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Preliminary Maps Showing Rainfall Thresholds for Debris-Flow Activity, San Francisco Bay Region, California

By RAYMOND C. WILSON AND ANGELA S. JAYKO[1]

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[1]MENLO PARK, CA 94025

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Raymond C. Wilson and Angela S. Jayko

Abstract

These maps show, for emergency service managers in the San Francisco Bay region, the threshold rainfall that may be capable of triggering a level of debris-flow activity likely to threaten public safety. The maps are products of a continuing series of studies that began after a catastrophic storm on January 3-5, 1982 triggered 18,000 debris flows in the San Francisco Bay region, causing 25 deaths and $66 million in property damage. The threshold rainfall values were estimated by re-evaluating a previous empirical analysis of data from the 1982 storm, and other historical rainfall records, that normalized the rainfall intensity data by dividing by the mean annual precipitation (MAP) of the corresponding rain gage. The present analysis also takes into account the rainfall frequency, the mean annual number of days with non-zero rainfall (#RDs), thereby adjusting for the difference in rainfall frequency between windward-facing slopes where rainfall is orographically enhanced and leeward-facing slopes and valleys that lie within rain shadows where precipitation is reduced.

The debris-flow threshold maps were created by digitally combining an existing regional map of mean annual precipitation, a newly compiled data set of #RDs from an analysis of long-term (20-40 years) records of daily rainfall for 33 rain gages in the region, and the re-normalized thresholds from the empirical analysis of historical storm data.

Introduction

In order to trigger debris flows in the San Francisco Bay region, a storm must have a critical combination of rainfall intensity and duration (Cannon and Ellen, 1985; Cannon, 1988). Previously, Campbell (1975) found that sustained periods (at least several hours) of rainfall at rates exceeding 0.25 in/hr are required to trigger hazardous debris-flow activity in southern California. Campbell hypothesized that the threshold combination of rainfall intensity and duration was related to the balance between the rate that rainfall infiltrates into the soils and weathered bedrock on a hillslope (colluvium) versus the rate that water drains out of the colluvium. Colluvium drains rapidly on the steep hillslopes where debris flows are most likely to occur and usually keeps pace with low or moderate rainfall rates. Intense rainfall, however, can overwhelm this established drainage, leading to saturation of the hillslope soils, generation of positive pore-fluid pressures within the soil, and ultimately, slope failure (Campbell, 1975).

As time passes, drainage on natural slopes becomes equilibrated with long-term precipitation conditions. Carlston (1963), for example, found a good correlation between the density of the drainage network and amounts of storm rainfall with return periods on the order of two years. The severe rainstorms that produce significant debris-flow activity, on the other hand, represent "extraordinary events, when rainfall at a particular site exceeds the commonly occurring conditions" (Cannon and Ellen, 1988, p. 30). Within the San Francisco Bay region, however, the winter storms coming off the North Pacific Ocean interact with the local topography in complex patterns, producing significant variations in the mean annual precipitation and the frequency of a given size of storm event (Rantz, 1971). These local variations are superimposed on a broad regional variation in the rainfall frequency, as measured by mean annual number of days with measurable rainfall (Weaver and Denney, 1964; Wilson, 1997a). These climatic factors produce the spatial variations in rainfall threshold depicted on the maps.

How the Maps were Prepared

There are two maps in this rainfall-threshold series, one depicting the rainfall thresholds for a 6-hour period, the other for a 24-hour period. The 6-hour map is intended for use with storms that are intense, but relatively brief, or as a tool for evaluating a prolonged storm in its early stages. The 24-hour map is intended for long-duration storms with moderate or strong rainfall intensities. Most of the rain storms in the San Francisco Bay region have durations of approximately 24 hours or less.

During storms, the topography in the San Francisco Bay region produces orographic lifting of the saturated air, with strong effects on precipitation. Thus, the same storm that produces 3 inches of rain at San Francisco International Airport, for example, could produce 7 inches at Kentfield, a few miles north, or more than 10 inches along the crest of the Santa Cruz Range. This interaction between atmosphere and topography produces the strong spatial variations in threshold rainfall shown in the maps. The threshold rainfall in the 24-hour map, for example, ranges from less than 3 inches on the eastern slopes of the Diablo range in Contra Costa and Alameda Counties, to over 10 inches along the crest of the Santa Cruz range in Santa Cruz county. However, these variations in threshold rainfall do not imply variations in susceptibility to or frequency of occurrence of debris-flows. In fact, the map is constructed on the assumption that the return period for storm rainfall that exceeds the thresholds is uniform throughout the area.

