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Significant Landslide Events in the United States

by Lynn M. Highland and Robert L. Schuster
Graphic presentation by Margo L. Johnson

Abstract

The purpose of this project was to identify and compile data relating to the most costly landslide events in the United States. Cost criteria were defined as either public or private property damage or loss of human life. Landslides were defined in a broad manner to include most types of gravitational mass movement such as rockfall, debris flow, and the failure of engineered soil materials. The phenomena that triggered the landslides are likewise varied and include heavy precipitation, earthquake, and reservoir drawdown. The collected data were compiled in a Geographic Information System (GIS) database to allow for easy graphical display in map form.

Damage cost figures and fatalities were compiled from the literature. Damage estimates are generally direct costs, or calculable expenses incurred by owners of private or public property that were impacted by a landslide. Many of the highest costs were the result of damage to transportation infrastructure. For example, the 1983 Thistle Landslide in Utah destroyed a section of both U.S. Highway 6 and the main line of the Denver and Rio Grande Western railroad. Much of the estimated cost of $200 million was attributed to the damage to these transportation routes. Indirect costs such as those incurred through increased travel times, loss of jobs, and reduced income as a result of a landslide event can be significant. However, an accurate accounting of these costs is often difficult. For example, the Anzar Road landslide in San Benito County, California, severed a utility line in April 1998 that provided natural gas service to an adjacent county. Restaurants and other businesses were forced to close for a time resulting in lost revenues, wages, and income for the people affected, an example of indirect costs.

A photographic record of the selected landslide events was compiled to illustrate the variety of physical and built environment settings in which landslide disasters have occurred. The record was compiled largely from non-copyrighted sources and is thus incomplete. Other sources of photography such as newspaper and university archives, and other private collections undoubtedly contain a wealth of historical information on significant landslide events. In making this incomplete record available we hope to encourage other collections to contribute pertinent photography to this project.

The GIS database contains two types of landslide events. Individual landslide events are defined as a single point in the database. Locations of these points were determined from published landslide maps and coordinates, and in several cases the points locate the nearest town or other geographic feature. In all cases the locations should be considered approximate. The extent of the regional events was drawn from the published literature, and the regional events are defined as polygons in the database. The regional extent should also be considered approximate. In several cases the polygons represent an arbitrary administrative boundary and not the extent of landsliding related to a storm or earthquake.

Note: the reference list is not exhaustive. There may be additional references in existence for each event. The reader is advised to check bibliographic databases if additional information is desired.♦

Index for Regional Landslides

Click on each date to read about the event.

Click on [camera icon] to view a photo taken of that landslide. If there is more than one photo, you will need to click on each [camera icon] separately.

Click on numbers in parentheses to link to page with references cited.

Date	
1906	San Francisco Bay region, California (16, 27)
1934	Jackson Springs, Lake Roosevelt, Washington (13, 21)
1964	Anchorage, Alaska (20)
1968-1969	San Mateo County, San Francisco, California (24)
1969	Nelson County, Virginia (26) (no photos)
1978	San Diego, California (22) (no photos)
1980	Six southern California counties (23) (no photos)
1982	San Francisco Bay region, California (5) (no photos)
1983	Utah (1)
1984	Utah (14) (no photos)
1989	Loma Prieta, California (15)
1989	Alani Paty, Hawaii (2)
1994	Northridge, California (10, 11, 12)
1995	Blue Ridge, Madison County, Virginia (25)
1995	Los Angeles and Ventura County, California (7, 18)
1996	Columbia Parkway, Hamilton County, Cincinnati, Ohio (4)
1996-1997	Puget Lowland, Washington (3)
1997-1998	El Niño storms, California (6, 9)

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Regional Events

Year	Locality	Fatalities	Damage[1]	Photograph	Reference(s)
1906	San Francisco Bay region, California	11	unknown	SanFran1	Lawson (1908);
				SanFran2	Youd and Hoose (1978)
1934-1970	Lake Roosevelt, Washington	0	2.05 billion	Roosevelt	Jones and others (1961);
					Schuster (1979)
1964	Anchorage, Alaska	0	960	1Alaska64	Youd and Hoose (1978)
				2Alaska64	
1968-1969	San Francisco Bay region, California	0	100.8	SanF1	Plafker and Kachadoorian (1966);
				SanF3	Taylor and Brabb (1972)
1969	Nelson County, Virginia	150	unknown	-------------	Williams and Guy (1973)
1978-1979	San Diego County, California	0	38	-------------	Shearer and others (1983)
1980	Six southern California counties	0	1.1 billion	-------------	Slosson and Krohn (1982)
1982	San Francisco Bay region, California	30	132	Oddstad	Ellen and Wieczorek (eds.) (1988)
1983	Utah, W. Colorado, E. Nevada	0	430	Utah	Anderson and others (1984)
1984	Utah, W. Colorado, E. Nevada	0	70.5	-------------	Kaliser personal communication (1984)
1989	Loma Prieta, California	0	34+	Loma	Keefer and Manson. (1989)
1989	Alani Paty, Hawaii	0	34	-------------	Baum and Reid (1992)
1994	Northridge, Southern California	6	unknown	Northridge1 Palisades	Jibson and others (1998); Jibson and Harp (1995); Harp and Jibson (1995);
					Jibson and others (1994)
1995	Madison County, Virginia	0	123.2	1MadisonCo	Wieczorek and others (1995)
1995	Los Angeles and Ventura counties,	0	unknown	LaConchita	O'Tousa (1995));
	California				Harp and others (1999
1996	Hamilton County, Ohio	0	11.2	Cinci	Baum and Johnson (1996);
					Personal communication, Rich Pohana, Engineering Geologist (2002)
1996-1997	Puget Lowland, Washington	4	unknown	Puget	Baum and others (1998)
				Stellawa	
1997-1998	El Niño storms, California	1	158	ElNino	Hillhouse and Godt (ed.) (1999);
				SFBay97	Godt and Savage (1999)

[1] [Damage is shown in millions of U.S. dollars unless otherwise stated, and all amounts have been converted to year 2000 dollar losses]

Index for Individual Landslides

Click on each date to read about the event.

Click on to view a photo taken of that landslide. If there is more than one photo, you will need to click on each separately.

Click on numbers in parentheses to link to page with references cited.

