NATURAL THREATS

Natural threats, the largest single category of repetitive threats to communities and emergency management coordinators, come from weather-, geological-, seismic- or oceanic-related events. They pose a threat to any area of the country; their impact can be localized or widespread, predictable or unpredictable. The damage resulting from natural disasters can range from minimal to major (depending on whether they strike major or minor population centers). The impact of extremely severe natural disasters can have a long-term effect on the infrastructure of any given location. Natural threats include avalanche, dam failure, drought, earthquake, flood, hurricane/tropical storm, landslide, subsidence, tornado, tsunami, volcano, wildfire and winter storm.

Avalanche

Definition *A mass of sliding snow in mountainous terrain with large snow deposits on slopes of 20 degrees or more*

National Frequency Approximately 10,000 avalanches are reported each year. There may be as many as 100 times more that are not observed or recorded. From 1980 to 1985, Alaska recorded 441 avalanches that affected people.

Regions at Risk The mountain ranges in New Hampshire, Vermont and the Far West have avalanches where the primary risk to people exists in recreational areas that feature climbing and skiing. Transportation corridors along numerous year-round highways and railroads in the western risk areas experience frequent avalanche activity. In Alaska alone, from 1975 to 1985, 205 avalanche events blocked highways, hitting or disabling 30 vehicles; 274 events blocked railroads, derailing 21 cars. Avalanches closed Colorado highways on 60 days during the winter of 1983-1984. The map in *Figure* 2 illustrates the risk severity for snow avalanches by State.

Season(s) Fall, Winter, Spring.

Effects Annually, an average of 140 Americans are caught in avalanches; 65 are buried and 17 are killed. While there are no national cost figures available, the economic impact of avalanches that damage and destroy public, commercial and private property and forest lands includes the costs for restoration, maintenance and subsequent litigation. The following examples of some of the costs incurred in specific areas have been taken from the *National Research Council 1990 Report entitled,* **Snozu Avalanche Hazards and Mitigation in the United States,** *pp. 17-19.*

- Avalanches cost the Washington State Department of Transportation an estimated $330,000 each year. That figure does not include State salaries and expenses for avalanche control or plowing and snow removal.
- Costs from damages caused by avalanches in Alaska were estimated to be at least $11.4 million during the years of 1977 through 1986.

- Rescue operations cost $74,250 for an avalanche on U.S. Forest Service land in Colorado that killed four people near a ski area on February 18, 1987. Additional undisclosed expenses related to preparation for anticipated litigation were also incurred.
- A March 31, 1981, avalanche in Californian's Alpine Meadows ski area resulted in seven deaths and caused approximately $1.5 million in property damages. The ensuing law suits (not including appeals) cost in excess of $1,500,000. The cost of the undisclosed out-of-court settlements potentially could have been $14 million.

Worst Event

Definitive data unavailable. The worst period in American history for avalanche-related deaths was during the Colorado gold and silver mining fields from 1880 to 1920 when about 400 people were killed.

Discussion

Avalanches, which are the most frequent form of lethal mass movement, can be triggered by various means, including earthquakes. They generally occur in the Rockies and other mountains of the western States. There is no centralized reporting of occurrences because most incidents happen in remote, sparsely populated locations and seldom inflict permanent damage. The avalanche threat is becoming more significant because of increased development and recreation in mountainous regions.

SNOW AVALANCHE SEVERITY

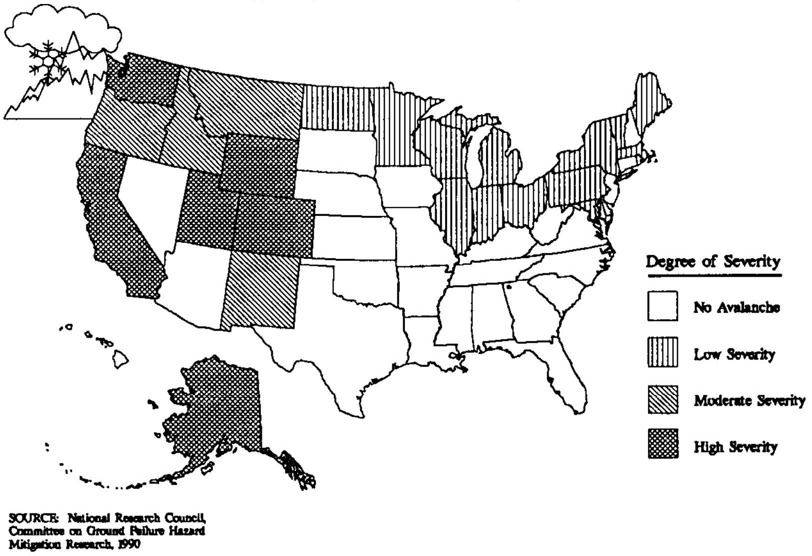


Figure 2

Dam Failure

Definition *Collapse or failure of an impoundment that causes downstream flooding*

National Frequency Dam failures occur several times annually, however, no national average is available.

Regions at Risk There are over 80,000 dams throughout the States. More than 20,000 of them are classified as posing "high" or "significant" hazards. These designations mean that, if such a dam failed, lives would be lost and extensive property damage would be suffered. *Figure* 3 lists some of the dam and levee failures from 1874-1982 in which lives were lost.

DAM & LEVEE FAILURES IN THE U.S.
1874 - 1982

YEAR	LOCATION	STRUCTURE	DEATHS
1874	Williamsburg, MA	Earth Dam	144
1889	Johnstown, PA	Earth Dam	2,209
1890	Walnut Grove/Prescott, AZ	Dam	150
1894	Mill River, MA	Dam	143
1900	Austin/Austin, PA	Dam	8
1928	St. Francis, CA	Dam (est.)	400- 700
1955	Yuba City, CA	Levee	38
1963	Baldwin Hill, CA	Earth Dam	5
1972	Buffalo Creek, WV	Slagheap Dam	125
1972	Rapid City, SD	Dam	200
1976	Newfound, NC	Earth Dam	4
1976	Teton, ID	Earth Dam	14
1977	Toccoa, GA	Earth Dam	35
1982	Estes Park, CO	Earth Dams (2)	3
	TOTAL		3,528-3,778

Source: Adapted from US. Nuclear Regulatory Commission/ A Risk Comparison.

Figure 3

Season(s) Dam failures usually occur as a secondary effect of storms or earthquakes.

Effects

The primary consequence of the dam failure hazard is loss of life and property damage downstream of the failure. Of the estimated 80,000 dams in the United States, about 95 percent are owned by State and local authorities and private organizations as opposed to the 5 percent owned by the Federal government.

