Controlled Burns on the Urban Fringe, Mount Tamalpais, Marin County, California[1]

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Abstract: The California Department of Conservation, Division of Mines and Geology provided technical assistance to the California Department of Forestry and Fire Protection in assessing potential geologic hazards that could be affected by proposed prescribed burns on Mt. Tamalpais. This research yielded the following conclusions: (1) landsliding and surface erosion have contributed to the denudation of Mount Tamalpais; (2) Debris flows and surface erosion could affect property and the environment on and below the mountain; (3) The removal of chaparral will reduce the stability of the slopes; and (4) Prescribed burning may reduce the risk and lessen the destructive effects of wildfire and may therefore have significantly less impact on both landsliding and surface erosion than the probable wildfire event modeled by the California Department of Forestry and Fire Protection.

The last conclusion is based on the following considerations: controlled burns separated in time and space would expose smaller slope areas to the effects of rainfall than would a wildfire; a hot wildfire would damage the soil much more than a cool controlled fire; slope-damaging fire-fighting measures, such as tractor-constructed fire trails, would not be needed for controlled burns; and areas of geologic concern, such as colluvial-filled hollows, will be included in the development of the prescription for controlled burns on Mount Tamalpais.

Mount Tamalpais, the highest point in Marin County, lies just 20 km. north of San Francisco (fig. 1). The slopes of the mountain rise steeply free the encroaching urbanization of Mill Valley, Larkspur and Kentfield. These slopes support a dense stand of decadent chaparral that poses a significant fire hazard to the surrounding area (Perry 1984).

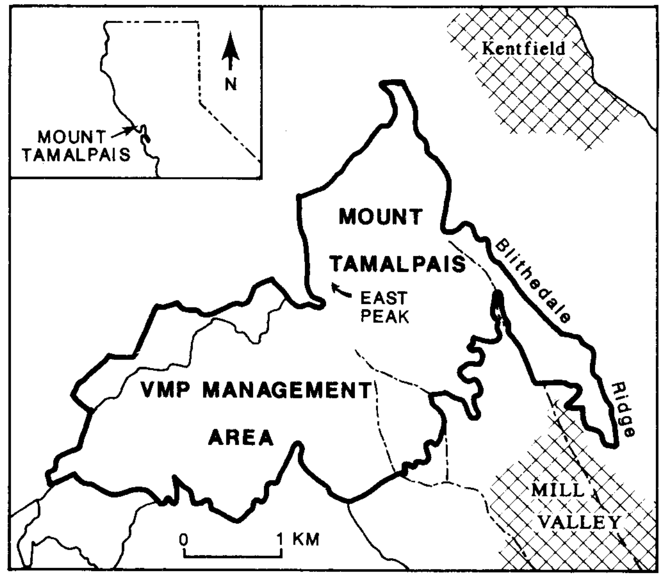

Fig. 1 Location map showing the boundaries of the Mount Tamalpais Vegetation Management Plan area and its relation to urbanizing areas of Marin County.

The Marin County Fire Department, in cooperation with the California Department of Forestry and Fire Protection, has developed a plan to reduce the threat of catastrophic wildfires through the use of prescribed burns on the south-facing slopes of Mount Tamalpais on lands managed by the Marin Municipal Water District and the Marin County Open Space District. These agencies do not, however, wish to reduce the wildfire hazard by increasing the hazards of erosion, flooding, and debris flow activity to unacceptable levels. Therefore, technical assistance was requested from the California Department of Conservation, Division of Mines and Geology to assess geologic hazards, particularly erosion and slope stability, that could be affected by proposed Vegetation Management Program controlled burns.

The primary goal of the prescribed burns is to create a mosaic of age and size classes of chaparral vegetation on the south face of Mount Tamalpais to limit the wildfire hazard (Selfridge 1966a). Four multiple burn areas, totaling 300 ha in size, are designed to break up brush fields that threaten life and property in the town of Mill Valley (Selfridge 1986a).

