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Fire and the Debris Flow Potential of Winter Storms

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Abstract. Heavy winter rains on burned-over mountainous watersheds have resulted in many disastrous floods and debris torrents (debris flows) in southern California. The relationship between summer or fall fires and winter floods and debris torrents, commonly called the fire-flood sequence, has resulted in a call from the public for governmental actions to reduce the threat to lives and property. Millions of dollars are spent for emergency watershed protection following major fires, but the results of some of the actions are questioned. Activities implemented in attempts to reduce the threat from floods and sediment discharges range from construction of check dams, debris basins, and flood control reservoirs, to artificially seeding large areas with grasses. To evaluate the effectiveness of post-fire remediations on flood and debris torrent generation, the physical processes acting on watersheds must first be understood. This report outlines the factors that contribute to flooding and debris torrent activity, the effects of fire on water and sediment yields, and the likelihood of success and consequences of post-fire remediation. Additional research is needed to quantify the relationships between the physical characteristics of watersheds, the effects of fire of varying intensities on those watersheds, and water and sediment yields. The research may take many years to complete because of the uncontrollable and unpredictable occurrences of both fire and winter storms.

Keywords: Debris torrents; erosion; fire effects; post-fire remediation; southern California.

Introduction

Seventeen large wild fires burned in late October and early November 1993 during hot, dry Santa Ana winds in Southern California. Collectively, the fires consumed roughly 80,000 ha (200,000 ac) of chaparral, coastal sage, grassland, oak woodland, and residential slopes. The California Department of Conservation, Division of Mines and Geology worked with the United States Department of Agriculture, Soil Conservation Service to develop a method to identify the scope of the post-fire hazards and to aid in setting priorities for appropriate remedial work. This work involved characterizing watershed conditions that could influence storm flows and sediment yields—the fire-flood sequence.

Following wildfires, the public, the press, and some professionals demand immediate emergency watershed erosion control work to mitigate the fire-flood hazard. However, in light of the expense involved, money for emergency work must be wisely spent. For comparison, if hillslope mitigation measures in southern California were the same as those conducted in Oakland following the 1991 fire (Booker et al. 1993), the cost of erosion control alone would be on the order of $500,000.

Mass Balance

The same geological factors that lead to the tremendous habitat diversity of the earth are also potentially hazardous to lives and property. If the earth were dormant there would be a world ocean with no continents or islands, and if life existed at all, there would be little diversity. Fortunately for all terrestrial life forms, the earth is dynamic. Earthquakes and volcanoes are constantly building mountains which wear down by landslides and erosion. In general, the more rapid the uplift in an area, the greater the gravitational forces that trigger earth movements. Mass wasting through landsliding and soil erosion is needed to keep up with tectonic uplift. This is definitely the case in southern California. The western margin of the Transverse Ranges near Ventura is experiencing uplift at rates of up to 4 mm per year (Lajoie and others 1982). Uplift episodes in the San Gabriel Mountains are also easily identified by the earthquakes that accompany them; e.g., the 1971 San Fernando earthquake was associated with up to 2 m of uplift (Savage and others 1975).

The driving force behind the uplift is the Big Bend of the San Andreas Fault. When Baja California drifted away from Mexico about 10 million years ago, new spreading centers in the Gulf of California produced an offset in the San Andreas Fault. If this tectonic regime acted relatively consistently for these millions of years, admittedly an oversimplification, without landsliding and soil erosion, the San Gabriel Mountains would be about 40,000 m (130,000 ft) tall. Without landsliding and erosion, sediment would not have been available to fill the down-warped Los Angeles basin, and the densely populated coastal plain would today be a marine deep trough. Soil erosion, landsliding, and debris flow/debris torrent activity are normal and necessary events in tectonically active areas in the world. These events cannot be stopped; if they could, southern California would be far less habitable.

Role of Vegetation in Slope Stability and Erosion

Even though landsliding and soil erosion are natural and necessary for dynamic habitats, unarrested denudation is not the normal condition in most areas. One of the reasons for this is the protection provided by vegetation. In order to predict the effects of a fire on a watershed, an understanding of the role of vegetation on the sediment budget is needed. Vegetation provides five major physical functions that help control soil erosion during winter rains:

1. Interception of rainfall to extend the time it takes for water to reach the ground and to absorb raindrop impact energy.

2. Litter that mulches the ground surface. This provides temporary water storage, slope roughness, and energy absorption.