<u>Development of the Thresholds</u>: Following the January, 1982 storm, which triggered 18,000 debris flows in the San Francisco Bay region, causing 25 deaths and $66 million in property damage, Cannon (1988) developed a regional set of threshold rainfall values for debris-flow initiation by comparing rainfall intensity and duration data from this storm to similar data from other large historical storms that did not trigger significant debris-flow

activity. She selected data from a series of rain gages that were closest to areas of intense debris-flow activity in the January, 1982 storm, then normalized the rainfall intensity data by dividing by the long-term MAP for the rain gages. The normalized intensity data were then plotted against the corresponding time interval and a line was drawn separating the January, 1982 storm data from the data from storms that failed to produce debris flows (Cannon, 1988, p. 41, fig. 4.3). This line of separation was assumed to approximate the rainfall threshold for debris-flow initiation.

Along with a network of radio-telemetered automatic rain gages (the ALERT network), Cannon's regional threshold served as the basis for a Landslide Warning System in the San Francisco Bay region, operated jointly by the USGS and the National Weather Service (NWS) during the period 1986 to 1995 (Wilson, 1997b). During the period of operation, several storms occurred that triggered debris-flow activity over localized areas (Wilson and others, 1993), and rainfall data from gages near areas of debris-flow activity generally exceeded, or at least approached, Cannon's (1988) threshold values. Data from ALERT gages in low-rainfall areas, however, appeared to yield "false alarms," with an inordinate frequency (R. Mark, unpub. data, 1995), bearing out Cannon's (1988, p. 38) caution that "normalization introduces inconsistencies in areas of low MAP."

Further, studies of rainfall thresholds in other regions along the U. S. Pacific coast (Wilson, 1997c) suggested that applying MAP-normalized thresholds from the San Francisco Bay region to southern California or to the Pacific Northwest produced significant under- or over-estimated thresholds, respectively. However, very similar threshold estimates could be produced in the three regions by normalizing with another parameter, the rainy-day normal (RDN), where

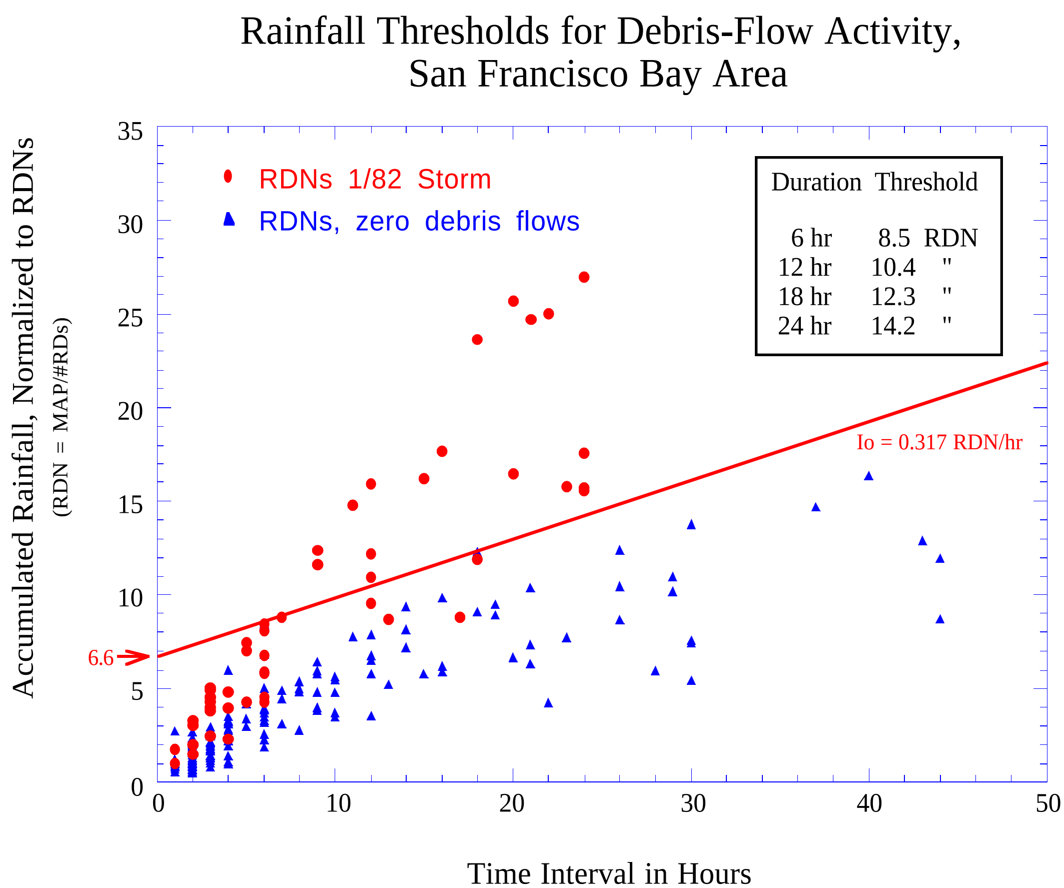
$$\mathrm{RDN} = \frac{\mathrm{MAP}}{\#\mathrm{RDs}},$$

It appears that RDN is a more reliable indicator of the frequency of severe storms than MAP alone (Wilson, 1997a; 1997c).