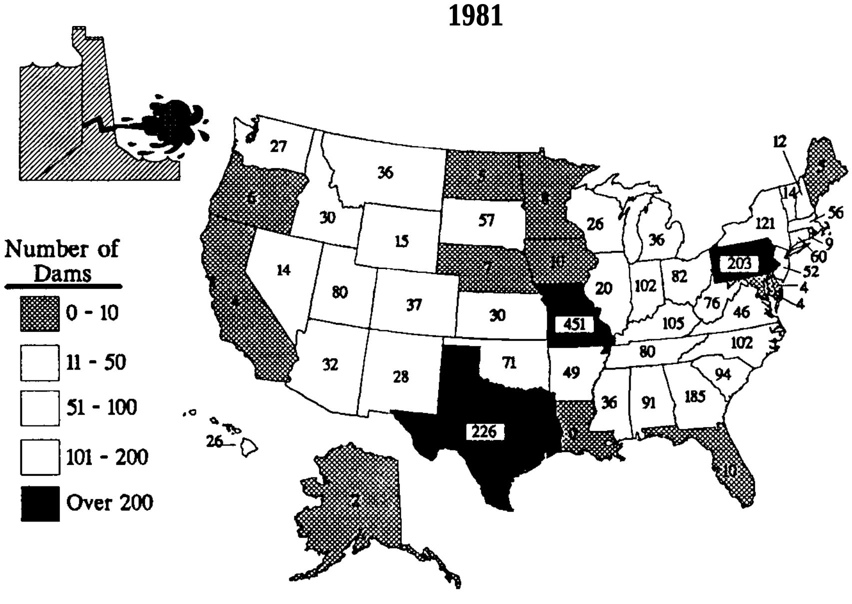
Worst Event

The Johnstown earthen dam collapse and flood on May 31, 1889, resulted in the deaths of more than 2,200 persons.

Discussion

Between 1972 and 1981, the U.S. Army Corps of Engineers had responsibility for the inspection of all non-Federal dams. The responsibility has since been returned to the States. Inspection of Federal dams continues to be the responsibility of the owner agency. The number of unsafe dams in 1981 is shown in *Figure* 4. It is important to note in the Figure, however, that the age of the data does not necessarily mean that the number of dams considered “unsafe” at the time of inspection remains at that level today--some deficiencies may have been corrected while other dams may have become unsafe due to poor maintenance. FEMA is working on a new survey of the condition of the nation’s dams, to be completed by the end of 1992.

UNSAFE DAMS IN THE UNITED STATES
1981



SOURCE: U.S. Corps of Engineers

Figure 4

Drought

Definition	*A prolonged period without rain*
National Frequency	The frequency is difficult to measure. Droughts can happen at any time of the year.
Regions at Risk	The entire country is at risk.
Season(s)	Year round
Effects	Drought in the farm belt devastates crops, resulting in low yields and economic losses. Winds blow away top soil and create dust storms further eroding the fertility of the land. Water tables are lowered. Parched forest lands are more susceptible to wildfires during periods of drought.
Worst Event	"Dust Bowl" of the 1930's in the Southwest

Discussion

Drought gripped much of the West and Midwest during 1987-1991. While beneficial rains in 1991 eased or erased drought conditions in some locations, other areas were not so fortunate. (See *Figure 5* for the changes in affected areas over the year.) Two areas in particular, the Missouri River Basin and California, continued to experience serious drought conditions during Fiscal Year 1991 as a result of several consecutive years of below average precipitation. Reservoir storage in both of these areas continued to be very low at the beginning of Fiscal Year 1991.

The economic effects of a drought are both direct and indirect. For example, crop losses affect farming income which, in turn, may mean foreclosure of farms because of unserviced debt. Estimating the economic losses attributed solely to drought-related damage is difficult to do and can be misleading when compared from year to year because of constantly fluctuating commodity markets. Also, some areas of the country may suffer drought-related losses while other areas that produce the same crops have record yields, as was the case during the 1989 and 1990 growing seasons.

Misuse of the land and lack of appropriate cultivation practices contributed to the severity of drought effects up until the last 50 years. Research, education and governmental financial aid has done much to restore the land and mitigate the impact of droughts since then. The trend for droughts may worsen in the long term because of the greenhouse effect and cause water shortages for irrigation in the west and for human consumption throughout the country (especially in overdeveloped areas).

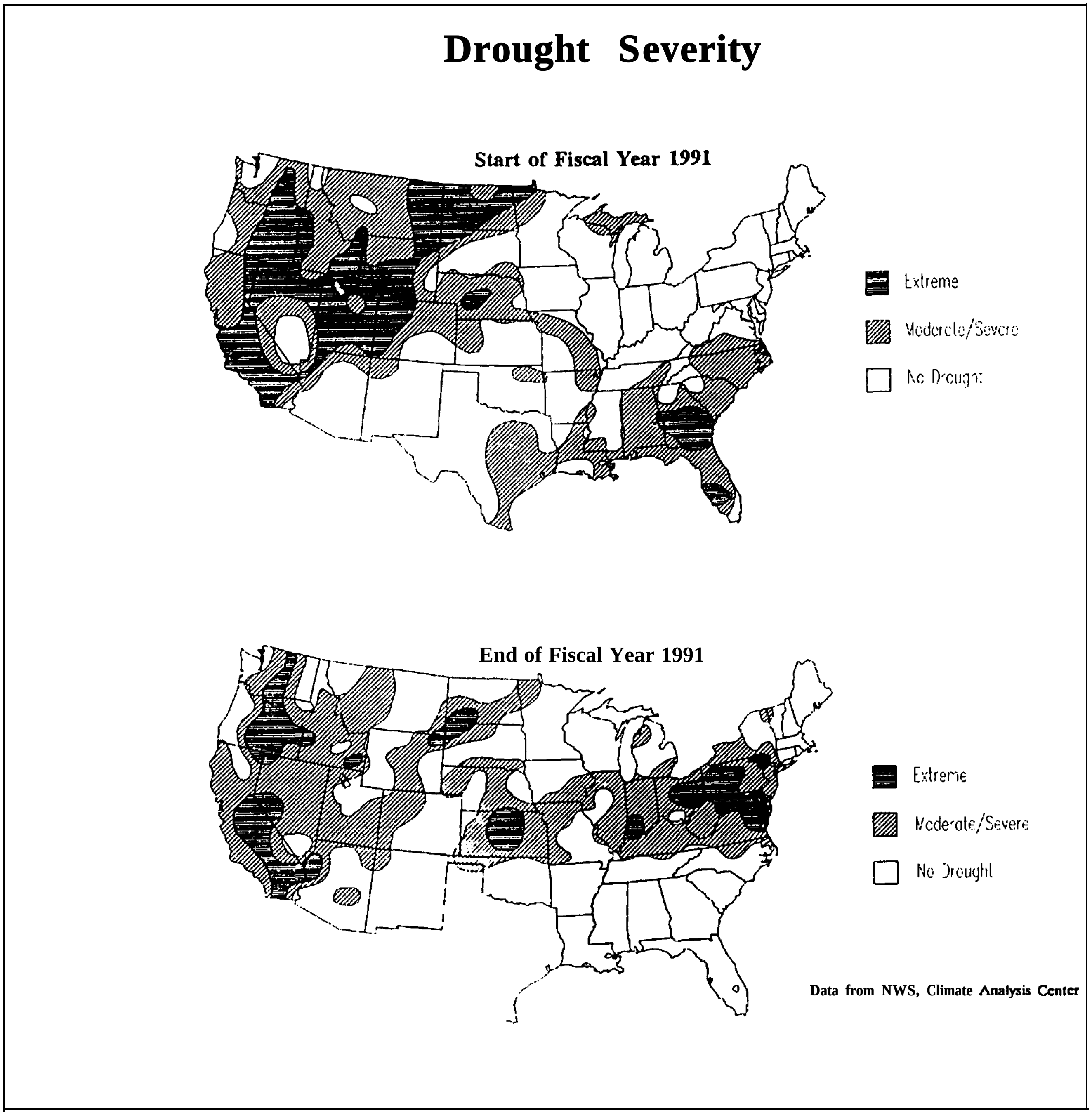


Figure 5

Earthquake

Definition *A sudden motion of the ground which may cause surface faulting (ground rupture), ground shaking and ground failure*