3. Structural support of loose material.

4. Roots that reinforce the soil, increasing the natural slope stability.

5. Conditions necessary for soil communities that provide soil structure.

On unburned slopes, live vegetation and the vegetative litter intercept and slowly transmit precipitation into the soil. Infiltration is generally very high and complete saturation of the soil and the overlying litter rarely occurs. Overland flow is rare in chaparral environments (Rice 1982). Water in excess of what the soil can hold (i.e., field capacity) percolates to the ground water table and migrates downslope. It may ultimately emerge as surface flow from springs and stream channels. Water flows slowly through soil, often traveling a few meters or less per day. This reduces the size of flood peaks and allows streams to run far beyond individual storms.

Stems of shrubs and trees, large organic litter, and accumulated leaves behind branches that touch the ground surface in dense chaparral stands can mechanically support large volumes of cohesionless materials. Without the supporting vegetation the debris would be transported by gravity down slope as dry ravel.

The tensile strength of a woody root is significantly higher than that of soil or fractured bedrock. In cases where an unvegetated slope would be unstable or only marginally stable, roots of plants may play a major role in increasing slope stability (Ziemer and Swanston 1977, Abe and Ziemer 1991).

Less well understood is the role of the soil mycorrhizal association in soil erosion potential. Roots and mycorrhizal hyphae are involved in the creation of water-stable soil aggregates (Miller and Jastrow 1992). Physical entanglements by roots and hyphae of mycorrhizal fungi appear to be a major mechanism for the bonding of micro-aggregates (<0.25 mm diameter) into macro-aggregates (>0.25 mm diameter). Although bacterial mucigels and polysaccharides also bind and stabilize aggregates, bacterial biomass and the size of aggregates may be smaller than that produced by fungi. Research suggests that the soil mycorrhizal association differs depending on the plant community (E. Allen, personal communication), with fungi more dominant beneath coastal sage and bacteria dominating below grasses. Further research may some day define a relationship between plant community and soil erosion that is at least partially dependent upon mycorrhizae.

Physical Properties and Processes Affecting Storm Flow and Sediment Yields

Storm flow in a stream channel is affected by the area of the watershed drained by the stream, by the inclination and lengths of side slopes, by the macrotopography of the area, by the infiltration and percolation rates of the earth materials, by the drainage density, by the stream channel geometry and longitudinal roughness, by hillside and riparian vegetation, and most importantly, by the intensity and duration of rainfall or snowmelt events.

Slope processes that can rapidly transport sediment from hillslopes to stream channels include debris avalanches (hillside derived debris flows), dry flows (dry ravel), and sheet and rill erosion. Once sediments enter stream channels they can be transported as suspended loads, bed loads, or as debris torrents (channel derived debris flows).

Debris avalanches occur when cohesionless soil and colluvium that accumulate in steeply inclined topographic depressions become saturated during high-intensity storms. The mixtures of rock, soil, surface vegetation, and water flow rapidly down slopes. Factors controlling debris avalanche potential are:

1. Cohesionless soil or colluvium.
2. Topographic or bedrock convergence, saturated colluvium.
3. Steep slopes.
4. Intense precipitation.

The triggering mechanism for debris avalanches is the rapid infiltration of precipitation into the cohesionless soil and colluvial regolith.

Dry flows (dry ravel) occur when sediment moves downslope in a dry condition because of a loss of structural support. Loose materials along artificially cut slopes often slough or ravel in a dry state. The principal factor controlling dry ravel is the structural support of the loose material.

Sheet and rill erosion occur when runoff flows over a bare surface. Sheet and rill erosion is uncommon in undisturbed vegetated environments. Slope length and macrotopography (roughness), as well as the volume and intensity of precipitation control rill initiation.

Once sediment reaches a stream, it can be transported if the critical power of the stream is great enough. If a stream is starved for sediment, as would occur in a bedrock (or concrete) channel, there may be little material to move. Where there is ample sediment, finer-grained materials can be transported by relatively low velocity flows. As the volume and velocity of flow increases, the size and quantity of sediment that can be transported also increases. When the critical power of a stream exceeds that needed to mobilize the sediment stored within it, the sediment can be transported as a debris torrent. The critical factors for debris torrent generation are quantity and velocity of storm flow and the volume, size distribution, cohesion, and embeddedness/induration of sediment.

