RECENT LANDSLIDES: AN ESTIMATE OF ECONOMIC LOSSES AND CORRELATIONS WITH SLOPE, RAINFALL, AND ANCIENT LANDSLIDE DEPOSITS

ALAMEDA COUNTY, CALIFORNIA

GEOLOGICAL SURVEY BULLETIN 1398

Work done in cooperation with U.S. Department of Housing and Urban Development, Office of Policy Development and Research

Recent Landslides in Alameda County, California (1940–71): An Estimate of Economic Losses and Correlations with Slope, Rainfall, and Ancient Landslide Deposits

By T. H. NILSEN, F. A. TAYLOR, *and* E. E. BRABB

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ABSTRACT

A total of 335 landslides that have caused damage to manmade structures and 659 parcels of land that have been devalued because of landslide damage from 1940 to 1971 have been recorded and mapped in Alameda County, mostly in the developed western parts of the county. About 85 percent of the landslides occurred on slopes greater than 15 percent. Over $5 million worth of damage was caused by landsliding in 1968–69; this cost averages out for that year to about $400 per developed acre of land on slopes greater than 15 percent, or about $100 per dwelling unit. Rainfall that year, although not unusually high, was marked by a six-week rainy spell which triggered many slides, resulting in damages that were probably greater than usual. Strict grading ordinances and required soils and geologic investigations have been shown to reduce substantially the public and private costs of landsliding in other parts of California and probably would have the same effect in Alameda County. The areas of abundant recent landslides correlate partly with areas of abundant ancient landslide deposits.

INTRODUCTION

This report summarizes the history of landslide activity in developed areas of Alameda County during the period 1940–71. Considerable damage to private and public property in the hillside areas of the county was caused by landsliding during this period. For example, during the winter rainy season of 1968–69, damage totalling at least $5,396,700 was caused by landslides in the county, compared with a total of $25,400,000 in the nine counties of the San Francisco Bay region (Taylor and Brabb, 1972). Only Sonoma and Contra Costa Counties, with about $6,450,000 and $5,200,000 respectively, suffered comparable damage that year. Our study of landsliding in Alameda County has three objectives: (1) to indicate to taxpayers the costs of landslide damage in developed hillside areas of the county; (2) to compare the amount and extent of the 1968–69 damage with other years; and (3) to determine some of the effects of slope, rainfall, and ancient landslide deposits on recent landslides.

Unfortunately, accurate records of landslide movements and damage are not generally kept by public agencies, so the data presented here do not cover all slides. Many more landslides have probably occurred but for various reasons have not been reported. Furthermore, records exist only for those landslides that have caused damage to manmade structures; those in open areas that have not damaged manmade structures generally are not reported, even though they may alter the landscape and damage it for some potential uses. Alameda is fortunately one of several counties in the San Francisco Bay region that has kept reasonably good records of landslides that have caused property damage or devaluation. These data permit a partial economic analysis of landslide problems in the urban parts of the county. Because such detailed records are generally not available in other counties of the San Francisco Bay region, detailed comparisons of economic losses caused by landslides cannot be made. The data available to Taylor and Brabb (1972) for the 1968–69 rainy season, however, indicate that Alameda County probably suffers comparatively large amounts of landslide damage.

LOCATION OF AREA

Alameda County extends across the Coast Ranges from San Francisco Bay on the west to the Great Valley on the east (fig. 1). The Livermore Valley forms a broad lowland in the central part of the county that extends westward into the Amador Valley and northward through the town of Dublin into the San Ramon Valley. The county is bounded on the north by Contra Costa County, on the east by San Joaquin County, and on the south by Santa Clara County. The Alameda County area includes parts or all of 29 U.S. Geological Survey 7½-minute quadrangle maps (fig. 2).

The population of the county generally is concentrated in the flatlands along the margins of the San Francisco Bay, the immediately adjacent hillside areas, and the Livermore Valley. Relatively little development has taken place in hilly terrain except for the westernmost ridges of the county, the hillsides surrounding Castro Valley, and a few hillside areas in the western part of the Livermore Valley. The flatlands along the margins of San Francisco Bay are occupied by a virtually continuous string of cities linked by an extensive freeway system and the Bay Area Rapid Transit System. The most extensive hillside developments are in the cities of Berkeley, Piedmont, Oakland, San Leandro, Castro Valley, Hayward, and Union City. There is substantial pressure from an increasing population to develop additional hillside areas in Alameda County.

The maximum relief in the county is south of the Livermore Valley, where the highest elevations are nearly 4,000 feet (1,220 m), compared

