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Living More Safely in the Chaparral-Urban Interface

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In recent years, urban development has extended into rural areas around many of our larger cities. Where the topography is relatively flat and open, this encroachment presents no great difficulty, but where the cities are surrounded by steep, brush-covered slopes, development has resulted in all-too-frequent loss of life and property. Although intense efforts have been made to deal with this problem, one pressing need is clear: greater coordination in planning for fire control and for the prevention of flooding, landslides, and erosion.

The brushland fire-flood-erosion sequence is particularly well known in chaparral areas of southern California. Urban encroachment accelerates the cycle and adds the potential for tragedy. Unless adequate measures are taken in new developments, fire protection and flood control agencies are hard pressed to safeguard life and property.

When hazardous conditions come about through improper land use or lack of planning, they are extremely difficult to correct by either private or public action. Government agencies should therefore work together to adopt comprehensive protection plans before permission is granted for wildland development. These plans must resolve the problem presented by new construction in ecologically sensitive areas, so that added services for safeguarding such developments are not paid for by society as a whole.

Living in the urban-wildland interface creates biological and social problems which cannot be readily resolved. Logically, zoning ordinances should exclude development on steep chaparral wildlands and in areas where flooding is a common occurrence. But these are also the areas most desirable to potential home buyers because they offer a view or serve as secluded, wooded hideaways. Most of the pioneer homeowners who initially settled in these areas were aware of the danger of fire and flood and were able to live in closer harmony with natural conditions. Most modern homeowners, however, are ill equipped to live in the wildlands and have come to depend on private and public organizations for support and safety. Today's homeowners want to live in natural surroundings, but often do not know how. To live more safely in the mountains, they must regain the pioneering spirit of self-help, neighborhood teamwork, and an understanding of nature's ways. Too often, home buyers fail to realize that fire protection agencies may not be able to save the "home" from fire, and that building and safety and flood control agencies may be powerless to save them from floods and mudslides.

This report is intended to bring about greater understanding of a fragile ecosystem—chaparral. It describes preventive maintenance measures that should help reduce the damage from fire and flood. The information provided here is addressed to homeowners, home buyers, developers, landscape architects, land use planners, wildland managers, zoning agencies, city and county boards of supervisors, and other interested persons.

Although the report sometimes deals with them separately, protection from fire and prevention of erosion go hand in hand. Fire protection that weakens slopes and causes slides, or slope protection that increases fire hazard, can give us only a dangerous illusion of safety. From a realistic view, the price we must pay to live in the chaparral is high; it can be lowered only through wise planning and management.

THE CHAPARRAL ENVIRONMENT

Chaparral is a plant community in California that has adapted over millions of years to summer drought and frequent fires. Similar vegetation is found in regions of Mediterranean climate throughout the world. These regions lie along the western edges of the continents, roughly between 28° and 37° latitude in the Southern Hemisphere and between 30° and 43° latitude in the Northern Hemisphere. Except in the Mediterranean Sea, the ocean water in these regions is comparatively cool; cold currents flow toward the equator, and local upwelling brings cold water to the surface. In summer, high-pressure systems bring dry air to these regions, but in winter, rain-producing fronts move in.

Mediterranean regions are found in the countries of Europe, Africa, and Asia that border the Mediterranean

Sea; in southwest Australia and South Africa; and in Central Chile, Mexico, and the State of California. The climate is characterized by hot, dry summers and wet, moderate winters. Rainfall ranges from about 10 inches (250 mm) to above 32 inches (800 mm). The mixtures of plant species within these areas are determined by such factors as aspect and steepness of slope, soils, elevation, fire frequency, and local climate.

Chaparral Vegetation

Two distinct subformations of chaparral called "hard chaparral" and "soft chaparral" are clearly distinguished in recent ecological literature and are commonly referred to as chaparral and coastal sage scrub communities, respectively (Paysen and others 1980, Westman 1982). This distinction is important for both fire and slope management.

The coastal sage scrub community or "soft" chaparral is rapidly becoming an "endangered" habitat because it is commonly found in California's coastal zone, where most urban expansion is taking place. It is generally restricted to the more xeric sites at lower elevations, because of orographic effects, and at higher elevations because of shallow soils (Miller 1981). The dominant species that compose the coastal sage scrub community are of smaller stature than those in the chaparral community and provide a more open habitat that encourages more herbaceous species including the sages, California sagebrush, and deerweed.[1] The chaparral community as a whole is drought-tolerant. In comparison with hard chaparral species, which tend to start growth in winter, coastal sage species tend to start growth soon after the first significant autumn rains. Additionally, both annual plant productivity and wildfires in this community tend to be related to the amount of rainfall, whereas hard chaparral species are more independent of rainfall in these respects (Minnich 1983).

Generally, plant adaptations to drought include thick leathery leaves, reduced leaf size, and summer dormancy, a condition which enables the plant to reduce its metabolic functions and drop leaves under prolonged drought. Two adaptations to fire are sprouting and fire-stimulated germination of seeds. Sprouting produces new shoots from the roots or root crown after the top has been injured by fire, browsing, pruning, or other means (Sampson 1944). It may begin soon after a fire if soil moisture is available to the deep root system. After an early summer fire, sprouts may grow more than a foot tall before the first rains come in the fall.

Both sprouting and nonsprouting plant species germinate prolifically after fires. The seeds of many chaparral species remain viable for a long time; often a thick seed coat protects the endosperm from drying out. Fire often injures this seed coat so that seeds germinate under proper conditions of moisture and temperature. In the air-dried state, many seeds can tolerate temperatures higher than 302° F (150° C) for 5 minutes within the seed zone (top half-inch of soil layer), but tolerance to high temperatures is sharply reduced when seed moisture content is high (Sweeney 1956). Seeds of some plant species may germinate readily with or without fire, whereas other species with a hard seed coat, such as certain *Ceanothus* species and many legumes, often require very hot fires to germinate. Nature has developed a set of survival mechanisms for the varying fire and environmental conditions in the chaparral region.

Besides the sprouts and seedlings of the perennial chaparral species, seedlings of herbaceous species are abundant in the first few seasons after fire. Seeds of many of these species lie in the soil for years awaiting stimulation by fire for germination. Fire-dependent annuals and perennials are responsible for the beautiful array of wildflowers that can be seen everywhere the first few seasons after a fire. They provide a natural vegetative cover that helps temporarily to reduce the heavy erosion that can be expected from steep mountain slopes once existing protective cover has burned off. These short lived, fire-adapted species convert mineral nutrients to organic form, thus conserving nutrients that could be lost by leaching and erosion. Some species, such as deerweed, are able to obtain mineralized soil nitrogen from symbiotic bacteria and may be an important means of returning it to the soil in an available form for other plants. Nitrogen is the plant nutrient most easily lost during a fire.

Many chaparral plants exude chemical inhibitors, commonly called allelopathic agents. These volatile or water-soluble antagonistic chemicals are carried by the heat of the day or by water to the soil and other plants, where they may effectively stunt growth and reduce or eliminate seed germination (Muller 1966, Muller and others 1968, Rice 1974). Allelopathy is widespread in nature and the chemical agents probably accumulate in the soil from one year to the next. Allelopathy may function as a plant defensive mechanism that assures availability of the limited moisture and nutrients to the dominant plants on the site. By removing litter and burning the soil surface, fire acts to reduce the effects of these chemical inhibitors in the soil.

Plant species diversity peaks in the first few seasons after a fire, but is reduced when, in the years after a fire, the fire-dependent annuals and short-lived perennials fail to reproduce. In hard chaparral, shrub species such as bush poppy and *Ceanothus* may decline in vigor after 10 and 20 years, respectively, and provide dry, dead fuel for future fires. Chaparral fires aid in the continued survival of these species. The oldest stands of hard chaparral generally have the lowest species diversity and tend to be even-aged. In contrast, most mature coastal sage stands are uneven-aged and have greater species diversity because of seedling

[1]Common names of plants and animals are used throughout this publication. For scientific names, see Appendix: List of Species Mentioned.

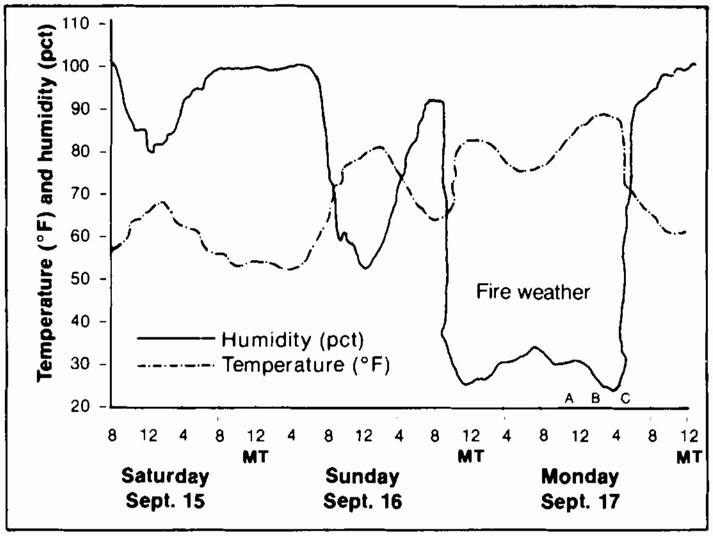

Figure 1—The 1923 Berkeley Fire—considered the most devastating in California's history—broke out in Wildcat Ridge (*A*), reaching the city (*B*) before finally coming under control (*C*). Wind velocity on September 17 was 40 mph (64.4 kph). (Source: Emanuel Fritz, University of California, Berkeley).

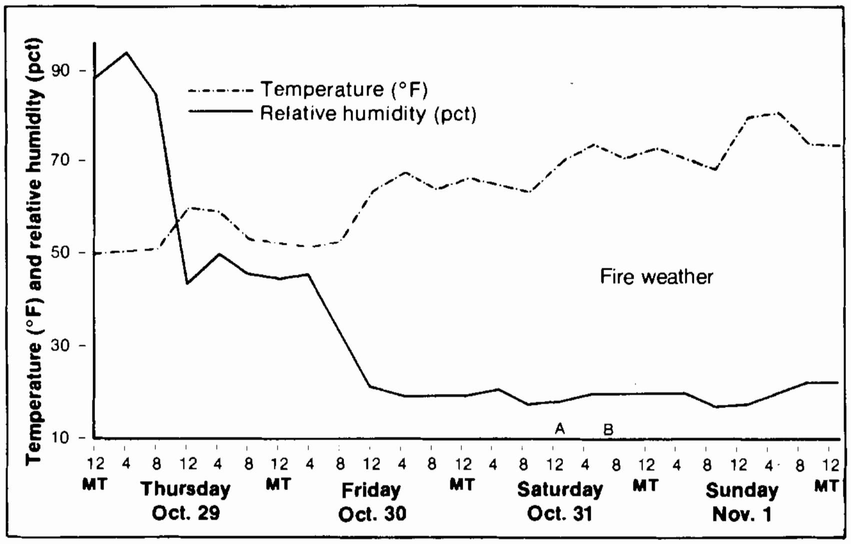

Figure 2—The Oat Fire in Los Angeles County, which started on October 31, 1981 (*A*) and burned 15,500 acres, was contained during the night (*B*) despite dangerous fire weather conditions characterized by low relative humidity. Young age classes (average: 11 years) of woody chaparral species offered relatively high resistance to fire spread.

establishment in the absence of fire and also greater herb diversity and cover.

Fire and Chaparral

Wildfires in California can occur at almost any time of year but are most prevalent during the dry season. Extreme fire conditions normally exist from September through December or until the winter rains end the dry season. Fires are more likely to occur during strong Santa Ana winds; these winds, also known as Santana, foehn, devil, or fire winds, blow from the north to northeast out of the Great Basin of Utah, Colorado, and surrounding northern States. As the air is compressed and forced southwestward to lower elevations, it becomes hot, dry, and gusty. When Santa Ana winds meet the local mountain winds, unpredictable weather patterns are often set up, making erratic fire fronts and spotting ahead of fires a common occurrence.

The rapid changes in temperature and humidity before, during, and after the 1923 Berkeley Fire illustrate the effects of fire winds on local climate (*fig. 1*). It was the most devastating fire in California history, with 624 houses burned in a single conflagration. High winds and wood shingles were the major factors in the heavy structural losses. Within 1 hour of the onset of the Santa Ana winds at 8:30 p.m., humidity had dropped from 92 to 25 percent. By midnight, temperature had increased from 63° F (17.2° C) to 82° F (27.8° C).

In southern California, humidity may approach 10 percent, as it did in the 1981 Oat Fire in Los Angeles County (*fig. 2*). Most major fires in the chaparral areas of southern California occur during this extreme fire weather. Under Santa Ana conditions, wildfires are extremely difficult to control unless the fuel supply is exhausted or the wind subsides. Studies of fire problems in Los Angeles County, particularly the coastal Santa Monica Mountains, point this out (Radtke 1978, 1982; Weide 1968). A study of frequency of fires burning more than 100 acres in the Santa

Monica Mountains from 1919 to 1982 indicates that the greater portion of wildland areas have burned at least once in the last 60 years; some have burned more than four times (*fig. 3*).

In the interior mountain ranges of Los Angeles County, fire frequency and number of acres burned are high in the summer months because of high summer temperatures and occasional lightning strikes. In the coastal ranges, fire frequency is lower in the summer, and lightning strikes are almost unknown as causes of fire. The number of acres burned is lower than in the interior ranges because the Catalina eddy, a marine breeze characterized by cool, moist air, penetrates the coastal mountains, primarily during June and July. This cool air is also responsible for the abnormal air circulation pattern of upslope instead of downslope winds during the evenings and into the night. In both the inland and coastal regions, the great toll of acreage burned from late September through December is the result of the Santa Ana wind, which has its highest frequency from September to February and is almost absent in July and August.

The pressure for urbanization of wildlands and open space is significant in the Santa Monica Mountain range. Before intensive settlement began, the north-facing slopes (those facing the San Fernando Valley) were relatively free from fire, but in the last 35 years large fires have greatly increased here. Presently the estimated fire-start probability in coastal sage scrub is about once in 14 years and in chamise chaparral once in 16 years (McBride and Jacobs 1980). This large increase in fire starts is the result of the population influx: almost every fire is started accidentally or deliberately by man.

The areas of highest fire frequency are at the fire perimeters, where fires burn together. In such a high-fire-frequency area, only the first fire burns hot because the quantity of fuel remaining for subsequent fires is reduced. The fire boundaries are determined by fire suppression activities, fuel types and their age classes, topography, fuel modification attempts (firebreaks, roads, and subdivisions), and wind conditions. Once a fire perimeter is established, it normally defines a portion of the boundaries for fires that burn as much as 20 to 30 years later (*fig. 3*). This becomes clear when we realize that chaparral fire intensity depends on the mixture and age of the individual chaparral species. The ratio of dead to live fuel is much greater in old than in young chaparral and varies from species to species. Past fire frequencies suggest that under natural conditions chaparral does not become highly fire-prone for about 15 to 20 years, or until some of the shorter-lived chaparral components die and increase the dead fuel (Philpot 1977). Coastal sage scrub, because of its shorter lived species and greater mixture of herbaceous species, can become highly fire-prone after 5 to 8 years.

The major flammable vegetation types found in the Santa Monica Mountains, namely chaparral, coastal sage scrub, and grassland, also have a direct bearing on fire

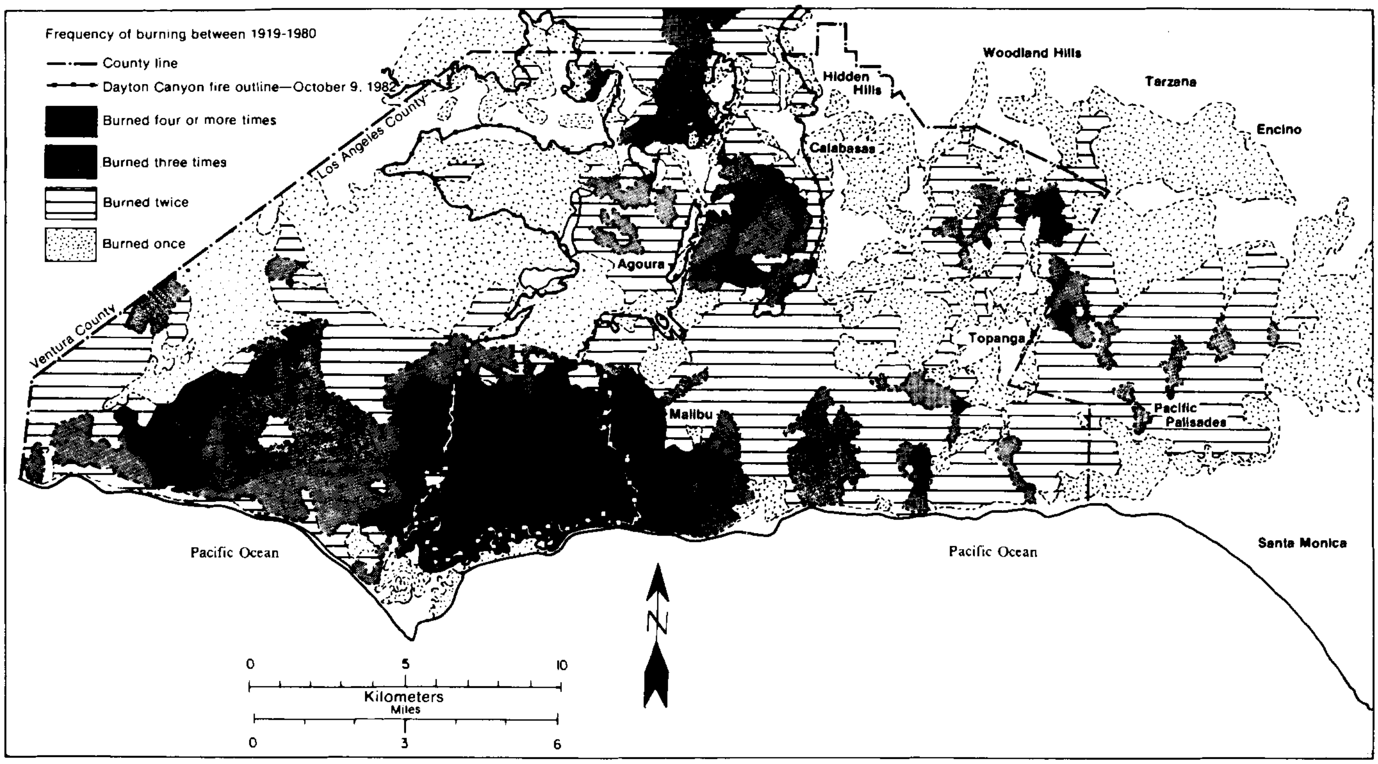

Figure 3—Frequency of fires exceeding 100 acres (40 hectares), in the Santa Monica Mountains (Ventura County line to the San Diego Freeway), southern California, 1919 to 1982. The outline on the left shows the extent of the Dayton Canyon Fire, October 1982.

frequency and fire intensity because of their different fuel loads and ease of ignition. For example, the flashy annual grassland fuel seldom exceeds 5 tons per acre (11.2 t/ha) whereas mature chaparral can exceed 30 tons per acre (67 t/ha). Grassland fires may be more frequent but are also more easily extinguished; however, they often carry the fire into the coastal sage scrub and chaparral. In any event, the fuels dictate the ease of fire starts and spread rates and this has a direct bearing on fire frequency. When the grasslands were grazed, reducing fuel loads, the highest fire frequency was found in coastal sage. With reduction in sheep grazing, fires in annual grassland, especially along roads and rights of way, have become the major source of fire starts. Nevertheless, fire starts have been historically concentrated in the coastal sage areas, where development has been greatest.

The predictable direction of fire spread in the Santa Monica Mountains during Santa Ana winds is south to southwest. This spread pattern is primarily influenced by fire winds and secondarily by topography. Because canyons in the eastern part of the Santa Monica Mountain range run in a south to south-westerly direction or parallel with the fire winds, fire is channeled up the canyons, spreads out as it reaches the ridges, contracts again as it is funneled downhill through the canyons, and may fan out in either direction as it reaches the beaches. The western portion of the Santa Monica Mountains does not have this pronounced linearity of canyons and fire winds, however. Fires therefore are more influenced by the direction of the winds and are more irregular in shape (Weide 1968).

PROBLEMS IN WATERSHED MANAGEMENT

A watershed is generally understood to be all the land and water within the confines of a drainage area. Vertically, it extends from the top of the vegetation to the underlying rock layers that confine water movement. A homeowner's watershed is the area of land whose drainage directly affects the safety of that person's property. Frequently this area includes adjacent properties over which the homeowner has little control. The drainage conditions may vary widely. Some homeowners have a well-manicured property adjacent to a street where all runoff is channeled into rain gutters. Others are in a watershed that includes steep slopes where most runoff finds its way eventually into intermittent stream beds. Sometimes the steep slopes are undercut by either natural stream channel erosion or development activities. To know how to safeguard their properties, homeowners should understand the erosional processes affecting a watershed, and the changes brought about by wildfire and their own actions.

Dry-Creep, Wet-Erosion Cycle

In chaparral, preserving the stability of the slopes is a major problem. Most chaparral in southern California grows on geologically young mountains where the steep slopes range from 25° to more than 70°. About 25 percent of the chaparral watershed exceeds the angle of repose, that is, the angle between the horizontal and the maximum slope that a particular soil or other material assumes through natural processes. On slopes that exceed the angle of repose, gravitational forces are likely to cause soil and rocks to slide or fall downhill unless anchored by plants. The angle of repose increases with the compaction of the material, with the average size of fragments, with the surface roughness and cohesion of soil particles, and, in sand, with an increase in moisture content up to the saturation point. For loosely heaped soil particles the standard angle of repose is approximately 9° for wet clay, 11° to 20° for dry sand and mixed earth, 21° to 25° for gravel, and 23° for moist clay (Van Burkalow 1945). Under natural conditions and where soil is anchored by deep-rooted plants, the angles of repose are much steeper than those given. Occurrence of landslides in chaparral is strongly related to the angle of repose for different soils, once cover, root depth, and root strength are taken into consideration.

On steep, harsh southern exposures, plant cover is sparse, and dry creep and dry ravel (downhill soil and debris movement during the dry season) become major erosional forces, especially where slopes beyond the angle of repose have been undercut. During low rainfall years, this dry creep and dry ravel often exceed wet erosion rates during the winter months. The debris settles at the foot of the slopes, where it is flushed out by the rainstorms of higher-than-usual intensity, which occur about every 5 years. Dry creep and dry ravel can also be greatly accelerated by animals, such as deer, rodents, and birds.

The dry-wet cycle on these slopes begins when summer drought encourages dry creep and dry ravel. The onset of the first light winter rains gives the soil cohesion and greatly reduces dry erosion. If further rains do not follow before the soil dries out, dry creep and dry ravel again accelerate. With heavier rains, dry erosion finally stops completely, so that erosion is at a minimum during the first part of the rainy season. As the rainy season continues, however, the soil mantle becomes saturated and rill and gully (overland) erosion accelerates. Toward the end of the rainy season and until the soil surface dries out and loses its cohesiveness, erosion is again low (Anderson and others 1959).

The erosion cycle is influenced by topography and vegetation. A north-facing slope is less exposed to the sun than a south-facing slope, and is therefore more moist for the greater part of the year. On north exposures, deeper soils and more dense plant cover of different species have developed over time, and these greatly reduce dry creep and overland erosion. Dry ravel occurs sporadically but may

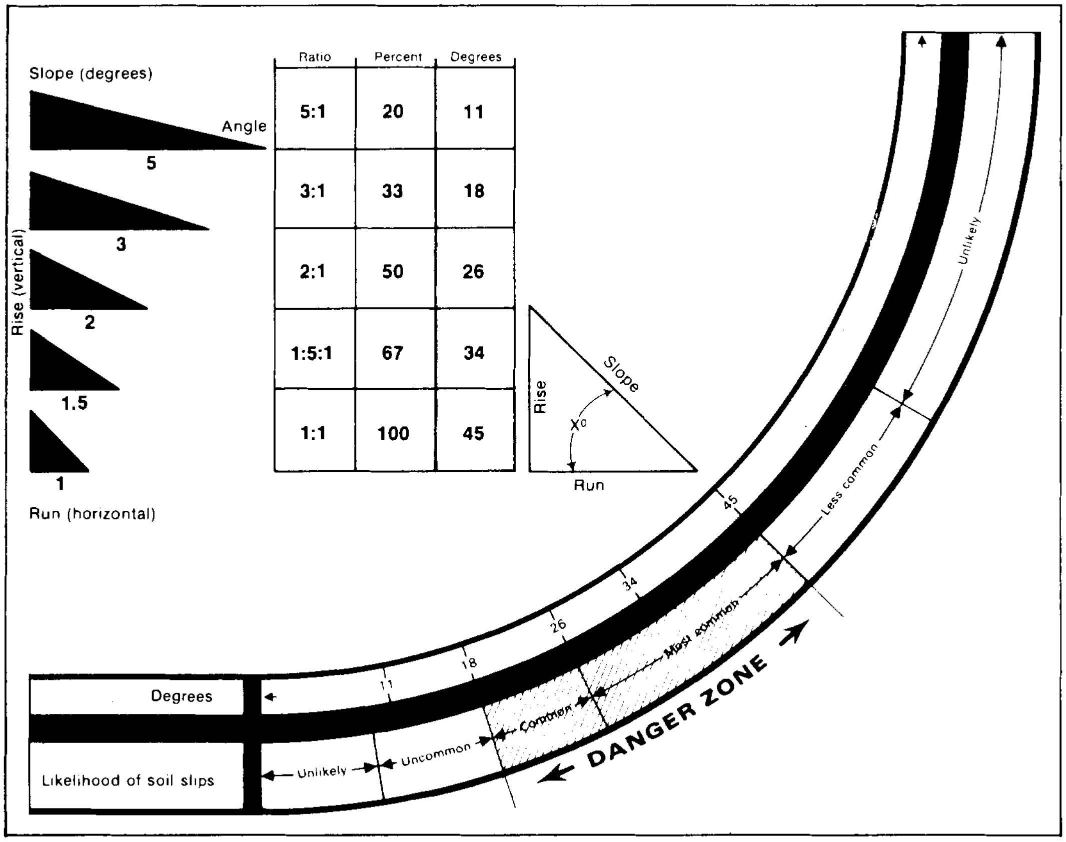

Figure 4—Slope ratio, percent slope, and degree of slope are shown for some hillsides of varying steepness. On natural slopes, the danger of soil slip failures is related to slope angles. The angle may be expressed as the ratio of run to rise, either as a percent (rise/run) or in degrees (angle between run and slope) (Campbell 1975).

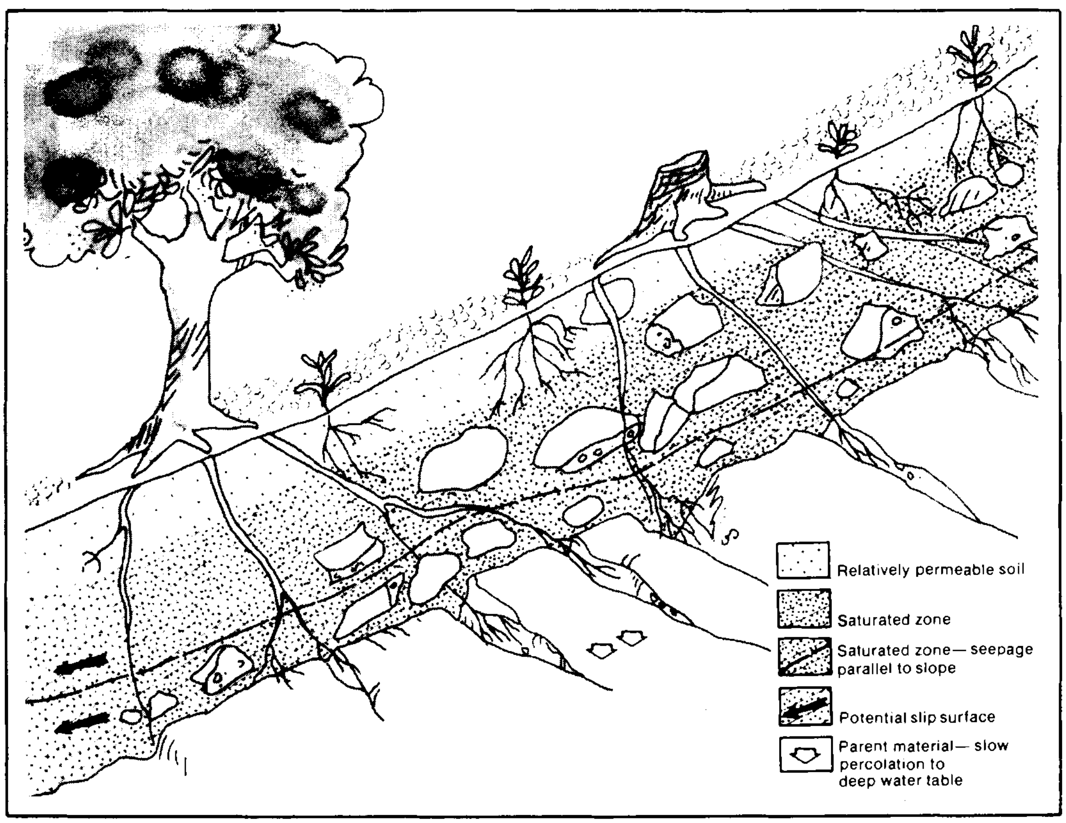

Figure 5—During heavy rains, the amount of water that infiltrates the soil layer may exceed the capacity of the parent rock material to transmit water. A zone of supersaturated soil may develop, with a potential slip surface as the lower edge. The chances of slope failure are increased when deep-rooted native vegetation is replaced by more shallow-rooted plantings. Even though little or no runoff and little erosion may occur at the surface, slope strength at the deeper levels is reduced.

be high during or immediately after a fire; plants that were anchoring the debris on their uphill side are burned off, and gravitational forces are again influential.

