SPECIAL REPORT 187

LANDSLIDES IN THE HIGHWAY 101 CORRIDOR BETWEEN LEGGETT AND PIERCY, MENDOCINO COUNTY, CALIFORNIA

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By

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Introduction

U.S. Highway 101 is the major North-South highway in coastal California. North of San Francisco US101 is known as the “Redwood Highway”. In the vicinity of Leggett and Piercy (northern Mendocino County) the highway follows the South Fork Eel River through rugged, mountainous terrain. The 9-mile-long segment of the highway between Red Mountain Creek and the Highway 1 junction at Leggett, crosses terrain that is in part rugged and landslide prone, and in part on flat river terrace. This segment (PM 91.2 to PM 100.4) consists of the old two-lane undivided highway that connects existing 4-lane divided highway segments. The Leggett-Red Mountain Creek segment includes two distinct types of landslides; each type has been active historically and has disrupted the highway, especially at PM 99.8 near the Confusion Hill amusement park. Recent landslide movements near Confusion Hill have repeatedly closed the highway for short periods of time and restricted the flow of traffic for days or weeks following each episode.

Steep canyon walls above and below portions of the existing roadway and tight curvature of the river canyon limits the width of the highway, and led Caltrans to investigate bypass options. Caltrans developed five possible routes to eliminate this two-lane segment. To place the landslides between Leggett and Red Mountain Creek in regional perspective and provide background data for proposed projects, the California Department of Transportation, Office of Infrastructure Research contracted with the California Department of Conservation's **California Geological Survey** (CGS) to prepare maps of the Highway 101 corridor between Leggett and Red Mountain Creek. These maps were to include a geologic map and a map of landslides in the highway corridor and the surrounding area. The mapping area includes the existing two-lane highway alignment and five possible bypass routes within a rectangular area 5.3 miles wide (East-West) by 12.5 miles long (North-South). During the course of the investigation, following repeated landslides at PM 99.8, Caltrans requested that the regional study be set aside and the focus be restricted to the immediate vicinity of Confusion Hill where a proposed bypass of the active landslide site is expected to be constructed. Reconnaissance-level geologic and landslide maps of the Confusion Hill vicinity have been prepared. In addition, the regional study had progressed to the point that a preliminary geologic map and a preliminary landslide map had already been compiled, but not yet verified in the field. All four maps are included as part of this report. The maps do not indicate the probability of movement of any individual landslide or the stability of areas outside of mapped landslides. However, the characteristics of each mapped landslide and physical properties of the geologic units can be used by engineers and geologists at Caltrans in planning of more detailed evaluations for roadway improvement projects. These maps will allow Caltrans to compare the scale and activity of landsliding at Confusion Hill with the landsliding found in the surrounding region, plan for mitigation of landslides and evaluate the proposed bypass route to avoid the landslides at Confusion Hill.

The maps presented here were prepared at a scale of 1:12,000 (1 inch = 1000 feet) by compilation of previous mapping, interpretation of aerial photographs and original field mapping. These maps were prepared using a computerized geographic information system (GIS) on scanned images of USGS 7½-minute topographic quadrangles. Portions of the Leggett, Piercy, Hales Grove and Noble Butte quadrangles form the base map of Plates 1 and 2. The geologic and landslide maps were drawn in the computer using ArcView v. 3.2®, and includes database tables describing each mapped feature.

REGIONAL OVERVIEW

The Leggett-Piercy area is within the Coast Ranges geomorphic province. The Coast Ranges geomorphic province extends for about seven hundred miles within California from Santa Barbara County to the Oregon border, and then continues northward through Oregon and Washington. South of Eureka and Cape Mendocino the province is characterized by northwest-trending mountain ranges and valleys bounded by right- lateral strike-slip faults that are part of the San Andreas fault system. The San Andreas fault itself lies offshore from Highway 101 in this area, and is only one of many faults within the system. The Brush Mountain shear zone and Maacama fault zone lie to the southeast of the study area, and the Piercy fault, Briceland fault and Garberville fault zone lie to the northwest. The San Andreas fault system forms the complex boundary between the offshore Pacific plate and the onshore North American plate. Movements along this fault system are caused by the Pacific and North American plates sliding obliquely past each other. The active plate movements result in tectonic compression and regional uplift. At Scotia Bluffs (on the Eel River about 40 miles northwest of the study area) dated river terraces indicate an uplift rate of 4 meters (13 feet) per thousand years (Norris and Webb, 1990, p. 23). Each seismic episode that causes uplift is followed by widespread downcutting of stream bottoms and oversteepening of hillslopes. Due to the weakening of the rock units by compression and fracturing, the oversteepened slopes are at greater risk of failure by landsliding.

Rocks of the northern Coast Ranges are typically sedimentary rocks of Cretaceous through Tertiary ages. The most widespread unit is the Franciscan Complex composed of fine- to medium-grained graywacke sandstone, highly sheared shale and several other rock types, including serpentine and ultramafic rocks, greenstone and chert. There are also areas where younger Tertiary sedimentary rocks overly the Franciscan north of the study area, and numerous patches of even younger (Quaternary-age) river sediments deposited on erosional surfaces cut into the bedrock. All of the rock types tend to be weak sheared sedimentary rocks or overlying unconsolidated deposits. Rapid uplift of such rocks leads to high rates of erosion and abundant landslides. “The Eel River is of special interest because it holds the record for the greatest average annual suspended load for any stream of its drainage area or larger in the United States; it exceeds both the Colorado and Mississippi in this respect! In tons of sediment per square mile of drainage basin, the Eel yields 4 times as much as the Colorado and 15 times as much as the Mississippi. One part of the Eel basin produced 1,079 metric tons of sediment per square kilometer (3,080 tons per square mile) per year. These very high rates are due to a combination of factors, including very high annual rainfall, soft, easily eroded sedimentary rocks in the basin, a multiplicity of landslides, and timber-harvesting practices" (Norris and Webb, 1990, p. 364).*

Figure 1: Geomorphic Provinces of California showing Confusion Hill Study Area

* The "timber-harvesting practices" noted here included deposition of large amounts of fill in creeks and river beds, and a total lack of erosion control facilities on unpaved forest roads. The large amounts of sediment flushed into the Eel and other California rivers as a result of these old-time practices have been greatly reduced under the Z'berg-Nejedly Forest Practice Act of 1973, and subsequent amendments. The bedrock of the Eel River drainage is still easily eroded, however.

The northern Coast Ranges does not have the broad northwest-trending valleys that make natural transportation corridors in the southern Coast Ranges. North of Santa Rosa US101 follows the valleys of the Russian River, several minor streams and the South Fork Eel River but is forced to climb or traverse numerous steep slopes. All of these slopes are more or less prone to landslides so maintaining this segment of the highway is a continuing challenge.

STUDY AREA

The Highway 101 corridor described herein extends along the South Fork Eel River from Big Dann Creek (near South Leggett; PM 89), northward past Red Mountain Creek to PM 101.65 (near the junction with Highway 271), approximately 2.1 miles south of Piercy. It includes steep bluffs that extend up to an elevation of 900 feet above the road, and narrow to broad river terraces. Some areas are part of the California State Park System. Much of the land west of the Eel River is owned by Hawthorne Timber Company. East of the river several large parcels are owned by Hawthorne Timber Company or by Coombs Tree Farm, Inc.

The route followed by Highway 101 between Leggett and Red Mountain Creek was established as a county wagon road in the late 1800's. It was originally recommended for the state highways map in 1896, and along with Highway 271 became part of the highway system in 1909. In 1926 the state highway became one of the original US highways. (http://www.pacificnet.net/~faigin/CA-HWYS/097-104.html#101; http://gbcnet.com/ushighways/US101/index.html)

GEOLOGIC MAPPING

The geology within this highway corridor is typical of the northern Coast Ranges of California. The main bedrock unit within the region, and the study area, is referred to as the Franciscan Complex. The Franciscan is an extensive sequence of rocks, most of which began as sedimentary deposits in a deep ocean environment. These rocks were intensively sheared and fractured as the oceanic crust they were deposited on was subducted beneath the North American continental plate. The deformed sedimentary rocks, along with fragments of volcanic and metamorphic rocks from the crust and mantle of the oceanic plate, were attached to the North American Plate along a series of faults.

We prepared the geologic map (Plate 1) by compiling previously published geologic maps (Davenport 1984a, 1984b; Jayko and others, 1989; Kelley, 1983a, 1983b) and performing additional interpretation of aerial photographs and field mapping. The previously published geologic maps had major differences in the identification and location of geologic units and landslides. Field mapping was necessary to resolve the differences between the sources of mapping, improve the accuracy of locations of contacts between rock units and add detail to the map.

