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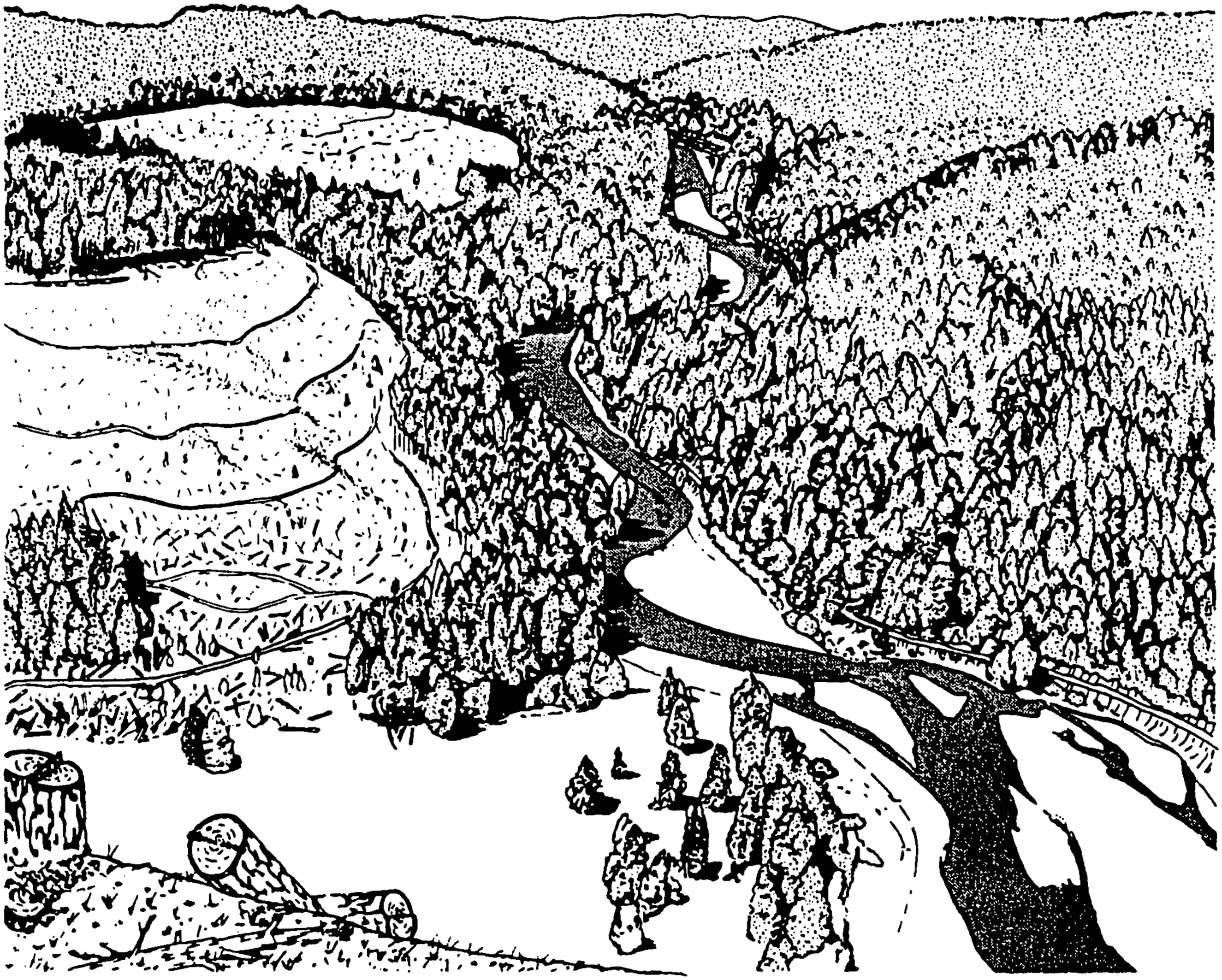
Mad River Watershed Erosion Investigation



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State of California The Resources Agency Department of Water Resources Northern District

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INTRODUCTION

This report summarizes a reconnaissance-level erosion study of the Mad River Basin. The Mad River drains an area of about 1 290 km^2 (497 mi^2) in the North Coastal Ranges Geologic Province (Figure 1). Erosion in this area relates to streamflow, sedimentation, and sediment discharge rates, which are abnormally high in some streams.

Sediment moves rapidly to stream channels by mass-wasting processes and runoff from storms. Large quantities are carried to the main river channel. Deposition of some sediment occurs at stream confluences and in low-gradient reaches of the river (Photograph 1), but most of it moves downstream as bedload or suspended sediment.

Aggradation of the riverbed has caused historical changes in the channel, raising the height of peak stormflows and resulting in damage to roads, bridges, agricultural land, fisheries, and dam and diversion facilities. Turbid water must undergo costly treatment before industrial and domestic use. Gravel mining is the only apparent beneficiary of the present high erosion-sedimentation rate.

Erosion in the Mad River Basin can be partly attributed to natural conditions, but often it is accelerated by land-use practices. In some cases it is the cumulative effect of land-use and sensitive slopes.

Natural erosion rates in the Mad River Basin are high, compared to watersheds of equal size elsewhere in the United States. Steep slopes, unstable geologic terrain, fragile soils, and high-intensity storms are typical and combine to produce a susceptible environment. Vegetation is the main deterrent to erosion.

Accelerated erosion rates are due to man's land-use activities, which disrupt local natural balances in the environmental system and increase runoff, erosion, and sediment discharge rates. Logging, agriculture, mining, recreation, and homesteading are primary land uses. Roads built to accommodate these activities are often the most serious offenders in terms of accelerating erosion.

The cumulative effects of numerous land-use activities create an imbalance in the river system and cause erosion and landslides in sensitive

Photograph 1

Aggradation (raising) of the riverbed in the lower reaches of the basin above Blue Lake. Sediment in the river channel is a result of rapid erosion and sediment transport during high flows. Aggradation can bury bridges and roads, cause frequent shifts of the river channel, and destroy fish spawning sites.

areas far removed from the land-use sites. Prior to disturbances by man, the Mad River Basin had lower runoff, erosion, and sedimentation rates than those seen today. The channels and banks of the river and affected tributaries are responding to the increased load. Such responses include landslides, channel aggradation or degradation, and bank erosion.

Purpose and Scope

The purpose of this study was to collect basic data on the sources of sediment and causes of erosion in the Mad River Basin and to record present conditions. These data will update existing baseline data and serve as a basis for comparison in future studies.