Dry creep is more continuous and at times almost imperceptible, but soil slips and slumps (landslides)—the major wet erosional processes on mature chaparral watersheds—are readily visible. A soil slip is a miniature landslide caused by downslope movement of soil under wet or saturated conditions. Slips and slumps account for almost 50 percent of the total erosional processes on a watershed (Rice 1974).

Soil failures are most common on slopes that range from 25° to 45° (*fig. 4*). As the slopes become steeper, the thickness of the soil mantle decreases and rockslides become more common. The minimum angle of soil failure is steeper for chaparral vegetation than for grasses. Slides occur primarily during rainfall of high intensity, after the soil has been saturated from a single major storm or from several medium- to high-intensity storms in close succession. In such cases, the rate of water infiltration into the soil mantle exceeds the rate of percolation into the underlying bedrock. This results in supersaturated soils (*fig. 5*).

Slips and landslides occur more readily when the interface of the soil and the parent material is low in shear strength (resistance to separation), but this is not easy to predict for a particular region. Slides may not add much to the immediate amount of downstream sediment eroded from a particular watershed because the eroded material may accumulate at the base of the slope. The sediment effect of slides is magnified after a fire because even moderately heavy storms can create high-velocity overland flow of water over bare hillsides, carrying away the accumulated sediment. Because flow velocity is further increased in the streambeds, the water can transport greater amounts of debris.

Fire-Flood Cycle

The amount of erosion after a fire depends on the storm intensity and the time elapsed since the fire (*table 1*). Postfire erosion may be more than 50 to 100 times greater than on a well-vegetated watershed. Understanding of the fire-flood cycle is vital to watershed management because the peak flows created by fire-denuded hillsides are responsible for accelerated erosion and flood damage.

Table 1—*Amount of erosion related to age of chaparral and maximum 24-hour precipitation*

Years since fire	Erosion at maximum 24-hour precipitation of . . .		
	2 inches	5 inches	11 inches
		Yd³/acre	
1	5	20	180
4	1	12	140
17	0	1	28
50+	0	0	3

Source: Kittredge 1973

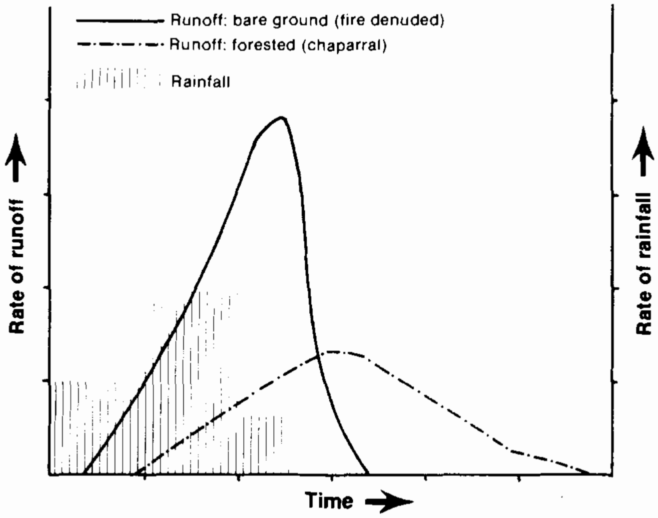

Figure 6—Water runoff from a watershed denuded by fire reaches a higher peak than that from a forested watershed.

Peak flow is the point of maximum streamflow, the result of precipitation that is added to the base streamflow after immediate losses for interception, infiltration, and soil moisture recharge have been satisfied. On bare ground, peak flow increases drastically as the rate of rainfall increases, and reaches its maximum about the same time as rainfall (*fig. 6*). As the rain stops, runoff is greatly reduced and is eliminated within a very short period thereafter. As shown in the graph, runoff on a well-vegetated watershed is often not noticeable until the storm is well underway. A much reduced peak runoff is normally reached at the end of the storm, and the constantly diminishing flow is fed for a considerable period of time. Grassland watersheds have greater peak flows than forested watersheds.

A well-vegetated watershed thus greatly reduces peak streamflow by increasing the time before runoff begins, and by spreading it over a longer period of time. This eliminates or greatly reduces watershed damage, as follows: Increasing the infiltration rate and lag time by as much as four times decreases the peak discharge rate (peak flow) by almost four times. On the other hand, a decrease in lag time and infiltration rate, caused by bare soils, produces a geometric increase in sediment-carrying capacity. Thus, as the velocity of the water (v) is doubled, its erosive power is increased 4 times (v^2) and its carrying capacity is increased 32 times (v^5). This carrying capacity dictates the quantity and size of material that can be carried by a given amount of water and adds to its destructiveness (Leopold 1980).

Of the wet erosional processes, scouring out of stream channels after fires accounts for the greatest sediment yield. Overland flow causing rill and gully erosion is next in importance. The debris that clogs a stream channel bed and is scoured out has been accumulating since the last fire and was reduced by intermittent nonfire-related flood peaks. Thus, even during nonfire years, channel scour is a major source of sediment. Both channel scour and overland flow increase with storm intensity, channel scour being responsible for two to three times more sediment than overland flow in almost all situations. The amount of channel scour depends on stream discharge and, therefore, the capacity of moving water to hold and carry sediments. Overland flow depends on other factors, such as the infiltration rate of the soil (related to soil texture and aggregation), the percolation and water storage capacity (related to soil texture and depth), the steepness of the slope, the heat of the fire (which affects development of water-repellency in soil layers), and the splash effect during heavy rains (which clogs the pores of fine-textured soils).

The production of water-repellent (hydrophobic) soils by hot fires is an important factor in overland flow (*fig. 7*). In nature, many soils are water-repellent to some degree, as a result of the breakdown of organic material and the presence of certain chemicals in the plant litter. Often fire volatilizes these chemicals and the resultant gases penetrate into the soil, where they cool, coat the soil particles, and reduce water penetration through the soil layer that has been affected. Water-repellency is more acute in coarse (sandy) soils than in fine (clay) soils. Fine soils have a greater surface-to-volume ratio, so that more of the water-repellent gases per unit area of soil are needed to coat all soil particles effectively. Depending on the heat of the fire, the water-repellent layer may be found almost at the surface or down as far as 2 inches (5 cm) (DeBano 1969, Osborn and others 1967). Nonwettable soils reduce germination and establishment of plants on sloping ground because of the lack of adequate soil moisture.

Immediately after a fire, the water-repellent layer acts as mulch by preventing evaporation from the lower wettable layer. Chaparral that resprouts during the hot summer after a fire draws moisture from the rock crevices and the water remaining in the lower wettable layer. With the onset of rains, the surface wettable layer becomes saturated; further precipitation cannot infiltrate except through the breaks in the water-repellent layer. The resulting overland flow is magnified by successive storms. However, if the first few winter rains are light and the thin wettable surface layer does not dry out between rains (that is, in cool, overcast weather), then the water-repellent layer becomes wettable from slow absorption of moisture from above. Once moist throughout, it retains its infiltration and percolation capacity. Surface runoff from later storms is greatly reduced as long as the layer does not dry out and become nonwettable again. Mechanical disturbance breaks up the nonwettable layer even more readily than gentle rains. The effect of water repellency is much lower after the first year and becomes negligible after 5 to 10 years (DeBano and Rice 1973). Such changes in soil wettability may partly explain the great differences observed in overland flow after a fire.

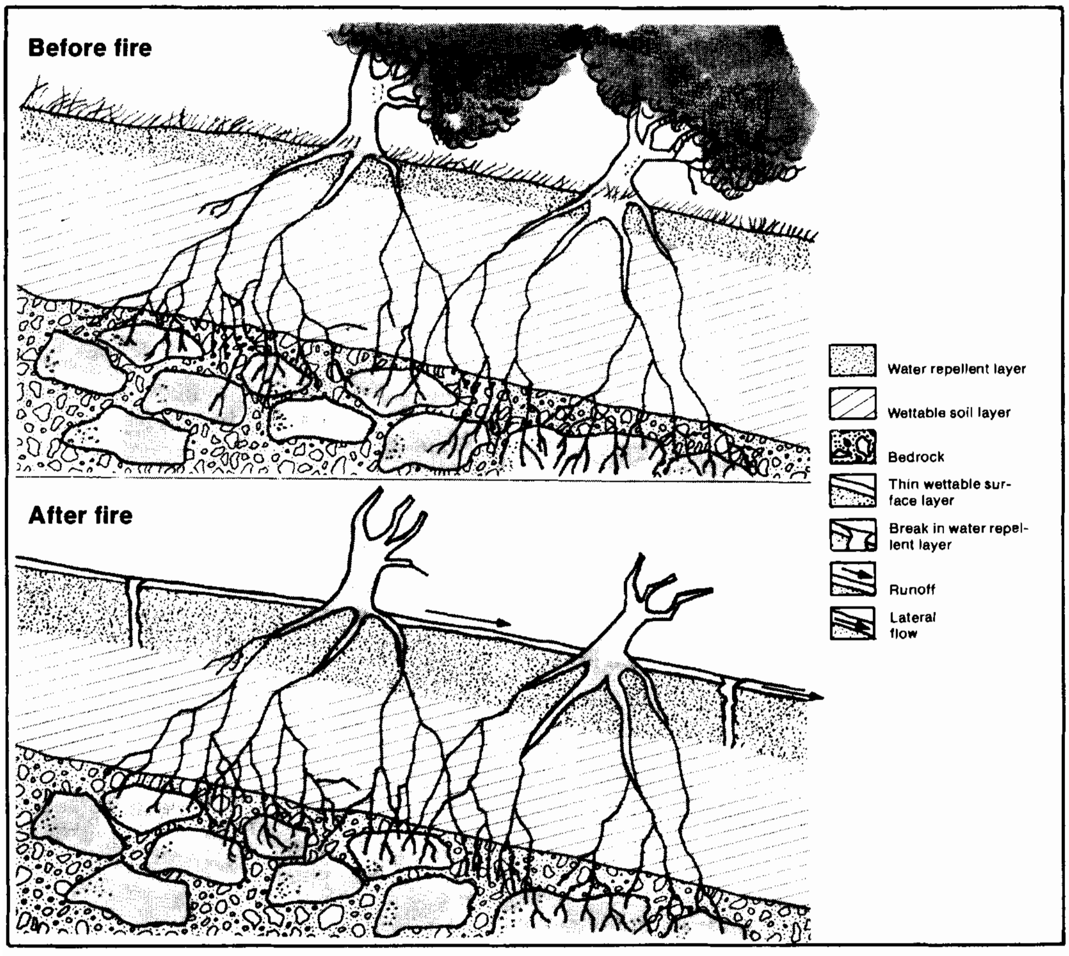

Figure 7—The effects of heat on the soil may increase the depth of the water-repellent layer, and increase repellency, so that water does not penetrate well to plant roots. Thus the establishment of seedlings is slowed down until the water-repellent layer is broken up. Water from frequent heavy rains flows overland, and rill and gully erosion is increased. With time, the water-repellent layer again becomes wettable.

During the season after a fire, if rainfall is low and storm intensities are light, overland flow and channel scour are lessened. Dry creep, dry ravel, and occasional landslides which started on steep slopes during the fire may then be the primary agents of erosion. On the other hand, dry erosion may be greatly reduced if the fire occurs immediately before the rainy period or between rainy periods.

Increases in landslides during the rainy period following a fire could be caused by well-spaced storms that permeate the nonwettable layer and completely recharge the water-holding capacity of the soil. Once the soil moisture is recharged, a high-intensity storm could quickly supersaturate the soil, thereby accelerating wet creep, starting slumps and slides, and greatly increasing overland flow. Under these conditions, postfire rainy season slumps and slides have a tendency to occur more frequently on a south slope than a north slope. On south slopes, a sparse prefire vegetative cover, coupled with thin soils and a smaller root network, provides less soil-binding and water-holding capacity.

Postfire slips and slumps during the first few years after a fire may be greatly reduced on nonwettable soils if high intensity storms follow each other in close order, thereby reducing rainfall penetration through the nonwettable layer. The soil below the nonwettable layer would remain dry, eliminating landslides, but the greatly increased overland flow would result in highly visible rill and gully erosion and would increase channel scour.

Erosion Factors

Erosion is the product of six factors: soils, climate, vegetation, animal activity, topography, and human activity. The climate, the degree of slope of the land, and the soil physical characteristics cannot be directly controlled to reduce soil erosion, but can be modified through soils engineering, whose principal aim is to change slope characteristics so that the amount and velocity of runoff is lessened.

Soils

Soil is developed through physical and chemical weathering of a thin surface layer of rock and mineral fragments (soil parent material). Soil texture, structure, depth, and fertility determine what kind of plant life a soil can support and what its infiltration rate, percolation rate, and water holding and water storage capacities will be. Soil texture and structure determine the erosiveness of soils. Texture is the proportion of mineral particles of various sizes in the soil; structure is the degree of aggregation of these particles.

In order of decreasing particle size, soil texture classes are sand, silt, and clay. Sand particles are visible to the naked eye; individual silt and clay particles are visible only under the microscope. Sandy soils are referred to as coarse textured, loamy soils as medium textured, and clay soils as fine textured. Generally, soils composed of coarser particles drain water more rapidly than soils composed predominantly of finer particles. Sandy soils allow fast water infiltration and percolation, but little storage; clay soils allow slow infiltration and percolation and greater storage. Sand, silt, and clay are easily eroded if the particles are not bound into stable aggregates. Organic materials and colloidal clays are primary cementing agents. Soils high in clay content and organic material are among the least erodible and most fertile soils. Sandy soils low in clay and organic material tend to have high erosion rates.

Good soil structure contains much airspace, which allows ready water infiltration into the soil, water percolation through the soil, and higher water storage capacity. Soils that have blocky or prismatic aggregates or that contain a high fraction of gravel (rock fragments larger than 2 mm) have higher infiltration rates than soils that are platy, such as most clay soils, or granular, such as some loamy soils.

Although geological relationships are too complex to analyze here, review of some geologic terms and principles should clarify the direct implication of geology in slope management. The type of rock and parent material present are good indicators of the weathering of rocks, the soil-forming processes, and erosion. The rock hardness, the size of the crystals, and the degree of crystal bonding and cementation are all important factors. For example, many granitic rocks erode rapidly because of weak crystal cohesion and large crystal size. This makes our granitic soils highly erodible. Rhyolite rocks weather more slowly, producing finer crystals, and soils derived from these rocks are therefore less erodible. Basalt rocks have even finer crystals that weather very slowly and soils derived from these rocks are less erodible still.

Generally, metamorphic rocks (rocks that were altered in form under extreme heat and pressure) are harder than igneous rocks (rocks formed by cooling and solidification of molten lava) and sedimentary rocks (rocks which were broken down by weathering and deposited by water, wind, and gravity and then consolidated by heat or pressure or cemented by silica, lime, or iron solutions).

Climate

The major climatic factors in erosion are precipitation, temperature, and wind. Precipitation, viewed as the interplay of amount, intensity, and duration, rather than as average rainfall, is the greatest erosional factor. The first rainfall after a dry period saturates a bare soil surface, causing little erosion. After that, raindrops hit the soil-water surface, causing breakdown of the soil aggregates. Splashing causes muddy water, in which the smaller soil particles are held in suspension. When this muddy water enters the soil, the pores become clogged; infiltration slows down and may almost stop. Amount and velocity of runoff are increased, causing surface erosion, rills, and finally gullies. If the runoff water is concentrated long enough on a particular portion of a slope, the soil becomes saturated and mud flows result.

Temperature and wind have some erosional effects. High temperatures have an indirect effect in creating a harsh environment for plants, so that revegetation is slow and there is little soil binding. Wind erosion at the surface is most critical on fine-grained dry soils devoid of vegetation. When large areas become exposed, as on recently tilled fields or sandy deserts, or in dry, overgrazed regions, wind erosion may become the dominant process.

Topography

Topography can be directly controlled or permanently altered to reduce soil erosion. Changes in topography influence climate (rainfall), soils, and vegetation. Degree and length of slope, the two most important factors that determine the amount of runoff and soil erosion (*table 2*), can often be manipulated. Cover crops, such as grasses, help to offset the effect of slope on surface erosion and contours can be very effective in reducing soil erosion and runoff. Rains of high intensity cause much greater amounts of erosion than do low intensity rains under similar slope conditions. Two rules of thumb emphasize these important relationships: doubling the degree of slope increases the erosion two to three times, and doubling the horizontal length of the slope increases erosion two to three times.

To visualize the amounts of sediment carried away by erosion, note that 1 mm (0.04 inch) of soil erosion approximates 2 tons of topsoil per acre (4.6 t/ha) or up to 4 cubic yards (3 m^3) of wet soil. Thus, 0.04 inch (1 mm) of soil erosion per acre equals about one large dump truck of debris. These estimates would be affected by the type of soil and the rainfall intensity. During high intensity rains, runoff and erosion increase with length of slope and shallowness of soil, because at high intensities there is less time for infiltration and water storage. For low intensity rains, runoff and erosion decrease greatly (*table 2*). If the soil has a low infiltration rate and low water storage capacity, excessive runoff and slope damage can be reduced only through engineering practices, such as installation of ter-

Table 2—*Effects on erosion and runoff produced by slope characteristics, protective cover, and rainfall intensity*[1]

Erosion factor, soil, location, time period, crop	Annual rainfall	Slope steepness	Slope length	Annual soil loss	Water loss
	Inches	*Degrees*	*Feet*	*Tons/acre*	*Pct rain*
Slope					
Steepness	40	2	91	20	29
(Shelby loam, Montana, 1918-35, corn, clean tilled):	35	5	73	69	28
Length (Shelby silt loam,	33	5	90	24	19
Montana, 1934-35, corn,	33	5	180	54	21
clean tilled):	33	5	270	66	24
Direction (Marshall silt loam, Iowa, 1933-35, corn, clean tilled):					
On contour	27	5	—	0	0.1
Up and down	27	5	—	12	12
Protective cover					
Palouse silt loam, Washington, 1932-35 wheat):					
Fallow	22	17	—	9	9
Bare	22	17	—	28	25
Rainfall intensity					
(Marshall silt loam, Iowa, 1932-34)	(2)	5	158	9	11
	(2)	5	315	18	18
	(2)	5	630	33	20
	(3)	5	158	8	28
	(3)	5	315	6	17
	(3)	5	630	6	14

Source: Bennett 1939.

[1]Rainfall in southern California is generally more concentrated and of higher intensity than in Montana or Iowa, and often causes more erosional damage than indicated here.

[2]High intensity = rains considerably exceeding infiltration capacity of the soil.

[3]Low intensity = rains twice the duration of high intensity rains and only slightly above the infiltration capacity of the soil.

races and drains which take the water off the slope before it can do any damage. Compaction of the soil reduces infiltration and surface roughness increases it.

Terracing reduces the length of the slope, mitigates the degree of slope, and disperses the water at a lower velocity, thereby reducing its cutting action. The greatly reduced runoff reduces the amount of soil eroded. Significant reduction in total runoff from terraced land compared with that from nonterraced land can be achieved; the soil becomes more permeable because the reduced velocity of the runoff allows more time for infiltration (*table 2*).

Spacing of terraces is determined primarily by the slope of the land. Spacing is also influenced by the ability of the soil to absorb water and transmit it through its profile, and by the plant material that covers the slopes. Permeable soils of high water storage capacity, erodible soils, soils underlain by weak bedrock, and soils on steep slopes require close spacing of terraces. In areas of intense rainfall, and in residential areas, concrete terraces (bench drains) and down drains are used to channel the water off the slope, but may not prevent slippage. During the intermittent high-intensity rains that occurred in southern California in the spring of 1978 and 1980, I noted many slope failures on manmade slopes despite concrete terraces. Slope failures often occurred on permeable soils on steeper slopes that were planted to grasses and shallow-rooted vegetation instead of deep-rooted plants. In areas of high-intensity rains, both concrete terraces and deep-rooted vegetation are therefore necessary. Bench drains, generally, should not be installed on natural slopes steeper than 20° because there may be weakening of slope stability at the steeper angles.

Contour planting, a system of small earth terraces constructed around the slope so as to follow the contour of the land, is used as a soil conservation measure. It is most successful on permeable soils during average storms of medium duration. Heavy, intense storms allow contours to break and permit the water to concentrate in channels down the slope. Grains such as barley have been used successfully for over 50 years in initial contour stabilization of highly erosive fill slopes of good permeability until deep-rooted, woody plant material has become established.

Vegetation

A good vegetative cover can greatly offset the effects of climate, soil, and topography on erosion. Vegetation achieves this effect by intercepting rainfall, and by decreasing the velocity of runoff and the cutting power of water, thus allowing more time for water to infiltrate. In addition, vegetation increases soil particle aggregation and porosity. Roots bind the soil particles and anchor the soil to the parent material. Transpiration through the leaves dries out the soil, enabling it to absorb more water.

Different types of vegetation reduce erosion to different degrees. Plants with interwoven rhizomes, plants that form a tight mat, or those that produce much litter and have tight aerial crowns normally decrease surface erosion more than plants that lack these characteristics. Most grasses are therefore well suited for surface erosion control, and deep-rooted woody plants for permanent slope stability especially on slopes with deep soils. This fact was reemphasized in studies which showed that during moderate- to high-intensity storms, soil slippage (shallow mass soil movement) was inversely related to the rooting pattern, size, and density of vegetation (Bailey and Rice 1969, Rice and others 1969, Rice and Foggin 1971). Analysis of the soil slips by vegetative types showed slippage on about 25 percent of the barren or sparsely covered natural slopes situated on harsh southern and eastern exposures. The roots of the sages, the predominant vegetation on these sites, are shallow and spread laterally through shallow soil instead of into bedrock. Slippage occurred on 12 percent of the area converted from brush to perennial grasses, but on only 6 percent of the area converted to annual grasses. Apparently a higher density and greater below-ground root biomass of annual grasses compared with perennial grasses more than compensates for their more shallow root system. On slopes converted from chaparral to grass, soil slip patterns were thus related to root patterns, whereas on natural slopes they were related to soil factors.

In all chaparral vegetation types combined (chamise, oak, broadleaf) there was slippage in less than 2.5 percent of the area. These vegetation types are characterized by plants with deep tap roots. California scrub oak with roots extending more than 30 feet (9 m) deep and occupying mesic northerly and easterly aspects, is one of the vegetative types least susceptible to slippage. Overall, dense broadleaved chaparral, which prefers the more mesic northern exposures, is much less susceptible to slippage than the more sparse chamise chaparral predominantly found on harsher southern exposures.

Vegetation, in general, increases the moisture storage capacity of the soil, particularly when plants are vigorously growing and transpiring. Most chaparral plants are evergreen and active in winter, thereby increasing the capacity of the soil for greater soil moisture storage during the critical winter period.

Any good vegetative cover will greatly reduce erosion during intense rainfall of short duration or extended rainfall of low intensity. In southern California's Mediterranean climate, however, almost yearly storms of high intensity and long duration are characteristic. Therefore, the most effective plant material possible is needed, along with proper land use planning. In chaparral, nature has provided a watershed cover that has become effectively adapted to dry, hot summers and long periods of summer drought. Modifying this cover for fire protection creates many problems.

Animals

The influence of animals on erosion is closely linked to that of vegetation. For example, beneficial soil fauna such as earthworms and beetles are more abundant under a good vegetative cover. They greatly improve soil structure by mixing humus with subsurface soil layers and by creating channels in the soil which increase soil permeability. A moderate number of rodents, such as pocket gophers, are also useful for this purpose. Too many rodents can be a nuisance, however, creating soil instability by damaging root structure, tunneling large underground waterways, and concentrating water in sections of hillsides. These conditions can induce slippage problems.

Animals, like plants, require a definite set of habitat conditions. A change in habitat often directly affects population dynamics. In an informal study made of a 90- by 150-foot (27.4 by 45.8 m) chaparral-covered urban watershed that was fenced but had not burned in 40 years, various changes in animal populations were observed. The chaparral was pruned for fire safety in 1977 and 1978 and the understory was thinned, thereby destroying the habitat for pack rats. The resident rattlesnake, measuring 44 inches (111.8 cm), was removed from the site. The understory was planted to low fuel plants, which were readily clipped by pack rats and mice that reinvaded from surrounding areas. California quail moved onto the site, but no California ground squirrels were sighted.

Within a year after the partial brush clearance, the October 1978 Mandeville Canyon Fire denuded the study area and surrounding watersheds. This prompted a rat invasion into nearby residential areas and created the open habitat preferred by ground squirrels. During July and August, 1979, 17 ground squirrels were trapped within the study area, accounting for 100 percent of the population sighted. Four rattlesnakes were also removed during the summer months. One rattlesnake was killed onsite; its stomach contained the remains of four gophers. With the removal of the rattlesnakes, the gopher population exploded with serious detriment to the reestablishment of the low fuel plants. Three western racers, two gopher snakes, and one mountain kingsnake were spotted during 1979, but these are no match for a mature gopher in its natural underground habitat.

From July 1 to August 15, 1980, 39 ground squirrels were trapped, accounting for every ground squirrel within the study area at the time. Trapping was continued on September 1 and an additional 15 ground squirrels were caught within the next 2 weeks. The great influx of ground squirrels into the area was supported by juvenile animals that moved into areas of low population densities created through trapping. It is estimated that 90 percent of the adult ground squirrels would need to be trapped every year to maintain effective population control. Rabbits were sighted for the first time, and along with rats and mice, are heading towards a population explosion. A coyote was observed to raise a litter each year during 1978-80, near the study area.

In this example, human interference changed the balance of nature by changing the natural habitat. The changes in the predator population resulted in increasing the gopher, rat, mouse, ground squirrel, and rabbit populations. This had an immediate detrimental effect on the watershed through reduction of ground cover and undermining of slope stability.

The detrimental effect of rodents on slope stability is also pointed out in hillside grading guidelines (Los Angeles County 1975) which specify that "fill slopes steeper than 2:1 (20 percent, 11°) with a grading project located next to undeveloped land infested by burrowing rodents, shall be protected from potential damage by a preventive program of rodent control."

Observations by the Los Angeles County Agricultural Commissioner's Office in Calabasas Park confirmed that ground squirrels were at least a significant contributing cause of a massive slope failure that cost more than $500,000 for rehabilitation. Control of rodents affecting sloping land is therefore a cost-effective undertaking.

Trapping and population control is most successful when the life history of the animal is known. The California ground squirrel causes extensive hillside damage (*fig. 8*) because it digs burrows from 5 to 39 feet (1.5 to 12 m) long, almost 5 inches (13 cm) in diameter and up to 4 feet (1.2 m) deep (Grinnel and Dixon 1918). Colonial burrows used by both sexes and their young may be more than 130 feet (40 m) long. At any time there are more burrows than individual squirrels, because the squirrels construct new burrows from time to time to have additional escape routes and probably to leave most of their fleas behind in the old nest. These fleas can be the carrier for the bacillus of the bubonic plague. Minimal handling of ground squirrels is therefore advisable.

