U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Debris Flows Triggered by the El Niño Rainstorm of February 2-3, 1998, Walpert Ridge and Vicinity, Alameda County, California

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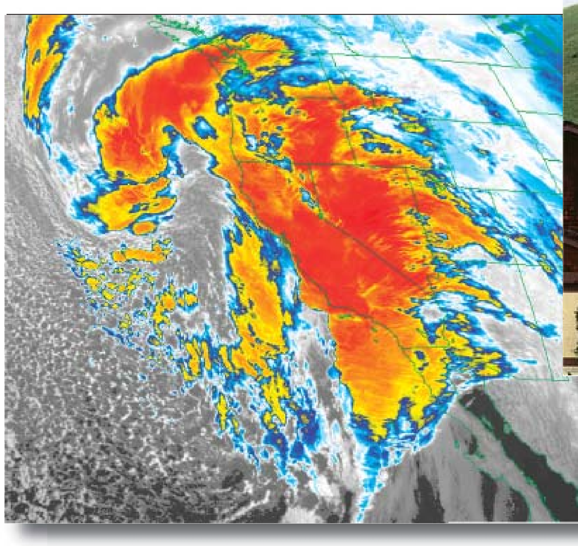


(Left) GOES-9 infrared image of the February 2-3 storm at 04:00 PST on February 3, 1998. (Top) Debris flows triggered by the February storm behind houses along Canyon Heights Drive in Fremont, California. See rows of hay bales on scar for scale. Photo taken March 26, 1998.

ABSTRACT

On February 2 and 3, 1998, a rainstorm generated by the 1997-98 El Niño moved through the San Francisco Bay region of California triggering widespread slope failures. In the Walpert Ridge area of Alameda County, just east of the East Bay cities of Fremont, Union City, and Hayward, 531 debris flows were triggered by the storm. Most of the flows mobilized from soil slips. Maximum concentrations of debris flows reached about 30 per 0.25 km^2. The highest concentrations occurred on west-facing hillslopes well below the crest of Walpert Ridge. Many occurred on the first and second major topographic rises along the western flank of the northwest-trending range front. The highest concentrations occurred on two geologic units having very different physical properties of bedrock and soil mantle, a bedded sedimentary sandstone unit and a rhyolite. Physical property information for each of the 14 geologic units in the study area (mapped at a regional scale) is not sufficient to explain the differences in abundance of debris flows. This disparity indicates that, at least in this part of Alameda County during this rainstorm, geologic materials were not good predictors of debris-flow source areas.

The occurrence of debris flows was controlled primarily by steepness of gradient, topographic curvature that systematically varied as a function of gradient, and the location of moderate to heavy rainfall. Gradients computed from a 10-m digital elevation model at debris-flow initiation locations are approximately normally distributed about a mode of 24°. Normalizing the debris-flow gradients with the gradients for the entire study area shows that debris-flow incidence increased with gradient. Upslope contributing areas computed from the digital elevation model were less than 10,000 m^2 for 99 percent of the debris flow initiation locations. Debris flows were initiated from both convergent (44%) and divergent source areas (56%) but data indicate that as gradient increased, debris-flow source areas tended to become more divergent. Travel distances were generally between 10 and 200 m.

NEXRAD data indicate that total rainfall from the storm in the study area ranged from about 38 to 139 mm with a maximum 1-hour intensity of about 20 mm/hour. Documented times of debris flow occurrence and end times for maximum rainfall of 1-, 6-, 12-, 18-, and 24-hour durations (as measured by rain gages) all occur within a 12-hour period between 22:00 Pacific Standard Time on February 2 and 10:00 PST on February 3. The close correspondence in end times resulted from a long period of moderate rainfall followed by about a 6-hour period of intense rainfall. In general, debris-flow concentrations corresponded with high cumulative and hourly rainfall, but there was not an exact correspondence between the highest debris-flow concentrations and the highest rainfall. Rainfall at the highest debris-flow concentration did not exceed previously established rainfall thresholds for the initiation of abundant debris flows in the San Francisco Bay region. A comparison of NEXRAD and gage data indicates that there is no systematic difference between cumulative rainfall and only a very slight tendency for NEXRAD to underestimate hourly rainfall. The overall root mean squared errors for cumulative and hourly rainfall are 25 mm and 6 mm, respectively.