Work began with compilation of a bibliography of geology, soils, precipitation, and sediment production in the north coastal region. Professional papers were studied on erosion and erosion control in forested and deforested lands, and on the problems of timber harvesting, road construction, and animal grazing in geologically unstable areas. Consultation with other agencies provided in-house reports, unpublished data, and relevant ongoing studies.

A geologic base map, with landslides, was compiled on 15-minute (1:62,500 scale) contour maps. Landslides were located from previous geologic mapping studies and aerial photographs. This map shows geologically sensitive areas, landslides that actively contribute sediment, and potential problem areas.

Using tax records from Trinity and Humboldt Counties, we made a road and land ownership map. We updated recent road maps using U-2 aerial photography flown in 1978. U. S. Forest Service (USFS), California Department of Forestry (CDF), and county tax records were used to make a watershed timber harvest map. It shows size, decade and method of harvest, and burned areas.

Turbidity samples from selected streams were collected during storms in the winters of 1979-80, 1980-81, and 1981-82. We chose representative sample stations where winter access was possible. A Hack Lab Turbidimeter model 2100A measured turbidity in Nephelometer Turbidity Units (NTUs). In some cases, 50 ml (3 in^3) aliquots were filtered through a .45 micron millipore filter. The relative densities of the filtrates provided visual comparison of stream turbidity.

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SUMMARY AND CONCLUSIONS

The Mad River is in northwestern California, a region of steep, unstable slopes with some of the most rapidly eroding terrain in the United States. Streams draining the area have some of the highest suspended sediment loads per unit area recorded in the world (Judson and Ritter, 1964). The Mad's watershed was studied to identify the sources and determine the causes of high turbidity.

In the data collection phase, the Department first reconnoitered the watershed and then compiled (1) a bibliography of pertinent references; (2) a geology and landslide map; (3) a timber harvest and burn map from county tax records, USFS, and CDF timber harvest files; (4) hydrologic data from the U. S. Geological Survey (USGS); and (5) turbidity data, showing areas producing the highest turbidity.

Three USGS stream gage stations appropriately divided the basin into northern, middle, and southern compartments. Water and sediment discharge rates measured at these gaging stations show that 60 percent of the sediment entering the river comes from 42 percent of the basin area, in the middle compartment.

Measurements made for this study show an increase in turbidity as you move downstream. There are large increases at the downstream end of the middle compartment and near the town of Blue Lake. Turbidity decreases below Ruth Reservoir.

Private land holdings are concentrated in the northern and middle compartments of the basin. These compartments comprise about 70 percent of the total basin area and yield nearly 95 percent of the basin's sediment, because land-use has been more intense than on the public lands in the study area.

Comparison of 1944, 1954, and 1975 aerial photographs shows that the number and size of active landslides in the basin are increasing. In these three decades, 35 percent of the Mad River Basin area has been logged. In the middle compartment, where severe erosion hazards exist, 42.5 percent of the area has been logged since 1947. Also, grassland prairies on the South Fork Mountain Schist and the Franciscan melange have been heavily grazed. Overgrazing of these grasslands increases runoff and causes gullies and landslides.

The complex lithology and sensitive structure of Franciscan bedrock create numerous potential landslide failure surfaces. Road construction in many areas should have site-specific geotechnical investigation to insure stability.

The South Fork Mountain Schist and Franciscan melange units in the southern compartment have severe erosion hazard ratings, but measurements at Ruth Reservoir and the stream gage station "near Forest Glen" suggest little erosion. Land-use in the southern compartment has been minimal. Only 11.5 percent of the area has been logged.

Sixty-one tributary streams were sampled, and analysis showed that the North Fork Mad River and Hall, Boulder, Madrone, Humbug, Maple, B, G, and Anada Creeks have comparatively higher turbidities. Land-use on sensitive slopes accounts for these high turbidities.

WATERSHED OBSERVATIONS AND STATISTICS

Soil forms at the earth's surface as a result of five soil-forming factors: climate, relief, organics, parent material, and time. Soil is the main storehouse for nutrients, the essential medium of plant growth, a major repository of water, and the physical support for plants. A significant proportion of plant nutrient elements are stored in the top 10 cm of the soil (Colwell, 1974, in Dodge, 1976).

Soil erosion is the removal of the soil mantle by running water, rainfall, waves and currents, moving ice or wind. Flowing surface water usually detaches most of the soil lost from rills and gullies, but splashing raindrops detach most soil that is lost from smooth surfaces (Ellison, 1947). Mass wasting, or loss of soil and rock by landsliding and by creep, are considered here as a separate process.

Of the many factors affecting soil erodibility and mass wasting, the more notable are rainfall distribution, geology, vegetation, geomorphology, physical and chemical properties of soils, and human activities.

The term "accelerated erosion" means loss of soil at rates greater than geologic rates due to human activities. The common causes of accelerated erosion are roads, timber harvests, burns, agriculture, mining, and urbanization.

The loss of soil due to erosion and mass wasting increases the difficulty and expense of reestablishing vegetative cover. Accelerated erosion increases sediment and turbidity in streams, lakes, reservoirs, and oceans. Sediment and turbidity reduce water quality and damage fisheries, restrict streams and drainage ways, and increase water treatment costs.

Roads

Most scientists involved in watershed and forest management agree that of human activities, road construction is the largest cause of accelerated erosion. Roads are the largest contributor per acre to rill-and-gully erosion (Hauge, 1977), and landsliding related to roads is the chief source of sediment in areas of the Pacific Northwest (Swanson, 1974; Swanson and Dyrness, 1975; Gray, 1973).

In the H. J. Andrews Experimental Forest in Oregon (Swanson and Dyrness, 1975) thirty times more soil material slid along road rights-of-way than in forested areas. In comparison, only 2.8 times greater volume of soil slid in clearcut areas than in forested areas. Dyrness (1967) found that the influence of roads on mass movements was overwhelming, with 126 events per 400 ha in road areas compared with 3.9 in logged areas and 0.4 events per 400 ha in undistrubed areas.

The Van Duzen Basin has geology and slopes similar to the Mad River Basin and adjoins it to the southwest. According to Kelsey's (1977) report on the Van Duzen:

> "County roads or main logging haul roads are associated with many of the debris slides which occurred on slopes subsequent to logging. On 33 of the 56 slope failures that occurred after logging, logging haul roads had been built across the top, middle, or toe of the slope that eventually failed. Considering just the 29 logged slopes which failed prior to the 1964 flood, 21 of these slope failures (72 percent) were associated with major logging haul roads or power line cuts, and all the slope failures were on tractor yarded slopes. The above inventory of roaded slopes does not include steep skid trails that cut across most logged slopes which subsequently failed either before or during the 1964 flood."

