term average sediment yield estimate for Zayante Creek is approximately twice as large as the estimates for San Lorenzo River at Big Trees. This is most likely due to several factors including:

- A larger fraction of the Zayante basin relative to the San Lorenzo River is characterized by steep terrain with high erosion potential
- Subwatersheds on the western margin of the San Lorenzo River have lower sediment yield than Zayante due to less erodible geology and lower channel gradients
- More channel and floodplain sediment storage occurs on the San Lorenzo River than on Zayante
- Sediment from Upper Newell Creek is blocked by Loch Lomond Dam, representing a lost sediment supply of about 8 percent of the total drainage area.

This study uses the sediment yield estimates to compare with independent sediment yield estimates derived from the application of CDF (1993) road and timber harvest area erosion rates to the GIS road and timber harvest areas database. In other words, the sediment yields measured at stream gages should represent Outflow (O) in the sediment continuity equation and should roughly equal sediment inflow (I) from natural and

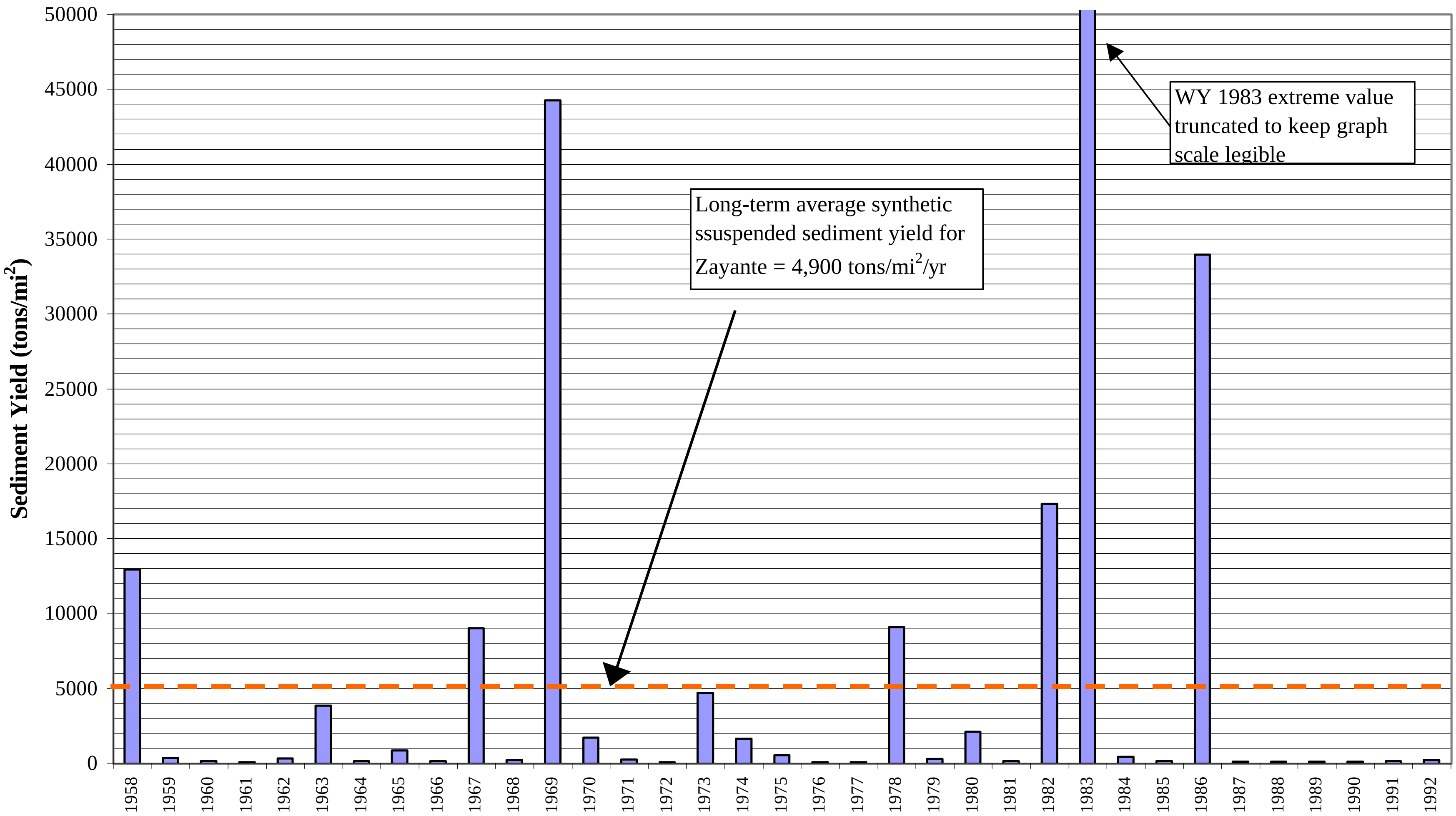

Figure B-4. Synthetic Suspended Sediment Yield for Zayante Creek at Zayante (Station 11160300). The synthetic record was developed from a rating curve of suspended sediment vs flow volume (Figure 14). The dashed line represents the long-term average sediment yield for the synthetic record, excluding 1983.

accelerated erosion sources. For this purpose, the Zayante Area streams are likely in the range of the 4,900-tons/mi^2/yr because the long term average at Big Trees should be less due to its location in the watershed (lower gradient/ higher order stream).

The differences in alluvial sediment storage changes (ΔS), in the long term, is probably zero or increasing slightly due to increased sediment supply since alluvial storage sites are limited in the deep narrow canyons of the Zayante Area Streams and the San Lorenzo River. This assumption simplifies the process of estimating a sediment budget and is appropriate for analyzing chronic sources of fine sediment. However, extreme events may load alluvial storage in stream channels and tributaries and re-distribute it in subsequent years. This process is known in fluvial geomorphology as alluvial "cut and fill" sequences. Episodic sediment events will often fill channels that are subsequently scoured by later storm events. On top of this, chronic erosion causes smaller-scale cut-and-fill sequences. **Figure B-5** shows a conceptual diagram of sediment storage changes through cut and fill sequences for chronic sources (annual sheet flow and gullies) and episodic sources (landslides and debris flows).

This model fits the Santa Cruz Mountain Landscape in some respects where extreme events of sediment loading from landslides on hillslopes are easily observed. However, there is a timing offset in the continuity equation as flushing and actual degradation of stream channels was documented after the January 2-4, 1982 storms (Nolan et al, 1984), an event legendary for landsliding in Santa Cruz County. Evidence of stream channel cut and fill have been found in Lower Bean Creek where successive stands of alders, a species that germinates and thrives near the low flow channel edge, are found distributed in zones of even aged stands from the channel bed to top of a 12-foot high bank. Other important factors of alluvial storage include formation of logjams and hydraulic controls that cause backwater disruption to sediment transport continuity.

There are probably some modifications to alluvial storage processes that are caused by human activity, most notably increases in landsliding caused by drainage modification of roads. However, they are likely linked to the same problems that cause chronic erosion (such as road drainage) and as a result are addressed to some extent in an estimate of surface erosion. Further research is warranted for the Santa Cruz Mountains to more precisely quantify the role of land disturbance in landsliding and to assess the implications to alluvial storage and stream channel instability under "normal" flow years subsequent to extreme events.

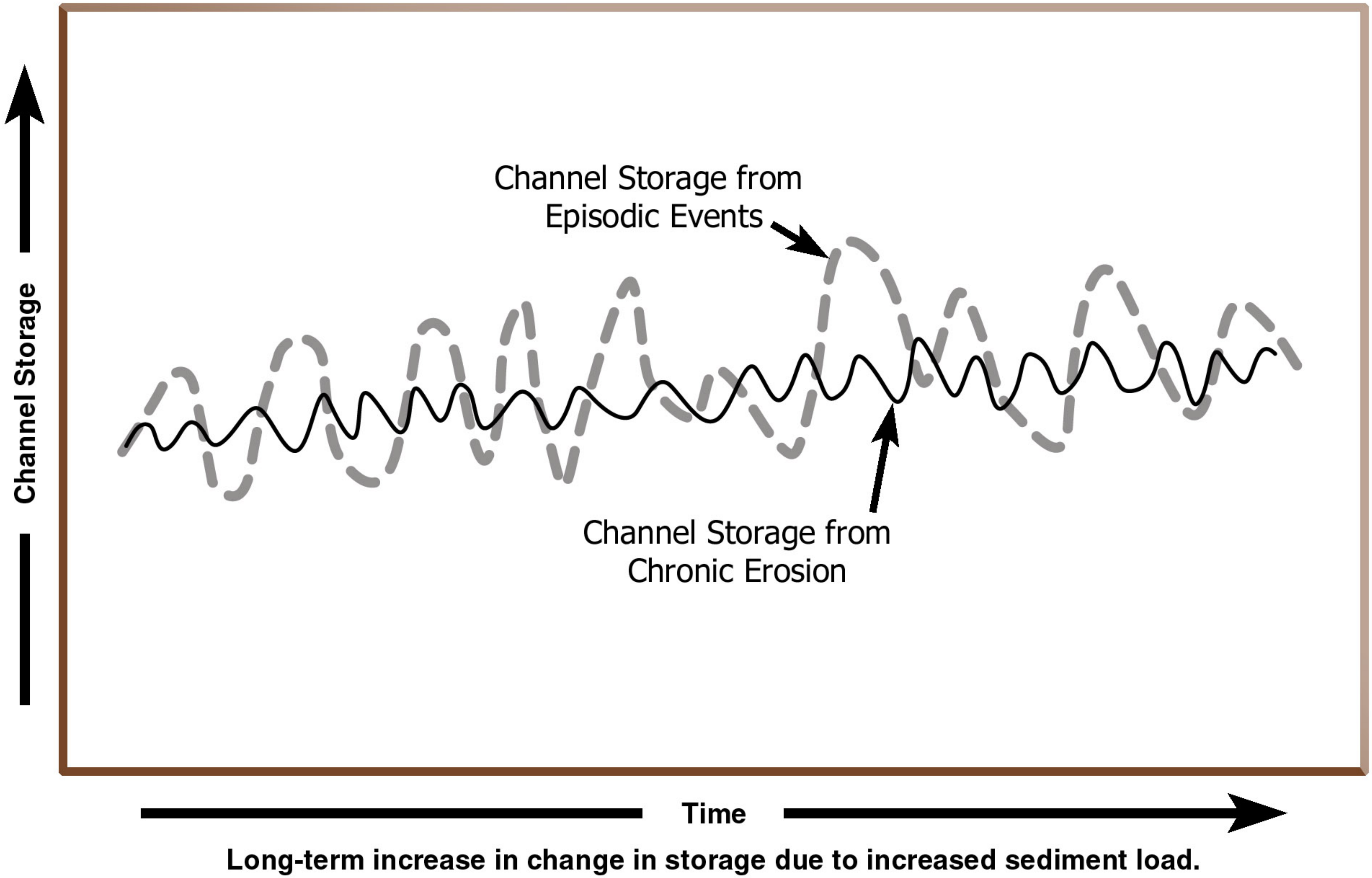

Figure B-5: Conceptual figure showing the effect of chronic and episodic sediment sources on channel storage. Episodic channel aggradation from mass wasting and large storm events can be characterized as low frequency and high magnitude, whereas, chronic aggradation from surface erosion can be characterized is high frequency and low magnitude. Channel responses to these different sediment events are similar though the timing of response and impact to biological systems are different.

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Appendix C

Sediment Generation Potential by Subwatershed

for the

Zayante Area Sediment Source Study

Appendix C. Sediment Generation Potential by Subwatershed

This section discusses sediment generation potential on a subwatershed level examining natural factors and human disturbance. Natural factors are examined by comparing available maps of landslides with geology. The distribution and magnitude of human disturbances over the natural terrain was analyzed by placing road layers and mapped landslides over the landscape and assessing relative densities.

Appendix C.1 Correlation of Landslide and Geology Maps

Excessive erosion and stream sedimentation can often be attributed to the combined factors of the weakness of underlying geologic formations and their susceptibility to erosion and overlying land-use disturbance. The geologic formations found in the Santa Cruz Mountains have erosion rates ranging from extreme (Santa Margarita Sandstone) to moderate (Lambert Shale) (Mount, 1979) with a relatively dense network of roads and related disturbance. A correlation of landslides with geology can reveal general weaknesses in different rock types and a source of potentially high sediment production, especially when disturbed.

