Brushfires in California Wildlands: Ecology and Resource Management
Edited by J.E. Keeley and T. Scott. 1995. International Association of Wildland Fire, Fairfield, WA.

The Oakland Hills Fire of 20 October 20: An Evaluation of Post-fire Response

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Abstract. The identification of hydrophobic soils and public concerns about landsliding and accelerated erosion in the urban/wildland interface of the Oakland Hills following the fire of October 20, 1991, prompted a massive and costly erosion control response. To evaluate the effectiveness of these measures and to analyze how wildfires influence runoff and erosion processes in the Oakland hills, we developed a program of winter field monitoring and summer and fall artificial rainstorm sprinkler experiments.

Hydrophobicity although noted throughout the fire area, was discontinuous, and allowed soil water to flow through to greater depths via preferential flow paths. Substantial overland flow was not evident during winter storms. As a result, total sediment loss during the winter of 1991-92, was several orders of magnitude less than that estimated by the multi-agency task force convened after the fire.

In order to observe post fire conditions under greater rainfall intensities than that experienced during the winter, artificial sprinkler experiments simulating a 100 year 1 hour storm of between 25 and 50 mm were conducted. Runoff as a result of increased precipitation intensities never exceeded the winter maximum value for plots in the burn area. Plots established in reseeded areas showed a decrease in runoff due to increased infiltration provided by the grass cover and due to increased bioturbation (pocket gophers) providing additional subsurface flow paths. Sediment loss as a result of the simulated 100 year storm was still several orders of magnitude less than the predicted response.

Keywords: Bioturbation; check dams; debris flows; erosion control; erosion; flow paths; gophers; hydromulch; hydrophobic soils; hydroseeding; landslides; overland flow; rills; sheetwash, simulated rainfall; sprinkler experiments; throughflow.

Introduction

In less than ten hours on October 20, 1991, hot dry winds blowing from the Central Valley swept flames across 1800 acres of the Oakland and Berkeley hills, killing 25 people and destroying 2,903 dwellings (Fig. 1). Immediately after the Oakland Fire was contained, intense media coverage began to draw parallels with the post fire erosional response in southern California, and to focus on the possibility of winter rains producing catastrophic landsliding and debris flows in the 1800 acres of the burned urban and wildlands. Steep burned hillslopes, the identification of strong to moderate soil hydrophobicity in association with eucalyptus (*Eucalyptus globulus*) and Monterey pine (*Pinus radiata*) (Howell 1991), and the classification of local wildland soils as extremely erodible by the Soil Conservation Service (SCS) (Welch 1981), heightened the anticipation of problems for land managers immediately after the fire.

An interagency emergency response task force was formed after the Oakland "Firestorm" to identify erosional and rehabilitation problem areas. Based on the task force's recommendations, the burn area was seeded, and the City of Oakland applied erosion and sediment control measures, developed primarily to control construction and mining reclamation site erosion, to the bulk of the burn within the City's jurisdiction, half of which could be considered wildlands. Although media and public agency concerns focused on catastrophic landsliding and debris flows resulting from winter rains and the protection of downstream water bodies, almost the entire erosion control effort was directed at preventing surface loss of soil, and the temporary control of sediment in streams. The cost of this erosion control project approached $5 million, the most expensive fire mitigation project in state history.