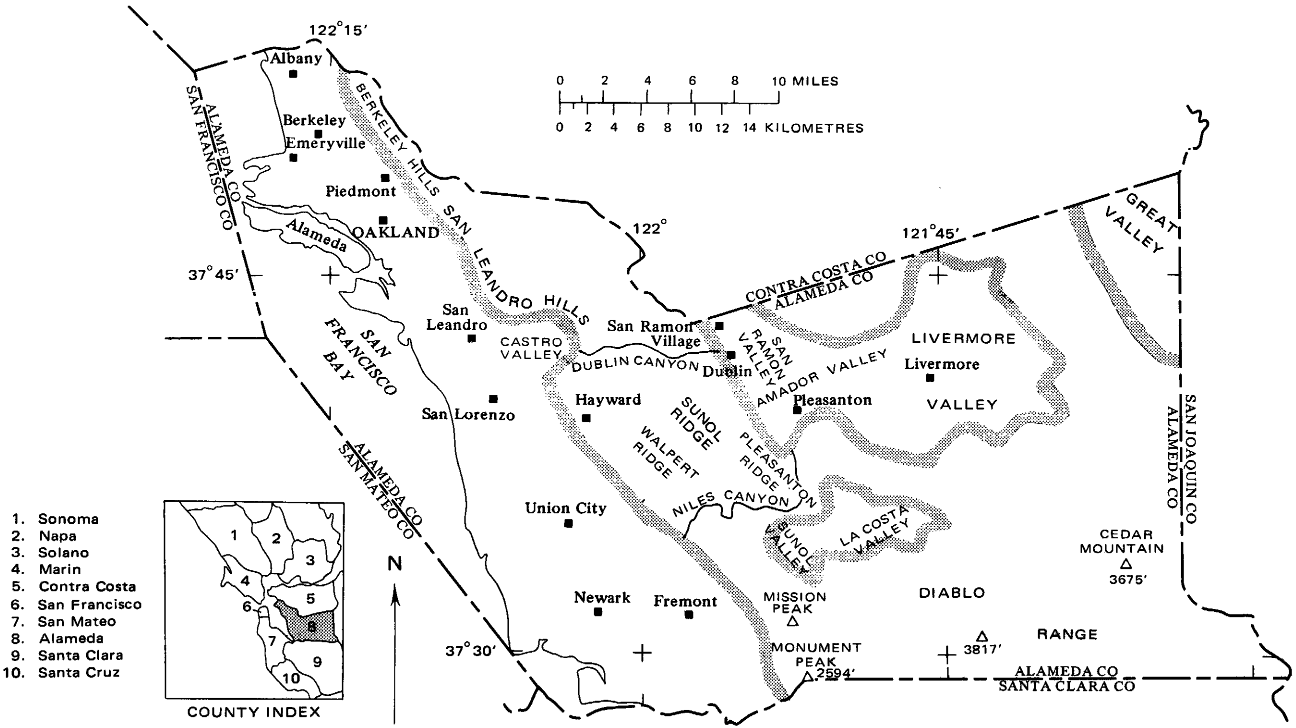

FIGURE 1.—Locations and geographic elements of Alameda County.

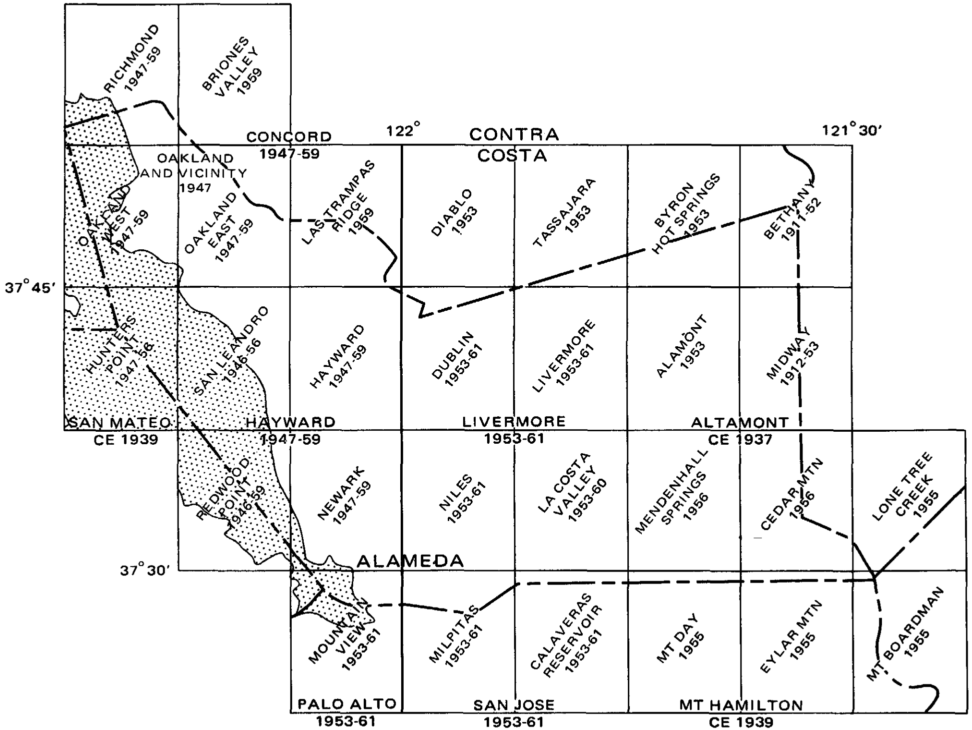

FIGURE 2.—Location of U.S. Geological Survey topographic quadrangle maps in Alameda County.

with 300–700 feet (90–210 m) in the Livermore Valley. The mountains east and north of the Livermore Valley are considerably lower, reaching a maximum elevation of 2,153 feet (655.3 m). The mountains to the west of the Livermore Valley comprise a series of rugged northwest-trending ridges and valleys, divided into three regions by east-west-trending Dublin and Niles Canyons. The northern region consists of the Berkeley and San Leandro Hills and attains a maximum elevation of about 1,400 feet (420 m). The central region, located east of Hayward, contains Walpert and Sunol Ridges and reaches a maximum elevation of 2,191 feet (667.8 m). The southern region, between the city of Fremont and the Sunol Valley, has elevations as high as 2,658 feet (810.2 m).

The rainy season generally extends from October to May. Snow falls in the very highest parts of the county during some but not all wet seasons. Because the source of the precipitation is moisture-laden air moving eastward across the region from the Pacific Ocean, the annual rainfall decreases eastward toward the Great Valley. Within the upland areas, highest precipitations correlate roughly with areas of highest elevation.

SOURCES OF DATA AND ACKNOWLEDGMENTS

The locations and amounts of damage caused by landslides were compiled by F. A. Taylor during the summer of 1972 from data obtained from the following sources, whose assistance we gratefully acknowledge: Alameda County Flood Control and Water Conservation District, Alameda County Planning Department, Alameda County Office of the Assessor, East Bay Municipal Utilities District, Hayward Department of Public Works, Office of the City Engineer of Oakland, and public officials of the cities of Alameda, Albany, Emeryville, Fremont, Livermore, Newark, Piedmont, Pleasanton, San Leandro, and Union City. Although the amount of available information about the landslides varied, we tried to ascertain the date and location of movement, the amount of damage, and the type of movement that occurred. Undoubtedly some landslides that caused damage were not officially recorded, and of these we have no information. Landslides in rural and undeveloped areas were not recorded and analyzed unless they caused damage to public or private property. Unfortunately, data regarding the exact date and type of landslide movement were scarce, although locations were carefully recorded.

The definition of urban or developed area is from the Atlas of Urban and Regional Change (U.S. Geological Survey, 1973) and includes areas used for residential, industrial, commercial, and transportation purposes. Transportation right-of-ways are not shown unless they exceed a minimum width of 300 feet (90 m).