Landslide maps for this study were prepared by the USGS (Roberts and Barron, 1998) from hard copy maps entitled, "*Preliminary Map of Landslide Deposits in Santa Cruz County, California*" (Cooper-Clark and Associates, 1975). Landslides were mapped using aerial photos dating between the 1950s and 1970 and compiled on a map scale of 1:62,500. Large landslides are represented by polygons and small landslides represented by points. One limitation of this information is lack of recent data (up to 1970 only), including significant storm years of 1982, 1983, 1995 and 1998. A second limitation is that mapping landslides in forested terrain is hampered by forest canopy and shadows. The detail of the USGS digital landslide maps is coarse, given the relatively small watershed areas. Discussions with several geologists experienced in the area revealed a general mistrust of its accuracy of the Cooper-Clark (1975) landslide map that serves as the basis of the USGS map.

For the broad level purposes here, it can be assumed that although landslide densities may vary from year to year these maps are a reasonable representation of landslide sediment sources and landslide susceptibility. Updating the landslide maps using data generated through the County's Geologic Hazard Ordinance could greatly improve map precision.

When considering the geology of the region **(Figures A-3 and A-4)** most of the subwatersheds with high landslide susceptibility are on the north side of the Zayante Fault. To understand this relationship, a value from 1 to 5 was assigned to each rock type based on erodibility indices of low to high developed by Brown (1973). The percent of each geologic type within the study area, mapped as landslide, was then calculated. The results, presented graphically in **Figure C-1** suggests a negative correlation exists between rock unit erodibility and incidence of landsliding (with a correlation factor of 0.67).

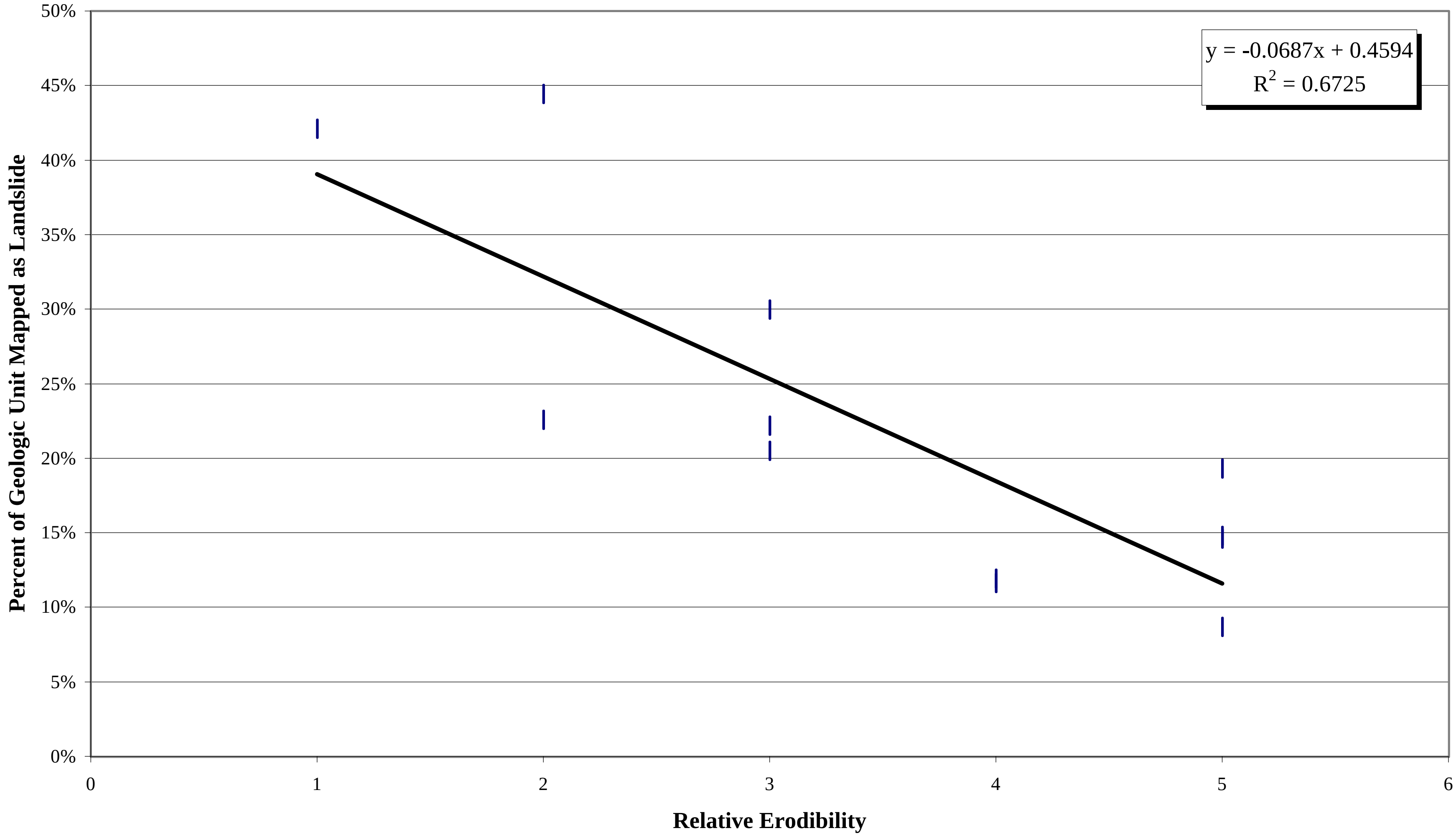


Figure C-1: Percent of geologic unit mapped as landslide within the Zayante Area Watersheds is plotted against the relative erodibility of each geologic unit from Brown (1973). The results show that landslide occurrence is inversely related to erodibility. This suggests that more cohesive geologic units are more suspeptible to landslides than less cohesive units.

Though this may seem counterintuitive, rock units that are highly susceptible to surface erosion are generally less cohesive and appear not to be as susceptible to mass failure landsliding as more cohesive but less erodible rock units. Highly erodible rock units may be constant surface erosion sources rather than episodic. This would tend to distinguish the area south of the Zayante Fault as susceptible to surface erosion and the area north of the Zayante Fault as more susceptible to large scale, deep seated landslides.

Appendix C.2 Landslide Density Mapping by Subwatershed

The percent of landslides occurring within each subwatershed was computed as a measure of potential sediment yield from landslide sources. Due to the coarse scale of the data and the fact that more recent landslide events are not included, the use of this product in our analysis is to show relative susceptibility of each subwatershed to landslide activity. Since small landslides were only mapped as points, assumptions about the size of each point were made. Roberts and Barron (1998) describe small landslides as being between 50 and 500 feet in size. Using an average width and length of 275 feet, each small landslide was assumed to have an area of 75, 625 ft^2 (275 ft * 275 ft). The percent of the total subwatershed mapped as “landslide” was calculated. Landslides falling within 200 feet of a stream corridor were selected to estimate how many slides affect the inner gorge slopes and may deliver sediment directly into the stream. Results for these calculations are presented in **Table C-1. Figure C-2** shows the overall density of mapped landslides by subwatershed and the density within inner gorge slopes.

The results suggest that Upper Zayante, Lompico, and Mountain Charlie subwatersheds are highly susceptible to landsliding. Conversely, MacKenzie, Upper Newell, and Lower Zayante show a low susceptibility to landsliding. The Upper Newell Creek watershed has the lowest density per unit area, which may reflect the relative lack of disturbance occurring in 1970. Low landslide density may reflect the relative low level of disturbance on City of Santa Cruz watershed lands.

Upper Zayante, Upper West Zayante, Lompico, Love Creek and Mountain Charlie Gulch watersheds all have over one quarter of their watershed areas mapped as landslides. This is significant because within these units, the slide proximity to stream corridors is high and major roads occur within inner gorge slopes. These roads fail and are closed recurrently during storms due to well-known geologic instabilities.

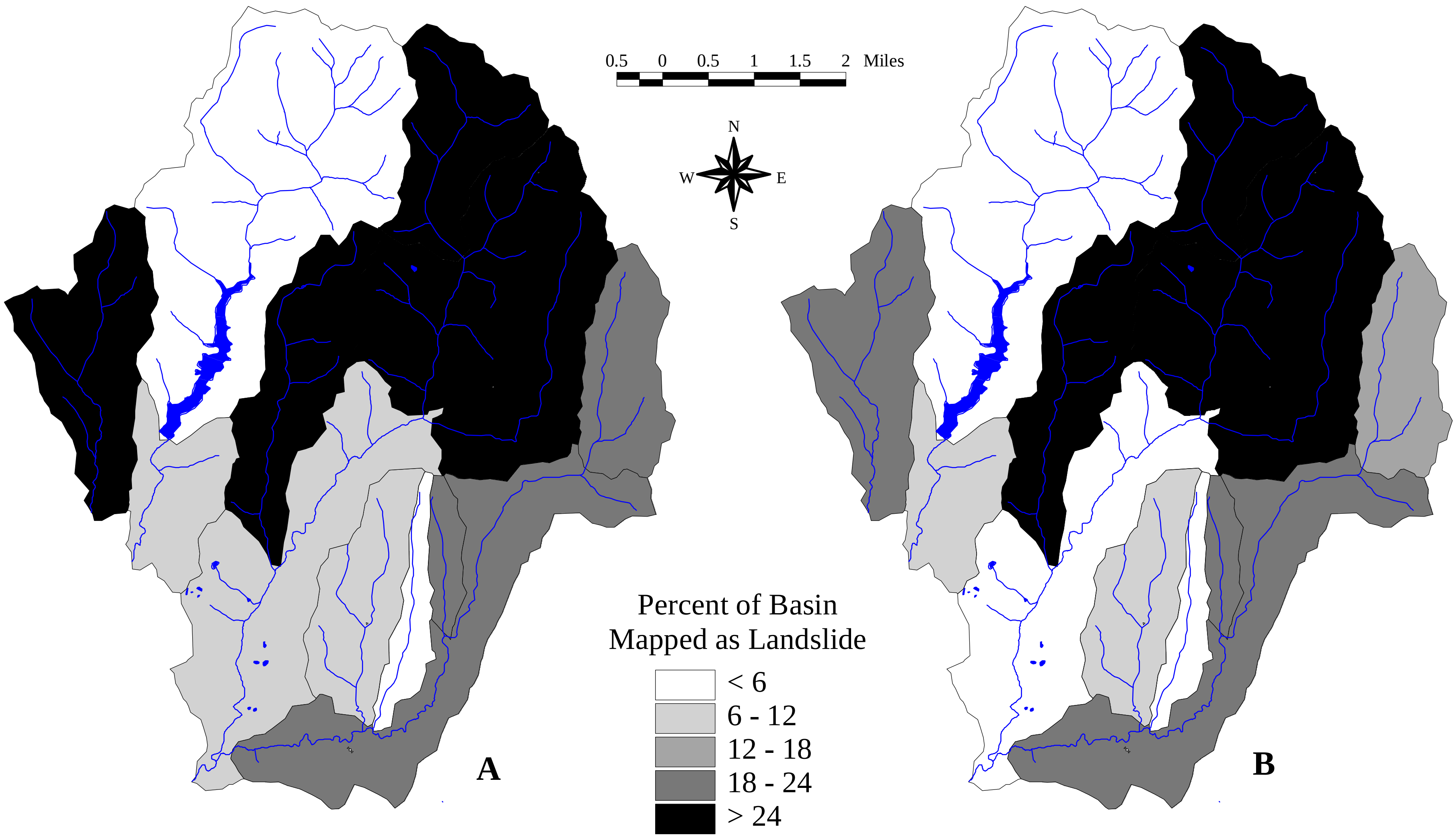
Appendix C.3 Roads Density Analysis

A variety of human induced land use disturbance sources result in sediment delivery to stream systems. These disturbances are mostly associated with road networks, however, accelerated erosion can also result from non-road uses such as equestrian stables, construction sites and timber harvest areas. Since road networks are necessary for access to other disturbances, their density should provide a good index of overall disturbance levels.