In this study, roads were classified as highways, major haul roads (including County and Forest Service roads) and minor haul roads (minor access and jeep roads). Twenty-four-inch focal length U-2 infrared photographs, flown in March 1972 and enlarged 12 times, were used with USGS quadrangle, County, and Forest Service maps to measure road lengths. Lengths of measured roads were:

	Kilometres	Miles	Percent
Highway	46	28	4
Major Haul Roads	420	252	41
Minor Haul Roads	562	337	55
Total	1 028	617	100

Roads accelerate erosion (Photograph 16). Their construction on steep slopes tends to: (1) oversteepen the cut-and-fill slopes of the road prism; (2) expose unprotected subsoils to erosion; (3) dump unconsolidated fill on the downslope; (4) intercept subsurface flow in the cut-slope; (5) collect, concentrate, and divert surface runoff; and (6) provide loose soil and debris to increase the scouring power of water. Road stream crossings are particularly vulnerable because their construction impinges directly on streams, and roadfill is often placed near or directly in the creek.

Photograph 16

Rotational slump in Franciscan melange on a road in the middle compartment.

Photograph 17

Poor drainage measures, such as undersized, unmaintained, or plugged culverts, cause creeks to become dammed and the culverts to fail abruptly. Streambanks below culverts are often scoured and corraded. Shown is gully erosion in Franciscan melange induced by a road culvert. Culverts and their associated drainage systems collect, concentrate, and divert surface runoff and increase the scouring power of the water.

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Landslides

Landsliding is a major geomorphic process and source of sediment in the Mad River Basin. Brown (1973) showed that about 60 percent of the suspended sediment derived from the basin in the 1971 water year came from the landslide-prone region between the USGS gaging stations near Forest Glen and Kneeland (42 percent of the basin area). Landslides in this region occur mostly in the melange unit of the Franciscan Complex.

Landslides have been divided into active and dormant, based on observable features that suggest recency of activity.

Active landslides show evidence of recent movement, such as fresh barren scarps, jackstrawed trees, displaced roads and stream channels, and clusters of large rocks in the stream channels. The active classification includes streams and gullies with extensive or accelerated bank erosion. Many of the active landslides originated during and after the December 1964 flood. Vegetation on active landslides is sparse, with willows, grass, and brush predominant.

Dormant landslides have landforms that are easily recognized as slide topography. Bowl- or spoon-shaped depressed areas are bounded by steep crown and flanking slopes. Flat lobes and irregular hummocky topography are well defined. Depressed sags and ponds, water seeps, and water-loving vegetation are common. In forested areas, vegetation on dormant slides is generally a well-established, mature forest stand that may vary in tree type and density from surrounding stable slopes. In grassland areas, oak- and brush-covered slopes spearated by grass-covered meadows and prairies are typical of dormant slides. Old-growth trees with bowed, tilted, and broken trunks occur within some of these slides and may indicate that deep-seated movement is presently occurring at slow rates. Dormant landslides define areas of past instability and indicate sensitivity to erosion and mass wasting.

Most landslides were identified on stereo-paired aerial photographs and transferred to the Geology Map (Plate 1). All active slides are not easily recognized from aerial photos due to dense vegetation and small scale of the photos. Ground observations suggest that a much larger percentage of the basin area is affected by active slide movement. Many large slides shown as dormant have obscure features, visible in the field, that may suggest recent periods of slow, deep movement. Only a small percentage of the landslides on the Geology Map were field checked.

Landslides were not mapped according to genetic type in this study. However, common types found in the basin are debris slides, rock slides, rotational slides, earth and debris flows, and complex (combination of types) slides (Figure 14). Gutted stream channels and areas of persistent soil mantle creep are also found.

Debris slides involve slow-to-rapid downslope movement of predominantly unconsolidated and incoherent soil, rock, and debris. The mass does not show backward rotation but slides or flows forward, forming an irregular, hummocky deposit.

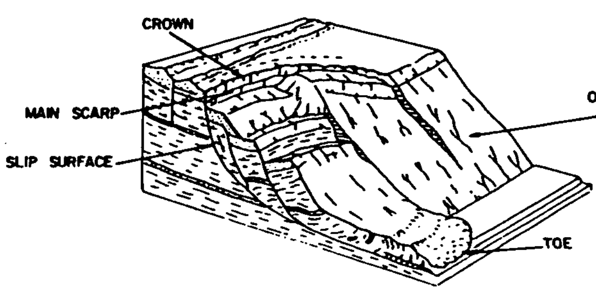
Debris slides generally occur near streams along the oversteepened slopes of the inner gorge (Photograph 18). These slides are particularly common on the Mad River and its major tributaries. Many debris slides occurred during and after the December 1964 flood. The high floodwaters undercut riverbanks and scoured canyon sides, causing slope instability. The slides dumped a tremendous amount of silt and gravel into channels, which further elevated the high flows and caused additional scouring and sliding downstream.

Photograph 18

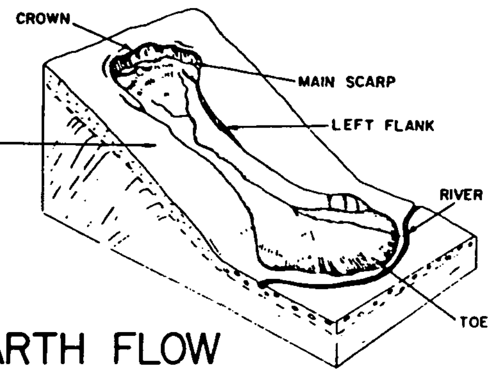
Section of the Mad River in the middle compartment of the basin. Note the debris slides in the oversteepened slopes of the inner gorge.

LANDSLIDE TYPES

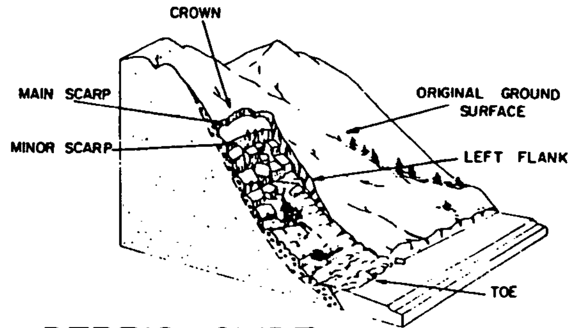
Figure 14



SLUMP-EARTH FLOW



EARTH FLOW



DEBRIS SLIDE

NOMENCLATURE OF THE PARTS OF A LANDSLIDE

WN - The material that is still in place (or practically undisplaced) and adjacent the highest parts of the main scarp.