The map of ancient landslide deposits of Alameda County (pl. 1) is compiled from published maps of Nilsen (1971, 1972a, b, c, 1973a, b) that were prepared by photointerpretation of vertical aerial photographs ranging in scale from 1:20,000 to 1:80,000. Landslides are recognized on the photographs by characteristic features such as scarps, toes, hummocky topographic surfaces, and transverse and longitudinal fissures and ridges (Nilsen and Wentworth, 1971; Nilsen, 1972d). The smallest landslide deposits mapped are about 200–300 feet (60–90m) in smallest dimension. They vary in age from probably several hundred thousand years up to the date of the most recent photography (1966). Most of the photographs used are pre-1960. We use the term "landslide deposit" for these mapped features because it is not known if they were actively moving at the time the photographs were taken or when they were last active; however, the outlines of the landslide masses are clearly shown. On the source maps of Nilsen, some landslide deposits were queried where their identification was uncertain; on plate 1, all landslide deposits are shown, including those queried on the source maps.

Precipitation records were obtained from the Climatology Bulletins of the U.S. Department of Commerce and from the Alameda County Flood Control and Water Conservation District. T. R. Simoni, Jr., and G. J. Edmonston assisted in the preparation of the maps and diagrams.

DISTRIBUTION OF RECENT LANDSLIDES THAT HAVE DAMAGED MANMADE STRUCTURES

The location and distribution of all parcels of land in Alameda County that have been damaged by landslides or devalued because they are near recent landslides are shown on plate 1. A total of 335 landslides and 659 devalued parcels of land of which the County Assessor has records have been plotted. Although the oldest records are from 1940, most of the data are from the 1958–71 period, when more accurate records were kept. The size of the circles on plate 1 is proportional to either the number of separate pieces of devalued property at the locations or the number of separate landslides at the location. Therefore, where lot sizes are smaller, a larger number of land parcels may be affected by a landslide of the same size. The size of the plotted circle, therefore, is not directly proportional to either the size of the landslide or amount of damage caused by it. The locations were originally recorded in various ways and on maps of varying scales by public officials, so that the circles plotted on plate 1 provide only an approximate location for the landslides and devalued land parcels. Unfortunately, the exact date of each landslide is not generally available from the records, so that a detailed chronological comparison of landslide and rainfall patterns, as was done for Contra Costa County by Nilsen and Turner (1975), is not possible.

The recent landslides and devalued parcels of land are strongly concentrated along the western edge of the northern upland area located west of the San Ramon Valley and north of Dublin Canyon. The highest density is in the cities of Berkeley, Piedmont, and Oakland, where the largest amount of hillside development has taken place. Other concentrations of landslides and devalued parcels are present in Hayward and Union City in the central upland area between Dublin and Niles Canyons. Other scattered landslides and devalued parcels are found south of Pleasanton at the southwestern end of the Livermore Valley, east of Fremont, in Albany, and on the southeastern end of Alameda Island. This last occurrence is in flat-lying terrain, as are some other occurrences in Oakland, indicating the presence of very unstable earth materials. Almost no recent landslides that have damaged manmade structures have been recorded in the relatively undeveloped upland areas north, east, and south of the Livermore Valley or in the developed flatland areas bordering San Francisco Bay, in the Livermore, Sunol, and La Costa Valleys, or in the Great Valley.

The distribution of recent landslides and devalued parcels shown on plate 1 clearly indicates that virtually every major development in the upland areas of Alameda County has had some problems with slope instability. The distribution of landslide damage is not uniform, however, for Berkeley, Piedmont, and Oakland certainly have a larger number of landslides and devalued parcels than San Leandro or Hayward. Many factors in combination are responsible for landsliding, including the type and properties of underlying bedrock, soils, and surficial deposits, angle and direction of slope, type of vegetation, amount and distribution of rainfall, type of construction, placement of cuts and fills, and the presence of ancient landslide deposits. We have neither the data nor the capability of analyzing all of these factors but present in this report some conclusions regarding the influences of rainfall, slope, and ancient landslide deposits on landslides generated between 1940 and 1971 that damaged manmade structures.

INFLUENCE OF SLOPE ON RECENT LANDSLIDING

About 85 percent of the recent landslides that have damaged manmade structures or caused the devaluation of parcels of land in Alameda County developed on natural slopes steeper than 15 percent (U.S. Geological Survey, 1972; pl. 1). Many of the landslides that developed on lesser slopes probably actually developed on over-steepened slopes formed during cutting operations for roadways or building foundations. Some of the exceptions may represent areas with steeper slopes that are too small to be shown on the 1:125,000-scale slope map used in our analysis (U.S. Geological Survey, 1972). Others may be located adjacent to areas of steeper slope and be affected by landsliding from above, where the slopes may be steeper. Some landslides, however, do occur on slopes less than 15 percent. Studies by Bonilla (1960) and Schlocker (1974) in San Francisco County and by Brabb, Pampeyan, and Bonilla (1972) in San Mateo County have also shown that most ancient landslide deposits and recent landslides in those areas occur on slopes greater than 15 percent. We conclude from these data that landsliding is a major geologic process on both natural and modified slopes greater than 15 percent.

INFLUENCE OF RAINFALL ON RECENT LANDSLIDING

Precipitation is a major factor in the generation of landslides in the San Francisco Bay region. During periods of very intense rainfall, abundant landslides generally occur, although the time, sequence, and amount of the annual rainfall vary greatly at any particular place. The effects of these factors complicate the relation between rainfall and landsliding. Studies in adjacent Contra Costa County indicate that (1) abundant landslides occur during and after precipitation greater than 7 inches (18 cm) from a single storm; (2) storms occurring after large amounts of rain have already fallen will generate more landslides than storms occurring at the beginning of the rainy season; and (3) the largest number of landslides will occur during and after long periods of relatively continuous rainfall (Nilson and Turner, 1975). Generally similar relations have been shown to exist in southern California by Cleveland (1971) and Campbell (1975), although the amounts of precipitation needed to trigger abundant landslides there are reportedly higher. Thus, the distribution of mean annual rainfall in Alameda County (pl. 1) may be only a very crude index of the yearly distribution of landslides.

