Subpart E

OTHER

NATURAL HAZARDS

Introduction

Volcanoes and wildfires are among the most frightening natural hazards and pose significant threats to people, property, and wildlife.

The United States has more than 65 potentially active volcanoes, with the greatest activity in the Western States, Alaska, and Hawaii. Nonexplosive and explosive volcanoes produce debris flows and avalanches, pyroclastic flows and surges, floods, lava flows and domes, volcanic ashfalls and gases, and lateral blasts. Lava flows tend to follow historic paths, simplifying identification of areas at greatest risk. Ashfall can spread well beyond the immediate eruption area. Volcanic activity often causes other hazardous events, such as landslides and wildfires.

Wildfires occur in virtually every State, however, more frequent incidents occur in the Western States, particularly California. Four types of wildfires constitute the hazard: wildland fires, interface or intermix fires, firestorms, and prescribed fires. Wildfires often are ignited by lightning. The severity of an event can be influenced by other natural hazards, such as drought and windstorms. As more people move into the forest interface and wildland settings, exposure to this hazard increases.

Photo: FEMA

CHAPTER

18

VOLCANIC HAZARDS

Chapter Summary

Hazards associated with the eruption of volcanoes endanger people, buildings, and infrastructure. Nonexplosive and explosive eruptions produce debris flows and avalanches, pyroclastic flows and surges, floods, lava flows and domes, ashfalls and gases, and lateral blasts. Areas at risk from volcanic eruptions primarily are those in or near the direct path of flows, although ashfalls affect people, the environment, and aircraft for extended distances.

In the 1980s, volcanoes worldwide killed over 28,500 people, more than during the first 80 years of this century (Wright and Pierson, 1992). This decade experienced more worldwide volcanic activity and crises than any other in recorded history (Lipman and Mullineaux, 1981). The cataclysmic Mount St. Helens eruption in 1980 resulted in approximately 60 deaths and over $1.5 billion in damage. Other volcanic activity during the 1980s included Mauna Loa and Kilauea in Hawaii, Long Valley Caldera in California, and Redoubt in Alaska.

More than 65 active or potentially active volcanoes exist in the United States, more than all other countries except Indonesia and Japan. Most are located in Alaska, and 55, including eight on the mainland, have been active since the United States was founded (Simkin and others, 1981).

Following the eruption of Redoubt in 1989, scientists monitored the volcano using ground and seismic signal amplitude measurements, slow-scan video photography, and lightning and debris-flow detection systems. Use of these technologies will enhance detection and warning. Disaster preparedness and evacuation planning may reduce injuries and loss of life. Identification of hazard zones for land-use planning may help address property damage.

Photo: Keith Ronnholm, FEMA

HAZARD IDENTIFICATION

Eruptions of U.S. volcanoes can generate serious hazards, any of which can be deadly (Wright and Pierson, 1992):

- Glowing rivers of molten rock or lava flows;
- Devastating shock waves and fiery blasts of debris from volcanic explosions, called pyroclastic surges;
- Red-hot avalanches of rock fragments racing down mountainsides, called pyroclastic flows; and
- Suffocating blankets of volcanic ash falling from the sky.

Volcanic eruptions are classified as nonexplosive or explosive. Nonexplosive eruptions generally are caused by an iron- and magnesium-rich magma (molten rock) that is relatively fluid and allows gas to escape readily. Lava flows on the Island of Hawaii are typically of nonexplosive eruptions.

In contrast, explosive eruptions are violent and are derived from a silica-rich magma that is not very fluid. These eruptions are common in the Cascade Range (Washington, Oregon, and California) and in the volcanic chain of Alaska. Explosive eruptions produce large amounts of fragmental debris in the form of airborne ash, pyroclastic flows and surges, debris flows, and other hazards on and beyond the flanks of the volcano, endangering people, infrastructure, and buildings (Hays, 1981).

Lava Flows. Lava flows are streams of molten rock that erupt relatively nonexplosively and move downslope. The distance traveled by a lava flow depends on such variables as viscosity, volume, slope steepness, and obstructions in the flow path. Lava flows typically extend from 6 to 30 mi (10 to 50 km).

Lava flows cause extensive damage or total destruction by burning, crushing, or burying everything in their paths. They need not directly threaten people, however, because they usually move slowly (a few feet to a few hundred feet per hour) and their paths can be roughly predicted. Lava flows that move onto snow and ice can cause destructive debris flows and floods, and those that move into forests can cause wildfires. The flanks of lava flows typically are unstable and collapse repeatedly, occasionally producing explosive blasts and small pyroclastic flows.

Pyroclastic Flows. Pyroclastic flows are high-density mixtures of hot, dry rock fragments and hot gases that move away from source vents at speeds of 30 to +90 mph (48 to +145 km/h), extending dozens of miles. They can result from explosive lateral eruptions of molten or solid rock fragments, from the collapse of vertical eruption columns of ash and larger rock fragments, or from the fall of hot rock debris from the surface of a dome or thick lava flow. Rock fragments in pyroclastic flows range widely in size and consist mostly of dense debris or pumice fragments (Hoblitt and others, 1987; Miller, 1989).

Pyroclastic flows are extremely hazardous because of rapid movement and very high temperatures. Objects and structures are destroyed or swept away by the impact of debris or associated hurricane-force winds. Wood and other combustible materials are burned, and people and animals may be burned or killed by contact with hot debris and gases.

Pyroclastic Surges. Pyroclastic surges are turbulent, low-density clouds of rock debris, air, and other gases that move over the ground surface at speeds similar to pyroclastic flows. Pyroclastic surges can be of two types: hot surges that consist of dry materials that have temperatures appreciably above 212ºF (100ºC); and cold surges that consist of cooler rock debris and steam or water. Both types can extend as far as 6 mi (10 km) from source vents and devastate life and property in their paths (Miller, 1989).

Lava Domes. Lava domes are masses of solid rock that are formed when viscous lava erupts slowly from a vent. If the lava is sufficiently viscous, it will pile up above the vent to form a dome rather than move away as a flow. The sides of most domes are very steep and typically are mantled with unstable rock debris formed by cooling during or shortly after dome formation.

Most domes are composed of silica-rich lavas that have a lower gas content than do the lavas that erupted earlier in the same eruptive sequence. Nevertheless, some dome lavas contain enough gas to cause explosions during formation. The direct effects of dome eruption include local burial or disruption of the preexisting ground surface by the dome itself, and widespread burial by rock debris if part of the dome collapses. Because of high temperatures, lava domes may start fires if they erupt into forests. Domes are extruded so slowly that they can be avoided by people and animals, but structures are endangered. The major hazard is pyroclastic flows that can occur without warning and move very rapidly, endangering life and property for distances up to 12 mi (20 km) from the source.

Volcanic Ash. Volcanic ash, called tephra, is composed of fragments of lava or rock blasted into the air by explosion or carried upward by a rising column of hot gases to form an ash plume. Fragments fall back to earth forming ash deposits, which blanket the ground with a layer that decreases in thickness and particle size away from the source.

Ash-producing eruptions range from short-lived weak ones that eject debris only a few feet into the air to cataclysmic explosions that throw debris dozens of miles into the atmosphere. Explosive eruptions that produce voluminous ash deposits commonly produce pyroclastic flows.

Close to an erupting vent, the main hazards to property posed by volcanic ash include high temperatures, burial, and impact of falling fragments. Large, falling blocks can kill or injure exposed people and animals. Significant property damage can result from the weight of volcanic ash, especially if it is wet: 8 in (20 cm) or more of ash depth may cause structures to collapse. Hot ash may set fire to forests and buildings.

Farther away from a vent, the chief danger to life is the effect of ash on respiratory systems. Even 2 in (5 cm) of volcanic ash will mechanically impair most vehicles and disrupt transportation, communication, and utility systems. Machinery is especially susceptible to the abrasive and corrosive effects of volcanic ash. These effects, together with decreased visibility or darkness during an eruption, may further disrupt normal services, and may cause psychological stress and panic among people whose lives may otherwise not be endangered.

Volcanic Gases. Volcanic gases consist predominately of steam, followed in abundance by carbon dioxide and compounds of sulfur and chlorine. Minor amounts of carbon monoxide, fluorine and boron compounds, ammonia, and several other compounds are found in some volcanic gases.

Distribution of volcanic gases is controlled primarily by wind. Gases may be concentrated near a vent, but become rapidly diluted downwind. However, even very dilute gases can have noticeable odors and can harm plants and some animals dozens of miles downwind from a vent.

Close to a vent, volcanic gases can endanger people's lives and health as well as property. Acids and ammonia and other compounds present in volcanic gases can damage eyes and respiratory systems of people and animals. Accumulations of gases heavier than air, like carbon dioxide, can lead to suffocation. Other harmful effects of volcanic gases and corrosion of metals and other property can be severe near and downwind from very active vents.

Lateral Blasts. Lateral blasts are inflated mixtures of hot rock debris, ash, and gases and may be hundreds of feet thick and move at high speeds along the ground surface with little or no influence by the underlying topography. Blasts are known to reach speeds up to 370 mph (595 km/h). Lateral blasts can produce pyroclastic flows or surges or both (Hoblitt and others, 1987).

Lateral blasts are among the most destructive of volcanic phenomena. Within minutes, they can devastate hundreds of square miles and kill virtually all living things in their wake by abrasion, impact, burial, and heat (Miller, 1989). A lateral blast at Mount St. Helens in 1980 devastated an area of 230 mi^2 (596 km^2), extending as much as 17 mi (27 km) from the volcano and killing more than 60 people.

Debris Avalanches. A debris avalanche is a sudden and very rapid movement of an incoherent and unsorted, wet or dry mixture of rock and soil that is mobilized by gravity. Debris avalanches commonly originate in massive rock slides which, during movement, disintegrate into fragments ranging from small particles to blocks hundreds of feet across. Debris avalanches occur occasionally on large, steep-sided volcanoes and are among the most hazardous of volcanic events (Voight and others, 1981; Crandell, 1984).

Deposits from volcanic debris avalanches can extend for dozens of miles and cover as much as 300 mi^2 (777 km^2). The debris avalanche and landslide associated with the May 18, 1980, eruption of Mount St. Helens deposited 0.7 mi^3 (2.8 km^3) of poorly sorted debris to an average depth of 150 ft (45 m) over approximately 25 mi^2 (60 km^2) of the North Fork Toutle River Valley. The level of Spirit Lake was raised approximately 200 ft (60 m) (Lipman and Mullineaux, 1981).