Date	
1925	Gros Ventre, Lincoln County, Wyoming (1, 25)
1928	St. Francis Dam, Los Angeles County, California (18, 28)
1937-1983	Devil's Slide, California (23)
1938-1970	Cloverdale, Sonoma County, California (15)
1956	Portuguese Bend, California (15, 17)
1958-1971	Pacific Palisades, California (16)
1959	Hebgen Lake, Madison Canyon, Montana (9, 10)
1959	Panorama Point, California (23) (no photos)
1960	Alta, California (23) (no photos)
1961	Mulholland Cut, California (23) (no photos)
1967	Portrero Hill, California (23) (no photos)
1969	Interstate 5, Collier, California (23)
1969	Glendora, California (22)
1969	Seventh Avenue, California (15) (no photos)
1970	Princess Park, California (23) (no photos)
1971	San Fernando, California (14, 29, 30)
1972	U.S. Highway 1, Big Sur, California (5)
1974	Canyonville, Oregon (4)
1977-1980	Monterey Park, Repetto Hills, California (11, 27) (no photos)
1978	Bluebird Canyon, Laguna Beach, California (15)
1979	Big Rock, California (23) (no photos)
1980	Mount St. Helens, Washington (20)
1981	San Luis Dam, California (7) (no photos)
1982	Love Creek, California (6) (no photos)
1983	Pony Express, California (19, 26) (no photos)
1983	San Clemente, California (8, 23) (no photos)
1983	Thistle, Thistle, Utah (24)
1983	Big Rock Mesa, California (2) (no photos)
1985	Mameyes, Puerto Rico (13)
1998	Anzar, Aromas, California (21)
1999	Sacred Falls, Hawaii (3)

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Individual Events

Year	Locality	Fatalities	Damage[1]	Photograph	Reference(s)
1925-1927	Lower Gros Ventre, Wyoming	6	unknown	GroVentre	Alden (1928) ; Voight (1974)
1928	St. Francis Dam, California	500	$672.1	StFran	Willis (1928); Rogers (1995)
1937-1983	Devil's Slide, San Mateo County, California	0	12.3	Devils	Taylor and Brabb (1986)
1938-1970	Preston Bridge, Cloverdale, California	0	25.7	Cloverdale	Taylor and Brabb (1986)
1956	Portugese Bend, California	0	45 14.6	Portbend	Merriam (1960)
1958-1971	Pacific Palisades, California	0	29.1	Pacificpal1 Pacificpal2	McGill (1982) Taylor and Brabb (1986)
1959	Madison Canyon, Montana	26	unknown	Hebgen2 Hebgen4 Hebgen5	Hadley (1964); Hebgen Lake Ranger District, (2001)
1959-1984	Panorama Point, California	0	25.8	-------------	Taylor and Brabb (1986)
1960	Alta, California	0	16.8	-------------	Taylor and Brabb (1986)
1961	Mullholland Cut, California	0	41.5	-------------	Taylor and Brabb (1986)
1967	Potrero Hill, California	0	14.6	-------------	Taylor and Brabb (1986)
1969	Collier, California. on Interstate 5	1	11.2	Collier	Taylor and Brabb (1986)
1969	Glendora, California	0	26.9	Glendora	Scott (1978)
1969	Seventh Ave., California	0	14.6	-------------	Leighton and Associates and Cotton (1979)
1970	Princess Park, California	0	29.1	-------------	Taylor and Brabb (1986)
1971	San Fernando, California	0	302.4	VanNorman jvhall JvHall2	Kachadoorian (1971); Youd and Olsen. (1971); Youd (1971)
1972	Big Sur, California	1	26.9	BigSur	Cleveland (1973)
1974	Canyonville, Oregon	9	unknown	Cynville	Busby (1998)
1977-1980	Monterey Park - Repetto Hills, California	0	14.6	-------------	Hsu (1983); Weber (1980)
1978	Bluebird Canyon, California	0	52.7	Bluebird1 Bluebird3 Bluebird8	Leighton and Associates and Cotton, (1979)
1979	Big Rock, California	0	1.08 (billion)	-------------	Taylor and Brabb (1986)

[1] [Damage is shown in millions of U.S. dollars unless otherwise stated, and all amounts have been converted to year-2000 dollar losses]

Individual Events—Continued

Year	Locality	Fatalities	Damage[1]	Photograph	Reference(s)
1980	Mount St. Helens, Washington	5-10 (estimates vary)	900 12.3	MtStHelen 2MtStHelen	Schuster (1983)
1981	San Luis Dam, California	0	11	-------------	Engineering News-Record, (1982)
1982	Love Creek, California	10	unknown	-------------	Cotton and Cochrane (1982)
1983	San Clemente, California	0	65	-------------	Faucher (1984); Taylor and Brabb (1986)
1983	Thistle, Utah	0	688	Thistle83	University of Utah (1984)
1983	Pony Express, California	0	107.5	-------------	Walkinshaw (1992); San Francisco Chronicle (1983)
1983	Big Rock Mesa, California	0	706	-------------	Association of Engineering Geologists (1984)
1985	Mameyes, Puerto Rico	129	unknown	Mameyes Mameyes2	Jibson (1986)
1998	Anzar Road landslide, California	0	757.2	Anzar	Schusterand others (1998)
1999	Sacred Falls, Hawaii	8	unknown	SacredFalls1 SacredFalls2	Baum and Reid (1995)

[1][Damage is shown in millions of U.S. dollars unless otherwise stated, and all amounts have been converted to year-2000 dollar losses]

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- Nathan Trevor and Matt McKeever built the GIS database
- Margo Johnson and Marge Henneck processed the digital imagery.
- Margo Johnson designed publication.

LIST OF INDIVIDUAL EVENTS

1925-1927
Lower Gros Ventre, Wyoming

Thirty-eight million cubic-yard slide dammed the Gros Ventre River on June 23, 1925. In 1927, the landslide dam failed and the resulting flood destroyed the small town of Kelly, Wyoming. Six people drowned in the floodwaters. The slide location is approximately 40 miles south of Yellowstone National Park.

1928
St. Francis Dam failure

Los Angeles County, California.The dam gave way on March 12, and its waters swept through the Santa Clara Valley toward the Pacific Ocean, about 54 miles away. Sixty five miles of valley was devastated, and over 500 people were killed. Damages were estimated at $672.1 million (year 2000 dollars).

History: The dam was built in San Francisquito Canyon, a short distance north of the now heavily populated San Fernando Valley. The plan was to store aqueduct water behind the dam and distribute it by gravity to local storage reservoirs and eventually to users in the San Fernando Valley and the Los Angeles basin. The St. Fancies Dam was a massive gravity dam; that is, it was designed to hold back water by its sheer weight alone, rather than with the support of an arch to distribute stresses into the foundation rock. The dam failed because of a pre-existing landslide in the east abutment that became soaked by water from the reservoir. It is now agreed that this paleeolandslide on the abutment moved, causing failure of the dam.

1937-1983
Devil's Slide, California

Cost, $12.3 million (2000 dollars)—California Highway 1, reactivated in 1996.

1938-1970
Preston Bridge, Cloverdale, California

Cost, $25.7 million (2000 dollars), U.S. Highway 101.

1956
Portuguese Bend, California

Cost, $14.6 million (2000 dollars)—California Highway 14, Palos Verdes Hills. Land use on the Palos Verdes Peninsula consists mostly of single-family homes built on large lots, many of which have panoramic ocean views. All of the houses were constructed with individual septic systems, generally consisting of septic tanks and seepage pits. Landslides have been active here for thousands of years, but recent landslide activity has been attributed in part to human activity. The Portuguese Bend landslide began its modern movement in August 1956, when displacement was noticed at its northeast margin. Movement gradually extended downslope so that the entire eastern edge of the slide mass was moving within 6 weeks. By the summer of 1957, the entire slide mass was sliding towards the sea.

1958-1971
Pacific Palisade, California

Cost, $29.1 million (2000 dollars)—California Highway 1 and houses damaged.