INTRODUCTION

As early as the summer of 1997, the 1997/98 El Niño phenomenon was predicted to be one of the most intense in the past 100 years (Monteverdi and Null, 1997; Leetmaa and Higgins, 1998). In the San Francisco Bay region, above average rainfall associated with the El Niño event was also expected to promote an increase in landslide activity (USGS Report, 1997; Godt and others, 1997). By the fall of 1997, the general public in the region experienced an uneasy anticipation of possible 1997/98 El Niño winter storms and associated flooding and slope failures (Diaz, 1997; Perkins, 1997; Perkins and Whetzel, 1997; Richards, 1997; Rogers, 1997). By the end of

Total topographic curvature has been shown to control the downslope transport of colluvial soils, surface runoff, and shallow, sub-surface flow on colluvial mantled hillslopes (Dietrich and others, 1995). Diffusive processes such as soil creep generally dominate below a critical gradient and where total curvature is divergent (Roering and others, 1999). Materials transported by diffusive processes accumulate in convergent areas. As a result, soils tend to be thicker and more susceptible to the initiation of shallow landslides in convergent areas (Dietrich and others, 1986). Previous studies of debris flows in the San Francisco Bay region indicate that convergent areas, commonly called hollows or swales in the Bay region, are commonly the source areas of debris flows (Reneau and Dietrich, 1987;

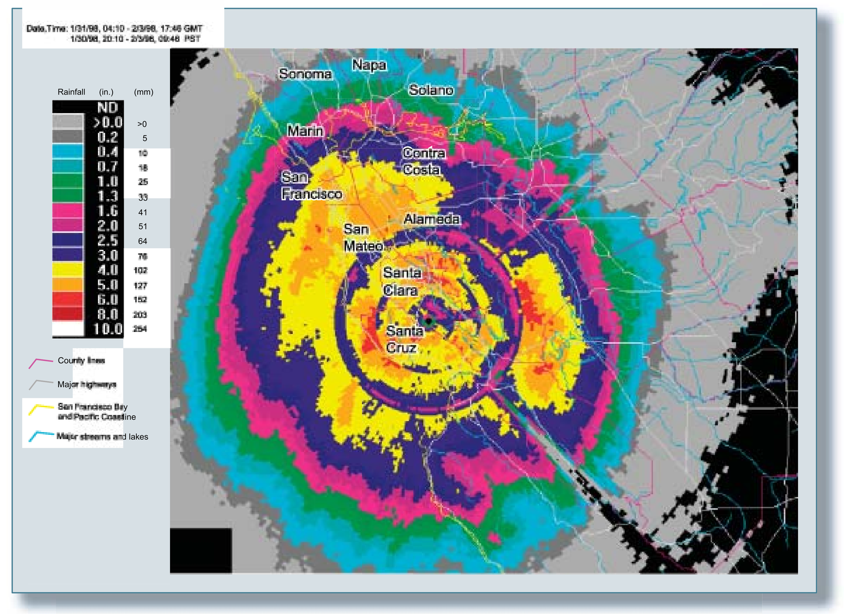


Figure 1. NEXRAD cumulative rainfall in the San Francisco Bay region measured between 20:10 on January 30 and 10:03 on February 3, 1998. Counties bordering San Francisco Bay are labeled. Times are given in Greenwich Mean Time and Pacific Standard Time. Prominent concentric band is described in methods section.

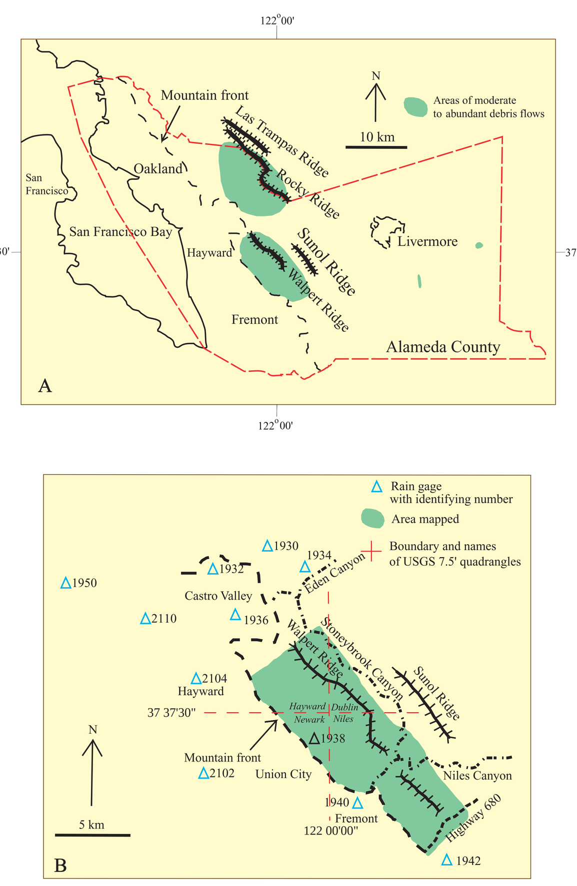


Figure 2. A, Map showing San Francisco Bay, Alameda County, and areas of moderate to abundant debris flows resulting from the February 2-3 storm. B, Map showing the Walpert Ridge study area and rain-gage locations.