Debris avalanches can destroy everything in their path by direct impact or by burial beneath dozens of feet of debris. Because debris avalanches can occur with little or no warning and can travel at high speeds (Voight and others, 1981), areas that might be affected should be evacuated if an avalanche is anticipated.

Debris Flows. Debris flows are mixtures of water-saturated rock debris that flow downslope under the force of gravity. They are sometimes called mudflows or "lahars," an Indonesian word. Debris flows consist of material varying in size from clay particles to blocks several dozens of feet in dimension. When moving, they resemble masses of wet concrete and tend to flow along channels or stream valleys. Debris flows are formed when loose masses of unconsolidated debris become unstable due to wetting by rainfall, melting snow or ice, or by overflow of a crater lake.

Debris flows can travel great distances down valleys, and debris-flow fronts can move at speeds up to 60 mph (97 km/h). The debris flows that descended the southeast flank of Mount St. Helens in 1980 had initial flow velocities that exceeded 60 mph (97 km/h). Average flow velocities were approximately 40 mph (64 km/h) over the 14 mi (23 km) distance traveled before the flows entered a reservoir (Pierson, 1985).

The primary danger posed by debris flows to people is from burial or impact of boulders and other debris. People and animals can be severely burned by hot debris flows. Buildings and other property in the path of a flow can be buried, smashed, or carried away. Because of their relatively high density and viscosity, debris flows can move and even carry away vehicles and objects as large as bridges and locomotives (Miller, 1989).

Floods. Floods and hyperconcentrated flows can result from melting of snow and ice during eruptions, heavy rains that often accompany eruptions, and by transformation of debris flows to streamflows. Hyperconcentrated flow originally was defined by Beverage and Culbertson (1964) as streamflow with sediment concentrations between 40 and 80 percent by weight (20 and 60 percent by volume).

The sequence of flow events is from debris avalanche to debris flow to hyperconcentrated flow to flood, as the coarser materials come to rest and the water content increases. Pierson and Costa (1987) provide additional details on the classification of flows.

Floods carrying unusually large amounts of rock debris and sediment can leave thick deposits of sand and gravel at and beyond the mouths of canyons and on valley floors leading away from volcanoes. Eruption-caused floods can occur suddenly and can be large in volume if rivers are already high because of heavy rainfall or snowmelt. Floods also can be generated by eruption-caused seiches (waves) that overtop dams or move down outlet streams from lakes.

RISK ASSESSMENT

Probability and Frequency

An inverse relation exists between the size of the eruptions (volume of material erupted) and how often they occur. Small eruptions occur much more frequently than large ones. The volumes and frequencies of past eruptions provide the major criteria for defining hazard zones.

Newhall (1984) describes a procedure for quantifying the short-term (week-to-week or shorter), intermediate (month-to-month) and long-term (year-to-year) frequency of volcanic eruptions. Newhall's conditional probability analysis is very detailed and has not been applied to all U.S. volcanoes. One simplified approach to estimate the annual probability of exceedance is to divide the number of known explosive eruptions by the duration of the eruptive record (Mullineaux, 1976; Hoblitt and others, 1987). The annual probability of exceedance or frequency of active and potentially active volcanoes can be estimated from historical records which are summarized in Table 18-1 (Wright and Pierson, 1992).

TABLE 18-1.—Selected *active and potentially active U.S. volcanoes.*

Volcano	Eruption Type(s)	Eruptions in Past 200 Years	Last Active	Remarks
Kilauea, HI	Lava, most common; ash, rare	47	Ongoing from 1983	Explosive eruption at Kilauea summit in 1790 killed approximately 80 Hawaiian warriors. Eruptions presenting lava-flow hazard to coastal areas: four in the 19th century; five in the 20th century.
Mauna Loa, HI	Lava	30	1984	Eruptions presenting lava-flow hazard to coastal areas; eight in the 19th century; eight in the 20th century.
Hualalai, HI	Lava, ash	1	1800-1801	High hazard due to unusually fluid lava.
Mount Baker, WA	Ash, lava	1?	1870	Increased heat output and minor melting of summit glacier in 1975; some debris flows not related to eruption. History of extensive pyroclastic flows.
Mount Rainier, WA	Ash, lava	1?	1882 (?)	History of massive debris avalanches and debris flows. Occasional very shallow seismicity.

TABLE 18-1.—*Selected active and potentially active U.S. volcanoes. (continued)*

Volcano	Eruption Type(s)	Eruptions in Past 200 Years	Last Active	Remarks
Mount St. Helens, WA	Ash, dome, lava	2-3	1980 - present	Continuing intermittent volcanic activity.
Mount Jefferson, OR	Ash, lava	0	More than 50,000 years ago	Debris flows in 1934, 1955; young basaltic flows in nearby area.
Three Sisters, OR	Ash, lava	0	950?	Debris flows in this century.
Crater Lake, OR	Ash, lava, dome	0	4,000 years ago	Largest known eruption from Cascade Range volcano. Catastrophic, caldera-forming eruption 7,000 years ago; post-caldera lava and domes.
Mount Shasta, CA	Ash, dome	1	1786?	Debris flows in this century.
Lassen Peak, CA	Ash, dome	1	1914 - 1917	Lateral blast occurred in last eruption.
Clear Lake, CA	Lava, ash	0	Not known	Geothermal energy and long-period (volcanic) seismicity suggest “active” status.
Long Valley Caldera, CA	Ash, dome, ashflow	3?	About 1400	Youngest activity represented by nearly simultaneous eruptions of rhyolite at several of the Inyo craters; currently restless, shown by seismicity and ground deformation.
San Francisco Field, AZ	Lava	2	1065-1180	Sunset Crater; disrupted Anasazi settlements.
Bandera Field (McCarty’s Flow), NM	Lava	1	About 1000	Most voluminous lava within past 1,000 years.
Craters of the Moon, ID	Lava	About 1	2,100 years ago	Youngest activity in the Snake River Plain.
Yellowstone Caldera, WY, MT, ID	Ashflow	0	70,000 years ago	Numerous hydrothermal explosions, geysers, geothermal activity; currently restless, shown by seismicity and ground deformation.
Wrangell, AK	Ash	1?	1902?	Emission of gases and vapors from vents (fumarolic activity).
Redoubt Volcano, AK	Ash, dome	4	Ongoing	Eruption began December 1989.
Mount Emmons—Pavlof Volcano, AK	Ash, lava	30	1987	Pavlof is most frequently active volcano in Alaska.
Kiska Volcano, AK	Ash, lava	7	1990	Steam and ash emission.
Pyre Peak (Seguam), AK	Ash, lava	5	1977	Eight lava fountains, as high as 90 meters.
Mount Cleveland, AK	Ash, lava	10	1987	1945 eruption resulted in only known fatality from Alaska volcanism.

Source: *Wright and Pierson, 1992.*

Exposure

With the exception of ashfalls, the areas at risk from volcanic eruptions primarily are those in or near the direct paths or channels of flowing material and debris. Thus, beyond the flanks of volcanoes, the most hazardous areas are the floors of valleys that head on volcanoes. Risks associated with volcanic hazards decrease as distance increases.

Western Conterminous United States. Mullineaux (1976) defined hazard zones for volcanoes in the Western States based on three categories: ashfall, lava flows, and other flow phenomena such as avalanches, debris flows, or floods. The major categories of hazards were described in terms of origin and characteristics, location, size of area affected by a single event, general effects, areas endangered by future eruptions, frequency in the conterminous United States as a whole, and degree of risk in affected areas.

Areas of the conterminous United States affected by volcanic hazards are shown on Map 18-1, adapted from Mullineaux (1976). Hazard zone boundaries are only approximate and the degree of hazard varies gradually from one zone to the next. The darkest areas shown are subject to lava flows and/or 2 inches or more of ashfall and include groups of volcanic vents termed volcanic fields, where future eruptions chiefly of lava flows and moderate volumes of ash are more likely than in nearby areas.

Areas subject to 2 in (5 cm) or more of ashfall from a large eruption that would occur once every 1,000 to 5,000 years (0.10 to 0.02 percent annual chance of exceedance) are the medium shaded regions. Finally, those areas subject to 2 in (5 cm) or more of ashfall from a very large eruption that would occur about once every 5,000 to 10,000 years (0.02 to 0.01 percent annual chance of exceedance) are shown lightly shaded.

Hoblitt and others (1987) provide a detailed analysis of hazards from 13 major volcanoes in the Cascade Range in the Western States, identifying areas subject to directed blasts, pyroclastic flows and surges, debris avalanches, lava flows, debris flows and floods, and accumulations of ashfall.

Hawaii. There are seven active or potentially active volcanoes in Hawaii. Six are on or just offshore of the Island of Hawaii. Kilauea and Mauna Loa have erupted 47 and 30 times, respectively, during the last 200 years, making them two of the most active volcanoes in the world. Kilauea has erupted continuously since 1983. The Haleakala volcano is located on Maui.

Lava flows are the most common direct volcanic hazard in Hawaii. Using data on the location and frequency of historic and prehistoric eruptions, Heliker (1990) developed a lava flow hazard zone map for the Island of Hawaii (Table 18-2).

Alaska. Most of the active or potentially active volcanoes in the United States are in a chain of volcanoes that extends 1,550 mi (2,500 km) from near Anchorage southwest along the Alaskan Peninsula to the western Aleutian Islands (Map 18-2). On average, at least one lcano in the chain erupts each year (Simkin and others, 1981). In 1912, Novarupta produced the largest eruption of the 20th century (Wright and Pierson, 1992).