The California ground squirrel was an asset to the Indians because both its fur and meat could be used. The squirrel became a pest when the settlers drove out the Indians and destroyed many other natural enemies such as the golden eagle, redtailed hawk, coyote, badger, wildcat, weasel, rattlesnake, and gopher snake. The importance of natural enemies for population control is well documented. One study showed that a nest of golden eagles consumed 6 ground squirrels per day for a total of about 540 squirrels during a 3-month period (Grinnel and Dixon 1918). Intensive agriculture also supplied a dependable food source for the ground squirrels; thus two primary factors of population control, seasonal scarcity of food and natural enemies, were greatly reduced or eliminated.

In the wildlands, ground squirrels gather almost any seeds and fruits available, but prefer the young leaves and seeds of alfilaria, star thistle, and bur clover. The animals are also fond of prickly pear. In urban areas and agricultural lands they gather grain and grass seeds. Successful revegetation methods with grasses can therefore contribute to population explosions by providing a plentiful seed source from early ripening seeds. Among cultivated nuts, ground squirrels prefer almonds and walnuts, and among fruits they like apples, prunes, peaches, apricots, figs, and olives. Poultry and wild bird eggs, as well as potatoes, are also sought after. Grapes, if harvested while ripening, are normally safe from ground squirrels.

The breeding season of the California ground squirrel extends from about February until April. At higher altitudes and in colder climates, the breeding season is later and shorter. A litter varies from 4 to 11 and averages 7 or 8. Under favorable conditions of climate and food supply, two litters are produced in 1 year. The gestation period lasts about 30 days and the young are born towards the end of March. They may appear above ground near their burrows towards early May. They start digging their own burrows within 4 to 6 weeks thereafter, and fend for themselves from then on. If the population density is too high locally, they migrate by July and August. By September, the young have matured.

Human Interference

The homeowner must remember that on steep terrain almost every stone and plant has its place. Anything that changes the natural relationships of soil, vegetation, and runoff may create a potential hazard. Random clearing or tunneling or other disturbance of the soil may channel overland flow or groundwater seepage in such a way as to weaken slopes and eventually lead to failure of an entire slope. Undercutting of the toe of a slope is one of the major reasons for eventual slope failures. Development above such slopes should be severely restricted unless the slope can be totally restabilized by mechanical means. Restabilization should be a logical prerequisite for issuing a building permit. With the rapid mobility of the urban population, the original owner and builder are seldom faced with the hillside problems and financial losses they helped create.

The urban hillside homeowner normally lacks the knowledge necessary and year-round commitment to property management, so that small problems magnify and watershed deterioration progresses from year to year. For example, a bench drain—a concrete sidehill drain—that is partially blocked by soil, or a pipe filled with leaves, will eventually cause uncontrolled overland runoff, supersaturated soils, and slope failures. Slopes cleared of deep-rooted vegetation but not properly replanted will slowly weaken because the strength of the remaining root system is steadily deteriorating. Root decay starts rapidly with the death of the plant and is completed in about 10 years (Rice and others 1982). Since landscape plants that replace native plants take a longer time to provide an equal biomass of live roots to the soil, it is therefore best to thin and prune, leaving deep-rooted native plants alive as permanent specimens or at least until the replacement vegetation is well anchored.

A row of water-demanding landscape plants, such as roses or fruit trees, planted along the edge of a slope may be responsible for supersaturated soils during intense rains. Backyards that are leveled to accommodate lawns may be responsible for channeling water over the slope. A broken or leaky pipe or sprinkler system or improperly laid out drains are causes of slope failures, especially in older developments. Improper or loosely compacted fill may settle, thereby often breaking drainage pipes laid across or through them. The displacement of natural enemies of slope-damaging rodents increases their population and also accelerates their damage potential. Any hillside development has the potential for creating serious problems for

Figure 8—Hillsides in southern California are often damaged by ground squirrels that burrow deep into the soil and dig for distances up to 40 feet (12.2 meters).

lower-lying homes; however, the unwillingness of a downslope or sideslope resident to provide drainage easement may affect the drainage patterns of the whole watershed, and dangerously undermine its stability.

On a larger scale, the hydrologic characteristics of a watershed can be altered in two ways by urbanization (Strahler and Strahler 1973):

1. The percentage of surface runoff made impervious to infiltration is increased through the construction of buildings, driveways, and so on. This leads to increased overland flow (runoff) and greater discharge directly into streams, increased flood peaks, and reduced recharge of groundwater.
2. Storm sewers allow storm runoff from paved areas to be taken directly to the stream channels (or the ocean) for discharge.

The effects of these two changes combine. Runoff time to the stream channels is shortened at the same time that the proportion of runoff is being increased. The lag time between precipitation and runoff is reduced, thereby increasing peak flow and frequency of floods.

Two basic methods of control are possible to decrease peak flows that exceed the stream channel capacity (Satterlund 1972):

1. Increase the capacity of the channel to handle excess flow, as by dredging, building levees to increase bank height, widening the channel or straightening it to increase speed of flow.
2. Decrease the volume of water so that it does not exceed the capacity of the channel, as by means of reservoirs, spreading grounds, and diversion overflows.

Sometimes it is possible to shift a problem from one place to another. This approach is useful if the problem is shifted away from a high value area to a low value area. Problems arise, however, when determining what can be done if homes are located at the edge of a streambed, at the mouth of a channel, or on a flood plain. In such flood-hazardous locations proper flood control then becomes impractical if not impossible and should be thought of as flood reduction rather than flood control.

COPING WITH WATERSHED PROBLEMS

Maintaining Slope Stability

If slopes on a particular property range from about 25° to 45° (47 to 100 percent), landslides may be the major long term erosional process (Campbell 1975). They can be reduced by maintaining deep-rooted woody vegetation, such as chaparral, on the hillside. The deep roots serve the dual function of anchoring the soil and pumping the water out of the deeper soil layers. Woody chaparral vegetation is more deeply rooted than any other low-fuel plant vegetation that could replace it, and also has an extensive, strong lateral root system. Therefore, chaparral should not be grubbed out. Occasionally the volume of fuel should be reduced through pruning that removes dead material, trims lower branches, and tops larger branches, and through occasional thinning of crowded plants. The chaparral plants should be interspersed with deep-rooted, drought-tolerant low-fuel plants of somewhat similar water requirement or tolerances that will form low-growing, dense ground covers. Sprinkler irrigation may be necessary until the low-fuel plants are well established; after that, they can be given a few deep waterings in the summer. Proper watering of new plantings may have to be continued throughout the winter season if rainfall is sparse or intermittent. If drought-tolerant landscape plants are heavily watered, they may not be able to use all of the water so that the soil mantle is partially saturated at the start of the rainy season, with greater likelihood of soil slips and slides. Water-demanding plants should therefore not be used for hillside planting.

When chaparral is thinned or removed for fire protection, great care must be taken not to remove plants over more area than can be safely replanted and covered with low-fuel plants the same season. Any disturbance or removal of the native vegetation represents at least a temporary instability in a particular portion of the watershed. Erosion during brush conversion can be severe on even moderately steep slopes of about 15° (27 percent). First-year erosion rates on such slopes can exceed 1 inch (2.54 cm) of loose topsoil. On an acre basis (1 acre = 0.4 ha), this would amount to as much as 100 cubic yards (76 m^3) of soil (enough to fill up to 25 dump trucks) that would find its way into properties at the base of the slope. Such heavy soil loss can be greatly reduced through the use of erosion netting, such as jute matting, which is very effective in protecting soil from washing away. Erosion netting should be used at planting time whenever it is anticipated that heavy rains will return before a plant cover can be reestablished. The loss of topsoil in itself is very critical because topsoil contains more nutrients, has better structure, a greater infiltration rate, and more water storage capacity than subsoil and is therefore more capable of producing vigorous, rapidly growing plants.

Brush conversion on slopes approaching 30° (58 percent) should not be attempted unless appropriate soils engineering practices such as terracing are used or unless the slope is short. In some instances slopes are steeper than the natural angle of repose for the geologic material. For most standard soils on natural slopes, this angle is about 34° (67 percent), but it depends on the many factors discussed earlier. Because of internal static friction, the angle of maximum slope (angle at which slope failure occurs) may be up to 10° greater than the angle of repose. Los Angeles County Grading Guidelines (1975) also emphasize the maximum slope angle by stating the "cuts shall not be steeper than 1.5:1 (34°) unless the owner furnishes a soils engineering or soils geology report. . .certifying that a cut at a steeper slope will be stable and not create a hazard to

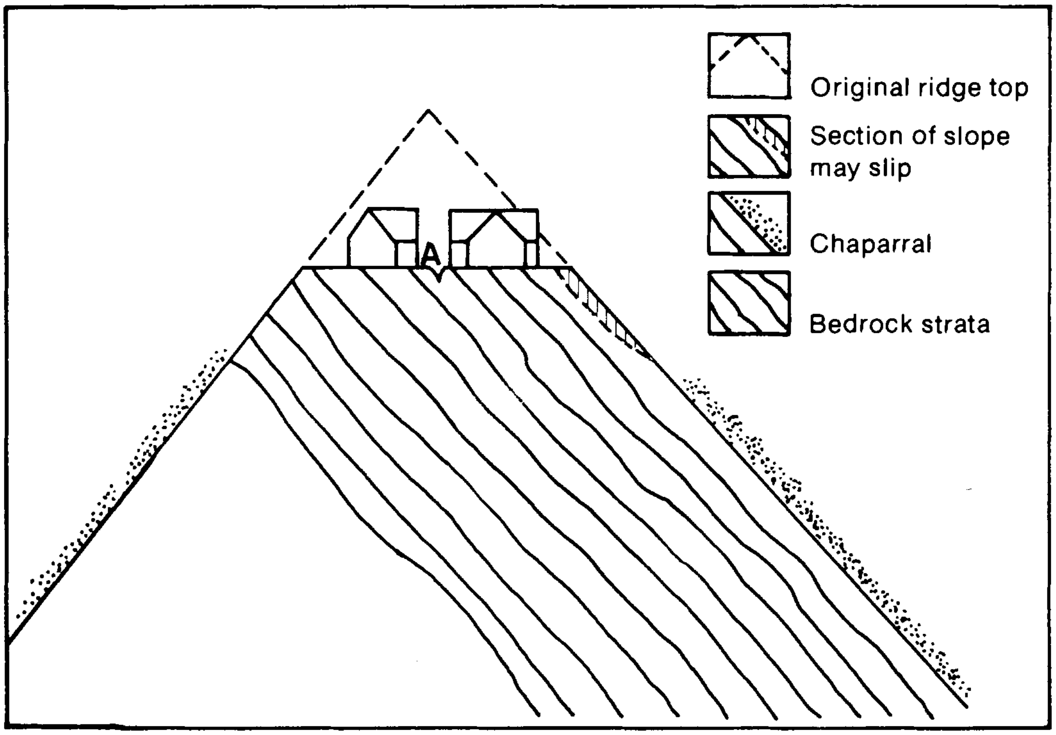

Figure 9—Rock strata can contribute to hillside problems. A break in the pavement next to the house (*A*) caused by sewer or water lines can lead to major slippage. More slippage occurs on the right side of this hill than on the left.

public and private property." Even so, the building inspector has the right to insist on a more gentle slope if necessary for stability and safety. Large-scale brush conversion for fire safety should not be attempted on slopes beyond the angle of repose, because the soil will slide under the force of gravity once the plant cover is removed. Most landscape plants cannot establish themselves unless the hillside is reshaped. If this cannot be done, permanent accelerated erosion results, leading to eventual large-scale slope failures if the underlying parent material is unstable.

The bedrock from which most soils are derived is important to slope stability. For example, fractured rocks, or rock layers that are parallel to the slope, especially on a northern exposure, cause more hillside problems than consolidated rock or rock layers at right angles to the slope (*fig. 9*). Soil stability can be greatly reduced by an underlying clay bed; this acts as a lubricating agent once it is wet. High rates of water infiltration cause local soil saturation that may result in mudflows and major slides, especially when they occur on geologically unstable material. Therefore erosion and slope problems will be accelerated if water is concentrated on any particular portion of a slope, unless the water finds its way immediately into storm drains or rain gutters.

Controlling Drainage

Homeowners must understand the purpose of grading regulations and should not defeat their intent through ignorance or lack of maintenance. Much of the hillside damage in the Los Angeles area in the 1978, 1980, and 1983 floods could have been reduced by homeowners through preventive maintenance and by following the grading requirements spelled out in the Los Angeles County grading guidelines, summarized below:

- A 2 percent overall gradient must be maintained from the rear of the lot to the curb or drainage structure.
- A berm must be installed at the top of the slope to prevent water from draining onto the slope.
- A 1 percent flow line is required around the house to a drainage structure or the street.
- No roof drainage over slopes is permitted.
- Any gradient greater than 5 percent that carries yard drainage must have a paved swale (wide open drain with low center line) or V driveway.
- When fill is used to repair even a small slip on a slope, benches are required if the natural slope exceeds 5:1 (20 percent or 11°).
- Cut slopes more than 5 feet (1.5 m) high or fill slopes more than 3 feet (0.9 m) high must be planted with grass or ground cover. Slopes more than 15 feet (4.6 m) in vertical height must also be planted with shrubs not more than 10 feet (3 m) on center or trees not more than 20 feet (6 m) on center, or a combination of shrubs and trees at equivalent spacing in addition to grasses or ground covers.
- Irrigation must be provided covering all portions of the slope.

To protect the homeowner from damage caused by nearby developments, the guidelines stipulate that "no grading permit shall be issued for work to be commenced between October 1 of any year and April 15 of the following calendar year unless the plans for such work include details of protective measures, including desilting basins or other temporary drainage or control measures or both as may be necessary to protect adjoining public or private property. . . ." Additionally, a standby crew for emergency work must be made available by the builder at all times during the rainy season, and necessary materials must be available immediately when rain is imminent. Furthermore, all removable protective devices must be in place at the end of each working day when the 5-day rain probability forecast exceeds 40 percent. A guard must be on site whenever the depth of water in any device exceeds 2 feet (61 cm). A 24-hour emergency phone number of the person responsible for the project must be listed when submitting the temporary erosion control plans. (It is wise also to post this number on the construction site at all times.)

A field inspector visits building sites periodically, but would not be aware of any accelerated erosion problems unless requested by a homeowner to make an emergency inspection of a property, or unless an inspector is checking the building site to make sure that drainage plans have been adhered to. Concerned neighbors may also call the field inspector to point out erosion problems on construction sites. A final inspection is done at the time the land is occupied, and the inspector does not return unless requested to do so or unless a construction permit is taken out for improvements. Under these circumstances, new owners may not be aware of the consequences of any additional work they are doing, however minor. For example, major slope failure affecting several properties was observed after the heavy 1980 rains. The homes had an adequate setback from the slopes and the canyon below, but the large backyards and lawns sloped more than 1 percent toward the rear, thereby draining all excess water down the hill. Chances are that the backyard landscaping was done after the final inspection and the result was a disastrous financial loss to the owners. In another newer home extending over a hillside, part of the roof drained onto the slope, Apparently this was a late change in the design, or it would not have passed inspection. Again, the result was major slope failure with great financial loss.

Even gently sloping hillsides are not immune from slope failure. Therefore, hillsides sloping more than 5 percent for any appreciable distance should not be planted to lawns. The slope should be broken up by terraces or stone walls so that the actual lawn is level or has a very gentle slope.

Weakening the slope structure through undercutting of its toe, as for further development below a steep property, should be avoided at any cost. Retaining walls may reduce slide hazard, but are very costly and rarely can duplicate the stability of the natural toe of a slope. If a slope is being undercut by a small stream, it may be possible to rechannel the stream and reduce its velocity in the affected area. Streambank control is often a more feasible alternative.

Vegetation, as described earlier, can reduce both wet and dry erosion. Overland erosion in the form of rills and gullies can be greatly reduced by maintaining a thick ground cover on the slopes and allowing plant litter to accumulate. Once gullies have started, they cut rapidly into the soil mantle and should be immediately controlled through small check dams, stacking of cut brush, and temporary soil-binding cover, such as grasses. Dry creep and dry ravel on steep slopes where vegetation is sparse can be reduced by use of plants adapted to harsh sites with thin soils; these add cohesion to the soil.

The annual weed clearing of hillsides down to mineral soil for fire hazard reduction is a source of accelerated erosion. Weedy flash fuels such as introduced annual grasses and wild mustard are well adapted to the climate and soils of southern California. Clearing them on a yearly basis with handtools removes much valuable soil while establishing an excellent seedbed for the next weed crop, which becomes quickly established with the onset of winter rains. Motor-powered machines that use nylon filaments for weed trimming cause less erosion than handtools do, because a small stubble of the plant is left to protect the soil surface. Nevertheless, yearly eradication of annual flash fuels around homes is a never-ending task; such areas should be planted to low-growing, drought-tolerant ground cover, interplanted if necessary with deep-rooted vegetation such as chaparral or carefully selected introduced trees and shrubs.

Controlling Animal Activity

Rodent activity should be reduced and controlled. It adds to slope instability by reducing the cover of low-fuel plants while weakening their root system. Water is concentrated on the particular parts of the slope where rodents have been active. Hillside animal pests can be controlled most effectively by their natural enemies. If these are not present, cats can effectively control rodents, including gophers and ground squirrels. Cats and dogs also manage to keep the rabbit population under control.

Occasionally, the homeowner must act to minimize hillside damage by animals. Instruments that send shock waves through the soil, such as noisemaker windmills attached to metal rods that send out electrical impulses, have been used with varying success on hillsides for rodent control, especially for gophers. They may be worth trying because they require little maintenance once installed. Control of pests that have reached epidemic proportions, such as ground squirrels, is best achieved through poisons placed in strategically located bait stations. Gopher poison placed directly into the rodent runways is effective. Advice on the use and availability of poisons is available from the local office of the Agricultural Commissioner; in Los Angeles County, these offices provide rodent control service for a minimal fee based on the size of the problem and the followup service required. Some poisons can be bought without a license, but in using these poisons, extreme care must still be taken to ensure that natural predators and domestic animals are not affected.

Trapping is often effective in animal control. To catch gophers, small box traps work occasionally and Macabee[2]

[2]Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture or the County of Los Angeles is implied.

traps have worked well. The Macabee traps are used to block both sides of the major underground tunnel; the small box traps are placed at the end of a side tunnel. Larger box traps placed above ground and baited with apples work well for rabbits; ground squirrels prefer peanut butter or nuts but can also be caught with fruits, especially when these are not in season. For catching rabbits, the traps should be hidden under larger shrubs; for catching ground squirrels, they can be left in plain view. These traps also easily catch young gophers and other underground rodents when they wander above the ground in search of food. Rats, mice, occasionally a bird, and even a young curious cat, may enter the traps. Live traps such as the "have-a-heart" traps (standard size, 30 inches long by 7 inches high) are also effective for the small, curious ground squirrels. The larger traps are better suited for larger animals.

Effectiveness of traps tends to vary with the season, the animal, and the bait used. Maintenance of these traps requires frequent walking on hillsides which accelerates soil erosion. Daily disposal of the animals is a chore that falls upon the trapper.

Shooting, where permissible, is also an effective way to control most animal pests. Homeowners must be aware of the danger of firearms and must comply with local ordinances concerning their ownership and use.

Raptor (bird of prey) roosts are used effectively by Los Angeles County foresters to control rodents in young tree plantations. In areas where no natural resting sites, such as trees, are present, the roosts serve for sighting, attacking, and devouring of prey. A homemade raptor roost is easily installed and should consist of a vertical post or pipe at least 15 feet (4.6 m) tall on which a wooden crossbeam 3 to 5 feet (0.9 to 1.5 m) long is mounted horizontally. The pipe should be in one piece, or it may break at a joint from wind action. (A completed roost looks like an elongated letter T.)

Eradication attempts by homeowners are normally of short duration and poorly organized. Continuous effort is necessary for long-term population control and hillside safety, as demonstrated by the following projection for ground squirrels:

The projection assumes that one litter of eight young is raised each year, there is no natural mortality, plenty of food is available, and the rodents can freely emigrate. A mated pair of ground squirrels present on a watershed in early spring will then increase its population to 10 by summer. If an eradication program is 80 percent efficient, 2 animals are left at the end of the first season. If there is no followup campaign, the population climbs back to its original 10 at the end of the second season, to 50 the third season, 250 the fourth season, 1250 the fifth season, and 6250 the sixth season. Because, during a lifespan of 5 years, the original pair could be responsible for 6250 offspring, the initial intensive eradication campaign was responsible for limiting the population to 1250 at the end of the fifth season; a difference of 5000 animals. However, even the relatively low number of 50 animals on an acre of urban watershed could greatly undermine the hillsides. Neighborhood teamwork is therefore essential to keep hillside pests under control and eliminate the breeding population on a regular basis. Just eliminating the young will not prevent reinfestation.

LANDSCAPING FOR FIRE AND EROSION CONTROL

When a community greenbelt or a homeowner's undeveloped acreage is to be planted for minimum maintenance and little irrigation, the most important consideration should be low fuel volume. On hillsides, low-fuel landscape plants should form a solid cover; they should therefore have a spreading and not mounting growth habit. This will suppress weeds and reduce the dry flash fuel. Drought tolerance and resprouting ability are other important considerations. Ground covers like ivy and vincas, low-growing shrubs like coyote brush, hedges such as oleander and myoporum, and even a conifer like Canary Island pine (the only fire-sprouting conifer readily available from nurseries) do not need to be replanted. They all readily sprout after fires, thereby assuring that the greenbelt reestablishes itself at little or no cost. The resprouting ability of ground covers is extremely important on steep slopes. Chances are that with additional watering after a fire, ground cover that was well established can partially reestablish itself within 3 or 4 months, often in time for the winter rains. Chaparral plants should not be overlooked in this respect. All are drought tolerant and most resprout.

Scrub oak, *Ceanothus* species, chokecherry, and sugarbush can be readily shaped into beautiful short-stemmed trees. At distances of about 25 feet (7.6 m) or more apart they can be kept relatively fire retardant by occasional pruning. Oak, California pepper, Brazilian pepper, California laurel, sycamore, and black locust, to name a few, are trees that can be effectively blended into a landscape setting. They all resprout after fire. However, trees generally have greater fuel volume than shrubs and receive less pruning. For fire safety, trees can be planted farther apart than shrubs.

Often overlooked in landscaping are the vinelike low-growing natives, such as honeysuckle, which are quite drought tolerant, have a low fuel volume, and are excellent for slope stabilization. They will resprout after fire. Resprouting ability also allows the plant to recover from gopher and other rodent damage.

The choice of plants for landscaping is related directly to fire safety and protection from erosion. All plants burn during extreme fire weather conditions, specifically, high temperatures, strong winds, and low relative humidity. The labeling of plants as *highly flammable*, *fire retardant*, or *fire resistant*, is therefore misleading. For many years, the term "fire resistant" or "fire tolerant" has been used in ecological literature to denote plants that are adapted to fire and can survive it. For example, a nonsprouting pine such as ponderosa pine is called fire resistant because trees at maturity are protected from firekill by their thick bark. Coast live oak is a fire-resistant (fire-tolerant) tree because it readily resprouts from dormant shoots underneath the bark; however, a mature oak located next to a home, because of its fine dead aerial fuel that consists of twigs and branchlets, can readily catch fire and produce flames that are two or more times greater than its height and diameter. Some plants that do not sprout, such as Mediterranean *Cistus* species (many of which are highly flammable but used in landscaping), and also many native *Ceanothus* species are fire adapted, because they readily reestablish themselves from seeds stimulated by fire. Thus, if properly used and maintained, plants can reduce the spread of fire; if improperly used, they may increase fire spread. Proper choice of plants for landscaping depends on specific conditions, but must be combined with measures to improve the fire safety of the structure itself.

The term *fire retardant,* as used in a flammability context, means that the plant so described is less flammable than another that contains the same amount of fuel. This difference may be due to the proportions of live and dead fine fuel present, to the oil and mineral content (ash) of the foliage, to the percent fuel moisture, or to the age of the plants. For example, the needles of plants like pines, cham-

Table 3—*Chemical composition of 11 low-fuel plant species*

Species and plant part[1]	Length, type[2]	Moisture content[3]	Ash[4]	Crude fat[4]	Crude protein[4]	Crude fiber[4]
				Percent		
Prostrate acacia						
Leaves		275	2.5	5.8	16.2	15.7
Stems	12 in., H to SW	215	1.9	6.4	10.9	30.7
Twin peaks coyote brush[5]						
Leaves		335	4.3	9.8	14.7	11.7
Stems	4 in., H to SW	277	3.9	5.2	8.3	21.1
Carmel creeper						
Leaves		225	2.6	4.3	10.8	14.1
Stems	H to SW	200	2.3	2.5	5.7	26.5
Green galenia[6]						
Leaves		221	10.9	3.5	18.2	9.7
Stems	8 in., H to SW	198	10.0	1.5	12.1	17.8
Descanso rockrose						
Leaves		226	7.1	3.3	10.1	26.5
Stems	H to SW	187	2.6	2.1	5.7	13.5
Purple rockrose[7]						
Leaves		239	7.2	4.5	10.5	13.1
Stems	H to SW	226	5.3	4.2	6.4	28.9
Prostrate rosemary[5]						
Leaves		349	4.3	12.1	8.8	15.1
Stems	8 in., H to SW	242	3.2	4.2	3.3	47.3
Chilean saltbush[6]						
Leaves		337	10.5	3.3	24.3	6.3
Stems	SW	216	3.3	1.4	13.1	29.1
Green saltbush[7]						
Leaves		527	9.2	1.9	27.1	8.3
Stems	Green to H	401	6.5	1.1	12.3	26.4
Mueller's saltbush[5]						
Leaves		392	10.5	2.5	20.6	7.3
Stems	4 in., H to SW	353	8.1	1.8	12.5	24.7
Gray santolina[3]	Composite	322	9.1	11.1	16.4	16.6

[1]Late fall growth of tip cuttings consisting of leaves and small twigs was analyzed. Large seasonal variations in moisture content and fat, protein and fiber contents are often encountered.

[2]H = herbaceous, SW = semiwoody, W = woody, Composite = herbaceous to semiwoody tip cuttings consisting of leaves and stems.

[3]Moisture content of the living plant sample as percentage of its oven dry weight.

[4]Percentage of dry residue in relation to the total oven dry weight of plant sample.

[5]Plants that are inherently flammable (high oil content) but low in fuel volume.

[6]Fire retardant plants: low in fat (oil) and high in ash.

[7]A related species, gum rockrose, which grows 6 to 8 feet tall, is often recommended for low fuel planting, but it has a high crude fat content (14.9 percent) and is highly flammable.

Table 4—*Heat values of four wildland fuels*

Species, fuel type	Heat value	
	Kcal/g	Btu/lb
Annual grass		
Early green	0.418	753
In bloom	1.668	3,005
Mature, dry	3.956	7,128
Blue gum eucalyptus		
Leaf litter	5.732	10,328
Bark	4.616	8,317
Duff	5.454	8,272
Branches/twigs	4.591	8,272
Chamise		
Leaves	5.439	9,800
Twigs	5.009	9,025
Branches	4.742	8,544
Scrub oak		
Leaves	4.571	8,236
Twigs	4.480	8,072
Branches	4.490	8,090

Source: Agee and others 1973

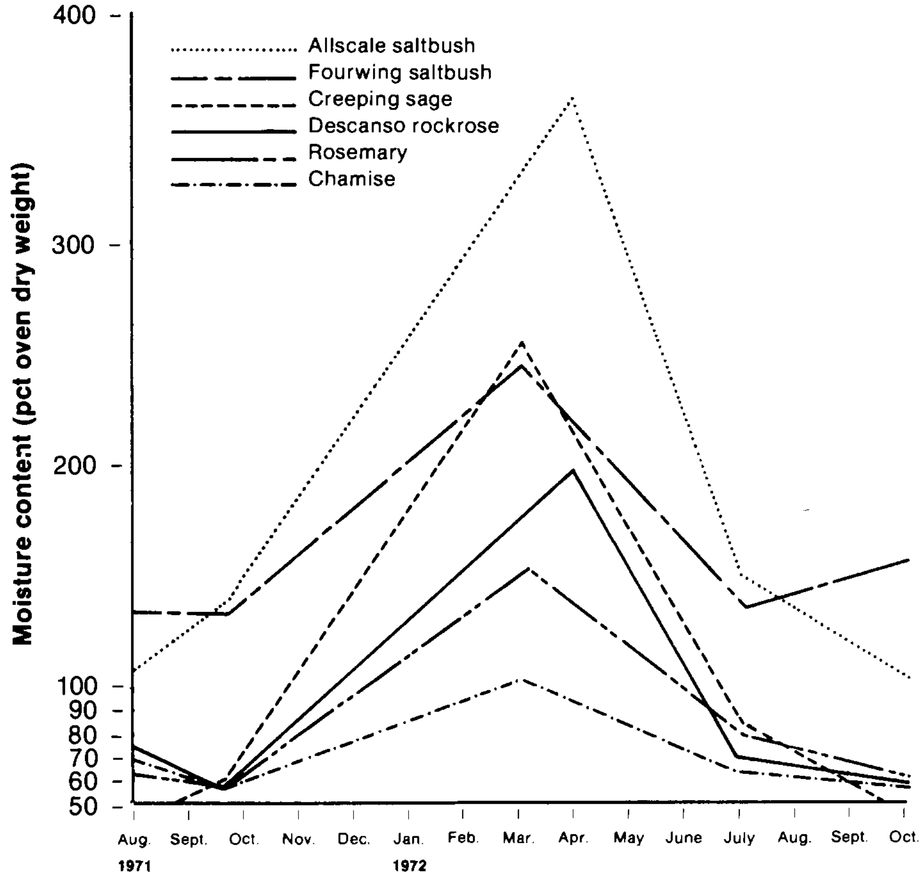

Figure 10—Seasonal fuel moisture content of foliage (leaves and current year's stem growth) of seven native and introduced shrub species varies widely among species, and by season.

ise, and rosemary have a high oil content and fine fuel characteristics. They are therefore inherently more flammable during the fire season than saltbushes, which have broad leaves and lower oil content, with higher ash content (*table 3*). Other plants fall into intermediate categories.