1959
Madison Canyon, Montana

As a result of the magnitude 7.5 Hebgen Lake, Montana, earthquake, a landslide dammed the Madison River, impounding Earthquake Lake. The slide moved at 100 miles per hour and the force of the slide created an air blast. A total of 28 people were killed, 23 in the Rock Creek Campground. Five people were killed by a wall of water from the displaced Madison River. Hundreds of campers were trapped the night of the quake and landslide. There is a visitor center located on Highway 287, 17 miles west of the town of West Yellowstone, Montana, explaining the events August 17, 1959.

1959-1984
Panorama Point Landslide

Cost, $25.8 million (2000 dollars)—On Interstate 5, 5 miles south of Dunsmuir, Shasta County, California.

1960
Alta, California

Cost, $16.8 million (2000 dollars)—On Interstate 80 in California, 15 miles west of Emigrant Gap, Placer County.

1961
Mulholland Cut, California

Cost, $41.5 million (2000 dollars)—On Interstate 405, 11 miles north of Santa Monica, Los Angeles County.

1967
Potrero Hill, California

Cost, $14.6 million (2000 dollars)—On Interstate 280, 3 miles east of the James Lick Freeway exchange, San Francisco, County.

1969
Collier landslide, California

Cost, $11.2 million (2000 dollars)—One death, on Interstate 5, 8 miles north of Yreka, Siskiyou County.

1969
Glendora, California

Cost, $26.9 million (2000 dollars)—Los Angeles County, 175 houses damaged, mainly by debris flows.

1969
Seventh Ave. Los Angeles County, California

Cost, $14.6 million (2000 dollars)—California Highway 60.

1970
Princess Park, California

Cost, $29.1 million (2000 dollars)—California Highway 14, 10 miles north of Newhall, near Saugus, northern Los Angeles County.

1971
Upper and Lower Van Norman Dams, San Fernando, California

Earthquake-induced landslides—Cost, $302.4 million (2000 dollars). Damage due to the February 9, 1971, magnitude 7.5 San Fernando, California, earthquake. The earthquake of February 9 severely damaged the Upper and Lower Van Norman Dams. The principal damage to the Lower Van Norman Dam (built in 1918) was a massive upstream slope failure which dislodged a major segment of the earthfill embankment and deposited it on the reservoir floor. The slide carried with it the upstream concrete lining and crest of the dam and moved along a rupture surface which intersected the downstream face of the dam at an elevation only 1.5 meters above water level. This dam appeared to have been on the brink of failure, which would have created catastrophic inundation of the heavily populated area below. Eighty thousand people were forced to abandon their homes for 4 days while the water level in the reservoir was lowered to a level that would preclude flooding in case of further damage to the dam during strong aftershocks. The massive slope failure in the Lower Van Norman Dam may have been caused by seismically induced inertia forces alone or in concert with liquefaction of the embankment materials, tectonic deformation, or foundation soil failures.

The Upper Van Norman Dam (built in 1921) subsided about 0.9 meters (2.8 feet) and shifted downstream about 1.5 meters (6 feet) during the earthquake shock. Extensive cracking and slumping disrupted the upstream concrete lining of this dam, and the downstream slope of the embankment also was cracked. Possible causes for the subsidence and downstream movement of the Upper Van Norman Dam include seismic compaction, lateral spreading of the embankment, and foundation movements associated with landslides. Damage to the canals in the vicinity was generally in the form of cracked and broken concrete linings and displaced canal banks. In nearly all places this damage was related to slumping of the canal structure by an underlying landslide.

1971
Juvenile Hall, San Fernando, California
Landslides caused by the February 9, 1971, San Fernando, California, earthquake—Cost, $266.6 million (2000 dollars). One of the most damaging slides caused by the San Fernando earthquake (magnitude 7.5) was in the vicinity of the Van Norman Lakes. In addition to damaging the San Fernando Juvenile Hall, this 1.2 km-long slide damaged trunk lines of the Southern Pacific Railroad, San Fernando Boulevard, Interstate Highway 5, the Sylmar, California, electrical converter station, and several pipelines and canals. Because this slide occurred in an area of relatively low gradient, the most reasonable explanation for the slippage of the Juvenile Hall slide was that the underlying soils were partially or completely liquefied during the earthquake. The many sand boils observed on or near the slide are evidence that this occurred.

1972
Big Sur, California
Cost, $26.9 million (2000 dollars)—California Highway 1 and surrounding areas. A wildfire, on August 1, 1972, developed west of California Highway 1, north of Big Sur Village, burning 4,300 acres of chaparral, grass, and timber. A series of rainstorms occurred in mid-October and lasted for several days, with a repeat performance again in mid-November. Both storm periods brought flooding and mudflow activity, the second period being more destructive. Damage included highways blocked by mud and debris, dozens of cars smashed into trees by the flows, and inundation of houses and other buildings by water, mud, and debris.

1974
Canyonville landslide, Oregon
January 16, Douglas County, nine were killed when a catastrophic landslide, although small, caused great loss of life to a construction crew working on a coaxial cable. This was one of the most deadly single slides of the 20th century in the U.S.

1977-1980
Monterey Park, Repetto Hills, Los Angeles County, California
Cost, $14.6 million (2000 dollars)—100 houses damaged in 1980 due to debris flows.

1978
Bluebird Canyon Orange County, California
October 2, cost, $52.7 million (2000 dollars)—60 houses destroyed or damaged. Unusually heavy rains in March of 1978 may have contributed to initiation of the landslide. Although the 1978 slide area was approximately 3.5 acres, it is suspected to be a portion of a larger, ancient landslide. The Bluebird Canyon landslide was determined to be a “block glide” or “rock block” slide—a slide with little or no rotational movement.

1979
Big Rock, California, Los Angeles County
Cost, approximately $1.08 billion (2000 dollars)—California Highway 1 rockslide.

1980
Mount St. Helens, Washington
Cost, $12.3 million (2000 dollars)—5 to 10 people killed. This rock slide/debris avalanche, resulting from a volcanic eruption, is the world’s largest historic landslide (volume = 2.8 km^3). A debris flow from the surface of this landslide continued 90 km downstream into the Columbia River. The debris avalanche and debris flow destroyed nine highway bridges, many kilometers of highways, roads and railroads, and numerous private and public buildings. The debris avalanche also formed several new lakes by damming the North Fork Toutle River and its tributaries. The largest landslide-dammed lake is 260-million-m^3 Spirit Lake, which was prevented from overtopping its natural dam by construction of a 2.9-km-long bedrock outlet tunnel that was completed in 1985 at a cost of $44 million (2000 dollars). Although the Mount St. Helens debris avalanche moved down-valley at high velocity, it killed only 5-10 people. The low casualty rate was a direct result of the evacuation of residents and tourists in anticipation of a possible eruption of the volcano.

1981
San Luis Dam Monterey County, California
Cost, $12.3 million (2000 dollars)—Reservoir-induced landslide.

1982
Love Creek
Santa Cruz County, California

Ten fatalities, nine houses buried—slide and debris flows caused by rainfall.