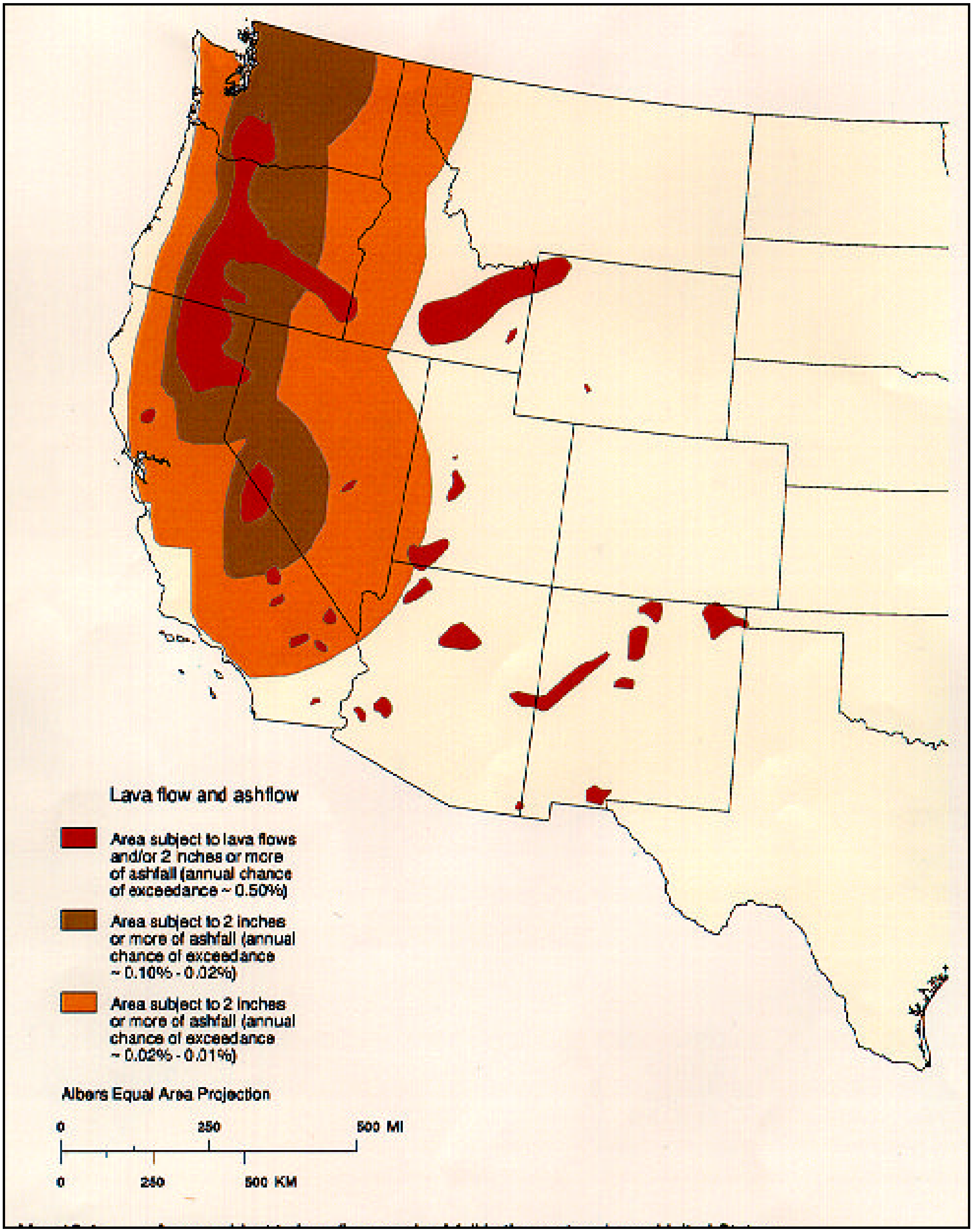
Scientists have identified more than 40 historically active volcanic centers along the chain. Eruptions could affect the Cook Inlet region, where 60 percent of Alaska's population resides and which is the State's major supply, business, and financial center (Brantley, 1990).

Consequences

Western Conterminous United States. Mount St. Helens, WA, erupted explosively in 1980, preceded by more than 10,000 local earthquakes and hundreds of steam blasts. Timber worth several million dollars was destroyed in a 596 km^2 (230 mi^2) area. Over 290 tons of ash were spread across 57,000 km^2 (22,000 mi^2) and extended as far east as North Dakota. Landslides along the volcano's flanks traveled about 14 mi (22.5 km) and mudflows destroyed bridges, temporarily halted shipping on the Columbia River, and disrupted highways and rail lines. Nearly 60 people were killed, and total costs exceeded $1.5 billion.

Despite no significant activity in the past 500 years, Mt. Rainier, WA, is considered to be the most hazardous volcano in the Cascades, primarily due to the threat of mudflows and floods. Twenty-six glaciers on the volcano contain large volumes of water that could be melted during active periods.

In western central California, the caldera known as Long Valley-Mono Lake was revealed to have some activity when an upward bulge of nearly 25 cm (10 in) was discovered during a 1980 survey of U.S. Route 395. The bulge is thought to be due to accumulations of rising magma. Geologic evidence of extensive ashfall from Long Valley has been found more than 1,000 km (600 mi) east and south of the site, covering all of Southern California, the entire States of Utah, Arizona, Colorado, and significant portions of New Mexico, Wyoming, Nebraska, and Kansas.



Map 18-1. Areas subject to lava flows and ashfall in the conterminous United States.
Data not available for Alaska, Hawaii, Puerto Rico, U.S. Virgin Islands, and Pacific Territories.
Source: *Data from Mullineaux, 1976.*

Hawaii. Kilauea on the Island of Hawaii has been active since the early 1980s. By June 1991, the shield was over 60 m (37 ft) tall, had covered 78 km^2 (30 mi^2) of forest and grassland, and had destroyed 180 homes and closed highways. Land values in the area dropped rapidly, and some insurance companies refused to sell new policies. During the period 1984-86, fumes released from Pu'u ‘O'o vent 12 mi (19 km) from the summit damaged crops. In 1790, Kilauea erupted with pyroclastic surges and ash fell 30 km (18.5 mi) from the summit. Suffocating gas killed many people.

Mauna Loa, the largest volcano on the Island of Hawaii, has erupted 15 times since 1900. Events lasted from 1 to 145 days. In 1984, the three-week long lava flow came within 6.5 km (4 mi) of buildings in the City of Hilo.

Alaska. Although sparsely populated, violent eruptions could threaten Alaska’s towns and villages. At least one or two eruptions have occurred each year since 1900 (Brantley, 1994).

Ash is the most common and widespread volcanic hazard in Alaska, and is especially dangerous to aircraft (Brantley, 1990). At least four commercial jet aircraft suffered damage during the 1989-90 eruption of Redoubt Volcano. Ash generated by numerous explosive episodes caused significant damage to aircraft, severely disrupted air traffic above southern Alaska, and resulted in local power outages and school closings. The explosions produced hot, fast-moving clouds of ash, rock debris, and gas (pyroclastic flows) that swept across Redoubt's heavily glaciated north flank.

The most serious incident occurred on December 15, 1989, when a Boeing 747 jetliner carrying 231 passengers entered an ash cloud approximately 150 mi (240 km) northeast of Redoubt Volcano. The jet lost power in all four engines and dropped approximately 13,000 ft (4,000 m) before the pilot succeeded in restarting the engines. The plane landed safely in Anchorage, but sustained an estimated $80 million in damage (Steenblik, 1990). This near-tragic incident prompted government agencies to search for better ways to track ash plumes and to improve information for the airline industry.

The Redoubt eruption triggered massive debris flows in Drift River Valley, threatening an oil tanker terminal near the river's mouth. On two occasions, partial flooding of the terminal compound forced authorities to modify operating procedures which temporarily curtailed oil production from 10 platforms in Cook Inlet. The damage and loss of revenue from ash and debris

Table 18-2.—*Lava flow hazard zones for the Island of Hawaii*

Hazard Zone	Percent of Area Covered by Lava Since 1800	Percent of Area Covered by Lava in Last 750 Years	Explanation
Very high	>25 percent	>65 percent	Kilauea and Mauna Loa rift zones where vents have been very active in historic time.
High	15-25 percent	25-75 percent	Areas adjacent to and downslope of active rift zones.
Moderately high	1-5 percent	15-75 percent	Areas less because of greater distance from active vents or areas protected by topography.
Moderate	About 5 percent	<15 percent	Includes all of Hualalai, where frequency of eruptions is less than Kilauea and Mauna Loa.
Low	None	Very Little	Areas currently protected by topography or no eruptions in recorded history.

Source: *Modified from Heliker, 1990.*

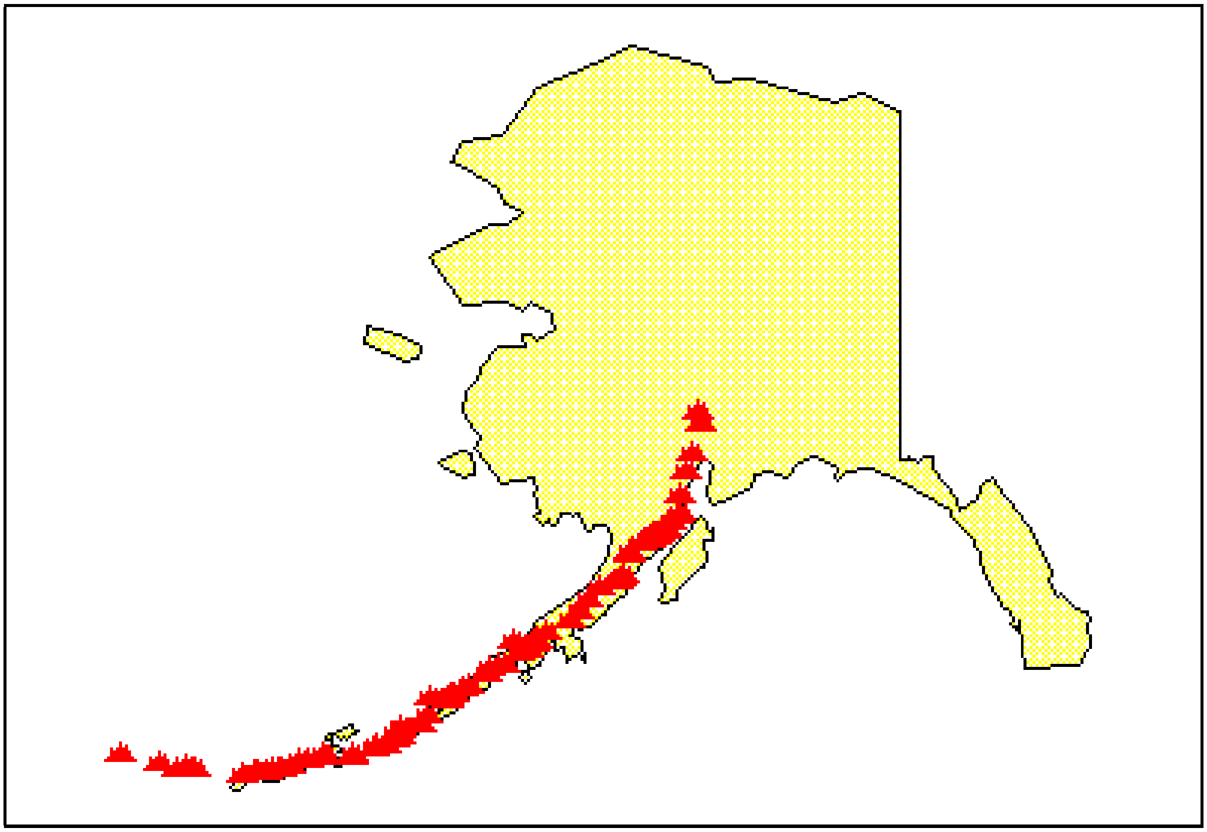


FIGURE 18-1.—Volcanoes of the Aleutian Arc.