Subwatershed	Probable Landslide	Questionable Landslide	Definite Landslide (Rapid)	Definite Landslide	Small landslides	All Landslides
Lower Bean	9%	9%	0%	2%	1%	20%
Upper Bean	1%	19%	0%	0%	1%	20%
Ruins	1%	21%	0%	0%	0%	21%
MacKenzie	0%	3%	0%	0%	0%	3%
Lockhart	3%	9%	0%	0%	0%	12%
Love	16%	9%	0%	0%	0%	25%
Lower Newell	0%	10%	0%	0%	1%	10%
Upper Newell	0%	5%	0%	0%	1%	5%
Lower Zayante	0%	8%	0%	0%	0%	8%
Upper Zayante	5%	30%	0%	0%	0%	35%
Lompico	3%	26%	0%	0%	1%	29%
Mountain Charlie	0%	29%	0%	0%	1%	29%
W Upper Zayante	3%	22%	0%	0%	0%	25%

Subwatershed	Probable Landslide within 200-ft of channel	Questionable Landslide within 200-ft of channel	Definite Landslide (Rapid) within 200-ft of channel	Definite Landslide within 200-ft of channel	Small landslide within 200-ft of channel	All Landslides within 200-ft of channel
Lower Bean	9%	7%	0%	2%	0%	18%
Upper Bean	0%	16%	0%	0%	0%	16%
Ruins	1%	19%	0%	0%	0%	19%
MacKenzie	0%	3%	0%	0%	0%	3%
Lockhart	3%	7%	0%	0%	0%	10%
Love	16%	7%	0%	0%	0%	23%
Lower Newell	0%	10%	0%	0%	0%	10%
Upper Newell	0%	4%	0%	0%	0%	4%
Lower Zayante	0%	6%	0%	0%	0%	6%
Upper Zayante	5%	29%	0%	0%	0%	34%
Lompico	3%	26%	0%	0%	0%	29%
Mountain Charlie	0%	27%	0%	0%	0%	27%
W Upper Zayante	3%	21%	0%	0%	0%	25%

Table C-1: Percent of each subwatershed mapped as landslide is shown along with landslides that affect inner gorge slopes (assumed to be 200 feet on either side of stream corridors).



A) All mapped landslides

B) Landslides within 200 feet of EMIS stream corridors

Figure C-2

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Road density is expressed here as road length per subwatershed area. The principle dataset used in the analysis was the County of Santa Cruz Environmental Management Information System (EMIS) "*streets*" layer **(Figure C-3)**. Road densities for the EMIS *streets* layer were calculated by summing up the total length of roads within each subwatershed and dividing by the size of the basin. The same calculations were made for EMIS *streets* located within 200 feet of a stream corridor or the estimated width of the inner gorge slopes. At this broad level of analysis, no attempt was made to field check or verify the EMIS *streets* map layer.

The EMIS *streets* layer does not include roads and skid trails developed as part of a timber harvest plan (THP). SH&G team members digitized all road and trail features on timber harvest planning maps dating back to 1987. With consultation from local foresters, mapped roads in the timber harvest plans were classified into seasonal, permanent, or skid trails resulting in the map shown in **Figure C-4** (this map also includes harvested areas). To account for the differences in construction and maintenance standards for THP roads, densities were calculated by type of road or skid trail feature. Occurrences of THP road types were also calculated for the 200-foot wide inner gorge slopes. The results are shown by road type.

The results for road density calculations are presented in **Table C-2.** These results are displayed graphically in **Figures C-5 through C-8.** The results indicate two patterns of modern watershed land use and disturbances. Public and private (EMIS) roads infringe upon fragile inner gorge areas of streams in the lower subwatershed areas, leading to the conclusion that management of these roads as chronic fine sediment sources is a significant issue. The subwatershed with the highest density of inner gorge roads is Lockhart Gulch followed by Bean Creek and Love Creeks.

The results for THP roads and skid trails indicate higher densities in the headwater zones and less so in the inner gorge area with the exception of Upper Bean Creek. This infers greater THP-type disturbance on higher gradient slopes. In general, the THP areas are outside of dense residential areas as expected, therefore the subwatersheds with high EMIS road densities (e.g. Lompico Creek, Upper Bean Creek, and Mackenzie Creek) have low THP density and visa versa. The exception is Lockhart Gulch, which has a relatively high density of public, private and THP roads. The subwatersheds with the highest THP permanent road densities are Upper Zayante Creek, Lompico Creek, and Lockhart Gulch. For THP seasonal roads, the subwatersheds with the highest densities are Mountain Charlie Gulch and Lockhart Gulch. For THP skid trails, the subwatersheds with the highest densities are Lockhart and Love Creek.

A dense public road network is associated with residential developments on steep hillslopes of the lower watershed areas the Zayante Study Area. In fact, road densities are high in all study area streams except for Ruins Creek, Mountain Charlie Gulch, and Upper Newell Creek. The main conclusions of this analysis for hillslope disturbances are that roads are widespread, dense in many areas and that where public roads do not exist THP roads usually do.

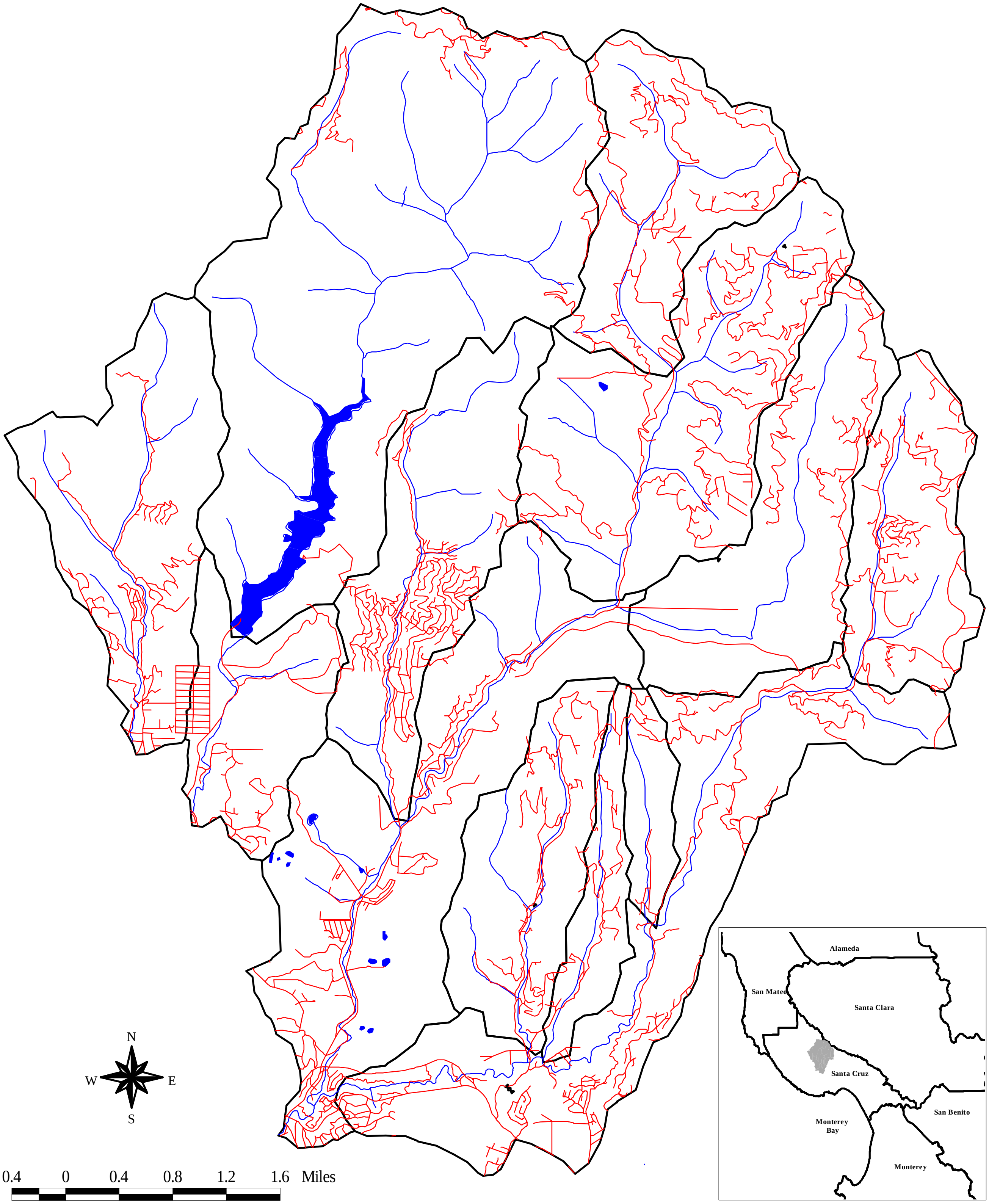

Figure C-3: Mapped Santa Cruz County Environmental Management Information System (EMIS) roads.

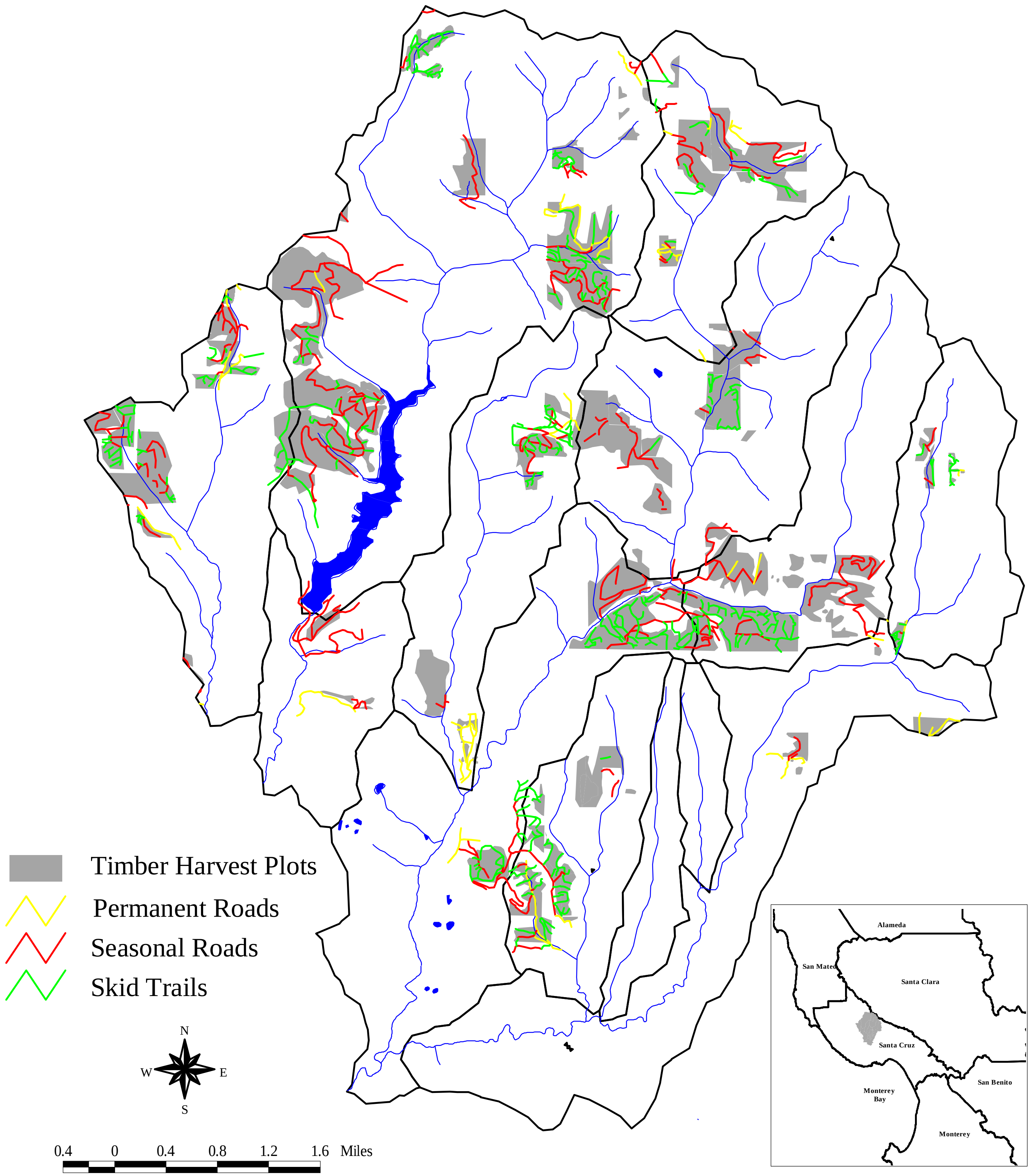

Figure C-4: Timber Harvest Plan (THP) boundaries, roads, and skid trails for Zayante, Newell, and Love Creek watersheds. The data was developed from THP plans dating from 1987-1998.