1983
Pony Express, California

Cost, $107.5 million (2000 dollars)—U.S. Highway 50

1983
San Clemente, California, Orange County

Cost, $65 million (2000 dollars), California Highway 1. Litigation at that time involved approximately $43.7 million (2000 dollars).

1983
Thistle, Utah

Cost, $688 million (2000 dollars), direct and indirect costs. Debris slide caused by rainfall and snowmelt—most expensive U.S. landslide in history. This landslide which occurred in the spring of 1983, dammed the Spanish Fork River (forming a lake), and severed three major transportation arteries: U.S. Highways 6/50 and 89, and the main transcontinental line of the Denver and Rio Grande Western Railroad. A twin-bore tunnel had to be constructed around the slide to restore the railroad route. This landslide continues to experience occasional movement. An economic analysis by the University of Utah (1984) evaluated both direct and indirect costs of the Thistle landslide. Direct costs totaled $200 million ($344 million). In addition, numerous indirect costs were reported; most of these involved temporary or permanent closure of highways and railroads to the detriment of local coal, uranium, and petroleum industries, several types of businesses, and tourism. Perhaps the largest single loss due to the Thistle slide was $81 million ($139 million) in revenue lost by the D&RGW during 1983. These indirect losses from the Thistle landslide disaster may exceed the direct costs. Although there were no casualties as a result of the Thistle slide, it ranks as the most economically costly individual landslide in North America, and probably the world.

1983
Big Rock Mesa, California

Cost, $706 million (2000 dollars) in legal claims—condemnation of 13 houses, and 300 more threatened—rockslide caused by rainfall

1985
Mameyes, Puerto Rico

October 5—129 people killed, 120 houses destroyed. Heavy rainfall from tropical storm Isabel, plus possible sewage leak, and additionally, a leaky water pipe caused this major rock slide. This event obliterated much of the Mameyes district of the city of Ponce on the south coast of the island. This slide caused the greatest death toll in North American history from a single landslide.

1998
Anzar Road landslide
San Benito County, California

April 22—rainfall reactivated old landslide deposits near San Andreas Fault. One house was destroyed. Slide severed a natural gas pipeline serving thousands of customers in Santa Cruz, California, and surrounding areas. Area was without gas service for 3 days. $11.2 million (2000 dollars) in pipeline repair. Anzar Road repair was approximately $746 million (2000 dollars). Indirect costs were extremely high because of lost natural gas service to area businesses, restaurants, hospitals, etc. PG & E (Pacific Gas and Electric) had to manually relight all gas pipeline outlets.

1998
Sacred Falls, Hawaii

Rockslide—8 people killed, many injured. This event occurred about 2:30 p.m. on Sunday, May 9, 1999. Sacred Falls State Park is located near the town of Hauula on the north shore of Oahu, Hawaii. The source of the rockfall, which occurred in Kaluanui Gulch, is at an elevation of about 800 feet above sea level on the southeast canyon wall directly above the plunge pool of Sacred Falls. The source area consists of a scar of freshly exposed rock about 5-6 meters (15-20 feet) wide by 3.3 meters (10 feet) high on a nearly vertical slope. The thickness of the slab of rock that failed appears to have been about 1-2 meters (3-6 feet). The rockslide occurred as a result of long-term, gradual degradation of the slope rather than by being triggered by external factors, such as an earthquake, or heavier-than-normal rainfall. The continuing (long-term) level of landslide hazard in the Kaluanui Gulch and nearby Maakua Gulch in the park is very high because of the steep, high canyon wall, narrow valley floors, and ongoing slope weathering and rock fall. Traditional methods of mitigating rock-fall hazards are generally not considered viable in these steep, narrow canyon environments.

LIST OF REGIONAL EVENTS
(Broad Areal Impact)

1906
San Francisco, California

Earthquake-induced landslides—11 total fatalities from landslides.The following narrative was reported shortly after the 1906 earthquake occurred. The earthquake started a number of landslides. A few of these were on the line of the fault, especially where its trace intersected a cliff facing Bolinas Lagoon. Others were from cliffs of earth or weak rock bordering the ocean, one of the bays, or a creek. Many of these slides obstructed roads. There were many dry landslides on hillsides, masses of earth and rock breaking away on steep slopes and tumbling to the bottom. The largest seen were on the high ridge west of Tomales Bay, in the vicinity of Sunshine Ranch. Closely related to these were small falls of earth and rock from the low cliffs created in the construction of sidehill roads. They occurred at a few places within the Rift and east of it, but mostly in the district to the west, where all of the country roads were more or less obstructed.

On the west side of the main ridge west of the head of Tomales Bay there occurred two wet slides. In one case a hillside bog was loosened from the slope on which it rested and descended as flow of mud to a canyon bottom 100 or 200 feet below. In the other case the earth beneath a wet meadow in a rather steep canyon flowed down the canyon for about 0.5 mile, overpowering trees on its way and leaving a deposit 15 or 20 feet deep in places. This was the largest individual slide observed.

On the steep southern face of Mount Tamalpais a number of rocks were loosened and rolled down the slope, some of them being large enough to cut swaths through the thicket, which were visible for months afterward. Similar swaths were seen under a crag in the vicinity of Willow Camp. There were numerous hillside cracks, which marked incipient landslides. In such cases the downward motion apparently began during the earthquake agitation, but the momentum acquired was not sufficient to continue the motion after the earthquake stopped. In a large number of these localities motion was resumed and landslides occurred during a period of excessive rainfall in the spring of 1907.

Cache Creek Landslide, 1906—An earthquake thought by some to be an aftershock associated with the great San Francisco quake, occurred upstream in the Cache Creek Canyon area between what are now known as Wilson Valley and Buck Island. After the earthquake, local residents saw the stream flow of Cache Creek dry up; a large landslide had dammed the creek. Fearing calamity, a band of men set out with mules to assess the situation upstream, but only a solitary journalist found his way several days later to the landslide, which had damned Cache Creek and created a lake 8 miles long. Riding back down the canyon to warn the locals of the situation and the possibility of a catastrophic failure of the "dam". As it turned out, the dam eroded away slowly, and although barns and buildings near the town of Rumsey were temporarily inundated, no loss of human life occurred.

1934-1975
Lake Roosevelt

Construction of Grand Coulee Dam by the U.S. Bureau of Reclamation began in 1933. Roosevelt Lake slowly and intermittently was filled as construction proceeded until the dam was completed in 1942. The resulting reservoir created a lake 232 km (145 miles) long and raised the level of the Columbia River 107 m (35.6 feet). Landslides occurred with great and unexpected frequency as Lake Roosevelt filled. Many additional landslides have occurred since filling, particularly during periods of drawdown of the reservoir. Damages due to the slides have not been economically catasrophic and no deaths have resulted. Research outlined Jones et al. (1961) has shown the importance of both the rising reservoir and drawdown as causes of landslide activity.

In summary the shores of Roosevelt Lake have been subject to several hundred landslides since the reservoir began to be filled during construction of Grand Coulee Dam during the 1930's and early 1940's. The greatest percentage of landslide activity occurred during initial filling of the reservoir, but many slope failures also have been caused by intermittent drawdown of the reservoir level. In addition, occasional slope failures have occurred as natural phenomena, related more to wet winters than to fluctuation of the reservoir.