Our information on the dates of recent landslides in Alameda County is very limited, so that temporal relations between landsliding and rainfall patterns cannot be derived. In addition, because the recent landslides and devalued parcels are concentrated along the western edge of the county, it is not possible to demonstrate a positive geographic correlation between the distribution of mean annual rainfall and the number of recent landslides throughout the county, even though one might exist. The main area of recent landslide damage in the county is in an area of relatively low mean annual rainfall, 18 to 26 inches (46–66 cm) per year, compared with the highest mean annual rainfall of 32 to 34 inches (81–86 cm) per year in the mountains south of the Livermore Valley, an area without recorded recent landslide damage. This relation suggests that mean annual rainfall may not be the controlling factor in the distribution of recent landslide damage.

The pattern of rainfall in 1968-69 can be compared with that of other years in order to hypothesize what might have made the damage that occurred that year more or less than average. The location and elevation of 10 selected stations in Alameda County recording precipitation are shown in figure 3 and the total seasonal rainfall for these stations from 1957–58 to 1971–72 in figure 4. Although the mean annual rainfall at each station varies greatly from year to year, the relative amounts of rainfall at each station are similar from year to year, indicating that the yearly rainfall value from any recording station can be used as a rough guide to the relative rainfall from year to year throughout the county. The 1968–69 precipitation data from the Oakland Airport Station, which is located near the areas of extensive recent landsliding and which has an intermediate amount of yearly rainfall, are compared with those of other years in figure 5. During 1968–69, 24.54 inches (62.3 cm) of rain fell at this station, compared with a mean annual rainfall of 18.6 inches (47.2 cm) in the 30-year period 1940 to 1970. In the 17-years from 1954–55 to 1970–71, the 1968–69 total was equalled or exceeded three times, in 1957–58, 1962–63, and 1966–67 (fig. 5).

In the 16 years from 1936–37 to 1951–52, however, this amount was equalled or exceeded 10 times. Earlier precipitation records in Oakland indicate that more than 24 inches (61 cm) of rain per year accumulated in 43 of the 99 years from 1873–74 to 1971–72. These precipitation data indicate that although 1968–69 was a relatively wet year compared with the last 18 years, rainfall equal to or exceeding that amount occurs about 44 percent of the time, or about 4 out of every 10 years. The abundance of landslides and damaged parcels in 1968–69, then, if correlated only with mean annual rainfall, should not be considered an unusually large total, but one that occurs fairly regularly.

The precipitation of 1968–69 is distinguished from that of other years by a long period of relatively continuous rainfall from the middle of January to the end of February, totalling almost 14 inches (36 cm). Because abundant landslides have been shown to occur during and after long periods of relatively continuous rainfall in nearby Contra Costa County (Nilsen and Turner, 1975), we may conclude that the amount of landsliding in 1968–69 may have been high because of the continuity and long duration of a single period of rainfall without dry intervals, rather than the total rainfall that year. Thus, the amount of damage and number of devalued parcels of land caused by landslides in Alameda County in 1968–69 are probably higher than average for the county. Additional studies of landslide damage in other years of the type made by Taylor and Brabb (1972) would help clarify the problem.

INFLUENCE OF ANCIENT LANDSLIDE DEPOSITS ON RECENT LANDSLIDING

Plate 1 shows the widespread distribution of ancient landslide deposits in Alameda County. Although the deposits are abundant in

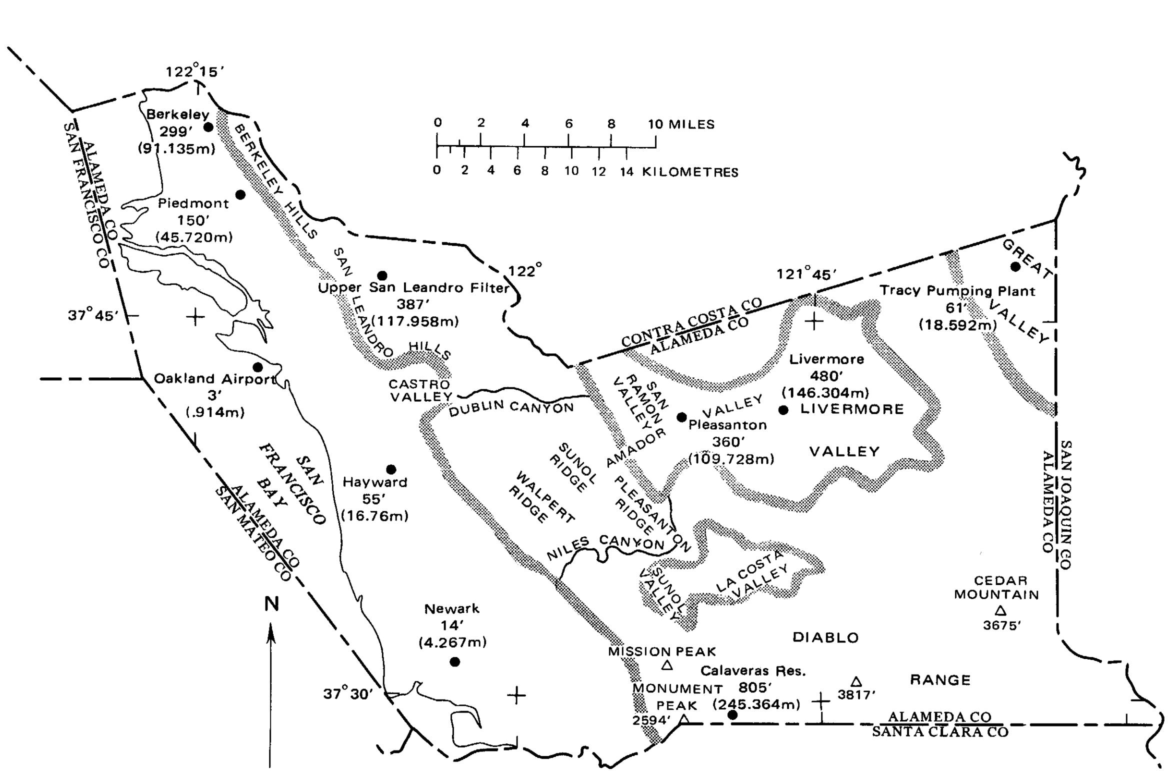

Figure 3.—Location and elevation of 10 selected stations recording precipitation in Alameda County.

virtually every upland part of the county, their concentration and size vary considerably. The largest landslide deposits are found in the Diablo Range south and southeast of the Livermore Valley. Other large landslide deposits have been mapped on the east-sloping hills at the west edge of the Amador Valley along the Calaveras fault zone near Pleasanton and the west-sloping hills east of Berkeley and southeast of Fremont. Very dense concentrations of generally smaller landslide deposits have been mapped in the upland areas east of the San Leandro Hills and extending southeastward toward Pleasanton, in the hills bordering the north-central and south-central parts of the Livermore Valley, and locally east and northeast of Piedmont and east of Union City. Areas marked by generally lower concentrations of landslide deposits include parts of the Berkeley and San Leandro Hills, the region surrounding Castro Valley, the area extending eastward from Fremont to San Antonio Reservoir that is adjacent to Interstate Highway 680, and the hills extending eastward and northeastward from the Livermore Valley to the Great Valley.