T FLANK - The left side of the landslide as viewed from the crown.

N SCARP - A steep surface on the undisturbed ground around the periphery of the ide, caused by the movement of slide material away from the undisturbed ground. e projection of the scarp surface under the displaced material becomes the ip surface.

MINOR SCARP - A steep surface on the displaced material produced by differential movements within the sliding mass.

ORIGINAL GROUND SURFACE - The slope that existed before the most recent landsliding took place. If this is the surface of an older landslide, that fact should be noted.

SLIP SURFACE - The interface between displaced material and material remaining in place.

TOE - The margin of displaced material most distant from the main scarp.

[Modified after Varnes, 1978]

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Gutted stream channels are those that have been severely scoured and corraded by debris torrents or by debris-carrying floodwaters reaching well above the normal elevation of channel flows. The scouring is often accompanied by sloughing and sliding of the channel bank. In the watershed, gutted streams, or "guts", are most abundant in areas underlain by Franciscan melange or in areas severely affected by land-use management. Most of the damaged channels are in tributary streams that descend old fault zones or drain dormant landslides. Portions of the Mad River channel between Pilot Creek and Butler Valley in the middle compartment have also been gutted.

Rock slides are less common but do occur. They involve a sudden, rapid downward movement of newly detached segments of bedrock, which usually break up into small pieces while moving.

Earth and debris flows in this watershed are numerous and are usually larger features than debris slides. The flows are mass movement landforms characterized by downslope movement of water-saturated soil and weathered rock over a discrete basal shear surface and within well-defined lateral boundaries. Some minor rotation may occur in the vicinity of the crown scarp. The surface of the flow is hummocky with a series of parallel pressure ridges that ends at the toe in a broad lobelike form.

A translational-rotational slide combines a rotational mechanism in the upper part with translational movement in the lower part. In the crown-scarp region, failure takes place on a well-defined, concave-upward shear surface, producing a backward rotation in the displaced mass. The slide below the crown-scarp region moves downslope on a failure plane that is roughly parallel to the ground surface. Rates of movement vary. Initial failure is generally rapid with later seasonal movement at a slower rate.

<u>Causes of Landslides</u>

The stability of a mountain slope depends upon the equilibrium between forces acting to resist slope failure and forces acting to cause it. These are called passive and active forces, respectively. Passive forces are properties inherent in rock and soil, including natural strength, cohesion, capillarity, and root support forces.

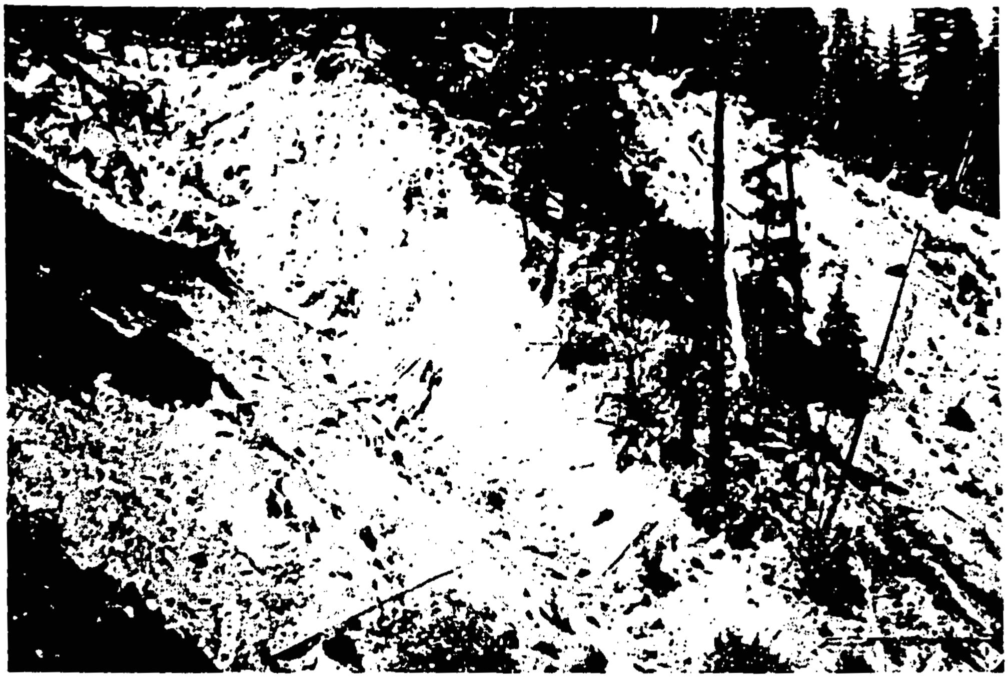
Active forces that reduce slope stability include: (1) natural slope plus increased slope caused by stream or road undercutting; (2) ground water conditions that contribute to pore pressure, seepage, and uplift forces; (3) planes of weakness that include joint, fracture, fault, bedding, foliation, or ancient landslide failure planes; (4) localized weight increase caused by road fills or soil saturation during storms; and (5) removal of vegetation, causing loss of root support over a period of years and reduction of ground water dissipation through transpiration.

When the sum of active forces exceeds the sum of passive forces, slope failure occurs. Shearing stress exceeds shearing resistance. Failure may occur rapidly, in minutes, or slowly, over a period of years. It continues until a new state of equilibrium is reached between the active and passive forces. Once failure has occurred, the strength of the material involved is permanently altered to a weaker state, and reactivation of sliding requires much less provocation.

Landslides that occur at the base of a hill remove support from uphill slopes and may lead to progressive upslope failures. In this situation, areas of complex landsliding are created in which slope stability is sensitive to any manipulation. Smaller slides often occur within the weakened material of larger slides.

Active landslide movement commonly occurs in winter and spring, when heavy rains have thoroughly saturated the regolith (soil mantle) and streamflows are high. Increased moisture in soils causes an increase in the unit weight of soil and pressure, a decrease in capillary forces, an increase in plasticity, and a decrease in cohesive properties. Movement of ground water increases with infiltration of runoff, and creates seepage and uplift force that act normal to the slip surface (Zaruba and Mencl, 1969). All of these factors adversely affect the slope stability of the regolith and contribute to landsliding.

Tectonic mountain-building processes affect slope stability in several ways. Regional tilting and uplift of tectonic blocks increases the overall slope, leading to reactivation of stream channel erosion and unstable slopes. Earthquakes associated with tectonic processes promote the movement of landslides by shaking. The "Earthquake Epicenter Map" (Figure 5) indicates that the Mad River area has experienced shaking from many earthquakes in historic time, ranging in magnitude from less than 3 to less than 8 on the Richter scale.