Climatologists have noted a correlation between rainy-day normal and rainfall from storms with return periods of approximately 2 years (Linacre, 1992, p. 288). These moderate, but relatively frequent, storms have been described as playing an important role in equilibrating the density of the surface drainage network with the long-term precipitation climate (e.g. Carlston, 1963). The surface drainage network strongly influences the rate at which surplus rainfall drains from a hillslope, leading to the conjecture that rainfall/debris-flow thresholds might also correlate with the rainy-day normal parameter, RDN (Wilson, 1997c).

The threshold rainfall values for debris-flow initiation for these maps were estimated in much the same way as Cannon (1988), using the same data base, except that the rainfall intensity data was normalized using the RDN value for each gage instead of only the MAP. The results are shown in Figure

1. There is a clear distinction between the January 1982 storm and other large, non-debris-flow producing storms for time intervals beyond 6 hours. The rainfall threshold corresponds to 8.5 RDN for the 6-hour map, and 14.2 RDN for the 24-hour map.



Mapping Spatial Variations in Threshold Values: The next step in developing the maps was to convert the spatial variations in MAP and #RDs into spatial variations in the RDN value, and thus to the corresponding rainfall/debris-flow thresholds for 24 hours (14 RDN) or 6 hours (8.5 RDN). This was accomplished by digitally overlaying an existing map of mean annual precipitation (Rantz, 1971) with a newly developed digital data set showing rainfall frequency.

Preparing the MAP layer was fairly straightforward--the Rantz (1971) map was digitized and gridded to form a digital database for MAP. The second step, developing a spatial database for rainfall frequency (#RDs), required a more involved process. First, long-term daily precipitation data were collected from 33 rain gages listed by NOAA's National Climatic Data Center (NCDC) with at least 20 years to more than 40 years of record (Table 1; names and locations shown on both maps). These long-term data were used to constrain a frequency model for daily precipitation, based on a square-root normal distribution (Wilson, 1997a), from which the precipitation frequency, measured as rain days per year (#RDs), was estimated. The two parameters together, MAP and #RDs, provide a complete description of the size-frequency distribution of precipitation at that gage site. This, in turn, allows one to estimate the magnitude of the "extreme" storm events which are most likely to trigger debris flows (Wilson, 1997c).

Using the #RDs for each gage as point data, digital mapping methods (gridding with an exponential kriging function) were used to spatially interpolate the rainfall frequency data across the ungaged areas of the region. At this point, the two digital layers for MAP and #RDs were registered, and the ratio, RDN = MAP/#RDs was re-gridded and mapped over the area. Finally, the RDN values were multiplied by the appropriate value (8.5 for the 6-hour map; 14 for the 24-hour map), and contours of the resulting threshold values were plotted on the respective maps.

How to Use The Threshold Maps

<u>The Requirement for a Minimum Amount of Seasonal Rainfall</u>: Precipitation is highly seasonal in the California Coast Ranges, with wet winters and dry summers, resulting in a lagged seasonal variation in the soil-moisture content of hillslope colluvium. Thus, at the beginning of the winter rainfall season, the colluvium has been dehydrated by evaporation and transpiration during the long dry season in summer and fall. Remaining soil moisture is under strong tensile forces (soil suctions). Until this moisture deficit is restored by early seasonal rainfall, conductivity will be slow and high soil suctions will prevent the formation of the positive pore-fluid pressures necessary for slope failure. Thus, debris flows are unlikely early in the rainfall season (Campbell, 1975).

The total amount of early seasonal rainfall required to rehydrate the colluvium depends on a complicated function of the initial moisture content, the losses to evapo-transpiration, and the thickness of material that has been dehydrated. However, because the resumption of rainfall in the late autumn coincides with lower temperatures and shortened daylight, when evapotranspiration is reduced, the rehydration of the hillslope soils proceeds rapidly. In a normal rainfall season, the antecedent rainfall condition is generally reached in most areas within a few weeks after the winter solstice (Wilson, 1997c). The threshold rainfall amounts depicted on these maps are predicated on the assumption that the minimum soil-moisture requirement has already been satisfied by early seasonal rainfall.