Effects of Fire

Fire is natural. Try as we might to prevent and stop wildfires, it appears that chaparral and coastal sage will continue to burn. Minnich (1983) has documented that the average annual percentage of the chaparral and coastal sage landscape that burns each year is similar between southern California and northern Baja California. Fires were burning the southern California landscape prior to European settlement: varved cores from the Santa Barbara Channel inferred to have been deposited in the 16-17th century include sections with extremely high values of carbon that are higher than the average by a factor of at least 10 (Byrne, et al. 1977).

Post-fire increases in sediment production are also natural. Data collected by the Los Angeles County Flood Control District reveals that up to a 40-fold increase in sediment production can occur during the first storm season following a watershed fire if high intensity rainfall occurs (Bruinton 1982). Understanding the potential impacts of a fire on landsliding and soil erosion must be based on physical processes.

Hydrophobic soils

When a watershed is burned, rainfall can rapidly flow down a slope, eroding rills and causing "flash" flows down main channels. Instead of the volume of rain water being metered through the system over a period of days to months as soil water and groundwater, it may force its way through the system over several hours as surface flow. This is particularly true where a water-repellent layer is formed.

As most gardeners have experienced, when dry mineral soil and organic material are mixed, the first water that is applied tends to bead up. In some instances puddles may form on the ground surface while the soil just below the surface remains dry. This phenomenon is variously referred to as non-wettable, water repellent or hydrophobic soil. After the water has been in contact with the soil for a time, the hydrophobic properties diminish, and subsequent waterings are readily absorbed. Organic substances that are leached from plant litter induce the non-wettable condition in sands and coarse-grained soils (the surface area- to-volume ratio of fine-grained soils limits the effectiveness of the production of water repellency) and microbial by-products may coat mineral soil particles (DeBano 1981). Non-wettable soil is common in chaparral communities, in part because of the high resin content of the organic litter.

Under unburned conditions, the non-wettable substances do not form a continuous layer. This is because the duff and litter allow significant storage of water and can bridge accumulations of hydrophobic material. In addition, rodent, worm, insect, and root activity is continuously disrupting water repellent layers, as well as the rest of the soil column, making conduits for water to enter the soil.

When wildfire sweeps through a chaparral stand the soil temperatures may reach 840° C (Borchert 1995). This volatilizes the organic water-repellent materials which follow temperature gradients downward into the soil. The distilled non-wettable substances then condense on mineral soil particles and produce an extremely water-repellent layer (Wells et al. 1979, DeBano

1981). The one- to five-cm-thick layer of soil that overlies the water repellent zone is highly permeable and erodible.

Following a high-intensity fire, the effective storage capacity of the soil mantle is estimated to be reduced by 20 times or more (Wells 1981) and rainfall quickly exceeds its storage capacity. The excess water that cannot penetrate through the hydrophobic layer saturates the surficial wettable material which may fail as very small-scale debris flows (Wells 1987). In addition, the surface fill and gully wash rapidly runs off into stream channels. Peak flows in the channels may occur with less of a lag than those observed in unburned watersheds, and flood peaks are often much higher and more capable of eroding stored sediment. Large quantities of material are transported as debris torrents (debris flows that are initiated in stream channels as opposed to colluvial filled hollows).

Unbroken water repellent or soil hydrophobic layers are short-lived. Within one week of the fall 1993 fire above Banning, California, gopher and ant activity had provided conduits for surface water to enter the soil column. Similar observations were made following the 1991 Oakland Fire (Booker and others 1993).

Debris flow

Following a fire, the loose granular material that was supported by stems, branches, and litter can fail under the direct force of gravity as dry ravel. Cones of sand and gravel-sized dry ravel up to 50 cubic meters in volume were observed toeing into the live stream in Pasadena Glen within one week of the Kinelowa Fire that burned in the fall of 1993. During the Las Pelitas Fire in the San Luis Obispo area in 1985, substantial volumes of granular ravel were observed failing into stream channels while the fire was still burning. The quantity of dry ravel that may be available for downstream transportation is highly variable between watersheds and is a function of slope and material strengths. In some watersheds, such as Pasadena Glen, dry ravel may be a major component of sediment yield.

Over a longer time period, if woody vegetation is killed or replaced by grasses after a fire, the reinforcing effects of roots will decrease. This can substantially decrease the stability of marginally stable slopes. Bailey and Rice (1969) observed that where natural brush was converted to grass in the San Dimas Experimental Forest, both the number of landslides (soil slips) and the area they affected were about five times greater on the converted grassland areas than on comparable brush areas.