Photograph 19 - A strip stabilized by growing vegetation separates this debris slide into two sections. The slope drainage, altered by the slide, has cut a deep gully in the section at left.

Photograph 20 - A rockslide enters a stream channel. High flows during the wet season have washed away the fine sediments at the slide's toe, leaving coarser materials behind.

Timber Harvest

Timber production and related industries are a major part of the basin's economy. Lumber mills are found from Korbel to the coast in the northwestern portion of the basin, and logs are shipped to mills in Arcata, Eureka, and other nearby industrial centers.

Nearly 35 percent of the basin has been logged. Before timber harvesting, about 64 percent of the basin was covered with forests, 14 percent brush, 21 percent grass, and about 1 percent was barren (Wallis, 1947, in Anderson, 1963). These data suggest that nearly 55 percent of the forest-covered land in the Mad River Basin has been logged since 1947.

The "Timber Harvest and Burn Map" (Plate 2) was prepared from County, State, and Federal documents. Information on private land harvests in Humboldt County from 1950 to 1976 came from the County Tax Assessor's "Timber Type" maps.

Different government entities use different designations for extent of timber harvests. For example, Humboldt County uses categories of "no merchantable timber remaining" and "one or more species removed and one original species remaining". When 70 percent or more of the merchantable timber is removed from an area, we call it "clearcut". All other harvests are "partial cuts".

Harvests from 1977 to 1980 in Humboldt County came from CDF files and maps. Where only seed-trees are left at a harvest site, we use the CC symbol.

Information on private land harvests in Trinity County for 1947 to 1953 came from a Six Rivers National Forest Fire Atlas Map, "Cutover Lands in SRNF". These harvests were assumed to be clearcut, since 70 percent or more of the timber in a harvest area was usually removed before tax law changes in 1977. No data were available for the 1954-66 period. Data for 1977-80 were obtained from CDF, using the same CC and PC categories as for Humboldt County.

Six Rivers National Forest harvest data came from the Mad River Ranger Station and covered the entire period of harvest activity, up to the present.

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TABLE 5

AMOUNT AND METHOD OF TIMBER HARVEST FOR THE MAD RIVER BASIN AND COMPARTMENTS 1/ BY DECADE
1981

	Southern 2/ Compartment		Middle 3/ Compartment		Northern 4/ Compartment		Total Basin	
	Area km² (mi²)	5/ Percent	Area km² (mi²)	5/ Percent	Area km² (mi²)	5/ Percent	Area km² (mi²)	6/ Percent
Area	370 (143)	100	541 (209)	100	376 (145)	100	1 287 (497)	100
Pre-1960 7/ Selective Cuts	0 (0)	0	7.0 (2.7)	1.3	17.9 (6.9)	4.8	24.9 (9.6)	1.9
Pre-1960 7/ Clearcuts	13.5 (5.2)	3.6	153.8 (59.4)	28.4	55.4 (21.4)	14.8	222.7 (86.0)	17.3
Pre-1960 7/ Total Cuts	13.5 (5.2)	3.6	160.8 (62.1)	29.7	73.3 (28.3)	19.5	247.6 (95.6)	19.2
1960 to 1970 Selective Cuts	1.6 (0.6)	0.4	0.5 (0.2)	0.1	0 (0)	0	2.1 (0.8)	0.2
1960 to 1970 Clearcuts	7.5 (2.9)	2.0	25.1 (9.7)	4.6	63.5 (24.5)	16.9	96.1 (37.1)	7.5
1960 to 1970 Total Cuts	9.1 (3.5)	2.4	25.6 (9.9)	4.7	63.5 (24.5)	16.9	98.2 (37.9)	7.7
Pre-1970 Total Cuts	22.6 (8.7)	6.0	186.4 (72.0)	34.4	136.8 (52.8)	36.4	345.8 (133.5)	26.9
1970 to 1981 Selective Cuts	9.3 (3.6)	2.5	7.5 (2.9)	1.4	18.6 (7.2)	5.0	35.4 (13.7)	2.8
1970 to 1981 Clearcuts	10.9 (4.2)	3.0	35.7 (13.8)	6.6	15.8 (6.1)	4.2	62.4 (24.1)	4.8
1970 to 1981 Total Cuts	20.2 (7.8)	5.5	43.2 (16.7)	8.0	34.4 (13.3)	9.2	97.8 (37.8)	7.6
Pre-1981 7/ Total Selective Cuts	10.9 (4.2)	2.9	15.0 (5.8)	2.8	36.5 (14.1)	9.7	62.4 (24.1)	4.9
Pre-1981 7/ Total Clearcuts	31.9 (12.3)	8.6	214.7 (82.9)	39.7	134.7 (52.0)	35.9	381.3 (147.2)	29.6
Pre-1981 7/ Total Cuts	42.8 (16.5)	11.5	229.7 (88.7)	42.5	171.2 (66.1)	45.6	443.7 (171.3)	34.5

1/ For the ease of comparing timber harvest effects with Mad River water and sediment discharge, the basin was subdivided into compartments based on the location of USGS stream gage stations.

2/ The southern compartment is defined here as the entire area from the USGS stream gage station, Mad River near Forest Glen (11-4805.00), and its hydrologic divide to the upper most headwaters of the river.

3/ The middle compartment contains the area between USGS station 11-4805.00 and the USGS stream gage station, Mad River near Kneeland (11-4807.50), and its hydrologic divide.

4/ The northern compartment contains the basin area from the mouth to the USGS station 11-4807.50 and all intervening tributary streams. Note that only 24 ha (60 acres) of harvest area are located below the USGS station Mad River near Arcata (11-4810.00).

5/ Percent computed from the area of the compartment.

6/ Percent computed from the area of the entire basin.

7/ Records of private timber harvests were not begun until 1954. Pre-1954 timber harvests were determined from aerial photographs.

County tax records of timber harvests did not begin until about 1950, and timber harvests on private land before that time were (or were not) determined by the counties from aerial photographs. Therefore, private land logged before 1950 and supporting second growth timber may not be shown on Plate 2. (For example, almost the entire North Fork Mad River watershed above Korbel was logged before 1930, yet only a small portion of the logged area is documented and shown on the timber harvest map.) Determination of undocumented pre-1950 logged areas in the basin was beyond the scope of this study.

In multiple entry areas, only the last logging date is shown on Plate 2. Some areas have been selectively cut two or more times, and in some of these no commercial trees remain.