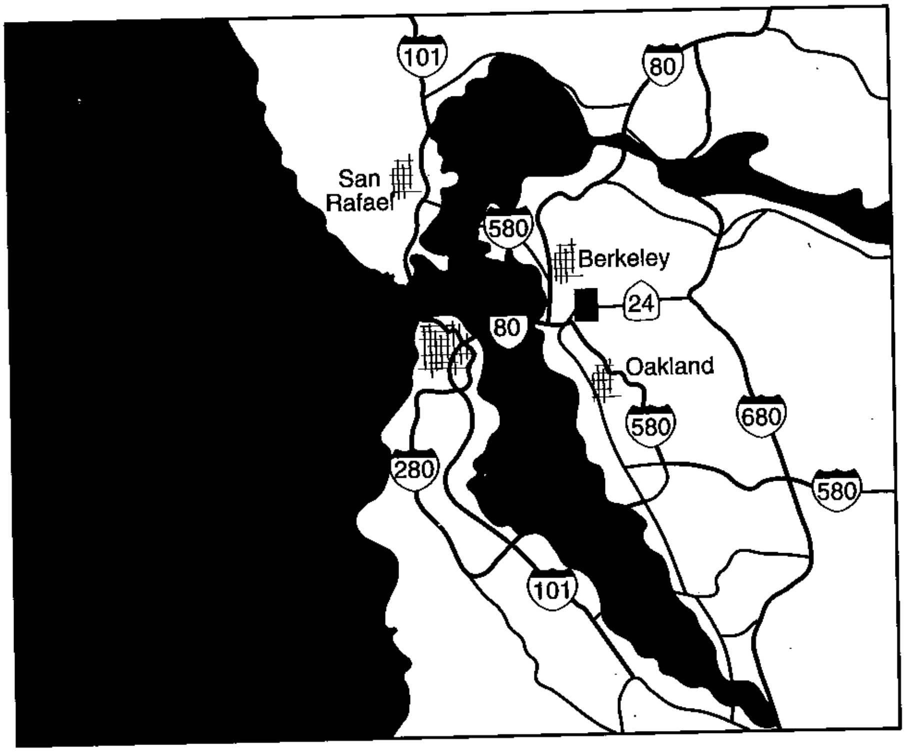

Figure 1. Map of the San Francisco Bay Area, the black rectangle delineates the location of the Oakland Firestorm (Tunnel Fire) of 1991.

The Southern California Model

The erosional response of burned lands to winter storms in canyon lands in southern California has been well documented by researchers (Barro and Conard 1991, Rice 1982, Wells 1981,1987), and has commonly been referred to as the "fire-flood" sequence (USDA 1954). Immediately after a fire, in some cases during the fire, as organic debris dams are incinerated, debris and coarse sediments flow downslope into channels, washes, and gullies accentuating a process called "dry ravel" (Anderson et al. 1959, Wells 1981, Rice 1982). The process of dry ravel is most closely associated with very steep hillslopes underlain by granitic rocks or coarse-grained sandstones in areas that are tectonically active and undergoing rapid uplift, resulting in background erosion rates as high as 1.4 mm/yr to 2.3 mm/yr (Wells 1985; Scott and Williams 1978). In parts of southern California, the process of dry ravel, independent of fire, accounts for half of all hillslope erosion (Anderson et al. 1959, Krammes 1965, Rice 1974, Howard 1982). Ongoing studies in the California chaparral wildlands demonstrate that dry ravel and to a lesser extent the formation of extensive rill networks, account for most of the increased sediment production following a fire (Wells 1985).

Hot fires can also vaporize organic compounds within the burning vegetation. The vapor moves through the soil to a depth where it will condense, forming a water repellent layer or hydrophobic soil (DeBano 1981, Savage 1974). This water repellency is strongest in coarse textured soils (DeBano 1981), and can produce increased runoff and sediment loading through the development of an extensive rill network (Wells 1986). The increased flow to channels during periods of intense rainfall, can mobilize all sediment and debris stored within the channel, as a debris flow, or what was originally thought of as a debris rich flood event, hence the name "fire-flood sequence (USDA 1954).

Will the "Fire-Flood" Sequence Occur in the Oakland Hills?

Although at least 14 wildfires have occurred in the East Bay hills since 1923, no written record or field evidence of past catastrophic erosional response as a result of fire has been located. Nevertheless, the primary concern echoed by the media and public agencies, following the 1991 fire, was the possibility of a fire-flood response such as those thought to be common to southern California watersheds.

If we approach the problems of hazard and risk assessment without any knowledge of fire history and postfire erosional response in the East Bay hills, how could we assess the likelihood of possible catastrophic response to the October 20, 1991 Oakland Fire? We could start by looking for similarities in landscape between southern California and the Oakland Hills that would suggest a debris flow/fire-flood response could be possible (Table 1).

The immediate evidence, especially in the critical areas of slope, soils, background erosion rate, and most importantly rainfall intensity, suggests that these two areas are very different; and it does not suggest that processes thought to be common to landscapes in southern California should apply to a very different landscape in the Oakland hills (Spittler 1993).