If plant communities are converted, the mycorrhizal association may also be converted. Fungi-dominated associations could potentially be replaced by bacteria-dominated ones if brush fields are replaced by grasslands. This may result in more easily erodible soils.

Fire increases the peak flow of streams in burned watersheds by allowing rapid runoff. This will reduce the size of storms necessary to surpass the critical stream power necessary to mobilize stored sediment. Boyle (1982) reported that most of the sediment that destroyed or damaged 41 homes in San Bernardino came from debris flows (debris torrents) in Harrison Canyon the winter after the watershed burned was stored alluvium. The incised channel grew from 2 meters deep and 3 meters wide to over 10 meters deep in places and up to 40 meters wide.

Fire also increases the delivery of sediment from hillslopes to stream channels. The loss of vegetation, litter, and the resulting macro-topography, as well as the development of a water-repellent layer results in overland flow that rapidly develops an extensive rill network (Wells 1987). The rills provide an efficient means for transporting surface runoff and sediment to stream channels. Micro debris flows of the wettable soil above water repellent layers is an efficient means of transporting sediment to stream channels. In Las Flores Canyon above Malibu, the storms of November 1993 triggered numerous small-scale debris flows on slopes burned in the Old Topanga Fire.

One additional way sediment is routed from hillslopes to stream channels is the mobilization as a debris avalanche of sediment that rapidly accumulates in steeply inclined V-shaped draws following a fire. The mechanism is similar to that for U-shaped hollows, but accumulation and mobilization can occur within days of the fire. These types of failures have been responsible for many deaths and significant local property damage, yet they can be mitigated at a local level.

Where a large percentage of a watershed has been burned, formerly predictable streams can respond as raging debris torrents. For example, heavy rains at the end of December 1933, following an earlier storm, caused a disastrous flood in La Canada Valley, a part of the San Fernando Valley in southern California. As a result of the flooding, about 600,000 cubic meters of debris was moved from the mountain area to the foothill region and the valley floor. Thirty-nine lives were known to have been lost with forty-five persons missing. Over 400 homes were demolished or rendered uninhabitable. Streets, highways, and yards were strewn with wreckage and debris; automobiles and garages were rolled and piled in a conglomerate mass; bridges were destroyed; and culverts and drains were clogged (Troxell and Peterson 1937).

Post-fire debris flows require both sediment and debris that can be mobilized, and a high intensity and volume of stream flow. The physical factors that contribute to debris torrent mobilization can be identified and mapped. The results of an analysis of debris flow potential can then be used to identify appropriate emergency watershed protection measures.

The principal factors that contribute to debris torrent mobilization are:

1. Available sediment source.
2. Steep side slopes.
3. Bare soils (high percentage burned).
4. Development of water repellent soils.
5. High volume (intensity/duration) rain storms.

Of these, only the intensity and duration of post-fire rain storms cannot be predicted.

In contrast to channel-derived debris torrents, hillslope-generated debris flows (debris avalanches) of stored colluvium are less likely to occur in burned areas than in unburned ones. This is because surface runoff is greater following a fire, so that failure triggering the infiltration is reduced. Morton (1989) mapped eight times the number of debris flows in unburned compared with burned slopes in the San Timoteo Badlands of southern California. Photographic plates of the slopes above the La Canada Valley included in the report by Troxell and Peterson (1937) include panoramas of both burned and unburned watershed areas. In the unburned areas, debris avalanches of colluvium in U-shaped draws were common, whereas in the burned areas they were rare.

Fire Suppression — Emergency Watershed Protection

The long history of fire suppression in California chaparral and coastal sage communities has resulted in a fire regime that promotes major fires that burn over large areas at high intensities compared with fires in areas where they are not suppressed (Minnich 1983). The effect of the post-suppression fires may be an increase in the scale of flooding, erosion, and debris torrent activity from pre-suppression conditions.

Evaluating potential soil and debris losses

The rate of erosion and sedimentation following a fire is a factor of the percentage of the watershed burned and intensity of the fire, among other things. If post-suppression fires are larger and more intense than those that were common prior to the practice of suppressing all fires, it follows that erosion and sedimentation will also be greater. Therefore, the most effective method of managing extreme soil erosion events would be to develop a fire pattern more similar to pre-suppression conditions. This can be done through controlled burns and other appropriate vegetation management practices. When working with natural systems, the nature of any management must consider potential environmental impacts to other components of the system beyond the one immediately being addressed (Spittler 1989a, 1989b).