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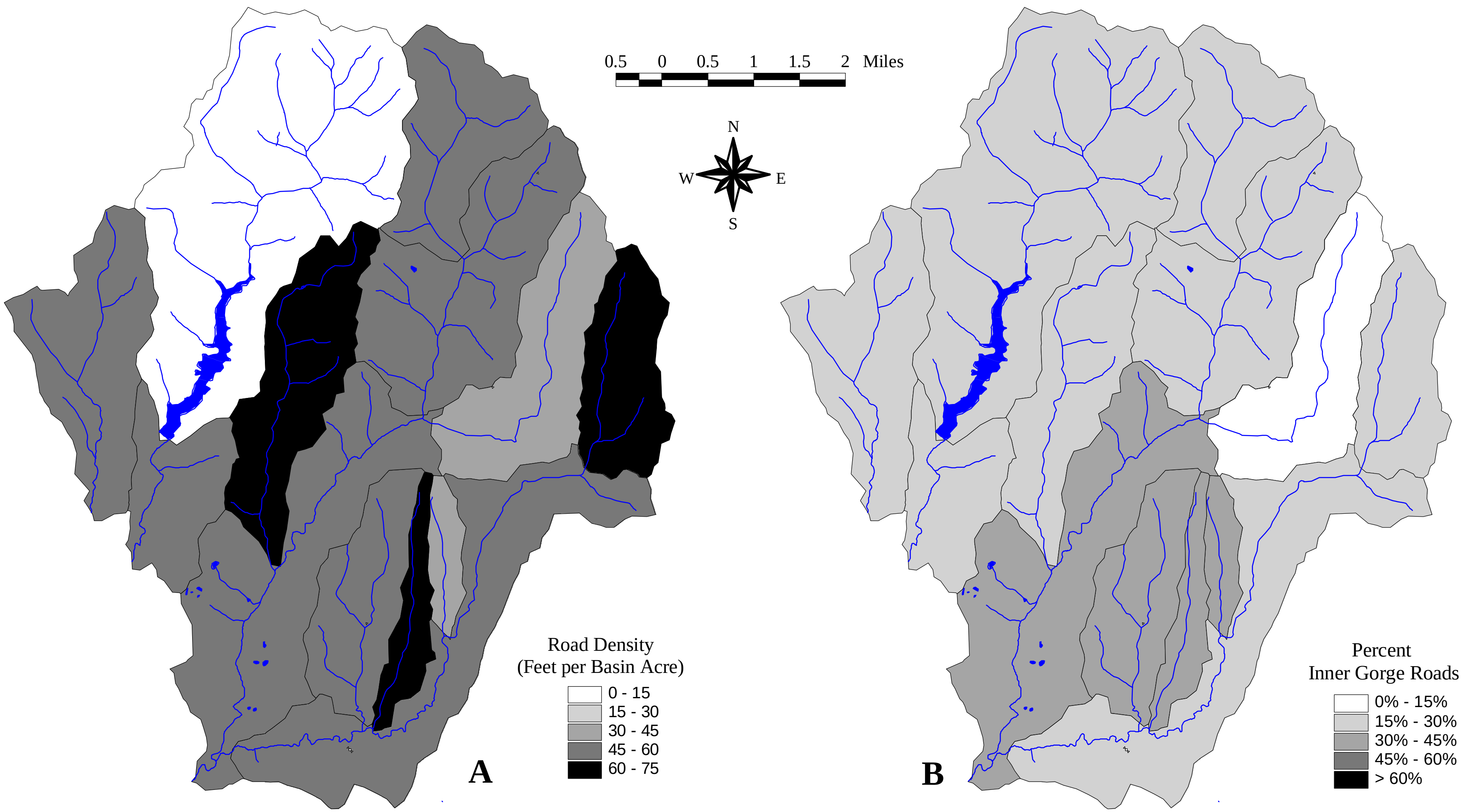
Subwatershed	Gravel THP Roads (ft/acre)	Gravel THP Roads within Inner Gorge (ft/acre)	Percent Inner Gorge	Seasonal THP Roads (ft/acre)	Seasonal THP Roads within Inner Gorge (ft/acre)	Percent Inner Gorge	THP Skid Trails (ft/acre)	THP Skid Trails within Inner Gorge (ft/acre)	Percent Inner Gorge
Lower Bean	4.3	0.0	0%	0.8	0.0	0%	0.0	0.0	0.00
Upper Bean	3.6	2.3	63%	1.6	0.6	38%	5.6	1.6	0.29
Ruins	0.0	0.0	0%	0.0	0.0	0%	0.0	0.0	0.00
MacKenzie	0.0	0.0	0%	0.0	0.0	0%	0.0	0.0	0.00
Lockhart	6.5	3.7	57%	14.4	1.9	13%	16.0	1.6	0.10
Love	5.8	3.0	52%	12.4	3.1	25%	11.8	1.9	0.16
Lower Newell	3.5	0.0	0%	12.8	3.2	25%	0.0	0.0	0.00
Upper Newell	3.7	1.2	32%	13.3	2.3	18%	8.5	2.0	0.24
Lower Zayante	0.8	0.0	0%	11.7	0.4	3%	9.8	0.8	0.08
Upper Zayante	7.0	0.0	0%	5.8	0.2	4%	3.2	0.4	0.12
Lompico	7.3	0.0	1%	4.7	0.8	17%	7.9	0.7	0.09
Mountain Charlie	2.9	0.0	0%	18.2	0.6	4%	10.1	1.5	0.15
W Upper Zayante	10.1	1.7	17%	11.7	2.3	20%	7.3	0.7	0.10

Subwatershed	EMIS Roads (ft/acre)	EMIS Roads within Inner Gorge (ft/acre)	Percent Inner Gorge	Percent of EMIS Roads Paved	Percent of EMIS Roads Unpaved	Percent Timber Harvest Plots	Percent Non-Timber Harvest Plots
Lower Bean	60.2	9.5	16%	69%	31%	1%	99%
Upper Bean	67.1	13.9	21%	42%	58%	1%	97%
Ruins	38.7	14.4	37%	37%	63%	0%	100%
MacKenzie	62.6	24.1	39%	21%	79%	0%	100%
Lockhart	50.5	19.7	39%	17%	83%	6%	85%
Love	46.4	14.1	30%	18%	82%	10%	83%
Lower Newell	56.3	9.4	17%	38%	62%	1%	98%
Upper Newell	10.1	1.7	17%	21%	79%	26%	84%
Lower Zayante	50.9	17.9	35%	43%	57%	8%	91%
Upper Zayante	52.3	8.5	16%	46%	54%	10%	87%
Lompico	69.6	18.8	27%	28%	72%	5%	91%
Mountain Charlie	34.3	0.1	0%	41%	59%	12%	78%
W Upper Zayante	54.6	11.8	22%	47%	53%	8%	82%

Table C-2: Road densities for EMIS road, THP roads, and THP skid trails are shown for all roads and roads within inner gorge slope (considered to be 200 feet on either side of stream corridors) for each subwatershed. Percent of roads within the inner gorge, percent paved and unpaved EMIS roads, and the amount percent of land under timber harvest plans is also shown. All numbers were generated from GIS map layers of subwatersheds, roads, and timber harvest plan boundaires.

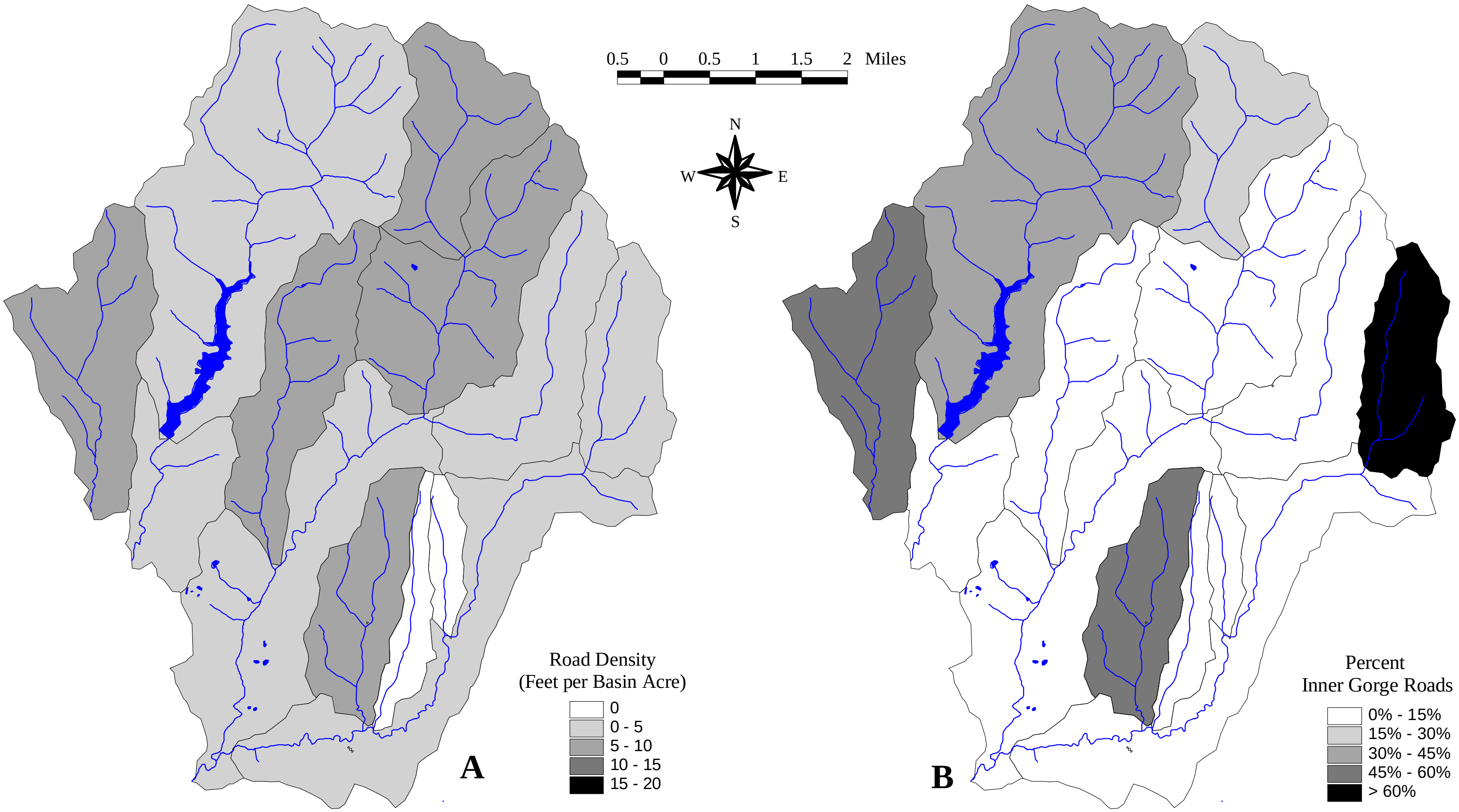


A) Density of all EMIS mapped roads.

B) All EMIS mapped roads that fall within inner gorge slopes. Inner gorge slopes are estimated to be 200 feet on either side of EMIS defined stream corridors.