A reconnaissance of the Oakland Hills burn area immediately after the fire on October 22, 1991, and again after the first storm of the winter on October 25, 1991, showed no evidence of natural rilling except that which was a result of road runoff. Significant piles of ravel at the base of hillslopes or in the channels was also not evident. Rainfall for the October 25 storm at a station 5 km south of the fire area reported 75 mm during 13 hours of rainfall (a 10 year return interval; Rantz 1971) with maximum intensities of 30 mm/hr for a 6 minute interval and 25 mm an hour for a fifteen minute interval. Rainfall intensities such as these produced debris flows and flood events in burned canyons in both the Laguna Beach and the Malibu fire areas during the winter of 1993-94, but did not result in the catastrophic erosional response predicted for the Oakland Fire area.

Table 1. Watershed parameters for southern California and the Oakland Hills.

	Fire-Flood Watersheds	
Parameter	Coastal Southern California	Oakland Hills
Max. Relief:	2800 m	335 m
Slope:	Ave: 65%; Max: >100% (Wells, 1981)	Ave: 35%; Max: 90%
Watershed area:	1 km^2 - 13 km^2 (Wells 1981; Taylor 1983)	< 2 km^2
Soils:	coarse (granitic, sandy) soils, shallow, no soil profile development (Wells 1981)	loams, shallow, moderate to well developed profiles (Welch 1981)
Background erosion rate:	1.4 mm/yr - 2.3 mm/yr (Wells 1981; Scott and Williams 1978)	0.08 mm/yr (Reneau 1988)
Rainfall intensity:	25 mm/hr ≈2-10 year return interval (Phil Holland, personal communication)	25 mm/hr ≈100 year return interval (Rantz 1971)

Estimation of erosion potential

The identification of hydrophobic or water repellent soils in the Oakland Hills fire area by members of the USDA Soil Conservation Service (SCS) (Howell 1991) and the perception that rainfall intensities of 50 mm/hr (>100 yr storm) were possible for the Oakland Fire area (SCS video of post-fire conditions, Oct. 23, 1991), resulted in a predicted hillslope response similar to the southern California fire-flood sequence outlined. Water repellency was evaluated using the standard water drop test. A large drop of water is placed on the mineral soil and the time required for the drop to soak into the soil determines its class of hydrophobicity (Howell 1991). For an infiltration time of less than 10 seconds, the soil is not considered hydrophobic, 10 to 40 seconds it is considered moderately hydrophobic, and longer than 40 seconds the soil is considered strongly hydrophobic. Of the six wildland sites tested, five showed evidence of hydrophobicity. Hydrophobicity was most pronounced in intensely burned eucalyptus groves, with slight to strong hydrophobicity evident in burnt stands of Monterey pine. Water repellency was also noted at an unburned eucalyptus site. Subsequent tests that we have performed show these two vegetation types to be relatively equal in hydrophobic development beneath healthy (unburned) stands. As a result of an anticipated increase in runoff and erosion, an interagency estimate of possible soil loss for the Oakland Hills, was 142 m^3/ha (75 yds^3/acre, Interagency Meeting Notes 1991) a total that is consistent with measured soil losses following southern California fires. Conversely, geologists from both the United States Geological Survey (USGS) and California Division of Mines and Geology felt that water repellent soils were discontinuous and that there was not a serious erosion hazard in the firestorm area (Spittler 1993).

Mitigation efforts after the firestorm

As a result of this estimated potential erosion, 720 ha of the burn area were initially aerially seeded (32 kg/ha) on October 23 and 24, 1991. The seed mixture consisted of a total of six species, three of which were not natives (Libby and Rodrigues 1992). This seeding was accomplished two days prior to the first storm of the season which occurred on October 25, 1991. The fire area was again reseeded as part of a hydromulch application over much of the burn area (Booker et al. 1993). In addition, 1,700 straw bale check dams were placed in gullies, channels, hollows, and on landslide features, in an attempt to moderate channel flow and hillslope overland flow. Roadside areas were treated with seed, straw mulch and a copolymer glue and silt fences were placed along hillslope contours at breaks in slope(I.E.C.A. 1992). Additionally over 35 acres of steep hillsides overlooking buildings that survived the fire were treated with straw, fiber and monofilament erosion blankets. It is important to point out that all these treatments have only one purpose, to prevent the surface loss of soil by overland flow, and are not designed to mitigate the larger effects of landslides or debris flows (I.E.C.A. 1992). Additional landscape modifications included channel excavations and the installation of concrete and steel debris racks.