1964
Alaska earthquake landslides

Landslides induced by the magnitude 9.2 earthquake. Most expensive landslide disaster in U.S. History. Damage—$960 million (2000 dollars). Five major landslides caused damage to housing, public and industrial buildings, and lifelines in Anchorage, Alaska's largest city.

1968-1969
San Francisco Bay area landslides

30 deaths resulted from this landsliding—$100.8 million (2000 dollars)

1969
Hurricane Camille landslides

Damage in central Virginia was due to debris flows and associated flooding from the hurricane. Most of the 150 people who died in debris flows were killed by broken bones and other blunt-force injuries, rather than by drowning.

1978-1979, 1980
San Diego County, California

Experienced major damage from storms in 1978, 1979, and 1979-80, as did neighboring areas of Los Angeles and Orange County, California. One hundred and twenty landslides were reported to have occurred in San Diego County during these 2 years. Rainfall for the rainy seasons of 78-79 and 79-80 was 14.82 and 15.61 inches (37.6 and 39.6 cm) respectively, compared to a 125-year average (1850-1975) of 9.71 inches (24.7 cm). Significant landslides occurred in the Friars Formation, a unit that was noted as slide-prone in the Seismic Safety Study for the City of San Diego. Of the nine landslides that caused damage in excess of $1 million, seven occurred in the Friars Formation, and two in the Santiago Formation in the northern part of San Diego County (Leighton & Associates—Gizienski and Assoc., 1974.

1980
Southern California slides

$1.1 billion in damage (2000 dollars)—Heavy winter rainfall in 1979-90 caused damage in six southern California counties. In 1980, the rainstorm started on February 8. A sequence of 5 days of continuous rain and 7 inches of precipitation had occurred by February 14. Slope failures were beginning to develop by February 15 and then very high-intensity rainfall occurred on February 16. As much as 8 inches of rain fell in a 6-hour period in many locations. Records and personal observations in the field on February 16 and 17 showed that the mountains and slopes literally fell apart on those 2 days. According to records, over 90 percent of the losses were associated with pre-1963 constructed houses and structures. The remaining approximately 10 percent of the losses appeared to be related primarily to structures on natural and post-1963 engineered fill slopes.

1982
San Francisco Bay area

$132 million in damage (2000 dollars), 30 deaths—Rainfall induced; mainly debris flows. Various lawsuits exceeded $400 million.

1983
Utah landslides

$430 million—now attributed to heavier-than-normal rains due to El Niño Southern Oscillation (2000 dollars)

1984
Utah landslides

Direct costs about $70.5 million (2000 dollars)

1989
Loma Prieta earthquake landslides

Destroyed 100 residences, blocked many roads—$34 million + in damage (year 2000 dollars)

1989
Alani Paty landslide, Hawaii

Costs, $34 million (2000 dollars)—The very slow-moving Alani-Paty landslide near the City of Honolulu, Hawaii, damaged houses, streets, and utilities on 60 lots of a residential neighborhood built on a debris apron. The slide is similar to several others near Honolulu that have caused millions of dollars in property damage. The slide area showed signs of movement in the mid or late 1970s and residents have reported damage to houses and streets during and immediately following rain periods, especially during the winters of 1987 and 1988.

1994
Northridge, California earthquake landslides

As a result of the magnitude 6.7 Northridge, California, earthquake, more than 11,000 landslides occurred over an area of 10,000 km^2. Most were in the Santa Susana Mountains and in mountains north of the Santa Clara River Valley. Destroyed dozens of homes, blocked roads, and damaged oil-field infrastructure. Caused deaths from Coccidioidomycosis (valley fever) the spore of which was released from the soil and blown toward the coastal populated areas. The spore was released from the soil by the landslide activity.

1995
Madison County, Virginia

Costs: $123.2 million (floods and landslides, 2000 dollars)—In the summer of 1995, a major landslide event occurred in Madison County, central Virginia. The area affected is characterized by working farms in the foothills of the Blue Ridge Mountains. During an intense storm on June 27, 30 inches of rain fell in 16 hours. In the mountainous areas of the county, rain-saturated landslides, known as debris flows, were triggered by the hundreds. The Rapidan, Robinson, and Conway rivers flooded the lowlands, causing widespread destruction. The most severe effects of the storm occurred in areas of heaviest rainfall. In addition to flooding along the main rivers and streams, landslides on steep hillsides rapidly transformed into fast-moving debris flows. Damage to manmade structures commonly occurred where debris flows emerged from mountain channels, spreading large quantities of rocky material. Houses and barns were inundated or crushed by the debris. Pastures and cornfields were covered, and livestock perished. Many trees stripped of their bark, branches, and leaves were carried into swollen streams and rivers, and acted as battering rams against buildings and bridges. Such debris greatly increased the destructive power of the flood waters. One woman was killed in a debris flow near Criglersville, Virginia, and seven other fatalities were caused by flooding elsewhere in the state.

March 1995
Los Angeles and Ventura Counties, southern California

Above normal rainfall triggered damaging debris flows, deep-seated landslides, and flooding. Several deep-seated landslides were triggered by the storms, the most notable was the La Conchita landslide, which in combination with a local debris flow, destroyed or badly damaged 11 to 12 homes in the small town of La Conchita, about 20 km west of Ventura. There also was widespread debris-flow and flood damage to homes, commercial buildings, and roads and highways in areas along the Malibu coast that had been devastated by wildfire 2 years before.

1996
Hamilton County, Cincinnati, Ohio

Cost, $11.2 million (2000)—many slides in soil and shale, most were characterized as slumps

1996-1997
Puget Lowland, Washington

Snowmelt and rainfall events triggered many landslide and debris flows in the Seattle, Washington, area during late December 1996 and January and March 1997. Landslides caused the deaths of at least four people, millions of dollars in damage to public and private property, lost revenues, traffic diversions, and other direct and indirect losses. Although shallow slides and debris flows were the most common slope failures, many deep-seated slides also occurred. Comparative maps that show distribution of historic landslides with reports of landslides compiled by city and county governments for the winter of 1996-97 and USGS reconnaissance of recent landslide deposits and scars indicated that many bluffs and steep hillsides were sites of recurring failures. Investigation of the 1996-97 landslides indicates that houses and other structures built downslope from steep bluffs were in particular danger of impact by debris flows, while those on the benches, slopes, or rim of bluffs were subject to severe damage by deep slides. Four deaths were attributed to the landslides.

1997-98
El Niño storms, California

Heavy rainfall associated with a strong El Niña caused over $156.5 million (2000 dollars) in landslide damage in the 10-county San Francisco Bay region during the winter and spring of 1998. Reports of landsliding began in early January 1998 and continued throughout the winter and spring. On February 9, President Clinton declared all 10 counties eligible for Federal Emergency Management Agency (FEMA) disaster assistance. In April and May of 1998, personnel from the U.S. Geological Survey (USGS) conducted a field reconnaissance in the area to provide a general overview of landslide damage resulting from the 1997-98 sequence of El Niña-related storms. For the study, landslides were defined in the broadest sense: any hillside material, both natural and engineered, that failed and impacted the built environment qualified as a landslide. Damage from flooding was excluded. Approximately 300 landslides were documented.