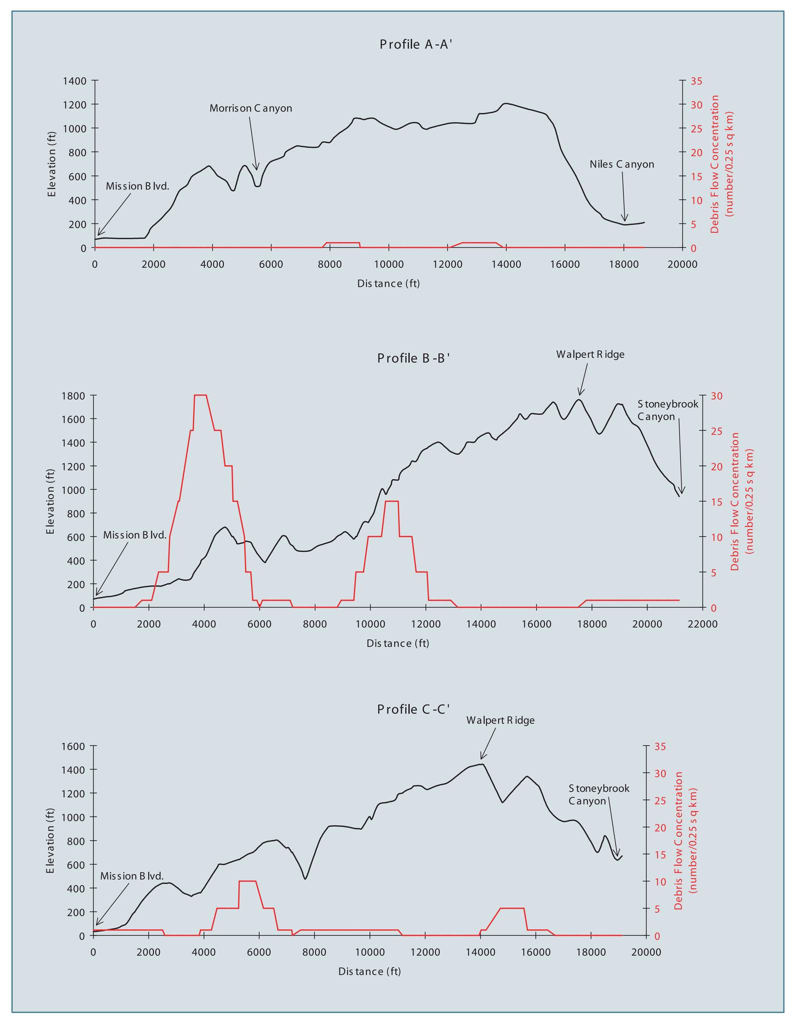
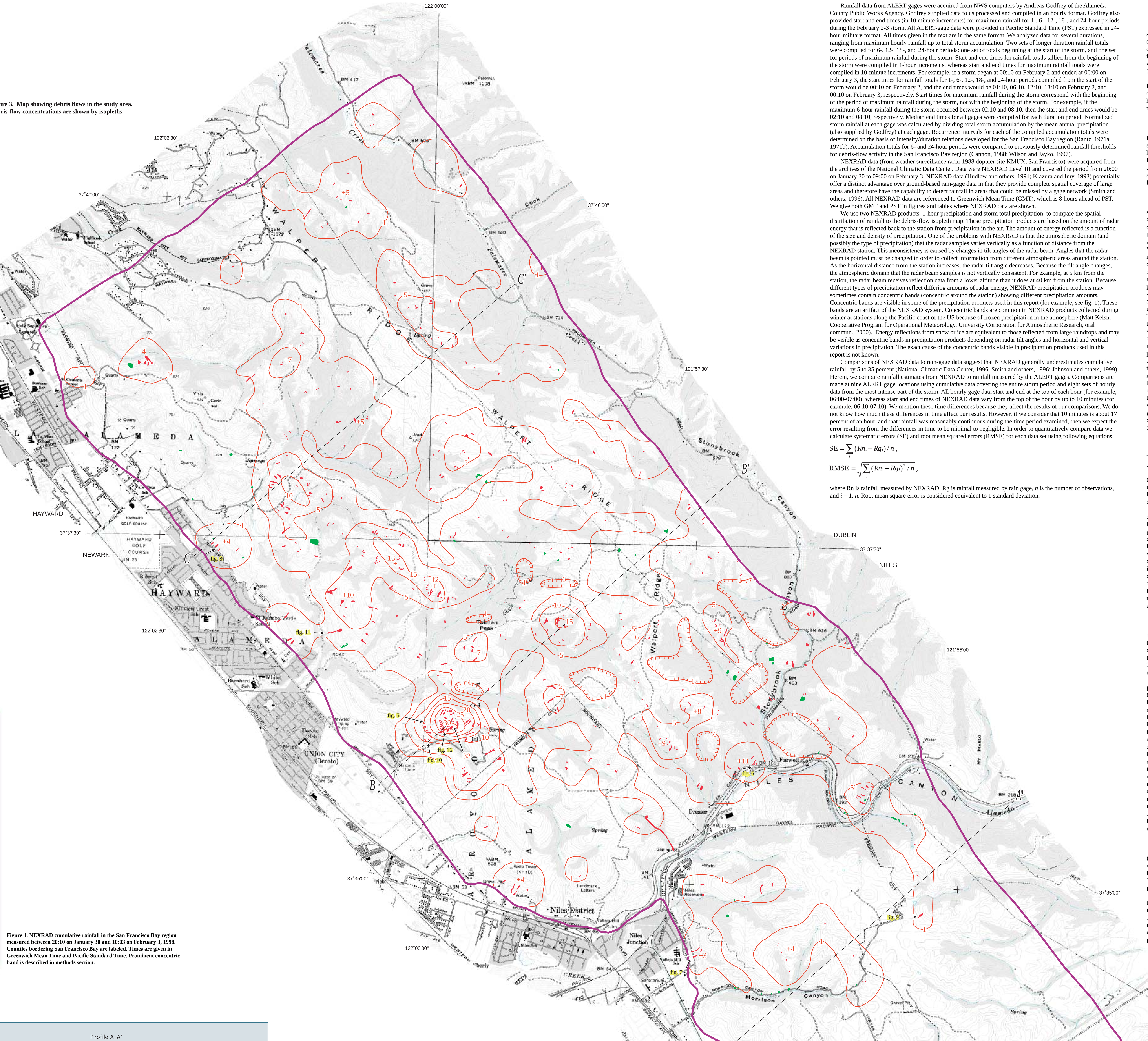
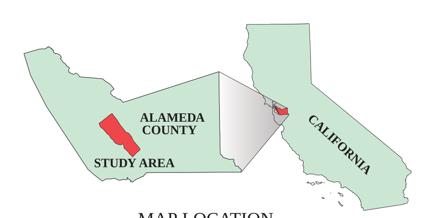