National Frequency Each year, there are literally thousands of earthquakes in the United States, most of which are of such small magnitude that they are not felt by the population.

Regions at Risk Wide areas of the United States have some vulnerability to earthquakes (see *Figure 6).* The most frequent earthquake events occur in States west of the Rocky Mountains, although historically the most violent earthquakes have occurred in the central United States. California is especially vulnerable because of its high seismic activity. Other highly vulnerable areas are those of Charleston, South Carolina, and the central United States (the New Madrid Seismic Zone), both of which were devastated by earthquakes in the last century.

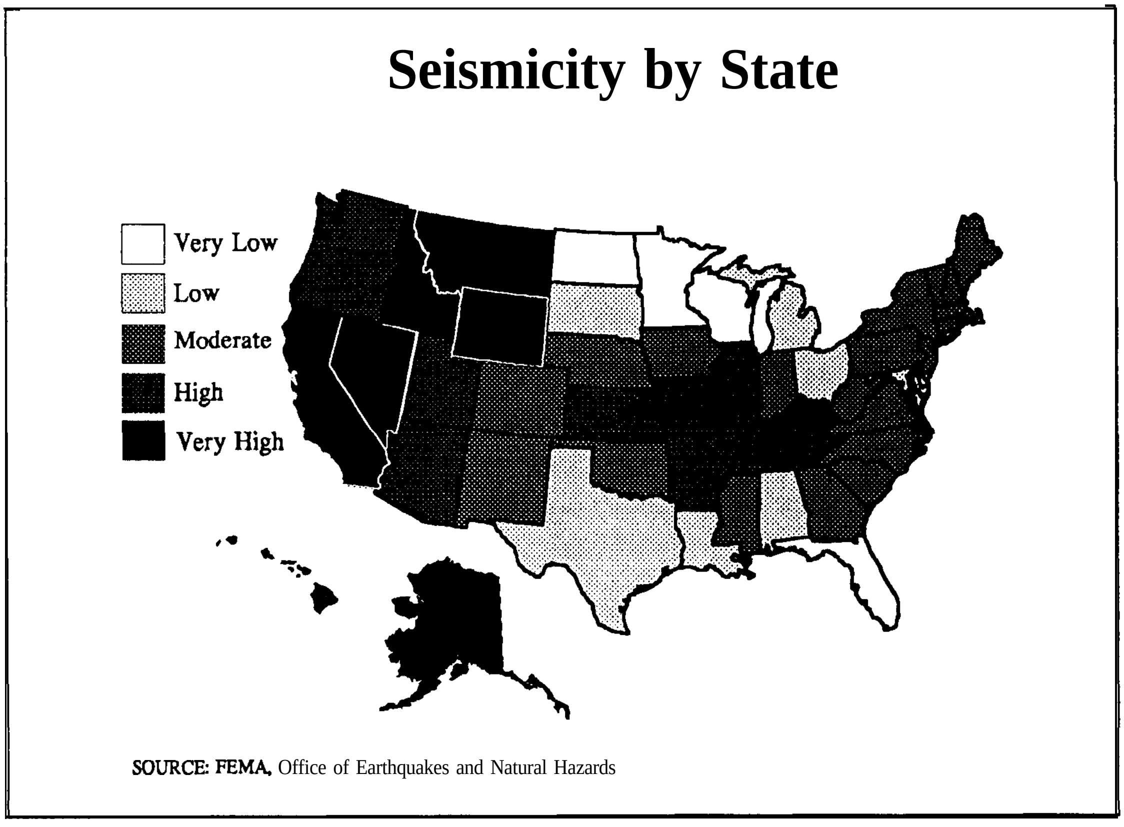
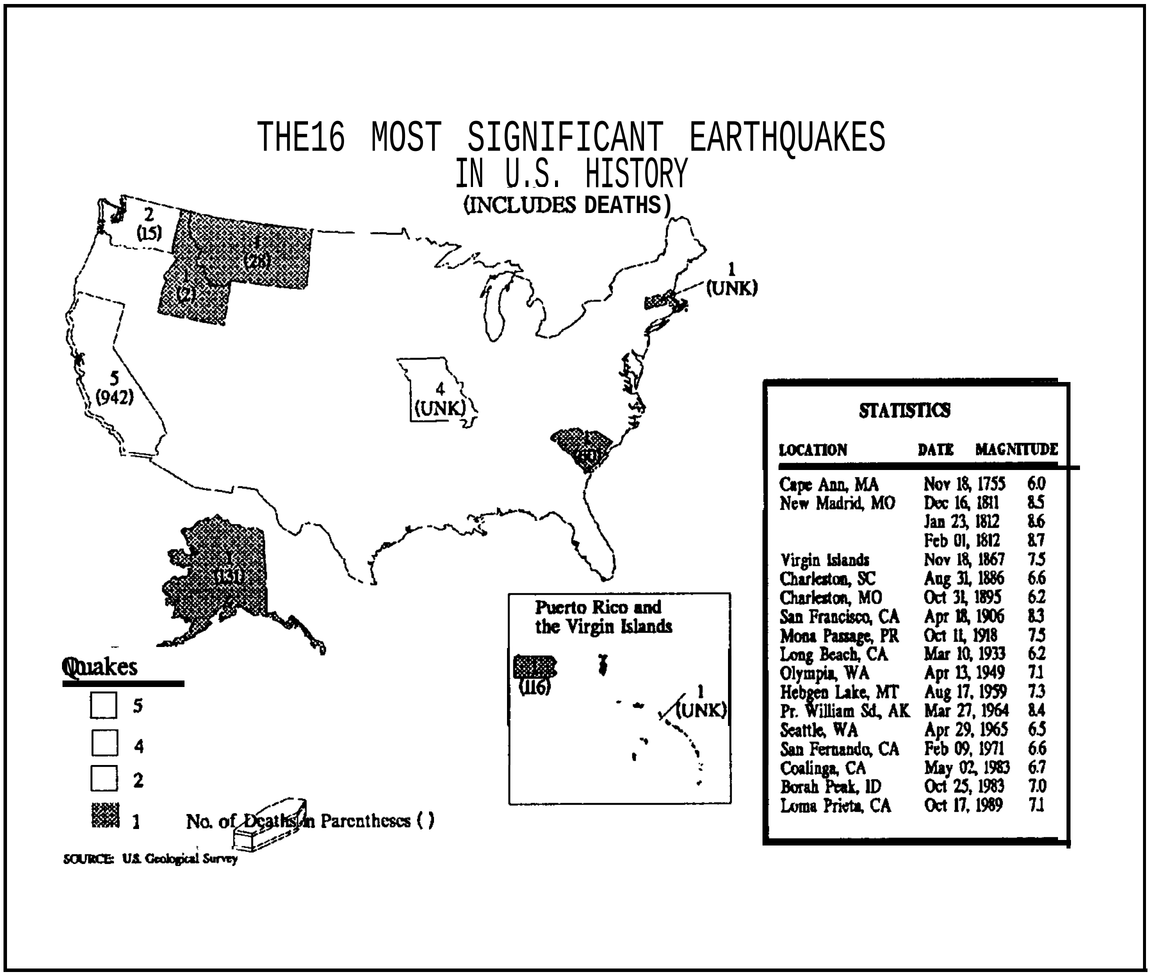