Geologic units

The study area is underlain by the Coastal Belt of the Franciscan Complex (Davenport, 1983a,b; Kelley, 1984a,b). Subsequent regional mapping by Jayko and others (1989) divided the Coastal Belt within the study area, into the Coastal terrane and the Yager terrane. They describe the Coastal terrane as follows:

"The Coastal terrane is composed of a relatively homogeneous sequence of interbedded arkosic sandstone and argillite with scare pebble and cobble conglomerate, and even more scarce pelagic limestone, chert, and basalt. The sedimentary rocks, for the most part, represent turbidite and other mass-flow type deposits. Rare concretions have yielded a few Late Cretaceous microfossils and more common Paleocene and Eocene faunas…. The metamorphic grade is zeolite facies, and laumontite veins are widespread … Potassium feldspar is also characteristic of fresh sandstone samples… The Coastal terrane is typically a broken formation … characterized by zones of brittle anastamosing shears, boudinage, tight folding, and faulting, as well as by zones of relatively coherent bedded sections. The Coastal terrane has been interpreted as trench and trench-slope deposits that accumulated in an east-dipping subduction zone along the western margin of North America during latest Cretaceous and early Tertiary time…"

The "broken formation" described above consists mainly of gray, thickly bedded sandstone with siltstone and shale interbeds. Although the sedimentary bedding is prominent in outcrops, it is not possible to trace individual beds for great distances. The outcrops commonly represent relatively intact blocks of rock bounded by shear zones. The massive, hard sandstone blocks, bounded by weak, sheared zones leads to steep slopes and slides of large intact blocks of rock. Davenport (1983a) noted that pillow basalts are present along the axis of the Julius anticline in the southwest corner of the study area.

"The Yager terrane lies east of the Coastal terrane and consists solely of the Paleocene and (or) Eocene Yager Formation of Ogle (1953) (Blake and others, 1985). The Yager terrane consists of thin-bedded arkosic sandstone and argillite that are commonly less deformed than the coeval Coastal terrane. The Yager terrane has been interpreted as an early Tertiary trench-slope deposit that accumulated essentially in its present location …" (Jayko and others, 1989). Within the study area, the Yager terrane underlies much of a massive landslide north of Red Mountain Creek and east of the South Fork Eel River. The southern end of the present divided highway at Red Mountain Creek and the original road that it bypassed lie within the massive landslide.

In addition to the Franciscan bedrock, there are several surficial geologic units in the study area:

Quaternary young debris fan: The upland area east of Leggett contains a broad incised fan. This fan was described by Davenport (1984b) as consisting of unconsolidated alluvial fan deposits that have coalesced into a small piedmont alluvial plain. Because this deposit is outside of the Confusion Hill study area, it was not examined in the field.

Quaternary river terrace deposits: Sand and gravel was deposited in a fluvial environment in at least five different episodes. These deposits are now above the active channels of South Fork Eel River and its tributaries – Red Mountain Creek, Rock Creek and Cedar Creek. Some of the deposits were examined during the course of this study, while others are mapped from previous works or photo-interpretation. The larger, older deposits along South Fork Eel River may be of Tertiary age (Davenport, 1983a).

Stream channel deposits: Stream deposits are found in the active floodplains of South Fork Eel River, Red Mountain Creek, Rock Creek, Bridges Creek and Cedar Creek. These deposits are unconsolidated sand and sandy gravel with some layers of finer grained materials.

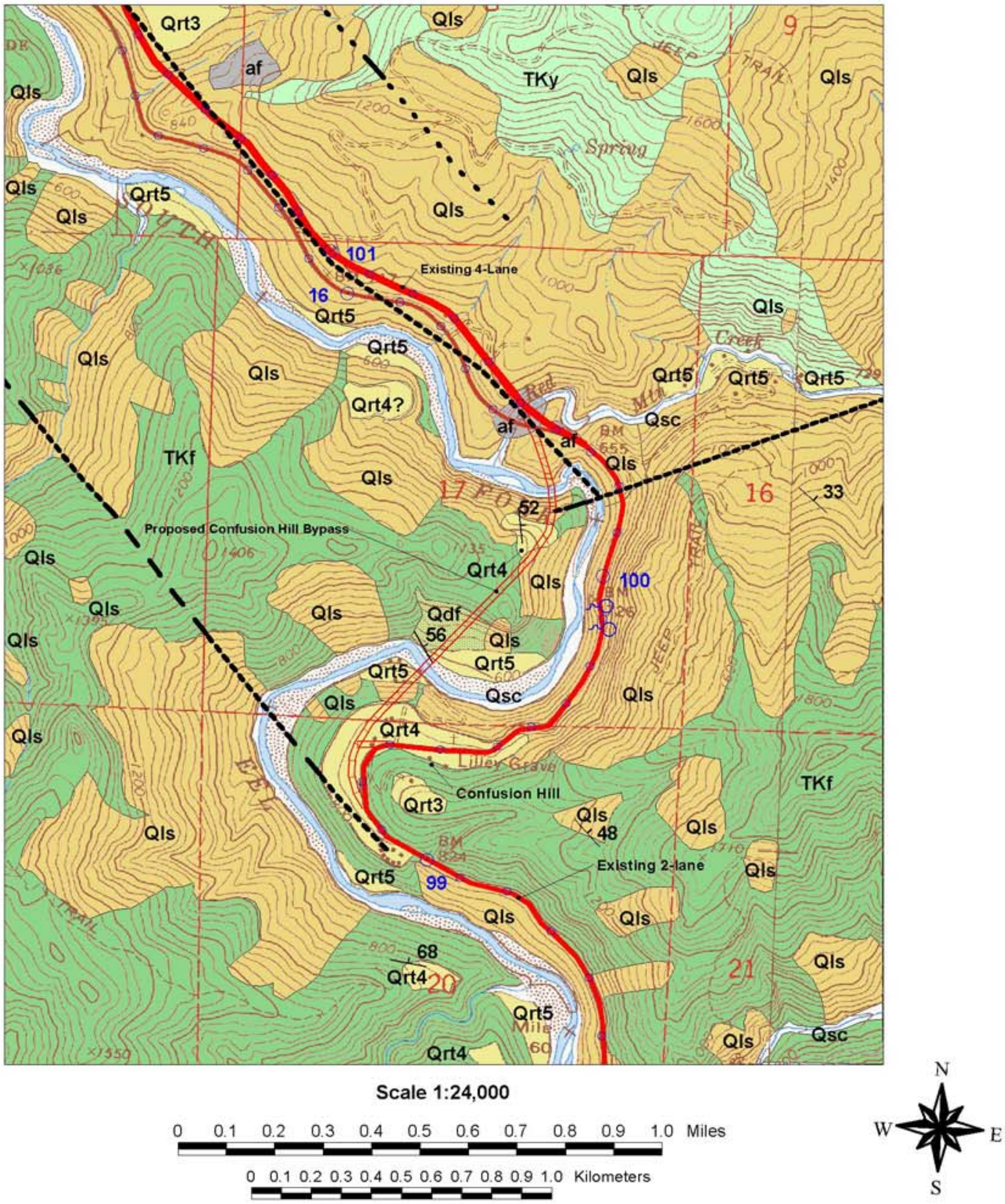
Landslide deposits: Landslide deposits on the geologic map are the larger and deeper slides from the landslide map. Smaller slides are not shown on the geologic map for clarity and because small, shallow landslide scars can have the best outcrops of fresh, intact rock in places where the landslide has removed the soil and weathered rock. The materials in the landslide deposit are highly variable, depending on the source material and range from nearly intact sandstone to completely disrupted clay soils.

LANDSLIDES

More than 300 landslides were mapped in the Highway 101 corridor area (Plate 2). These landslides tend to be the larger, deep-seated slides that affect large areas. Although we have attempted to show all landslides, thick forest cover obscures many small shallow slides.

The landslide map (Plate 2) was prepared primarily by interpretation of aerial photographs, with review of previous reports and some field checking. Landslides shown on previous maps (Davenport, 1984a, 1984b; Jayko and others, 1989, Kelley, 1983a, 1983b) were checked on aerial photos and in the field, if possible. The boundaries of landslides from previous work were revised and additional landslides were added based on geomorphic interpretation for this investigation. Two of the aerial photography sets chosen for this study were taken shortly after logging had occurred in portions of the study area. These photo sets showed much of the existing land surface that was not visible in the photo sets used by the other investigators. Field access for Davenport and Kelley was restricted in large portions of the study area.