Figure 4. Profiles of topography and debris-flow concentration across the study area. Topography shown in black, vertically exaggerated 2x; debris-flow concentration in red. See figure 3 for location of profiles.

Figure 3. Map showing debris flows in the study area. Debris-flow concentrations are shown by isopleths.





MAP LOCATION

EXPLANATION

Debris-flow soil slip, flow path, and deposit

Landslide; see text for further explanation

Study area boundary

Isopleth, indicating debris-flow concentration. Isopleths drawn at 1, 5, 10, 15, 20, 25, and 30 debris flows/0.25km^2; hachures indicate closed isopleth depression. Maximum determined number within closed isopleth

A —— A' Location of profile shown in figure 2

fig. 4 → Location of oblique photo shown as figure in text. Arrow indicates direction of photo

Tree cover (from USGS 7.5' quadrangle)

Urban area (from USGS 7.5' quadrangle)

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET

Figure 5. Debris flows located about 1 km northeast of the Masonic Home in Union City. See figure 3 for location and dirt road for scale. Photo taken April 22, 1998.

Antecedent soil moisture

[...] gages recorded rainfall near the study area in the winter of 1997/1998 (fig. 2b, table 6). [...] these gages ranges from 460 to 685 mm and generally exhibits a positive correlation [...]. [...] ALERT gages for the 1-month period (January 1 to February 1, 1998) prior to the [...] from 153 to 264 mm (33 to 46% of the mean annual precipitation, table 6). Previous [...] of 254-280 mm of pre-storm seasonal rainfall is needed to reach antecedent moisture [...] occurrence of debris flows in the San Francisco Bay area (Campbell, 1975; Wieczorek [...]