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Within these multiple burn areas, 20 to 35 percent of the vegetation, approximately 80 ha, are anticipated to be burned in the next year the project is active. This represents 8 percent of the 1000 ha area managed by the Marin Municipal Utilities District and the Marin County Open Space District.

The initial burns will be in the winter or early spring, when live fuel moistures are high, to allow for better fire control (Selfridge 1986b). Once the extreme fire hazard is reduced, controlled burning will take place during favorable weather conditions in the fall (Selfridge 1986b). Fall burns are desirable because they mimic natural conditions and would pose less of a threat to endangered plant and animal species. The ultimate goal of the vegetation management project on Mount Tamalpais is to burn approximately 5 percent of the chaparral vegetation each year to maintain a 20 year rotation of the fire climax species (Nehoda 1988). In this context, the review by the Division of Mines and Geology addresses the entire management area.

GEOLOGIC SETTING

Bedrock

Mount Tamalpais is underlain by the Marin Headlands terrane of the Franciscan Complex (Blake and others 1984). Bedrock exposed in the proposed burn area is a weakly metamorphosed lithic sandstone with serpentinite along fracture zones (Wright 1982). The sandstone beneath East Peak is very hard and strong and is cemented by authigenic tourmaline. This tourmalinized sandstone is recognizable within sane transported old landslide masses (Rice 1986). The serpentinite is highly sheared, very weak, and has failed as earth flows, slumps, and debris slides on relatively gentle slopes.

Colluvium

Colluvium accumulations in bedrock hollows are a main source of debris flow landslides (Reneau and Dietrich 1987). On Mount Tamalpais, the dominant colluvium is poorly consolidated with sandstone clasts supported by a poorly sorted sandy matrix. This is the type of material that is highly prone to failure by debris flow events (Ellen and Fleeting 1987).

Most of the areas of colluvium accumulation on Mount Tamalpais can be identified by their surface morphologies, however, some of the colluvium-filled, pre-existing topographic lows are not reflected in the surface topography (Wright 1982). These obscure hollows were identified by using false color infrared aerial photographs taken during the summer. Because of the greater moisture capacities of colluvium compared with the surrounding soil, plants growing over the hollows are not stressed by water deficiencies to the same degree as those over bedrock. This difference in plant stress causes the strong differences in the reflectances of near infrared radiation (Glass and Slemmons 1979) that was used to identify the obscure, colluvium-filled bedrock hollows. All of the identified colluvium deposits larger than approximately 1 ha, both those that are exhibited in the surface topography and those that are not, are shown on fig. 2.

A few small areas were observed where the colluvium consists almost entirely of serpentine detritus. For geotechnical purposes, the serpentine colluvium was included with either the serpentinite or the serpentine-derived landslide deposits over which it lies.

Landslides

Rotational landslides, earthflows, debris slides, and debris flows (nomenclature from Varnes 1978) were identified in the Mount Tamalpais Vegetation Management Plan burn area (fig. 2). Features with physiomorphic properties that are associated with rotational sliding, but which have been modified by erosion, are the most extensive in the area. These large, apparently deep-seated features are interpreted to be related to an earlier, very wet climate.

Earthflows have affected the serpentinite and serpentine colluvium in the western portion of the Vegetation Management Plan area. Portions of the individual earthflows are prone to reactivation in response to accumulated soil moisture, whether the area is burned or not.

Debris slides of unconsolidated rock, colluvium, and soil that have moved downslope along relatively shallow failure planes were identified as affecting both the Franciscan Complex sandstone and the serpentinite. Most of the mapped debris slides are along roads and trails where cut banks are continuing to ravel. In a few locations, sidecast fill and portions of the underlying soil and colluvium have failed. Debris slides were also identified in steep areas well away from cut or fill slopes. Unlike the large, deep ancient rotational landslides that may be thousands or even tens of thousands of years old, the surface morphology of a debris slide rapidly degrades by erosion. The debris slides mapped on fig. 2 are either active or recently active.