Figure 2: Confusion Hill Study Area Geology



Geologic Units

af	Artificial Fill
Qsc	Stream Channel Deposits
Qdf	Debris Fan
Qls	Landslide
Qrt5	Youngest River Terrace Deposits
Qrt4	Younger River Terrace Deposits
Qrt3	Middle River Terrace Deposits
TKf	Franciscan Coastal Belt - Coastal terrane
TKy	Franciscan Coastal Belt - Yager terrane

Structure

- Fault, approximately located
- Fault, approximately located, concealed
- Fault, inferred
- Fault, inferred, concealed

Geologic Points

- 56 Bedding Strike & Dip
- Spring

Road Types

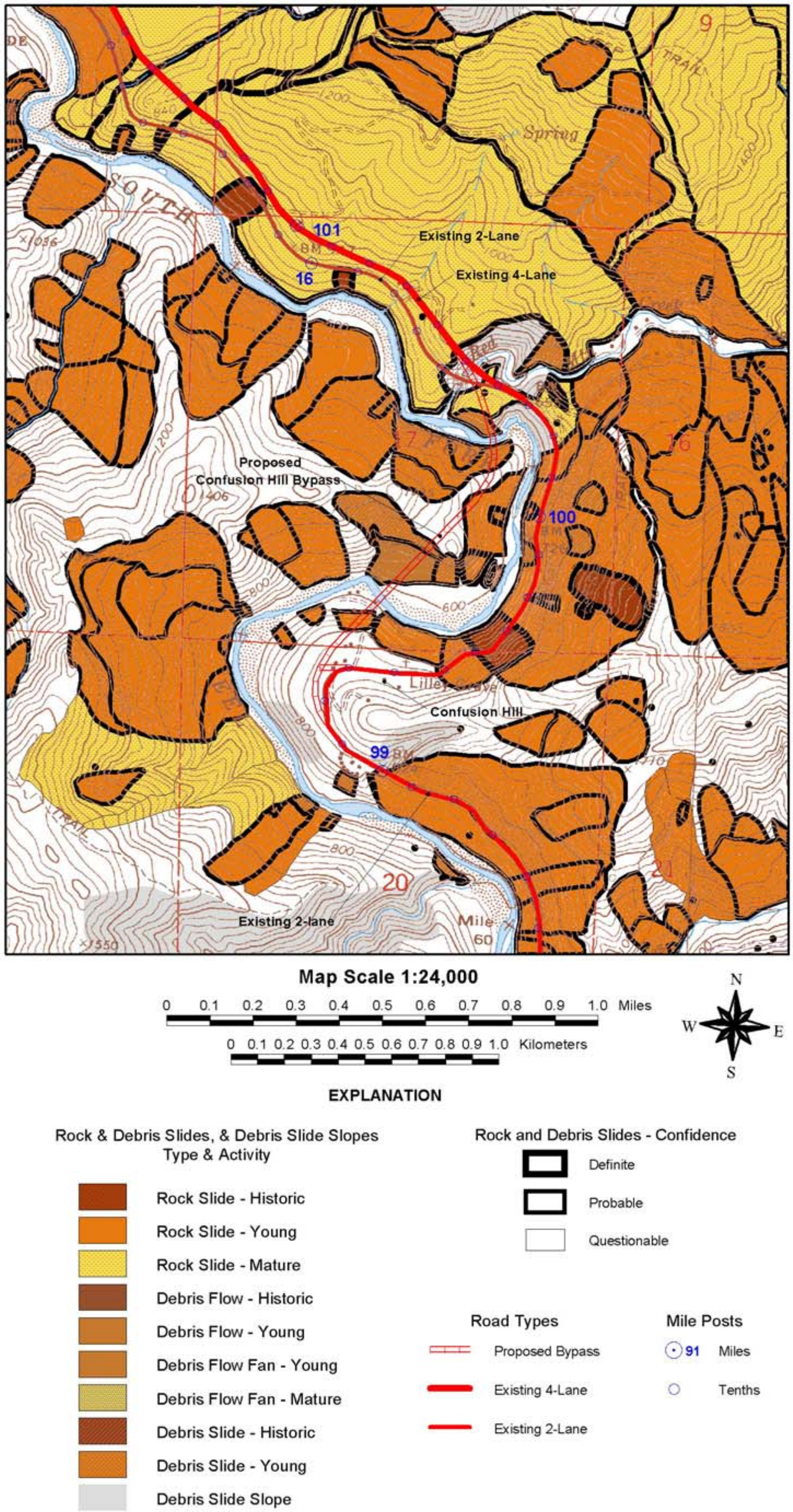
- Proposed Bypass
- Existing 4-Lane
- Existing 2-Lane

Mile Posts

- 99 Miles
- Tenths

Landslides and Slope Stability in the Highway 101 Corridor

Figure 3: Confusion Hill Study Area Landslides



In this study we have recognized, classified and mapped landslides based on their geomorphology. Landslides displace parts of the earth's surface in distinctive ways, and the resulting landforms can show the extent and characteristics of the landslide. Recognition of these landforms (scarps, troughs, benches and other subtle topographic features) allows the geologist to recognize, map and classify most landslides. For this study, landslides were recognized by their topographic expression, as interpreted from topographic maps and aerial photographs, and seen in the field. For each landslide we have attempted to record the characteristics of the slide, generally following the recommendations of Wieczorek (1984).

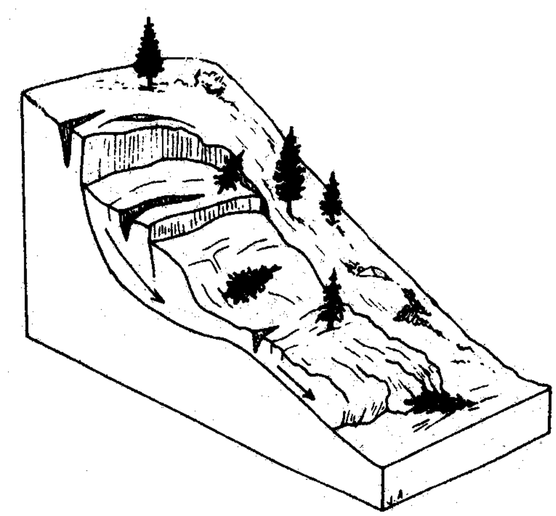
Portrayal of landslides on the map includes a pattern, which designates the type of slide (materials and type of movement). The color of the slide area signifies its level of activity, and the thickness of the outline signifies the confidence of our interpretation as described below.

Types of landslides

Each landslide is classified according to the materials involved and the movement type, as deduced from the associated landforms. A two-part designation is given to each slide, based on the system of Cruden and Varnes (1996). Materials are called either rock or soil, and soil is subdivided into fine-grained (earth) and coarse-grained (debris).

This system was designed to allow a series of names that completely describes the materials and processes involved in a landslide. We have simplified the system slightly to use it in preparing an inventory map of an area. We use the terms and definitions of Cruden and Varnes, but have attempted to simplify the designations by listing only the primary classification of a given landslide. For example, our example diagram of a rock slide (see below) is a rotational rock slide-flow in which the upper part of the slide has moved by sliding, but the lower part has disaggregated and is flowing. On this map this type of slide is shown simply as a rock slide. Use of the Cruden and Varnes system to classify rock versus soil is also complicated by the various vague and overlapping meanings of those terms in common usage. In California, many geologic formations are not hard or indurated rock and it is possible to find all gradations between weak, soil-like, and hard rocks. Our general system is to call material "rock" if it has a geologic formation name and the original geologic structure can be discerned. By these criteria, numerous weak, poorly consolidated formations are "rock.

By applying the system of Cruden and Varnes, with the criteria described above, we have identified four predominant types of landslides in this area.

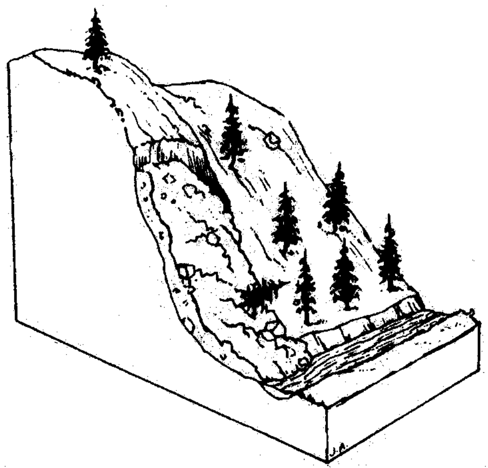


ROCK SLIDE: A slide involving bedrock in which much of the original structure is preserved. Strength of the rock is usually controlled by zones of weakness such as bedding planes or joints. Movement occurs primarily by sliding on a narrow zone of weakness as an intact block. Typically these landslides move down-slope on one or several shear surfaces, called slide planes. The failure surface(s) may be curved or planar. In some older classification systems, slides with curved failure surfaces are commonly referred to as slumps, while those with planar failure surfaces are called block glides.