Hillslope failure and fire

After the fire, the vegetation-free landscape offered a clear view of the numerous landslide scars that had formed during previous winters. Most are relatively shallow slope failures that occur as a result of increasing soil moisture to a point of saturation. These landslides were hillslope features, in contrast to the fire-flood debris flows that are generated in steep canyon bottoms in freshly deposited ravel. An effective cause of fire-related landsliding, would be the reduction of vegetative root strength, which would not occur until several years after a fire. Soil pits dug after the fire typically showed roots below 8 cm to be strong and unburned, and during the winter many species of pre-fire plants resprouted. The dominant brush species Coyote brush (Bacharris pilularis) is fire adapted, and it maintained its ability to crown sprout following the fire. Bluegum eucalyptus, introduced into the Oakland Hills in the early 1900's, have the capability of epicormically sprouting, and thus they survived the fire, while Monterey pines, which were introduced at the same time, did not survive the fire, and their root deterioration will continue to occur over several years.

In the event that there was a severe loss of root strength in fire damaged plants, reseeding hillslopes with grasses, should not be an effective deterrent to landsliding here. The shallow landslide features common to the Oakland Hills, typically have failure planes at depths below the rooting zone of grasses. We think that heavy densities of reseeded grasses would only increase infiltration, and therefore soil moisture, without providing additional vertical and lateral root strength.

Monitoring program

To evaluate the effectiveness of the erosion control measures and to analyze how wildfires influence runoff and erosion processes in the Oakland Hills, we developed a program of winter monitoring, followed by summer artificial rainfall experiments. Winter runoff and erosion were monitored on several small erosion plots established in the upland areas of the burn. Seven plots were established for winter monitoring in four drainage basins within wildland areas of the Oakland Hills on slopes of 30° to 40°. Plots were established on these steeper than average slopes because they are typical of slopes found in fire-flood landscapes in southern California, and maximum erosion rates will occur on these steeper slopes. Five of the plots were within the fire area, while 2 plots were within an unburned canyon adjacent to the burn. Plots were approximately 5 m long by 1.2 m wide with sheet metal boundaries. A covered trough at the downslope end trapped sediment and directed overland flow to a storage container. An additional seven plots were constructed on similar site conditions during the summer of 1992 for the simulated rainfall experiments.

Rainfall totals for each plot were monitored using static raingages set up at each of the sites. Rainfall intensity was monitored through the Alameda County Flood Control District's ALERT network. Fourteen winter storms occurred between January and April, 1992, with no storm exceeding 12 mm of rain in an hour, or 57 mm in 24 hrs, a storm event with approximately a two year return period. Total rainfall for the winter approximated the mean annual precipitation of 558 mm for the Oakland Hills.

As the winter progressed, it became clear that, although there was significant evidence of hydrophobic soils throughout the burn area, overland flow and erosion on the natural undisturbed slopes were limited. Intermittent minor rilling developed at the base of some large bare eucalyptus trees as a result of concentrated stem flow onto exposed soils. This process did not continue once new growth on the eucalyptus acted to disperse the flow. Additional small rills developed downslope of game trails and exposed bedrock. Rills were observed in only two other areas: where concentrated road runoff was directed onto the hillsides; and where runoff from fire hoses had been concentrated. Existing natural rills were subsequently smoothed out by rain splash, sheetwash, and animal activity.

On all the untreated plots, sediment loss as a result of overland flow was very low, something in the order of 1 m^3 of sediment/ha (Booker et al. 1993). If we take the total sediment collected from each untreated plot and divide it by the plot area, we get an equivalent surface lowering rate or soil loss, of about 0.1 mm during the winter. This amount is much smaller than the equivalent soil loss of 14 mm or the 142 m^3/ha (75 yds^3/acre) predicted by the Interagency Task Force group (Interagency memo 1991).

There was an overall decrease in sediment loss on all plots (treated, untreated & control) through the winter. This steady decline in sediment loss was observed even though the largest storm events came later in the season (Figure 2), a pattern observed elsewhere, (e.g., Morris and Moses 1987).

This observation suggests that soil loss in the Oakland Hills is a function of sediment availability, rather than solely a function of potential runoff.

Summer sprinkler experiments

Because the winter immediately after the fire did not provide an opportunity to study the impact of a large storm on the Oakland Firestorm area, we decided to simulate an approximate 100 year storm event of between 25 mm and 51 mm rainfall per 1 hour. Artificial rainfall experiments were conducted between July and October, 1992.