The most abundant type of landslide mapped in the Mount Tamalpais Vegetation Management Plan burn area is the debris flow. Debris

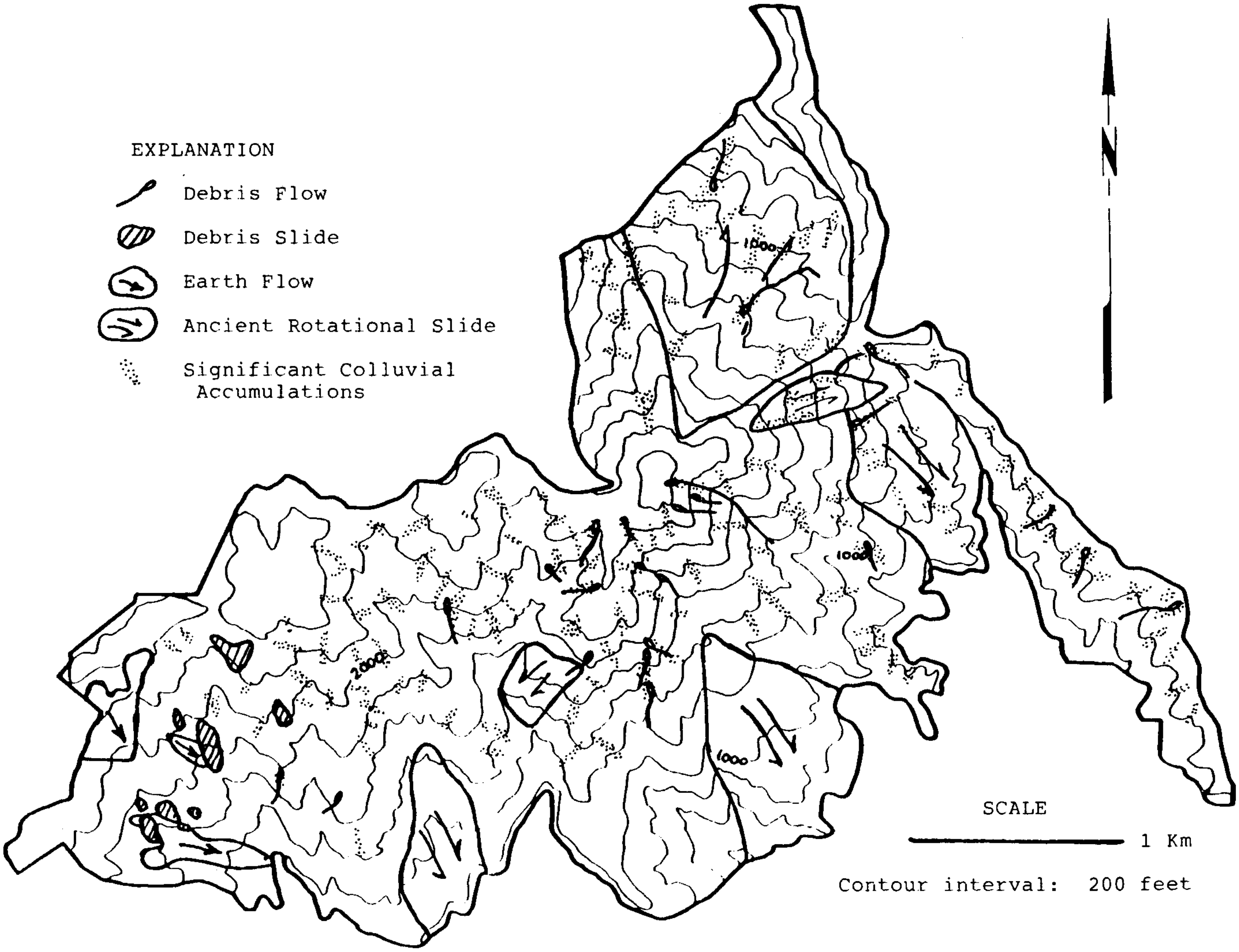

Fig. 2 Map of landslides and colluvium deposits within the Mount Tamalpais Vegetation Management Plan