Source: *Motyka, and others, 1993.*

flows was estimated at more than $100 million, the second most costly eruption in the history of the United States.

RESEARCH, MONITORING, AND DATA COLLECTION ACTIVITIES

The seismicity associated with earthquakes often provides the earliest warning of volcanic unrest, as earthquake swarms immediately precede most eruptions. Geodetic networks are set up to measure changes in volcano surface caused by the pressure of moving magma. Changes in the gas composition, or in the emission of sulfur dioxide and other gases, may be related to variation in magma supply rate, changes in magma type, or modifications in the pathways of gas escape induced by magma movement. Changes in electrical conductivity and magnetic field strength also trace magma movement. Changes in groundwater temperature or levels, rates of streamflow and sediment transport, and changes in lake levels, snow, and ice accumulation may be indicative of impending volcanic activity.

State-of-the-art technology was used to monitor the 1989 eruption of Redoubt Volcano. These techniques can improve detection and monitoring to enhance warning capabilities that lead to reduction of losses (Brantley, 1990):

- **Real-Time Seismic Amplitude Measurement (RSAM).** Unlike other seismic data acquisition systems that continuously record the oscillation of the ground, RSAM computes and stores the average amplitude of ground oscillation over 10-minute intervals. As either the magnitude or number of earthquakes increases, and as volcanic tremors increase, the average amplitude of ground oscillation also increases. The advantage of the RSAM system is its ability to measure the level of seismicity during intense activity, especially during eruptions and volcanic tremor, and when earthquakes are so numerous that individual events cannot normally be distinguished and counted.

- **Seismic Spectral Amplitude Measurement (SSAM).** SSAM measures the relative amplitude of the seismic signal in specific frequency bands, permitting seismologists to determine which frequencies dominate a signal. Different seismic events generate signals with different characteristics. The system aids recognition of patterns of subtle seismic change prior to eruptive episodes.

- Slow-Scan Video Camera. Approximately 50 mi (80 km) east of Redoubt Volcano on the Kenai Peninsula, a slow-scan video camera was installed to provide images of the volcano during clear weather. It is nearly 3,500 times more sensitive to light than most home-video cameras, and thus can record at night. An image is transmitted every 35 seconds and displayed on a black-and-white monitor. The video system helps seismologists correlate seismic events with volcanic activity.

- Lightning-Detection System. This system was deployed experimentally, because the cause of eruption lightning is uncertain. It may result from friction between ash (tephra) particles and steam and other gases within an ash plume. Eruption lightning discharges include both cloud-to-ground and cloud-to-cloud strikes. During a large seismic event when the volcano is not visible, the presence of lightning dispels uncertainty in interpreting the seismicity. An ash plume is almost certainly present when sustained seismic signals and lightning occur together. For some episodes at Redoubt, lightning detection allowed scientists to conclude within minutes that an ash plume was forming above the volcano even though a plume could not be seen.

- Debris-Flow Detection System. This installation consists of three stations located adjacent to Drift River at increasing distances from the volcano. Each station consists of a seismometer sensitive to high-frequency (10-300 Hz) ground vibrations caused by flowing mixtures of water and rock debris and a radio to send the data to a receiving station. The signals are separated into frequency ranges and continuously analyzed by computer. Flow events can be detected on the basis of high-frequency character, even during volcanic activity and earthquakes. When the system is operating, all debris flows triggered by volcanic activity are detected.

MITIGATION APPROACHES

Losses from volcanic eruption can be reduced in several ways, described below.

- Past eruptive activity can be used to define the potential type, scale, location, extent, effect, and severity of future eruptions and to define hazard zones which can guide development through land-use planning.

- Establishment of detection and monitoring systems to measure physical changes that precede activity can enhance forecasting of impending eruptions and provide warning.

- Disaster preparedness and emergency evacuation can provide substantial loss reduction when the locations and types of hazards for a particular volcanic eruption are taken into consideration. Plans should be based on hazard-zone maps showing the relative severity, extent, and effect of specific volcanic eruptions. An important element is the development of emergency communication systems to warn and inform the public of potentially hazardous events.

- Protective measures can be effective in reducing losses from certain volcanic hazards. Relatively simple actions such as providing high-efficiency dust masks and goggles can protect people from respiratory damage and eye irritation. Changing oil and air filters can reduce damage to vehicles due to ashfalls. However, effective and economically feasible diversion or control lava flows, pyroclastic flows, and debris flows generally is not possible.

- Risk assessment, especially coupled with land-use planning, provides a strategy for reducing losses from volcanic hazards. Risk assessment involves determining the value of affected resources, the exposure of those resources, and the probability that a volcanic eruption of a certain magnitude will take place within a certain period of time. On the basis of the risk assessment, land-use decisions can be made that are consistent with goals for public safety.

RECOMMENDATIONS

Wright and Pierson (1992) describe several challenges for the future to improve the understanding of volcanic activity and the ability to communicate scientific results in a way that can be used by communities facing volcanic hazards:

- Early detection of volcanic unrest and potential eruption through establishment of telemetering networks to monitor baseline seismic activity (seismometers) and ground deformation (Global Positioning Systems);

- Volcanic hazard assessments at several active or potentially active U.S. volcanoes using GIS technology and computer models to study the paths of lava flows, debris flows, and debris avalanches;

- Research in volcanic processes using sophisticated geophysical techniques to improve the understanding of magma-water interactions, large-scale debris avalanches, large debris flows and related sediment-laden flood waves; and

- Improved communications and the development of emergency response plans that can be put in place quickly in areas that show signs of volcanic unrest, and the development and distribution of nontechnical publications that describe volcanic hazards and lessons learned from previous eruptions

BIBLIOGRAPHY AND REFERENCES

Brantley, S.R. (Ed.) 1990. ***The Eruption of Redoubt Volcano, Alaska, December 14, 1989-August 31, 1990.*** U.S. Geological Survey Circular 1061.

Brantley, S.R. 1994. ***Volcanoes of the United States.*** U.S. Geological Survey.

Beverage, J.P., and J.K. Culbertson. 1964. "Hyperconcentrations of Suspended Sediment." ***Journal of the Hydraulics Division.*** American Society of Civil Engineers. Vol. 90, No. HY6, pp. 117-126.

Coch, N.K. 1995. ***GEOHAZARDS: Natural and Human.*** Upper Saddle River, NJ: Prentice Hall.

Crandell, D.R. 1984. “Catastrophic Debris Avalanche from Ancestral Mount Shasta Volcano, California." ***Geology.*** Vol. 12, pp. 143-146.

Hays, W.W. 1981. ***Facing Geologic and Hydrologic Hazards: Earth-Science Considerations.*** U.S. Geological Survey Professional Paper 1240-B.

Heliker, C. 1990. ***Volcanic and Seismic Hazards on the Island of Hawaii.*** U.S. Geological Survey.

Hoblitt, R.P., C.D. Miller, and W.E. Scott. 1987. ***Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest.*** U.S. Geological Survey Open-File Report 87-297.

Lipman, P.W., and D.R. Mullineaux (eds). 1981. ***The 1980 Eruptions of Mount St. Helens, Washington.*** U.S. Geological Survey Professional Paper 1250.

Miller, C.D. 1989. ***Potential Hazards from Future Volcanic Eruptions in California.*** U.S. Geological Survey Bulletin 1847.

Motyka, R.J., S.A. Liss, C.J. Nye, and M.A. Moorman. 1993. ***Geothermal Resources of the Aleutian Arc***. Alaska Division of Geological and Geophysical Surveys Professional Report 114.

Mullineaux, D.R. 1976. ***Preliminary Overview Map of Volcanic Hazards in the 48 Conterminous United States.*** Scale 1:7,500,000. U.S. Geological Survey Miscellaneous Field Studies Map MF-786.

Newhall, C.G. 1984. ***Semiquantitative Assessment of Changing Volcanic Risk at Mount St. Helens, Washington.*** U.S. Geological Survey Open-File Report 84-272.

Pierson, T.C. 1985. "Initiation and Flow Behavior of the 1980 Pine Creek and Muddy River Lahars, Mount St. Helens, Washington." ***Geological Society of America Bulletin.*** Vol. 96, pp. 1056-1069.

Pierson, T.C., and J.E. Costa. 1987. "A Rheologic Classification of Subaerial Sediment-Water Flows." ***Geological Society of America, Reviews in Engineering Geology.*** Vol. 7, pp. 1-12.

Simkin, T. 1981. ***Volcanoes of the World: A Regional Directory, Gazatteer, and Chronology of Volcanism During the Last 10,000 Years.*** Stroudsburg, PA: Hutchinson Ross Publishing Co.

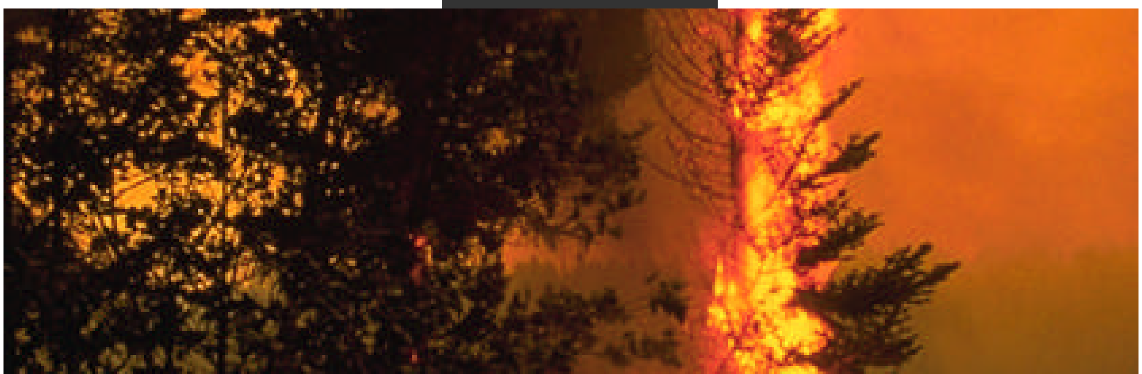
Steenblik, J.W. 1990. "Volcanic Ash: A Rain of Terra." ***Airline Pilot***, pp. 9-15.

Voight, B., H.X. Glicken, R.J. Janda, and P.M. Douglass. 1981. "Catastrophic Rockslide Avalanche of May 18." In ***The 1980 Eruptions of Mount St. Helens***, Lipman, P.W., and D.R. Mullineaux (eds.). U.S. Geological Survey Professional Paper 1250.