Some other plants used in landscaping may be just as flammable as chamise, one of the most flammable chaparral species. The heat content of bluegum eucalyptus is comparable to that of chamise (*table 4*). So, once ignited, both species may burn equally hot, and the eucalyptus may present added problems of greater fuel volume and litter production. During the 1977 Santa Barbara Fire, 244 houses were lost when sundowner winds (downhill evening wind patterns) carried the fire from tree to tree and from one wood shingle roof to another.

Live fuel moisture is important because plants with higher fuel moisture ignite less readily. For example, the live fuel moisture of many saltbushes that are recommended as "fire-resistant plants" is higher than that of most chaparral species except for succulents. Live fuel moisture content of such wildland fuels may be low from June to November and high from December to April (*fig. 10*). The late summer and fall Santa Ana (fire winds) coincide with this period of low fuel moisture. Within a few hours the dry, hot winds can reduce fuel moisture of fine dead plant material to the critical level for ready ignition and can further decrease live fuel moisture by a few percentage points over several days. The amount of fine, dead fuels determines rate of fire spread because such fuels dry rapidly, ignite quickly, and preheat live fuels to the ignition point.

It is clear, then, that inherent fire-retardant characteristics of landscape plants cannot be depended on to prevent ignition during severe fire weather. Young plants and new shoots on pruned plants have a high moisture content, and can be considered slow burning (fire retardant), but as these plants become older and more woody and the amount of dry fuel and dead litter increases, they become more flammable. This fact may explain some of the contradictory literature about "fire retardant" plants. For example, old man saltbush is often recommended in California as a fire-resistant plant. In Tunisia, the plant is grown as firewood because it is excellent for baking bread in the traditional domestic ovens and also for charcoal. In well-managed, nonirrigated plantations, it can produce up to 17 tons/acre (38.25 t/ha) of firewood during the first year after outplanting, and 30 tons/acre (67 t/ha) within 2 years (Franclet and LeHouerou 1974). With irrigation, the wood production is even higher. In Australia, where the plant is browsed periodically by sheep, it is kept vigorous, and does not readily contribute to fire spread.

Other plant species often mislabeled as fire resistant or fire retardant are rosemary, coyote brush, and rockrose. The foliage of these plants has a high oil content, and once ignited burns readily. Nevertheless, these plants are drought tolerant, esthetically pleasing, very versatile for landscaping, generally low growing (except for gum rockrose), and well adapted to southern California's climate. Their rooting depth approaches that of coastal sage species. Prostrate coyote brush resprouts readily after a fire, and it is an excellent candidate for erosion control on the steeper hillsides as it does not require replanting after fire.

The fire resistance of plants is relative and depends on fuel moisture and the amount of dead fuel. Generally, a low-growing plant has an inherently lower fuel volume than a taller plant, and therefore has less fine dead fuel. Two key factors of fire control and fire safety are related directly to low fuel volume: *fuel discontinuity,* whereby the continuity of any flammable cover is broken up, and *reduction in fuel load,* whereby plants are pruned and dead fuel is cleared away.

The low fuel volume objective suggests creation of greenbelts around subdivisions and individual homes. As space permits, these areas could include flammable fuels such as chamise, eucalyptus, coyote brush, and rosemary, as well as relatively fire-resistant fuels such as ice plants. Aerial fuel (trees) can be kept reasonably fire retardant through periodic pruning; however, the general tendency is to leave them unpruned and they are therefore more flammable and carry fire more readily than low-growing plants. Conifers should not be planted close to a home, because their needles have a high resin content, provide fine fuels, are quite flammable, and are likely to be on the roof when fire strikes. However, both conifers and broadleaf trees planted a distance away from the home can serve the important function of channelling the initial convection heatwave away from a home and thereby perhaps saving it (assuming, of course, that the flames from the burning trees can be extinguished before they ignite the house).

Brush clearance ordinances are based on the low fuel concept and are good guidelines for reducing fire hazard. They are self-defeating if they do not take into account the increasing flammability of many landscape plants as they grow and mature, and ignore the danger of potential slips and slides on steep slopes owing to the removal of the deep-rooted chaparral vegetation.

Establishing Greenbelts

Homeowners trying to comply with the brush clearance ordinances and faced with a brush surcharge on their fire insurance policies should reduce the unwanted native vegetation in an ecologically sound way. They must realize that it may not be possible to reduce flammable fuels on slip areas and on erosive, steep, and unstable terrain to the point of receiving a favorable insurance rate. The added expense of paying the surcharge then becomes one of the costs of living with nature and may be much cheaper, even in the long run, than slope failures caused by improper or excessive clearing of native vegetation.

There are several alternative methods of reducing flammable fuels and establishing a greenbelt. The first is to eliminate the native vegetation and relandscape a greenbelt buffer strip of 100 to 200 feet (30.5 to 61 m) around the home. This practice may also be the only possible solution where the developer or builder has already eliminated most of the native plants, or where, because of harsh climate or site characteristics, only highly flammable vegetation exists. This method is effective if the native plants can be readily replaced by drought-tolerant vegetation of less fuel

Figure 11—Native plants can be used effectively as foundation plants in landscapes. To separate ground fuels from aerial fuels, prune the lower branchlets and thin the plant. Yearly light pruning can make it difficult for such plants to burn and support a fire.

volume and similar rooting characteristics. Moreover, more gentle terrain with deep soils is often well suited for the establishment of a wider greenbelt buffer zone that may include recreational facilities and commercial agriculture such as orange or avocado groves. This requires strong community support and long-range planning but may be the most effective way of separating wildland fuels from flammable structures.

A second alternative for landscaping in wildland areas is to reduce the fuels of the native vegetation and use the remaining plants as foundation plants in the landscape setting (*fig. 11*). To do this, an expert familiar with the native plants of the area should be consulted to oversee the selection of plants, thinning, pruning, and relandscaping. All native vegetation that is not to be removed during the initial thinning should first be identified. The unwanted vegetation should then be removed. The consultant who is selected should be well trained in the principles of pruning for fire safety and should oversee the pruning of all desirable woody overstory plants into upright short-stemmed trees. On multistemmed plants, several stems should be selected and the plant so pruned that a fuel separation is created between the overstory canopy and the ground cover that is to be planted next. This method works well in areas where the native vegetation has not been disturbed by fire for about 7 to 10 years, and where the fire frequency is low.

The careful selection of native plants as a foundation for landscaping is critical, because of differential watering requirements, differences in year-round appearance, growth, flowering habits, resprouting characteristics, and rooting depth. For example, native mountain lilacs (*Ceanothus* species) come in many shades of color from white to deep blue, and even the highly flammable chamise, left as a specimen plant, is delightful when displaying its attractive white flowers. Chokecherries, toyon, elderberry, and California walnut provide food for wildlife. When there is doubt about what plant to retain, it is best to choose a sprouting plant over a nonsprouting one.

Native understory plants can add accent to the landscape setting but can also act as ladder fuels to the woody overstory vegetation. Highly flammable plants such as sages (white, black, purple), buckwheat, California sagebrush, and deerweed should therefore be eradicated wherever permanent slope stability permits. Woody perennials such as fuchsias and gooseberries and even woody-based perennials such as sunflowers that die back to the base every year should be included in the landscape setting because they are low-fuel plants with showy flowers and provide food for wildlife. Perennial grasses should not be eradicated.

Once thinning and pruning of native plants is completed, erosion netting should be spread and anchored on steeper slopes and erosive soils. This is especially critical if slow-growing ground cover such as coyote brush is interplanted among the native plants or if the ground cover chosen will not grow fast enough to cover the soil surface by late fall. A "noncompetitive" protective cover crop such as alyssum can be sown in the fall for temporary control of surface erosion and rilling. When heavy first-year planting failures have occurred through such conditions as lack of proper maintenance, rodent activity, or browsing, it may be necessary to sow highly competitive annual grasses with the coming of the winter rains. These should be immediately eradicated in the spring, when replanting should begin.

Ideally, the greenbelt should be established early in spring, or even towards the end of winter, when soil moisture has been fully recharged through rainfall. Regular watering will be needed to get the plants established, especially the ground covers planted from flats, as these have a very shallow root system at first. Early establishment provides a better rooted cover before the hot weather and summer drought return. With this technique, less watering is required during the summer, and water can be withheld from plants earlier in the fall. The soil moisture is then well below field capacity when the winter rains return. Well-established plants several years old should not receive deep watering after mid-September. If plants are not established until summer, more frequent watering is needed and an abundant late weed crop may compete vigorously with the planted stock.

When planting is done in early spring at the end of the rainy season, weed killers or preemergent herbicides that selectively kill spring weeds can be used to full advantage. A reduced crop of winter weeds will still germinate and help cover the slope until the ground cover becomes fully established. Using selective weed killers for fall planting on hillsides is not advisable unless slopes are covered with jute matting, because the newly established ground cover will not prevent excessive erosion. For hillside use of preemergent herbicides or herbicides that kill the seedlings as they germinate, follow these four rules:

1. Select a herbicide that does not affect the planted stock.
2. Treat a small test area first.
3. Always use less than recommended.
4. Do not use a preemergent herbicide whose effectiveness lasts for more than one season.

Maintaining Compatibility of Plants

A critical concept when establishing a greenbelt is the compatibility of landscape species and native plants, especially in regard to watering and maintenance requirements.

Information on the compatibility of existing native plants and introduced species is scant, but the moisture and habitat requirements of native plants often provide a clue to their tolerance. In general, native plants found in moist canyons and draws have a higher tolerance to landscape irrigation than plants on north and east slopes. These, in turn, seem to have a higher tolerance than plants on harsh exposures such as south-to-west slopes and thin soils.

Among individual species, those with higher moisture requirements also seem to have greater tolerance to landscape irrigation than the most drought-tolerant species. The time and amount of watering also plays a critical role. Occasional deep watering during the summer at nighttime when the exotic plants show signs of wilting, such as drooping of leaves, is less damaging than intermittent, more shallow watering in the daytime. Heat and moisture both encourage root rot, so that plants growing in heavy soils, such as those with a high clay content, or in dark soils that heat up more readily, seem to be most affected. Examples to clarify the above points are given below.

Sumac species, such as laurel sumac, sugarbush, and lemonade berry, are quite drought tolerant and deep rooted. These native plants make excellent landscape specimens, but do not tolerate the watering required when interplanted with more water-demanding plants. The combination of sumacs with a surrounding groundcover of African daisy, ivy, or vinca is likely to result in root rot and death of the sumacs within a few years because regular watering is normally required to keep these ground covers alive. On the other hand, interplanting the sumacs with Twin Peaks coyote brush for groundcover may not adversely affect the sumacs if the coyote brush is watered only enough to keep it alive. Native oaks are also very susceptible to watering of an understory ground cover or surrounding lawns. A good technique which allows the use of more water-demanding plants is to keep an unplanted and unwatered buffer near the base of the intolerant shrubs and trees. However, situations can be found where the above-named plants seem to be compatible with landscape ground covers. Examples are long, steep slopes on north or east exposures, where, due to deep soils, water seepage from above and the shading of the native plants, the understory groundcover needs little or no watering. These situations are common when one owner has managed the property for many years. A change of ownership and a different management regime that results in increased watering may cause root rot and mortality of the woody native species. The soil around most native plants is normally well aerated and covered with litter and humus. Soil compaction around these plants may therefore also affect them more adversely than it would landscape plants.

Laurel sumac is of great interest in landscaping with native plants because it is an excellent soil binder on steeper slopes and harsher sites. Its prolific resprouting ability and fast growth enables it to survive in areas of repeated disturbance by fire and grazing. This resprouting ability from roots and root crowns makes it a nuisance plant in a landscape setting. However, once the soil surface around the plant is shaded with a noninvasive ground cover such as Twin Peaks coyote brush, and any disturbance has stopped, the resprouting will also greatly decrease or stop. This greatly reduces maintenance. When laurel sumac and sugarbush grow close to each other on nonerosive, moderately steep slopes, it may be better to select sugarbush as a foundation plant because it is usually much slower growing and does not require regular maintenance. It is also esthetically more pleasing throughout the year. Furthermore, laurel sumac is not cold-tolerant and freezes. All of the sumacs tend to be susceptible to insects and disease and pruning of dead material is therefore recommended.

On steep, erosive slopes, laurel sumac should not be replaced with landscape plants. For its fuel volume, the plant is one of the deepest rooted and most drought-tolerant plants available to the homeowner. Its reputation has been tainted by labeling as extremely flammable, because the species has been observed during wildfire as bursting into flames. Actually, in comparison to many other chaparral species of the same stature, fuel loading, and age, individual plants are quite fire-resistant. Except when the plant freezes, the dead-to-live fuel ratio is often much lower than that of other species. More important, perhaps, in fuel moisture it ranks among the highest of native plant species during the high fire weather conditions encountered in late fall. (Under wildland conditions, high fuel moisture of leaves and stems requires that the plant be preheated to higher temperatures, than for example, chamise, mountain mahogany, and most *Ceanothus* species, in order to ignite or burst into flames.) Once the surrounding fuels are removed and laurel sumac is pruned to treelike form, the understory vegetation rarely will preheat it to the ignition point. Leaves may be totally scorched by the heat of the fire, without the plant carrying the fire. Thus, the different ignition requirements of individual species and plants are the key to flaming and firespread.

Choosing Low-Growing Species

Ideally, plants should be selected for these qualities: (1) low growth habit, (2) drought tolerance, (3) fire retardance, (4) deep rooting habit, (5) esthetically pleasing effect, and (6) compatibility among different species (*fig. 12*). The usefulness of some commonly used low growing landscape plants and other plants in particular situations, with emphasis on southern California, was evaluated according to their suitability for various sites and conditions, growth characteristics, and fire retardance (*table 5*). The table is a general guide, but cannot substitute for onsite professional opinions rendered by expert consultants familiar with specific sites and problems. Homeowners who must deal with individual landscaping problems should make their own decisions from the table and descriptions, using the general advice on fire safety and more effective watershed management given elsewhere in this report.

The plant species listed, except where indicated, are able to form a solid ground cover for the slopes recommended. However, there is no guarantee that the species prevent slippage when the soil becomes saturated. Interplanting ground covers with shrubs and trees, as discussed earlier, will maximize slope stability. Landscape plants that require high maintenance or that are readily browsed, such as most prostrate *Ceanothus* species, are not included in *table 5*.

The columns in *table 5* headed "aspects," "soil depth," and "if irrigated" should be read as a unit. The values for soil depth apply to medium textured, loamy soils. Those for irrigation apply to coastal regions of southern Califor-

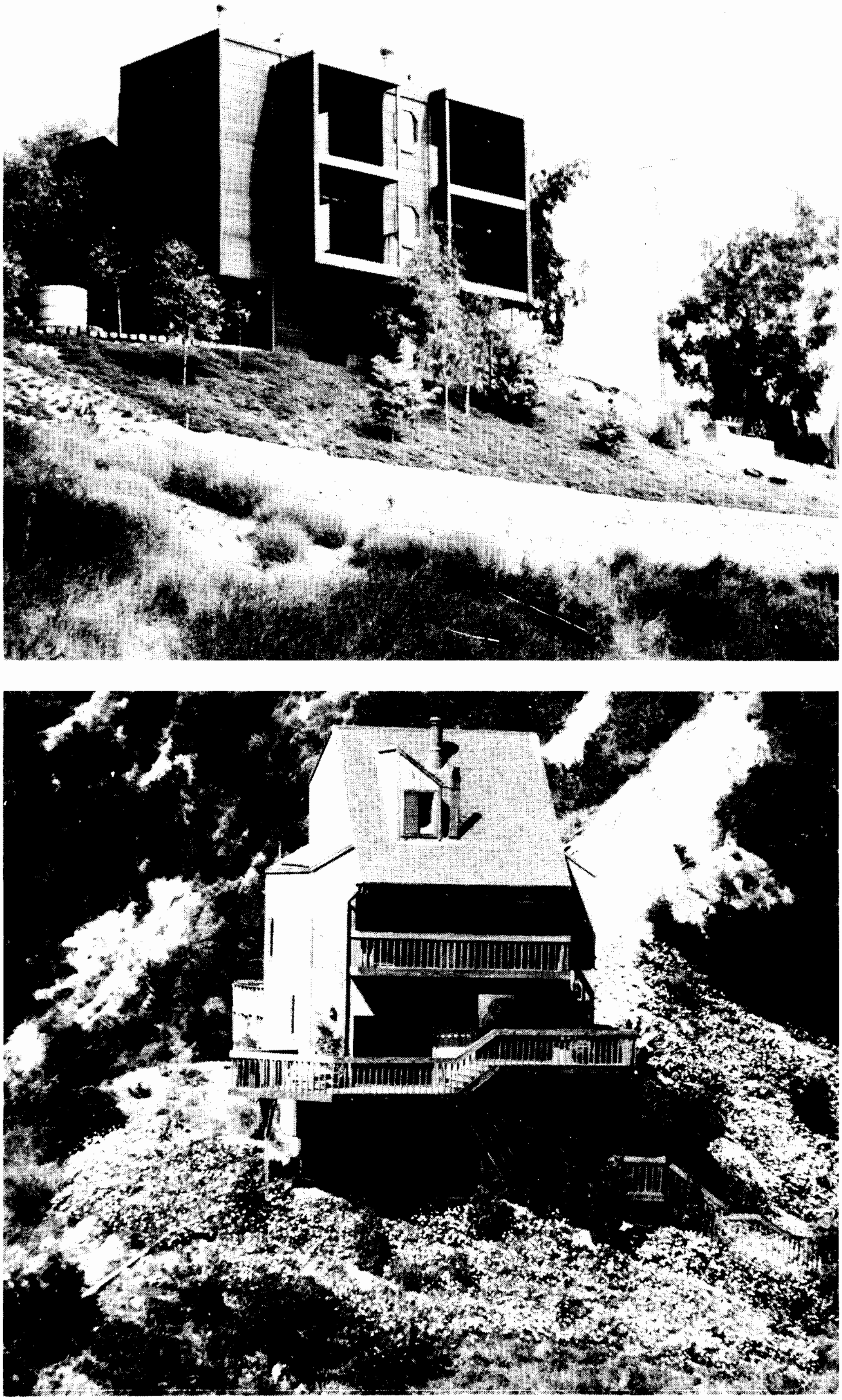

Figure 12—A greenbelt of coyote brush surrounds the house at the *top*. Trees provide added slope stability, but will increase the fire hazard as they grow. A greenbelt of African daisy plants provides minimal fire safety for the flammable house at the *bottom*. The probability of damage from fire and soil slippage is high.

Table 5—*Evaluation of 20 low-growing plants used in wildland-urban hillside landscaping*[1]

Species	Effective . . . On slopes (degrees) <25	25-35	>35	On aspects N-E	S-W	At soil depths (feet) . . . <1	1-3	>3	If irrigated summer to fall[2]	At elevations (feet)	Characterized by . . . Growth habit, height (inches)	Fire retardance	Re-sprouting ability	Rooting depth (ft) (effective)	Comments
Aaron's beard	X	X	Z	X		X			>2 M	Up to 4000	Spreading shrub, 12-24	Medium	If watered	<3	Low maintenance. Little foot traffic. Spreads by underground runners. Good soil binder. Invasive if well watered. Yellow flowers. Draws bees. Sun to shade.
				X			X		1 M						
				X				X	2-3 S						
					X	X			1 W						
					X		X		<1 W						
					X			X	1 M						
Acacia ongerup, prostrate	X	X	Y	X		X			<1 M	Up to 2000	Spreading shrub, 12-30	Low; decreases with increase in fuel	Poor	>6	Low maintenance. No foot traffic. Showy yellow flowers. Draws bees. Most drought-tolerant and quickest-spreading woody plant tested. Full sun. Spreads to more than 8 feet in diameter in full sun and deep soils.
				X			X								
				X				X	0						
					X	X			>1 M						
					X		X								
					X			X	1 S						
African daisy	X	Y	Z	X		X			2 M	Up to 2000	Trailing groundcover, <12	Medium to high	If watered	3	Moderate to high maintenance. Tolerates some foot traffic. Showy white flowers and other hybrid colors. Freezes at 25°F. Fertilize and water regularly. Full sun to partial shade.
				X			X								
				X				Y	<1 M						
					Y	X			1 W						
					X		X		2 M						
					X			X	1-2 M						
Algerian ivy (freeway ivy)	X	X	Y	X		X			1 W	Up to 2000	Trailing groundcover, 8-12	Medium	If watered	3-4	Low maintenance. Tolerates foot traffic. Excellent for minimizing erosion on long, steep cuts. Leaves will burn if watering is neglected. Excellent understory to a variety of trees. No flowers. Full sun to shade.
				X			X		1 M						
				X				Y	2 S						
					Y	Y									
					X		X		2 M						
					X			X	1 M						
Australian saltbush	X	X	Y	X		X			1 S	Up to 2000	Trailing groundcover, to 12	Generally high	Resprouts even on dry sites	3-4	Low to medium maintenance. Moderate foot traffic. Readily established from seeds. Naturalized on harsh, rocky sites. May not form persistent solid cover because it is affected by disease if overwatered or crowded (variety *corta* may be disease resistant). Relatively short lived (5 years +). Full sun (no north slopes).
				X			X		0						
				X				Z							
					X	X			1-2 S						
					X		X		0						
					X			X	0						
Capeweed	X	Y		X		X			1-2 M	Up to 2000	Spreading groundcover, 6-8	High	If watered	1-3	Very low maintenance. Takes occasional foot traffic. Showy yellow flowers. Weedy in manicured setting. Frost sensitive. Draws bees. Spreads by runners. Full sun to partial shade.
				X			X		1 M						
				X				X	2 S						
					X	X			2 M						
					X		X		1 M						
					X			X	<1 M						
Carmel creeper ceanothus	X	X	Y	X		X			<1 M	Up to 4000+	Spreading shrub, 18-30	Low to medium; decreases with increase in fuel	If watered after light fire	6	Moderate maintenance (renovate occasionally by thinning old branches). No foot traffic. Readily browsed. Showy blue flowers. Draws bees. Full sun to partial shade.
				X			X		<1 M						
				X				X	2 S						
					X	X			1 M						
					X		X		<1 M						
					X			X	<1 S						

Table 5—*Evaluation of 20 low-growing plants used in wildland-urban hillside landscaping*[1] *(Continued)*

Species	Effective . . . On slopes (degrees) <25	25-35	>35	On aspects N-E	S-W	At soil depths (feet) . . . <1	1-3	>3	If irrigated summer to fall[2]	At elevations (feet)	Characterized by . . . Growth habit, height (inches)	Fire retardance	Re-sprouting ability	Rooting depth (ft) (effective)	Comments
				X		X			<1 M						Prune back every 5 years or less often. No foot traffic. Inconspicuous flowers. Hard to establish from flats in midsummer. Healthy green color. Sensitive to herbicides. Full sun. Spreads to more than 5 feet across in full sun and deep soils.
				X			X								
				X				X	0	Up to	Spreading				
Coyote bush	X	X	Y		Y	Y			>1 M	4000	shrub,	Low	Vigorous	6	
(brush)					X		X				12-24				
					X			X	1 S						
				X		X			>1 S						Low maintenance. Tolerates some foot traffic. Stem layers readily. Prefers acid soil. Excellent understory in pine plantations. Readily killed by overwatering and heavy soils. Sensitive to herbicides. Needs extensive seed scarification. Showy blue flowers. Draws bees. Sun to shade.
				X			X		0						
				X				X	0	2000-	Trailing	Medium	If		
Creeping sage	X	X	Y		X	Z				6000	groundcover,	to	watered	3-4	
					X		X		>1 S		<6	high			
					X			X	1 S						
				X		X			1 M						Medium to low maintenance. No foot traffic. Showy pink flowers; draws bees. Ground cover for easily accessible dry site areas. Attractive if watered; unattractive if not maintained. Full sun.
				X			X								
				X				X	0	Up to	Semi-upright	Low			
Descanso rockrose	X	X	Z		X	X			<2 M	4000	shrub,	to	Poor	3-4	
					X		X				12-24	medium			
					X			X	1-2 S						
				X		X			1 M						Medium maintenance. No foot traffic. Does not stem layer. Excellent for border effect. Clip back dead flower stalks every year to maintain higher fire retardance. Yellow flowers. Draws bees. Full sun to partial shade.
				X			X								
				X				X	0	Up to	Semi-upright	Low	Resprouts		
Green lavender	X	X	Z		X	X			2 M	4000+	shrub,	to	even on	3-5	
cotton					X		X				16-30	medium	dry sites		
					X			X	1 S						
				X		X			<1 M						Low maintenance. No foot traffic. Showy multicolored flowers. High foliage moisture and weak root system causes slippage on steeper slopes, especially fills. Full sun to partial shade.
				X			Y								
				X				X	0	Up to	Trailing	Generally	Depends on		
Ice plants	X	See text			X	X			1 M	2000	groundcover,	high	severity	1-2	
					X		Y				4-18		of fire		
					X			Y	'1-2 S'						
				X		X			2 M						Low maintenance. Tolerates foot traffic. Takes neglect and will recover with watering. Good soil binder among pruned shrubs. Excellent drysite lawn. Lilac to rose flowers. Draws bees. Mow off flowers to eliminate bees. Full sun to partial shade.
				X			X								
				X				X	<1 S	Up to	Trailing		If		
Lippia	X	Y	Z		X	X			1 W	2000	groundcover,	High	watered	<3	
					X		X				<4				
					X			X	<1 M						
				X		X			>2 M						Low maintenance. Occasional foot traffic. Showy blue flowers. Does well under partial overstory where somewhat neglected. Excellent understory ground cover. Sun to shade.
				X			X			Up to	Trailing		If		
Periwinkle	X	X	Z	X				X	<1 M	4000	groundcover,	Medium	watered	3	
					Y		X				<18				
					X			X	1-2 M						

[1]< = less than
\> = greater than
X = suitable
Y = not totally suitable
Z = not recommended

[2]0 = None
1 = Once
2 = Twice
W = Week
M = Month
S = Summer
No entry = intermediate watering schedule (see entry above or below)

Table 5—*Evaluation of 20 low-growing plants used in wildland-urban hillside landscaping*[1] *(Continued)*

Species	Effective . . . On slopes (degrees) <25	25-35	>35	On aspects N-E	S-W	At soil depths (feet) . . . <1	1-3	>3	If irrigated summer to fall[2]	At elevations (feet)	Characterized by . . . Growth habit, height (inches)	Fire retardance	Re-sprouting ability	Rooting depth (ft) (effective)	Comments
Point Reyes ceanothus	X	X	Y	X		X			<1 M	Up to 4000+	Spreading shrub, 8-24	Low to medium	Poor	6	Moderate maintenance (renovate occasionally by thinning old branches). No foot traffic. Readily browsed. Showy bright blue flowers. Draws bees. Full sun to partial shade.
				X			X								
				X				X	0						
					X	Y			1 M						
					X		X								
					X			X	1 S						
Prostrate ceanothus	X	X	Y	X		X			>1 S	4000-7000	Trailing groundcover, >4	Generally high	No	3-4	Low maintenance. Tolerates some foot traffic. Stem layers readily. At lower elevations in southern California plant prefers north slopes. Best on coarse textured soils. Needs extensive seed treatment. White to blue flowers. Draws bees. Sun to shade.
				X			X		1 S						
				X				X	0						
					X	Y			<1 M						
					X		X		0						
					X			X	0						
Prostrate myoporum	X	Y	Z	X		X			1 M	Up to 2000	Spreading groundcover, <6	Generally high	No	3	Low maintenance. No foot traffic. Stem layers. White flowers. Draws bees. Full sun to partial shade.
				X			X								
				X				X	2 S						
					X	X			2 M						
					X		X								
					X			X	<1 M						
Prostrate rosemary	X	X	Y	X		X			<1 M	Up to 4000+	Spreading shrub, 12-24	Low; decreases with increase in fuel	No	3-5	Low maintenance. No foot traffic. Stem layers readily. Hardy plant with dark green needle foliage. Showy blue flowers. Draws bees. Prefers full sun.
				X			X								
				X				X	1 S						
					X	X			2 M						
					X		X								
					X			X	<1 M						
Silver saltbush	X	X	Y	X		X			1 S	Up to 2000+	Spreading shrub, 16-30	Low to medium; decreases with increase in fuel	Without water after light fire	6	Moderate maintenance (renovate occasionally). No foot traffic. Stem layers, underground runners. Seeds germinate readily and are preferred by birds. Deer browsing maintains vigor, low growth, greater fire retardance (less fuel). Loamy to sandy soils. Flowers inconspicuous. For dry site landscaping away from house. Full sun.
				X		X	X		0						
				X				X	0						
					X	Y			2 S						
					X		X		0						
					X			X	0						
Wavy leaf saltbush	X	X	Y	X		X			1 S	Up to 3000	Semi-upright shrub, to 36	Low to medium decreases; with increase in fuel	Without water after light fire	6-9	Moderate maintenance (renovate occasionally). No foot traffic. Stem layers. Moderately browsed when young. Avoid heavy soils. Flowers inconspicuous. Good for dry site landscaping away from house. Full sun.
				X			X		0						
				X				X	0						
					X	Y			'2 S'						
					X		X		0						
					X			X	0						

[1] < = less than
> = greater than
X = suitable
Y = not totally suitable
Z = not recommended

[2] 0 = None
1 = Once
2 = Twice
W = Week
M = Month
S = Summer
No entry = intermediate watering schedule (see entry above or below)

nia and attempt to show relative watering needs of the plants listed. These values assume that soil moisture is recharged to 12-inch (30.5 cm) depth during watering. In reality, this goal is rarely achieved through overhead watering because of sprinkler design and time period necessary for irrigation. The effective rooting depths indicated in *table 5* are based on moisture withdrawal by roots after soil moisture has been depleted in the upper soil layers.