flows, often termed debris avalanches when velocities are greater than about 10 miles per hour (Varnes 1978), are shallow landslides that fail as muddy slurries during periods of intense precipitation (Campbell 1975). Many researchers -- for example, Dietrich and Dunne (1978) and Lehre (1981) -- have recognized that most debris flows start in swales or hollows at heads of small hillside drainage courses. These are areas where the potential source material (loose colluvium) and ground water accumulate, resulting in focused high pore-water pressures in weak materials (Reneau and others 1984).

Three debris flows on the east face of East Peak originated on hiking trails where surface water was intercepted and diverted into the swales. The debris flows that are mapped on fig. 2 are almost all products of a major storm which occurred free January 3 through January 5, 1982.

Lehre (1981) measured erosion and sediment discharge in a small watershed on the western slope of Mount Tamalpais and concluded that debris slides and flows account for most of the sediment yield there. Sediment that is mobilized during years without extreme flow events generally returns to storage, chiefly on the lower parts of slopes and in channel and gully beds and banks. Large net removal of sediment occurs during storm events with recurrence intervals greater than 10 to 15 years (Lehre 1981). Most of the stream channels on Mount Tamalpais have transported sediment without resulting in severe aggradation.

THE EFFECTS OF FIRE ON SLOPE STABILITY AND EROSION

The primary effect of a fire is the removal of vegetation. Where slopes are steep and soils are cohesionless, as on Mount Tamalpais, stems and trunks of vegetation and organic litter support loose clasts, preventing them from rolling downslope. Burning removes the mechanical support, allowing material to dry ravel. Wells (1981) quotes USDA Forest Service research that dry ravel is responsible for aver half of all sediment movement on many slopes.

A major effect of fire on chaparral soils is the production of a water-repellent layer beneath the soil surface. DeBano (1981) noted that chaparral plant communities produce a degree of water repellency under normal conditions because organic substances are leached from the plant litter and coat sand and coarse-grained soils (the surface area-to-volume ratio of fine-grained soils limits the effectiveness of the production of water repellency). The water-repellent material under unburned chaparral stands is only partially effective in restricting infiltration. When wildfire sweeps through a chaparral stand, the soil temperatures may reach 840°C (DeBano 1981). This volatilizes the organic water-repellent materials which follow temperature gradients downward into the soil. The vaporized substances then condense on mineral soil particles and produce an extremely water-repellent layer. The 1- to 5-centimeter-thick layer of soil that overlies the water-repellent zone is highly permeable and erodible.

Following a high-intensity fire, the effective water storage capacity of the soil mantle is estimated to be reduced by 20 times or more (Wells 1981) and rainfall quickly exceeds the soil's storage capacity. The excess water that cannot penetrate through the hydrophobic layer saturates the surficial wettable layer, which may fail as small-scale debris flows (Wells 1987). This material, in addition to the surface rill and gully wash, rapidly runs off into stream channels.

Peak flows in stream channels downslope of burn areas may occur with less of a delay from rainfall peaks than those in unburned watersheds. Flood peaks are often much higher and more capable of eroding stored sediment. The high flows of sediment-charged water can erode large quantities of material and transport it as debris torrents (debris flows that are initiated in stream channels as opposed to colluvium-filled hollows).

Landsliding, principally debris flows, has also been shown to increase in frequency after vegetation is removed from met-stable slopes (Rice and Foggin 1971). The maximum incidence of landsliding occurs several years after a fire because of the time it takes for the soil-reinforcing root biomass to decay and for the water-repellent layer to be disrupted and permit infiltration.