Rock slides commonly occur on relatively steep slopes in competent rocks. Slopes are commonly from 35% to as steep as 70%. Movement of an intact rock mass along a curved slide plane leads to a steep headscarp at the upper boundary of the slide. Immediately below the headscarp is a block that is commonly rotated so that it is less steep than the surrounding hillslopes. Below the bench, the slide mass may be intact and similar gradient to the surrounding slopes or may have additional scarps and benches. The lower parts of the slopes may bulge outward and be steeper that the surrounding slopes.

The rotation of the block that typically occurs in the upper part of a “slump” rock slide leads to a less steep area or in some cases a closed depression. These areas may accumulate and hold water more than the surrounding slopes. Recognition of landslides is aided if the accumulated water leads to significantly different vegetation in such areas, especially phreatophytic (water loving) vegetation. The increased water accumulation of these areas decreases the overall stability of the slide mass by allowing more water to infiltrate the slide, thereby increasing the unit weight of the slide mass and increasing the pore water pressure within the slide mass.

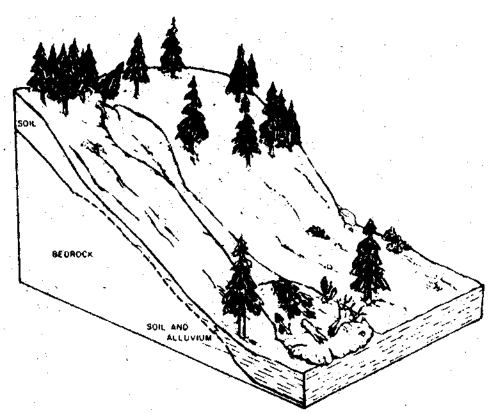
The larger and deeper rock slides are sensitive to conditions that affect the entire slope. A rise in the water table that may occur in high rainfall years, or even in normal rainfall years following the removal of vegetation, can decrease the overall stability. Undercutting of the base of the hillslope or addition of fill to the upper slope also tends to destabilize an existing slide. Movement is usually slow, on the order of millimeters per year, and incremental, sometimes only occurring in years of higher than normal rainfall. However, movement can accelerate in some cases to the point that the mass fails more rapidly, moving several meters in the course of a few days, or by breaking up into smaller rock falls and debris slides that can move several meters in a few seconds.



DEBRIS SLIDE: A slide of coarse-grained soil, commonly consisting of a loose combination of surficial deposits, rock fragments, and vegetation. Strength of the material is low, but there may be a very low strength zone at the base of the soil or within the weathered bedrock. Debris slides typically move initially as shallow intact slabs of soil and vegetation, but break up after a short distance into rock and soil falls and flows.

Debris slides commonly occur on very steep slopes, commonly as steep as 60% to 70%, usually in an area where the base of a slope is undercut by erosion. They are most common in unconsolidated sandy or gravelly units, but also are common in residual soils that form from the in-place weathering of relatively hard rock. Movement of the slide mass as a shallow slab leads to a smooth steep, commonly curved scar. The debris is deposited at the base, commonly as a loose hummocky mass, although the deposit may be rapidly removed by erosion. Debris slides form steep, unvegetated scars. Debris slide scars are likely to remain unvegetated for years. Revegetated scars can be recognized by the even steep slopes, and the shallow amphitheater shape of many scars.

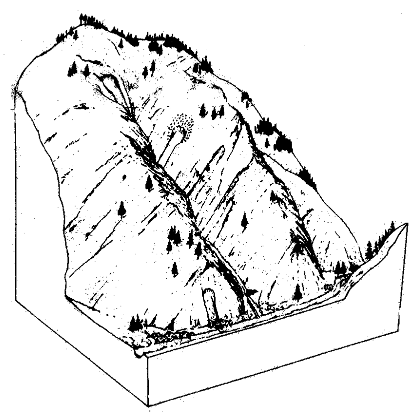
Because debris slides are relatively shallow they are sensitive to changes that are smaller and may occur over shorter times than those that affect deeper slides. A single heavy rainstorm or series of storms may deliver enough rain to trigger debris slides. Individual debris slides may move at rates ranging from meters per day to meters per second. Debris slide scars are extremely steep and therefore are very sensitive to renewed disturbance. Natural erosion at the base of debris slide scars may trigger additional slides. Excavating into the base of a debris slide scar may also trigger renewed slides. Even without additional disturbance, debris slide scars tend to ravel and erode, leading to small rock falls and debris slides from the same slope.



Debris flow: A landslide in which a mass of coarse-grained soil flows downslope as a slurry similar to ready-mixed concrete. Material involved is commonly a loose combination of surficial deposits, rock fragments, and vegetation, including trees. High pore water pressures, typically following intense rain, cause the soil and weathered rock to rapidly lose strength and flow downslope.

Debris flows commonly begin as a slide of a shallow mass of soil and weathered rock. Their most distinctive landform is the scar left by the original shallow slide. The path of the debris flow may be marked by a small drainage that has been stripped of vegetation. The debris flow may not leave any deposit if it flows directly into a larger creek and is immediately eroded away. Many debris flow deposits are ephemeral, but in some cases successive debris flows may deposit material in the same area leading to a debris fan, which resembles a small, steep alluvial fan.

Because debris flows are relatively shallow they are sensitive to pore water pressure changes that are smaller and occur over shorter time frames than those that affect deeper slides. Debris flows are triggered in natural conditions by factors that increase the pore pressures in the shallow subsurface, commonly at the base of the soil. A single heavy rainstorm or series of storms may deliver enough rain to trigger debris flows. Individual debris flows may move at rates ranging from meters per hour to meters per second, and can be extremely dangerous. Works of man that tend to concentrate water on steep slopes or that may increase pore water pressures on those slopes have to be carefully designed and constructed to avoid increasing the potential for debris flows.

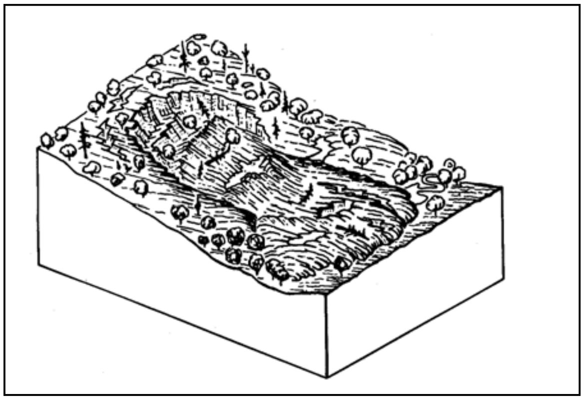


DEBRIS SLIDES and DEBRIS FLOWS are commonly found on a landform called a DEBRIS SLIDE SLOPE, which represents the coalesced scars of numerous landslides that are too small to depict on a map of this scale. These landforms are generally very steep, and have developed in areas of weak bedrock mantled with loose, thin soils and covered with sparse vegetation.

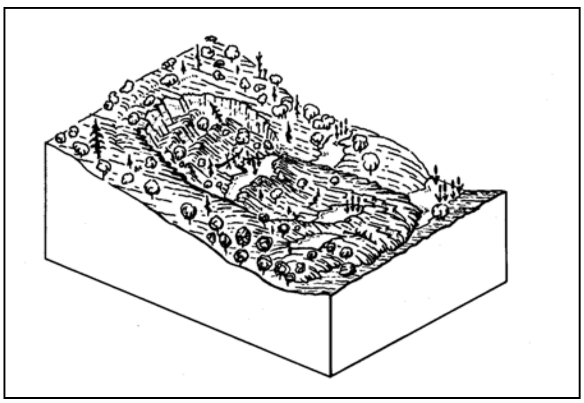
Debris slide slopes are typically very steep, 60% and steeper is common. Areas in which the dominant form of erosion is by debris slides and debris flows are characterized by uniformly very steep slopes, commonly with each small canyon having rounded amphitheater-shaped heads.