The term "fire retardance" as used in *table 5* reflects differences in fuel volume, inherent flammability characteristics of the plant, and ease of fire spread. For example, under extreme autumn fire conditions, on steep slopes with nongusting winds of 30 mph (48.3 kph), a 2-foot (61 cm) tall solid ground cover with "high" fire retardance is expected to produce a flame less than 10 feet (3 m) long and to reduce the rate of fire spread. Under similar conditions, a plant with "low" fire retardance may ignite readily, will carry the fire, and can produce flames approaching 25 feet (7.6 m) in length. For comparison, mature chaparral under these conditions can produce flames exceeding 80 feet (24.4 m) in length.

The following example for capeweed will illustrate the use of *table 5*. Column 1 shows that the species is most effective for planting on slopes not exceeding 25°, but may be used on a limited scale on slightly steeper slopes. The shallow root system of capeweed may trigger soil slippage. The next three columns of data are to be read as a unit and show the relationship between aspect, soil depth, and irrigation requirements. For example, the first line shows that on a north-to-east aspect with less than 1 foot of soil depth, established plants require summer irrigation once or twice a month.

The importance of microclimate should be kept in mind. A north or east slope provides an opportunity for using less drought-tolerant plants, such as vinca or ivy, whereas the harsh south- and west-facing slopes are best suited for the most drought-tolerant plants. Canyons and valleys provide for a wide choice of plant species, but may also increase the danger of frost due to cold air drainage.

Plants suitable to landscape needs can be identified by their performance in the neighborhood. Comparisons should take into account such variables as steepness and exposure of slopes, soil type and depth, and watering schedule. Further advice is available at nurseries and in literature on landscaping in California (Williamson 1976). The plants described in the rest of this section are rated according to the six qualities listed earlier.

Ice Plants

Ice plants (*Carpobrotus, Delosperma, Drosanthemum* spp.) generally are rated excellent in low growth habit, fire retardance, and esthetics, but fail in deep rooting habit. The coarse-leaved "freeway ice plants" (*Carpobrotus*, formerly classified as *Mesembryanthemum*) are recommended for soil binding of marginal, seldom-watered but not steep areas; white trailing ice plant (*Delosperma alba*) for soil binding of steeper slopes, and finally *Drosanthemum* species for soil binding of steep slopes even where soil is very poor (Williamson 1976). Professional landscapers recommend ice plants for extensive plantings on slopes as steep as 25° or more and these plants do an admirable job most of the time. However, when high-intensity storms occasionally follow each other in short order, dumping additional rain on supersaturated soils, by far the greatest proportion of soil slips in landscaped areas occurs on slopes planted with ice plant. As a general rule, a written opinion by a geologist should be obtained before ice plants are used extensively on landscaped slopes of more than 15°. Exceptions are extremely harsh slopes where only ice plants would grow anyway. Ice plants are so extensively used because the plants cover quickly, soon giving the appearance of a completed landscape job. Unfortunately, the combination of a weak root system with high foliage moisture that adds weight may produce slope failures (Ilch 1952).

Coyote Brush

Coyote brush (*Baccharis pilularis* var. *prostrata* or cultivar Twin Peaks) rates excellent in drought tolerance, deep rooting habit, and esthetics. Its flowers are inconspicuous. The plant is prostrate to semiprostrate but is deep rooted and quite drought tolerant. In coastal areas on deeper soils it requires little, if any, summer watering. Mature coyote brush is highly flammable once ignited but resprouts readily after fire. It is therefore recommended for steeper slopes even in chaparral areas because its high flammability is countered by its relatively low fuel volume. The plant should not be planted too close to the house, however. Initially slow growing and therefore hard to establish, a 5-year-old plant may measure 6 to 8 feet (1.8 to 2.4 m) in diameter on better soils, and its compact growth will eliminate weeds almost completely. Plants will mound after they have grown together and thinning out may be required. When coyote brush becomes overmature and quite woody (usually within 5 to 10 years, depending on soils, watering, and exposure) it should be cut back to a few inches above the base in the springtime toward the end of the rainy season. Regrowth will be rapid, and during the regrowth period the plant will be essentially fireproof. Most of the slope will again be clothed before the rains arrive; thus, occasional renovation of coyote brush should be considered. Only the prostrate variety is recommended. On slopes, it does not exceed 12 to 18 inches (30.5 to 45.7 cm) in height. Other varieties may grow to be more than 4 feet (1.2 m) tall.

Rosemary

The prostrate variety of rosemary (*Rosmarinus officinalis*) also rates excellent in drought tolerance, deep rooting habit, and esthetics, but does not spread as extensively as coyote brush and therefore should not be used for large-scale slope plantings where weed control is necessary. It is also highly flammable but has low fuel volume (semiprostrate). It will not resprout. Its blue flowers are quite attractive and lure bees.

Prostrate Acacia

Prostrate acacia (*Acacia rodelens* cultivar *ongerup*) rates excellent in drought tolerance, deep rooting habit, and esthetics. Mature plants are flammable and have a greater fuel volume than prostrate coyote brush. Where fire danger is not great, in many ways the plant is superior to coyote brush. In coastal regions it is the most drought-tolerant, quick-spreading, low-growing woody plant tested under wildland conditions. With adequate rainfall and good soils, it can form a thick mat 3 to 4 feet (0.9 to 1.2 m) in diameter within 1 year and up to 15 feet (4.6 m) in diameter within 5 years. In late spring the plant is covered with showy yellow flowers. It may mound to 4 feet (1.2 m) high (thereby greatly increasing fuel volume), if its growth is obstructed. Thinning is then required. This species is the most underrated and underplanted species for greenbelt establishment that our research has encountered in 5 years. Its one drawback is the lack of resprouting ability; however, some of its seeds develop true to the prostrate habit.

Rockrose

Many species of rockrose (*Cistus* spp.) are available. They are rated good in drought tolerance and esthetics, and have beautiful showy white or pink flowers. In growth form they range from semiprostrate to over 6 feet (1.8 m) tall. The genus is flammable but generally has low fuel volume; the major exception is gum rockrose, which has the highest oil content (crude fat) of any plant listed in *table 3*. The genus is recommended for border effect but not for mass planting because its semiprostrate-to-upright growth form does not eliminate weeds. It also aids fire-spread (Laure and others 1961, Martin and Juhren 1954, Olsen 1960).

Periwinkle

The *Vincas* (*Vinca major*, *V. minor*) are rated excellent in low growth habit, and esthetics. They are fairly deep rooted and somewhat drought tolerant. They form an excellent weed-free cover, will readily resprout after fire, and have showy flowers. *Vincas* are well adapted as an understory cover to deep-rooted vegetation, especially on northern and eastern exposures when deeper soils are present. Without an overstory, they may require frequent watering in the summer. The taller-growing periwinkle (*Vinca major*) is more drought tolerant and is a better soil binder on slopes than the smaller-growing dwarf running myrtle (*V. minor*). On fertile soils with ample soil moisture, periwinkle covers the soil faster than any other species discussed in this section. However, it can become an unwanted nuisance similar to ivy.

Ivy

Algerian ivy (*Hedera canariensis*) and English ivy (*Hedera helix*) are the two species of ivy most commonly used in landscaping. They form an excellent weed-free cover. Algerian ivy, known as freeway ivy, is more commonly planted and also more drought tolerant and more deeply rooted than the more dainty English ivy. Because of its aggressiveness, it may be considered a nuisance in manicured landscape settings and it chokes out other plants. However, because of its climbing habit, it can effectively cover old fences and keep them standing, and reduce erosion scars on very steep slopes as it climbs downward. It is excellent for erosion control and its fuel buildup with age is not considered a major problem if the plant is kept away from the home. Frequent watering is required in summer. The daintier-looking English ivy is more shallow rooted, and also needs constant watering in the summertime or its leaves will be sunburned. It should, therefore, not be planted on south slopes or in harsh areas and does best under partial overstory.

African Daisy

African daisy (*Osteospermum fruticosum*) is a trailing ground cover with very showy flowers. It is somewhat drought tolerant but is best planted in full sun and on moderate slopes with good soil and ample soil moisture. Overwatering in hot weather may cause disease. This plant is not suitable for harsh cut slopes or other harsh sites, such as south-to-west exposures with thin soils. It does best in the vicinity of the coast and freezes at about 25° F (-4° C). After fires, it reestablishes prolifically from seeds. Two to three years after establishment, it may require regular maintenance such as fertilization and thinning of dieback caused by drought, cold, and fungus.

Watering Plants

Proper watering is the key to maintaining healthy and functional plants anywhere, even in a drought-tolerant greenbelt in the chaparral-urban watershed. Ideally, such a greenbelt should require no supplemental irrigation, but even the most drought-tolerant plants require a minimum amount of rainfall for survival.

A practical rule of thumb is that most drought-tolerant landscape shrubs can survive on ½ inch (12.7 mm) of water per week during the hot summer months but may require a greater amount of water where esthetics are important. Most other landscape plants can survive on about 30 inches (762 mm) of supplemental irrigation per year. Since the average household uses more than 60 inches (1524 mm) of water per year for landscape irrigation, this represents a tremendous saving to the homeowner as well as to society. In California, where future water shortages are foreseen, such saving has great importance, and can be achieved simply by sharply reducing and thoughtfully regulating watering in the late winter and spring months when plants have plenty of ground water.

Water-Saving Plants

When soil moisture is recharged to field capacity late in the season, even chaparral plants can be moderately heavy water users. They can transpire more than 5 inches (127 mm) of water per month (*table 6*). Most chaparral plants are true water savers (hydrophytes), however, and are able to conserve water by restricting transpiration before permanent wilting occurs; they may become dormant in the summer (*table 6*). Miller (1979) showed that in a stand of chamise chaparral on a southern exposure, maximum transpiration was slightly over 1 inch (25.4 mm) in June, but dropped to less than ¼ inch (6.4 mm) in October before the fall rains. Maximum transpiration on north slopes was much higher than on south slopes; the maximum of 1.7 inches (43.2 mm) per month was reached a month later. The transpiration rates reached a minimum of 0.0024 inches (0.06096 mm) in October, primarily because the soil moisture had been used up.

In order to survive for several months on practically no soil moisture uptake, after being a moderately heavy water user just weeks before, water-saving plants have developed effective drought-adaptive mechanisms (Rundel 1977). These include

- Leaves which are small, thick, and leathery (having thick-walled cells) and high in oil content, all of which tend to reduce transpiration. Relative vertical orientation of leaves so as to present the edge but not the surface to the sun, as well as changes in the angle of leaves in response to sunlight regulate the uptake of solar radiation and water loss.
- Stomata (minute openings in the leaf surface) that open during the daylight only for a short period of time and are able to close quickly, thus reducing water loss; stomata may be recessed and have cavities covered with hairy protrusions, which aid in reducing water loss.
- Cutin (a waxy substance on the leaf) that reduces transpiration to a much greater degree after the stomata have closed.
- Reduction of exposed leaf surface, as through shedding, rolling, or folding of leaves.
- Reverse transpiration—the ability of leaves to take up atmospheric moisture.

In general, the major means of control of water loss are the stomata; the other mechanisms help control water loss even further. Additionally, the gradient of increasing aridity and lack of available ground water supply between evergreen shrub communities and summer deciduous

Table 6—*Rates of transpiration and evaporation on loamy soils, California*

Plant or surface	Location	Conditions	Time of year	Rate of transpiration	Source
				Inches/mo	
Lawn grasses	Coastal zone		Summer	4.0	Williamson 1976
Bermuda grass	Santa Ana River Valley	Water table:	Summer		
		2 ft		6.5	Blaney and others 1930
		3 ft		5.5	
Weedy herbs	Santa Ana River Valley	Level	Winter	2.0	Blaney and others 1930
Brush 5 ft tall: Chamise, sage, Yucca	San Bernardino	Soil moisture recharge to field capacity in May	Apr.	3.0	Blaney and others 1930
			June	3.9	
			July	5.2	
Reeds, tules	Temescal Creek, Corona	Streambed	Apr.-May	12.9	Blaney and others 1930
Mixed chaparral: Desert buckbrush, Scrub oak	Northern exposure	Before fall rain	July	1.7	Miller 1979
			Oct.	0.0024	
				0.0	
Chamise chaparral	Southern exposure	Before fall rain	June	1.1	Miller 1979
			Oct.	0.2	
Navel orange trees, mature, 10 ft spacing	Santa Ana River Valley	Level	Jan.	1.0	Blaney and others 1930
			Mar.	1.6	
			May	2.1	
			July	3.1	
			Sept.	2.0	
			Nov.	1.5	
Bare ground	Santa Ana River Valley	Water table:			Blaney and others 1930
		2 ft	Winter	0.3	
		2 ft	Summer	0.8	
		3 ft	Jan.-Apr.	0.1	
		4 ft	Summer	0.0	
Swimming pool	Coastal zone	—	Summer	5-10	Klaus W. H. Radtke
Evaporation pan	Coastal zone	—	—	[1]40.0	Strahler and Strahler 1973
	Riverside ("desert")	—	—	[1]67.0	Blaney and others 1930

[1]Per year

coastal scrub communities is reflected in a change from deep, penetrating roots to shallow, fibrous roots and an increase in shedding of leaves. Furthermore, some plants such as hoary-leaf ceanothus make more complete use of the available moisture by starting their active growing season early in the year during the cooler temperatures which normally coincide with the onset of the fall or winter rainy season. Chaparral plants that have deep root systems draw moisture even from deep rock crevices. Many drought-tolerant plants are also able to lower the soil moisture percentage well below the so-called wilting point, at which water absorption by roots theoretically stops and leaf turgor cannot be maintained even in the absence of transpiration.

Water Requirements

The ability of most chaparral plants to extract the maximum amount of moisture possible leaves the soil mantle and rock crevices dry to absorb moisture when the winter rains return. Proper watering of greenbelts should, therefore, be patterned after this natural water withdrawal-recharge cycle. The yearly irrigation requirements of landscape plants depend on the amount and distribution of rainfall and are governed by the timing of the last effective rain in the spring and the first effective rain in the fall. Such rainfall is sufficient to be absorbed by plants. The time of first summer irrigation depends on the amount of moisture stored in the soil at the end of the rainy season, and on the root depth and moisture requirements of plants (*table 7*). During years of well-distributed rainstorms, most of the water infiltrates the ground and recharges the soil moisture to field capacity throughout the plant root zone; moisture for evaporation and transpiration is thus supplied throughout the winter months. During years when the rainstorms come early and are more closely spaced, more water percolates below the root zone and is lost to the plant. Soil moisture recharge occurs less often and much available soil moisture is used up early in the season by evaporation and transpiration. On deep soils, less water penetrates below the root zone, but on coarse soils, there is greater moisture percolation to the underground water table. The approximate amount of water available per foot of soil is as follows (Stefferund 1957):

Soil type:	*Available water (inches/ft)*
Sand	0.25 - 0.75
Loamy sand	0.75 - 1.25
Sandy loam	1.0 - 1.5
Fine sandy loam	1.5 - 2.0
Clay loams	1.75 - 2.25
Clays	2.0 - 3.0

Table 7—*Hypothetical water use by nine species of chaparral plants and ground cover, based on soil moisture recharge to field capacity by March 15, coastal zone, California*

Plant	Effective rooting depth	Moisture available to roots	Transpiration: Mar. 15 to June 15	Transpiration: June 16 to Aug. 15[1]	Date first watering needed	Response to drought
	Feet	*Inches*	*Avg. inches/mo*			
Lawn grass	2	3.5	3.5	4.5	Apr. 15	Plant dies
Periwinkle	3	5.25	2.5	3.5	May 22	Leaves go limp, above-ground portions die, root systems usually survive
Algerian ivy	4	6.75	2.5	3.5	June 5	Plant dies
Descanso rockrose	5	8.25	1	2	Sept. 1	Plant goes partially dormant
Australian saltbush	6	9.25	1	0.5	None	Plant drastically reduces transpiration, "shuts down"
Coyote brush	7	10.25	1	1.5	None	Plant drastically reduces transpiration, "shuts down"
California buckwheat	8	11.0	1	1.5	None	Plant drastically reduces transpiration, "shuts down"
Prostrate acacia	9	11.75	1	1.5	None	Plant drastically reduces transpiration, "shuts down"
Laurel sumac	20	17.0	3	2.5	None	Plant drastically reduces transpiration, "shuts down"

[1]From August 15 to October 15 transpiration for all species increases drastically if soil moisture is readily available.

[2]See *table 8* for available moisture by soil profile.

Sandy soils have the lowest moisture-holding capacity and release the available water most easily. Clay soils have a greater water-holding capacity but do not release the water as easily because water is more tightly held by adsorption to the smaller soil particles. Plants compensate for the lower water-holding capacity of sandy soils with a wider root network, but are restricted in their root penetration and water withdrawal on shallow, compacted or heavy soils. Plants do not withdraw moisture at equal rates from all depths of the root zone, but initially concentrate withdrawal on the upper half of the root zone. When the available moisture is withdrawn from any appreciable part of the root zone, growth slows down. As more moisture is withdrawn, the soil layer reaches the point at which no further moisture uptake is possible by the plant roots of the particular species. Before this point is reached, however, most plants show that they require water. For example, temporary wilting of the plants during the daytime indicates water need; this wilting is readily apparent in the water-demanding plants such as periwinkle and ivy. Other plants may change leaf color from green to yellowish. Once plants are well established, irrigation should be sparing enough to reduce the available soil moisture to the point at which plant growth is reduced without permanent injury. Growth stops as the wilting point is approached, but again increases rapidly for most landscape plants after irrigation.

Because of the many variables, a specific watering schedule for each plant species cannot be given here. General watering recommendations for plant species (*tables 5, 7*) take into account such variables as soil depth, rooting depth, and transpiration rates. The minimum hypothetical transpiration rates and rooting depths given in *table 7* for ground covers and chaparral species suggest how soon after the last effective rains the landscape plants may need irrigation. Transpiration rates depend on the total leaf structure area of the plant as well as its growth rate, with greater growth resulting from a larger area and volume of foliage. Humidity, wind, and temperature are also important; for example, at constant relative humidity, transpiration of English oak was found to be five times greater at 104° F (40° C) than at 68° F (20° C) (Kittredge 1973). In general, transpiration is related to the species and age of the plant and to the site. Water requirements are less per unit volume on good soils, but the total transpiration is greater because the plants grow better and have more leaf surface area.

During dry years, or when rains have come late in the winter season, fairly complete soil moisture recharge is initially necessary through irrigation. One deep watering early in the summer may be required by the most drought-tolerant species. When late winter rains have recharged the soil to field capacity, no watering may be required at all, or a more shallow watering to perhaps 1 foot (30.5 cm) depth late in summer may be sufficient for plant survival. Moisture withdrawal by plant roots will then leave the soil dry, ready for heavy winter rains that may come early in the rainy season.

Under the conditions shown in *tables 7, 8,* Algerian ivy would require watering by about mid-May to remain turgid. This is within 9 to 10 weeks after the last storm (mid-March) recharged the soil moisture to field capacity within the root zone of the plant. By this time, approximately 3 inches (76 mm) per month of spring transpiration would have used up the 6.75 inches (171 mm) of available soil moisture to a depth of 4 feet (1.2 m). The plant would attempt to send out new roots into the deeper moist soil layer, but transpiration needs of the leaves would soon outstrip the capacity of the roots to expand. Moisture absorption for all practical purposes stops and the plant dies unless irrigated.

Periwinkle, like ivy, is a water loving plant, and its water needs also increase throughout the spring and summer

Table 8—*Water availability is determined by root depth and differences in moisture availability throughout the soil profile. Data are based on soil moisture recharge to field capacity by March 15 (see* table 7*)*

Soil profile (depth in feet)	Available moisture	Total available moisture	Species and root depth	
	Inches/ft soil	*Inches*		*Feet*
1	1.75			
2	1.75	3.5	Lawn grass	2
3	1.75	5.25	Periwinkle	3
4	1.5	6.75	Algerian ivy	4
5	1.5	8.25	Descanso rockrose	5
6	1	9.25	Australian saltbush	6
7	1	10.25	Coyote brush	7
8	0.75	11.00	California buckwheat	8
9	.75	11.75	Prostrate acacia	9
10	.75	--	--	
11	.75	--	--	
12	.75	--	--	
13	.75	--	--	
14	.75	--	--	
15	.75	--	--	
16	.75	17.0	Laurel sumac	20

months. On deeper soils, however, and especially in partially shaded areas, its root crown can survive without summer irrigation and can send out new shoots when winter rains return. It is, therefore, an excellent ground cover for neglected areas.

Prostrate acacia and coyote brush are two deep-rooted ground covers that have drought-adaptive mechanisms similar to chaparral plants and can drastically reduce transpiration as the wilting point is approached. Thus, once these plants are established, irrigation is hardly necessary. Prostrate acacia and coyote brush have the added advantage of being esthetically pleasing despite drought shutdown.

Overhead Impact Sprinklers

For both initial establishment and later maintenance of hillside ground covers, overhead impact sprinklers and drip irrigation systems are recommended. They are easy to install, maintain, and inspect. Overhead sprinklers are not efficient water users when compared to drip irrigation.

Great care should be taken in designing the irrigation system, so that it will evenly cover the affected areas without causing undue erosion. When there is doubt about how to design a hillside irrigation system, an expert should be consulted. A well-designed system will pay off over the years in water saved and possible damage to hillsides avoided.

The greatest efficiency rate or maximum spacing is normally achieved by spacing impact heads at 60 percent of their throw diameter. Thus, 60 percent of a 72-foot-diameter sprinkler would be 43 feet. For tight soils and initial establishment of ground covers, impact heads that deliver only about 0.1 inch (2.5 mm) of water per hour, or that rotate quickly, can be used. Such heads greatly reduce the impact of the falling water drops on the bare soil, preventing damage to soil structure and allowing for greater infiltration and therefore less runoff. These are important considerations for compacted fills that normally have a much lower infiltration rate than chaparral soils.

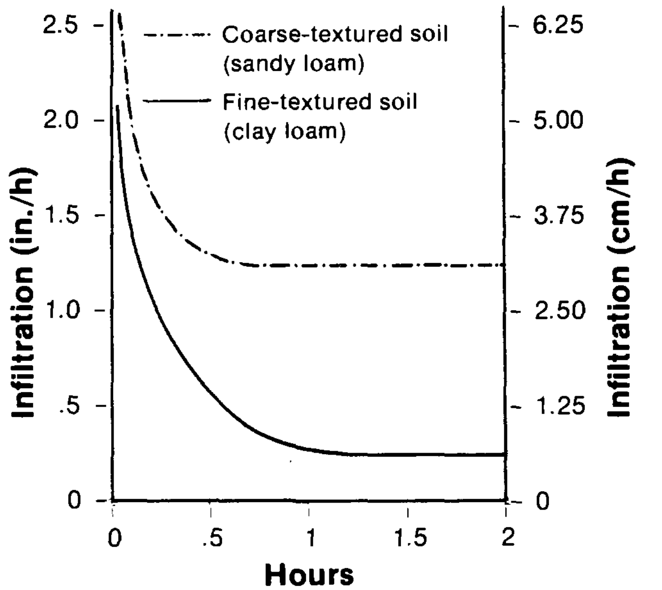

Figure 13—Infiltration rates for coarse-textured soils are higher than that for fine-textured soils.

Once the ground cover is well established, the nozzle of the impact head can be changed to deliver approximately 0.2 inch (5 mm) per hour. For soils that have a high infiltration rate, sprinklers are available to deliver as much as 0.4 to 0.5 inches (10 to 12.7 mm) per hour. When using these sprinklers, it may be advisable to irrigate several times a day to replenish soil moisture to the desired depth. Infiltration into soils is high during the initial watering period, but levels off very quickly as the soil surface becomes well moistened (*fig. 13*), as a result of closing of soil pores by soil particles or swelling of colloidal clays. For home use, high impact sprinklers are not normally recommended because they may saturate soil if left on too long. When sprinklers are automatically timed, there is danger that too much water may be applied and that a broken pipe may go unnoticed until hillside slippage occurs. Drip irrigation allows for deep watering with a minimum amount of water. Thus, a superior root system is developed.

To summarize, the proper watering of newly established greenbelts does not accelerate the natural erosion rates nor damage the soil structure. Deep watering is more beneficial to hillside plants than shallow watering because it recharges soil moisture more completely throughout the root zone and encourages some plants to develop a deeper root system. Water should be withheld from mature plants as much as possible to force slowdown of growth, which also results in reduction in transpiration. Water should be withheld towards the end of summer, allowing plants to harden off while they can still withdraw moisture from their root zones. Withholding water as fall approaches leaves the soil relatively dry at the onset of the rainy season and allows it to absorb water readily to greater soil depths. Constant shallow watering, on the other hand, only partially recharges the root zone, wastes water through evaporation, and may induce a more shallow root system that makes hillside plants less drought-tolerant. Deep watering should not be done after about mid-September. If effective rains do not occur until late in the season, occasional shallow watering may then be required to keep the more-water-demanding plants alive.

PLANNING FOR HOME SAFETY FROM FIRE

In most cases the fire safety of a home can be greatly improved. There are, however, special conditions of topography, wind, and heat patterns under which, in spite of all precautions, a home may literally explode in flames during a wildfire disaster. Through neighborhood teamwork, community action, and proper land use planning, the likelihood of such events can be reduced, but homeowners must realize that there is a risk in living in chaparral areas.