Two artificial storms were applied to most plots, with all vegetation (if present) being removed prior to the second sprinkler experiment. Runoff as a result of increased precipitation intensities never exceeded the winter maximum value for plots within the burn area. There was in fact a decrease in runoff for all plots within reseeded areas. This decrease in runoff can be attributed to an increase in gopher activity providing additional subsurface flow paths, and to increased infiltration provided by the grass cover.

Sediment loss as a result of increased precipitation intensities was minimal. The maximum sediment loss for a single $\approx$100 year storm was about 50% of the total soil loss for the winter of 1991 (Booker et al. 1993). The cumulative net soil loss for all winter storms monitored and a single simulated 100 year event was only 0.15 mm (1.5 m3/ha), still two orders of magnitude less than the maximum soil loss estimated by the task force. It is conceivable that greater soil loss would have occurred if the 100 year storm had occurred shortly after the fire. If that were the case, we would expect to see a sharp decrease in sediment loss for the rest of the winter, as the limited supply of available sediment would have been eroded during the storm.

Bioturbation

During the course of the winter, a lattice of deer trails developed across the hillslopes. Occasional hoof prints appeared in the plots, with attendant disruption of soil and rock fragments. When cleaning out sediment troughs after storm events, it was obvious from the large particle size of some of the stored sediment, that some of the material was a result of this disturbance.

As vegetation cover increased as a result of the reseeding effort, gopher activity and total sediment flux within the plots increased. Previously undisturbed soils were churned up, with mounds of loose soil spilling downslope, and in some cases filling sediment troughs

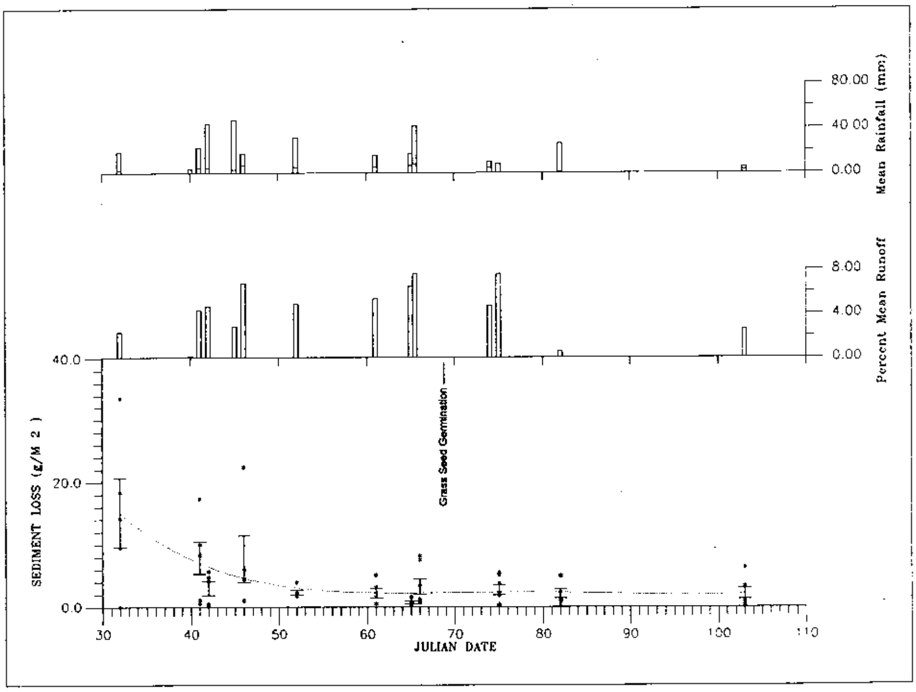

Figure 2. Sediment loss during the winter of 1991-92, for 14 rain events between January 30, 1992 and April 20, 1992.

that had remained empty during the previous winter. This disturbance was most obvious in those areas that had a cover of reseeded grasses. The measured sediment loss as a result of this bioturbation during the spring, summer and fall of 1992 was an order of magnitude greater than sediment loss due to overland flow during the winter of 1991 following the fire (Fig. 3). This process is very similar to observations reported by Taskey et al. (1989) following the Las Pilitas burn in 1985. Hence, as odd as it may sound, the largest hillslope response after the fire resulted from ground disturbance caused by gophers!