El Niño storms, California

*Direct costs by county

County	Population (1998)[1]	Reported landslide costs	Per-capita costs	Per-capita income[2]
Alameda	1,408,100	$20,020,000.00	$14.22	$27,368.00
Contra Costa	900,700	27,000,000.00	29.98	32,881.00
Marin	245,900	2,540,000.00	10.33	45,305.00
Napa	123,300	1,120,000.00	9.08	29,336.00
San Mateo	715,400	55,000,000.00	76.88	38,380.00
Santa Clara	1,689,900	7,600,000.00	4.50	35,395.00
San Francisco	789,600	4,100,000.00	5.19	39,249.00
Solano	383,600	5,000,000.00	13.03	21,323.00
Sonoma	437,100	21,000,000.00	48.04	27,353.00
Santa Cruz	250,200	14,680,000.00	58.67	27,896.00
totals	6,943,800	158,060,000.00	22.76	32,448.60

[1] State of California Department of Finance, City and County Population Estimates, May 1998

[2] State of California Department of Finance, California Statistical Abstract, 1998, Table D-7

(Godt and Savage, 1999)

Landslide caused by the San Francisco, California, earthquake of 1906, located 2.5 miles northwest of Bolinas Lagoon. *Photograph by G.K. Gilbert, U.S. Geological Survey.*

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This landslide, caused by the San Francisco, California, earthquake of 1906, is located 4 miles northwest of Bolinas Lagoon. Observer is looking south-southwest. *Photograph by G.K. Gilbert, U.S. Geological Survey.*

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Gros Ventre landslide, Lincoln County, Wyoming, June 6, 1925, twenty-five people were killed and the landslide destroyed the town of Kelly. The view is south across foot of the lake created when the Gros Ventre River was dammed. Slumped surface of inner side of the dam in right foreground.
Photograph by W.C. Alden, U.S. Geological Survey.

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St. Francis dam failure, March 12, 1928—Los Angeles County, California. The bottom photo was taken March 17, 1928, and shows destroyed dam.
Photographs by H.T. Stearns, U.S. Geological Survey.

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Devil's landslide along U.S. Highway 1 in San Mateo County, California. The landslide first began in 1937 and was reactivated as recently as 1996.
Photograph by Earl Brabb, U.S. Geological Survey.

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Cloverdale landslides, Sonoma County, California. These landslides occurred during the period 1938 to 1970. *Photograph by Fred Taylor, U.S. Geological Survey (taken July 1971).*

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Landslide of February 3, 1956 off of Via de las Olas Palisades, Pacific Palisades area, Los Angeles, California.
Photograph used with permission, Los Angeles (Calif.) Times, February 4, 1956.

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Head-scarp of the Portuguese Bend landslide that caused about 45 million dollars in damage in 1956.
Photograph by J. Schlocker, U.S. Geological Survey.

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Landslides occurred in Pacific Palisades, California during the 1958-1971 period. The photograph of the Friends Street landslide shows detail of damage and overhanging corner of Friends Street. The view of the photograph is north-northeast. *Photograph by Jack McGill, U.S. Geological Survey.*

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This home in Pacific Palisades near Santa Monica was damaged when the coastal bluff on which it was built failed during the earthquake. The landslide caused half the house to be torn loose and cascade down the steep slope.
Photograph by E.L. Harp, U.S. Geological Survey.

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Headscarp of the 1959 Madison Canyon landslide. The magnitude 7.5 Hebgen Lake earthquake caused the massive slide that killed 28 people. *Photograph courtesy of the U.S. Forest Service.*

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The 1959 Madison Canyon landslide, Montana caused by the Mg 7.5 Hebgen Lake earthquake. This view is from a point down river from where this massive slide dammed the Madison River. The resulting blockage of the river formed Earthquake Lake. *Photograph courtesy of the U.S. Forest Service.*

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Landslide resulting from the Hebgen Lake, Montana earthquake of August 17, 1959. The massive rockslide dammed the Madison River, impounding Earthquake Lake.
Photograph courtesy of the U.S. Forest Service.

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Subsidence of the graben at the head of the Government Hill landslide in Anchorage tore apart an elementary school and converted the schoolyard into a jumble of fissures, scarps, and tilted and subsided blocks of broken ground. The flat and relatively unbroken large slide block in the foreground moved away from the school horizontally and as a single mass, creating a void into which the graben block spread and subsided.
Photograph, U.S. Geological Survey.

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Damage resulting from landslides caused by the 1964 earthquake near Anchorage, Alaska. *Photograph , U.S. Geological Survey, Circular #491, 1964.*

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Landslide in Belmont, California, resulting from 1968-69 storms. *Photograph by Fred Taylor, U.S. Geological Survey.*

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San Mateo County, California. Damage from the 1968-69
San Francisco Bay Area landslides.
Photograph by Earl Brabb, U.S. Geological Survey.

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Debris-flow damage, Glendora, California. In 1969, 175 homes were damaged or destroyed during this event.
Photograph courtesy of the L.A. Times.

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Jackson Springs landslide on the Spokane arm of Franklin D. Roosevelt Lake, Washington. This earth slump, with a volume estimated at more than 11 million cubic meters (14 million cubic yards), occurred in 1969 during a period of extreme draw down necessitated by excavation for a forebay dam preliminary to construction of the Third Powerplant at Grand Coulee Dam. *Photograph courtesy of the U.S. Bureau of Reclamation.*

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Landslide on Interstate 5 in northern California which occurred in 1969. There was a single fatality and the cost of repair to the highway was over 10 million dollars. *Photograph by E. Pampeyan*.

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Scarp of upstream slope failure in the Lower Van Norman Lake Dam.

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The landslide caused over 238 million dollars in damage to the Juvenile Hall facility; building and facility shown in the photograph. *Photograph courtesy of Lloyd Cluft.*

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Oblique photograph of San Fernando Valley Juvenile Hall area and approximate boundaries of the Juvenile Hall slide.
Photograph courtesy of T.L. Youd.

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Photograph showing the damage to U.S. Highway 1 near Big Sur, California in 1973. Damage costs were estimated at over 23 million dollars.