Activity of landslides

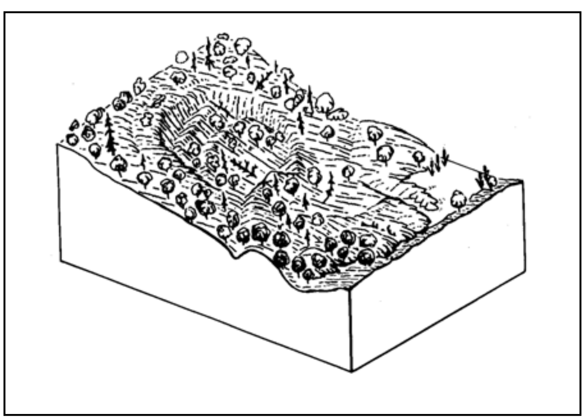
Each landslide is classified based on the recency of activity into one of four categories based on the system of Keaton and DeGraff (1996). The diagrams below illustrate levels of activity (diagrams from Wieczorek, 1984).



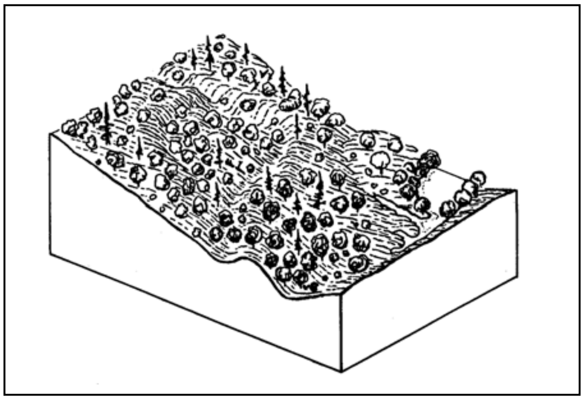
active or historic: The landslide appears to be currently moving or movements have been recorded in the past. Fresh cracks, disrupted vegetation or displaced or damaged man-made features indicate recent activity. Water may be ponded in depressions created by rotation of the slide mass or blockage of stream drainage.



dormant-young: The landforms related to the landslide are relatively fresh, but there is no record of historic movement. Cracks in the slide mass are generally absent or greatly eroded; scarps may be prominent but are slightly rounded. Depressions or ponds may be partly filled in with sediment, but still show phreatophytic vegetation.



dormant-mature: The landforms related to the landslide have been smoothed by erosion and re-vegetated. The main scarp is rounded, the toe area has been eroded and some new drainages established within the slide area. Benches and hummocky topography on the slopes are subdued and commonly obscured by dense, relatively uniform vegetation.



dormant-old: The landforms related to the landslide have been greatly eroded, including significant gullies or canyons cut into the landslide mass by small streams. Original headscarp, benches and hummocky topography are now mostly rounded and subtle. Closed depressions or ponds now filled in. Vegetation has recovered and mostly matches the vegetation outside the slide boundaries.

Confidence of Interpretation

Each area is classified as a Definite, Probable or Questionable landslide. Because landslides are mapped based on their landforms, the confidence of identification is dependent on the distinctness of those landforms. Confidence of interpretation is classified according to the following criteria:

DEFINITE LANDSLIDE. Nearly all of the diagnostic landslide features are present, including but not limited to headwall scarps, cracks, rounded toes, well-defined benches, closed depressions, springs, and irregular or hummocky topography. These features are common to landslides and are indicative of mass movement of slope materials. The clarity of the landforms and their relative positions clearly indicate downslope movement.

PROBABLE LANDSLIDE. Several of the diagnostic landslide features are observable, including but not limited to headwall scarps, rounded toes, well-defined benches, closed depressions, springs, and irregular or hummocky topography. These features are common to landslides and are indicative of mass movement of slope materials. The shapes of the landforms and their relative positions strongly suggest downslope movement, but other explanations are possible.

QUESTIONABLE LANDSLIDE. One or a few, generally very subdued, features commonly associated with landslides can be discerned. The area typically lacks distinct landslide morphology but may exhibit disrupted terrain or other abnormal features that strongly to vaguely imply the occurrence of mass movement.

Each landslide is also classified by a number of other factors not portrayed on the map, but listed in the accompanying database table. The records in the database table include a unique number for each landslide in each quadrangle and a listing of the quadrangle. Other factors recorded for each landslide are the following:

FIELD	VALUES	NOTES
Depth	s,m,d	As interpreted from the geomorphology and classified into one of the following three categories: **s**hallow <3 m, **m**edium 3-15 m, **d**eep >15 m.
Scarp or Deposit	s,d,b	As interpreted from the geomorphology and classified into one of the following three categories: **s**carp, **d**eposit, or **b**oth.
Direction of movement	Azimuth	Generally estimated in 45° increments.
Photo year	Date	Date of earliest photography showing landslide feature.
Primary geologic unit	TKf, TKy	The geologic unit from the geologic map. In this area all landslides involve either TKf, Franciscan Coastal terrane or TKy, Franciscan Yager terrane.
Primary lithology	ss, sh, ss-sh	Corresponding to the unit on the geologic map. In this area the lithologies are ss, sandstone, sh, shale and ss-sh, sandstone with lesser shale.
Secondary geologic unit	TKf, TKy	If a landslide involves two bedrock geologic units
Secondary lithology	ss, sh, ss-sh	If a landslide involves two bedrock geologic units
Strike of bedrock	Azimuth	Estimated from nearby strike and dip values.
Dip of Bedrock	0-90 degrees	
Source of geologic data	CGS, USGS	Reference of previous geologic map containing strike and dip information or field locality number where strike and dip measured
Source of landslide data	MWM, FRK, CWD	CGS geologist who mapped the landslide.
Comments		Comments concerning the landslide, if any.
Quadrangle	Name	Hales Grove, Leggett, Noble Butte or Piercy
Symbol	Qls, Qols, Qdf, Qydf	Geologic unit symbol, if applicable.
Initial movement & Activity	RSY, RSM, DSY	Combination of Initial Movement and Activity; used for application of landslide legend file in ArcView.
Area	Value	
Acres	Value	
Perimeter	Value	

FACTORS INFLUENCING SLOPE STABILITY IN THIS HIGHWAY CORRIDOR

The undercutting and inclination of slopes, their underlying rock types and geologic structures, landforms, and rainfall all influence the slope stability along the Highway 101 corridor between Leggett and Piercy.

Slopes along the Highway 101 corridor range from nearly flat to extremely steep. The steepest slopes are along the river canyon bluffs. Slopes at PM 100 east of Confusion Hill are almost 1000 feet high and average steeper than 55% slope. Other cliffs along the river are as steep as 140%. Slopes that are this steep are characterized by bare rock outcrops and landslide scars. Most landslides on these very steep slopes involve shallow soil and loose rocks, moving as debris slides and rock falls. The river terraces along South Fork Eel River between Leggett and Confusion Hill are nearly flat.

Bedrock geology also has a very strong influence on the types and activity of landslides. The Franciscan Coastal Belt's Coastal terrane and Yager terrane, which contain hard blocks of bedrock separated by weak beds and shear zones, tend to have large, deep masses of rock that slide on narrow zones of weakness. These rock slide-type landslides are characteristic of the two terranes.

The northwest trend of geologic structure, and similar orientation of bedding, shear zones and faults, controls the general trend of ridges and stream valleys. Bedding and shear zones dip to both northeast and southwest, leading to planes of weakness that favor landslides that move in those directions. The overall structural grain and orientation of common planes of weakness leads to relatively common large landslides on slopes that face northeast and southwest.

In some cases the landforms created by landslides help to perpetuate the slides. Closed depressions, troughs and benches that commonly form near the headscarps of landslides result in the reduction of runoff and allow increased percolation of water into the slide mass and along the slide plane, tending to destabilize the slide. Shallow debris slides, which tend to form on oversteepened slopes following the downcutting of stream channels, may destabilize the adjacent area upslope when they move. This leads to successive landslides that fail progressively up slope.

Precipitation is a major factor influencing landslides. The segment of Highway 101 between Leggett and Piercy passes through one of the highest rainfall regions in California. According to the Oregon Climate Center the study area received between 70 and 100 inches of rainfall per year between 1961 and 1991 (Figure 4). This amount of rainfall adds to the level of saturation of the landslide masses, decreasing their stability. Long-term steady rain leads to deep saturation of landslide masses and tends to de-stabilize the larger, deeper types of landslides. Shorter term, but very intense rain tends to de-stabilize the shallower types of landslides, such as debris slides and debris flows.

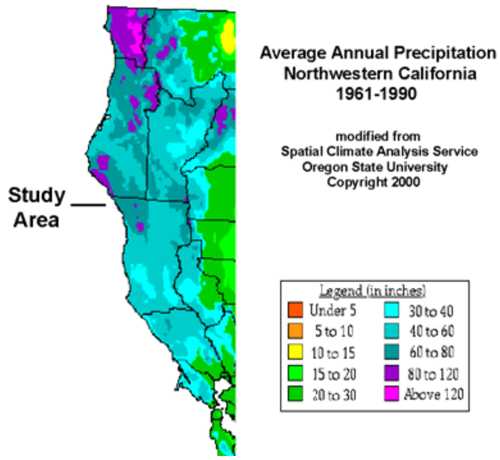


Figure 4. Average annual precipitation in northern coastal California.