In developing appropriate emergency watershed protection plans, the first task should be to identify potential problems. Where soil loss, debris torrent activity, and sedimentation are recognized as potential hazards to property and lives, a hazard analysis can be performed. For the southern California fires that burned during October and November 1993, the geologic and geomorphic factors contributing to post-fire channel-derived debris torrents include:

1. Friable bedrock units, including highly fractured hard bedrock and cohesionless soil, colluvium, and alluvium;
2. Long regular slopes inclined more steeply than 65 percent that are denuded of vegetation;
3. Concentrations of dry ravel from steep slopes;
4. Development of a continuous layer of water-repellent soil; and
5. Removal of woody structural support from stream channels or riparian vegetation where sediment is stored in or adjacent to the channels (Spittler and others 1994).

The geologic history of an area can also aid in identifying post-fire debris torrent potential. Steeply inclined fans composed of poorly sorted sediment, including large boulders at the mouths of mountain streams, indicate a history of debris torrents and flooding. Where material on the fan surface is fresh and soil development is minimal, debris torrents are still a dominant process. Where the outflow area below a mountain front is not steeply inclined and the sediment is not coarse and weathered, large-volume debris torrents are probably not a significant hazard. Analysis of the area burned by the Tunnel Fire that burned through Oakland in 1991 indicated that there were no areas where there was an immediate hazard to life or property from post-fire debris torrents (Spittler 1993). The same could not be said for the southern California fires.

Using the above-listed criteria, the various southern California fires were prioritized as to their relative potential for debris torrent activity. The data collected were also useful in identifying individual watersheds most prone to debris torrents (Spittler et al. 1994).

Emergency watershed protection by seeding

Emergency watershed protection has historically meant the seeding of burned watersheds with grasses. Eaton (1935), Kotak and Kraebel (1935), and Troxell and Peterson (1937) identify that post-fire erosion rates are much higher in burned watersheds compared with "natural conditions." The belief at the time was that the low erosion and sediment transport rates in the unburned watersheds was the ideal that could be realized by active fire suppression and by "helping" to revegetate "damaged" areas. The planting of cover crops on burned slopes came directly from agricultural erosion control practices which developed to counter the loss of fertile soil. Increases in erosion and related sedimentation following land use activities, particularly agriculture, have been observed worldwide (Duijsings 1987, Krank and Watters 1983, Mosley 1980). In some areas, the degradation has affected the environment for far longer than the lives of those who triggered it. For example, deforestation of the cedars of Lebanon by the Phoenicians rapidly depleted the formerly fertile soil of the area (Loudermilk 1943). In ancient Syria, evidence of the depth of soil erosion is found in doorsills of stone houses now 1 to 2 meters above bare rock (Loudermilk 1943). In Rome, the erosion rate increased 700 to 2000 percent during the second century BC due to deforestation and grazing (Judson 1968). These deforested and over-grazed areas still suffer from reduced soil fertility thousands of years later. Citrus orchards in the early 1900s seeded tilled ground with mustard (spp.) to help fix nitrogen as well as to reduce erosion. Mustard was one of the first plants used to revegetate burned slopes. It was later concluded that ryegrass (*Lolium multiflorum*) covered the slope as well as mustard and was less expensive. Ryegrass is also now the principal surface cover used to protect disturbed soils in agriculture and construction. Research has shown that a ryegrass cover substantially reduces erosion from tilled plots (Kay and Slayback 1986). Visual inspection of seeded slopes also suggested that it was effective at reducing erosion from burned areas.

Ryegrass seeding continued to be the principal response to fires until recently when biologists have shown that it may adversely affect native species. Barrow and Conard (1987), Beyers et al. (1993), and Conard et al. (1991), all concluded that post-wildfire seeding of non-native grasses to reduce erosion and sedimentation is negatively correlated with cover of natural herbaceous species and with shrub and tree seedling density.