The amount of watershed area logged is shown in Table 5 according to the method of logging--selective cut and clearcut--and the decade in which the harvest occurred. (Selective cut is used here interchangeably with partial cut.) The table also gives the same information for the three compartments in the basin. Most heavily logged are the northern compartment (45.6 percent) and the middle compartment (42.5 percent). The southern compartment, which is managed mostly by the USFS, has had 11.5 percent of its area logged.

Effect of Logging on Erosion Processes

The removal of forest cover alters the hydrologic regime, affects the soil mantle stability, and results in soil nutrient loss and higher-than-normal erosion rates. Logging removes the protective forest canopy and soil duff cover, baring soil to raindrop splash erosion and overland flow (Photograph 21). Road construction associated with timber harvesting is a major cause of watershed erosion and mass wasting.

Soil compaction occurs in some areas. This is a problem in tractor-yarded areas on sensitive soils, because it reduces the rate at which precipitation enters the forest floor, thus increasing runoff and erosion (Photograph 22). Reinhard (1964) observed a fifty-fold decrease in infiltration on heavily compacted roads compared with nearby undisturbed forest floor.

With complete denudation of a watershed, more than 70 percent of precipitation during a storm may be delivered as overland flow (Dodge, 1976).

Photograph 21 - Cable-yarded clearcut. Although cable yarding reduces the number of roads needed for timber harvest, complete removal of the forest results in exposure of the soil to erosive processes.

Photograph 22 - Large gullies in this timber harvest block resulted from increased and concentrated runoff. Canopy removal, soil compaction, and alteration of natural drainage channels have caused accelerated erosion and landslides in many areas of the basin.

The USGS (Lee, K., Kapple, G., and Dawdy, D., 1975) has shown that in the Redwood Creek Basin, which has similar geology and neighbors the Mad River Basin to the northeast, the storm season runoff is about 20 percent greater after intensive logging than for the period of record before the beginning of intensive logging. In laboratory experiments, Singer et al (1978) found that for a full mulch cover: (1) runoff volume was significantly less, (2) runoff started significantly later, and (3) runoff continued longer.

Recognition of forest cover and its relation to runoff and floods in the North Coast is not new. In the "First Biennial Report of the State Board of Forestry", Kinney et al (1886) state:

> "Mr. Wagoner, in his report, alludes to the opinion of some old settlers, that the cutting of trees upon the immediate banks of some of the streams in the north either actually increased the flow of those below, or did not diminish it. This sometimes occurs, particularly in moist or cloudy counties where the direct evaporation caused by the sun is not great. The effect where produced is caused by the detention of the stream by tree roots, and the diffusion into the air by the leaves of the water taken up by the trees themselves. We mention this because an instance of this kind might confuse the opinions of those not understanding the phenomena. In mountains, the number of actual cubic feet of water delivered annually under the same rainfall from a watershed, is undoubtedly less when forested than when bare; but the advantage of the forest is, that it attracts the moisture and holds and detains the rainfall so that it flows off in a slow and gentle manner, either by the streams or by springs caused by the water's seeping through rock veins. But the bare watershed throws off all the rainfall at once in one great destructive flood, carrying before it rocks, gravel, soil, and everything; with these it ruins the valley lands below. Nothing illustrates these effects better than the fact that the heavy rains of the coast counties, falling upon forested mountains, run off in well defined channels, and seldom, if ever, cause destructive floods; whereas, the very light rainfall of the Colorado Desert seldom over four inches per annum, and often not two, falling on perfectly bare mountains, covers the whole country with a

sheet of rushing water, and washes away miles of railroad track at a time. We believe that there is nothing more important to the welfare of this commonwealth than the preservation of its splendid forests."

After logging, regeneration of conifers may be slow or may fail altogether. For the Mad River Basin, Stoate and others (1975) found that regeneration rates varied greatly from one soil type to another and that a tentative soil chemical standard for regeneration may be set at: soil reaction less than 5.6, organic matter 10 percent, available phosphorus 11 ppm, and total nitrogen 0.2 percent. Where at least three of these standards are met, regeneration should take place. Many of the soils they tested from grassland prairies showed moisture contents that fell below the wilting point during summer months. Grass competition, animal browsing, and insect damage also contribute to the slow rate or failure of conifer regeneration.

A long-term effect of timber harvesting is often a decrease in slope stability. Removing trees on steep slopes can lead to accelerated creep rates and increases in mass wasting (Gray, 1973). This is due to the wetter condition of cutover slopes from reduced evapotranspiration and from a loss of root strength in decaying stumps. Healthy tree roots may increase soil shear strength two to four times (Gray, 1973) and greatly increase slope stability by providing a continuous long fiber adhesive binder to the entire slope soil mass. Roots can also penetrate a shallow soil to reach into fractures and joints in bedrock, thereby anchoring the soil mass (Swanston, 1974). This strengthening is lost three to five years after timber is harvested (Bishop and Stevens, 1964). According to Kelsey's (1977) report on the adjacent Van Duzen River Basin:

"...67 percent of the lower watershed slope failures occurred on slopes after they had been logged, and of these post-logging landslides, 52 percent started before the 1964 flood. In contrast, only 31 percent of the slope failures started on unlogged slopes, and the vast majority of these landslides, 77 percent, occurred at the time of the 1964 flood. Of the total amount of lower watershed debris slide and debris avalanche material generated during the study period, 81 percent came from slope failures that commenced after the slope had been logged. Slightly less than half of the above amount came from logged slopes which initially failed before the 1964 flood. Unlogged areas contributed only 18.5 percent of the total amount of landslide debris."

Burns

Available records indicate that only a small portion of the Mad River Basin has been burned since 1950. Inland timber areas had little value until the 1920s, and large areas of land were burned and converted to grazing land. Pioneer ranchers set fires to clear the land and many of these fires spread through the forest unchecked. The engineer of the State Board of Forestry of California, Davison (1888), described the statewide fire problem thusly:

> "The forests of California have suffered serious losses from forest fires.
>
> "Nearly every year since the settlement of the State, destructive fires have raged throughout the mountains, unheeded, unchecked, destroying thousands of acres of our finest timber.
>
> "The yearly loss caused by fire alone is immense.
>
> "In 1880 it was estimated that an area of over three hundred and fifty thousand acres were burned over by fire, and this was greatly exceeded in 1887.
>
> "Throughout the entire State, citizens deplore the fearful ravages of forest fires, and their inability either to prevent or to check them."

Indians set fires to stimulate growth of deer browse. A general observation by Vischer (1886) states:

> "As regards the growth of young timber--save only among the heavy redwood forests--the number of young trees which within the last decade or two has sprung up is very great. All the open pine forests, back of the coast, are becoming rapidly stocked with young trees, and much of the open grazing land is rapidly being converted into brush or becoming covered with young saplings--generally Douglas spruce or yellow pine.