Figure 6

Season(s) Year round

Effects The greatest danger to life in significant earthquakes comes from falling objects, broken glass and structural failures. Severe earthquakes destroy power and telephone lines and gas, sewer or water mains which, in turn, may set off fires and/or hinder fire-fighting or rescue efforts. They may also trigger landslides, rupture dams and generate seismic sea waves (tsunamis).

Worst Event The worst event for deaths occurred in the 1906 San Francisco quake when 700 lives were lost. The worst event for economic damage was the more than $10 billion loss caused by the 1989 Loma Prieta earthquake. *Figure* 7 displays the 16 most significant earthquakes in the history of the United States and the number of deaths from each event.



STATISTICS

LOCATION	DATE	MAGNITUDE
Cape Ann, MA	Nov 18, 1755	6.0
New Madrid, MO	Dec 16, 1811	8.5
	Jan 23, 1812	8.6
	Feb 01, 1812	8.7
Virgin Islands	Nov 18, 1867	7.5
Charleston, SC	Aug 31, 1886	6.6
Charleston, MO	Oct 31, 1895	6.2
San Francisco, CA	Apr 18, 1906	8.3
Mona Passage, PR	Oct 11, 1918	7.5
Long Beach, CA	Mar 10, 1933	6.2
Olympia, WA	Apr 13, 1949	7.1
Hebgen Lake, MT	Aug 17, 1959	7.3
Pr. William Sd, AK	Mar 27, 1964	8.4
Seattle, WA	Apr 29, 1965	6.5
San Fernando, CA	Feb 09, 1971	6.6
Coalinga, CA	May 02, 1983	6.7
Borah Peak, ID	Oct 25, 1983	7.0
Loma Prieta, CA	Oct 17, 1989	7.1

Figure 7

Discussion

Tens of potentially damaging earthquakes of a magnitude equal to 5 or greater on the Richter Scale occur annually in the United States. For example, in a typical year such as 1982, 70 earthquakes of a magnitude equal to 5 or greater on the Richter scale occurred throughout the country. Of these, there were 45 in Alaska, 22 in the contiguous 48 States and 3 in Hawaii. Great magnitude earthquakes (equal to 8 or greater on the Richter Scale), which are more infrequent, occur in the United States on an average about once every 12 years.

Earthquakes occur in virtually all 50 States, Puerto Rico and the Virgin Islands. They happen most frequently in California, Alaska and the Caribbean in the grid of faults, chains of volcanoes and mountains and deep oceanic trenches which are the boundaries between the great crustal plates that form the Earth's outer shell. Intraplate earthquakes-shocks within the interior of the giant crustal plates-are less common occurrences, but they can be equally destructive. Intraplate earthquakes are more typical of the types of earthquakes that occur in the eastern United States.

While earthquakes are relatively infrequent in the eastern States, an earthquake the magnitude of Loma Prieta could cause significantly more damage in the eastern States than it did in California. Because of unique factors relating to the length of time seismic waves take to diminish in the East, the ground shaking in eastern earthquakes extends over much larger areas than it does in western earthquakes of comparable magnitude. For example, the distributions of intensities of the 1811 New Madrid, Missouri, earthquake and the 1886 Charleston, South Carolina, earthquake were substantially greater than those of the 1906 San Francisco, California, earthquake and the 1971 San Fernando, California, earthquake.

Landslides, lateral spreads, differential settlements and ground cracks induced by earthquake ground shaking are a principal cause of damage and casualties. In the 1906 San Francisco, California, earthquake, lateral spreads and ground settlement were responsible for considerable damage in the city. This damage included the breaking of several water pipelines that, in turn, left the city largely defenseless against the conflagration that followed.

Earthquake magnitude is a measure of the strength of an earthquake, or the strain energy released by it, as calculated from the instrumental record made by the event on a calibrated *seismograph.* Seismographs record a zig-zag trace that shows the varying amplitude of ground oscillations beneath the instrument. Sensitive seismographs, which greatly magnify these ground motions, can detect strong earthquakes from sources anywhere in the world. The time, location and magnitude of an earthquake can be determined from the data recorded by seismograph stations.

The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included in the magnitude formula to compensate for the variation in the distance between the various seismographs and the epicenter of the earthquakes.

On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude of 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude. As an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

Earthquakes with magnitudes of about 2.0 or less are usually called microearthquakes. They are not commonly felt by people and are generally recorded only on local seismographs. Events with magnitudes of about 4.5 or more-there are several thousand such shocks annually—are strong enough to be recorded by sensitive seismographs all over the world.

Floods

Definition

Four types of floods are included in this discussion.

- *Riverine—periodic* overflow of rivers and streams
- *Flash-quickly rising small streams after heavy rain or rapid snowmelt*
- *Urban—overflow of* storm *sewer* systems, *usually* due to *poor drainage, following heavy rain or rapid snowmelt*
- *Coastal--flooding along coastal areas associated with severe storms, hurricanes or other events*

National Frequency

The frequency is undetermined, but there are numerous floods each year.

Regions at Risk

Floods occur in every State and territory.

Season(s)

Flooding can happen any time of the year, but predominates in the Spring.