The urbanized or developed hillside areas of the county, which are primarily located in the westernmost foothills, are therefore located in an area of variable density of ancient landslide deposits, ranging from abundant large deposits or abundant small deposits to few deposits. The developments in this area are scattered (pl. 1), so that the effects of development on the ancient landslides in terms of recent landsliding are not clearly defined. Nevertheless, the influence of the ancient landslide deposits on recent landsliding can be seen in some parts of the county. In Contra Costa County to the north, Nilsen and Turner (1975) noted that most of the recent landslides had occurred in areas where abundant ancient landslides were present. We are convinced that this relationship would also be evident in Alameda County if hillside development were more uniform and widespread so that the correlation could be examined more easily.

Comparison of the recent landslides and damaged parcels of land with the ancient landslide deposits (pl. 1) indicates that while many recent landslides have occurred in areas of abundant ancient landslide deposits, many more have not. Areas where both are found include the hillside areas east of Berkeley and Piedmont in the northwestern part of the county, part of the area east of Oakland near the Oak Knoll Naval Hospital, a developed hillside area between Hayward and Union City, and small developed hillside areas southwest and southeast of Pleasanton at the edges of the Amador Valley. We conclude that developments in these areas have probably caused renewed movement of marginally stable old landslide deposits. The movement could have been initiated by cutting and filling, addition of water to the ground, removal of vegetation, addition of weight to the

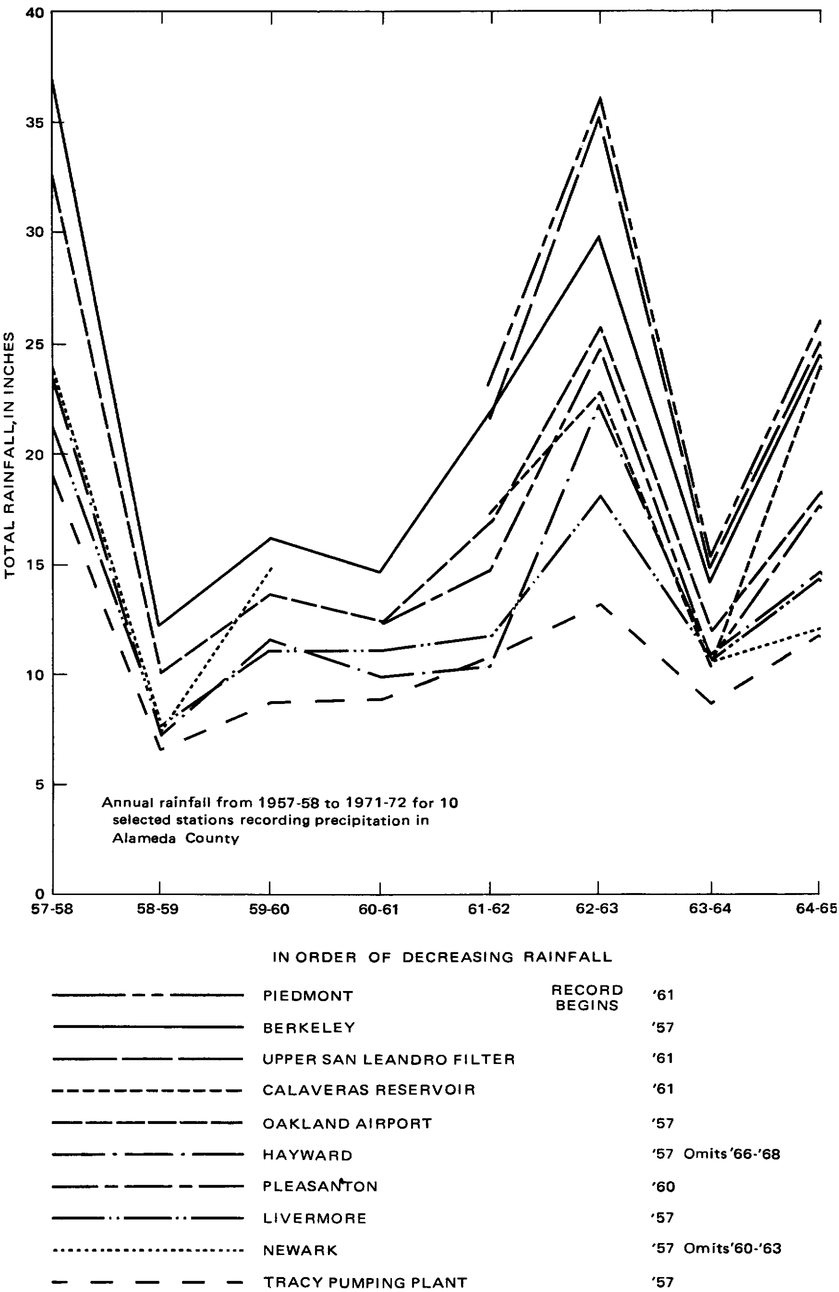

FIGURE 4.—Annual rainfall from 1957–58 to 1971–72 for 10 selected stations recording precipitation in Alameda County.