Figure C-5

Swanson Hydrology & Geomorphology
*115 Limekiln St * Santa Cruz * CA * 95060*
tel: 831.427.0288 www.swansonh2o.com

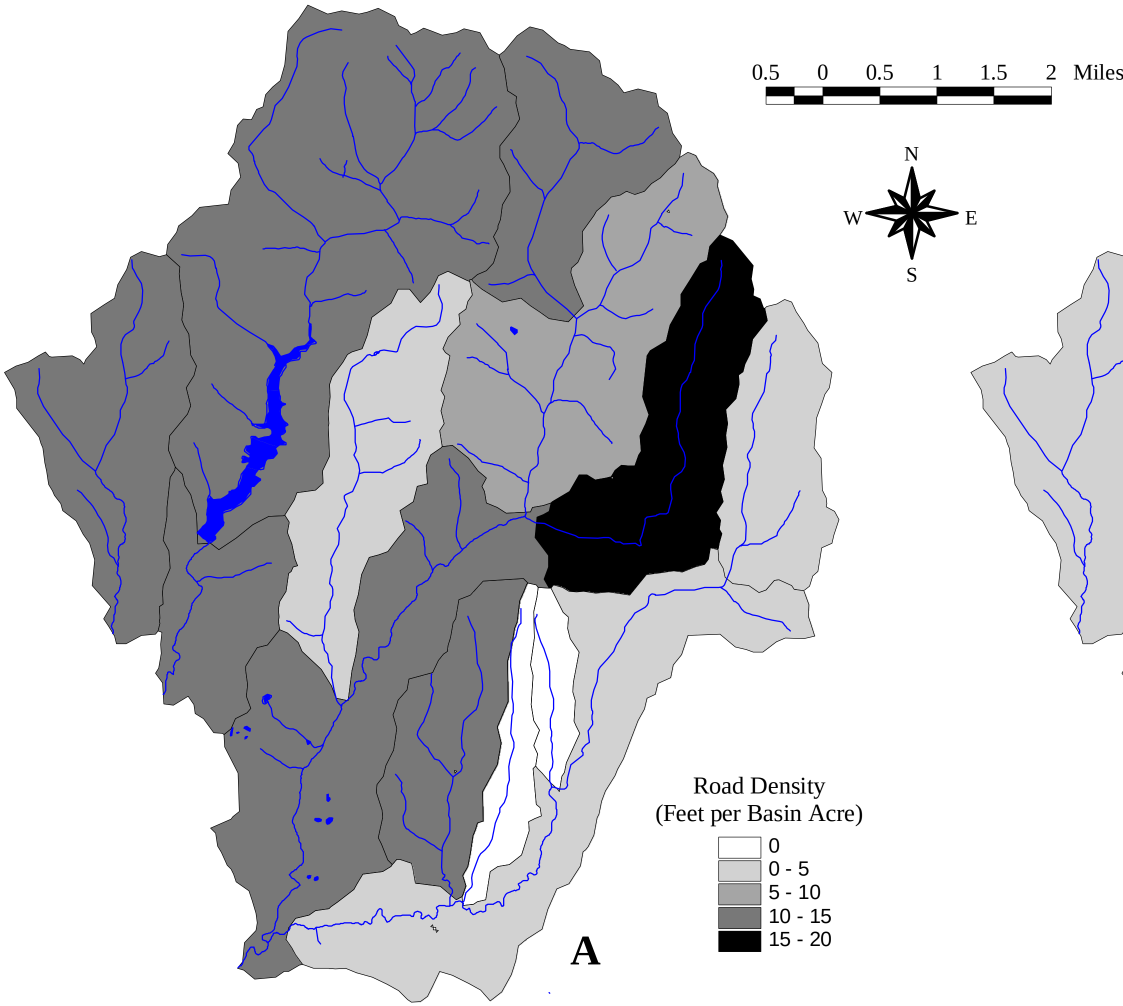


A) Density of all THP roads mapped as permanent.

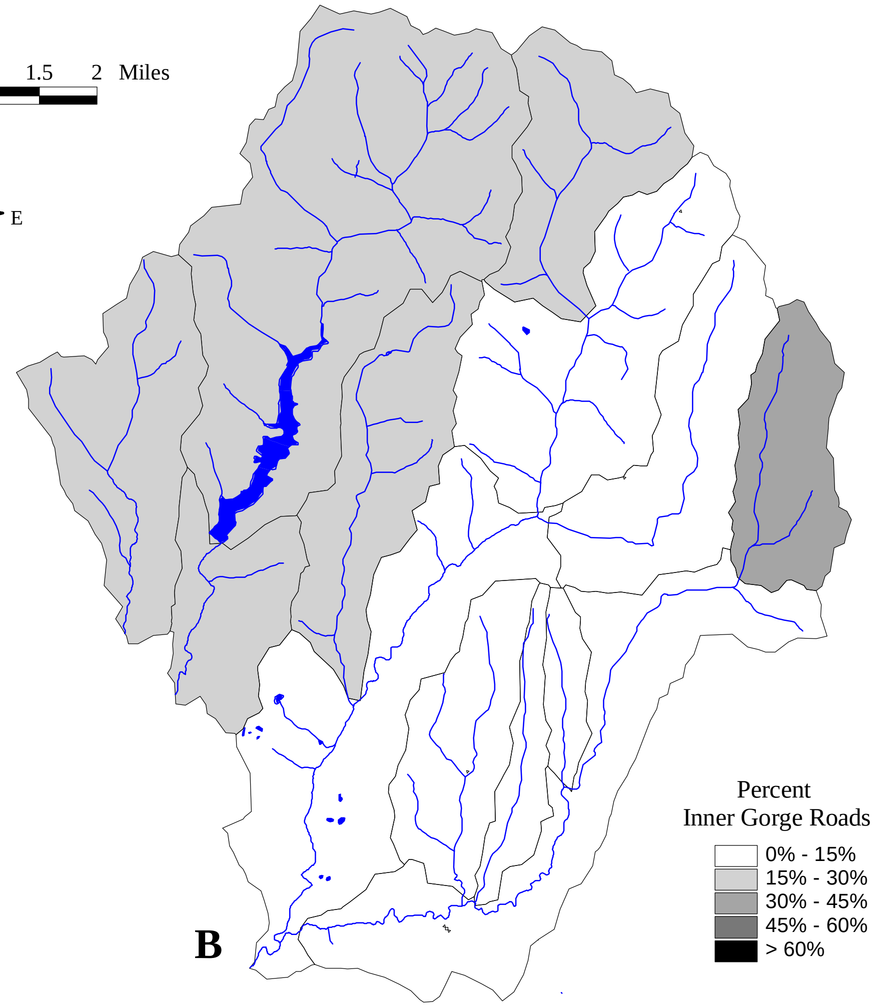
B) All THP roads mapped as permanent that fall within inner gorge slopes. Inner gorge slopes are estimated to be 200 feet on either side of EMIS defined stream corridors.

Figure C-6

Swanson Hydrology & Geomorphology
*115 Limekiln St * Santa Cruz * CA * 95060*
tel: 831.427.0288 www.swansonh2o.com



A) Density of all THP roads mapped as seasonal.



B) All THP roads mapped as seasonal that fall within inner gorge slopes. Inner gorge slopes are estimated to be 200 feet on either side of EMIS defined stream corridors.

Figure C-7

Swanson Hydrology & Geomorphology
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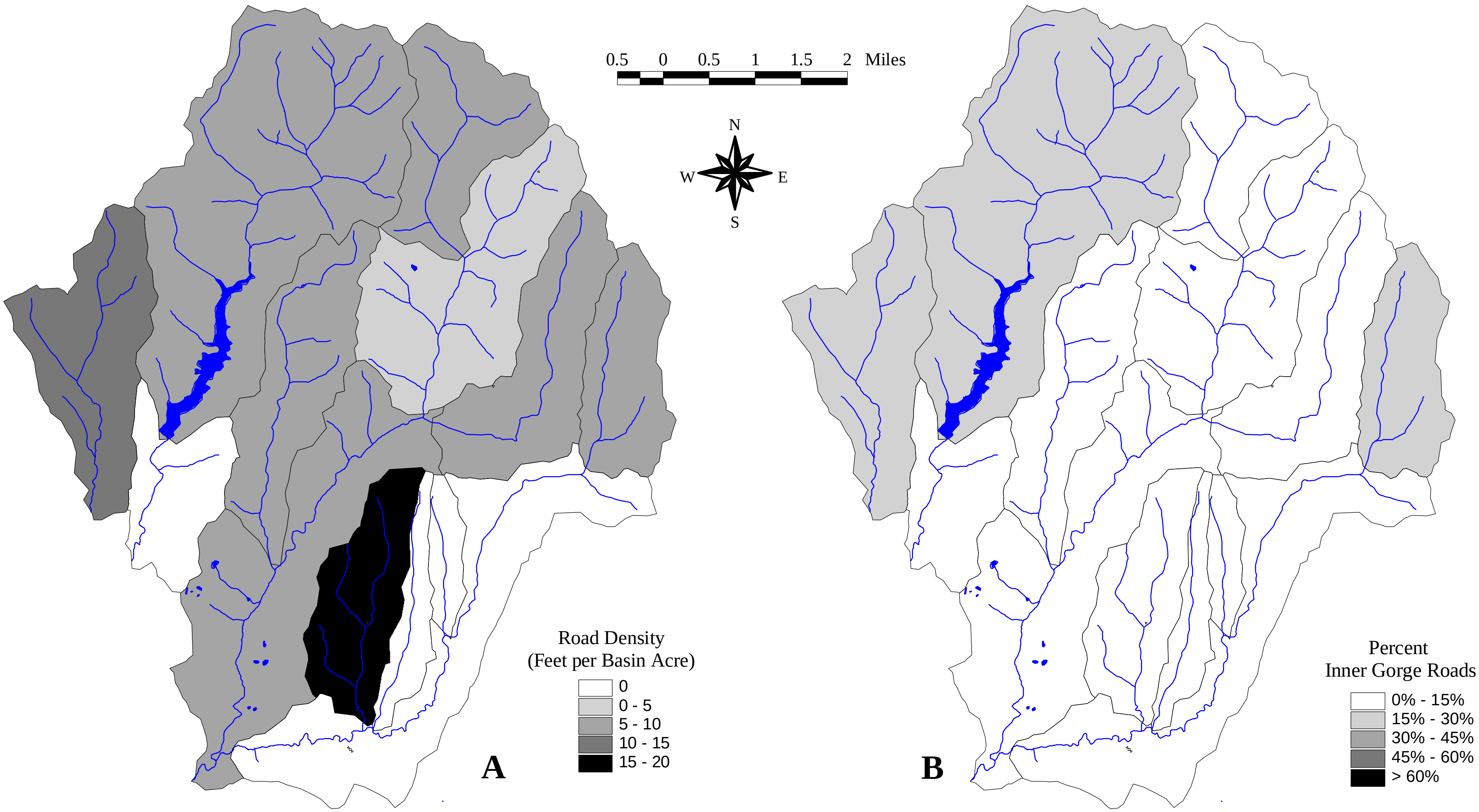

A) Density of all THP roads mapped as a skid trail.

B) All THP roads mapped as a skid trail that fall within inner gorge slopes. Inner gorge slopes are estimated to be 200 feet on either side of EMIS defined stream corridors.