Reducing Fuel Load

Fire safety around a home is achieved by reducing the fuel load and breaking the fuel continuity, and by building a "fire safe" home in an area where it can be defended from wildfires. Landscaping to lessen the fire without fireproofing the home itself may be a futile effort. This was dramatically demonstrated during the June 22, 1973, Crenshaw Fire in Rolling Hills, Los Angeles County, where 12 homes burned, 11 of which had wood shingle roofs. The shingles caught fire, even though most homes were surrounded by an excellent green belt. The fire burned through 897 acres (359 ha) of light fuel which consisted of grass, mustard, and coastal sage.

The California State Resource Code 4291 is the basic vehicle for creating minimum fire safety by reducing the fuel load and breaking the fuel continuity. The code requires that all flammable vegetation must be cleared to a distance of 30 feet (9.1 m) around a structure. If additional hazards exist, the Director of the California Department of Forestry can require clearance up to 100 feet (30.5 m). Individual fire jurisdictions may differ as to the enforcement of the 30-to-100-foot-clearance law. For example, the County of Los Angeles brush clearance law (Section 27301 of the Los Angeles County Fire Code) requires a minimum of 30 feet legal clearance, but the Fire Chief can enforce clearance of up to 100 feet. The City of Los Angeles brush clearance law (Section 57.21.07) is more inclusive and requires the removal of all native brush (specimen plants excluded) and other flammable vegetation to a distance of 100 feet. The Chief Engineer has the authority to insist on more extensive brush clearance beyond 100 feet.

Homes burned in the 1961 Bel Air Fire showed the interdependence of brush clearance and roof type (Howard and others 1973). The destruction rate for homes with wood roofs ranged from 14.8 percent with brush clearance over 100 feet (legal clearance limit) to 49.5 percent with clearance of 0 to 30 feet. Nonwood roofs of approved types fared much better; the corresponding rates were 0.7 and 24.3 percent. With a legal brush clearance of 100 feet, a home with a wood roof therefore may be 21 times more likely to burn during a wildfire than a home with a nonwood roof. Gable roofs, large wooden overhangs (eaves), wood siding, large picture windows facing in the direction of the fire hazard, and houses located too close to a slope are some of the additional safety hazards that need to be eliminated in fire-prone areas. Pressure-treated wood shingles cannot be considered fire resistant indefinitely, because the safety edge wears off with time through weathering. Placing wood shingles over a layer of nonflammable material gives an individual home an added safety margin, but adds to fire spread by producing airborne incendiaries and creating radiation and convection heat that affects neighboring homes.

When a home with a nonwood roof and brush clearance of more than 100 feet (30.5 m) ignites, other conditions are

Figure 14—Winds tend to channel through chimneys, making narrow canyons and saddles particularly fire-prone.

responsible, the most critical being topography. Topography is becoming increasingly important as homes are being built in areas that are often indefensible from fire. Such areas include natural chimneys (narrow canyons that concentrate heat and updraft) (*fig. 14*), saddles (low points in a rolling landscape) (*fig. 15*), steep canyons, and ridges (*fig. 16*). Analysis of the apparently random burning of homes in the 1961 Bel Air Fire in Los Angeles showed that along Roscomare Road the burning was not random but was directly correlated with the intersection of a tributary canyon and the main canyon (Weide 1968). Wind eddies and associated fire winds quite common in such situations are normally found on leeward sides of objects that create a barrier to airflow. They can, therefore, be expected on the lee side of ridges, hills, large rocks, and even vegetation. If the prevailing wind is either up or down canyon, the eddies are magnified behind spur ridges, at sharp bends in the canyons, and especially in areas where two or more canyons meet (Countryman 1971). In very steep and narrow canyons the heat may also be a major factor in fire spread and home losses. In the areas considered indefensible from fire, a safety margin can nevertheless be created by reduction of brush and other fuel beyond the legal 100-foot clearance. Terrain permitting, this can be done through wide fuelbreaks surrounding the larger developments.

Understanding Fire Behavior

Understanding the basics of fire behavior will prove helpful to the homeowners. They will be able to judge fuels around their homes in terms of flammability, heat intensity, heat duration, and fire spread. A fire can be visualized as the flame, heat, and light caused by burning (oxidation) after an object has reached ignition temperatures and has been ignited. Ignition temperatures are influenced by the rate of airflow (supply of oxygen), rate of heating, and size and shape of the object. Once ignition has occurred, sustaining combustion requires a continuous supply of oxygen.

The different major wildland fuels, such as grasses, coastal sage scrub, chaparral, and trees, have various ignition requirements. Heat of ignition is greatly influenced by fuel particle size distribution, live-to-dead ratio of these particles and moisture content of live and dead tissues. The physiological condition of the living tissues greatly affects live fuel moisture. A vigorous growing plant has high living tissue moisture and a plant under stress or in poor vigor has relatively lower living tissue moisture. For example, growing grass has a living tissue moisture content greater than 100 to 150 percent of dry weight. Dead tissue moisture content is determined by the ambient air moisture and therefore changes rapidly. Dry grass has the lowest heat requirements for ignition and is therefore easily ignited; it has the longest fire season and also the highest fire frequency. Coastal sage scrub, because of its summer dormancy, its high amount of fine dead fuels, aromatic oils, and the relatively short life cycle of individual species, is next in heat requirements for ignition and in fire frequency. Woody chaparral shrubs in coastal areas have a higher live moisture content than the same vegetation inland and normally do not become dangerously dry until late summer or fall. However, even among these plants, several species, such as chamise, have greater amounts of fine fuel and tend

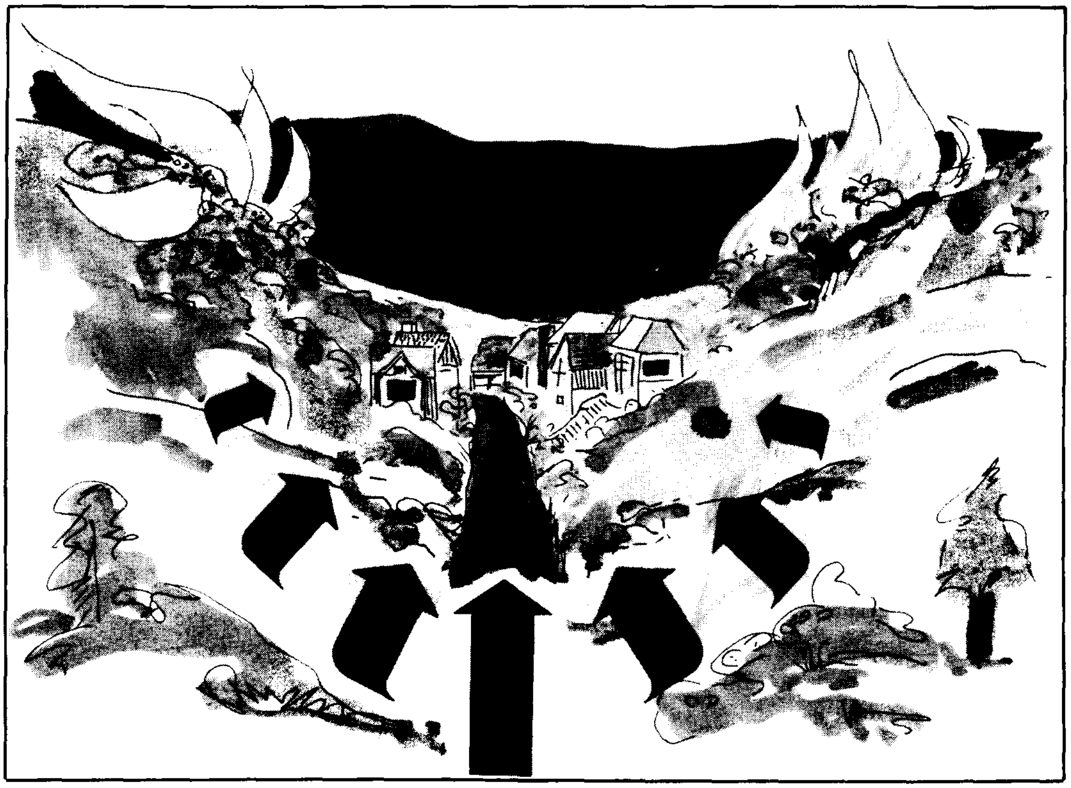

Figure 15—Natural saddles are wide paths for fire winds, and vegetation growing there will normally ignite first.

to have more flammable secondary compounds during the annual dry season.

Heat transfer is by conduction, convection, and radiation. The flame is the visible burning gas produced by the fire and provides (along with airborne sparks) a direct ignition source for fuels that have reached ignition temperatures.

Convection heat is the transfer of heat by atmospheric currents and is most critical under windy conditions and in steep terrain. With light wind and on level terrain, the convection heat column is almost vertical, and radiation heat becomes a critical factor in fire safety. Radiation heat is transfer of heat by electromagnetic waves and can, therefore, travel against the wind. For example, it can preheat to the ignition point the hillside opposite a burning slope in a steep canyon (*fig. 17*). Conduction is the direct transfer of heat by objects touching each other. It is not a critical process during a fast-moving wildfire but can be responsible for igniting a home, as when burning firewood stacked against the side of the garage causes the house to catch fire.

The interaction of the three types of heat transfer with topography can be illustrated by visualizing a burning match (*fig. 18*). When the match is held up, heat transfer is by conduction only, and the match burns slowly. This is comparable to a wildfire burning downhill. If the match is held horizontally, heat transfer is by conduction and radiation, and the match burns a little faster. When the match is held down, it is consumed rapidly because conduction, convection, and radiation heating are occurring together. The situation is comparable to a wildfire burning uphill, and such a fire travels much faster than one on level ground or burning downhill.

The key objective in breaking up the fuel load and fuel continuity around structures is to reduce the amount and duration of thermal radiation the home or the firefighter receives. For a point source of radiation this heat intensity decreases with the square of the distance from the source. The radiation intensity 100 feet (30.5 m) from the burning brush or landscape plants is therefore only one-fourth that at 50 feet (15.2 m). A tree burning within 20 feet (6 m) from a roof or picture window transfers only one-fourth of the heat to the house compared with a tree burning within 10 feet (3 m), and only one-sixteenth the heat compared with a tree within 5 feet (1.5 m) (*fig. 19*). A line source of radiation such as a burning hedge of junipers or cypresses is even more critical than a point source of radiation because the house receives heat from all points along the line (*fig. 19*). In this case, intensity varies with the distance instead of the square of the distance, so that the intensity at the home located within 20 feet from the burning hedge is still one-half that at 10 feet. Increasing the number of flammable landscape plants around the home and increasing the number of trees, or both, will make a house more fire-prone, despite legal brush clearance.

During a wildfire, flames more than 100 feet (30.5 m) long can roar over homes on ridgetops and consume seemingly safe homes a distance away. These flames directly transmit the greater part of the thermal heat of the radiating source (wildland fuel) to the home and thus ignite it. Flame length is controlled by the height and density of the radiating source, by windspeed, steepness of the slope, live and dead fuel moisture, fire spread, and such other specific characteristics of the fuel as ash and oil content and the arrangement and amount of fine fuels present. Reducing

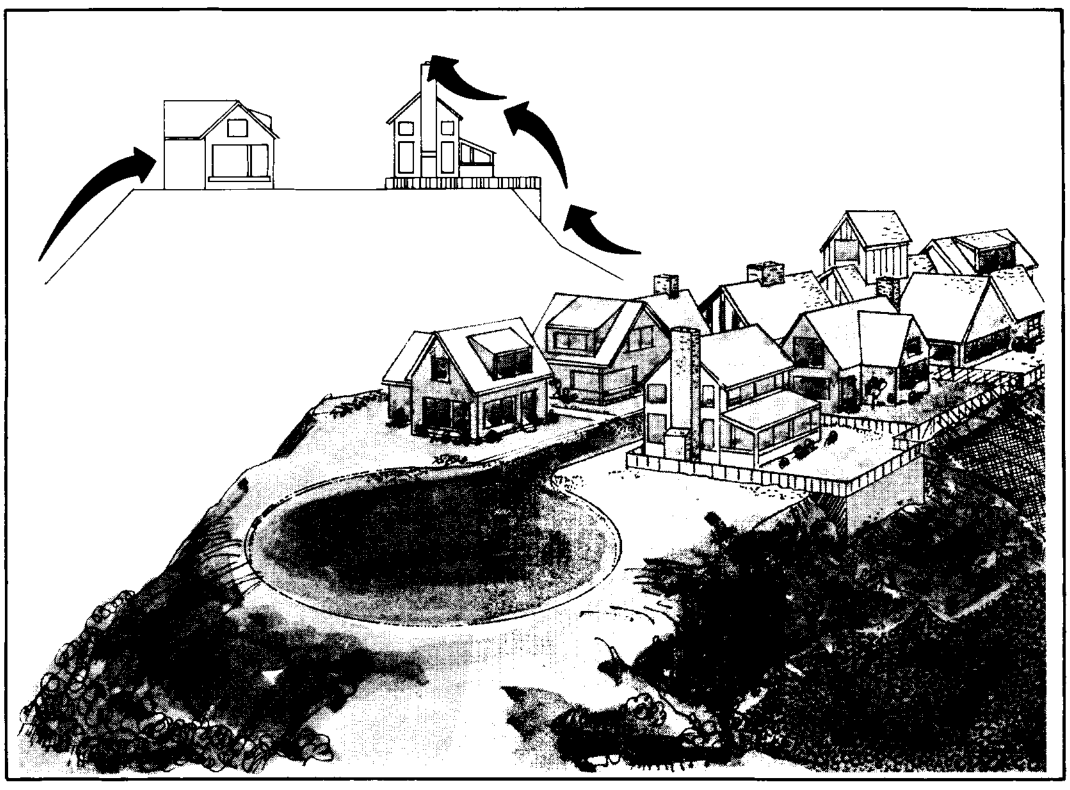

Figure 16—On narrow ridges, homes without adequate setbacks, such as those depicted, are especially vulnerable to fire.

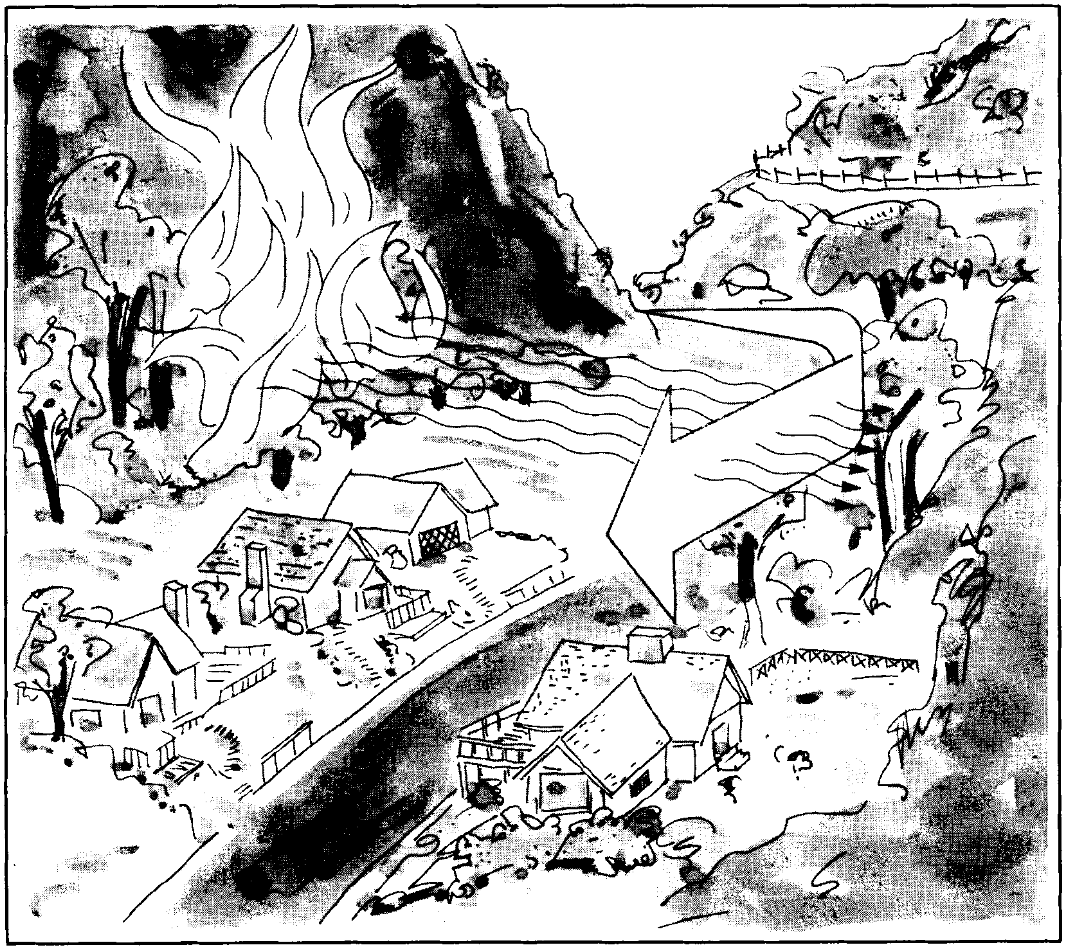

Figure 17—Radiation transfers heat in all directions—even against a wind sweeping through a canyon. In the process, the hillside opposite a burning slope can be ignited.

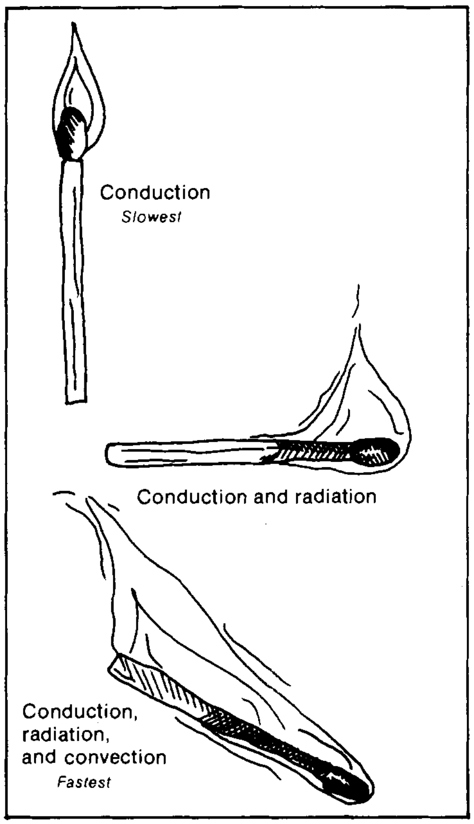

Figure 18—The interaction of three types of heat transfer—conduction, radiation, convection—is illustrated by three burning matches.

6-foot-tall (1.8-m-tall) chaparral to 2-foot-tall (0.6-m-tall) low fuel plants on a 45° slope can reduce flame length by one-third—a powerful incentive for fuel modification (Albini 1976) (*table 9*).

Wildland fires that produce flame length greater than 30 to 35 feet (9.1 to 10.7 m) are considered to be burning out of control. In 6-foot-tall chaparral this critical flame length is already reached at a windspeed of less than 10 mph (16.1 kph), whereas in 2-foot-tall low fuel volume plants the windspeed would have to approach 50 mph (80.5 kph) to produce flames of this length (*table 8*). Low fuel volume plants thus reduce but do not completely eliminate the risk of a wildfire conflagration; they do allow the fire to be contained in a shorter time.

Insurance companies realize that the many factors discussed above have to be taken into consideration for fire safety and therefore affect calculation of brush surcharge on insurance rates. Where there are slopes of more than 30° below the home, twice the 100-foot (30.5 m) legal brush clearance distance may be required to qualify for the same insurance rates (*fig. 20*). This approach, so vital for fire safety, works against maintaining slope stability, as discussed earlier.

The 1983 insurance rates in brush areas in southern California (*table 10*) show that the rates are primarily determined by the protection class of the area and the distance of brush to the building. Roof types are not adequately accounted for; with brush clearance less than 30 feet (9.1 m), costs for unapproved roofs are only 25 percent higher. Surcharges are eliminated with 400-foot (122-m) clearance for both approved and unapproved roofs, even though unapproved roofs can readily ignite from flying embers. This is poor incentive for a homeowner to include a more fire-safe roof in plans for building or remodeling. A homeowner who is concerned with fire safety therefore subsidizes a careless homeowner. Making insurance rates correspond closely to the risk factors is a good way to provide greater fire safety. More direct attempts at regulation tend to fail because building and zoning codes reflect political realities. Insurance incentives have been used to some extent: reductions in rates may be gained by having a swimming pool with an electric, gas, or battery-driven pump or other safety devices. An insurance agent can provide further details.

Promoting Fire Safety

Principles of topography, vegetation, and architectural design can be applied to improve the fire safety of a planned or an existing home (*figs. 21, 22*). Drastic fuel reduction on steeper slopes will result in slope instability (at least temporarily) unless the new vegetation offers the same network of root strength and depth. A basically "fire-safe" home design gives greater flexibility in fuel modification, thereby retaining slope stability to a greater degree.

Table 9—*Effect of windspeed and fuel height on flame length*[1]

Windspeed at midflame height (mph)	2-ft low-fuel plants	6-ft chaparral
	Flame length	*(ft)*
5	9.1	27.7
10	12.9	39.5
15	16.2	49.9
20	19.3	59.5
25	22.1	68.3
30	24.7	76.6
35	27.2	84.4
40	29.6	91.9
45	31.9	99.1
50	34.1	106.0

[1]Source: Albini 1976; adapted by Ronald H. Wakimoto, University of Montana.

Exterior materials used on wildland homes should have a minimum fire-resistive rating of 1 hour. This requirement is especially critical for parts of a home exposed to winds from the north or east, and for homes positioned at the top of a slope, stilted or cantilevered sideslope, or without a slope setback. For further information applicable to residential development see the fire safety guides issued by the California Department of Forestry (1980).

Homes can be designed with specific features to promote fire safety (*fig. 19*). Reduced overhangs or boxed eaves can protect the house from ignition and heat or flame entrapment. Under eaves, vents should be located near the roofline rather than near the wall. Exterior attic and underfloor

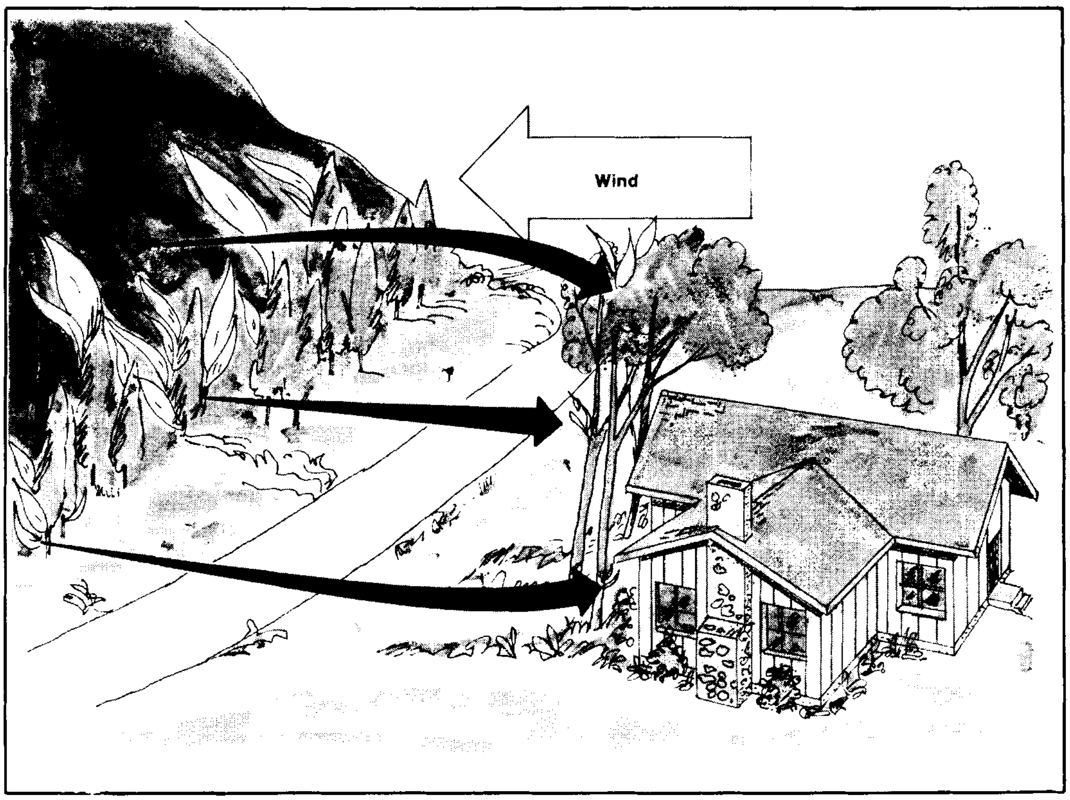

Figure 19—Fire safety is directly affected by the intensity and duration of thermal radiation that a home receives from flammable fuels.

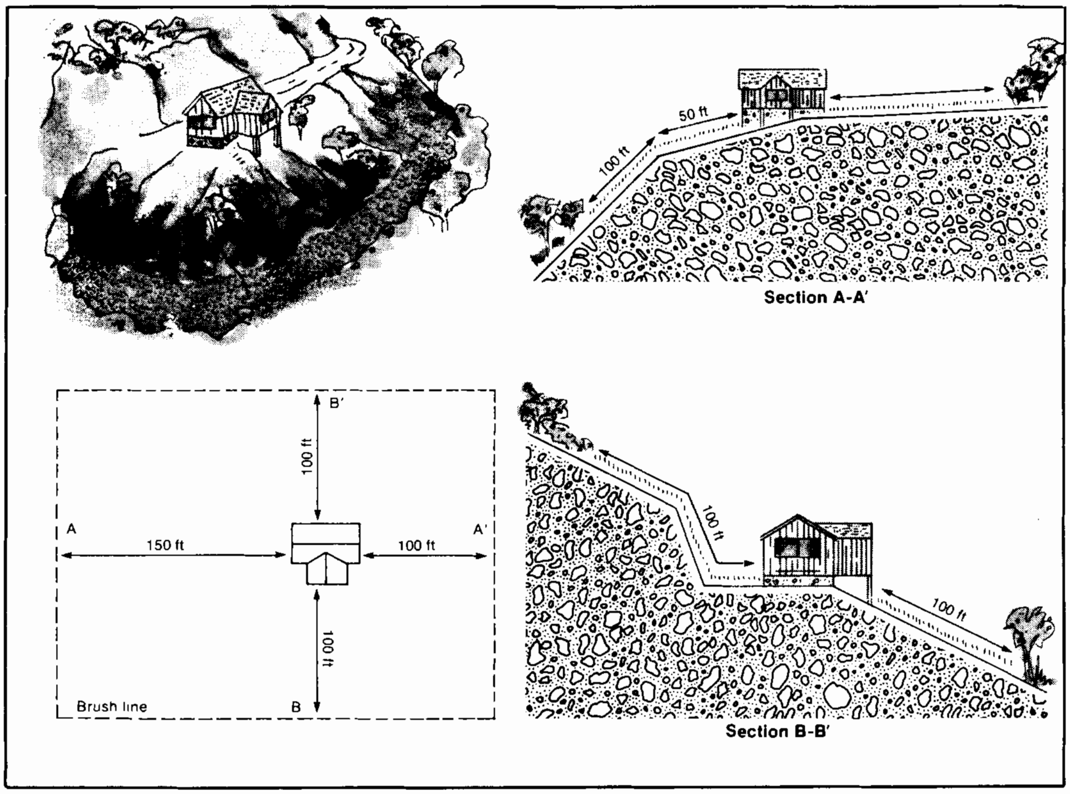

Figure 20—Minimal safety distances from a building to brush recommended by insurance firms will vary by the slope of the land.