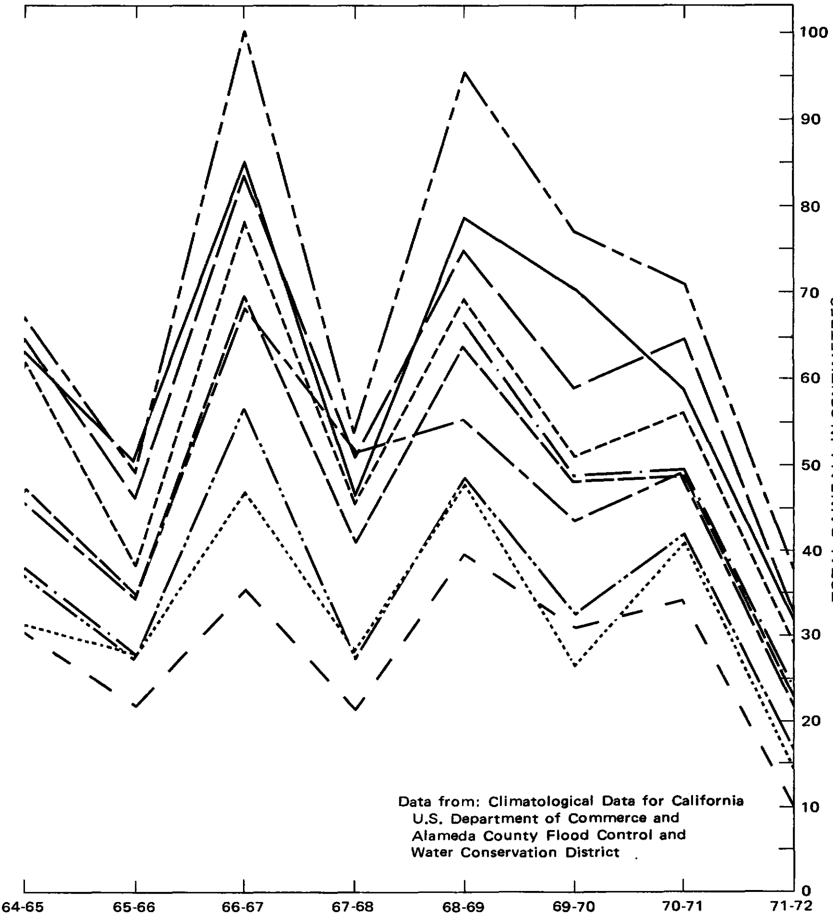

FIGURE 4.—Continued

slopes, or other man-induced changes in the natural environment.

Areas where abundant recent landslides have occurred but where few ancient landslide deposits have been mapped include parts of Piedmont and Oakland west of Interstate Highway 580, hillside areas east of San Leandro, and the northern and southern margins of Castro Valley. There are probably several reasons for the lack of coincidence between the ancient and recent landslides in these areas.

First, the Piedmont and Oakland areas consist of older alluvial fan deposits (Helley and others, 1972) of weathered, weakly consolidated, poorly sorted silt, sand, and gravel, incised by channels partly filled by younger deposits. The flat upland surfaces of these deposits are generally stable, but landsliding commonly occurs on the walls of the

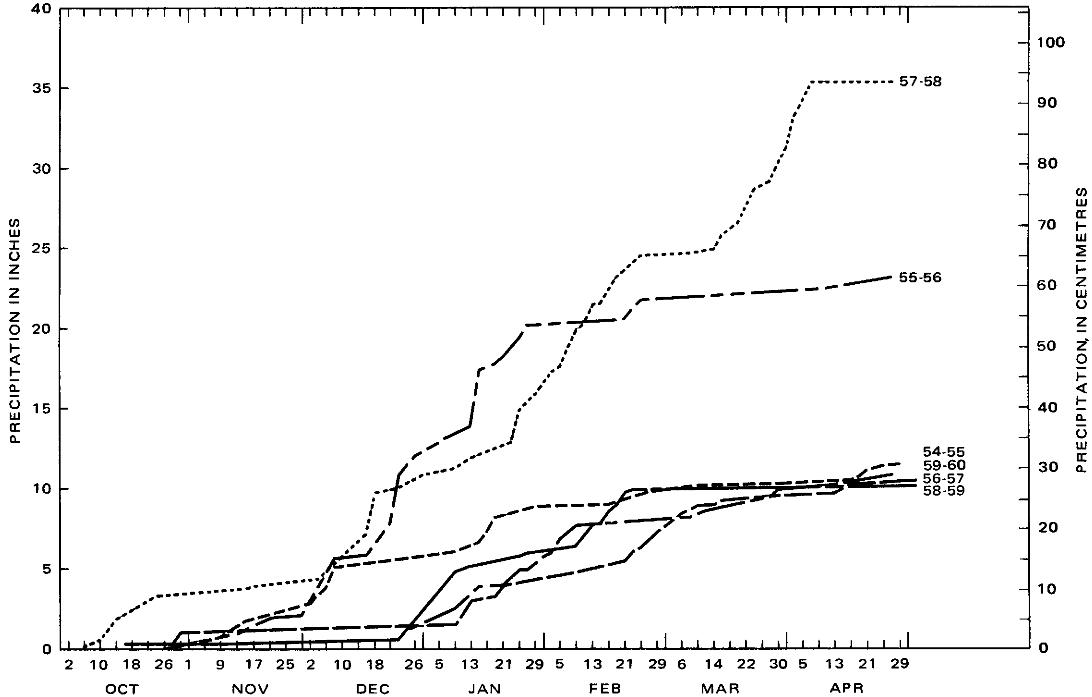

FIGURE 5.—Cumulative precipitation curves from 1954–55 to 1971–72 at Oakland Airport.