Wright, T, L., and T.C. Pierson. 1992. ***Living with Volcanoes: The U.S. Geological Survey's Volcano Hazards Program.*** U.S. Geological Survey Circular 1073.

CHAPTER

19



WILDFIRE HAZARDS

Chapter Summary

Periodic forest, grassland, and tundra fires are part of the natural environment, as natural and as vital as rain, snow, or wind (Mutch, 1995a). Wildfires are fueled by naturally occurring or non-native species of trees, brush, and grasses. Topography, fuel, and weather are the three principal factors that impact wildfire hazards and behavior.

Wildfires occur in virtually all of the United States. The Western States, with their more arid climate and prevalent conifer and brush fuel types, are subject to more frequent wildfires. Wildfires have proven to be the most destructive in California, but they have become an increasingly frequent and damaging phenomenon nationwide. People are becoming more vulnerable to wildfires by choosing to live in wildland settings, and the value of exposed property is increasing at a faster rate than population.

Most of the tools, data, and methodologies necessary to accurately assess wildfire risk and exposure on a national basis are not yet in place. However, the use of GIS technology, combined with the increased availability and utilization of satellite data, should facilitate progress.

Mitigation and rapid emergency response are the most effective activities for reducing the short-term impact of wildfires. However, the emphasis of Federal land management agencies is shifting from suppression toward mitigation and overall fire management, including the use of prescribed fires to reduce future risks.

Successful wildfire mitigation strategies can be complex, involving the participation of property owners who choose to live in at-risk areas, as well as many agencies, organizations, and individuals.

Photo: Red Cross

HAZARD IDENTIFICATION

The four categories of wildfires that are experienced throughout the United States are described below.

- **Wildland fires** are fueled almost exclusively by natural vegetation. They typically occur in national forests and parks, where Federal agencies are responsible for fire management and suppression.

- **Interface or intermix fires** are urban/wildland fires in which vegetation and the built-environment provide fuel.

- **Firestorms** are events of such extreme intensity that effective suppression is virtually impossible. Firestorms occur during extreme weather and generally burn until conditions change or the available fuel is exhausted.

- **Prescribed fires and prescribed natural fires** are fires that are intentionally set or selected natural fires that are allowed to burn for beneficial purposes.

U.S. Forest Service (USFS) figures for 1990 indicate that 25.7 percent of wildfires reported were caused by arson. Other ignition sources were debris burns (24 percent); lightning (13.3 percent); and other (16.7 percent). Lightning can present particularly difficult problems when dry thunderstorms move across an area that is suffering from seasonal drought. Multiple fires can be started simultaneously. In dry fuels, these fires can cause massive damage before containment.

Three principal factors have a direct impact on the behavior of wildfires: topography, fuel, and weather. Other hazards may trigger wildfires, and wildfires contribute to other hazards

TOPOGRAPHY. Topography can have a powerful influence on wildfire behavior. The movement of air over the terrain tends to direct a fire's course. Gulches and canyons can funnel air and act as a chimney, intensifying fire behavior and inducing faster rates of spread. Similarly, saddles on ridgetops tend to offer lower resistance to the passage of air and will draw fires. Solar heating of drier, south-facing slopes produces upslope thermal winds that can complicate behavior.

Slope is an important factor. If the percentage of uphill slope doubles, the rate of spread of wildfire will likely double. On steep slopes, fuels on the uphill side of the fire are closer physically to the source of heat. Radiation preheats and dries the fuel, thus intensifying fire behavior. Terrain can inhibit wildfires: fire travels downslope much more slowly than it does upslope, and ridgetops often mark the end of wildfire's rapid spread.

FUEL. Fuels are classified by weight or volume (fuel loading) and by type. Fuel loading, often expressed in tons per acre, can be used to describe the amount of vegetative material available. If fuel loading doubles, the energy released also can be expected to double. Each fuel type is given a burn index, which is an estimate of the amount of potential energy that may be released, the effort required to contain a fire in a given fuel, and the expected flame length. Different fuels have different burn qualities. Some fuels burn more easily or release more energy than others. Grass, for instance, releases relatively little energy, but can sustain very high rates of spread.

Continuity of fuels is an important factor. Continuity is expressed in terms of both the horizontal and vertical dimensions. Horizontal continuity is what can be seen from an aerial photograph and represents the distribution of fuels over the landscape. Vertical continuity links fuels at the ground surface with tree crowns via understory or "ladder" fuels.

Another essential factor is fuel moisture. Like humidity, fuel moisture is expressed as a percentage of total saturation and varies with antecedent weather. Low fuel moistures indicate the probability of severe fires. Given the same weather conditions, moisture in fuels of different diameters changes at different rates. A 1,000-hour fuel, which has a 3- to 8-in (8- to 20-cm) diameter, changes more slowly than a 1- or 10-hour fuel.

WEATHER. Of all the factors influencing wildfire behavior, weather is the most variable. Extreme weather leads to extreme events, and it is often a moderation of the weather that marks the end of a wildfire's growth and the beginning of successful containment. High temperatures and low humidity can produce very vigorous fire activity. The cooling and higher humidity brought by sunset can dramatically quiet fire behavior.

Fronts and thunderstorms can produce winds that are capable of radical and sudden changes in speed and direction, causing similar changes in fire activity. The rate of spread of a fire varies directly with wind velocity. Winds may play a dominant role in directing the course of a fire. The radical and devastating effect that wind can have on fire behavior is a primary safety concern for firefighters. In July 1994, a sudden change in wind speed and direction on Storm King Mountain led to a blowup that claimed the lives of 14 firefighters. The most damaging firestorms are usually marked by high winds.

Interaction of Other Hazards. Other hazard events can cause wildfires, and wildfires can intensify other hazards. According to a 1991 case study, winds gusting to 62 mph (100 km/h) downed powerlines, resulting in 92 separate wildland fires in Washington (The National Wildland/Urban Interface Fire Protection Initiative, 1992). Earthquakes have the potential to cause wildfires.

Large firestorms can create very powerful convective winds as air rushes in to feed the flames. These winds are capable of causing extensive damage but the ground effects are local. To the ground-level observer, fire and wind are perceived as one event. The upward rush of air in the convection column is powerful enough to carry burning embers far ahead of the fire before falling to the ground. By this spotting process, a fire may enlarge or create new fires.

By removing vegetative cover, wildfires can contribute to mudslides, landslides, and floods. According to the National Commission on Wildfire Disasters, the 1992 Foothills Fire near Boise, ID, was so hot that not only was the vegetation removed, but the soils were ". . . so heat damaged that they resist water penetration and cause flash runoff and erosion, as well as some that slide off steep slopes like dry sugar . . . " (MacLeary, 1993).

RISK ASSESSMENT

Using NWS data, the U.S. Forest Service administers the National Fire-Danger Rating System, used to assess the risk of wildfire at a given time. The system is used to make wide-scale estimates of real-time fire potential and behavior for very large acreages, but not structures. Fuel moisture, indicative of antecedent weather, combined with current and forecasted weather conditions are the main factors considered, but a variety of data are used.

A computerized network, the Weather Information Management System (WIMS), is the main tool used to organize data and to provide fire weather information. Input includes data from hundreds of remote automatic weather stations which provide data on temperature, humidity, wind, and fuel moisture for 1- and 10-hour fuels. The fuel moisture of larger fuels is determined by inference.

Input data collected by the TIROS-N series of polar orbiting weather satellites operated by NOAA are fed into WIMS (Loveland and others, 1991). The data are downloaded daily to the Earth Resources Observation System (EROS) and used to compile maps showing U.S. land cover characteristics.

One instrument aboard the TIROS-N satellites is the advanced very high resolution radiometer, an infrared sensor. Data from this instrument have been used to create a Normalized Difference Vegetation Index, which is essentially a measurement of vegetative "greenness" from which vegetative fuel moisture contents may be inferred. Figure 19-1 is an example of a departure from average greenness map which shows how green vegetation is compared to its average greenness for the current week. Similarmap products show relative green where each pixel is normalized to its own historical range, therefore all areas (dry or wet) can appear relatively green at some time during the growing season (USDA U.S. Forest Service, 1997).

Data from these sources can be accessed from any computer networked to WIMS. The most commonly used output is organized into reports of local Fire Danger Ratings. These reports include the adjective class rating (low to extreme), Manning Class (an indication of resistance to suppression), burn index (an estimate of flame length in light grasses), moisture content reading for 1,000-hour fuels, and energy release component (expressed in BTU per second per square foot). The public is informed of the adjective class rating through media reporting and roadside signs. Figure 19-2 is a sample of a Fire Danger Rating Map (USDA U.S. Forest Service, 1997).

Exposure

More and more people are being exposed to wildfires by choosing to live in or next to wildland settings. The value of exposed property is increasing more rapidly, especially in the Western States. With their more arid climate and conifer and brush fuel types, Western States are subject to more frequent wildfires than the rest of the United States. Western ecosystems have adapted to, and have even become dependent on, wildfires. Wildfires play an essential role by thinning forests and creating stands of different species and age groups.

Most of the tools, data, and methodologies necessary for accurate assessments of risk and exposure as they relate to wildfires have not been developed. However, the use of GIS technology by many Federal, State, and local agencies, combined with the increased availability and utilization of satellite and other remote-sensing data, provide a sound base for the development of advanced tools.