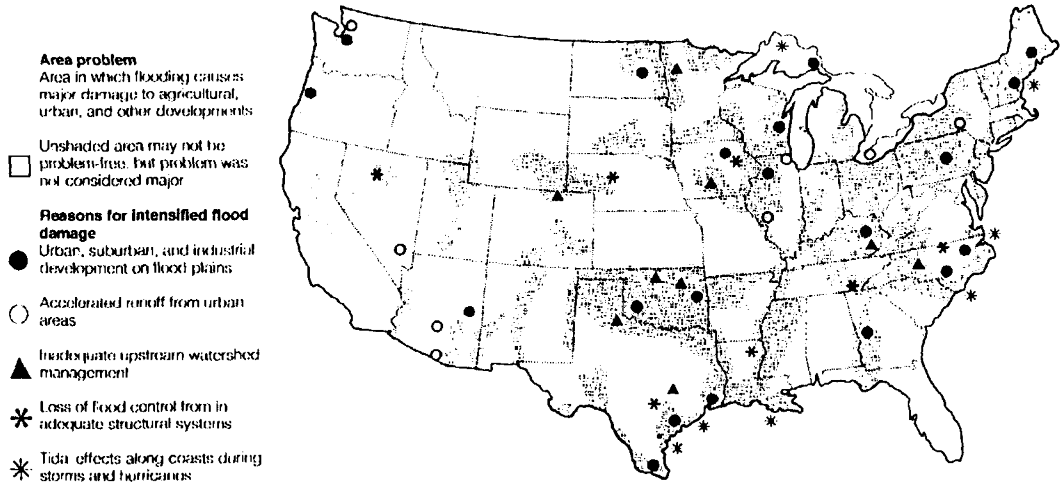
Effects

The National Weather Service attributed 46 deaths due to flooding in 1991. Property damage and agricultural losses for the 1991 fiscal year were estimated to be $1.7 billion. The annual death toll from floods has averaged 146 over the past 20 years. The average annual figure for economic damage, derived from losses during the years of 1981 through 1990, stands at $2.2 billion. The map in *Figure* 8 shows the areas of the US with the greatest flood problems. Other effects from floods include crop damage and soil erosion. Flooding can also trigger secondary events such as power failure and landslide. In spite of risk reduction mitigation efforts for floodplain management, increasing numbers of households are at risk and increased damage is projected for the future.

Worst Event

The worst recorded event (loss of lives) was the 1889 flood in Johnstown, Pennsylvania, in which more than 2,200 lives were lost. (The flood itself was actually caused by the failure of a dam upstream from Johnstown. This flood is a classic example of the "secondary effects" that can occur from another event.) The worst economic losses were incurred in the 1972 floods that resulted from Hurricane Agnes ($4 billion) and the 1973 spring flood of the Mississippi River system ($1.2 billion).

United States Areas Subject to Flooding



FEMA-15, **Damage Guidelines for Flood Damage Reduction**

Figure 8

Discussion

Flooding, perhaps the most pervasive natural hazard in the United States, occurs from a variety of causes. Floods often accompany hurricanes and tornadoes. While some floods develop over a period of days, "flash floods" can result in raging waters in a matter of minutes.

In an attempt to alleviate flood losses, Congress established the National Flood Insurance Program with the passage of the National Flood Insurance Act of 1968. The intent was to mitigate future damage and provide protection for property owners against potential losses through an insurance mechanism that was not formerly available. Over 2.5 million insurance policies have been issued under this program, and claimants have received $2.5 billion for 350,000 insurance losses since 1978. Claim payments of $365 million covered flood damage caused by Hurricane Hugo in South Carolina. Communities participating in the National Flood Insurance Program are required to adopt and implement measures to reduce future flood losses in Special Flood Hazard Areas.

Hurricanes/Tropical Storms

Definition

A large cyclonic storm accompanied by high winds; extreme rainfall and storm surge

National Frequency

The national annual average for hurricane incidents within the continental United States, based on figures from 1871 to 1989, is 1.9. During the same period, Florida experienced the largest number of hurricanes of any State, 57. Texas was second with 37. During the last 10 years, the Western Pacific Insular Areas have experienced 14 hurricanes. An average of 29 tropical storms or hurricanes occur each year in the West Pacific Ocean.

Regions at Risk

Vulnerable areas in the United States include the territories in the Caribbean, the coast from Texas to Maine and tropical areas of the western Pacific Ocean, including Hawaii. (Typhoons are the Pacific Ocean version of hurricanes.) *Figure* 9 depicts the number of hurricanes by State during the period 1871-1989.

Season(s)

Summer and Fall. Hurricanes and tropical storms occur seasonally (June through November) with August and September being the peak months.

Effects

The consequences of hurricane winds and storm surge, which are often accompanied by other devastating events such as tornadoes, include loss of life, coastal erosion, coastal and inland flooding, structural failures, felled trees which cause other damage, power failures and significant economic disruption. The annual rate of hurricane-related deaths is 33. In Fiscal Year 1991, four hurricanes were blamed for 27 storm-related deaths and an estimated $1.6 billion dollars in damage.

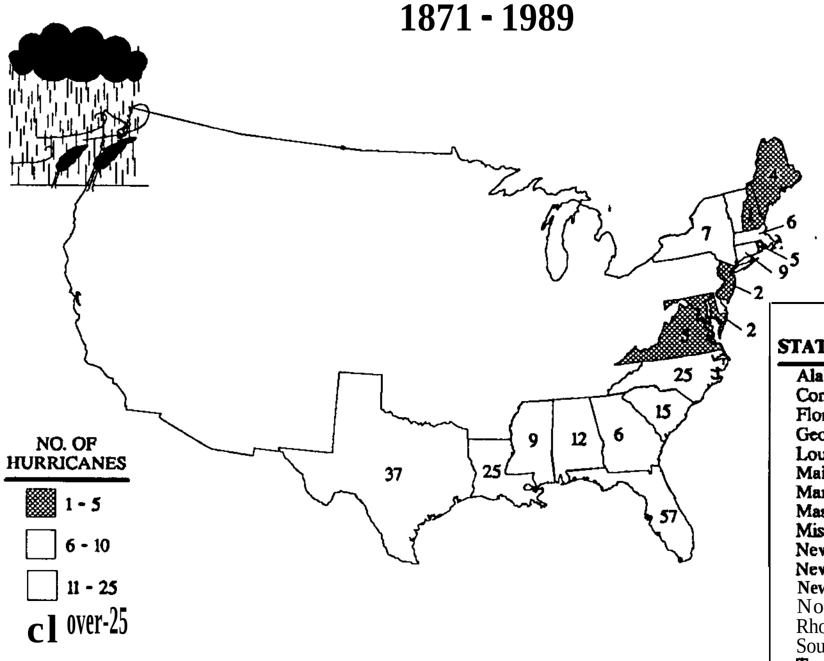
Worst Event

The worst event happened in Galveston, Texas, in 1900 when 6,000 lives were lost. The greatest economic damage resulted from Hurricane Hugo in 1989 with an estimated ***direct*** loss of $9.2 billion. (See *Figure 10* for a list of the 20 costliest U.S. hurricanes during the period 1900-1989; note that hurricanes were not assigned names prior to 1951).