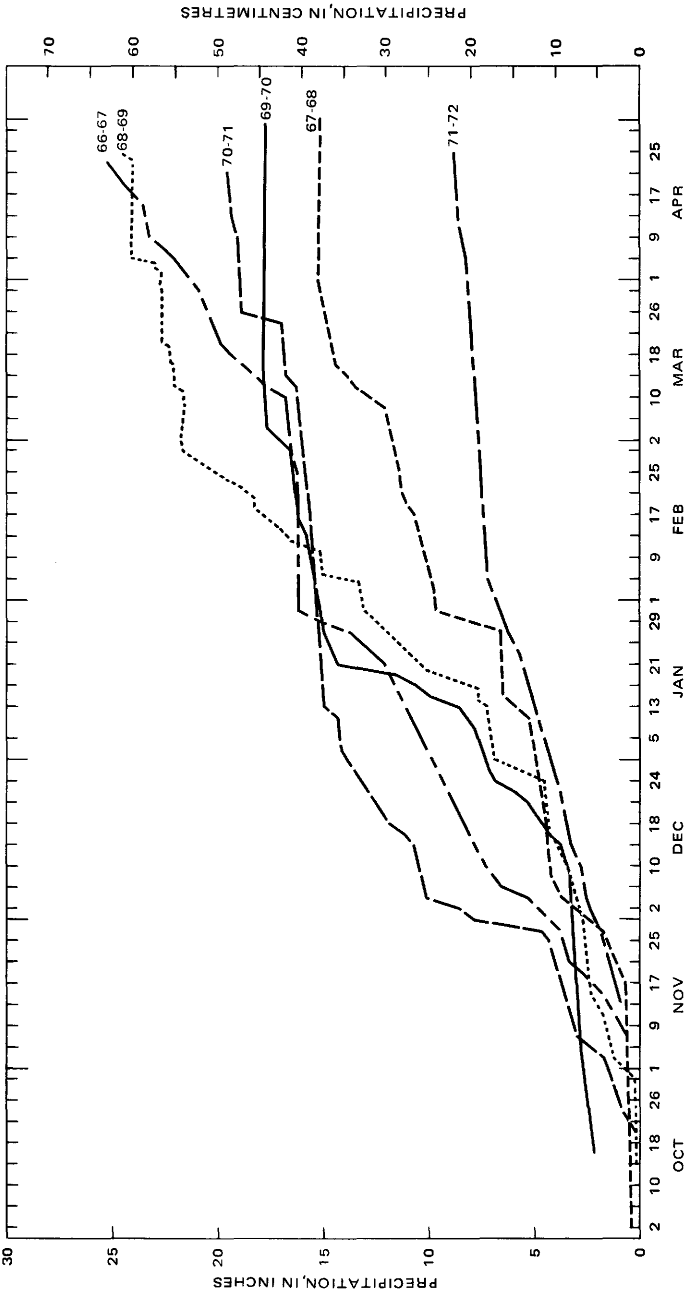

FIGURE 5.—Continued

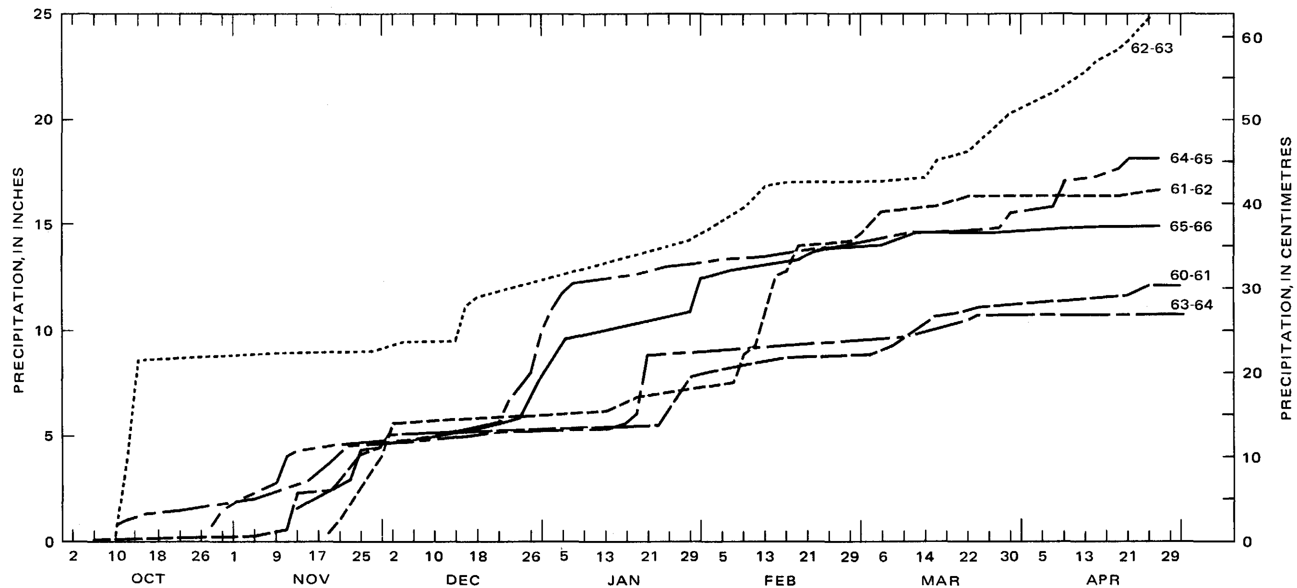

FIGURE 5.—Continued

incised channels. These channel walls were probably marginally stable before development, and large numbers of recent landslides followed extensive development along them.

Second, any ancient landslide deposits along the channel walls are probably small in area, since the walls are generally less than 50 feet (15 m) high. Therefore, they are probably smaller than the minimum landslide length of 200–500 feet (60–150 m) mapped by Nilsen (1973a), and would not be shown on plate 1.

Third, although some larger circles are plotted in these areas on plate 1, indicating a larger number of recent landslides or devalued parcels of land in a small area, the landslides are probably still small but have affected many lots because the lot sizes in these areas are generally relatively small.

Fourth, ancient landslide deposits are generally very difficult to map in extensively urbanized areas, not only because of the surface cover of buildings and streets but also because the geomorphic features that permit the deposits to be recognized, such as scarps and toes, have generally been so strongly modified by cutting and filling that they cannot be recognized by photointerpretation. We may conclude, therefore, that ancient landslide deposits might be present in this area but cannot be recognized owing to limitations in the mapping process.

The same geologic conditions are present in the Castro Valley and San Leandro areas and may explain the lack of coincidence of recent landslides and ancient landslide deposits there.

The developed parts of Berkeley, Piedmont, Oakland, and San Leandro east of Interstate Highway 580 and the base of the Berkeley Hills that contain abundant ancient landslide deposits but few or no recent landslides present a different problem. Some of these areas represent pre-1950 developments so that landslide damage within them might not have been properly recorded or might have occurred before the establishment of record-keeping operations by the county. Other areas such as Castro Valley may possibly represent well-engineered and sited developments, where the landslide hazard was neutralized by proper, albeit expensive, construction techniques. On the other hand, there may not yet have been sufficient time for recent developments on ancient landslide deposits to trigger new landslides.