Figure C-8

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Appendix D

Geologic Conditions, Roads and Stream Corridor Maps

for the

Zayante Area Sediment Source Study

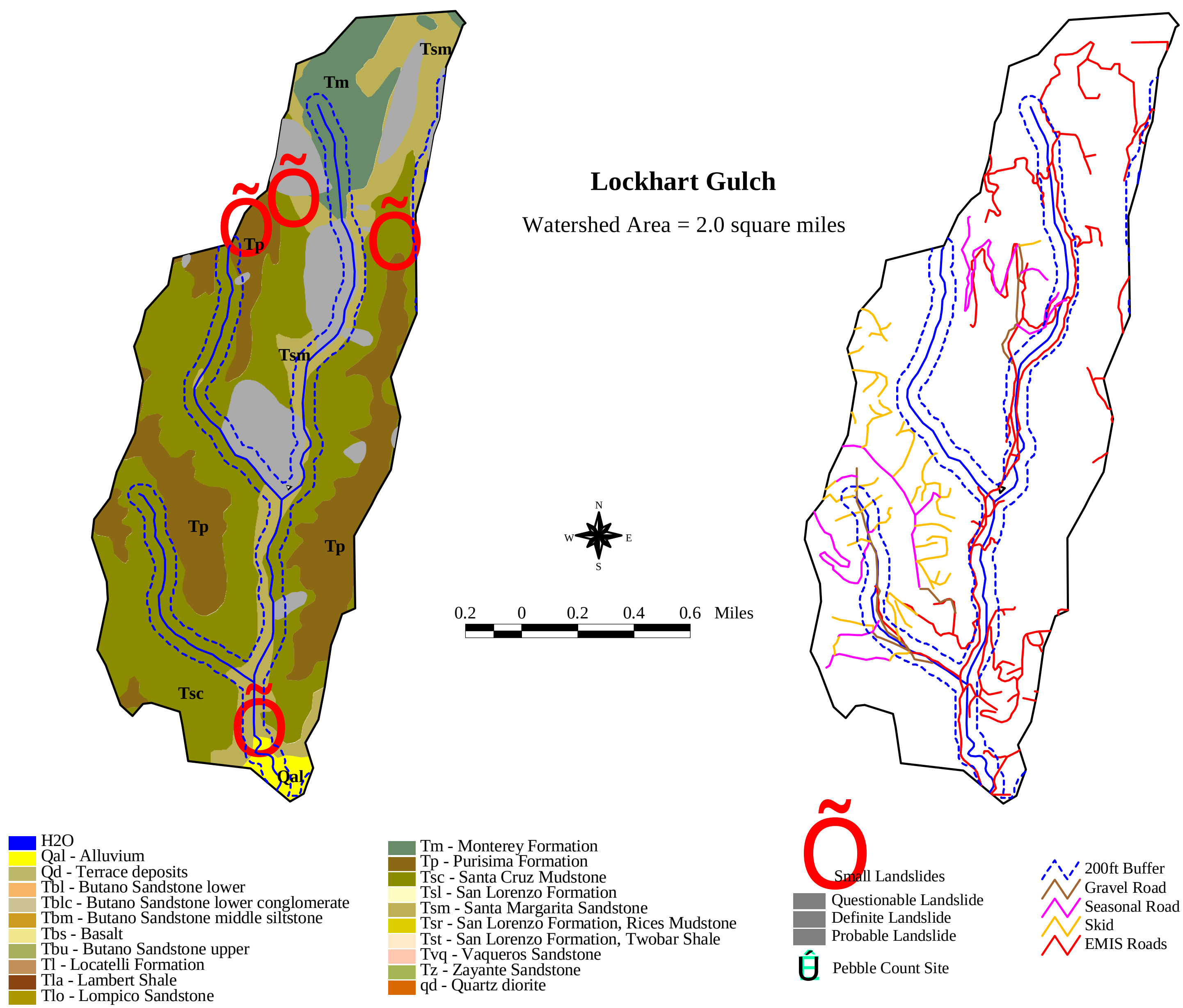

Figure D-1: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Lockhart Gulch. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels.

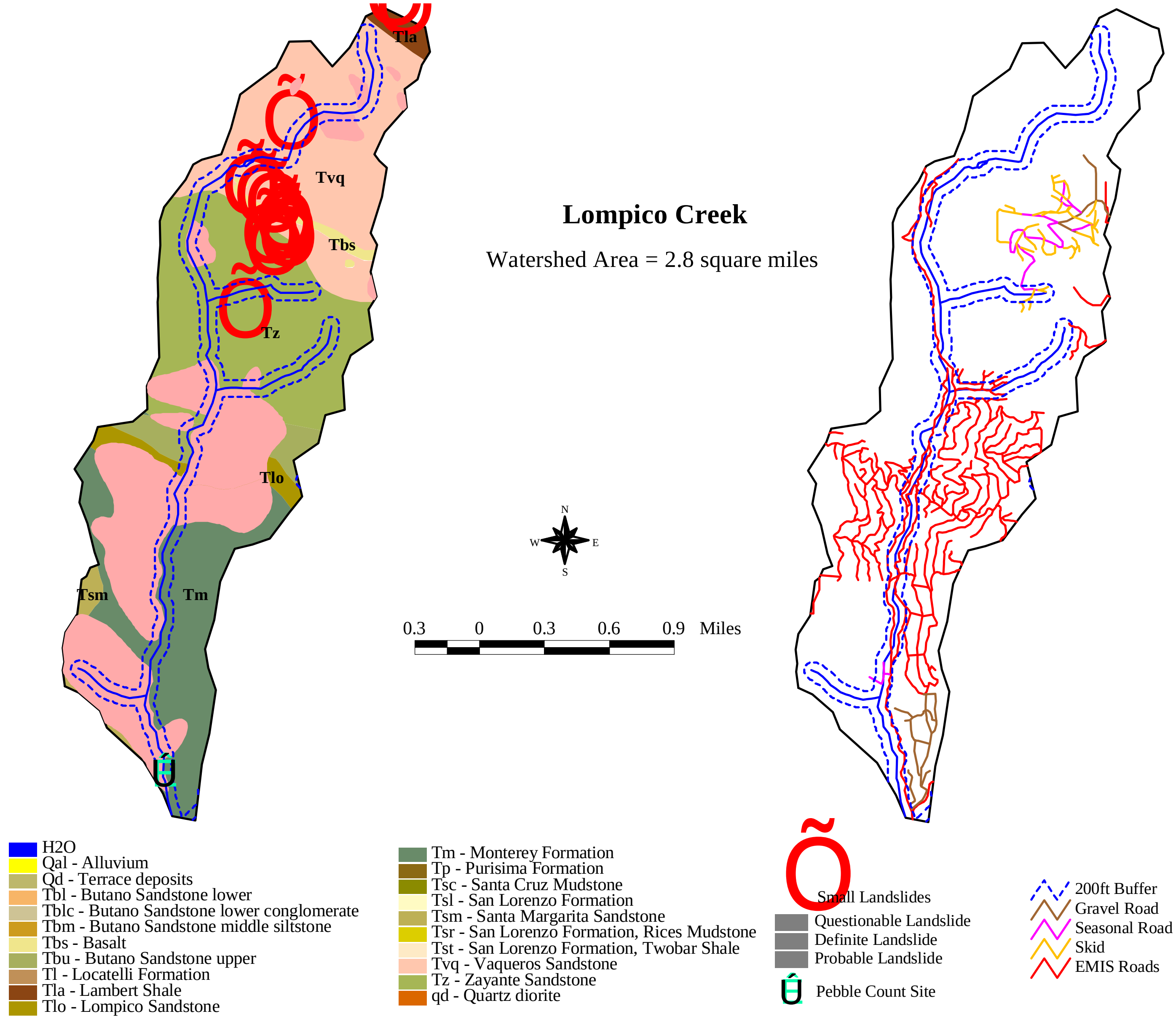

Figure D-2: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Lompico Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

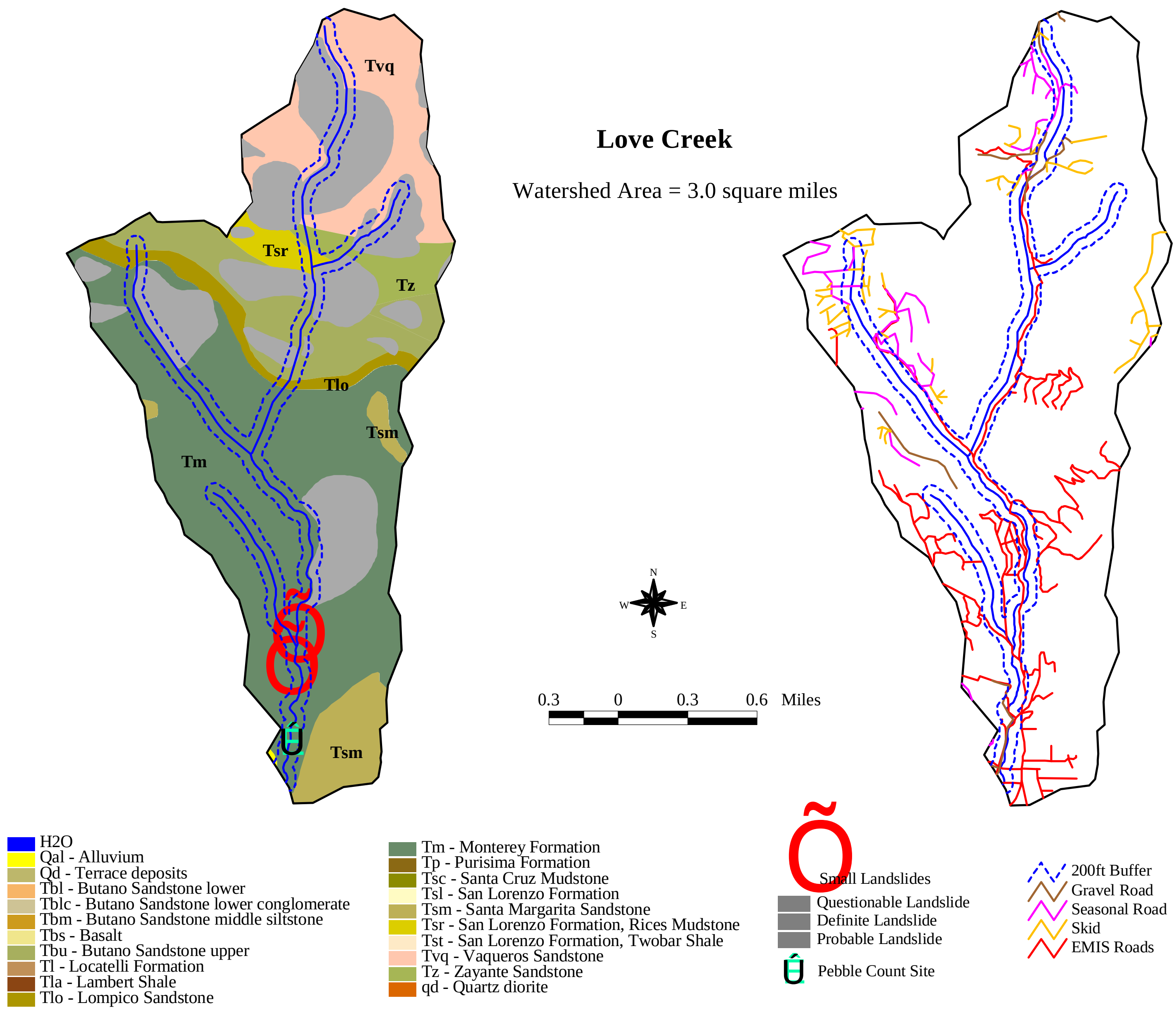

Figure D-3: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Love Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

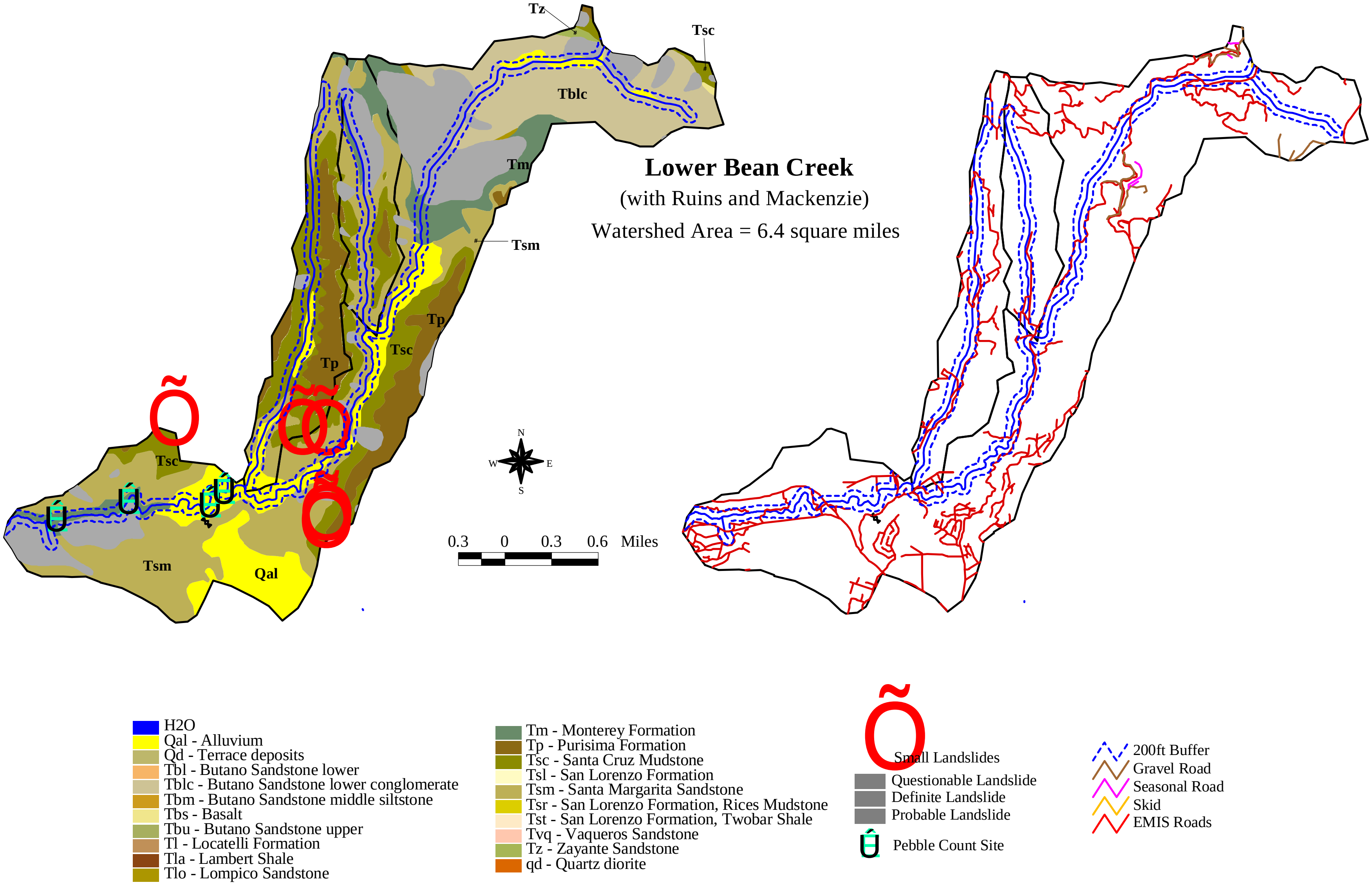

Figure D-4: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Lower Bean Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