<u>Evaluating Forecast Rainfall for the Threat of Debris Flows</u>: In using the maps to evaluate the potential for debris-flow activity in a given area from a storm that has been forecast to occur, one should first determine exactly to what location the rainfall forecast is referenced. Because of topographic

effects, the same storm may produce widely varying rainfall amounts in different places within the region. Quantitative precipitation forecasts (QPFs) are generally prepared by the NWS either in relative terms (e.g. rainy-day-ratios) or, if precipitation is forecast in absolute terms (inches), the forecast is for a specific rain gage. Common reference points for the San Francisco Bay region are San Francisco International Airport (SFO) or the NCDC gage at Mission Dolores in downtown San Francisco (SFMD).

Quantitative Precipitation Forecasts prepared by the Weather Service Forecast Office in Monterey, California, specify rainfall amounts for the following 24-hour period in four segments of 6 hours each. The highest 6-hour amount, therefore, should be compared to the 6-hour threshold map, and the total for the 24-hour period should be compared to the 24-hour threshold map. (Caution: both the 6-hr and the 24-hr thresholds are referenced to peak rainfall periods while the 6-hr intervals used in a QPF are tied to absolute (clock) times, so that a 6 -hr peak rainfall period may be split between two 6-hr intervals in the QPF.)

In the San Francisco Bay region, the winter storm track usually trends from southwest to northeast, although individual storms may arrive from any point between due west and due south. Along the same storm track, the amount of rainfall produced within a given time interval should be roughly proportional to the ratio of the threshold amounts, but this is only a rule-of-thumb. If the rainfall forecast for SFO, for example, exceeds 3 inches in 24 hours, or 2 inches in 6 hours, then debris-flow thresholds may be exceeded not only on San Bruno Mountain above SFO, but also in upwind areas (e.g. the hills above Pacifica and Half Moon Bay) and downwind areas (e.g. the East Bay Hills above Oakland and the Mt. Diablo area).

An estimate of the storm track direction may be included in the NWS forecast discussion. Studying a loop of satellite or Doppler radar images may provide other clues. Storms can change direction suddenly as they make landfall, however, so that continued monitoring of NWS information may be necessary.

<u>Monitoring Rainfall in Real-Time</u>: In addition to the threshold contours, these maps also show the 4-digit ID numbers and locations of the automatic, radio-telemetered rain gages in the ALERT network in the San Francisco Bay region (station locations supplied by the NWS Forecast Office, Monterey CA). Rainfall data from a specific ALERT gage can be compared to the 6-hour or 24-hr thresholds corresponding to the gage location. If either threshold is exceeded, then debris-flow activity is possible not only in the vicinity of the gage, but in nearby areas and areas upwind or downwind along the storm track. In addition to collecting data from local gages, therefore, a monitoring plan for a given area should also include regular checks on rainfall from ALERT gages located upwind (i.e. south or west) of the area of concern to look for bursts of intense rainfall that may be moving toward your area.

Emergency Response Planning: The primary intended use of these maps is to facilitate response planning for debris-flow related emergencies. The maps are intended to be used in conjunction with the debris-flow susceptibility map developed by Ellen and Mark (1997) in this same series. A simplified image from Ellen and Mark's susceptibility map is included as a layer in these threshold maps (see map legend). The location of areas of debris-flow susceptibility, together with the climatic effects depicted by the threshold contours, should provide both a spatial portrayal of the debris-flow hazard and quantitative thresholds to compare with storm rainfall, either forecast or observed. Users may also combine the digital layers from the threshold and susceptibility maps with more detailed databases showing roadways, utilities, critical facilities, or other facilities of interest to them for a more detailed level of planning within their jurisdictions.