Few quantitative studies have been undertaken on the effects of ryegrass seeding on erosion from burned slopes. The agricultural model is not appropriate because fire does not have the same impact on soil structure as tilling. Two studies that did measure sediment yields from seeded and unseeded plots conclude that seeding did not substantially reduce erosion, and may even increase the quantity of sediment that erodes from a site (Taskey et al. 1989, Booker et al. 1993). Both of these studies document an increase in gopher activity in seeded plots compared with unseeded ones. Apparently the gophers disturb the soil to the degree that increased erosion occurs the first year following the seeding. In subsequent years sediment yields from seeded plots were higher than unseeded areas because suppression of woody vegetation resulted in greater bare areas (Taskey et al. 1989). A caveat on the research by Taskey et al. (1989) and by Booker et al. (1993) is that no major storms affected the areas they studied during the winter following the fires.

Another possible cause for increased erosion from seeded plots may be a change in the mycorrhizal association. If fungi are replaced with bacteria, the soil structure may be adversely affected. Further, if seeding is successful in converting a chaparral site to grassland, the debris flow potential can be increased many times due to the loss of root support.

This is not to say that there is not a use for grasses in emergency watershed protection. It is just that the negative as well as the positive effects of grass must be considered in developing mitigation measures. Grass seeding does have a role in soil stabilization following a wild fire in mechanically disturbed areas.

There is a demand to do something following a fire and now it appears to be politically correct for that something to be planting "native" grasses. "Native" is placed in quotes because the seed stocks now being used are not from the burned slopes. The effects of "native" grasses on sediment yields have not yet been studied. Without proper scientific research on the sediment yields from seeded and unseeded plots it is impossible to know whether or not the desired outcome will occur. Even if "native" grasses reduce immediate surface soil erosion, they could potentially replace the woody vegetation that holds a slope together and increase long-term erosion rates. The biological impacts of importing "native" grasses from other areas into a burned watershed that may have an adequate natural seed reservoir should also be questioned (see also Keeler-Wolf 1995).

Prior to large-scale seeding of a burned watershed, the first questions that should be asked are 1) whether or not grass seeding reduces either the intensity and duration of a potential storm flow or 2) reduces the yield of sediment from hillslopes or stored along channels. For major storms early in the year following a fire, grasses will have little or no effect in reducing flood peaks. Where the major sources of sediment are dry ravel that enters stream channels during and immediately following a fire, seeding will have no effect. Where sediment is derived from alluvium stored along channels, seeding will have no effect. Grasses may to some degree reduce sediment yields where rilling is the major process by which sediment is transported to stream channels. The criterion for whether or not seeding will be effective at all has to do with the erosive power of runoff. Although the erosive power of rills is relatively low, it exceeds the resistance of the soil that is eroding. The scale of a rill is roughly similar to the scale of the added resistance to erosion from growing grass, assuming the grass germinates and grows an adequate amount prior to the first storm. Unfortunately, this does not always occur. It is not uncommon to observe rilled hillslopes with a dense blanket of grass growing from small fan cones deposited at the base of the slope. For streams, the scale of the erosive power is likely to be orders of magnitude greater than the added resistance to erosion from growing grass.

Emergency watershed protection with physical barriers

A recent approach to controlling erosion from slopes in wildfire areas is the use of straw bale check dams. Straw bale dams are used on construction sites to capture sediment when equipment is on-site prior to the establishment of a permanent erosion control plan. Their design and installation is important. Straw bale dams are not engineered structures. If they are placed in stream channels they may be successful in capturing sediment during low flows. However, the size of a high-intensity, storm-derived debris torrent could potentially be increased by the temporarily stored sediment behind an in-channel dam, as well as by the straw itself. Unless full consideration is given to the potential impacts as well as the benefits of in-channel straw bale dams, they are potential time bombs.

Additional scientific research is needed to document sediment yields from watersheds of varying dimensions that have been burned at different intensities and affected by distinct storm intensities. This empirical information could then be combined with laboratory research to predict a range and relative probability of floods and debris torrents. Until then, post-fire emergency watershed protection should be based on a rational assessment of potential factors that can contribute to local erosion and deposition hazards as well as watershed scale debris torrent activation.

Debris torrents are powerful events that can cause extreme damage to people and structures that are in harm's way. The most efficient means of dealing with the problem of post-fire debris torrents is through long-term planning. Where this has not been rigorously practiced (i.e. virtually everywhere in California) emergency planning is needed. Because watersheds differ, the approach cannot be "one-size-fits-all" that is pulled from an emergency cookbook. The physical and biological properties of an impacted watershed must be identified and the resources at risk tabulated. From this position, resource professionals can a plan for protection of natural resources while defending lives and property.

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