Discussion

Hurricanes are cyclonic storms with counterclockwise winds of 74 miles per hour or higher. The coastal areas that receive the full brunt of hurricane winds and storm surge sustain the most damage. Since hurricanes dissipate quite rapidly to less than hurricane

NUMBER OF HURRICANES BY STATE
1871 - 1989



STATE	NUMBER HURRICANES
Alabama	12
Connecticut	7
Florida	57
Georgia	6
Louisiana	25
Maine	4
Maryland	2
Massachusetts	6
Mississippi	9
New Hampshire	1
New Jersey	2
New York	9
North Carolina	25
Rhode Island	5
South Carolina	15
Texas	37
Virginia	5

SOURCE: NOAA, National Hurricane Center

Figure 9

THE 20 COSTLIEST U.S. HURRICANES, 1900 - 1989

(Adjusted to 1980 Dollars, in Billions)

HURRICANE	YEAR	DAMAGE
Hugo (VI, PR, SC, NC)	1989	$10.000
Agnes (Northeast US)	1972	4.700
Betsy (FL, LA)	1965	4.670
Camille (MS, LA)	1969	3.810
Diane (Northeast US.)	1955	3.086
New England	1938	2632
Frederic (AL, MS)	1979	2550
Carol (Northeast U.S.)	1954	I.733
Carla (TX)	1961	1.412
Donna (FL, East coast)	1960	l.335
Celia (South TX)	1970	L142
Haze.1 (SC, NC)	1954	LO57
Florida (Miami)	1926	936
Eloise (Northwest FL)	1975	.880
Dora (Northeast FL)	1964	.850
Northeast U.S.	1944	.677
Beulah (south TX)	1967	.608
Southeast FL, LA, MS	1947	516
Audrey (LA, TX)	1957	510
Claudette (TX)	1979	.444

Figure 10

Discussion

Hurricanes are cyclonic storms with counterclockwise winds of 74 miles per hour or higher. The coastal areas that receive the full brunt of hurricane winds and storm surge sustain the most damage. Since hurricanes dissipate quite rapidly to less than hurricane strength after they make landfall, inland areas receive less severe damage, usually from flooding associated with the exceptionally heavy rains commonly associated with the remaining storm system.

Figure *11* contains data on the deadliest hurricanes, those causing *25* deaths or more (1900 to 1989).

DEADLIEST U.S. HURRICANES
(1900 - 1989)

HURRICANE	YEAR	CATEGORY	NUMBER OF DEATHS
Texas. Galveston	1900	4	6,000
Florida (Lake Okeechobee)	1928	4	1,836
Florida (Keys/S. Texas)	1919	4	600-900
New England	1938	3	600
Florida (Keys)	1935	5	408
Audrey (LA & TX)	1957	4	390
Northeast US	1944	3	390
Louisiana (Grand Isle)	1909	4	350
Louisiana (New Orleans)	1015	4	275
Texas (Galveston)	1915	4	275
Camille (MS & LA)	1969	5	256
Florida (Miami)	1926	4	243
Diane (Northeast U.S.)	1906	1	184
Florida (Southeast)	1906	2	164
Mississippi/Alabama/ Pensacola, Florida		3	134
Agnes (Northeast U.S.)	1972	1	122
Hazel (SC & NC)	1954	4	95
Betsy (FL & LA)	1965	3	75
Carol (Northeast U.S.)	1954	3	60
Southeast Florida, Louisiana, Mississippi	1947	4	51
Hugo (SC, NC, PR & VI)	1989	5	26

Figure 11

Landslides

Definition

Downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills or combinations of these materials. The moving mass may be preceded by any of three principal types of movement: falling, sliding or flowing, or by their combinations.

National Frequency

Precise data are not available, however, a 1985 report on "Reducing Losses from Landsliding in the United States," by the Committee on Ground Failure Hazards of the National Research Council, cited statistics which are representative of the magnitude of some of the major landsliding problems in recent years:

- In eastern West Virginia in 1969, a single storm associated with Hurricane Camille resulted in 1,534 landslides in one small drainage basin, the Spring Creek watershed.
- Between 1966 and 1981, Orange County, California, experienced 40 major bedrock landslides that resulted in a total economic loss of over $40 *million.*
- Storm-triggered landslides in the Los Angeles area during the winters of 1951-52, 1957-58, 1961-62, 1964-65, 1968-69, 1977-78 and 1978-79 produced an average loss of $500 *million* in each season of heavy storm activity.

An additional incident cited ***in Landslide Loss Reduction: A Guide*** *for* ***State and Local Government Planning,*** *FEMA 182, August 1989,* happened in 1982 when 24.3 inches of rain, falling within a 34-hour period, triggered *thousands* of landslides in the San Francisco Bay Region that killed 25 *people* and caused more *than $66 million in* damages.

Regions at Risk

According to the report of the Committee on Ground Failure Hazards of the National Research Council: "Landsliding is widely distributed in the United States and is not restricted to a few localized areas. Many different physiographic and climatic regions are subject to landslides, and in much of the United States landsliding is a dominant process of landscape alteration." The same report stated that: "Landslides are indigenous to much of the Appalachian Highlands, particularly southwestern Pennsylvania, southeastern Ohio and northern West Virginia. More than two million mappable landslides are estimated to have occurred in the Appalachian Highlands from New England to the Gulf coastal plain. These include landslides in the portions of the highlands that extend into New England, New York, Maryland, Kentucky, Virginia, Tennessee, North Carolina, South Carolina, Georgia and Alabama."

See *Figure 12* for a map of the regions at risk from landslides in the United States.

Season(s)

Year round.