Landslides are most abundant where several factors that negatively influence stability converge. In the Leggett-Piercy highway corridor, landslides are most abundant long the South Fork Eel River and Red Mountain Creek where the active channel undercuts the hillslopes and erosion helps to maintain extremely steep slopes.

POTENTIAL FOR LANDSLIDES ALONG HIGHWAY 101

Landslides can and do damage and close roads, resulting in significant repair and maintenance costs. Economic losses can be significant to an entire region of the state if a major route is closed for an extended period of time. Besides the costs associated with landslide damage, some types of landslides pose a risk to the safety of the traveling public. None of these risks can be eliminated. If roads are to pass through regions like the northern Coast Ranges where landslides are common, travelers will be exposed to some risk.

An evaluation of the potential consequences of landslides along Highway 101 between Leggett and Red Mountain Creek can help Caltrans plan for future landslide mitigation projects and prioritize more detailed studies of individual landslides. A thorough evaluation of the probabilities of landslide movement, or of the economic consequences of that movement is beyond the scope of this study. The California Geological Survey has neither the detailed geotechnical data to evaluate the probability of movement of landslides, nor the economic data to measure their consequences. We can, however, assess the types of landslides and the general consequences of movement of those types of landslides. In the table below are the size, movement type, materials and activity level of a landslide, the velocity of movement that is typical of a type of landslide, and the proximity to the highway. Those landslides that have moved most recently are most likely to move in the future, and that the types of movement that have occurred in the past will occur again.

The consequences of landslide movement are related to the location, type and size of a landslide, and the amount and velocity of movement. Larger slides may displace more of a roadway, resulting in greater repair costs. Larger displacements also translate to greater repair costs. If large movements accumulate slowly, over years or decades, they may be a continuing maintenance problem where cracks are filled and pavement re-leveled frequently. Large, rapid, displacements of even small volumes of material may undermine the road or deposit sufficient material on the road to force the closure or partial closure of the roadway. These smaller volume but rapidly moving slides are most likely to pose a safety risk to the traveling public. Movement of large, deep landslides is less likely to occur rapidly, but could have particularly severe consequences. Large displacements of large, deep landslides may result in the roadway being closed for repair, or in the worst case closed for long periods for reconstruction or rerouting.

ID#	POST MILE*	TYPE	RECENCY OF MOVEMENT	SIZE	DEPTH	PROBABLE RATE OF MOVEMENT	POSSIBLE CONSEQUENCES	COMMENTS
98	99.6-100.2	RS	Young	73.79	Deep	Slow	Lane - hwy closure, risk to public	
99	99.7	RS	Historic	7.47	Medium	Slow	Lane - hwy closure, risk to public	
93	99.85	RS	Active	9.57	Medium	Slow	May extend down slope; lane - hwy closure, risk to public	Smaller slide within # 98
94	100.2	RS	Young	3.98	Medium	Slow	May reactivate & move hwy; risk to public	Smaller slide within # 98
77	100.1	RS	Young	2.34	Shallow	Slow	May extend down slope; lane - hwy closure, risk to public	Smaller, shallow slide within # 98
78	99.9	DS	Young	2.11	Shallow	Rapid	May reactivate & deposit onto hwy; risk to public	Smaller, shallow slide within # 98
79	99.9	DS	Young	0.95	Shallow	Rapid	May undercut lane-hwy; lane closure	Smaller, shallow slide within # 98
80	100.0	DS	Young	0.43	Shallow	Rapid	May undercut lane-hwy; lane closure	Smaller, shallow slide within # 98
53	99.8	DF	Historic	0.72	Shallow	Rapid	May reactivate & deposit onto hwy; risk to public	Smaller, shallow slide within # 98
54	99.8	RS	Historic	0.38	Shallow	Slow		Smaller, shallow slide within # 98
546	99.5 - 99.6	RS	Young	6.74	Medium	Slow	Lane - hwy closure, risk to public	
22	100.3	DSS	Young	4.29	Shallow	Rapid	May undercut lane-hwy; lane closure	

ID #	POST MILE*	TYPE	RECENCY OF MOVEMENT	SIZE	DEPTH	PROBABLE RATE OF MOVEMENT	POSSIBLE CONSEQUENCES	COMMENTS
608	100.5-101.4	RS	Mature	265.8	Deep	Slow	May reactivate & move hwy; risk to public	
607	100.4	RS	Mature	12.05	Deep	Extremely Slow		Remnant (?) of #608
23	100.4	DS	Young	2.29	Shallow	Rapid		
56	H 271 15.93	RS	Historic	1.19	Shallow	Slow	Lane – road closure	Pavement distress
611	101.4-101.5	RS	Mature	50.08	Deep	Slow	Lane - hwy closure	
97	H271 16.16	RS	Historic	4.85	Medium	Slow	May move H 271 & undercut H 101; lane closures	
545	H 271 16.50	RS	Young	0.44	Shallow	Slow	May undercut lane-road; road closure	
111	H 271 16.59	RS	Young	1.11	Shallow	Slow		
174	101.6	RS	Mature	27.22	Deep	Slow	May move both H 271 & H 101; lane closures	
172	101.6	RS	Young	16.73	Deep	Slow	May move H 271 & undercut H 101; lane closures	Springs along Hwy 101
539	98.5-99.0	RS	Young	19.39	Deep	Slow	May undercut lane-hwy; road closure	
541	98.5-99.0	RS	Young	57.67	Shallow	Slow	May reactivate & deposit onto hwy; risk to public	
5	99.0	DF	Young	0.22	Shallow	Rapid		
83	98.6	RS	Young	5.72	Medium	Slow	May undercut lane-hwy; road closure	Smaller slide within #541

84	98.6	RS	Young	1.45	Deep	Slow	May reactivate & deposit onto hwy; risk to public	Smaller slide within #539
106	98.7	RS	Young	7.62	Medium	Slow	May extend down slope; lane - hwy closure, risk to public	Smaller slide within #541