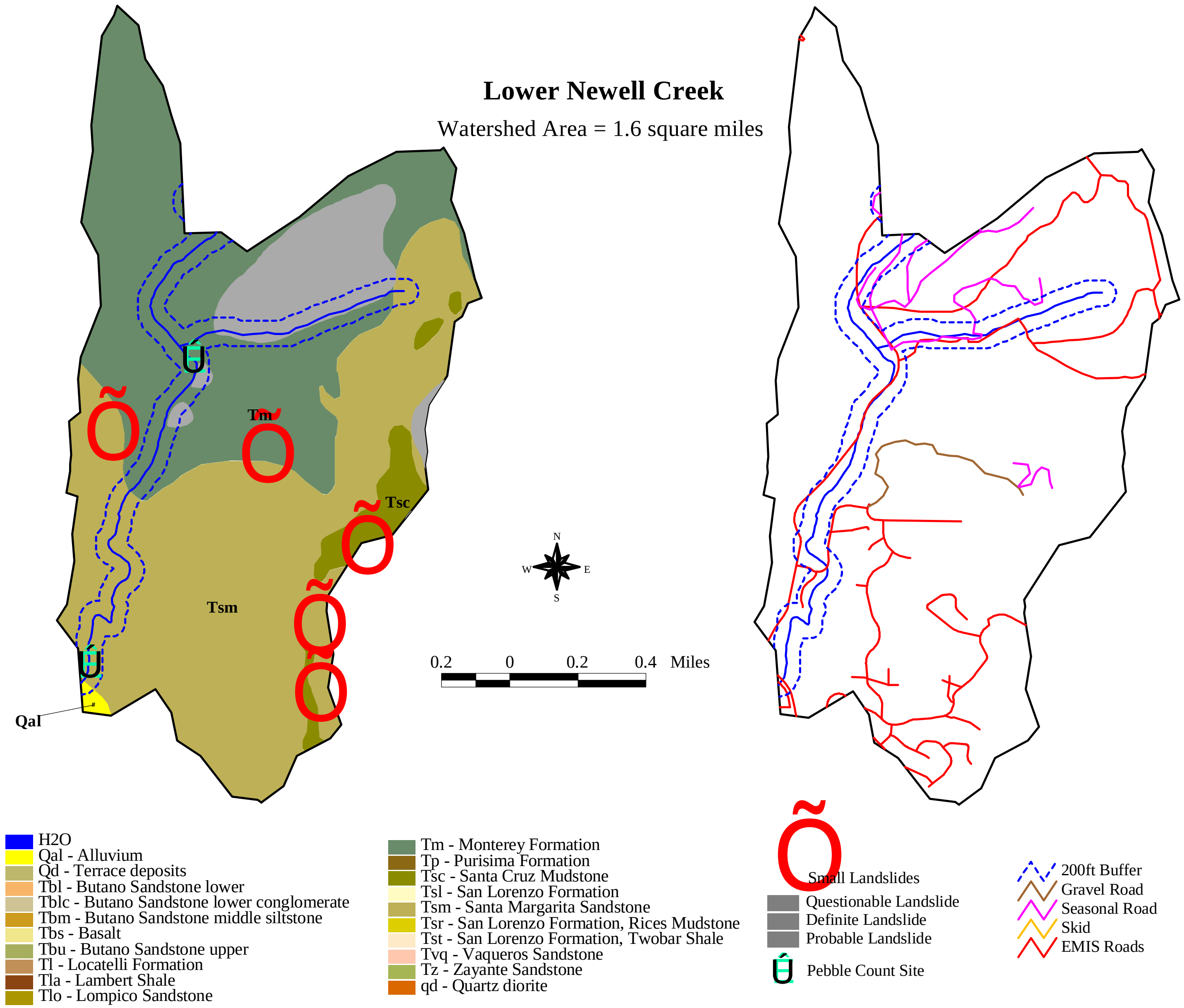

Figure D-5: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Lower Newell Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

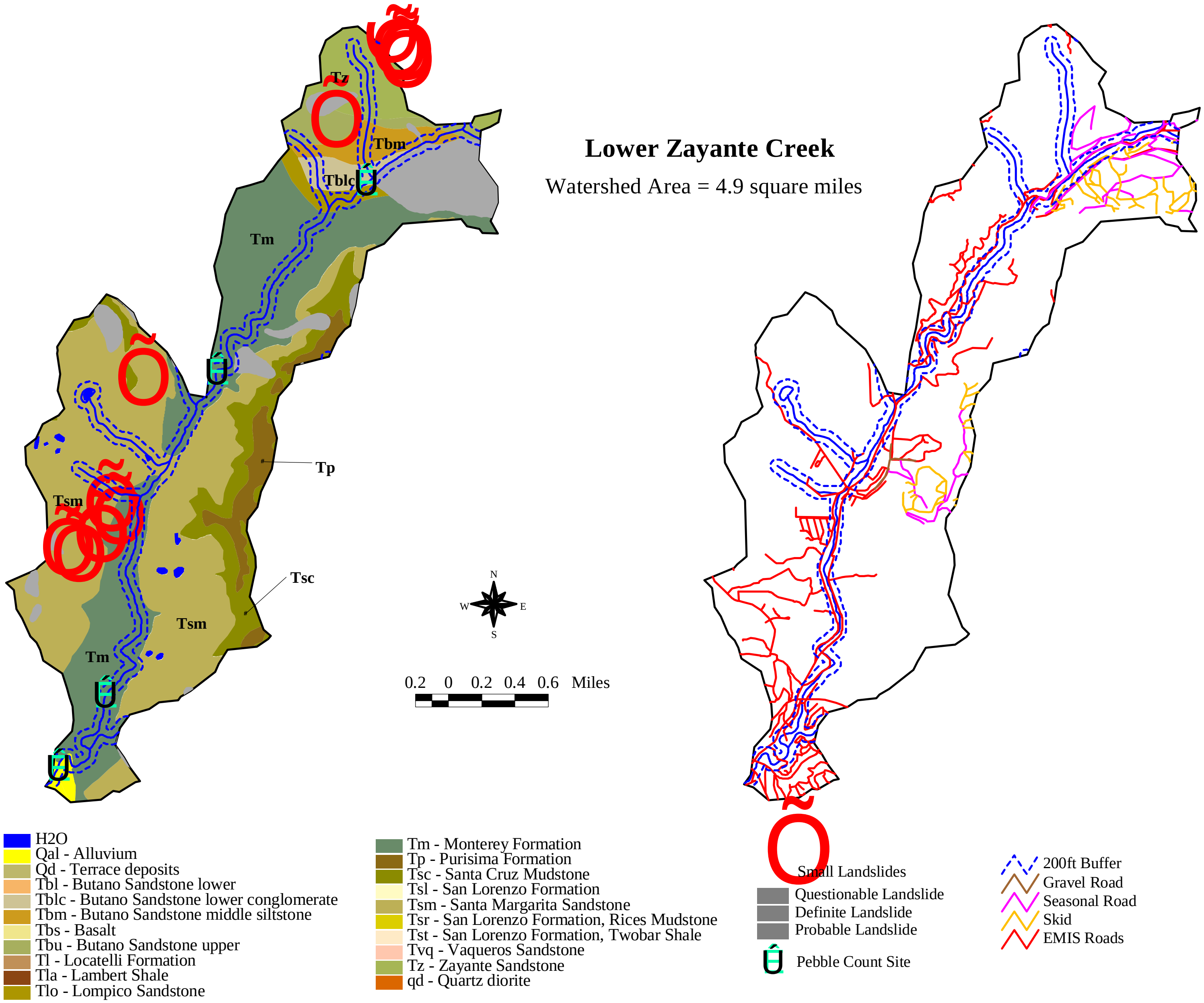

Figure D-6: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Lower Zayante Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

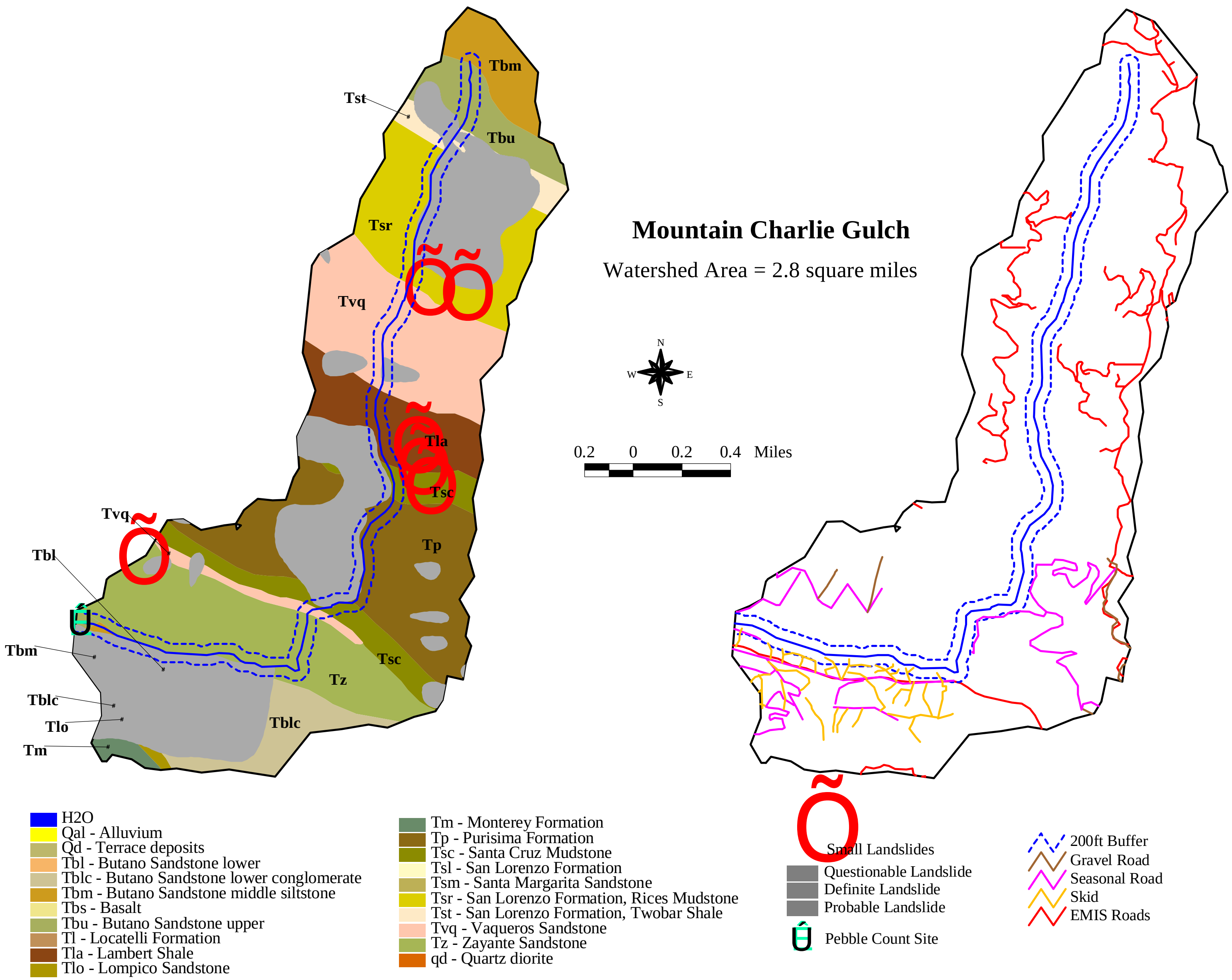

Figure D-7: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Mountain Charlie Gulch. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