"The cause of this increase is unquestionably the cessation of the old Indian practice (formerly general) of running fires through the country to keep it open to facilitate hunting, or in driving game before the flames into inclosures set with snares. Under this system about half the ground was burned over each year, in alternate halves; thereby the open lands were kept free of brush and all growth of young trees was checked in the forests. The older, well matured trees, however, suffered very little, as so little undergrowth could mature between one fire and another, that sufficient heat was not developed to hurt older trees, fairly covered with bark and with limbs some distance above the ground. In fact, the Indian system became in some sense a method of forest preservation, and to it we undoubtedly owe the noble forests which were transmitted to our hands."

The Mad River Basin undoubtedly suffered from many pre-twentieth century fires that removed vegetation and increased runoff and erosion rates, but these fires are not documented.

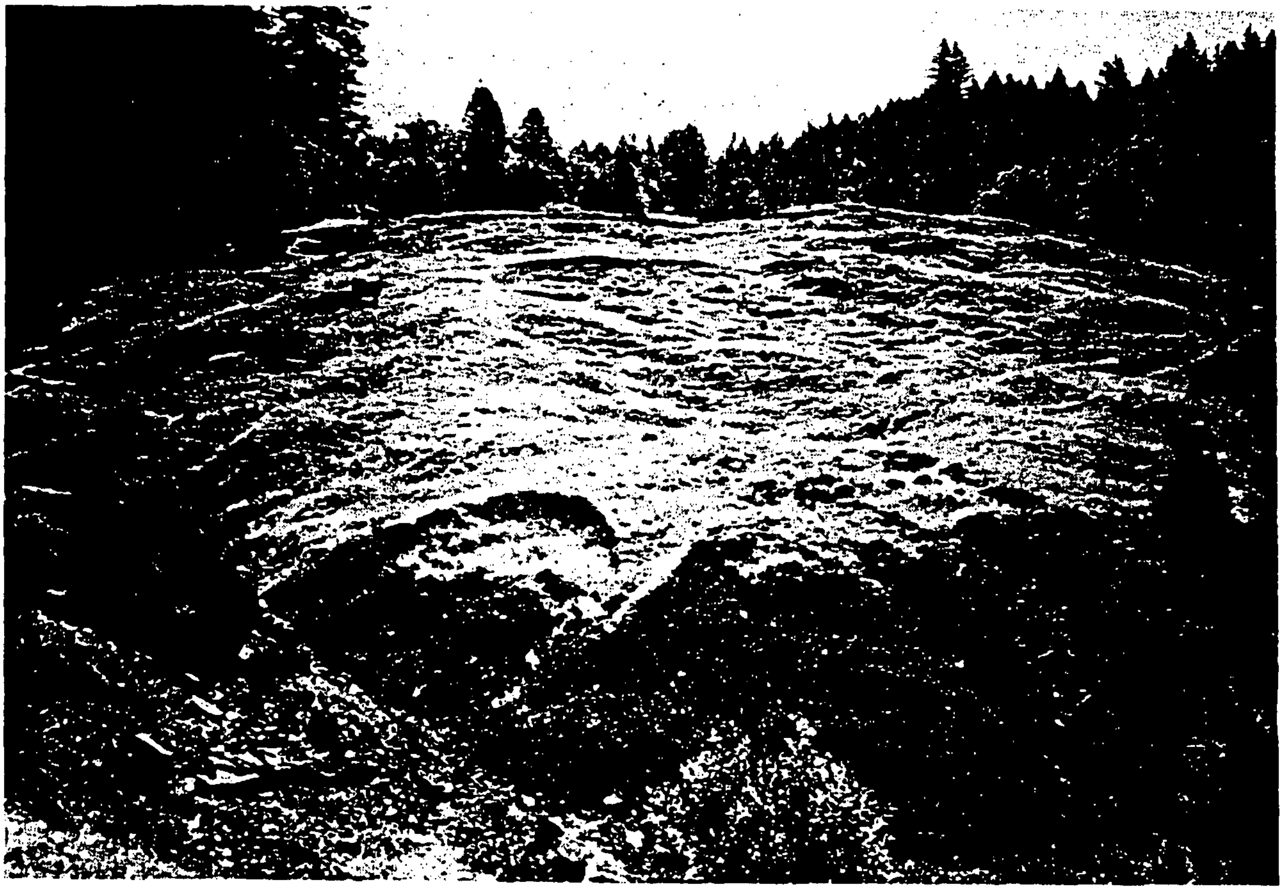
Grazing

Cattle and sheep grazing can increase runoff and contribute to accelerated erosion and landslide movement (Photograph 23). Vast areas covered with grass, grass and oak, and brush are used by ranchers for livestock production. Numerous wildlife species also feed on these herbaceous lands.

Stoate and others (1975) found that several soil types support the prairie regions. The highest forage production occurs on Mattole, Zanone, and McMahon soils. These develop primarily on the Franciscan melange and South Fork Mountain Schist. Fencing areas by soil type and controlling grazing can produce higher yields of forage per acre and prevent erosion related to overgrazing (Cooper and Heady, 1964).

The introduction of sheep and cattle in the 1800s led to the disappearance of the original perennial grass species of the northwest prairie. Annual grasses replaced the native species. The root system of annual grass is shallow and imparts substantially less strength to the slope surface than that of perennial grass (Burcham, 1957).

Additional problems are caused by stock trails and the destruction of channel banks by wandering cattle. The steady tread of grazing livestock accelerates the downslope movement of top soil. Intense trampling causes soil compaction, decreases infiltration of rainwater, and increases runoff from storms.



Photograph 23 - Sheep and cattle grazing, introduced in the 1800s, destroyed the deeply rooted perennial grass species, resulting in loss of strength in the slope surface. This induces slope failure, particularly in sensitive Franciscan melange terrain.

Urbanization

Major urban centers are in the northwest part of the basin, primarily on terraces in the broad river valley and on the coastal plain. A land use study (DWR, 1968) shows that urbanization affects 1.3 percent (1 640 ha--4,055 ac) of the Mad River Basin (Table 6). While urbanization in some areas of California causes accelerated erosion, towns within the Mad River Basin contribute minor amounts of sediment compared to other sources. As population growth extends into mountainous areas, the sediment yield attributable to land development may increase substantially.

TABLE 6

LAND USE IN THE MAD RIVER BASIN

Land Use	Area km^2	Area mi^2	Percent
Irrigation 1/	6.8	4.2	0.85
Non-Irrigated 2/	5.1	3.2	0.65
Urban 3/	10.1	6.3	1.30
Recreation	0.6	0.4	0.09
Riparian	0.5	0.3	0.07
Other	764.4	475.0	97.05

Modified after DWR, 1968

1/ Includes alfalfa, pasture, general field, miscellaneous truck, and orchard crops.