Table 10—*Insurance surcharge rates for homes in brush areas with approved roofs (composition, rock, tile, slate, asbestos, or metal) and for nonapproved roofs (wood shingle, wood shake), by exposure distance to brush and protection class, Counties of Los Angeles, Santa Barbara, San Bernardino, and Ventura, in southern California, 1983*

Exposure distance to brush (ft)	Protection class[1]							
	1 to 4		5 and 6		7 and 8		9 and 10	
	A[2]	B[3]	A	B	A	B	A	B
	Annual charge (dollars for $100 property valuation)							
	Approved roofs							
0-29	0.40	0.40	0.48	0.49	0.64	0.64	1.28	1.28
30-59	.28	.36	.36	.48	.56	.64	1.28	1.28
60-99	.20	.28	.24	.32	.32	.48	1.28	1.28
100-199	.08	.16	.12	.24	.24	.32	.96	1.12
200-299	0	0	0	0	.16	.24	.64	.80
300-399	0	0	0	0	0	0	.32	.48
400-over	0	0	0	0	0	0	0	0
	Nonapproved roofs							
0-29	.50	.50	.60	.60	.80	.80	1.60	1.60
30-59	.35	.45	.45	.60	.70	.80	1.60	1.60
60-99	.25	.35	.30	.40	.40	.60	1.60	1.60
100-199	.10	.20	.15	.30	.30	.40	1.20	1.40
200-299	0	0	0	0	.20	.30	.30	1.00
300-399	0	0	0	0	0	0	.40	.60
400-over	0	0	0	0	0	0	0	0

[1]Insurance representatives have listings of the protection class of your area.

[2]Fire station within 5 miles; access road; public water hydrant with 4-inch main with 2½-inch outlet within 1,000 ft.

[3]One or more of the above requirements not met.

vents should not face possible fire corridors and should be covered with wire screen (not to exceed ¼ inch mesh). Picture windows and sliding glass doors should be made only of thick, tempered safety glass and protected with fire-resistive shutters. Stone walls can act as heat shields and deflect the flames. Swimming pools, decks, and patios can be used to create a setback safety zone as well as to provide safety accessories. Pools can provide a convenient auxiliary water source, often of critical importance for firefighters or homeowners before and during a fire, but should not be in lieu of an adequate community water system. Fire engines should be able to get within 10 feet (3 m) of the pool because this is usually the optimum distance for the drafting hose. If this is not possible, the pool should have a bottom drain and pipe system that terminates horizontally or below pool level in a 2 ½-inch valved standpipe equipped with a fire hydrant with national standard thread. This is the thread which most fire equipment in southern California can hook up to without adapters. (The local fire protection agency can specify the thread used and provide other suggestions.) A floating pool pump or portable gasoline pump with a suction hose that can reach the bottom of the pool can assure a usable water source, even when water pressure and electricity fail. A fire hose and nozzle are also needed.

Fabric fire hoses are fine for high pressure equipment such as pool pumps that are designed for firefighting, but should not be used on home faucets because such hoses readily kink as water pressure drops. All outdoor faucets should be equipped with strong ⅝-inch rubber hoses that will not burst when the nozzle is shut off. This system of hoses should be able to reach any part of the house and roof. A ladder should always be available to reach the roof, and should be placed against the part of the house least exposed to fire.

In summary, fire risk can be reduced by installing:

- Fire-resistive roof—preferably Class A, such as tile.
- Stucco or other fire-resistive siding of at least 1 hour fire-resistant rating.
- Reduced overhang (preferably closed eaves with vent covers).
- Roof slanted to accommodate convection heat.
- Safety zone (slope setback of at least 30 feet (9.1 m) for single story home.
- Pool used to create safety zone.
- Shrubs and trees not directly adjacent to home nor overhanging the roof.
- A deck with exterior materials of at least 1 hour fire-resistant rating.

Overhead (roof) sprinklers can increase the fire safety of an existing home. Under favorable conditions, they can provide fire protection by keeping the roof and surrounding landscaping wet (Fairbanks and Marsh 1976), but they can not take the place of a fire-safe building design. The high winds normally associated with wildfires often prevent the water from effectively wetting the roof. Also, the system will break down if there is no water pressure because of power failure or heavy demand on the water supply. Systems that can operate on minimal water pressure, such as full circle, low-pressure impact sprinklers, provide added safety.

The extensive use of water by many neighbors can quickly drain the community water supply, leaving little or no water or pressure for fire suppression use. Fire suppression agencies, therefore, may not recommend the use of roof sprinklers operated by the community water system.

If water is available from an auxiliary source such as a swimming pool, roof sprinklers could be installed in con-

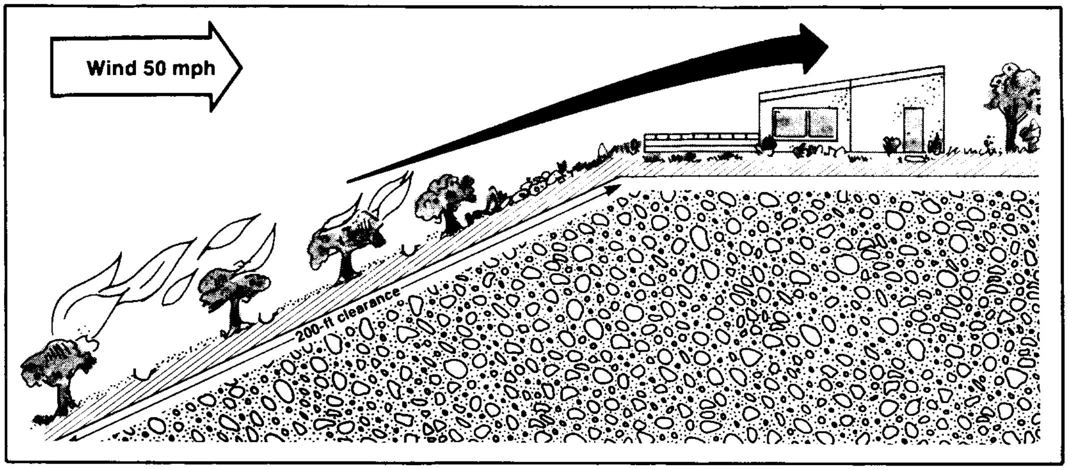

Figure 21—Fire safety can be increased by reducing fuel to twice the legal minimum distance of 100 feet (30.5 meters). To maintain slope stability, retain native plant species within the 18-foot (5.5 m) recommended distance for fuel separation. Flame length is still continuous, but the amount and duration of heat output is less than when brush is cleared to the legal minimum.

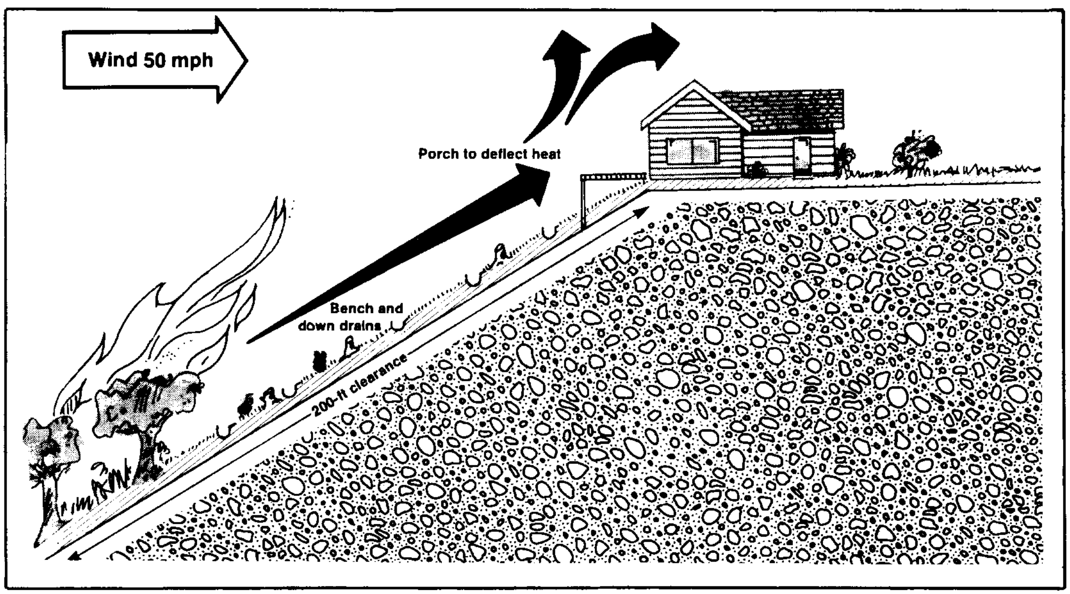

Figure 22—Homeowners can modify their homes to overcome negative characteristics. But they should seek the help of geological, engineering, and erosion control specialists when planning intensive fuel modification on steep slopes. Drastic fuel reduction can lead to slope instability.

junction with a portable pump utilizing the water from the swimming pool only. However, roof sprinklers cannot offer the degree of fire protection obtained by a fire-safe building design.

Modifications to an existing property (*fig. 22*) that could overcome negative characteristics include:

Negative characteristics	*Modifications*
1. Wood shingle roof	Fire-resistive roof
2. Wood siding	Fire-resistive siding (or fire-resistive paint)
3. Large overhand (open eaves)	Reduced overhang (closed eaves); vent covers for fire emergency
4. High gable roof	Redesigning may be too expensive
5. No safety zone (no slope setback)	Create setback with a deck where exterior material has a fire-resistant rating of 1 hour or more
6. Large picture windows	Install fire-resistive shutters
7. Tree crown overhanging the roof	Prune trees

Clearing Brush Around Homes

Some typical fire hazard reduction requirements are set forth below. Local homeowners may receive such information from their jurisdictional fire agency or the California Department of Forestry. Residents of fire-prone areas should be aware of the local ordinances that require such hazard reduction, should understand them and help make them applicable to their particular area. Living more safely in chaparral areas requires a balance of both watershed and fire safety. Clearing brush according to local ordinance will not in itself guarantee fire safety (*fig. 23*). Other measures described in this report should be followed. For additional guidance on fire safety, see reports by the California Department of Forestry (1980), Moore (1981), Perry and others (1979).

You are only required to clear your own property. Clearance on other property is the responsibility of the owner. Contact your local forestry or fire personnel if such clearance is needed.

1. Clear all hazardous flammable vegetation to mineral soil for a distance of 30 feet (9 m) from any structure. Cut flammable vegetation to a height of 18 inches (45 cm) for another 70 feet (21 m). Exception: This requirement does not apply to single specimens of trees, ornamental shrubbery or cultivated ground cover such as green grass, ivy, succulents, or similar plants used as ground cover, provided that they do not form a means of readily transmitting fire from native growth to any structure.
2. Remove limbs within 10 feet (3 m) of the chimney. Cut away dead branches and limbs that overhang the roof.
3. Screen the chimney outlet to prevent sparks from igniting the roof or brush. Use ½-half inch mesh.
4. Clean leaves, needles and twigs from roof gutters and eaves.
5. Clear flammable vegetation within 10 feet (3 m) of liquefied petroleum gas storage tanks.
6. Stack wood piles away from buildings, fences and other combustible materials.

TREATING NEWLY BURNED CHAPARRAL SLOPES

After brush fires, erosion from burned watersheds covered with natural vegetation may be more than 20 times

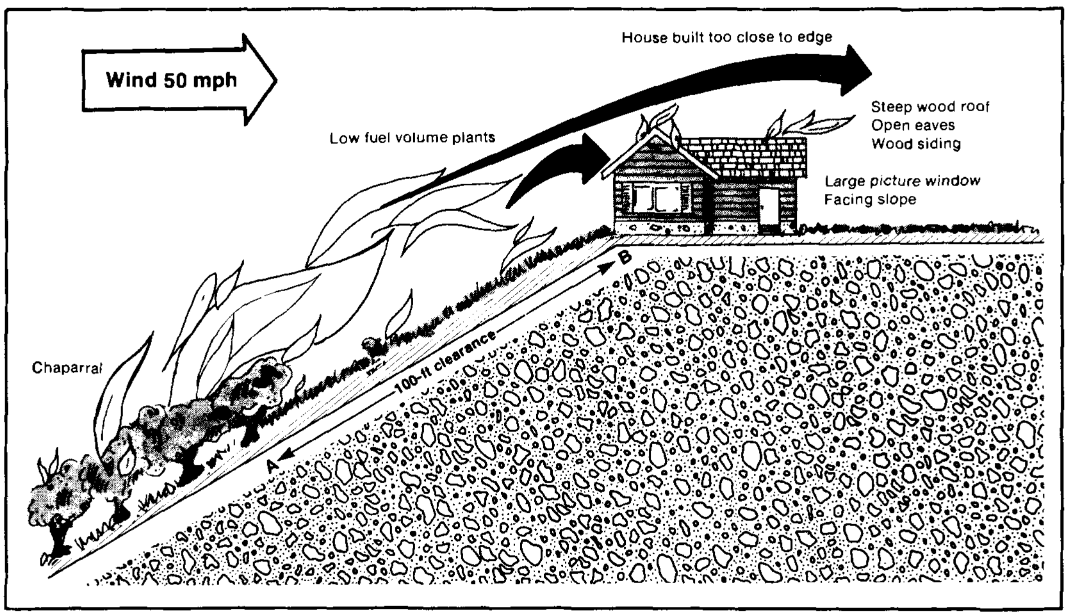

Figure 23—Fire can travel uphill 16 times faster than downhill. At wind speeds of 50 mph (80.5 kph), flames produced by a solid cover of chaparral can exceed the 100-foot (30.5 meter) length of brush clearance. Therefore, a solid flame front will be produced that reaches from the edge of the chaparral (*A*) over the low-fuel plants to the house(*B*).

greater than from unburned watersheds, although it is normally much less. Fire intensity, steepness and length of slope, soil type and parent material, and intensity, duration, and frequency of winter rains all affect the amount of erosion. In any event, immediate action by the homeowner is imperative to reduce property damage from the winter rains. But, what to do? Some suggestions are illustrated in *figure 24.* Additional information can be gathered from other sources (for example, Amimoto 1978, Los Angeles County 1982, Los Angeles Dep. Bldg. and Safety 1978, Maire 1962, Zinke 1962). The appropriate County Flood Control office can provide immediate help when need is urgent.

Direct Seeding

After major fires, Federal, State, and local agencies may immediately start aerial seeding of the hillsides with annual ryegrass (Blanford and Gunter 1971). This is an emergency measure and often seeds exposed on the soil surface will not germinate and start rooting unless encouraged by 4 or 5 days of moist weather. Much of the season's rainfall may be passed before the seeded grasses become well established. Seeds of resident annual grasses, when they are present, germinate more quickly because many of the seeds are buried in the soil layer and therefore have moisture available. This abundant seed source quickly germinates wherever moisture collects. Perennial grasses will resprout soon after the first winter rains.

Annual Ryegrass

Aerially seeded ryegrass is less effective on steep slopes and needs fertile soils (provided by nature after a fire), moisture (rain or sprinklers), and warmth to germinate. When ryegrass is used by the homeowner the best course is to seed the slopes by hand, preferably raking the grass seed in, and then installing a sprinkler irrigation system. If the slope is to be replanted immediately with landscape plants, ryegrass must be seeded in contour rows or it will choke out the newly planted stock. To germinate the seeds before the winter rains, the first few inches of the soil surface must

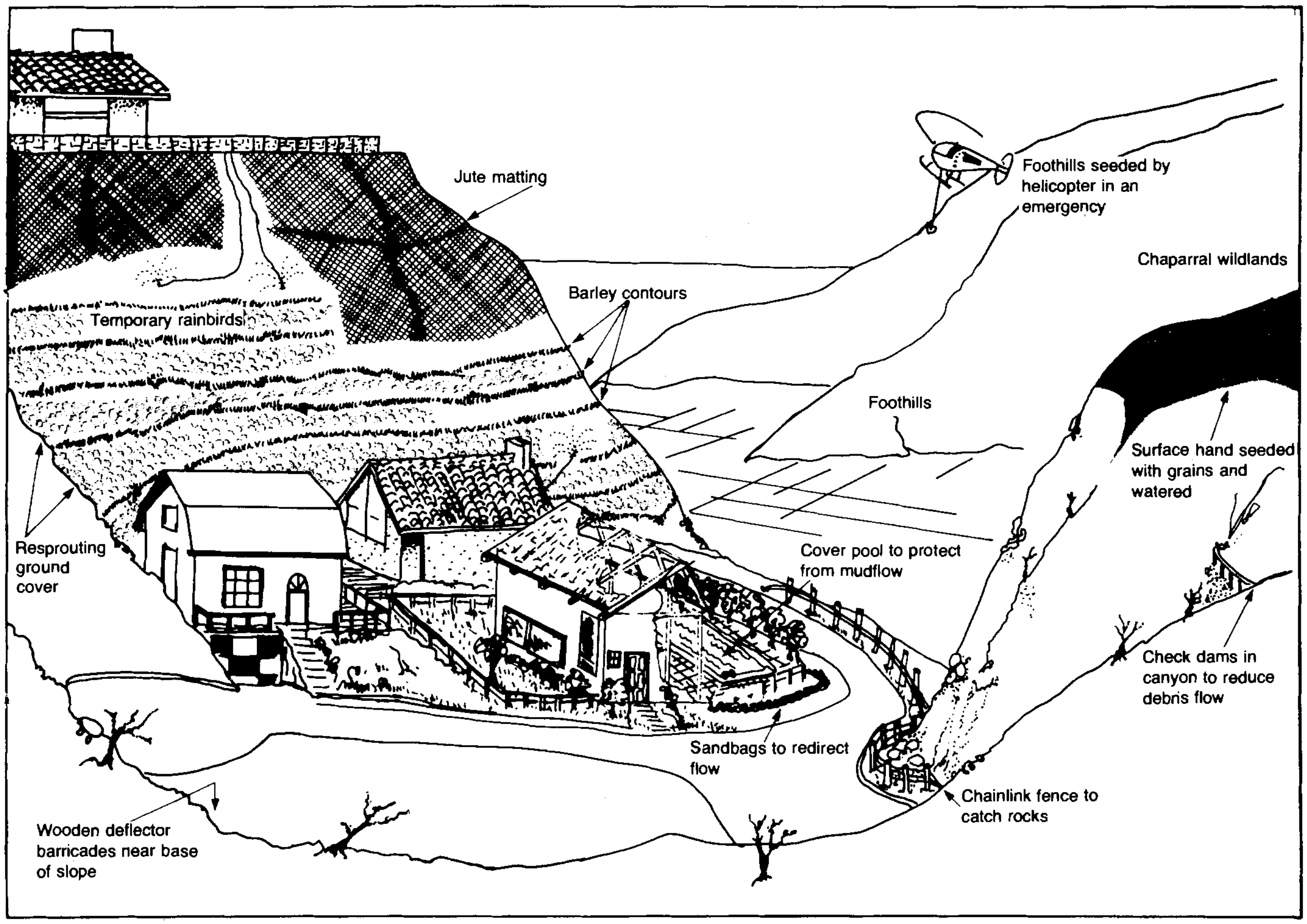

Figure 24—Immediately after a fire, emergency measures should be taken to rehabilitate a chaparral watershed. They include the use of direct seeding, check dams, boards, jute matting, chain link fences, sandbags and deflector barriers, drains, dry walls, plastic sheeting, and guniting on slopes.

be kept moist through frequent light watering. Deep watering should be avoided.

Seeds can be pregerminated to save water, to prevent overwatering of slopes, and to assure a good, quick cover (Esplin and Shackleford 1978, Radtke 1977) (*fig. 25*). This is readily done by putting the seeds into gunnysacks (sandbags) and soaking them thoroughly in large containers, such as trash cans that have small holes or openings for drainage. The excess water, which may contain germination-inhibiting chemicals leached from the seed coat, should be channeled into the street gutter. After the seeds have been kept moist in the sacks for about 1 day, they should be hand seeded on the hillsides or raked in. They will germinate immediately if moisture is continuously supplied.

Ryegrass should be viewed by the homeowner as a management tool for temporary emergency surface erosion control of bare slopes during the immediate rainy season. Eradicating the ryegrass plants on landscape slopes towards the end of the rainy season, before they go to seed, and replanting the areas to deep-rooted low-fuel plants can be an effective method for reducing topsoil erosion. The ryegrass treatment greatly reduces surface erosion but can compete heavily with the deeper-rooted woody plants. Spring and summer annual grasses will become dry, weedy flash fuels. New seeds germinate year after year as long as the soil is disturbed. Perennial ryegrass should not be used, as it can become a weedy pest.

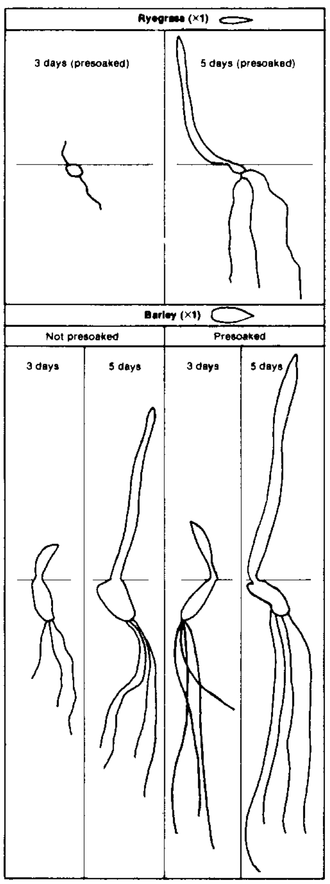

Figure 25—Soaking barley and ryegrass seeds stimulates pregermination, thereby hastening rooting and establishment as ground cover.

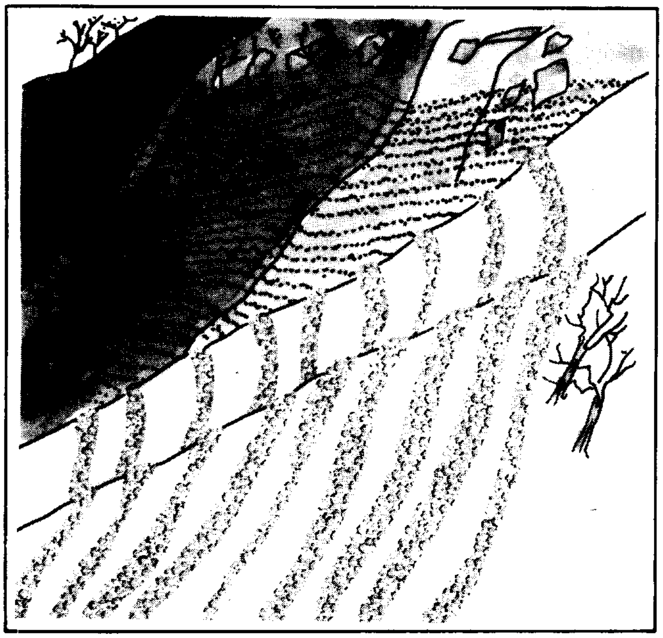

Figure 26—Barley planted on contours is effective in minimizing erosion.

Homeowners should avoid broadcast seeding or contour seeding grasses on recent slippage areas or actively sliding hillsides. The additional infiltration of water into the soil by the shallow-rooted grasses may cause local soil liquefaction and further slippage and mudflow. Plastic sheets should be spread over these areas until a proper slope engineering job can be done.

Barley

Hand planting of barley in contours spaced about 3 feet (0.9 m) apart has proven very effective in minimizing erosion, even on steep slopes (*fig. 26*). The ridges and trenches of the contours form a series of miniature terraces that allow water to infiltrate the soil. This increases plant growth, reduces runoff, conserves soil moisture, and prevents soil loss. On slopes with lower infiltration rates, such as steep, long slopes and hillsides with finer, less coarse soils, contours should be spaced more closely than on watersheds with high infiltration rates. Similarly, contours should be closer in areas where the runoff problems are critical, as near homes at the base of the slopes.

Strip cropping could also be practiced by interplanting the barley rows with rows of low-fuel ground covers in catching and holding water and soil. This method allows for reestablishment of ground covers while at the same time greatly reducing postfire soil erosion. Several years can therefore be saved in relandscaping of fire-prone hillsides. Quick cover and healthy plants are produced through saving the topsoil which is so valuable for plant growth.

For seeding barley, recommended rates are about 150 pounds of barley per acre (167 kg/ha) with about an equal amount of diammonium phosphate fertilizer added to the rows at planting time. Barley is readily available from feed stores and can be ordered immediately after a fire. Care should be taken to order only recleaned barley, as rolled

Figure 27—Check dams can reduce gully erosion.

barley (used for feed) will not germinate. Recleaned barley may be cheaper than ryegrass when the demand for it is low.

For quick establishment, barley seeds should be pregerminated no longer than 1 day and should be covered with soil to a depth not exceeding 2 inches (5 cm). Seeds lightly covered with soil germinate with the first winter rains, whereas seed lying on the soil surface need an extended period of moist weather for germination. Compared with ryegrass, barley germinates and grows more vigorously in cooler weather. Broadcast seeding (sowing the seeds on the slope without covering them) is less effective with barley than with ryegrass seeding. Barley seeds are much larger than ryegrass seeds, and very seldom find enough moisture at the soil surface to allow germination. Rodents and birds also tend to eat the seeds before they have a chance to germinate. Even after the barley plant dies, the strong roots can hold the surface soil for another 2 years. When reseeding is not desired, the plants should be cut in the spring before they go to seed. Barley is an annual plant and becomes a flashy fuel after it dies in late spring or early summer.

Check Dams

The object of check dams is to hold back rocks, brush, and other debris, and to slow down the flow of water in canyons or large gullies (*fig. 27*). Reseeding and replanting should go hand in hand with these temporary erosion control measures. Check dams should be repeated about every 50 ft (15 m). Small mesh fencing will act to impede water flow. Additional information regarding liability to downstream residents may be obtained from local flood control officials.

Boards

Redwood boards as thin as 1 inch (2.5 cm) can be used effectively to stabilize steep slopes before planting and to keep existing soil slips from getting worse (*fig. 28*). The boards are the homeowner's emergency soils engineering tools to reduce the effective length and steepness of hillsides by dividing a larger watershed into smaller sections. Boards can be very effective if well engineered and supported by a proper plant cover, but should not be looked upon as a substitute for permanent soils engineering methods. Boards should not be placed closer than 5 feet (1.5 m) vertical distance and should be held by old pipes or rebars at least 4 feet (1.2 m) long and about 1 inch (2.54 cm) or more thick (old pipes may be gathered from a local plumber). Rebars are round, solid construction steel bars that are ridged and anchor themselves in the soil more effectively than smooth pipe, provided the soil is firmly tamped around the rebar after it has been hammered into the ground.

A board 10 feet (3 m) long and 1 foot (30.5 cm) high should be held by a minimum of three rebars. Unless the boards are used as terraces, there should be 1 or 2 feet (30.5 or 61 cm) of clearance between horizontally placed boards.

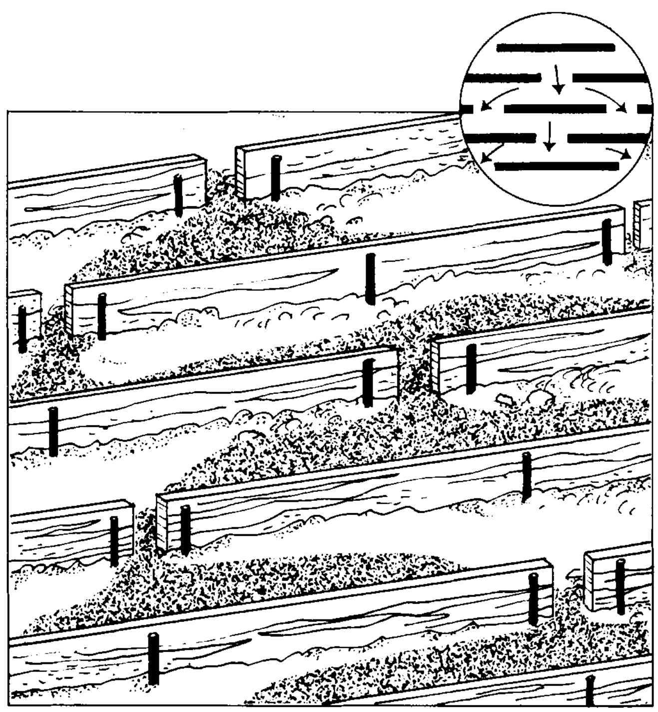

Figure 28—Pretreated or redwood boards help stablilize the face of soil slips.