Spatial factors include topography, fuels, weather, and population distribution. Topographic data are available and are applicable to the degree of risk at a local level. Knowledge of where fuels and people co-exist is essen-

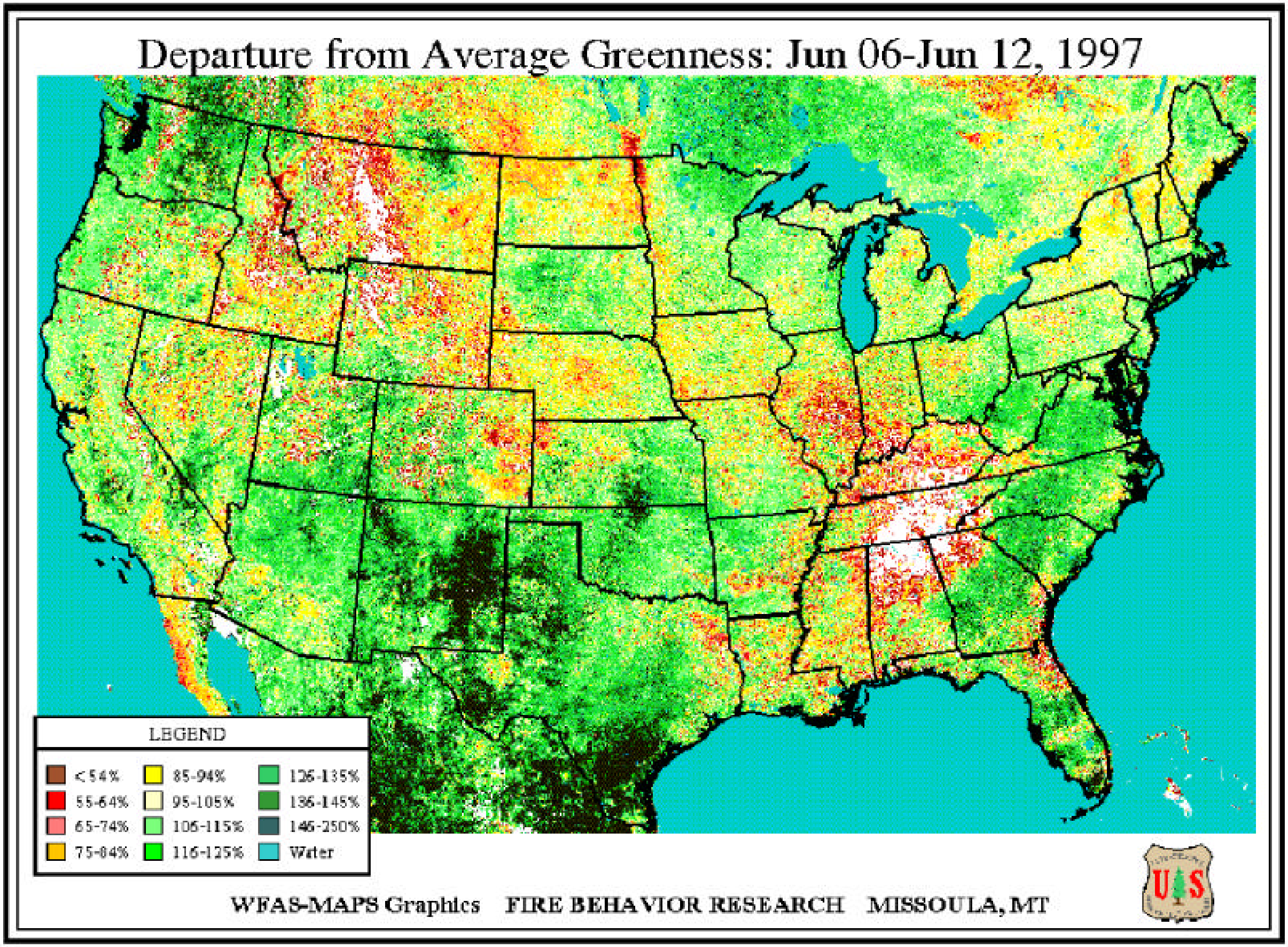


FIGURE 19-1.—Live fuel moisture - departure from average greenness.

Source: USDA Forest Service, www.fs.fed.us/land/wfas, 1997.

tial, but good fuel data generally are unavailable while the population density in some areas can be estimated only.

Weather, a short term temporal factor, is a critical indicator of fire potential and severity. the changes that time provides to the density of vegetation is a long term temporal factor.

Consequences

Historical statistics on the economic impact of wildfires, including resource and property losses, are available for specific, large incidents. However, reporting is incomplete and national statistics are not compiled. Therefore, accurate estimates of the economic impact of wildfires cannot be made.

Virtually all of the continental United States has experienced and will continue to experience wildfires. Wildfires are the most destructive in California, but they have become an increasingly frequent and damaging phenomenon elsewhere. It is impossible to assess fully the extent of wildfire damage due to incomplete reporting. The U.S. Forest Service (USFS), which compiles statistics for wildfires on Federal lands, is the primary Federal source of information.

According to National Interagency Fire Center statistics for fires on Federal lands from 1985 to 1994, an average of nearly 73,000 fires occur each year, resulting in over 3,000,000 acres (1,215,000 ha) burned and more than $411.5 million expended in suppression costs. The single worst event in terms of deaths in U.S. history occurred in Wisconsin in 1871, killing 1,182 people (FEMA, 1990).

The National Fire Protection Association (NFPA) is the best source of data for interface losses. The NFPA maintains two separate databases: the Fire Incident Data Organization (FIDO), which is a file of news clippings of actual incidents; and a statistical database of outdoor fires to which a fire department responded. The file is incomplete because not all fires are reported. In addition, the data do not permit determination of the number and value of structures lost to wildfires.

The available statistical data on interface fire losses tend to be specific to a particular event or region and, therefore, do not facilitate tracking of long-term national trends. According to Phillips (1994), 3,500 homes were destroyed by wildfires in California between 1920 and 1989, and well over 4,200 homes were destroyed between 1990 and 1993.

In 1988 in Alaska, wildfires destroyed 2.2 million acres (891,000 ha) of tundra and spruce forest, nearly twice the normal yearly average for the State. In California, over 9,800 fires burned more than 175,000 acres (70,875 ha), destroying 400 homes, barns, and other structures. The majority of the damage was the result of a 35,000-acre (14,175-ha) fire near Sacramento in September, which caused an estimated $22 million in damage (FEMA, 1990).

Some particularly devastating interface events that occurred during the 1990s are described below.

- During the 1,600-acre East Bay Fire in Oakland, CA, on October 20, 1991, 25 people were killed and 150 were injured; and 3,354 single-family homes and 456 apartments were damaged. The total estimated damage was $1.5 billion (California Office of Emergency Services, 1992).

- In October 1991, rural residents of counties near Spokane, WA, where the population increased by 76 percent between 1970 and 1990, reported 92 separate fires that burned 114 homes and 35,000 acres (14,465 ha). The winds that fanned the fires reached speeds of 62 mph (NFPA, 1992).

- Between October 25 and November 3, 1993, 21 major wildland fires broke out in California, fanned by two waves of hot, dry Santa Ana winds. The fires collectively burned over 189,000 acres (76,500 ha) and destroyed 1,171 structures. Three people died and hundreds were injured. Combined property damage was estimated at approximately $1 billion (Hazard Mitigation Survey Team Report, 1993).

- In 1994, one of the worst years since the early 1900s, 79,107 fires burned 4,073,579 acres (1,648,577 ha), and cost $924 million for suppression. Only 325 homes were lost, fewer than the 10-year average between 1985 and 1994 (900 homes per year). Tragically, 34 firefighters lost their lives. On July 6, 1994, 14 firefighters died in one terrible incident during the South Canyon Fire just west of Glenwood Springs, CO.

Federal agencies bear a significant portion of fire suppression costs and losses in interface areas. Of the nearly $1 billion in Federal funds spent on wildfire suppression in 1994, 30 to 50 percent was expended on protecting interface areas (Federal Wildland Fire Management Policy and Program Review, 1995).

During the past 20 years, seven wildfires resulted in major disaster declarations, with six occurring in California. An additional 95 wildfires have qualified for Federal fire suppression grants.

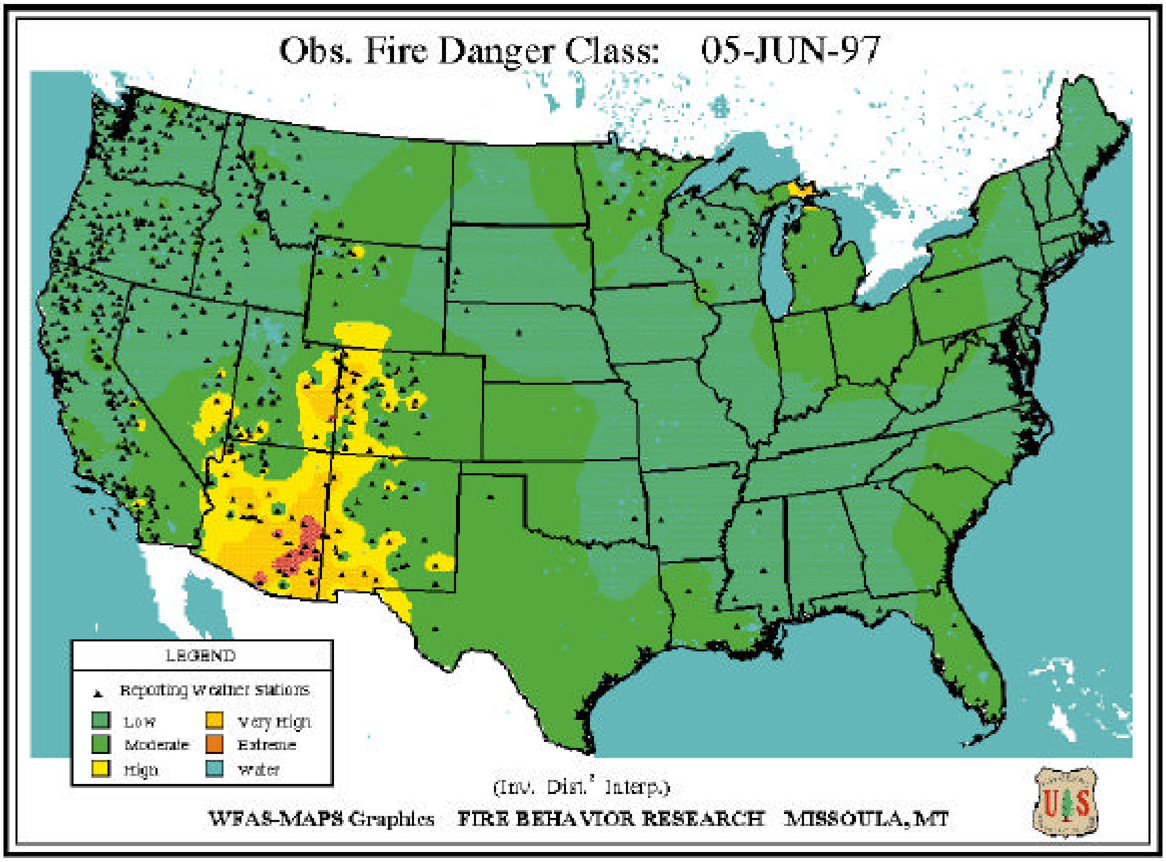


FIGURE 19-2.—Sample of a fire danger rating map, June 1997.