*Estimated

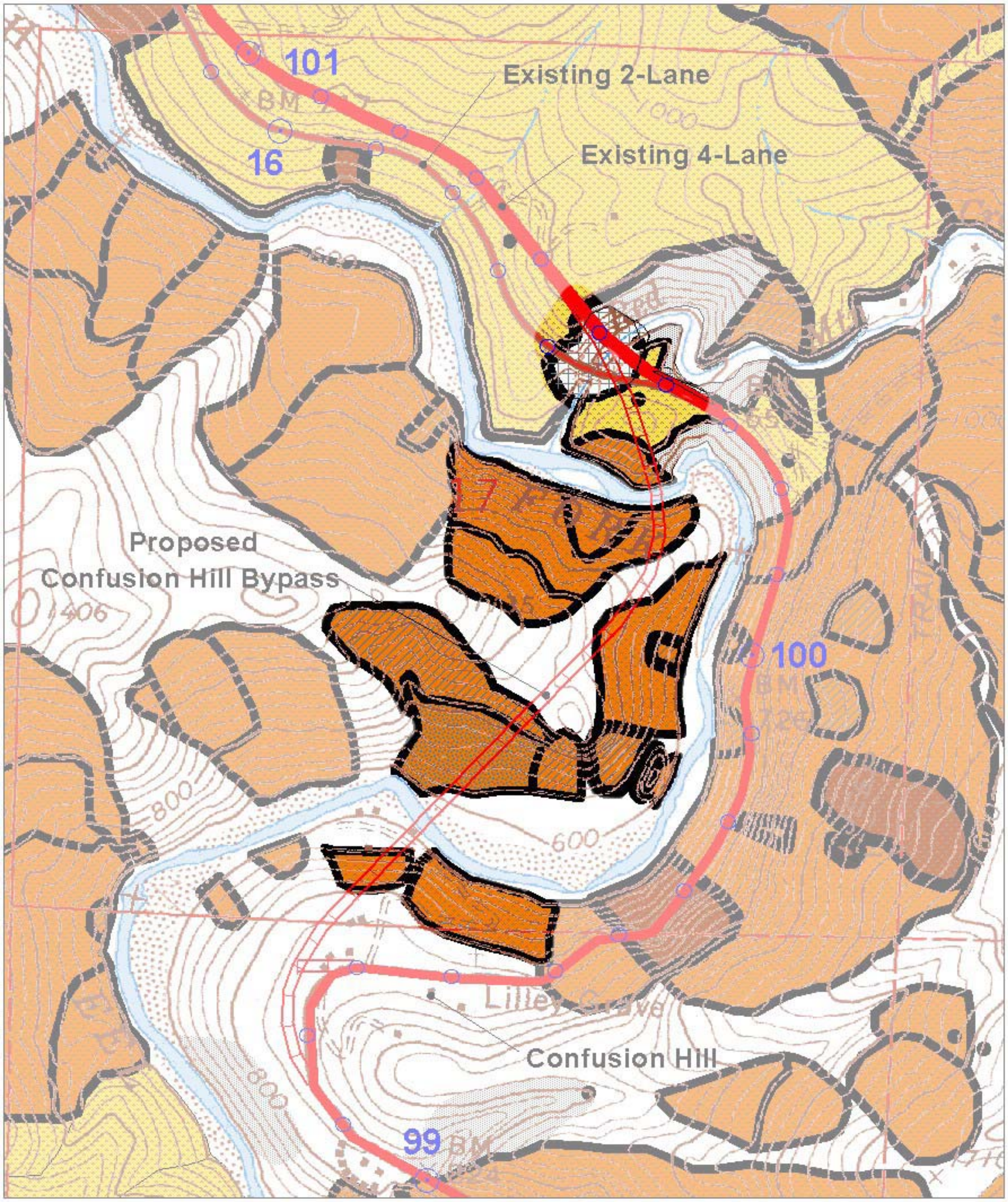


Figure 5a. The proposed bypass would cross the South Fork Eel River twice. The southern end is situated on a river terrace. The southern crossing would be anchored at its south end on a small landslide that could easily be removed or stabilized. The north end crosses a young debris fan and debris slide slope. The mid section of the bypass crosses the upper portions of two landslides. The northern crossing is anchored at its northern end in the toe of a massive landslide, as mentioned below in Figure 5C.

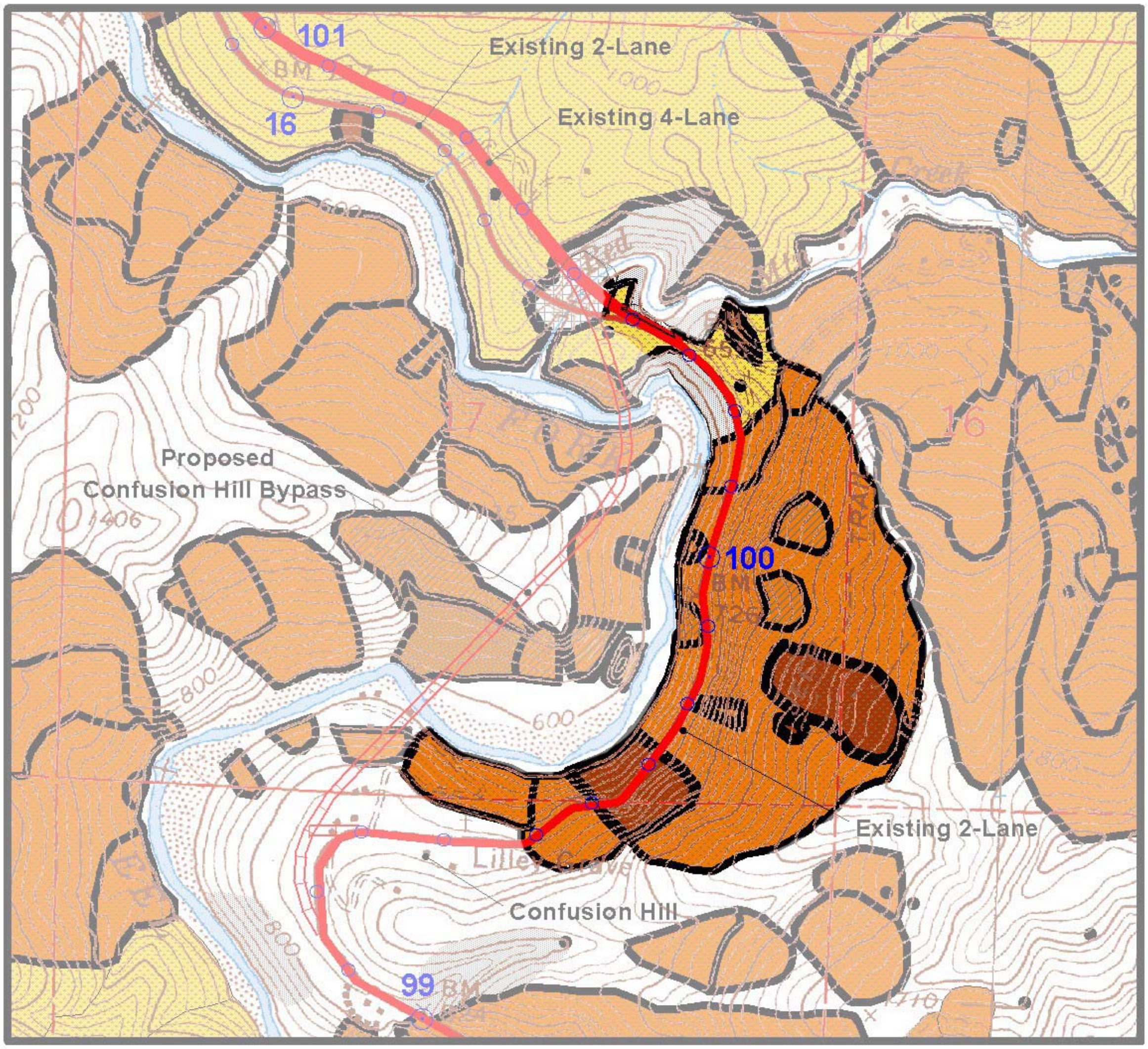


Figure 5b. The existing highway near Confusion Hill is subject to landslides and debris flows, especially at PM 99.8. Recently active slides have resulted in repeated lane closures and traffic control. The proposed bypass would eliminate this segment of Highway 101,

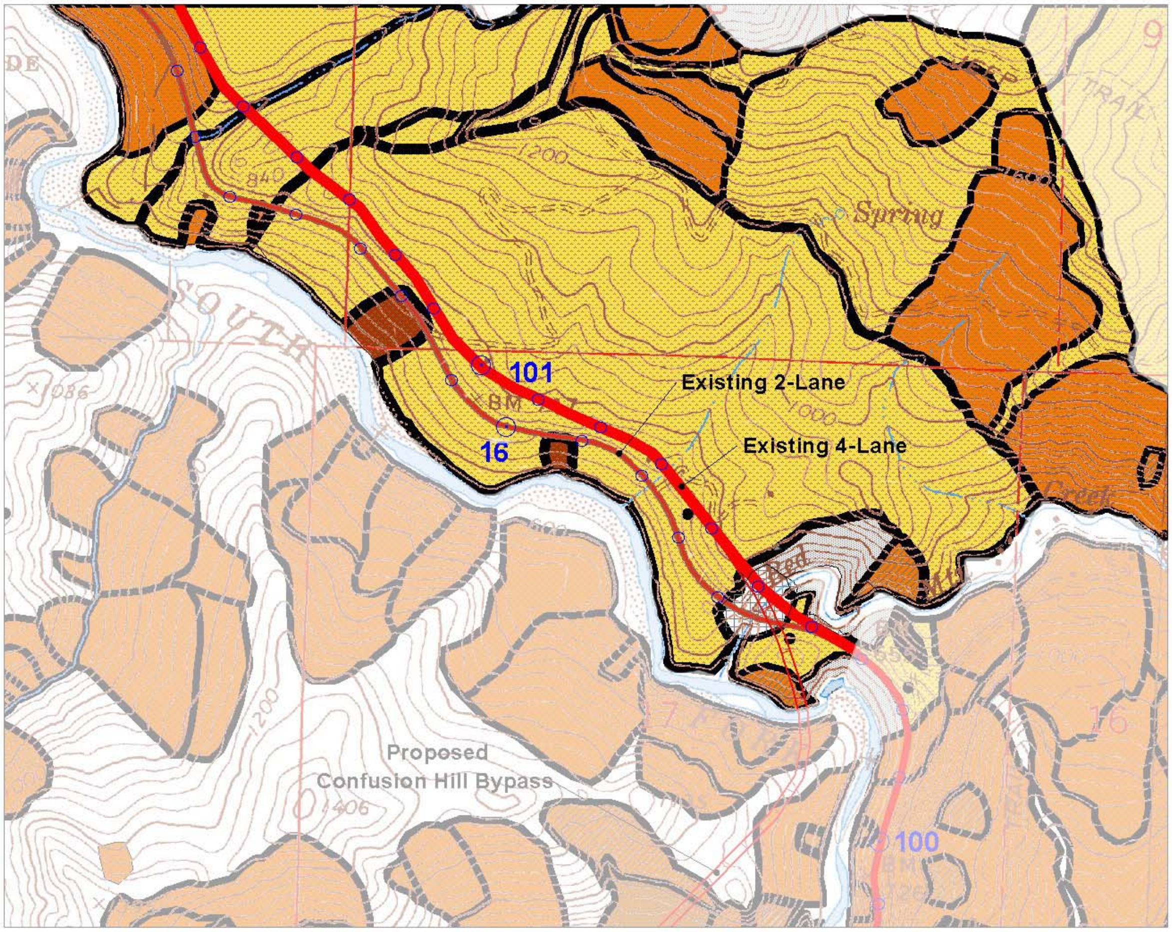


Figure 5c. North of Red Mountain Creek both the old and new highways cross a recently identified massive landslide on the right side of South Fork Eel River. The north end of the proposed bypass would start near the upstream toe of the old landslide. A small landslide exists on the old highway just south of PM 16; this small landslide has distressed the road pavement on the old highway. Another small landslide is distressing the old road at PM 16.15. This small slide has been instrumented by Caltrans to keep track of its movements. If either slide were to reactivate and enlarge, the new highway could be affected