2/ Includes grain, grain hay, alfalfa, improved pasture, general field, miscellaneous truck, potato, and orchard crops.

3/ Includes U, U11, U12, U13, U16, and UV land use designations.

Mining

Manganese ore bodies are in the southern compartment near Ruth Reservoir. Bulldozers once stripped the overburden, and open pit mining yielded ore containing 40 to 50 percent manganese. The Blue Jay Mine, about 26 km (16 mi) southeast of Ruth, was one of the principal producers of high grade lump ore in California (O'Brien, 1965). Mining of these deposits ceased in the 1950s.

Sand and gravel aggregate is mined from the braided river channel between Blue Lake and the ocean. This reach of the river has been extensively altered by the gravel mining. DFG issued 21 gravel mining permits to 14 operators in 1981. The permits allow for the removal of 188 000 m^3 (247,000 yd^3) of gravel. Turbidity measurements made from the river at the Highway 101 bridge were three to four times greater than those made from the river near Blue Lake. This may be caused in part by gravel mining operations.

Instability and Erosion Hazard

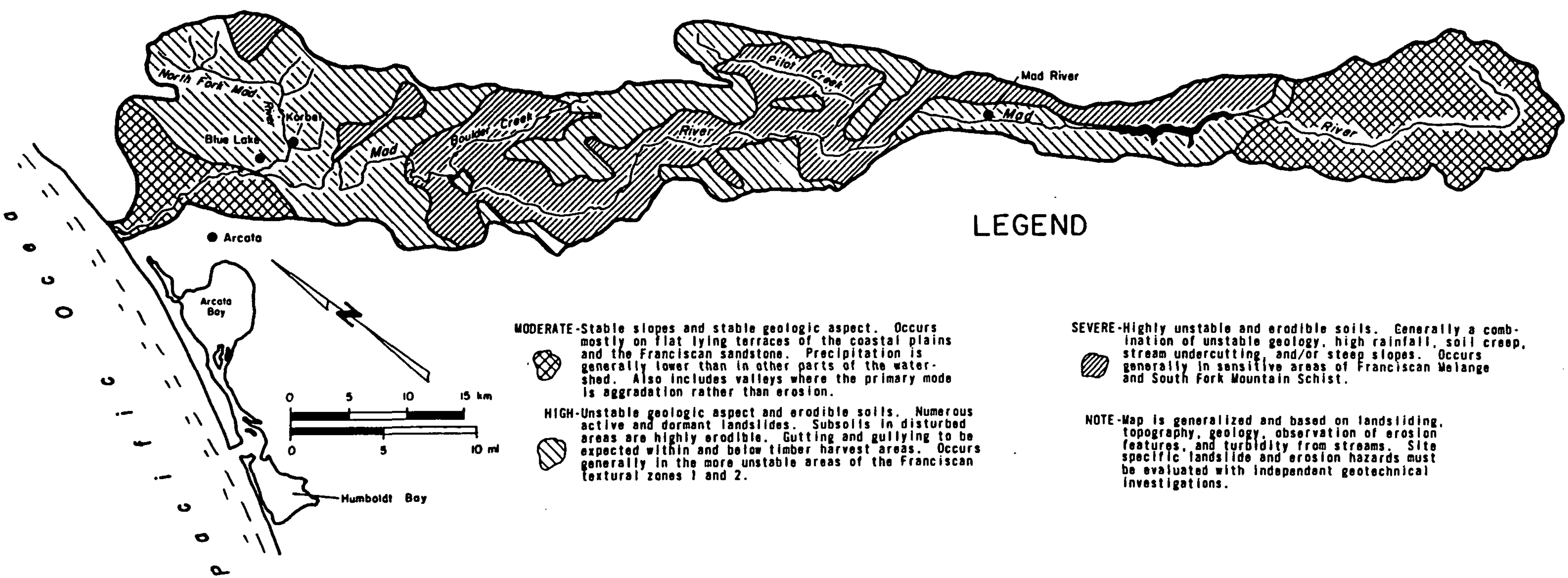
The "Instability and Erosion Hazard Map" (Figure 15) shows the potential for sediment yield from general areas within the basin. This map is not intended to be site specific. Potential hazard was determined from turbidity measurements, geology, landslides, and field observations. These factors were considered independently for each section of a grid system. Each section is about 1.6 km^2 (1 mi^2), and ratings were assigned according to the degree of hazard. The total of the values for each grid section was used for the overall hazard rating.

The watershed is divided into areas of moderate, high, and severe erosion hazard potential. These classifications do not relate to rating systems used in other reports. Indeed, the California Department of Conservation (1971) classified the entire basin above the coastal plain as "severe" in terms of overall soil erodibility.

In terms of distribution, severe hazard conditions generally correspond closely with areas underlain by Franciscan melange and South Fork Mountain Schist. Severe conditions also occur on the western flank of South Fork Mountain. Moderate hazard conditions occur only in the headwaters of the basin and in the coastal plains near the mouth. The rest of the basin has high erosion hazard potential.

Figure 15

Instability and Erosion Hazard Map
Mad River Basin



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Cumulative Effects

The stream channel morphology in the Mad River Basin developed over millions of years. It depends for its stability on the stability of channel and canyon slopes. Man-induced alterations to nature may cause severe onsite and/or offsite damages. As more alterations are made within a basin, their cumulative effects increase the potential for offsite channel damages. Offsite damage, or cumulative effects, can occur far below the altered area. According to Dodge (1976):

> "...increase in surface runoff, with attendant increase in stream velocity further aggravated by bulking by entrained sediment, could be expected to erode streambanks, undercutting the toes of steep slopes and initiating slides. The slides, in turn, act as positive feedback mechanism in supplying greater quantities of sediment to the stream channel, creating small dams that give temporary surges in peak flows as they are breached, and intercepting subsurface flow high above the channel. This, in turn, further aggravates the situation by contributing additional volumes of water to streamflow, increasing bank cutting, slope instability, and the probability of further slides."

Landslides and stream gutting along the Mad River and some tributaries show evidence of this feedback mechanism.

The cumulative effects of logging, roads, and/or grazing operations on a particular basin depend on slope, aspect, geology, soils, rainfall, method or quality of the operation, regeneration rate, and amount of area disturbed within the basin. The net long-term effect in the more stable areas is probably minor, while in other areas the net result is a significant, very long-term decrease in site productivity.

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