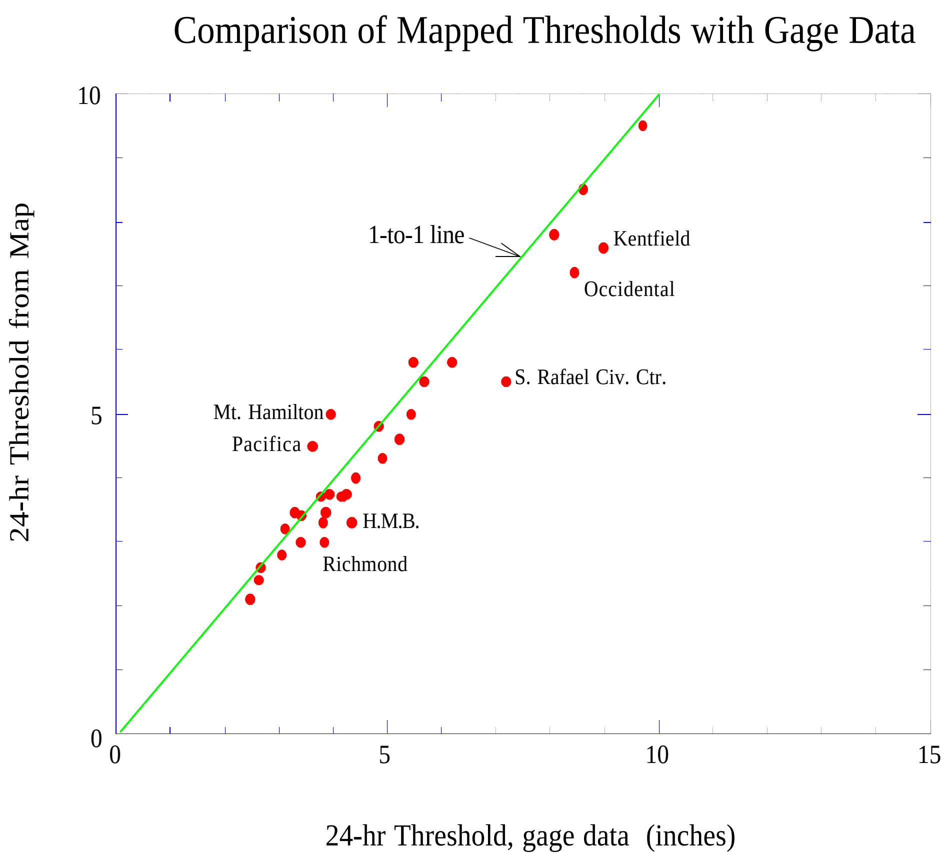
Users are cautioned that the variations in threshold rainfall depicted by the contours do not correspond to variations in overall probability of debris-flow activity. On the contrary, the map contours are constructed in such a way that the annual probability for storm rainfall exceeding the indicated thresholds are approximately uniform (about 6 per cent in non-El-Nino years) throughout the region. This probability increases significantly (to approximately 20 %) in winters with strong El Nino characteristics (e.g. 1983, 1997-98).

Levels of Debris-Flow Activity: The rainfall thresholds depicted on these maps are intended to correspond to a fairly high level of debris-flow activity, approaching that produced by the January 1982 storm when debris flows reached densities of more than 25 per square kilometer in some areas and a total of over 18,000 debris flows were mapped throughout the 10-county region (Ellen and Wieczorek, 1988). Several more recent storms have also produced debris flows, but not at such high densities over such large areas (Keefer and others, 1987; Wilson and others, 1993).

Even on a susceptible slope, however, the probability of a debris flow actually occurring on a given spot is significantly lower than the probability of the storm rainfall exceeding the threshold at that location. The mapped rainfall thresholds mark the beginning of significant debris-flow activity within an area of a few square kilometers, but not necessarily at any specific site. In the more susceptible areas with steep slopes and thin, sandy soils, there are tens to hundreds of potential debris-flow sources per square kilometer, only a small percentage of which will fail in a single storm that exceeds the threshold. The probability of at least a few of these sites failing in any storm exceeding the threshold is, however, relatively high.

Moreover, some significant debris-flow activity may occur at lower levels of rainfall intensity and duration, particularly along roadways or drainage channels where cuts and embankments may be more susceptible to failure than nearby undisturbed natural slopes. Debris flows along roadways may still pose a hazard to life and property by creating an unexpected obstruction in the roadway. Debris flows may also obstruct natural streams or artificial drainage channels, impound or divert heavy storm runoff, and cause damage as a result of flood inundation and erosion.

<u>Discrepancies Between Maps and Rain Gage Data</u>: Users of these maps should take into account the inevitable errors and ambiguities inherent in a regional analysis. One measure of the accuracy of the mapping methods is to look up the locations of the long-term NCDC rain gages on the maps and compare the estimated thresholds from those calculated from the gage data themselves. Such a comparison is shown in figure 2, where a perfect match would fall on the 1:1 line. Two gaged points--Pacifica and Mt. Hamilton show significant overestimates from the map; five--Kentfield, Occidental, San Rafael Civic Center, Half Moon Bay, and Richmond--are significantly underestimated.