Soil moisture

Soil moisture was measured six times between January and late March, 1992. Cores were taken to bedrock, which was typically between 0.6m to 0.9m at most sites. Samples were then analyzed for soil moisture content by drying at 105°C for 24 hours. Soil moisture averaged over the length of the sample was used to compare sites. Except for the first sampling period in January, sites treated with hydromulch and the grass seed mixture always had higher soil moisture contents than untreated sites. By the end of March, 1992, treated sites had soil moisture contents that were on the average 23% higher than sites with similar soils that received no treatment. While the increased moisture content in the treated sites points to the success of the treatments in retaining water on site thus reducing overland flow and potential surface erosion, it raises another issue. Many areas that had landslide scars, or were steep enough to generate landslides, received treatments of hydromulch, erosion mats, or straw bales, and presumably would have had elevated soil moisture contents. Although the moisture increase is relatively small, increasing soil moisture in potential slide areas decreases the amount of precipitation needed to cause local landsliding. It has even been argued by some (Morton 1989) that burned slopes may be less susceptible to landsliding where significant overland flow due to shallow water repellency reduces soil moisture content.

Effectiveness of erosion control procedures

The identification of hydrophobic soils following the fire served as the basis for a predicted hillslope response: the fire-flood sequence. However, the practice of using the water drop test to determine the hydrophobic nature of the soil yields information about infiltration and water repellency at only a single point

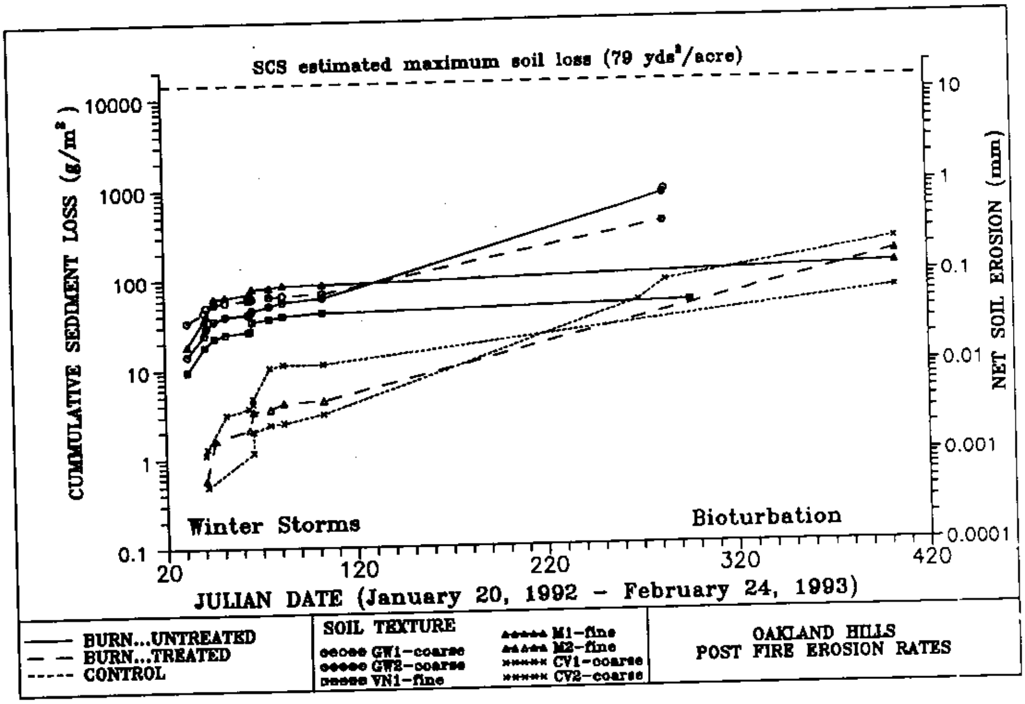

Figure 3. The graph depicts the cumulative sediment loss (sediment flux) and equivalent soil loss at the seven runoff and erosion plots between January 20, 1992, and April 10, 1992, and the increased soil disturbance by gophers at the same sites, monitored between September 27, 1992 and February 24, 1993. The left-hand axis represents the weight of sediment collected in the troughs of the seven plots, whereas the right-hand axis represents the equivalent lowering of the soil surface, assuming an average soil density of 1 g/cm3 for the eroded sediments.

in space. For the test to provide useful information, it needs to be repeated at several points at each site. The test also does not reflect the true flow paths of soil water or the runoff process mechanisms for an area larger than a water drop. Hydrophobicity in the Oakland Hills was spatially discontinuous. Areas that were typed as highly water repellent (such as hot fires within a eucalyptus grove) did not generate the predicted response because of the predominance of flow paths into the deeper soil horizons .