Source: *USDA Forest Service, www.fs.fed.us/land/wfas, 1997.*

RESEARCH, DATA COLLECTION, AND MONITORING ACTIVITIES

Nationally accepted models have not been developed to make wildfire risk or vulnerability assessments. However, models and methods do exist for predicting wildfire behavior. A computer modeling tool, BEHAVE uses topographic, fuel, fuel moisture, and weather data. BEHAVE is used by the U.S. Forest Service at its Florida and Missoula, MT Fire Research Laboratories. While a reliable indicator of fire intensity and rates of spread in simple fire events, the model has some severe limitations. Output is limited to surface fire behavior and more extreme wildfire events, such as crown fires, cannot be modeled. Farsite, a more advanced modeling tool configured for GIS, is currently under development.

BEHAVE's shortcomings are related primarily to the quality of available data and the complex relationship between the variables. Fuel moisture and weather data are probably good enough to support somewhat more advanced models. Topography, however, is dealt with in only a general way and may oversimplify much of the intricate interaction of air flow over terrain. An even more significant data quality issue lies in how fuel data are collected. The current approach involves observers matching photographs of fuel models to the appearance of local vegetation. This is often then extrapolated to apply to a wide area. Although useful for providing a comparative fuel rating, this simple approach does not support advanced fire behavior modeling.

A project under development by the Fire Behavior Research Work Unit of the U.S. Forest Services' Intermountain Research Station in Missoula, MT seeks to incorporate EROS data into an integrated fire danger/behavior system. Part of this project will involve the development of a national fuels map (Burgan and Hartford, 1993). This project has significant potential for a coarse-filter, national wildfire risk assessment approach.

MITIGATION APPROACHES

Since the 1920s, aggressive fire suppression has effectively excluded fire from a significant portion of the forestlands in the United States. As a result, stand densities and fuel loadings have reached unprecedented levels. Therefore, when wildfires do occur, they exhibit more unusual behavior, are more intense and damaging, and thus are more difficult and costly to suppress.

The paradox of aggressive fire suppression policies is that putting out most small fires creates conditions that are conducive for large fires. The emphasis of Federal land management agencies is shifting from suppression toward mitigation and overall fire management, including the use of prescribed fires.

Wildfire mitigation in the urban/wildland interface has primarily been the responsibility of property owners who choose to build and live in this vulnerable zone. Local officials are responsible for emergency management, fire protection, and land-use, building, and zoning regulations. State officials are involved in wildfire hazard issues primarily through the State forest services and emergency management offices. When property owners, local fire protection authorities, and local, State, and federal agencies work cooperatively, there is a high probability that wildfire mitigation projects will be developed.

Federal participation often begins with sharing of suppression and recovery costs. Federal land management agencies have the greatest fire suppression resources and often participate in suppression of interface fires. Agency roles and cost-sharing formula depend on specific agreements with State and local agencies.

The U.S. Fire Administration (USFA), a unit within FEMA, provides a training course on firefighting techniques for interface fires through the National Fire Academy. USFA also serves on the Federal Wildfire Coordination Group. FEMA provides funding for educational brochures and other publications addressing wildfire issues.

The Emergency Education Network (EENET), an outreach tool used by FEMA to enhance the training and education of fire and emergency management specialists nationwide, is produced at FEMA's Emergency Management Institute campus. EENET programs, which have won national videoconferencing awards, cover a wide array of problems, programs, and issues, including public awareness aspects of the wildland/urban interface.

In practice, successful wildfire strategies can be quite involved. The most important aspect of successful suppression is disruption of the continuity of fuels, achieved by creating firelines and fire breaks. Fuel is removed from the course of the fire. The time necessary to install firelines is gained by giving up space. For interface fires, where homes and other structures fill the space, fuel reduction is best accomplished before the fires begin.

In the interface, proximity to natural fuels, building materials, and construction features are crucial to the survival of homes in a wildfire. According to the NFPA, the principal causes of structure loss in interface fires are lack of defensible space and structures built with combustible materials and features (Baden, 1995).

Fuel-modification measures, such as fuel breaks and defensible spaces, can withstand a fire's run even in heavy fuels and during the worst fire conditions. The following is testimony to the effectiveness of fuel-modification measures:

> "At the height of the fire's fury, it encountered a stand of ponderosa pine that had been thinned two years earlier through a careful logging operation, then burned in the winter to reduce ground fuels. The racing crown fire, totally out of control at that encounter, dropped immediately to the ground as the greener, moister tree canopy refused to ignite, and then began to slow in response to reduced fuels on the ground. Firefighters were able to move in, build fire lines, and halt its advance. The thinned forest was virtually undamaged." (McLean, 1993)

For those involved in mitigation efforts, the resistance or apathy of property owners causes the greatest frustration. For many years, the public was told that all wildfires are "bad" and suppression is the cure. Public consciousness changes very slowly (Gardner and others, 1987). It will probably take considerable time, a vigorous re-education effort, and many disasters before the hazards posed by wildfires are well understood.

The adoption of regulations requiring fire-safe construction, such as NFPA's *Standard for Protection of Life and Property from Wildfire* (1991) and the International Fire Code Institute's *Urban-Wildland Interface Code* (draft, 1995), will likely gain more support. Land-use regulation issues may be more difficult to address. The appreciation of land values and other short-term economic advantages of development often create an active constituency strongly opposed to regulatory efforts which are perceived to increase the cost of construction.

With understanding and cooperation, much can be done to prevent or mitigate wildfire hazards. However, according to the report of the Operation Urban Wildfire Task Force, ". . . in spite of all the reports and good work, the message is still not reaching the public, and effective action is not yet being taken to reduce the fire threat" (Peterson, 1992).

Boulder County, CO. It often takes a damaging and frightening wildfire event to initiate an intensive mitigation program. On July 9, 1989, a human-caused wildfire blown by strong upslope winds swept out of Black Tiger Gulch into the foothill community of Sugarloaf. Within 6 hours, 44 homes and other structures were destroyed and many others were damaged. Property losses exceeded $10 million and suppression costs totaled another $1 million (NFPA, 1990). As a result, the State of Colorado and Boulder County updated their wildfire mitigation plans. Concerned citizens and firefighters approached the County Commissioners for help in mitigating the wildfire hazard in their communities.

The County Commissioners responded by creating the Boulder County Wildfire Mitigation Group, headed by staff of the County Land Use Department. The group grew to include representatives of the USFS, Sheriff's Department, Parks and Open Space, City of Boulder Fire Department, Colorado State Forest Service, U.S. Bureau of Land Management, University of Colorado, Colorado State University, volunteer firefighters, and homeowners. The cooperative effort was aimed at educating homeowners, providing support for community mitigation, and communicating needs to the County Commissioners.

To identify the people and structures vulnerable to wildfire, to quantify the hazards, and to present information in a useful and meaningful format, the Wildfire Mitigation Group used the Land Use Department's GIS to develop the Wildfire Hazard Information and Mitigation System (WHIMS). WHIMS combines expertise in hazard assessment, forest management, land use planning, wildfire behavior, and suppression with fire district and community involvement. Elements of BEHAVE are incorporated into the hazard rating modeling capability.

The City of Boulder adapted WHIMS for use under the name FIRMIT. Data related to each home are collected by volunteer firefighters during onsite visits. The Colorado State Forest Service provides fuel data and other support.

A pilot map produced by Boulder County from WHIMS data, indicating roof materials by lot, is shown in Figure 19-3. Rated from low to high flammability, roof materials are: metal or tile; composite or asphalt; treated shake; and untreated shake.

The Boulder County Wildfire Mitigation Group provided the impetus and support for regulations requiring that homebuilders in interface areas meet reasonable wildfire mitigation standards. A flexible rating system is used, permitting a great deal of choice. All new construction must meet the standards through the County's Site Plan Review process. These standards and the rating system are based on the WHIMS assumptions that the hazard rating elements are, in order of importance, topography or site location, building construction and design, landscaping/defensible space, access, and water.

In the year after the first pilot area survey, in the Pine Brook Hills Fire Protection District, 22 percent of the homeowners took mitigative actions such as changing roof type, limbing tree branches, moving firewood away from houses, and properly identifying street addresses. In subsequent years, additional homeowners have participated through such activities as a joint defensible space plan for 22 adjoining properties that is now serving as a model for others in Boulder County.

Since the first pilot area survey, 8 of the County's 16 fire districts have become involved in the WHIMS project, scheduled for completion by 1999. To date, almost 2,000 parcels have been impacted by WHIMS (in Boulder County) or FIRMIT (in the City of Boulder), with an estimated 6,000 more needed for completion. WHIMS has encouraged participation by local fire departments and has created a direct interface between firefighters and homeowners, resulting in increased knowledge and awareness for both.

Other Local Initiatives. Use of GIS as a wildfire assessment and mitigation tool is underway in Oakland and Laguna Beach, CA, and Missoula, MT (Mullenix, 1995).

The Northern Rockies Coordinating Group is another example of how cooperation leads to progress. This multi-jurisdictional group, formed in 1984, includes both wildland and structural fire protection agencies. A long-range interface program was initiated in 1988, including public education, legislative action, and modifications of engines serving interface areas. Group members approached local zoning and planning commissions to urge fire protection consideration in covenants and regulations.

In Billings, Helena, Dillon, and Kalispell, MT, Coeur d'Alene, ID, and other States, interagency dispatch centers have been formed. Response time has improved by eliminating jurisdictional disputes and confusion when fires occur in interface areas (NFPA,1991).