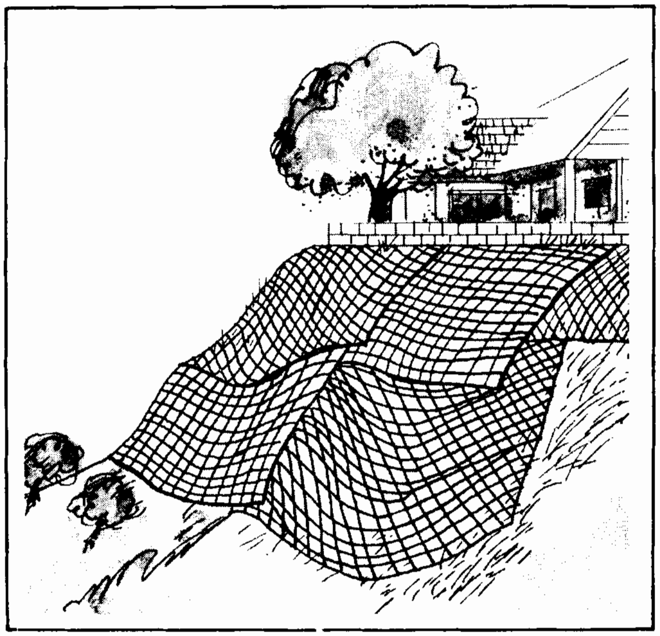

Figure 29—Jute mating reduces surface erosion.

Boards minimize slippage during heavy rains, when both soil and excess water can ooze out between the boards. Remember that a supersaturated slope will slip.

Localized slope instability may result if the pipes that hold the boards are hammered into highly fractured and weak bedrock, especially in areas where such rock layering parallels the slope. Pipes may also fail to hold the boards, especially on steep slopes with thin soils, if much new soil is placed behind the boards to establish a foothold for new plants.

Jute Matting

Matting made from natural fibers can be bought in carpetlike rolls. It is unrolled over the slope and anchored with pins in areas where heavy erosion is expected (*fig. 29*). Every square of the matting acts as a miniature check dam and effectively catches soil particles. The matting eventually decomposes but holds long enough for plantings to become established. Information on how to to use the matting is obtainable from a nursery. Potato sacks (gunny sacks) can be effectively used for both erosion control and weed control of smaller areas.

Chain Link Fence

Where life and property are endangered by falling rocks, chain link fencing can be useful (*fig. 30*). The chain link is flexible enough to catch even large boulders. When these are likely to fall, steel posts or telephone poles should be installed to anchor the fence, but not 4-by-4 wooden posts, because a rock has a better chance of glancing off a round object than a square one without breaking it. Telephone poles should be buried at least 3 feet (0.9 m) deep. Professional help is advisable when designing a chain link fence system to reduce the danger from falling rocks.

Sandbags and Deflector Barriers

Sandbags are used to direct the flow of mud and water to areas where they will do less harm (*fig. 31*). The flow of mud away from one home should not be directed toward another, however. Sandbags can be used effectively to build a berm at the top of slopes to prevent water from running downhill. Channeling water down the slope causes supersaturated soil and slippage.

After major fires, a limited number of sandbags may be supplied by fire protection agencies or the flood control district. The sandbags should be filled half full with sand or soil, and the flaps tied and folded under, pointing toward the direction of water flow. When one layer of bags is in place, bags should be stomped on to eliminate spaces between them. The next layer of bags should be staggered. Sandbags should never be more than three layers high unless they form a pyramid or unless a building is used as backing.

Wood deflector barricades may need to be used in critical areas where emergency revegetation may not be very effective. They serve the same purpose as sandbags but are semipermanent structures. The local flood control district office can provide expert advice regarding these diversion devices.

Figure 30—Chain-link fences stop rocks, even large boulders.

Drains

Concrete bench and downhill drains reduce the effect of topography on erosion (*fig. 32*). They reduce runoff and erosion by dividing a portion of a large watershed into smaller watersheds and by removing excess water safely from a slope. Every year before the rains return, all drains in the neighborhood should be inspected and cleared of debris. Clogged drains are a major cause of flood damage and hillside slippage. All drains should be reinspected before sandbags are placed in position and after every heavy rain, especially the first few years after a fire.

Dry Walls

Where slippage has occurred or is imminent, dry walls can be effectively installed, provided they have a firm foundation, as at the base of slopes (*fig. 33*). Dry walls can be made from unwanted concrete pieces from patios or driveways, and the wall can then be put up piece by piece without cement. Such materials are free, except for hauling. No cement is needed and there is no mess. Such a wall may last a lifetime and is more effective than a block wall during an earthquake. If the wall is more than several feet tall, it should be sloped slightly toward the hill as new layers are added. Dry walling against a fill slope leads to slope failure (mudflow) during intense rains unless the fill is well compacted, anchored by plants, and only a few feet high. Lateral drains inserted 20 feet or more horizontally into the slope will lessen the chance of slope slippage by draining the excess water out of the slope.

Plastic Sheeting

Plastic sheeting can keep a slope relatively dry during heavy rains and prevent surface erosion especially after a fire in late fall (*fig. 34*). After a slippage, it will prevent further saturation and movement of the soil. The entire slope or slope area should be covered with the plastic so that water is not channeled from one part of the slope to another. The flow of water at the base of the plastic must be controlled to avoid damage to homes below. Improperly placed sheets that concentrate runoff in selected areas or that cover only portions of a hillside are a leading cause of slope failure. Therefore plastic spread on hillsides must be properly tied down or constantly maintained throughout the rainy season. Broken pieces should be replaced and windblown sections retied. The thicker 6-mil (0.006-inch)

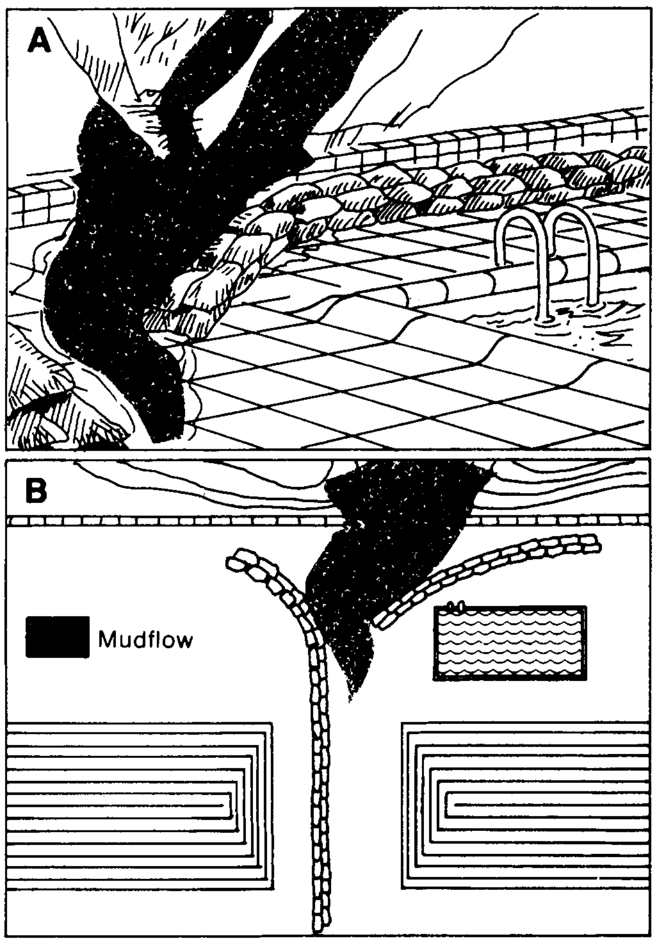

Figure 31—Sandbags divert flow mud.

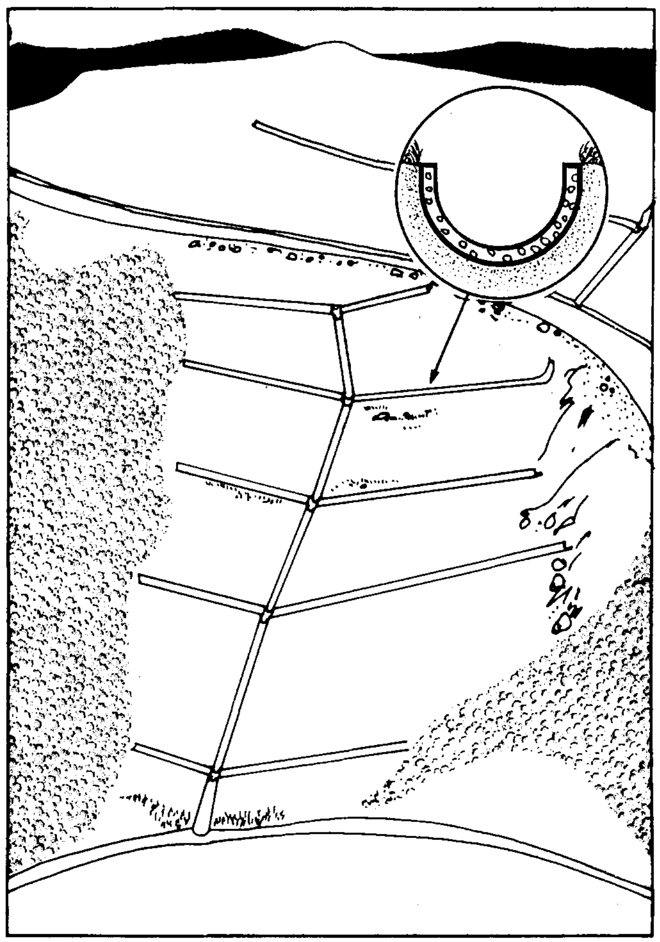

Figure 32—Drains control water flow and reduce excess surface runoff.

plastic is preferred because it rips less easily and covers the slope better, thereby reducing maintenance problems. Sandbags partially filled with soil are used to anchor the plastic. On steeper slopes, sandbags should be tied to ropes that are anchored at the top of the slope. Rocks or stakes should not be used to anchor the plastic because rocks wear through the plastic and stakes are ineffective when winds whip underneath the plastic. Rainstorms bring rain *and* wind. The plastic sheets must therefore be sealed on all edges and on overlaps, to prevent them from becoming sails as the wind whips underneath them.

Guniting

Guniting of slopes above or below homes or on road cuts is the most effective way to eliminate soil erosion in areas where plants are ineffective because slopes are steep and soil erosion is rapid. In effective guniting, a network of construction steel is anchored into bedrock and concrete is poured over this web of steel after drain pipes have been installed at appropriate intervals. The unattractive effect of the gunited hillside can be greatly reduced by coloring the concrete approximately the natural soil color of the area and planting trailing groundcovers at all edges. For safe disposal of the runoff water, the base of gunited slopes must be tied into permanent steel, asphalt, or concrete drains.

Guniting is most effective on slopes not exceeding 25 feet (7.6 m) in vertical distance. It requires a high initial investment but is cost-effective in the long run. It is often the only effective way to stabilize steep roadcuts and slopes already undercut by roads when building is begun. Without treatment, debris from steep or undercut slopes settles at the foot of the slope. Although this process eventually establishes a new, stable slope angle, the debris may also partially block the road and need to be cleared and hauled away periodically. This process continuously undercuts the slope causing further accelerated erosion and larger slides. Building should therefore not be allowed on top of any undercut slope unless the cut is first completely stabilized or unless it consists of a solid rock cliff. Retaining walls and guniting are only a partial solution to hillside problems.

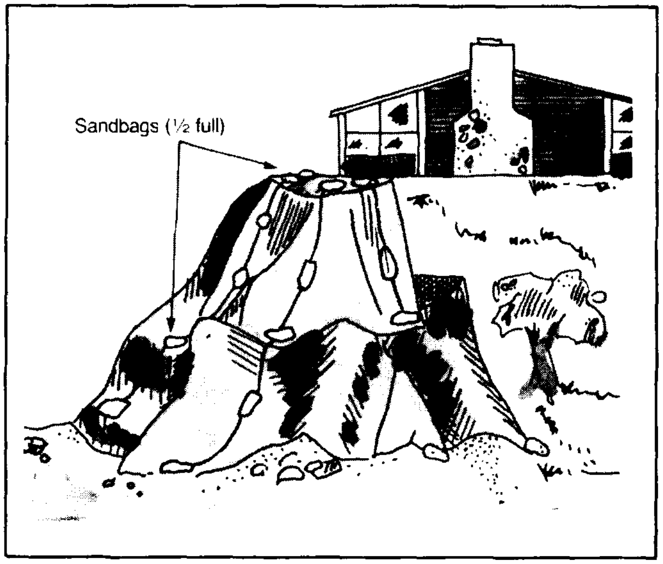

Figure 34—Plastic sheets remove further rainfall from saturated soils.

The suggestions made here are quick self-help methods for the homeowner, using materials often readily available. Planting of woody plants, such as shrubs and trees, is not effective as erosion control in the season after a fire. These deep-rooted plants are needed, however, to minimize slippage on steeper slopes, and herbaceous cover such as

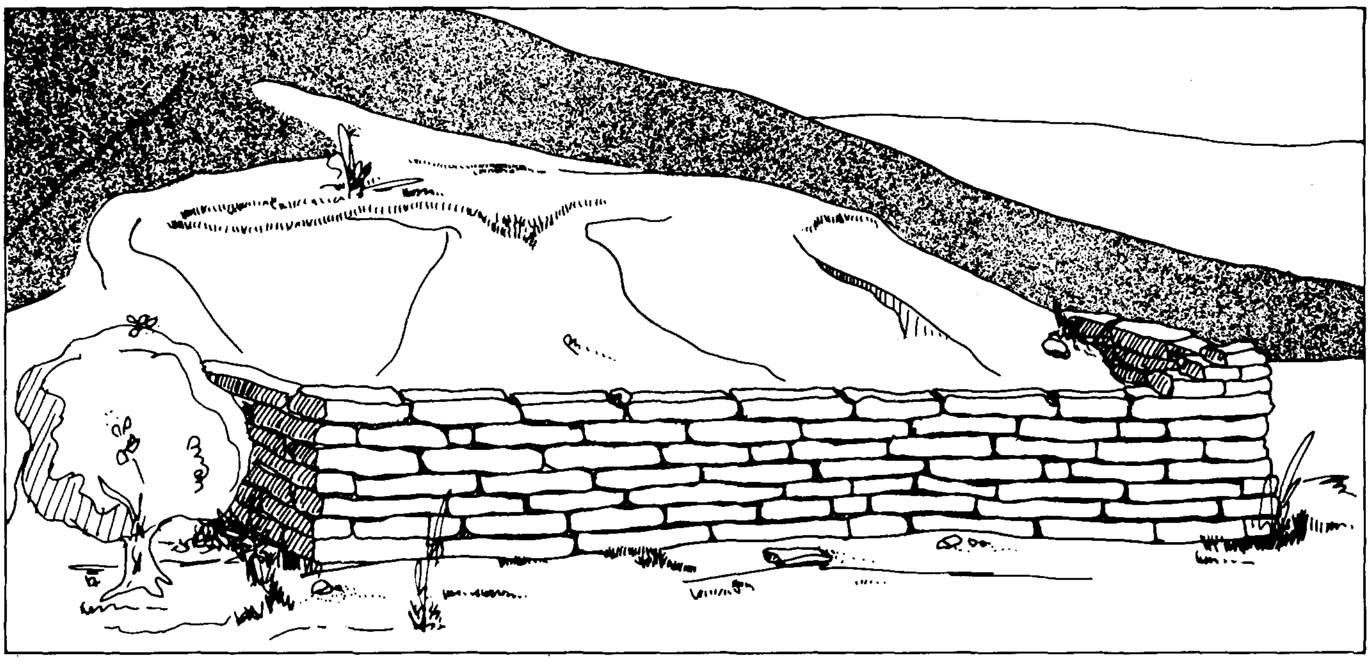

Figure 33—Dry walls can stabilize the toe of slopes.

grasses is needed to reduce surface erosion. Shrubs and trees must be replanted if the burned woody plants do not resprout. Research has shown that converting chaparral to grass covered watersheds after a burn greatly reduces erosion for the first 5 years or more, as compared with the untreated stand where chaparral is resprouting. After this, erosion on the grass-covered site greatly increases because the old chaparral roots that were still holding the hillside have finally rotted away and the grass root zone becomes supersaturated and slips out (Corbett and Rice 1966). Thus, the homeowner must be careful in landscaping a hillside after fire. Steep hillsides converted from chaparral to low-fuel plants often show little subsurface instability in the form of slips and slides for some years. The slips and slides that occur during high intensity rains 5 to 10 years later are therefore seldom attributed to the earlier brush conversion, but they can be prevented.

WHAT TO DO WHEN CAUGHT IN A WILDFIRE

If your home is threatened by wildfire, you may be contacted by a fire or law enforcement official and advised to evacuate. If you are not contacted in time to evacuate, or if you decide to stay with your home, the following suggestions will increase your chances of safely and successfully defending your property.

Before Fire Approaches

1. If you plan to stay, evacuate your pets and all family members who are not essential to protecting the home.
2. Be properly dressed to survive the fire. Cotton and wool fabrics are preferable to synthetics. Wear long pants and boots and carry with you for protection a long-sleeved shirt or jacket, gloves, a handkerchief to shield the face, water to wet it, and goggles.
3. Remove combustible items from around the house. This includes lawn and poolside furniture, umbrellas, and tarp coverings. If they catch fire, the added heat could ignite your house.
4. Close outside attic, eave, and basement vents. This will eliminate the possibility of sparks blowing into hidden areas within the house. Close storm shutters.
5. Place large plastic trash cans or buckets around the outside of the house and fill them with water. Soak burlap sacks, small rugs, large rags. They can be helpful in beating out burning embers or small fires. Inside the house, fill bathtubs, sinks, and other containers with water. Toilet tanks and water heaters are an important water reservoir.
6. Locate garden hoses so they will reach any place on the house. Use the spray-gun type nozzle, adjusted to a spray.
7. If you have portable gasoline-powered pumps to take water from a swimming pool or tank, make sure they are operating and in place.
8. Place a ladder against the roof of the house opposite the side of the approaching fire. If you have a combustible roof, wet it down. Do not waste water. Waste can drain the entire water system quickly.
9. Back your car into the garage and roll up the car windows. Disconnect the automatic garage door opener (in case of power failure you could not remove the car). Close all garage doors.
10. Place valuable papers and mementos inside the car in the garage for quick departure, if necessary. Any pets still with you should also be put in the car.
11. Close windows and doors to the house to prevent sparks from blowing inside. Close all doors inside the house to prevent drafts. Open the damper on your fireplace to help stabilize outside-inside pressure, but close the fireplace screen so sparks will not ignite the room. Turn on a light in each room to make the house more visible in heavy smoke.
12. Turn off all pilot lights.
13. If you have time, take down your drapes and curtains. Close all venetian blinds or fire-resistive window coverings to reduce the amount of heat radiating into your home. This gives added safety in case the windows give way because of heat or wind.

When the Fire Front Arrives and Passes

As the firefront approaches, go inside the house. Stay calm, you are in control of the situation. After the fire passes, check the roof immediately. Extinguish any sparks or embers. Then, check inside the attic for hidden burning sparks. If you have a fire, call the Fire Department and then get your neighbors to help fight it until the fire units arrive. The water in your pool and the water in your garbage cans, sinks, toilet tanks, etc., will come in handy now. For several hours after the fire, recheck for smoke and sparks throughout the house.

In a major conflagration, fire protection agencies will probably not have enough equipment and manpower to be at every home. You cannot depend totally on their help. One of the firefighter's principal responsibilities is to stop the spread of fire from house to house. Therefore, if one home is on fire, firefighters might have to pass it by to save another in the path of the fire. Your careful planning and action during a fire can save your home. Be prepared. Talk with your neighbors to see what resources you have. Ask your fire or forestry personnel for professional advice and assistance.

When Caught in the Open

When you are caught in the open, the best temporary shelter will be found where fuel is sparse. Here are comments on some good and bad places to go:

• Automobile: Move the car to bare ground or sparse fuel areas, close all windows and doors, lie on the floor and cover yourself with a jacket or blanket. The fuel tank of the car will normally not explode until the car is well on fire or may not explode at all. So, keep calm and let the fire pass.

• Road cut: If you are caught without shelter along a road, lie face down along the road cut or the ditch on the uphill side (less fuel and less convection heat). Cover yourself with anything that will shield you from the heat of the fire.

• Canyons: Never be caught by fire in canyons that form natural chimneys. These are narrow, steep canyons that concentrate heat, explosive gases, and updraft. Within chimneys, temperatures may exceed several thousand degrees Fahrenheit during a fire.

• Saddles: When you are hiking out of an area where fire is in progress, avoid topographic saddles if possible. Saddles are wide natural paths for fire winds, and vegetation here will normally ignite first.

• Other areas: Look for areas with sparse fuel (for example, soft chaparral such as black sage or grassland rather than chamise chaparral), if possible, within a depression. Clear as much fuel as you can while the fire is approaching and then lie face down in the depression and cover yourself with anything that will shield you from the heat. Smoke may create as great a survival problem as the flames do. If you are caught on a steep mountaintop or sharp ridge, the back side away from the approaching fire will be safer than the front side. Be aware, however, that fire eddies often curl over sharp or narrow ridges.

Before you hike in fire-prone areas, seek additional advice from wildland firefighting agencies. They may supply pamphlets and can give you specific tips for wildland fire survival.

Evacuation and Road Closure

Fire protection agencies are responsible for determining when the need for evacuation exists, and the jurisdictional law enforcement agency is responsible for carrying out an ordered evacuation. The purpose of evacuation is to protect people from life-threatening situations. Section 409.5 of the California Penal Code provides the legal authority for law enforcement officers to close and restrict access to disaster areas. The news media are legally exempt from this provision.

Owners have the right to stay on their property if they so desire, if in doing so they are *not* hindering the efforts of fire personnel or contributing to the danger of the disaster situation. In fires or floods, able-bodied persons who wish to remain may be able to aid fire personnel in saving their property, and those who are desirous of remaining may be permitted to do so.

In a fire or flood, there may be several different phases of road closure within the disaster area: (a) in an area that forseeably could be involved in the disaster, but presently is not, people without purpose will be restricted from entry to reduce traffic problems or the potential for looting; (b) in an area of imminent danger with limited access or egress, people would be discouraged from entry, though they live in the area, and those who are adamant after being informed of the danger would be permitted entry; (c) in an area presently involved in the emergency where extreme danger to life exists and where traffic must be restricted due to movement of emergency vehicles, people, including residents, will be refused entry.

Road closures around emergency incidents are essential to the expeditious movement of persons leaving the area and mobility of emergency equipment. On major incidents, closures become immediately essential to permit accessibility of firefighting forces, orderly evacuation, and exclusion of unauthorized persons.

In summary, here is what you should do:

• Notify the local fire protection agency.

• Stay calm—you are in control of the situation.

• If you decide to stay with your home during a wildfire, evacuate all family members who are not essential to protecting the home.

• Dress properly to shield yourself from the heat and flames.

• Take steps to prepare your home for the approaching fire.

• If caught in the open, seek shelter where fuel is sparse.

• **Remember—wildfire is erratic, unpredictable, and usually underestimated. Life safety is always the most important consideration.**

APPENDIX

List of Species Mentioned

Flora (native or naturalized)[1]

Common name	Scientific name
Aaron's beard	*Hypericum calycinum*
Acacia ongerup, prostrate	*Acacia rodelens* cultivar *ongerup*
African daisy	*Osteospermum fruticosum*
alfilaria	*Erodium* species
Algerian ivy (freeway ivy)	*Hedera canariensis*
alyssum	*Alyssum* species
annual ryegrass (H)	*Lolium multiflorum*
Australian saltbush	*Atriplex semibaccata*
barley (H)	*Hordeum vulgare*
Bermudagrass	*Cynodon dactylon*
black locust (P)	*Robinia pseudoacacia*
black sage	*Salvia mellifera*
bluegum eucalyptus	*Eucalyptus globulus*
Brazilian pepper	*Schinus terebinthifolius*
buckwheat	*Eriogonum wrightii* ssp. *subscaposum*
bur clover	*Medicago hispida*
bush poppy	*Dendromecon rigida*
California buckwheat	*Eriogonum fasciculatum*
California laurel	*Umbellularia californica*
California pepper	*Schinus molle*
California sagebrush	*Artemisia californica*
California scrub oak	*Quercus dumosa*
California walnut (D)	*Juglans californica*
Canary Island pine	*Pinus canariensis*
capeweed (P)	*Arctotheca calendula*
Carmel creeper	*Ceanothus crisseus*
ceanothus	*Ceanothus* species
chamise	*Adenostoma fasciculatum*
Chilean saltbush	*Atriplex undulata*
chokecherry (P)	*Prunus* species
coast live oak	*Quercus agrifolia*
coyote brush (Twin Peaks)	*Baccharis pilularis* var. *pilularis*
creeping sage	*Salvia sonomensis*
currant, gooseberry	*Ribes* species
cypress	*Cypress* species
deerweed	*Lotus scoparius*
Descanso rockrose	*Cistus crispus*
desert buckbrush	*Ceanothus greggii*
dwarf running myrtle	*Vinca minor*
elderberry	*Sambucus* species
English ivy (P)	*Hedera helix*
english oak	*Quercus robur*
eucalyptus	*Eucalyptus* species
fuchsias	*Fuchsia* species
gooseberries	*Ribes* species
gray santolina	*Santolina chamaecyparis*
green acacia	*Acacia* species
green galenia (P)[1]	*Galenia pubescens*
green lavender cotton	*Santolina virens*
green saltbush	*Atriplex glauca*
gum rockrose	*Cistus ladaniferus*
hoary-leaf ceanothus	*Ceanothus crassifolius*
hollyleaf cherry	*Prunus illicifolia*
honeysuckle	*Lonicera* species
ice plants	*Carpobrotus, Delosperma, Drosanthemum* species
junipers	*Juniperus* species
knotweed	*Polygonum equisitiforme*
laurel sumac (D)	*Rhus laurina*
lawn grass	*Cynodon dactylon*
lemonade berry (D)	*Rhus integrifolia*
lippia	*Phyla nodiflora (Lippia repens)*
mountain lilac	*Ceanothus* species
mountain mahogany	*Cercocarpus* species
Mueller's saltbush	*Atriplex muelleri*
myoporum, prostrate (P)	*Myroporum parvifolium* cultivar *horshum*
navel orange	*Citrus sinensis*
oak	*Quercus* species
old man saltbush	*Atriplex nummularia*
oleander	*Nerium* species
periwinkle	*Vinca major*
pines	*Pinus* species
Point Reyes ceanothus	*Ceanothus gloriosus*
ponderosa pine	*Pinus ponderosa*
prickly pear	*Opuntia* species
prostrate ceanothus	*Ceanothus prostratus*
purple rockrose	*Cistus villosus*
purple sage	*Salvia leucophylla*
reed	*Arundo* species
rockrose	*Cistus* species
rosemary, prostrate	*Rosmarinus officinalis* var. *prostratus*
roses	*Rosa* species
ryegrass, annual (H)	*Lolium multiflorum*
sages	*Salvia* species
saltbush	*Atriplex* species
scrub oak	*Quercus dumosa*
silver saltbush	*Atriplex rhagodioides*
star thistle	*Centaurea* species
sugarbush (D)	*Rhus* species
sugarbush (D)	*Rhus ovata*
sunflowers	*Helianthus* species
sycamore	*Platanus racemosa*
toyon, christmasberry (P)	*Heteromeles arbutifolia*
wavy leaf saltbush	*Atriplex undulata*
white sage	*Salvia apiana*
white trailing iceplant	*Delosperma alba*
wild mustard	*Brassica* species
yucca	*Yucca* species

[1]Tucker and Kimball (1978)
P = plant parts poisonous to ingest
D = may cause dermatitus
H = may readily cause hay fever or other allergic reaction

Fauna

badger	*Taxidea taxus*
California ground squirrel	*Otospermophilus beecheyi*
California quail	*Lophortyx californica*
coyote	*Canis latrans*
golden eagle	*Aquila chrysaetos*
gopher snake	*Pituophis melanoleucus*
mountain kingsnake	*Lampropeltis zonata*
pack rat	*Neotoma fuscipes*
pocket gopher	*Thomomys* species
rabbit	*Sylvilagus* species
rattlesnake	*Crotalus viridis*
red-tailed hawk	*Buteo borealis*
weasel	*Mustela frenata*
western racer snake	*Coluber constrictor*
wildcat	*Felis lynx*

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Urban encroachment into chaparral areas has accelerated the fire-flood-erosion cycle. Preventive maintenance measures can help reduce the damage from fire and flood. This report describes the chaparral environment; how to cope with problems in watershed management, how to landscape for fire and soil erosion control, how to plan for home safety from fire, how to treat newly burned chaparral slopes, how to clear brush around homes; and what to do when caught in a wildfire. The information reported is addressed to homeowners, buyers, and developers; and architects, planners, and other officials in municipalities and agencies.

Retrieval Terms: brush clearance, fire control, fire safety, landscaping, erosion, watershed management, wildfire, California