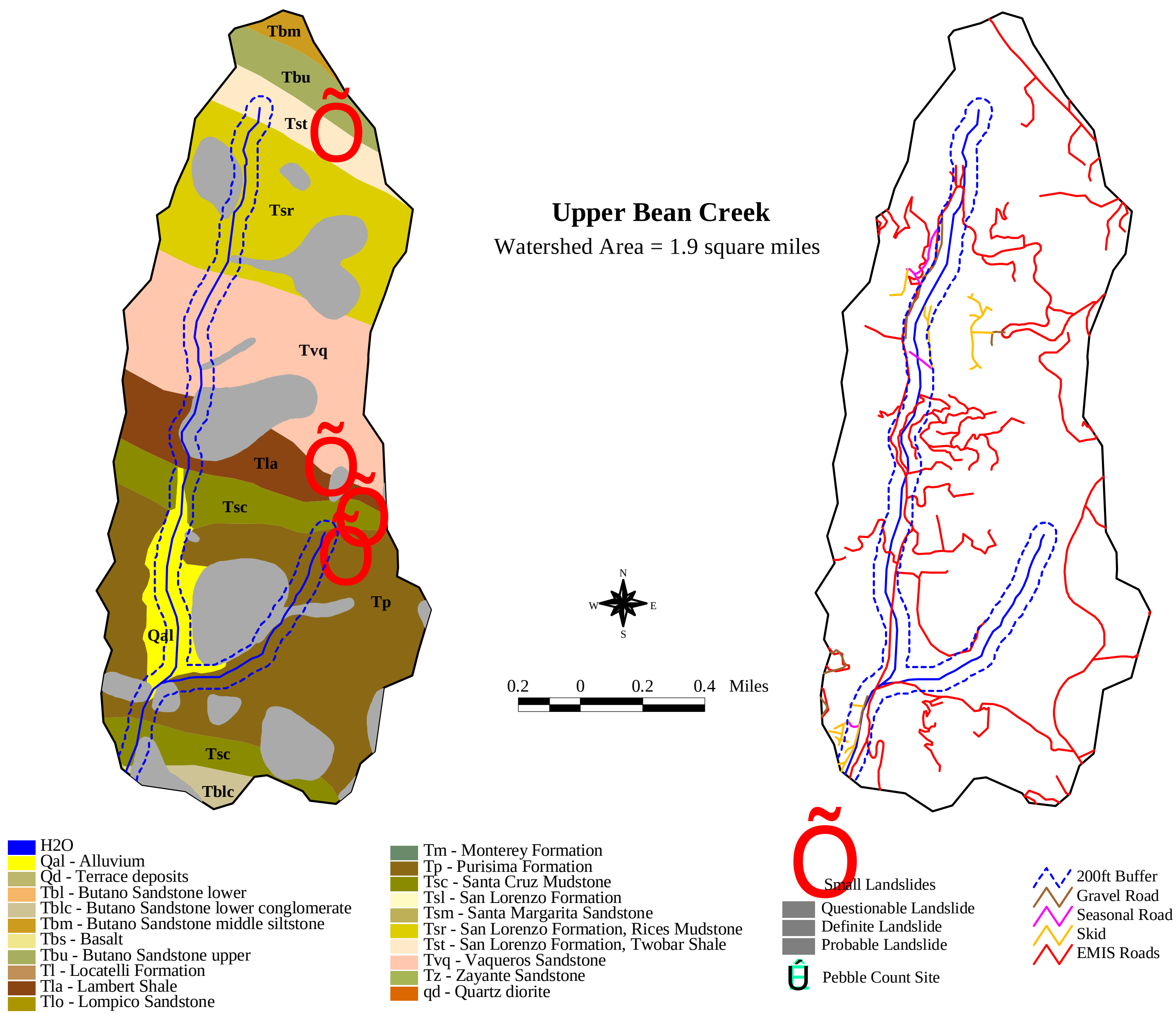

Figure D-8: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Upper Bean Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels.

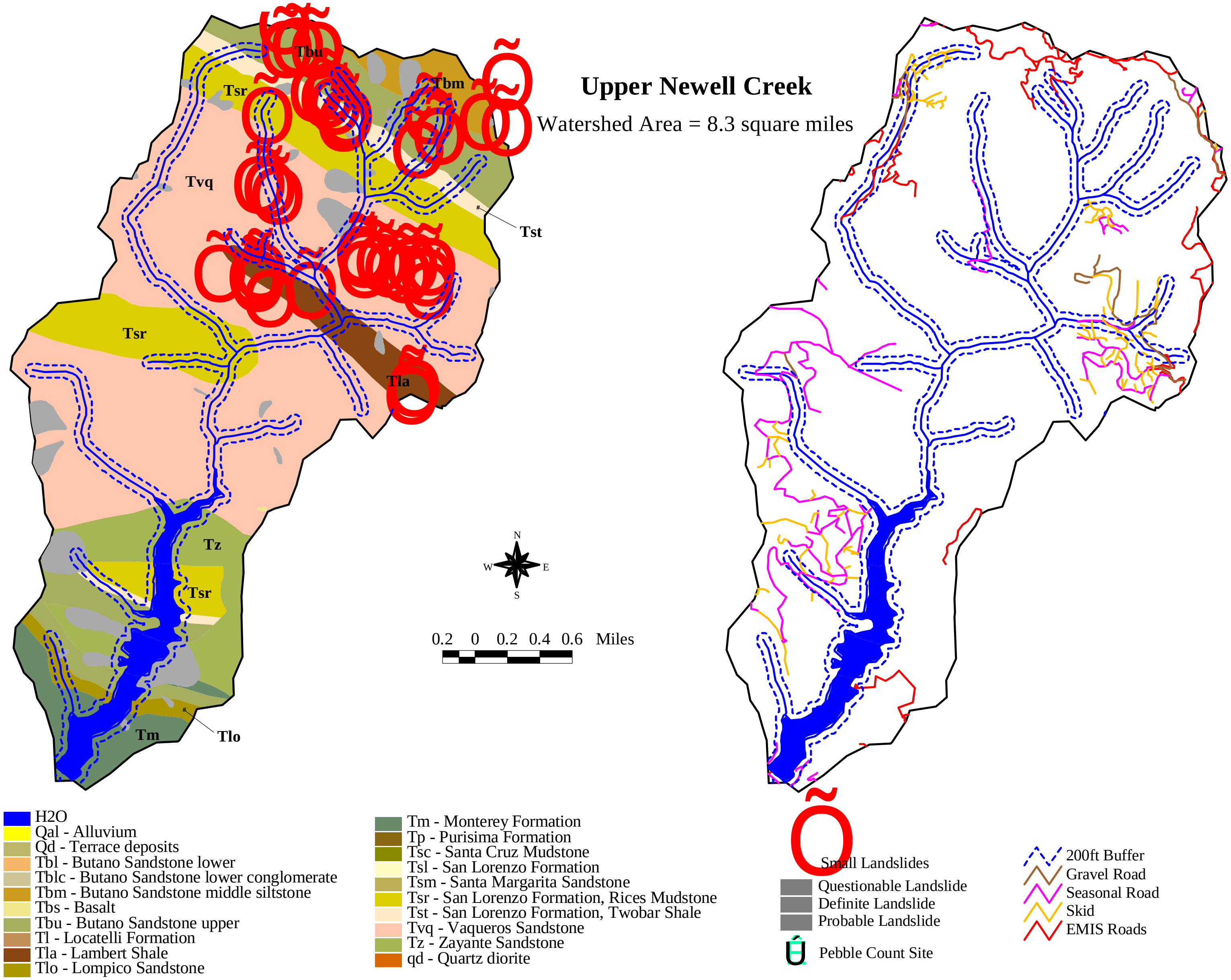

Figure D-9: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Upper Newell Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels.

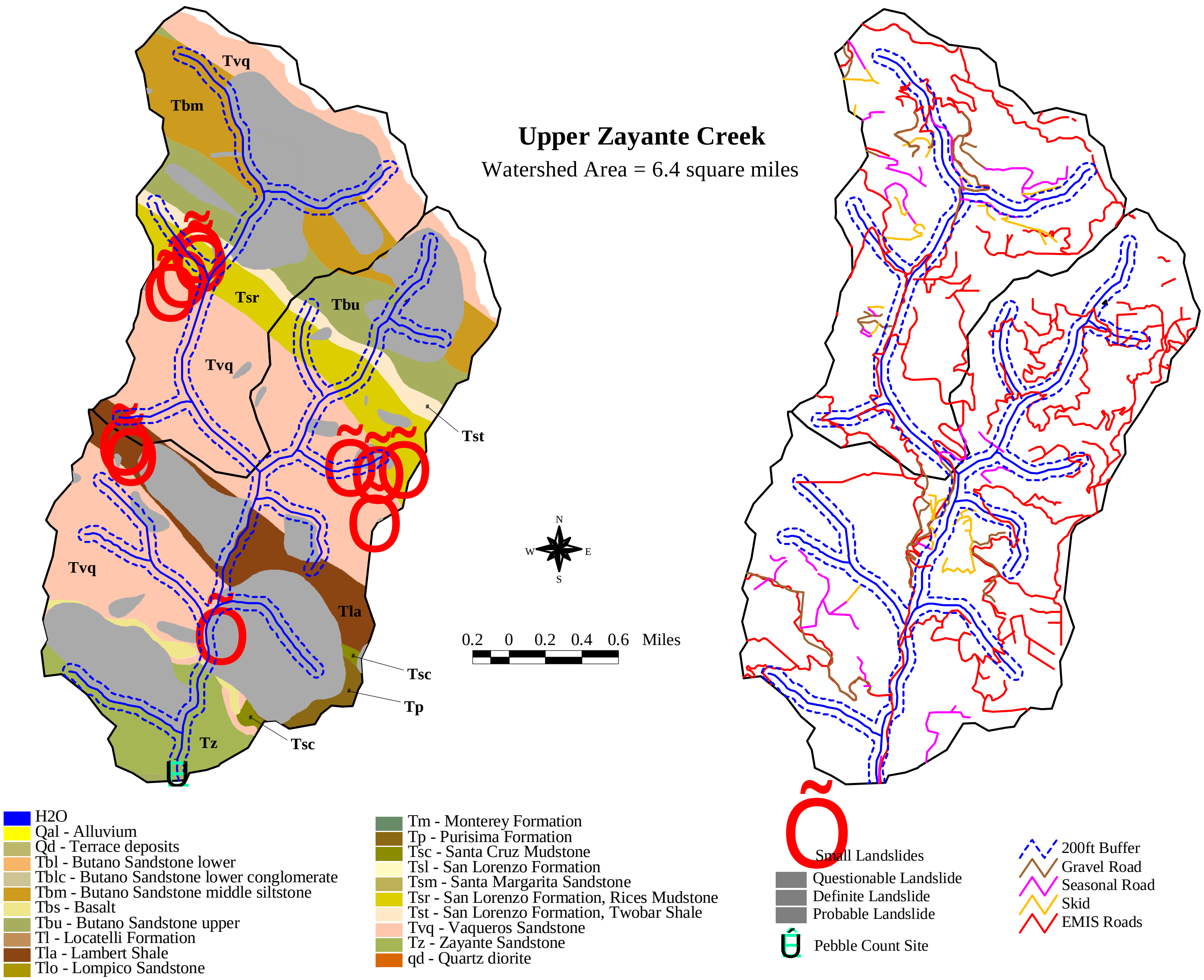

Figure D-10: Geologic rock type, landslides, Timber Harvest Plan roads, and EMIS roads are shown for Upper Zayante Creek. A 200-ft stream buffer is also shown to visually determine proximity of erosion features to stream channels. Numeric target pebble count locations are also shown.

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