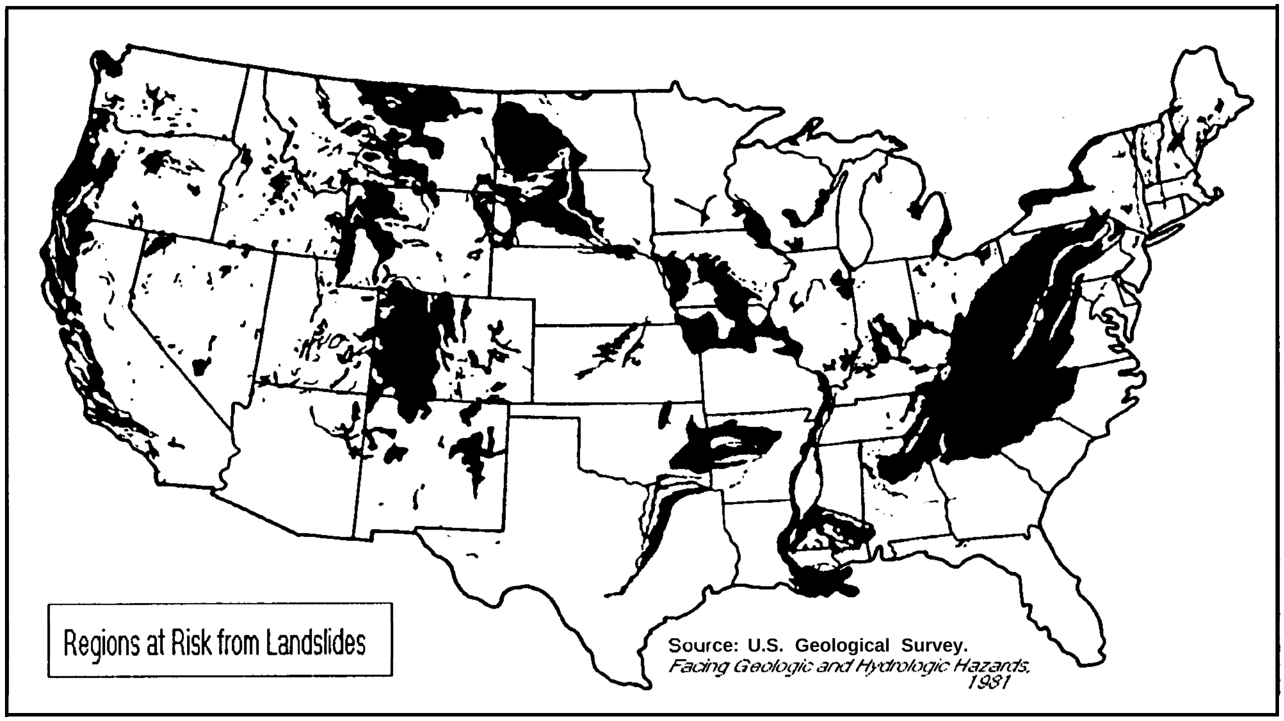


Figure 12

Effects

The annual death rate from landslides is 25 to 50, with annual economic losses estimated at $1 to $2 billion. According to the National Research Council report mentioned above, "The loss of life from landsliding is comparable to the total loss of life from floods, earthquakes and hurricanes (Krohn and Slosson, 1976)." Economic losses are extensive, including not only the replacement and repair of damaged facilities but associated costs relating to lost productivity, disruptions to utility and transportation systems and losses of revenue for affected communities.

Worst Event

In terms of sheer volume (2.8 billion cubic meters), the collapse of the northern part of the cone of the Mt. St. Helens volcano immediately before the May 18, 1980, eruption is the world's largest landslide in historical terms (because of evacuation and other preparedness measures taken beforehand, only 5-10 people were killed by the landslide).

Discussion

Landslides can occur either very suddenly or slowly. They can be triggered during earthquakes, heavy rainstorms or rapid snowmelt, volcanic eruptions, storm generated ocean waves or by other landslides. Landslides can also be triggered by freeze-thaw and shrink-swell cycles, root wedging, animal burrows, natural erosion or deposition or the thaw of ice-bearing soils such as permafrost. While most landslides are single events, more than one-third of the cases are associated with heavy rains or the melting of winter snows.

Although the term *landslide* is generally assumed to mean any slide of rock or soil down a mountainous or hilly location, the term actually encompasses a number of different types of earth movements. For example, lateral shifts, even in soil that appears to be nearly flat to the naked eye are, in reality, landslides. Such movement is often caused by heavy saturation or liquefication of the soil following heavy rains or snowmelt, but it can also be the result of an earthquake. Classic examples of lateral shifts occurred in Sylmar, California, during the 1971 San Fernando earthquake. Another type of landslide can come from the "rotational" movement of land. During the earthquake in Alaska in 1964, for example, acreage in some areas moved as much as 11 feet, yet the buildings standing on the land were undamaged. (It is believed that liquefied soil beneath the earth supported the buildings and absorbed much of the shaking from the earthquake.)

Earthquake shaking can dislodge rock and debris on steep slopes, triggering rock falls, avalanches and slides. Ground shaking can initiate shallow debris slides on steep slopes and, less commonly, rock slumps and block slides on moderate to steep slopes. Though rare, shaking can reactivate dormant slumps or block-slides. Earthquake shaking can also trigger soil avalanches in some weakly cemented fine-grained materials, such as loess, that form steep stable slopes under non-seismic conditions. (Source: ***Earthquakes, Volcanoes, and Tsunamis-An Anatomy of Hazards, by*** *Karl V. Steinbrugge. Skandia America Group*, 1982. *pp. 69-72.)*

The effects of landslides can be both dramatic and devastating. Most of the 150 people killed in Virginia in the 1969 flooding associated with the remnants of Hurricane Camille did not drown. They actually died from blunt-force injuries when struck by debris in the numerous debris flow avalanches caused by the heavy rain (Williams and Guy, 1973). In 1972, three coal-refuse impoundments at Buffalo Creek, West Virginia, collapsed during heavy rains. The flow of mud and debris from this event traveled almost 15 miles downstream, killing 125 people and leaving 4,000 homeless (Davies and others, 1973).

In the past two decades, the expansion of the population into seismic risk areas (including relatively flat terrain) and/or steeply sloping terrain has contributed to the increase of damaging landslides. Building residential and other structures and developing irrigated landscape areas in such terrain alter soil or hillside configurations and aggravate the instability of many slopes. Such development can also reactivate older landslides or create conditions for new landslides.

Subsidence

Definition

Any vertical displacement or downward movement of a generally level ground surface resulting from either natural or man-induced surface or subsurface conditions

National Frequency

As is the case with landslides, definitive data on the annual frequency of subsidence is unknown. However, subsidence results in millions of dollars of damage each year, with additional millions being spent in mitigation efforts.

Regions at Risk

Subterranean limestone regions; active or abandoned underground mining sites; areas subject to other hazards such as earthquakes or areas of extensive oil, gas or groundwater withdrawal are highly vulnerable to subsidence. States with the highest rates of subsidence activity include Alabama, California, Florida, Kansas, Louisiana, Missouri, Montana, New Jersey, Oklahoma, Pennsylvania, Tennessee, Texas and Washington.

Season(s)

Year round

Effects

While few deaths are recorded, the annual damage from subsidence nationwide exceeds $125 million-the annual rate in Florida alone is $10 million. The cities of Long Beach, California; Houston, Texas, and New Orleans, Louisiana, each have *cumula*five damage costs from subsidence of more than $100 million. (Source: ***Mitigating Losses from Land Subsidence in the United States,*** National Research Council Committee on Ground Failure Hazards Mitigation Research, National Academy of Sciences, 1991.) The degree of damage depends on whether the subsidence occurs in an urban area or a rural, sparsely populated area. In the case of urban areas, extensive damage and disruption can occur to utility lines, residential or business areas, transportation systems, water canals and dams.

Worst Event

Because there are four major subsidence conditions found in the United States, a "worst event" is somewhat difficult to characterize. However, some of the most serious subsidence damages have been the result of ground sinking around abandoned metal or coal mines in Montana, New Jersey, Pennsylvania, Washington and a triState area formed at the junctions of Missouri, Oklahoma and Kansas.