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Earthflow in Cincinnati, Ohio. Material being removed by highway crew along the Columbia Parkway, Cincinnati, Ohio. Hamilton County, in the metropolitan Cincinnati area, experienced an average annual economic loss of $5.80 per person (1975 dollars) between 1973 and 1978, the highest calculated per capita loss of any municipality in the United States. *Photograph by Earl Brabb, U.S. Geological Survey.*

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Small catastrophic landslide near Canyonville, Oregon, which occurred on January 16, 1974, killing nine construction workers. This landslide is one of the single most costly in the United States in terms of lives lost in the 20th century. *Photo by Ed Busby, GeoWest, Inc.*

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Bluebird Canyon landslide, Laguna Beach California. The landslide occurred on April 21, 1978. *Photograph courtesy of Bruce Clark, Leighton & Associates, California.*

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Bluebird Canyon landslide, Laguna Beach, California. This slide occurred on April 21, 1979. Houses affected were a total loss and could not be rebuilt on the site. *Photograph by Bruce Clark, Leighton & Associates, California.*

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Bluebird Canyon landslide of April 21, 1979. This slide took out telephone lines, blocked roads, and seriously damaged other lifelines in the area. *Photograph courtesy of Bruce Clark, Leighton & Associates, California.*

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This downstream view of the North Fork Toutle River valley, north and west of St. Helens, shows part of the nearly 2/3 cubic miles (2.3 cubic kilometers) of debris avalanche that slid from the volcano on May 18. This is enough material to cover Washington, D.C. to a depth of 14 feet (4 meters). The avalanche traveled approximately 15 miles (24 kilometers) downstream at a velocity exceeding 150 miles per hour (240 km/hr). It left behind a hummocky deposit with an average thickness of 150 feet (45 m) and a maximum thickness of 600 feet (180 meters). *Photo by Lyn Topinka, USGS, November 30, 1983.*

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Home damaged by a mudflow (lahar) along the Toutle River, about 25 miles west northwest of Mount St. Helens, Washington. This lahar resulted from the May 18, 1980, eruption of Mount St. Helens. The depth of the flow was recorded by mud coatings on tree trunks. *Photograph by D.R. Crandell, U.S. Geological Survey.*

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Oddstad Boulevard debris flow occurred in 1982 in Pacifica, San Mateo County, California. Three children were killed and two homes destroyed. *Photograph by Gerald Wieczorek, U.S. Geological Survey.*

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The 1983 Thistle landslide at Thistle, Utah. The landslide began moving in the spring of 1983 in response to groundwater buildup from heavy rains the previous September and the melting of a deep snow pack that fell during the winter of 1982-83. Within a few weeks of the start of movement, the landslide dammed the Spanish Fork River, obliterating U.S. Highway 6 and the main line of the Denver and Rio Grande Western Railroad. The town of Thistle was inundated under the floodwaters rising behind the landslide dam. The slide required extensive engineering to mitigate the impact on transportation infrastructure, including railroad tunnels that were excavated under the slide. Total costs (direct and indirect) incurred by this landslide exceeded $400 million, the most costly single landslide event in U.S. history. The slide remains today, and accommodates a small visitor center, which describes the history and engineering procedures. *Photograph by R.L. Schuster, U.S. Geological Survey.*

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Homes partially buried by debris flows resulting from snowmelt and rainfall. Damage was due to extensive number of landslides during the Spring of 1983, in Utah. Direct damage costs exceeded 330 million dollars. *Photograph by Earl Brabb, U.S. Geological Survey.*

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The 1985 Mameyes, Puerto Rico, landslide (areal view). This landslide destroyed 120 homes and killed at least 129 people, the greatest number of casualties from any single landslide in North America (as of early 2000). The catastrophic block slide was triggered by a tropical storm that produced extremely heavy rainfall. Contributing factors may have included sewage directly discharged into the ground in the densely populated area and a leaking water pipe at the top of the landslide. *Photograph by R.W. Jibson, U.S. Geological Survey.*

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The 1985 Mameyes, Puerto Rico, landslide (closeup). This landslide destroyed 120 houses and killed at least 129 people, the greatest number of casualties from any single landslide in North America. The catastrophic block slide was triggered by a tropical storm that produced extremely heavy rainfall. Contributing factors could also have included sewage directly discharged into the ground in the densely populated area and a leaking water pipe at the top of the landslide. *Photograph by Earl Brabb, U.S. Geological Survey.*

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Home damaged by the 1989 Alani-Paty landslide near Honolulu, Hawaii. *Photograph by Rex Baum, U.S. Geological Survey.*

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Landslide triggered by the 1989 Loma Prieta earthquake, north of Fort Funston, California. This slide mass has a volume of approximately 2,830 cubic meters (3,700 cubic yds) and is 30 meters (100 feet) high. *Photograph by D.M. Peterson.*

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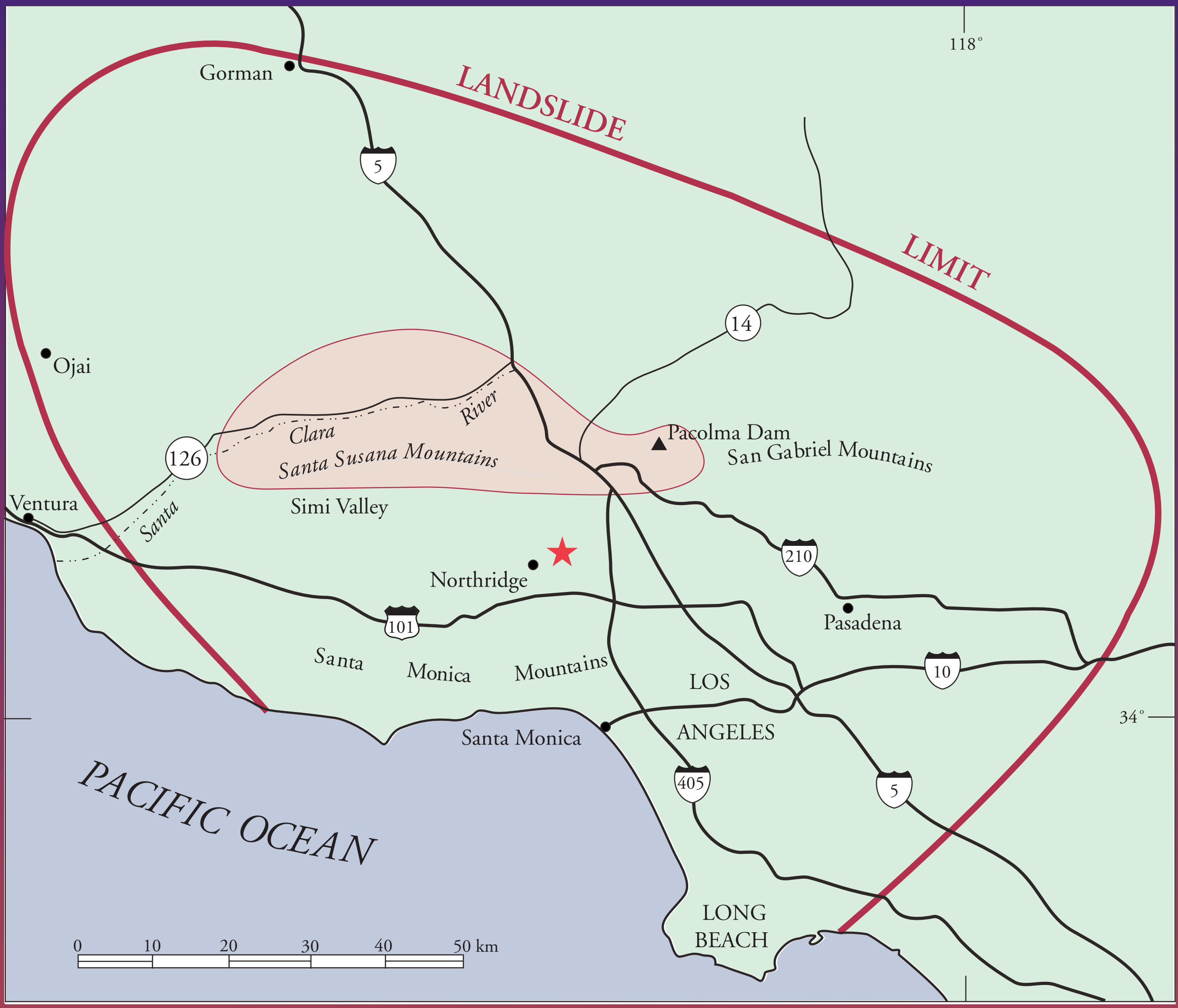