In summary, the influence of ancient landslide deposits on recent landsliding in Alameda County is not wholly clear. Locally, however, recent landslides are clearly situated in areas of ancient landslide deposits; further development of hillside areas in the county should be evaluated with this in mind. The evaluation should include an analysis of the slope stability characteristics of the terrain, incorporating factors such as degree of slope, bedrock and soil characteristics, seismic triggering of landslides, and other factors (Nilsen and Brabb, 1973; Brabb and others, 1972). Such slope stability analyses are presently in preparation by the U.S. Geological Survey for Alameda County as well as the rest of the Bay region.

ECONOMIC LOSSES CAUSED BY RECENT LANDSLIDES

The minimal cost of recent landslide damage per acre of developed or urbanized land in Alameda County on slopes greater than 15 percent can be derived from the cost of landslide damage in 1968–69, the amount of urban land on slopes greater than 15 percent, and average number of residential units per acre. The cost of landslide damage in the County during 1968–69 was $5,396,700 (Taylor and Brabb, 1972). Plate 1 indicates that about 85 percent of the landslides occurred on slopes greater than 15 percent, and 0.85 × $5,396,700 = $4,587,195. Approximately 18 mi^2 (47 km^2) of urban area in Alameda County, as defined in the Atlas of Urban and Regional change (U.S. Geological Survey, 1973), is on slopes greater than 15 percent, so that the landslide cost per square mile is about $254,800 ($97,600 per km^2). This is about $400 per acre. Residential densities in Alameda County vary from 0.91 to 18.09 units per acre and average about 4 (Betty Croly, written commun., 1973), so that the cost per dwelling unit is roughly $100.

The costs of recent landslides in Alameda County, based on 1968–69 data, are compared with costs in San Mateo and Santa Clara Counties in table 1. The data indicate that costs per acre of developed hillside

TABLE 1.—*Comparison of damage caused by recent landslides in Alameda, San Mateo, and Santa Clara Counties*

	Alameda	San Mateo	Santa Clara
Total area (excluding salt ponds and airports)	[a]714 mi^2	[b]432 mi^2	[c]1305 mi^2
Total urban area[d]	[a]162 mi^2	[b]90 mi^2	[c]184 mi^2
Urban area on slopes greater than 15 percent	18 mi^2	28 mi^2	10 mi^2
Percent of total urban area	11 percent	31 percent	5 percent
Cost of landslides 1968–69[e]	$5,396,700	3,599,018	1,899,278
Cost in urban areas (slopes greater than 15 percent)	4,587,195	3,059,165	1,614,386
Approximate cost per square mile	254,844	109,256	161,439
Approximate cost per acre per year	398	171	252

[a] Alameda County Planning Department, 1968 figures.
[b] San Mateo County Planning Department, 1970 figures.
[c] Santa Clara County Planning Department, 1967 figures.
[d] Based on data provided by James Feng, U.S. Geological Survey, and experimental U.S. Geological Survey slope maps.
[e] From Taylor and Brabb (1972).

property are higher in Alameda County than in San Mateo County, although San Mateo County has more developed hillside acreage. The difference can probably be attributed to the greater abundance in Alameda County of landslide-prone bedrock formations and ancient landslide deposits in developed hillside areas, as shown in maps by Brabb and Pampeyan (1972a,b), Nilsen (1972c, 1973a,b), and Wright and Nilsen (1974). The costs of recent landslide damage per acre in Santa Clara County are also considerably lower than in Alameda County.

In comparison with the $100 cost per developed hillside dwelling unit per year in Alameda County, the landslide cost estimate in the Los Angeles area was about $330 per developed unit per year before the passage of strict grading codes (Slosson, 1969, table 1). After both grading codes and required inspections by soils engineers and engineering geologists were adopted in the Los Angeles area, the cost was reduced to $7 per developed unit per year, based on a sample of 11,000 sites (Slosson, 1969).

These data indicate that the development of landslide-prone hillside areas can be very costly, both to private and public interests. In Alameda County, the more than 650 parcels of land devalued because of landsliding since 1940 attest to the extent of the costs. As shown in the Los Angeles area, careful soils and geologic studies and proper grading ordinances can diminish the costs.

SUMMARY AND CONCLUSIONS

The record of recent landslide activity in Alameda County indicates that landsliding in urbanized hillside areas has resulted in large amounts of damage of great cost to the public, of whom only a small percentage live in such areas. Approximately 85 percent of the landslides have been on slopes steeper than 15 percent; only scattered, infrequent landslides have occurred on more gentle slopes, and many of these are probably either immediately adjacent to areas of steeper slopes or in areas of steeper slope that were too small to differentiate on the 1:125,000-scale slope maps used.

Over $5 million worth of damage was caused by landslides in Alameda County during 1968–69 (Taylor and Brabb, 1972). Records indicate that a total yearly rainfall equal to or greater than the 24.54 inches (62.3 cm) that fell in that year occurs about 44 percent of the time, so that the amount of damage that year should not be considered unusual in terms of mean annual rainfall. Rainfall in 1968–69 included a long, relatively continuous period of rainfall of about 14 inches (36 cm), which probably contributed to the relative abundance of landslides. Nilsen and Turner (1975) have shown in Contra Costa

County that relatively continuous rainfall totalling more than 7 inches (18 cm) generates a large number of landslides.

Areas of abundant recent landslides often coincide with areas of abundant ancient landslide deposits. Accurate mapping of the ancient deposits, in conjunction with other factors, such as slope angles and bedrock geology, can yield sufficient data for regional analyses of slope stability.

The cost of landsliding in 1968–69 for Alameda County was about $100 per dwelling unit in residential areas on slopes steeper than 15 percent. In Los Angeles, after the adoption of strict grading codes and required site inspections by engineering geologists and soils engineers (Slosson, 1969), the cost of landsliding dropped from $330 to $7 per unit per year. These data strongly suggest that these measures should be adopted in Alameda County, particularly because of the strong pressures for expanded development of hillside areas. The economic losses from recent landsliding indicate that hillside development in the county should be preceded by regional and local geologic and soils investigations to determine the stability characteristics of large areas and individual slopes.

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