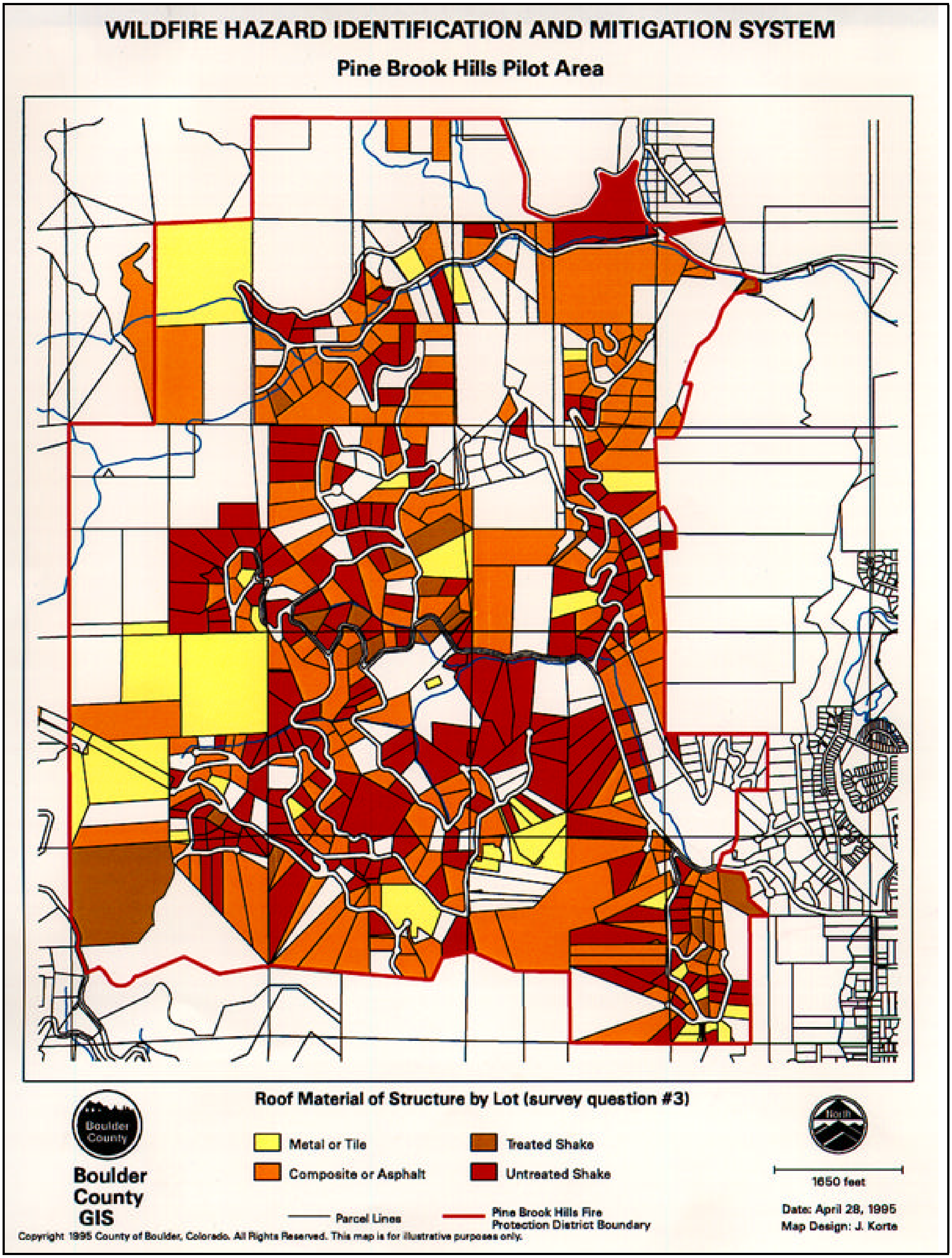


FIGURE 19-3.—Boulder County wildfire hazard pilot map.

Source: *Land Use Department, Boulder County, CO*

RECOMMENDATIONS

The development of a national wildfire hazard mitigation strategy will require the participation and cooperation of many agencies, organizations, and individuals. Recommendations from several sources have been considered and are described below.

- Design and implement a comprehensive educational campaign at both the national and local levels. The campaign should focus on fire ecology and ecosystem stewardship, wildfire risk, exposure, and sound mitigation measures. It should target homeowners, firefighters, local officials, landscapers, architects, foresters, builders, planners, insurance companies, and the media.

- Develop a practical way to use the EROS database in the development of a prototype GIS and remote-sensing wildfire risk and vulnerability assessment tool.

- Identify the temporal factors to be used in making wildfire risk and vulnerability assessments. The factors should be suitable for use with both EROS data and ground-level assessments. Methods to link historical data with advanced technologies should be considered.

- Develop a standard methodology, using an expert systems approach, to rate residential structures as fuels.

- Devise a methodology and provide training to local jurisdictions for use in the development of detailed, on-site wildfire risk and vulnerability assessments.

- Develop GIS-based wildfire hazard assessment tools for use by Federal, State, and local agencies. These tools should be configured to use both EROS data and locally collected data.

- Support development of advanced fire behavior modeling tools configured to run in the spatial context of GIS.

- Create a National Wildfire Mitigation Program and collect wildfire statistics for the past 10 to 20 years, estimates of current risk and exposure, and projections for all local jurisdictions.

- Test tools and methodologies by conducting a thorough wildfire risk and vulnerability assessment for a pilot project area. These data could then be provided to appropriate State and Federal agencies, and could be used for fine-filter ground-truthing of EROS data.

- Use the National Fire Information Reporting System for the collection, compilation, and reporting of comprehensive national wildfire statistics.

BIBLIOGRAPHY AND REFERENCES

Baden, W. 1995. National Fire Protection Association. ***National Wildland/Urban Interface Fire Protection Initiative***. Black Tiger Fire Case Study.

Boulder County Land Use Department. 1995. County of Boulder, CO. ***Wildfire Hazard Identification and Mitigation System (WHIMS) Maps.***

Burgan, R., and R. Hartford. 1993. ***Monitoring Vegetative Greenness with Satellite Data***. U.S. Forest Service, Intermountain Research Station, Missoula, MT.

California Governor's Office of Emergency Services. 1994. "East Bay Hills Fire Operations Review Group: A multi-Agency Review of the October 1991 Fire in Oakland/Berkley Hills" In: ***Report of the National Commission on Wildfire Disasters.*** Washington, DC.

Cortner, G., and Bridges. 1985. "Wildfire: Managing the Hazard in Urbanizing Areas." ***Journal of Soil and Water Conservation***.

Dodge, M. 1972. "Forest Fuel Accumulation: A Growing Problem." ***Science Magazine***, Vol. 177.

Federal Emergency Management Agency, Hazard Mitigation Survey Team Report. 1993. ***Southern California Firestorms***.

Federal Emergency Management Agency, Office of Civil Defense. 1990. ***Principal Threats Facing Communities and Local Emergency Management Coordinators: A Report to the United States Senate Committee on Appropriations***. FEMA 191. Washington, DC: U.S. Government Printing Office.

Federal Emergency Management Agency, Office of Emergency Management. 1993. ***Principal Threats Facing Communities and Local Emergency Management Coordinators: A Report to the United States Senate Committee on Appropriations***. Washington, DC: U.S. Government Printing Office.

Federal Emergency Management Agency, U.S. Fire Administration. 1992. ***Report to Congress, Fiscal Year 1991***. Washington, DC.

Federal Emergency Management Agency, U.S. Fire Administration, Wildfire Section. 1994. ***An Overview of Natural Hazards in the Vicinity of Boulder, CO***.

Federal Wildland Fire Management Policy and Program Review. 1995. ***Federal Register***. Vol. 60, No. 120, pp. 32492.

Gale, R., and H. Cortner. 1987. ***People and Fire at the Urban Wildland Interface***. U.S. Forest Service.

Gardner, P., H. Cartner, and J. Bridges. 1985. "Managing the Hazard in Urbanizing Areas." ***Journal of Soil and Water Conservation.*** Vol. 40, No. 4, P. 319.

Gardner, P., H. Cortner, and K. Widaman. 1987. "The Risk Perceptions and Policy Response Toward Wildland Fire Hazards by Urban Home-Owners." ***Landscape and Urban Planning***. No. 14, pp. 163-172.

Grant, C. 1995. "Pushed to the Limit." ***National Fire Protection Association Journal***.

International Fire Code Institute, Urban-Wildland Interface Code Committee. 1995 (draft). ***Urban-Wildland Interface Code***. Whittier, CA.

Kay, C. E. 1994. ***Aboriginal Overkill and Native Burning: Implications for Modern Ecosystem Management***. Salt Lake City, UT: Utah State University.

Loveland, T., and others. 1991. "Development of a Land-Cover Characteristics Database for the Conterminous U.S." ***Photogrametric Engineering & Remote Sensing***. Vol 57, No. 11, pp. 1453-1463.

MacCleary, D.W. 1994. ***Report of the National Commission on Wildfire Disasters***. Washington, DC.

Magill, A. Undated. ***Fire Managers Must Talk With People***. U.S. Forest Service, Wildland Recreation and Urban Culture.

McLean, H.E. 1994. "The Boise Quickstep" In: ***Report of the National Commission on Wildfire Disasters***. Washington, DC.

Mullenix, M. July 1995. "Preventing Wildfires." ***Firehouse***. Page 74.

Mutch, R. 1995a. "Prescribed Fire and the Double Standard." In ***Proceedings: Environmental Regulations and Prescribed Fire Conference***. Tampa, FL.

Mutch, R. 1995b. "Need for More Prescribed Fire." In ***Proceedings: Environmental Regulation and Prescribed Fire Conference***. Tampa, FL.

National Fire Protection Association. 1991. ***Wildfire Strikes Home***, 2nd Edition, pp. 59–60.

National Fire Protection Association. 1992. ***Report of the National Commission on Wildfire Disasters***, p.8.

National Fire Protection Association, Technical Committee on Forest and Rural Fire Protection. 1991. ***Standard for Protection of Life and Property***. NFPA 299.

National Wildland/Urban Interface Fire Protection Initiative. 1992. ***Fire Storm '91 Case Study***.

Peterson, G. 1992. ***Report of the Operation Urban Wildfire Task Force***. Federal Emergency Management Agency, Operation Urban Wildfire, p. 12.

Phillips. 1994. Personal Communication, excerpt from "Report of the National Commission on Wildfire Disasters," p. 9.

Pyne, S.J. 1982. ***Fire in America, A Cultural History of Wildland and Rural Fire***. Princeton, NJ: Princeton University Press.

Savage, M. 1989. ***Structural Dynamics of a Pine Forest in the American Southwest Under Chronic Human Disturbance***. Doctoral Thesis, Department of Geography. Boulder, CO: University of Colorado.

Shanks, Hammon, Jensen, Wallen, and Associates. 1992. "The Fire Next Time." ***Geo Info Systems***. Vol. 3, No. 2, p. 35.

Joffe, B. 1992. "Update from the Ashes: GIS Helps Oakland Organize to Rebuild." ***Geo Info Systems***. Vol. 3, No. 7, p. 43.

Sutphen, S. 1994. ***The California Fires of 1993: Coping in Orange County***. Working Paper 89. Boulder, CO: Natural Hazards Research and Applications Information Center, Institute of Behavioral Science, University of Colorado.

U.S. Department of Agriculture, U.S. Forest Service. 1997. ***Wildland Fire Assessment System***. [Online] Accessible at http://www.fs.fed.us./land/wfas.

U.S. Department of Agriculture, U.S. Forest Service, Fire Aviation Management. 1993. ***Fire Related Considerations and Strategies in Support of Ecosystem Management***. Washington, DC.

Veblen, T., and D. Lorenz. 1991. ***The Colorado Front Range: A Century of Ecological Change***. Salt Lake City, UT: University of Utah Press.

Veblen, T. 1994. ***Preliminary Report On: Fire Ecology in the Urban/Wildland Interface of Boulder County***. Boulder, CO: University of Colorado.