Map showing epicenter of the Northridge, California earthquake (star symbol), limit of landslides triggered by the earthquake (heavy, solid line), and area of greatest landslide concentration (shaded). *Figure from Jibson and Harp (1995), U.S. Geological Survey.*

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Numerous debris flows scarred the foothills of the Blue Ridge in Madison County, Virginia, after the devastating storm of June 27, 1995. The debris flows began on steep slopes and moved rapidly down stream channels. The smaller debris flows joined to form larger flows lower in the valleys and spread mud, boulders, and other debris, inundating residents' homes and farms. *Photograph copyright by Kevin Lamb, 1995, used with permission.*

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La Conchita is a small community along Highway 101 north of Santa Barbara. This landslide occurred in the spring of 1995. Many people were evacuated as about a dozen houses nearest the slide toe were destroyed. Fortunately, no one was killed or injured. *Photograph by R.L. Schuster, U.S. Geological Survey.*

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Large slump-debris flows near Stella, Washington, on State Highway 4. Over 800 million dollars in damage due to landslides, in western Washington State, was estimated following the severe winter storm of February 1996. The Columbia River is in the foreground. *Photograph by E.L. Harp, U.S. Geological Survey.*

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Labeled overview of the Portuguese Bend landslide, California looking toward the east. *Photograph by Josh Myers (1997), Department of Geological Sciences, California State University, Long Beach.*

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House in the Magnolia Bluffs area overlooking Puget Sound, Seattle, Washington, that was struck by a debris flow. The flow deposited material in the garage (upper level) and collapsed the front wall of the living quarters (lower level).
Photo by Alan Chleborad, U.S. Geological Survey, January 9, 1997.

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Damage due to El Nino storms and resultant heavy rainfall. Damaged house located on 19th Avenue in Oakland, Alameda County. *Photo by Jeff Coe, U.S. Geological Survey.*

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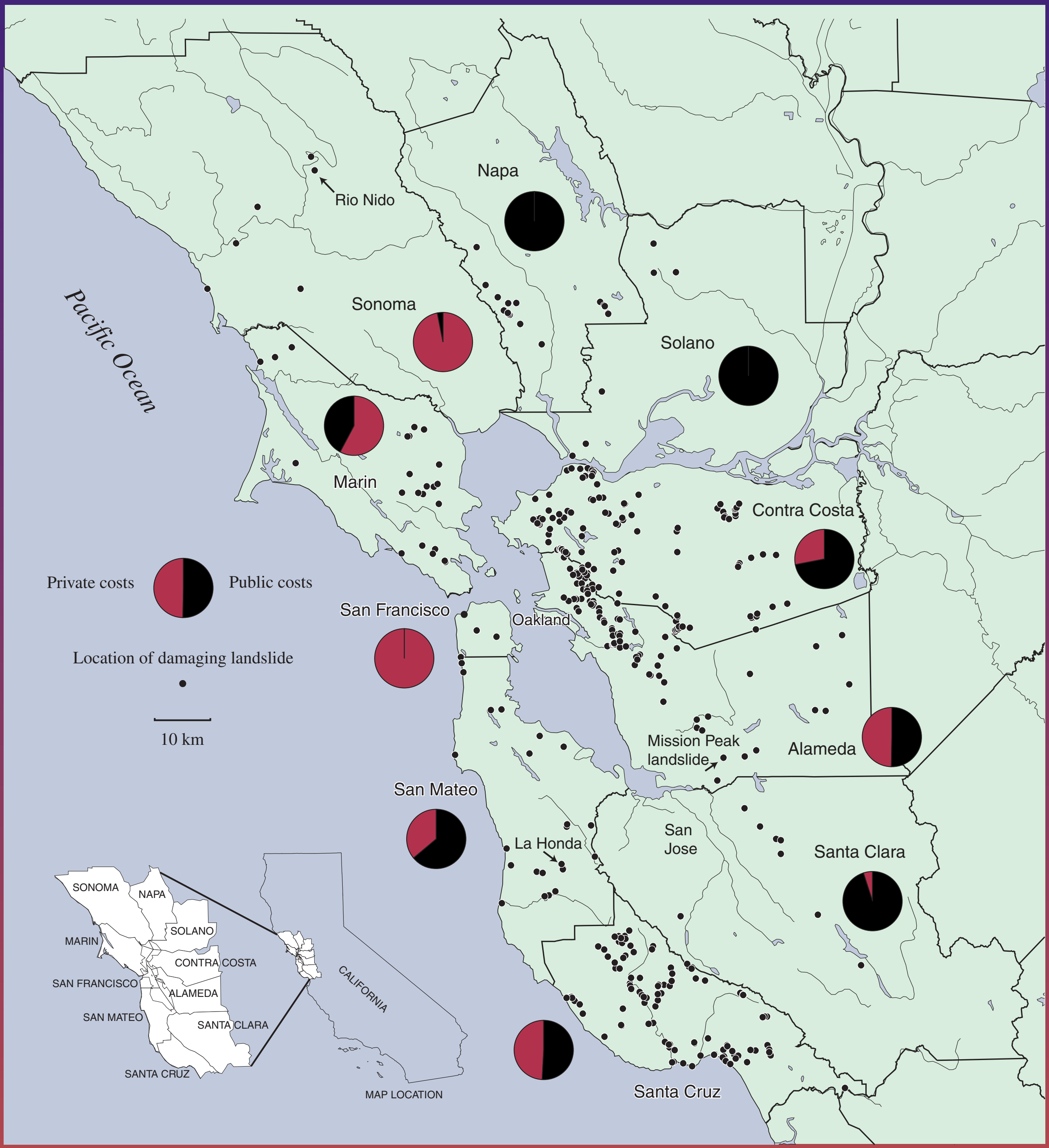

Map showing locations of damaging landslides in the San Francisco Bay region resulting from 1997-98 El Niño rainstorms. Pie charts divide the costs into those borne by public and private entities for each county. *From Godt (1999).*

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Anzar Road, San Benito County, California landslide of April 22, 1998.
Photograph by Lynn Highland, U.S. Geological Survey.

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Source area (indicated by arrow) of Sacred Falls, Hawaii, rock fall of 1999. *Photograph by R. W. Jibson, U.S. Geological Survey.*

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1991 Sacred Falls, Hawaii, rock-fall deposit. *Photograph by R. W. Jibson, U.S. Geological Survey.*

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