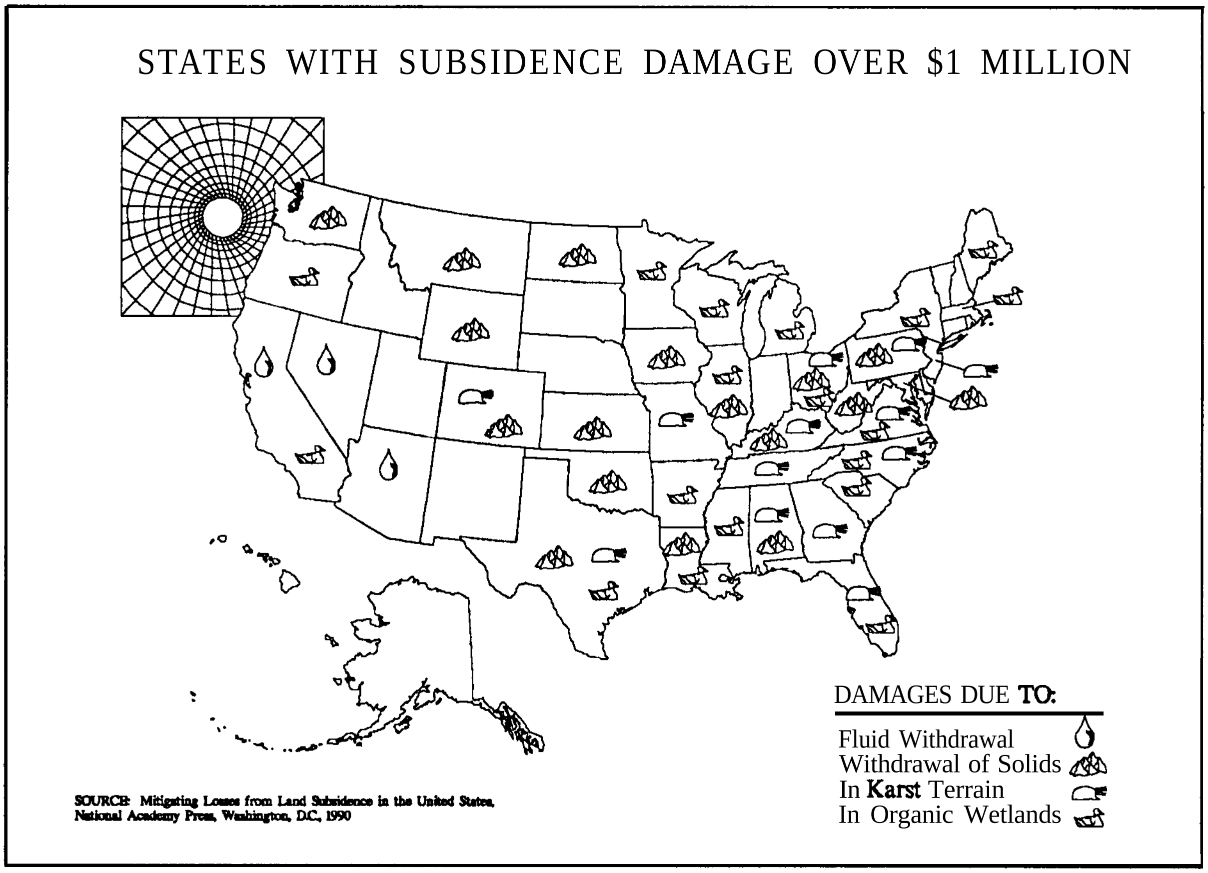


Figure 33

Discussion

Subsidence has affected at least 45 States in the United States (see Figure 13) and has lowered more than 17,000 square miles of land-an area equal to half the size of Maine. An additional 3,900 square miles are at risk. The principal causes of subsidence in this country are underground mining of coal, groundwater withdrawal and drainage of organic soil. Approximately 92 percent of the subsided surface is identified as either forest, idle or agricultural land. The remaining 8 percent (about 246 square miles) is generally urban.

Subsidence can be caused by either natural or man-induced processes. Natural processes include the changes relating to alterations in the earth's crust, the dissolution of underground minerals, thawing of ground ice in permafrost or alterations in the vegetative cover. Man-induced subsidence results from such activities as subsurface mining, excessive pumping or removal of groundwater, extraction of gas or oil from underground reservoirs, drainage of wetlands or the application of surface loads (such as buildings) on compressible soils.

Four primary types of subsidence conditions are found in the United States.

- subsidence resulting from the removal of underground fluid such as groundwater, oil or gas
- subsidence in organic wetlands
- subsidence due to mining, particularly coal mining
- subsidence (or "sinkholes") in *karst* terrain (subterranean limes tone areas)

Subsidence rates can be either sudden or extremely slow, such as those resulting from long-term geological changes. Subsidence that comes from the removal of underground fluids often can be nearly imperceptible in the early stages and usually continues to be relatively slow as the condition worsens. Such subsidence conditions, which generally cover areas of tens of miles in diameter, are often gradual enough that damage to buildings or other structures is relatively light. These areas are, however, generally more susceptible to secondary damages such as flooding or inundation, particularly when they lie in floodplains or in low coastal areas. Underground fluid withdrawal has caused more than 31 areas in 7 States to subside The highest risk areas for this type of subsidence are located in Texas (Houston-Galveston, Baytown and Texas City-Seabrook), Louisiana (coastal areas) and California (San Joaquin Valley).

The reclamation of organic wetlands has allowed many metropolitan areas with limited available land to extend their boundaries by building on lands that would normally be considered unsuitable for construction. This drainage of water from organic soil has caused the subsidence of about 3,629 square miles within the United States. The worst subsidence of this nature has occurred in the greater New Orleans, Louisiana, area; the Sacramento-San Joaquin River Delta, California, and parts of the Florida Everglades. For some urban areas, however, the threat of subsidence is deemed an acceptable risk and subsidence management is factored into their considerations.

An estimated 220 counties in 42 States have underground mining activities that create the potential for subsidence. Some 617 square miles of undermined land in urban areas is at risk-71 percent of the threatened area is in Illinois, Pennsylvania and West Virginia. The removal of the solid materials within the mines creates a void that is frequently unstable. Once the solid material, such as coal, is removed, the weight of the materials above the mine are redistributed. Subsequently, the land area above the abandoned mine subsides with the collapse of the timbers, support columns or other such structures that were developed during the mining phase but are no longer maintained.

In the lower 48 States, 18 percent of the land is susceptible to catastrophic collapse into sinkholes because of underlying cavernous Limestone, gypsum, salt or marble. Subsidence in subterranean limestone caverns can happen when underground water weakens the natural support structure by percolating through the limestone walls and causing cavities or dissolving the materials. Land overlying these caverns can collapse suddenly, forming sinkholes as much as 100 feet deep and 300 feet across. More than 11,583 square miles of land threatened by sinkholes are located in urban areas of the United States that are inhabited by 33 *million* people.

As noted earlier, subsidence damage on an annual basis totals in the millions of dollars. Added to this total are the millions of dollars spent annually for mitigation and preparedness measures, particularly in urban areas with large areas of reclaimed wetlands. While modern technology is assisting in the mitigation effort, much remains to be done.