These errors generally correspond to discrepancies between the mean annual precipitation (MAP) depicted by the Rantz (1971) map and the MAPs calculated from the gage records. Some of these discrepancies stem from differences in the period of record between the gages (late 1940's to 1996) and the Rantz (1971) map which, presumably, included data only from the early part of this period. Other discrepancies may stem from mislocations of the

NCDC gages that were plotted from lat/long descriptions truncated to the nearest minute of arc (about 1.86 km)--a difference which may be significant in areas with strong gradients in MAP (e.g. San Rafael Civic Center, Half Moon Bay).

The Rantz (1971) map, on the other hand, is based on data from many more rain gages than the NCDC subset and may be better, therefore, for depicting overall regional patterns of precipitation. Other than the seven gaged locations listed above, the mapped thresholds generally agree with the thresholds estimated from gage data to within 10 %, plus or minus. In practical use, however, these errors will often be exceeded by the uncertainties inherent in the precipitation forecasts currently available, which will provide the principal constraint to the use of these maps for emergency planning and response.

<u>Less Precision in the Northern Part of the Region</u>: North of latitude 38° 30' N, the long-term rain-gage network is too sparse to constrain the digital gridding of rainfall frequency (#RDs) well. For this region, the #RDs layer was constrained using a regional correlation of #RDs with latitude up the U. S. Pacific Coast (Wilson, 1997a) and a topographically based model to model "rain shadows" on the leeward (northeast) side of mountain ranges (Wilson and Jayko, unpub. map, Dec., 1997). The rain shadow map was generated using a shadow cast by a modeled source of illumination oriented N 60° E and 15° from the horizon, approximating the winter storm track direction and the depth of rain shadows estimated from gaged areas. The Rantz (1971) map of mean annual precipitation also appears to be rather loosely constrained in this northern area. Contours are included for the area north of 38° 30' N because they are judged to be better than no guidance at all, but they should be used with an extra degree of caution.

Concluding Statement

While every effort has been made to insure the accuracy of the input data and the validity and relevance of the algorithms and models used to estimate the rainfall thresholds for significant debris-flow activity, it must be noted that these maps are, in essence, predictions of future events. The validity of the assumptions and procedures used in their production will be demonstrated (or disproved) by how well they forecast debris-flow activity from storm rainfall that exceeds the mapped thresholds. A need for future re-calibration is virtually inevitable. Meanwhile, the guidance provided by these maps may help emergency managers and planners mitigate some of the effects of debris flows triggered by heavy rainstorms.

DATABASE DESCRIPTION

TABLES INCLUDED IN THE TEXT

Digital database

The digital database consists of three main parts: 1) two PostScript plot files of map sheets showing the "24 hour rainfall thresholds for debris flows in the San Francisco Bay region, California" and the "6 hour rainfall thresholds for debris flows in the San Francisco Bay region, California" with accompanying pamphlets, 2) a digital database containing the Rain Gage Stations with information about the average number of rainy days and the mean annual precipitation at each station, location of Alert Stations, contour maps for the 24 hr and 6 hr rainfall thresholds for debris flows, and gridded 24 hr and 6 hr rainfall threshold data, and 3) ASCII and PostScript versions of the accompanying pamphlet.

There is no paper map included in the Open-File report, however one can be readily produced from the PostScript plot file (see Open-File Report 97-745A). The digital database is in ARC/INFO export format, and therefore requires the use of ARC/INFO or another compatible GIS system to access the information contained within it. For those who don't use an ARC/INFO compatible GIS system, we have included a separate data package consisting of an ASCII text file containing rain gage information, Alert Station locations and texts to accompany the map plots.

Postscript files

sfbr-rt-dbdesc.ps	--The postscript text
sfbr-rt24.ps	--The postscript map file for the 24 hr threshold map
sfbr-rt6.ps	--The postscript map file for the 6 hr threshold map

The PostScript map plot files consist of 1:275,000 scale color maps showing the location and names of the rain gage stations, Alert Stations, major roads, coastline, county lines, 24 or 6 hr rainfall threshold contours, 24 or 6 hr rainfall threshold grids, a base layer showing Ellen and others (1997) debris flow map. Because this release is primarily a digital database, the plot file (and plots derived therefrom) has not been edited to conform to U.S. Geological Survey standards.

The PostScript image of the map sheet is 34 inches wide by 34 inches high, so it requires a large plotter to produce paper copies at the intended scale.