One additional negative environmental effect of wildfire that has received little attention is the damage to the soil caused by fire suppression efforts. During a major wildfire, earth moving equipment is used to build fire trails. These trails are often several tractor blades wide and may trend directly down steep slopes. It is fairly common for fires to jump individual lines, often requiring the excavation of many parallel downslope firebreaks. Each of these disrupted areas is often significantly more prone to erosion than the burned hillslopes adjacent to them. Additionally, erosion control structures, such as waterbars, are often placed where they divert water onto unstable slopes.

Sediment derived from burned areas is routed through drainages. If a channel is capable of carrying the additional load, the excess sediment is transported to an area of long-term deposition. If, on the other hand, the material eroded from burned slopes exceeds the carrying capacity of the stream, the sediment will settle out, aggrade the channel, and cause additional erosion and sedimentation.

EFFECTS OF FIRE SUPPRESSION

Fire suppression has been successful on Mount Tamalpais since the Great Mount Tamalpais Fire of 1929 burned 117 houses in Mill Valley. Fuel management has not been practiced during this time, resulting in the current critical fire hazard conditions. When the age class of chaparral vegetation is over 20 years, as is the case in the Vegetation Management Plan area on Mount Tamalpais, the live-to-dead plant ratio -- and therefore the potential for burning - increases (Perry 1984). The accumulation of fuel in areas where fire suppression has been practiced also results in fires that are unprecedented in size, intensity, and environmental damage when compared to unmanaged areas (Dodge 1972). Minnich (1983) compared adjacent portions of southern California, where fire suppression has occurred, with northern Baja California, where there has been little or no wildfire control. Although approximately 8 percent of the chaparral acreage was burned by wildfires in both areas during his study, in Baja California the fires occurred as many small events that were distributed in time throughout each summer, while in southern California, a few large, often catastrophic fires burned in the late summer and fall.

The stream channels on Mount Tamalpais evolved during the time when small wildfires produced a mosaic of age classes of chaparral vegetation. The carrying capacity of some of these channels would likely be overwhelmed if a large storm event were to occur following a catastrophic wildfire. Flood damage during the winters after the wildfire occurred could likely extend below the limits of the burn.

PRESCRIBED BURNING EFFECTS

Prescribed burns have the same types of impacts as wildfires on erosion and slope stability, but the intensity and areal extent of these impacts is much less. Prescribed burns can be small and separated in time and space. This results in a far lower exposure of soil to precipitation during any one time interval. Prescribed burns can be designed to prevent side slopes from being denuded from ridgetop to canyon bottom. Dry ravel may occur, but only a portion of the dry ravel on the side slopes will travel any significant distance downslope. Water- repellent conditions do not develop to the same degree under prescribed burn conditions, and changes in the particle size distribution reported by Wells (1981) are less pronounced. This is particularly true if burns are conducted when soils are wet. The law-intensity burns may induce hydrophobic soils, but only a thin layer of erodible material is likely to lie above a discontinuous water-repellent zone. Also, the use of heavy grading equipment on slopes, such as occurs when fighting wildfires, is much less likely to occur if an area is burned under prescribed conditions.

A controlled burn of only a portion of a watershed will have less of a potential for producing damaging peak flood events or surface erosion than would a complete removal of vegetation by a wildfire. As described above, prescribed burns do not produce the continuous water-repellent layer found beneath wildfire areas. Therefore, much of the post-fire rainfall infiltrates into the soil and does not rapidly run off. Smaller quantities of sediment are likely to erode more frequently from areas managed through controlled burns as compared to less frequent post-wildfire floods which may trigger catastrophic erosional events.

CONCLUSIONS

Fire is a natural part of a chaparral landscape. Where fires have been suppressed for a long period of time, such as on Mount Tamalpais, the effects of the ultimate wildfire event may be large. Removal of the vegetation, fire damage to the soil, and ground disturbance by fire suppression equipment will all contribute to a situation where post-fire floods and debris flows could pose a severe risk to lives and property downslope of the wildfire area. These conditions may also decrease slope stability in many areas. The proposed controlled burning program should lessen the potential for off-site damage due to floods, debris flows, and landslides from Mount Tamalpais.

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