There is no record of how the estimated soil loss of 142 m^3/ha (Interagency meeting notes 1991) following the Oakland fire was derived, but it is thought that the Universal Soil Loss Equation (USLE)was used, though there has been some debate of that fact. In the development of the USLE, much of the work characterizing storm erosivity and raindrop impact on soil detachment was performed on disturbed soils, namely agriculture and rangeland soils (Goldman et al. 1986). Such soils have been affected by activities which weaken and break up soil structure and particle cohesion and are therefore more susceptible to erosion. It is also possible that an average soil loss following fires in southern California was used to estimate the post-fire erosional response for the Oakland hills as urban/wildland interface fires are more frequent in southern California. A review of published soil losses following fires in southern California reflects an average soil loss of 17 mm, which is close to the estimated 14 mm for the Oakland Fire. Whatever methodology was used, it reinforces the feeling that we are still struggling to understand how different landscapes respond to fire and how we can mitigate the potential erosion hazards. However, what we have learnt is that the undisturbed urban wildland soils of the types found in the Oakland hills should not be considered highly erosive, especially when subjected to the low intensity storm events that are typical for the East Bay hills.

Aerial seeding and hydromulching were the primary techniques employed to protect hillslopes from erosion. These methods were successful in reducing the minimal effects of rainsplash and sheetwash. These techniques are designed to limit overland flow by increasing the vegetation cover and by gluing a mulch of paper and wood fiber to the hillslope. Additionally, hundreds of straw bale check dams were placed in hollows and on landslide scars and deposits to moderate further any overland flow. These erosion control techniques resulted in greater infiltration of overland flow into the soil mantle, which adversely elevates soil moisture within landslide prone areas. Additionally, the proliferation of grasses during the spring and summer in what was previously a shrub and woodland environment has led to a large increase in pocket gopher activity and soil disturbance.

Standard erosion control manuals state explicitly that: straw bale check dams should not be placed in areas that receive more than 102 m3/hr (1 cfs) flow; they have a useful life of ≈3 months; and if they fail there is frequently more damage than if no barrier had been installed (Goldman et al 1986). These assertions were reconfirmed both in the Oakland Fire and Laguna Beach burn areas. The straw bale check dam data for the Oakland fire area suggests that sediment storage is less than 50% effective for average winter rainfall conditions, and even much less effective for the extreme rainfall event for which planners were preparing (Booker et al. 1993). Straw bale check dams were about 60% effective in storing sediment following the Laguna Beach fire, although their failure rate increased with increasing watershed size, whereupon failure was 100%.

Conclusions

Mitigation response to the Oakland Firestorm was driven by the expectation that heavy winter storms would cause massive erosion in the Oakland Hills. Although most popular concern focused on the chances of destructive landsliding and debris flows, the mitigation measures employed concentrated on minimizing surface erosion due to overland flow. The increase in debris flow occurrence in burned areas is most commonly associated with the mobilization of post burn ravel deposits accumulated in steep ravines. Such deposits did not form in the Oakland hills, and as a result, rainfall events of similar intensities produced strikingly different responses between the Laguna Beach and Malibu fires of 1993, and the Oakland fire of 1991. Significant overland flow erosion will not occur in the Oakland Hills because the relatively undisturbed wildland slopes lack abundant easily erodible materials on the surface and retain a relatively high infiltration capacity (although locally such capacity can be greatly reduced by fire-induced hydrophobicity). Our analysis suggests that, even if heavy winter rains had arrived, landsliding would not have been higher on burned lands, and erosion by overland flow would have been minimal (Collins and Johnson 1995). In order to provide a rational and cost effective approach to post-fire land management, there is a need to understand how different landscapes respond to fire and how erosion control measures work within the context of the landscape and the processes that are acting on it.

Acknowledgments. This research was funded in part by NSF Grant BCS-9207383.

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