ASCII files

sfbr-rt-dbdesc.txt	--An ASCII file of the map report .
raingages.txt	--Rain gage location, identifier, mean annual precipitation, and number of rainy days -- also found in the digital database -- in an ASCII text file
alert.txt	--Alert Station location and identifier -- also found in the digital database -- in an ASCII text file

The contents of the raingages.txt ASCII text file is equivalent to the values of the items LOCATION, RAINDAYS, and MAP described for the point attribute sfbr-rtg.pat plus the latitude and longitude coordinates for each location. The contents of the alert.txt ASCII text file is equivalent to the values of the item PREC_UTM-ID described for the point attribute sfbr-rta.pat plus the latitude and longitude coordinates for each location (see *DIGITAL DATABASE*, *Table 4 and 5* for details. The ASCII text files can be printed on 8 1/2" by 11" paper. The text is delimited by ' # ' (the pound sign), and each feature description is confined to its own line. For example:

1.#Station#Latitude#Longitude##Rds#MAP
2.#Santa Cruz#36.98#122.02#80.8#29.72
3.#Ben Lomond 4#37.08#122.08#82.1#46.71

Arc/Info Coverages

ARC/INFO export file	Coverage	--Description of Coverage
sfbr-rt24c.e00	sfbr-rt24c	--Line coverage showing contours of 24 hour rainfall threshold for debris flows. Contour interval 0.5 inches
sfbr-rt6c.e00	sfbr-rt6c	-- Line coverage showing contours of 6 hour rainfall threshold for debris flows. Contour interval 0.5 inches

sfbr-rtg.e00	sfbr-rtg	--Point coverage showing rain gage locations, station identifier, average number of rainy days, and mean annual precipitation.
sfbr-rta.e00	sfbr-rta	--Point coverage showing the location of ALERT STATIONS and station identifiers
info/		--INFO directory containing the database files that accompany each ARC/INFO layer (coverage).

Tar files (Arc/Info grids)

sfbr-rt24.tar	sfbr-rt24	-- Arc/Info grid showing 24 hour rainfall threshold for debris flows
sfbr-rt6.tar	sfbr-rt6	-- Arc/Info grid showing 6 hour rainfall threshold for debris flows

Once the ARC export coverages have been imported, the sfbr-rt/ directory, or ARC workspace, will look like this:

sfbr-rt/

sfbr-rt24c/	line coverage
sfbr-rt6c/	line coverage
sfbr-rt24/	grid
sfbr-rt6/	grid
sfbr-rtg/	point coverage
sfbr-rta/	point coverage
sfbr-rt-dbdesc.txt	ASCII text file
sfbr-rt-dbdesc.ps	postscript text file
raingages.txt	ASCII text file
alert.txt	ASCII text file
sfbr-rt24.ps	postscript map plot, 1:275,000
sfbr-rt6.ps	postscript map plot, 1:275,000

Spatial Resolution

Uses of this digital geologic map should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data.

COVERAGE	SCALE OF SOURCE (editing scale)
sfbr-rt24c/	1:250,000
sfbr-rt6c/	1:250,000
sfbr-rtg/	1:1000000
sfbr-rta/	1:1000000

Plotting a coverage at scales larger than the scale it was edited at will not yield greater real detail, although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data.

Map Projection

The map database consists of ARC coverages and supporting INFO files, which are stored in a Universal Transverse Mercator projection (Table 1).

Table 1 - *Map Projection*

PROJECTION	Universal Transverse Mercator
UNITS	Meters (on the ground)
ZONE	10 (Arc/Info UTM zone code)
DATUM	NAD27 (North American Datum of 1927)
SPHEROID	Clarke1866
PARAMETERS	NONE

Arc/Info Database Format

The content of the database can be described in terms of the points, lines, and areas that compose the map. Descriptions of the database fields (items) use the terms explained in Table 2.

Table 2 - *Item Definition Terms*

ITEM NAME	--Name of the database field (item).
WIDTH	--Maximum number of digits or characters stored.
OUTPUT	--Output width.
TYPE	--B (binary integer), F (binary floating point number), I (ASCII integer), N (decimal number), or C (ASCII character string).
N. DEC.	--Number of decimal places maintained for floating point numbers or decimal numbers.

Point Coverages

Points are described in the point attribute table (PAT). The point coverages included in this database are *sfbr-rtg and sfbr-rta*, which contains positional and other information about rain gage information. The identities of the points are recorded in the several items shown below in Table 3. Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with point information will have a point attribute table, and these coverages will not have a polygon attribute table.