SUMMARY

U.S. Highway 101, the main transportation corridor in northern coastal California, traverses a particularly rugged and landslide-prone area between Leggett and Red Mountain Creek south of Piercy in Mendocino County. Landslides within this corridor, especially at Confusion Hill, have been an ongoing problem for decades. Movements in the 1990's necessitated consideration of several large and complex mitigation options. In order to evaluate these options, and the relative hazards of the landslides at Confusion Hill compared with other landslides in the area, Caltrans contracted with the California Geological Survey to map the geology and landslides of the corridor. This mapping will help Caltrans plan landslide mitigation along the existing roadway and evaluate potential means of avoiding the most severe hazards.

Over 300 landslides have been mapped within the corridor area. Landslide type and activity, the level of confidence of our interpretation and several other factors are recorded for each slide. Landslides within the corridor are controlled by the steepness of the slopes and the bedrock geology. Oversteepening of hillslopes along the highway often is the result of regional tectonic uplift and the resulting downcutting of watercourses, especially the South Fork Eel River, which is situated along Highway 101. Construction of the proposed Confusion Hill bypass would eliminate the most problem-plagued segment of the highway. However, the northern end of the proposed bypass and the existing 4-lane highway are situated in the lower portion of a massive ancient landslide. The stability of this massive landslide should be evaluated prior to construction of the bypass.

ACKNOWLEDGEMENTS

The Caltrans Office of Infrastructure Research funded this study. Cliff Roblee has provided contract management and coordination with Caltrans through the Corridors Project Advisory Panel (CPAP). Members of that panel are Cliff Roblee, Rod Prysock, Roy Bibbens, Ron Richman, Loren Turner, and Jim Springer. They have guided our efforts to provide an evaluation of geology and slope stability that is clear, technically sound and suited to the internal needs of Caltrans. Tom Spittler of CGS's Timber Harvest Review and Watersheds Protection programs loaned aerial photographs of the area. Rich Munoz of Coombs Tree Farm and Doug Mallory of The Campbell Group arranged for us to have access to their companies' property. Numerous private landowners granted permission for our visits to their properties.

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APPENDIX A: PARTIAL LIST OF RECENT REPAIRS TO HIGHWAY 101, HIGHWAY 271 AND HIGHWAY 1 IN THE LEGGETT-PIERCY STUDY AREA

Post Mile	Date	Notes for Highway 101 and Highway 271
89.24	12/28/96	Cedar Creek fish ladder at Highway 101 damaged by 12/28/96 storm. Interior baffles dislodged and washed away. File BMJ-CT1-256-0.
95.6	2/25/97	Debris slide removal. File CT1-217-0
97.3-97.4	2/16/98	Separated downdrain caused severe gullying.
97.5-97.6	2/5/97	Large landslide in east side of through cut (approximately 50,000 yds^3). Upper cut bank slump and rockfall in bedrock. Headscarp developed at top of cut slope is estimated to be 3' to 6' high. File CT1-135-0. Length of scarp is about 60 meters (from memo dated 8/19/97 in file BMJ-CT1-007).
97.7-97.8	4/15/98	Remove 4,671.4 m^3 of slide material from south slope of throughcut; disposed of at Bowers Disposal Site in South Leggett. Five photos in file JLL-CT01-073-0. Slide dimensions 75'x75'x20'.
R100.5	1/17/97	Debris and logs in Red Mountain Creek channel at inlet to box culvert beneath Highway 101; debris brought down in storm of 12/28/96-1/2/97. File BMJ-CT1-009. [Location given as R97.81]
99.84	2/25/97	Cribbing failure: Outside land damaged. Debris lost into Eel River. File CT1-218-0.
99.85	2/10/98	Confusion Hill slide: Large bare scarp appears to be debris flow headscarp. Large downdropped block at "Jeep trail" junction shown on topo map. Set of photographs and negative in file JLL-CT01-074-0.
99.7-99.9	12/29/96	Slide material removed and disposed of in South Leggett (Sullivan Disposal Site). Repaired existing crib wall and guardrail. Repaved surface with AC and repaired existing drainage inlet near slide chute. At 99.81 (Confusion Hill slide) roadway settlement due to failure of two bins of existing crib wall structure. Crib wall repaired with new H beam risers and guardrail stringers. Also, debris flow in existing chute closed highway with debris. File BMJ-CT1-D10.
99.7-100.0	1/11/01+ 1/12/01	At big landslide north of Confusion Hill. Two earthquakes felt in area. Rock fall from southbound shoulder @ 99.91 undermined road to within 1 foot from edgeline of pavement. Vertical face is about 12' high. The repaired large cutslope failed; will be repaired with a soil nail wall. A 25' cut into hillslope at 99.72, and a 50' high soldier pile wall constructed at 99.91, were contracted out June 2001. File #427204.
R101.7-R101.8	No date	On Route 271 upslope from Highway 101. A slide above Highway 101 is causing damage to Route 271. The toe of an earth flow is distressing the pavement of Highway 101. A damaged drainage facility on Route 271 is directing runoff onto the slide. File BMJ-CT1-007.

R101.7-R101.8	No date	Landslide causing pushup of lane pavement. Gabion structures installed on Route 271 @ PM 19.15 upslope from Highway 271. File BMJ-CT1-008.
R101.9	No date	A debris slide that originated 300 meters upslope, destroyed the drainage inlet, plugged a culvert and blocked northbound Highway 101. Surficial erosion.
102.0-102.7	2/24/97	Debris slide plugged culvert. File CT1-219-0.
102.0-102.7	4/20/98	Eroding old slide in cut bank. File JLL-CT01-075-0.

Post Mile	Date	Notes for Highway 1
104.5	12/25/96-1/2/97	Landslide below road. Install rock buttress, embankment and two culverts. Unsuitable and excess material removed to Sullivan Disposal Site in South Leggett. December and January storms caused initial damage; additional damage occurred during reconstruction. Four-ton rock needed for base of roadway. Roadway was closed during reconstruction. File BMJ-CT1-011.
104.5	11/15/96	This site has been slumping every year for past 15 years (memorandum with file number 01-MEN-1-PM 104.4). Landslide is about 800' long on slope, 300' wide; extends 600' upslope and 200' below road to river. File MEN-1-104.5 DEC-11.
104.35	1/1/02	Slipout caused by runoff from highway pavement during New Year 2002 storms. Vertical drop of 5'. File MEN-1-105.35.

APPENDIX B: PHOTOGRAPHS

Photo AA

Photo A is taken from PM 99.6 looking downriver (North). The junction of the South Fork Eel River and Red Mountain Creek is just to the left of the bare rock face in the center of the photo. The proposed bypass would skirt along the top of the tree-covered ridge in the foreground on the left side of the photo. The actual location would be off of the photo.

Photo B shows the Confusion Hill landslides at PM 99.8 (left) and 99.7 (right).

Photo C shows the Confusion Hill landslides at PM 99.9 (left), 99.8 and 99.7 (right).

Photo D shows the original 2-lane highway (left) and the existing 4-lane highway at PM 100.6.

Photo E shows the north end of the proposed bypass, at PM 100.5.

All photos by M.W. Manson.

Photo A

Photos B & C

Photos D & E


CGS CT101MEN
7/11/2002 10:30am


SPEED
LIMIT
55
RADAR
ENFORCED
CGS CT101MEN
6/5/2002 5:30pm