Table 3 - *Content of Point Attribute Table (PAT) sfbr-rtg.pat*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION OF ITEM
AREA	4	12	F	3	--Area of point in square meters (equals 0 for all points).
PERIMETER	4	12	F	3	--Length of perimeter in meters (equals 0 for all points).
SFBR-RTG#	4	5	B		--Unique internal control number.
SFBR-RTG -ID	4	5	B		--Unique identification number.
LOCATION	20	20	C		--Feature name.
RAINDAYS	5	5	N	1	--Mean Annual Number of Rainy Days.
MAP	5	5	N	2	--Mean Annual Precipitation

Table 4 - *Content of Point Attribute Table (PAT) sfbr-rta.pat*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION OF ITEM
AREA	4	12	F	3	--Area of point in square meters (equals 0 for all points).
PERIMETER	4	12	F	3	--Length of perimeter in meters (equals 0 for all points).
SFBR-RTG#	4	5	B		--Unique internal control number.
SFBR-RTG -ID	4	5	B		--Unique alert station identification number.

Line Coverages

The lines (arcs) are recorded as strings of vectors and are described in the arc attribute table (Table 5). They define contours for the 24 and 6 hour rainfall threshold maps for debris flows.

Table 5 - *Content of a generic Arc Attribute Table (AAT)*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION OF ITEM
FNODE#	4	5	B		--Starting node of arc (from node).
TNODE#	4	5	B		--Ending node of arc (to node).
LPOLY#	4	5	B		--Id number of polygon to the left of the arc.
RPOLY#	4	5	B		--Id number of polygon to the right of the arc.
LENGTH	4	12	F	3	--Length of arc in meters.
<coverage>#	4	5	B		--Unique internal control number.
<coverage>-ID	4	5	B		--Unique identification number.

Table 6 - *Content of Arc Attribute Tables sfbr-rt24c and sfbr-rt6c.aat*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION OF ITEM
FNODE#	4	5	B		--Starting node of arc (from node).
TNODE#	4	5	B		--Ending node of arc (to node).
LPOLY#	4	5	B		--Id number of polygon to the left of the arc.
RPOLY#	4	5	B		--Id number of polygon to the right of the arc.
LENGTH	4	12	F	3	--Length of arc in meters.
<coverage>#	4	5	B		--Unique internal control number.
<coverage>-ID	4	5	B		--Unique identification number.
CONTOUR	4	12	F	3	--Contour of rainfall threshold. Contour interval 0.5 inches

GRIDS

sfbr-rt24 and sfbr-rt6 are 90m grids of the rainfall threshold values recorded in inches (Tables 7 and 8). The coverages showing the 24 and 6 hour threshold contours were derived from these data.

Table 7 - *Contents of Grid sfbr-rt24*

Cell Size = 90.0 meters
Data Type: Floating Point
Number of Rows = 2635
Number of Columns = 2669

Statistics

Minimum 24 hour rainfall threshold Value = 1.583 inches
Maximum 24 hour rainfall threshold Value = 10.608 inches
Mean = 4.475 inches
Standard Deviation = 1.792 inches

Grid Corners (UTM Coordinates)

Xmin = 443136.531
Ymin = 4066655.250
Xmax = 683346.531
Ymax = 4303805.250

Table 8 - *Contents of Grid sfbr-rt6*

Cell Size = 90.0 meters
Data Type: Floating Point
Number of Rows = 2635
Number of Columns = 2669

Statistics

Minimum 24 hour rainfall threshold Value = 0.931 inches
Maximum 24 hour rainfall threshold Value = 6.350 inches
Mean = 2.678 inches
Standard Deviation = 1.073 inches

Grid Corners (UTM Coordinates)

Xmin = 443136.531
Xmax = 683346.531
Ymin = 4066655.250
Ymax = 4303805.250

OTHER SOURCES OF DIGITAL MAP DATA

Shown on the PostScript map plot file but not included in the released digital database:

Major Roads from:
http://www.basic.org/html/badger.html

San Francisco Bay area county boundaries from: (this source needs to be checked)
Bay Area Resource Database (BARD) U.S. Geological Survey
http://www-nmd.usgs.gov/www/gnis/gnisform.html

Coastline of San Francisco Bay area and Sacramento-San Joaquin River:
Coverage assembled by Florence Wong and Michael Hamer, U.S.Geological Survey Western, Menlo Park, California.

1. *Coastline of western conterminous U.S.:*
   Medium Resolution Vector Shoreline, 994, National Oceanic and Atmospheric Administration, v. 1Beta, September (on CD-ROM), scale 1:80,000.
2. *Sacramento-San Joaquin River delta east of 121 degrees 52.5' W:*
   National Wetlands Quads, U.S. Fish and Wildlife Service

Debris Flow Susceptibility Map from: USGS OFR 97-745 E
Ellen, S.D., Mark, R.K., Wieczorek, G.F., Wentworth, C.M., Ramsey, D.W., and May, T.E., 1997, Map of Principal Debris Flow Source Areas in the San Francisco Bay Region, California: U.S. Geological Survey OFR-97-945 E, scale 1:275,000.

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